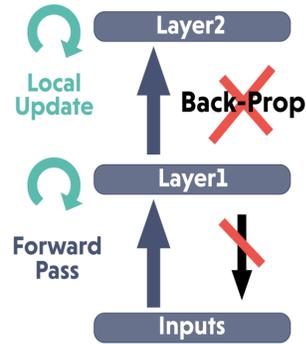


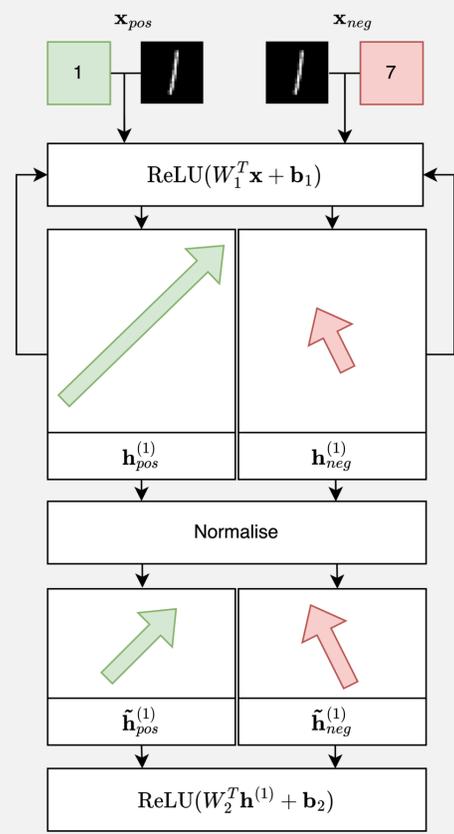


Method

The Forward-Forward algorithm is an **alternative to backpropagation** that computes **local** gradient updates without the need for a backward pass..



Training



$$\mathcal{L} = \sigma(\|\mathbf{h}_{neg}^{(1)}\|_2 - \theta) - \sigma(\|\mathbf{h}_{pos}^{(1)}\|_2 - \theta)$$

$$g = \|\mathbf{h}\|_2$$

Figure 1: During Training, maximize goodness for positive data and minimize goodness for negative data.

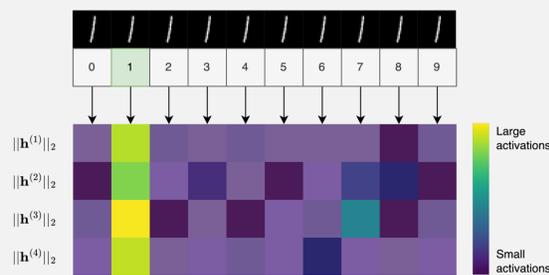
Motivations

- Local updates allow for asynchronous layer updates
- Biologically plausible
- Can be run on analog computers
- Can be easily adapted for unsupervised learning

Limitations

- Replace backpropagation outside of low-power environments
- Learns slower than backpropagation
- Lower layers do not receive higher-layer feedback

Inference



$$\hat{c} = \operatorname{argmax}_c \sum_{l=1}^{N_l} \|\mathbf{h}^{(l)}(c)\|_2$$

Figure 2: During inference, the label leading to largest activations is chosen.

Findings

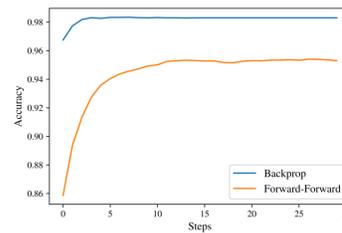


Figure 3: Performance of backpropagation vs Forward-Forward.

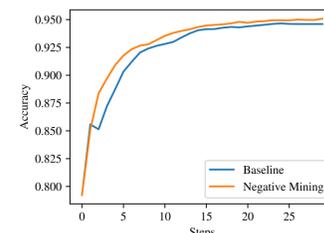


Figure 4: Hard negative mining improves accuracy.

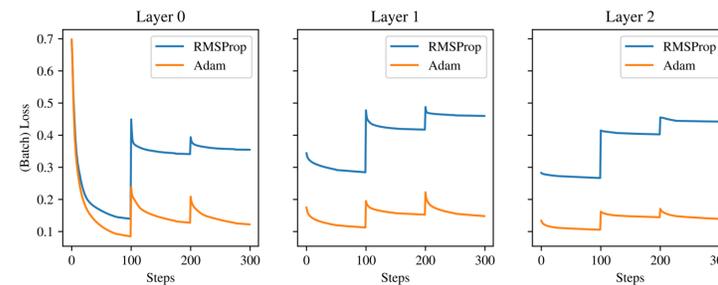


Figure 6: Adam significantly outperforms RMSProp, SGD never converges.

