Prediction, Resilience to Change, and Evolution of Consciousness

Yoonsuck Choe
Dept. of Computer Science and Eng.
Texas A&M University
College Station, TX, USA
choe@tamu.edu

Jaerock Kwon
Dept. of Electrical and Computer Eng.
Univ. of Michigan-Dearborn
Dearborn, MI, USA
jrkwon@umich.edu

Jaewook Yoo
AI&Software Center
Samsung Adv. Inst. of Tech.
Suwon, Korea
jaewook.yoo@samsung.com

***Abstract*—Various aspects of brain operation at all scales depend on temporal functions and properties such as delay, recurrent dynamics, etc. In this work, we discuss how predictive properties in the brain dynamics may allow the agent to be resilient to changes in the environment, thus leading to higher chance of survival; and how this could serve as an evolutionary precursor of consciousness.**

***Index Terms*—Prediction; Brain dynamics; Resilience; Evolution; Consciousness**

I. Introduction

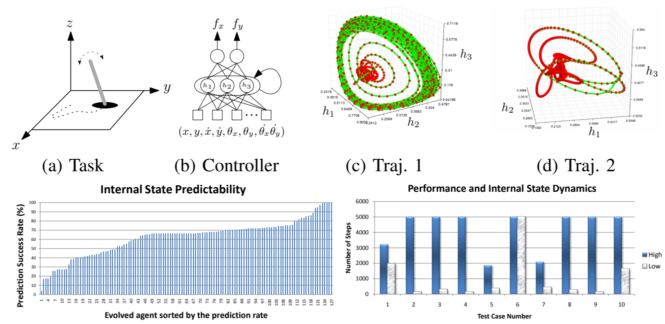
To understand the brain, it is important to investigate the internal dynamics of the brain [1]. In this work, we develop a measure of predictability in brain dynamics, and apply it to a simple recurrent neural network (RNN) controller in a simulated experiment (Figure 1), and use it to analyze the degree of consciousness in brain EEG data (Figure 2).

II. Experiment and Results

First, we set up a simple simulation experiment with a genetically evolved recurrent neural network (RNN) controller in a 2D pole balancing task (Figure 1a&b). We measured the predictability in the internal state dynamics (i.e., how accurately can the state at time t be predicted based on those at time $t-1$, $t-2$, ... $t-m$)[1] of the RNN controllers (e.g., see Figure 1c&d). Figure 1e show the predictability of 127 equally high-performance RNN controllers. This alone might suggest predictability does not matter (since they are all high-performance), but when we changed the environment (made the task more difficult by tilting the pole more, initially), we found that controllers with more predictable dynamics (Figure 2f "High" [Blue]) are more resilient than those will less predictable dynamics (Figure 2f "Low" [White]).

Next, we hypothesized that such predictive internal dynamics may underlie consciousness (see [3] for the rationale), so we analyzed the predictability in human EEG signals during awake, REM sleep, and slow-wave sleep, to test our hypothesis [3]. We find that internal state prediction error is lower in awake and REM sleep conditions (when subjects are "conscious") compared to that during slow wave sleep (deep sleep, thus "unconscious").

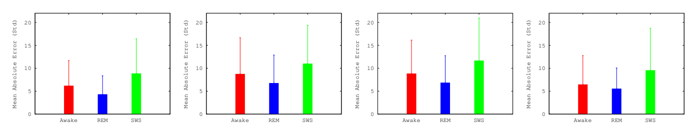
[1]This is measured by training a multilayer perceptron, with a supervised learning data set constructed from trajectories like Figure 1c&d.



(a) Task (b) Controller (c) Traj. 1 (d) Traj. 2

(e) Internal state predictability (f) Performance

Fig. 1. **Internal dynamics of a simple recurrent neural network controller in a 2D pole balancing task.** Traj 1 is more predictable than Traj 2. [2].



(a) Subj1 pred. err (b) Subj2 pred. err , (c) Subj3 pred. err (d) Subj4 pred. err

Fig. 2. **Prediction error in EEG time series during Awake, REM sleep, and Slow Wave Sleep.** [3].

III. Discussion and Conclusions

We showed that predictable internal dynamics may be intricately related to the resilience of an organism, and due to this, evolution may have promoted agents that have such an internal brain property. It also happens that this property may be a necessary condition of consciousness, thus our work also suggests how consciousness may have evolved. It is interesting to compare our work to that of Tani [1] (see Chapter 7): His emphasis of predictive dynamics is more on prediction of sensory consequences of action, which makes our work distinct from his, yet complementary.

References

[1] J. Tani, *Exploring robotic minds: actions, symbols, and consciousness as self-organizing dynamic phenomena*. Oxford University Press, 2016.

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