BME595 DEEP LEARNING Final Report
Towards Biologically Plausible Predictive Coding

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Abstract Predictive Coding is a long existing computational neuroscience theory which provide a framework for understanding redundancy reduction and efficient coding in the brain. There are different versions of predictive coding, either from theory derivation side or from neural network implementation side. In this work, we start from [1], comparing and integrating different aspects of the theory and propose a new neural network implementation of predictive coding. This approach is more biologically plausible than previous reported versions and experiment result shows that our framework achieves lower prediction error.

1 Introduction

As brain receives lots of visual signals which are highly redundant, there must be a efficient coding and transferring model in the brain that captures the spatial and temporal tendency of visual sensation and learns the internal model of the external world. In other words. In the informatic point of view, the neural system minimize the internal description length of visual information and optimize the posterior probability of the outside world. Let *r* represent internal parameters and *I* represent sensations, than we have following principles:

$$P(r|I) = P(I|r)P(r) / P(I)$$

$$H(P(r|I)) = -\log(P(I|r)) - \log(P(r)) + \text{constant}$$

One possible way of efficient dataflow in the hierarchical architecture of brain is that each higher stage makes prediction of the lower stage and the difference between lower stage prediction and true lower stage is sent back to update the state of higher stage. Thus the lowest stage is making the prediction of the external sensation. Originally proposed by [1], predictive coding theory is latter extended by [2], showing that a particular form of biased competition, in which neurons compete to receive inputs, is equivalent to predictive coding while the residual error is computed through lateral inhibitory connections (Fig. 1A). Researchers also gives the modern neural network implements of predictive coding [3]. However, in the implementation of [3] the information is transferred between layers through uploading error signal (Fig 1B), while in computational neuroscience predictive coding the higher stage is predicting lower level stage, not the lower level error.

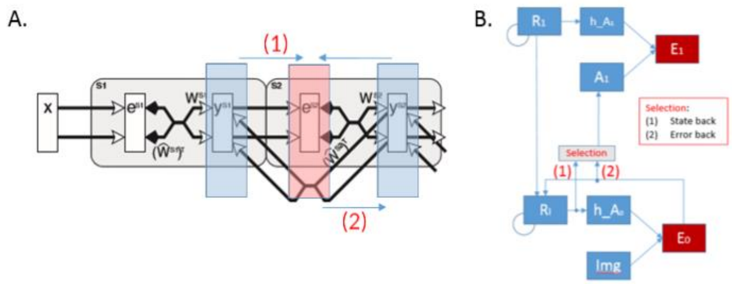

Figure 1 Two different implementation schemes in literatures. (1) represents state feedback and (2) represents error signal feedback. A. The scheme proposed by computational neuroscience [1] & [2], which feed state signal back; B. The scheme transferring error signal between different layers, which is proposed by[3].

Therefore there is an inconsistency between neuroscience predictive coding and modern deep-learning way of predictive coding. Towards filling this gap, we implement the similar structure as in [1, 2 & 4] to see the advantage and bottleneck of it. After analysis and improvement, we get a stable and efficient version, embedding the traditional neuroscience approach within modern neural network implementation.

2. Layer Depth Performance Comparison of PredNet

The scheme in [2] transfer the error signal between nearby layers, meanwhile the whole network is working on minimizing the error signal. So it is reasonable to doubt whether the higher levels of PredNet in [2] is actually learning something or of no real use. We compare the performance by using prediction error and replication error (Fig. 2A), finding that deep architecture is indeed helpful to improve the prediction accuracy of the network and enables the PredNet to learnthe internal representation and predict rather than simply replicating the last frame (Fig. 2BCD).

3. Update Scheme Affects the Prediction Accuracy of State Back Mode

We found that simply removing the link between lower error signal and higher input and linking the lower state signal to higher input cannot increase the accuracy performance. Instead, this will worse the prediction accuracy a lot. One vital reason is due to the update scheme of LSTM. LSTM usually synchronizes all its input and update once during one iteration. However, as for PredNet, different LSTM-input signals are not generated at the same time (Fig. 3). The input from higher state comes later and makes the error signal delayed for 1 iteration. The signal tracing illustrating the delay problem is shown in Fig. 3.