First Layer Features

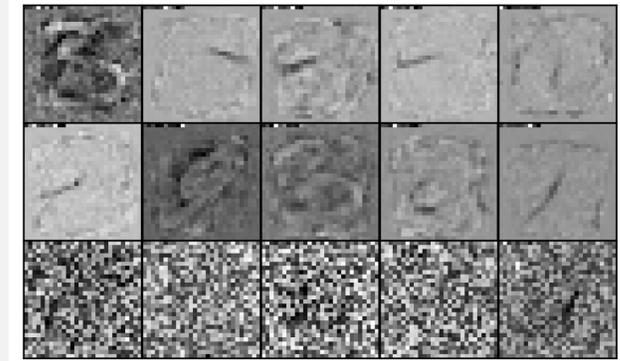
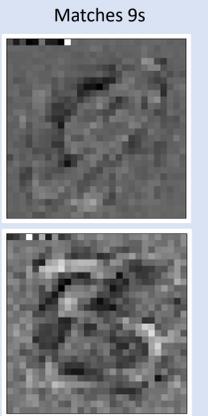


Figure 5: Some neurons learn sensible features (top), others do not (bottom).



Matches 3s

Extensions

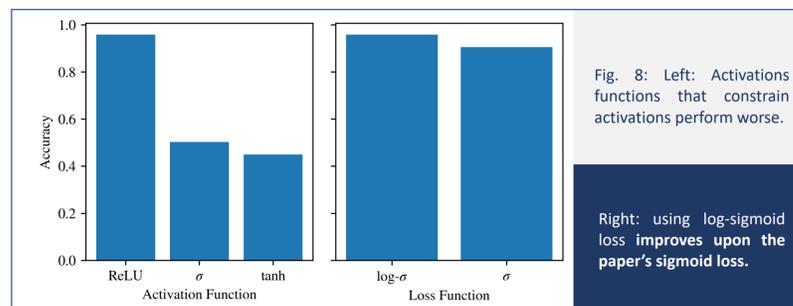


Fig. 8: Left: Activations functions that constrain activations perform worse.

Right: using log-sigmoid loss improves upon the paper's sigmoid loss.

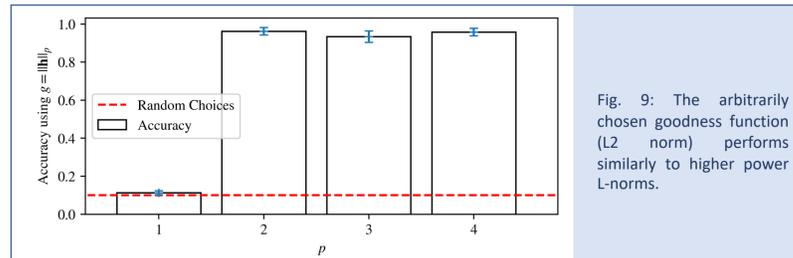
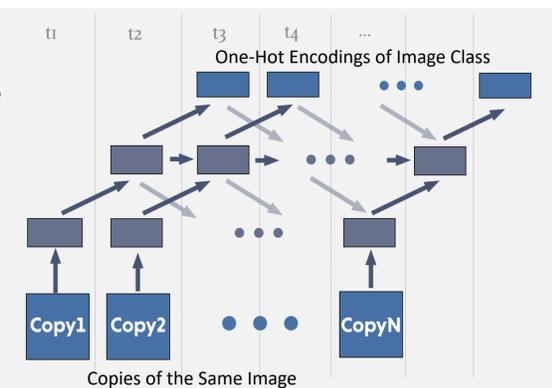


Fig. 9: The arbitrarily chosen goodness function (L2 norm) performs similarly to higher power L-norms.

Future Work

Replicate and explore the recurrent version of FF.

Figure 10: Recurrent architecture that resolves the major weakness of FF: copies of static image form a 'video' that enables learning of later layers from earlier layers.



References

[1] Hinton, Geoffrey. "The forward-forward algorithm: Some preliminary investigations." *arXiv preprint arXiv:2212.13345* (2022).



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