Do we look forward or backward when acting?

Readings for today

- Seligman, M. E., Railton, P., Baumeister, R. F., & Sripada, C. (2013). Navigating into the future or driven by the past. Perspectives on psychological science, 8(2), 119-141

Topics

- Where we have been
- Are we prospective?
- Why we look forward when acting

Where we have been

Let’s start by reviewing our past

How do we understand an intelligent system?

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Is randomness an effective strategy?

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What is life like at a low Reynold’s number?

We need to understand intelligent behaviors at multiple levels: from computation to neurons and back again. Logical constraints define the scope of your theory and empirical observations validate those constraints.

Organisms without brains can effectively explore by using random sampling behaviors like Levy flights.

The physics of the microscopic world dictates different strategies for exploring.

Let's start by reviewing our past

When to tumble & when to run?

E. coli run-then-tumble chemotaxis is a simple strategy of not making a decision until a sensory gradient changes.

How do you follow a scent?

Animals have a variety of approaches to chemotaxis beyond the E. coli strategy.

How do we extract signal from noise?

The detection of a signal relies not only on the distance of the signal from the noise, but also the information criterion that the perceiver uses to make a decision.

Let’s start by reviewing our past

How do you use evidence to make a decision?

Accumulation of evidence optimally occurs via a sequential probability ratio test (SPRT), which follows an information diffusion process and can be fit to behavior using methods like the drift diffusion model.

Does the cortex make a decision?

Cortical neurons show behavior qualitatively consistent with accumulation of evidence, though the multiple realizability problem introduces uncertainty.

Does the sub cortex make a decision?

The architecture of cortical-basal ganglia-thalamic pathways is ideal for implementing accumulation of evidence for decision-making.

Let’s start by reviewing our past

What is the nature of information?

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What is the value of information?

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Can information be its own signal?

Information is defined by its uncertainty. We call this entropy. Entropy can be shared (mutual information) and compared (KL divergence).

Sheridan proposes that the intrinsic value of information is the difference between the best expected value for given action, relative to ignorance and the cost of gaining information. Learning from information should rely on the same circuits as learning form rewards.

Infotaxis uses the information gained from sparsely occurring events as a policy to determine search, allowing for fast and efficient search behaviors in dynamic, low-signal environments.

Let’s start by reviewing our past

What makes patch foraging difficult?

The patch foraging problem is unique as it is a cyclical process of nested decisions.

What is the best way to forage in patches?

The Marginal Value Theorem describes the optimal solution to the problem of staying and harvesting a patch of resources or moving on to new patches.

What is the value of future actions?

Reinforcement learning approximates the Bellman equation to learn simple action value policies as the aggregate sum of previous rewards.

Let’s start by reviewing our past

How does the brain learn from feedback?

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When to explore rather than exploit?

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Can curiosity solve the e-e dilemma?

Phasic dopamine, reflecting the RPE, changes the relative balance between direct and indirect pathways to bias cortico-basal ganglia circuits towards (or away from) actions that lead to more rewards.

Any decision involves a balance of maximizing resources (exploitation) or exploring. Exploration can be random or directed (curiosity), with the latter being information seeking.

Treating exploration (maximizing E) and exploitation (maximizing R) as separate learning objectives resolves the e-e dilemma.

Are we prospective?

Now lets look to the future

Moving to the concept of prospection

Before:

- Behaviorism and early psychological theories emphasized the value of past events (causes) in understanding behavior (effects).
- This proved inadequate in explaining actions without teleological (goal-oriented) context.

Now:

- Time to consider **prospection**: i.e., the process of predicting or envisioning the future.
- Prospection influences perception, cognition, affect, memory, motivation, and action.

(Seligman et al. 2013)

Prospection in behavioral guidance

The reluctant acceptance of expectations

- Historical explanations of behavior show a trend toward guidance by prospective representations, emphasizing "if–then" possibilities.
- The brain needs to model its environment with "if–then" conditionals for effective interaction.
- Learning as a feed-forward/feedback process, transforming experience into experimentation.
- **Hypothesis**: animals with the ability to model potential futures are more effective and successful at generalizing to new contexts/ environments.

