# Feedback-Gated Rectified Linear Units

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## Abstract

Feedback connections play a prominent role in the human brain but have not received much attention in artificial neural network research. We propose a biologically inspired feedback mechanism which gates rectified linear units...

## 1. Introduction

Neocortex structure, clearly feedback plays a role

## 2. Neuroscientific Background

### 2.1. Neocortex

The neocortex, part of the cerebral cortex, is a part of the brain that evolved in mammals comparatively recently. It comprises around 80% of the human brain (Markram et al., 2004) and is therefore often speculated to be responsible for the emergence of higher intelligence.

The most abundant type of neuron in the neocortex are pyramidal neurons, constituting between 70-85% of cells. In contrast to the remaining neurons in the neocortex, so called interneurons, which are mostly inhibitory, pyramidal neurons are excitatory (DeFelipe & Fariñas, 1992).

AS the name suggests, pyramidal neurons have a cell body roughly shaped like a pyramid, with a base at the bottom and an apex at the top. Pyramidal neurons have two types of dendrites: basal dendrites, originating at the base, and one apical dendrite, originating at the apex. This apical dendrite terminates in what is called the apical tuft, where it branches off into ...(DeFelipe & Fariñas, 1992).

These apical and basal dendrites are not just differently located, but also serve different functions. Basal dendrites receive regular feedforward input, while the apical tuft dendrites receive feedback input.

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The neocortex appears to have a distinct structure which is characterised by its organisation into layers as well as columns. The columnar organisation is based on the observation that neurons stacked on top of each other tend to be connected and have similar response properties, while only few connections exist between columns. Columns are hence hypothesised to be a basic functional unit in the cortex, although this is somewhat debated in the neuroscience community (Goodhill & Carreira-Perpiñán, 2002).

The further organisation into six layers was proposed by Brodman in 1909 [citation]. Layers 1 and 6 are of particular interest here. Layer 1 consists of almost no cell bodies, but mostly connections between axons and the apical dendrites of pyramidal neurons (Shipp, 2007), i.e. is serves as a connection hub for feedback signals. Layer 6 sends signals to neurons in the thalamus which then in turn sends signals to layer 1 neurons in the same column (Shipp, 2007), i.e. layers 1 and 6 create a loop where feedback is sent from layer 6 and received by layer 1.

### 2.2. Distal Input to Pyramidal Neurons

$$f = g(\mu_S + \alpha\mu_D + \sigma + f\beta(\mu_D) - \theta) \tag{1}$$

where $f$ is the firing rate of the neuron, $g$ the gain, $\mu_S$ the average somatic current (i.e. feedforward input), $\mu_D$ the average distal current (i.e. feedback input), $\alpha$ is an attenuation factor, $\sigma$ represents fluctuations in the current, $\theta$ is the firing threshold, and $\beta(\mu_D)$ is an increasing function of the dendritic mean current which saturates for values above some current threshold.

## 3. Feedback Gated Rectified Linear Units

To arrive at something closer to a ReLu, $g$ and $\theta$ are dropped from equation 1, since the threshold is modelled through the bias unit and the gain (i.e. slope) of a ReLu is by definition 1 and can thus be safely dropped. Dropping the summands $\alpha\mu_D$ and $\sigma$ is less justifiable, but since they do not contribute to the core property of gain increase, they will be disregarded here, arriving at the following simplified relationship:

$$f = \mu_S + f\beta(\mu_D) \tag{2}$$

Removing $f$ from the right hand side:

$$f = \frac{1}{1 - \beta(\mu_D)} \mu_S \tag{3}$$

What remains is an exact definition of $\beta(\mu_D)$, which, according to (Larkum, 2004), is “an increasing function of the dendritic mean current $\mu$ which saturates for values above 1000pA“. In other words, the function is bounded, i.e. the gain cannot be increased to arbitrarily high values. Accordingly, some maximum value $\beta_{max}$ the function can produce and a threshold value $\eta$ which describes when this maximum is reached need to be defined. Assuming a piecewise linear model, $\beta(\mu_D)$ is thus defined as follows:

$$\beta(\mu_D) = min\left(\frac{\beta_{max}}{\eta} \mu_D, \beta_{max}\right) \tag{4}$$

As there are no obvious values to assign to $\beta_{max}$ and $\eta$, they are treated as hyperparameters. Since setting $\beta_{max}$ to 1 results in a division by 0 and a value of $\beta_{max} > 1$ causes a negative slope, $\beta_{max}$ should be smaller than 1.

Plugging equation 4 into equation 3 yields:

$$f = \frac{1}{1 - min(\frac{\beta_{max}}{\eta}\ \mu_D, \beta_{max})}\ \mu_S \tag{5}$$

Since negative values for $\mu_S$ are not taken account, it is replaced with $max(0, \mu_S)$, i.e. the classic ReLu function:

$$f = \frac{max(0, \mu_S)}{1 - min(\frac{\beta_{max}}{\eta}\ \mu_D, \beta_{max})} \tag{6}$$

### 3.1. Incorporation of Feedback Gated ReLus into ANNs

Feedback comes from higher layers, freedom to decide what exactly sends feedback to what

Since feedback from higher layers can only be computed if these higher layers have received feedforward input, multiple time steps are needed to incorporate the modified ReLus into a network. Concretely, some data, e.g. an image is fed into the network twice, where the first pass enables the computation of feedback which can be utilised in the second pass.

## 4. MNIST

## References

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