

# COSMOS

## Tutorial 1: Social Learning Tasks

Wataru Toyokawa & Charley Wu  
July 5th

# Goals of Tutorial 1

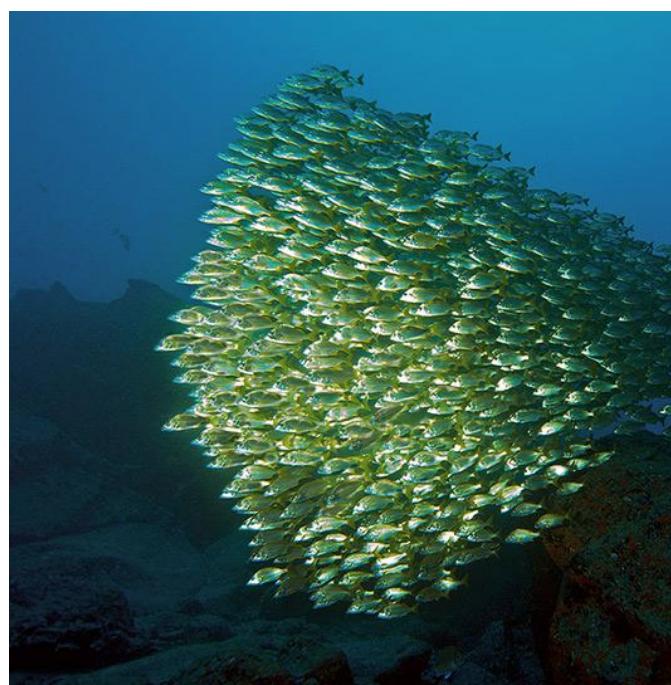
- Real world examples of social learning (SL)
- Taxonomy of SL problems
- Introduction to the multi-armed bandit task
- Interactive demonstration
- Connect bandit task to other social learning tasks
  - Foraging, spatial search, fitness landscapes
  - Other tasks that don't fit

# Social decision making in an uncertain world

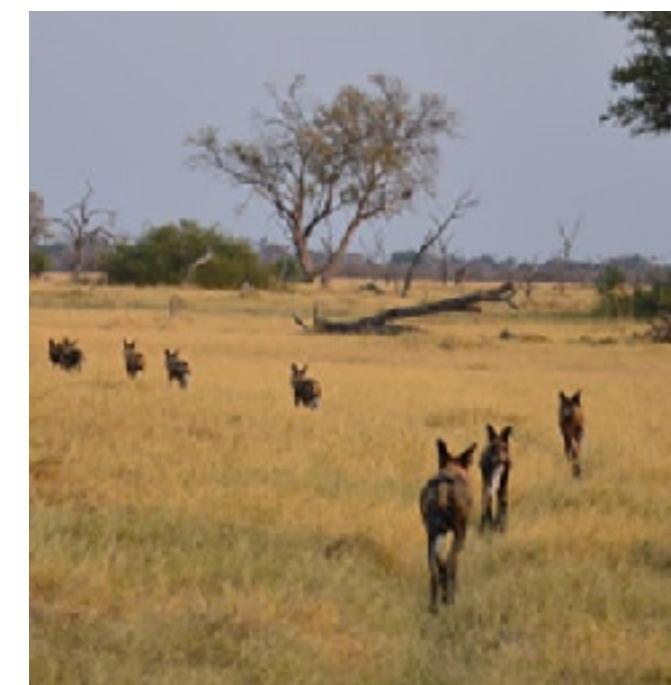
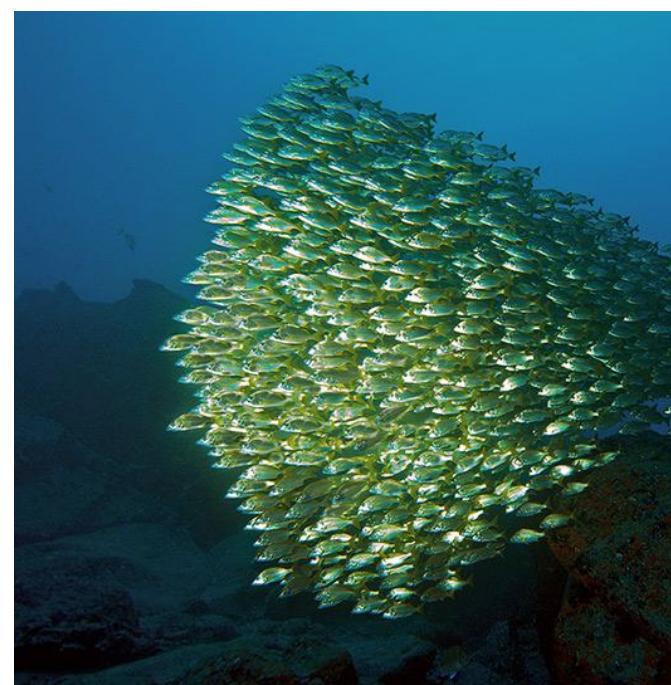
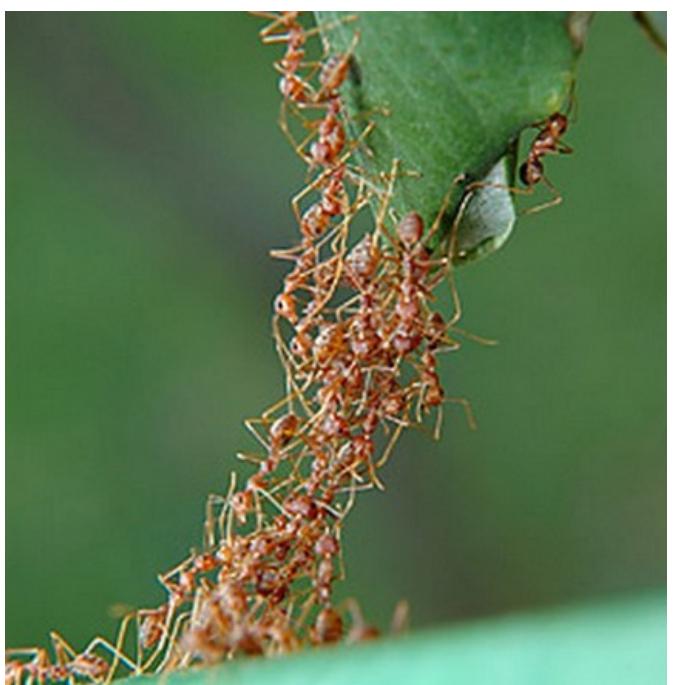
# Social decision making in an uncertain world



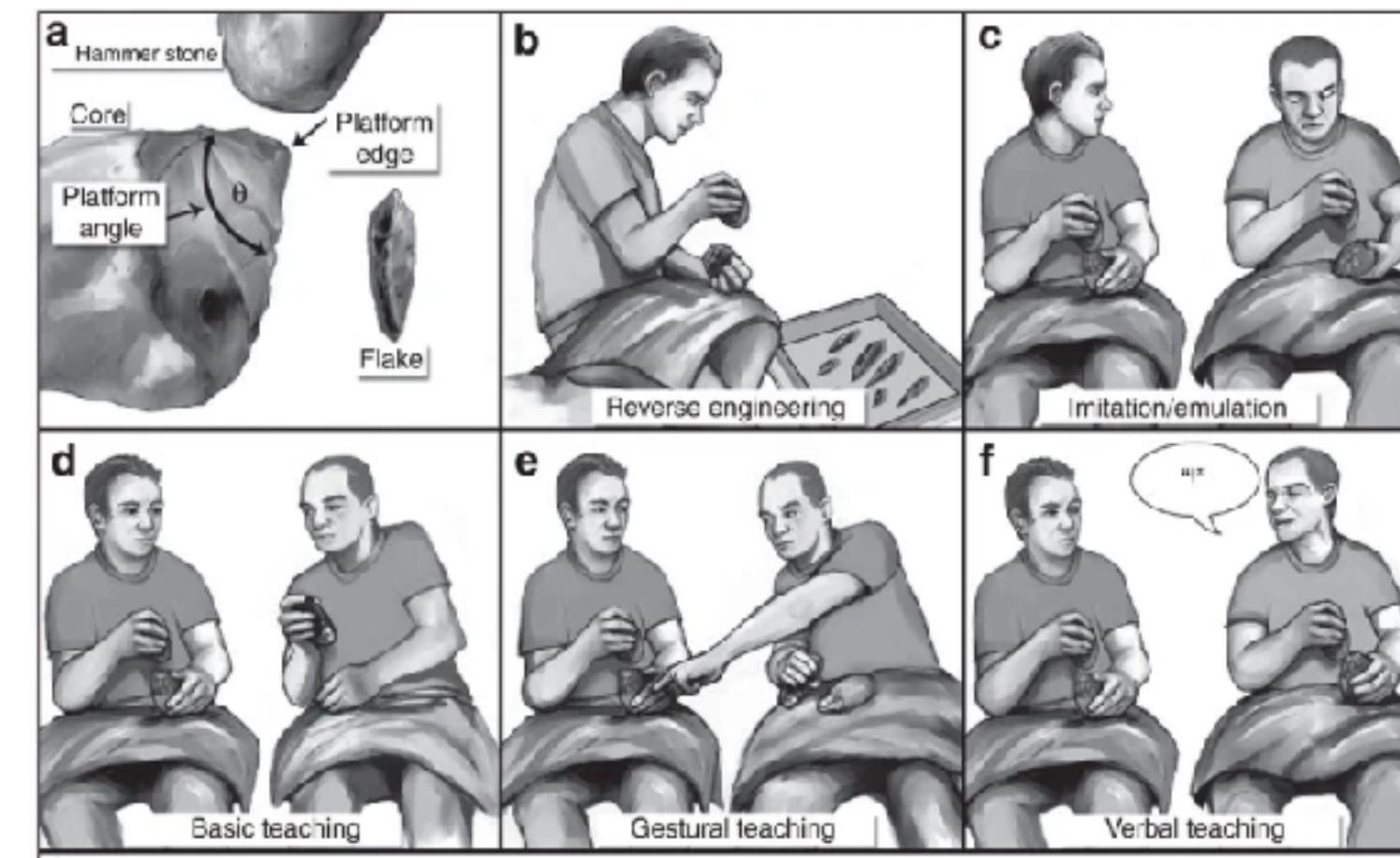
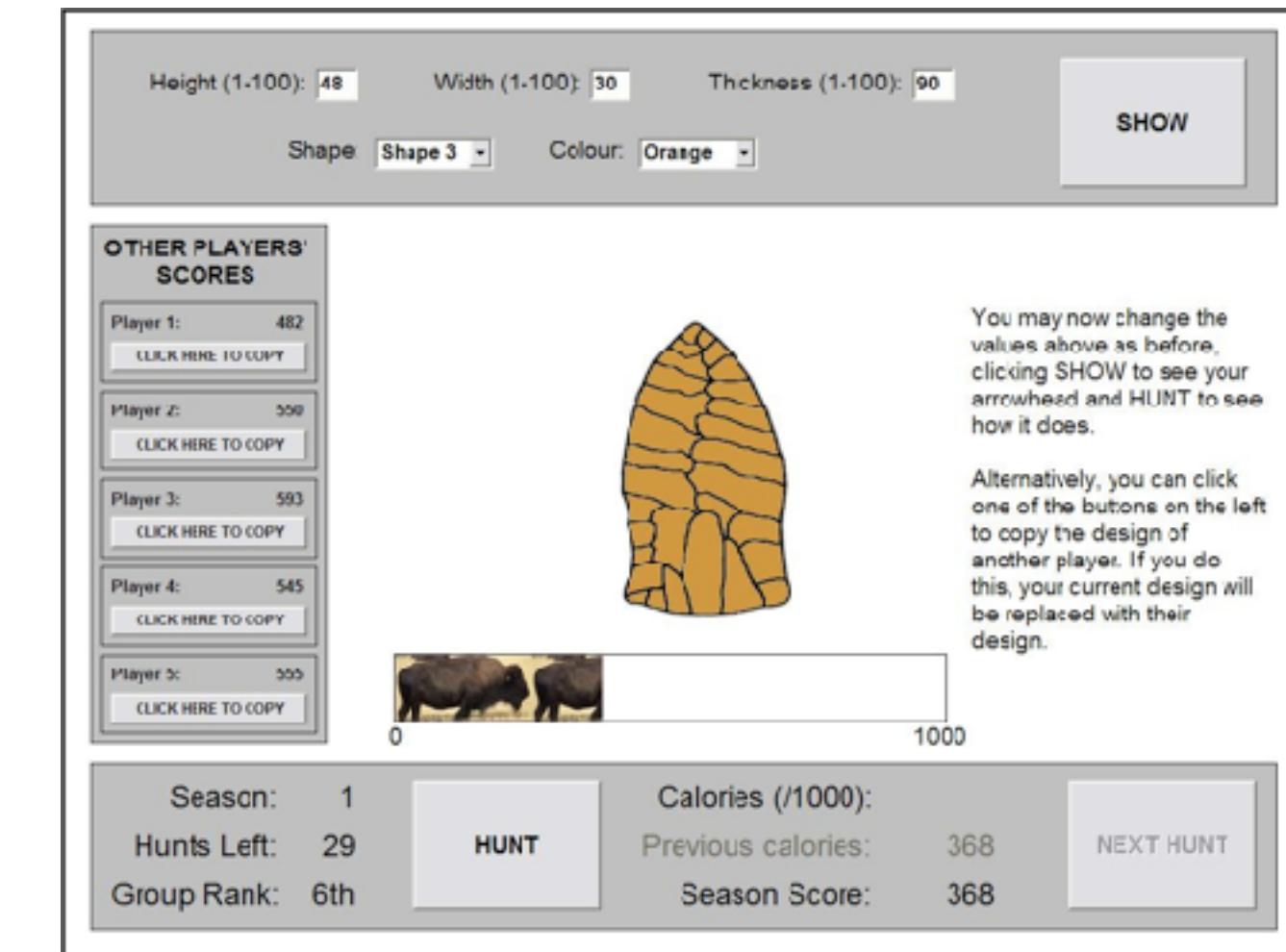
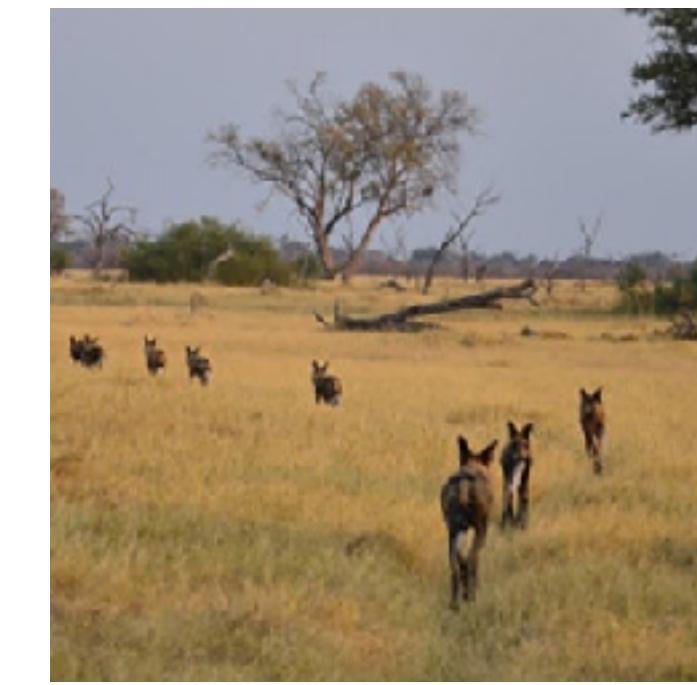
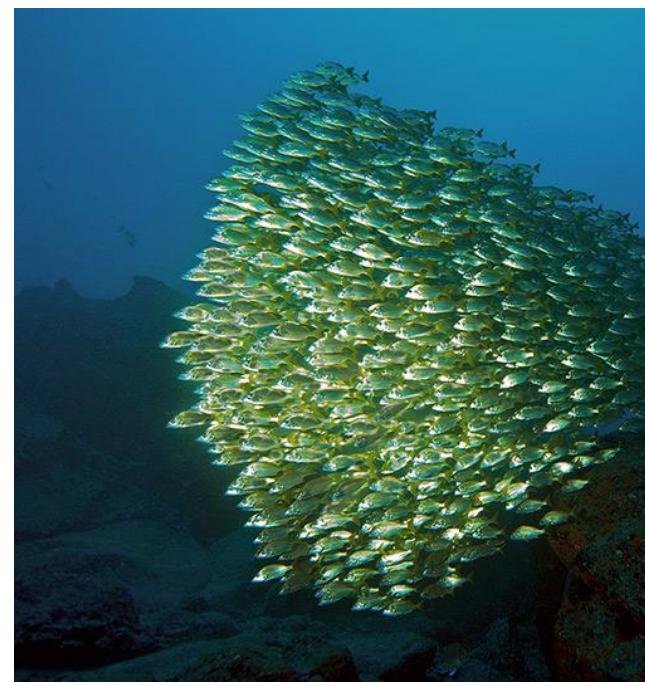
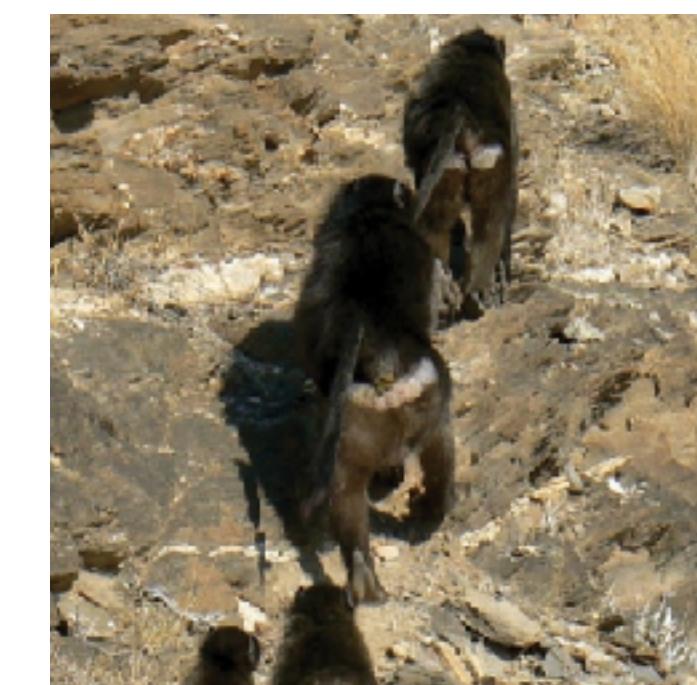
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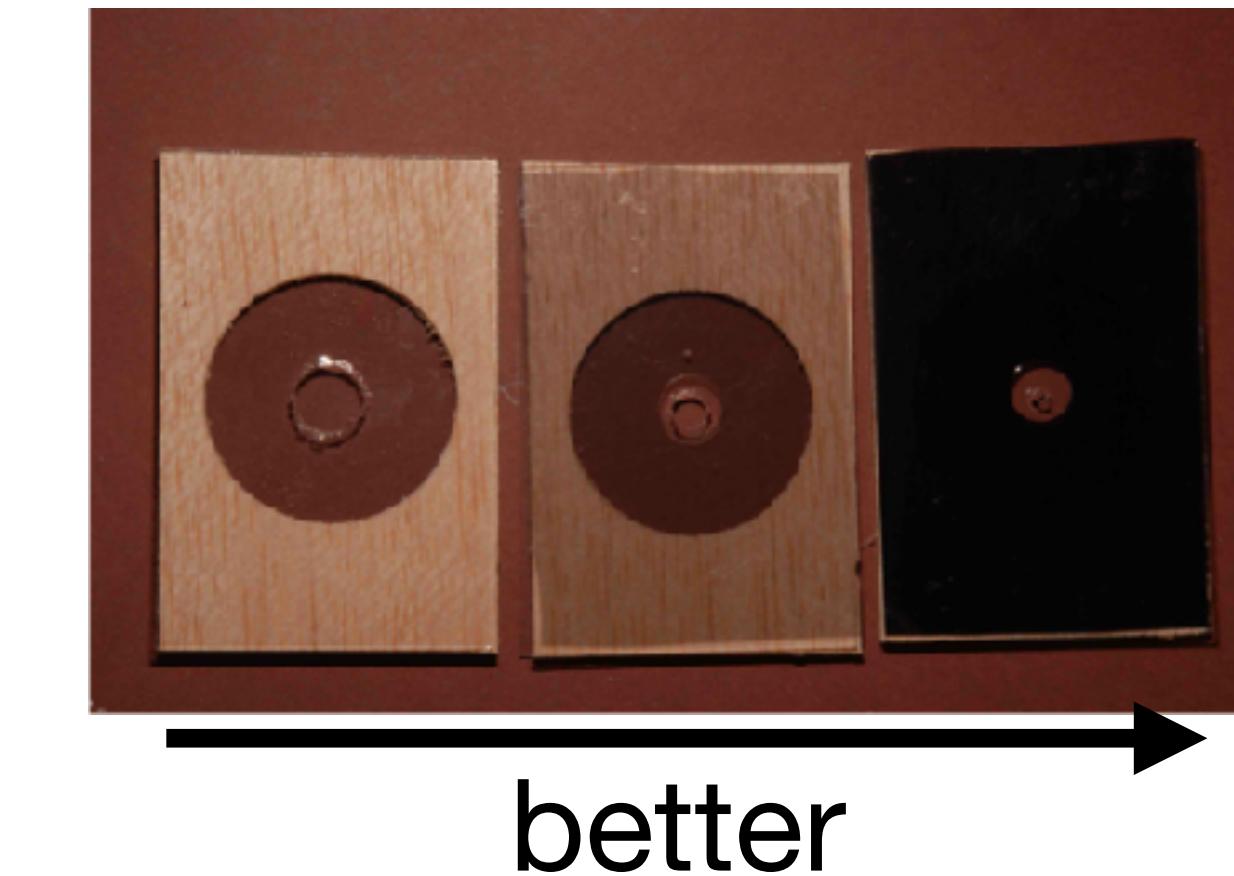


# ① Social learning as collective decision-making

## House hunting ants



Colonies & individuals have the same preference



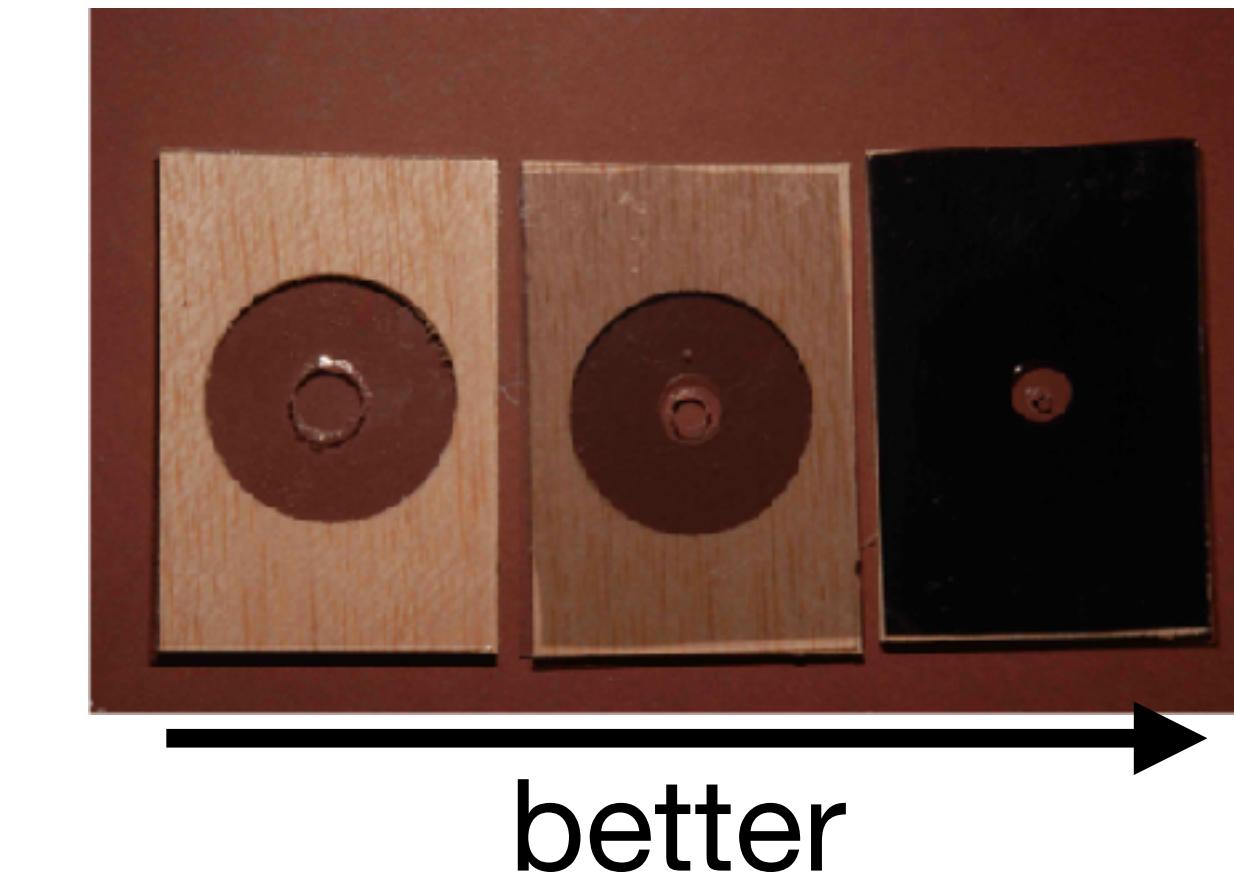
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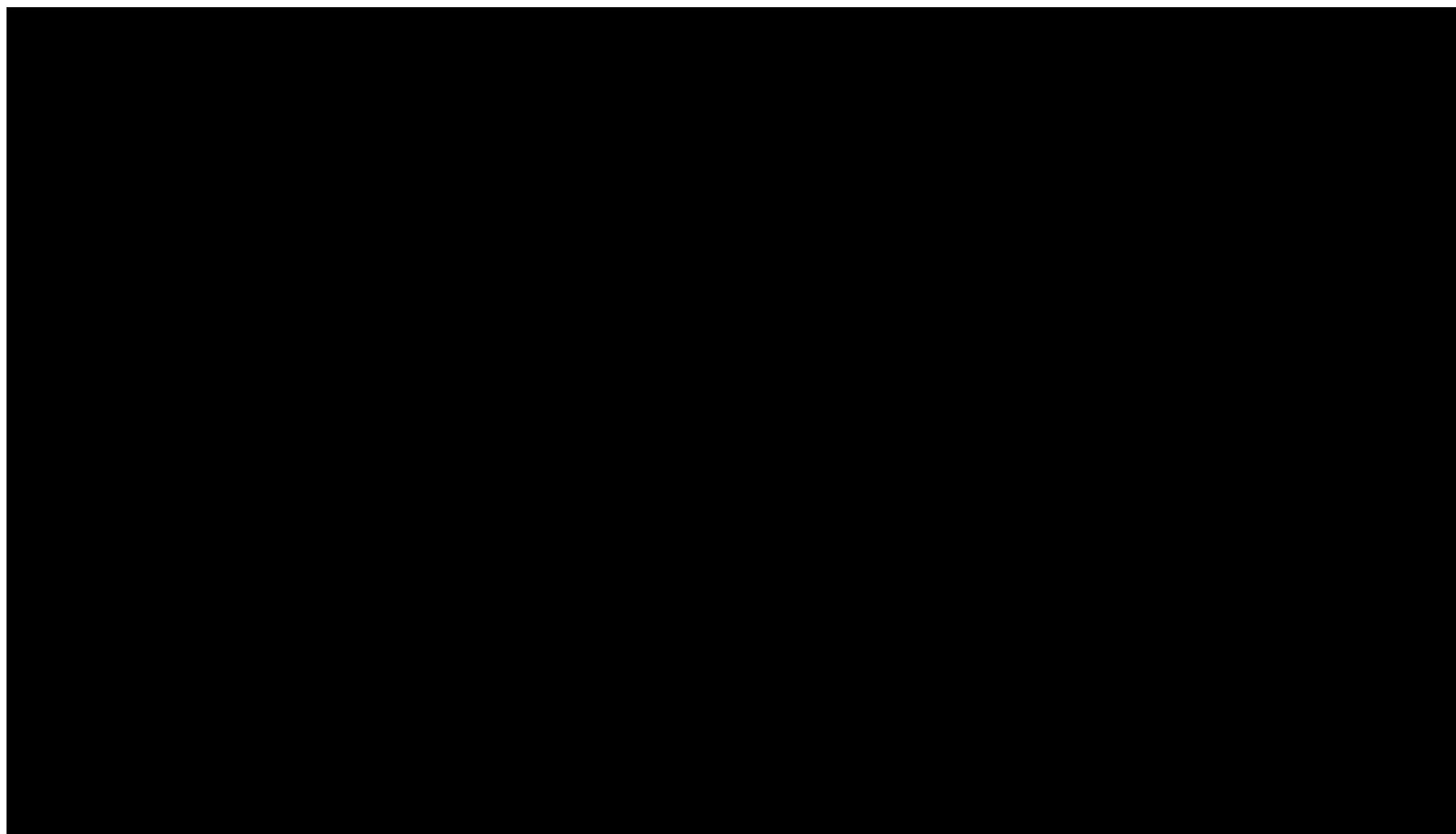
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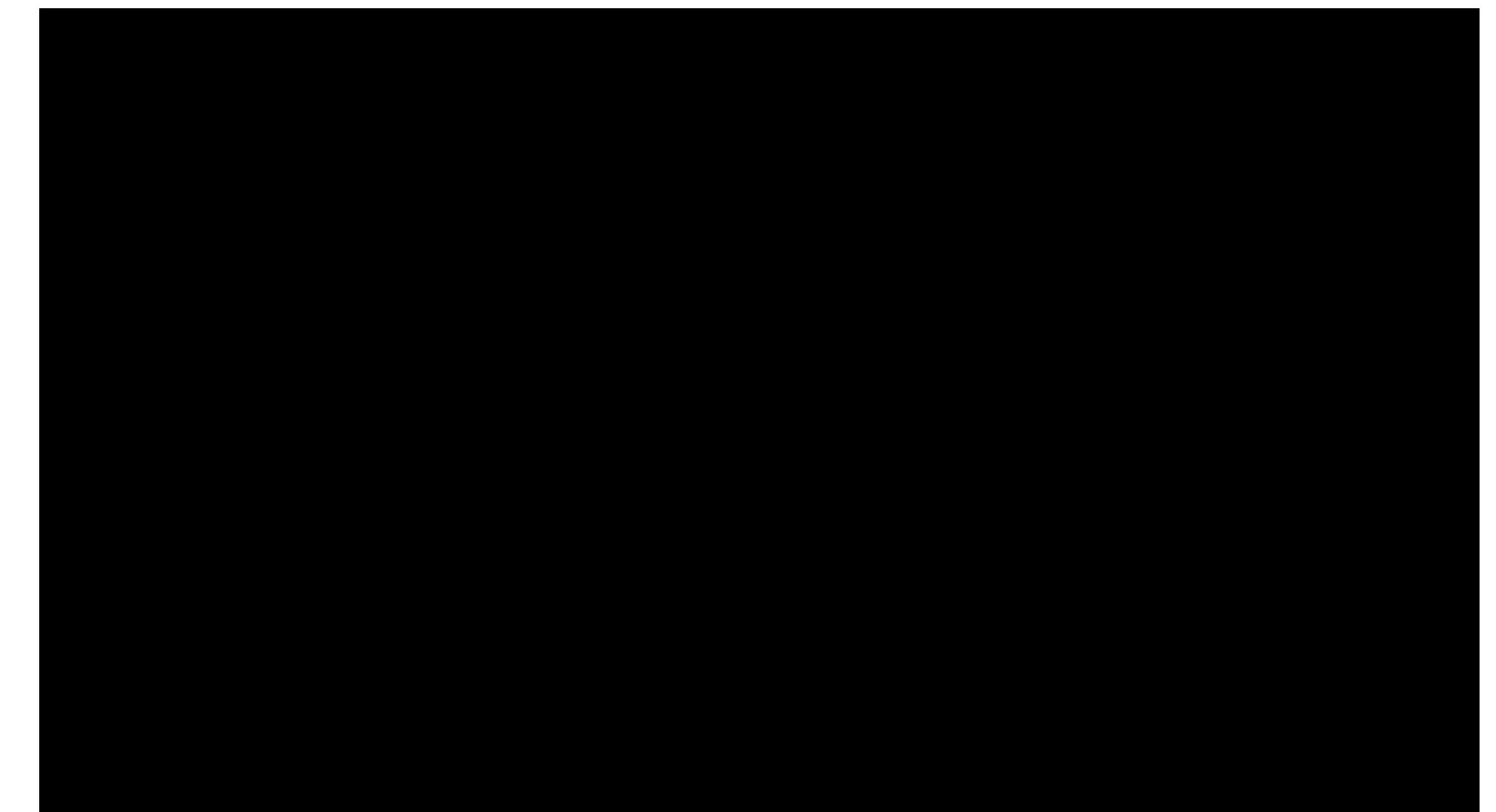
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## Two behavioural options



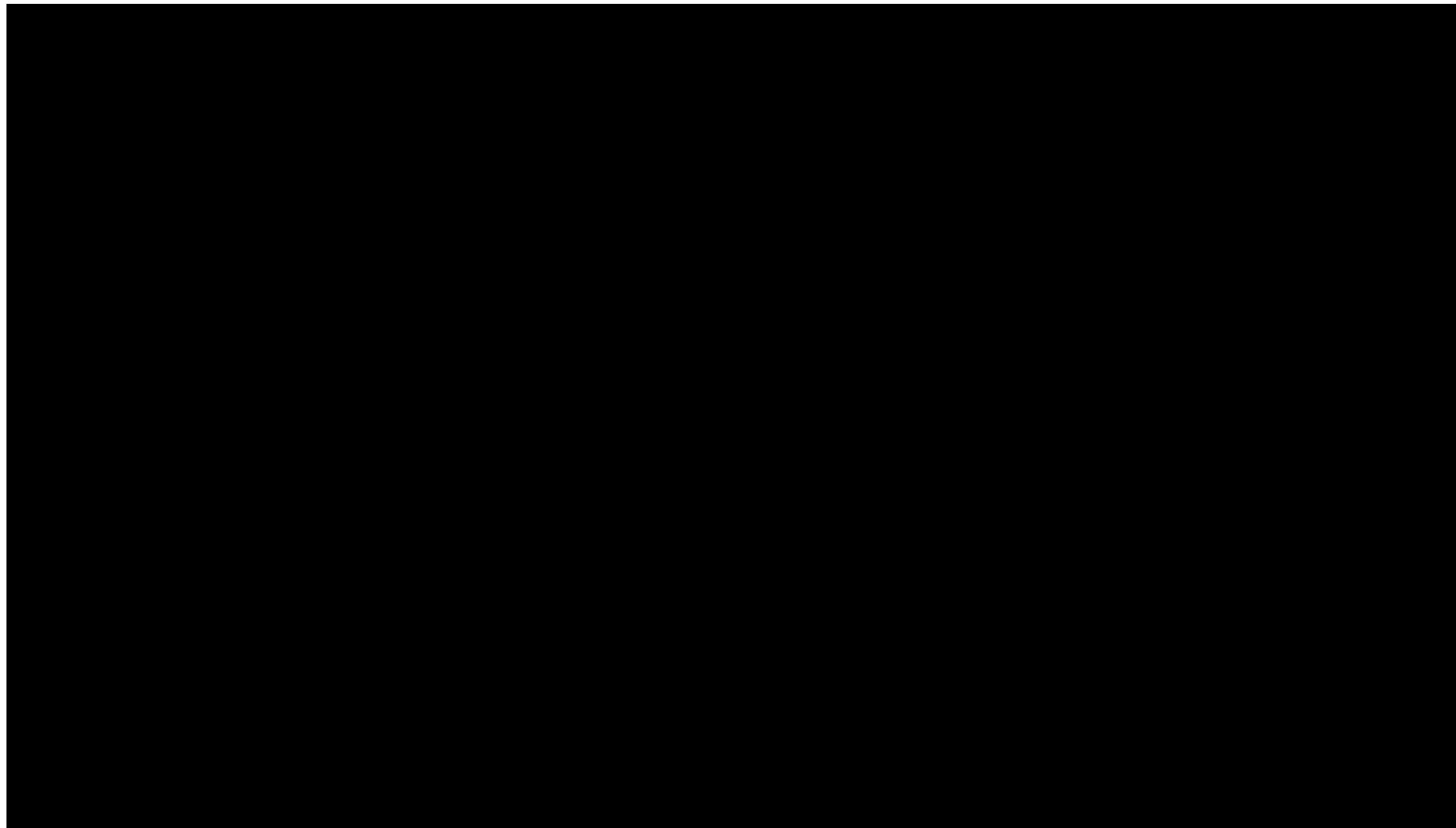
## Social learning (scrounging)



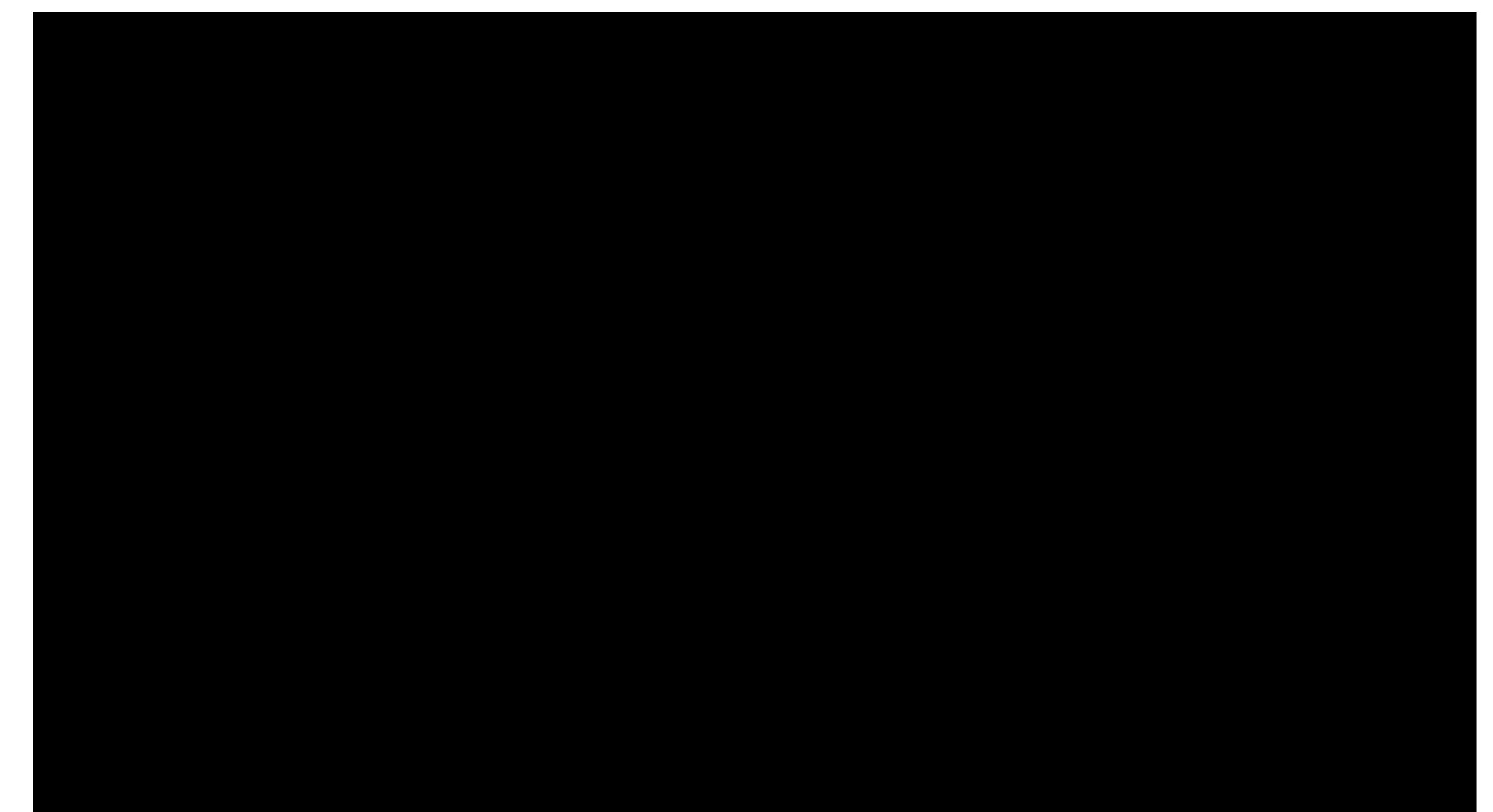
Aplin, L. M., Farine, D. R., Morand-Ferron, J., Cockburn, A., Thornton, A., & Sheldon, B. C. (2015). Experimentally induced innovations lead to persistent culture via conformity in wild birds. *Nature*, 518(7540), 538-541.