(Seligman et al. 2013)

Approaches to prospection

Contrasting Approaches to Prospection

- Early work focused on the errors and biases in prospection.
- Emphasis was on successful, accurate prospection sharing features with optimal models from philosophy and economics.

Desire Versus Drive in Motivation:

- Desire, unlike drive, represents its object as an attractive prospect, leading to motivation.
- The active role of the individual in using past experiences as information for future possibilities.

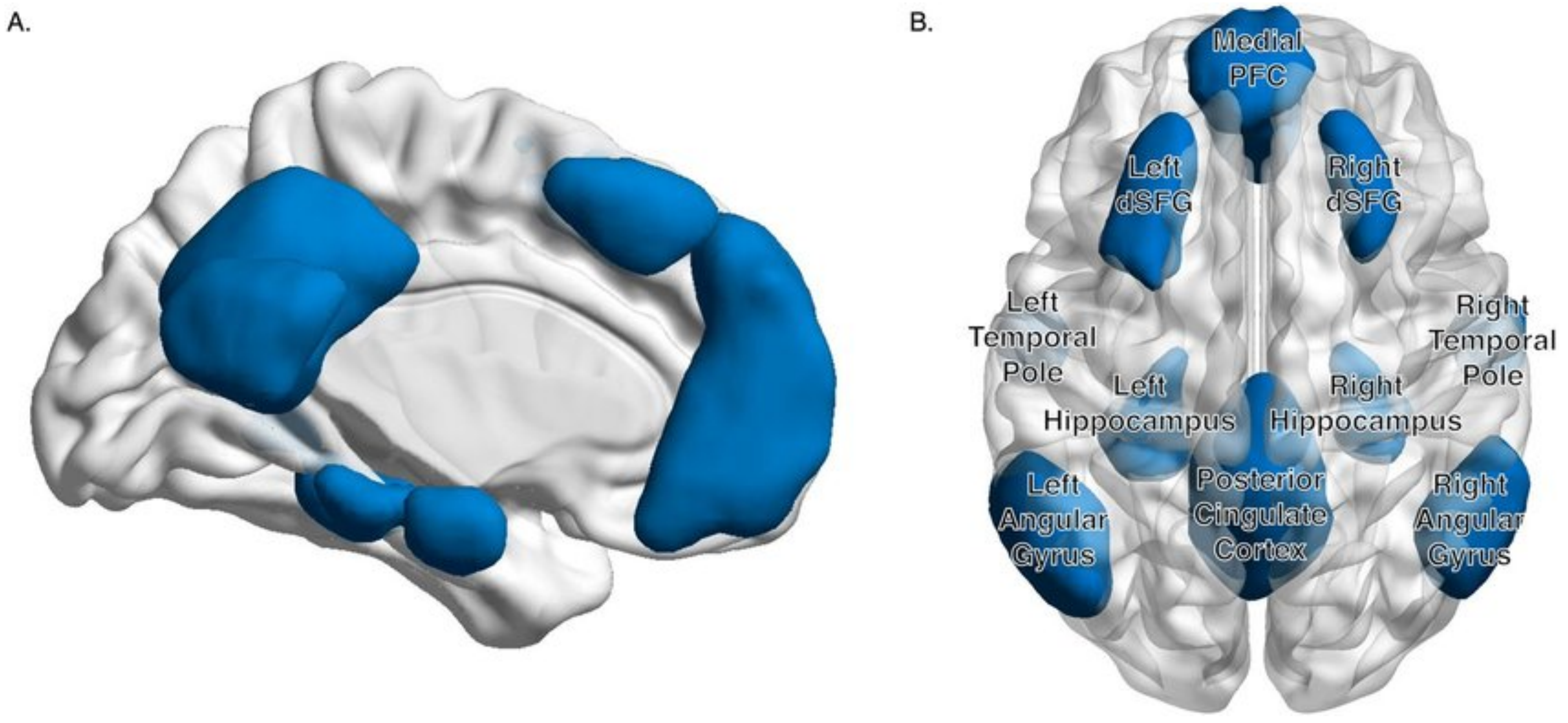
Spontaneous Aspects of Prospection:

- Both spontaneous and deliberate cognitive and emotional activities reflect the formation of future-oriented guidance.
- Prospection includes a mix of conscious consideration and spontaneous mental activities like intuition and mind wandering.

(Seligman et al. 2013)

The prospective brain

- **Prospection in Mental Simulations:** Prospection is central to four types of mental simulations: navigational, social (other minds), intellectual, and memorial (counterfactual simulations of the past).
- **The Default Network's Role**: Neuroimaging studies reveal a consistent activation pattern in the brain's default mode network during rest, indicating its involvement in internally directed mentation, including prospection.
- **Functional Connectivity of Default Mode Regions**: These regions form a coherent network that is functionally interconnected, suggesting their collective role in various forms of imagination and simulation.

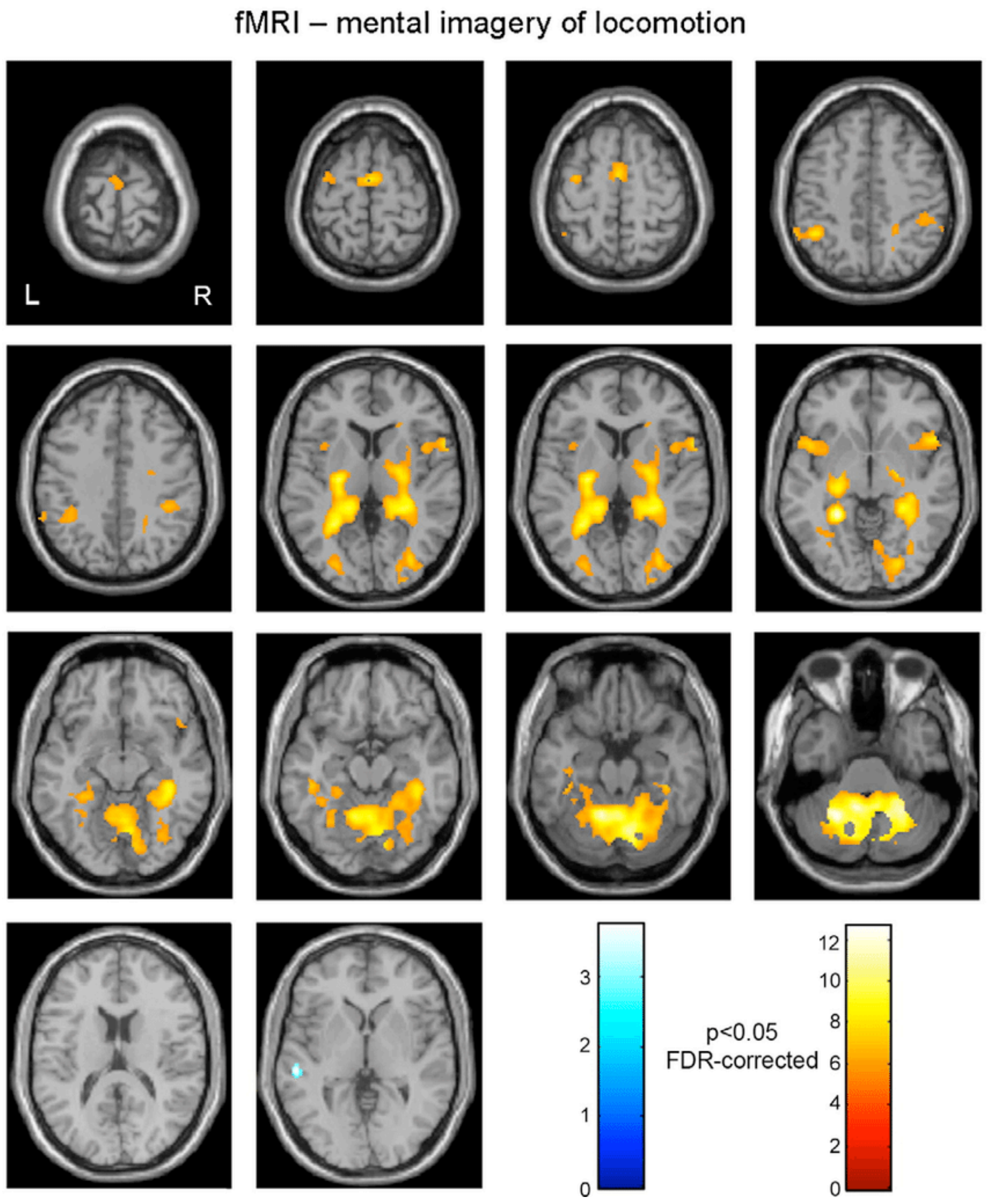


