

# **COSMOS**

## **Tutorial 1: Social Learning Tasks**

**Wataru Toyokawa & Charley Wu**

**July 5th**

# Goals of Tutorial 1

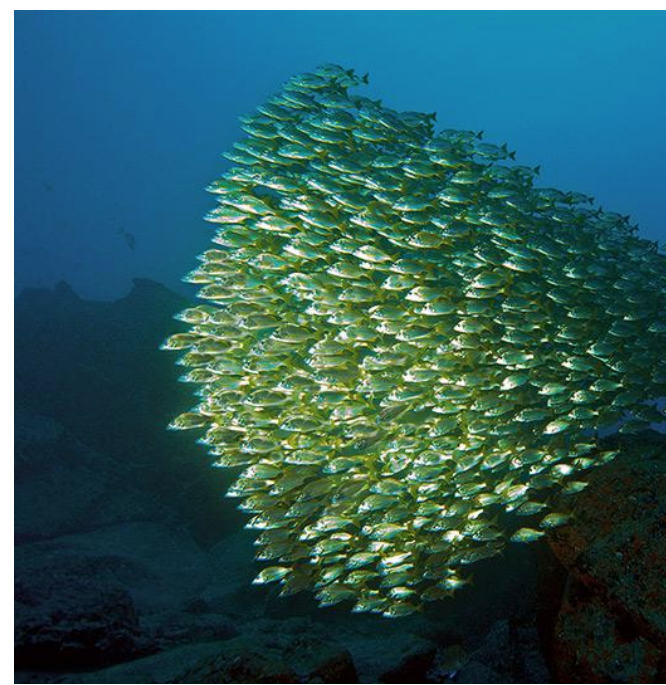
- Real world examples of social learning (SL)
- Taxonomy of SL problems
- Introduction to the multi-armed bandit task
- Interactive demonstration
- Connect bandit task to other social learning tasks
  - Foraging, spatial search, fitness landscapes
  - Other tasks that don't fit

# **Social decision making in an uncertain world**

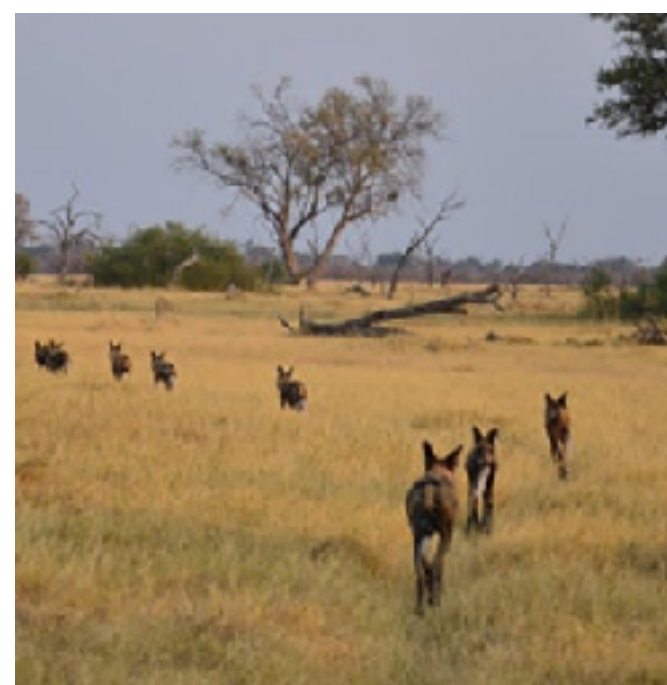
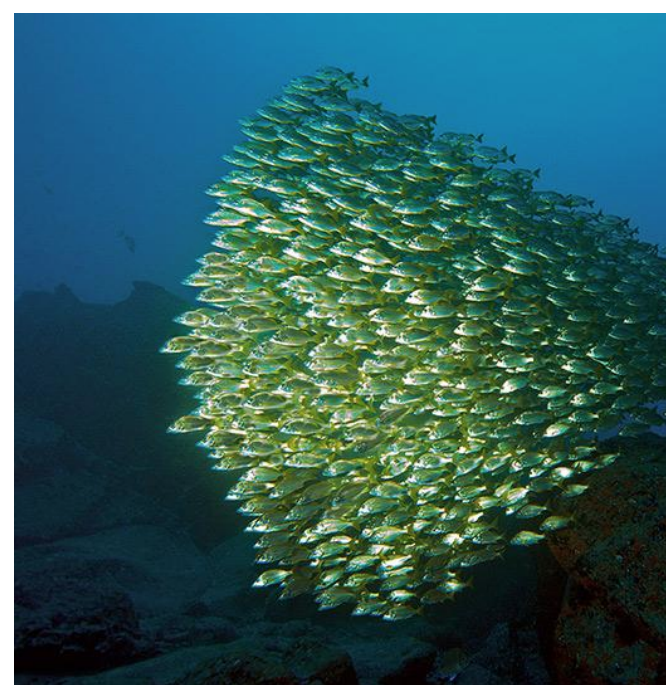
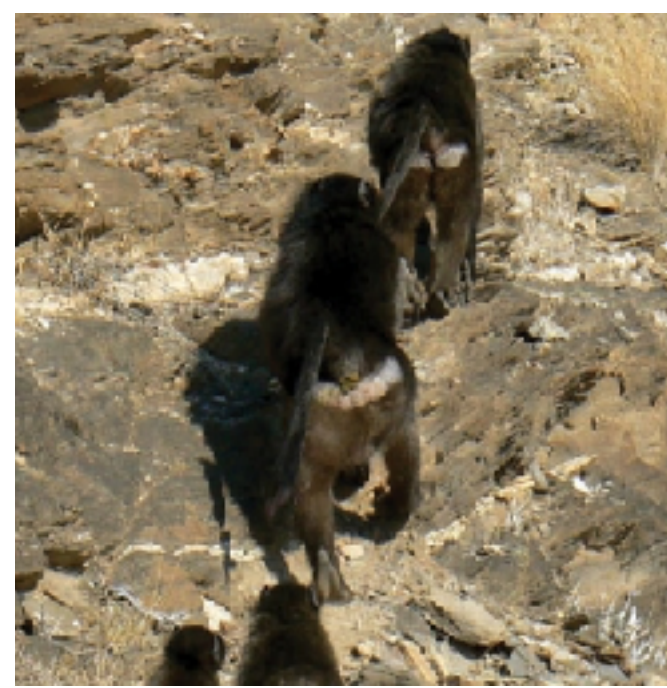
# Social decision making in an uncertain world



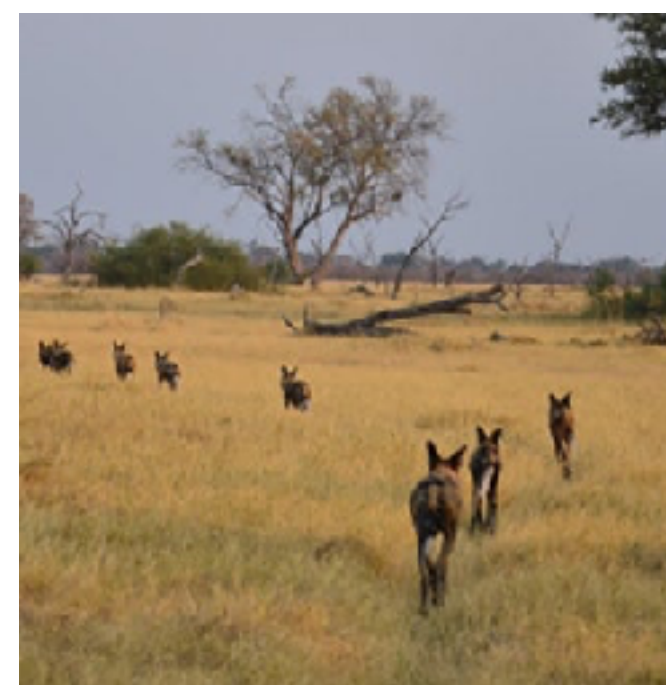
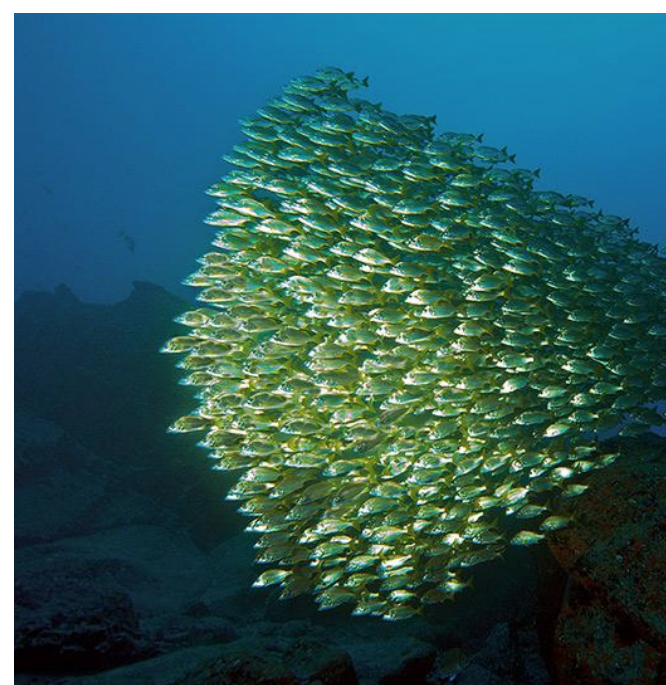
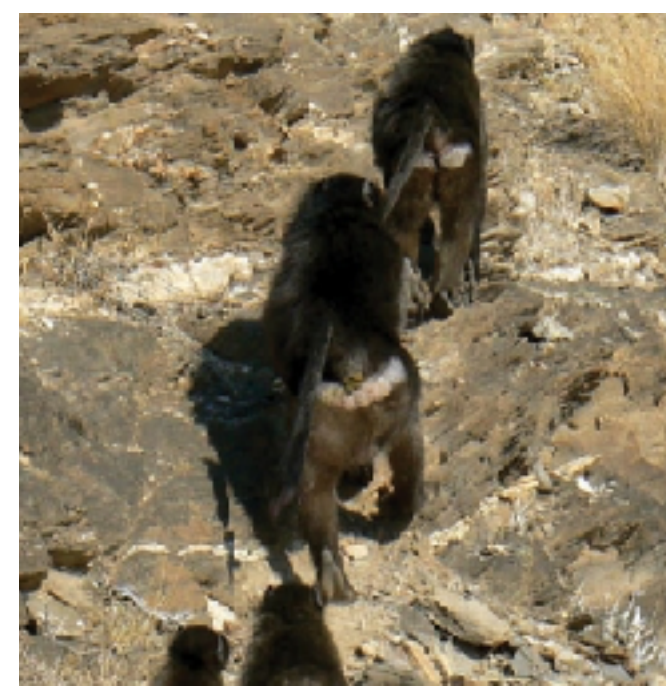
# Social decision making in an uncertain world



# Social decision making in an uncertain world



# Social decision making in an uncertain world




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

Shape: Shape 3    Colour: Orange


**OTHER PLAYERS' SCORES**

Player 1:	482
<a href="#">CLICK HERE TO COPY</a>	
Player 2:	300
<a href="#">CLICK HERE TO COPY</a>	
Player 3:	593
<a href="#">CLICK HERE TO COPY</a>	
Player 4:	545
<a href="#">CLICK HERE TO COPY</a>	
Player 5:	333
<a href="#">CLICK HERE TO COPY</a>	



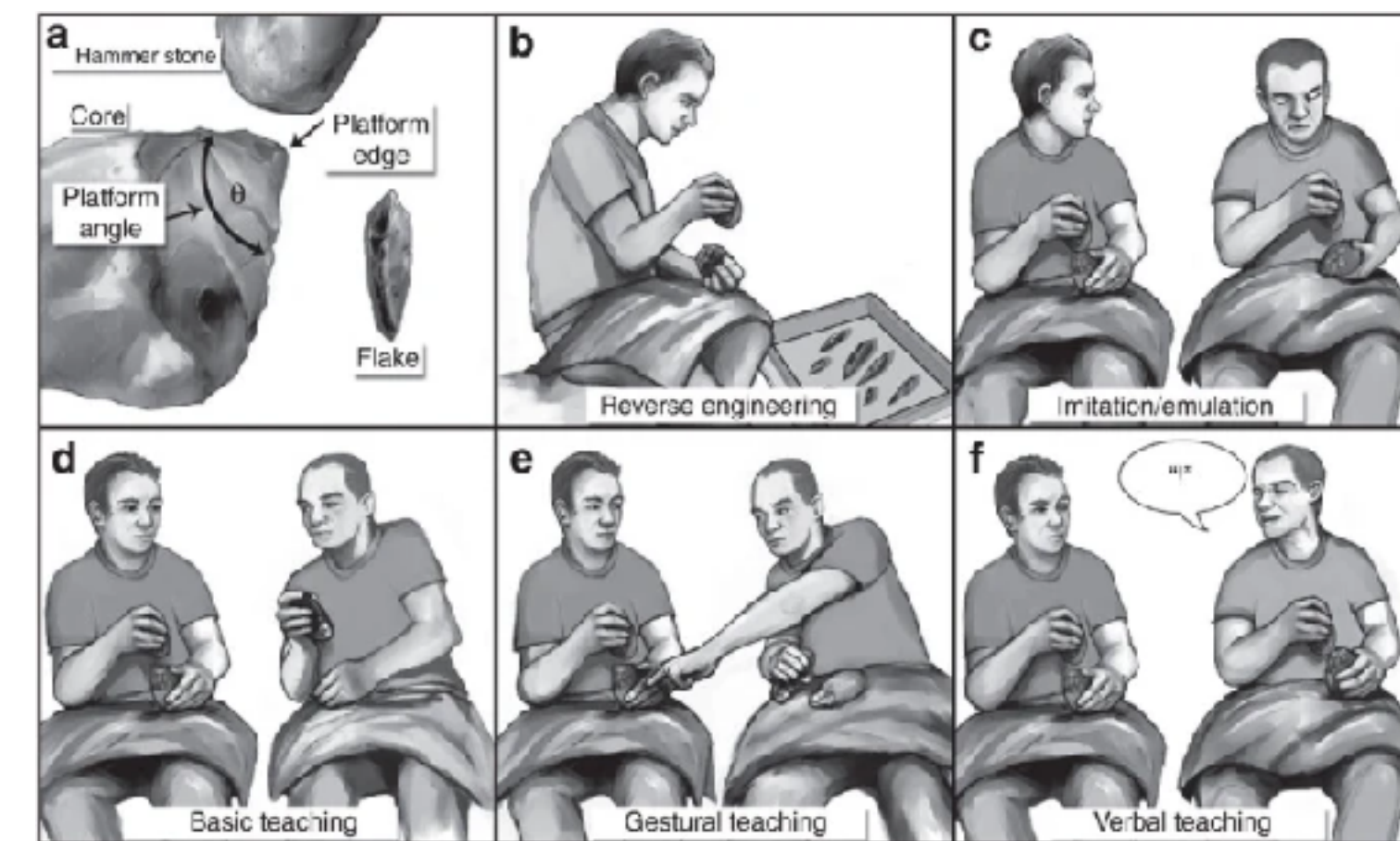
You may now change the values above as before, clicking SHOW to see your arrowhead and HUNT to see how it does.

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.

0  1000

Season:	1	Calories (/1000):	
Hunts Left:	29	Previous calories:	368
Group Rank:	6th	Season Score:	368

**HUNT**    **NEXT HUNT**

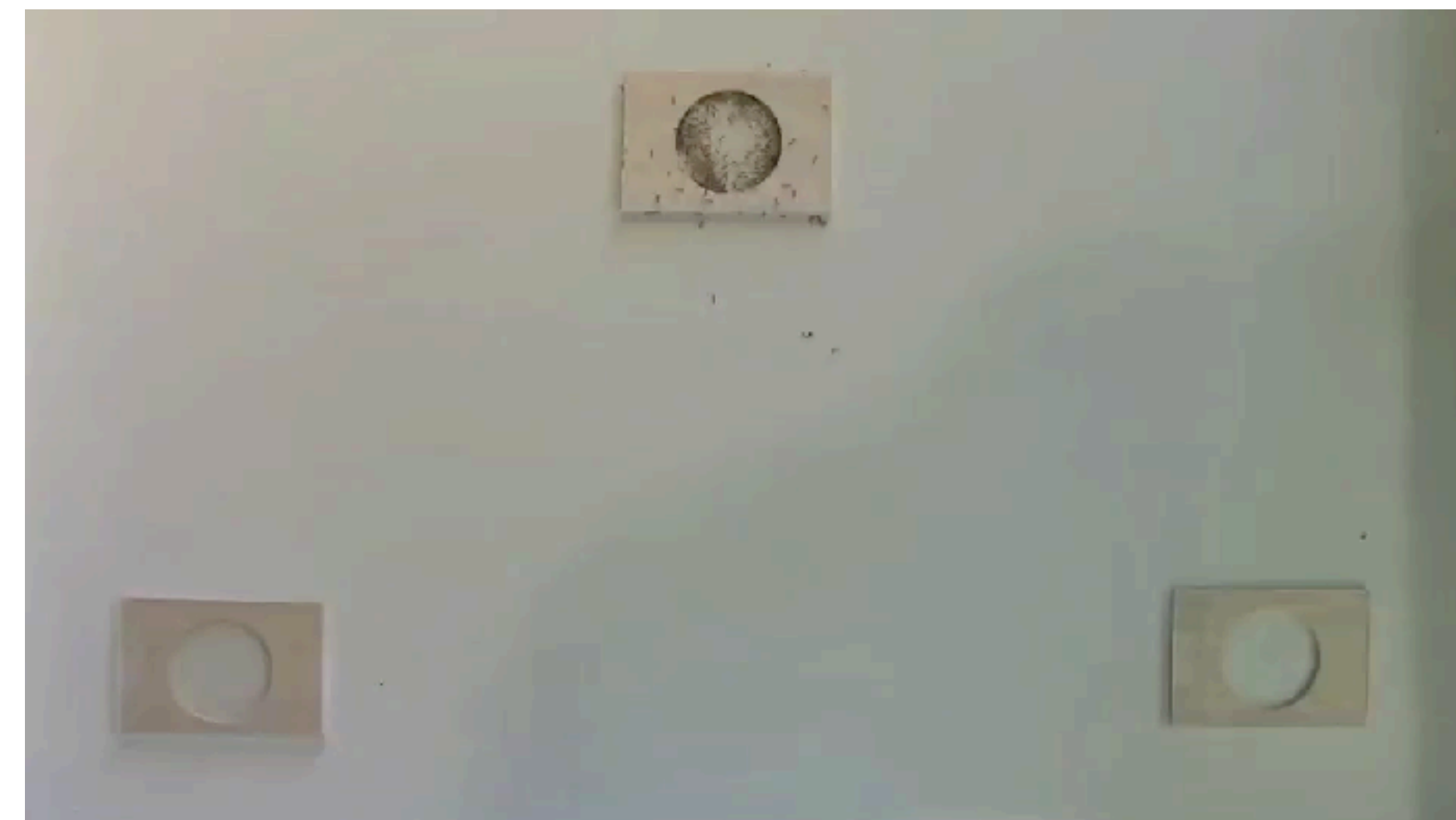
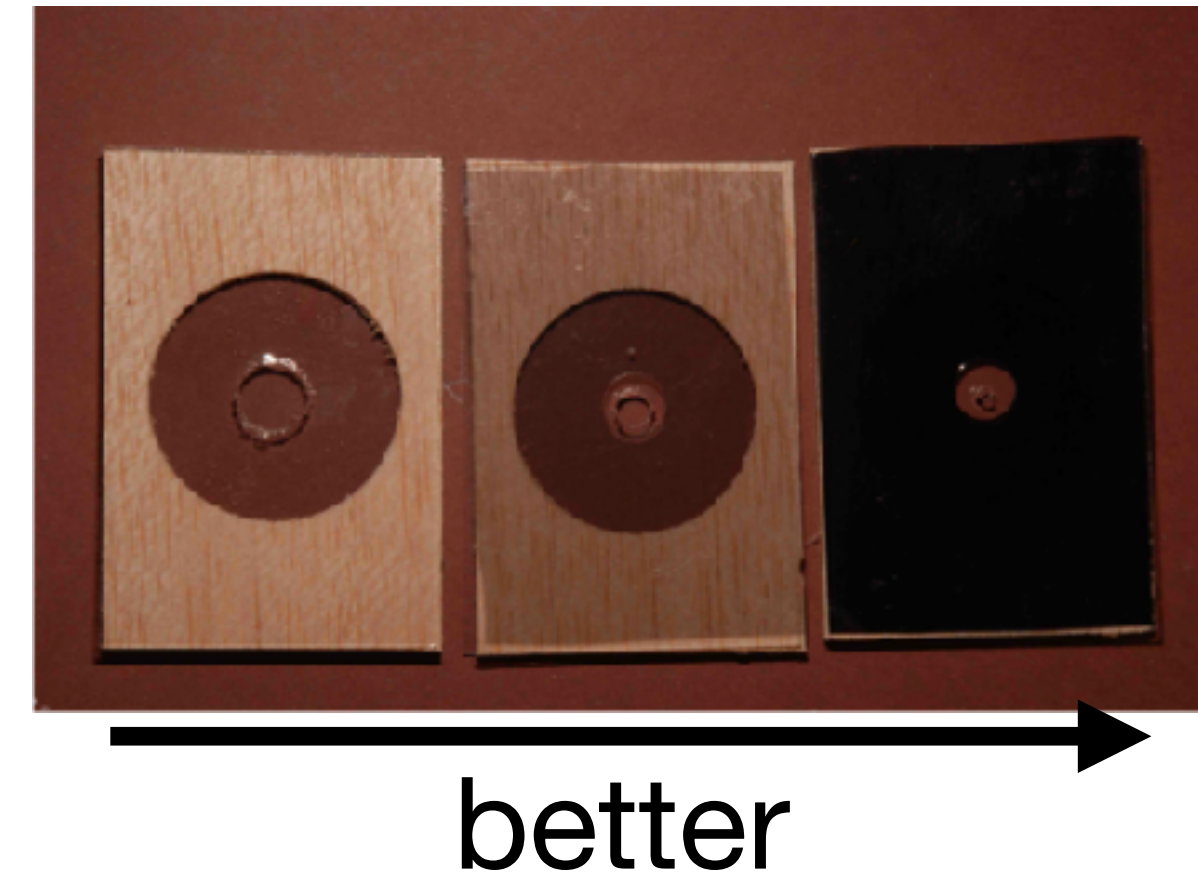


# ① Social learning as collective decision-making

## House hunting ants



Colonies & individuals have the same preference



Sasaki, T., Granovskiy, B., Mann, R. P., Sumpter, D. J., & Pratt, S. C. (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.

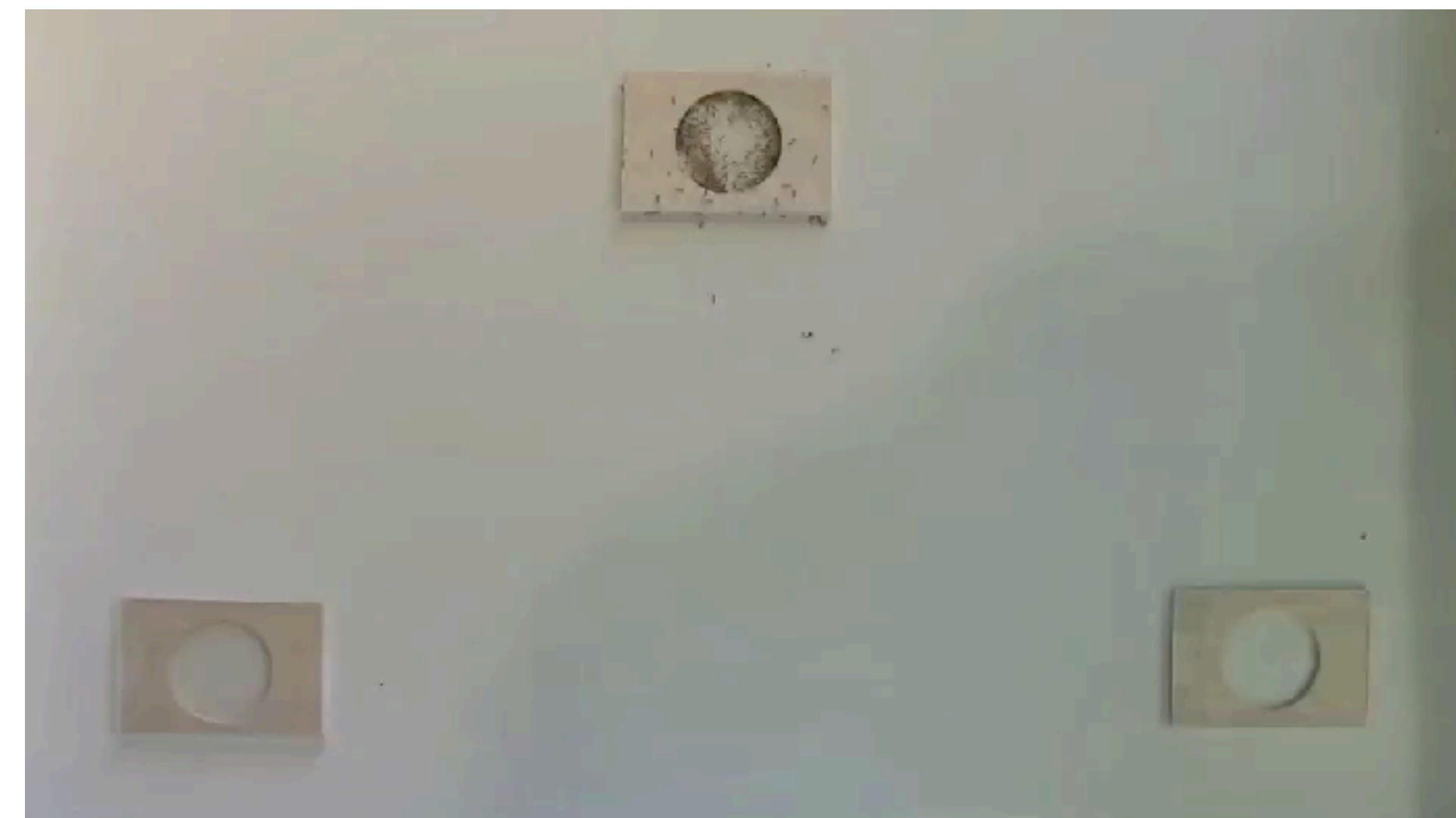
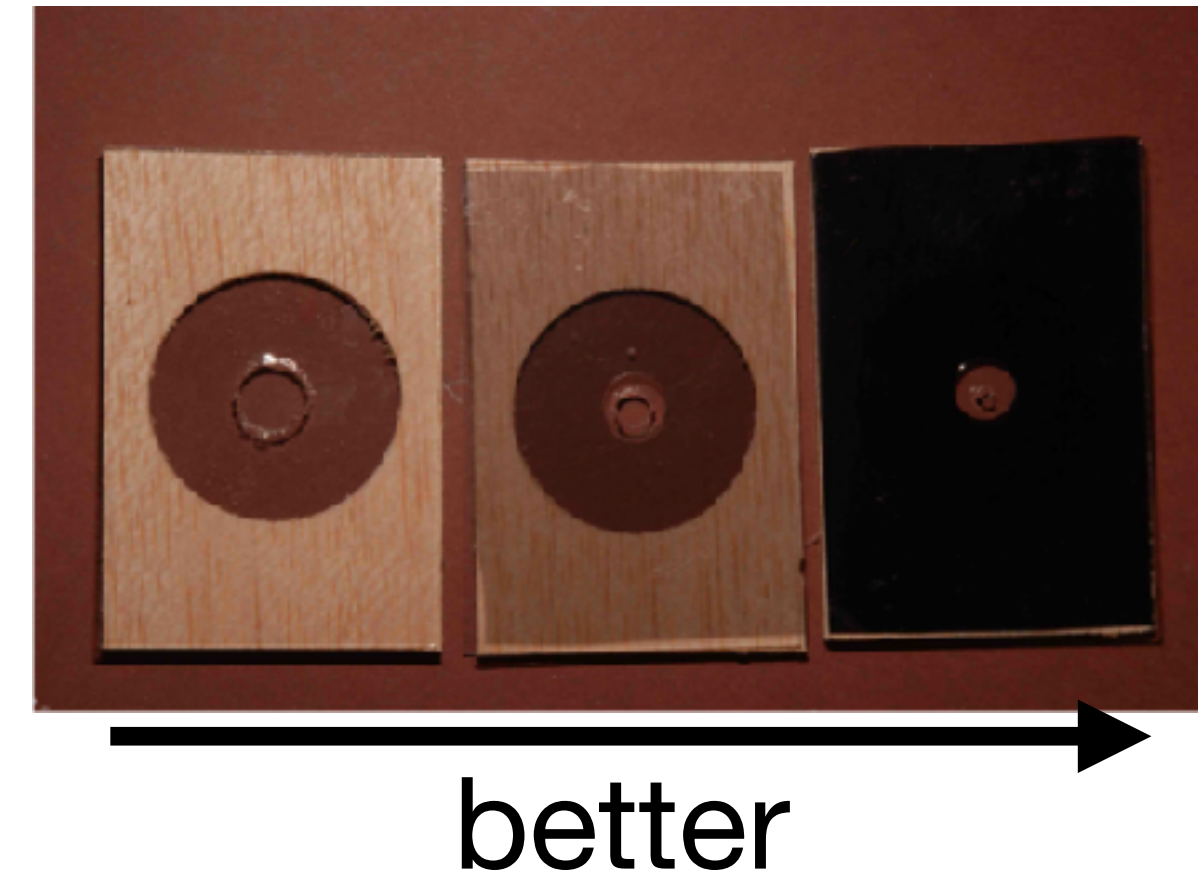


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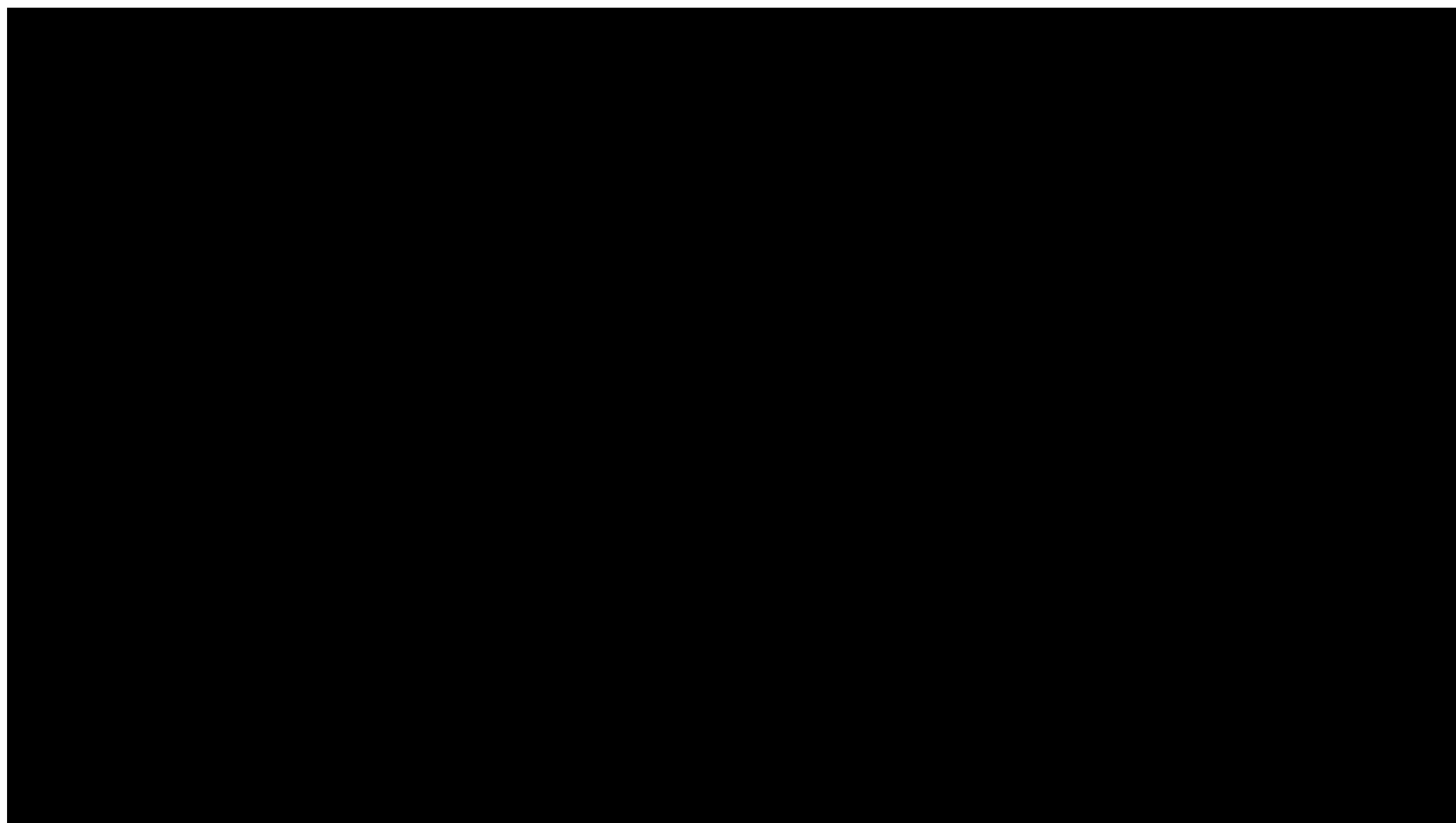
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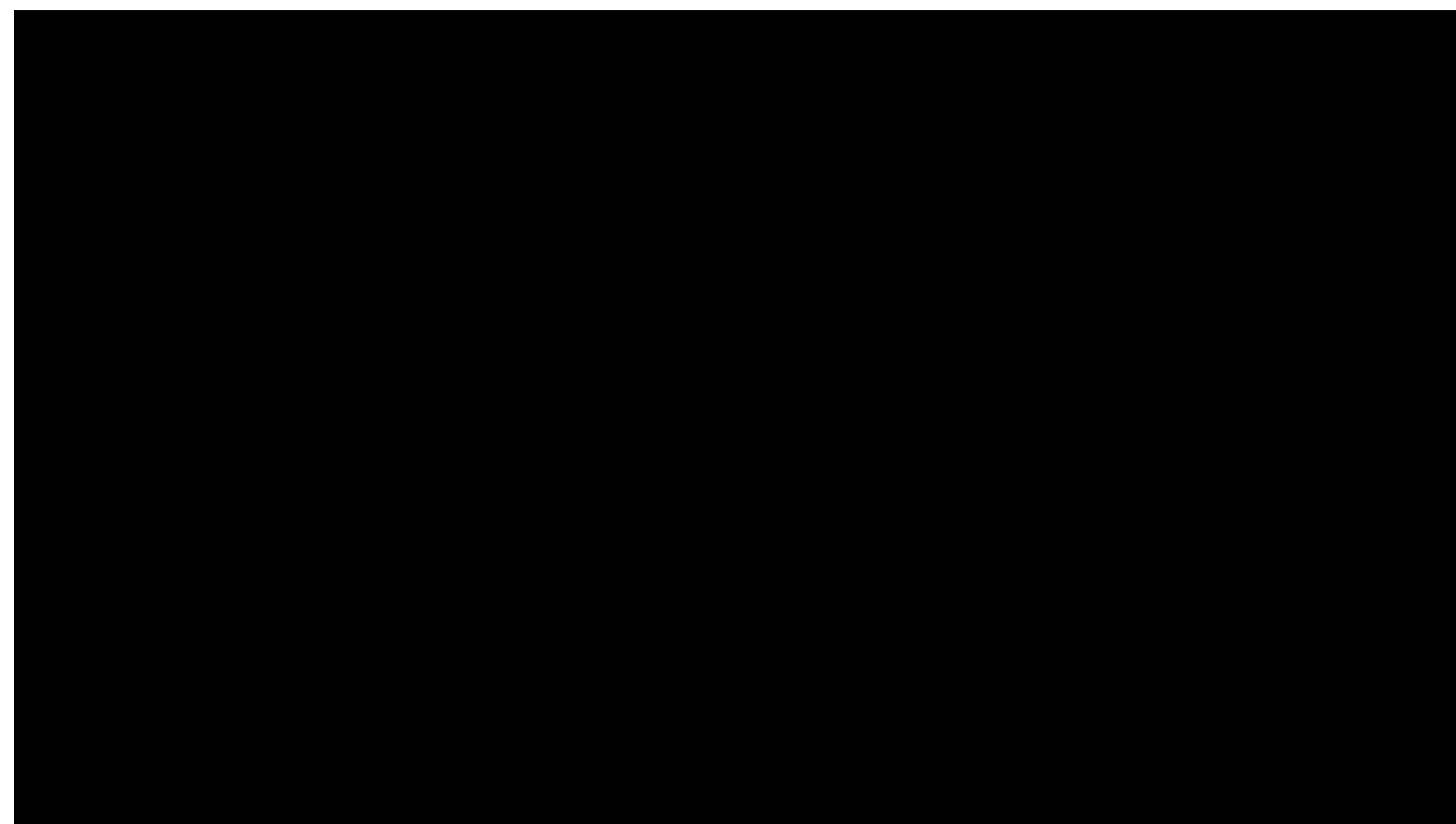
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## Two behavioural options



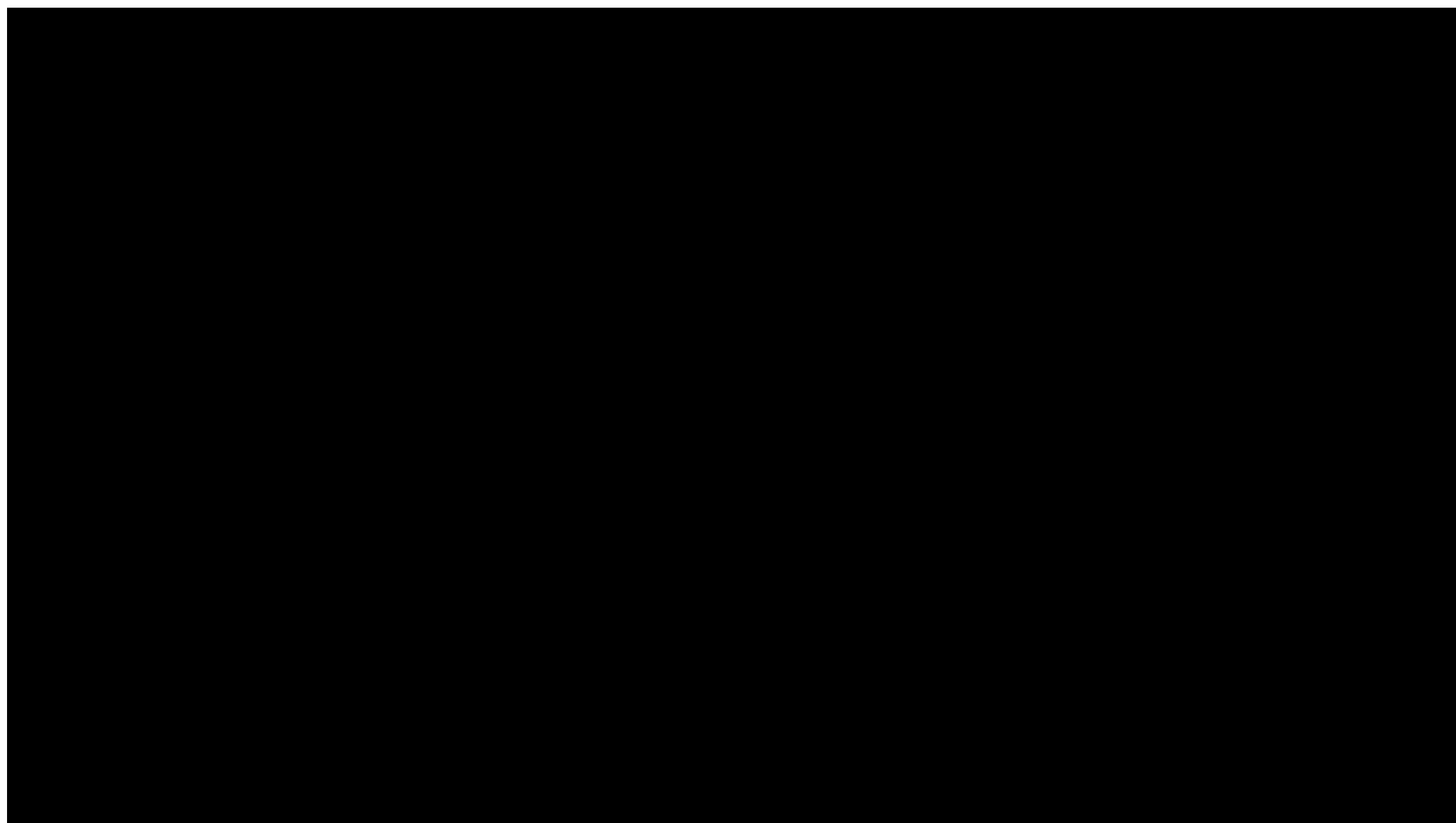
## Social learning (scrounging)



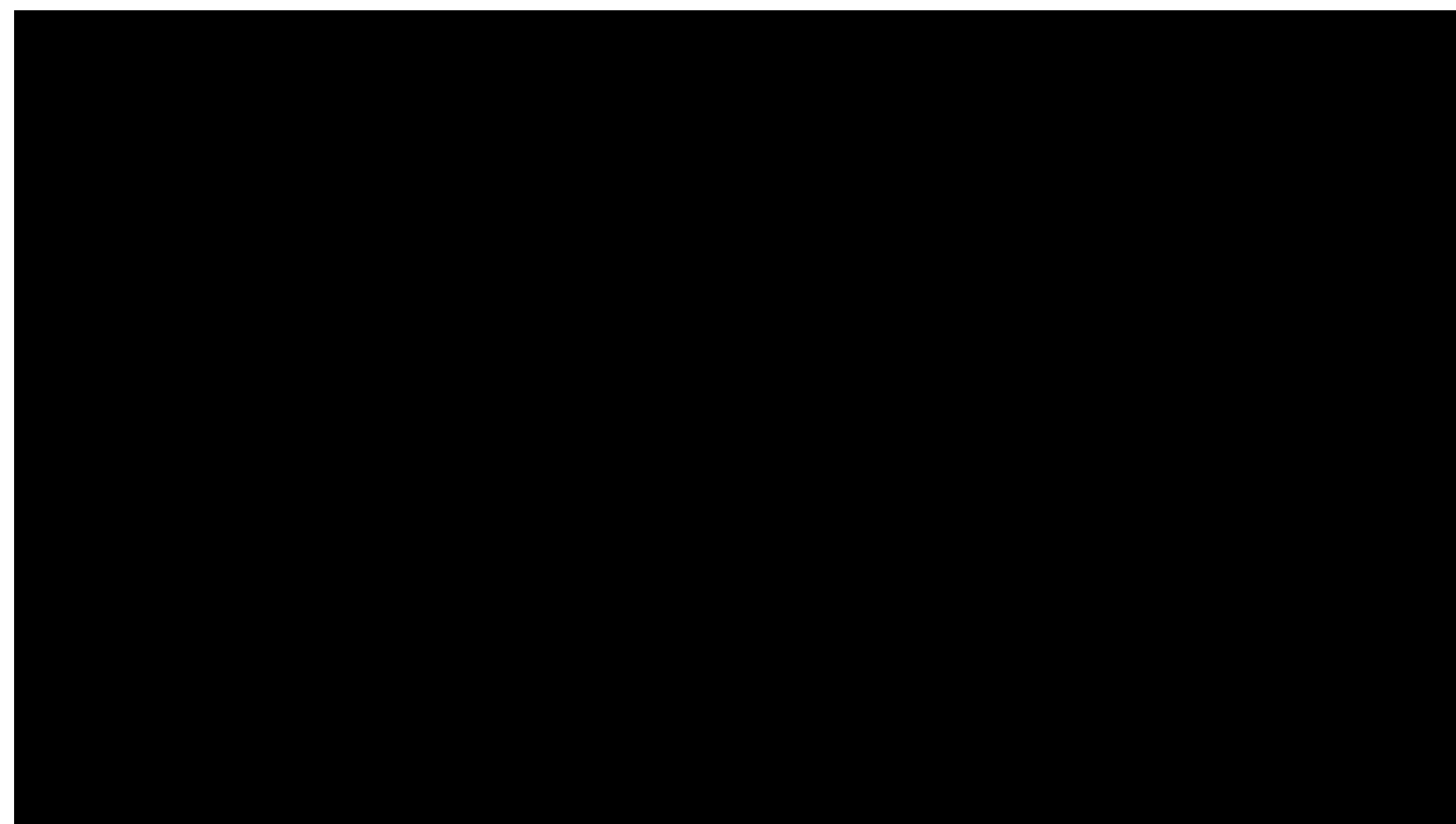
Aplin, L. M., Farine, D. R., Morand-Ferron, J., Cockburn, A., Thornton, A., & Sheldon, B. C. (2015). Experimentally induced innovations lead to persistent culture via conformity in wild birds. *Nature*, 518(7540), 538-541.