## Two behavioural options



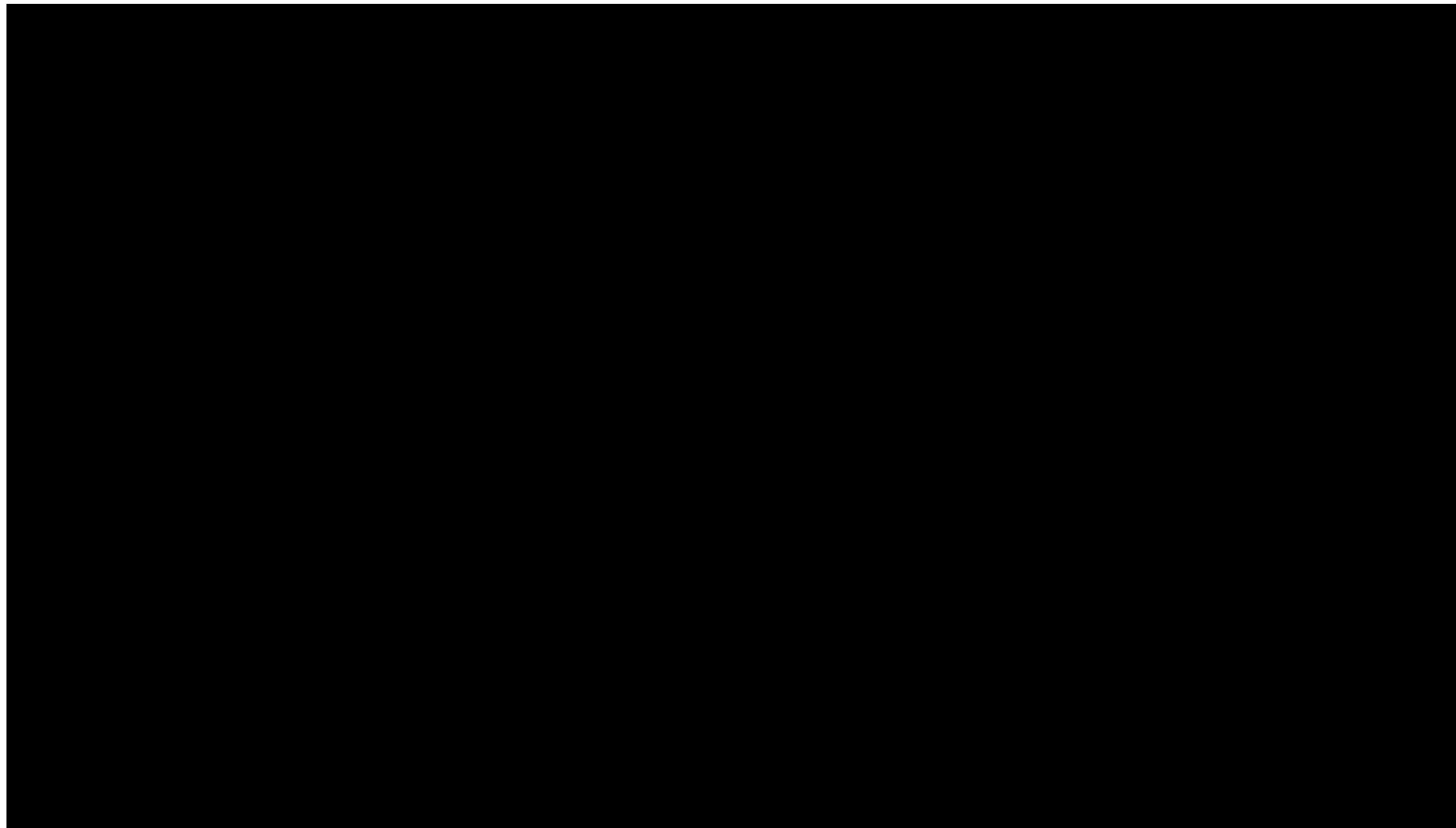
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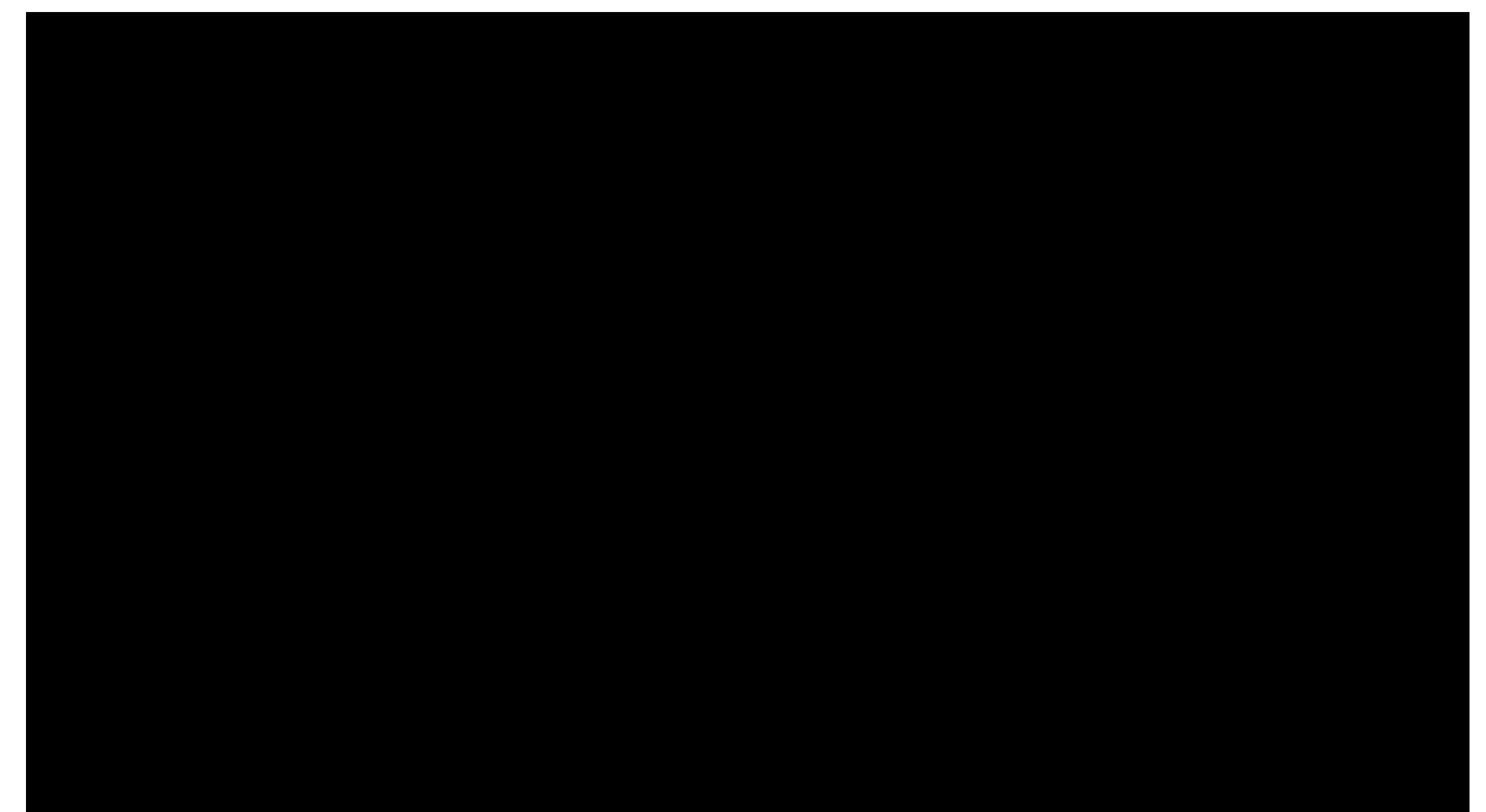
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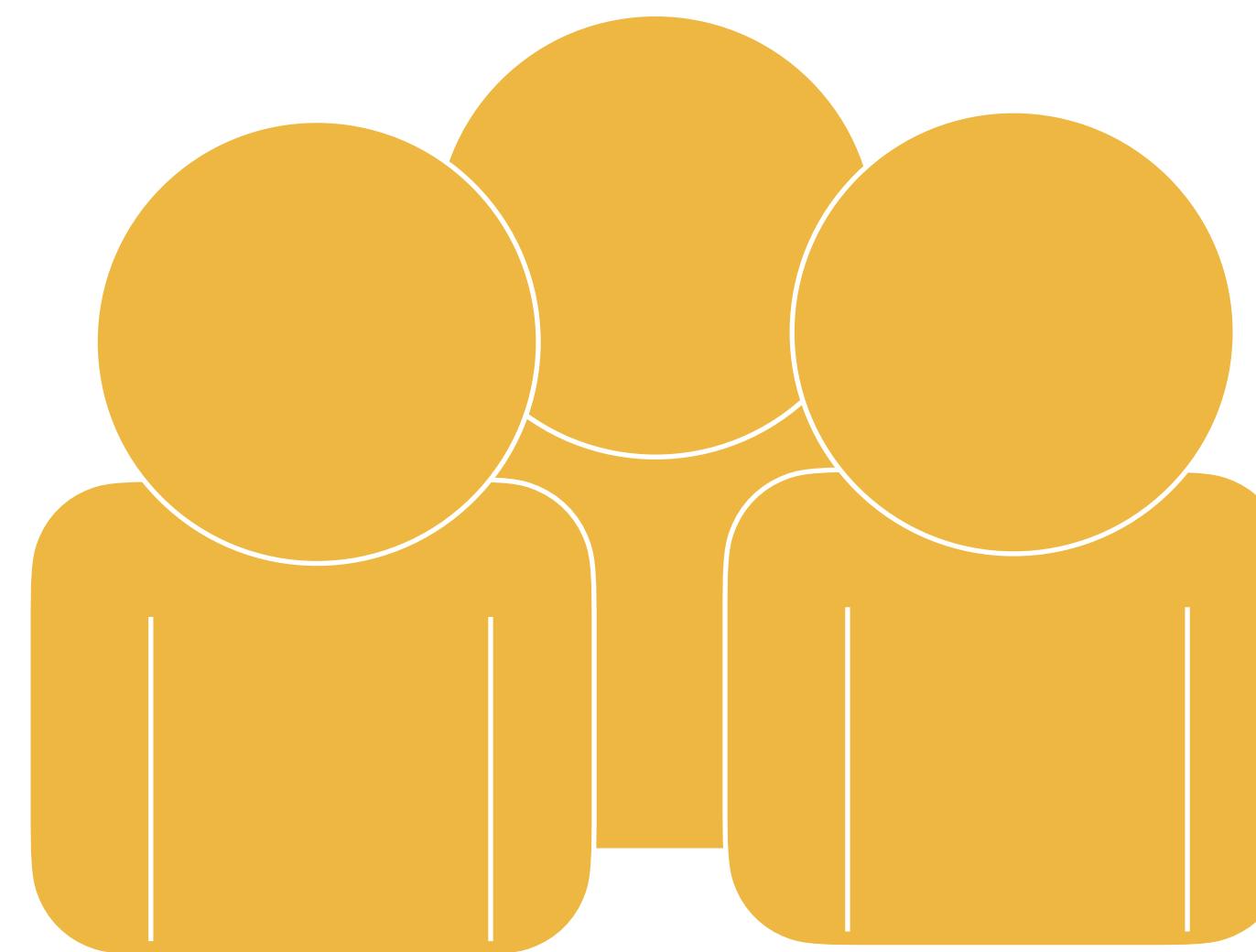
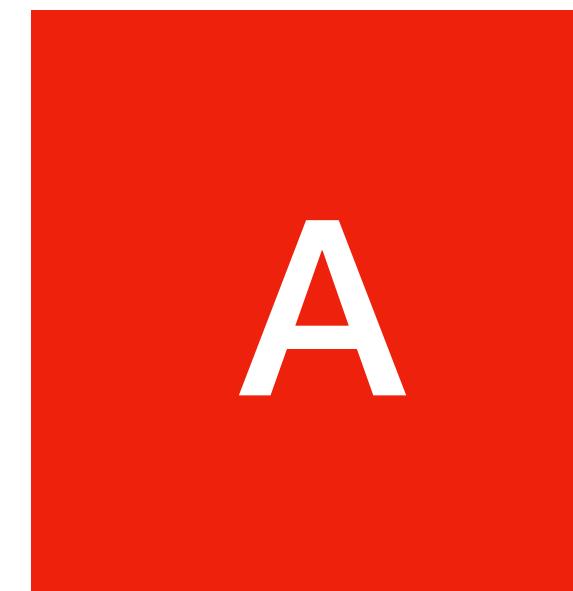


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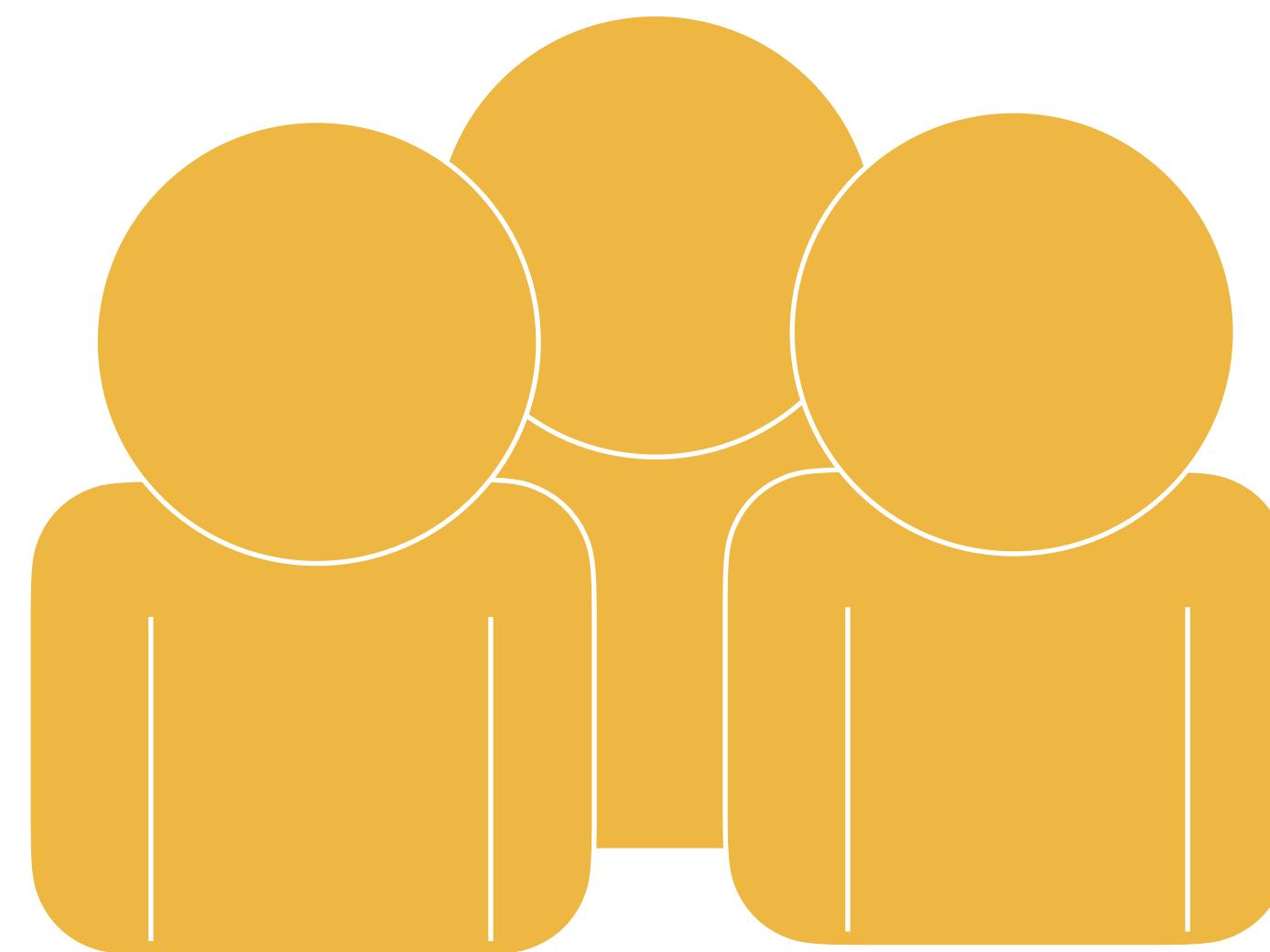
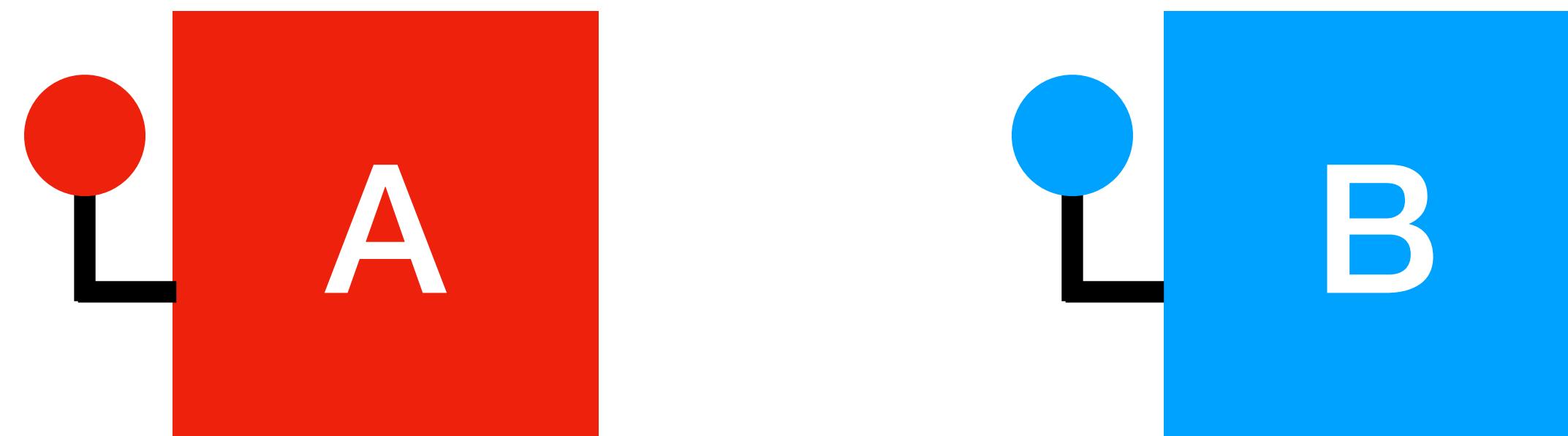


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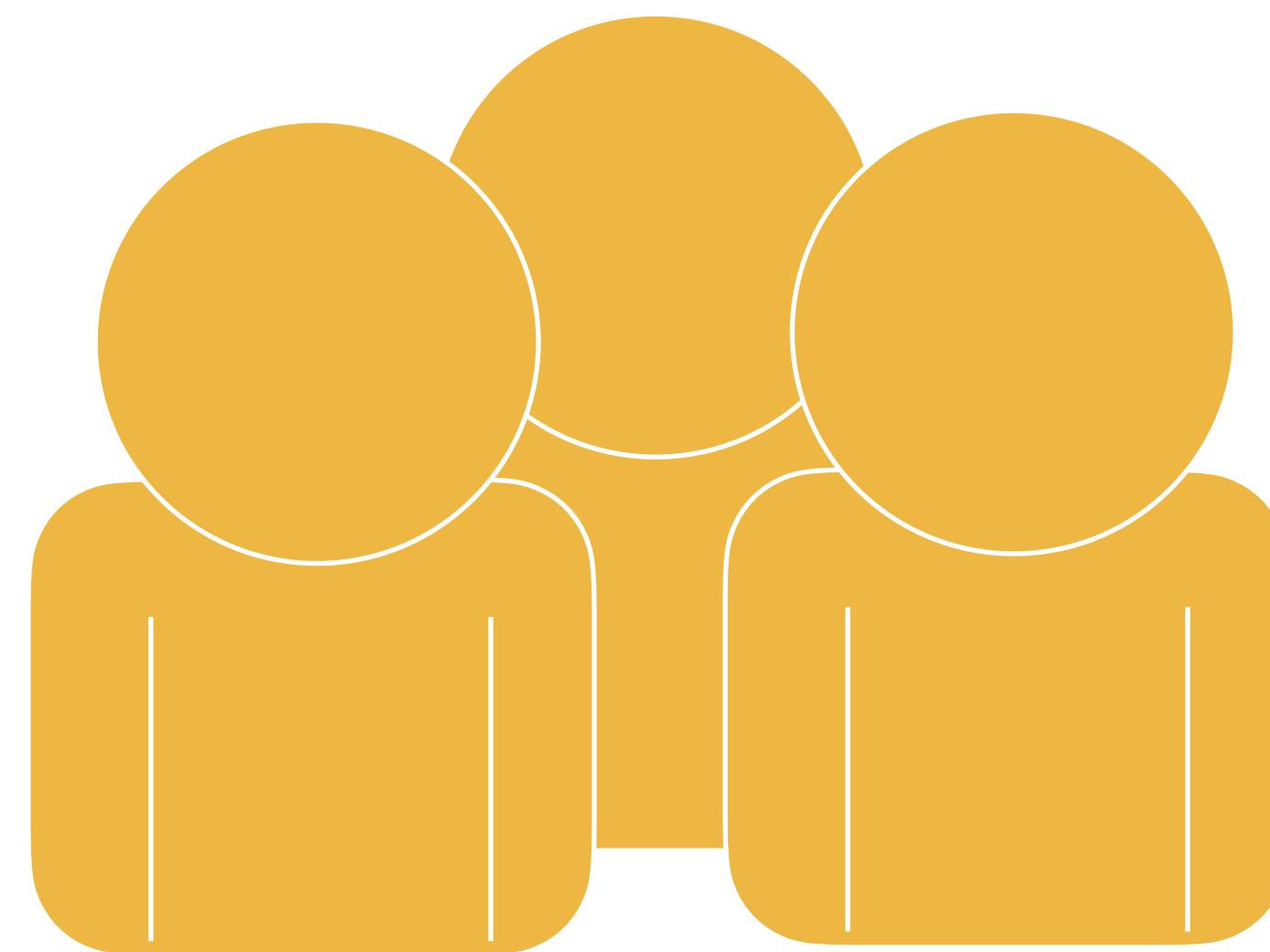
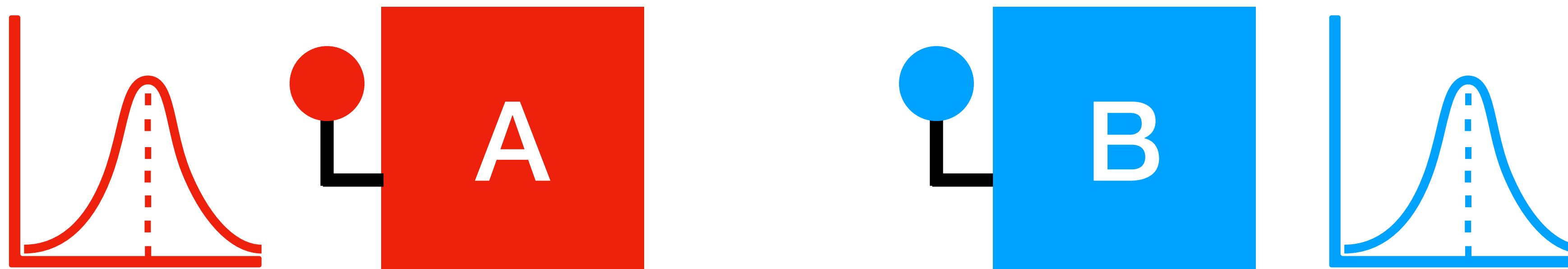
# Multi-armed bandit



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# Multi-armed bandit



# **More complex SL tasks**

## ② Spatial structure

### Spatial structure of environments

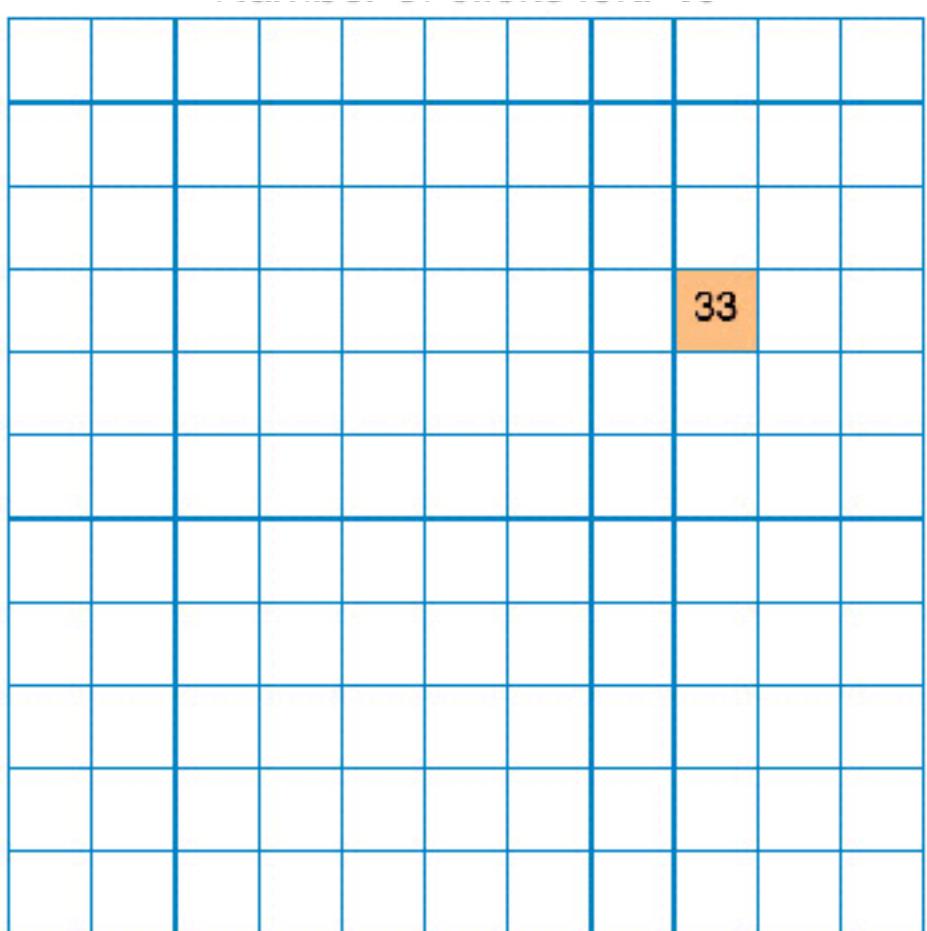
#### Crop yields



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39	19	18	29	46	33	32	55	35	37	57
27	19	21	21	47	46	19	72	38	42	40
22	23	20	18	44	35	36	53	27	45	47
23	14	15	24	35	55	51	53	46	38	63
19	17	12	25	38	74	77	71	46	65	63
20	19	21	23	6	57	60	63	58	60	69
19	19	14	28	31	33	47	58	68	70	61
16	19	19	22	28	31	54	69	74	74	65
21	11	31	30	21	43	50	69	70	72	57
27	21	27	31	45	45	66	56	53	60	42



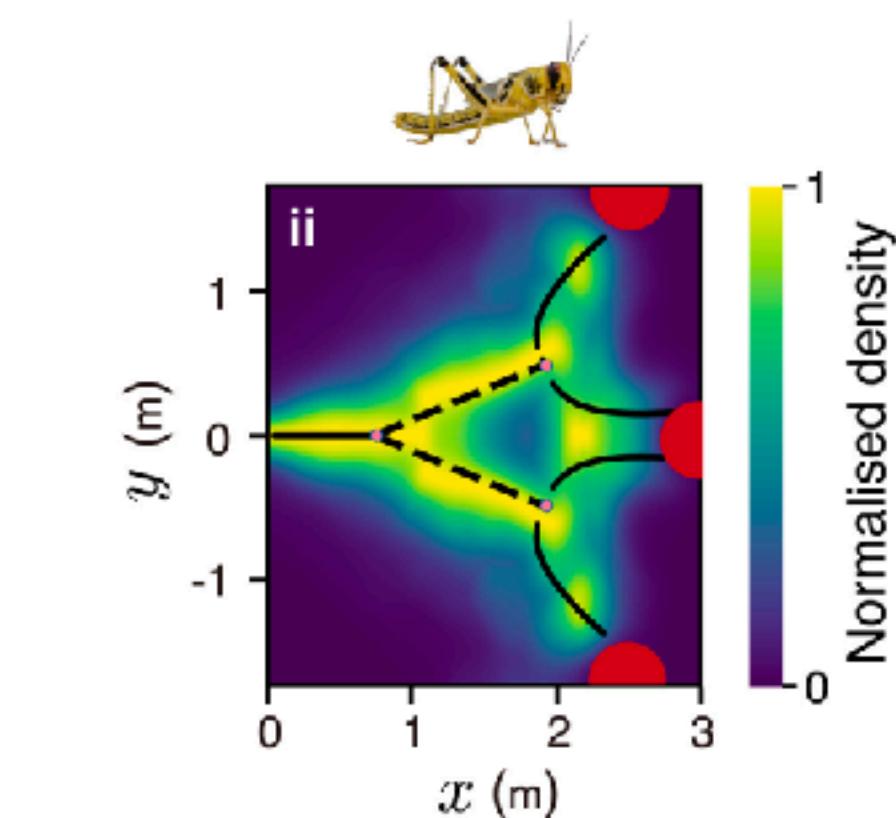
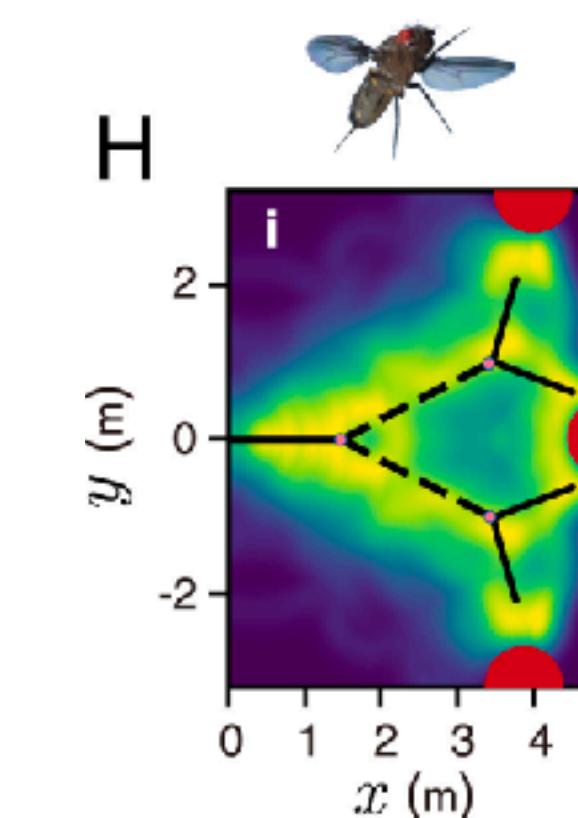
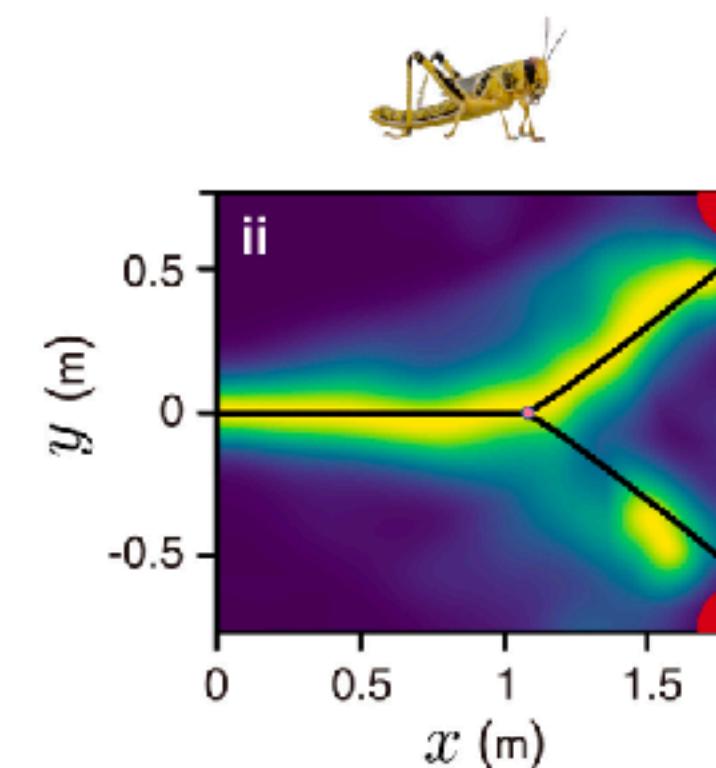
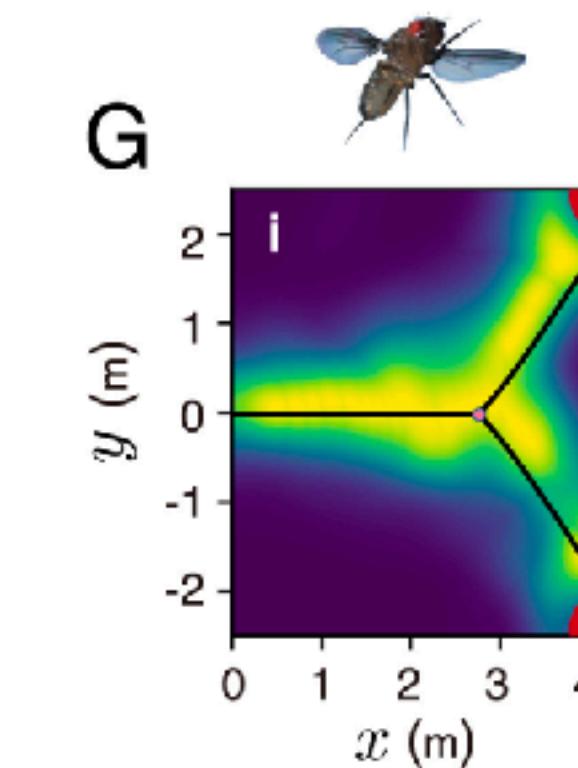
#### Spatially correlated bandit



- click tiles on the grid
- maximize reward
- each tile has normally distributed rewards
- nearby tiles have similar rewards
- limited search horizon

Wu, C. M., Schulz, E., Speekenbrink, M., Nelson, J. D., & Meder, B. (2018). Generalization guides human exploration in vast decision spaces. *Nature human behaviour*, 2(12), 915-924.

### Spatial geometry of decisions



Sridhar, V. H., Li, L., Gorbonos, D., Nagy, M., Schell, B. R., Sorochkin, T., ... & Couzin, I. D. (2021). The geometry of decision-making in individuals and collectives. *Proceedings of the National Academy of Sciences*, 118(50), e2102157118.

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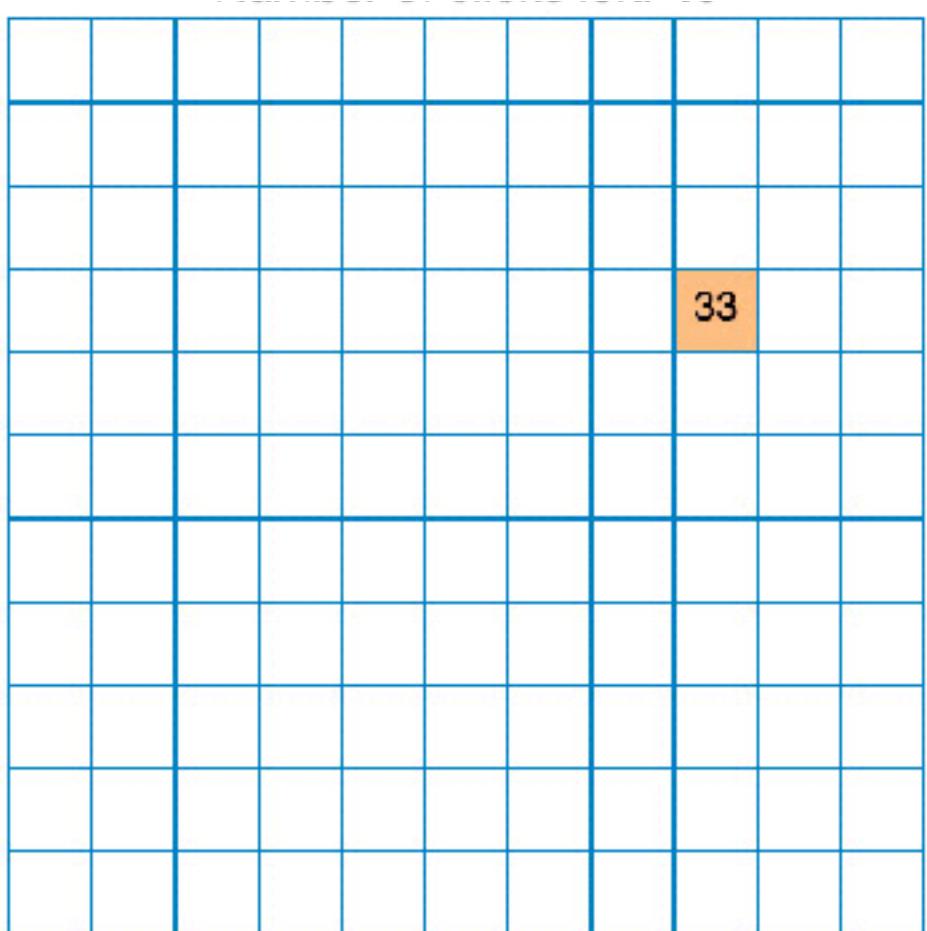
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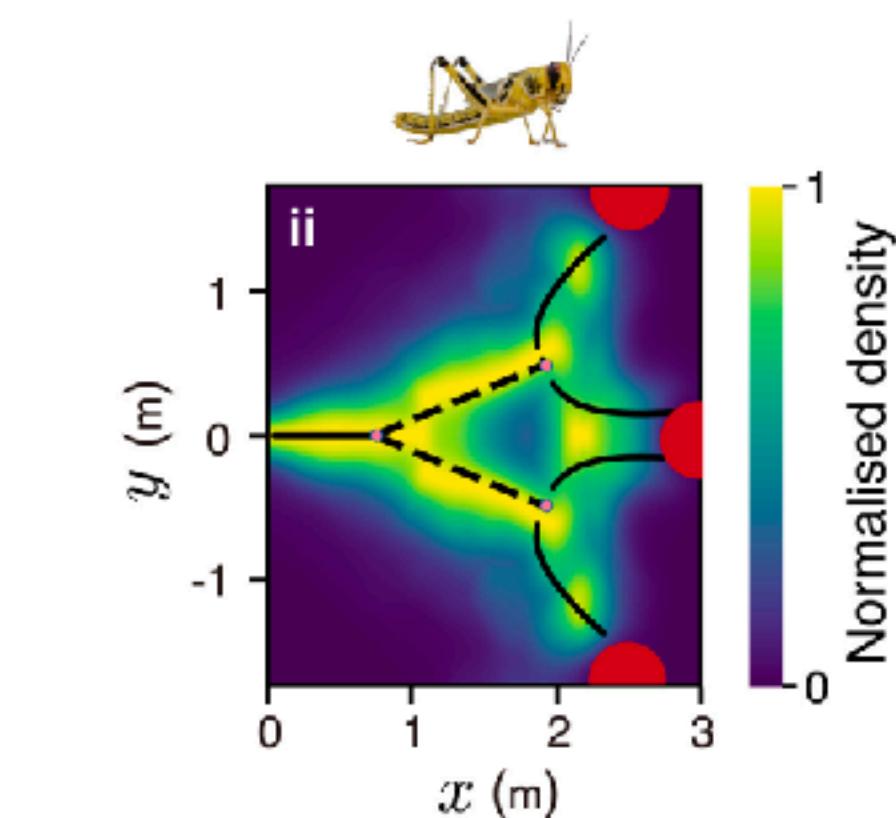
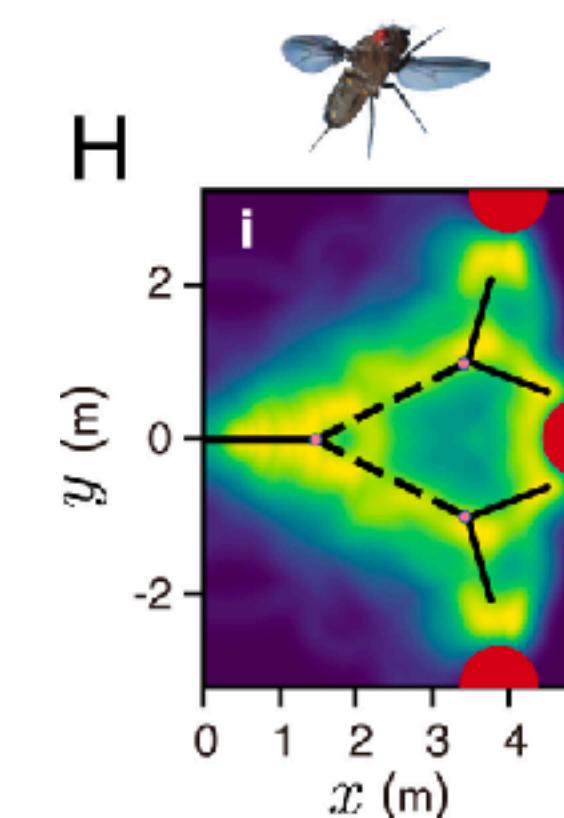
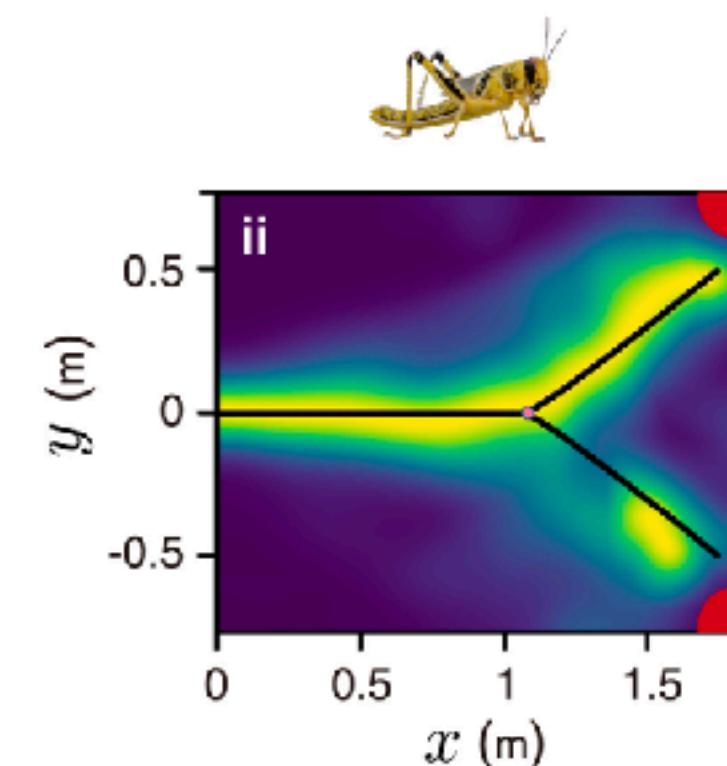
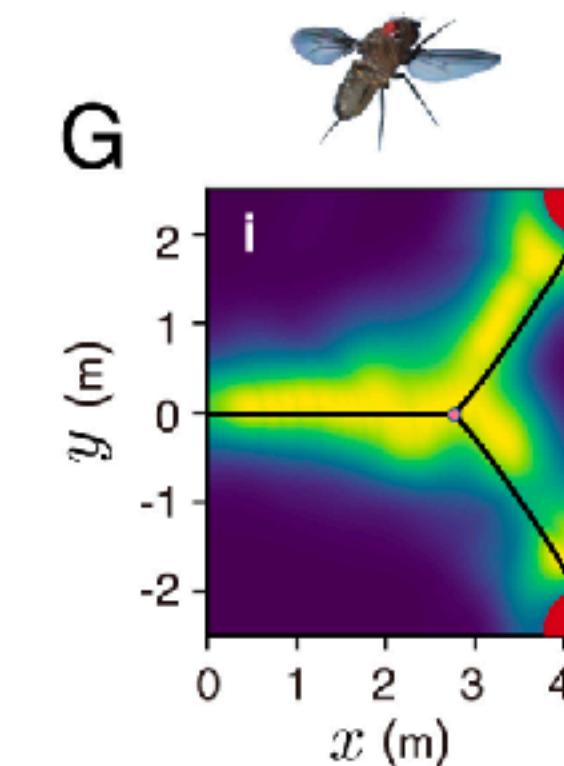
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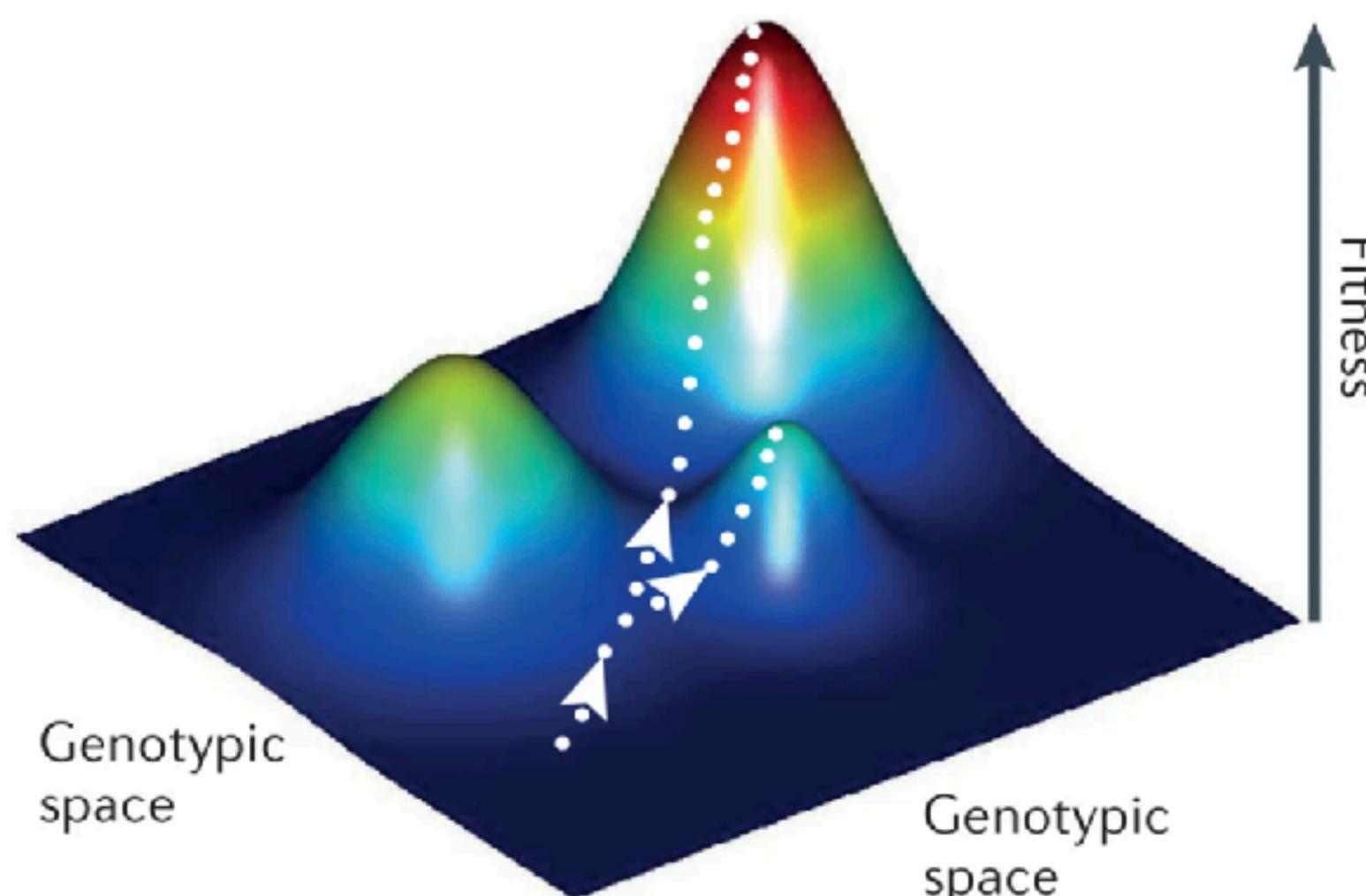
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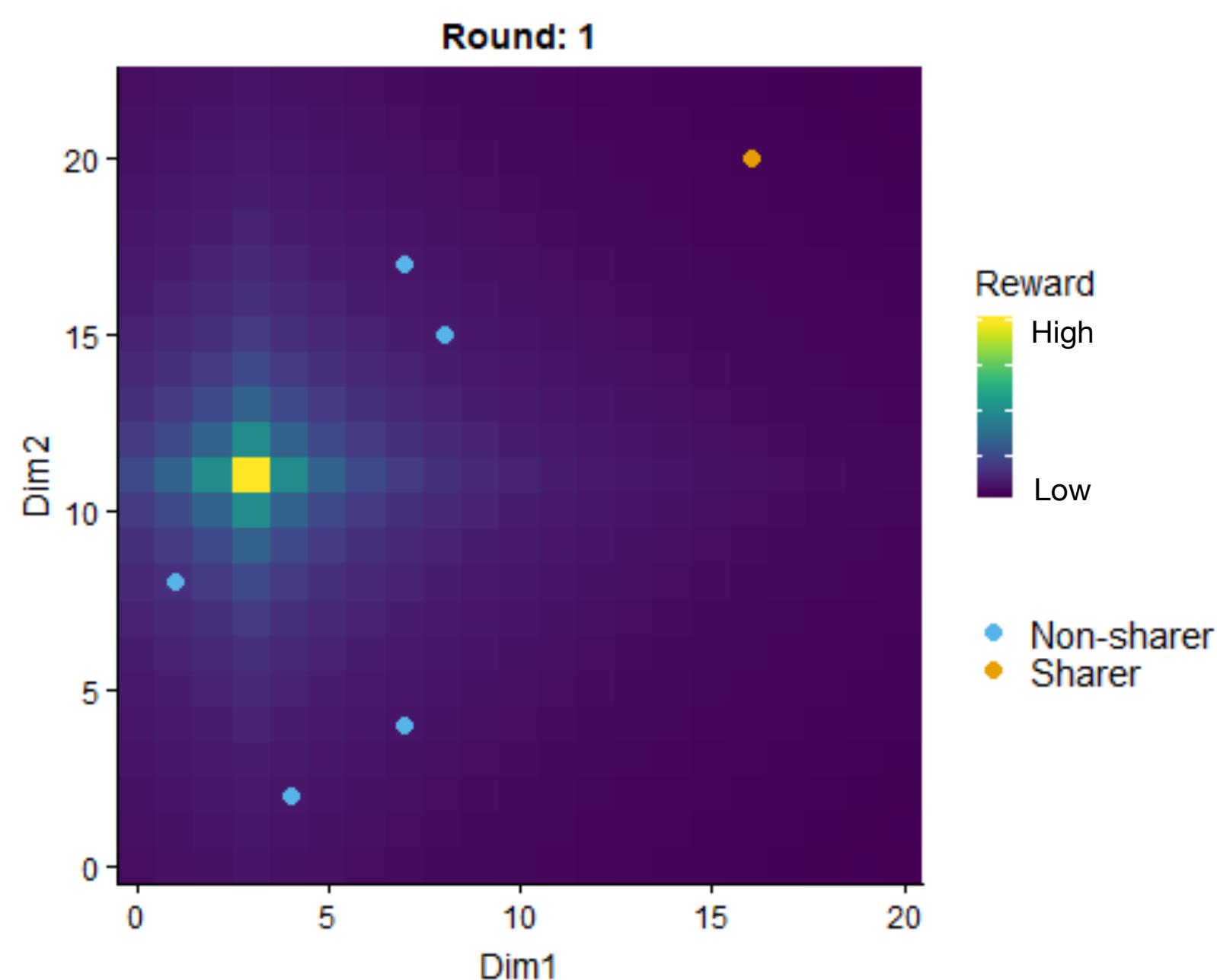
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# ③ High dimensional fitness landscapes

