

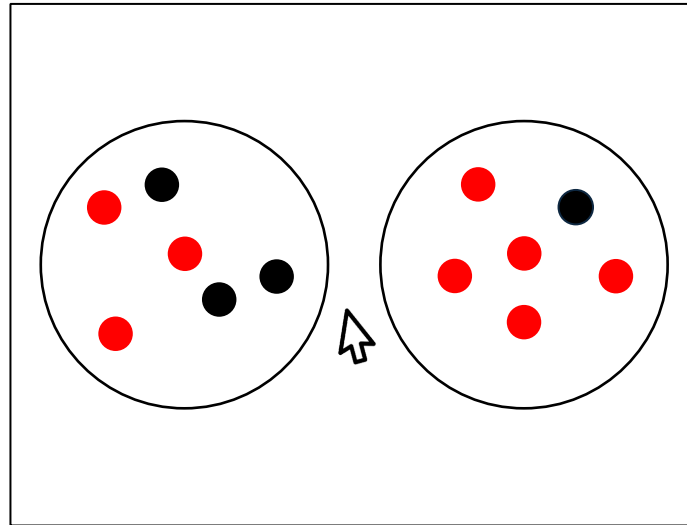


Discovering Predictive and Interpretable Models of Decision-Making via Hybrid Neural Networks and Symbolic Regression

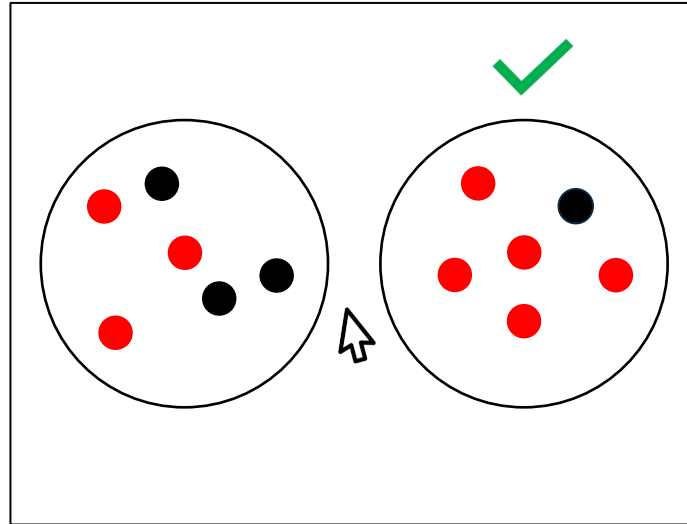
Simone D'Ambrogio Jan Grohn Nima Khalighinejad Marcelo Matter Laurence Hunt Matthew Rushworth

PsicoStat
9th May 2025

Information Sampling Task

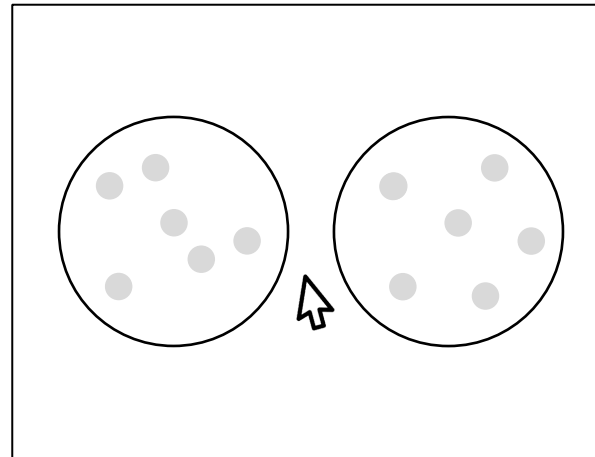
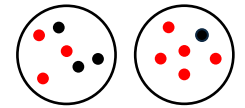


Information Sampling Task



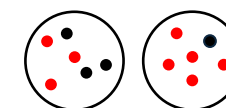
Information Sampling Task

Latent
Information

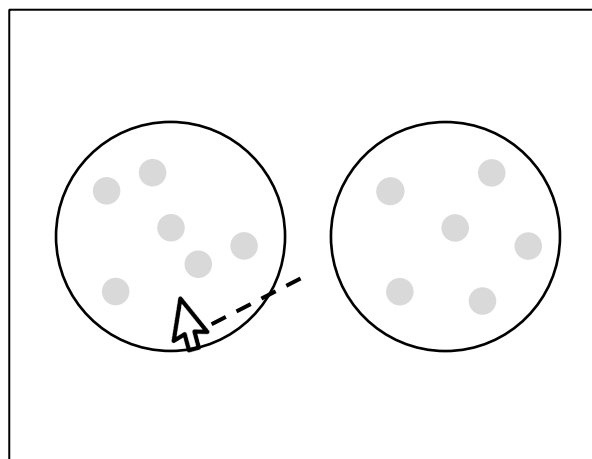


Information Sampling Task

Latent
Information

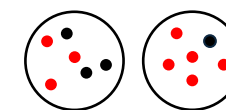


switch
wait 2s

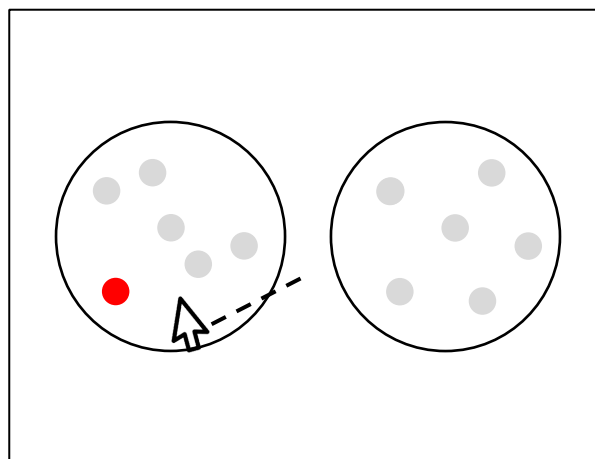


Information Sampling Task

Latent
Information

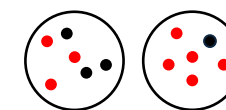


stay
wait 0.15s

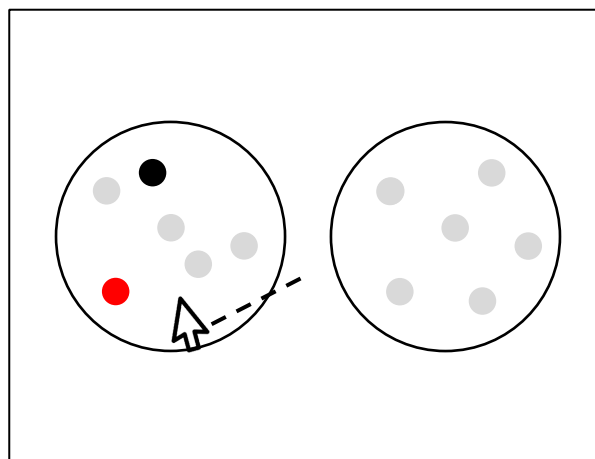


Information Sampling Task

Latent
Information

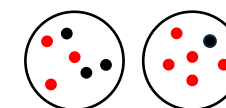


stay
wait 0.15s

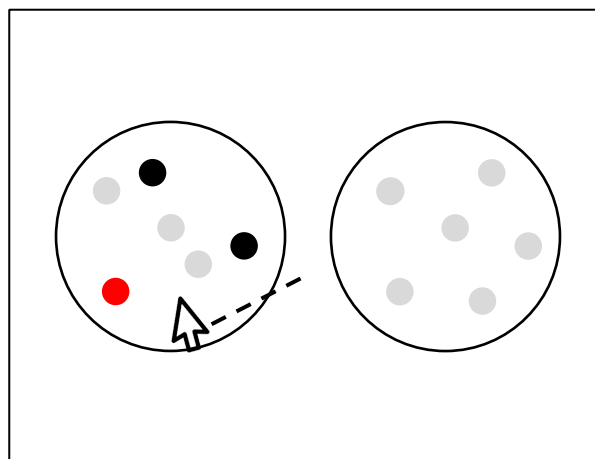


Information Sampling Task

Latent
Information

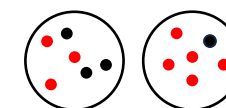


stay
wait 0.15s

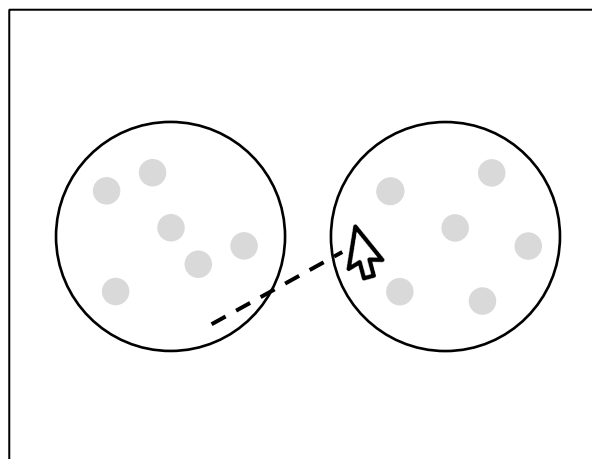


Information Sampling Task

Latent
Information

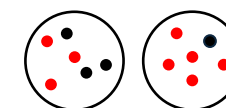


switch
wait 2s

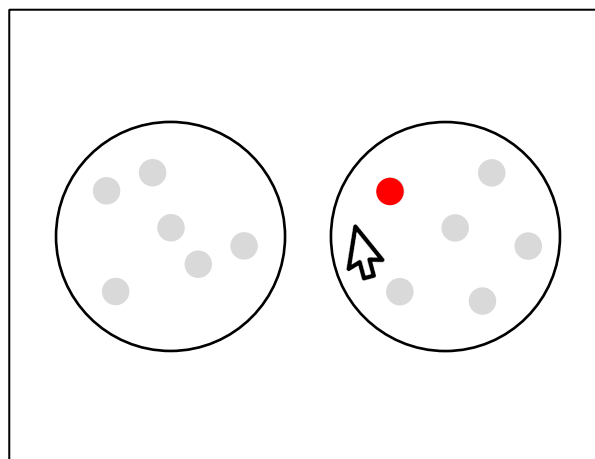


Information Sampling Task

Latent
Information

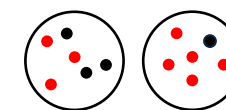


stay
wait 0.15s

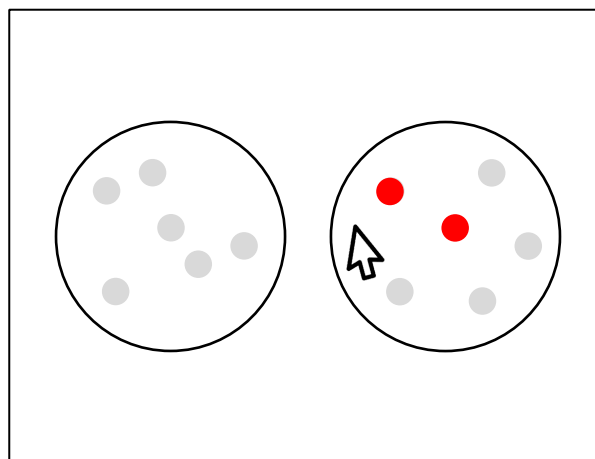


Information Sampling Task

Latent
Information

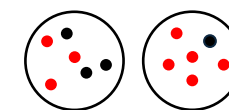


stay
wait 0.15s

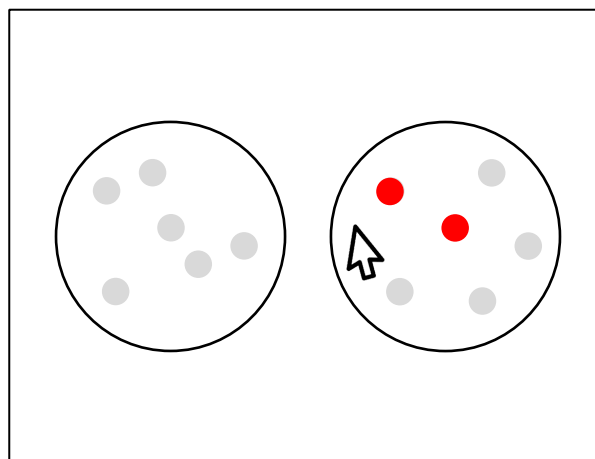


Information Sampling Task

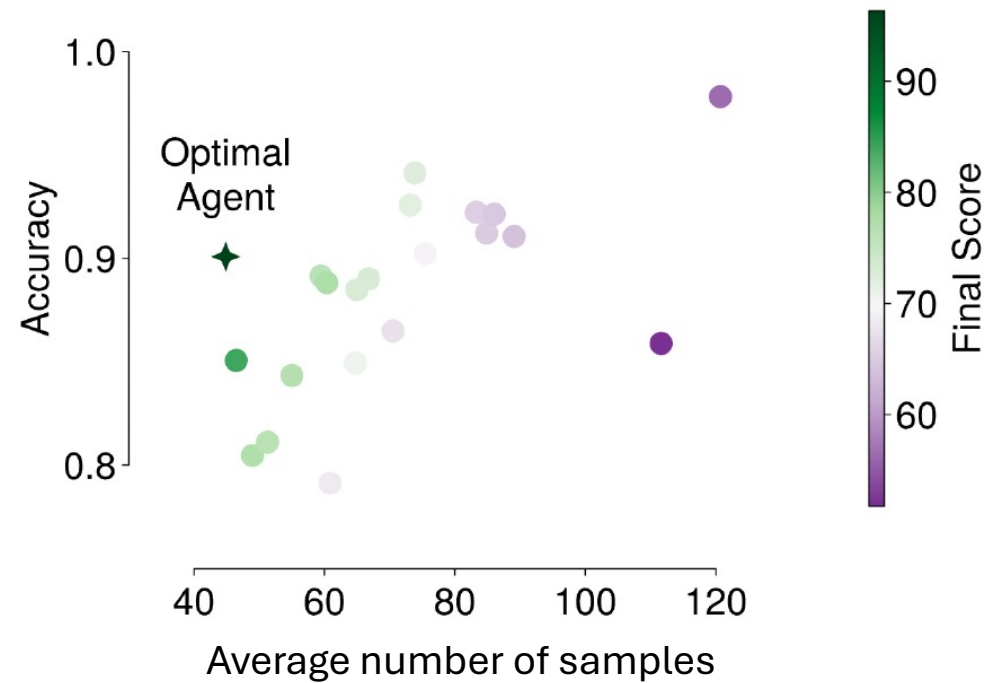
Latent
Information



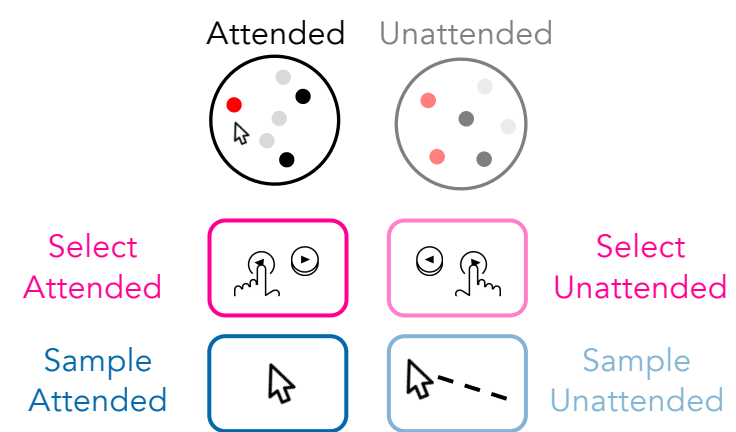
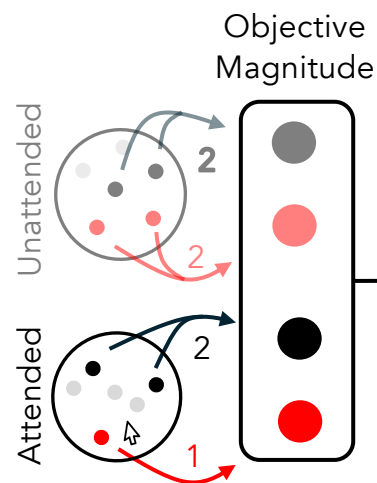
select



