Long range horizontal connectivity : Cost-effective circuit for natural image perception

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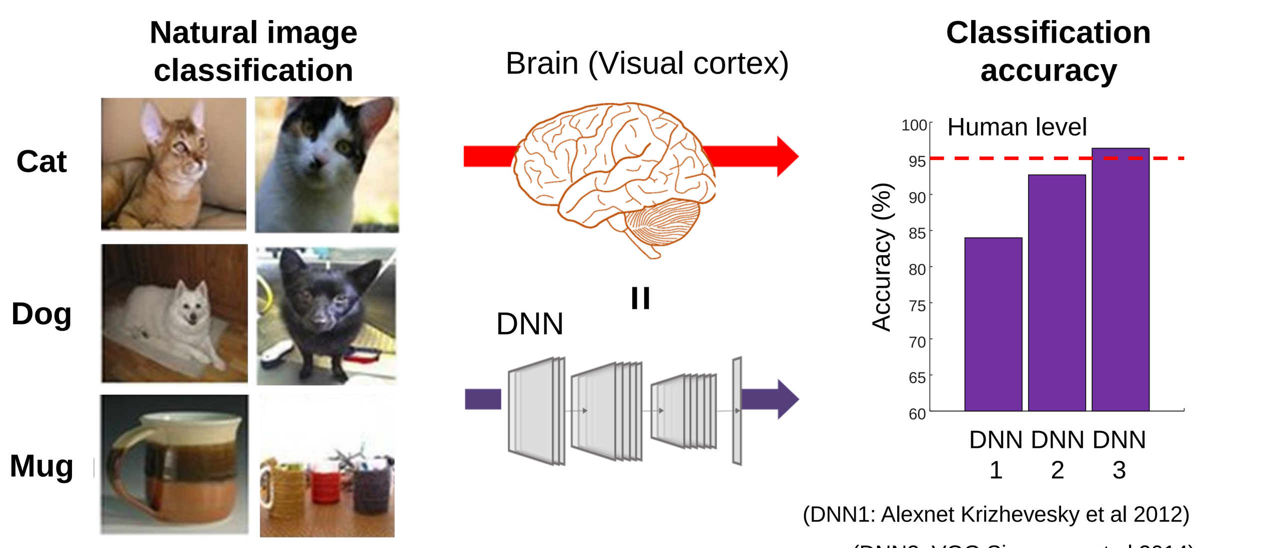
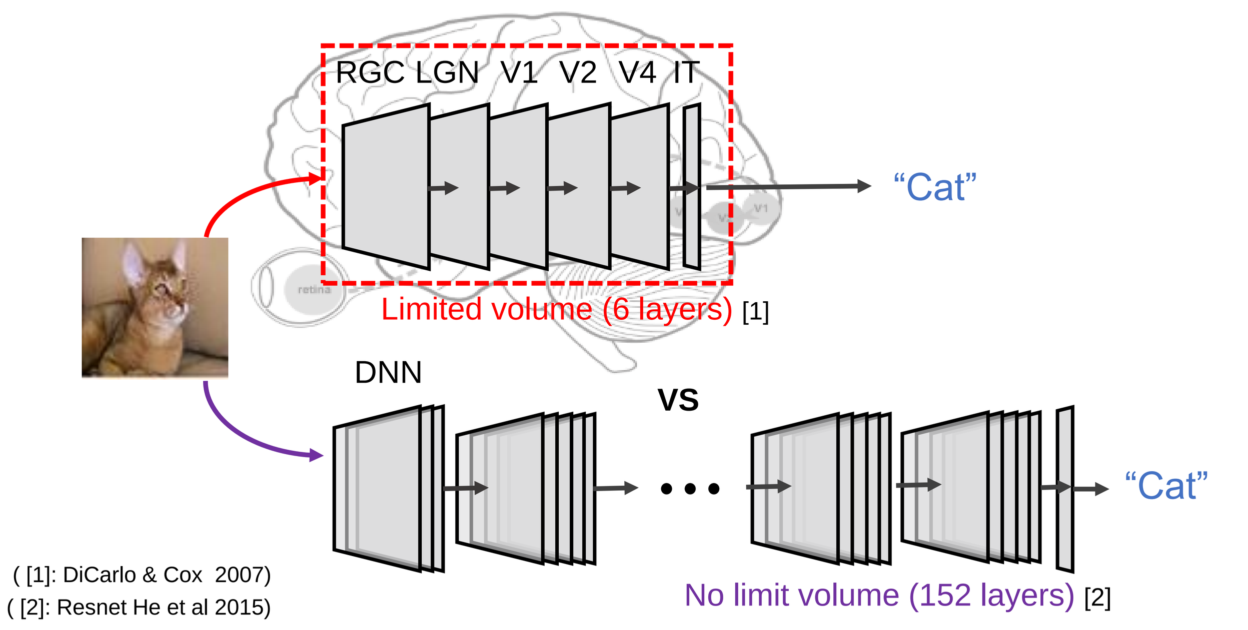
Introduction