# Fitness landscape

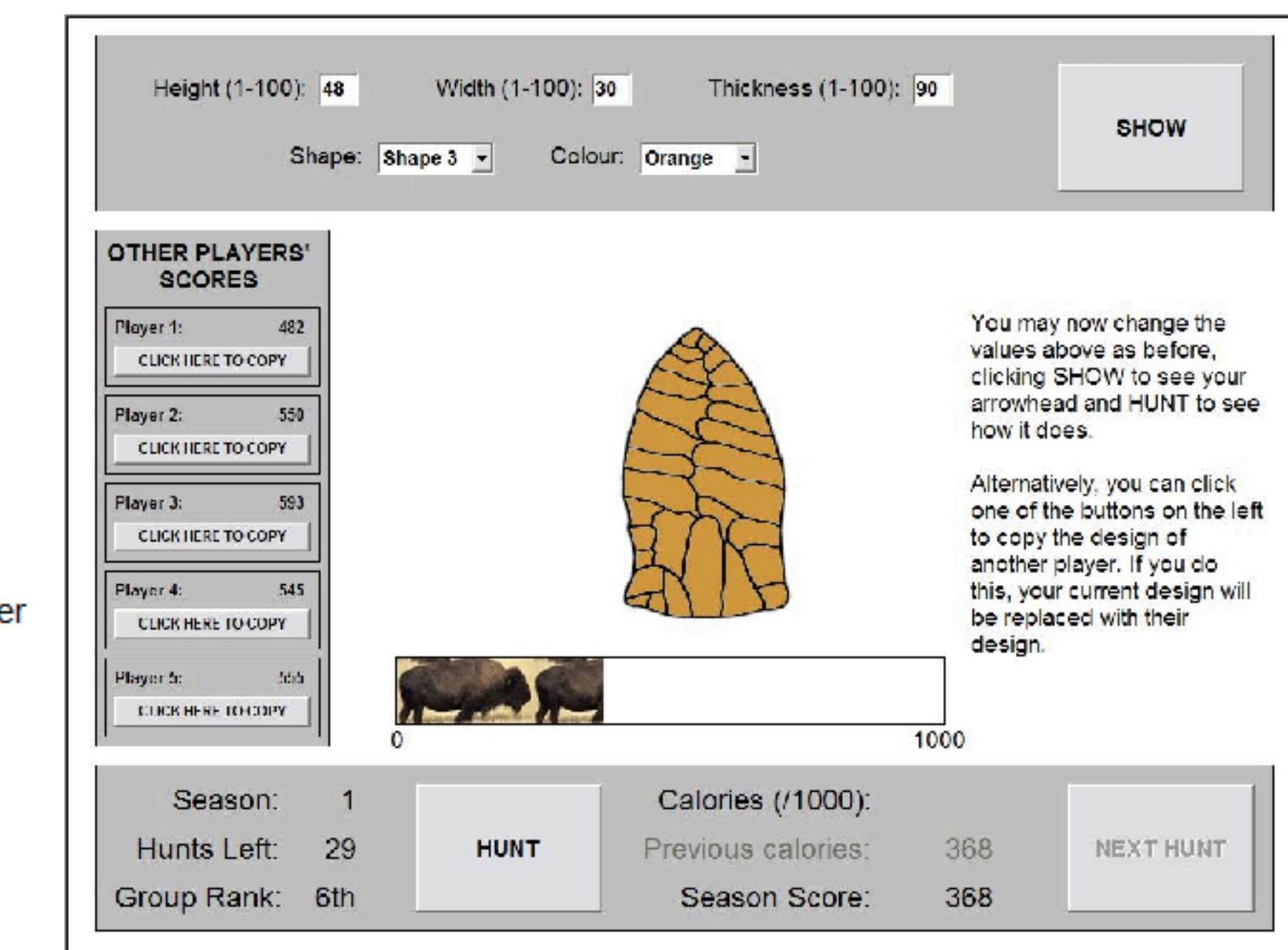


# Collective search



Tump, A. N., Wu, C. M., Bouhlel, I., & Goldstone, R. L. (2019). The evolutionary dynamics of cooperation in collective search. *bioRxiv*, 538447.

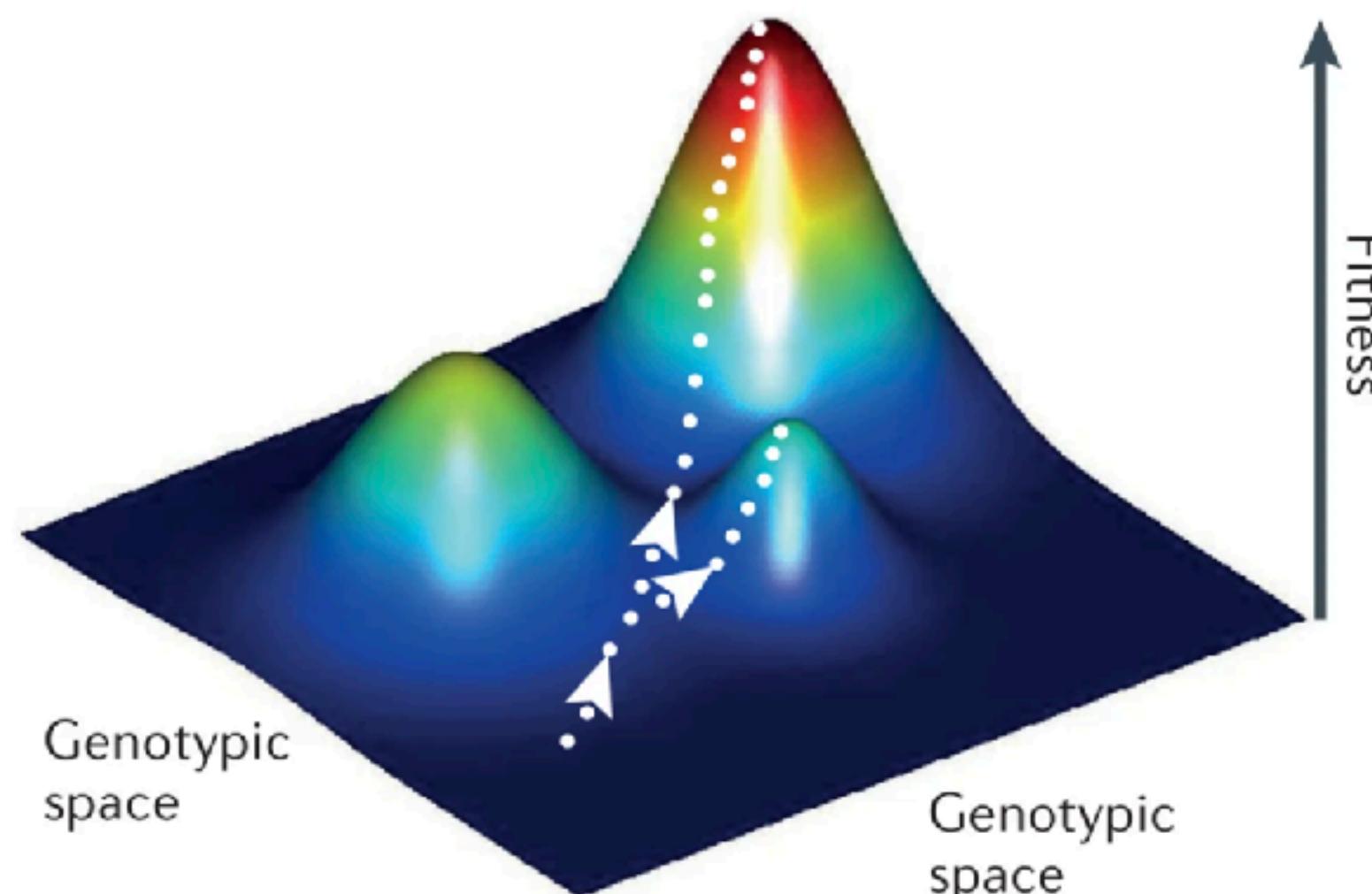
# Cultural innovation



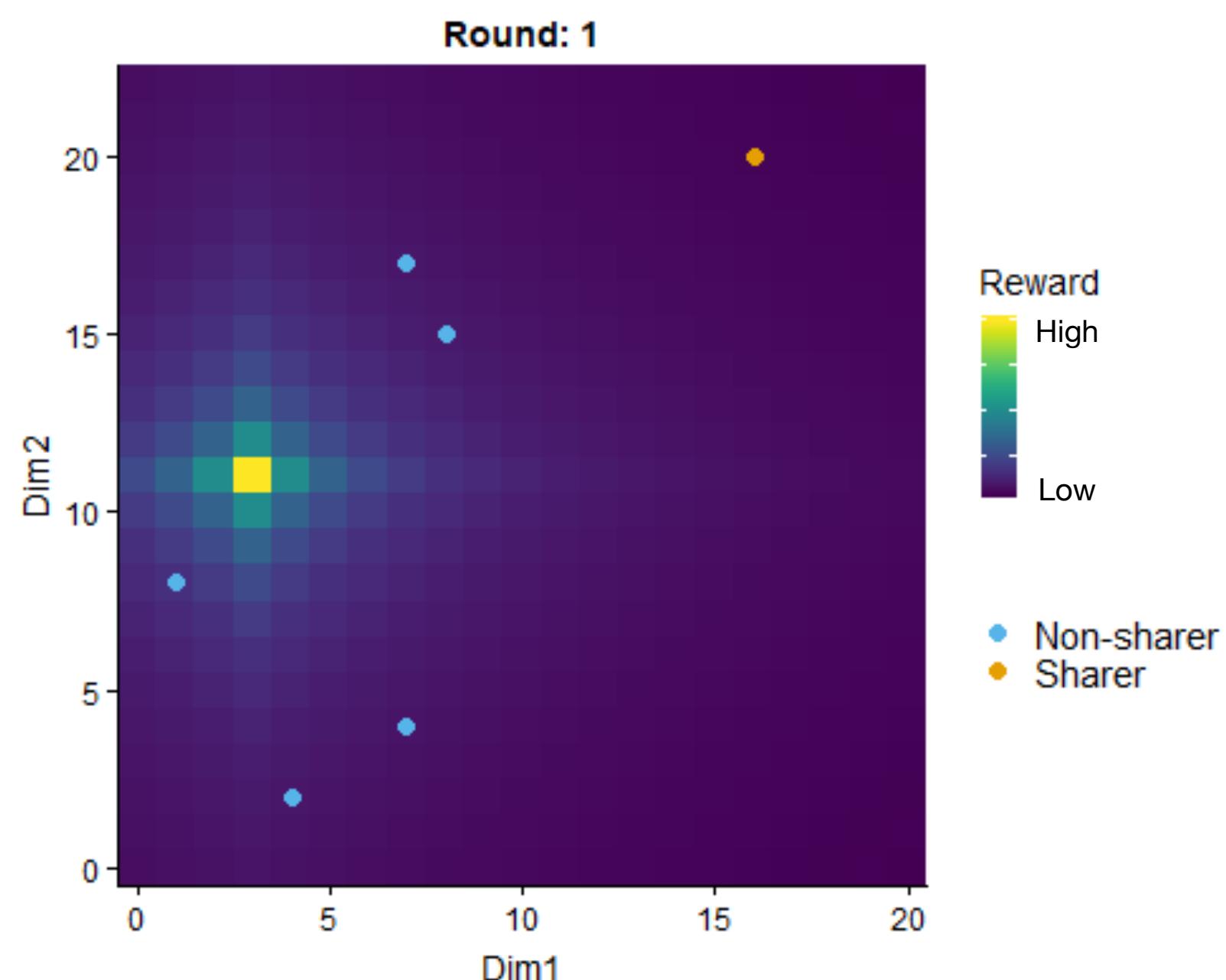
Mesoudi, A. (2011). An experimental comparison of human social learning strategies: payoff-biased social learning is adaptive but underused. *Evolution and Human Behavior*, 32(5), 334-342.

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# Fitness landscape

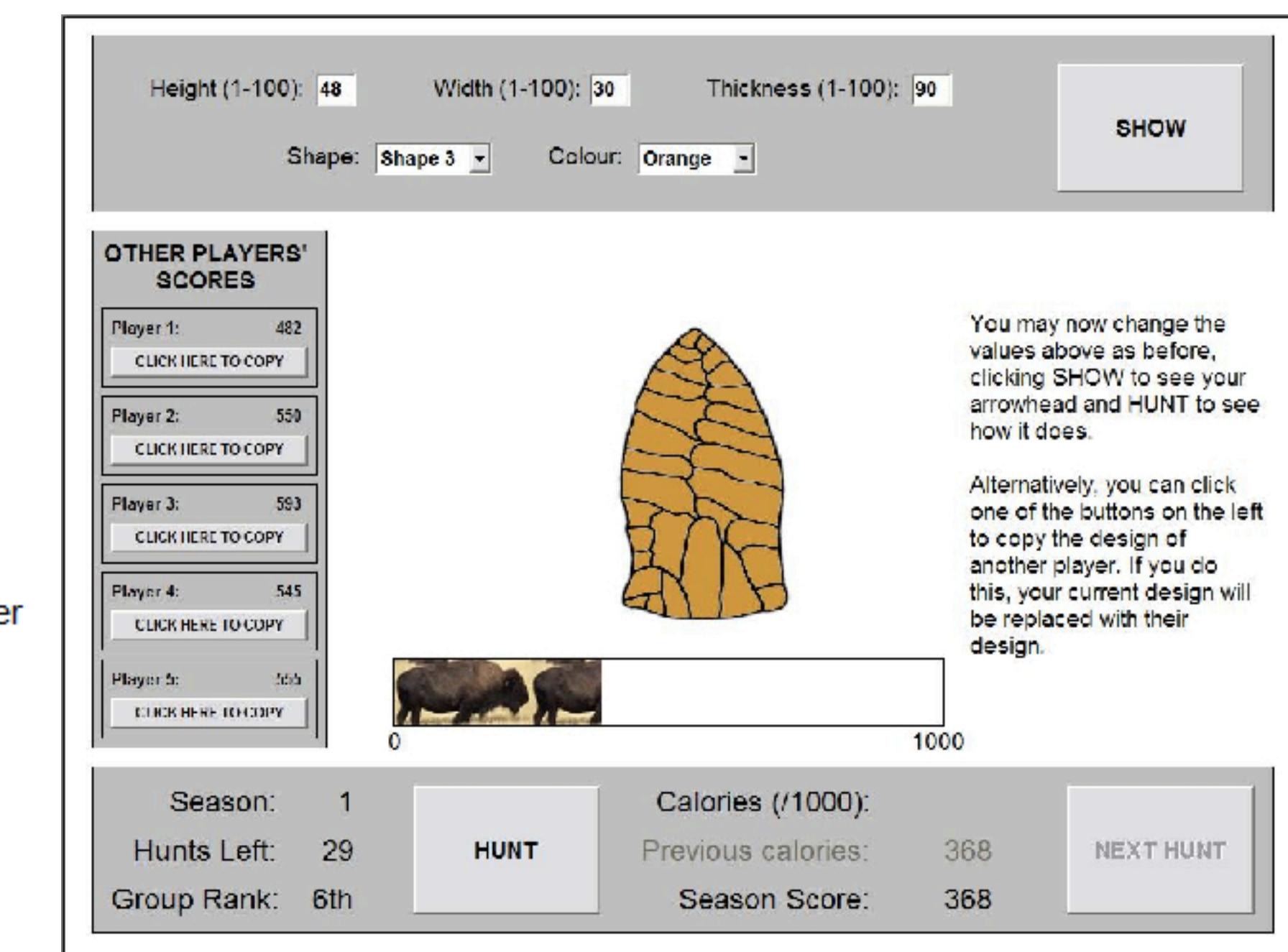


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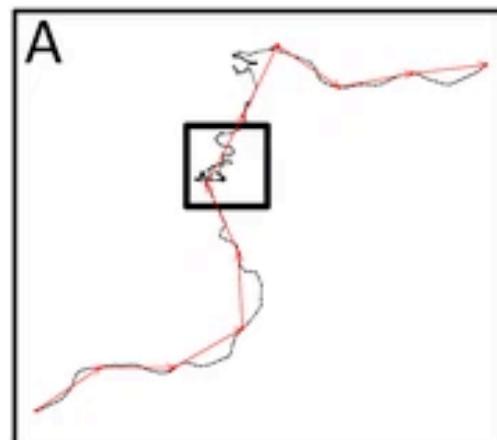
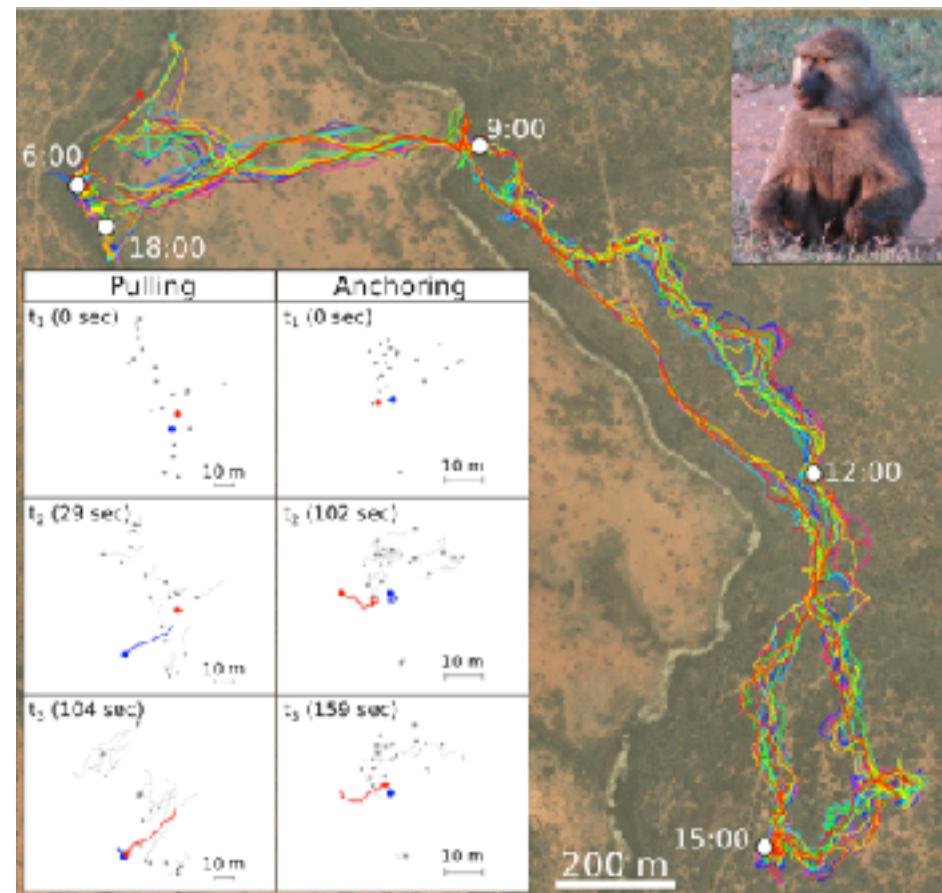
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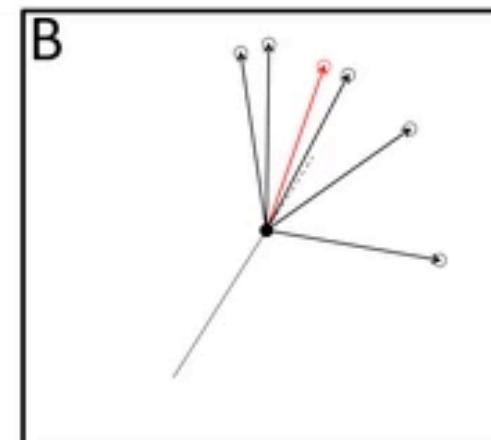


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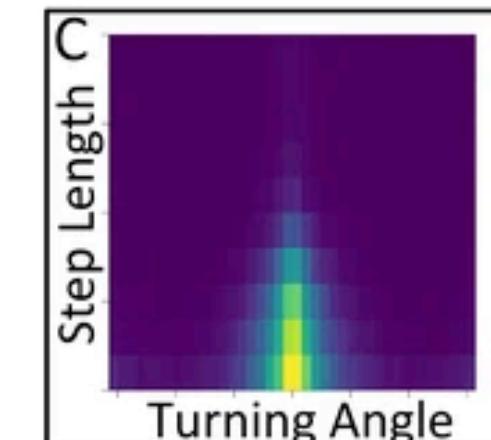
# ④ Spatial Navigation



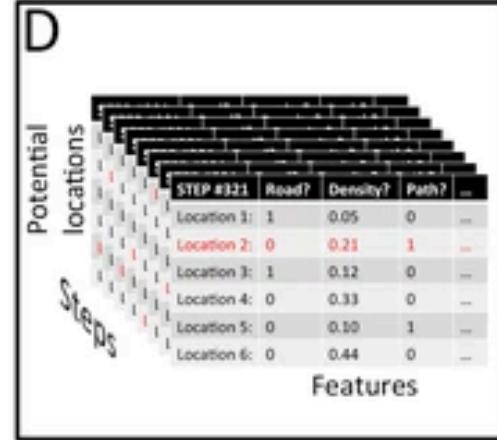
Break individual trajectory into steps.



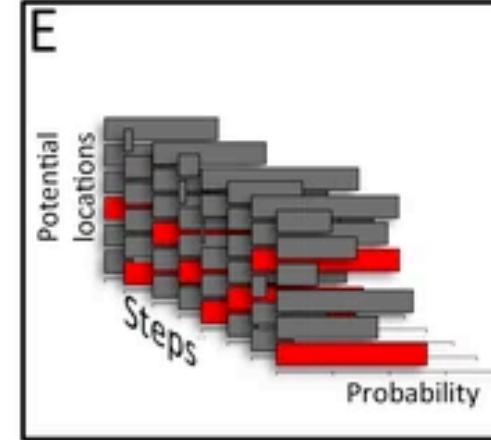
For each step, compare **real (chosen) location** to alternative locations...



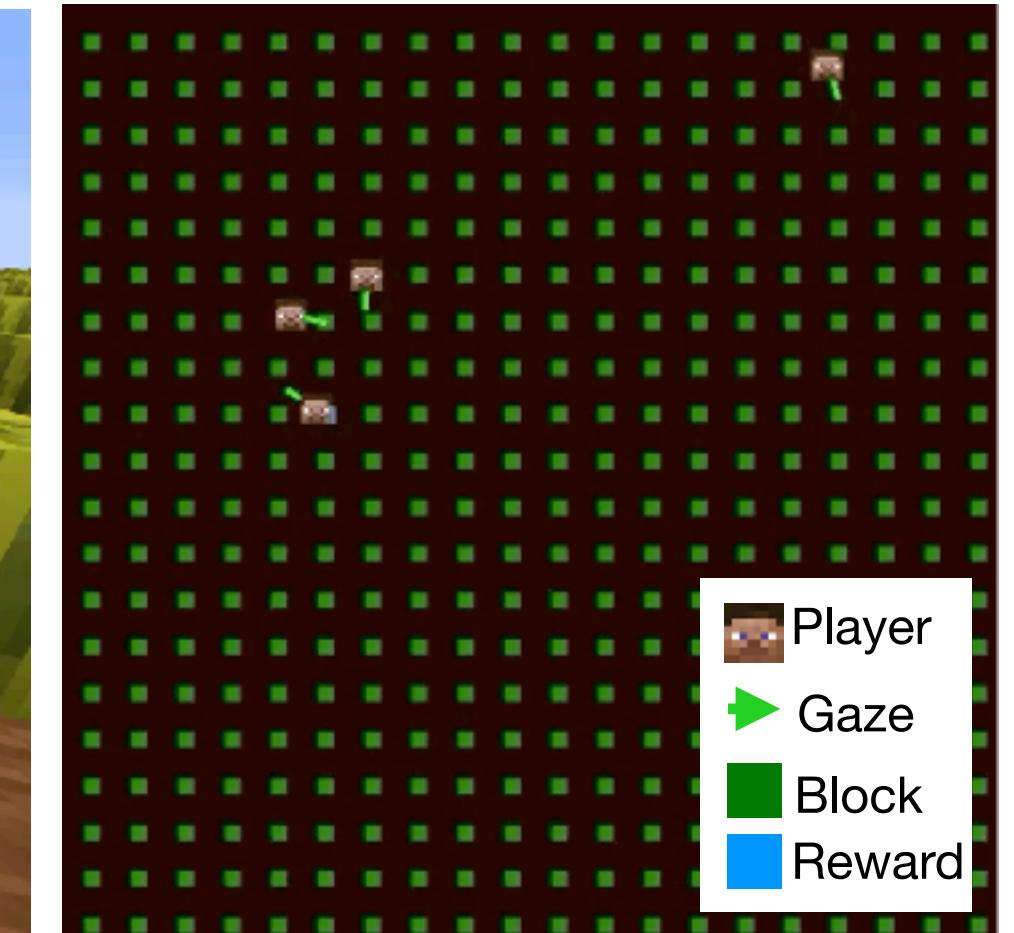
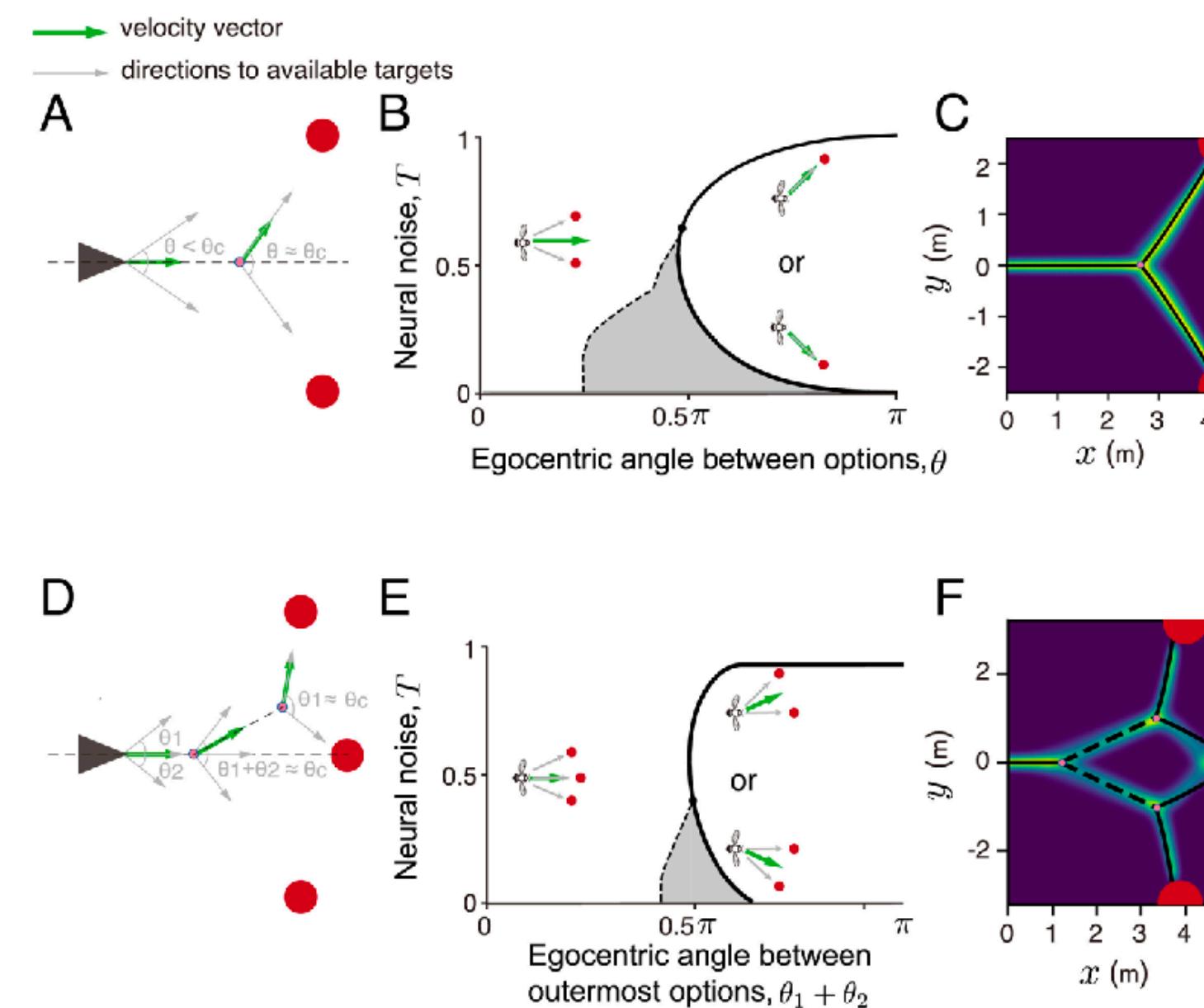
...drawn from individual's step length / turning angle distribution.



Extract features from each potential location (including **chosen** and alternative locations).



Fit a probabilistic model based on features to distinguish **chosen** location from amongst potential locations for each step.

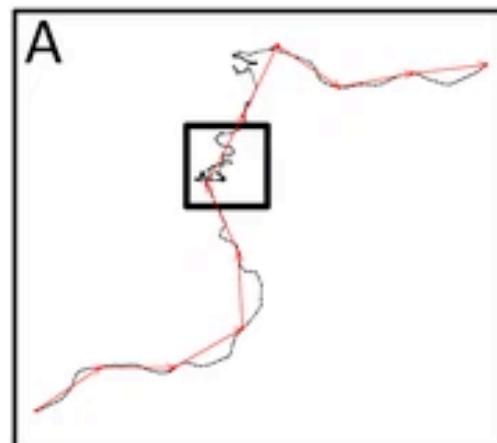
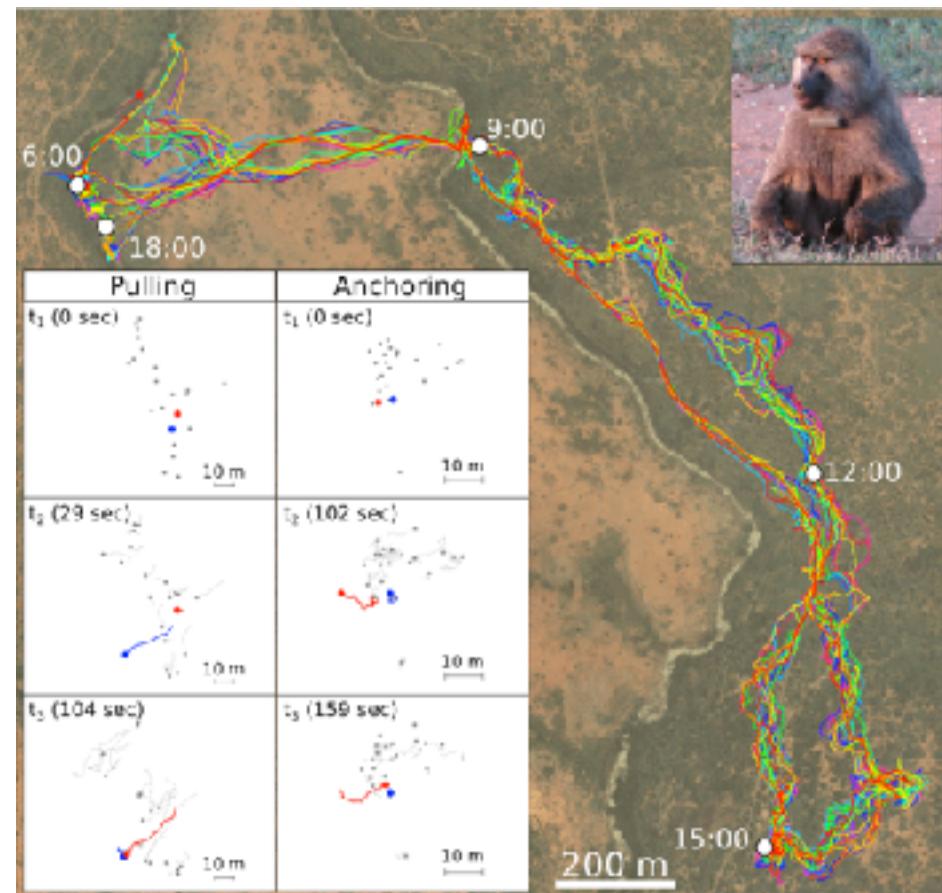


Strandburg-Peshkin, A., et al. (2017). Habitat and social factors shape individual decisions and emergent group structure during baboon collective movement. *elife*, 6, e19505.