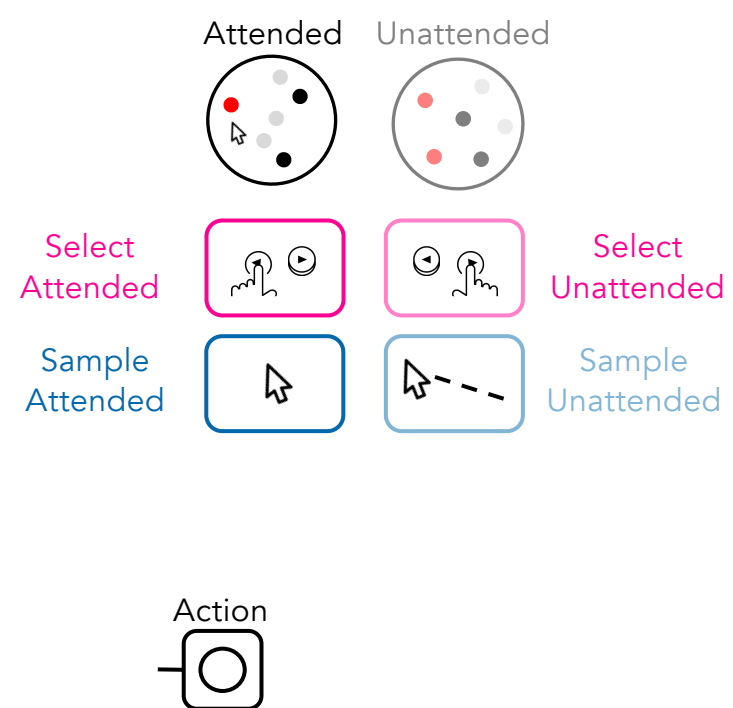
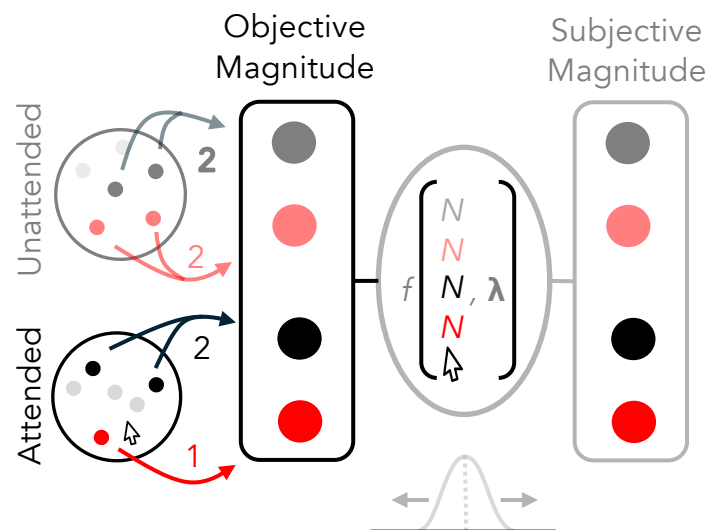
Sampling Behaviour Adaptively Scales with Task Difficulty and Uncertainty



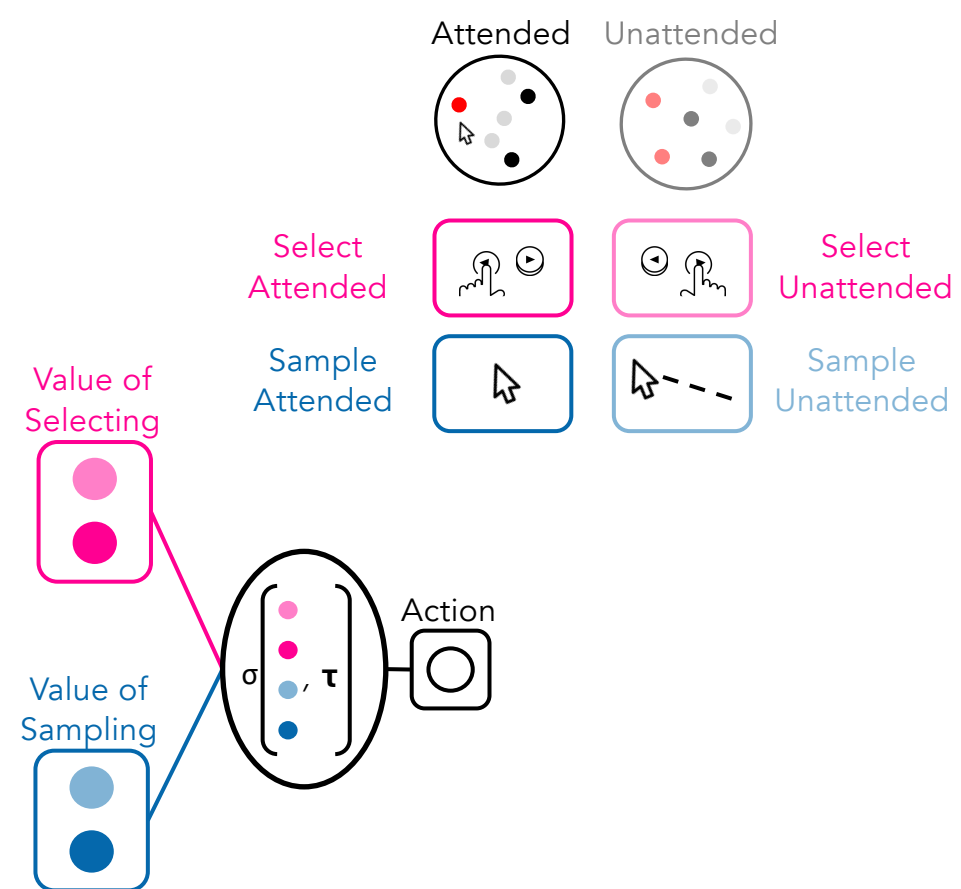
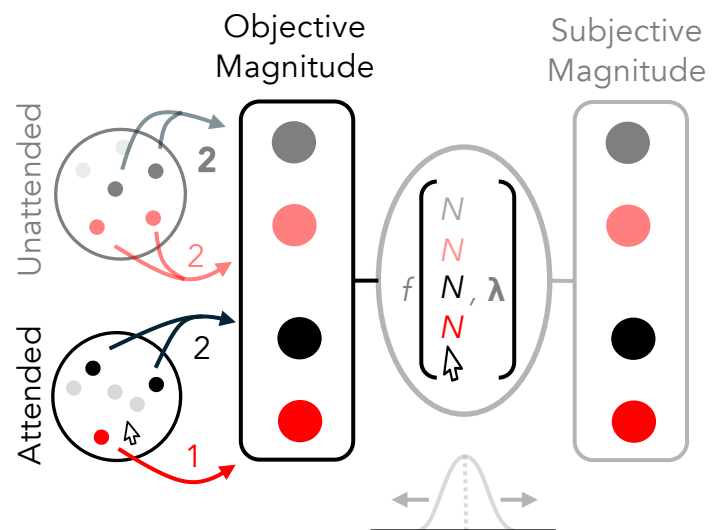
Computational process