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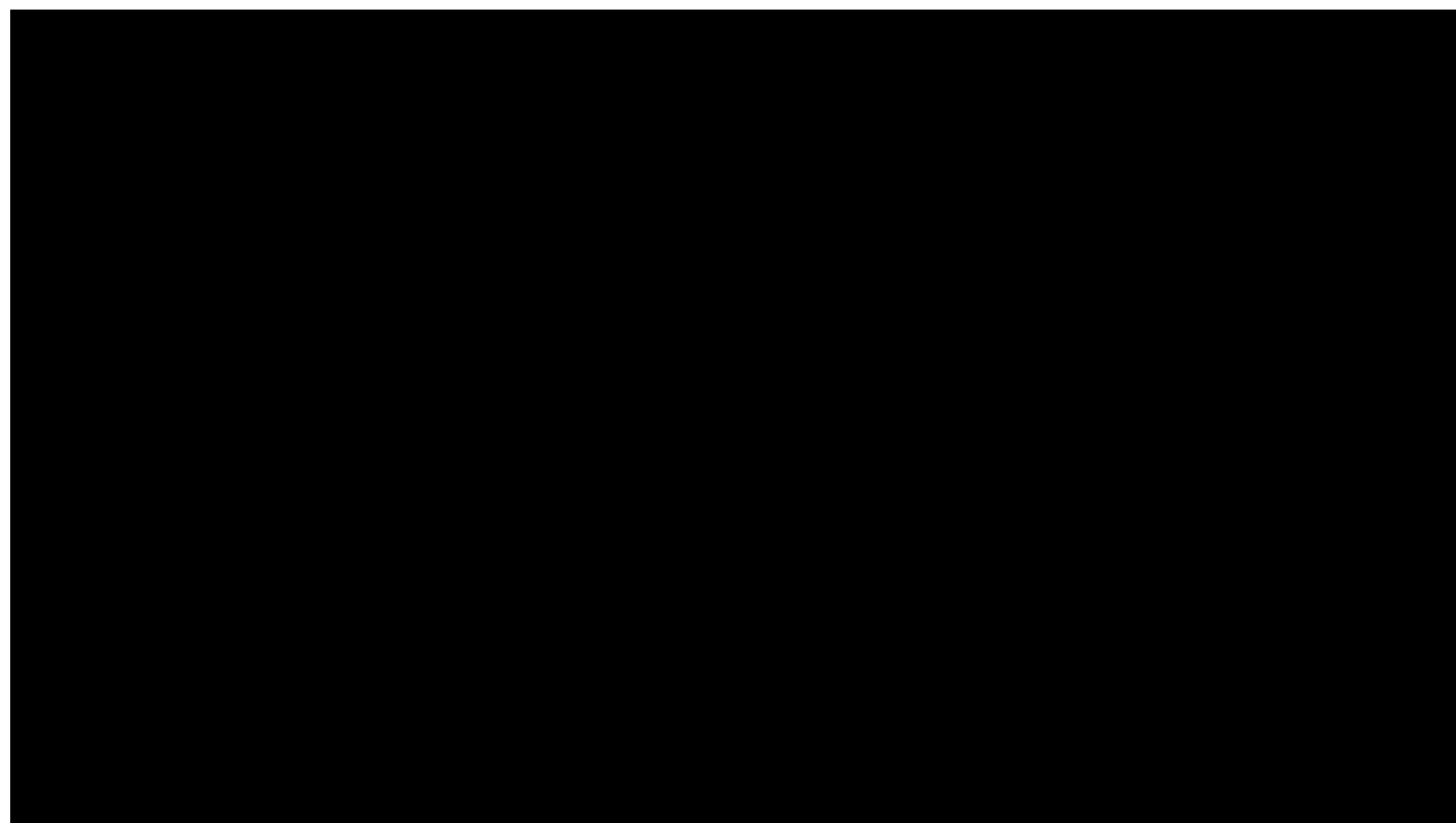
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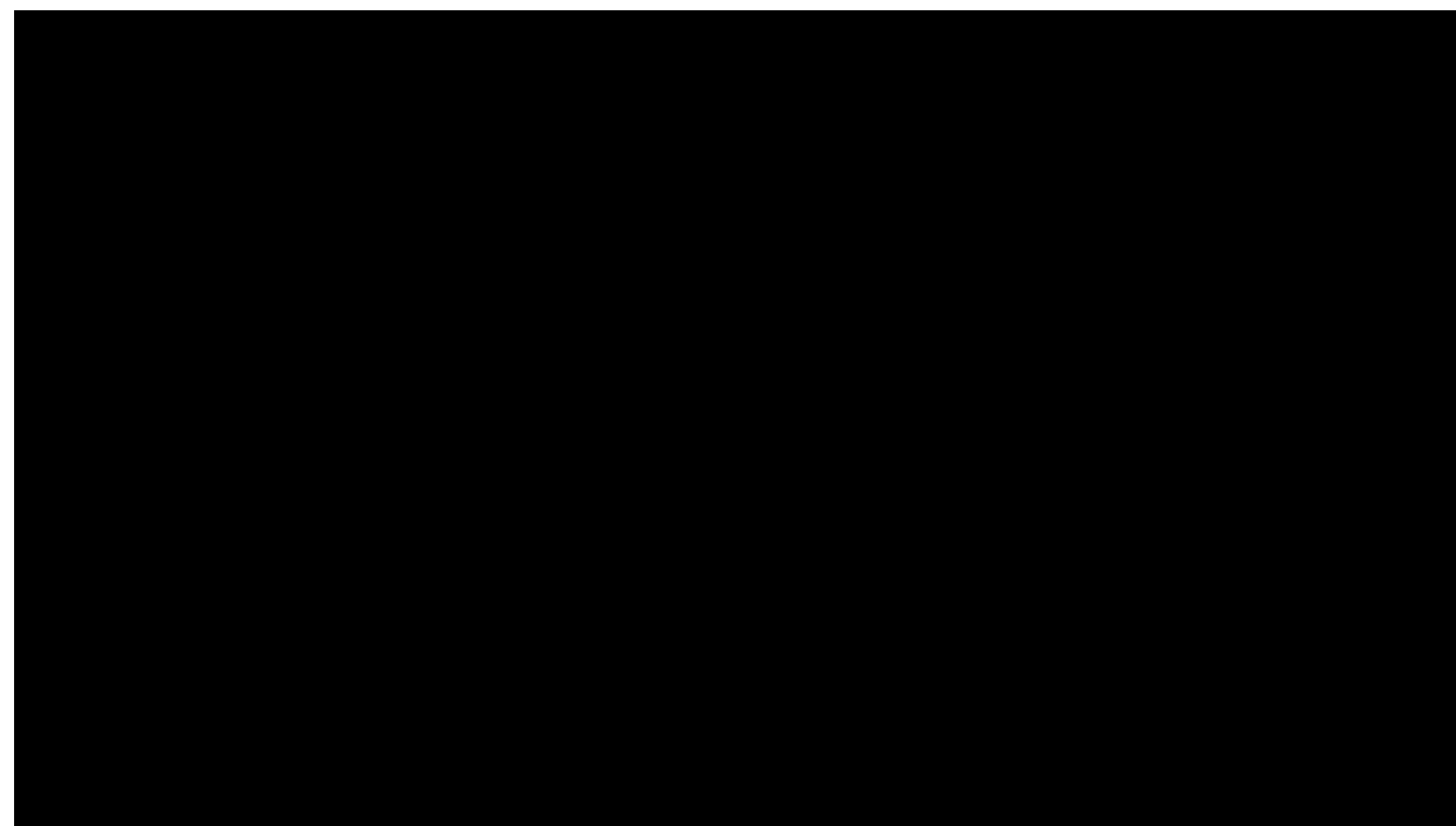
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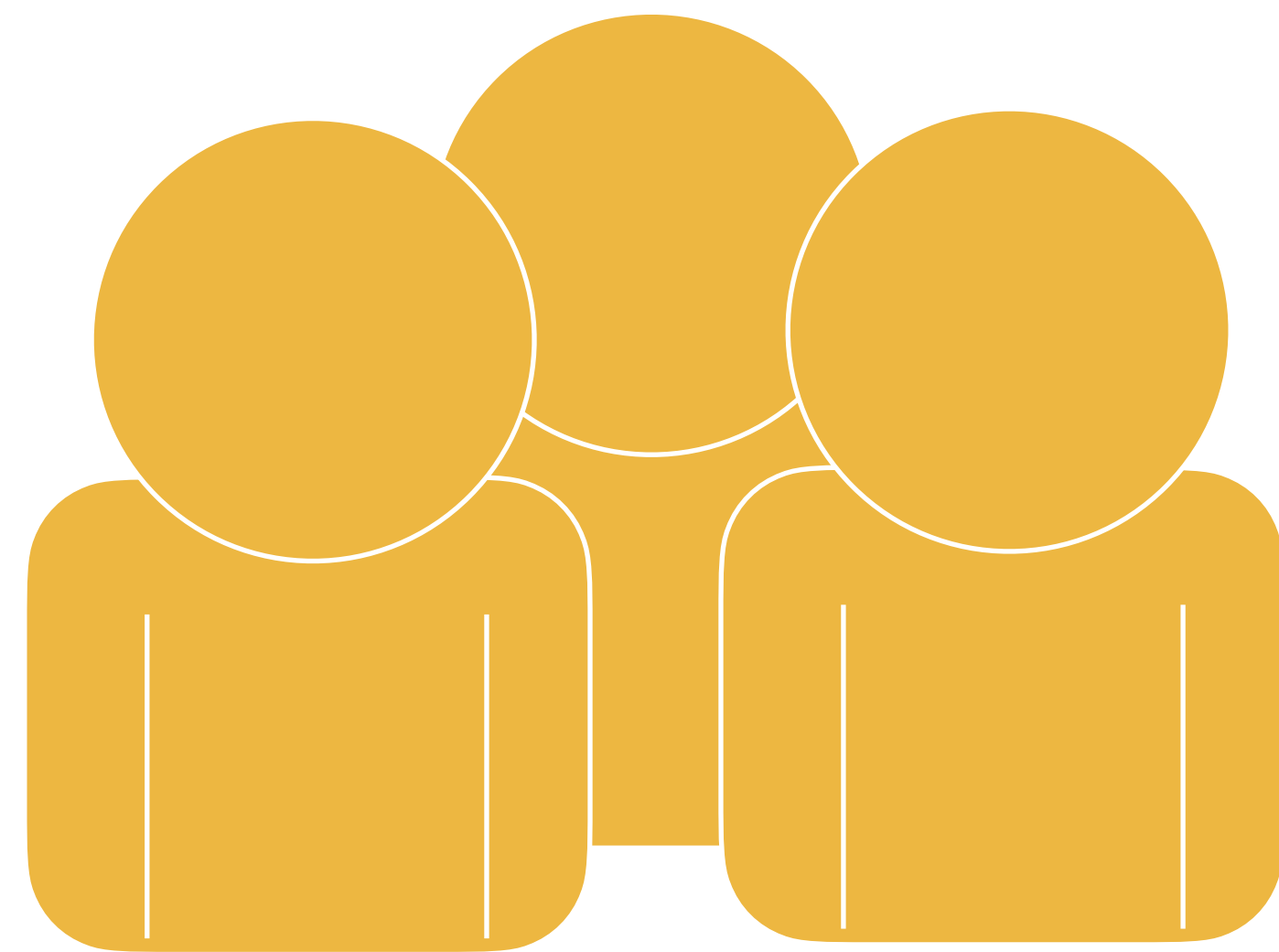
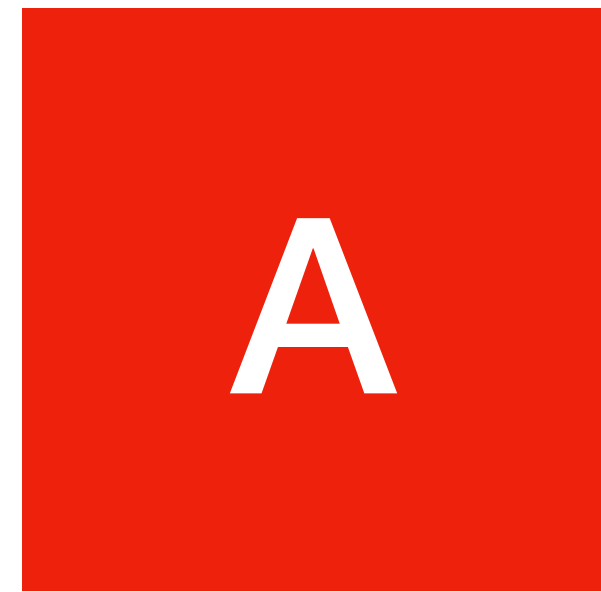


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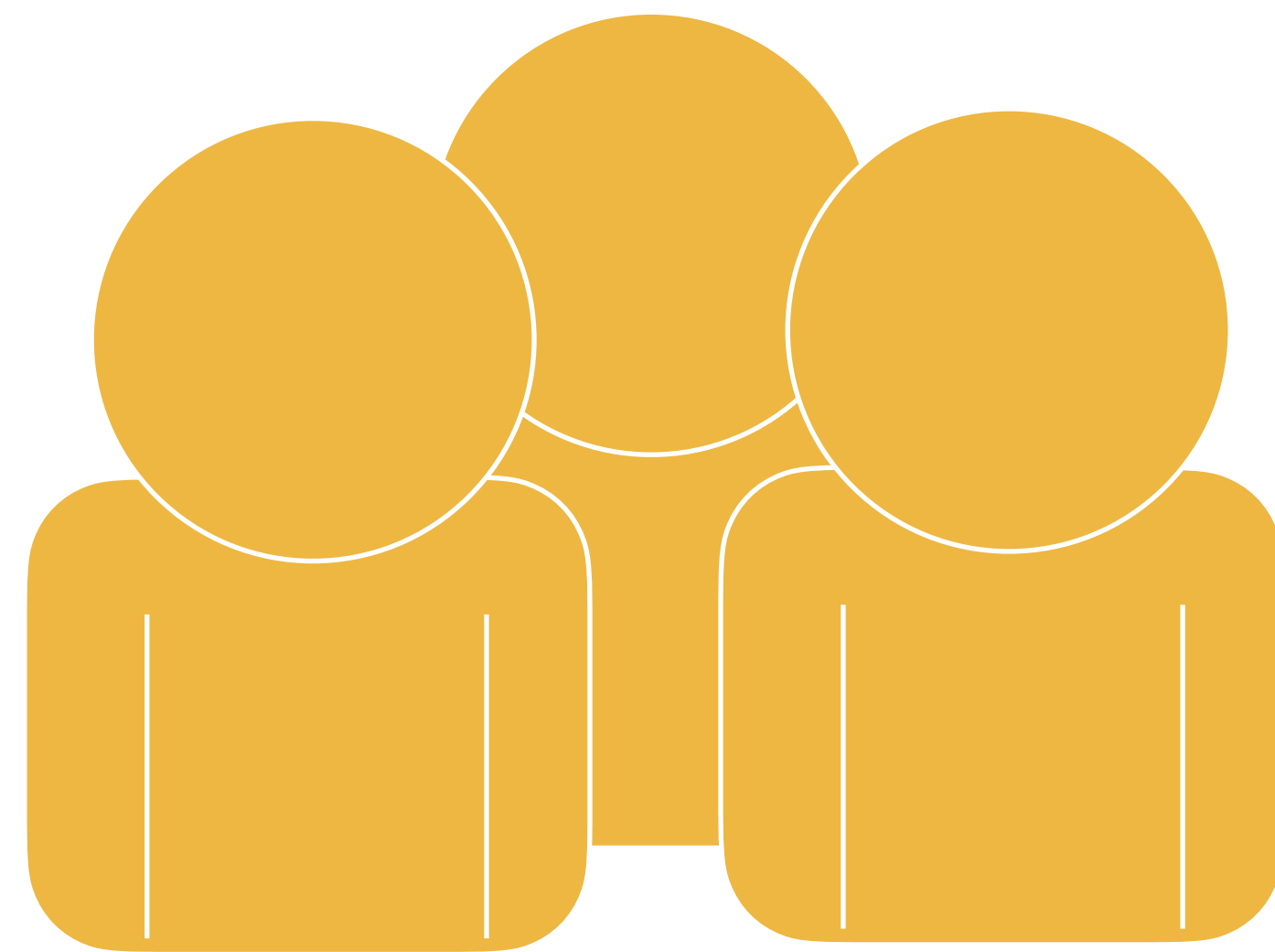


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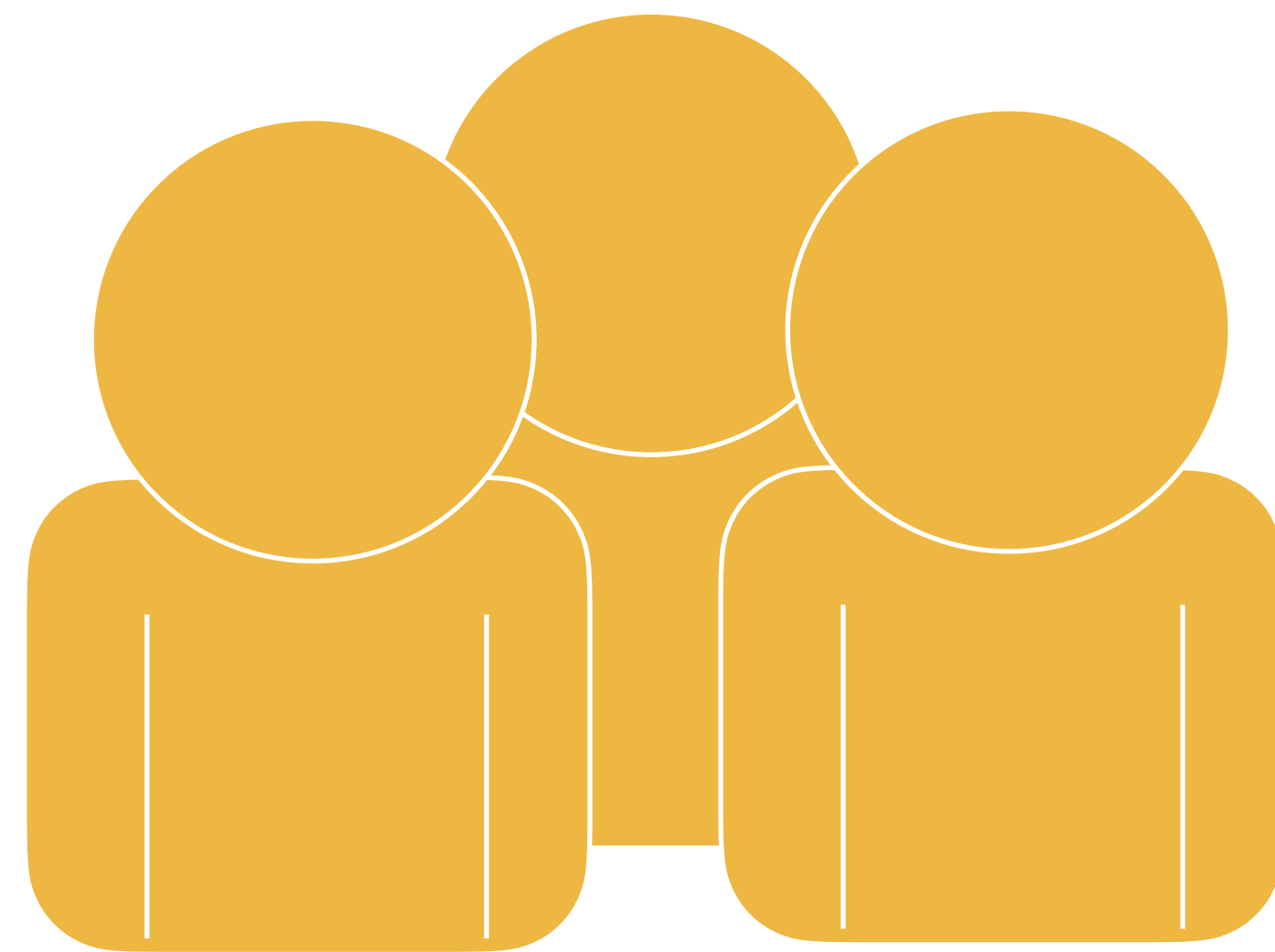
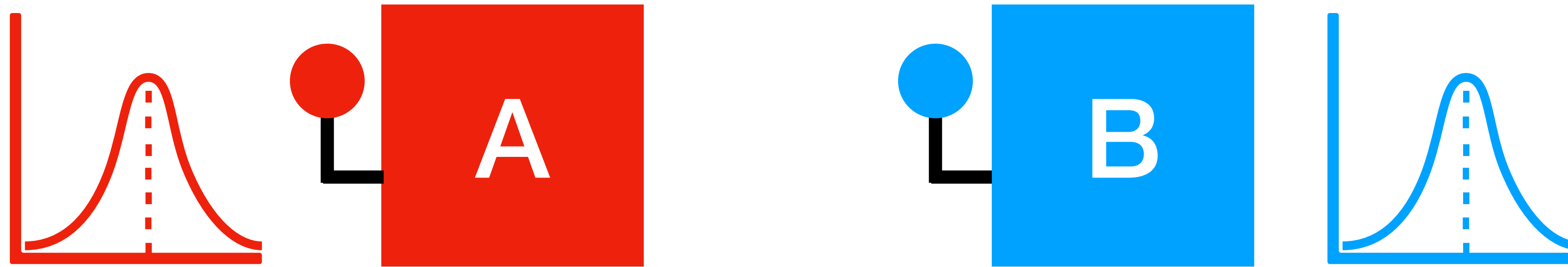
# Multi-armed bandit



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# Multi-armed bandit



**More complex SL tasks**



## ② Spatial structure

### Spatial structure of environments

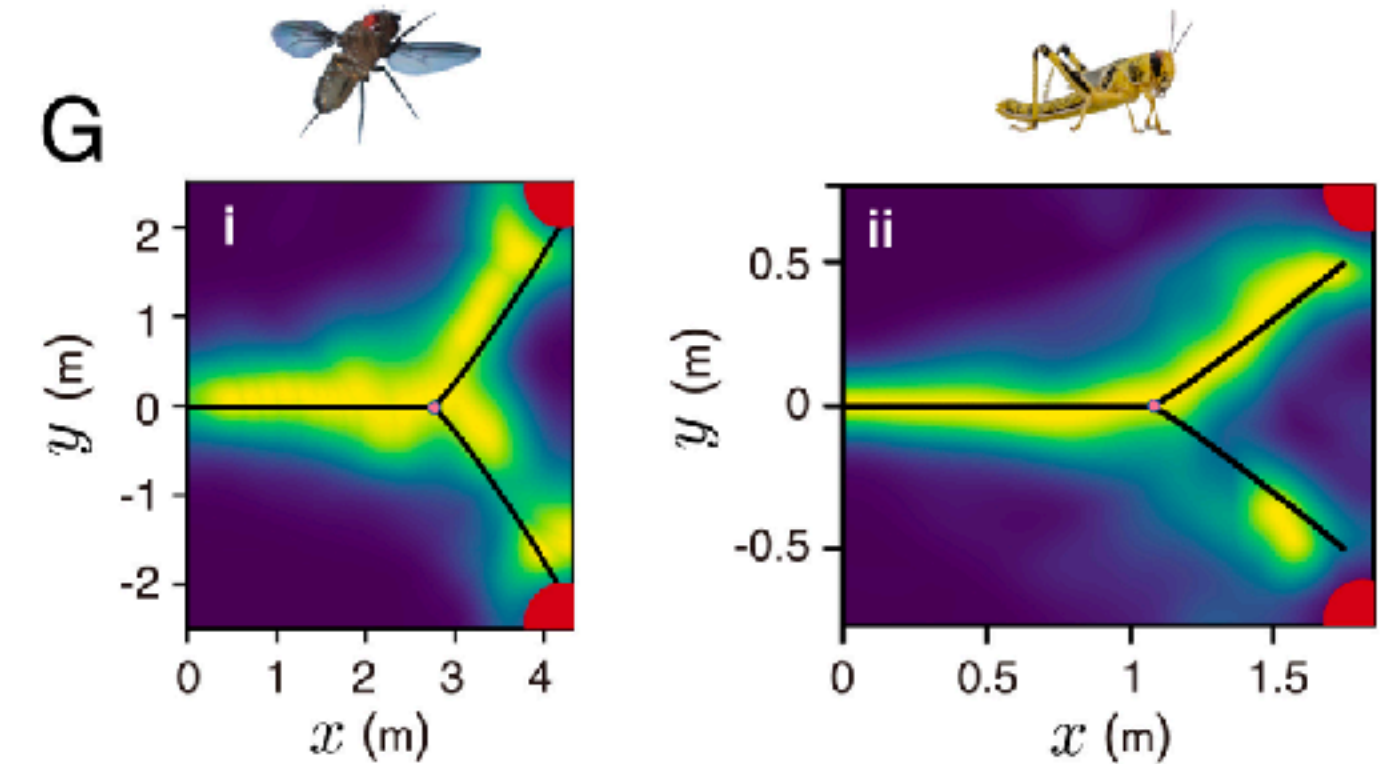
#### Crop yields



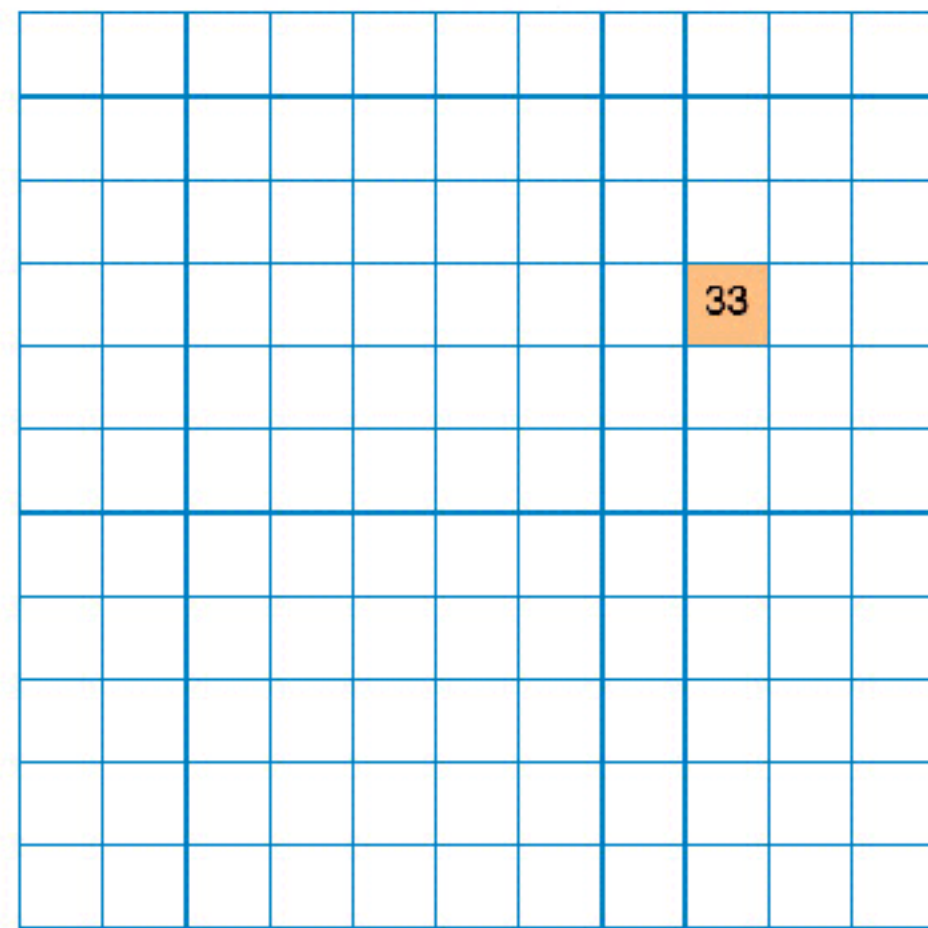
38	38	37	41	38	35	39	5	35	41	54
39	19	18	29	46	33	32	55	35	37	57
27	19	21	21	47	46	19	72	38	42	40
22	23	20	18	44	35	36	53	27	45	47
23	14	15	24	35	55	51	53	46	38	63
19	17	12	25	38	74	77	71	46	65	63
20	19	21	23	6	57	60	63	58	60	69
19	19	14	28	31	33	47	58	68	70	61
16	19	19	22	28	31	54	69	74	74	65
21	11	31	30	21	43	50	69	70	72	57
27	21	27	31	45	45	66	56	53	60	42



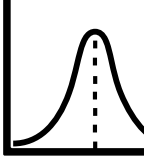




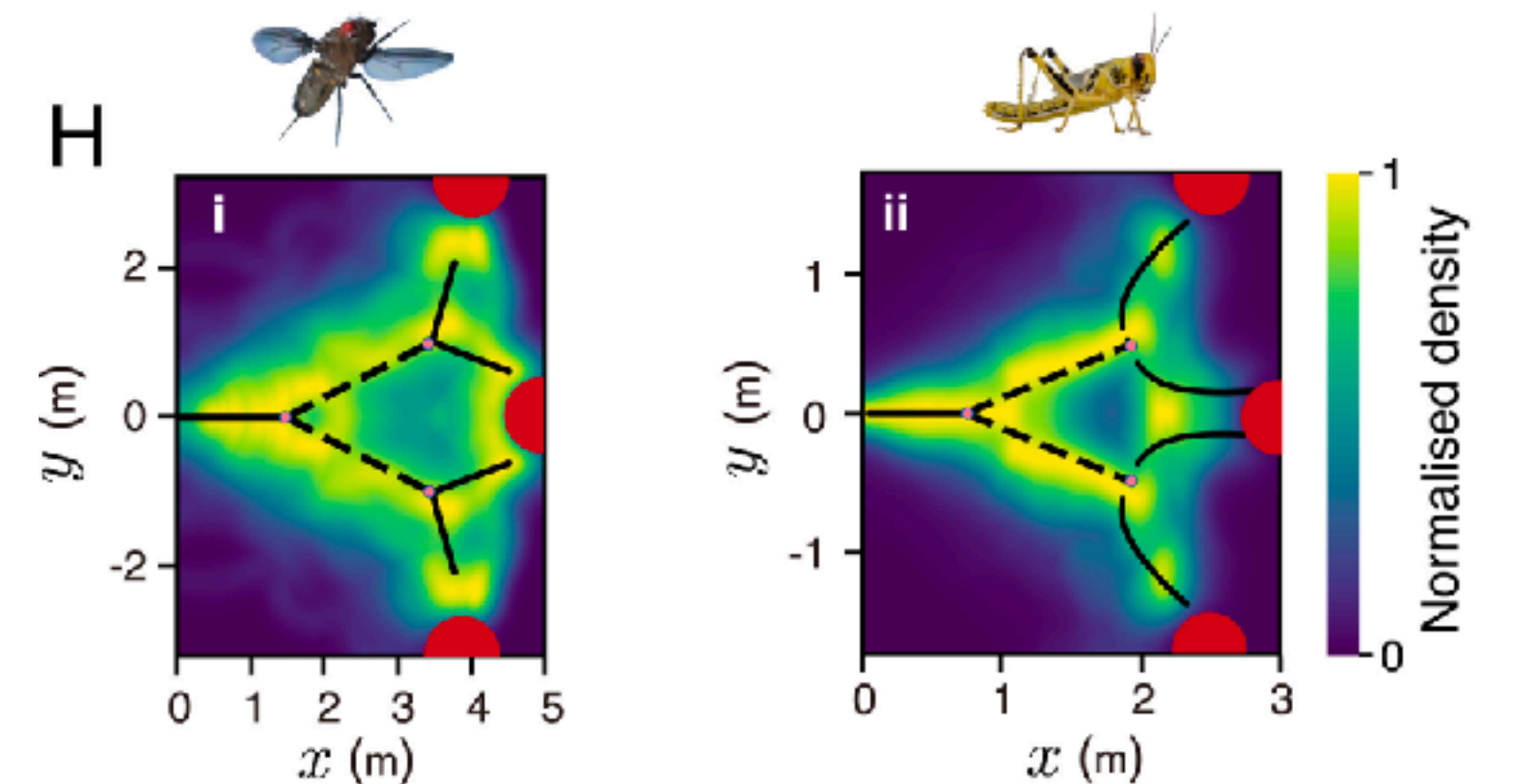
### Spatial geometry of decisions



#### 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.

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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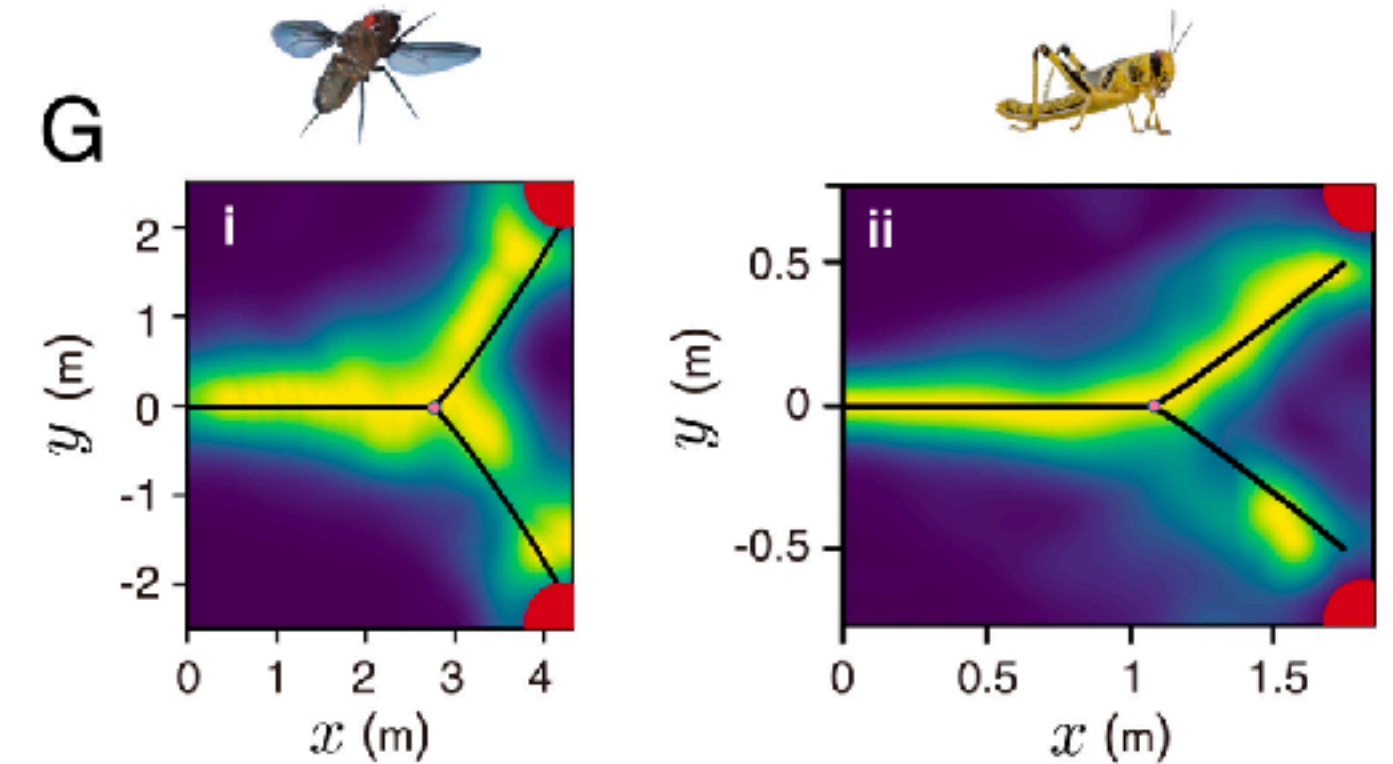
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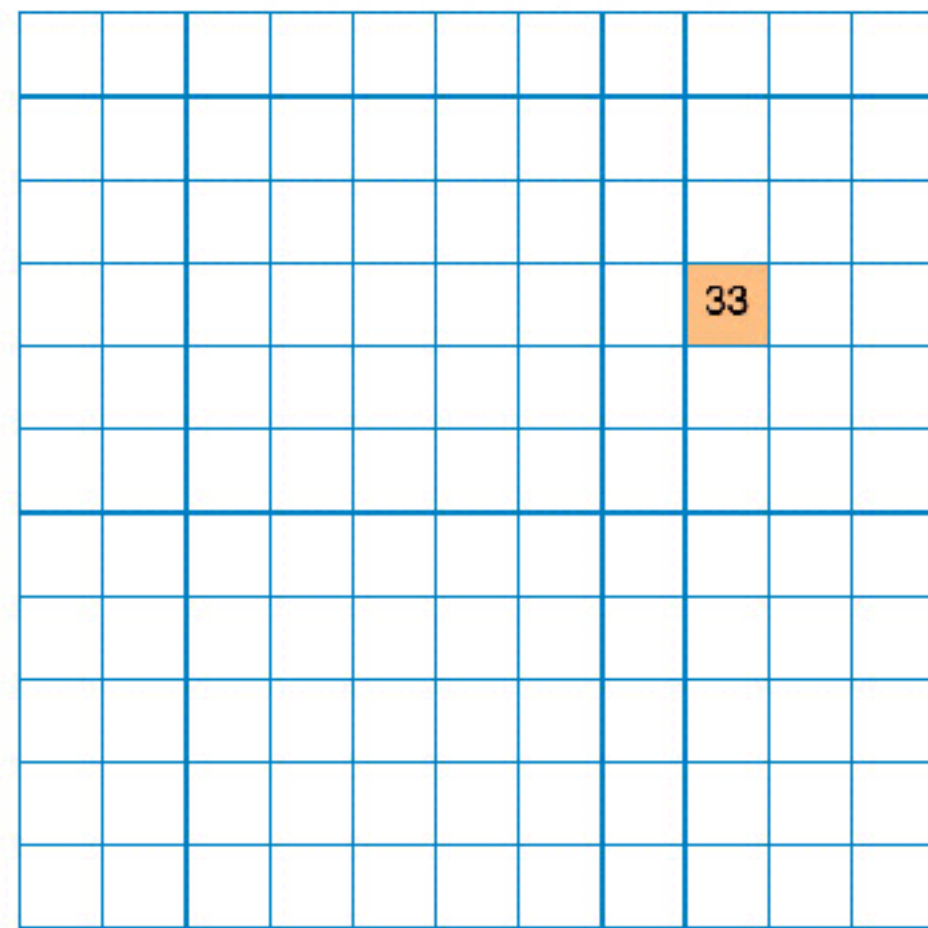
38	38	37	41	38	35	39	5	35	41	54
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22	23	20	18	44	35	36	53	27	45	47
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19	17	12	25	38	74	77	71	46	65	63
20	19	21	23	6	57	60	63	58	60	69
19	19	14	28	31	33	47	58	68	70	61
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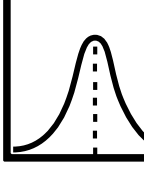




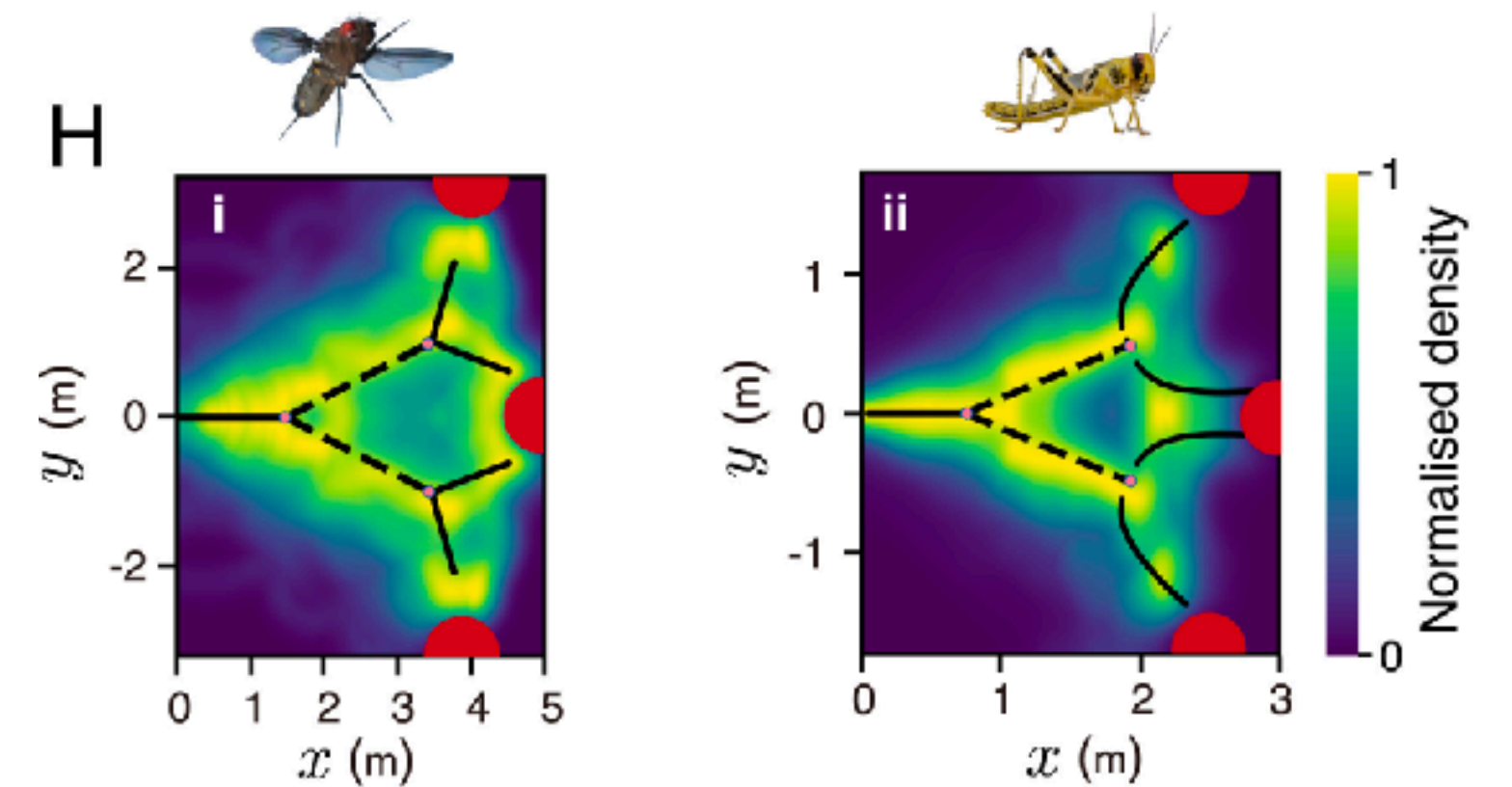
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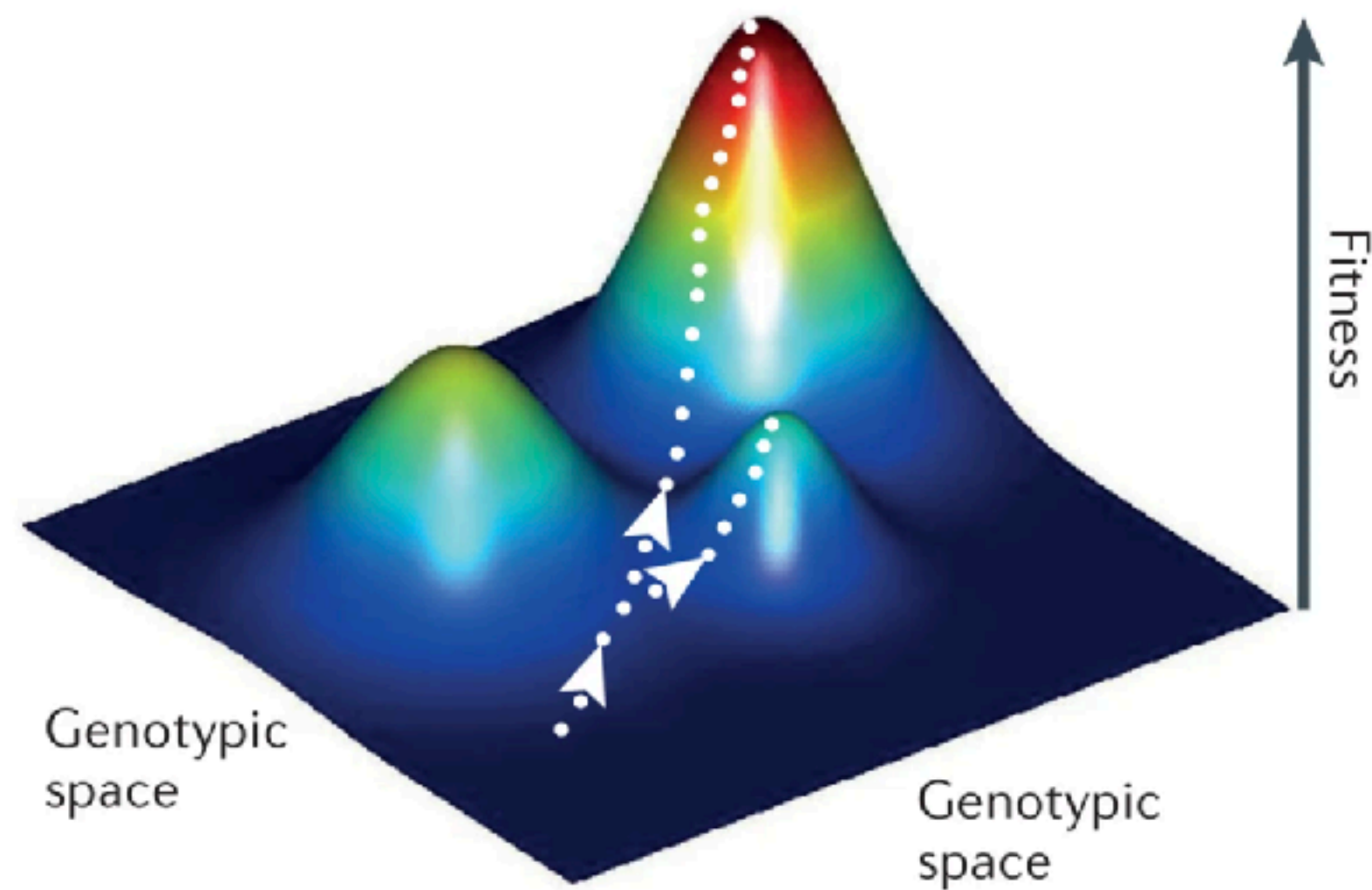