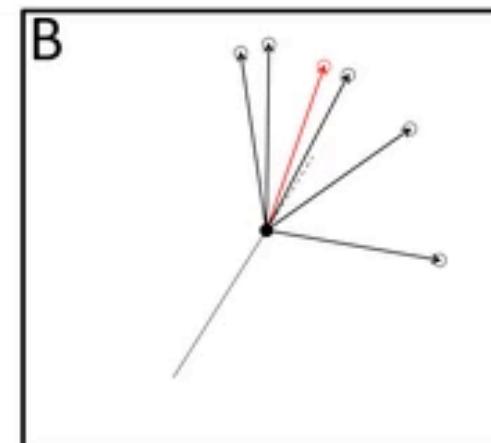
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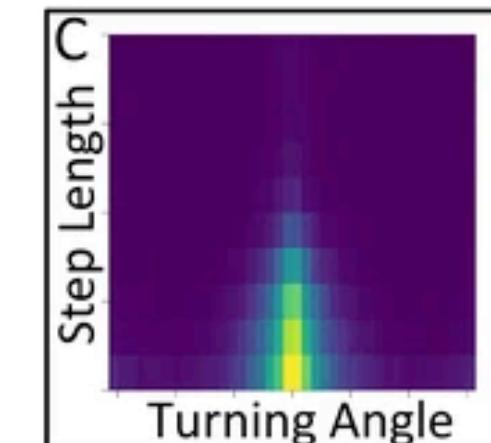
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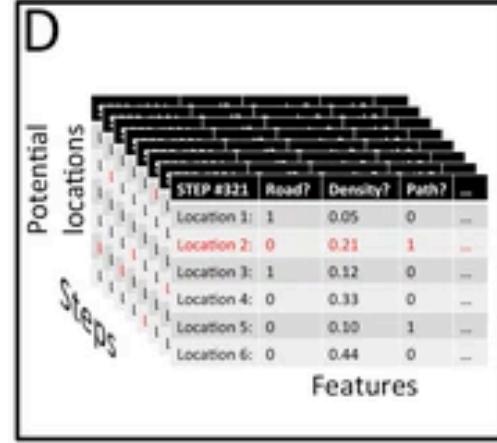
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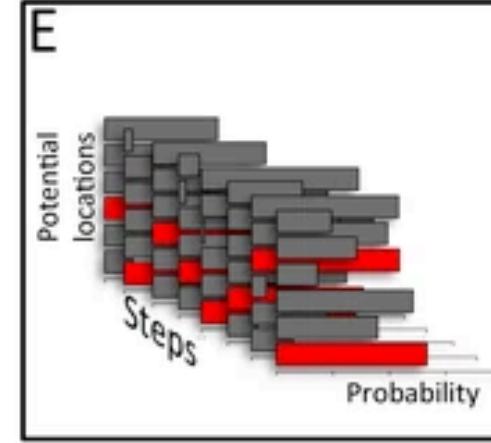
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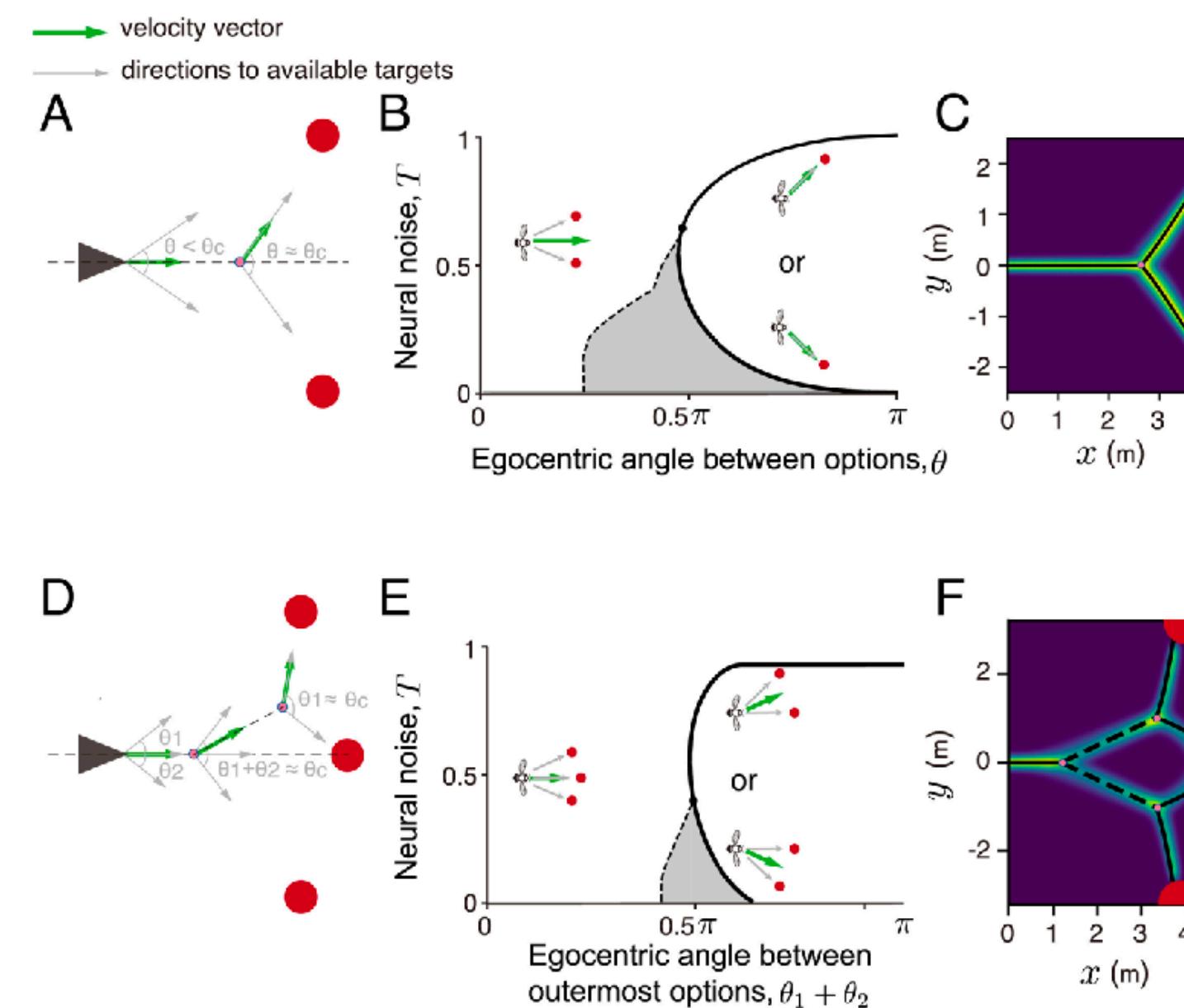
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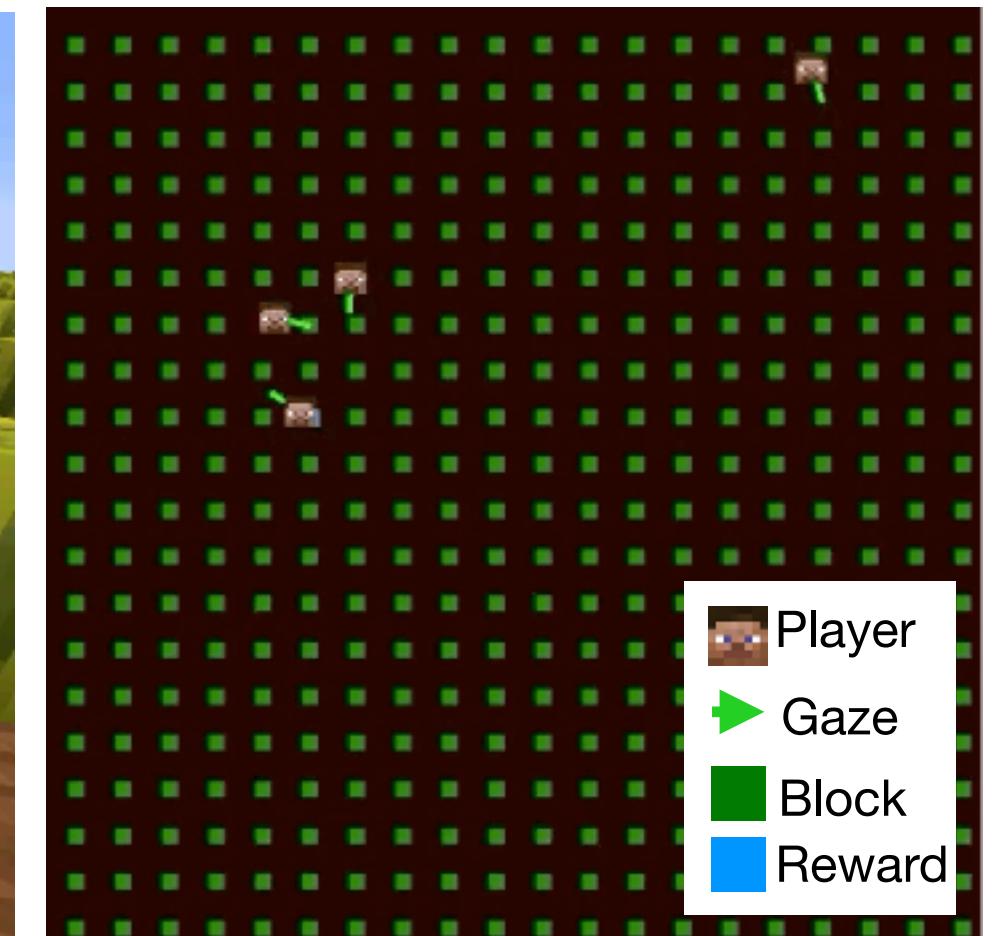
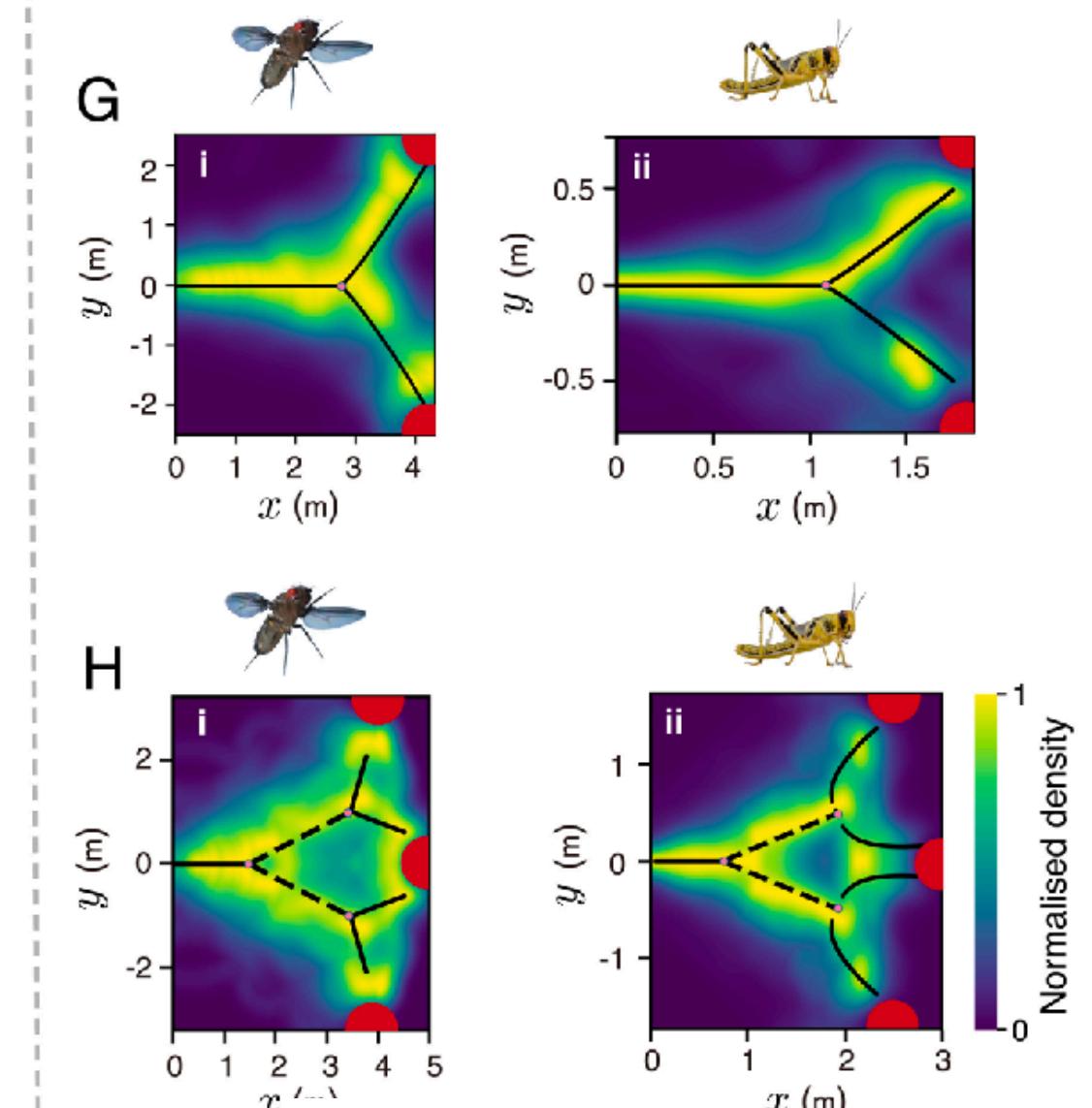
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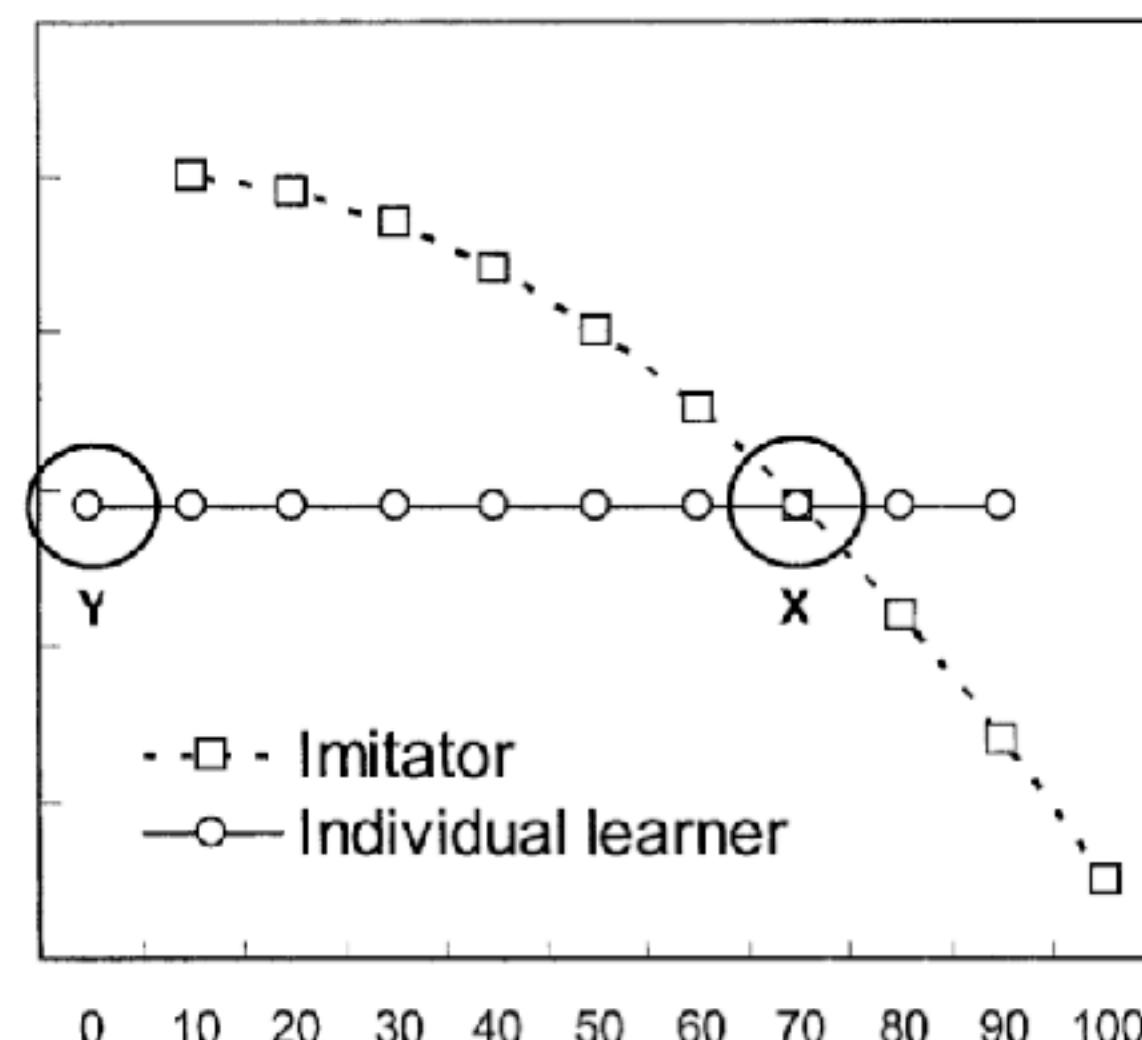
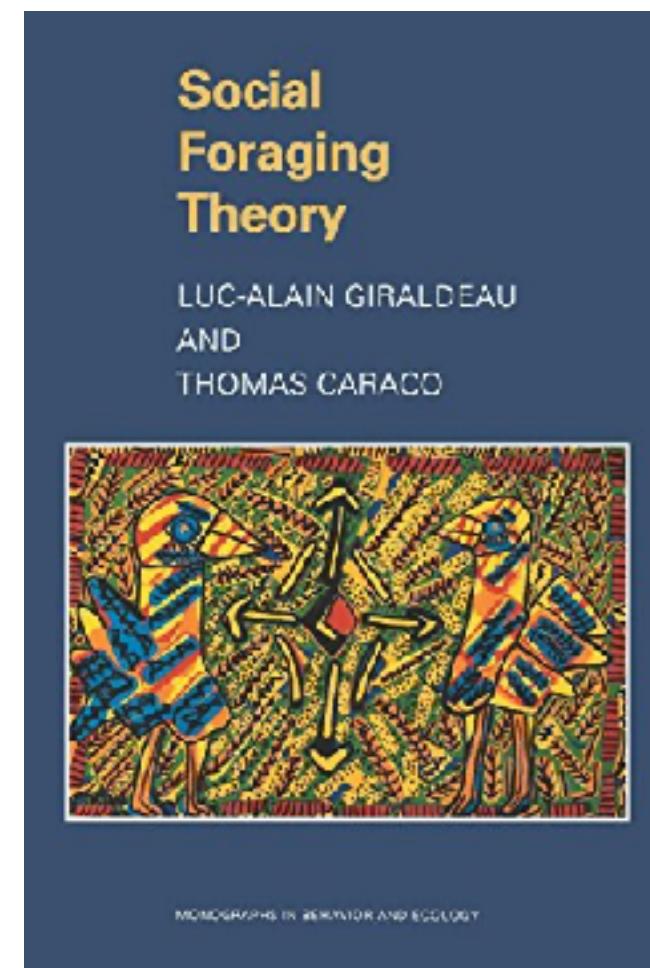
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# ⑤ Social learning as a public goods dilemma



- Information search incurs some costs (energy, predation risks, missing opportunities, etc)
- Information becomes public goods (free-riders (scroungers) emerge)
- Roger's paradox

Keynan, O., Ridley, A. R., & Lotem, A. (2015). Social foraging strategies and acquisition of novel foraging skills in cooperatively breeding Arabian babblers. *Behavioral Ecology*, 26(1), 207-214.  
Kameda, T., & Nakanishi, D. (2003). Does social/cultural learning increase human adaptability?: Rogers's question revisited. *Evolution and Human Behavior*, 24(4), 242-260.

## scrounger

/'skraʊndʒə/

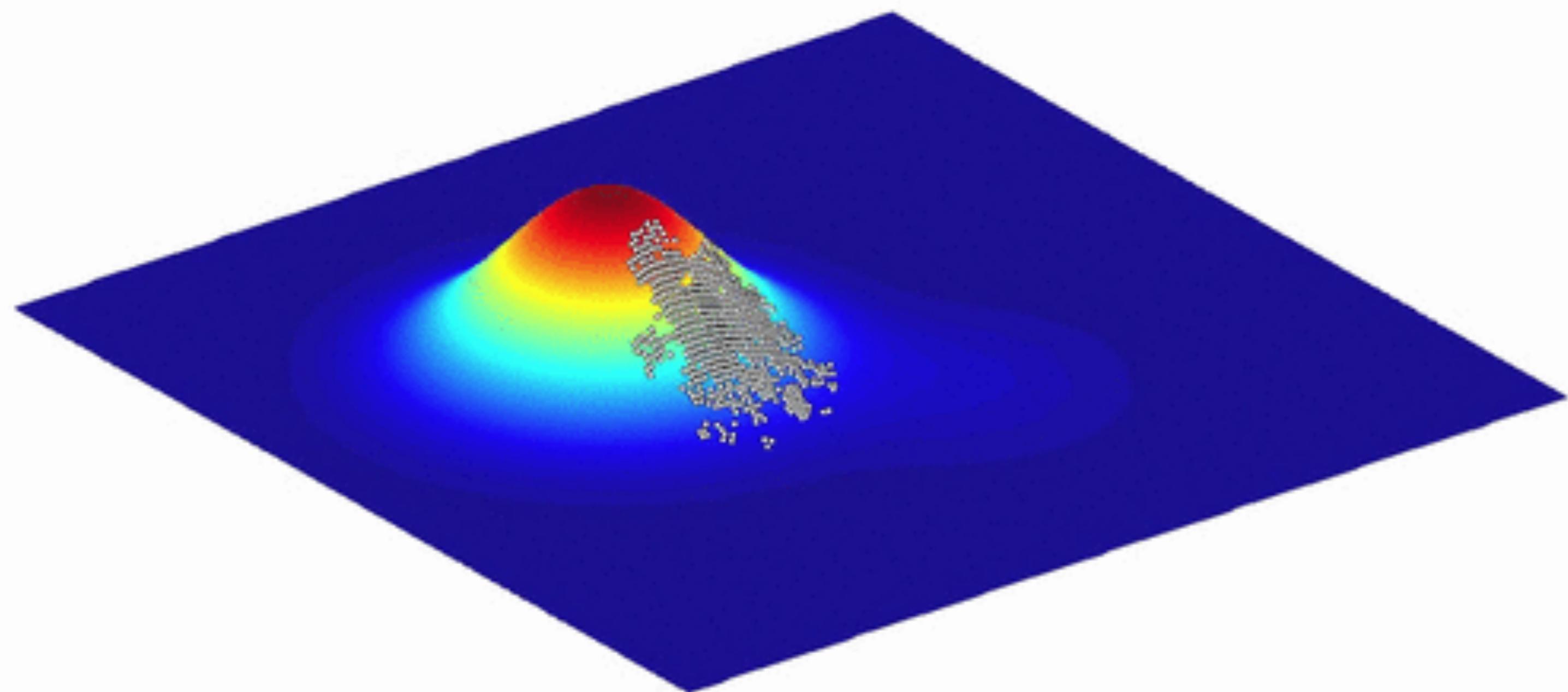
*noun* INFORMAL • DEROGATORY

a person who borrows from or lives off others.

"welfare scroungers"

*synonyms:* beggar, borrower, parasite, scrounge, cadger; [More](#)

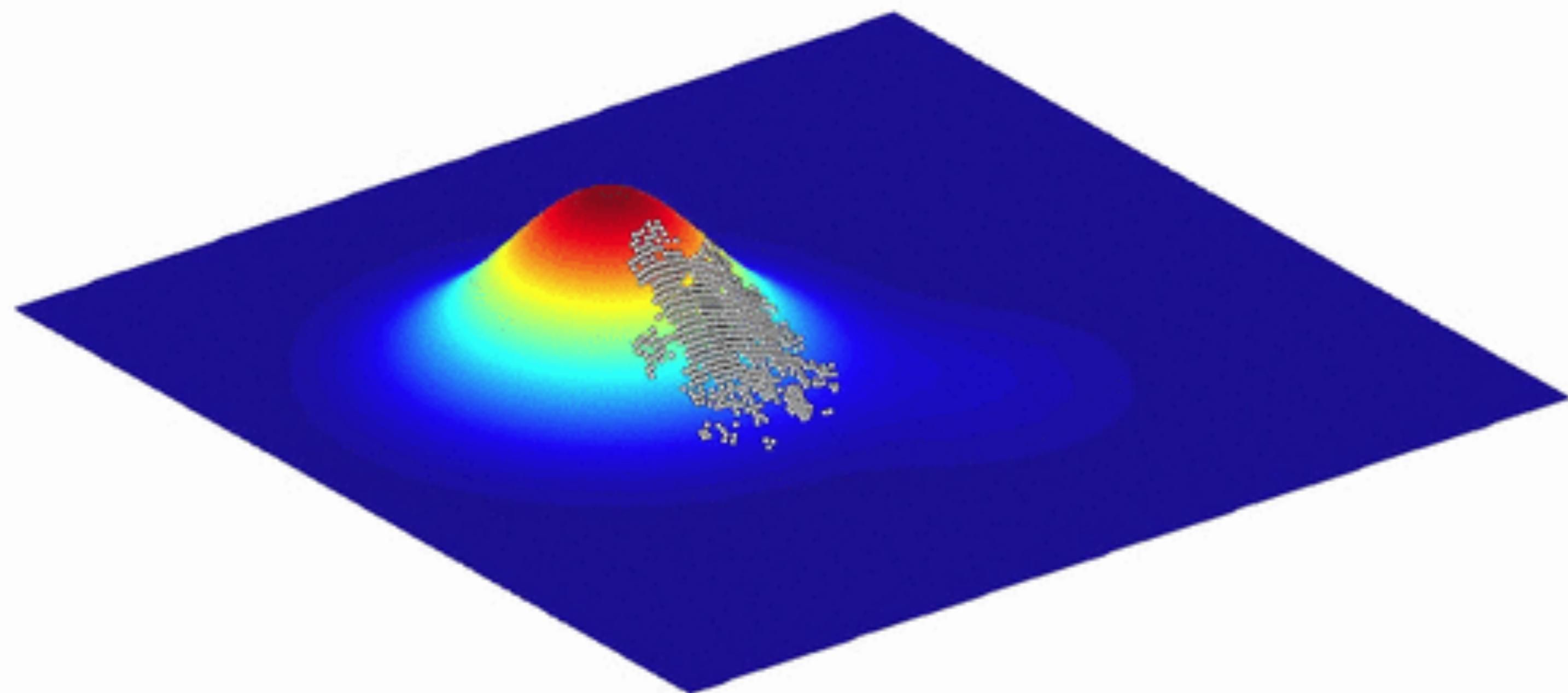
# Dynamic fitness landscape



Population size,  $N = 2,304$   
Mutation rate,  $\mu = 0.5$  per trait

© Randy Olson and Bjørn Østman

# Dynamic fitness landscape



Population size,  $N = 2,304$   
Mutation rate,  $\mu = 0.5$  per trait

© Randy Olson and Bjørn Østman

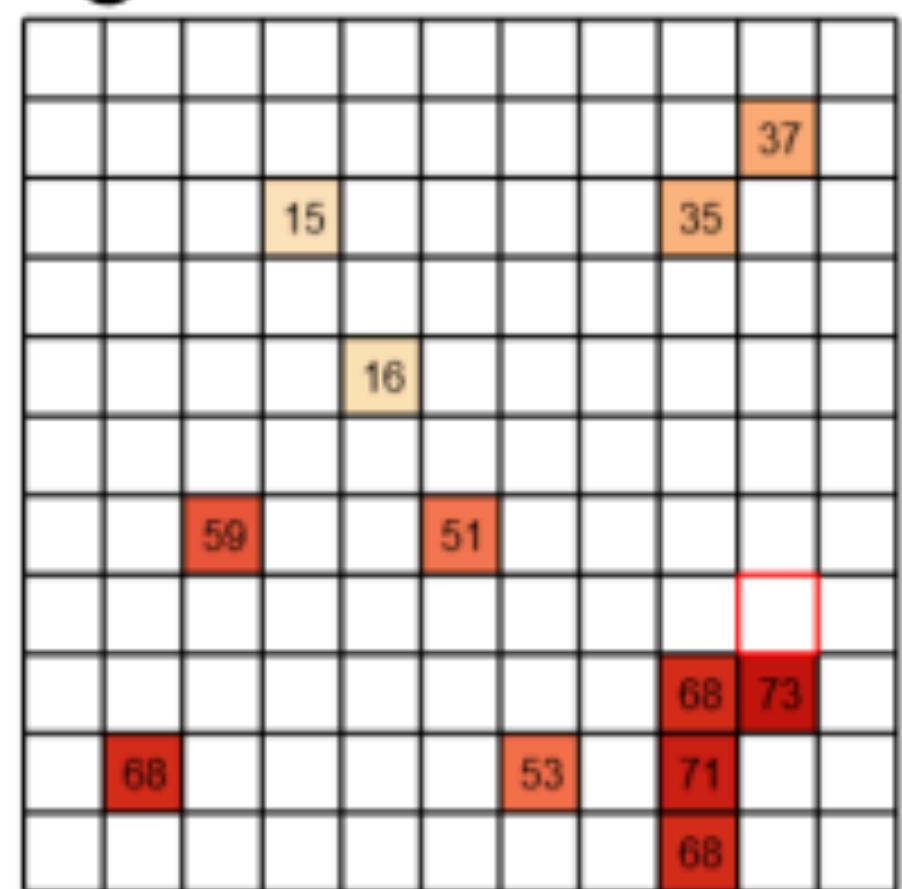
# Individual differences

**a**

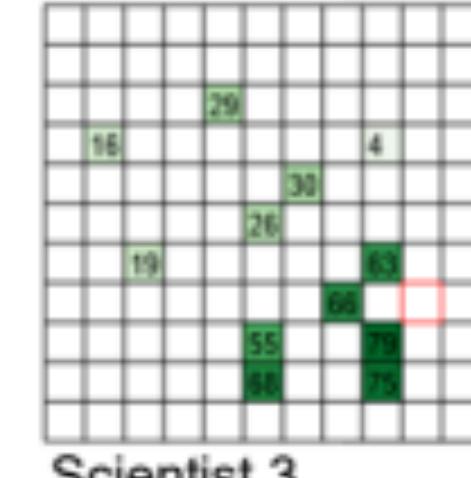
Gather as much salt as possible  
within 14 clicks

Salt concentration is correlated  
spatially...

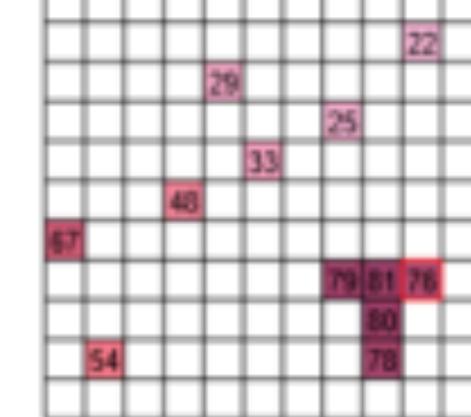
.... as well as socially



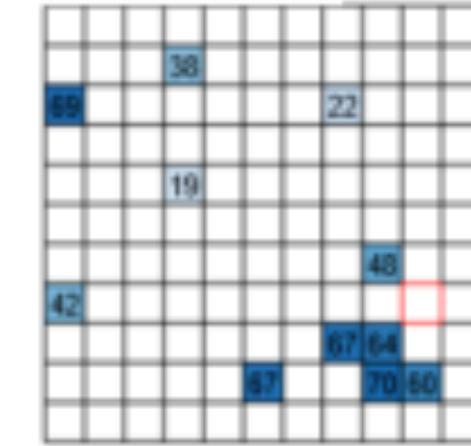
Scientist 2



Scientist 3

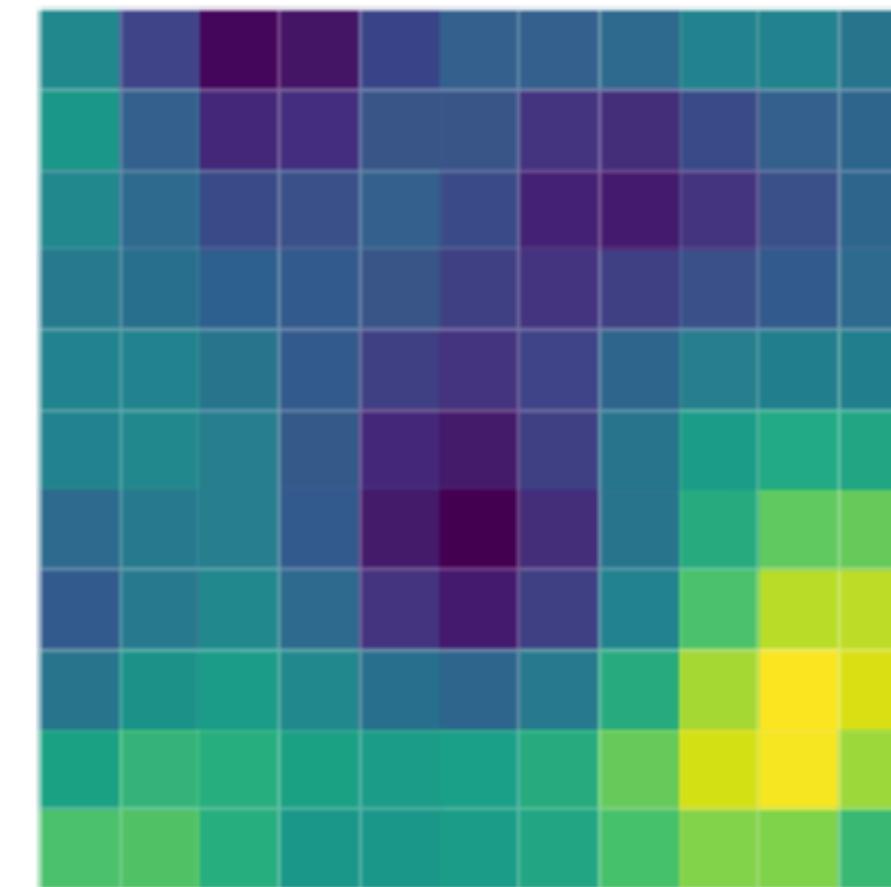


Scientist 4

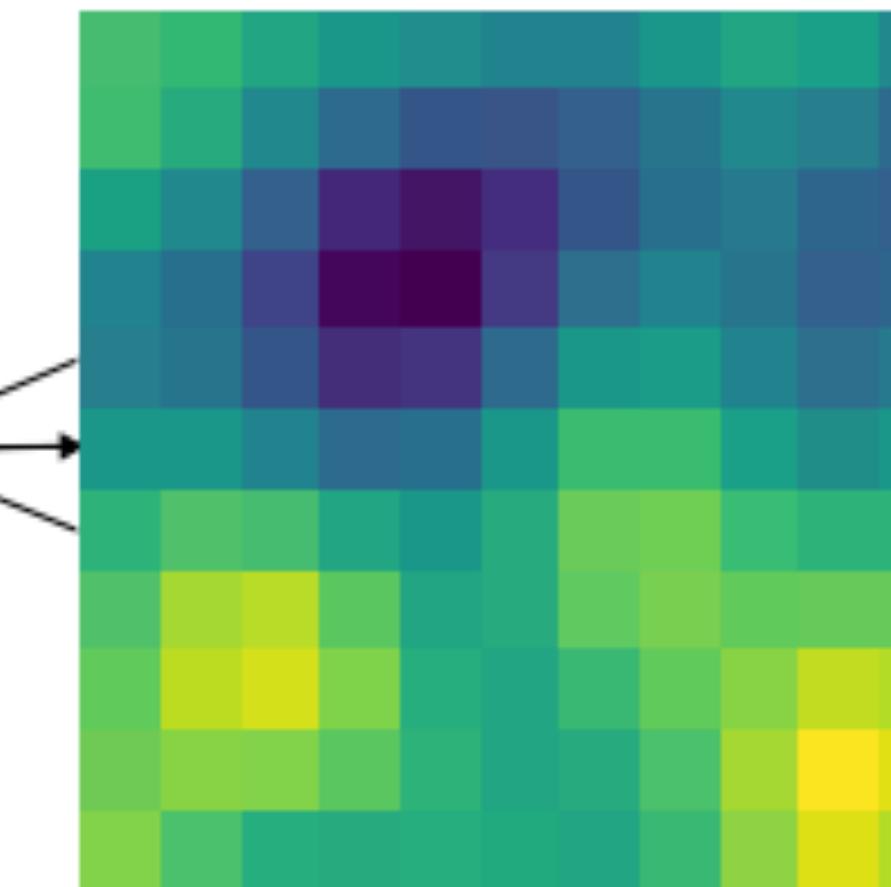


**b**

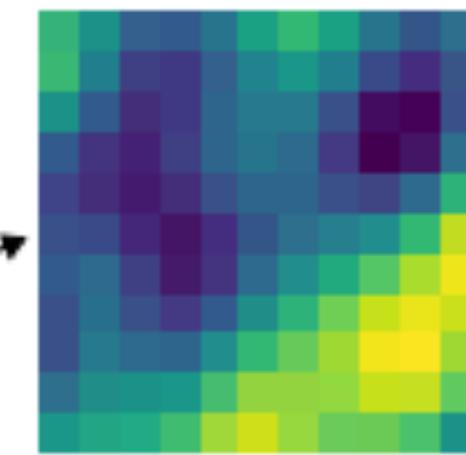
Parent



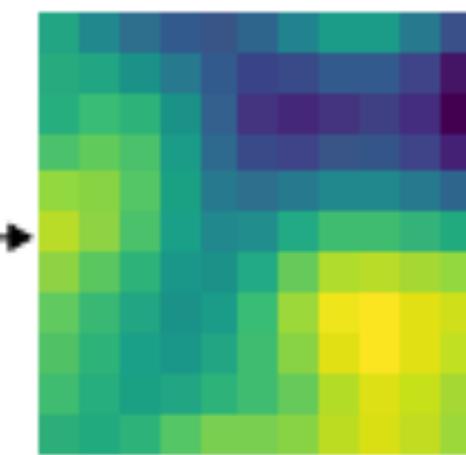
Bandit 1



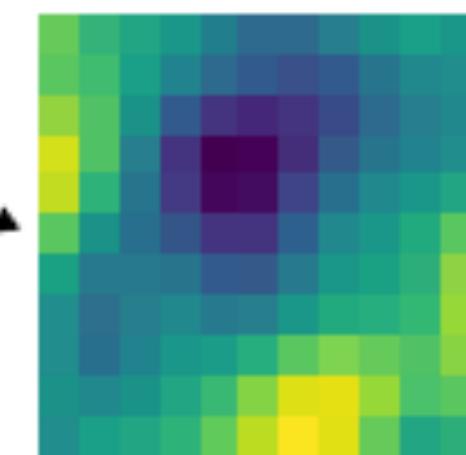
Bandit 2



Bandit 3



Bandit 4

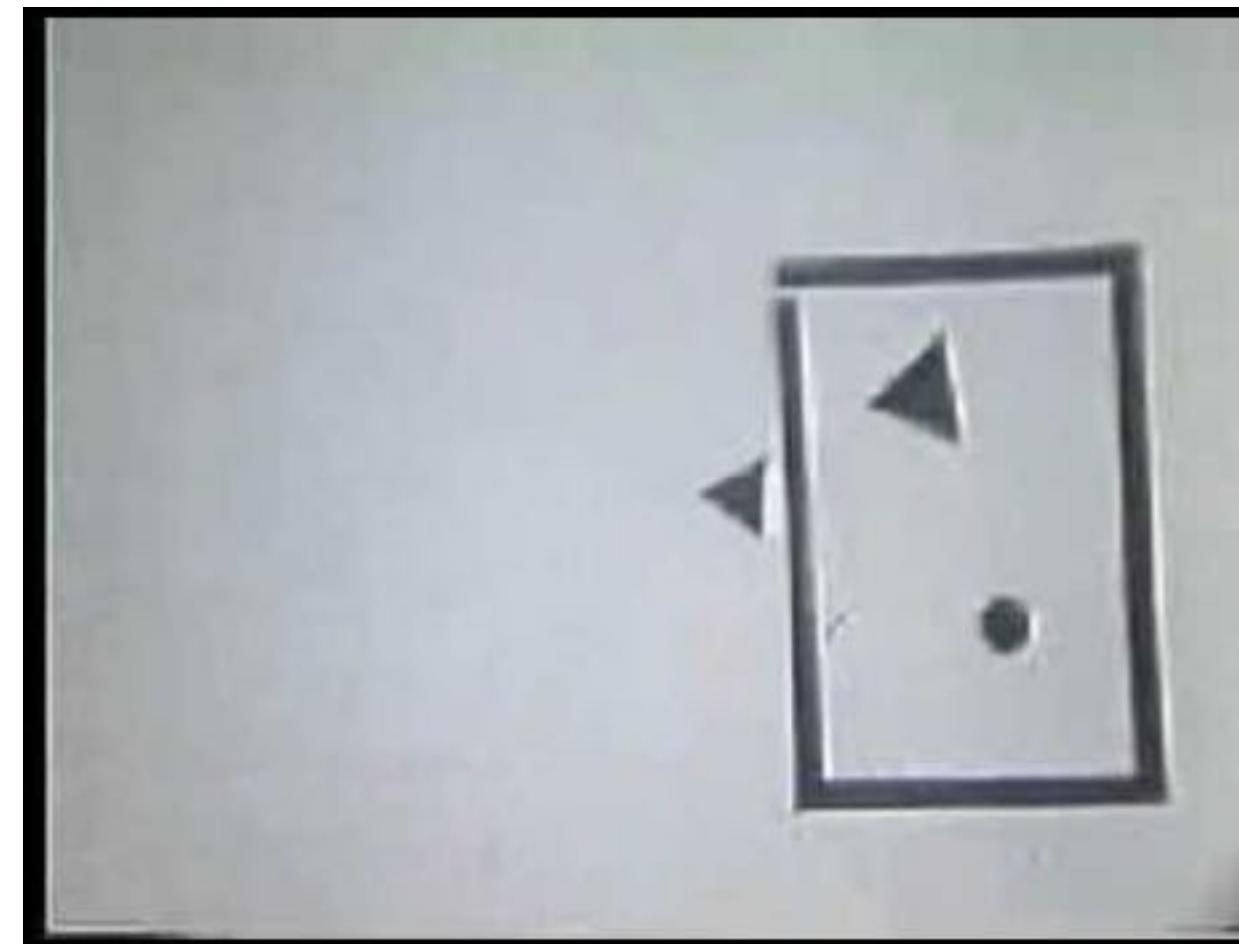


$$r_{parent.child} \geq 0.6; r_{child.child} \approx 0.6$$



## ⑥ Theory of Mind and metacognitive social learning

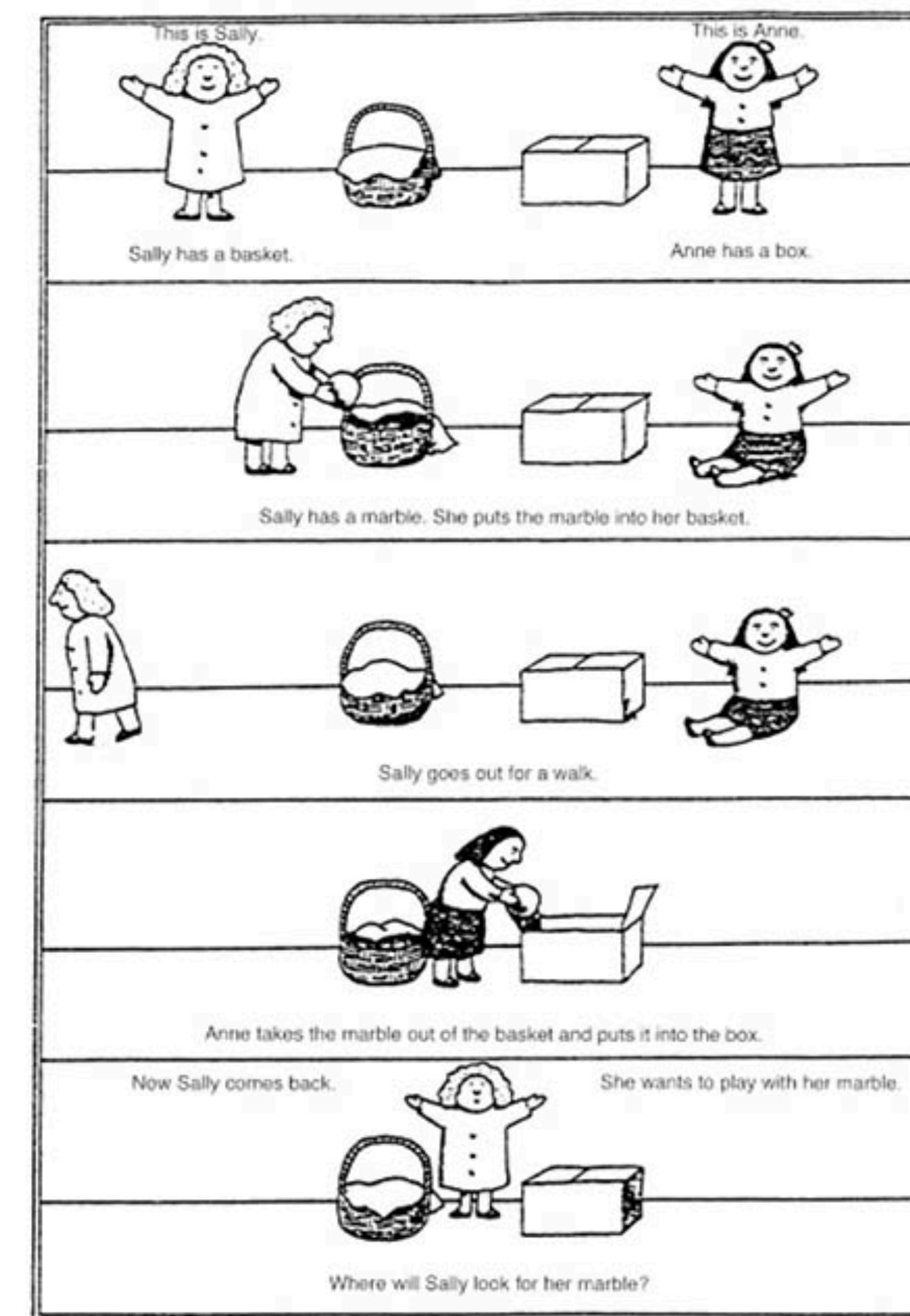
Inferring goals and beliefs from behavior



Heider, F., & Simmel, M. (1944). An experimental study of apparent behavior. *The American Journal of Psychology*, 57, 243–259.



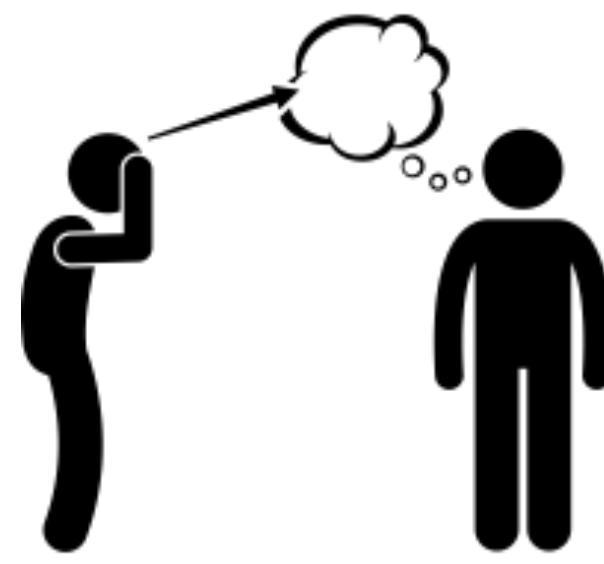
Kanakogi, Y., Miyazaki, M., Takahashi, H. et al. (2022) Third-party punishment by preverbal infants. *Nat Hum Behav* 6, 1234–1242.



Baron-Cohen, S., Leslie, A. M., & Frith, U. (1985). Does the autistic child have a “theory of mind”? *Cognition*, 21(1), 37-46.

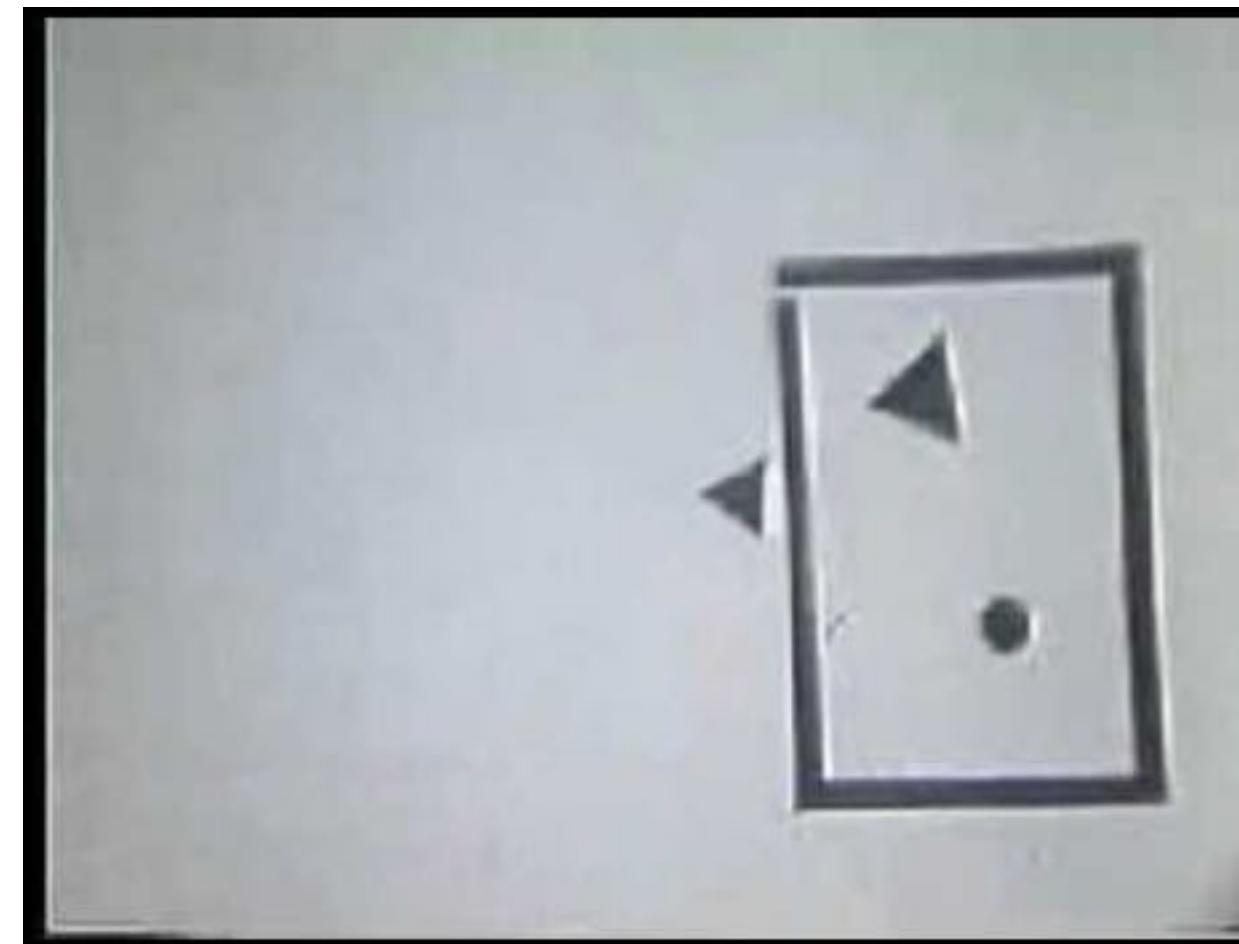


Whiten, A., & Byrne, R. W. (1988). Tactical deception in primates. *Behavioral and brain sciences*, 11(2), 233-244.



