PREDICTIVE CODING FOR DEEP NEURAL NETWORKS

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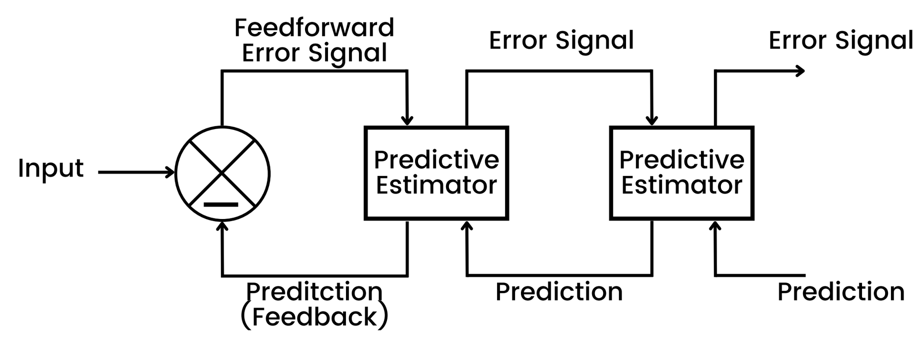
Predictive Coding is a popular framework in neuroscience for explaining cortical function. In this model, higher-level cortical areas try to predict lower-level neural activity and prediction errors are passed back to higher layers. Deep Neural Networks (DNN) , which use brain-inspired architecture, could be augmented with such a model, providing robustness and a better understanding of spatio-temporal dependencies. We investigate research in this direction and give a quick review on tasks in which Predictive Coding (PC) for DNN has demonstrated its interest, with a strong emphasis on vision-related tasks.

RAO & BALLARD



Rao & Ballard's Hierarchical model for predictive coding [4]

Activity of neurons in layer i

$$y^i = \underbrace{\alpha y^i}_{} + \underbrace{\beta W e^{i-1}}_{} - \gamma e^i$$

Feedback action of prediction by the upper layer

Feedforward transmission of previous layer residual error

$$e^i = y^i - \underbrace{V^{i+1}}_{} y^{i+1}$$

Residual error of layer i

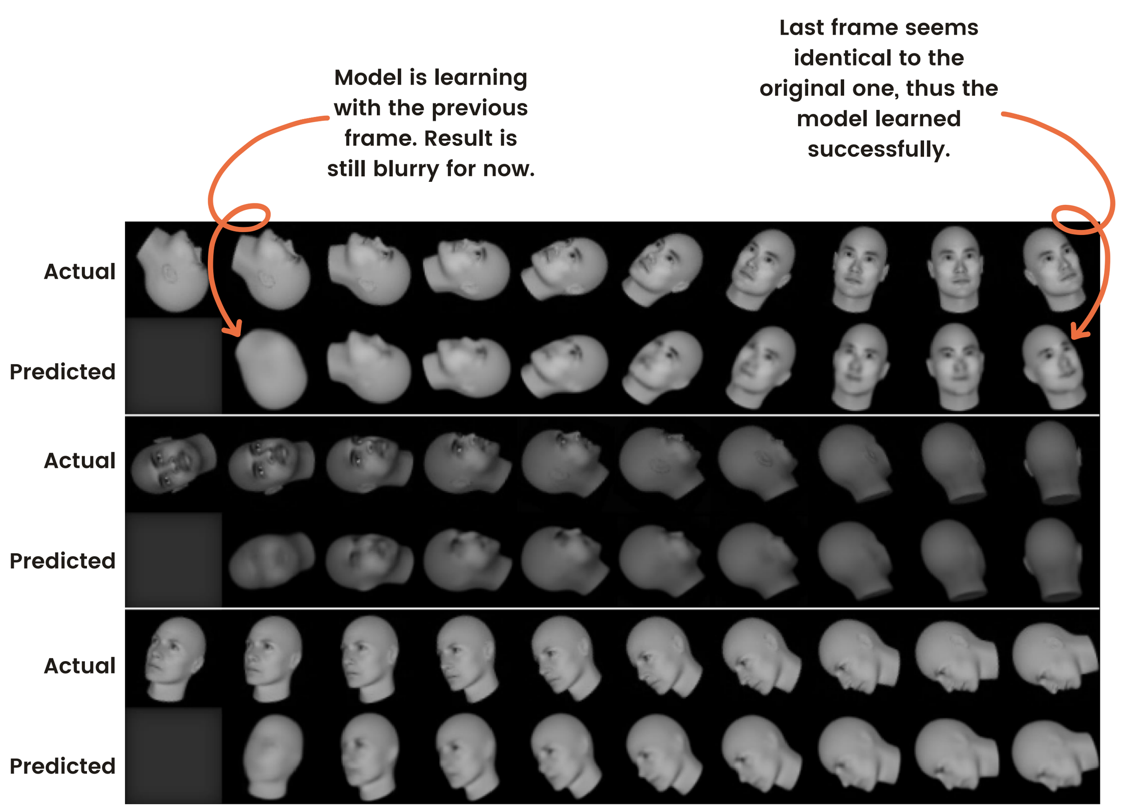
Weight of feedback connections between layer i and i+1