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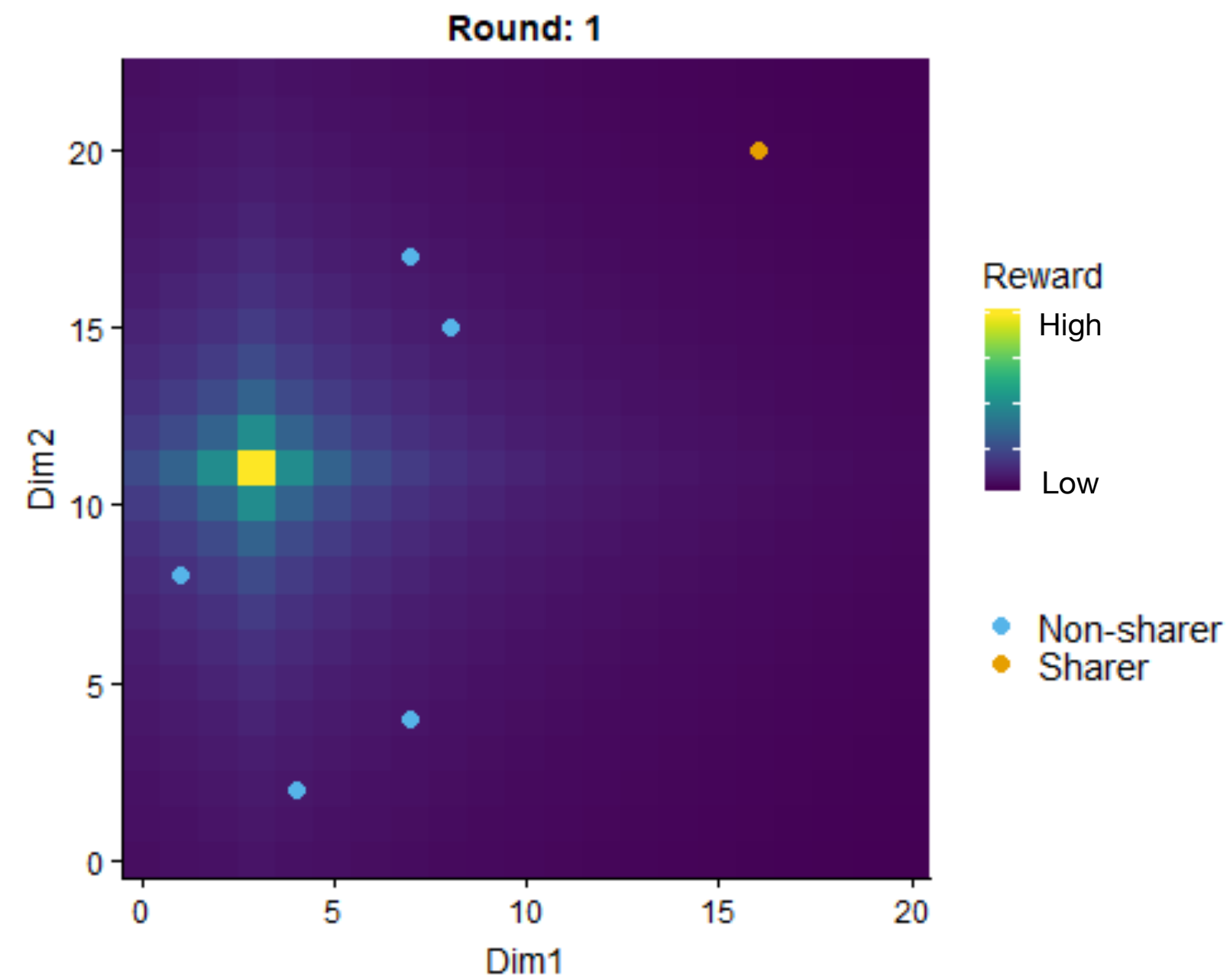
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### ③ High dimensional fitness landscapes

#### Fitness landscape

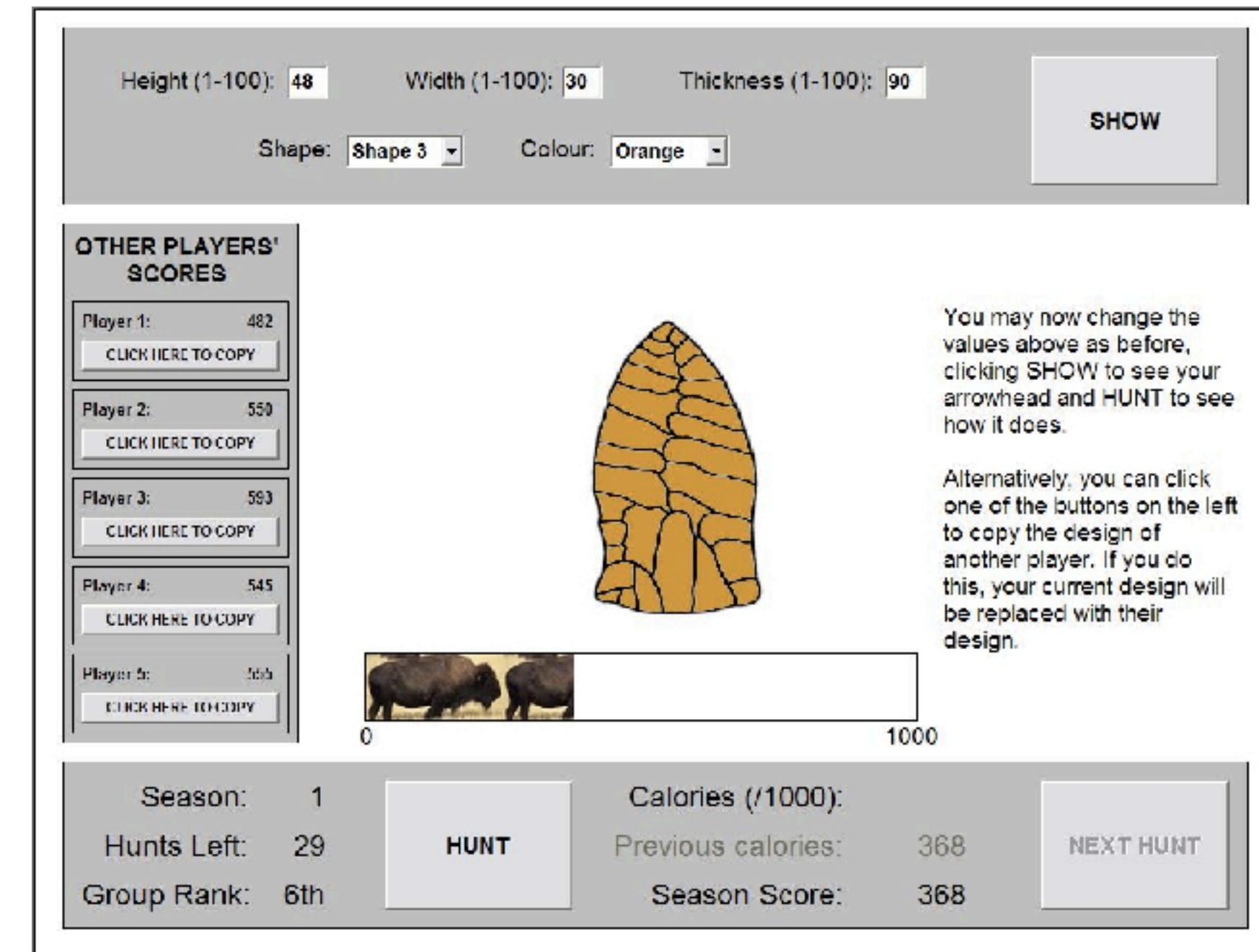


#### Collective search



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

#### Cultural innovation

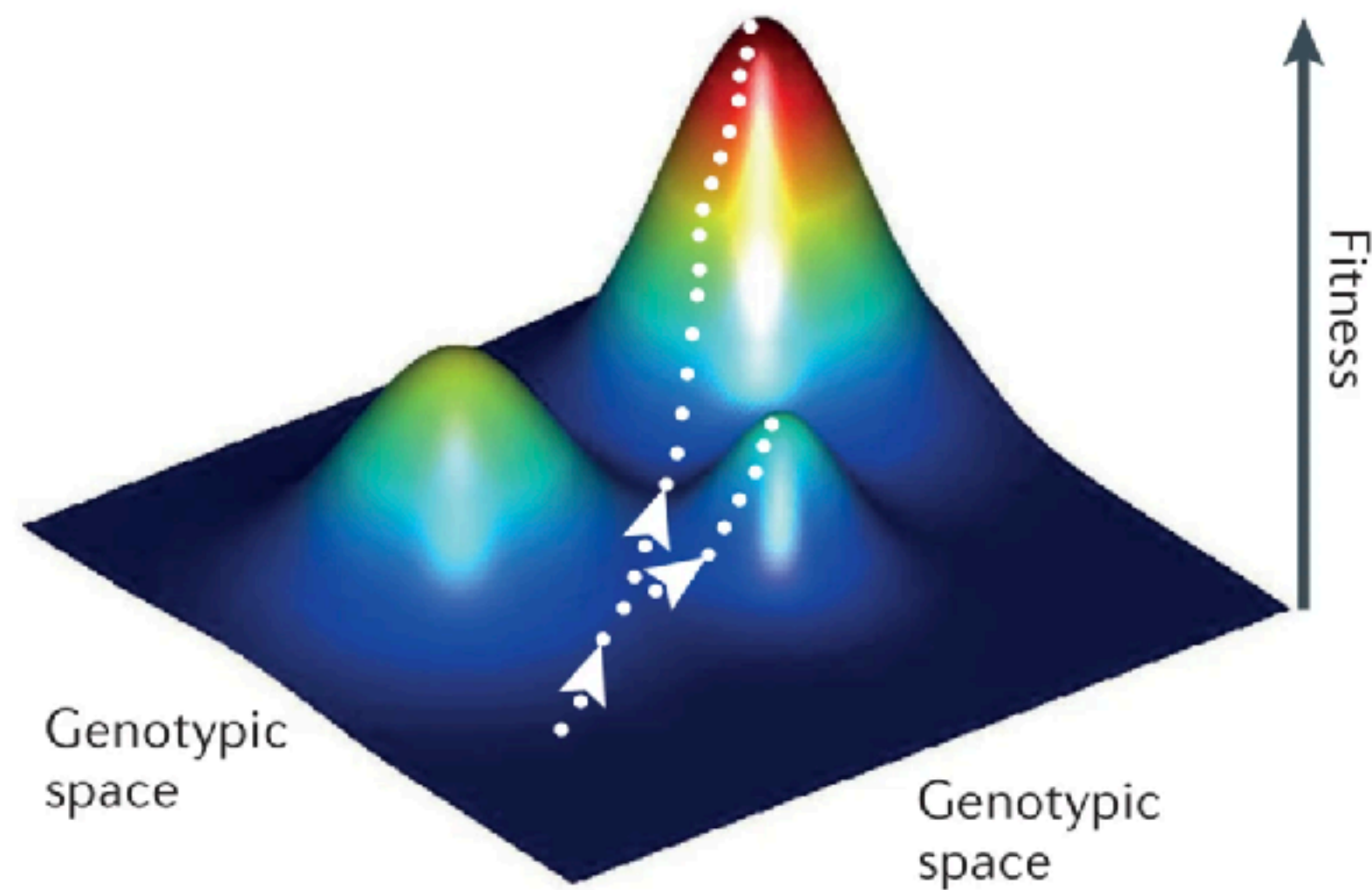


A screenshot of a game interface for cultural innovation. At the top, there are input fields for 'Height (1-100): 48', 'Width (1-100): 30', and 'Thickness (1-100): 90', along with a 'SHOW' button. Below this, there are dropdown menus for 'Shape: Shape 3' and 'Colour: Orange'. A 'SHOW' button is also present. In the center, there is a list of 'OTHER PLAYERS' SCORES' with five players and their scores, each with a 'CLICK HERE TO COPY' button. To the right of the scores is a 3D model of a spearhead. Below the scores is a progress bar with a small image of a bison and a scale from 0 to 1000. At the bottom, there are buttons for 'HUNT' and 'NEXT HUNT', and a 'NEXT HUNT' button. The bottom right corner shows 'Season: 1', 'Calories (/1000):', 'Hunts Left: 29', 'Previous calories: 368', and 'Group Rank: 6th', 'Season Score: 368'.

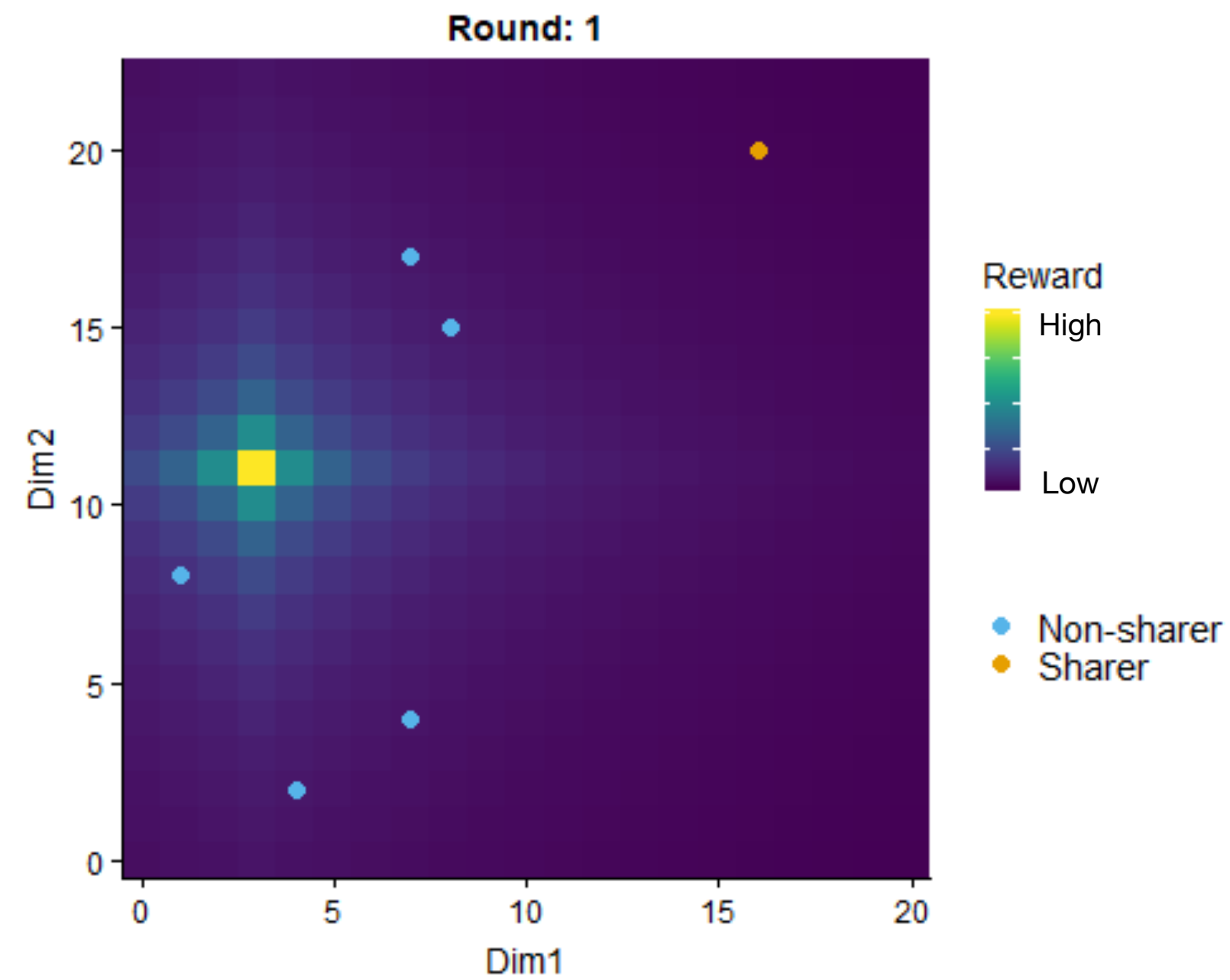
Mesoudi, A. (2011). An experimental comparison of human social learning strategies: payoff-biased social learning is adaptive but underused. *Evolution and Human Behavior*, 32(5), 334-342.

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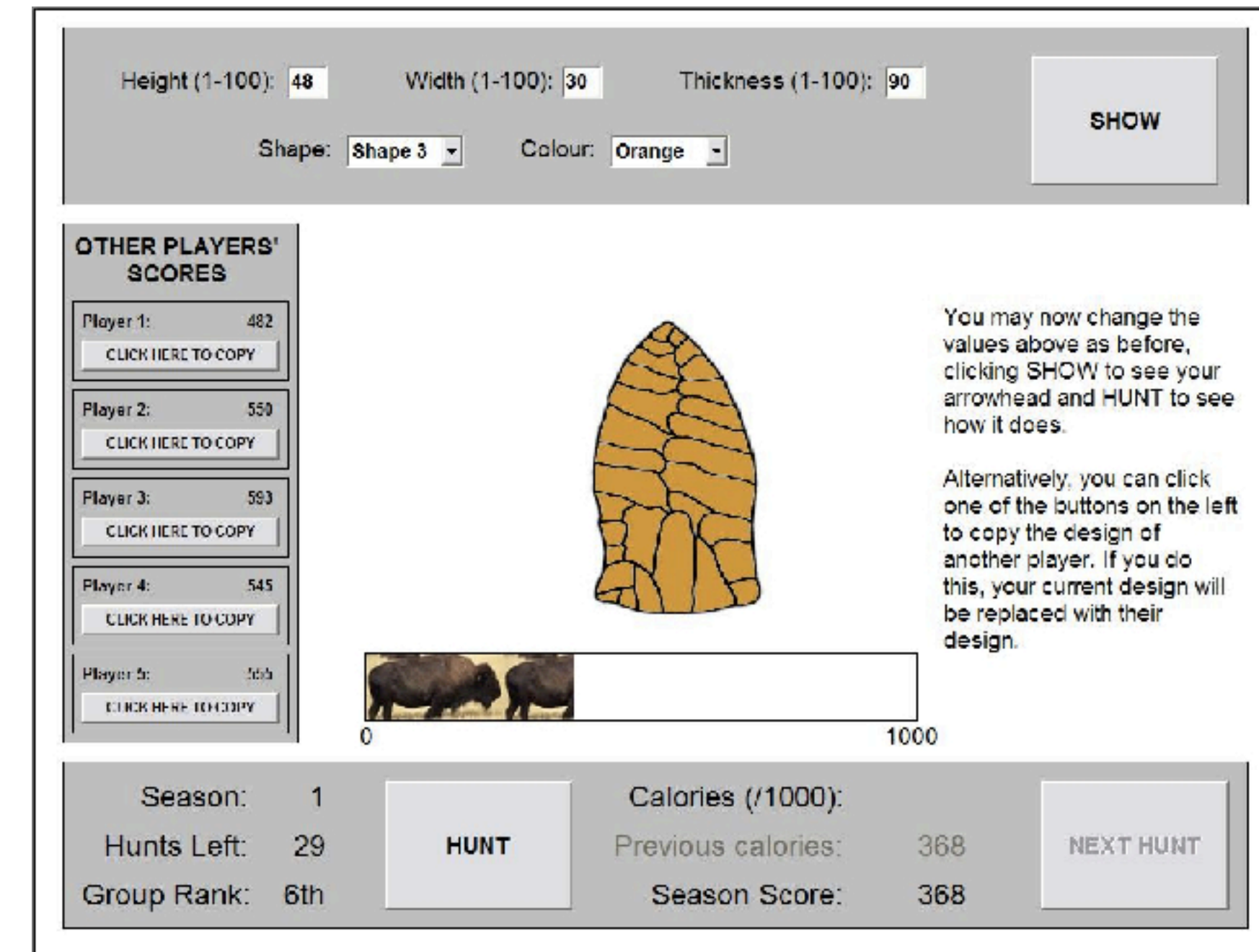


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#### Cultural innovation

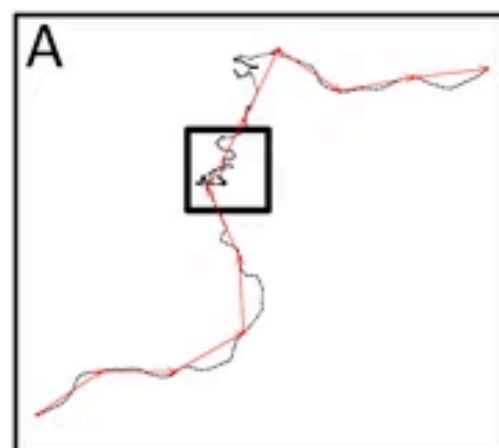
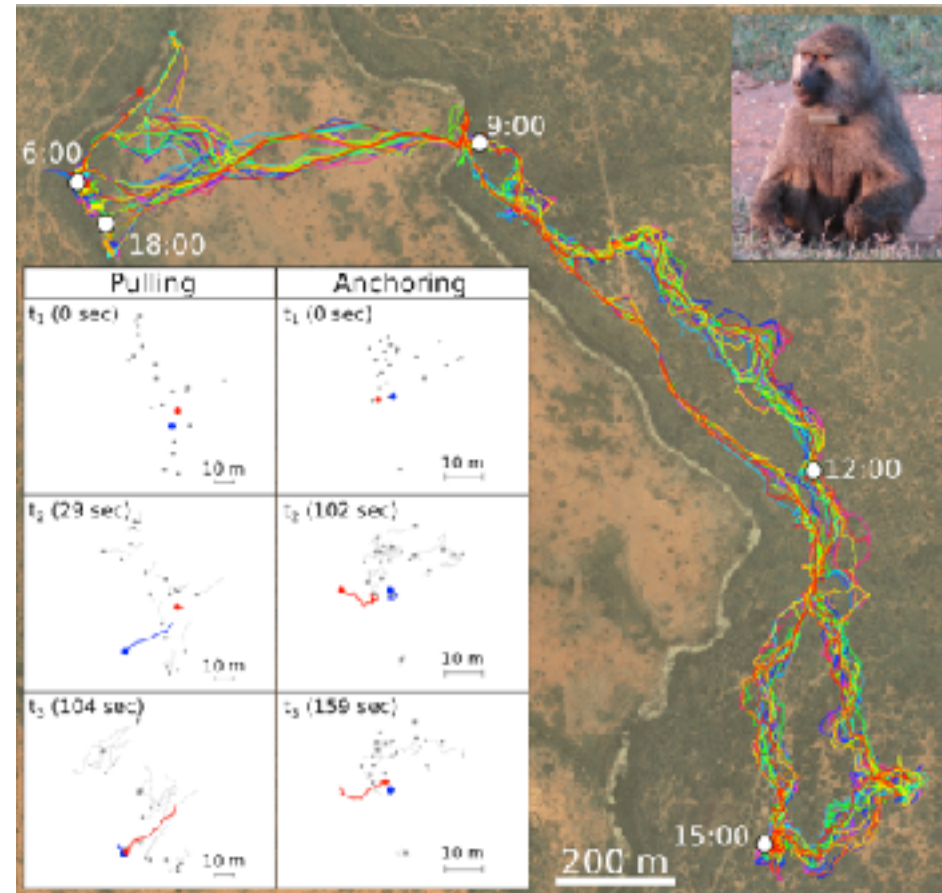


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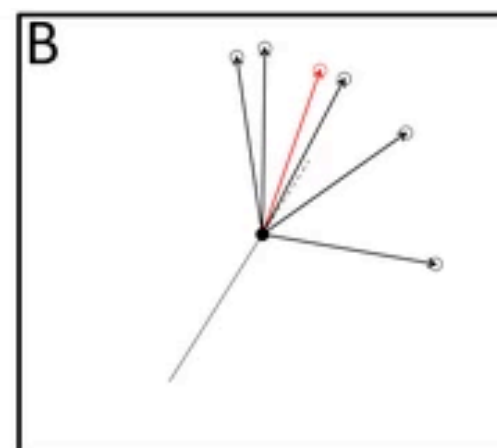
Player	Score
Player 1:	482
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Player 3:	563
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Mesoudi, A. (2011). An experimental comparison of human social learning strategies: payoff-biased social learning is adaptive but underused. *Evolution and Human Behavior*, 32(5), 334-342.

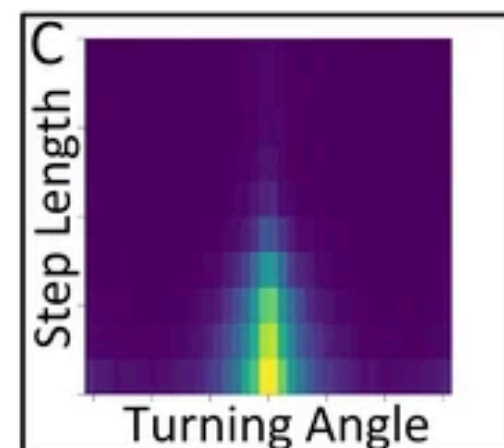
# ④ Spatial Navigation



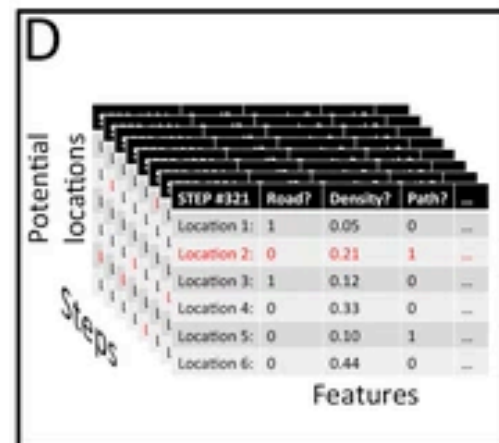
Break individual trajectory into steps.



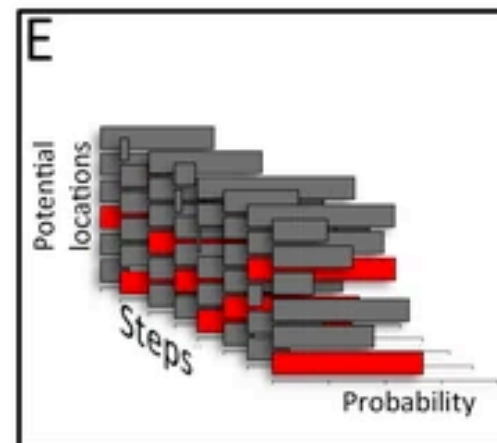
For each step, compare **real (chosen) location** to **alternative locations**...



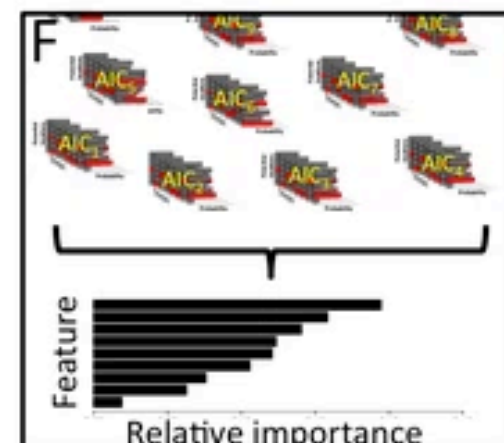
...drawn from individual's step length / turning angle distribution.



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

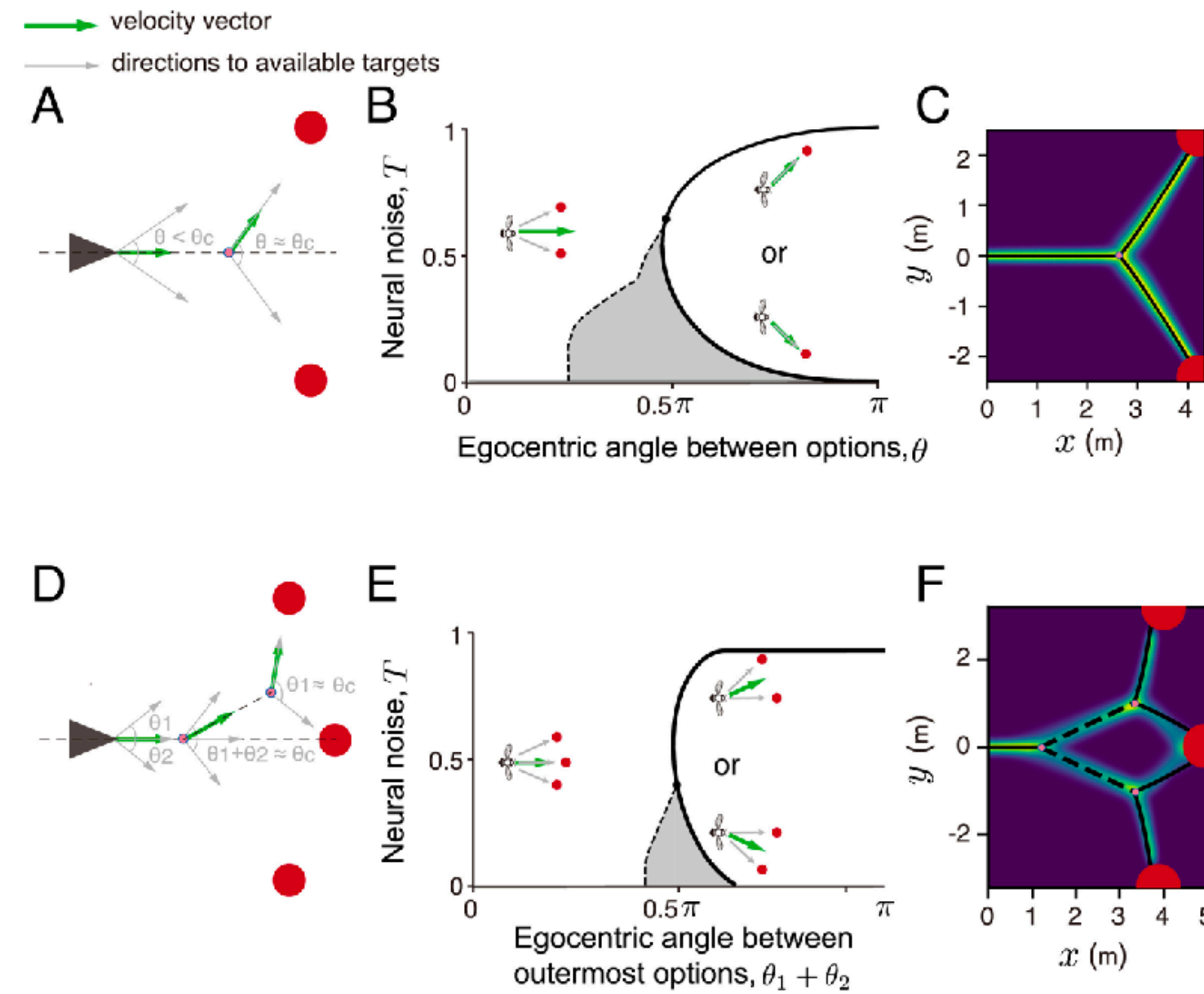


Fit a probabilistic model based on features to distinguish **chosen** location from amongst potential locations for each step.

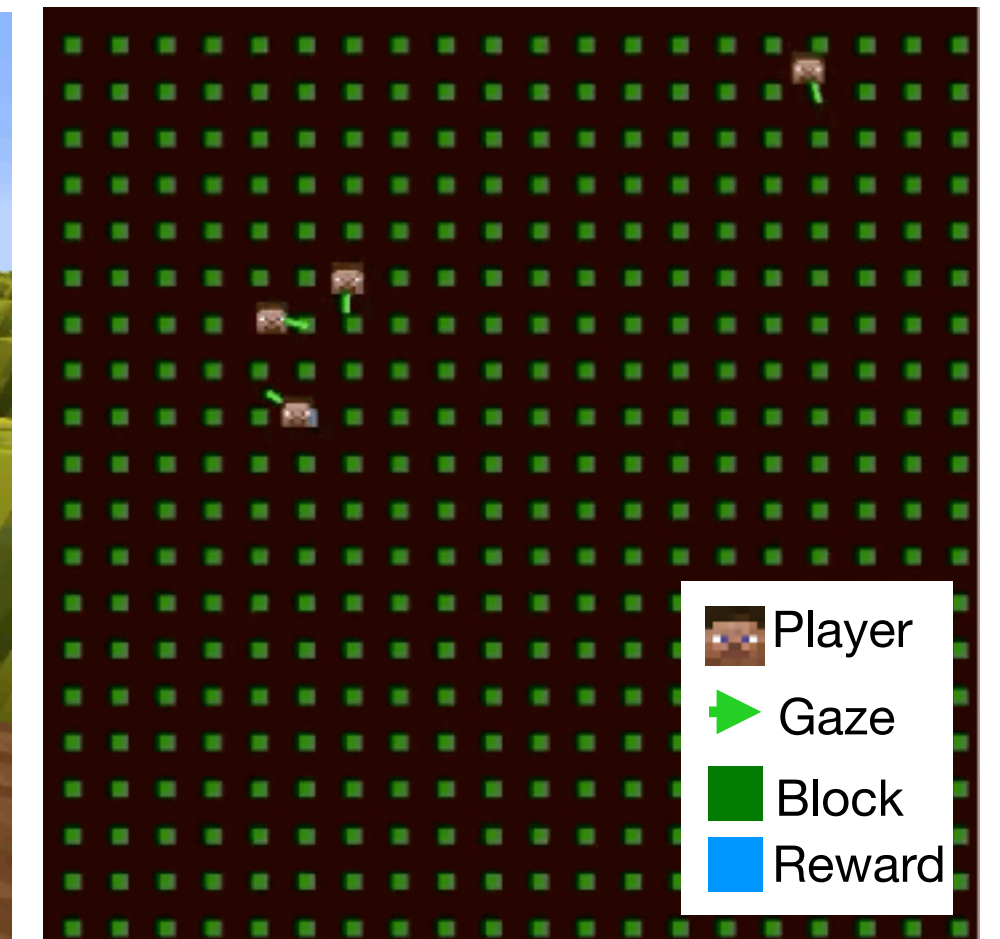
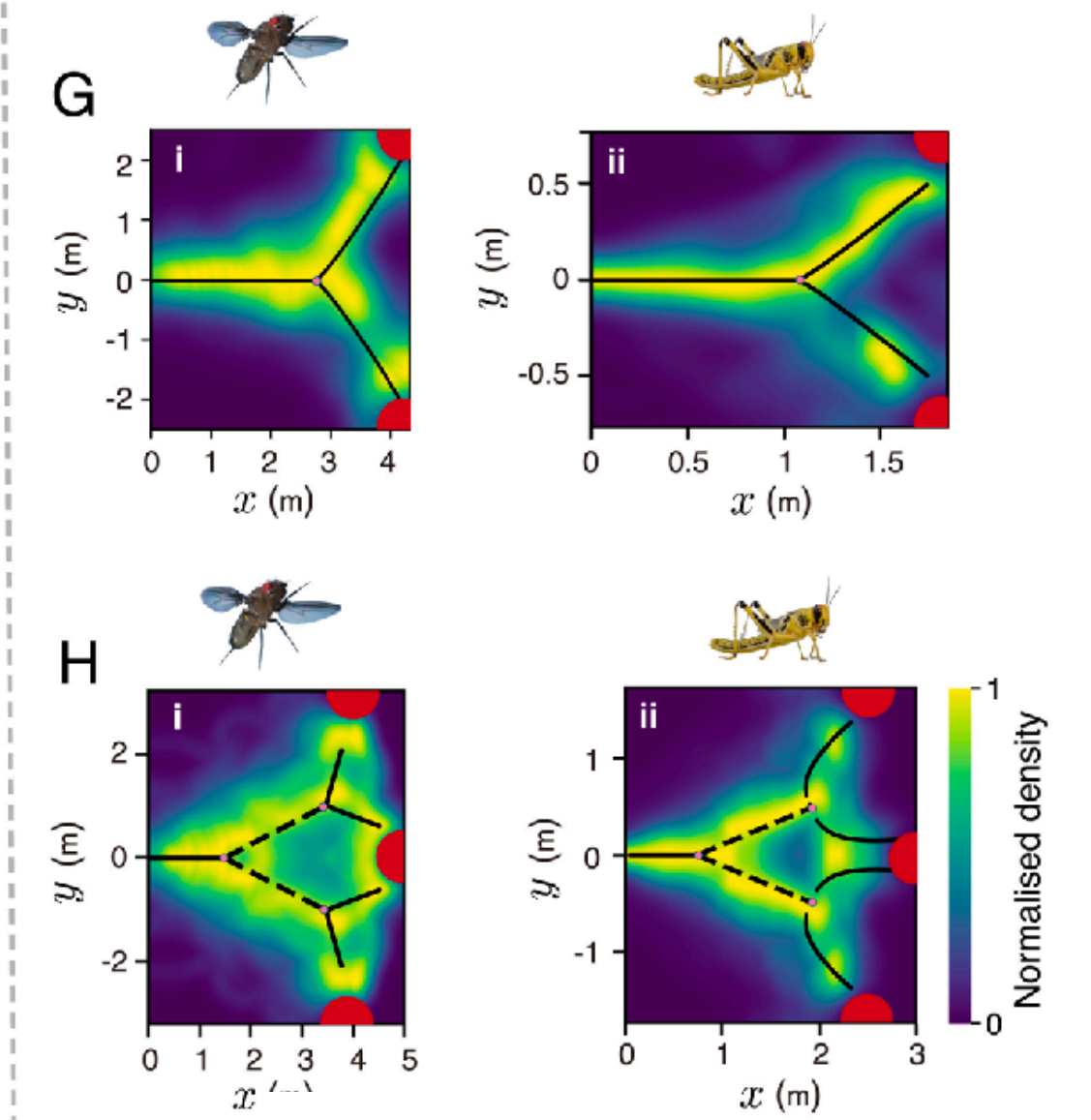


Identify most important features by fitting models containing all possible feature combos and computing weighted AIC scores.

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

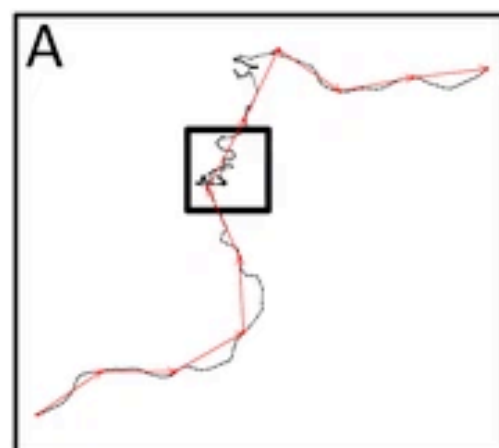
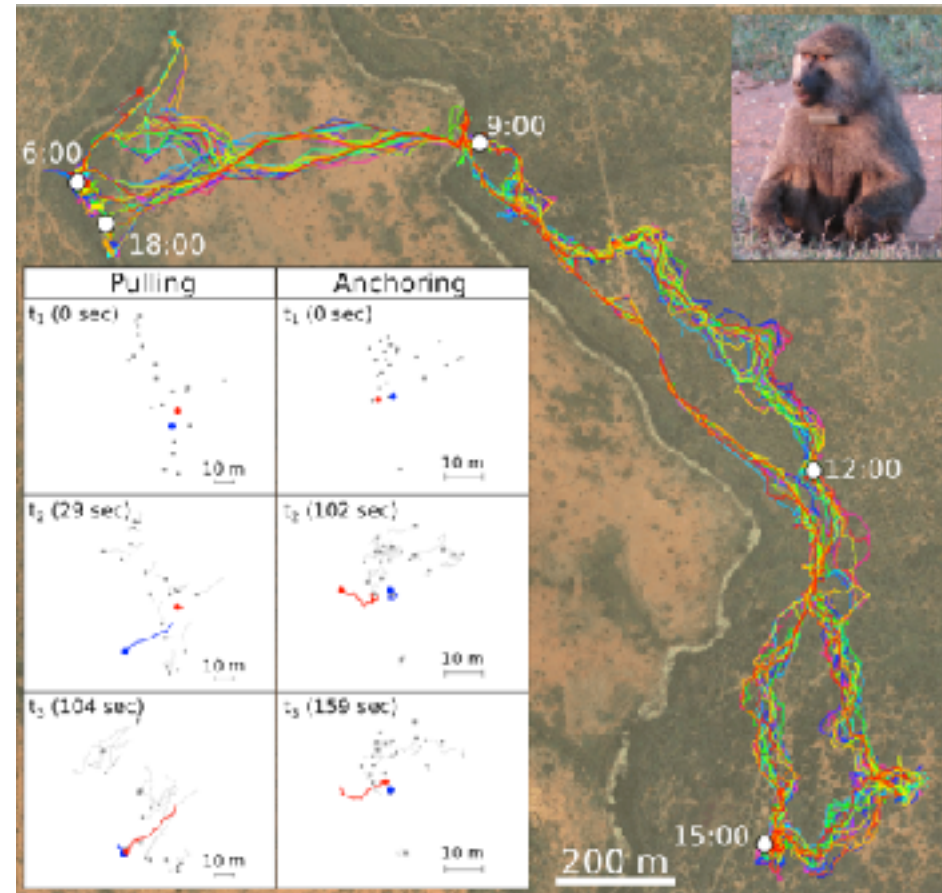


Sridhar et al. (2021)

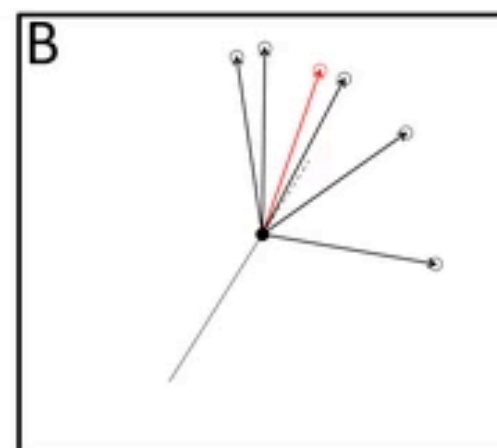


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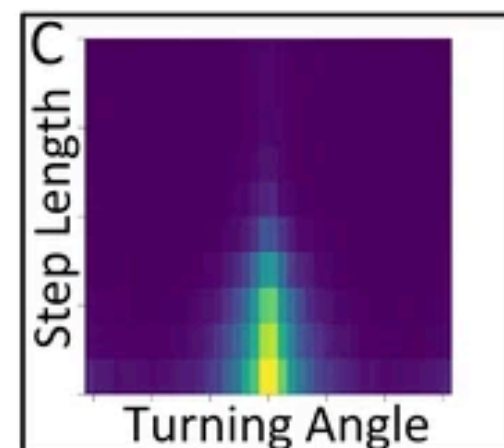
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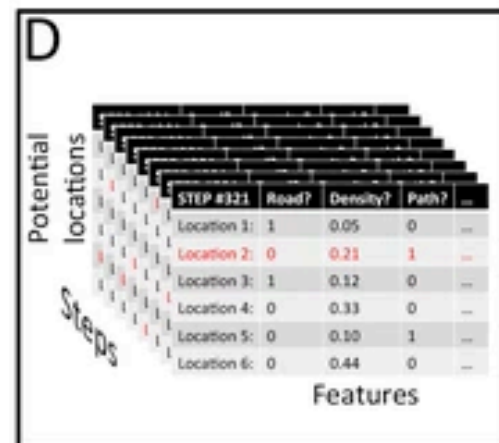
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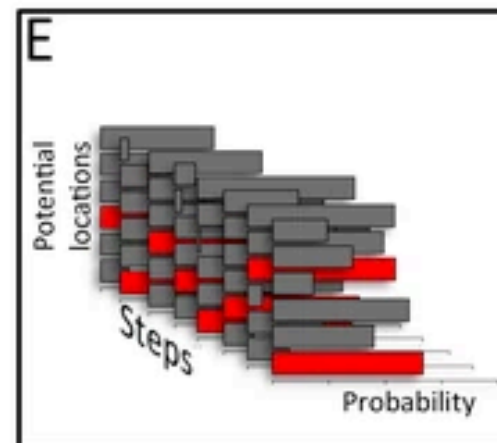
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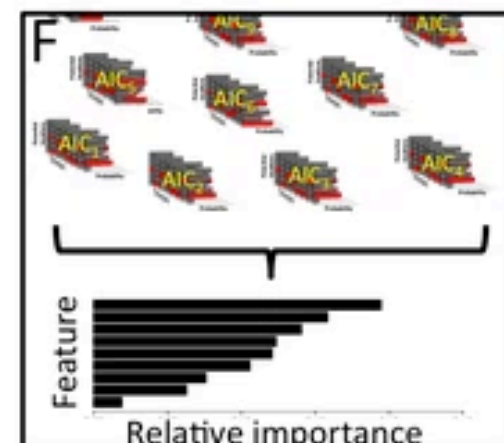
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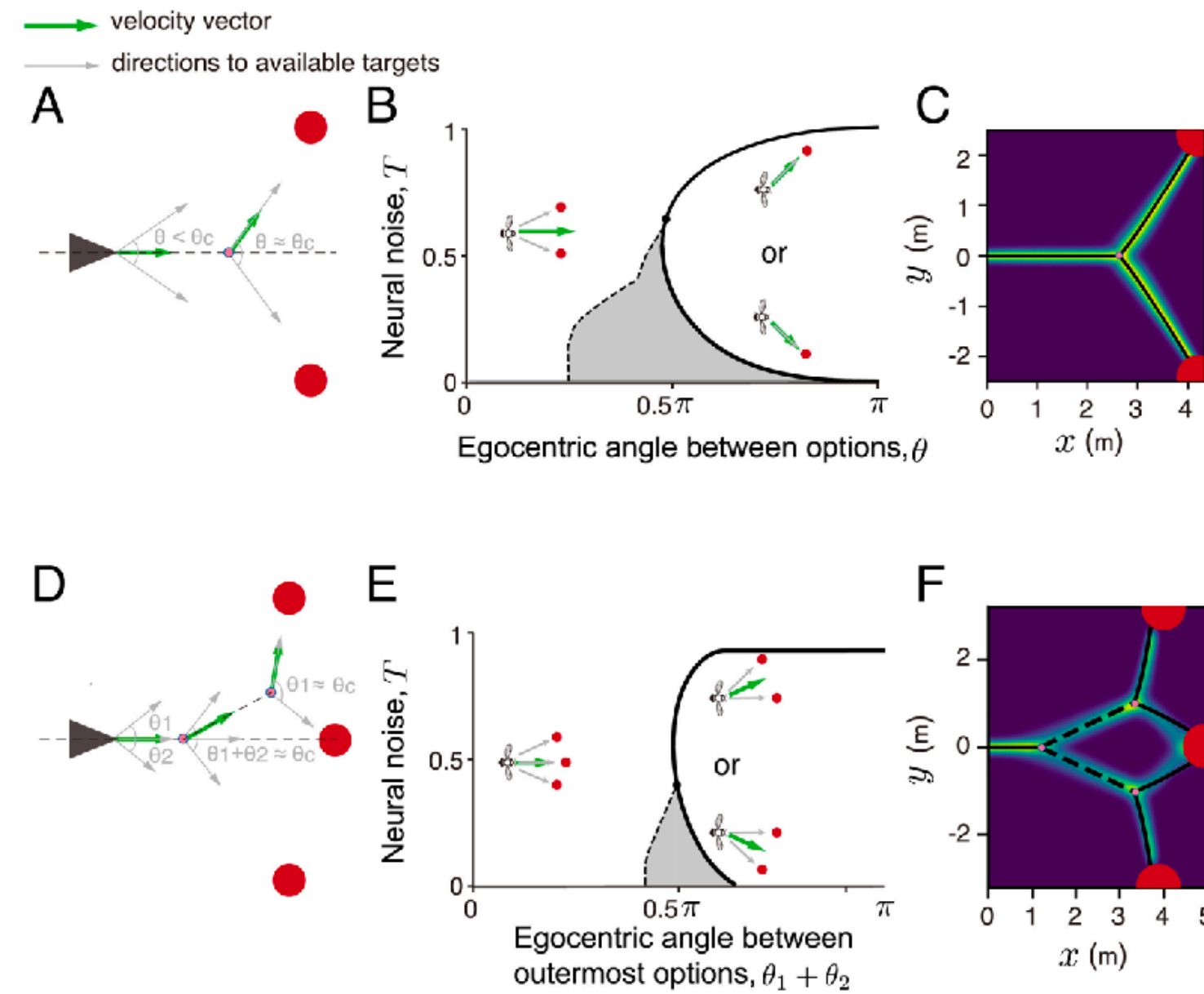