## ⑥ Theory of Mind and metacognitive social learning

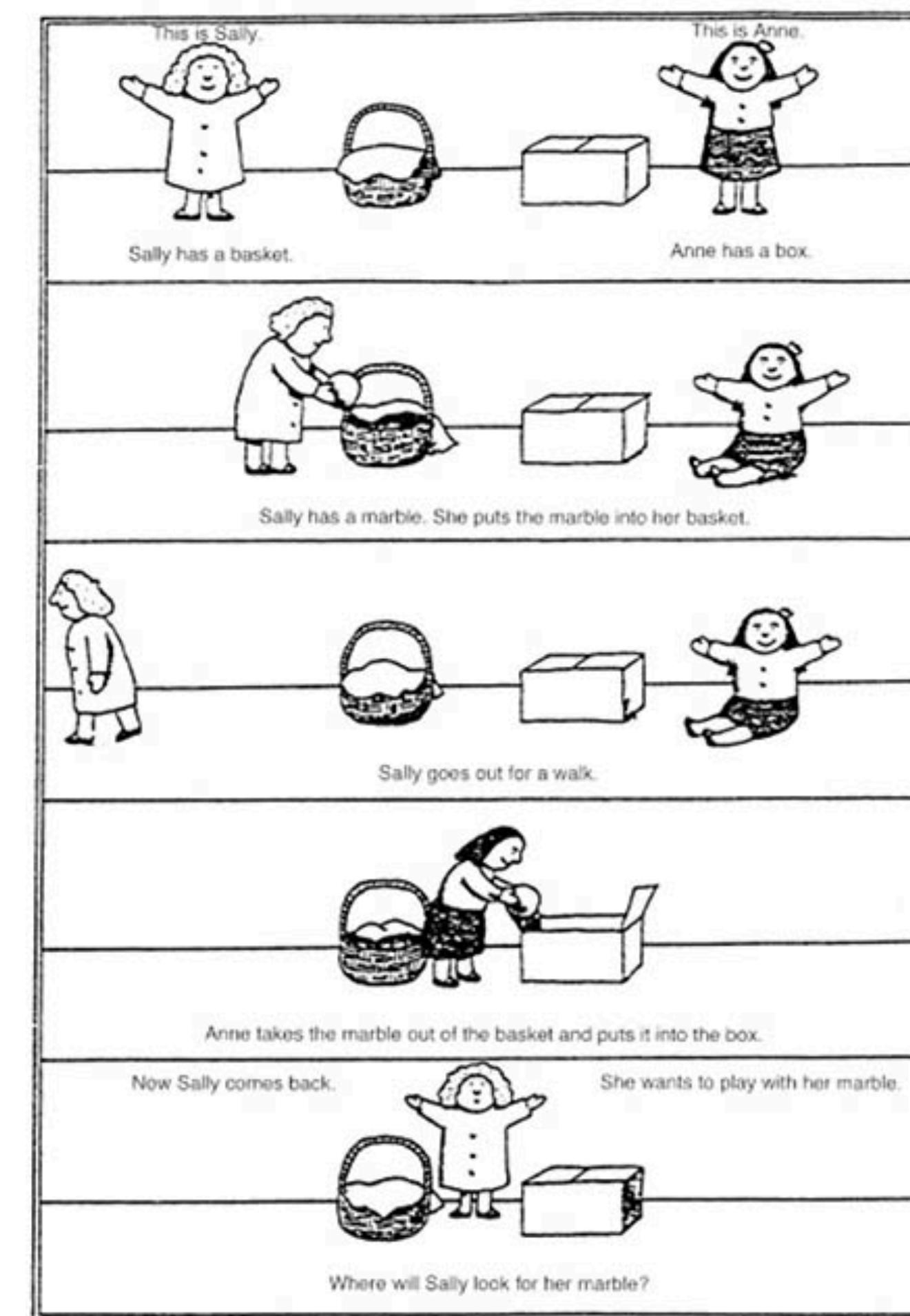
Inferring goals and beliefs from behavior



Heider, F., & Simmel, M. (1944). An experimental study of apparent behavior. *The American Journal of Psychology*, 57, 243–259.



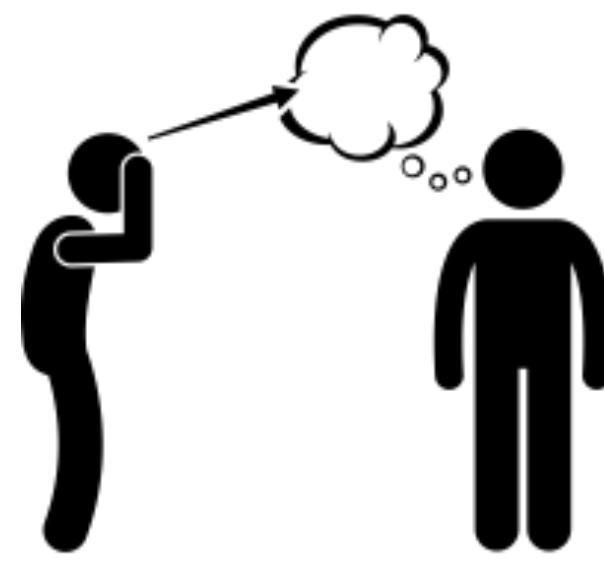
Kanakogi, Y., Miyazaki, M., Takahashi, H. et al. (2022) Third-party punishment by preverbal infants. *Nat Hum Behav* 6, 1234–1242.



Baron-Cohen, S., Leslie, A. M., & Frith, U. (1985). Does the autistic child have a “theory of mind”? *Cognition*, 21(1), 37-46.

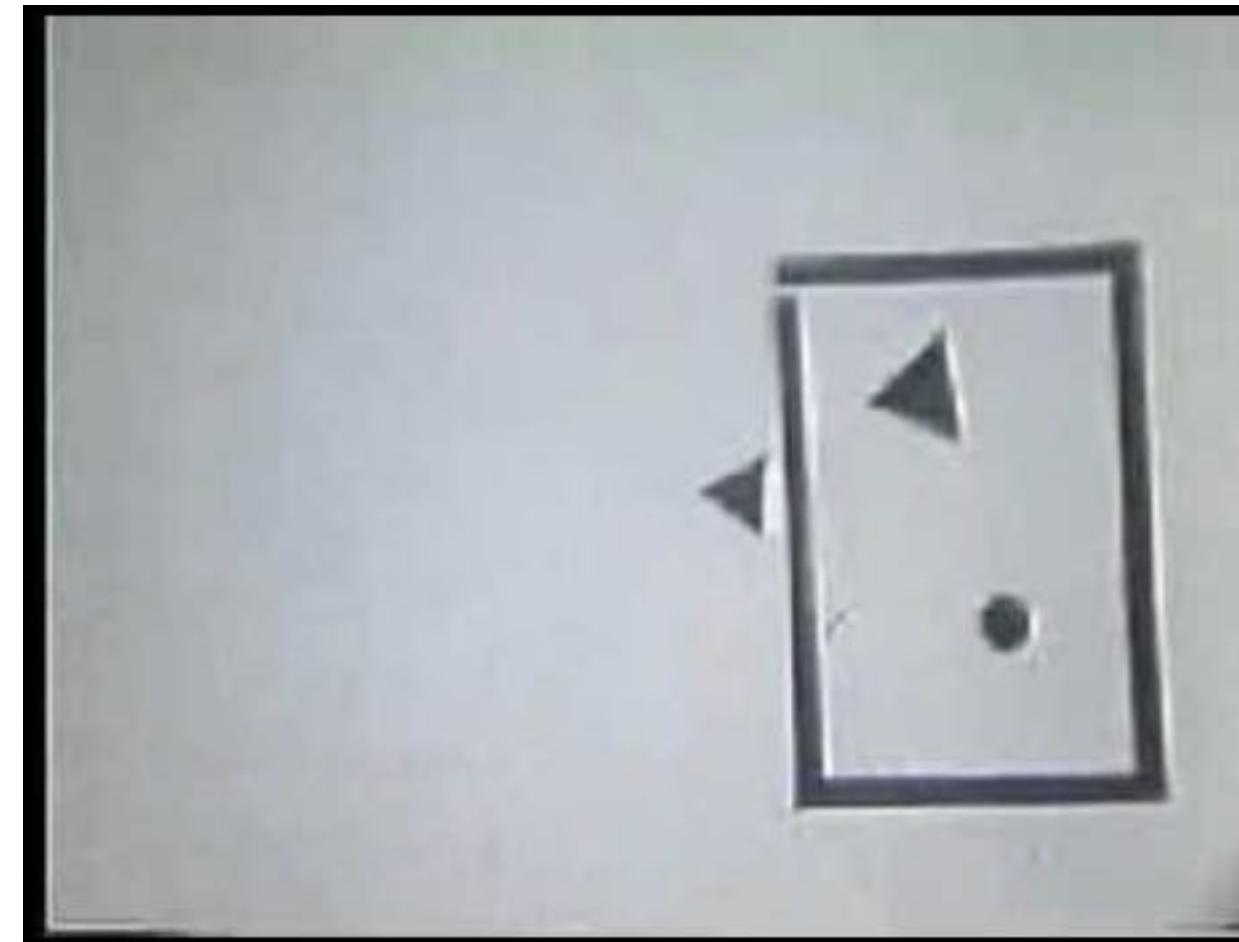


Whiten, A., & Byrne, R. W. (1988). Tactical deception in primates. *Behavioral and brain sciences*, 11(2), 233-244.



## ⑥ Theory of Mind and metacognitive social learning

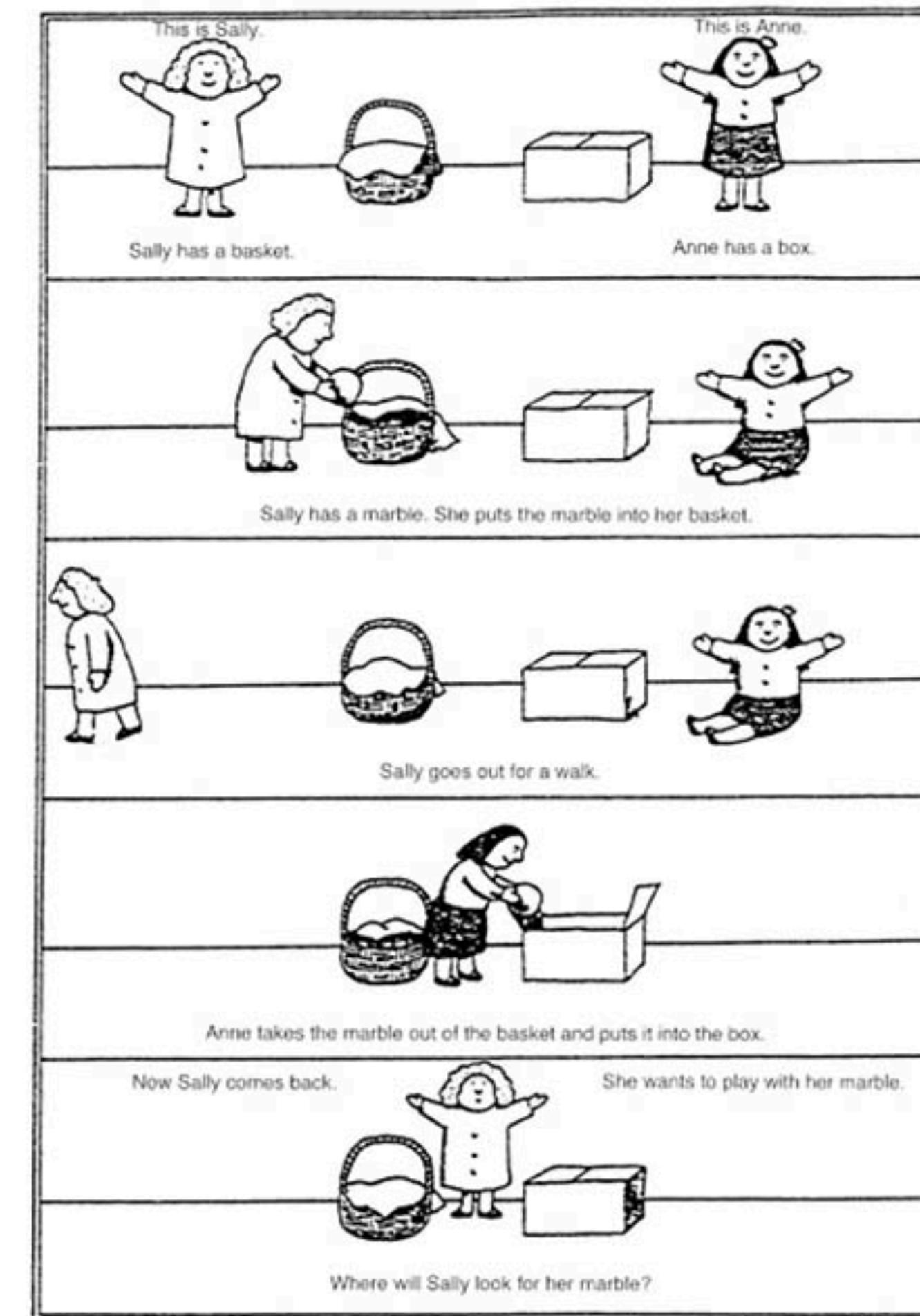
Inferring goals and beliefs from behavior



Heider, F., & Simmel, M. (1944). An experimental study of apparent behavior. *The American Journal of Psychology*, 57, 243–259.



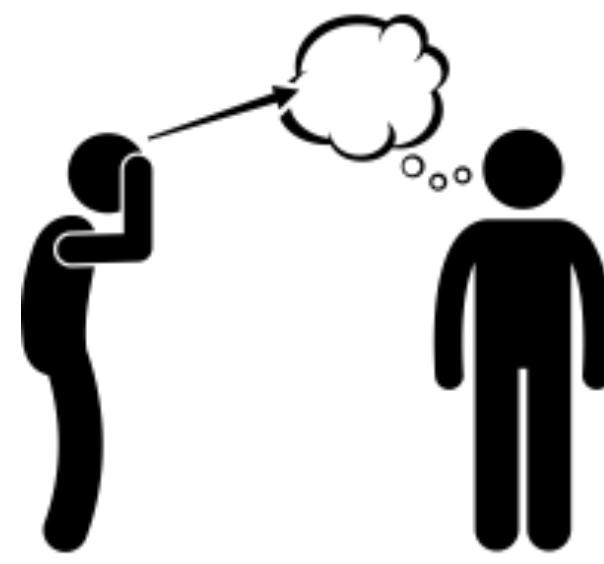
Kanakogi, Y., Miyazaki, M., Takahashi, H. et al. (2022) Third-party punishment by preverbal infants. *Nat Hum Behav* 6, 1234–1242.



Baron-Cohen, S., Leslie, A. M., & Frith, U. (1985). Does the autistic child have a “theory of mind”? *Cognition*, 21(1), 37-46.

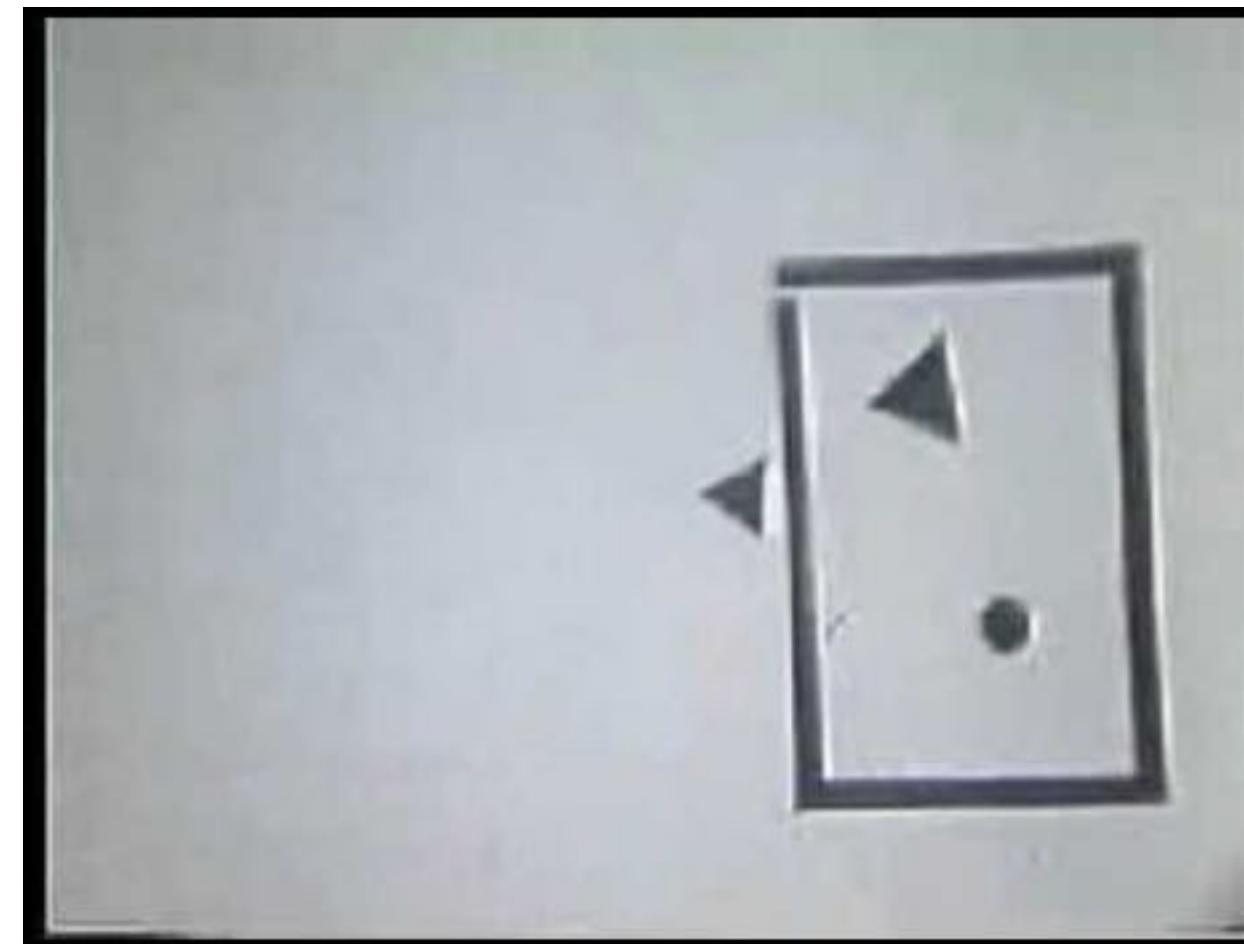


Whiten, A., & Byrne, R. W. (1988). Tactical deception in primates. *Behavioral and brain sciences*, 11(2), 233-244.

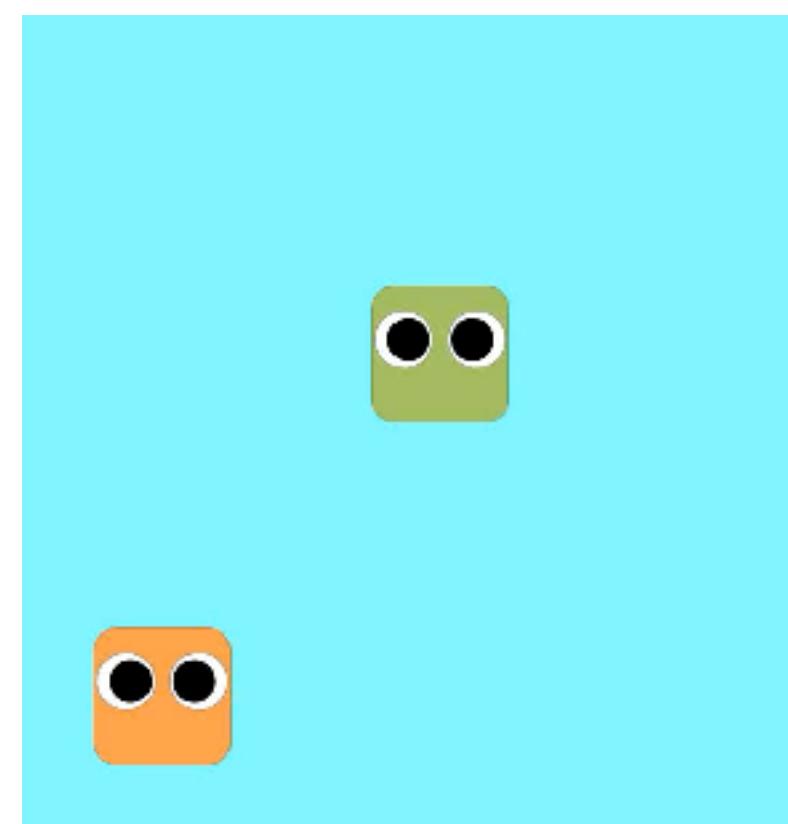


## ⑥ Theory of Mind and metacognitive social learning

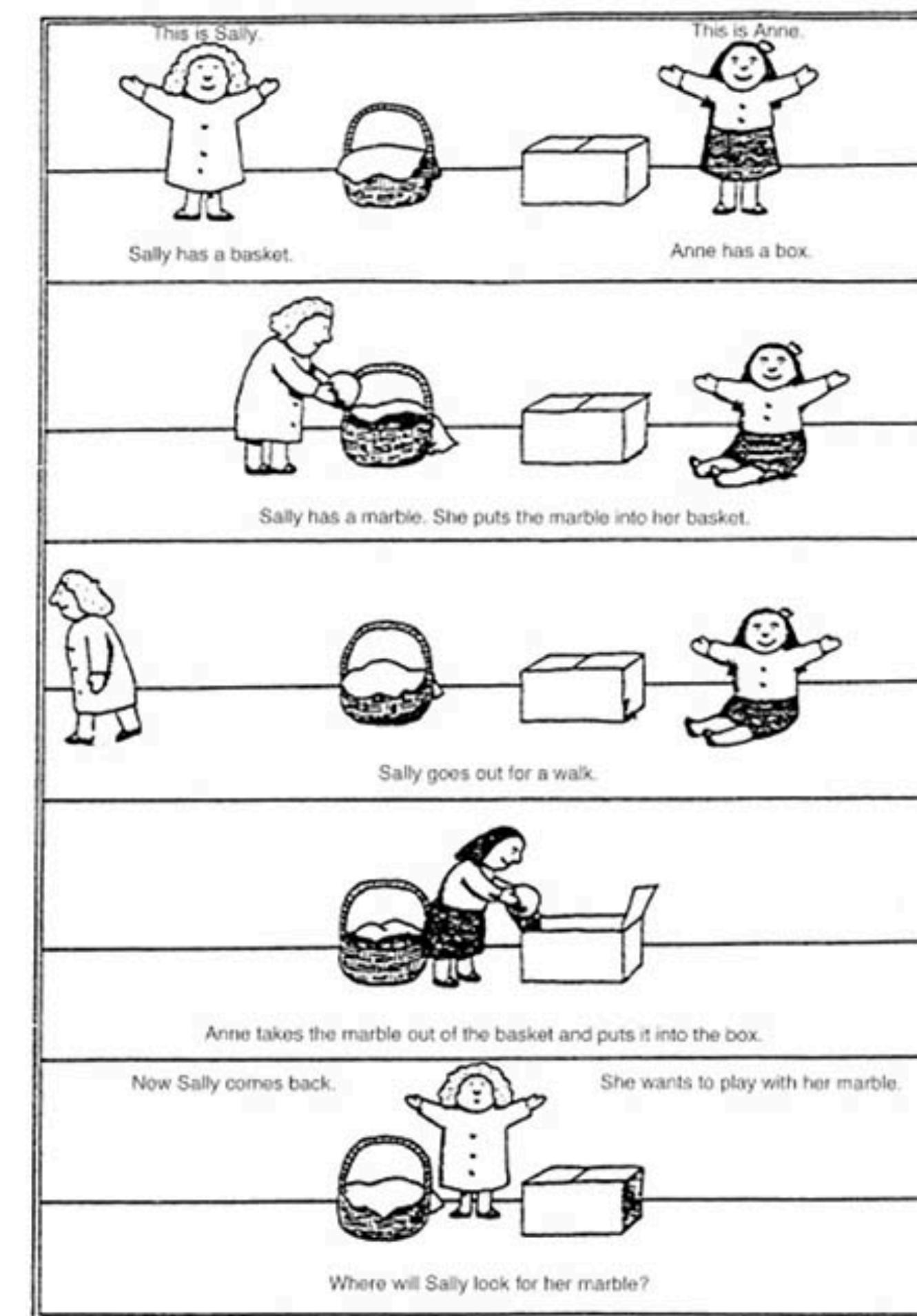
Inferring goals and beliefs from behavior



Heider, F., & Simmel, M. (1944). An experimental study of apparent behavior. *The American Journal of Psychology*, 57, 243–259.



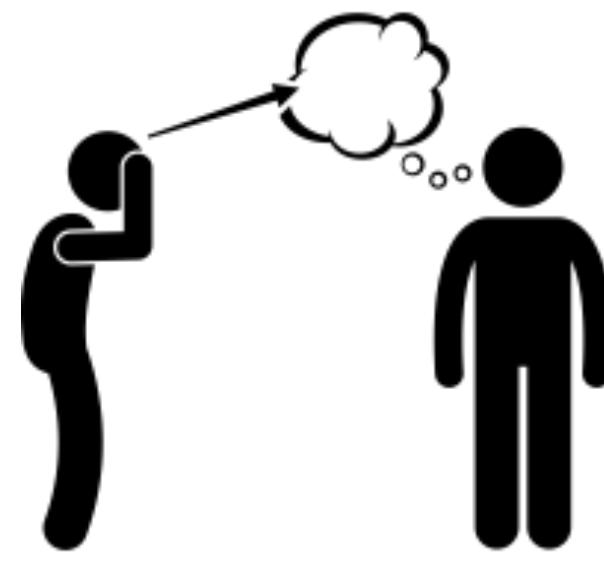
Kanakogi, Y., Miyazaki, M., Takahashi, H. et al. (2022) Third-party punishment by preverbal infants. *Nat Hum Behav* 6, 1234–1242.



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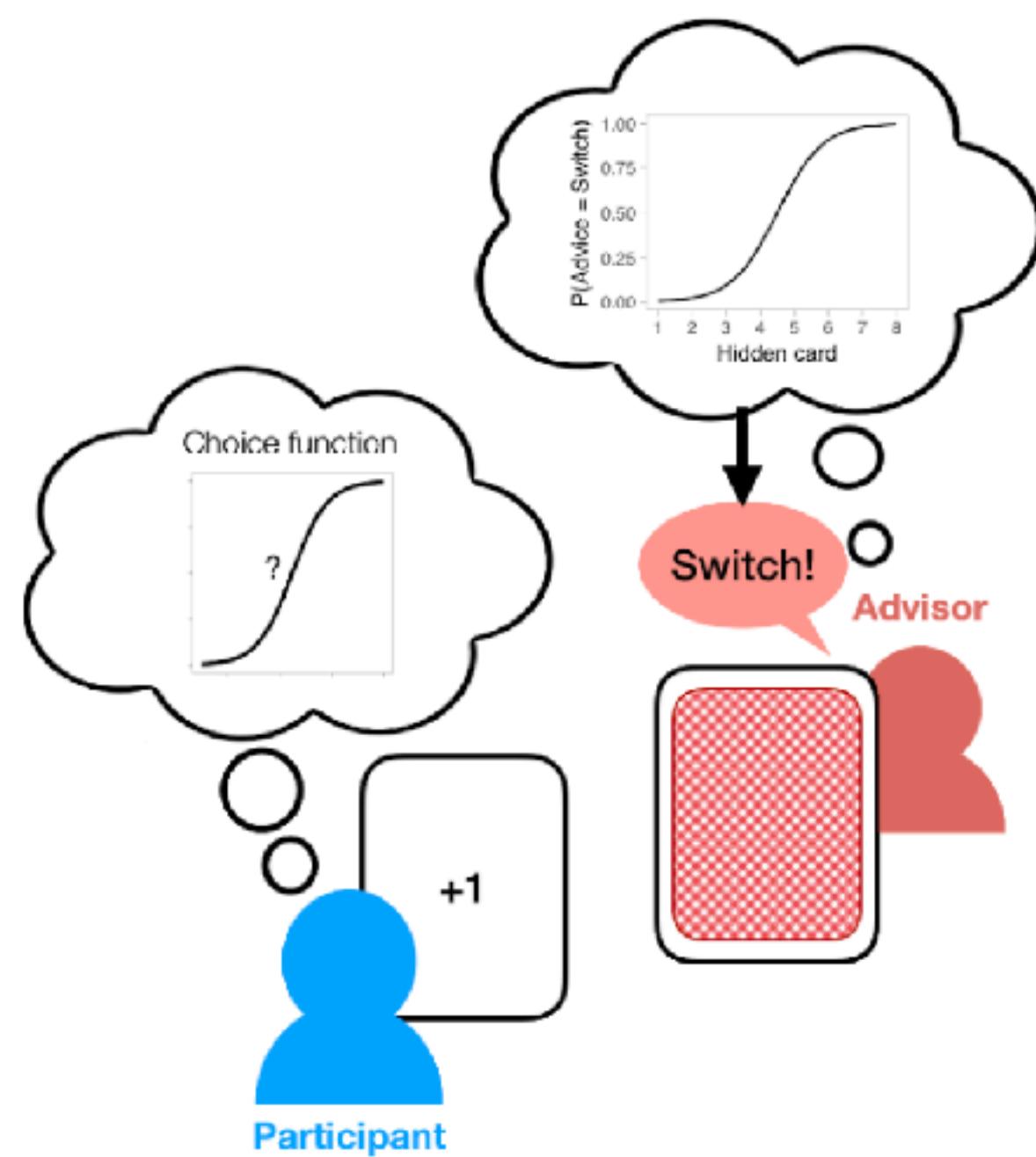


Whiten, A., & Byrne, R. W. (1988). Tactical deception in primates. *Behavioral and brain sciences*, 11(2), 233-244.

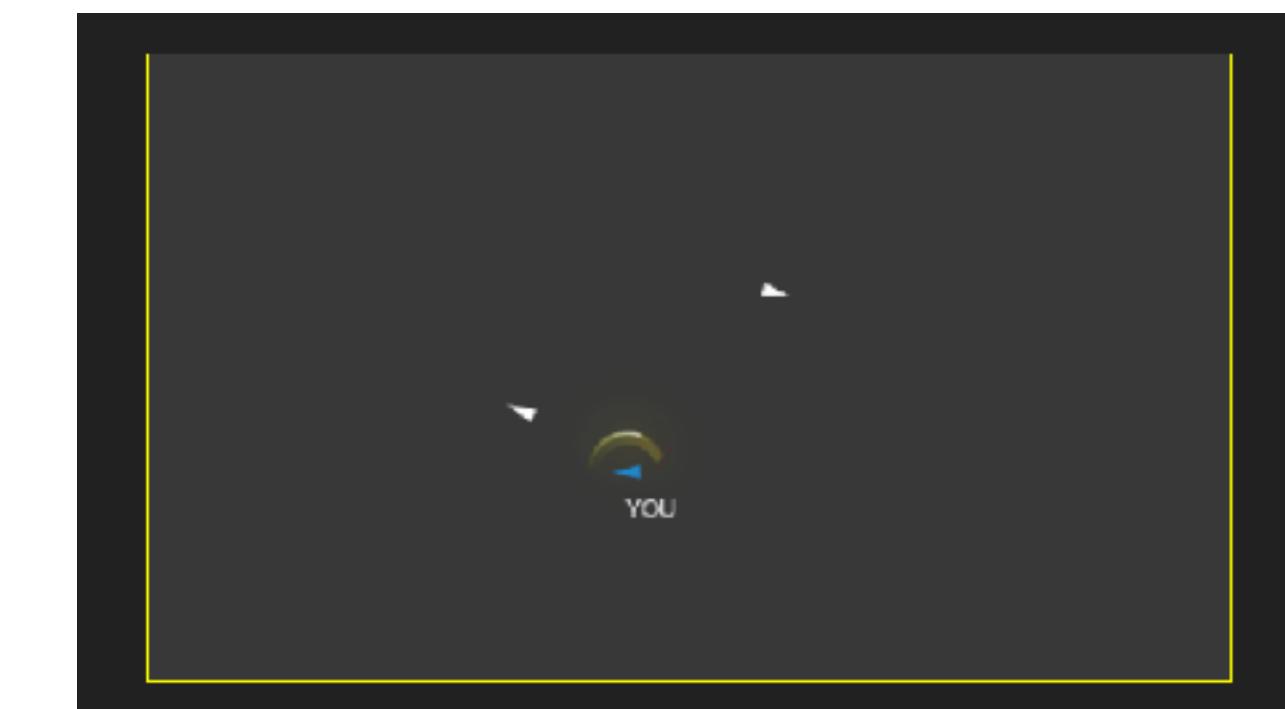
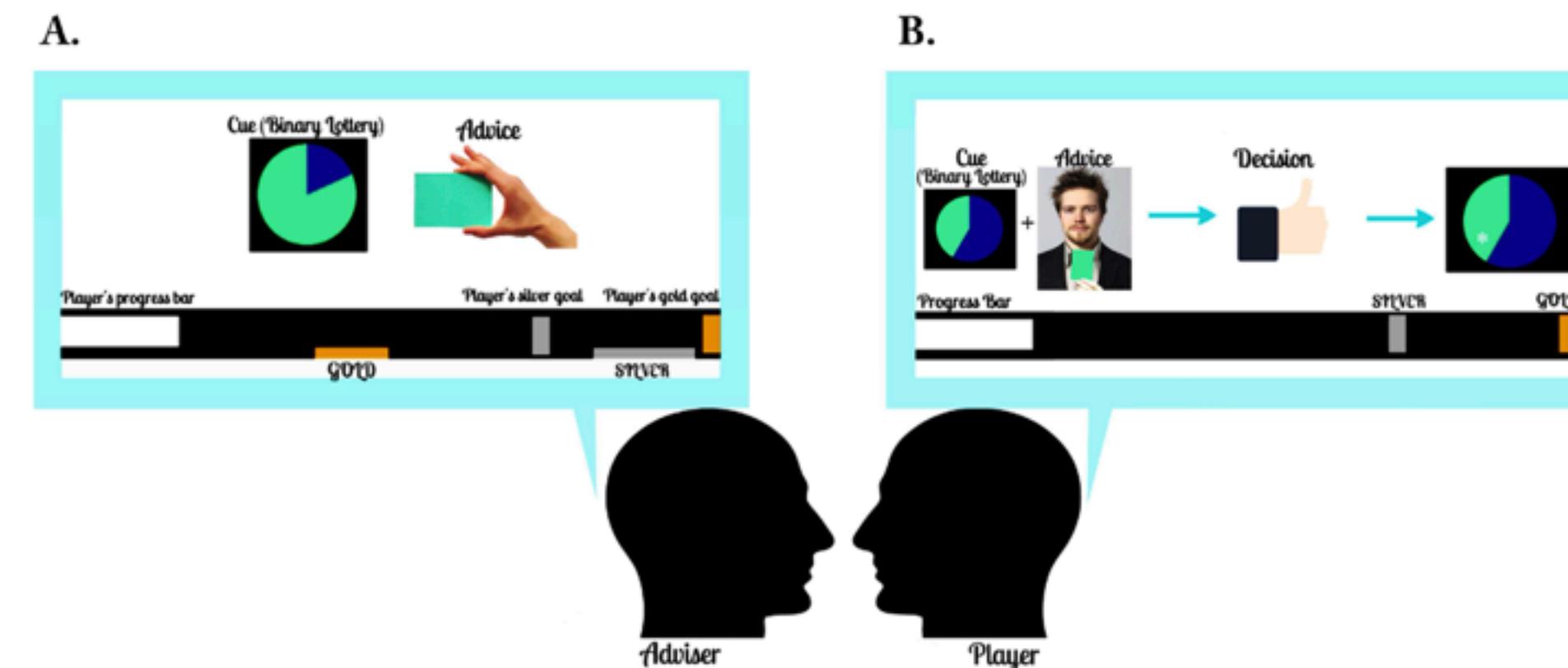


## ⑥ Theory of Mind and metacognitive social learning

ToM informs social information use



“Copy when the adviser intends to help”



Hawkins et al. (in press). Flexible social inference facilitates targeted social learning when rewards are not observable, *Nature Human Behaviour*.

Vélez, N., & Gweon, H. (2019). Integrating incomplete information with imperfect advice. *Topics in cognitive science*, 11(2), 299-315.

Diaconescu et al. (2014). Inferring on the intentions of others by hierarchical Bayesian learning. *PLoS Comput Biol*. 4;10(9):e1003810

# ⑦ Teaching and advice giving

## Teaching in non-human animals



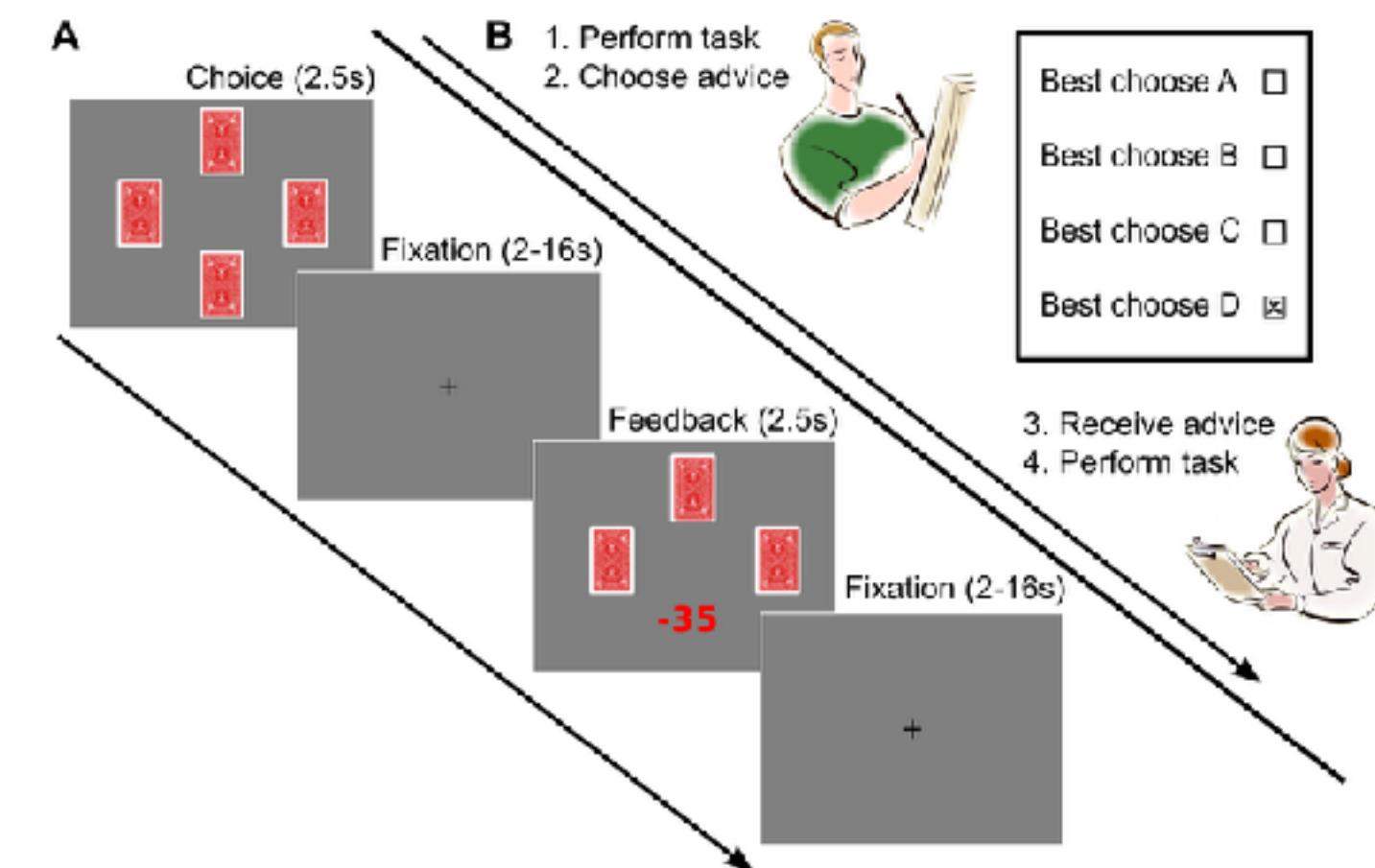
Sasaki et al. (2013). Ant colonies outperform individuals when a sensory discrimination task is difficult but not when it is easy. *Proceedings of the National Academy of Sciences*, 110(34), 13769-13773.



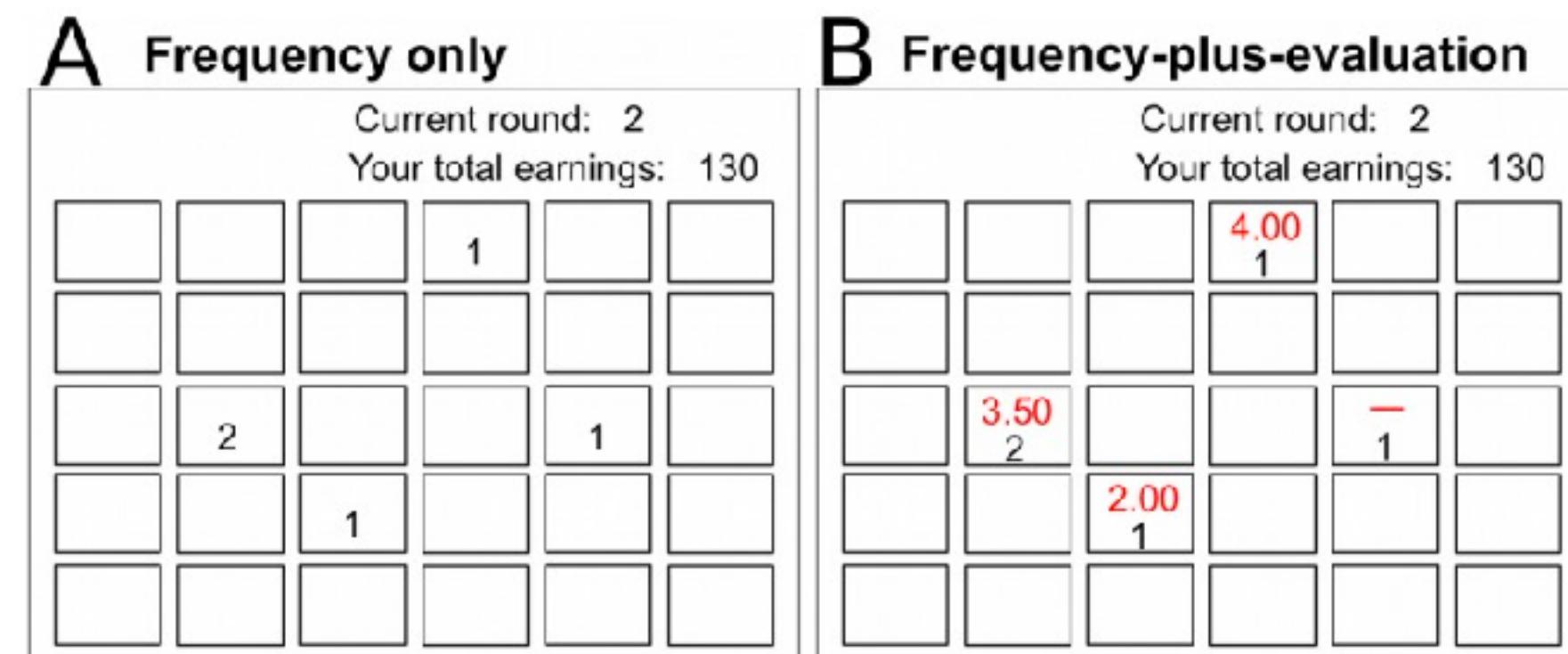
<https://youtu.be/48rhtgtNxRI>

Thornton, A., & McAuliffe, K. (2006). Teaching in wild meerkats. *Science*, 313(5784), 227-229.