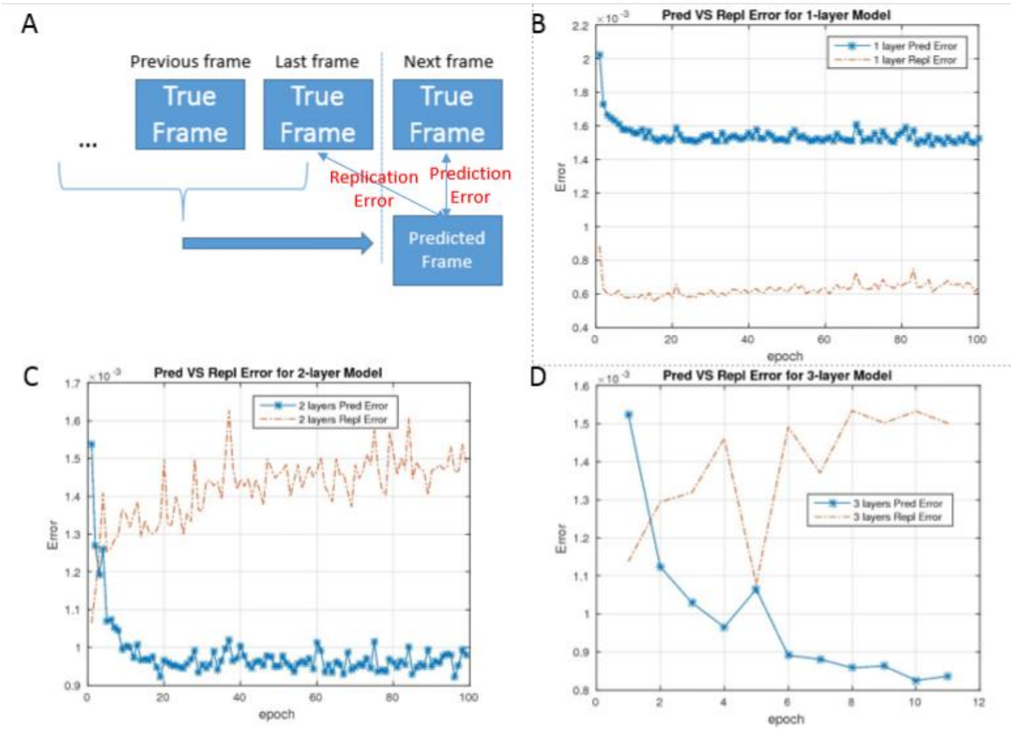

Figure 2 Comparison of prediction performance between different layers. A. Prediction Error is defined as the square error sum between predicted frame and the true nest frame; Replication Error is defined as the square error sum between predicted frame and last frame. B. C. D. The performance measurement of 3 different depths and the comparison. It shows that 1-layer version is just replicating the last frame while deep versions are really learning something.

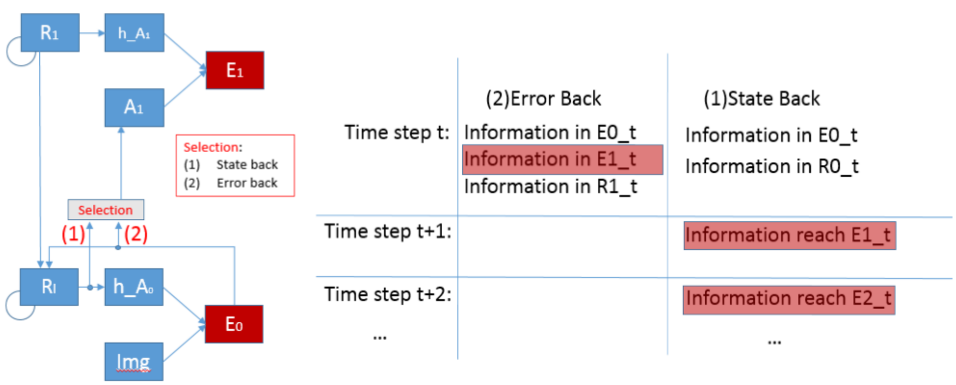

Figure 3 Trace of key information flow for state back version and error back version. If we only update R_l once during each iteration, under state back mode, the error signal cannot reach corresponding state representations in time, but in error mode there is no such problems

4. Comparing the final version (MatchNet) with previous version (PredNet).

We implement and compare state-back scheme and error-back scheme, also to see whether rnn is enough for updating state, we implement both rnn realization and LSTM realization within each scheme. The result is shown in Fig. 4.

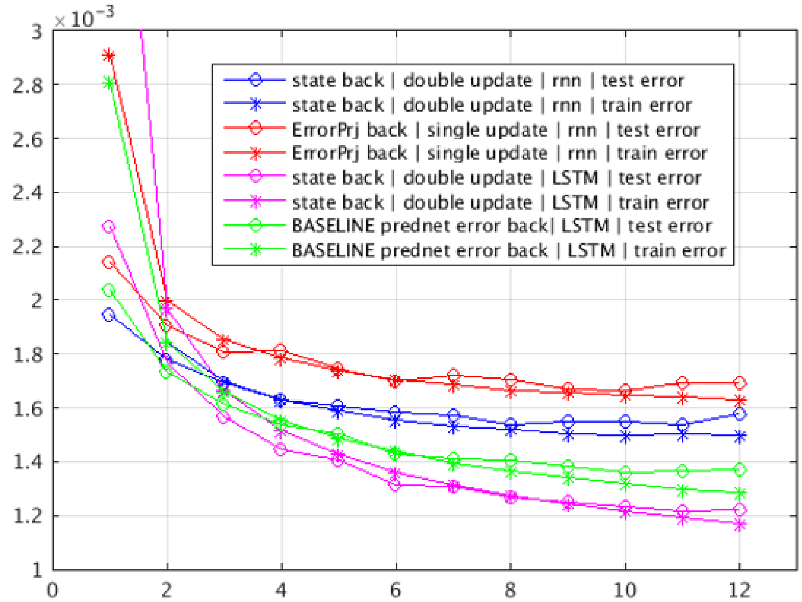

Figure 4. Comparison result between “State Back” and “Error Back”

5. Conclusion

The comparison result shows that bio-inspired predictive coding scheme indeed works better than original “error from error” one. Also, we see that using LSTM to update internal state works better than using rnn.

References

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