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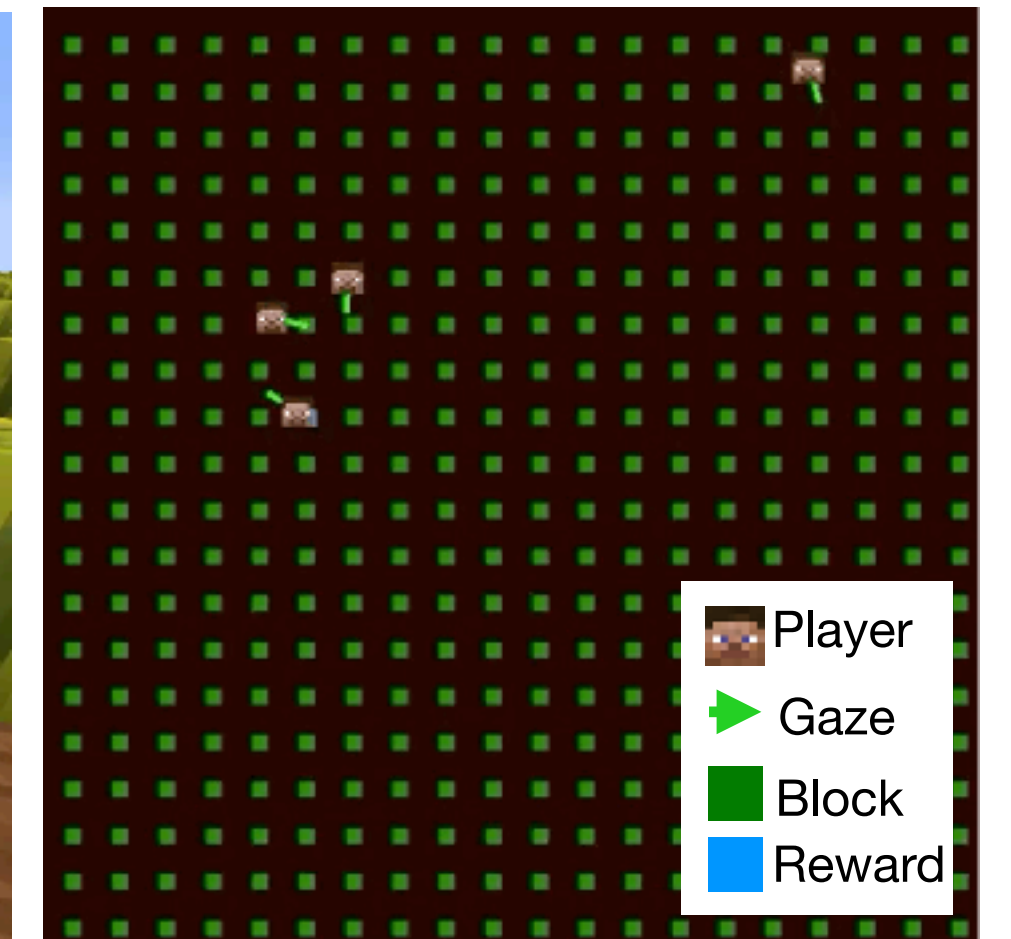
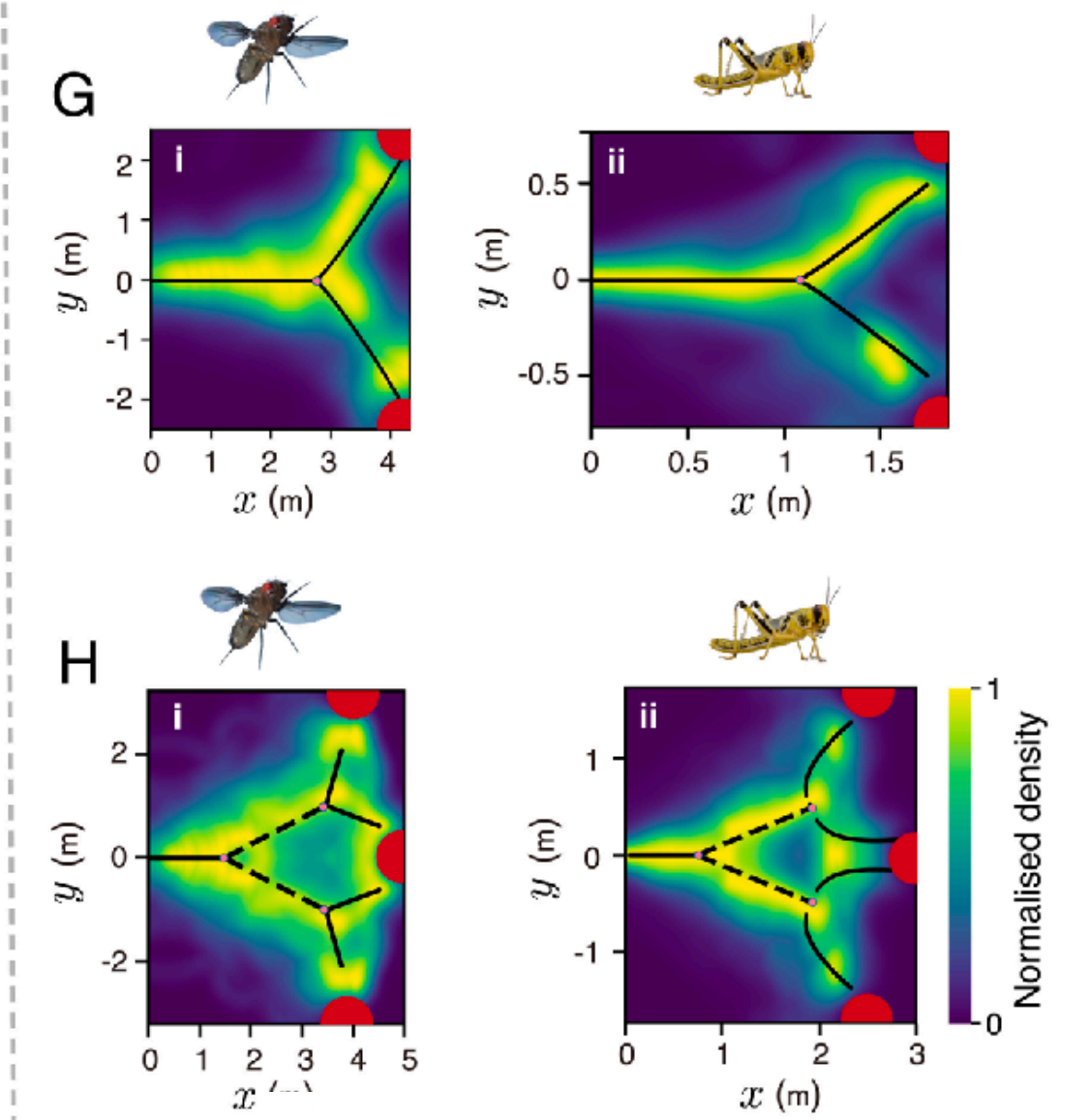


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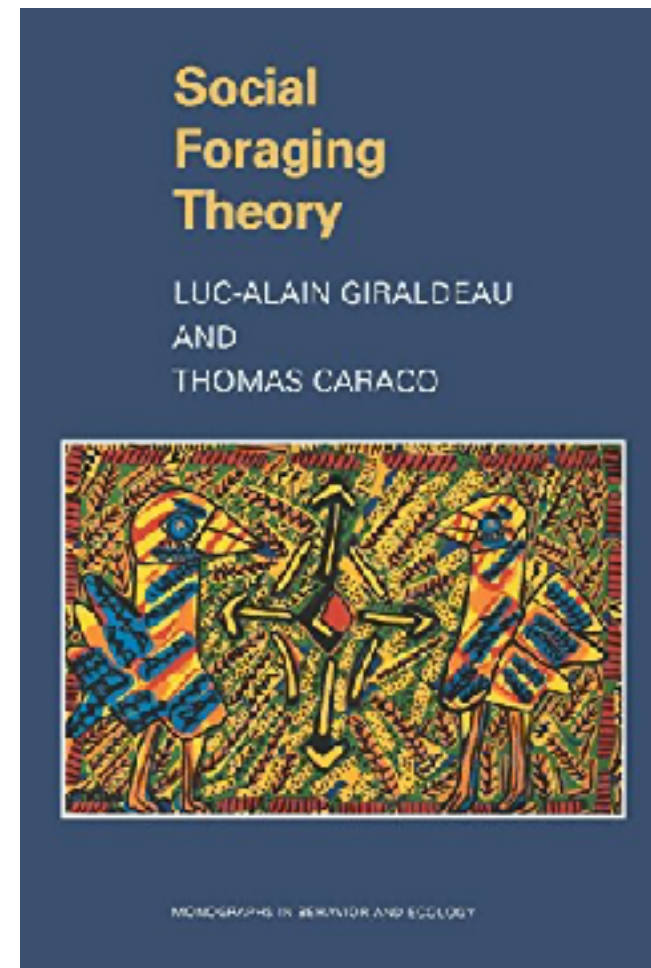


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## ⑤ Social learning as a public goods dilemma



**scrounger**

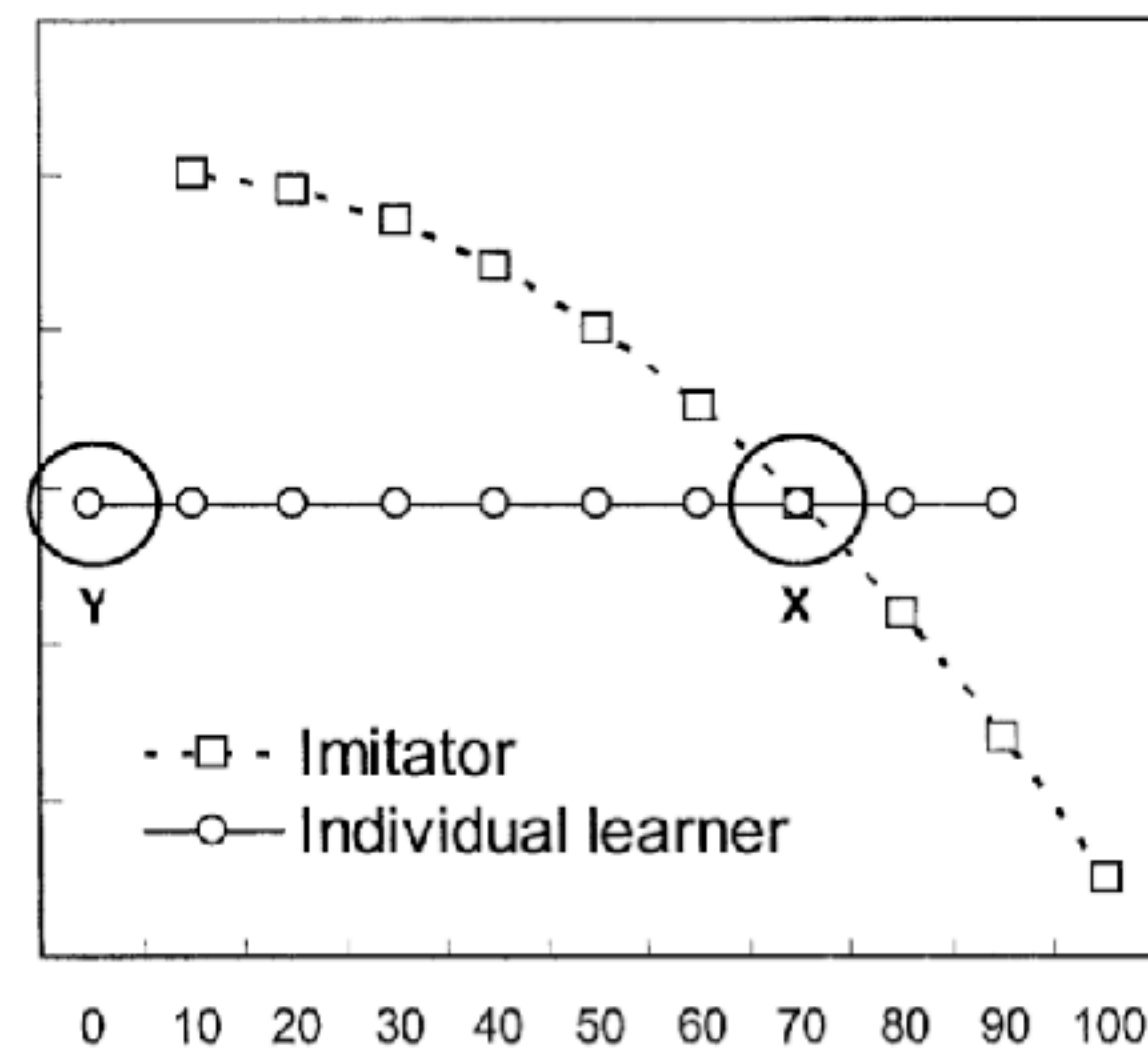
*/ˈskraʊndʒə/*

*noun* INFORMAL • DEROGATORY

a person who borrows from or lives off others.

"welfare scroungers"

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

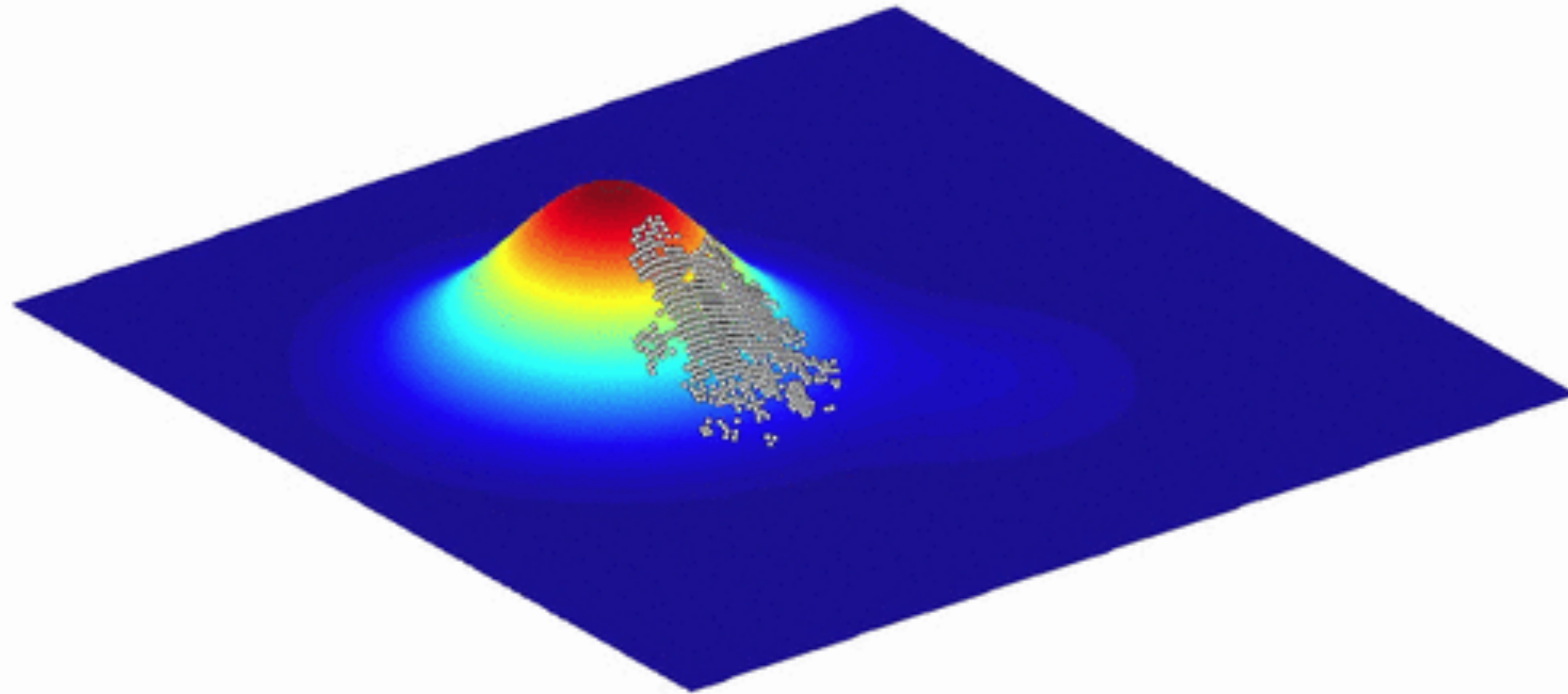


- Information search incurs some costs (energy, predation risks, missing opportunities, etc)
- Information becomes public goods (free-riders (scroungers) emerge)
- Roger's paradox

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.

# Dynamic fitness landscape

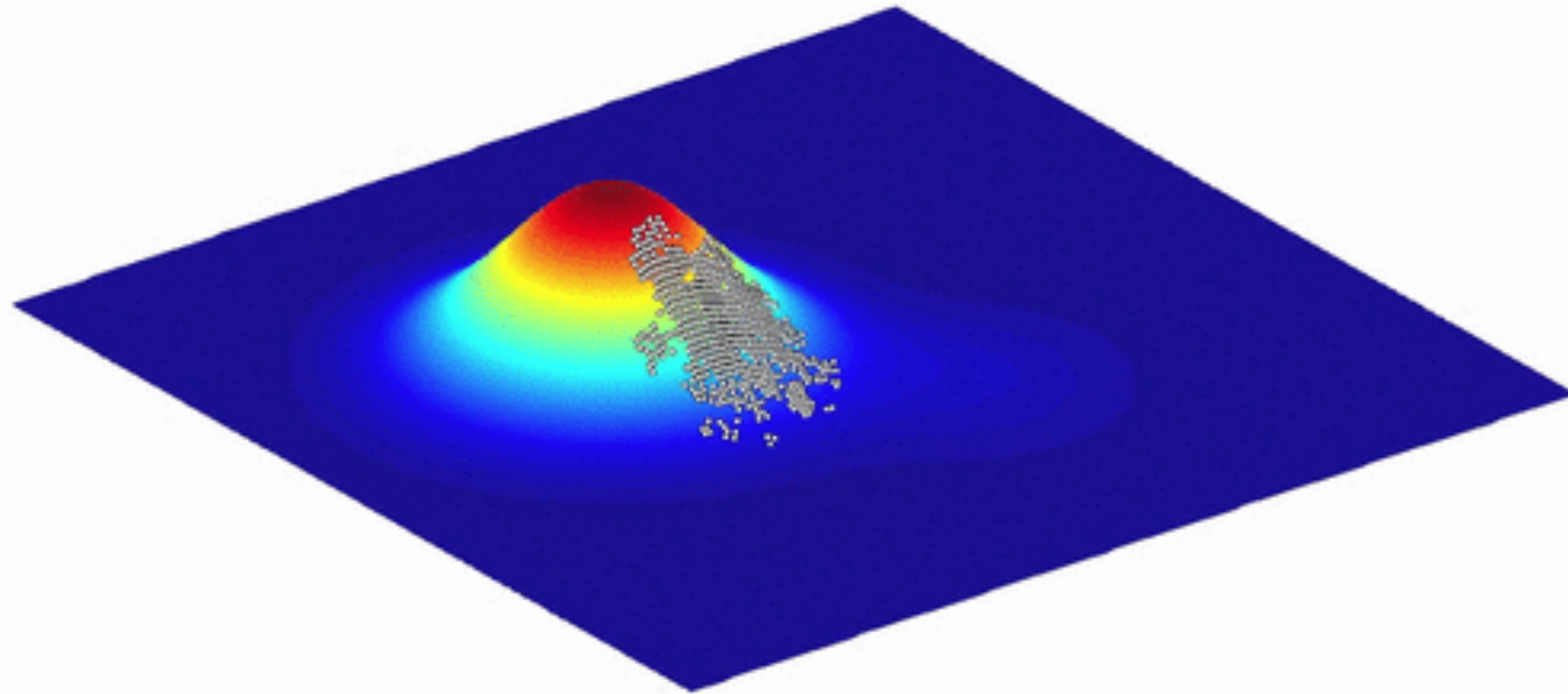


Population size,  $N = 2,304$   
Mutation rate,  $\mu = 0.5$  per trait

© Randy Olson and Bjørn Østman



# Dynamic fitness landscape






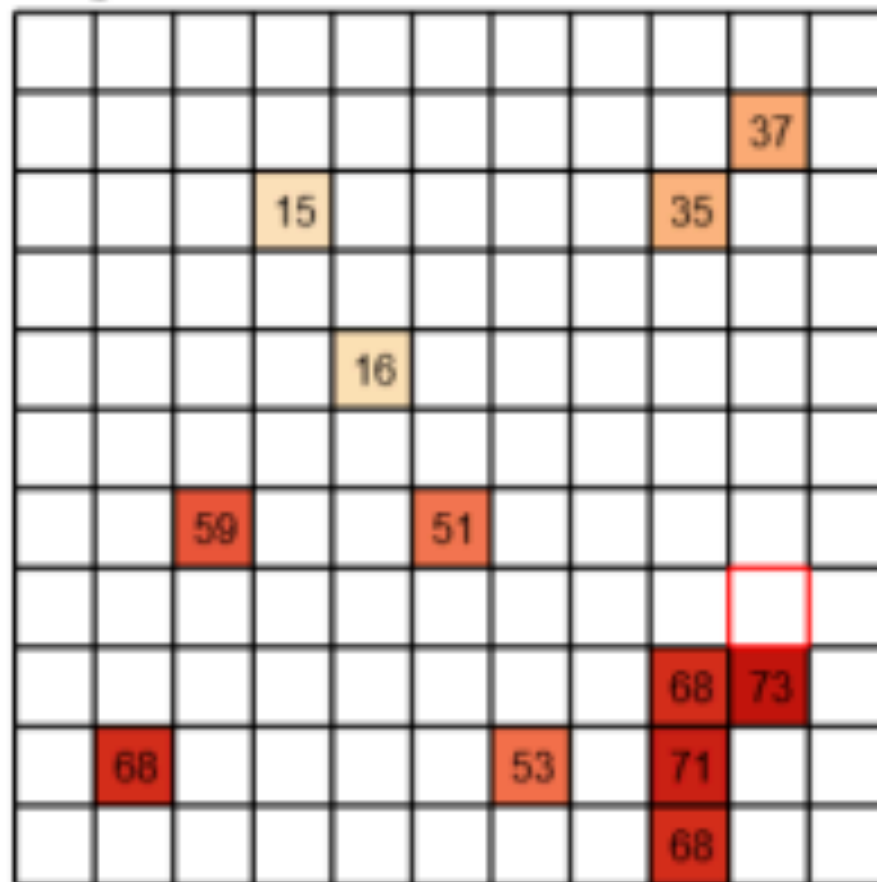
Population size,  $N = 2,304$   
Mutation rate,  $\mu = 0.5$  per trait

© Randy Olson and Bjørn Østman

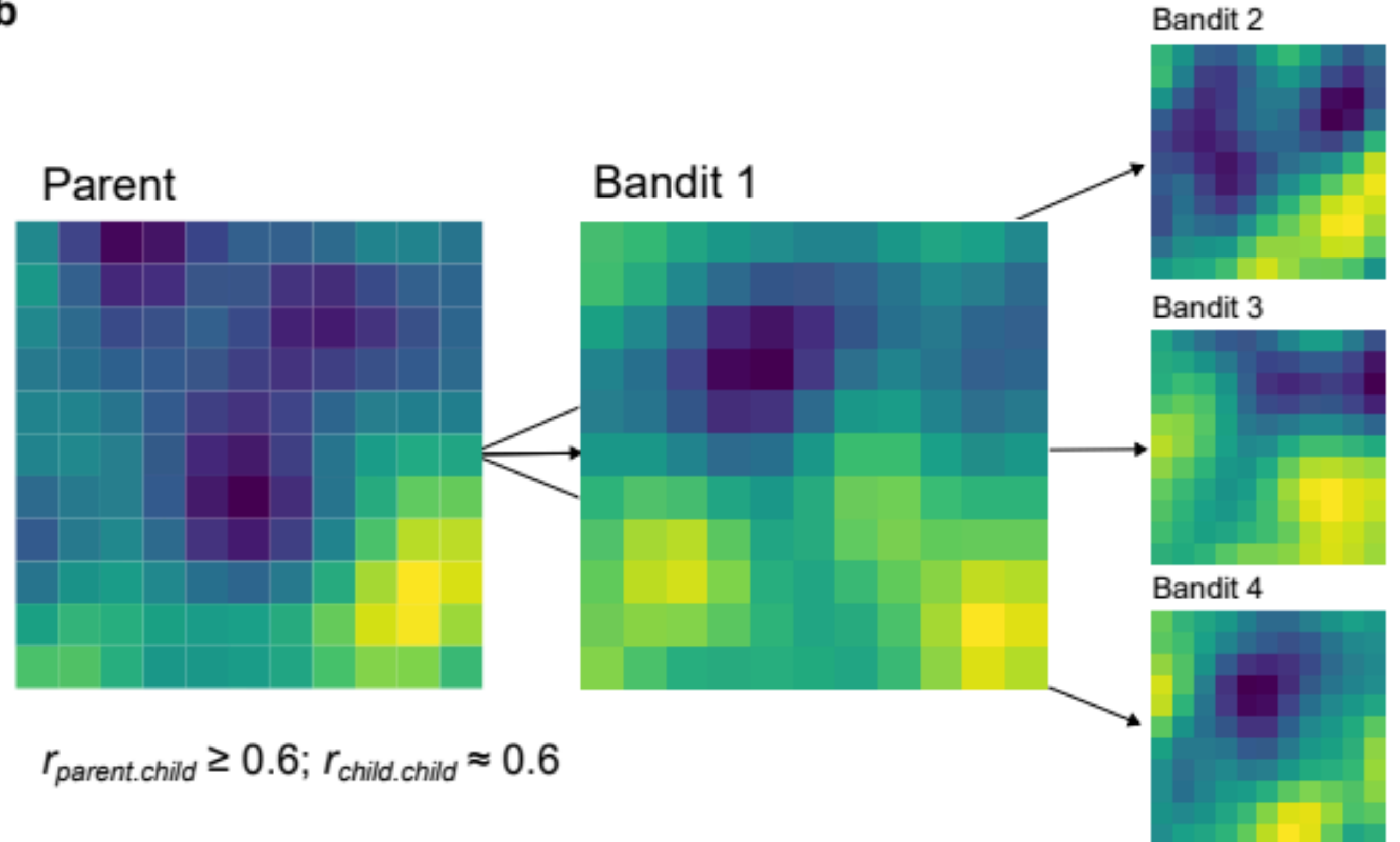
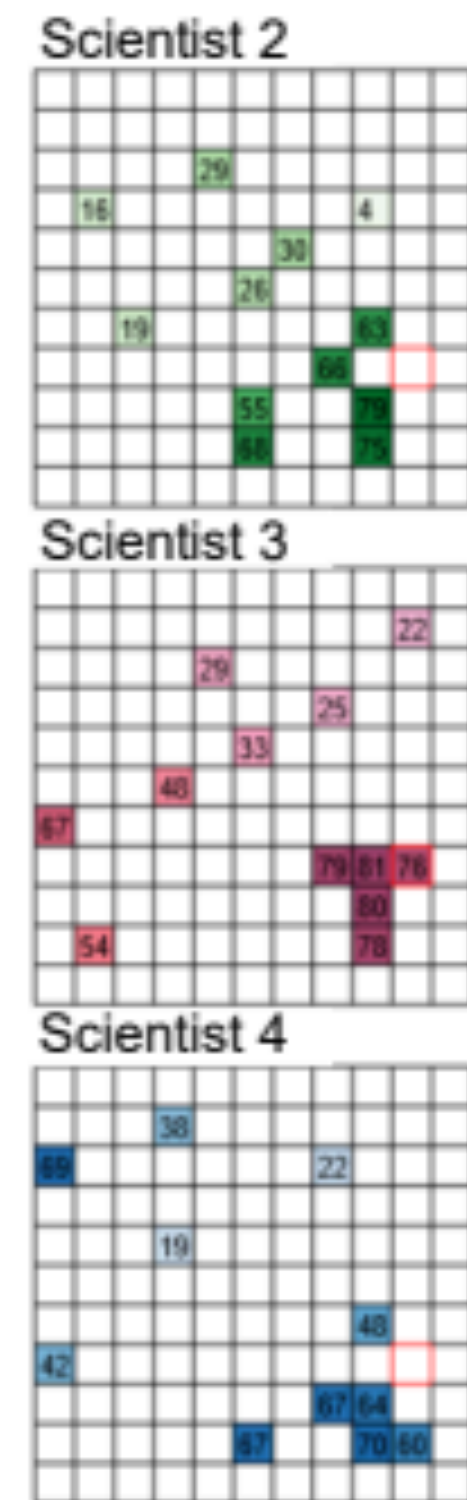
# Individual differences

a

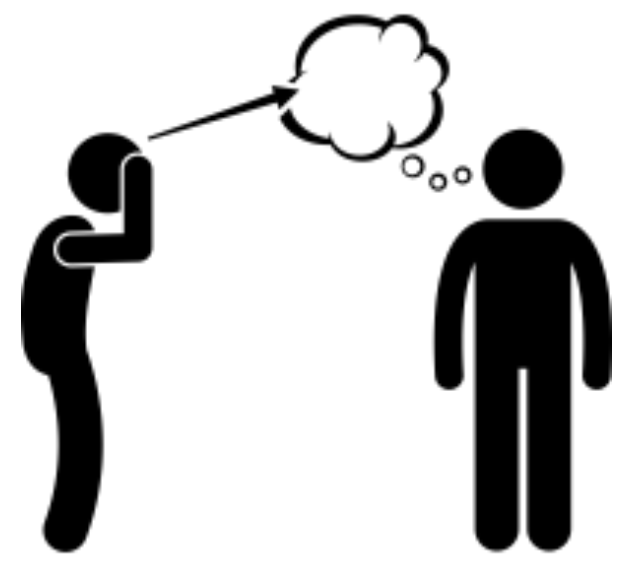
-  Gather as much salt as possible within 14 clicks
-  Salt concentration is correlated spatially...
-  .... as well as socially



b

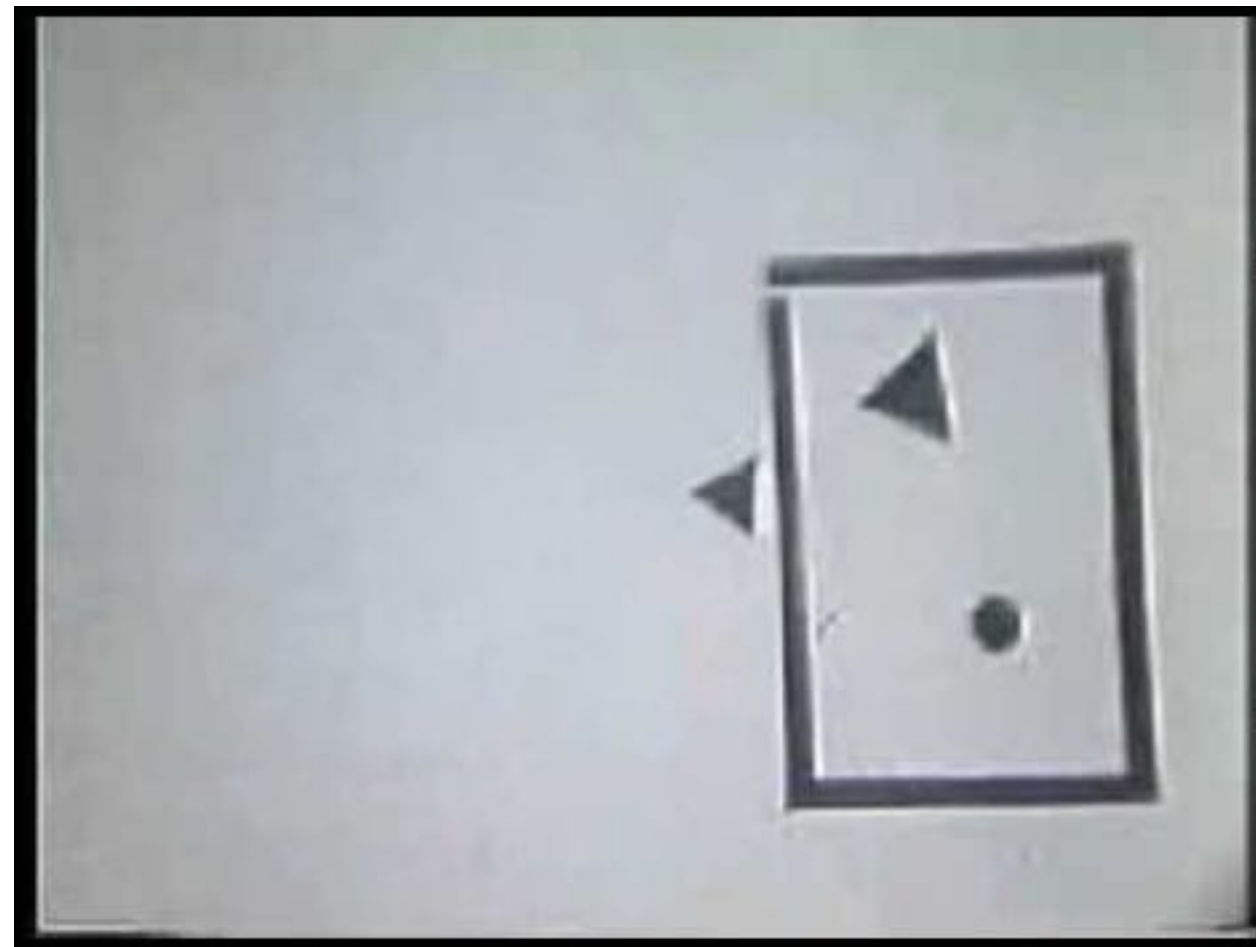


Witt, A., Toyokawa, W., Lala, K., Gaissmaier, W., & Wu, C. M. (2023). Social learning with a grain of salt. In M. Goldwater, F. Anggoro, B. Hayes, & D. Ong (Eds.), Proceedings of the 45th Annual Conference of the Cognitive Science Society. Sydney, Australia: Cognitive Science Society

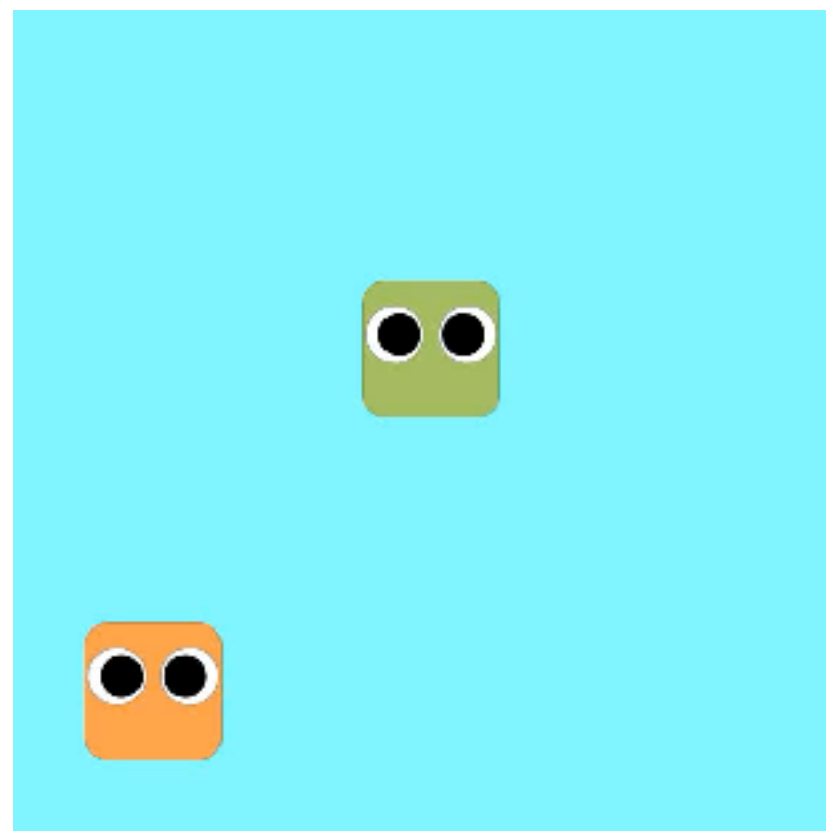


# ⑥ Theory of Mind and metacognitive social learning

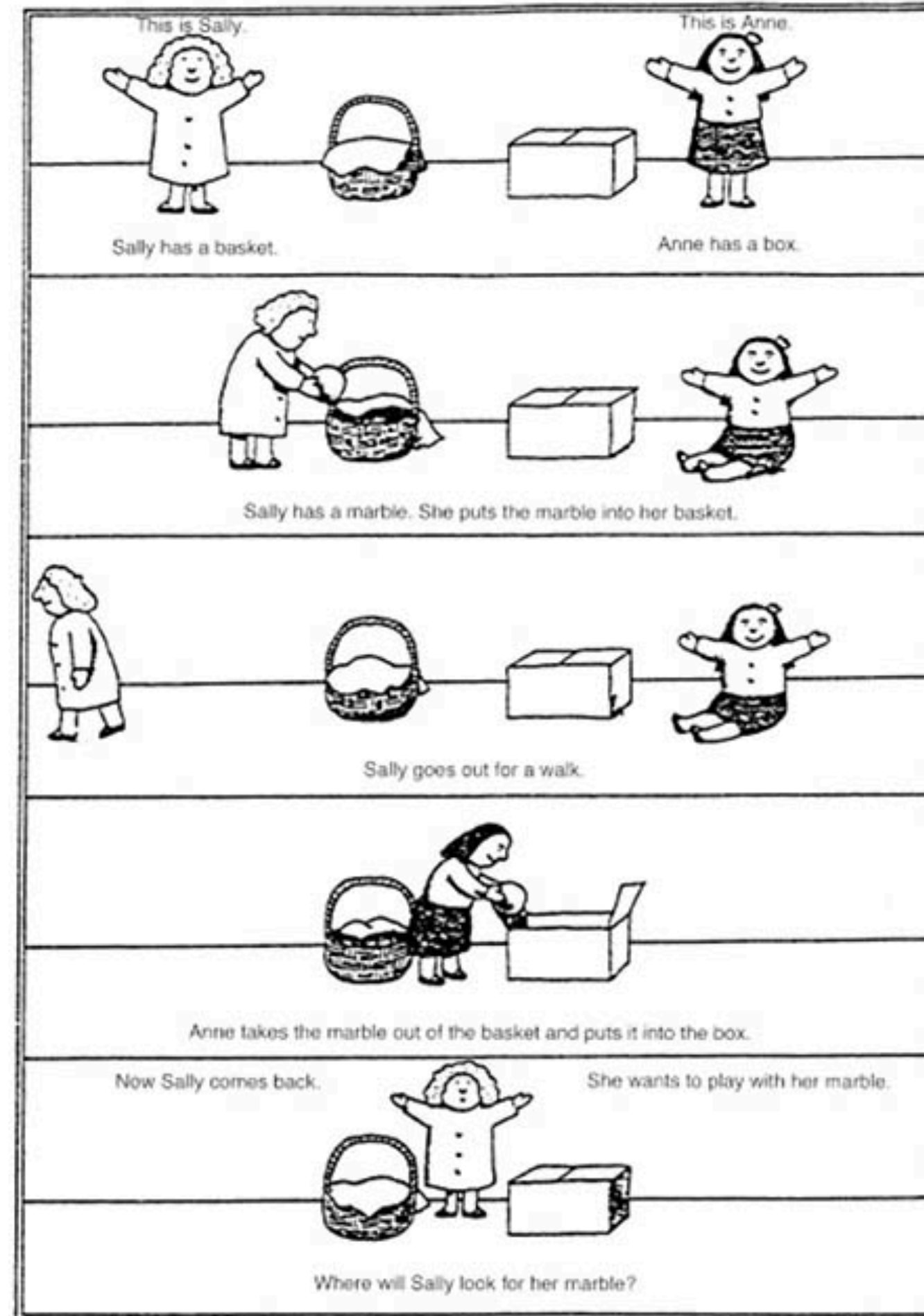
## Inferring goals and beliefs from behavior



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



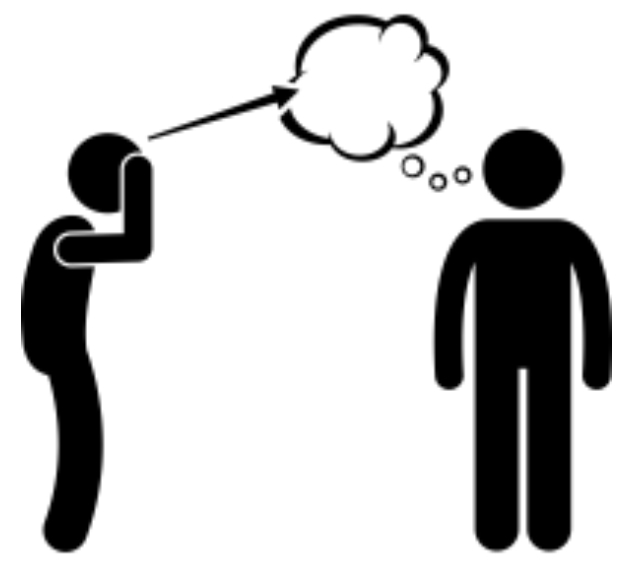
Kanakogi, Y., Miyazaki, M., Takahashi, H. et al. (2022) Third-party punishment by preverbal infants. *Nat Hum Behav* 6, 1234–1242.