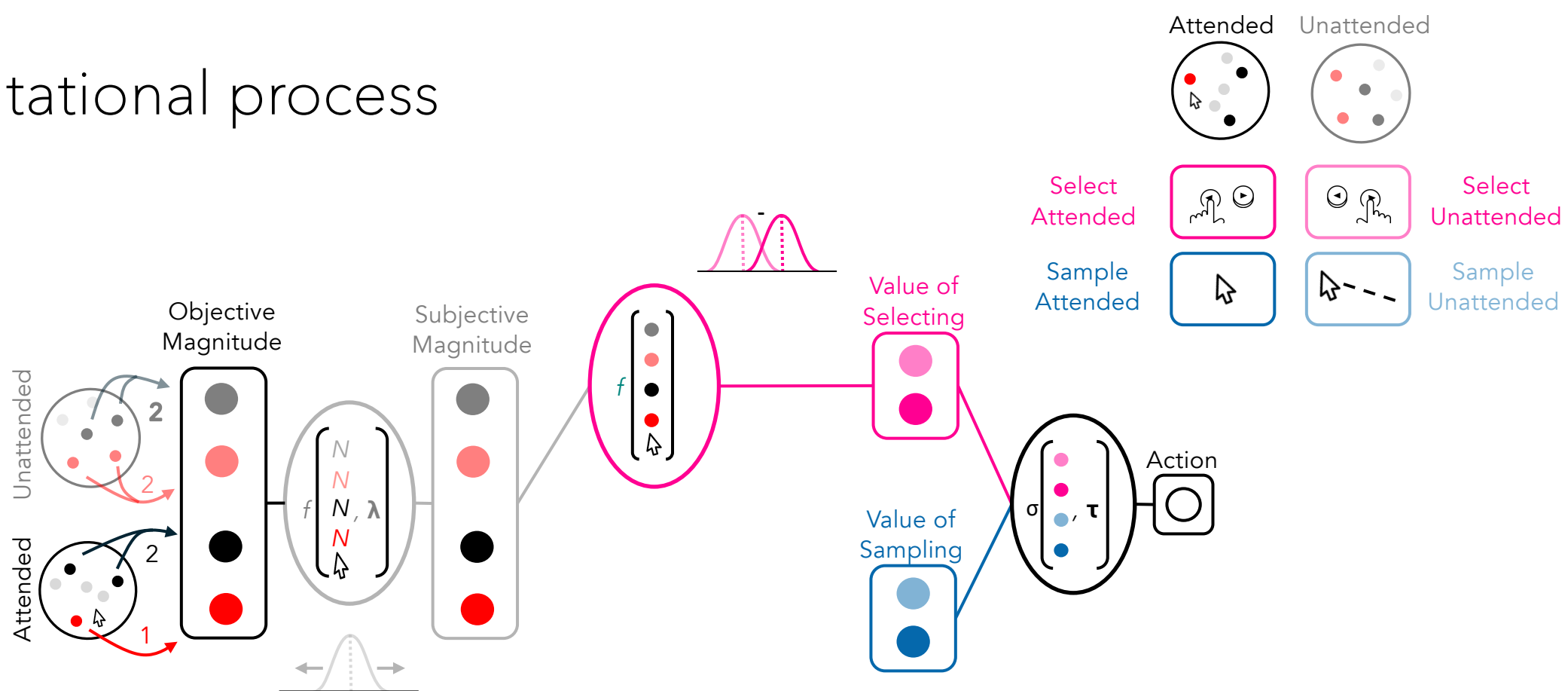
Computational process



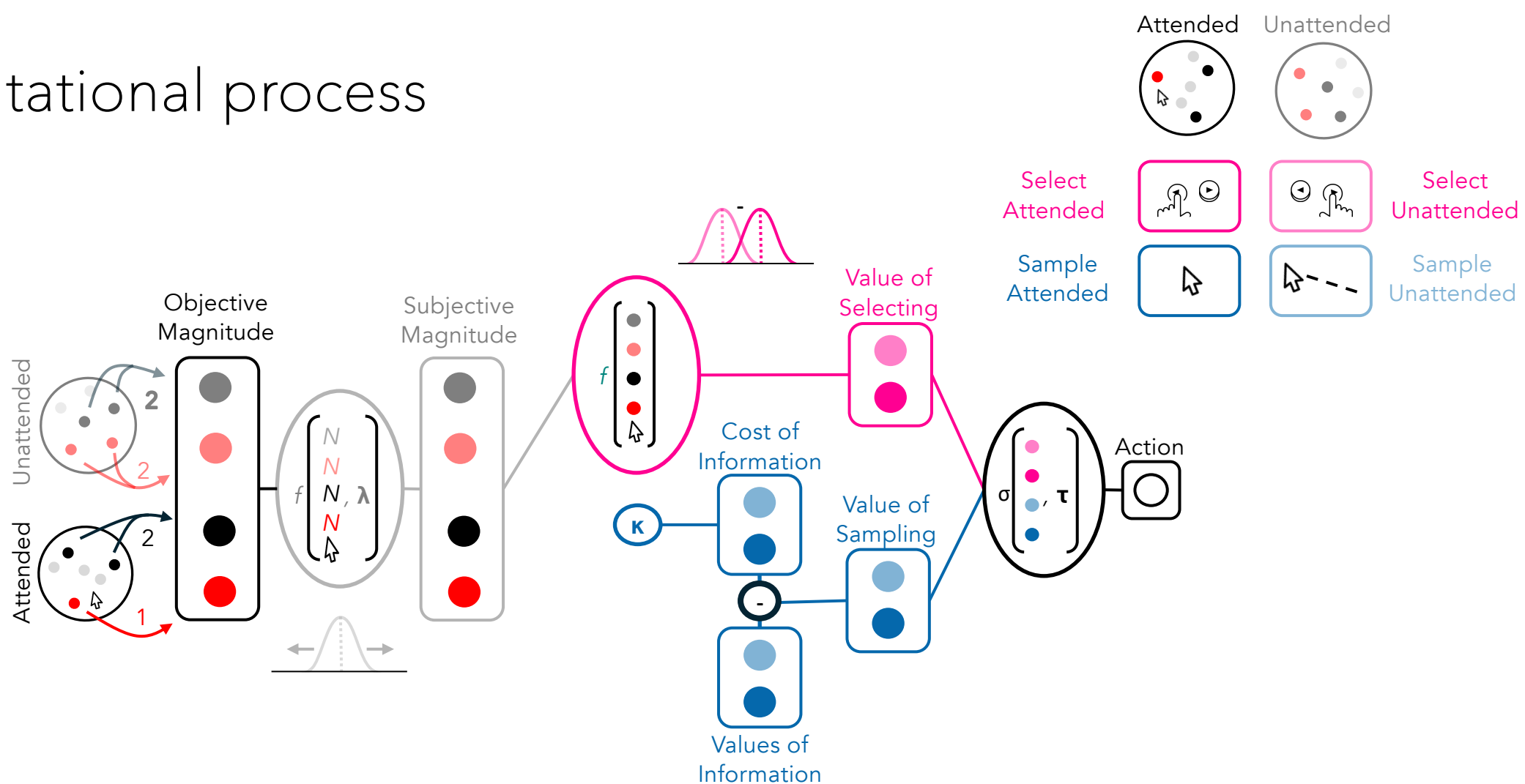
Computational process



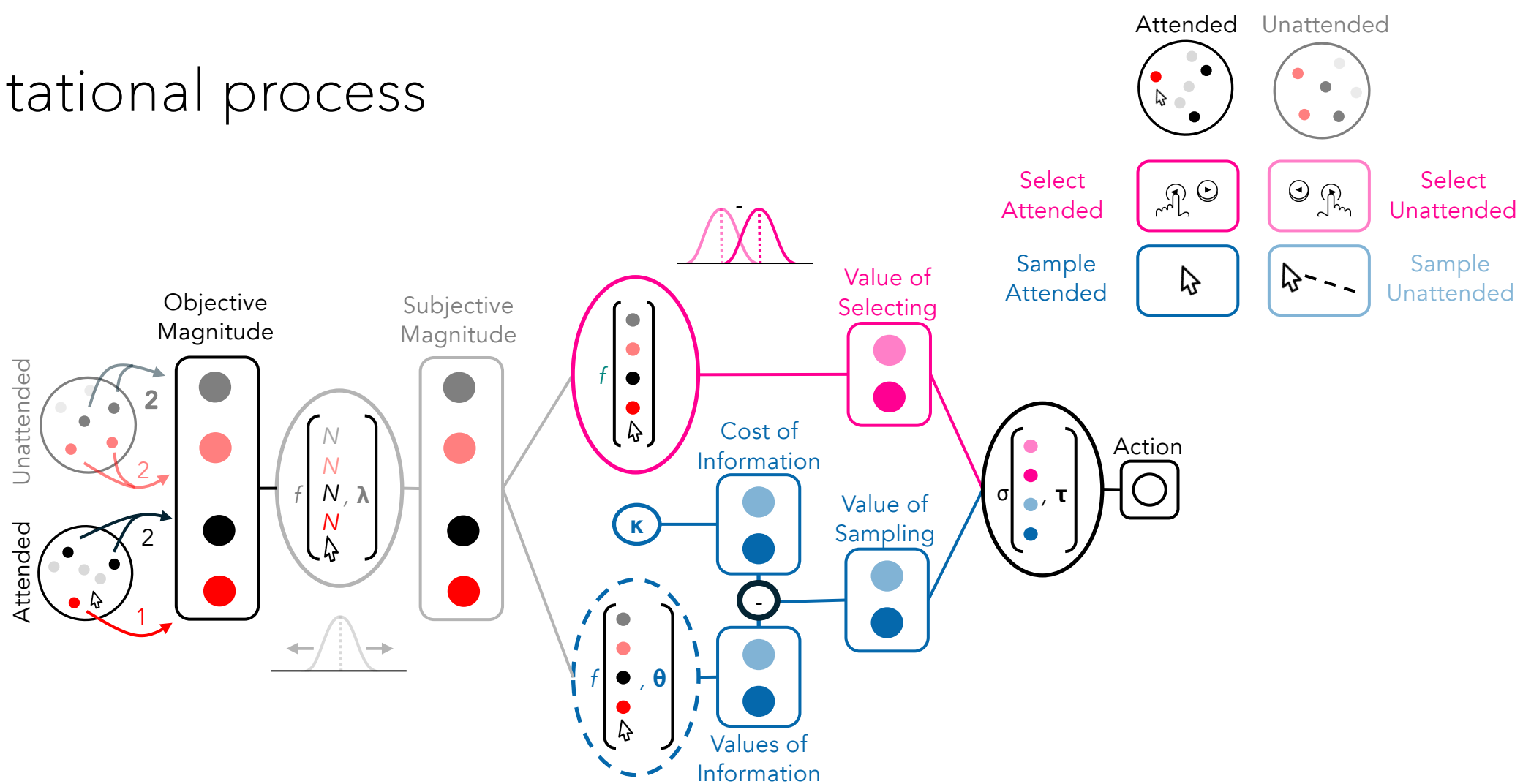
Computational process



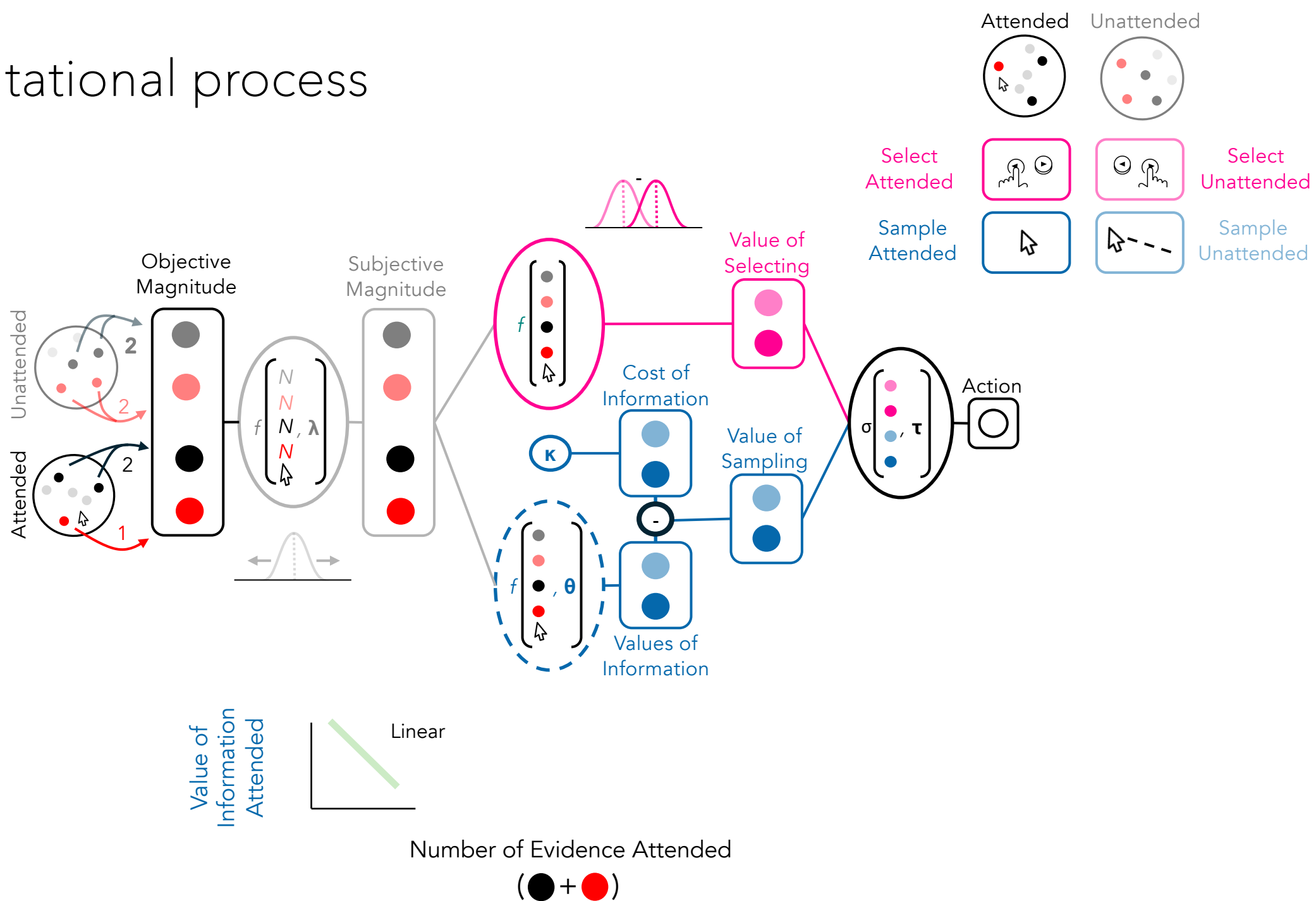
Computational process



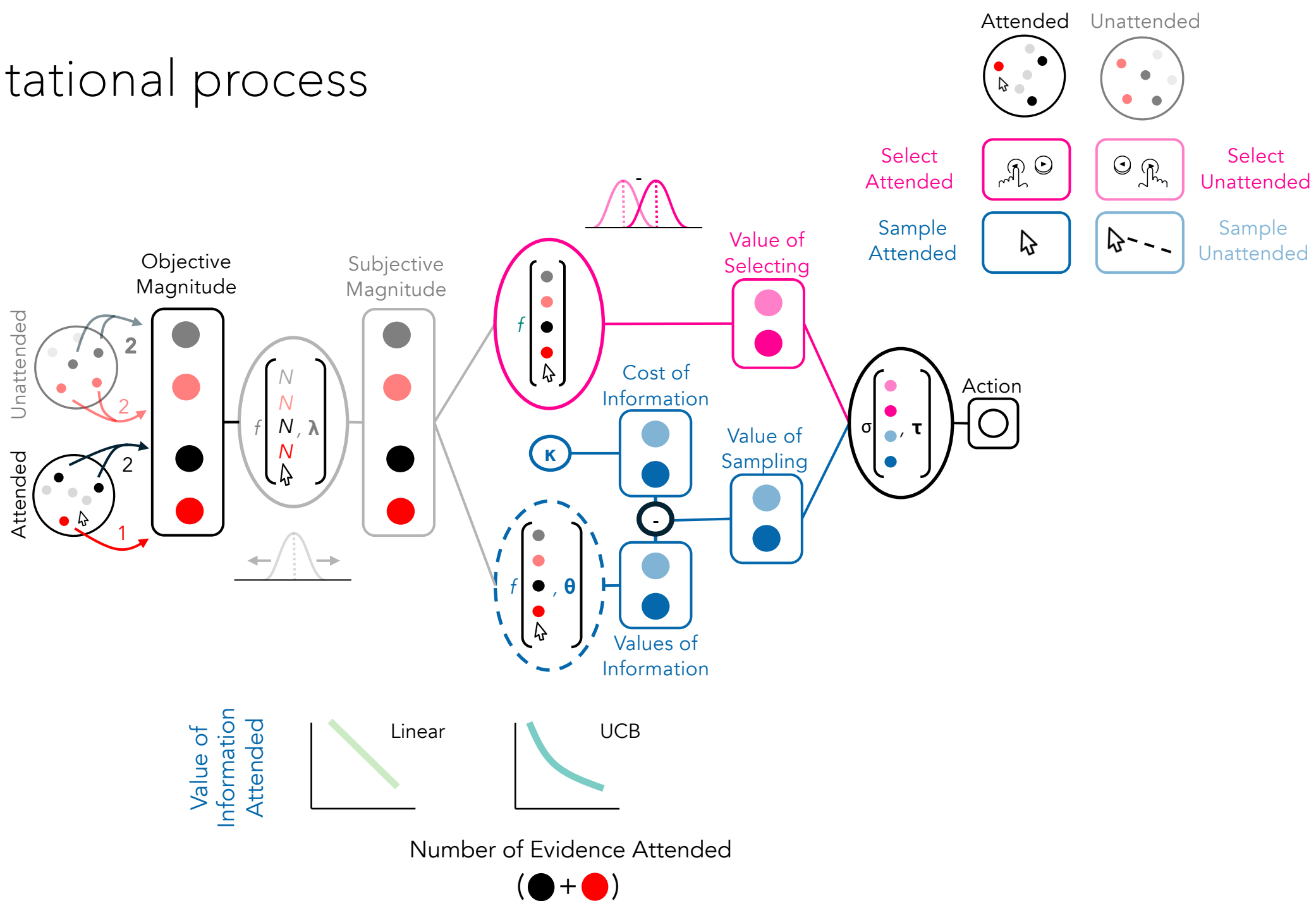
Computational process



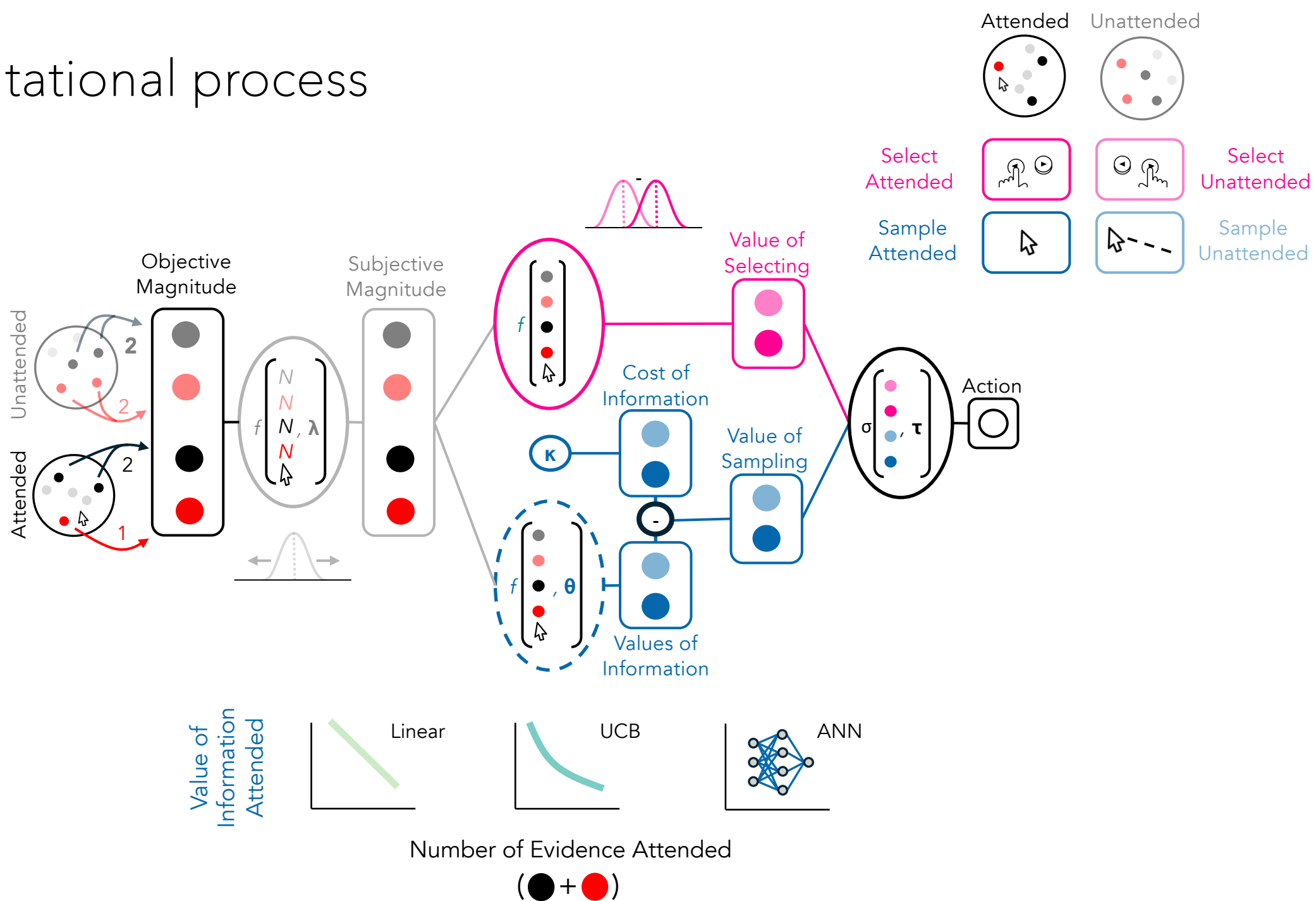