(McCormick and Telzer, 2018)

(Seligman et al. 2013)

The prospective brain

- **Interconnectedness of Memory and Future Thinking**: Episodic memory and future event simulation rely on similar processes, including the storage and recall of details and mental imagery. This suggests a common neural substrate for remembering past events and imagining future scenarios.
- **Simulation's Role in Counterfactual Reasoning and Understanding Others:** The ability to simulate different scenarios plays a key role in reasoning about hypothetical situations and understanding the mental states of others.
- **Evolutionary Advantage of Simulation Network**: The core neural network's ability to project into different times and perspectives may have provided an evolutionary advantage, shaping the neural architecture to support complex forms of prospection and social interaction.



(la Fougere et al. 2010)

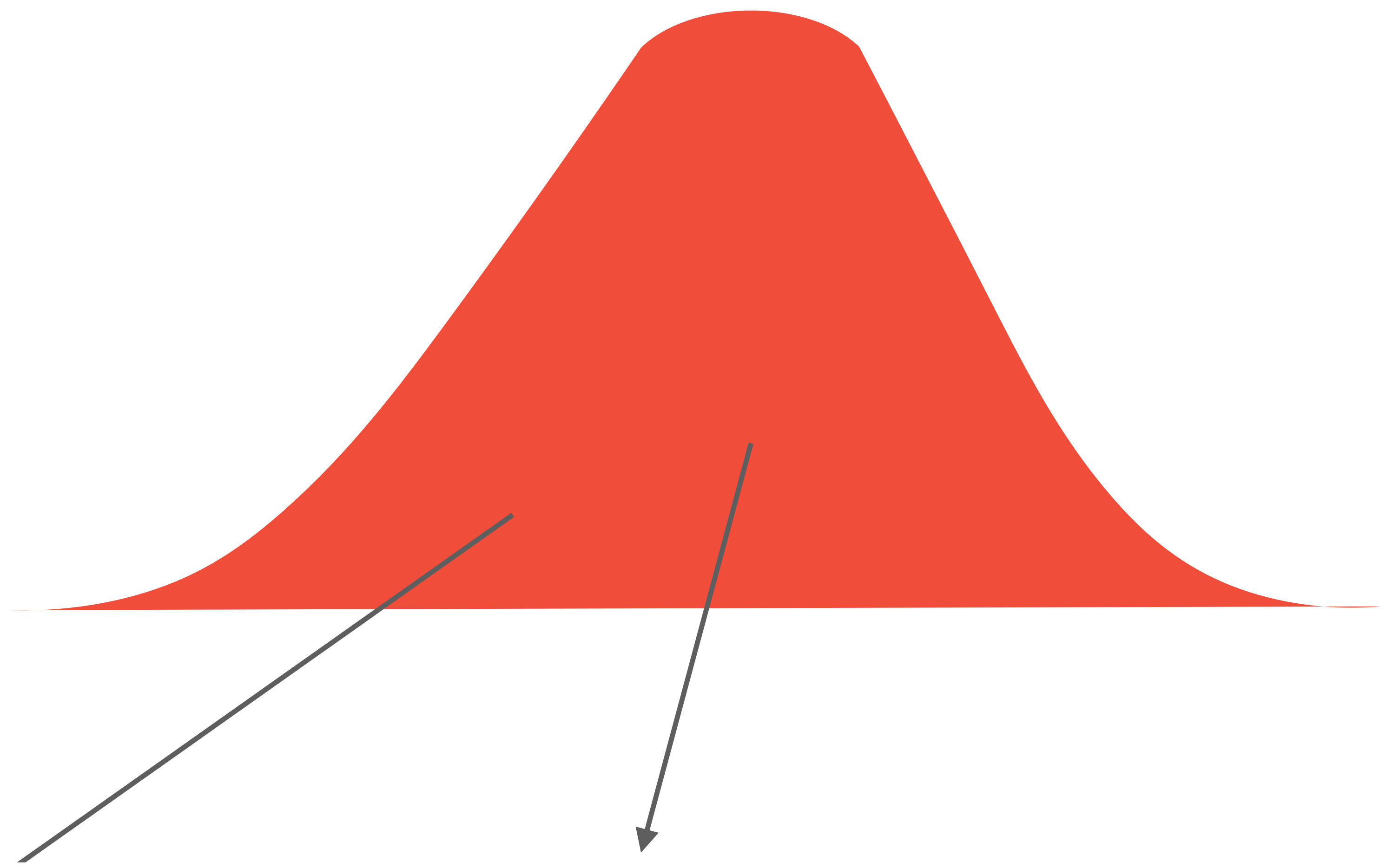
(Seligman et al. 2013)