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

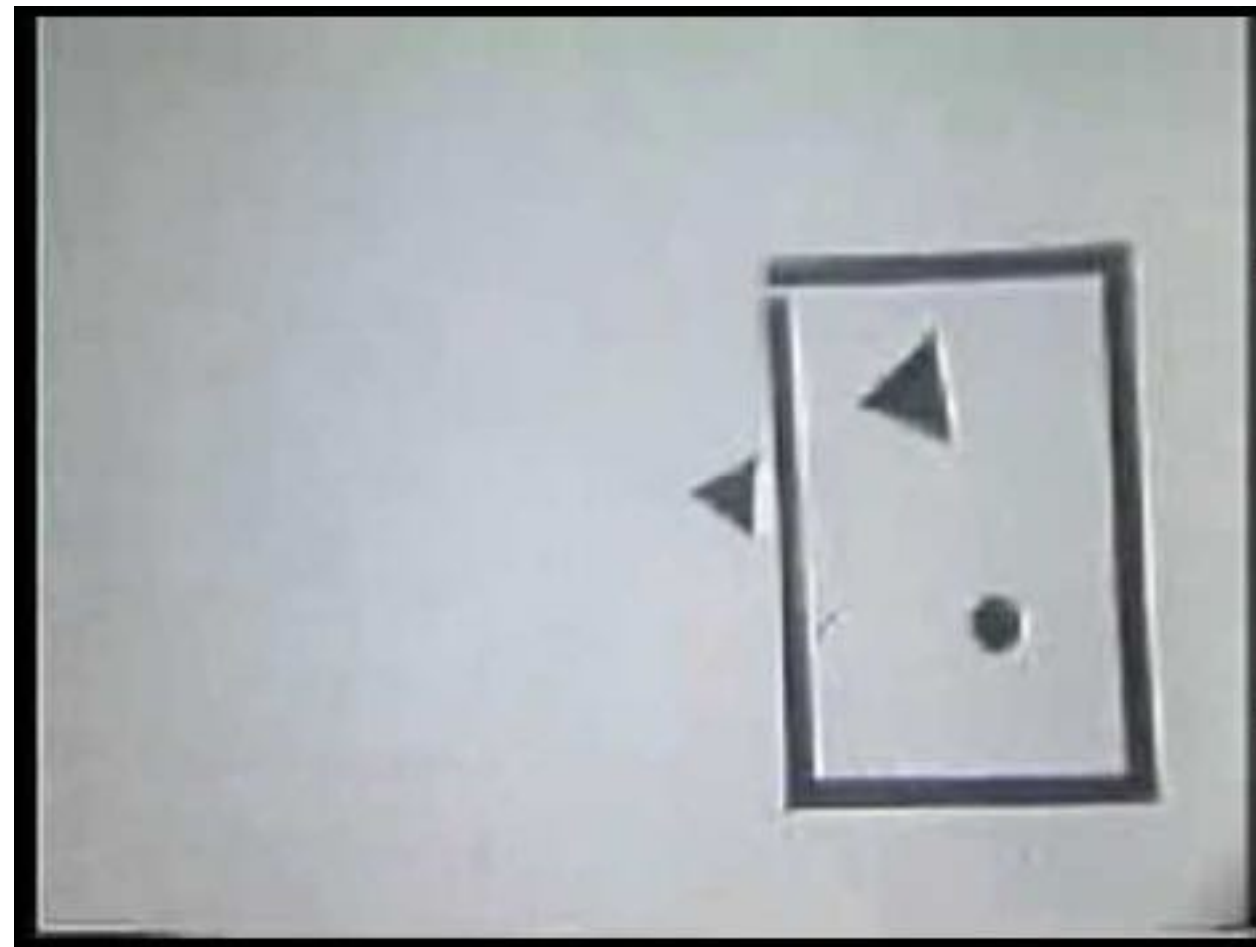


Whiten, A., & Byrne, R. W. (1988). Tactical deception in primates. *Behavioral and brain sciences*, 11(2), 233-244.

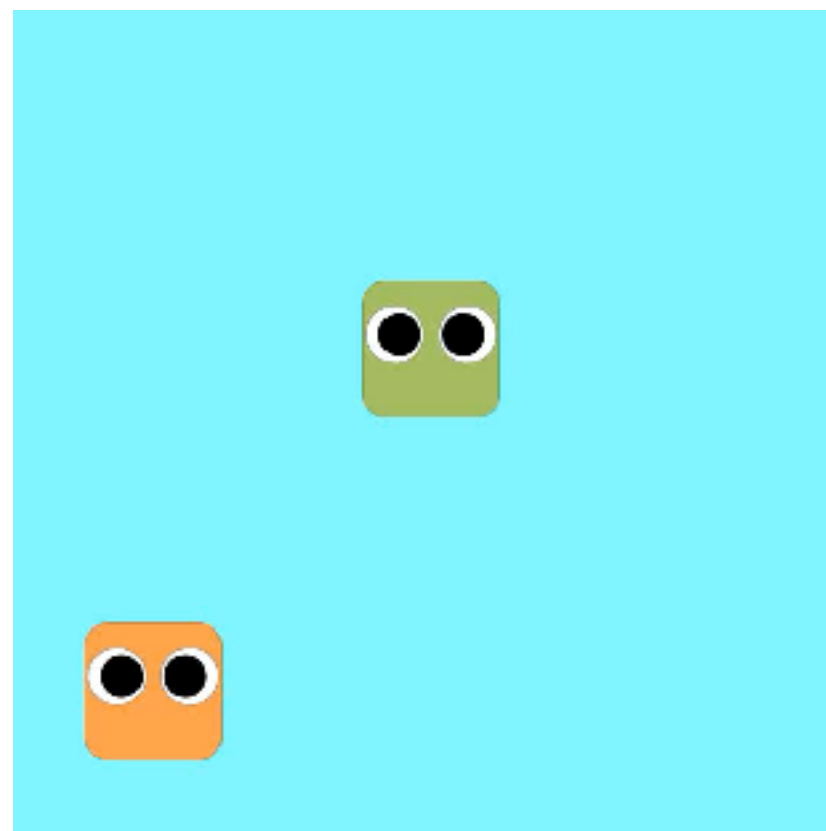


# ⑥ Theory of Mind and metacognitive social learning

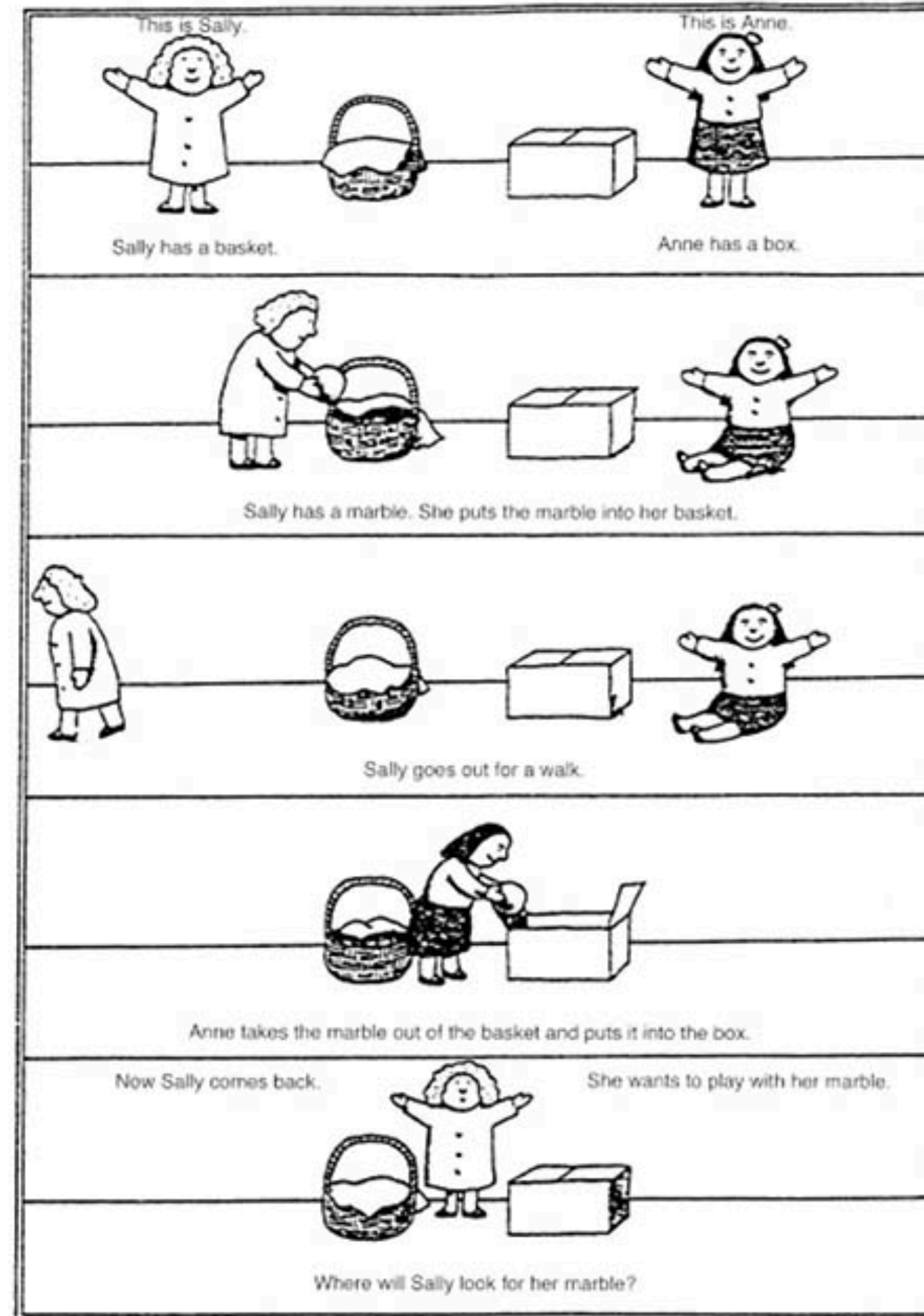
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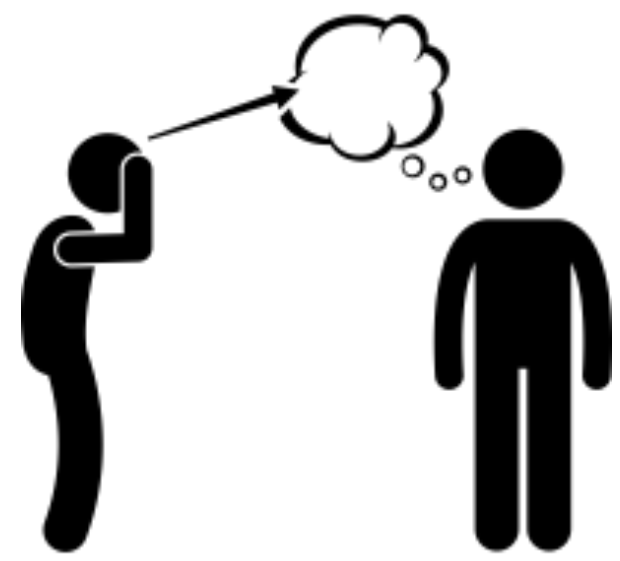
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Baron-Cohen, S., Leslie, A. M., & Frith, U. (1985). Does the autistic child have a “theory of mind”? *Cognition*, 21(1), 37-46.

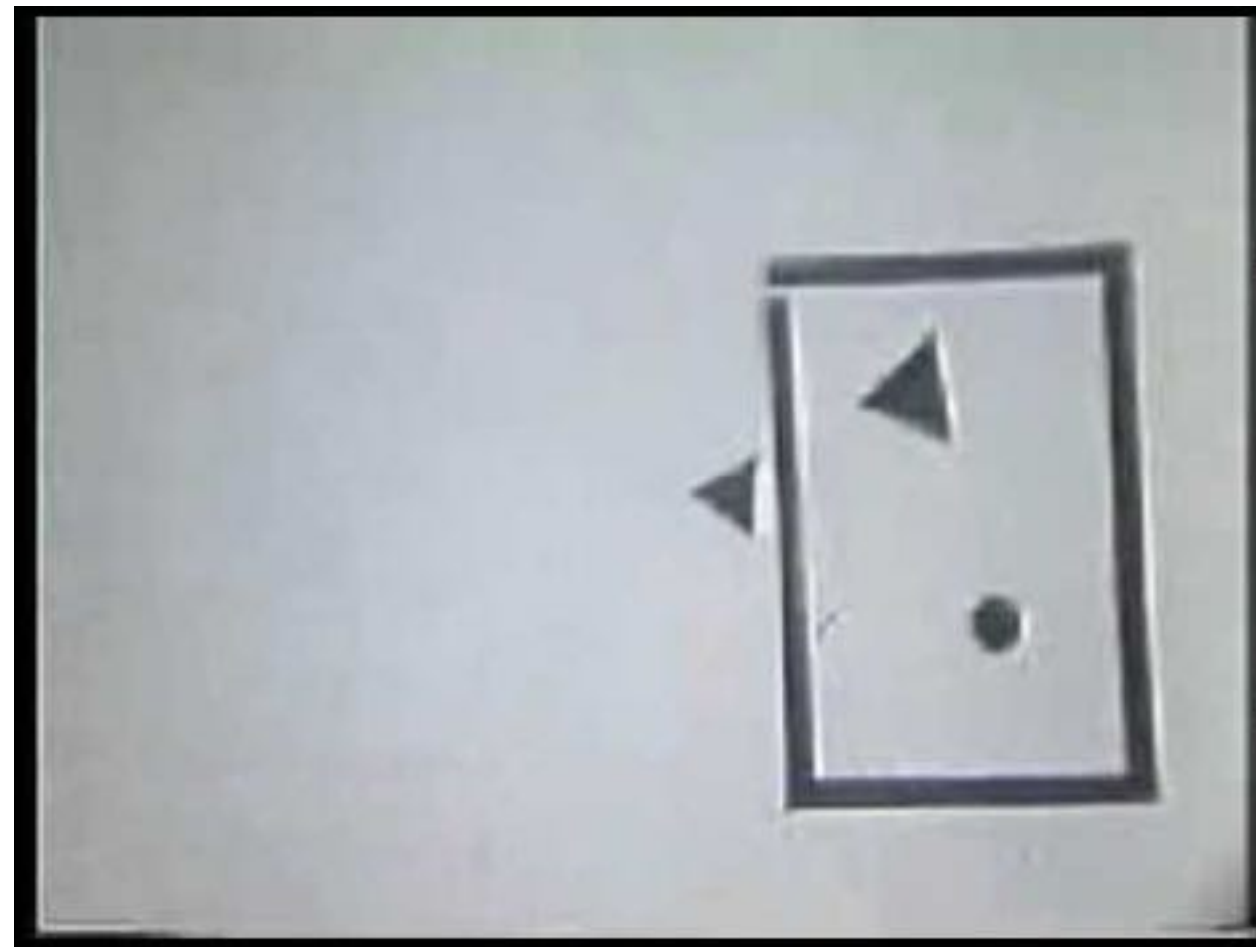


Whiten, A., & Byrne, R. W. (1988). Tactical deception in primates. *Behavioral and brain sciences*, 11(2), 233-244.

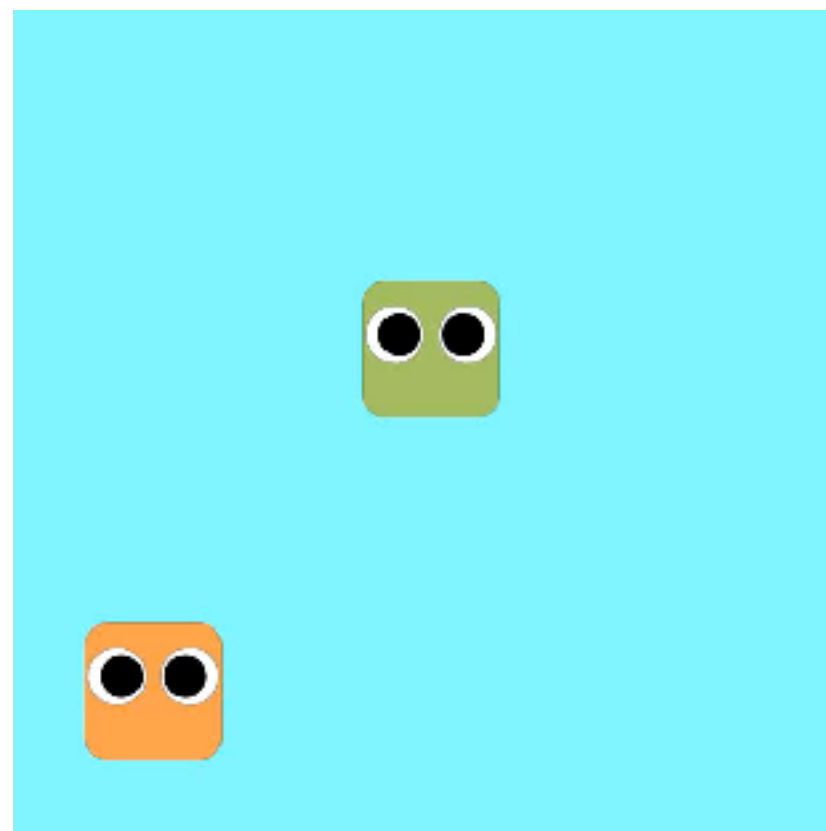


# ⑥ Theory of Mind and metacognitive social learning

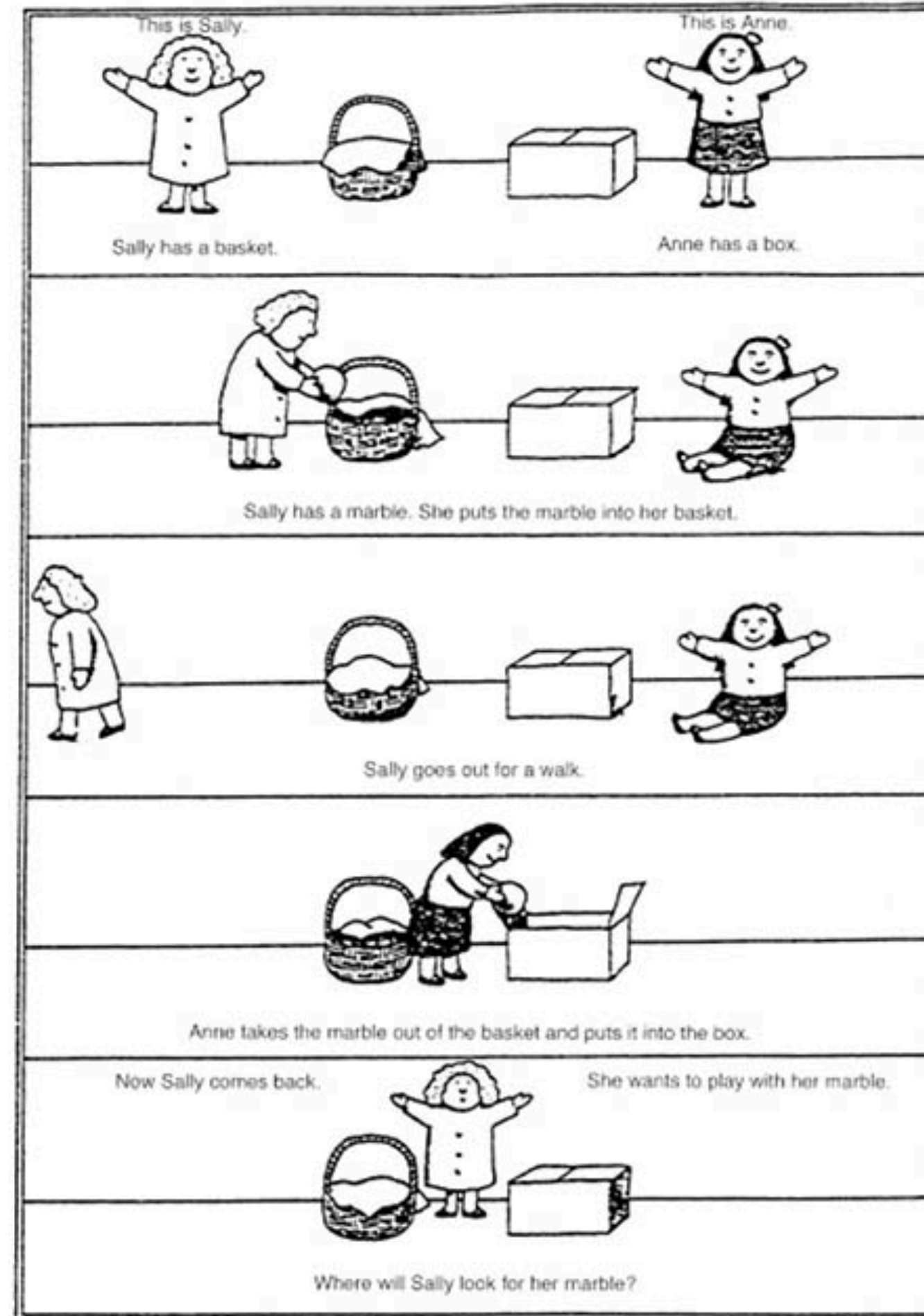
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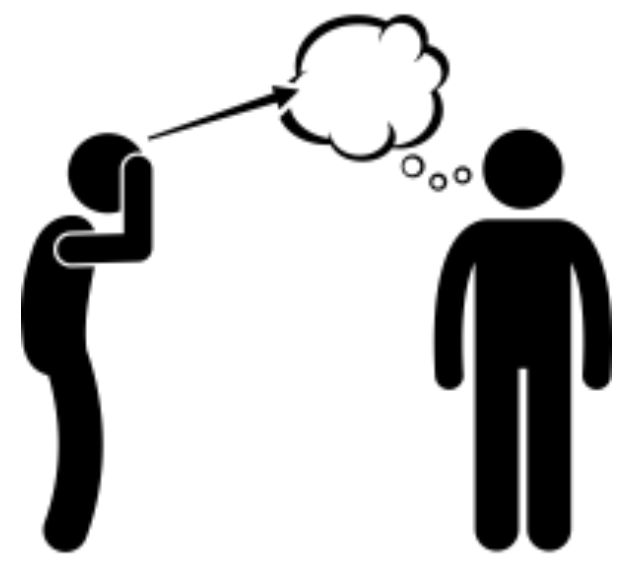
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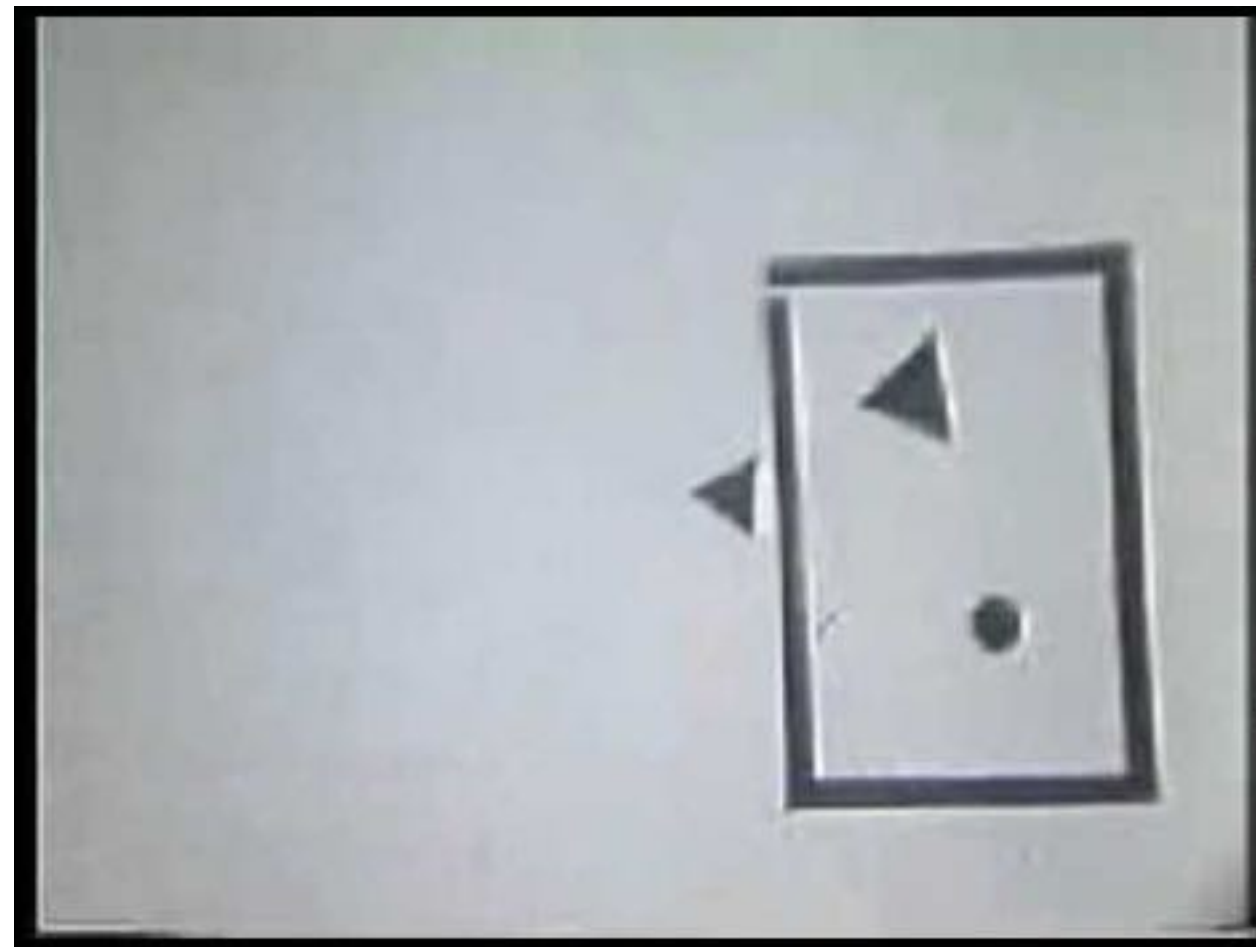


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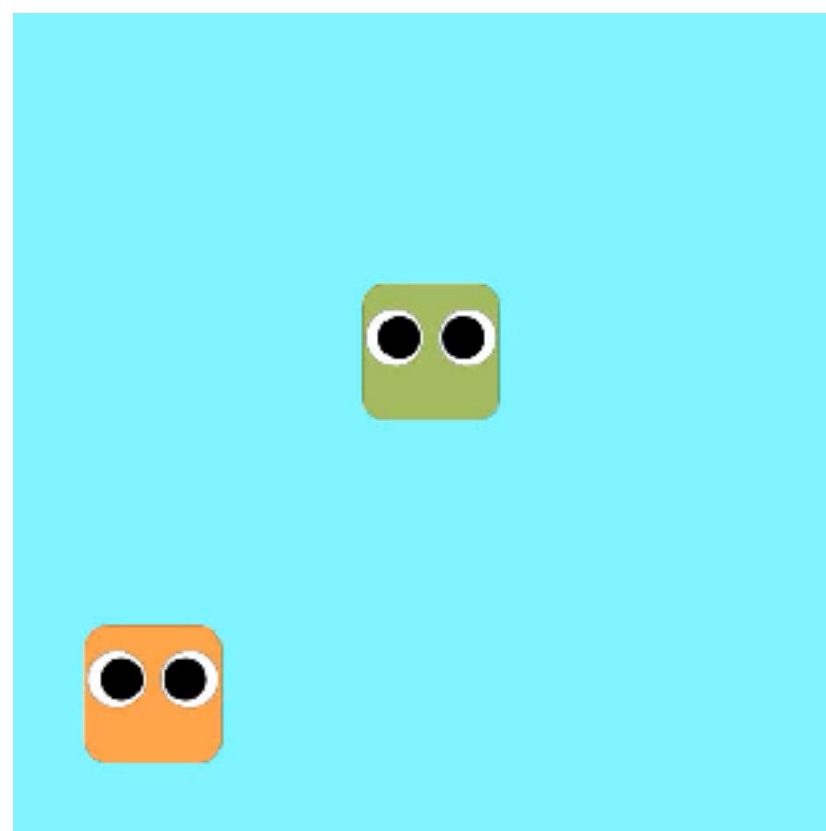


# ⑥ Theory of Mind and metacognitive social learning

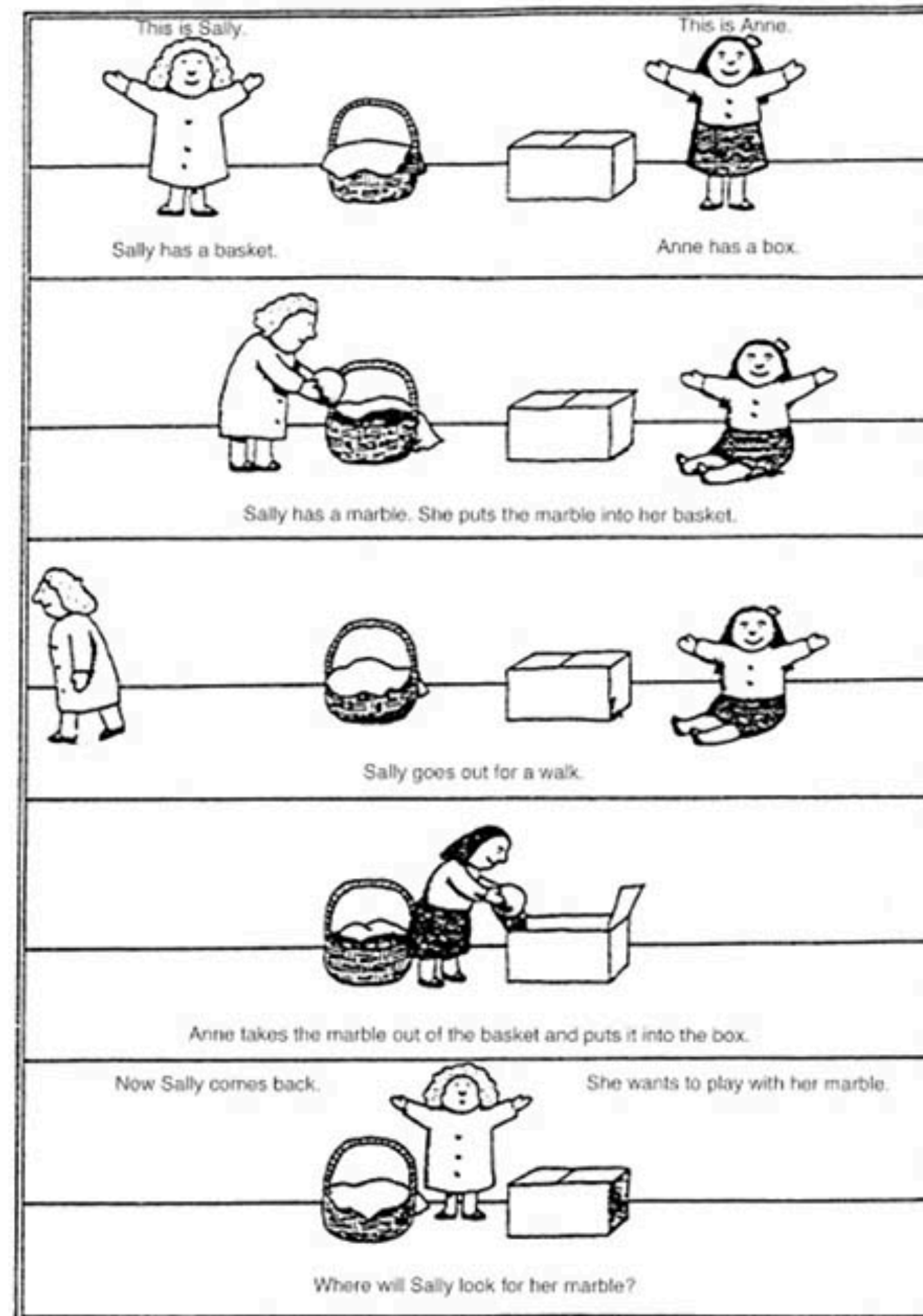
## Inferring goals and beliefs from behavior



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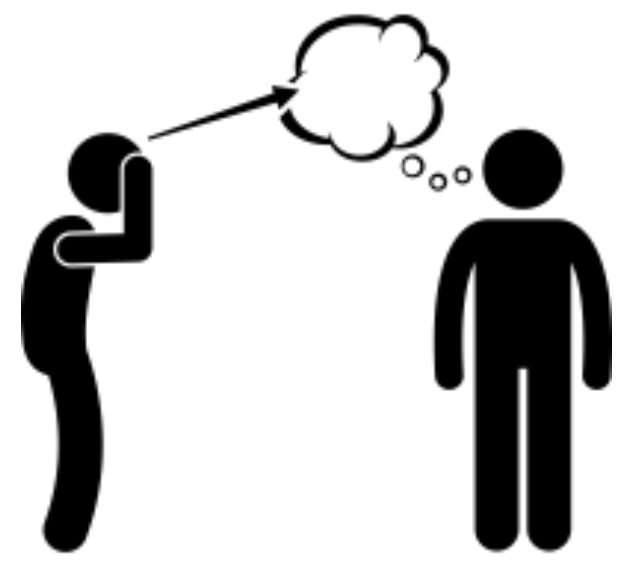
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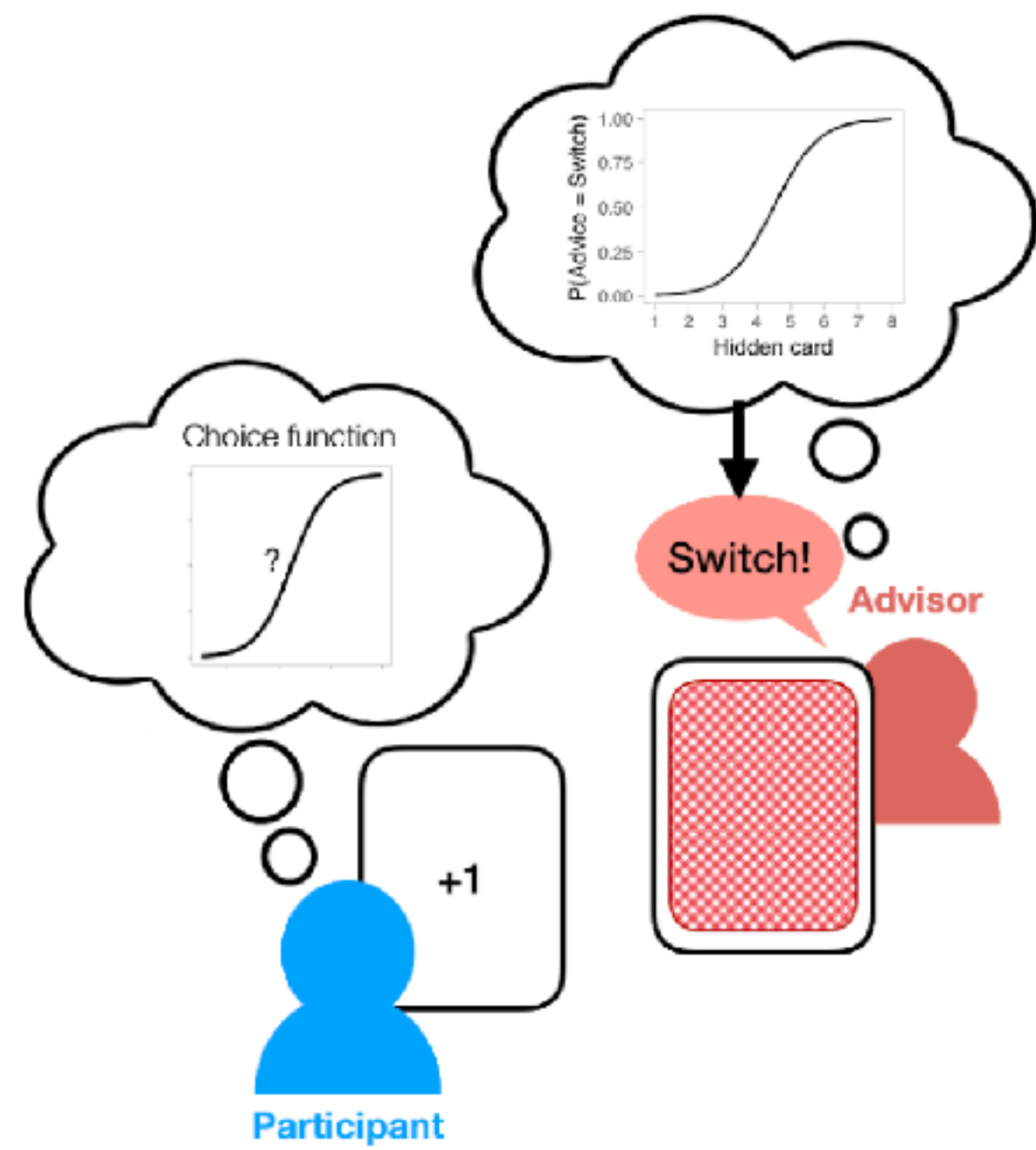


Whiten, A., & Byrne, R. W. (1988). Tactical deception in primates. *Behavioral and brain sciences*, 11(2), 233-244.

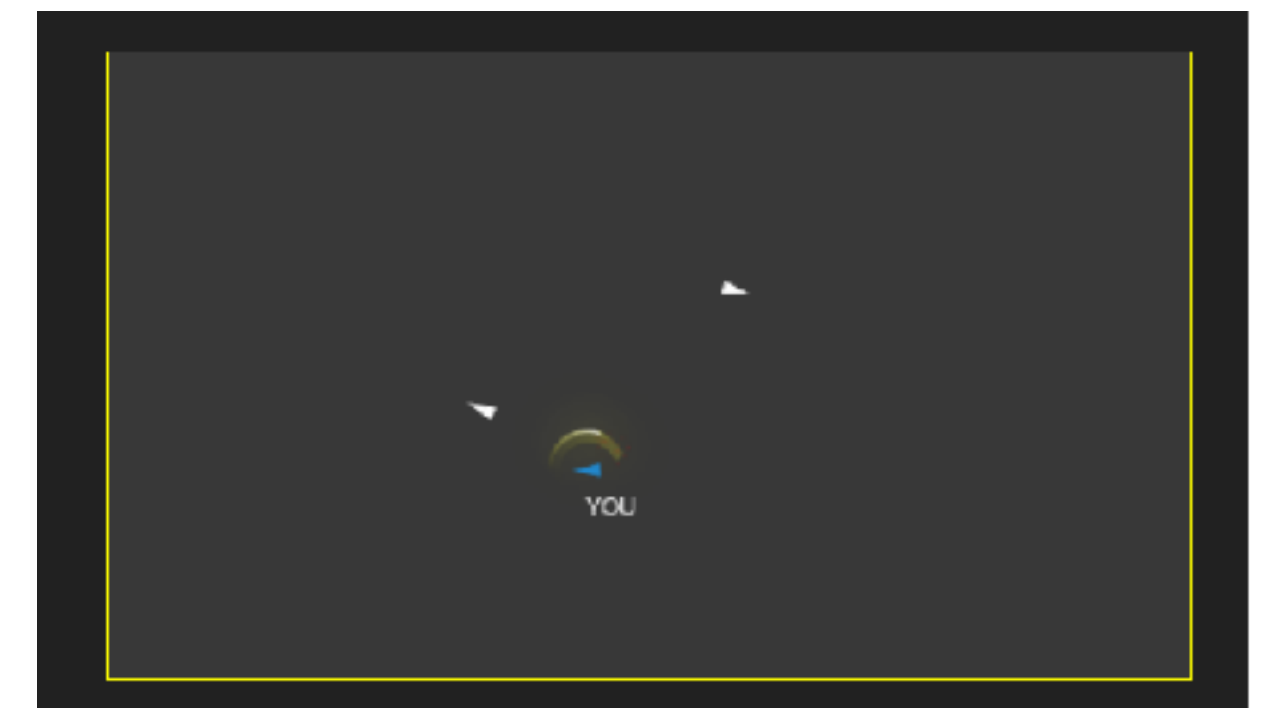
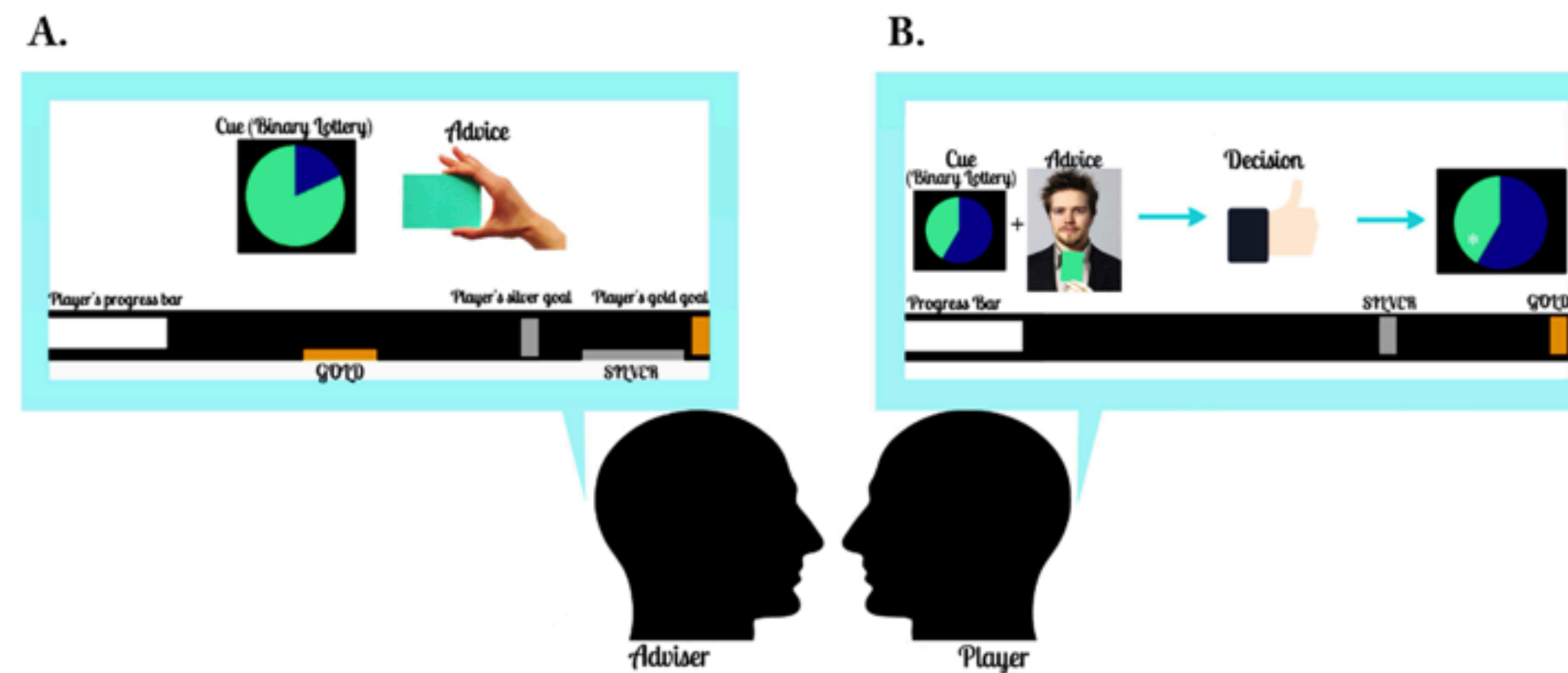


# ⑥ Theory of Mind and metacognitive social learning

ToM informs social information use



“Copy when the adviser intends to help”



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

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

# ⑦ Teaching and advice giving

## Teaching in non-human animals



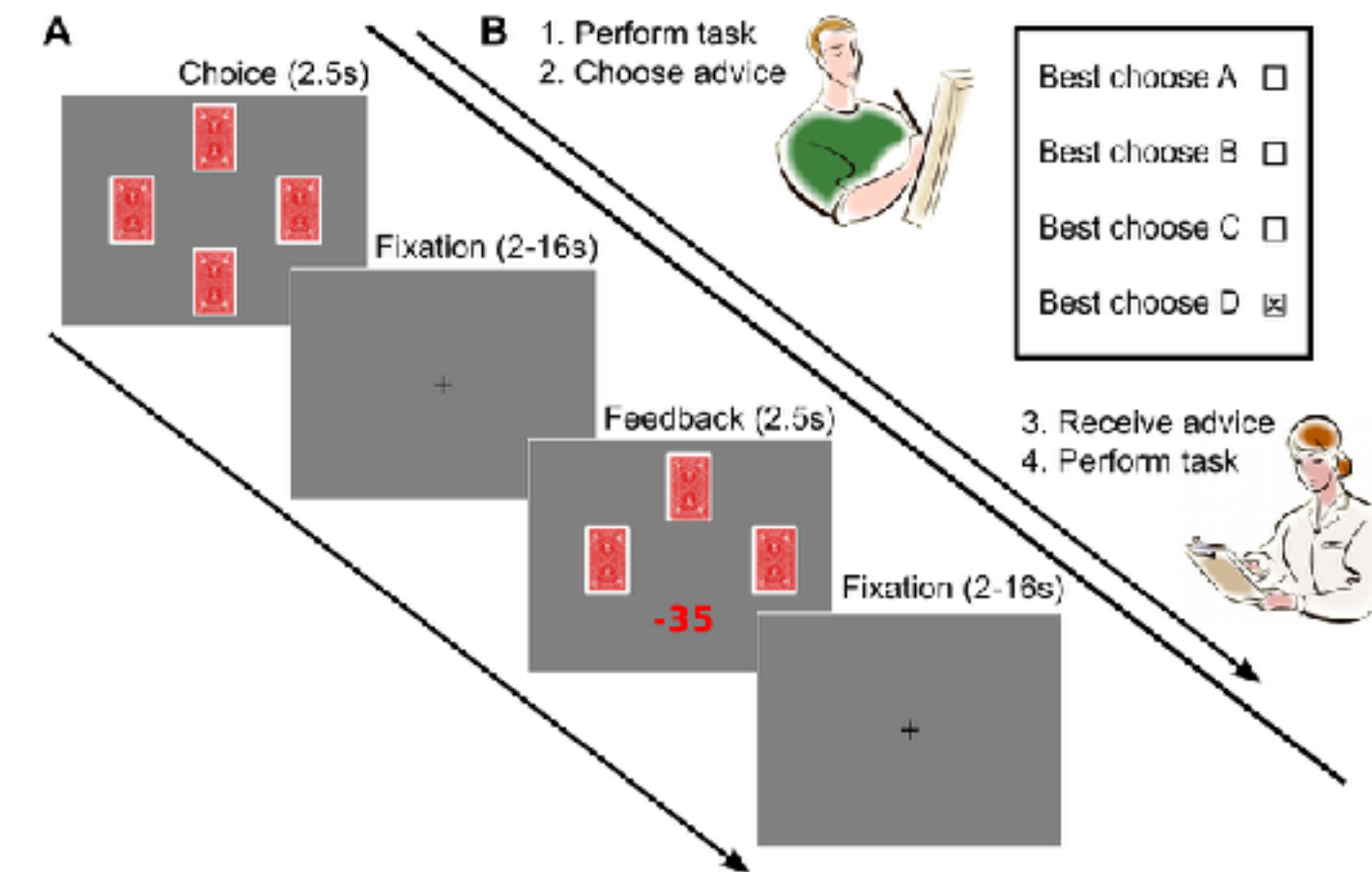
Sasaki et al. (2013). Ant colonies outperform individuals when a sensory discrimination task is difficult but not when it is easy. *Proceedings of the National Academy of Sciences*, 110(34), 13769-13773.