BIOLOGY

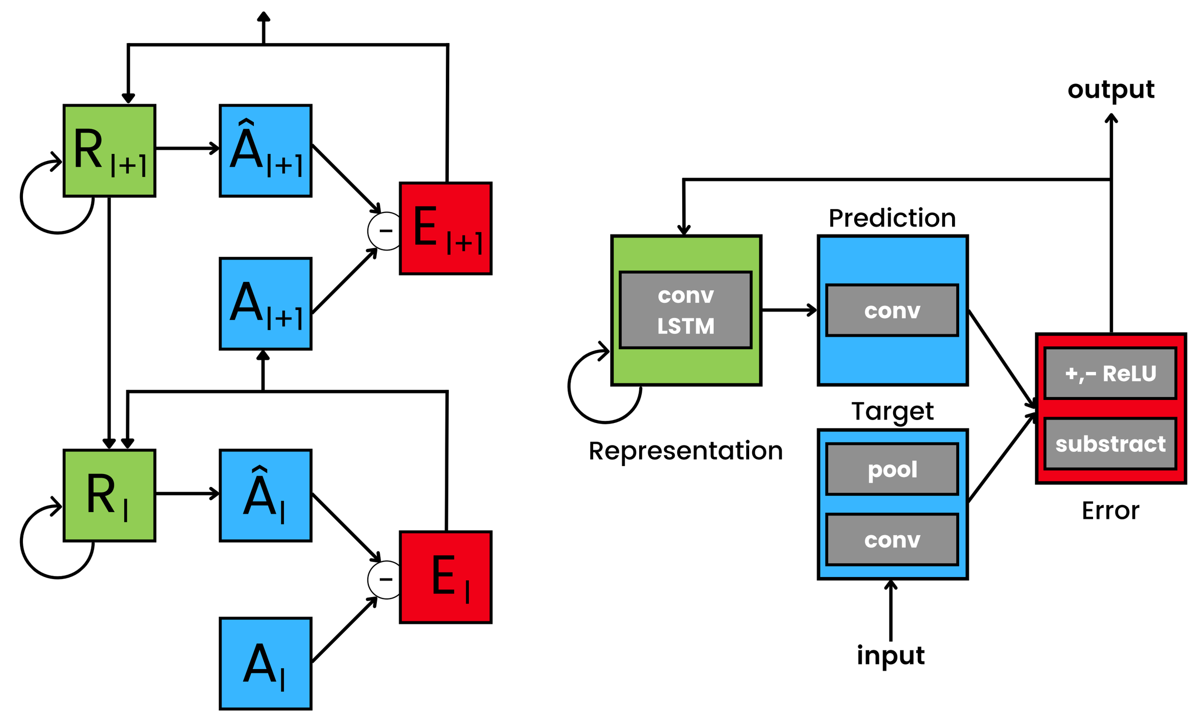
Alpha oscillations are historically the first observed oscillations by Electroencephalography. The article [1] has shown that a simple 2-level of PC model explains the emergence of alpha-band rhythms (neural oscillations, 8-12Hz) in the visual cortex.

PERCEPTION IN VIDEO

This task consists in trying to predict the next frame of a video, given all (or a part of) the previous ones. This is used in video games, to help graphic card to calculate the frames.