Visual cortex and deep neural network (DNN) both excel in natural image perception



(DNN1: Alexnet Krizhevesky et al 2012)
(DNN2: VGG Simonyan et al 2014)
(DNN3: Resnet He et al 2015)

Visual cortex consists of fewer layers than DNNs, presumably due to the limited volume of the brain



([1]: DiCarlo & Cox 2007)
([2]: Resnet He et al 2015)

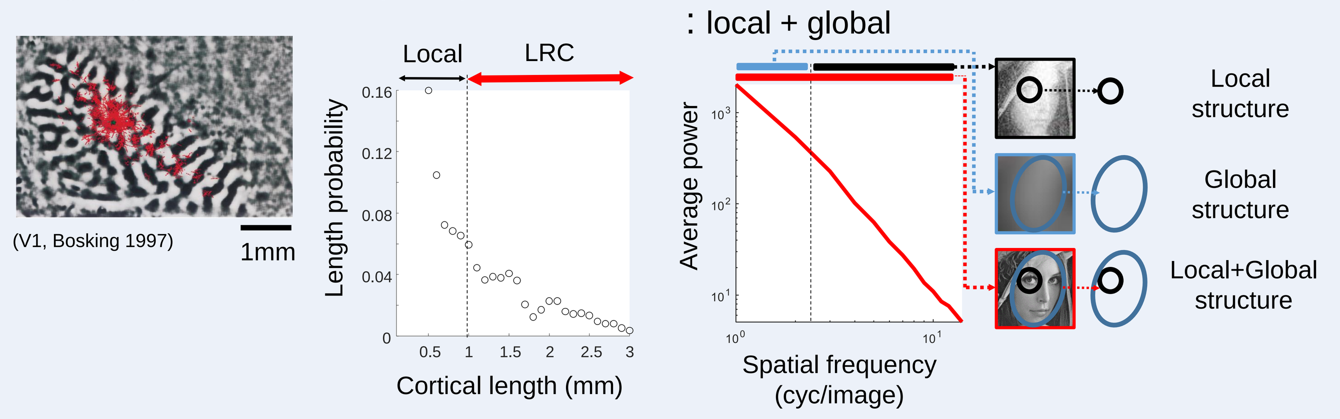
Q. What is the structure of the brain to recognize natural image efficiently ?

Hypothesis

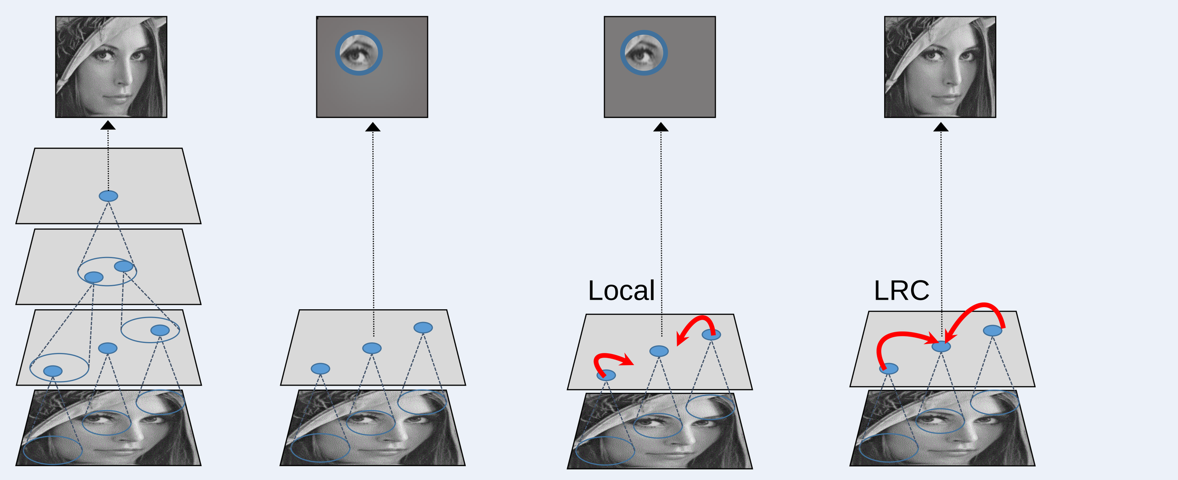
Long-range horizontal connections may allow cost-effective perception for natural image by integrating global information efficiently