Computational process



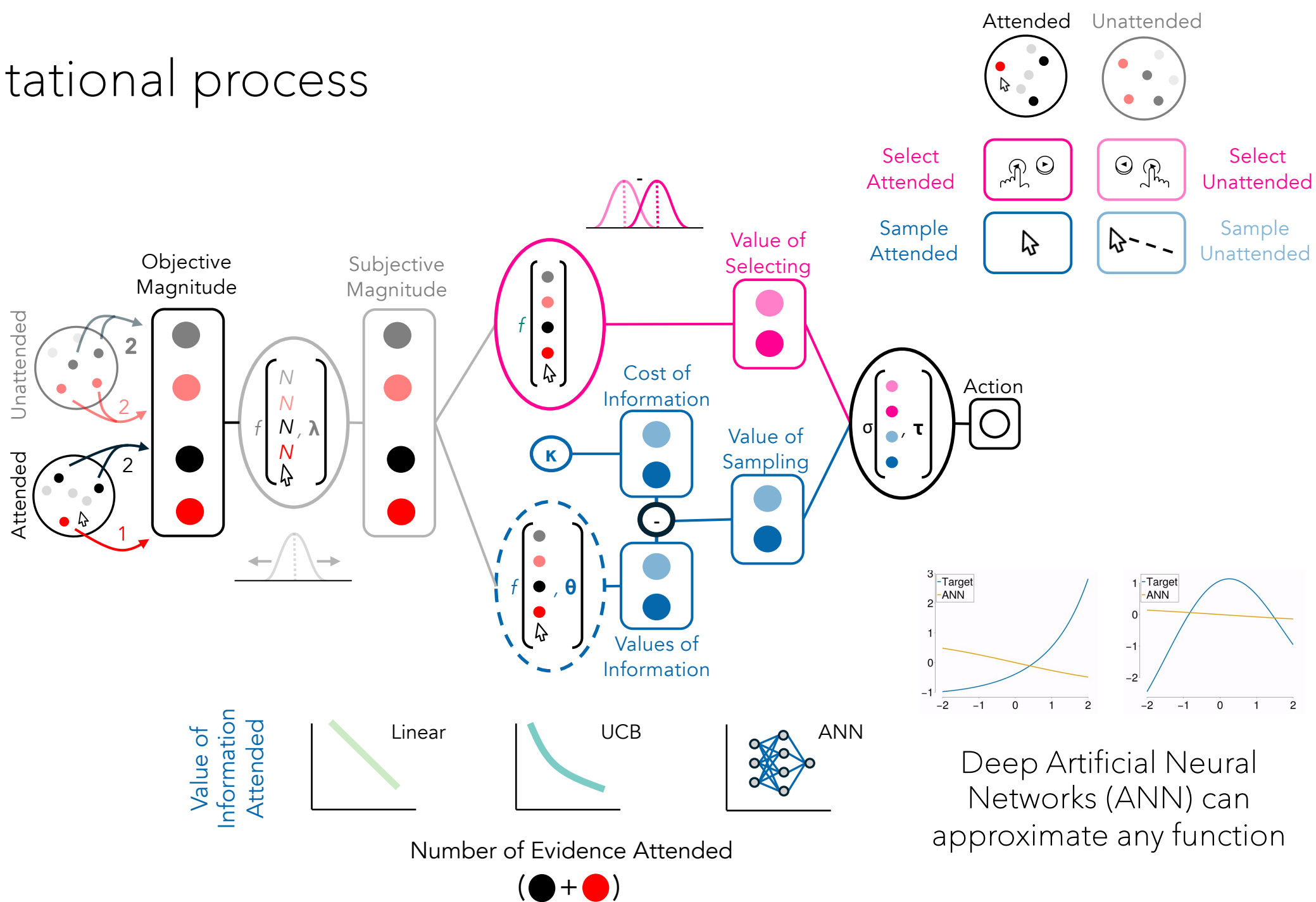
Computational process



Computational process

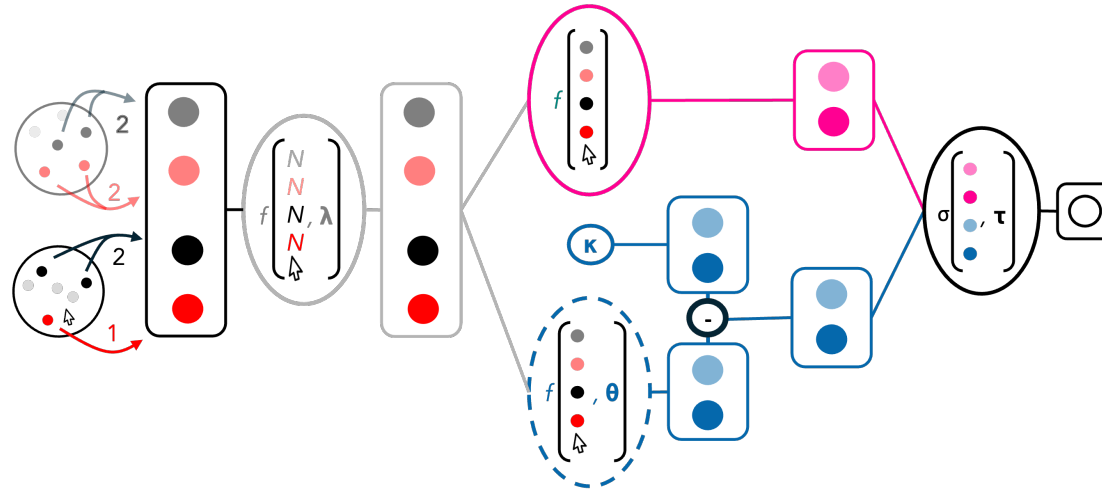


Computational process



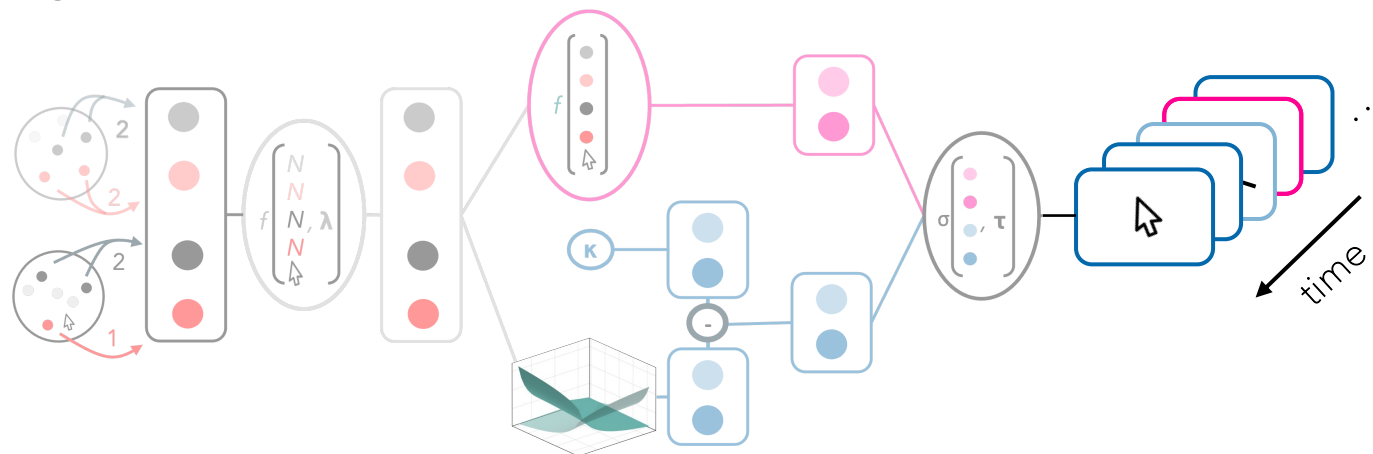
Computational Modelling

Function recovery



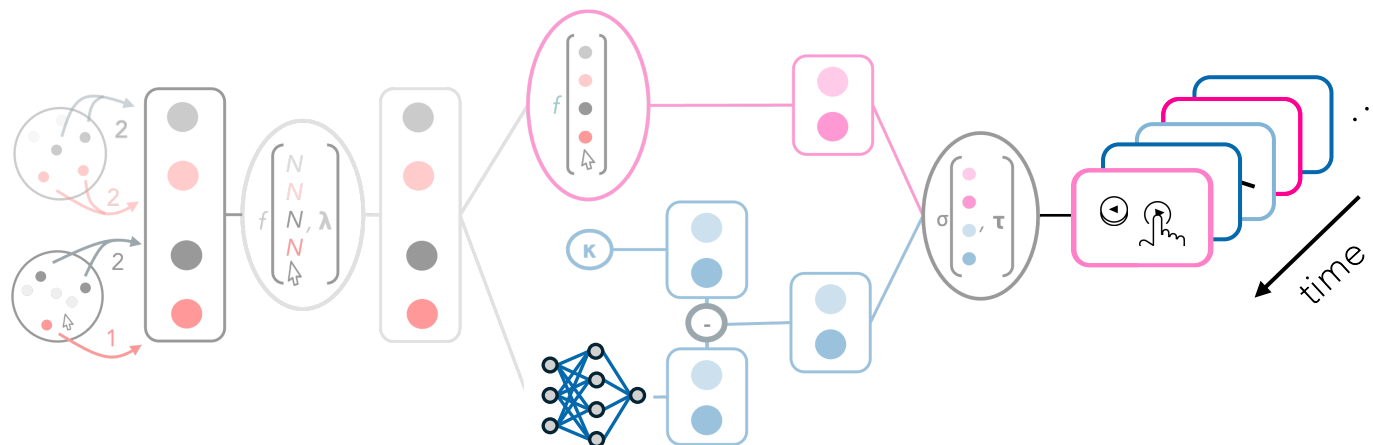
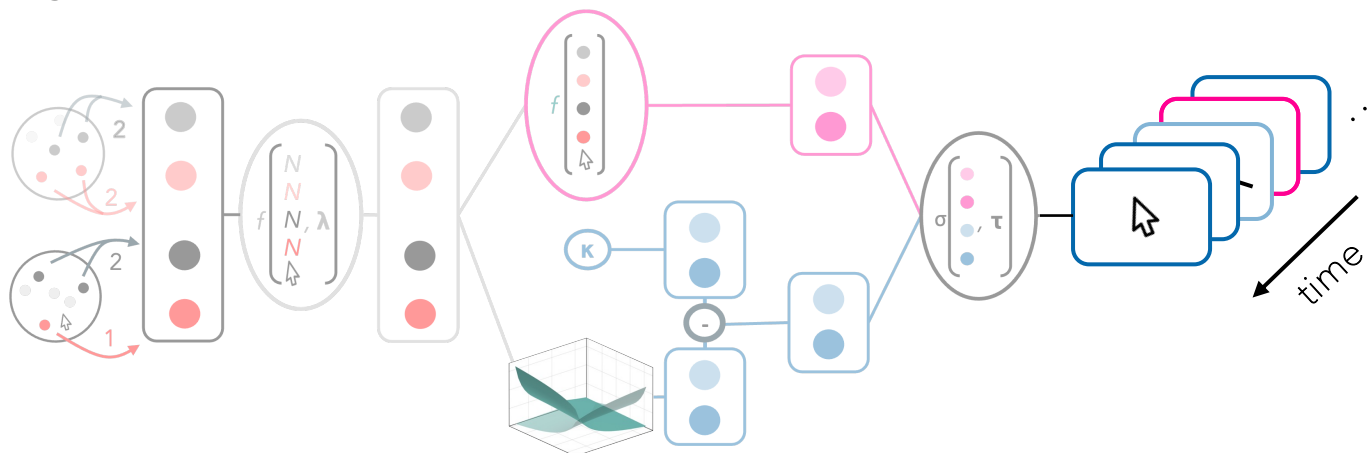
Computational Modelling