## Simple advice giving in humans



Biele, G., Rieskamp, J., Krugel, L. K., & Heekeren, H. R. (2011). The neural basis of following advice. *PLoS biology*, 9(6), e1001089.



Toyokawa, W., Kim, H. R., & Kameda, T. (2014). Human collective intelligence under dual exploration-exploitation dilemmas. *PloS one*, 9(4), e95789.

# ⑦ Teaching and advice giving

## Teaching in non-human animals



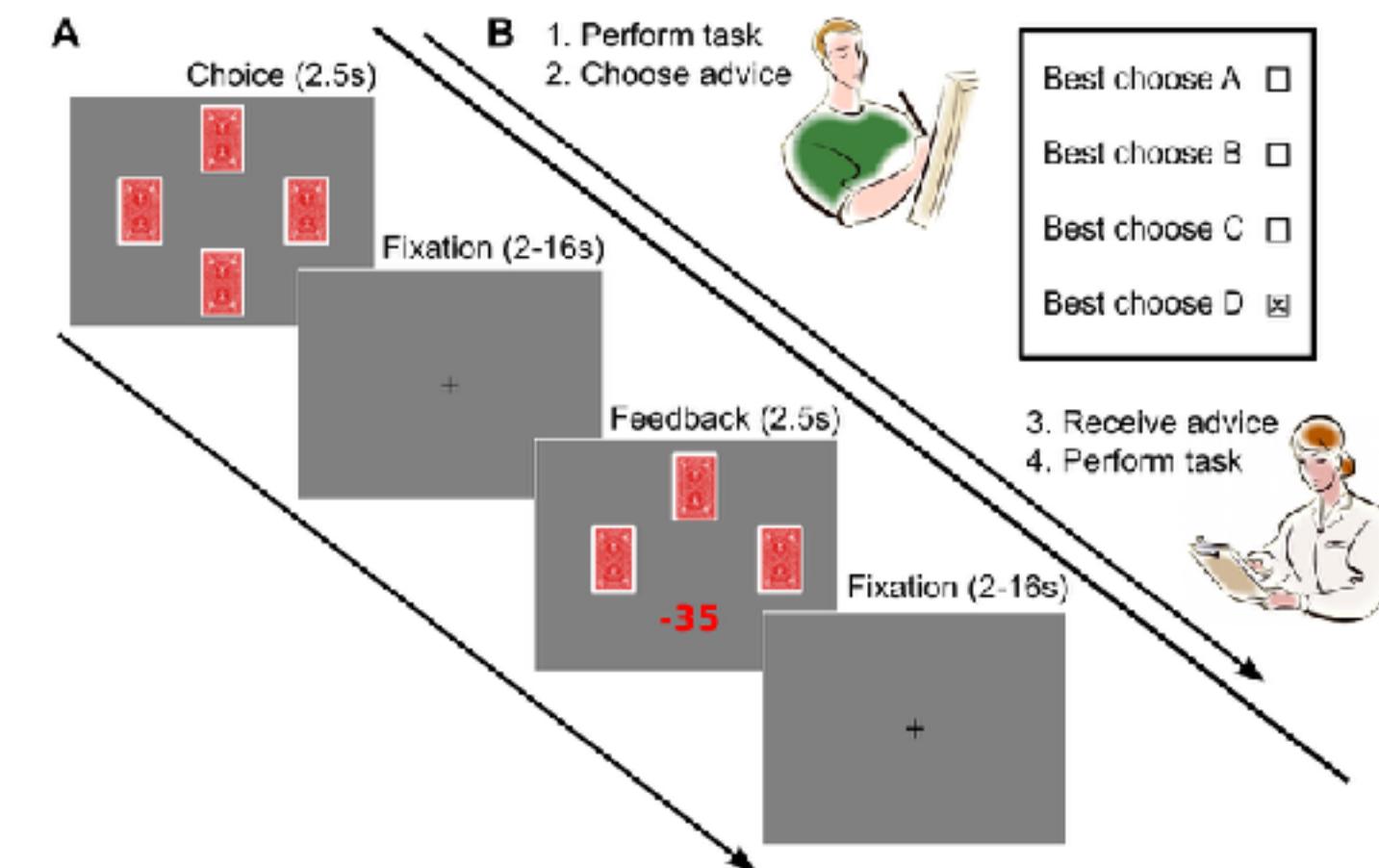
Sasaki et al. (2013). Ant colonies outperform individuals when a sensory discrimination task is difficult but not when it is easy. *Proceedings of the National Academy of Sciences*, 110(34), 13769-13773.



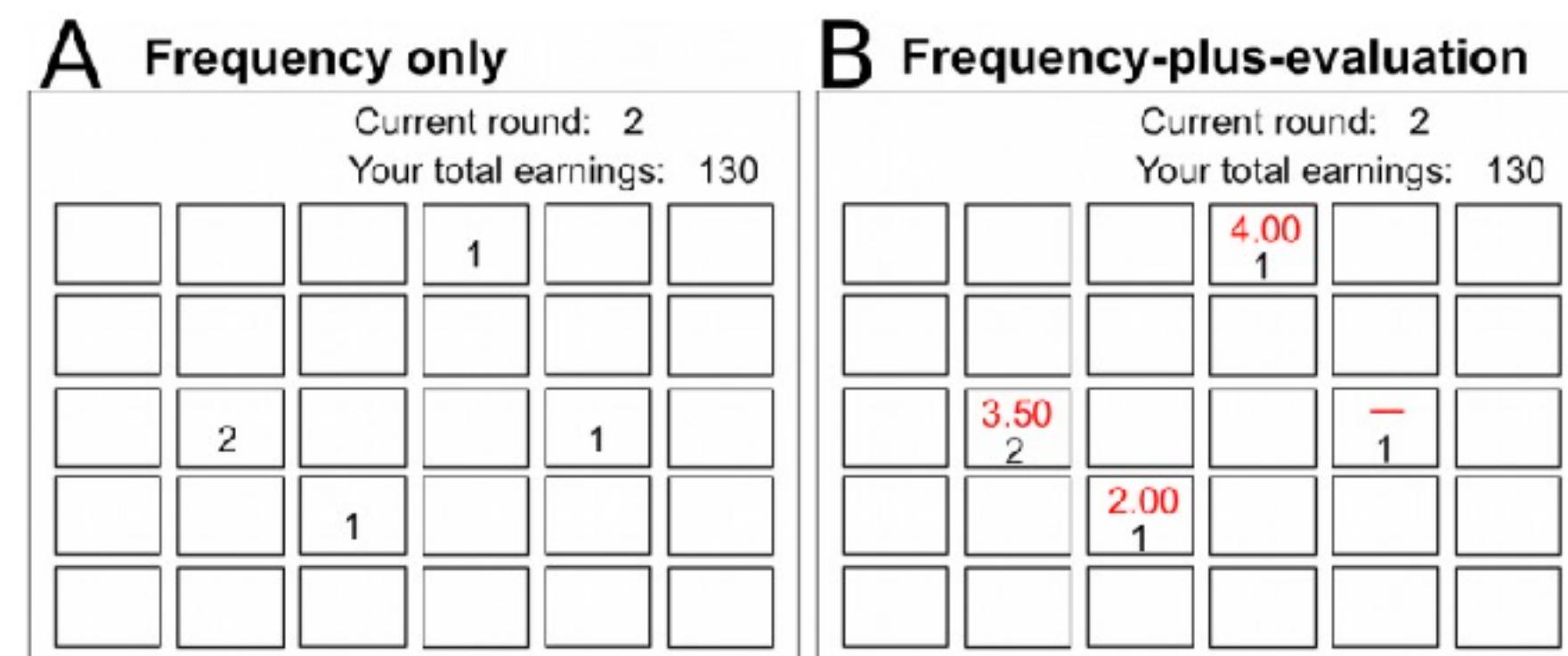
<https://youtu.be/48rhtgtNxRI>

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Toyokawa, W., Kim, H. R., & Kameda, T. (2014). Human collective intelligence under dual exploration-exploitation dilemmas. *PloS one*, 9(4), e95789.

# ⑦ Teaching and advice giving

## Teaching in non-human animals



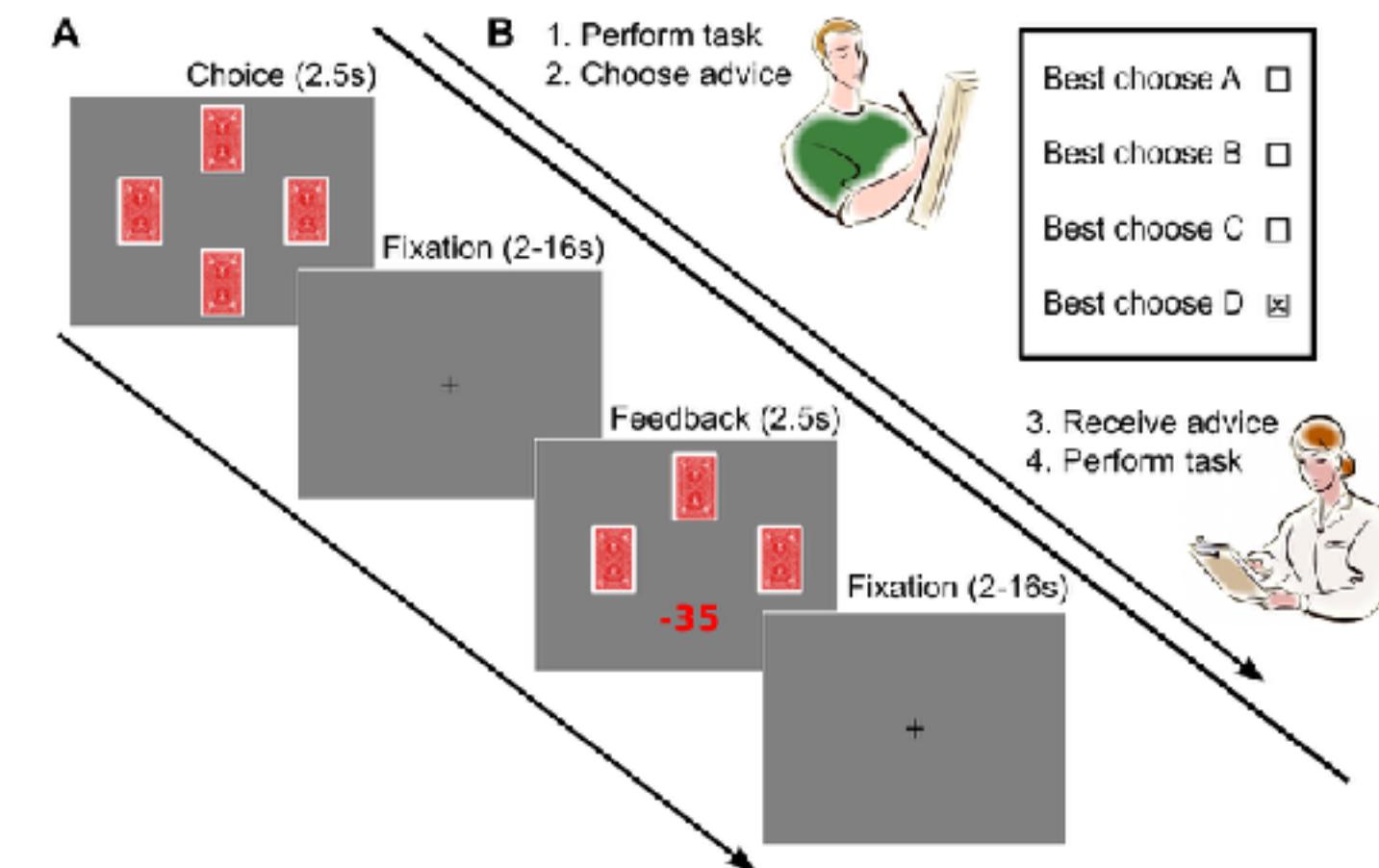
Sasaki et al. (2013). Ant colonies outperform individuals when a sensory discrimination task is difficult but not when it is easy. *Proceedings of the National Academy of Sciences*, 110(34), 13769-13773.



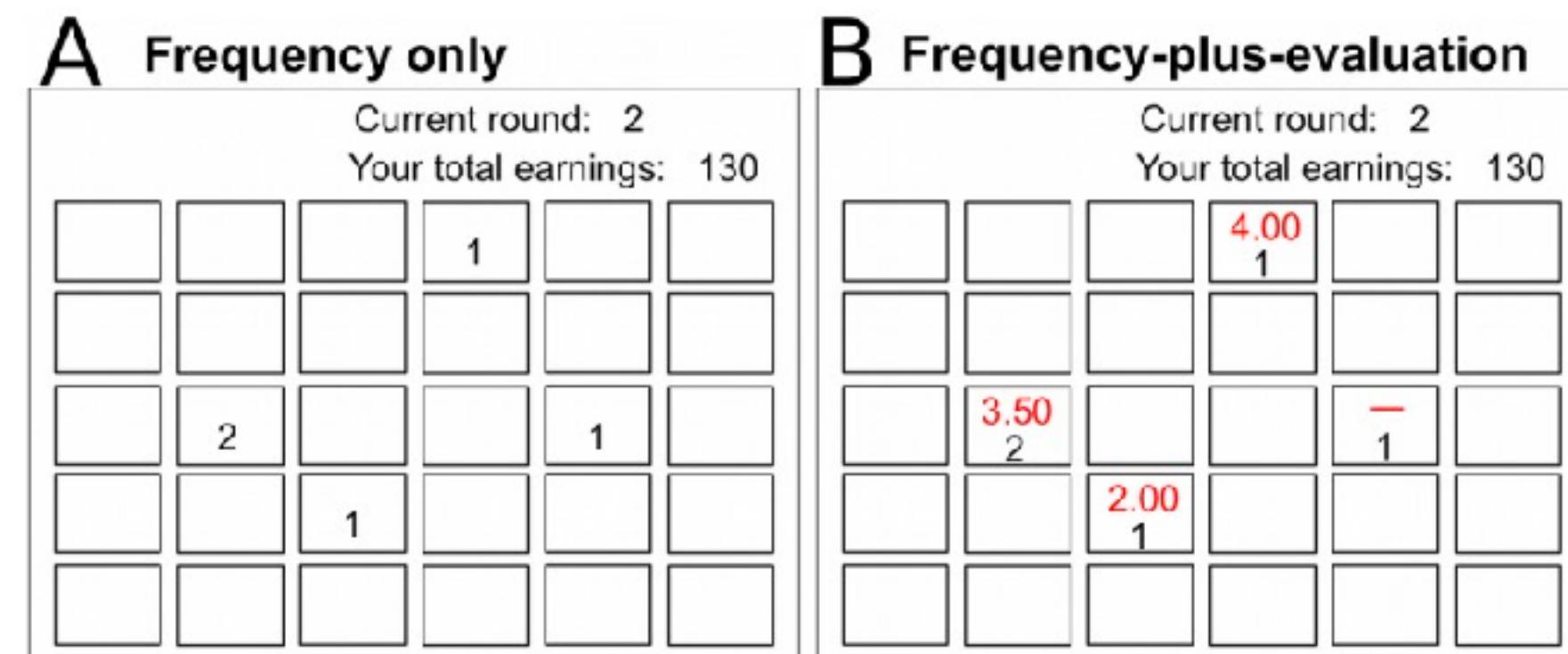
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## Simple advice giving in humans

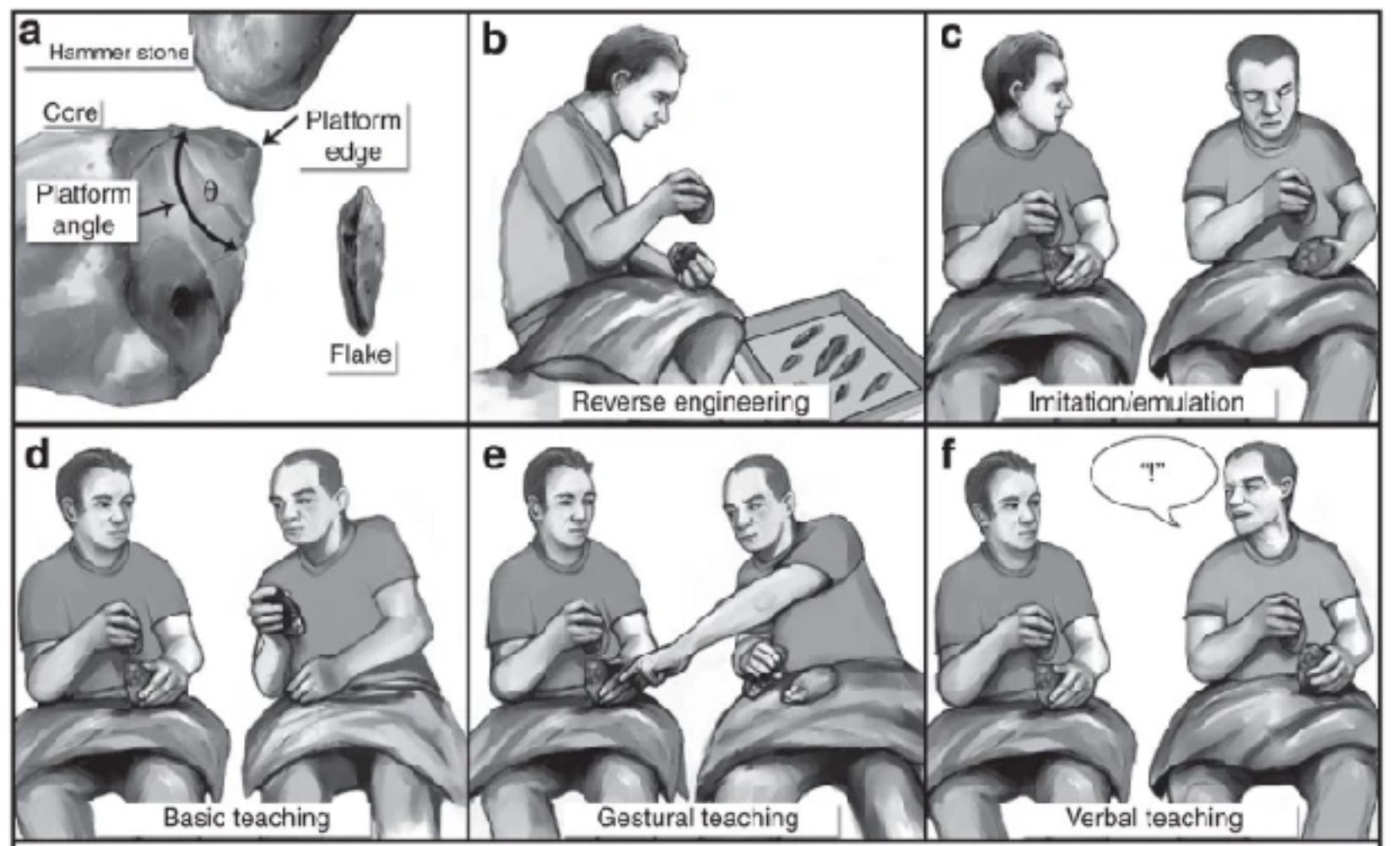


Biele, G., Rieskamp, J., Krugel, L. K., & Heekeren, H. R. (2011). The neural basis of following advice. *PLoS biology*, 9(6), e1001089.

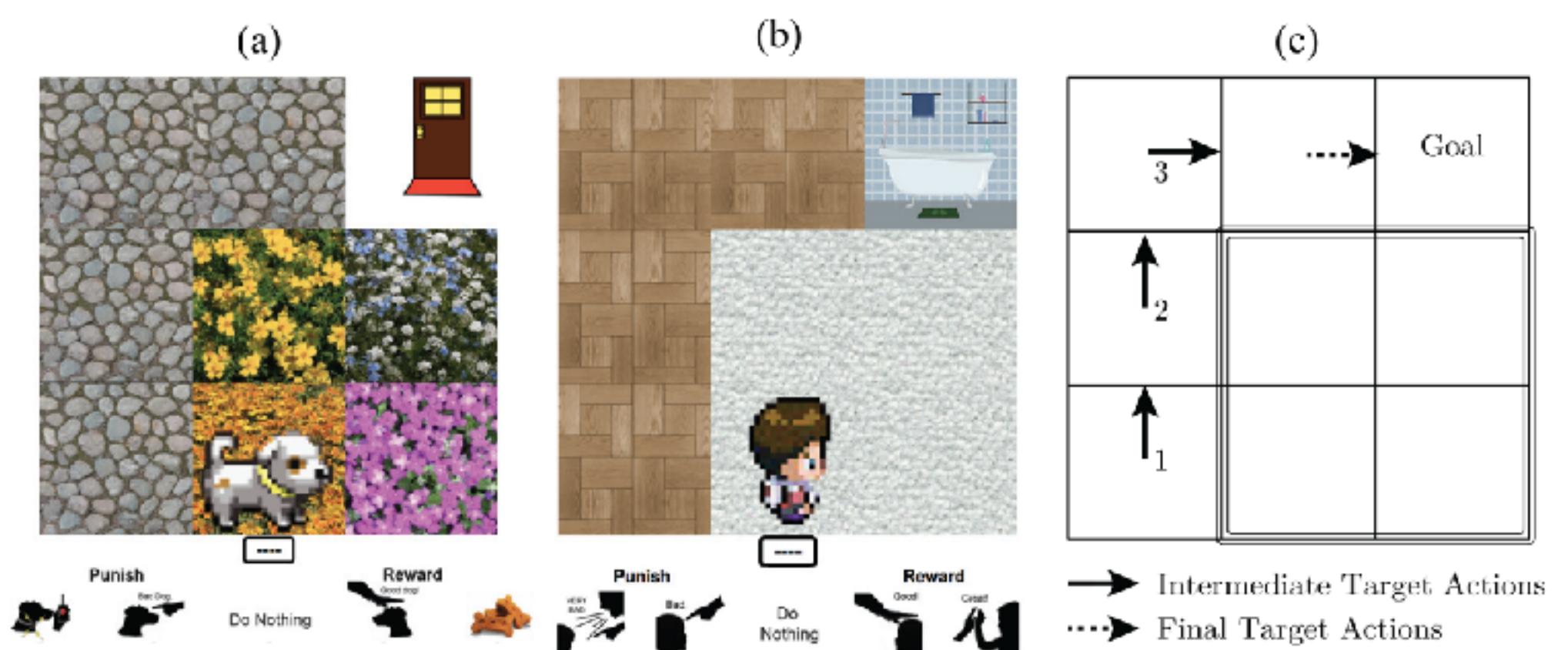


Toyokawa, W., Kim, H. R., & Kameda, T. (2014). Human collective intelligence under dual exploration-exploitation dilemmas. *PloS one*, 9(4), e95789.

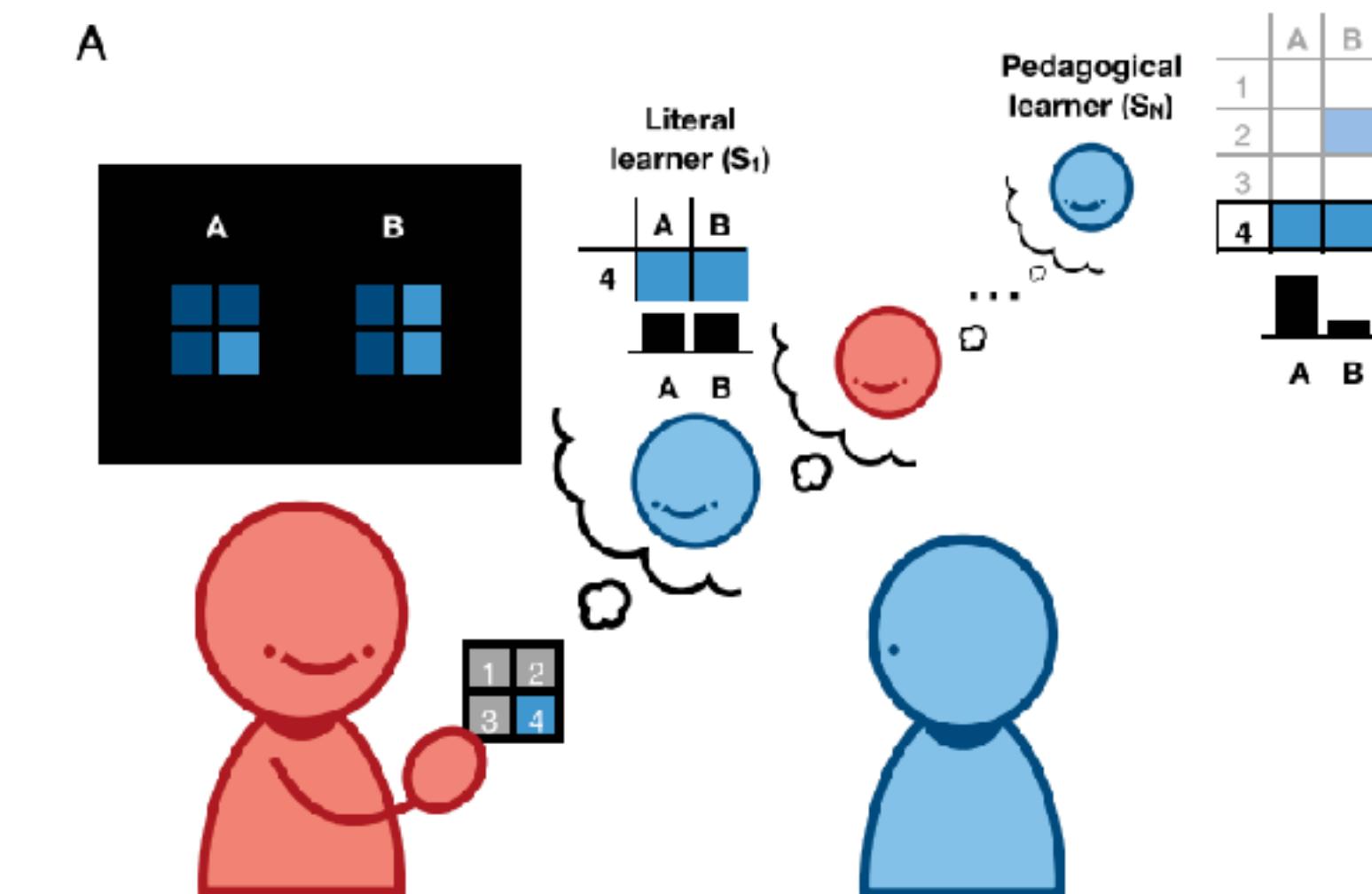
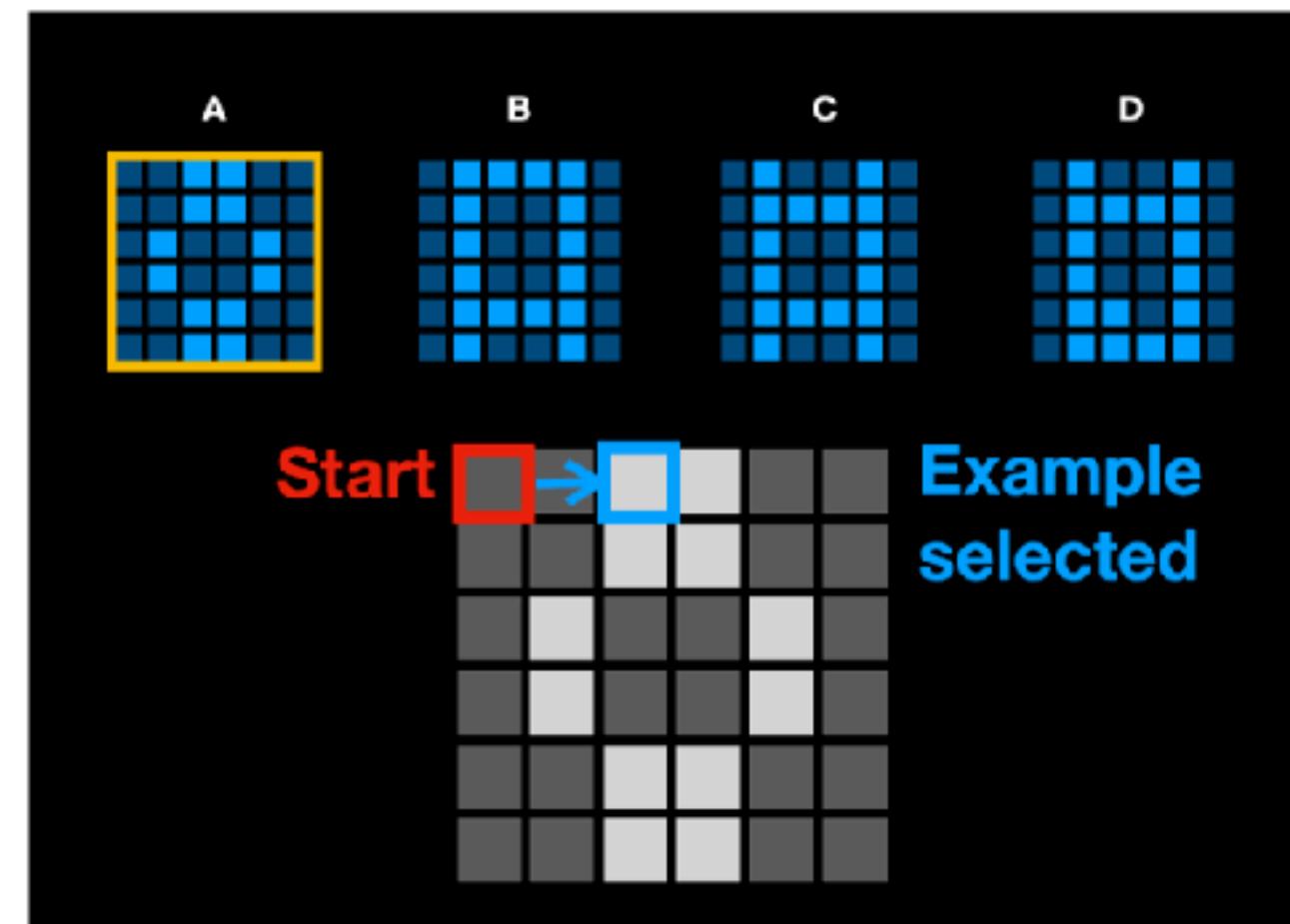
# Communicating and reasoning about beliefs



Morgan et al. (2015) Experimental evidence for the co-evolution of hominin tool-making teaching and language. *Nat Commun* 6, 6029.



Ho et al. (2019). People teach with rewards and punishments as communication, not reinforcements. *Journal of Experimental Psychology: General*, 148(3), 520–549.



Vélez et al. (2023) Mentalizing regions and anterior cingulate cortex represent learners' beliefs during teaching. <https://doi.org/10.31234/osf.io/5un89>

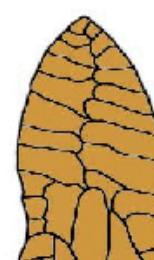
# ⑧ Evolving landscape

## Cultural evolution

Height (1-100): 48    Width (1-100): 30    Thickness (1-100): 90    **SHOW**

**OTHER PLAYERS' SCORES**

Player 1:	482
<b>CICK HERE TO COPY</b>	
Player 2:	559
<b>CICK HERE TO COPY</b>	
Player 3:	593
<b>CICK HERE TO COPY</b>	
Player 4:	545
<b>CICK HERE TO COPY</b>	
Player 5:	569
<b>CICK HERE TO COPY</b>	



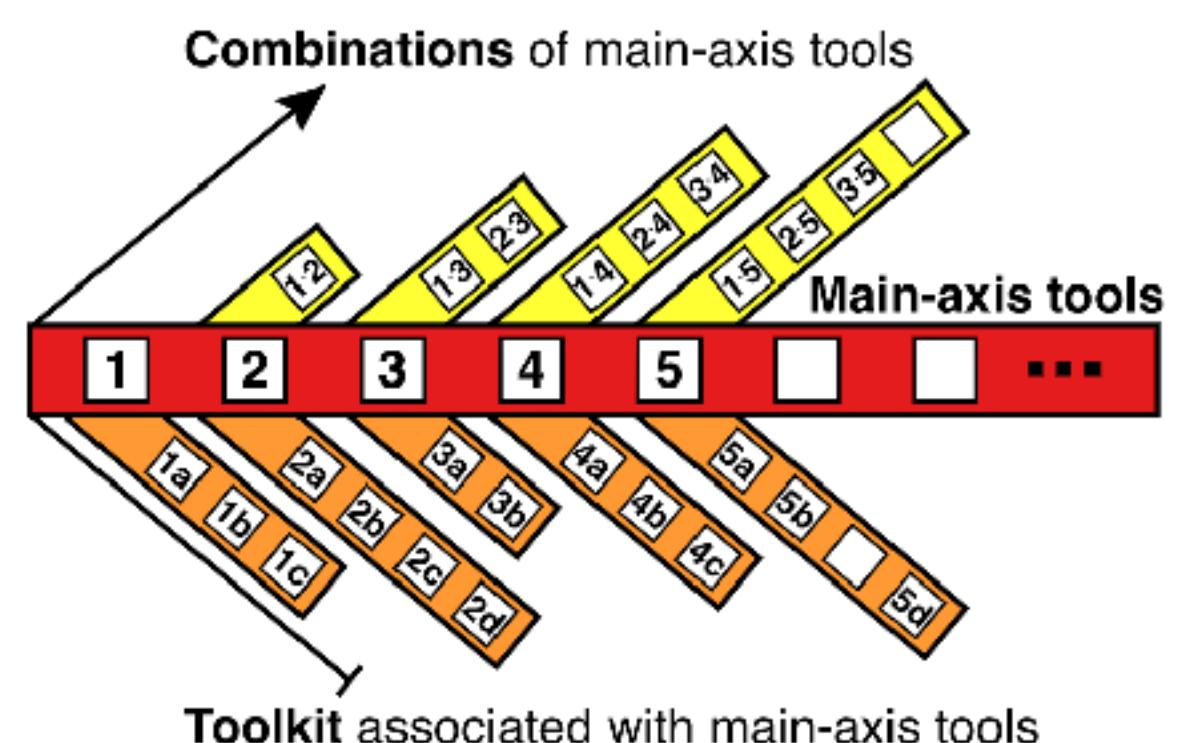
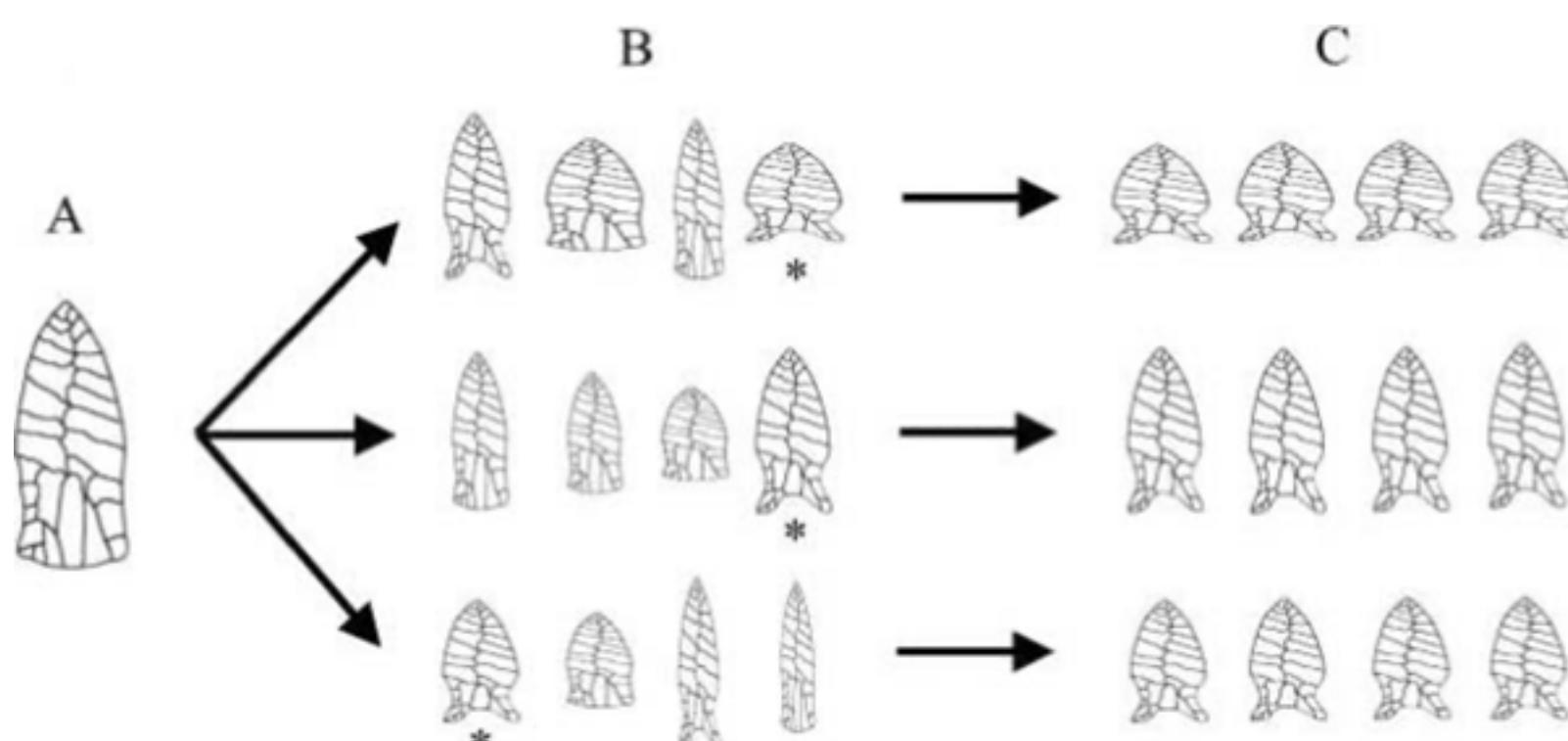
You may now change the values above as before, clicking SHOW to see your arrowhead and HUNT to see how it does.

Alternatively, you can click one of the buttons on the left to copy the design of another player. If you do this, your current design will be replaced with their design.

Bison image: 0    1000

Season: 1    Calories (/1000): 368    Previous calories: 368    Season Score: 368

Hunts Left: 29    **HUNT**    Group Rank: 6th    **NEXT HUNT**



Low-level tech  
(an arm of the multi-armed bandit)



High-level tech  
(Improved "arm")



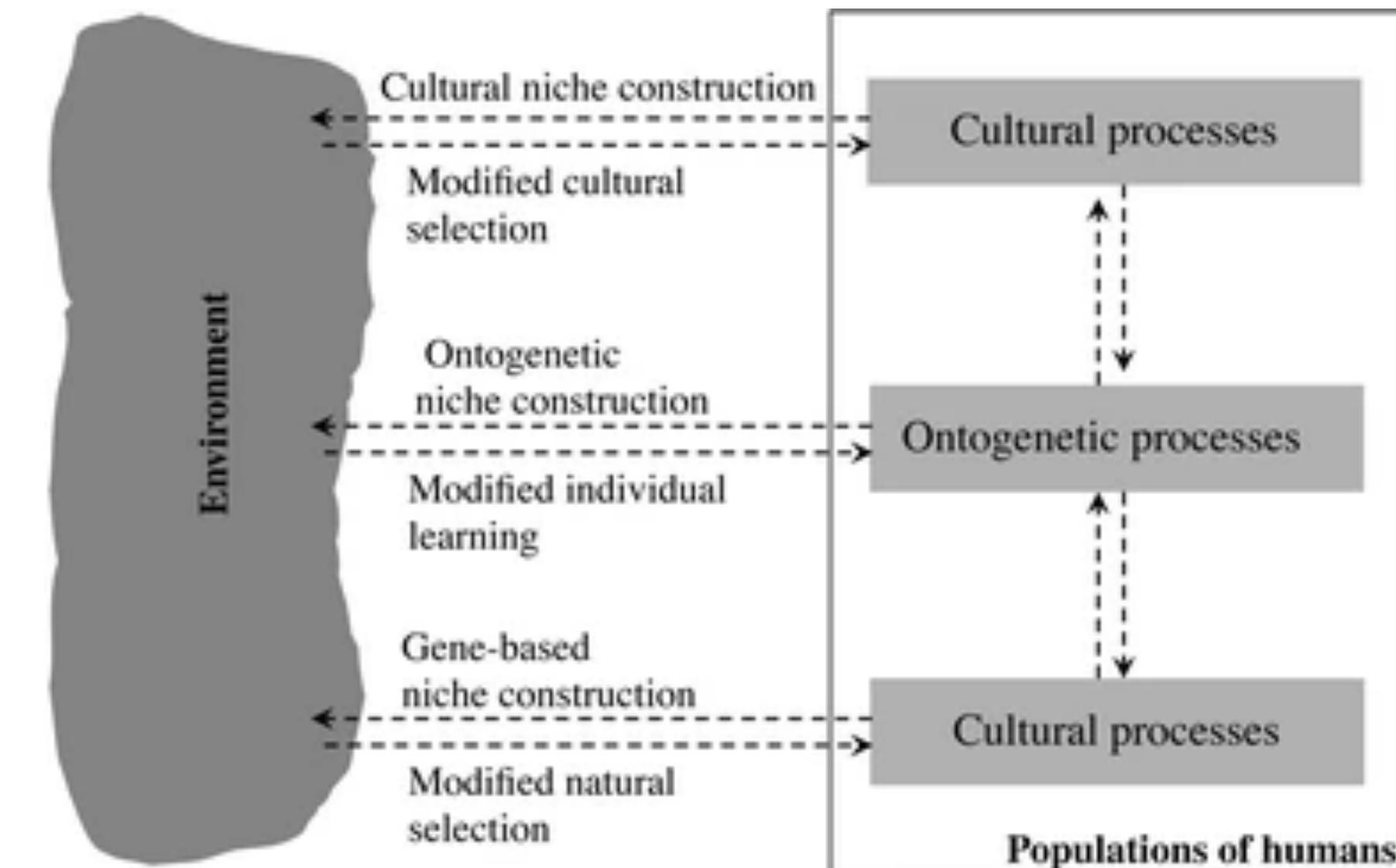
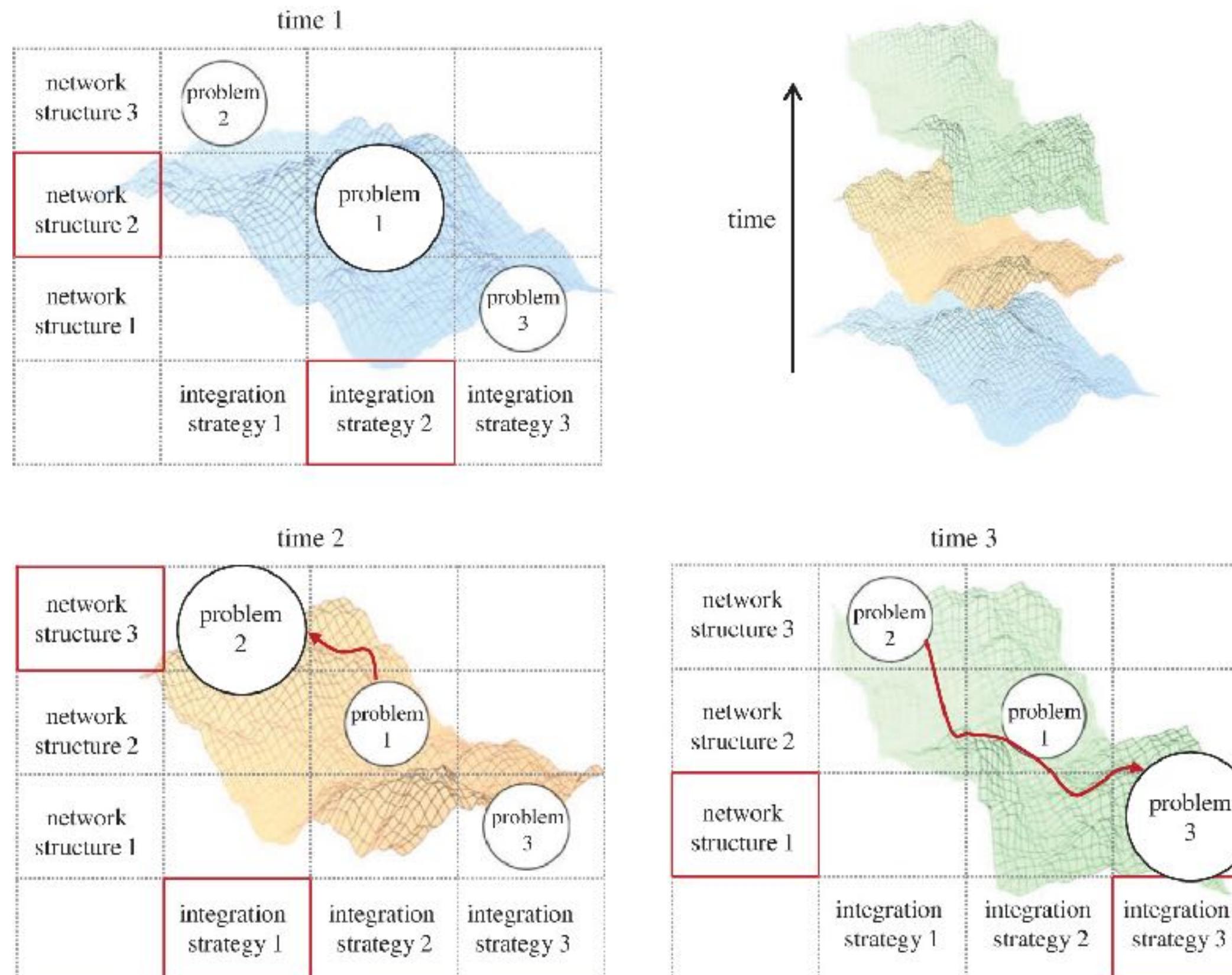
Mesoudi, A. (2011). An experimental comparison of human social learning strategies: payoff-biased social learning is adaptive but underused. *Evolution and Human Behavior*, 32(5), 334-342.