Long rage connection (LRC)

Spatial structure of natural image : local + global



Encoding spatial structure of natural image



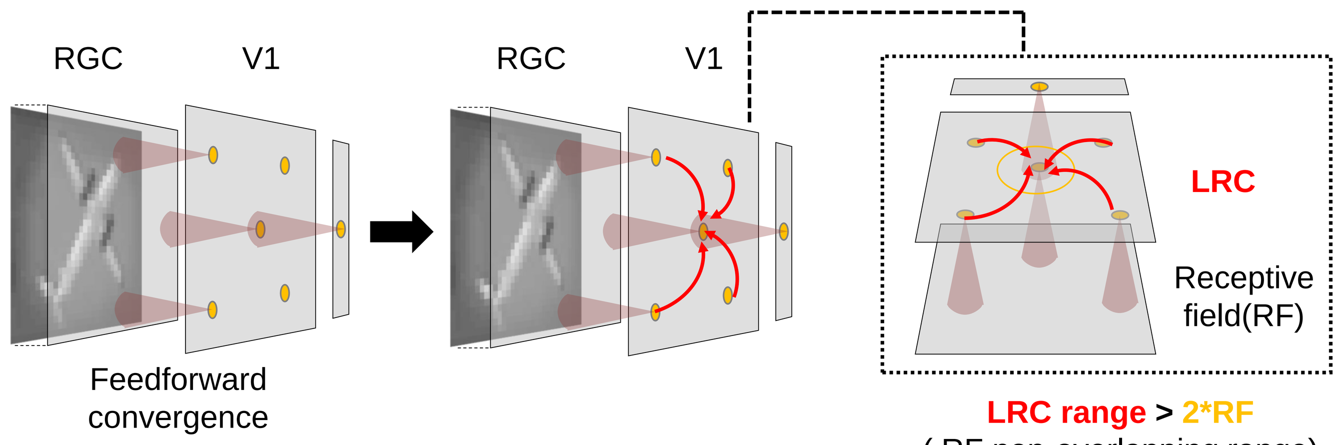
→ The combination of long-range horizontal connections and local convergent connections enables efficient coding of the natural image

Methods

Model network of visual pathway

- **Basic structure** : 3 layer MLP

1) **feedforward** - convergence connection
2) **lateral** – intra-layer connections



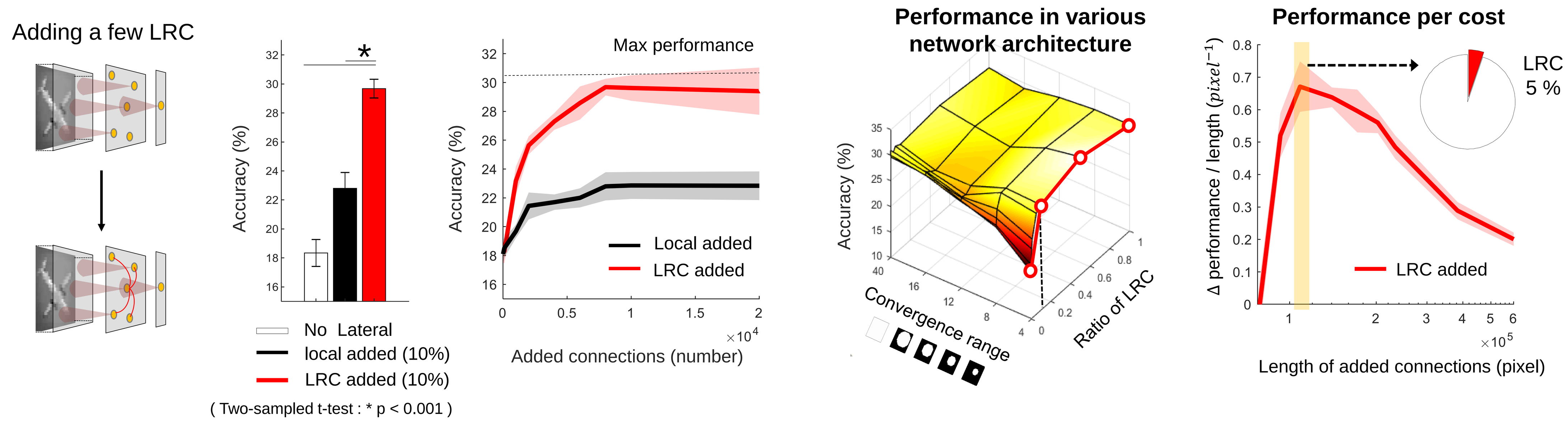
LRC range > **2*RF**
(RF non-overlapping range)