Function recovery



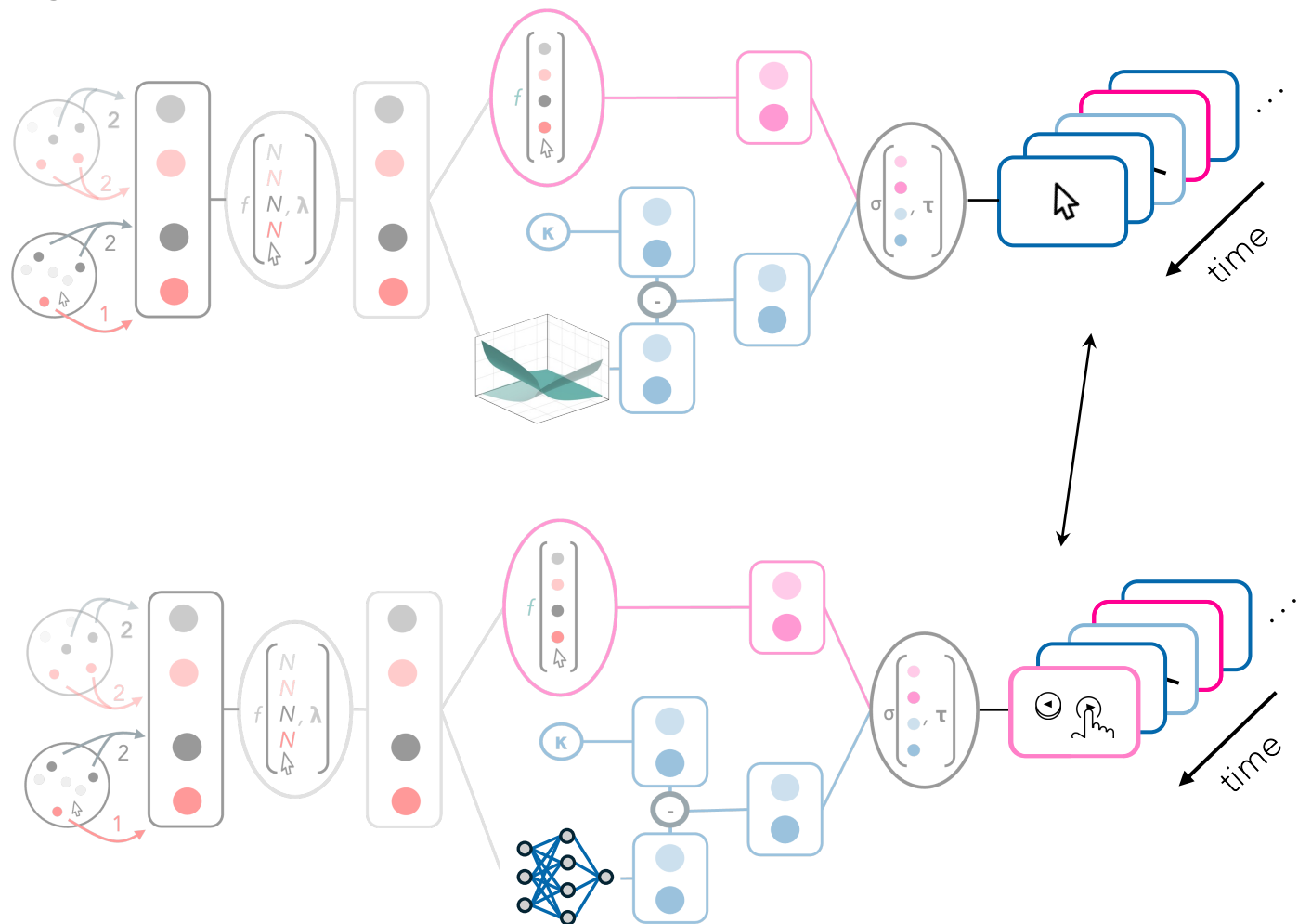
Computational Modelling

Function recovery



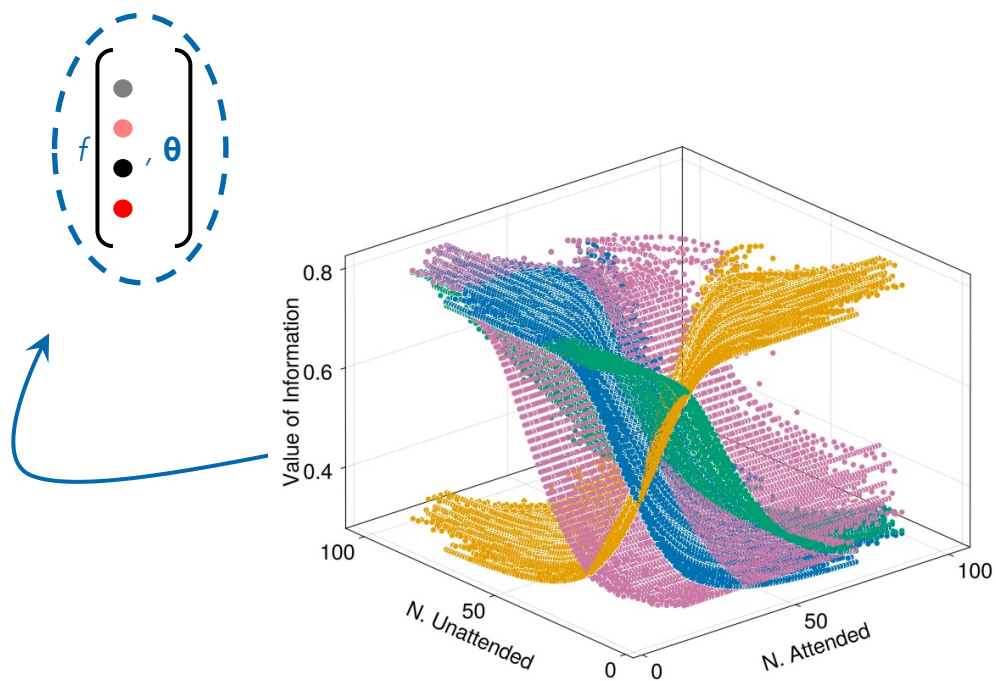
Computational Modelling

Function recovery

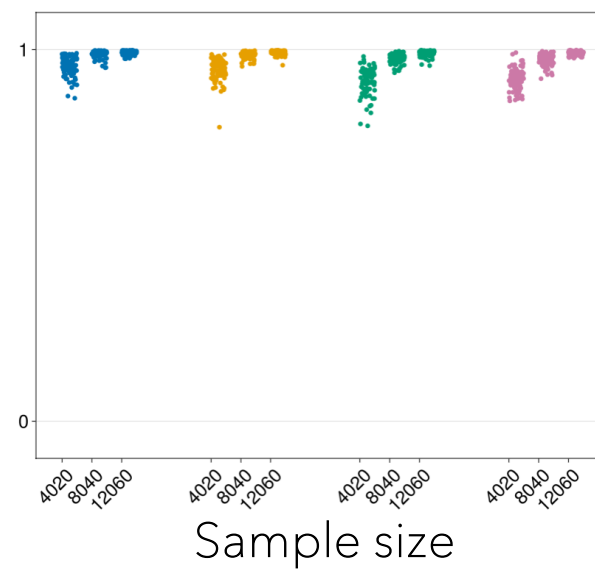


Computational Modelling

Function recovery

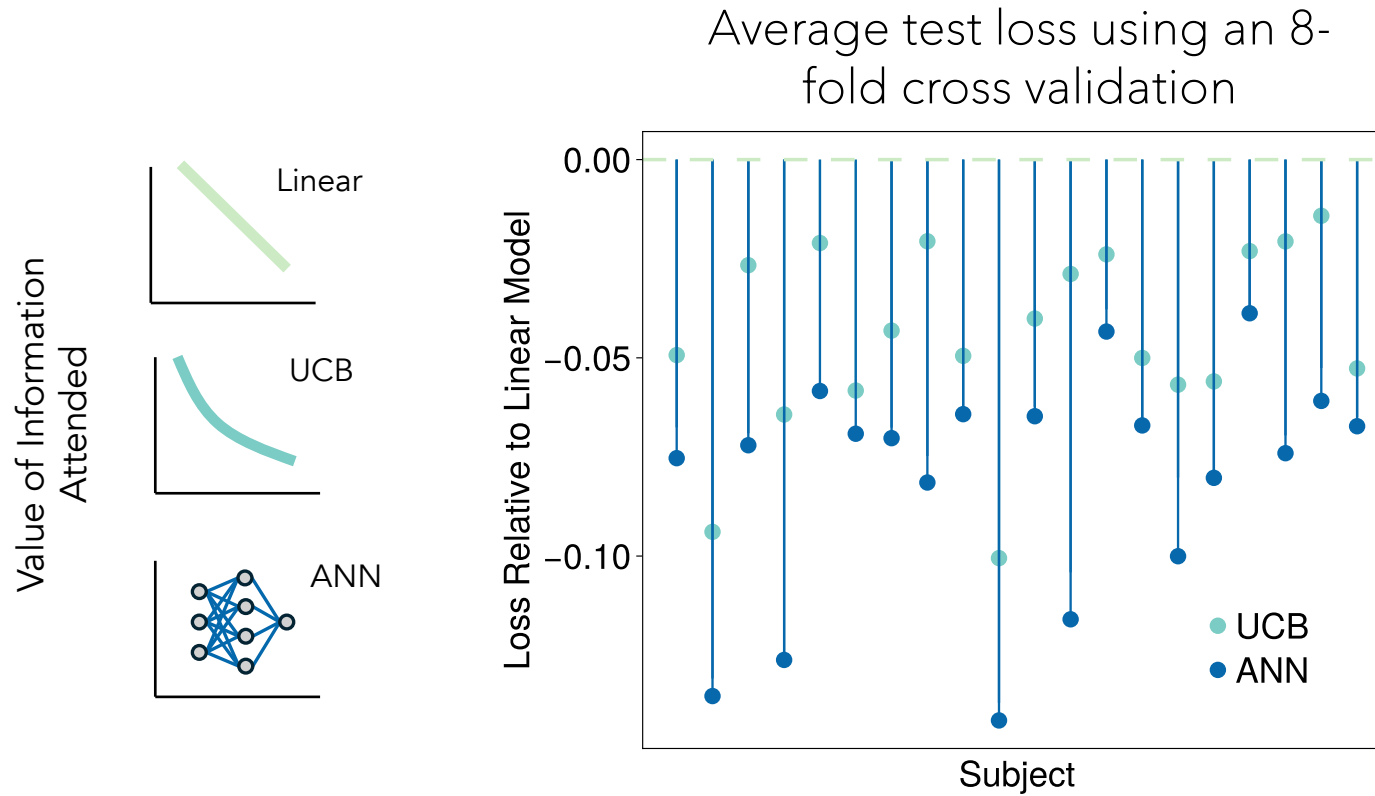


Correlation between true
and recovered function



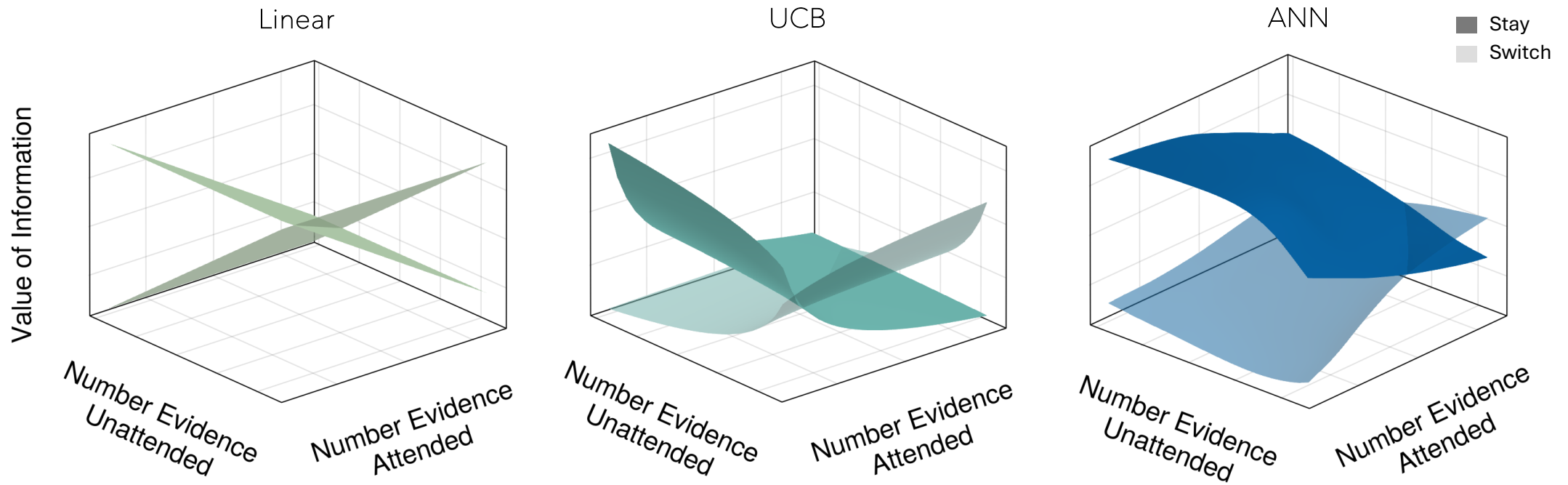
Computational Modelling

The ANN-derived value of information predicts participants' sampling decisions



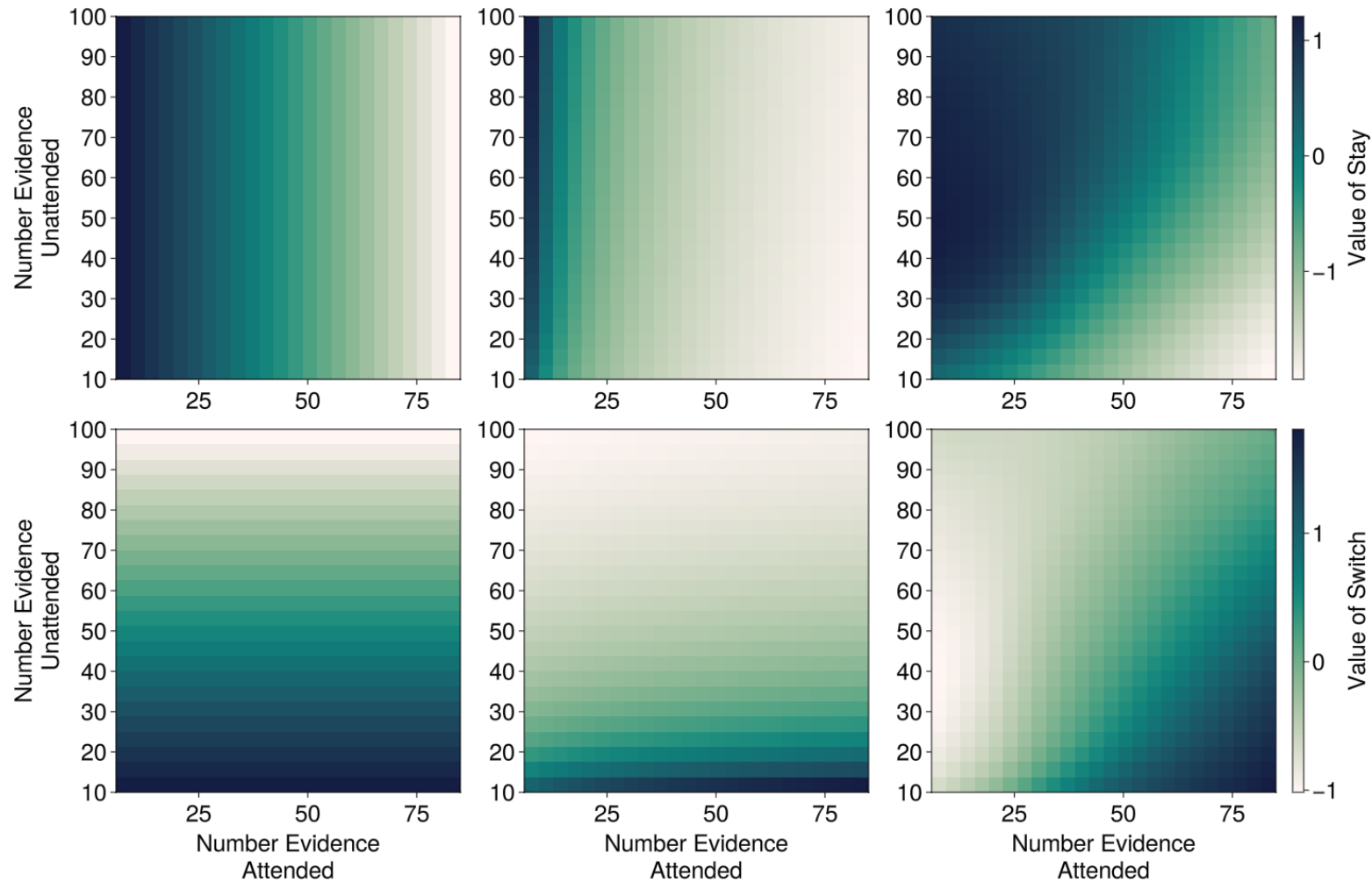
Computational Modelling

Interpretation of the ANN-discovered function



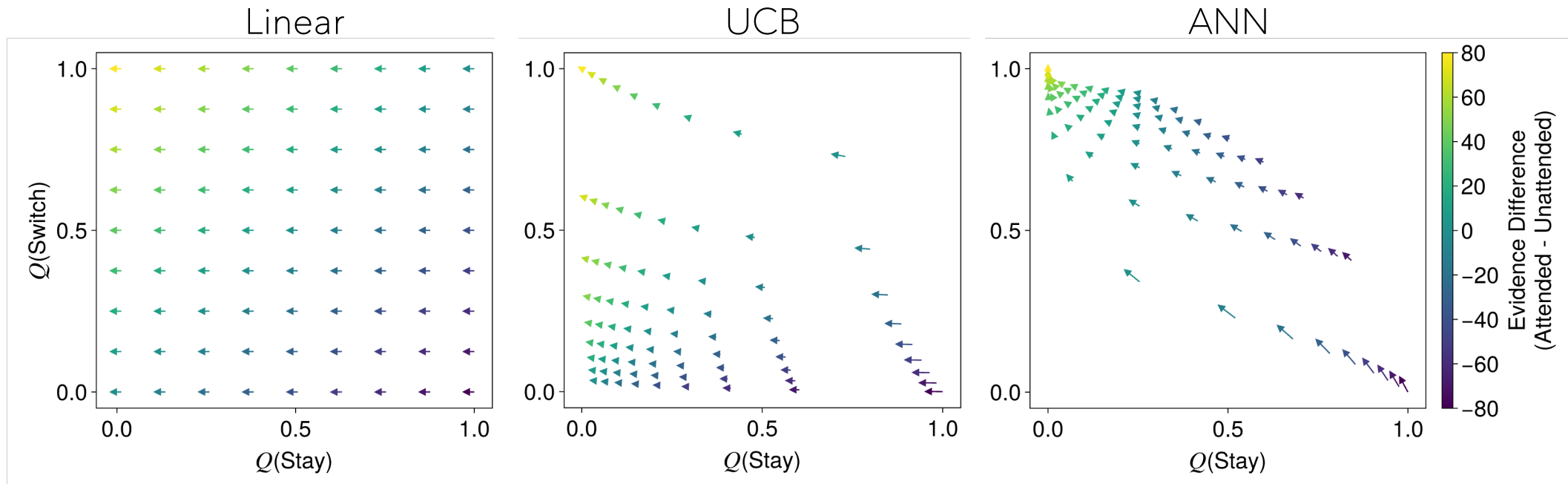
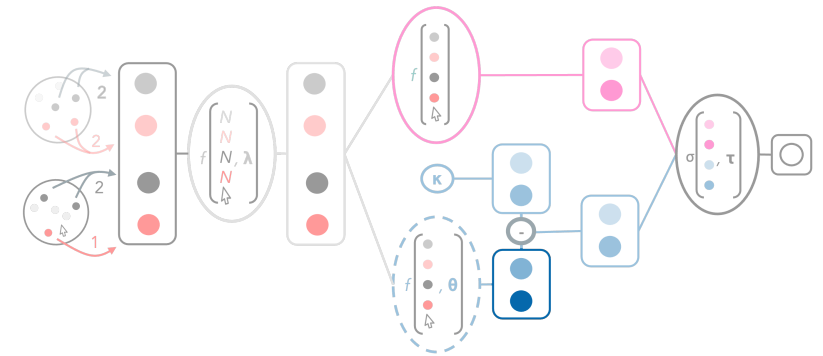
Computational Modelling

Interpretation of the ANN-discovered function



Computational Modelling

Interpretation of the ANN-discovered function



Computational Modelling

Interpretation of the ANN-discovered function using Symbolic Regression

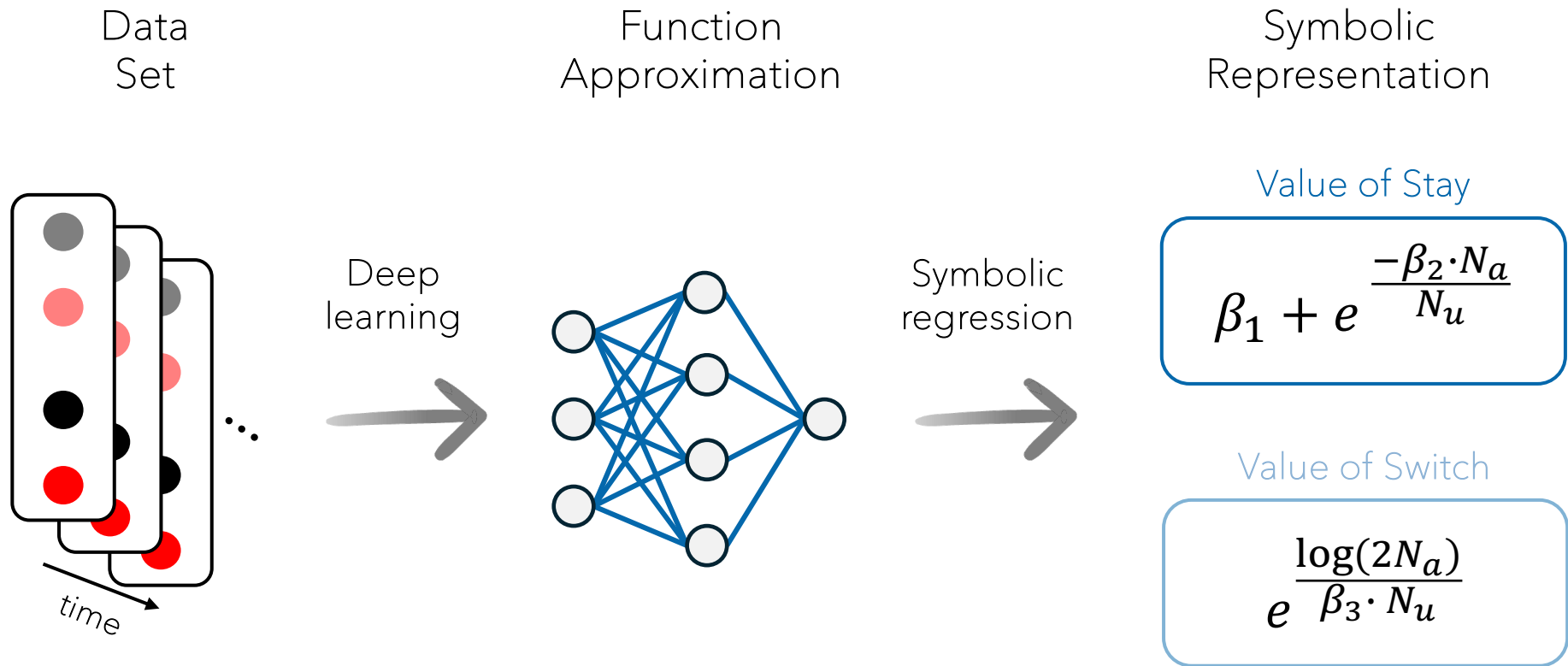


PySR and SymbolicRegression.jl

Source: <https://github.com/MilesCranmer/SymbolicRegression.jl>

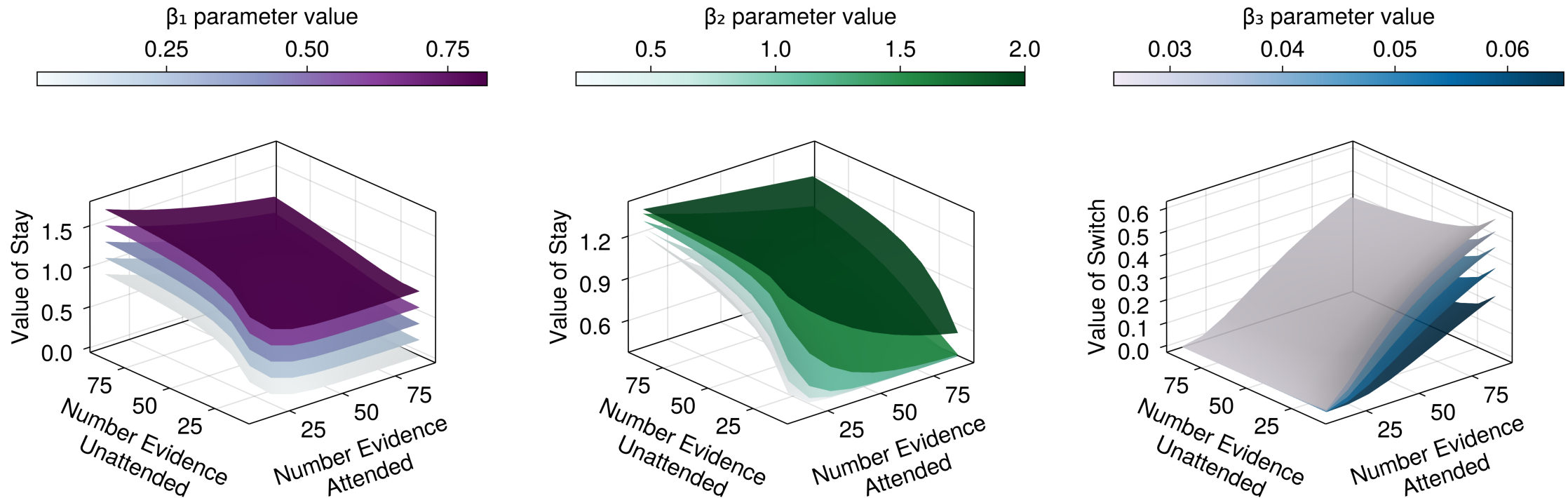
Computational Modelling