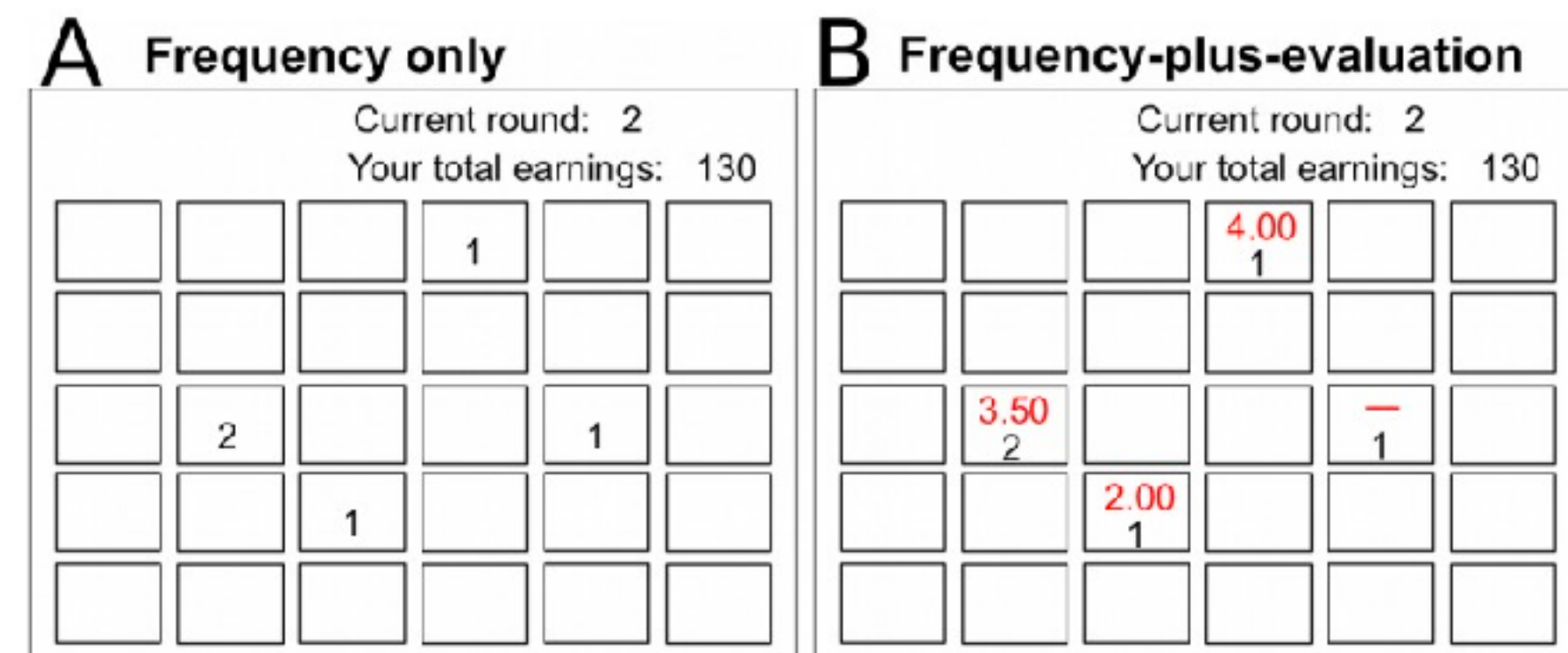
<https://youtu.be/48rhtgtNxRI>

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



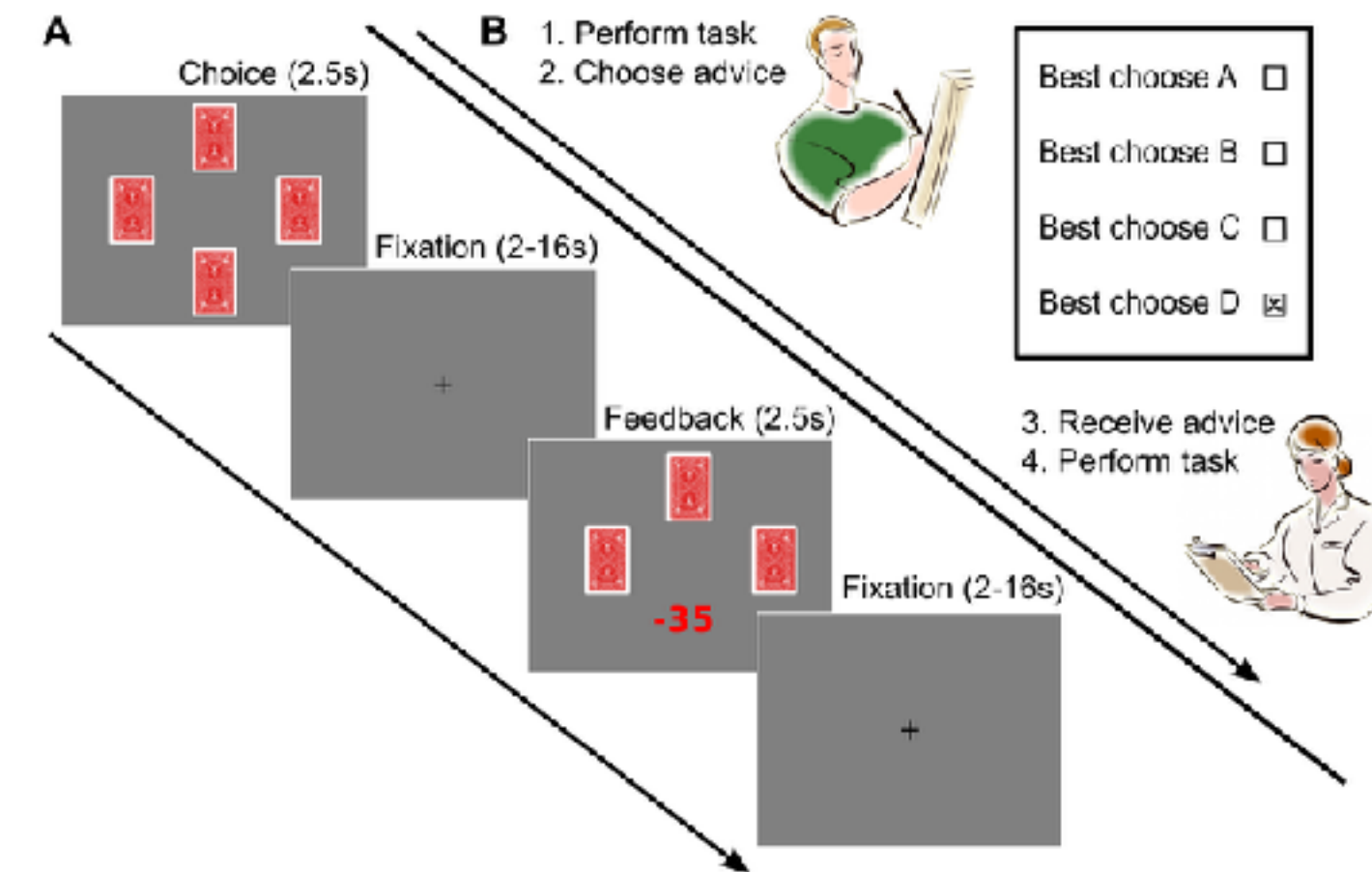
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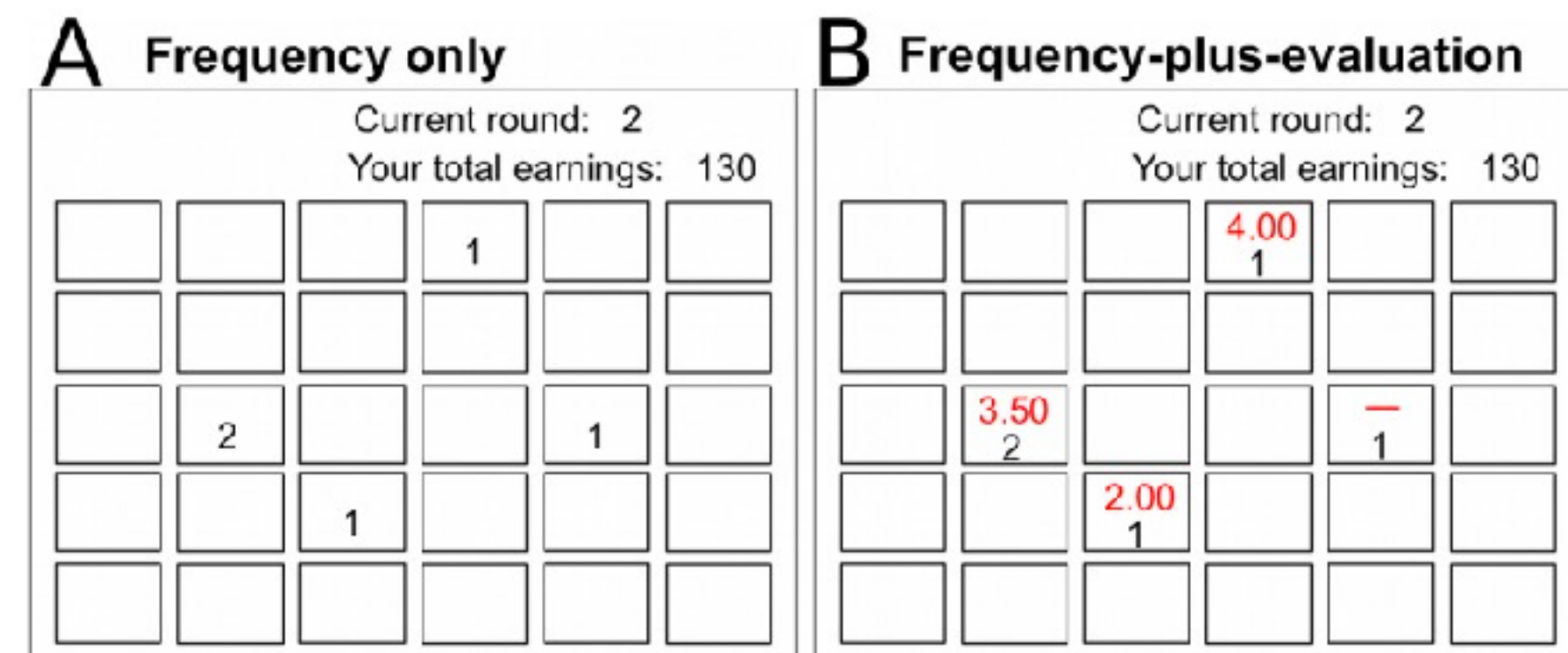
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# ⑦ Teaching and advice giving

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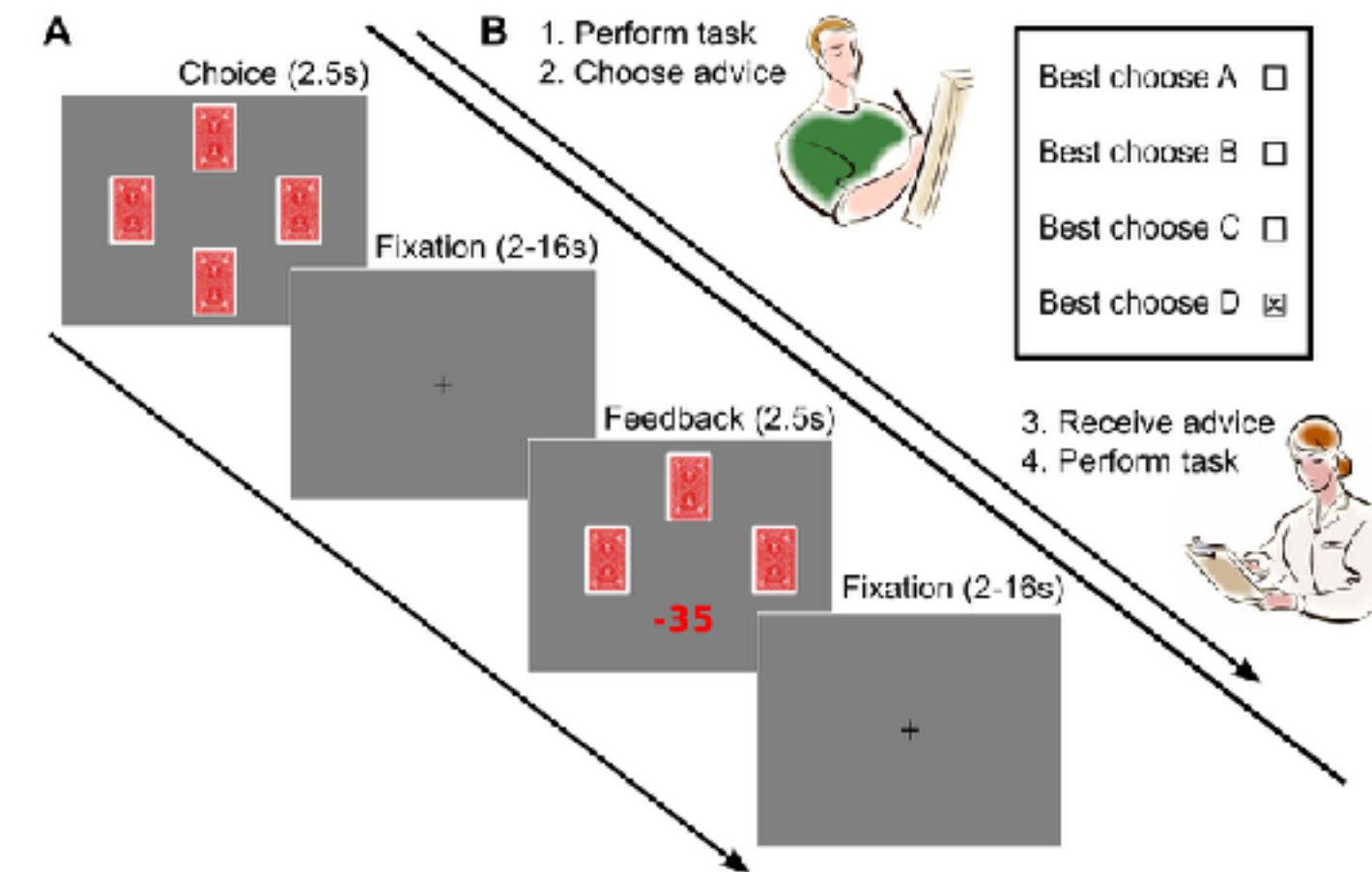
Sasaki et al. (2013). Ant colonies outperform individuals when a sensory discrimination task is difficult but not when it is easy. *Proceedings of the National Academy of Sciences*, 110(34), 13769-13773.



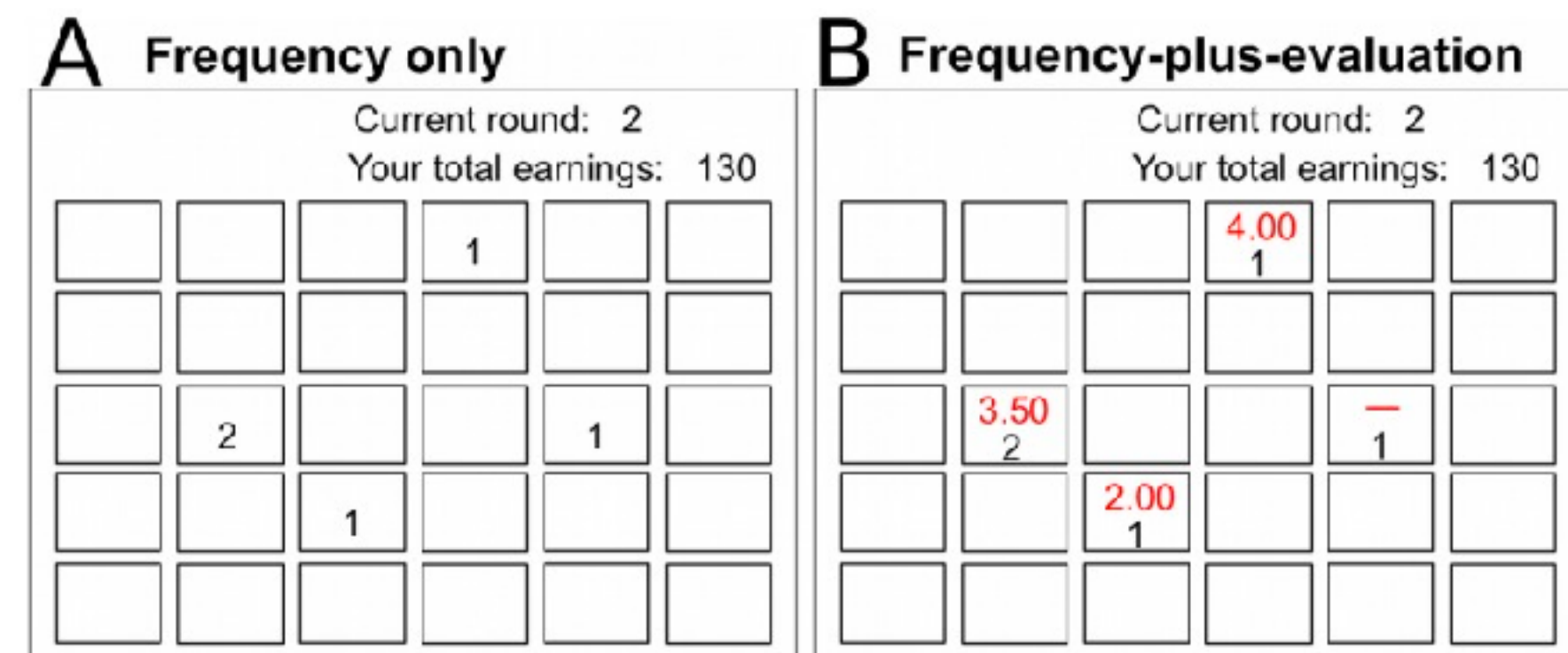
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## Simple advice giving in humans

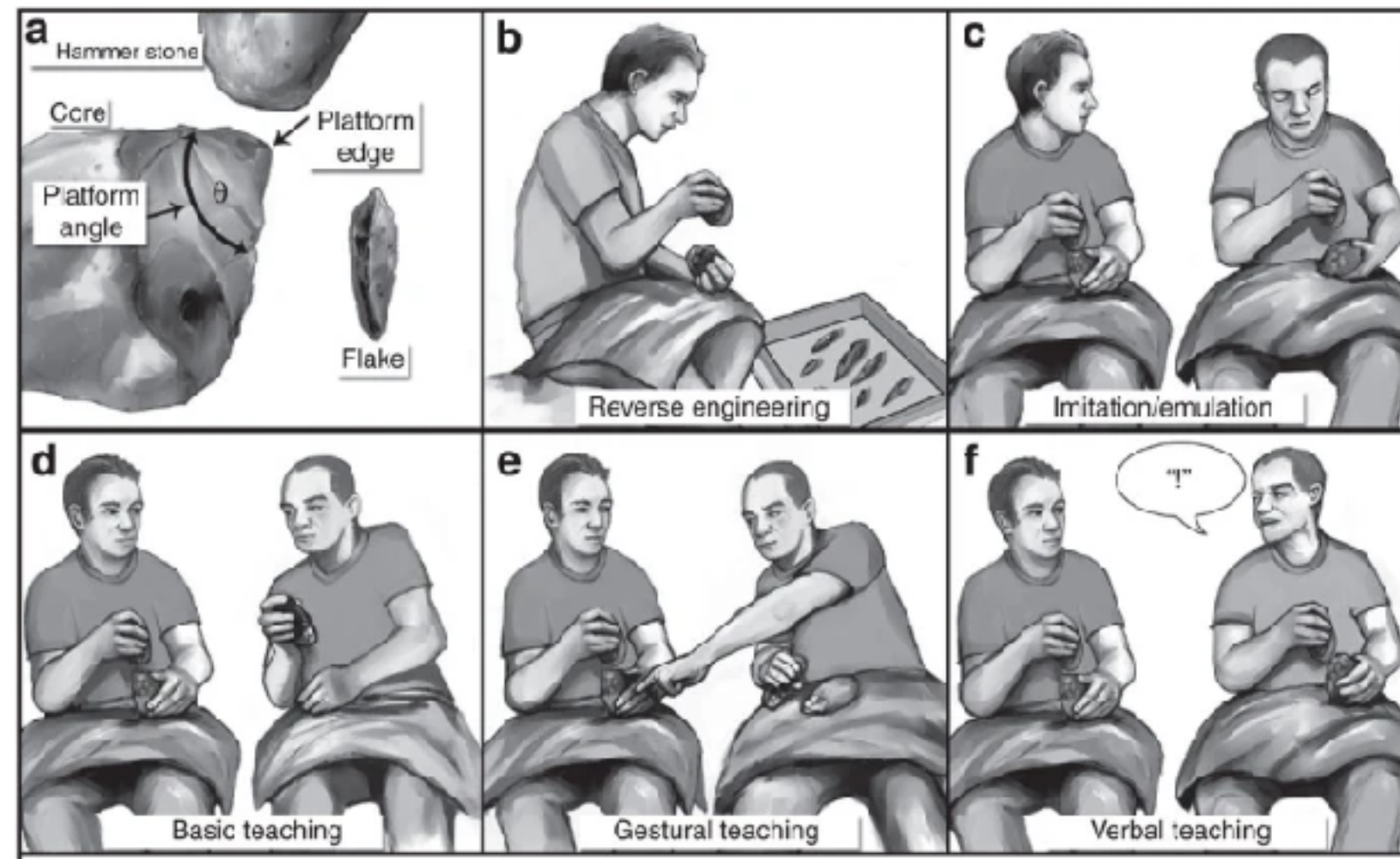


Biele, G., Rieskamp, J., Krugel, L. K., & Heekeren, H. R. (2011). The neural basis of following advice. *PLoS biology*, 9(6), e1001089.

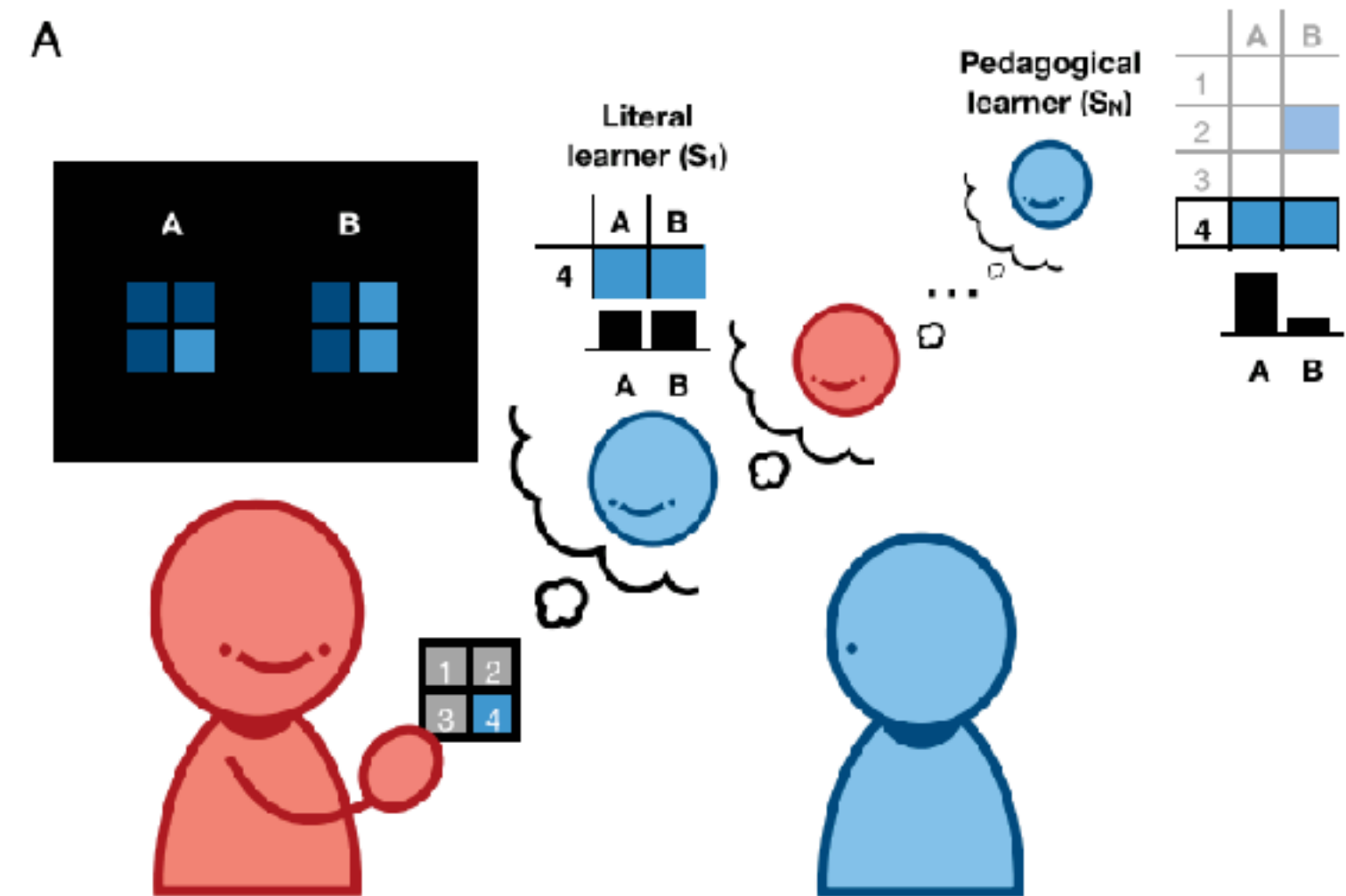
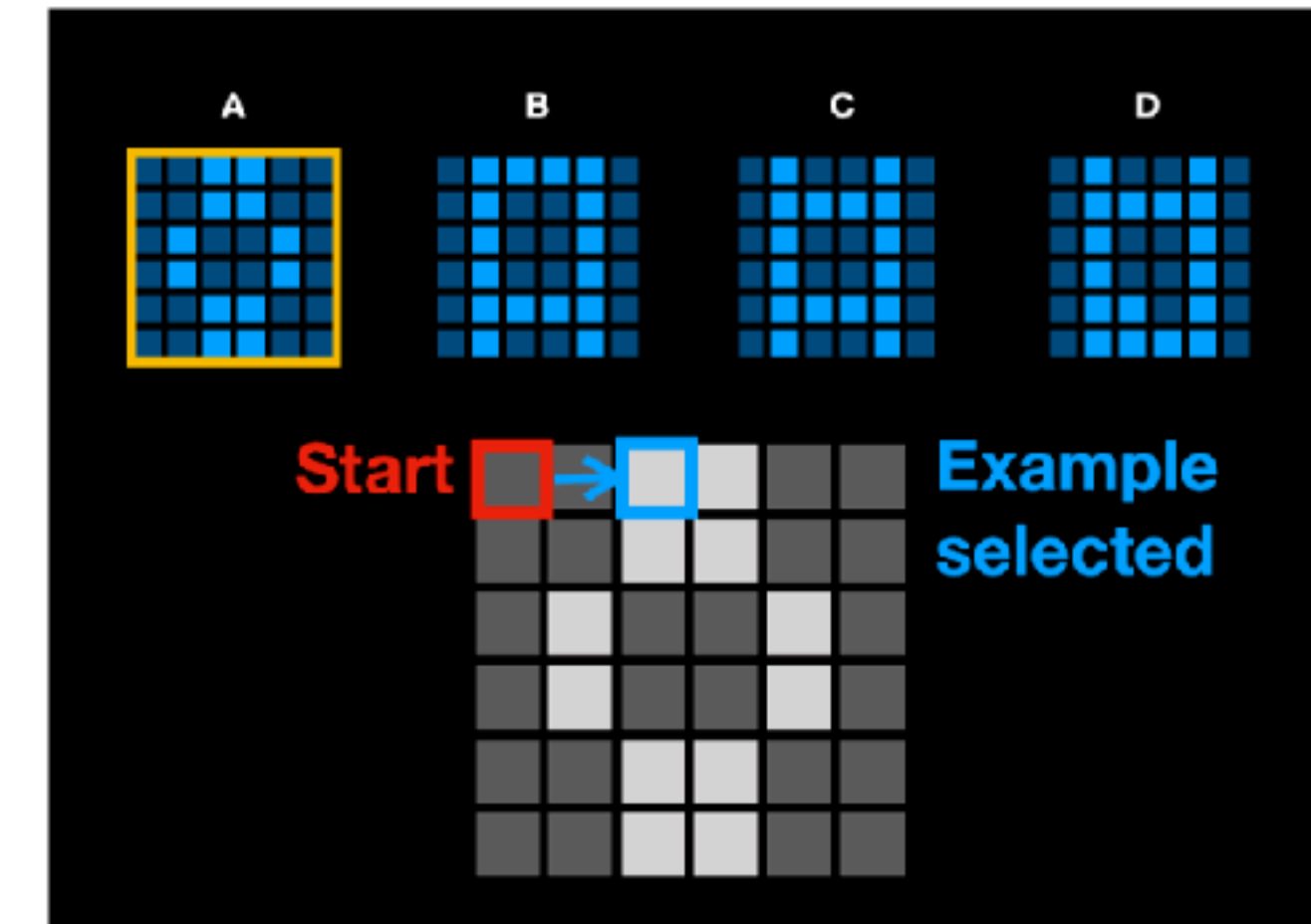


Toyokawa, W., Kim, H. R., & Kameda, T. (2014). Human collective intelligence under dual exploration-exploitation dilemmas. *PloS one*, 9(4), e95789.

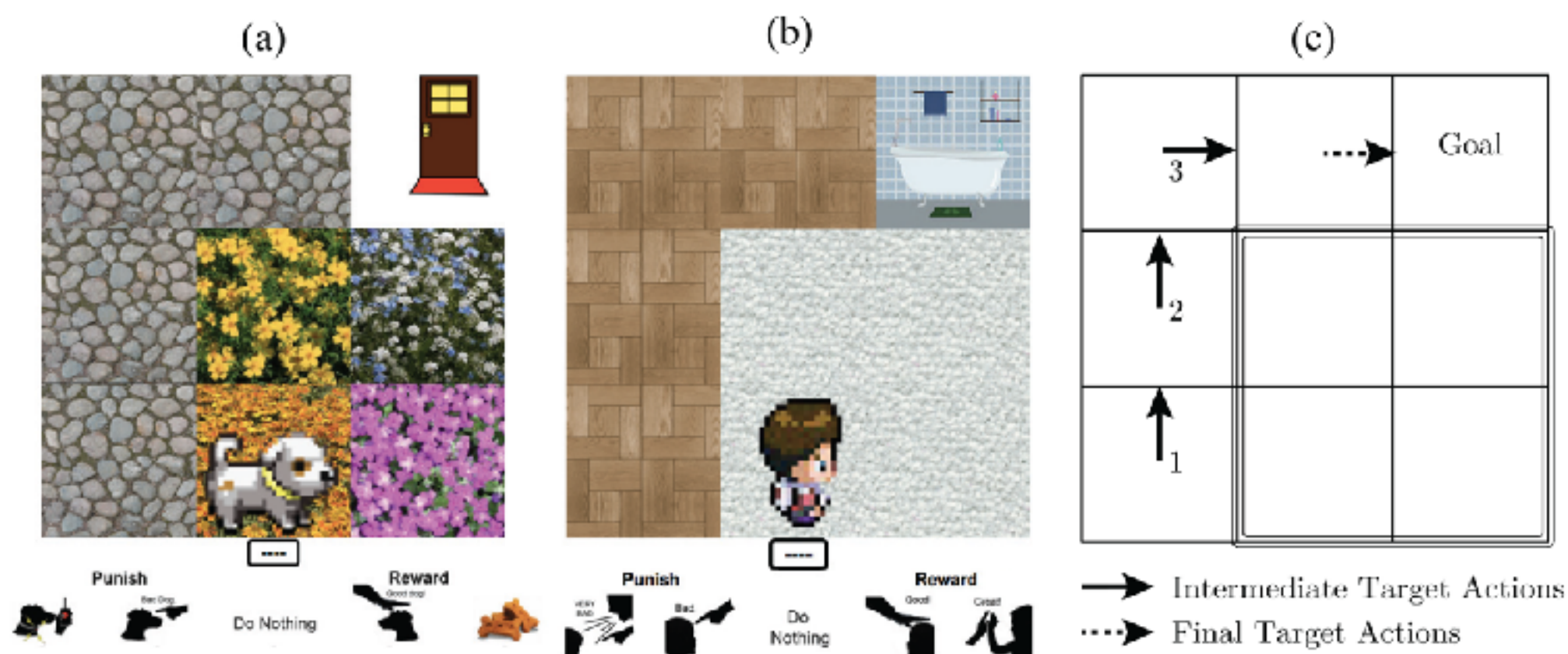
# Communicating and reasoning about beliefs



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



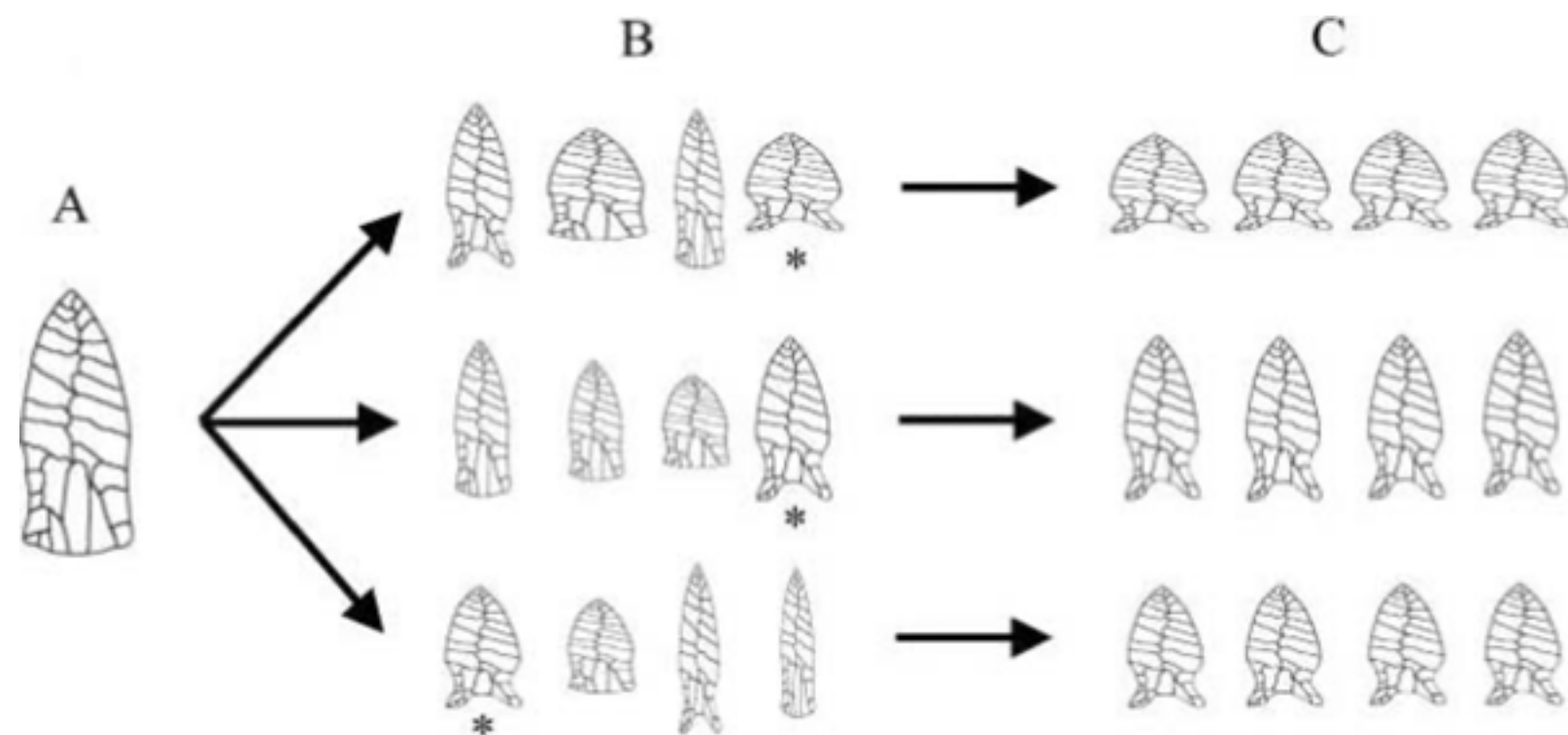
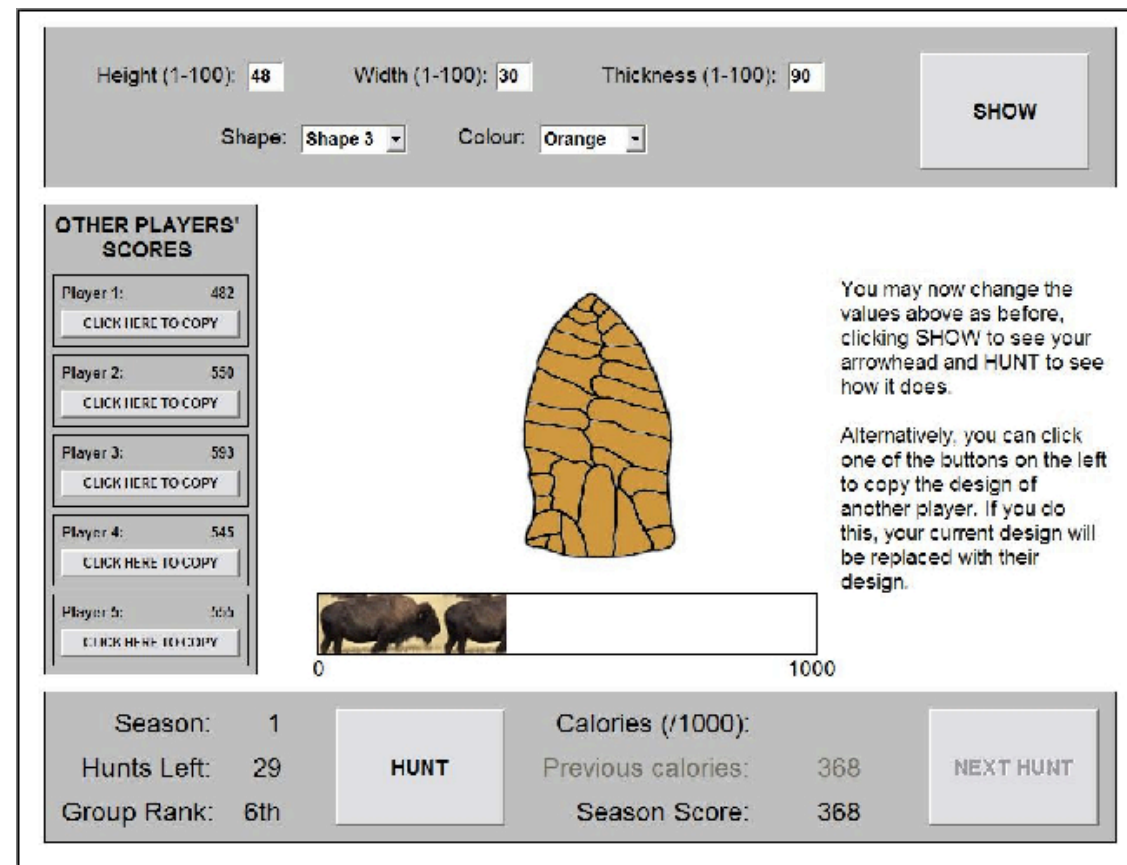
Vélez *et al.* (2023) Mentalizing regions and anterior cingulate cortex represent learners' beliefs during teaching. <https://doi.org/10.31234/osf.io/5un89>



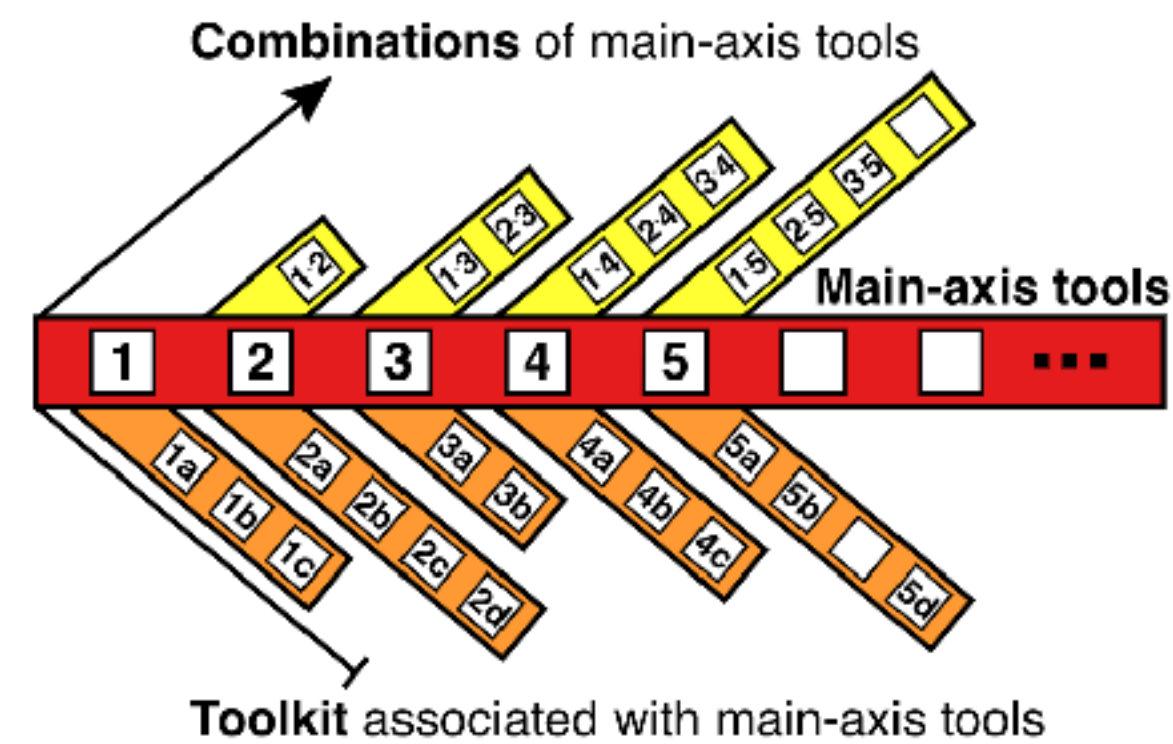
Ho *et al.* (2019). People teach with rewards and punishments as communication, not reinforcements. *Journal of Experimental Psychology: General*, 148(3), 520–549.

# ⑧ Evolving landscape

## Cultural evolution



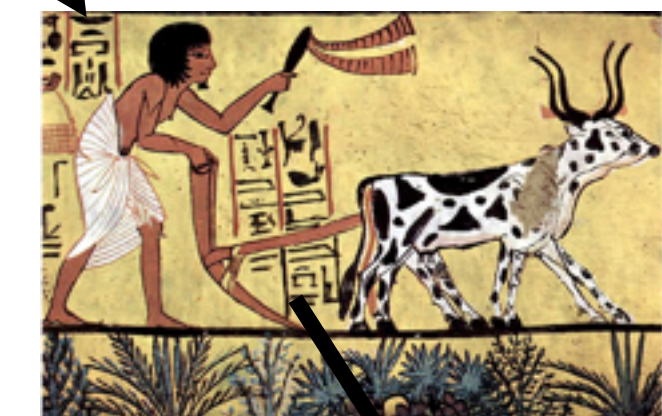
Mesoudi, A. (2011). An experimental comparison of human social learning strategies: payoff-biased social learning is adaptive but underused. *Evolution and Human Behavior*, 32(5), 334-342.



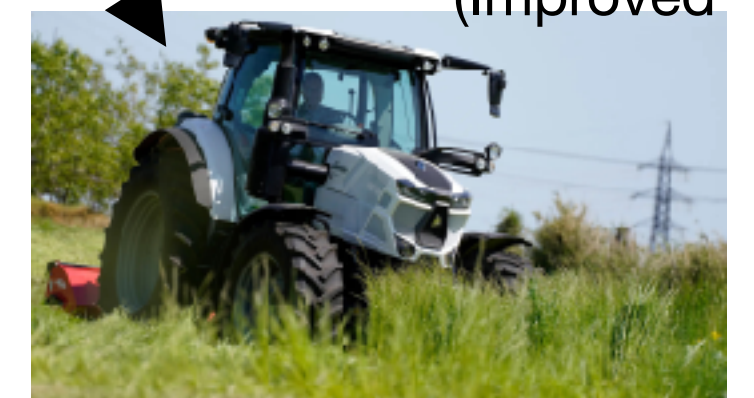
Kolodny, O., Creanza, N., & Feldman, M. W. (2015). Evolution in leaps: the punctuated accumulation and loss of cultural innovations. *Proceedings of the National Academy of Sciences*, 112(49), E6762-E6769.