Task : image classification

- **Dataset**: Cifar-10 (Natural image)
- **Training**: minimizing error of network's prediction by updating weights

Results

LRCs dramatically improve natural image classification performance

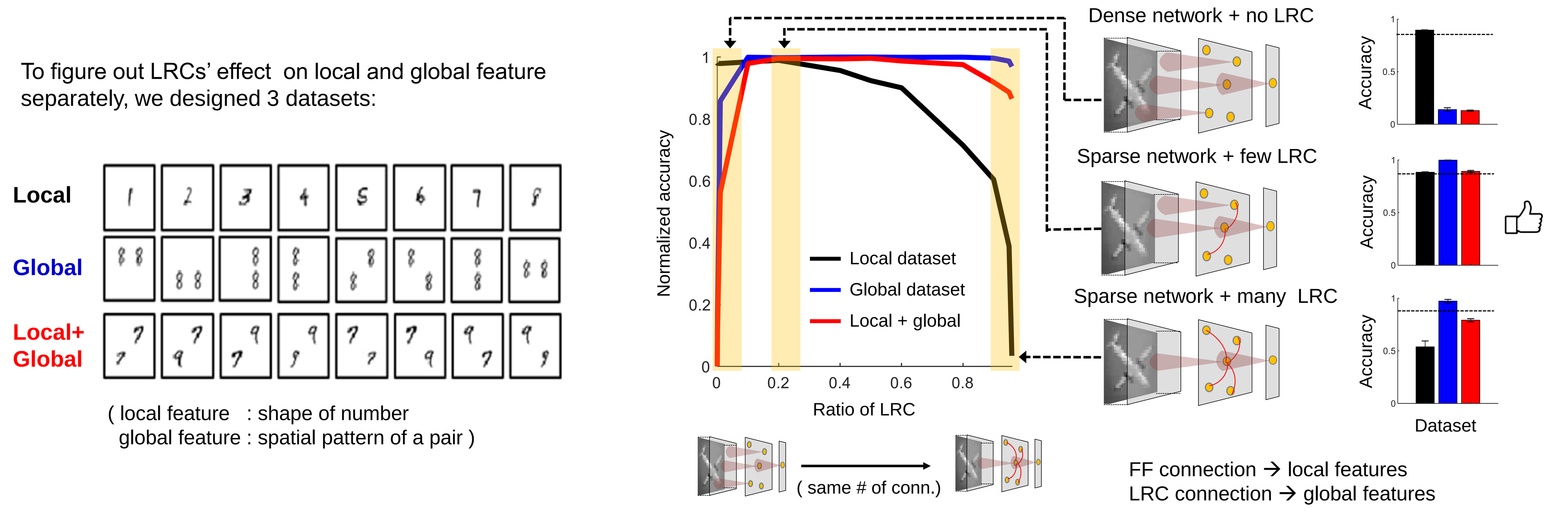


By adding only a small number of LRCs to the FF network, the performance of the network dramatically increased

The combination of a few LRC with local convergent connections maximize the cost-effectiveness of connections

LRCs contribute particularly to encoding global structure of input image

To figure out LRCs' effect on local and global feature separately, we designed 3 datasets:

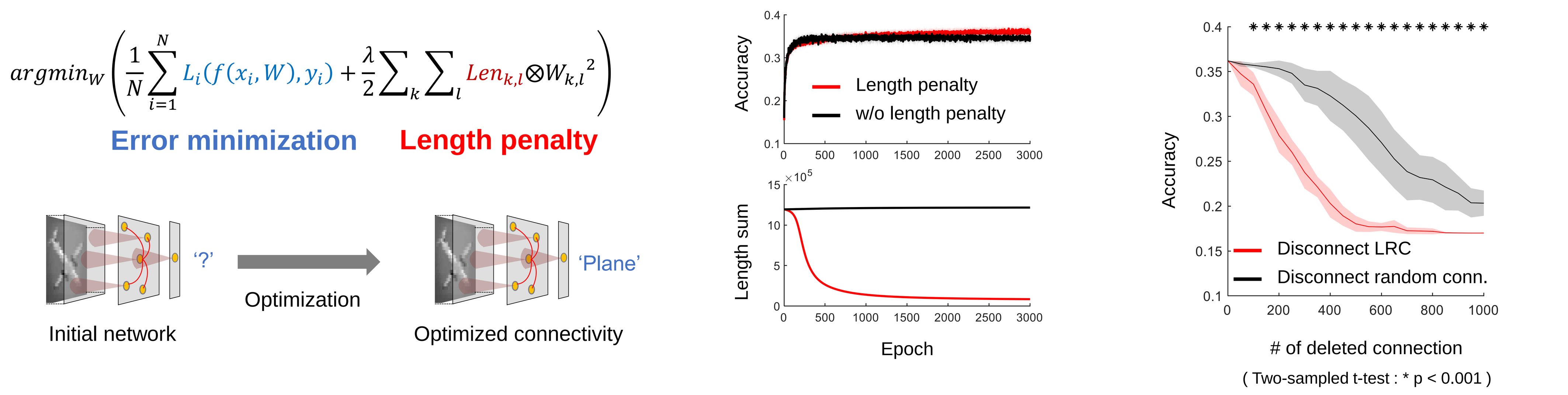


FF connection → local features
LRC connection → global features

LRC can be spontaneously evolved on the model network when total connection length is limited

$$\operatorname{argmin}_W \left(\frac{1}{N}\sum_{i=1}^{N} L_i(f(x_i, W), y_i) + \frac{\lambda}{2}\sum_k \sum_l Len_{k,l} \otimes W_{k,l}{}^2 \right)$$

Error minimization **Length penalty**

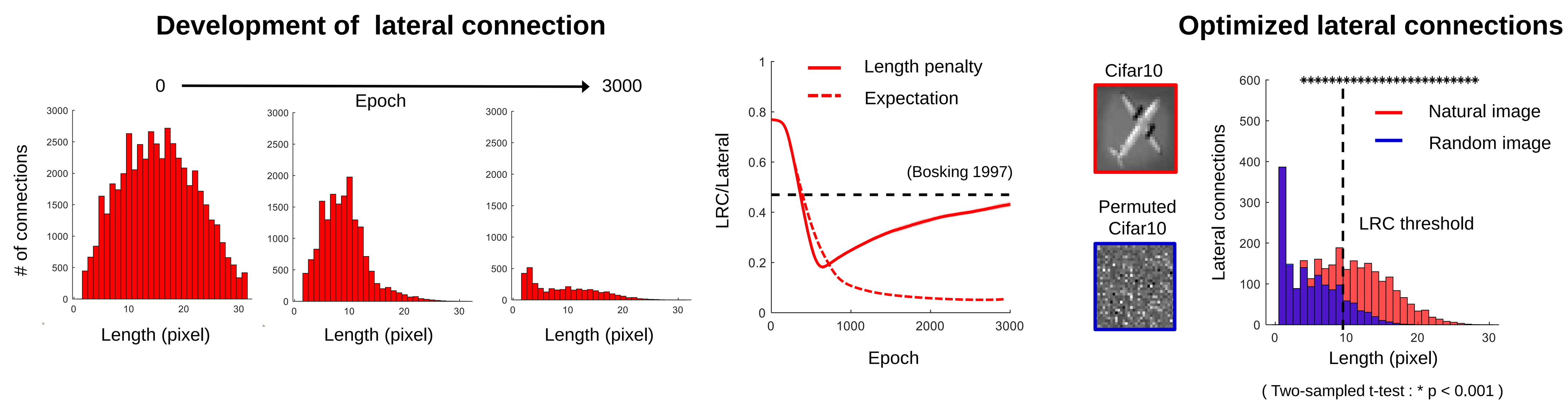


Starting from random initial connectivity, network was changed toward the direction that **minimizing the total length** while **recognizing image correctly**