Interpretation of the ANN-discovered function using Symbolic Regression



Computational Modelling

Interpretation of the ANN-discovered function using Symbolic Regression



Computational Modelling

Interpretation of the ANN-discovered function using Symbolic Regression

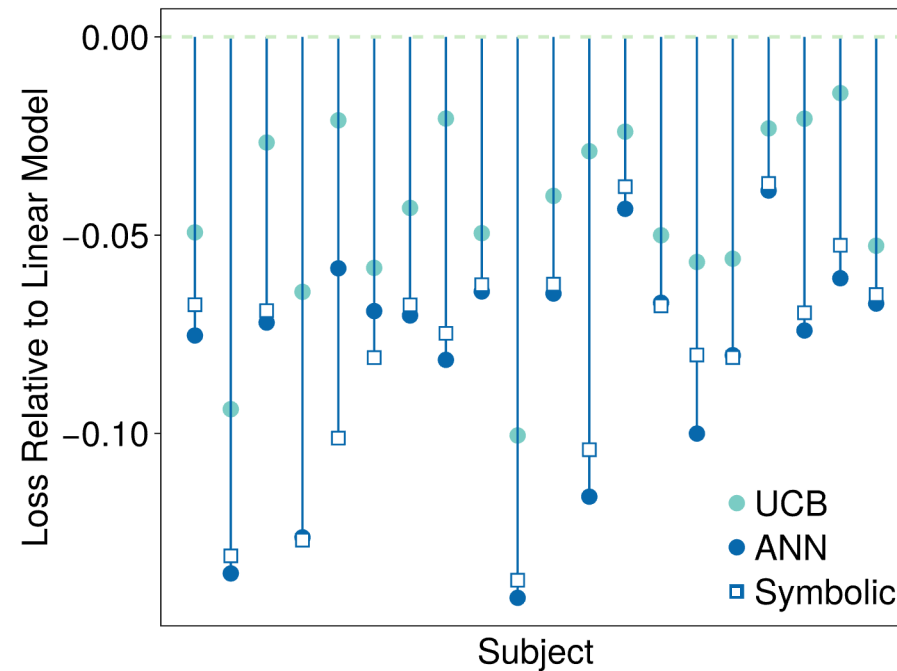
Symbolic

Value of Stay

$$\beta_1 + e^{\frac{-\beta_2 \cdot N_a}{N_u}}$$

Value of Switch

$$e^{\frac{\log(2N_a)}{\beta_3 \cdot N_u}}$$



Computational Modelling

Interpretation of the ANN-discovered function using Symbolic Regression

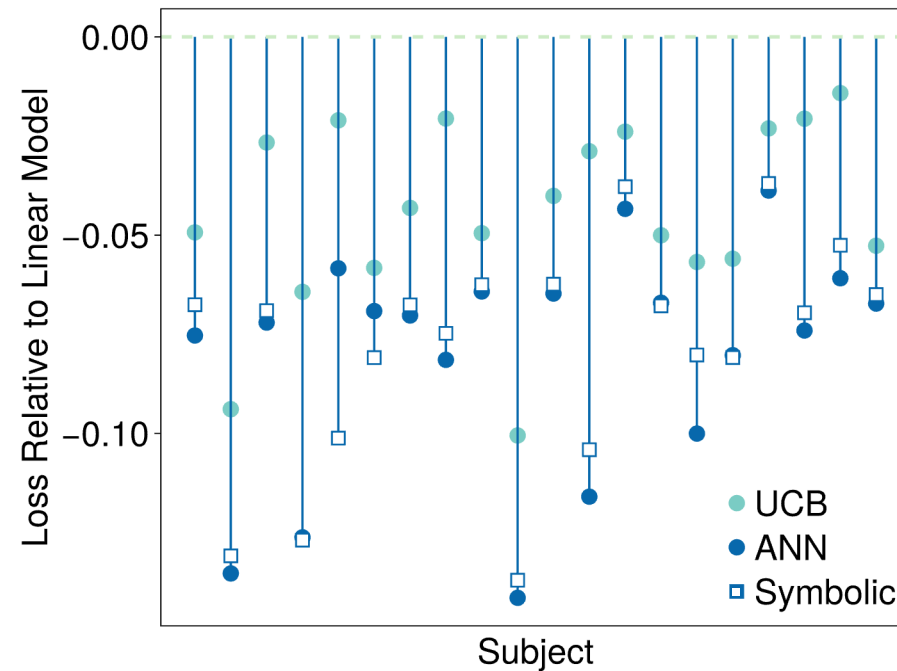
Symbolic

Value of Stay

$$\beta_1 + e^{\frac{-\beta_2 \cdot N_a}{N_u}}$$

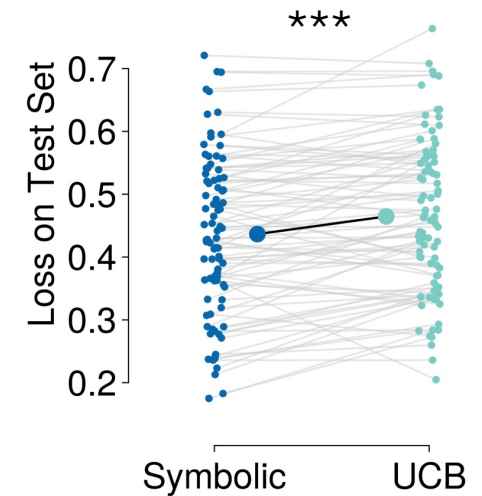
Value of Switch

$$e^{\frac{\log(2N_a)}{\beta_3 \cdot N_u}}$$



Generalization to a new task

Gershman, 2018



The ANN-derived value of information can predict neural activity



$$\text{BOLD} \sim \text{voi-attended}_{\text{linear}} + \text{voi-unattended}_{\text{linear}} + \dots$$

$$\text{BOLD} \sim \text{voi-attended}_{\text{UCB}} + \text{voi-unattended}_{\text{UCB}} + \dots$$

$$\text{BOLD} \sim \text{voi-attended}_{\text{ANN}} + \text{voi-unattended}_{\text{ANN}} + \dots$$