Why we look forward when acting

Returning to the fundamental problem

Empirical Risk

$$E_{\text{risk}}\left(h, n, P\right) = \int_{\underbrace{(\mathbf{X},\mathbf{Y})_n}_{\text{train}}} \underbrace{R(h)}_{\text{risk}} \quad \underbrace{dP_{(X,Y)_n}}_{\text{distribution}}$$



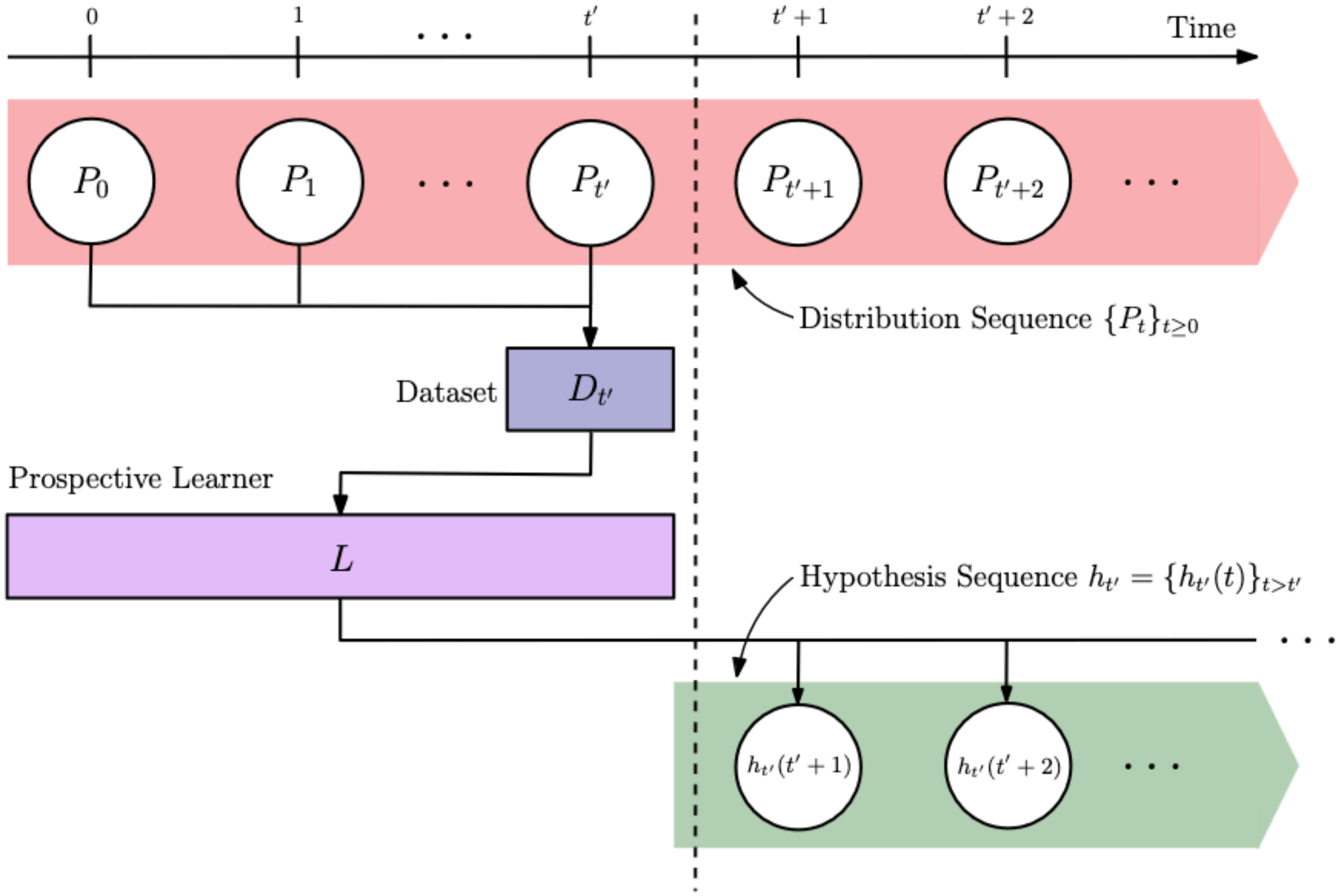
Assumption: Both the training and test data come from the same distribution.

(Vlastelica 2019; Vapnik 1991)

Is the future like the past?

The future is *correlated* with the past, but not identical to it. Thus the *i.i.d.* assumption of risk minimization breaks down.

How do we learn for the future?



(Vogelstein et al. 2022)

Prospective learning

Prospective learning defines a learning problem of minimizing risk in contexts where the distribution that you learn from (past) and the distribution you act with (future) are correlated but not identical.

Goal:

minimize $\mathcal{E}'\left(\text{do}(h), n, P\right)$,
subject to $g \in \mathcal{G}', h \in \mathcal{H}', \& P \in \mathcal{P}'$,

Form:

$$\mathcal{E}'\left(\text{do}(h), n, P\right) = \underbrace{\int_{(\mathcal{X},\mathcal{Y})_{\text{past}}}}_{\text{possible past}} \underbrace{\int_{(\mathcal{X},\mathcal{Y})_{\text{future}}}}_{\text{possible future}} \underbrace{\ell_{\text{future}}\left(\text{do}(h(X)), Y\right)}_{\text{loss function}} \underbrace{dP_{X,Y}^{\text{future} \mid \text{past}}}_{\text{distribution}} \underbrace{dP_{X,Y}^{\text{past}}}_{\text{distribution}}$$

(Vogelstein et al. 2022)

Take home message

- As this class has shown, even simple organisms can make complex decisions to explore their environment and learn to solve basic problems (assuming the past and future are similar enough)
- Animals with complex nervous systems learn and plan *for the future*, extracting information necessary to resolve novel problems effectively and expediently.

Final break out group discussion

- What capacities would an intelligence need in order to do prospective learning? Create a list of necessary capacities and explain why they are needed to learn for the future.