Total length decreased as the accuracy increased with length penalty

Developed LRCs are indeed more important than other connections

Development of lateral connection **Optimized lateral connections**

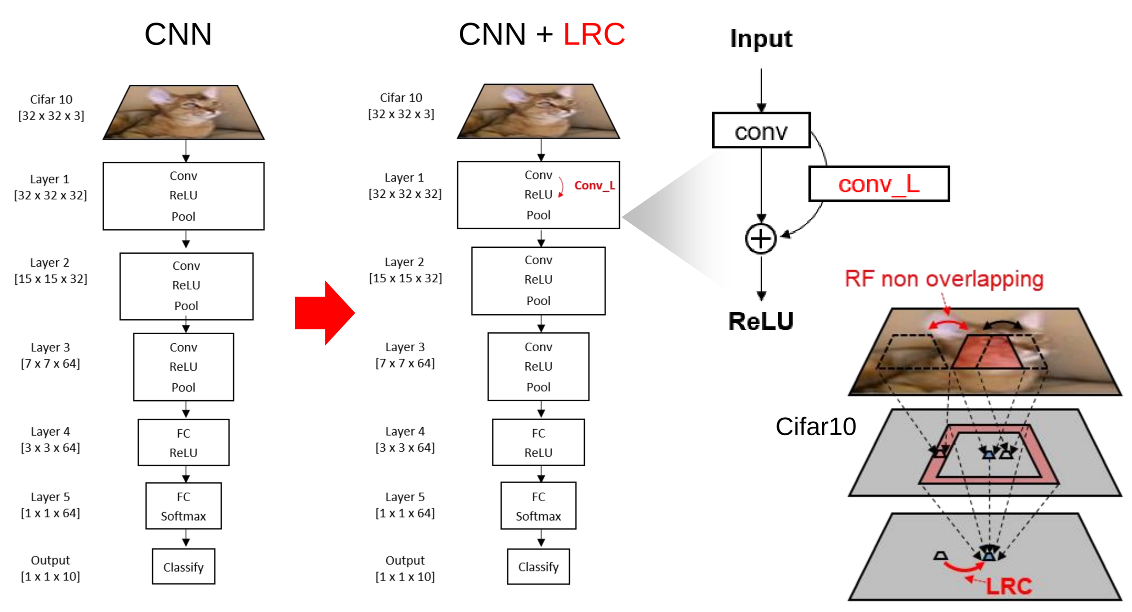


Most initial connections were pruned through learning, but a few long connections survived until the end of learning, even with length penalty

LRC distribution was not formed if the training data was not a natural image

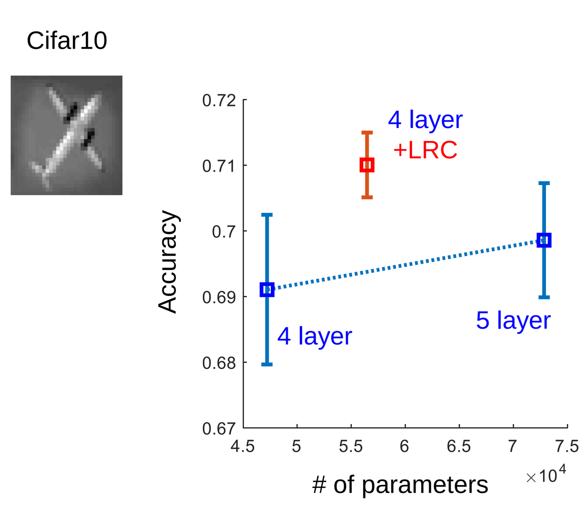
LRCs are applicable to conventional deep neural network for natural image perception

Implementation of LRCs on CNN



LRCs were implemented as skip connections covering RF non-overlapping range via dilated convolution layer

Cost effectiveness : LRC vs Layer



Adding LRCs is more efficient to resource usage than adding a layer

Summary

- The combination of LRCs and local connections dramatically enhances visual perception
- LRCs contribute to image perception by integrating low-frequency global information
- LRCs can be spontaneously evolved when total connection length is limited
- LRCs can be applied to conventional DNN for cost-efficient perception of natural images

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