The ANN-derived value of information can predict neural activity

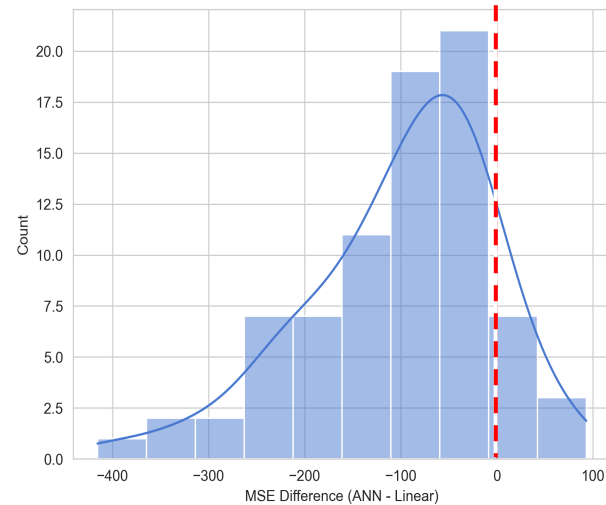


$$\text{BOLD} \sim \text{voi-attended}_{\text{linear}} + \text{voi-unattended}_{\text{linear}} + \dots$$

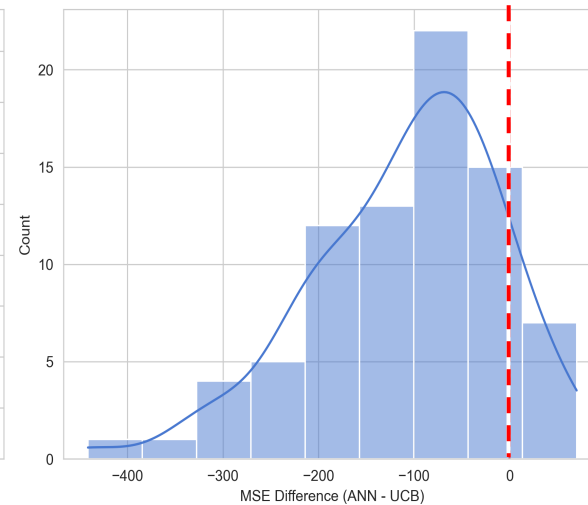
$$\text{BOLD} \sim \text{voi-attended}_{\text{UCB}} + \text{voi-unattended}_{\text{UCB}} + \dots$$

$$\text{BOLD} \sim \text{voi-attended}_{\text{ANN}} + \text{voi-unattended}_{\text{ANN}} + \dots$$

ANN - Linear

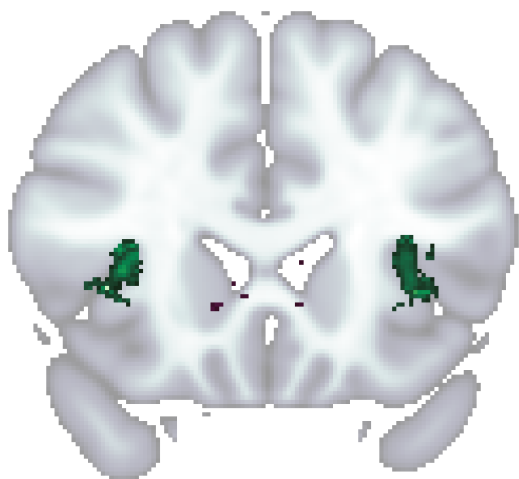


ANN - UCB

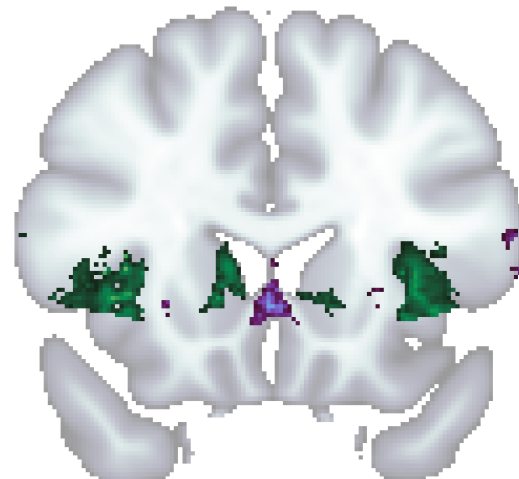


BOLD signal in the **Anterior Insula** and the Anterior Cingular Cortex covary with Value of Information

Value of stay - value of switch

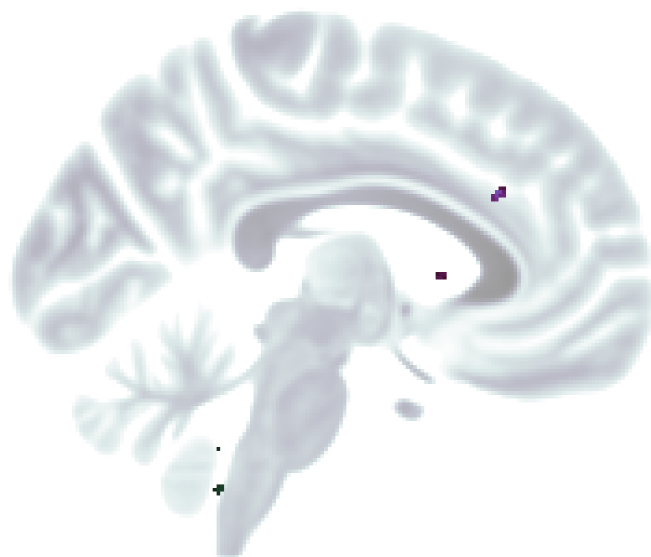


Value of stay + value of switch

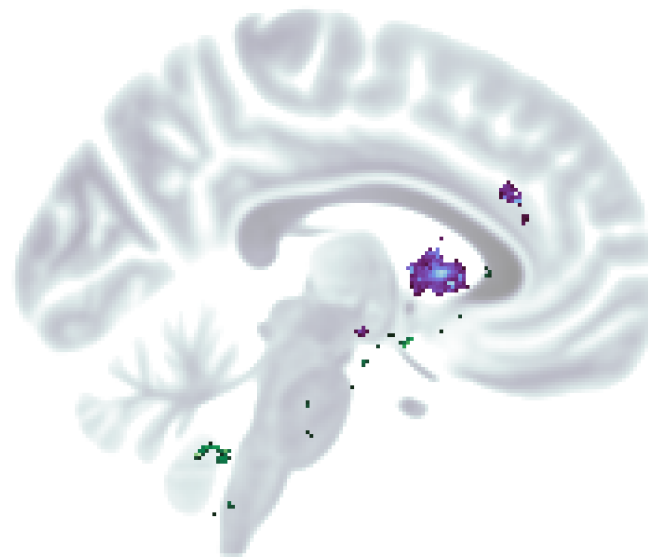


BOLD signal in the Anterior Insula and the Anterior Cingular Cortex covary with Value of Information

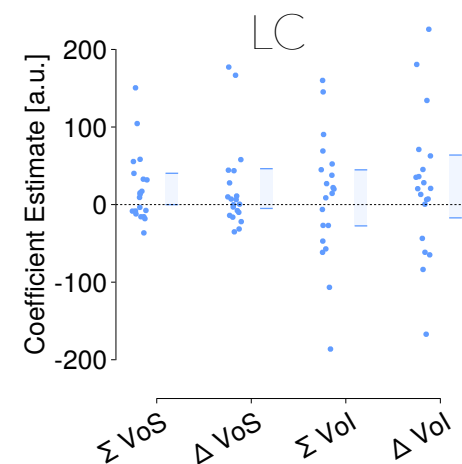
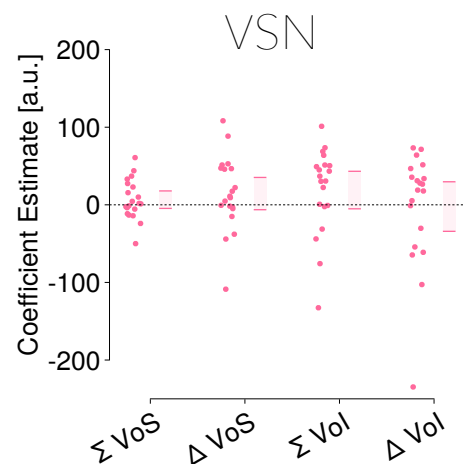
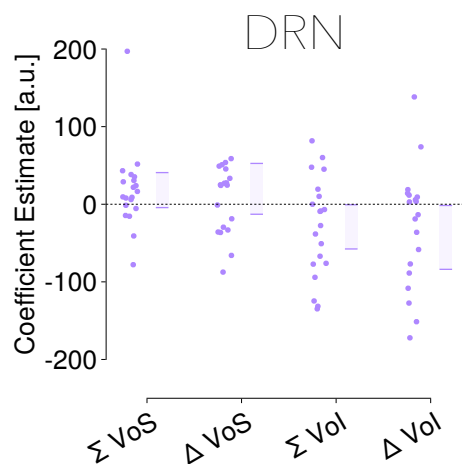
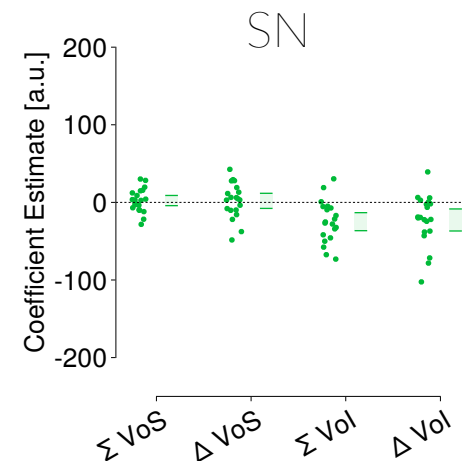
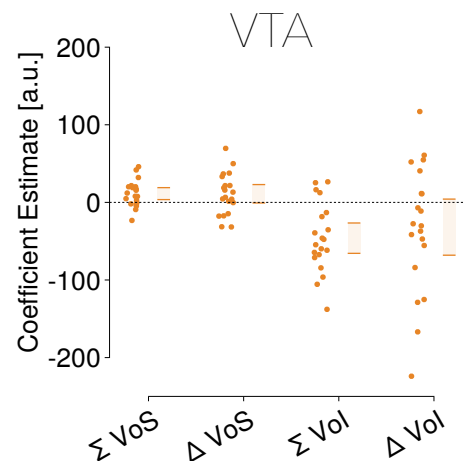
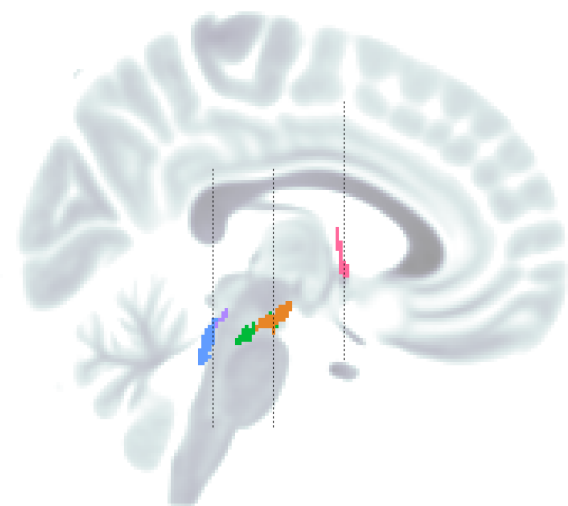
Value of stay - value of switch



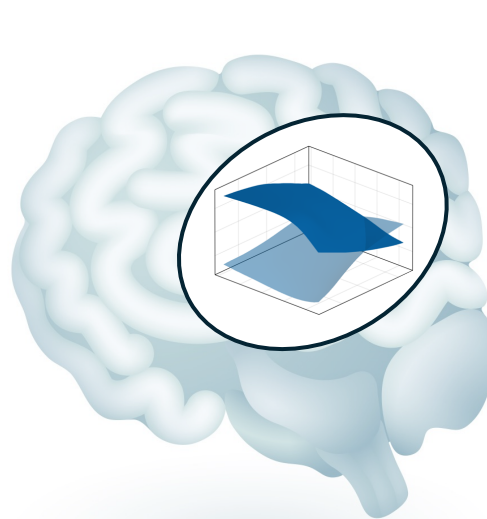
Value of stay + value of switch



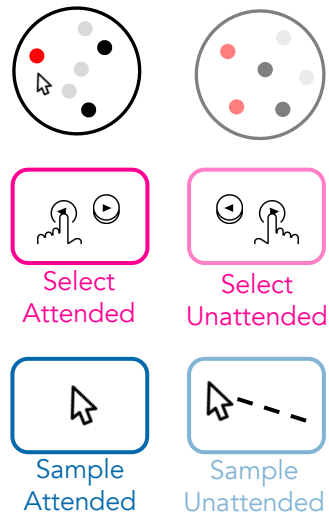
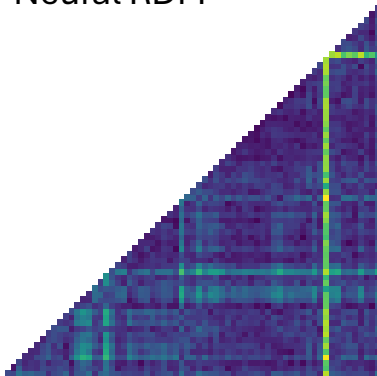
Value of Selecting and Value of Sampling correlated with BOLD signal in the VTA