Next-frame predictions. [3]

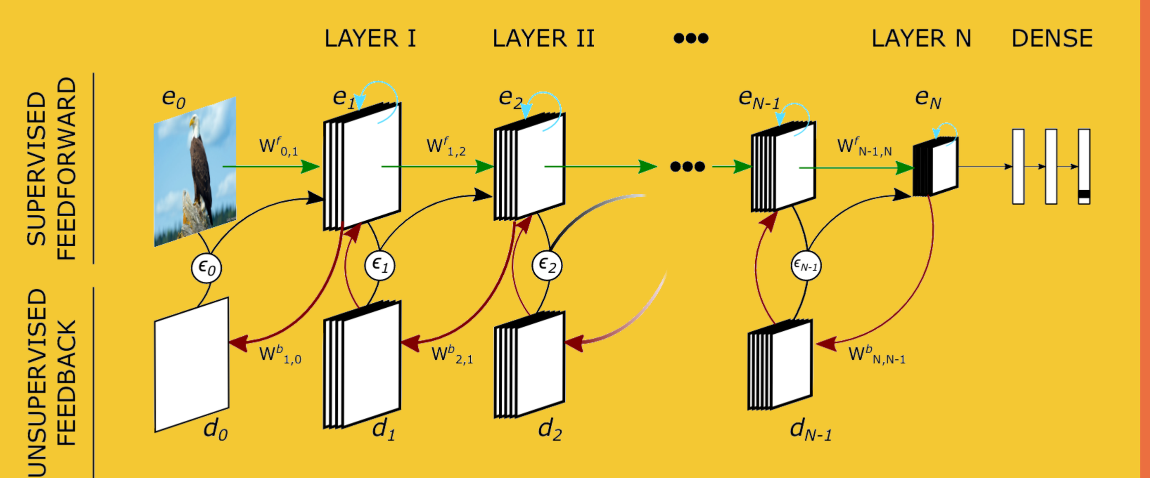


This is the PredNet model, used to predict next frame in a video. [3]

The model visible here is a succession of layers, and each layer predicts the next frame before sending the difference to the other layer.

TRAINING

The algorithm of error back-propagation is widely used to update parameters of a network. However, this update rule is considered as biologically implausible because of the non-locality of these updates. Using a variant of PC on the computational graph turned out to approximate exactly back-propagation. [5]



Predify's model for augmenting a CNN. The connections in green are the feedforward connections already existing in the CNN while blue and red ones are respectively recurrent and feedback connections. [2]

VISUAL PERCEPTION

CNN have reached good performances for tasks related to object recognition, classification, and segmentation, but they also have disclosed their limits and lack of robustness.
Most results in using PC for image classification tasks suggest that it provides robustness.

SIMILAR IDEAS

Auto-encoders

The concept of PC described here and some of the architectures considered (e.g. Predify [2]) are similar to stacked denoising auto-encoders [6]. The convolution and prediction layers of a CNN augmented with PC can be seen respectively as an encoder and a decoder.

FeedBack connections

The fact that the brains features not only feed-forward (bottom-up) but also lateral (recurrent) and feedback (top-down) connections is well known and massively supported by neurosciences observations. In CNN, feedback connections allow modifying the weights of the previous convolutional filter, which leads to focusing on specifics parts of the image.

Sparse Coding

Predictive coding implies imposing contextual prior knowledge on the representation of data. Sparse coding is also a biological inspired constraint on the representation of data (encouraging the proportion of activated neurons to be small, which is widely observed in cortical activity). However, sparse coding is a fixed prior that cannot adapt to a context while in a predictive coding framework these prior knowledge constraints are created contextually. Moreover, predictive coding is a much larger framework from a neurosciences point of view, whereas sparse coding is mainly this constraint.

Our state-of-the-art !

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CONCLUSION

The huge progression of DNN performances over the past years is mostly a consequence of the large quantity of computer science research in this domain that is allowed by its important potential in engineering. This led to more liberty regarding biological plausibility of architectures, which can be both beneficial to neurosciences,which may find in machine learning architectures interesting models, and of course to computer science because machine learning models end-up being more efficient.

The exchange between these two disciplines also occurs on the other way around. The human vision system remains way more efficient for general perception than computers while only requiring around 20 watts to work. A better understanding of the brain can probably lead to improvements in machine learning performances.