Kolodny, O., Creanza, N., & Feldman, M. W. (2015). Evolution in leaps: the punctuated accumulation and loss of cultural innovations. *Proceedings of the National Academy of Sciences*, 112(49), E6762-E6769.

Castro, L., & Toro, M. A. (2014). Cumulative cultural evolution: the role of teaching. *Journal of Theoretical Biology*, 347, 74-83.

# ⑧ Evolving landscape

## Niche construction

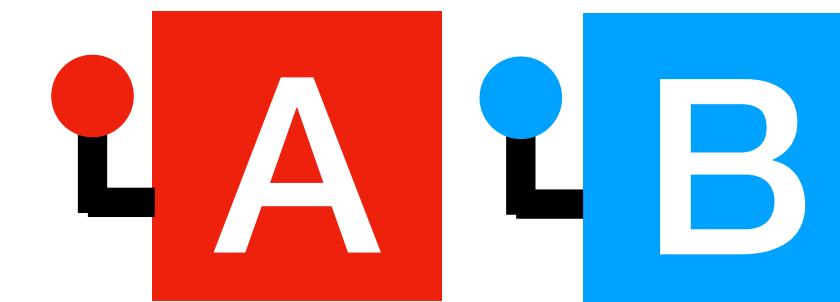


Galesic, M., Barkoczi, D., Berdahl, A. M., Biro, D., Carbone, G., Giannoccaro, I., ... & Stein, D. L. (2023). Beyond collective intelligence: Collective adaptation. *Journal of the Royal Society Interface*, 20(200), 20220736.

Laland, K. N., & O'brien, M. J. (2011). Cultural niche construction: An introduction. *Biological Theory*, 6, 191-202.

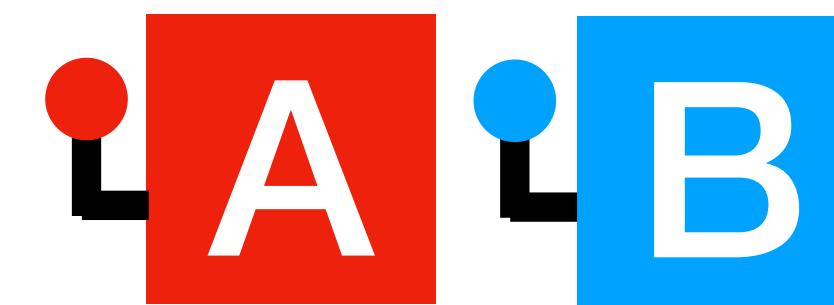
# A galaxy of social learning problems

## ① Multi-armed Bandit



# A galaxy of social learning problems

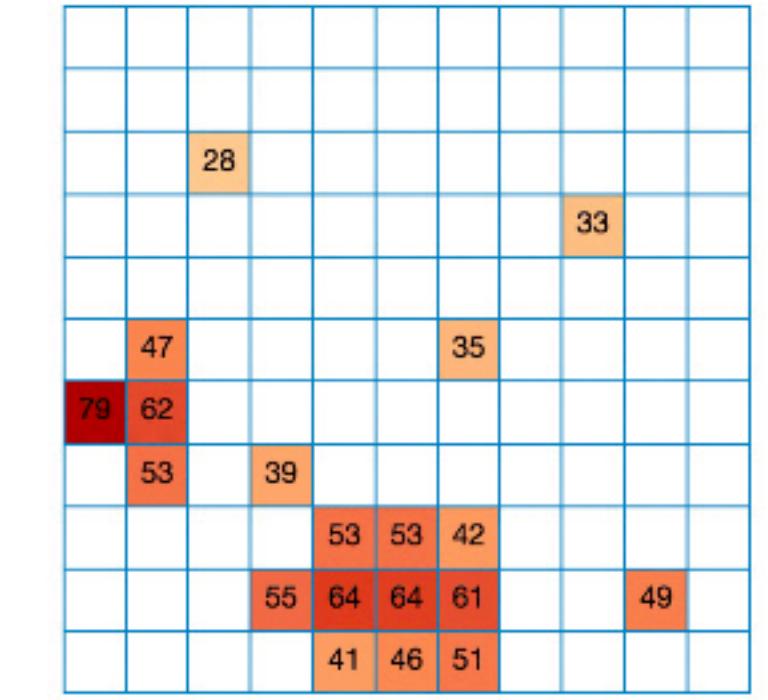
## ① Multi-armed Bandit



Spatial structure

## ② Spatially correlated bandit

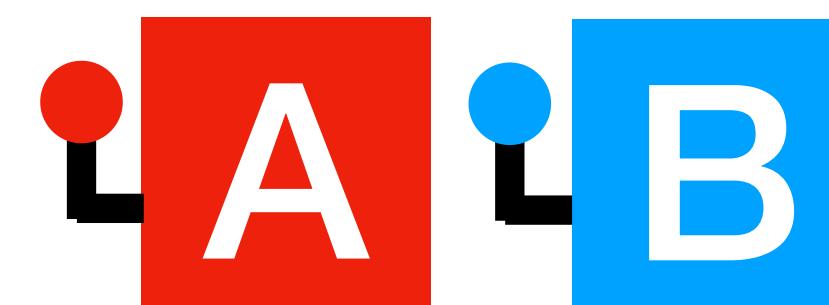
Current Score: 2400  
Number of grids left: 5  
Number of clicks left: 1



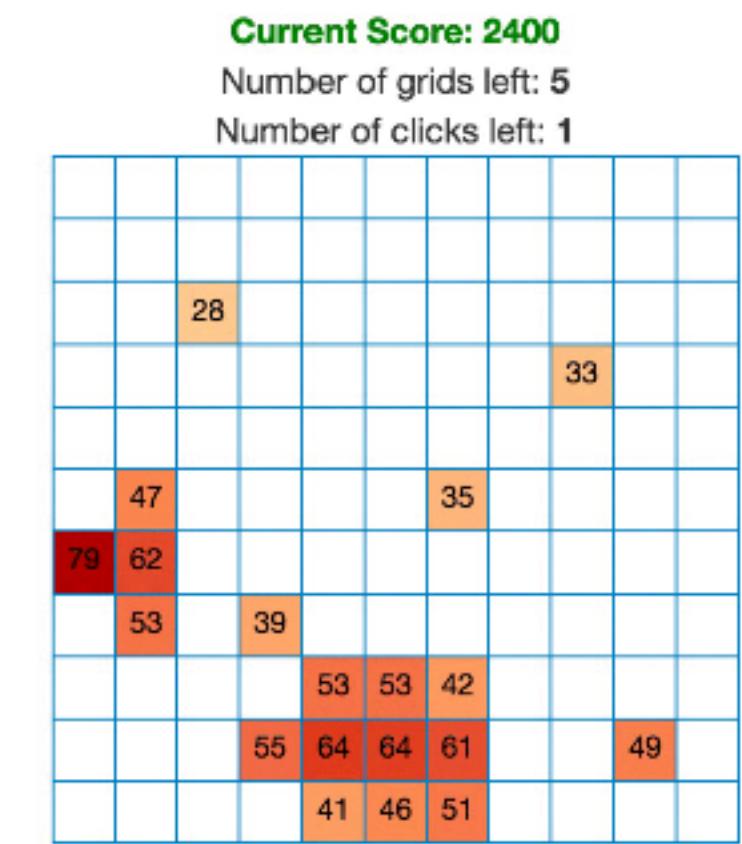
# A galaxy of social learning problems

② Spatially correlated bandit

① Multi-armed Bandit

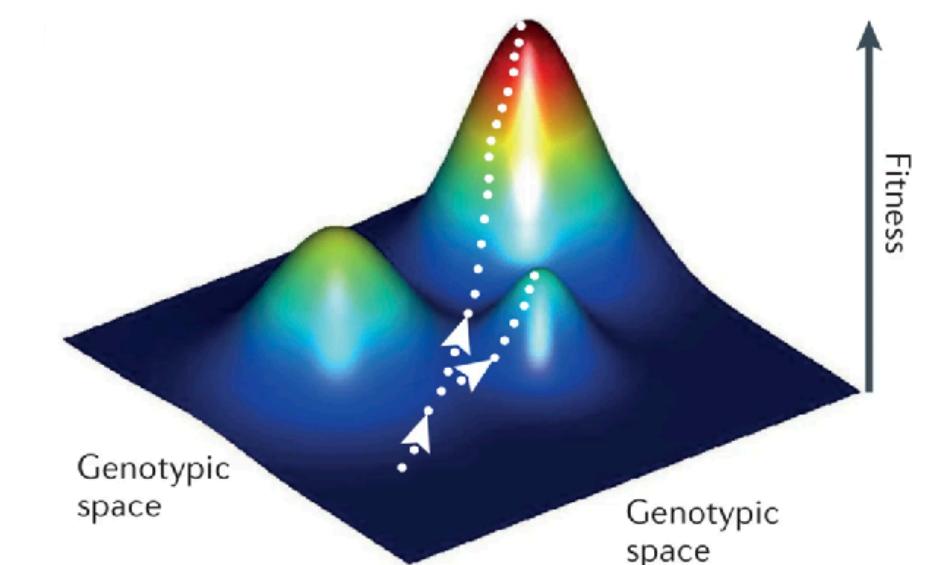


Spatial structure



High/Abstract Dims

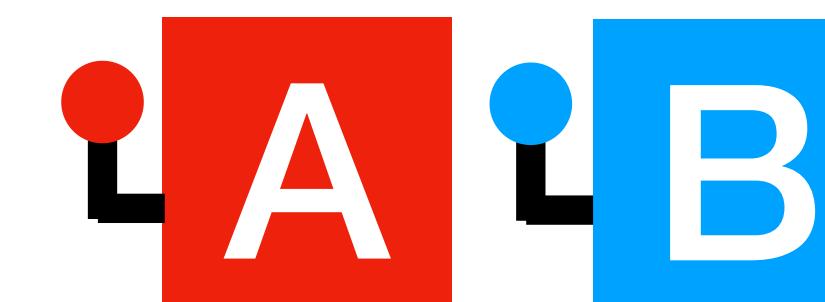
③ Fitness landscape



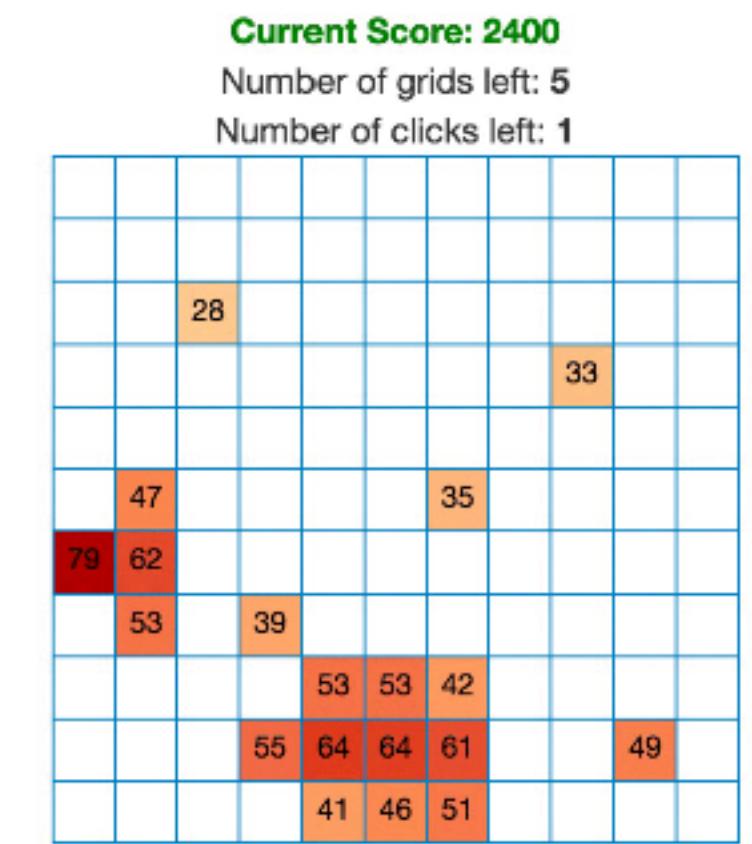
# A galaxy of social learning problems

② Spatially correlated bandit

① Multi-armed Bandit

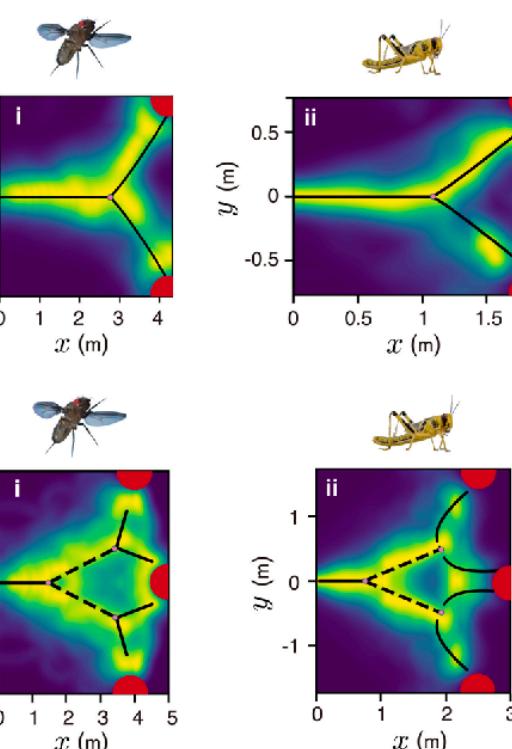


Spatial structure



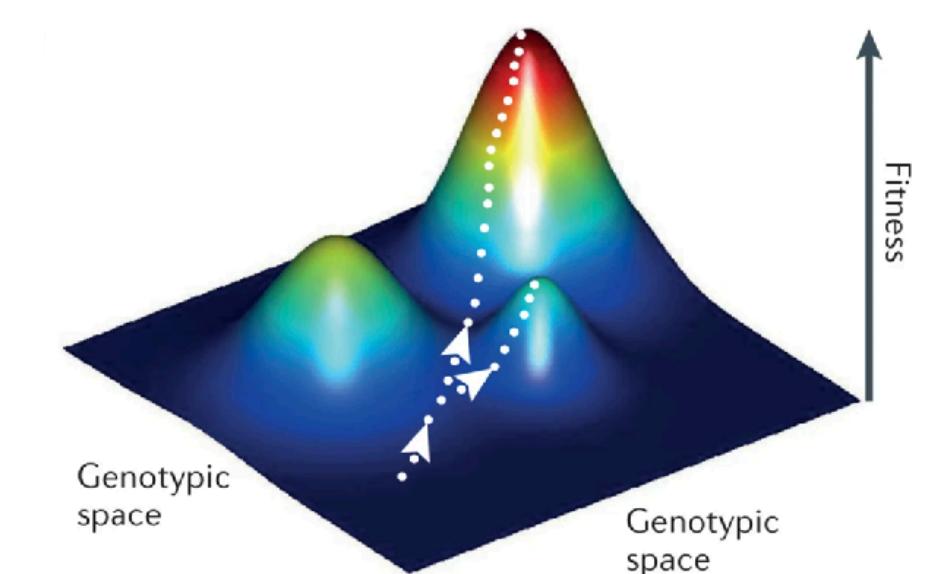
④ Spatial navigation

③ Fitness landscape



Sequential planning

High/Abstract Dims



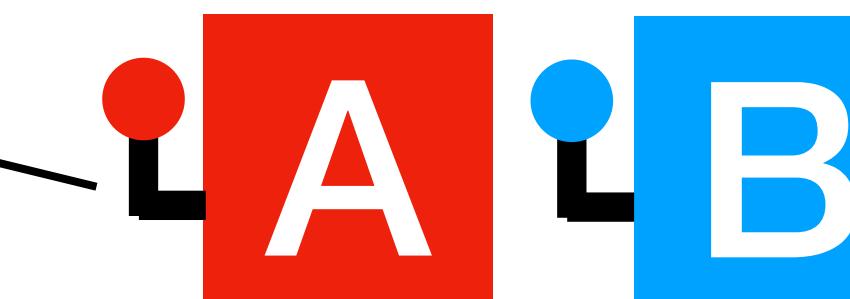
# A galaxy of social learning problems

## ⑤ Social Foraging



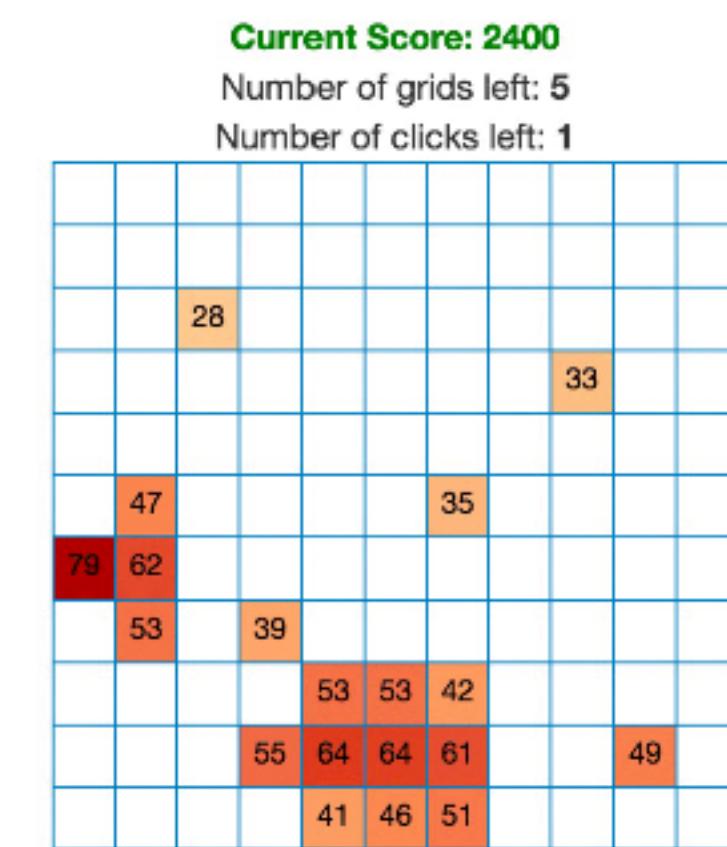
Competing interests  
Depleting rewards  
Individual differences

## ① Multi-armed Bandit



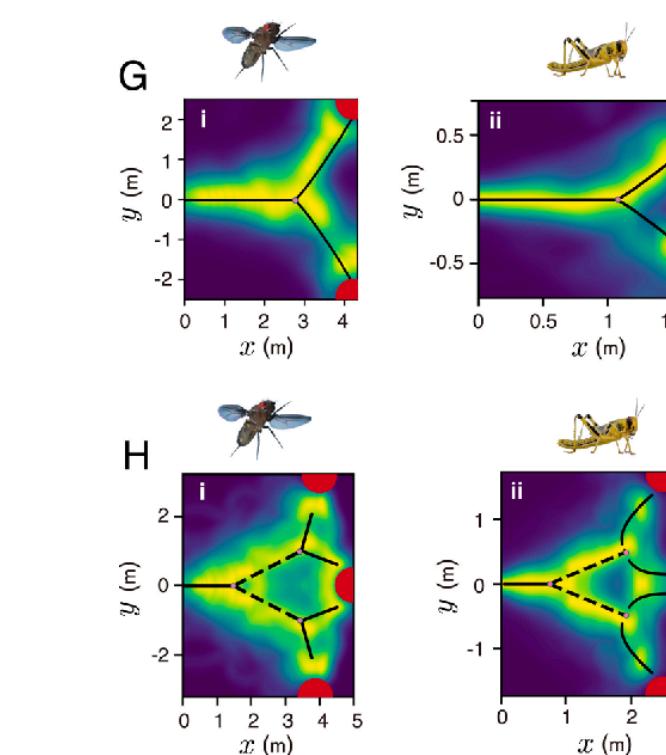
Spatial structure

## ② Spatially correlated bandit

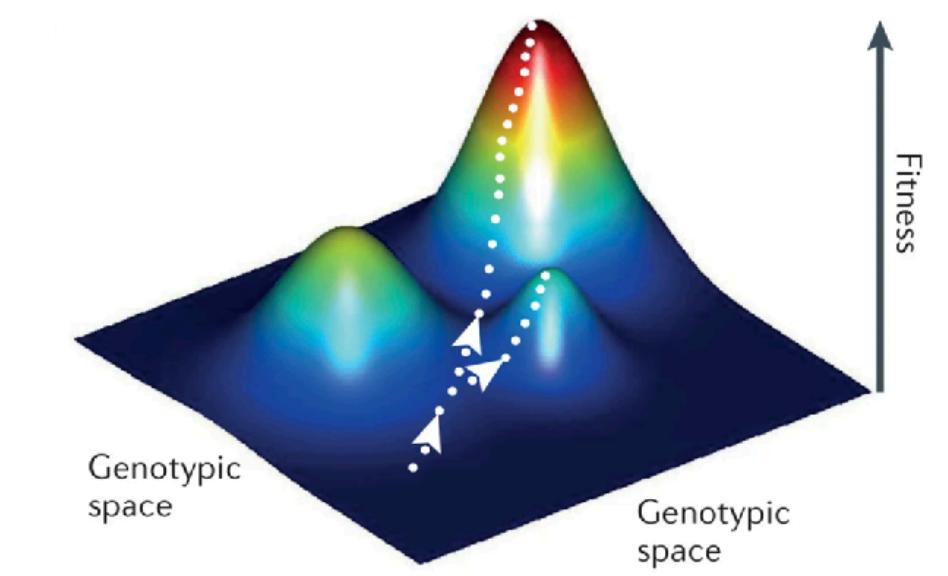


Sequential planning

## ④ Spatial navigation



## ③ Fitness landscape



High/Abstract Dims

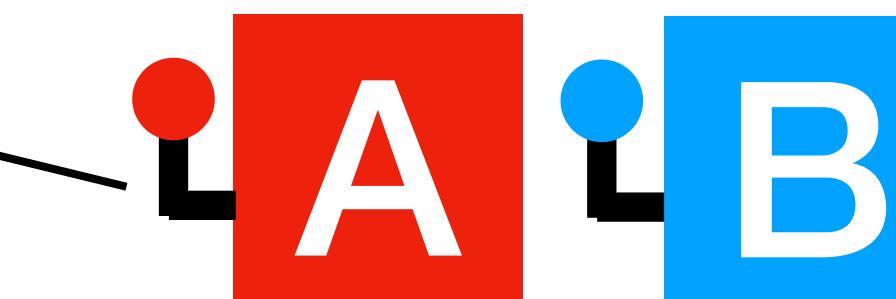
# A galaxy of social learning problems

## ⑤ Social Foraging



Competing interests  
Depleting rewards  
Individual differences

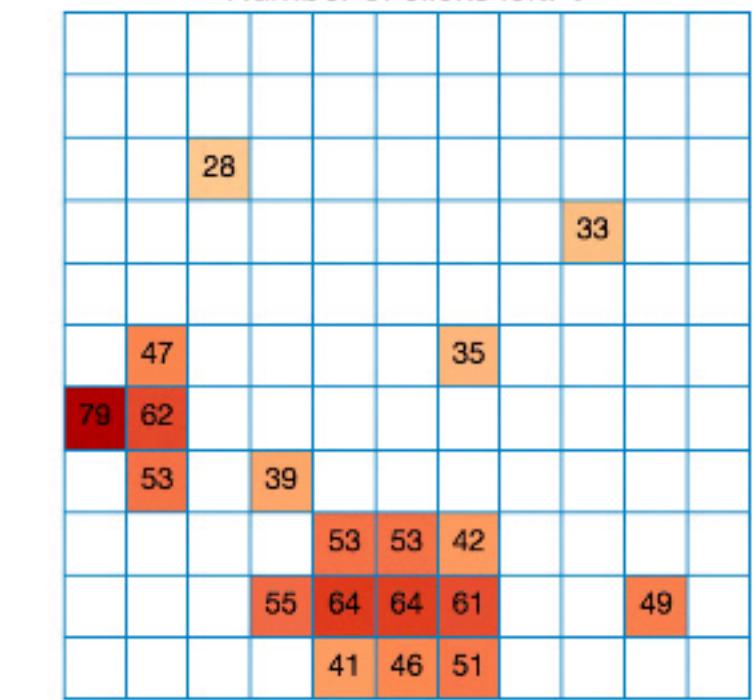
## ① Multi-armed Bandit



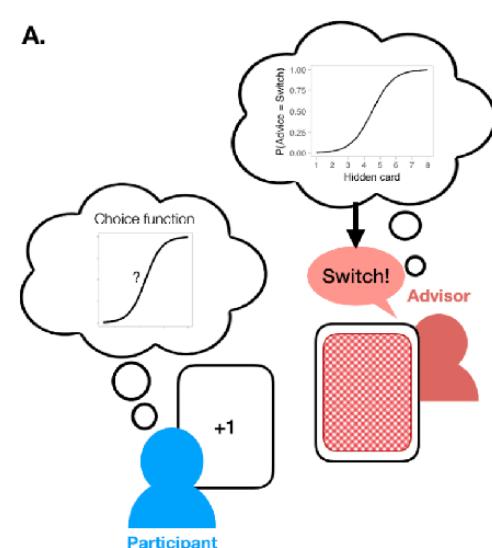
Spatial structure

## ② Spatially correlated bandit

Current Score: 2400  
Number of grids left: 5  
Number of clicks left: 1

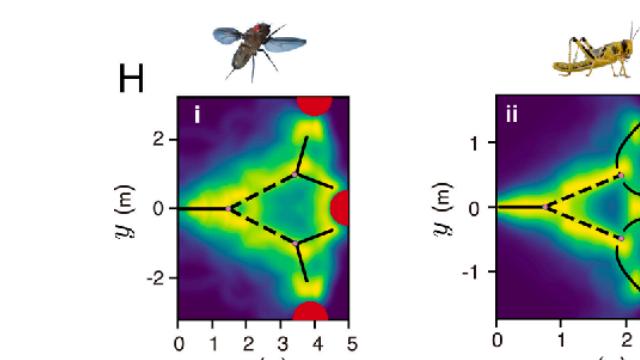
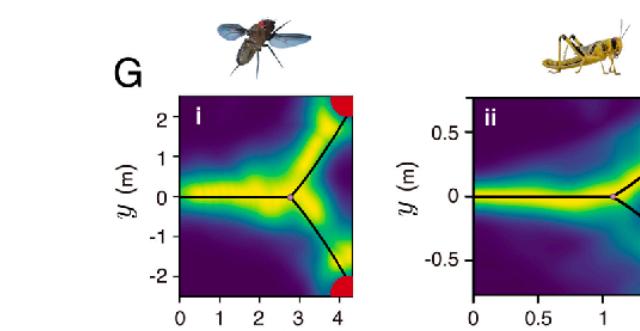


## ⑥ Theory of Mind

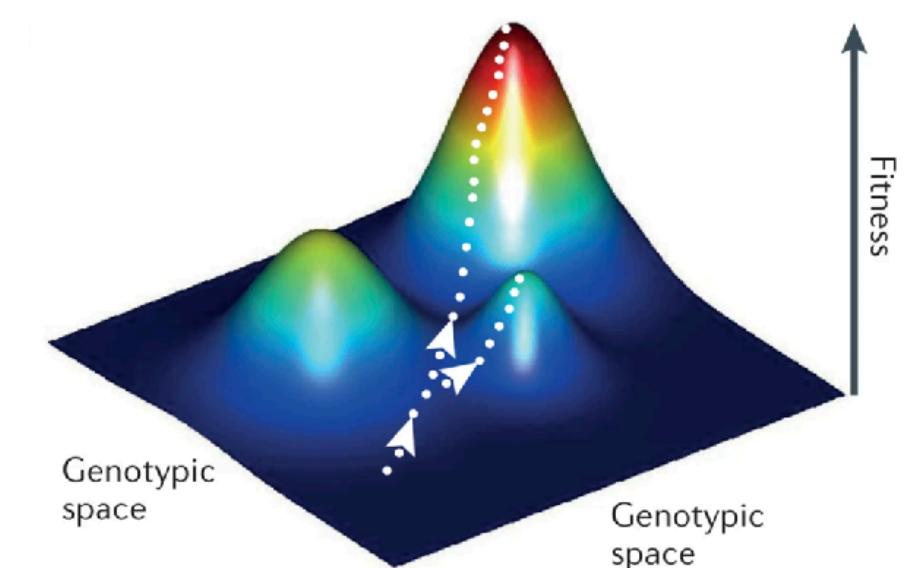


Social inference

## ④ Spatial navigation



## ③ Fitness landscape



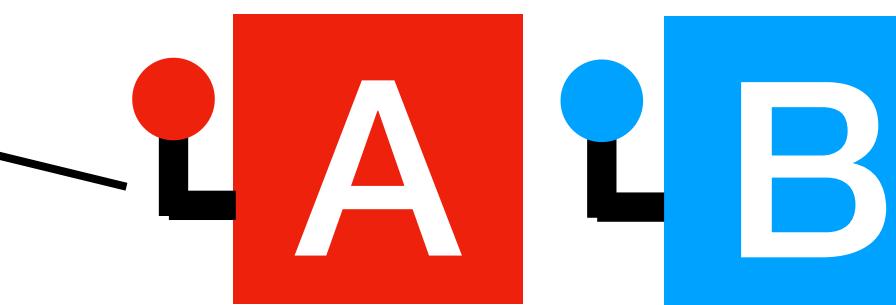
# A galaxy of social learning problems

## ⑤ Social Foraging



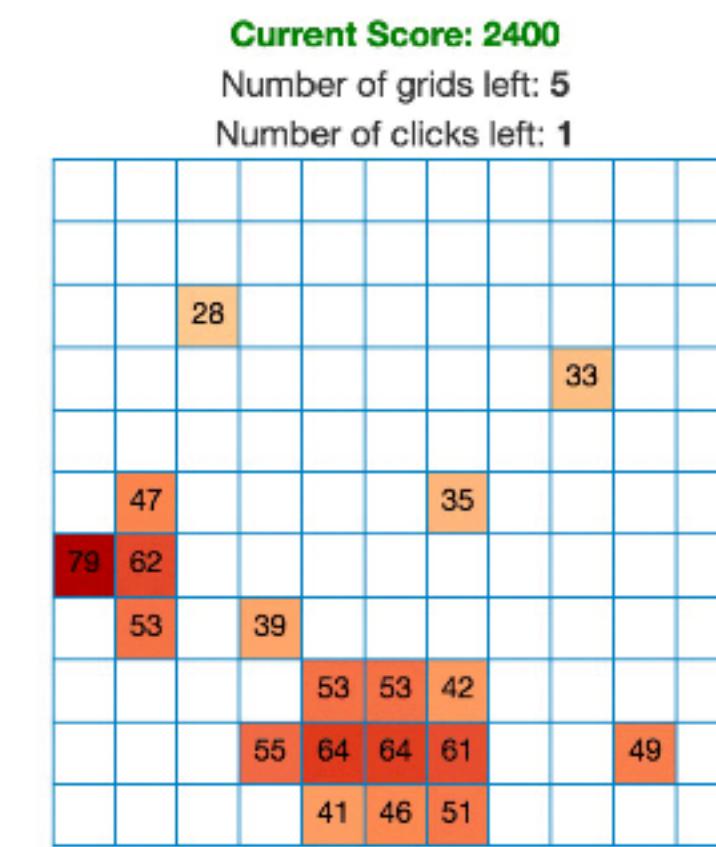
Competing interests  
Depleting rewards  
Individual differences

## ① Multi-armed Bandit

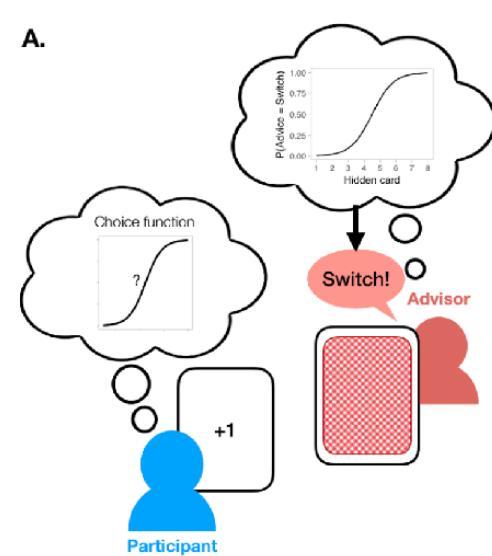


Spatial structure

## ② Spatially correlated bandit

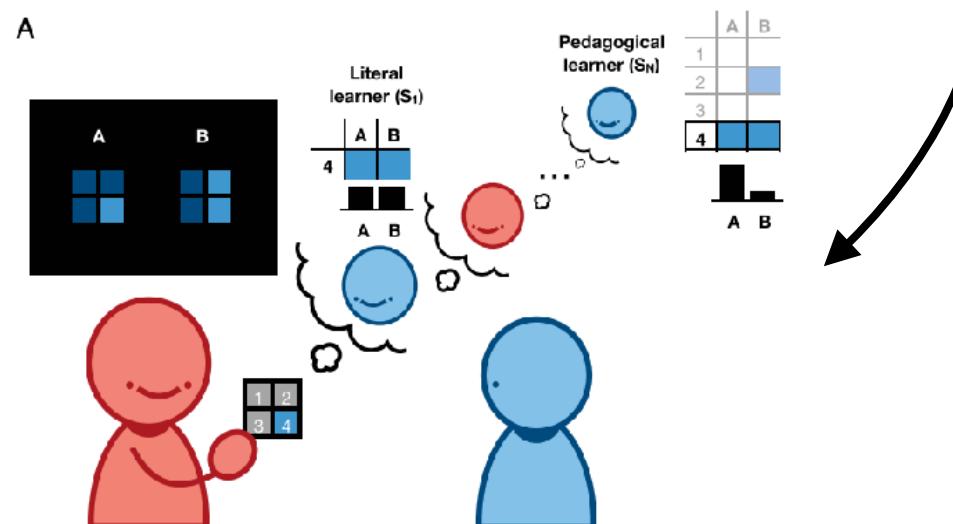


## ⑥ Theory of Mind



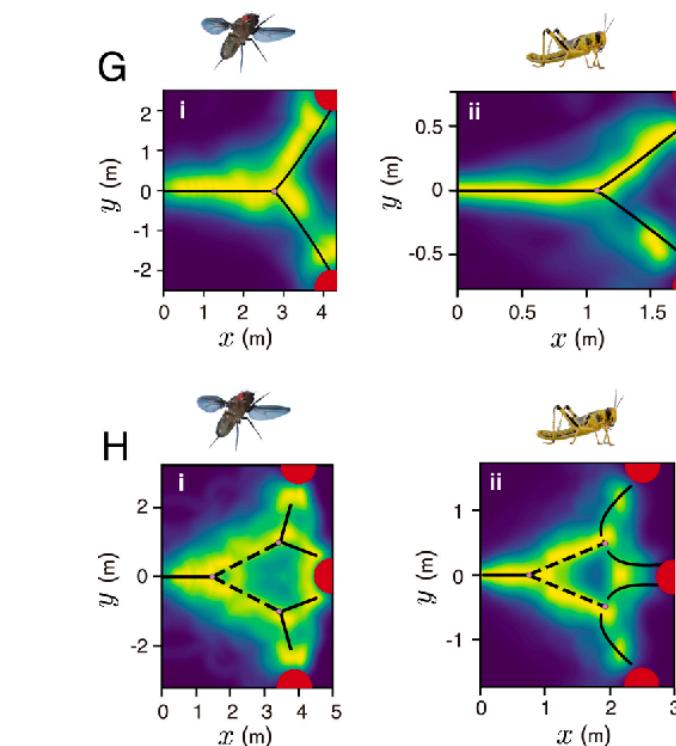
Social inference

## ⑦ Teaching and advice giving

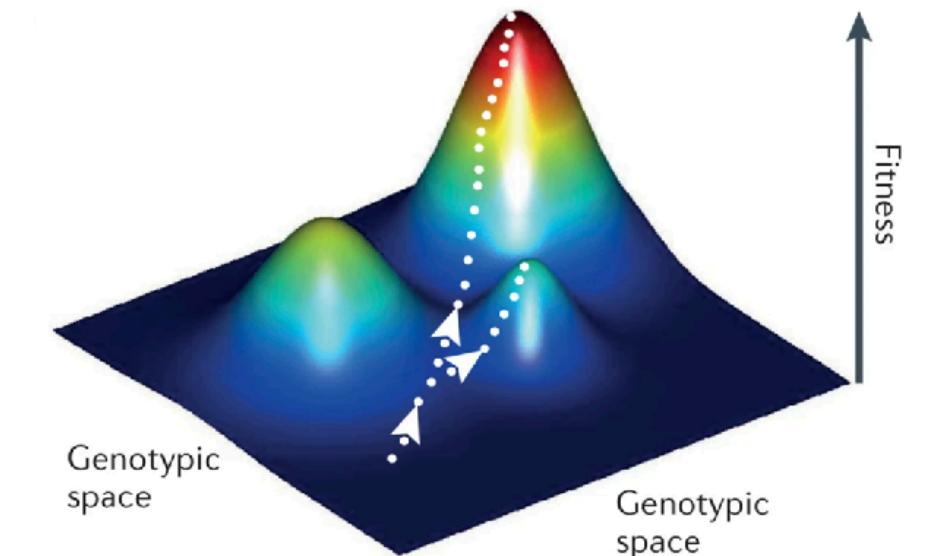


Pedagogy

## ④ Spatial navigation



## ③ Fitness landscape



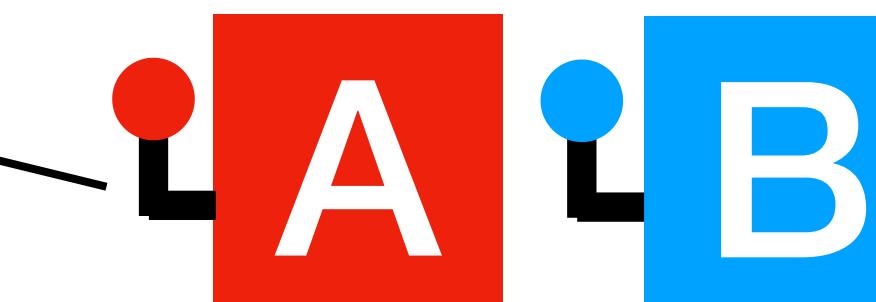
# A galaxy of social learning problems

## ⑤ Social Foraging



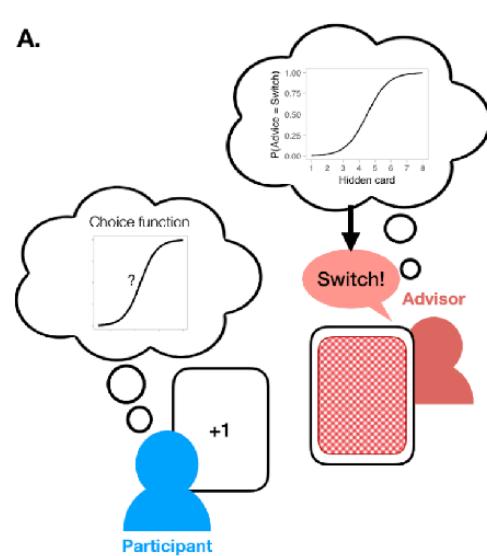
Competing interests  
Depleting rewards  
Individual differences

