

# Born Again Neural Networks

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## Ensembles

Diverse models with similar validation performances can be often be combined to achieve predictive power superior to each of the constituent models. [3]

## Born again trees

Learn a single tree that is able to recover the performance of a multiple-tree predictor. [4]

## Knowledge distillation = model compression

Transfer knowledge acquired by a learned teacher model to a new simpler student model. [5]

# Knowledge distillation

## Teacher

- high-capacity model
- good performance

## Student

- more compact model
- not as good performance as the teacher but better than if it was trained without it

By transferring knowledge, one hopes to benefit from the student's compactness while suffering only minimal degradation in performance.

Teacher produces soft targets = probabilities of incorrect classes = the key to generalization outside of the training dataset.

Training student = minimize weighted average of:

- cross entropy with the soft targets
- cross entropy with the hard targets = labels

# Knowledge distillation results

System	Test Frame Accuracy	WER
Baseline	58.9%	10.9%
10xEnsemble	61.1%	10.7%
Distilled Single model	60.8%	10.7%

Figure: DNN acoustic models used in Automatic Speech Recognition. [5]

# Born Again Networks (BANs)

- not compressing models
- students are parameterized identically to their parents
- students outperform teachers
- knowledge transfer between dense networks and residual networks of similar capacity

$$\min_{\theta_2} \mathcal{L}(y, f(x, \theta_2)) + \mathcal{L}(f(x, \arg \min_{\theta_1} \mathcal{L}(y, f(x, \theta_1))), f(x, \theta_2))$$

**Figure:** BAN loss function adding Kullback–Leibler divergence between the new model's outputs and the outputs of the original model. [1]

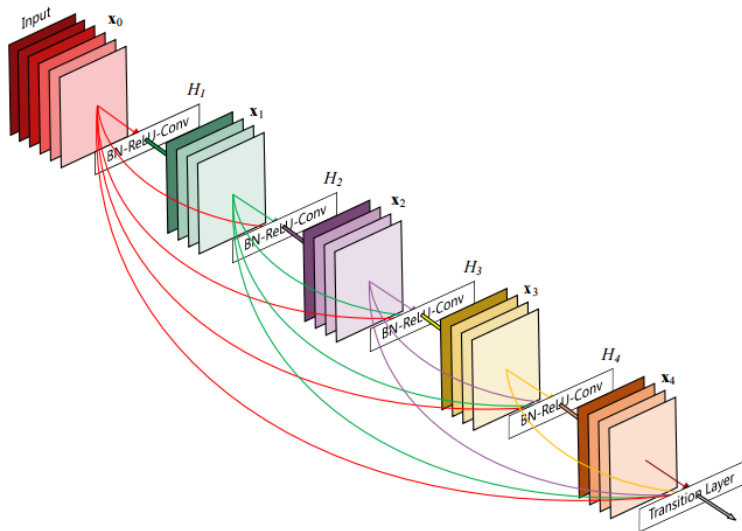
Apply BANs sequentially with multiple generations of knowledge transfer. In each case, the  $k$ -th model is trained, with knowledge transferred from the  $k - 1$ -th student:

$$\min_{\theta_k} \mathcal{L}(y, f(x, \theta_k)) + \mathcal{L}(f(x, \arg \min_{\theta_{k-1}} \mathcal{L}(y, f(x, \theta_{k-1}))), f(x, \theta_k))$$

## Born Again Network Ensemble (BANE)

Averaging the prediction of multiple generations of BANs.

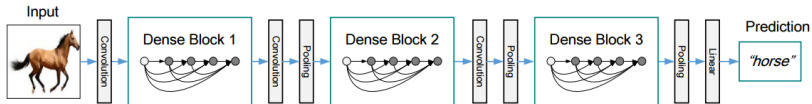
# DenseNets reminder: Dense block



**Figure 1:** A 5-layer dense block with a growth rate of  $k = 4$ .



# DenseNets reminder: Deep DenseNet



**Figure:** A deep DenseNet with three dense blocks. The layers between two adjacent blocks are referred to as transition layers and change feature-map sizes via convolution and pooling. [6]

# BAN DenseNets Experiments

All experiments on: CIFAR-100 (100 classes each containing 600 32x32 colour images).

- DenseNet-BC-(depth)-(growth rate)
- BAN-1/2/3 = sequential training by previous BAN-(k-1)
- Ens\*2/3 = ensembles of 2/3 BAN-x

Network	Parameters	Baseline	BAN-1	BAN-2	BAN-3	Ens*2	Ens*3
DenseNetBC-112-33	6.3 M	18.25	17.61	17.22	<b>16.59</b>	15.77	15.68
DenseNetBC-90-60	16.1 M	17.69	16.62	<b>16.44</b>	16.72	15.39	15.74
DenseNetBC-80-80	22.4 M	17.3	16.26	16.30	<b>15.5</b>	15.46	15.14
DenseNetBC-80-120	50.4 M	16.87	<b>16.13</b>	16.13	/	<b>15.13</b>	<b>14.9</b>

Figure: BAN training is clearly beneficial for DenseNets on CIFAR. [1]

Non-ensemble SOTA by BAN-3 80-80






Tommaso Furlanello et al. "Born Again Neural Networks." Workshop on Meta-Learning (MetaLearn 2017) at NIPS. Accessible from: [http://metalearning.ml/papers/metalearn17\\_furlanello.pdf](http://metalearning.ml/papers/metalearn17_furlanello.pdf)



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