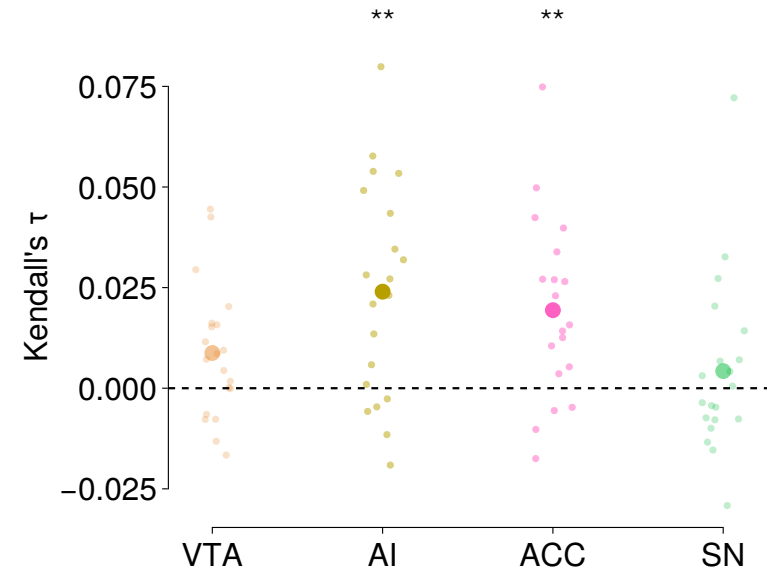
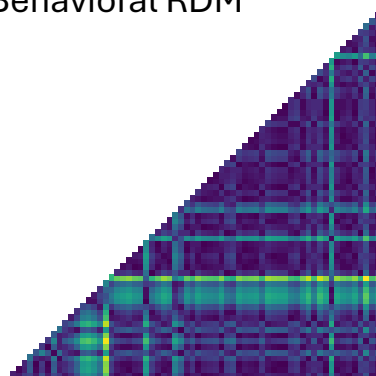
AI and ACC Activity Reflects Information Value and Predicts Sampling Behavior



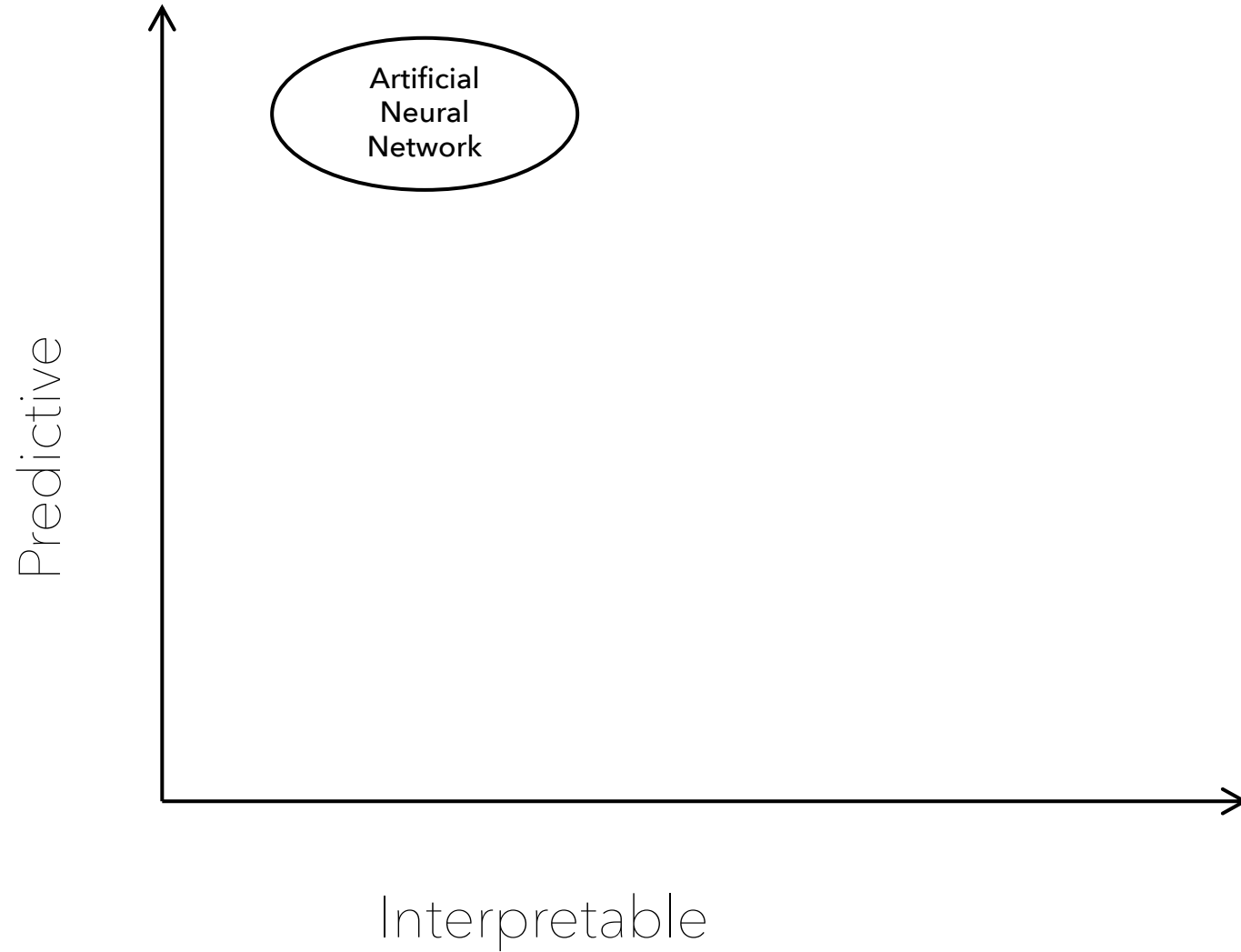
Neural RDM



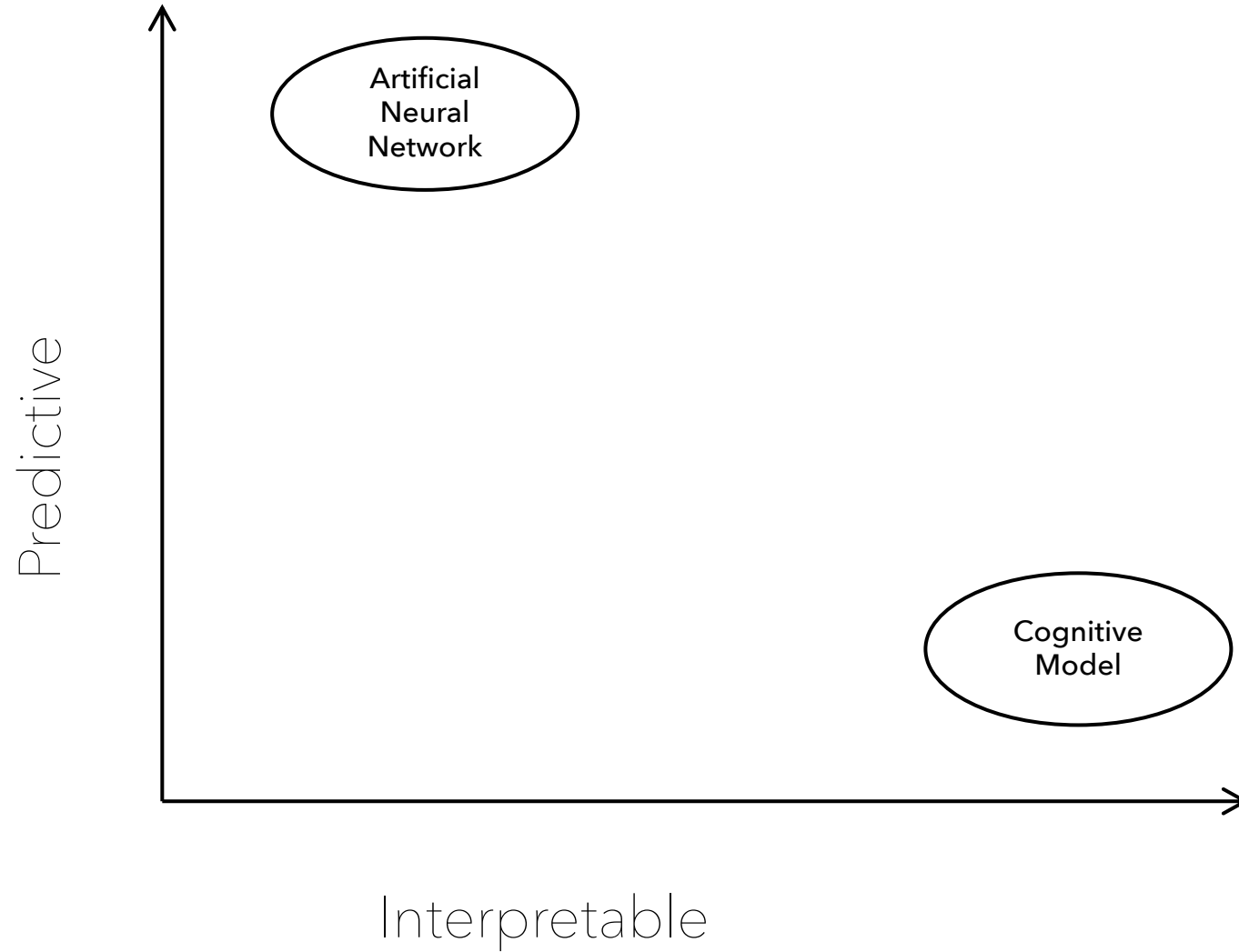
Behavioral RDM



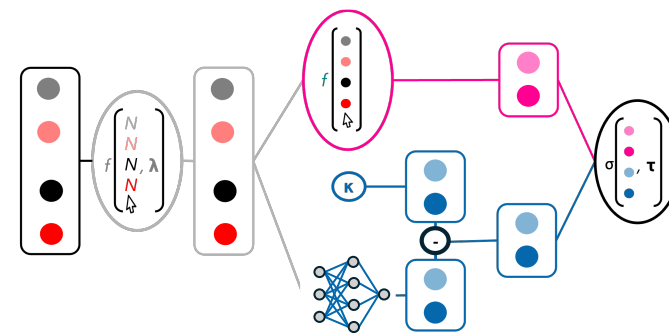
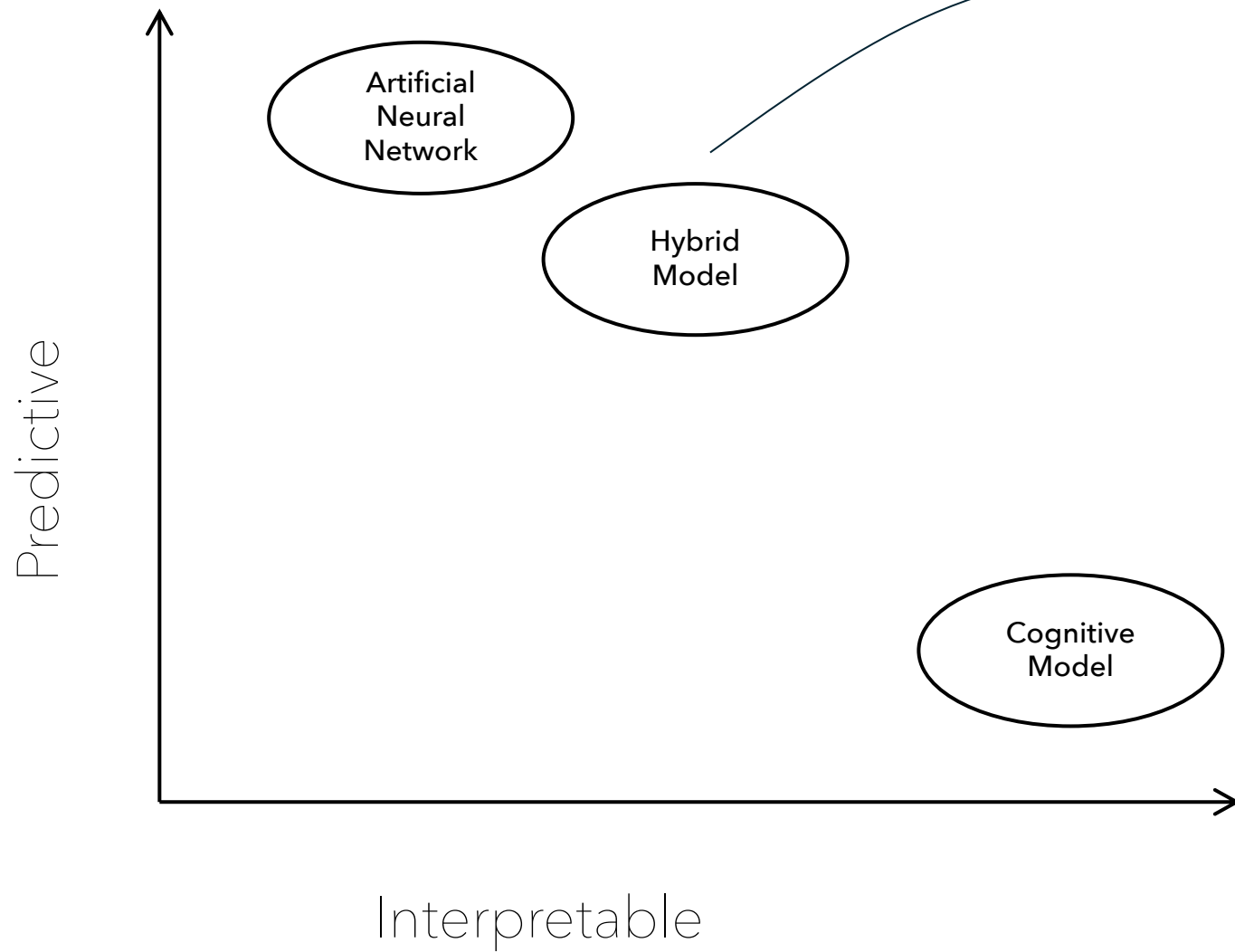
Summary



Summary



Summary



Summary

Predictive

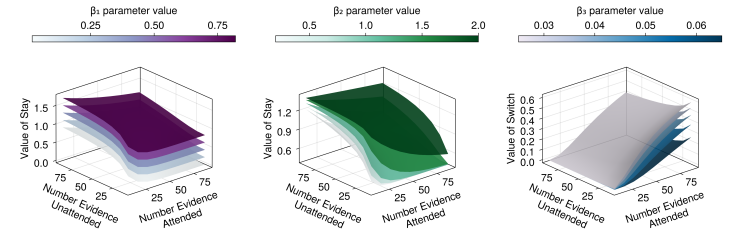
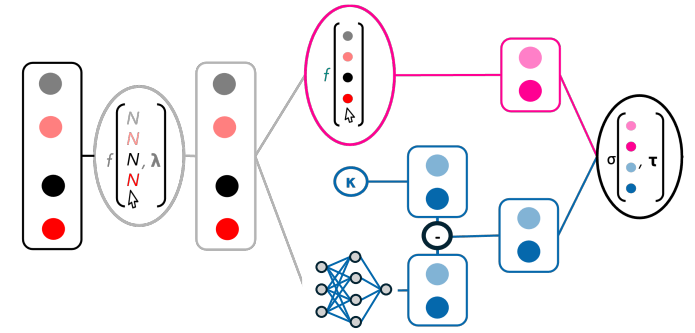
Artificial
Neural
Network

Hybrid
Model

Symbolic
Hybrid
Model

Cognitive
Model

Interpretable



Value of Stay

$$\beta_1 + e^{\frac{-\beta_2 \cdot N_a}{N_u}}$$

Value of Switch

$$e^{\frac{\log(2N_a)}{\beta_3 \cdot N_u}}$$