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



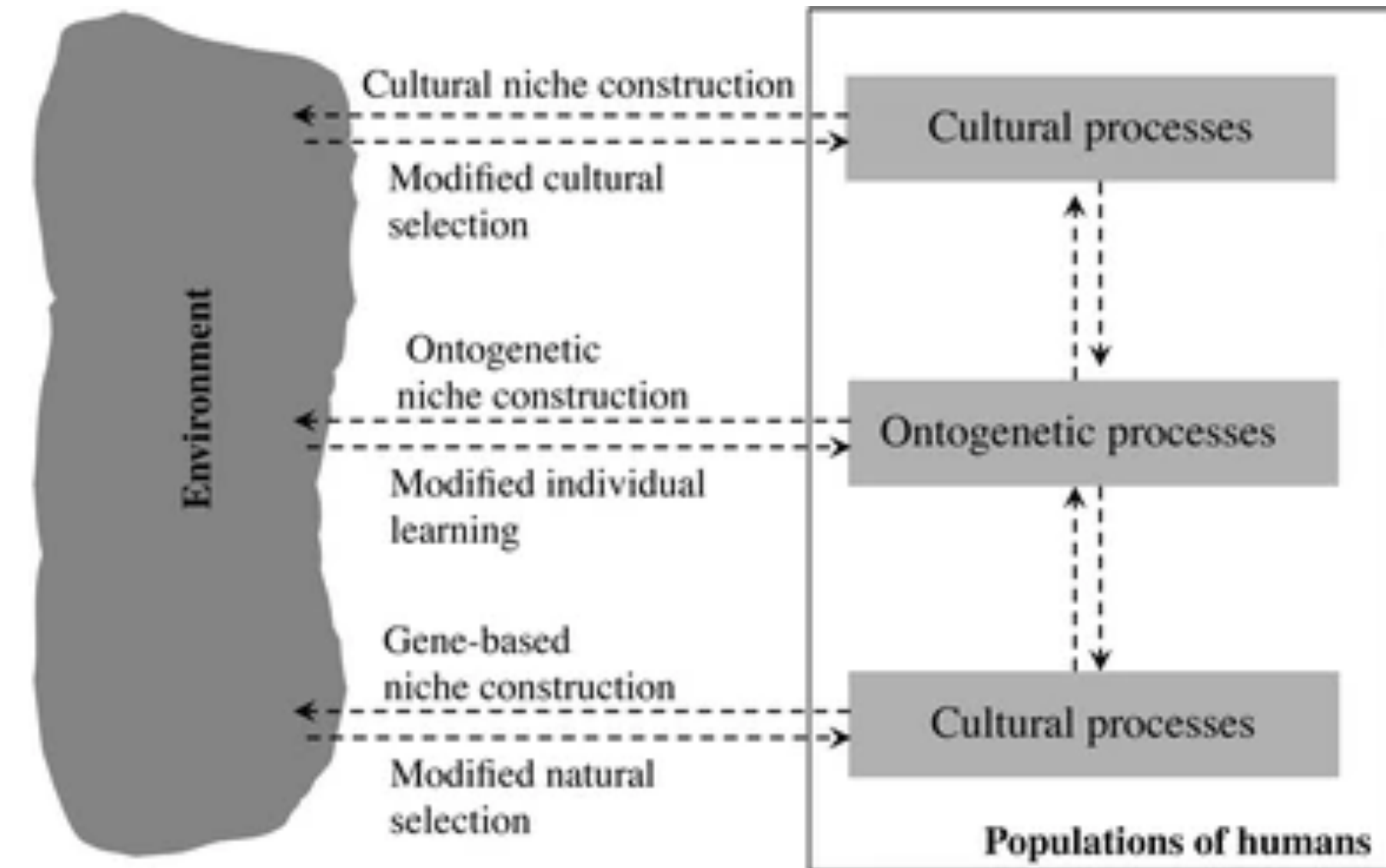
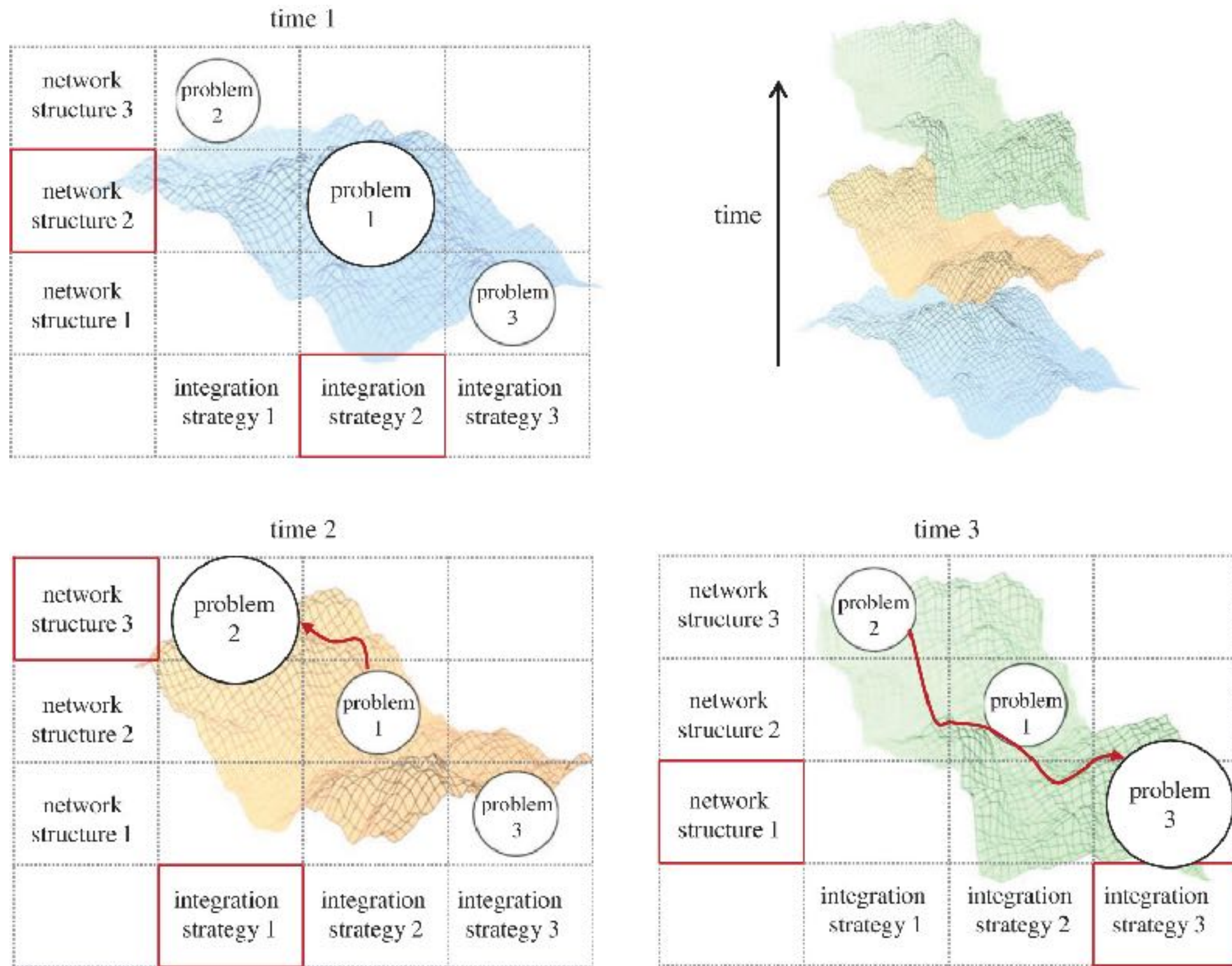
High-level tech  
(Improved "arm")



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

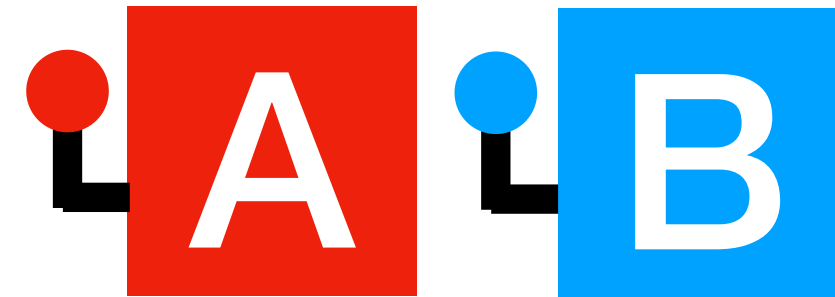


Galesic, M., Barkoczi, D., Berdahl, A. M., Biro, D., Carbone, G., Giannoccaro, I., ... & Stein, D. L. (2023). Beyond collective intelligence: Collective adaptation. *Journal of the Royal Society Interface*, 20(200), 20220736.

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

# A galaxy of social learning problems

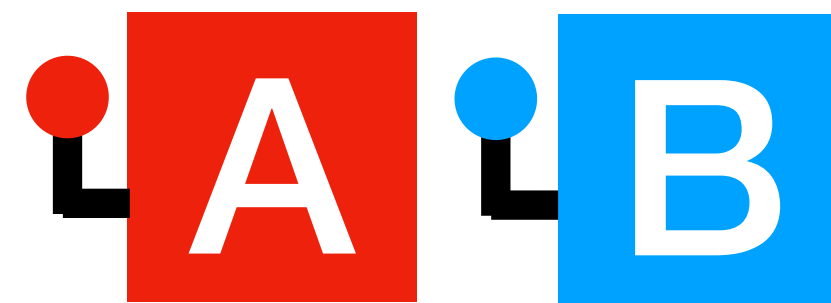
## ① Multi-armed Bandit





# A galaxy of social learning problems

## ① Multi-armed Bandit



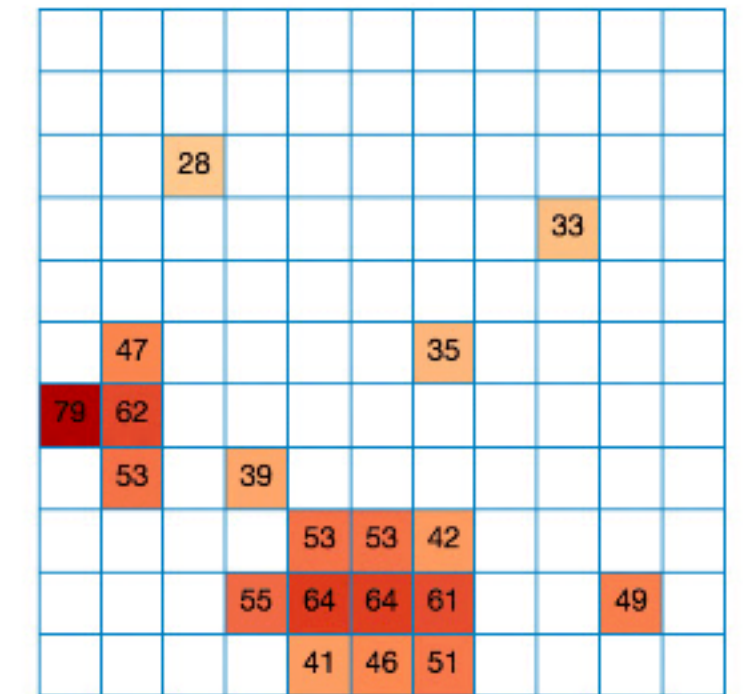
Spatial structure

## ② Spatially correlated bandit

Current Score: 2400

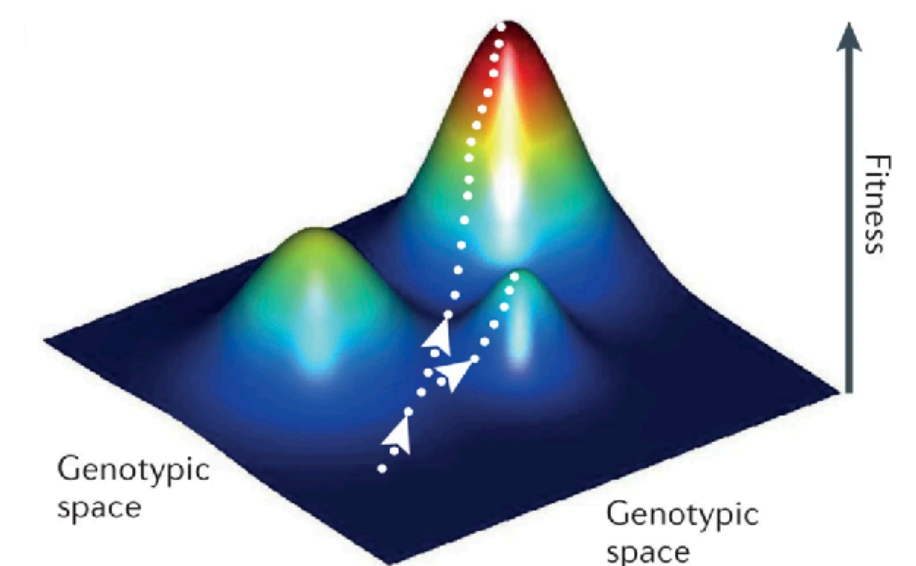
Number of grids left: 5

Number of clicks left: 1



High/Abstract Dims

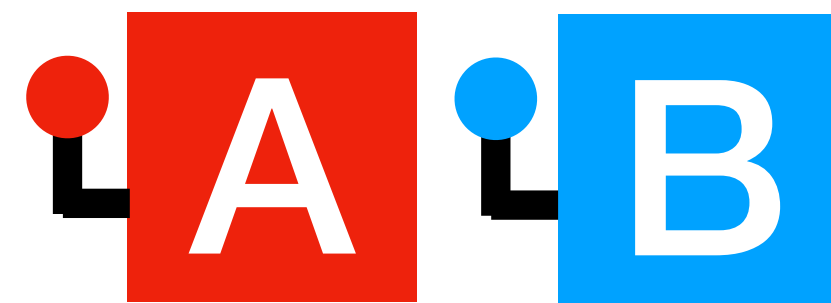
## ③ Fitness landscape





# A galaxy of social learning problems

## ① Multi-armed Bandit



Spatial structure

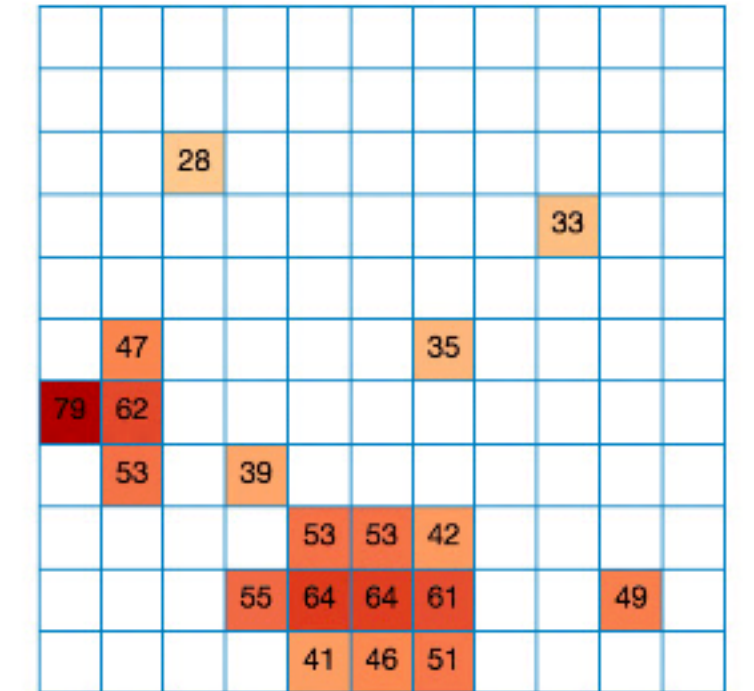


## ② Spatially correlated bandit

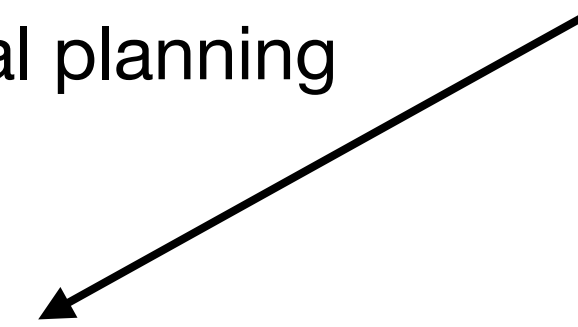
Current Score: 2400

Number of grids left: 5

Number of clicks left: 1



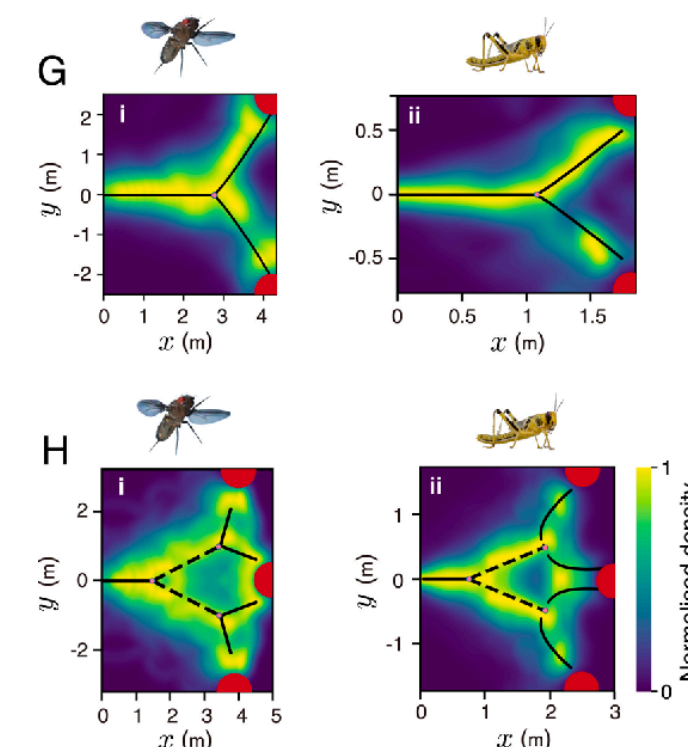
Sequential planning



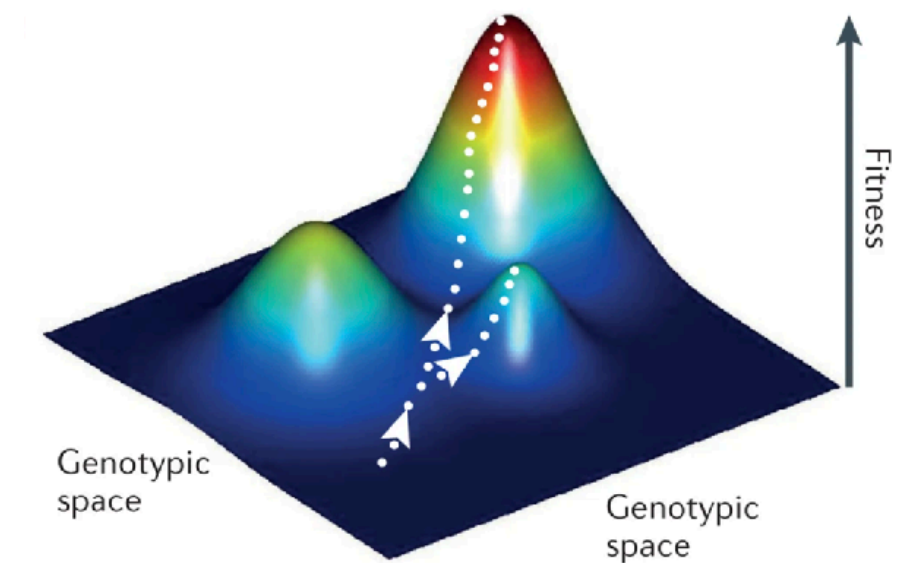
High/Abstract Dims



## ④ Spatial navigation



## ③ Fitness landscape



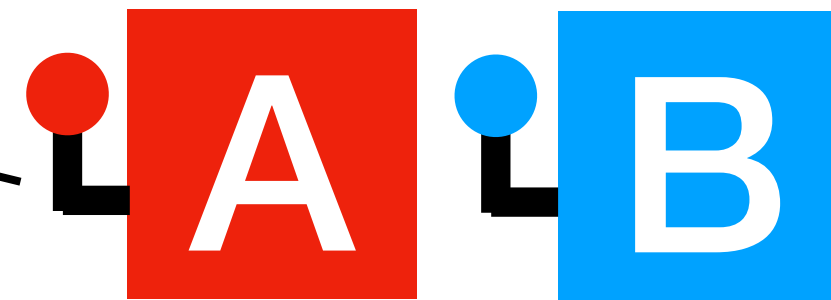
# A galaxy of social learning problems

## ⑤ Social Foraging



Competing interests  
Depleting rewards  
Individual differences

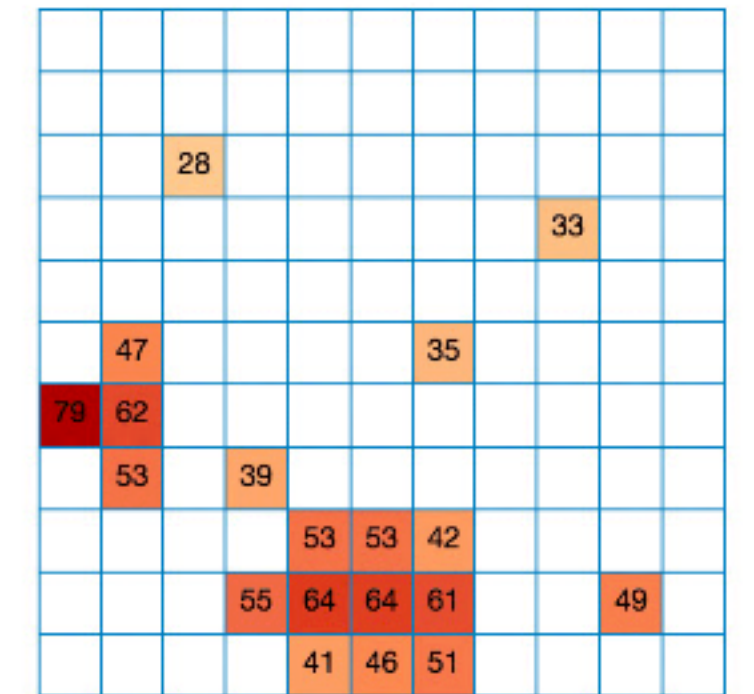
## ① Multi-armed Bandit



Spatial structure

## ② Spatially correlated bandit

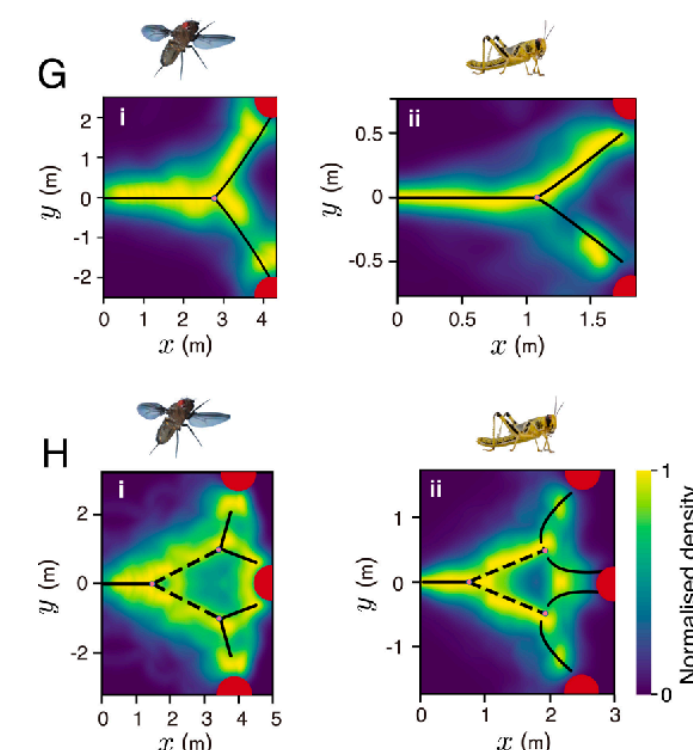
Current Score: 2400  
Number of grids left: 5  
Number of clicks left: 1