## ① Multi-armed Bandit



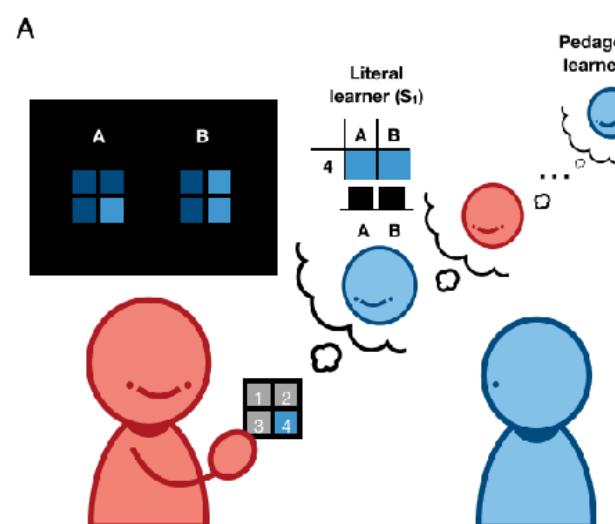
Spatial structure

## ⑥ Theory of Mind



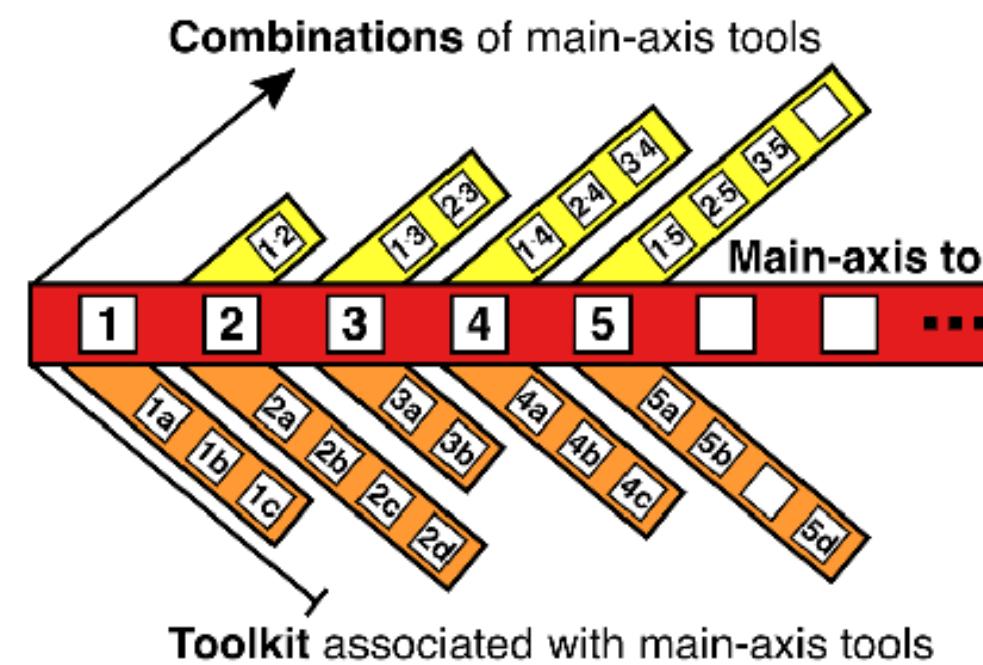
Social inference

## ⑦ Teaching and advice giving

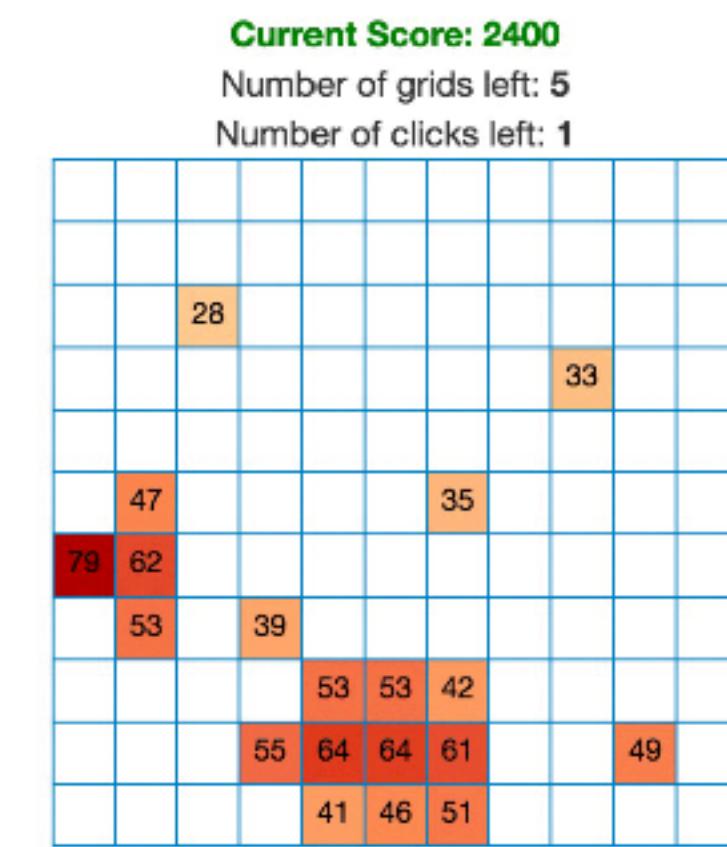


Pedagogy

## ⑧ Evolving landscape

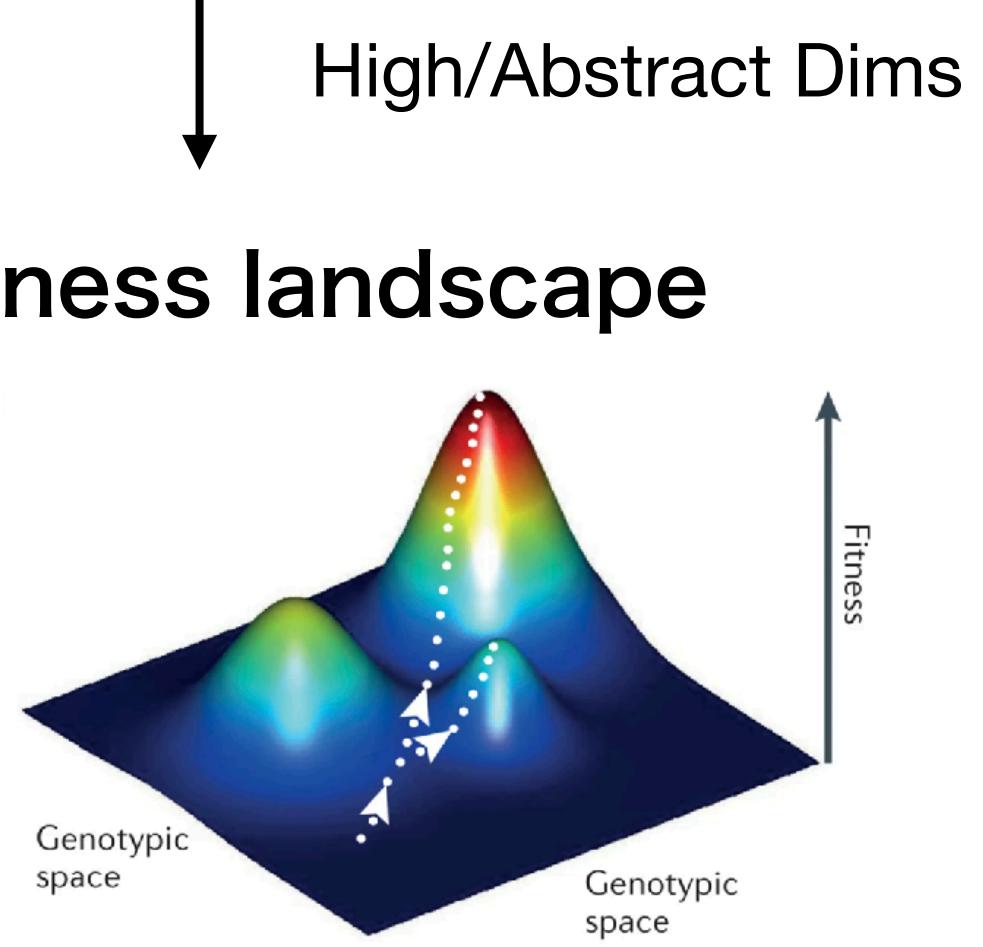
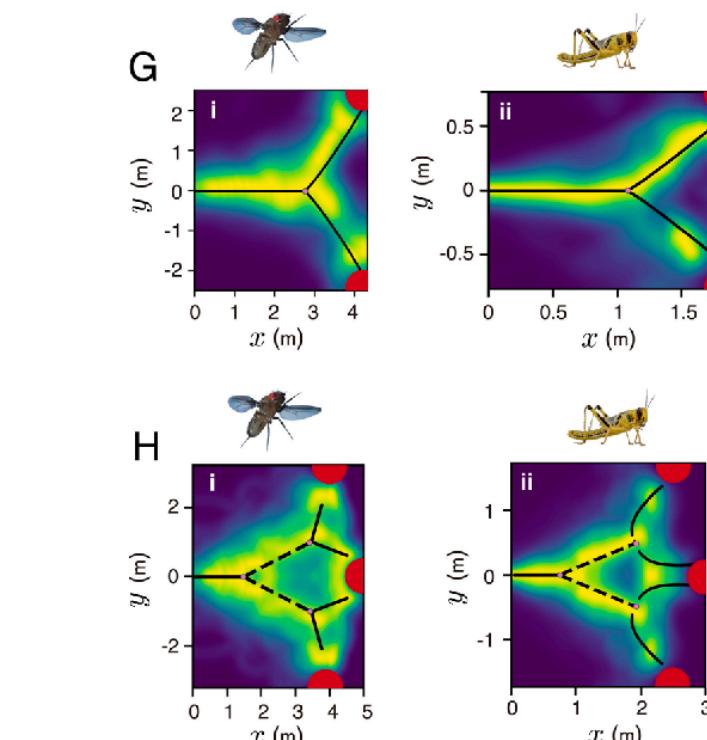


## ② Spatially correlated bandit



Sequential planning

## ④ Spatial navigation

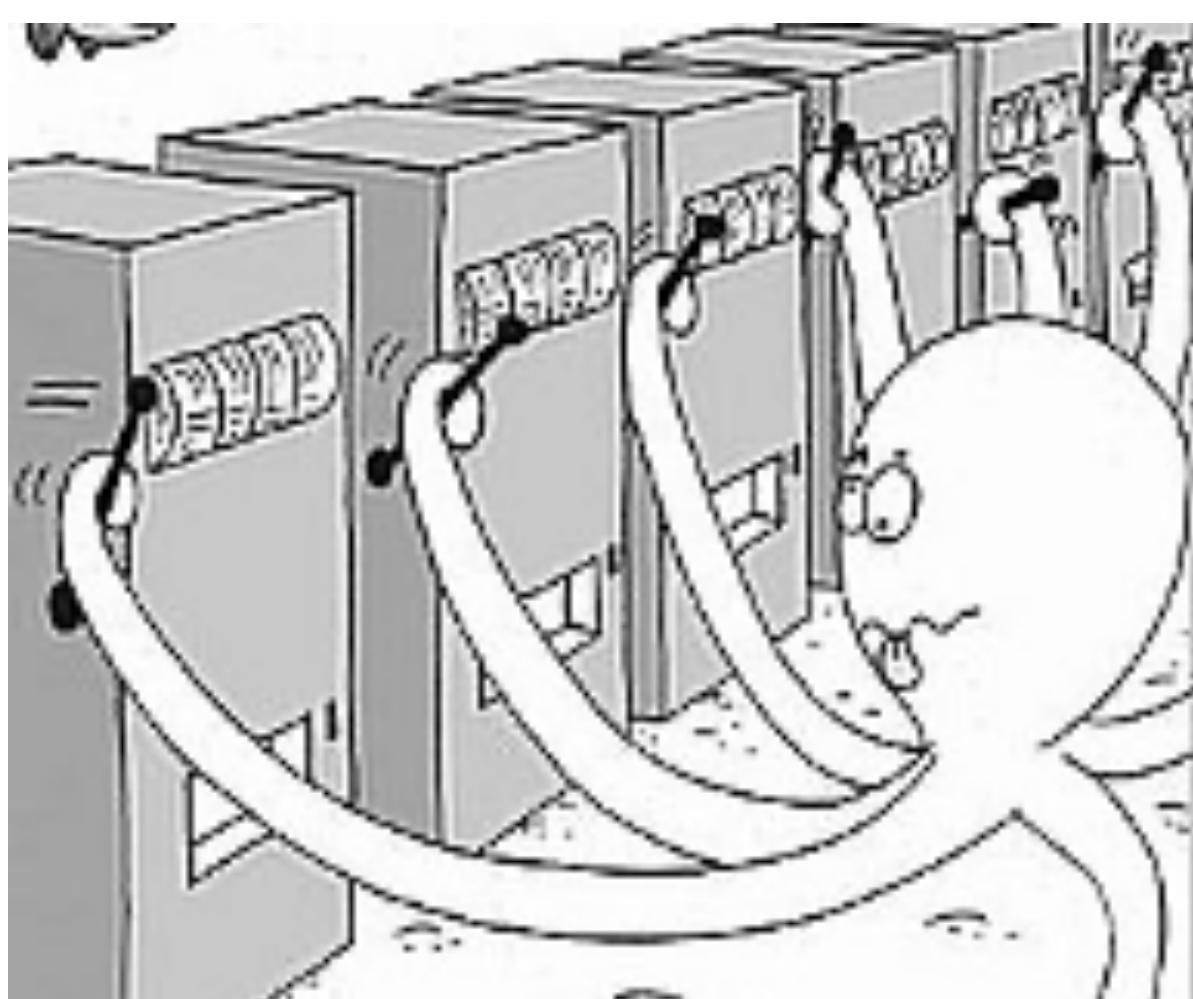


## ③ Fitness landscape

# Multi-Armed Bandit Problem

# Multi-armed bandit problem

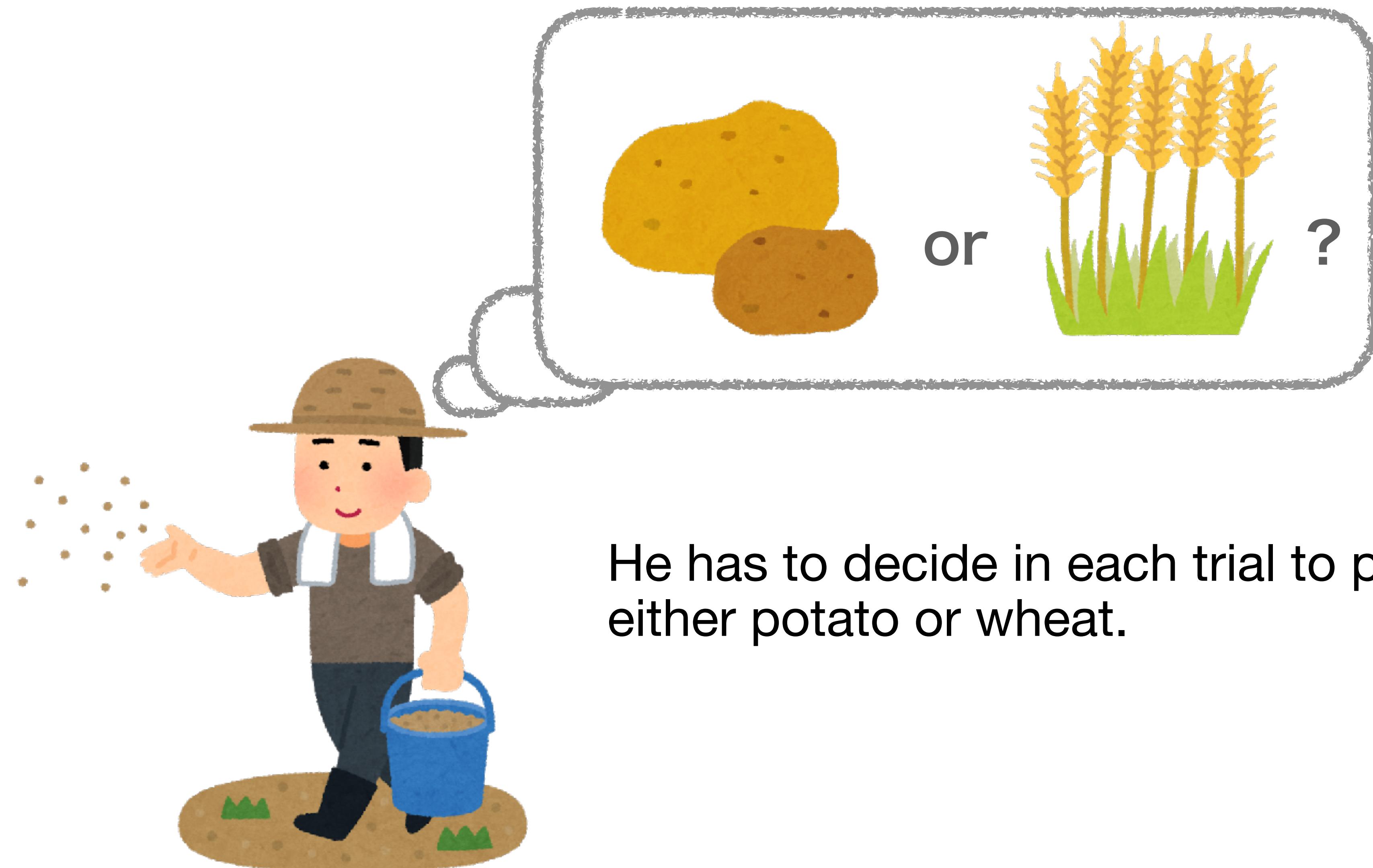
A simple model of the experience-based decision-making situations



Key features:

- Reward is unknown until the option is actually chosen
- The goal is to maximise your payoff, by sequentially playing one of the options at each time within a limited time horizon
- Exploration-Exploitation tradeoff arises

# A farming game



He has to decide in each trial to plant either potato or wheat.

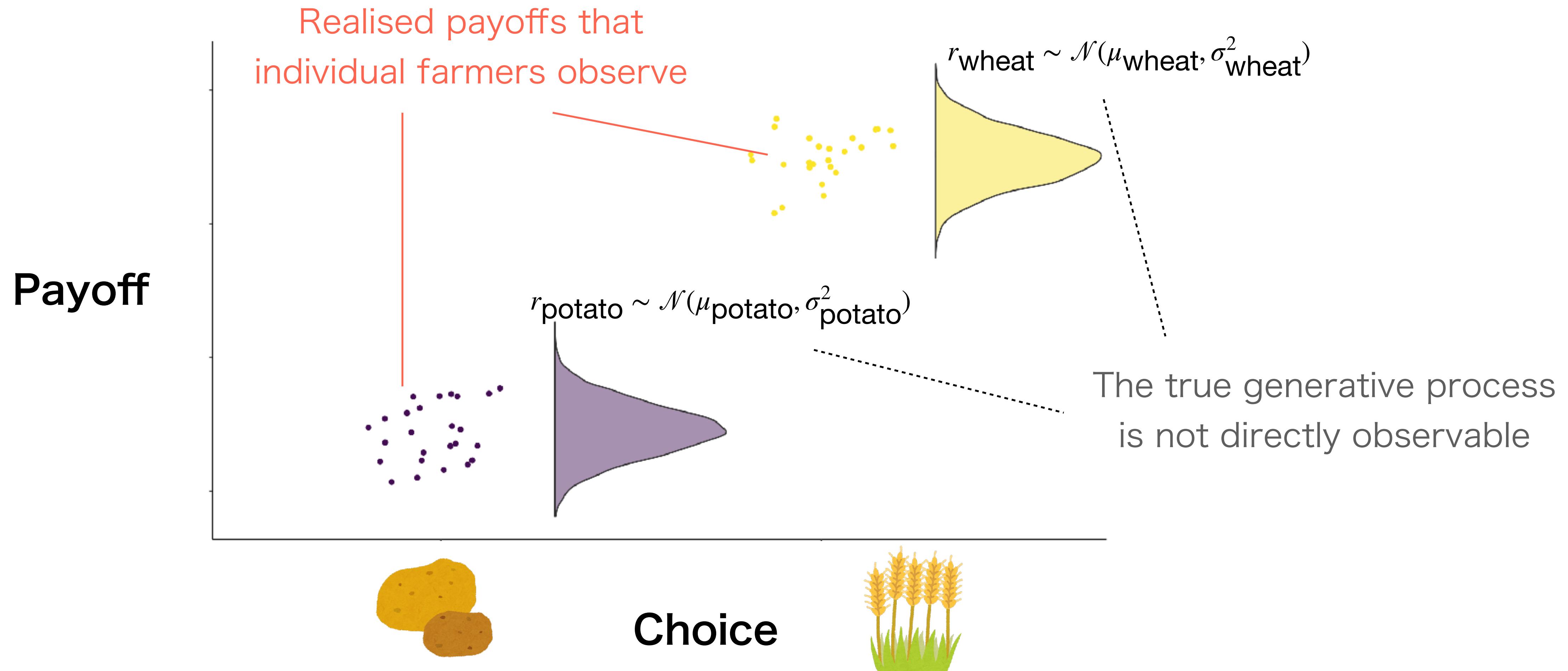
A naive decision maker

(McElreath et al., 2005; 2008; Deffner et al. 2020)

# Rewards drawn from a normal distribution

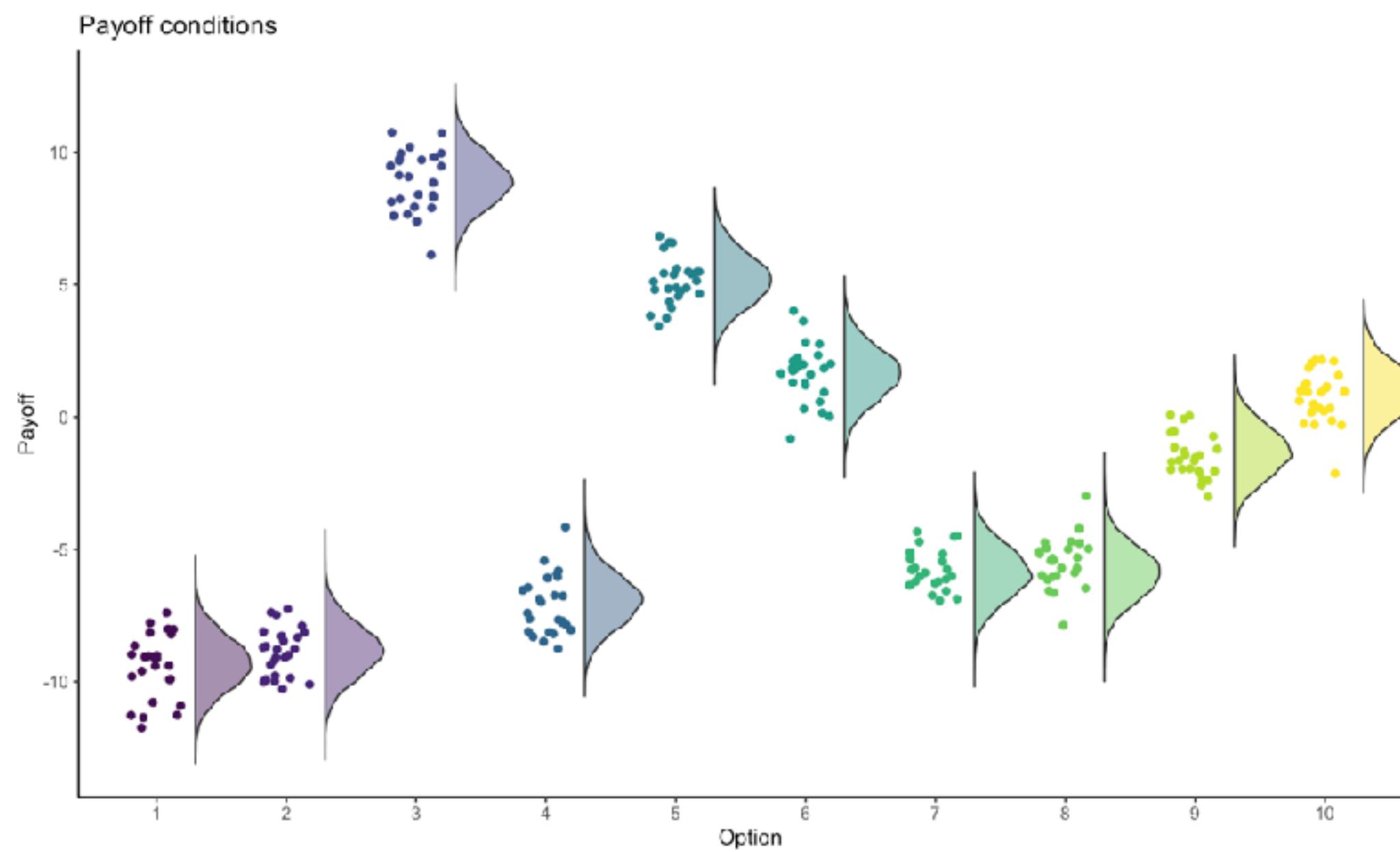


# Rewards drawn from a normal distribution

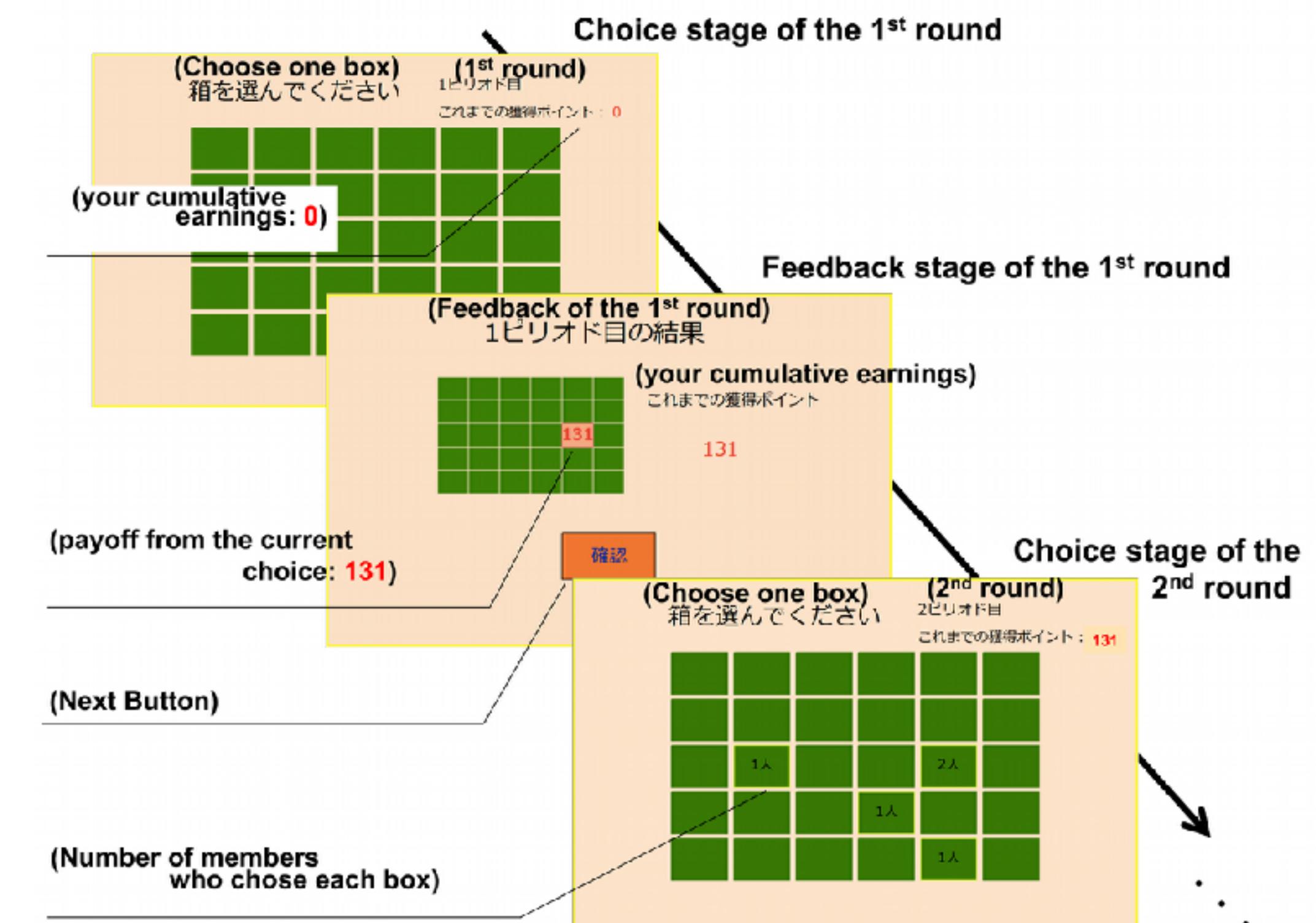


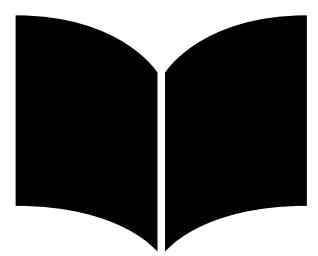
# Scaling up

## 10-armed bandit



## 30-armed bandit (Toyokawa et al. 2014)

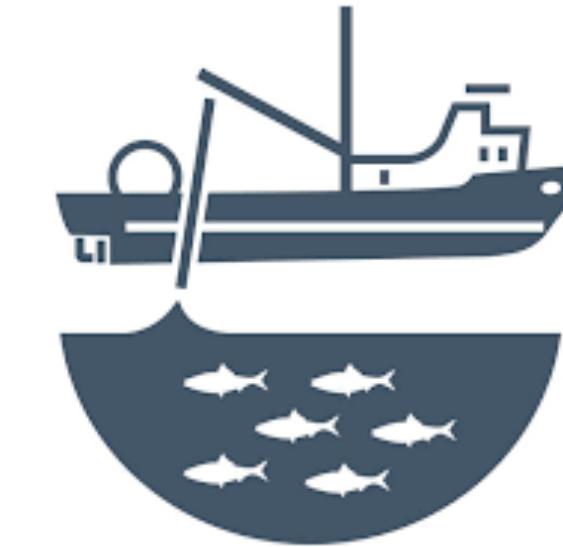


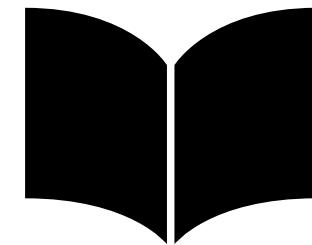


# Notebook

<https://cosmos-konstanz.github.io/notebooks/tutorial-1-n-armed-task.html#live-demonstrations>

## Live demonstration Fishing game!



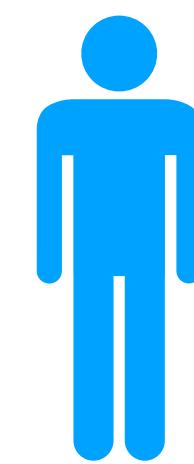


# Notebook

<https://cosmos-konstanz.github.io/notebooks/tutorial-1-n-armed-task.html#live-demonstrations>

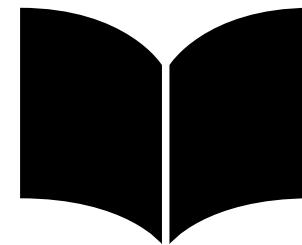
## (1) Individual learning task

Remaining clicks: 10



Q:

How would you learn which options provide the best rewards and how you navigate the explore-exploit dilemma?



# Notebook

<https://cosmos-konstanz.github.io/notebooks/tutorial-1-n-armed-task.html#live-demonstrations>

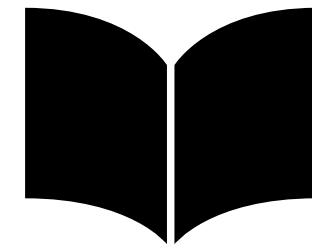
## (1) Individual learning task

Remaining clicks: 10



Q:

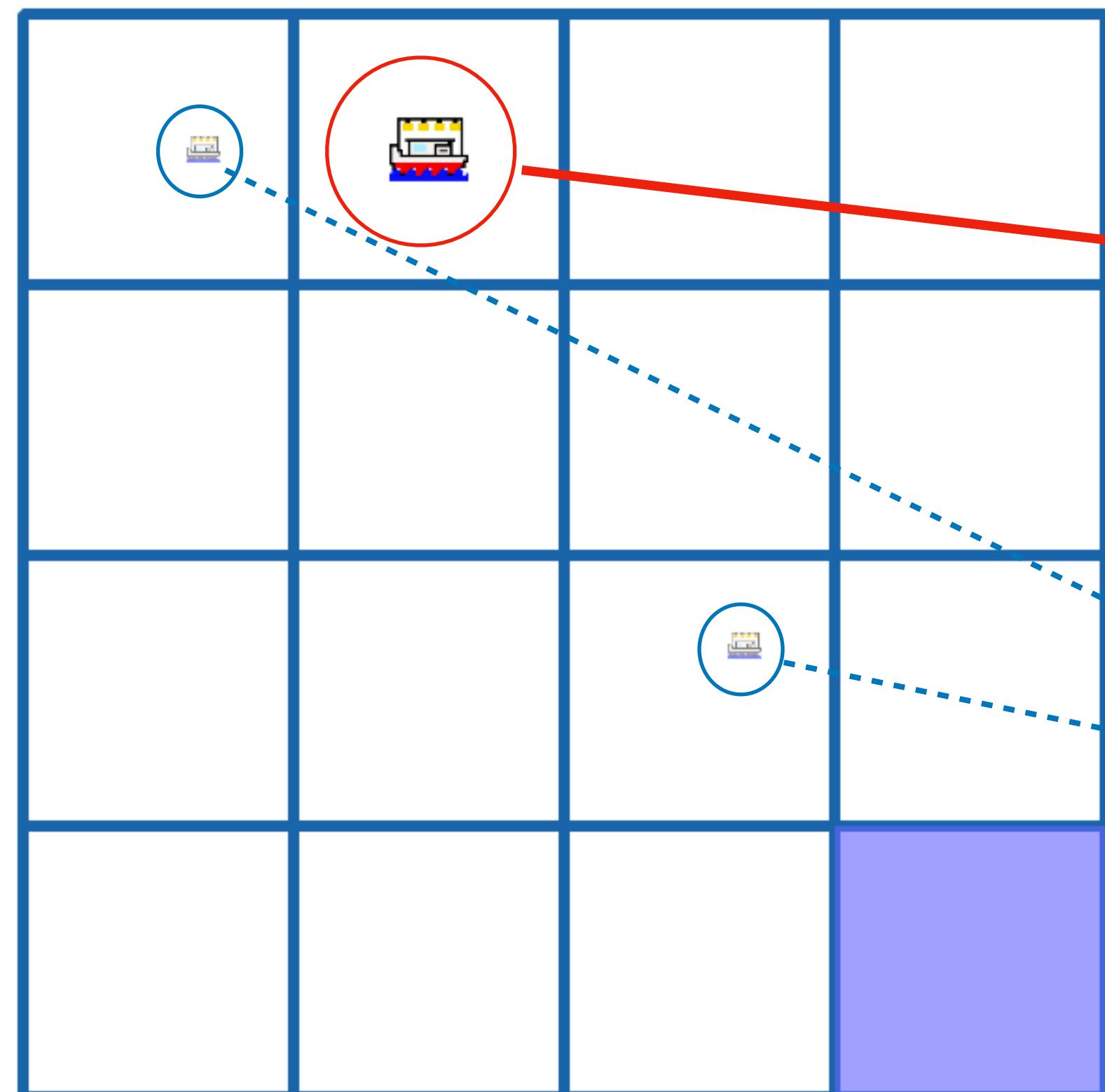
How would you learn which options provide the best rewards and how you navigate the explore-exploit dilemma?



# Notebook

<https://cosmos-konstanz.github.io/notebooks/tutorial-1-n-armed-task.html#live-demonstrations>

## (2) Social learning task (no competition)



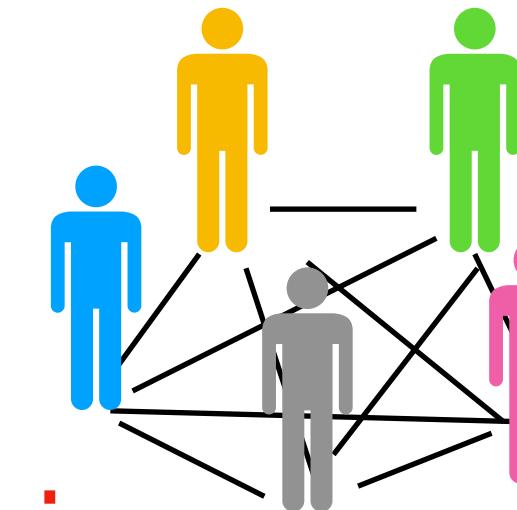
Remaining clicks: 9



Your ship

Other players' ship

You will be able to observe the actions of other players, but not see the rewards they earn.



Q:

When do you think social learning will outperform individual learning, and when would it fail?

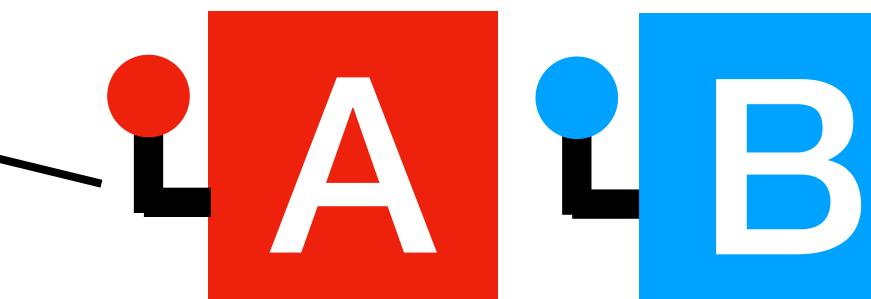
# What problems are outside this framework?

## ⑤ Social Foraging



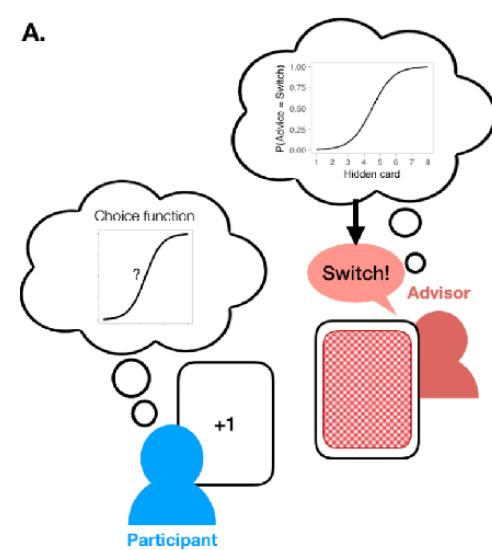
Competing interests  
Depleting rewards  
Individual differences

## ① Multi-armed Bandit



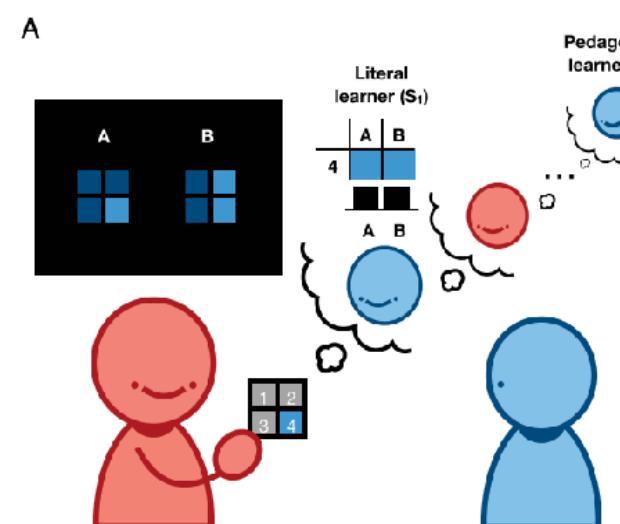
Spatial structure

## ⑥ Theory of Mind



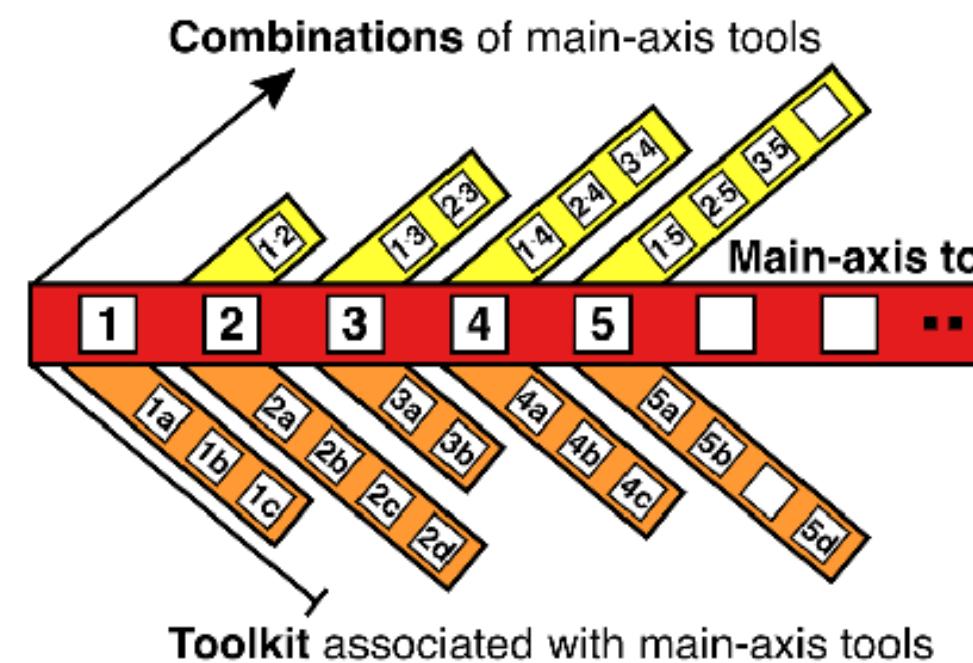
Social inference

## ⑦ Teaching and advice giving

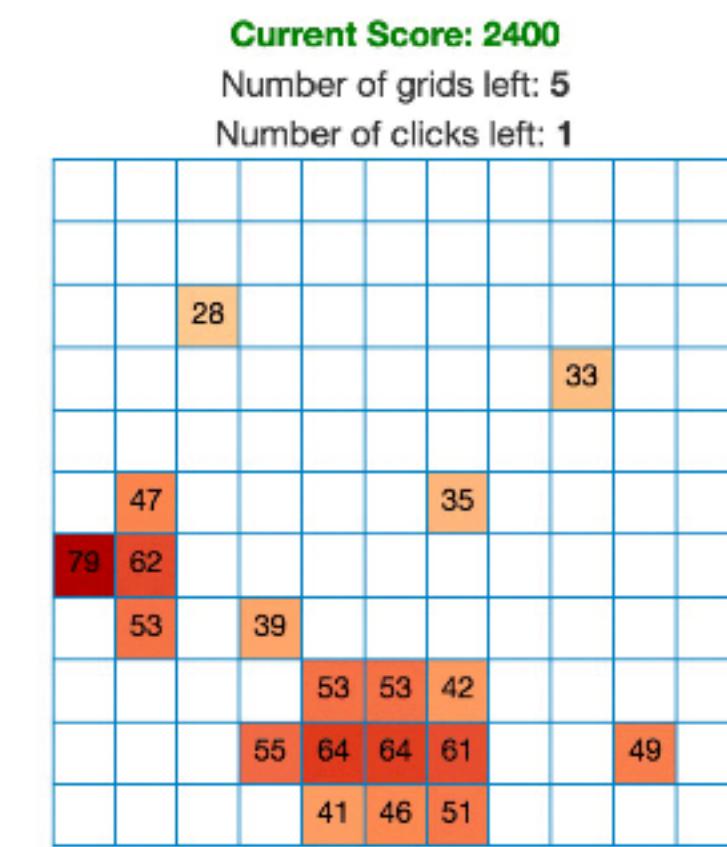


Pedagogy

## ⑧ Evolving landscape

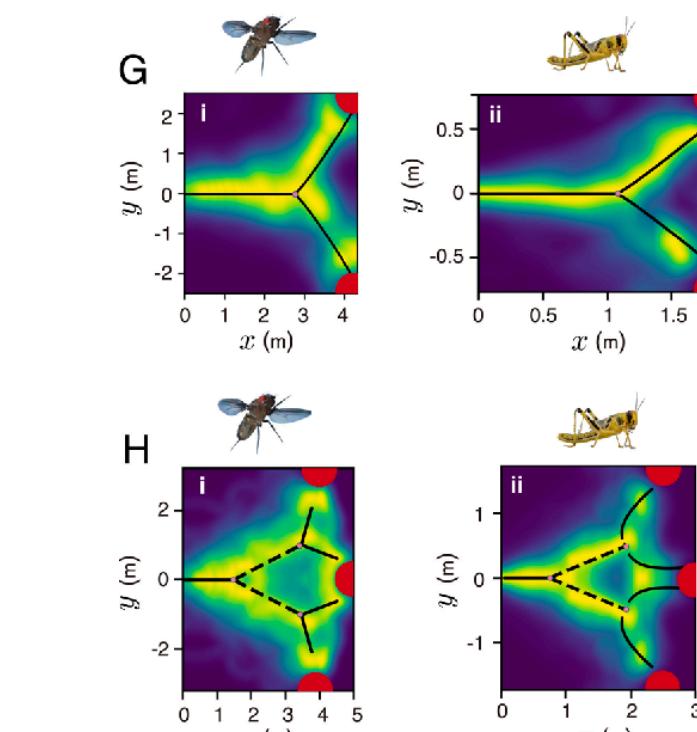


## ② Spatially correlated bandit

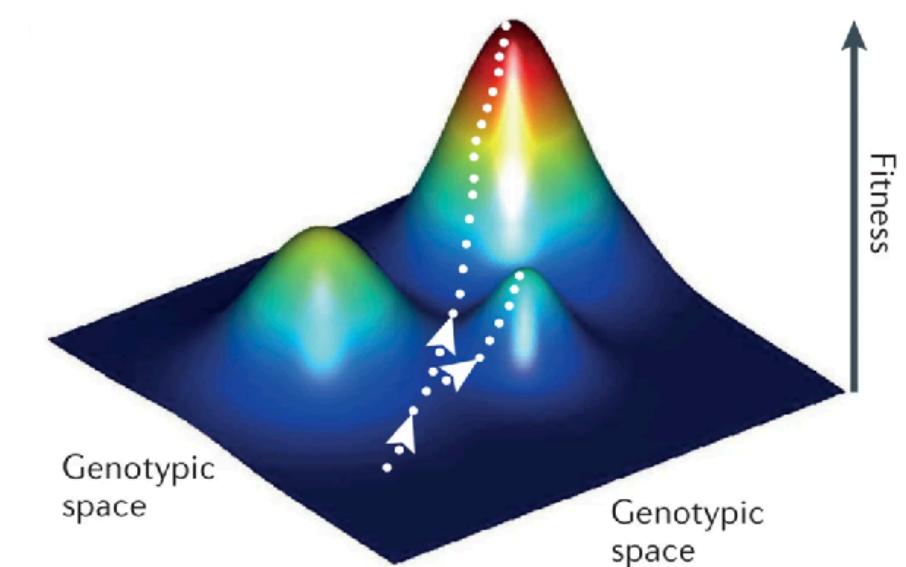


Sequential planning

## ④ Spatial navigation



## ③ Fitness landscape



# Tutorial structure

- ~~1. Introduction to social learning tasks~~
2. Models of individual and social learning
3. Model comparison and robustness
4. Cracking hierarchical Bayesian computational modeling with Stan

# Supplemental slides