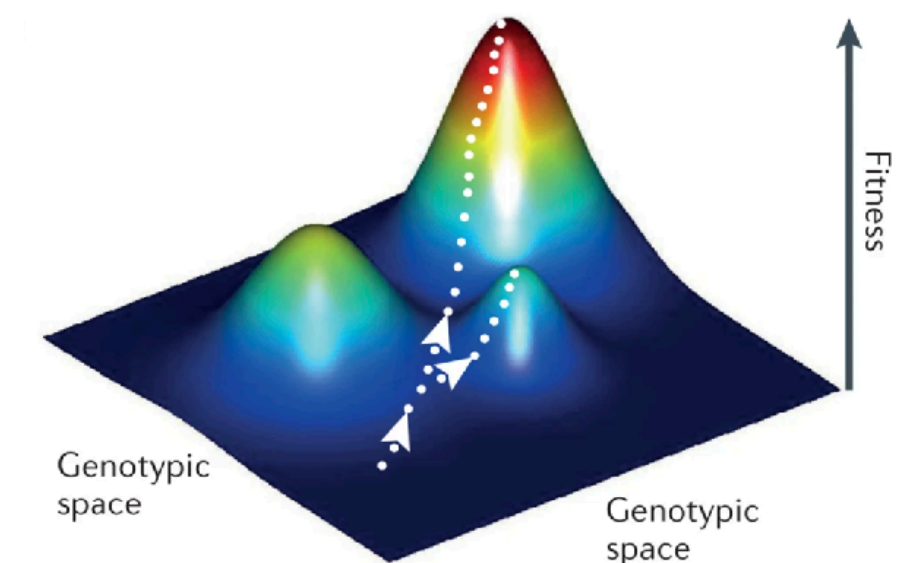
Sequential planning

High/Abstract Dims

## ④ Spatial navigation



## ③ Fitness landscape



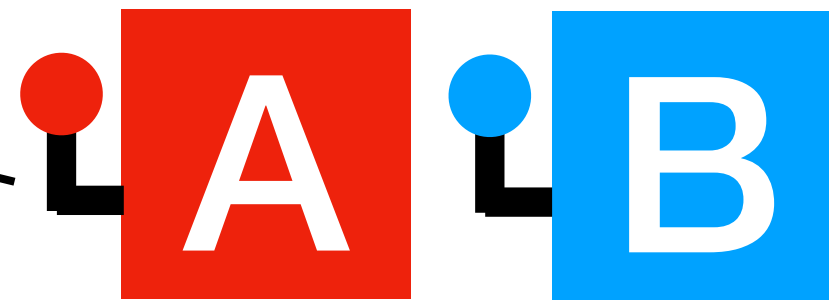
# A galaxy of social learning problems

## ⑤ Social Foraging



Competing interests  
Depleting rewards  
Individual differences

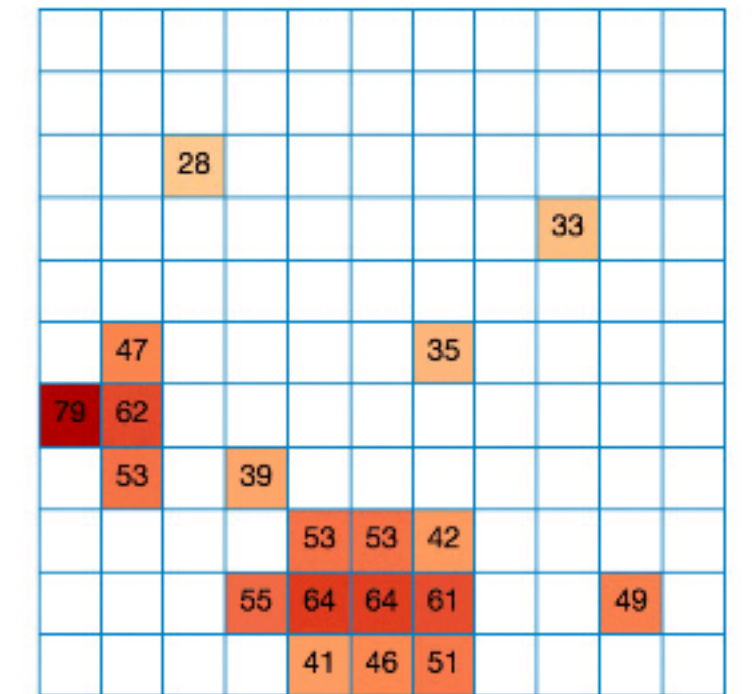
## ① Multi-armed Bandit



Spatial structure

## ② Spatially correlated bandit

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

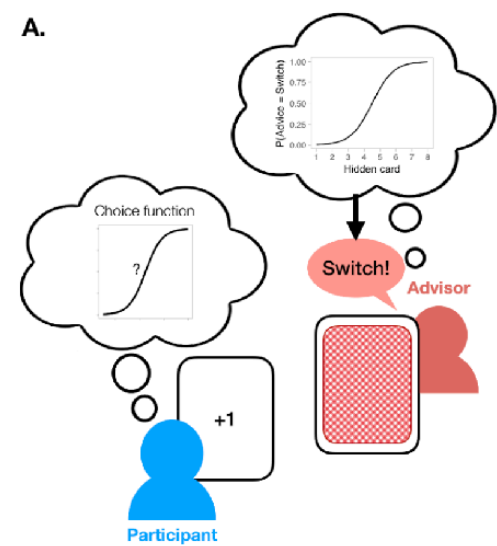


Sequential planning

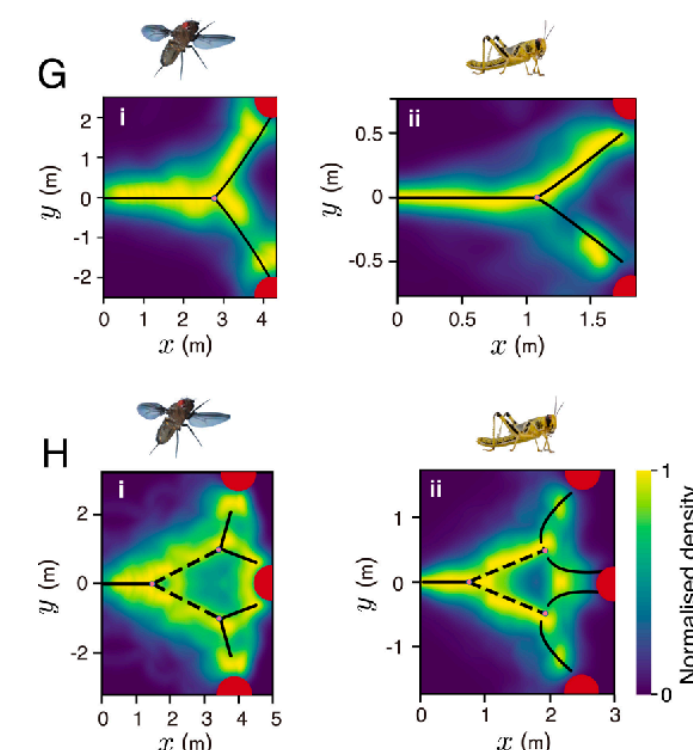
High/Abstract Dims

## ⑥ Theory of Mind

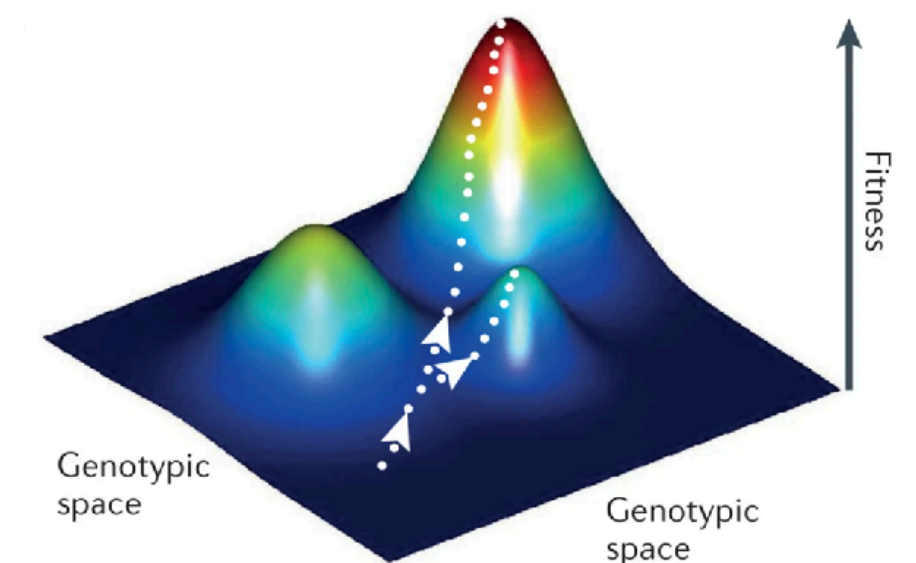
Social inference



## ④ Spatial navigation



## ③ Fitness landscape



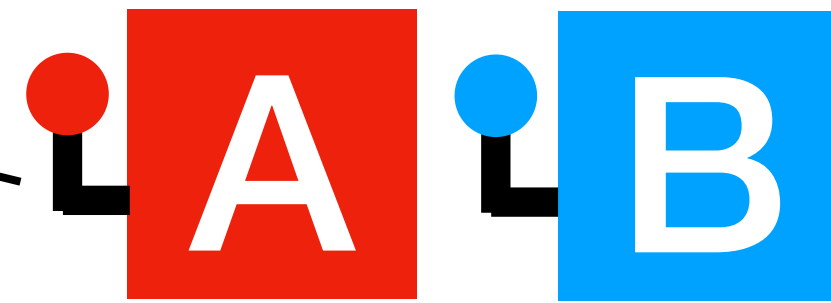
# A galaxy of social learning problems

## ⑤ Social Foraging



Competing interests  
Depleting rewards  
Individual differences

## ① Multi-armed Bandit



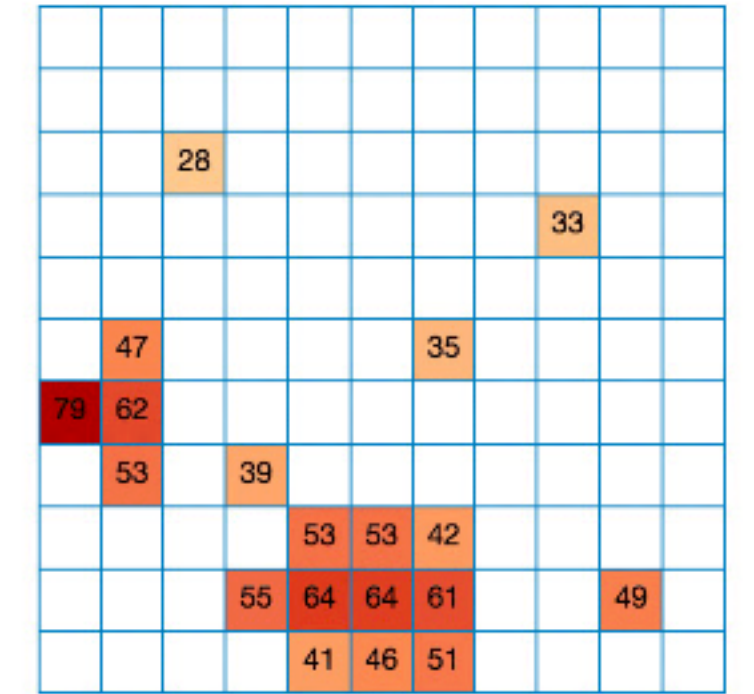
Spatial structure

## ② Spatially correlated bandit

Current Score: 2400

Number of grids left: 5

Number of clicks left: 1

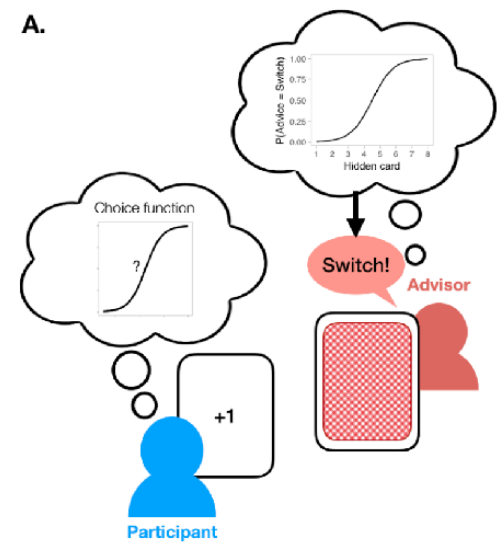


Sequential planning

High/Abstract Dims

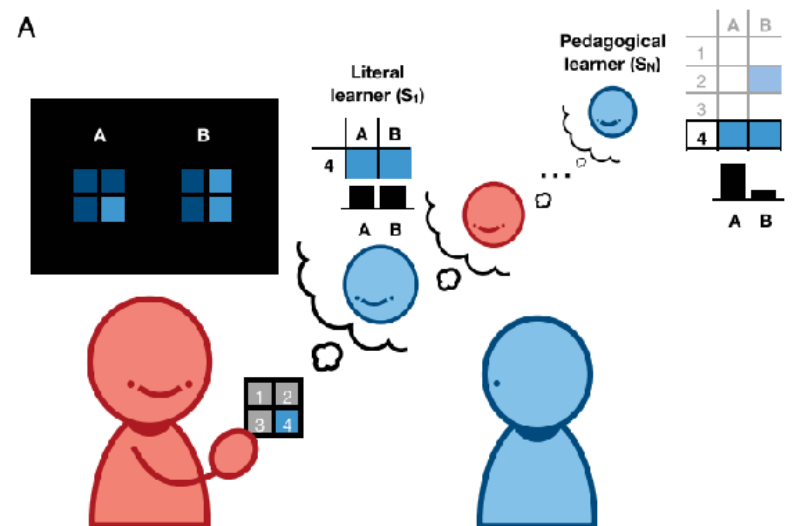
## ⑥ Theory of Mind

Social inference

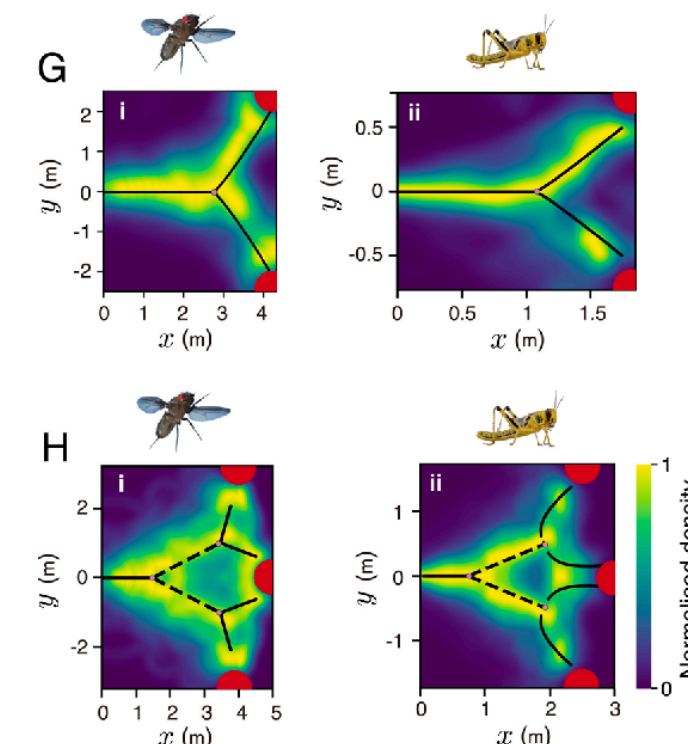


Pedagogy

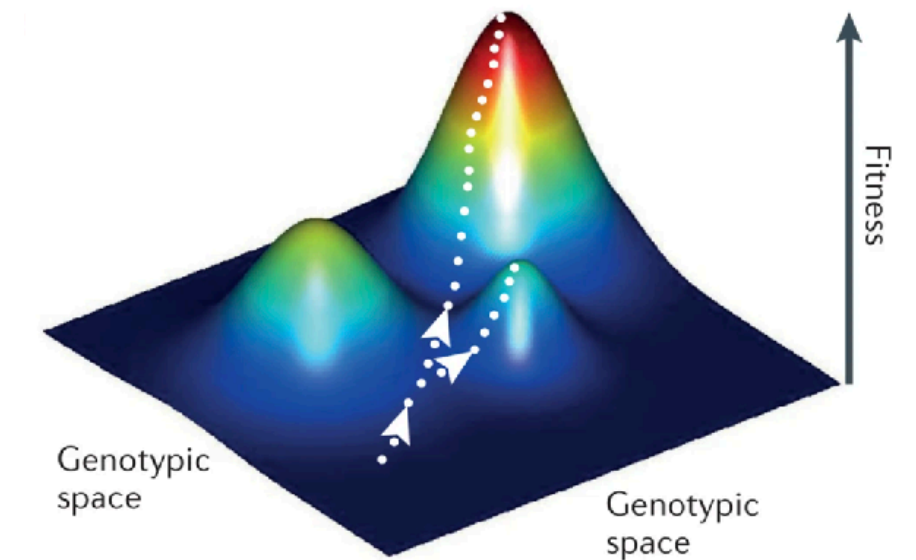
## ⑦ Teaching and advice giving



## ④ Spatial navigation



## ③ Fitness landscape



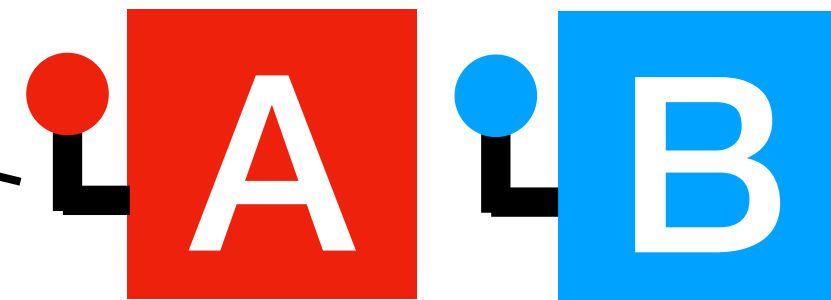
# A galaxy of social learning problems

## ⑤ Social Foraging



Competing interests  
Depleting rewards  
Individual differences

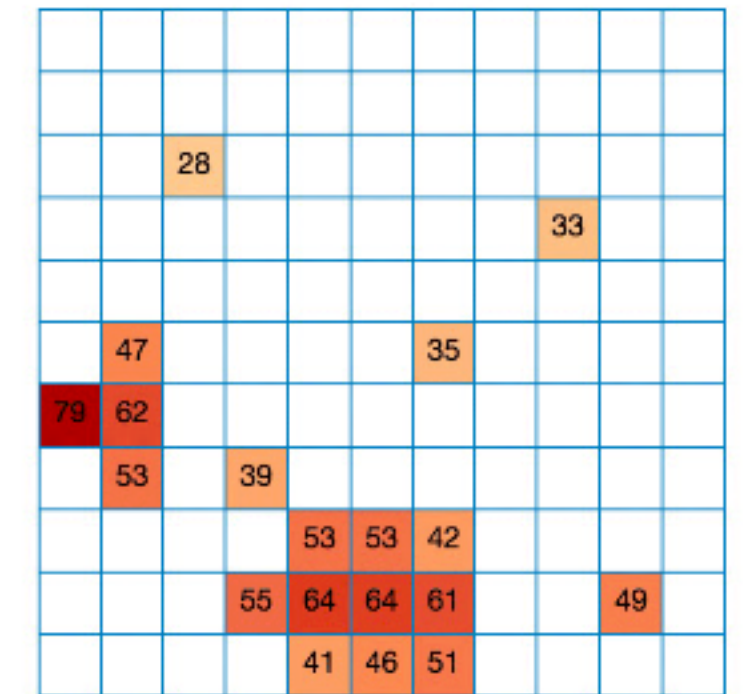
## ① Multi-armed Bandit



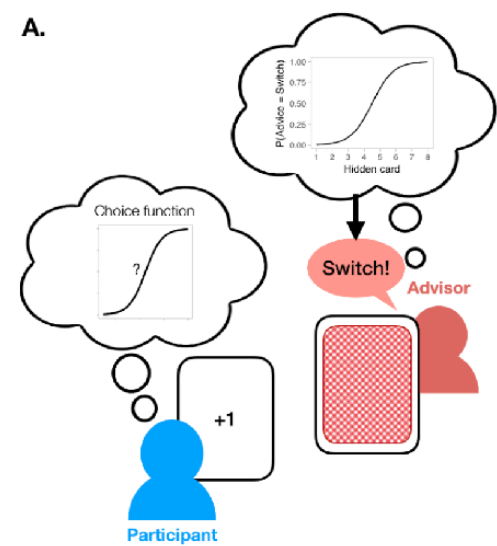
Spatial structure

## ② Spatially correlated bandit

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



## ⑥ Theory of Mind



Social inference

Cultural evolution

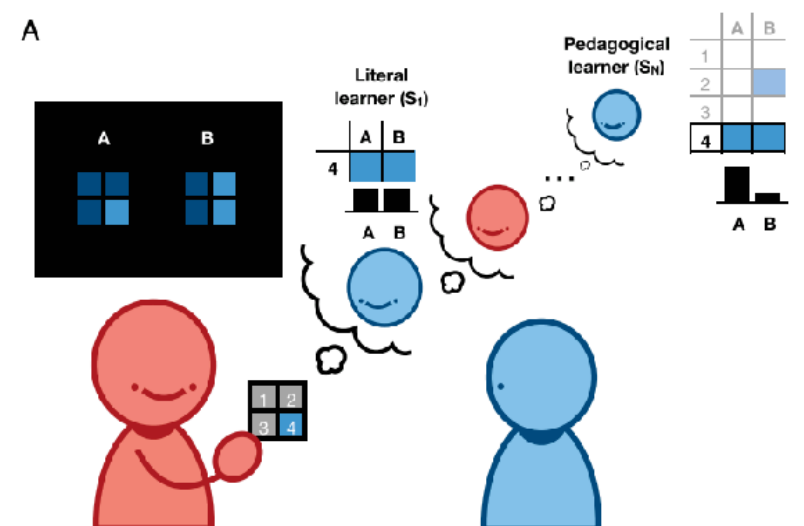
Niche construction

Sequential planning

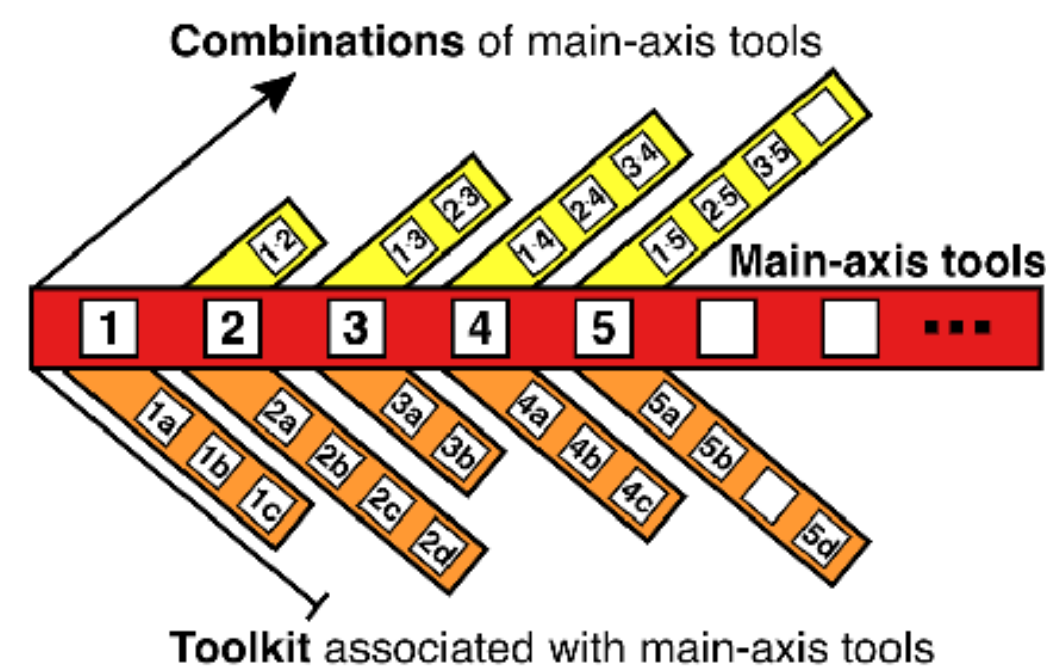
High/Abstract Dims

Pedagogy

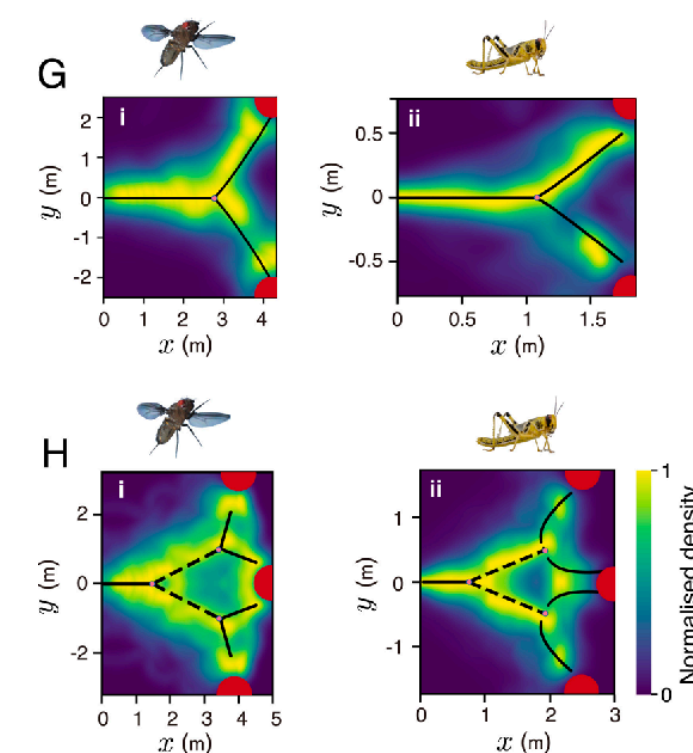
## ⑦ Teaching and advice giving



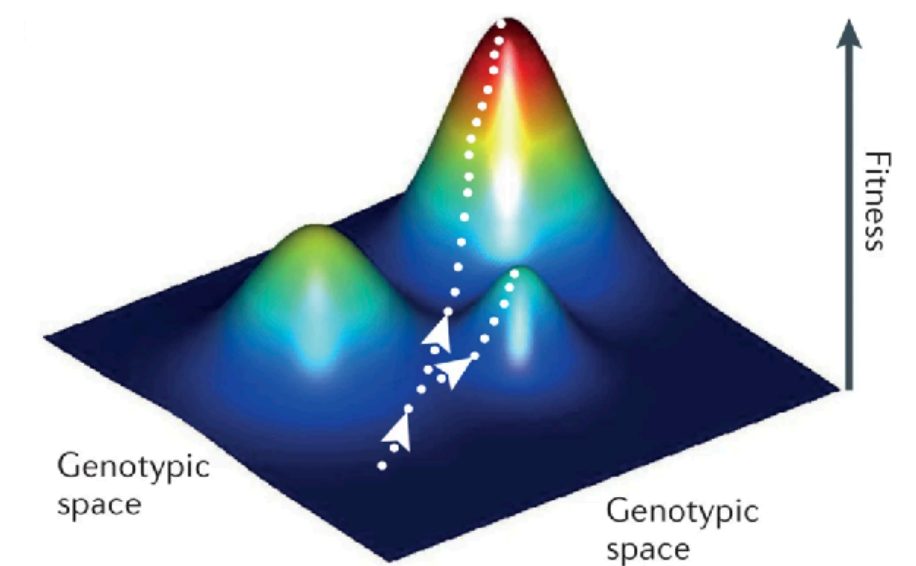
## ⑧ Evolving landscape



## ④ Spatial navigation



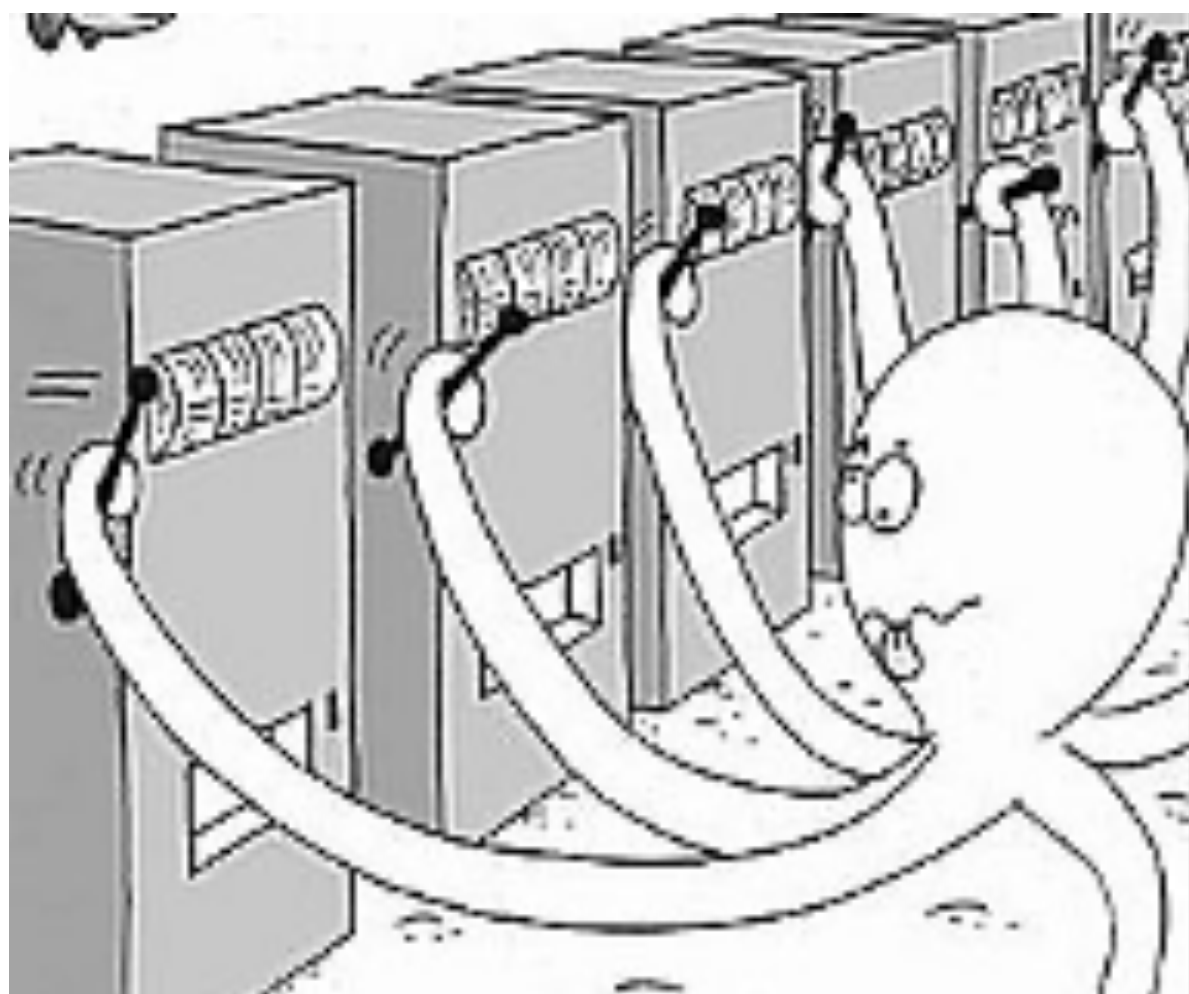
## ③ Fitness landscape



# Multi-Armed Bandit Problem

# Multi-armed bandit problem

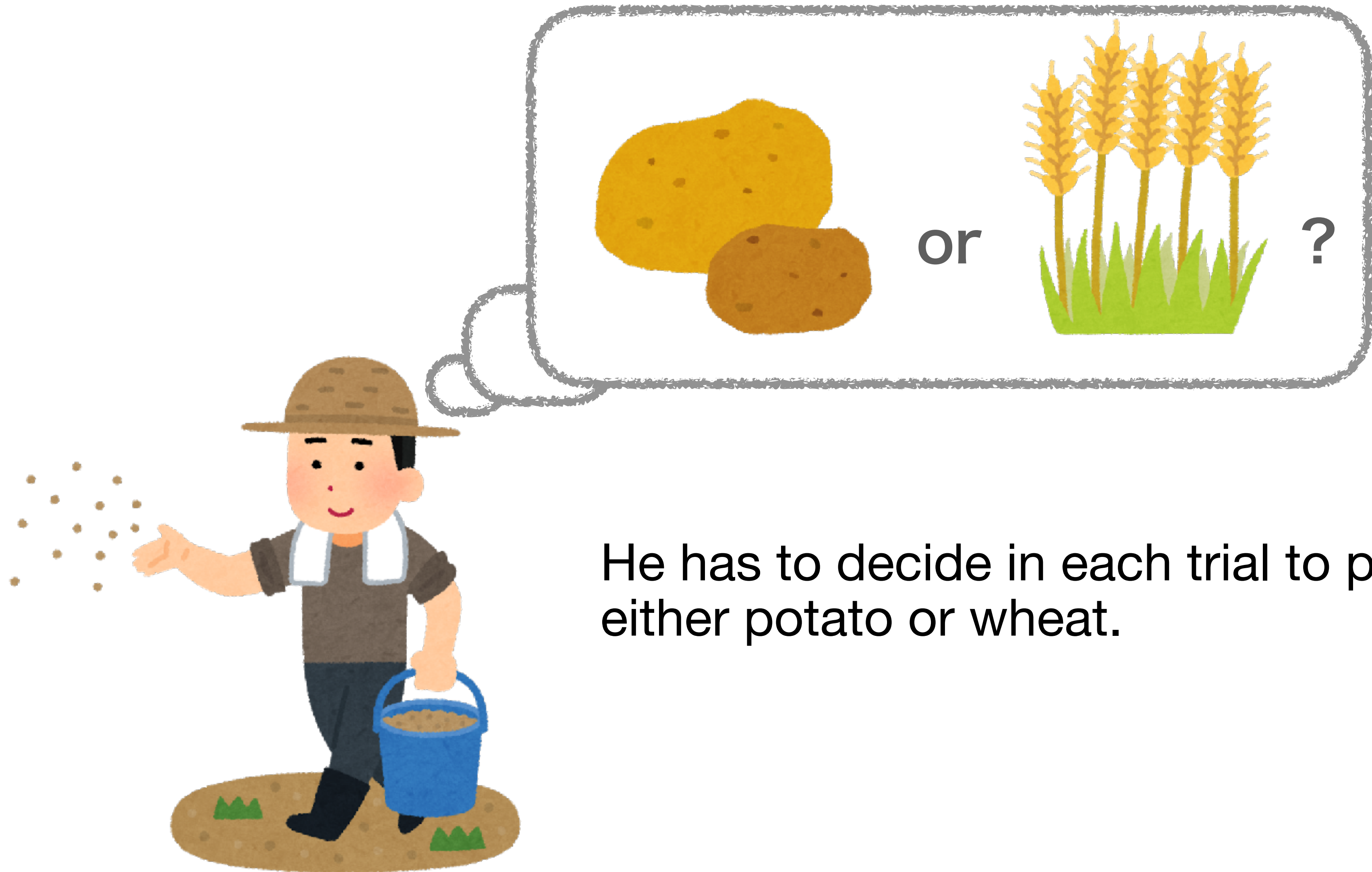
A simple model of the experience-based decision-making situations



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

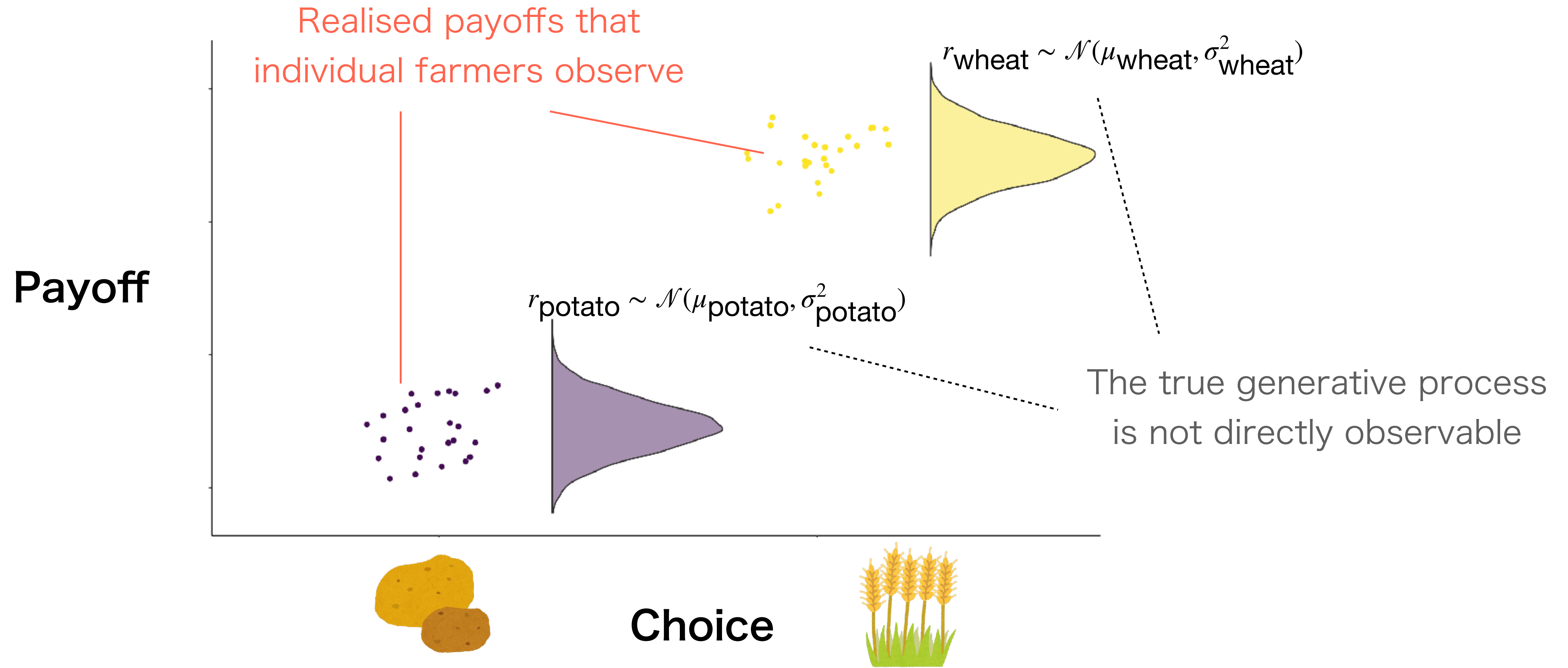
(McElreath et al., 2005; 2008; Deffner et al. 2020)



# Rewards drawn from a normal distribution

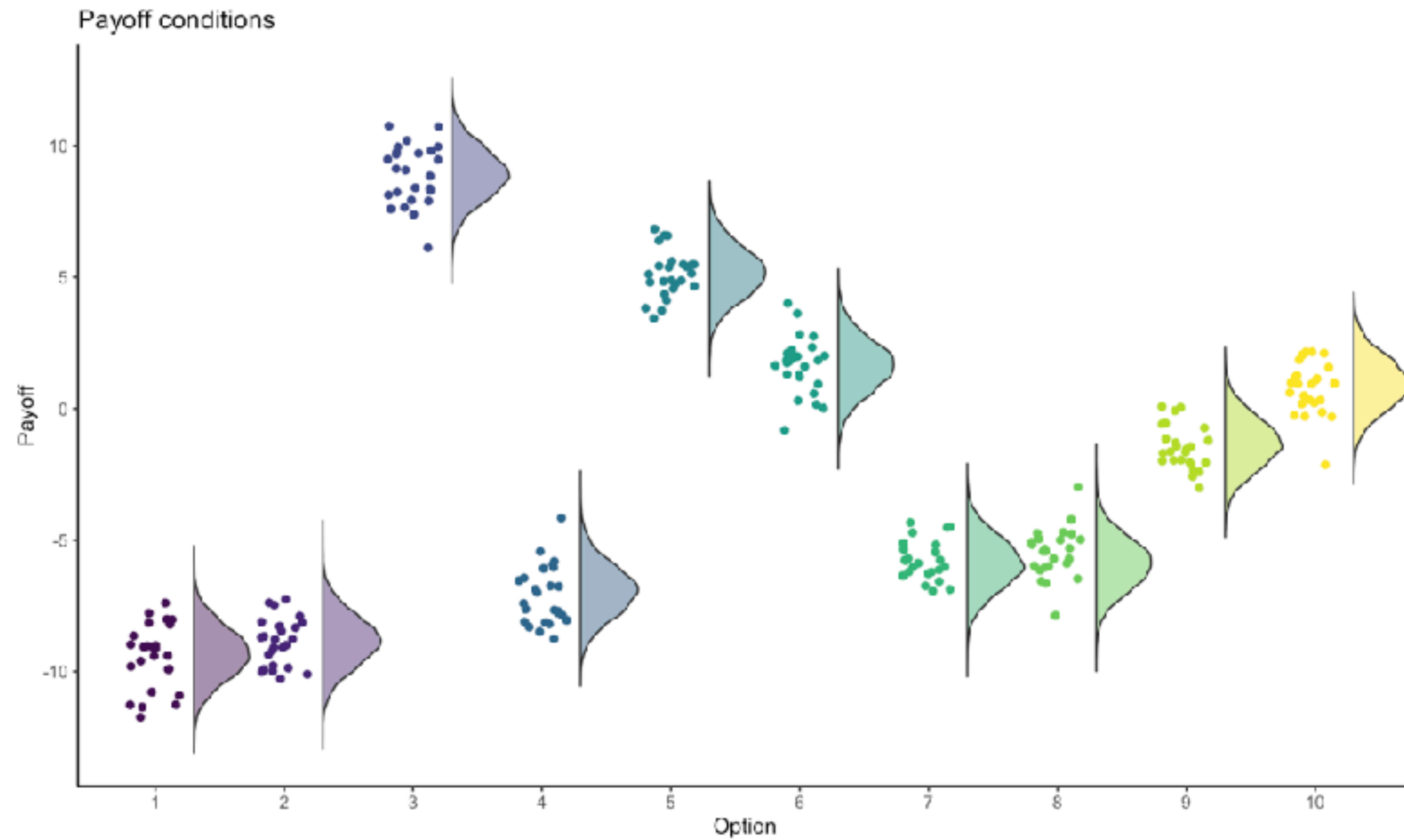


# Rewards drawn from a normal distribution

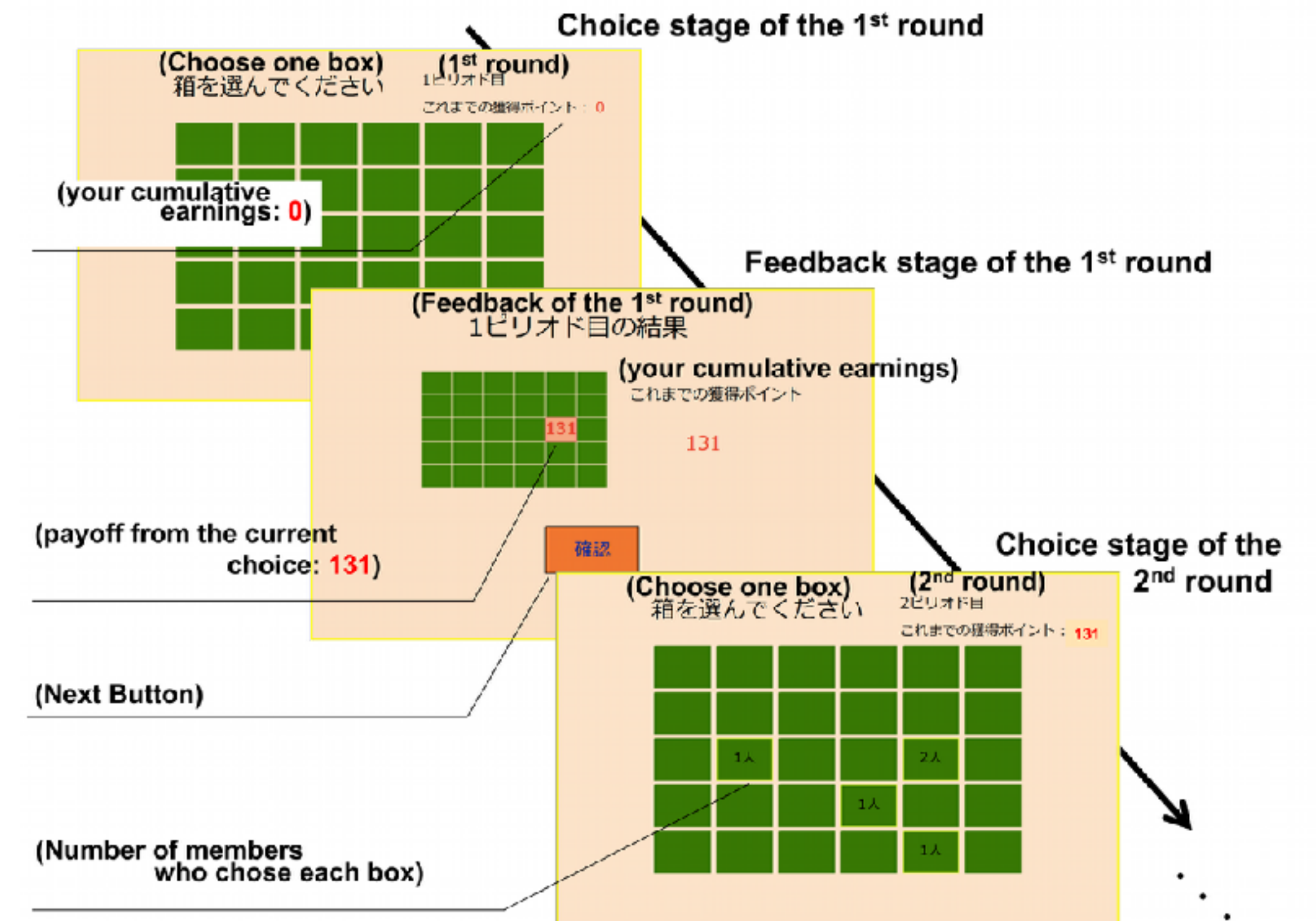


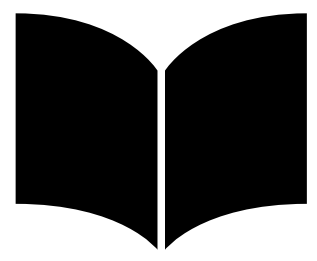
# Scaling up

## 10-armed bandit



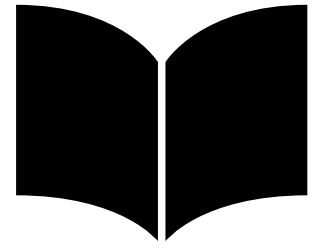
## 30-armed bandit (Toyokawa et al. 2014)





## Live demonstration Fishing game!

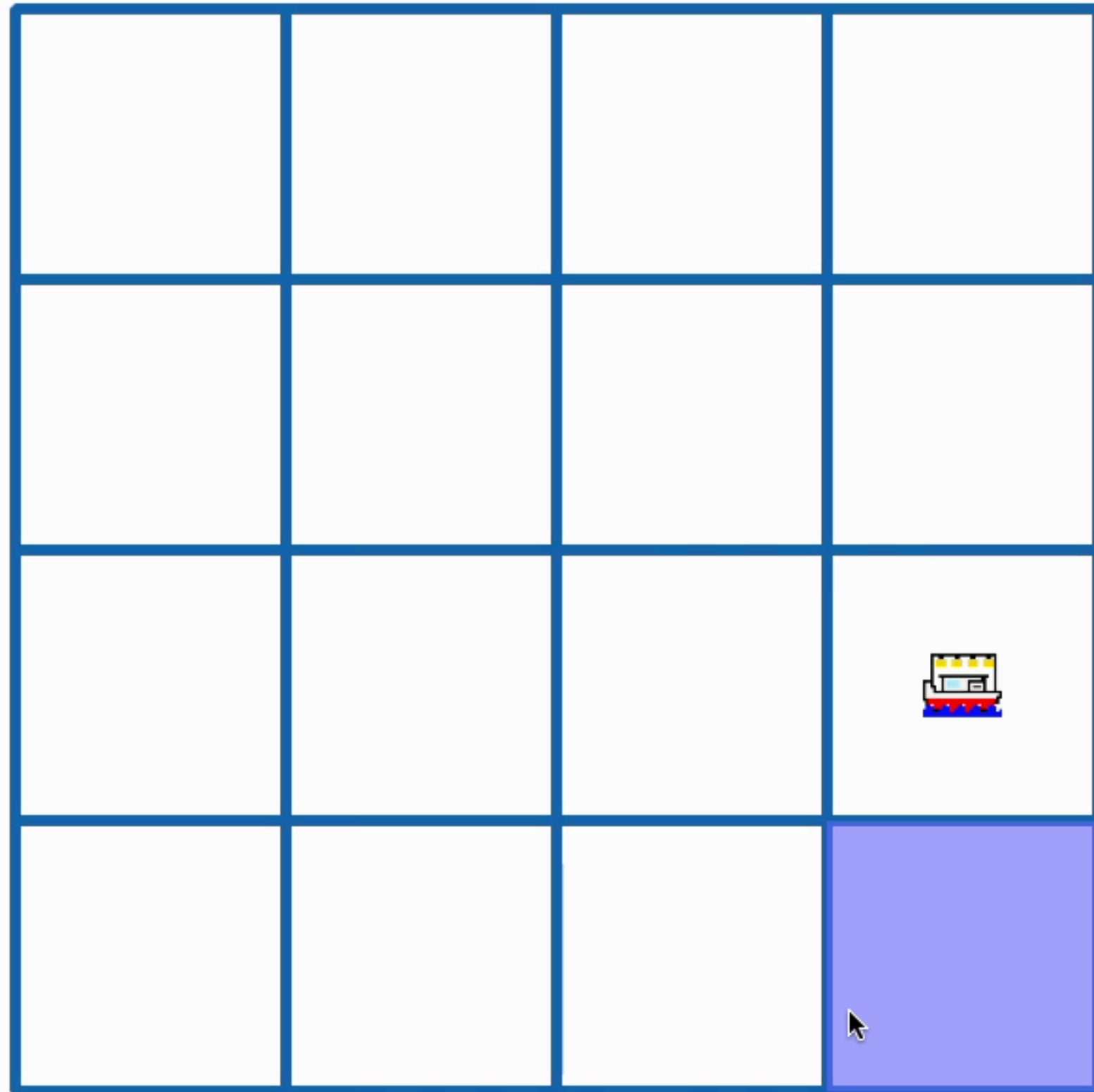




# Notebook

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

## (1) Individual learning task

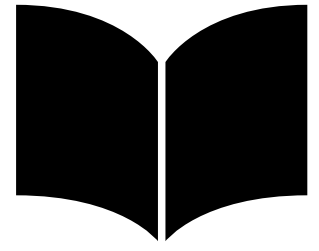


Remaining clicks: 10



Q:

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



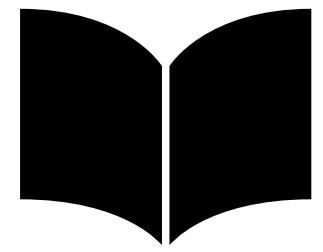
## (1) Individual learning task



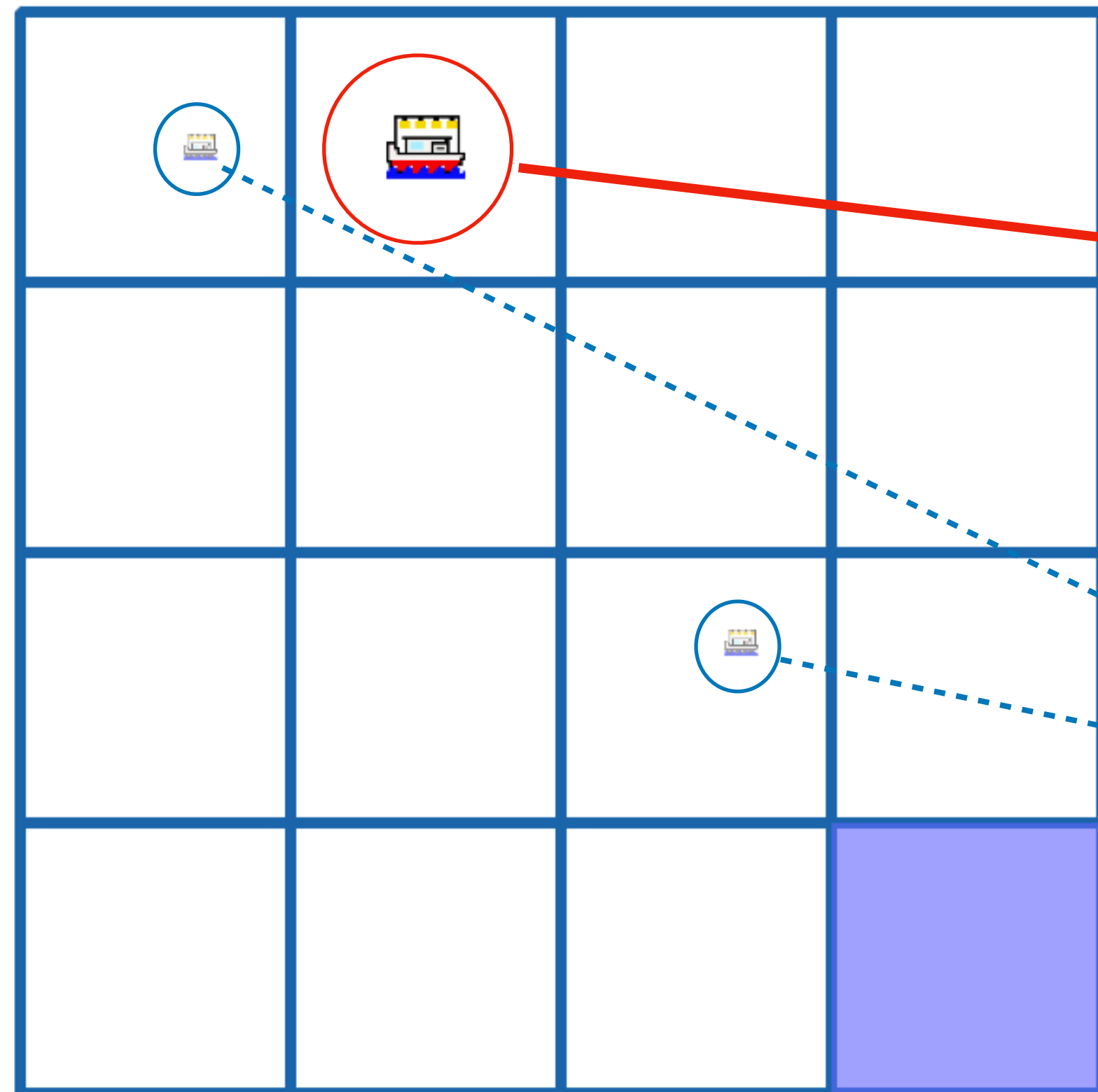
Remaining clicks: 10

Q:

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



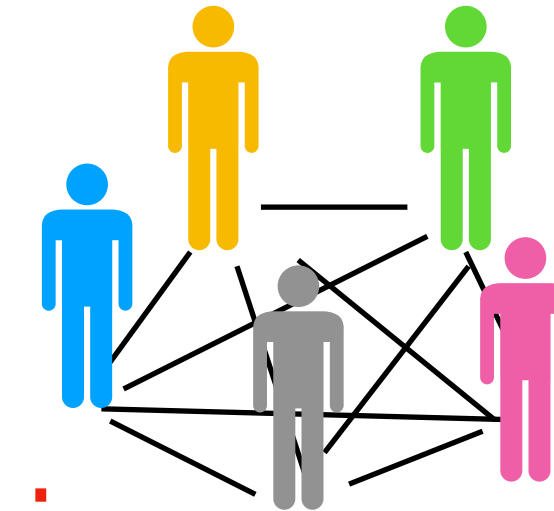
## (2) Social learning task (no competition)



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?

Remaining clicks: 9



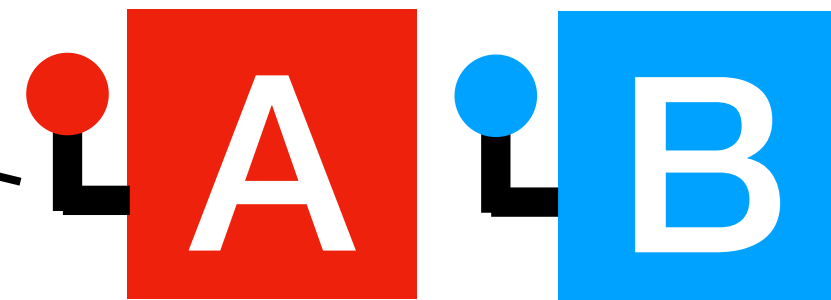
# What problems are outside this framework?

## ⑤ Social Foraging



Competing interests  
Depleting rewards  
Individual differences

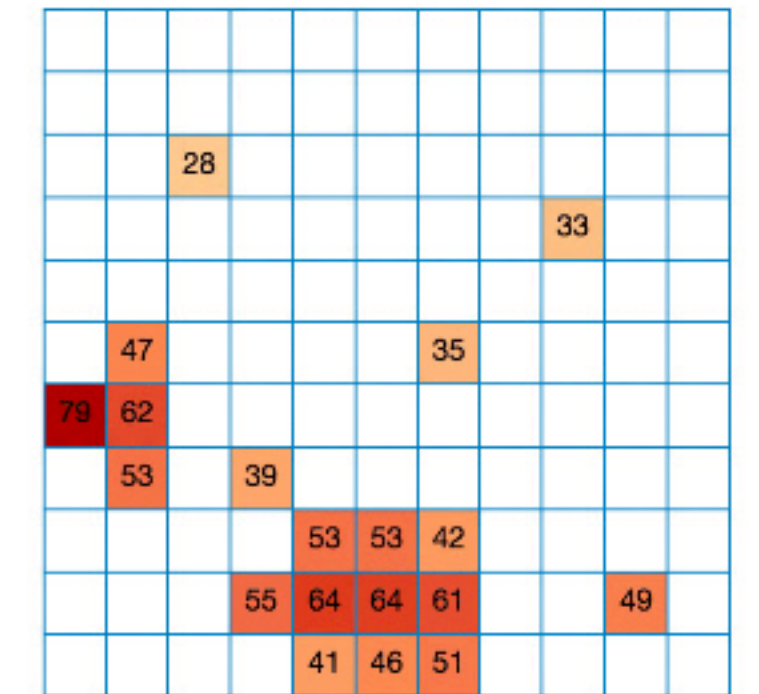
## ① Multi-armed Bandit



Spatial structure

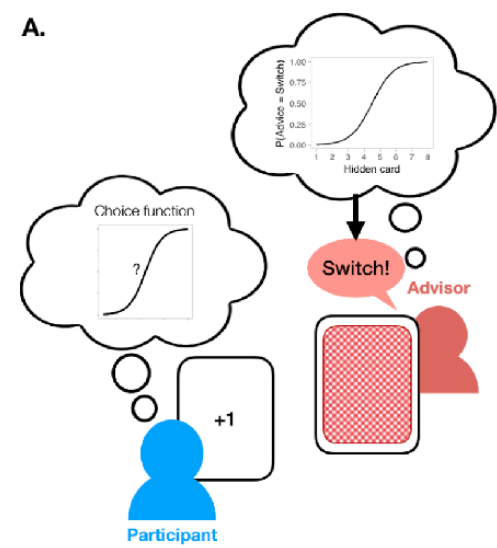
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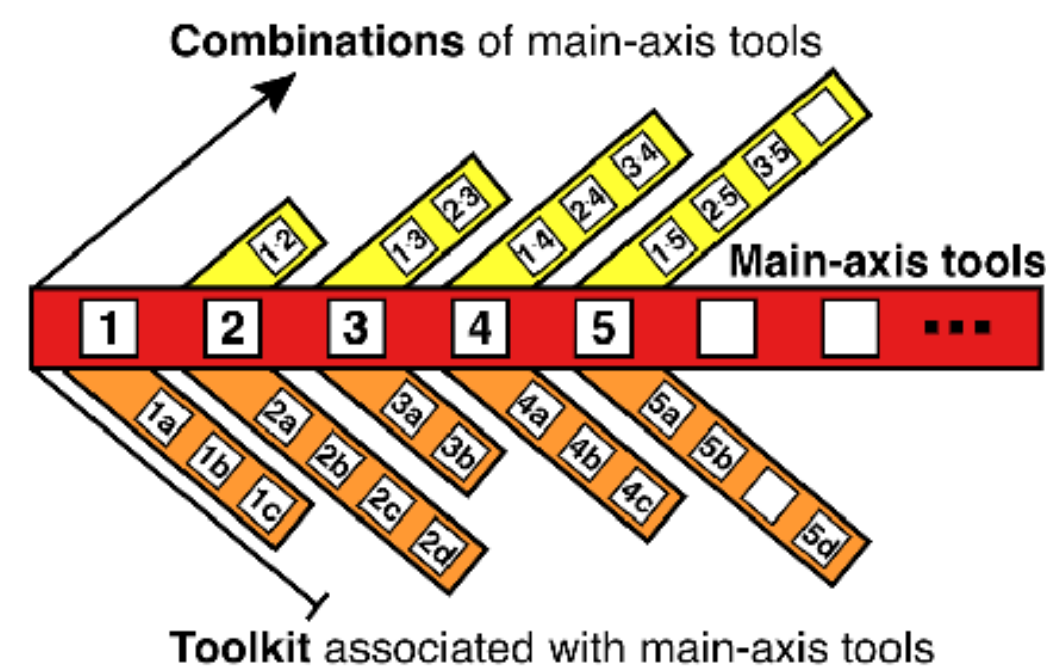
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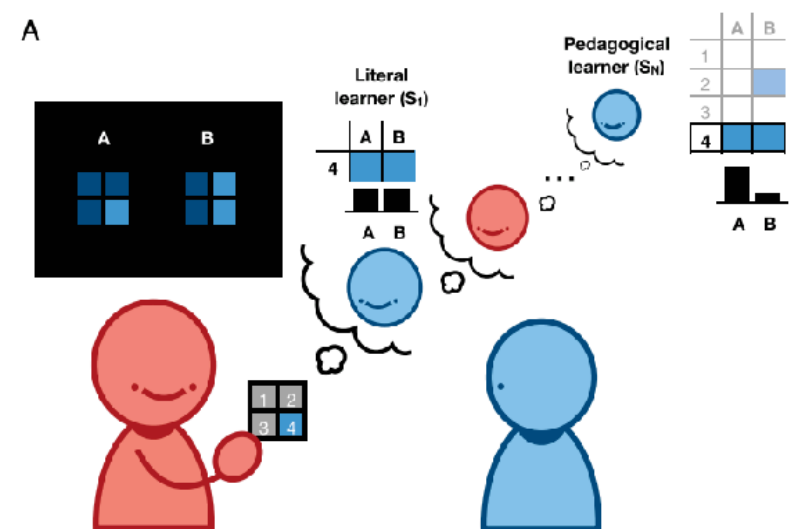
High/Abstract Dims

Pedagogy

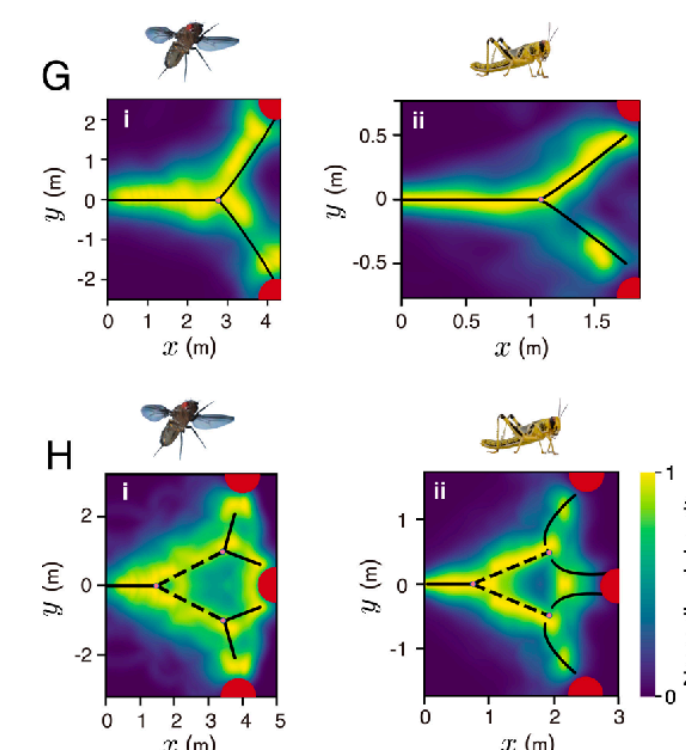
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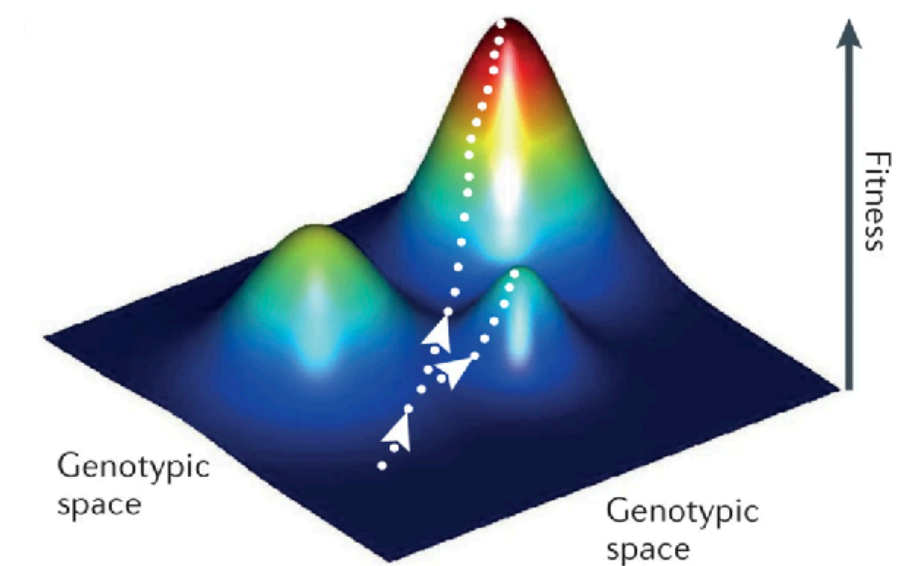
## ⑦ Teaching and advice giving



## 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