A Closer Look at AlexNet

Tutorial 6 – CNNs February 12, 2018

CSC321

The ImageNet Large-Scale Visual Recognition Challenge (ILSVRC) had ~1200 images for each of 1000 categories in 2012.

IM . GENET



AlexNet on ILSVRC-2012

AlexNet revolutionized the state-of-the-art in object recognition at the time.



Figure 1: Top-5 error rates on ILSVRC image classification over Time

Source: http://paddlepaddle.org/docs/develop/book/03.image_classification/index.html

The Overall Architecture

Consists of 8 layers: 5 convolutional + 3 fully connected



The split (i.e. two pathways) in the image above are the split between two GPUs.

Inputs: RGB images with $224 \times 224 \times 3 = 150528$ values

Consider an input of size $W \times H \times C$ going to a convolutional layer *L* with square kernel size *K* and *M* output maps (channels). Then *L* has:

- There are *WHM* neurons (output units) in *L*, one for each of the *WH* "pixels" in the input and across the channels in the output *M*.
- There are *K*²*CM* weights. *K*²*C* per filter (the size of each "piece" of the input run through the filter), and *M* filters in total (one per output channel).
- There are *WHK*²*CM* connections. A single kernel processes *K*²*C* values in the input; this occurs for each of the *WHM* output units.

In contrast, a fully connected layer mapping *WHC* inputs to *WHM* outputs has far more weights and connections for small filter size *K*.

	Fully Connected	Convolutional
Number of Neurons	WHM	WHM
Number of Weights	$W^2 H^2 CM$	К ² СМ
Number of Connections	$W^2 H^2 CM$	WHK ² CM

Notice that the *weight sharing* (i.e. using the same kernel per channel across the output units) has decreased the number of weights considerably.

We will omit the bias weights for simplicity.

Let $N_i = WHM$, $P_i = K^2CM$, and $U_i = WHK^2CM$ be the number of output units, parameters (weights), and connections of layer L_i . Note that stride and max pooling each reduce the input W and H by the given factor.

• Layer L_1

96 kernels (output channels) each of size $11 \times 11 \times 3$. Stride 4: the input *W* and *H* shrink by a factor of 4. Thus: W = H = 55, C = 3, M = 96, K = 11.

- $N_1 = 55^2 \times 96 = 290,400$
- $P_1 = 96 \times 11^2 \times 3 = 34,848$
- $U_1 = 55^2 \times 11^2 \times 3 \times 96 = 105,415,200$

The Convolutional Layers (II)

- Layer L₂: 256 kernels each of size 5 × 5 × 48. (Max pooling: 55/2 = 27.) So N₂ = 27² × 256 = 186,624; P₂ = 2(5² × 48 × 128) = 307,200; U₂ = 223,948,800/2 = 111,974,400.
- Layer L_3 : 384 kernels each of size $3 \times 3 \times 256$. (Max pooling: 27/2 = 13.) So $N_3 = 13^2 \times 384 = 64,896$; $P_3 = 3^2 \times 256 \times 384 = 884,736$; $U_3 = 13^2 \times 3^2 \times 256 \times 384 = 149,520,384$.

Note: layers 2, 4, & 5 are not connected to the preceding layer between GPUs; thus, one computes them separately and multiplies by 2. Recall: $N_i = WHM$, $P_i = K^2CM$, $U_i = WHK^2CM$

The Convolutional Layers (III)

- Layer *L*₄: 384 kernels each of size $3 \times 3 \times 192$. So $N_4 = 13^2 \times 384 = 64,869; P_4 = 2(3^2 \times 192^2) = 663,552;$ $U_4 = 13^2 \times 3^2 \times 384^2/2 = 112,140,288.$
- Layer L_5 : 256 kernels each of size $3 \times 3 \times 192$. So $N_5 = 13^2 \times 256 = 43,264$; $P_5 = 2(3^2 \times 192 \times 128) = 442,368$; $U_5 = 13^2 \times 3^2 \times 384 \times 256/2 = 74,760,192$.

Note: layers 2, 4, & 5 are not connected to the preceding layer between GPUs; thus, one computes them separately and multiplies by 2. Recall: $N_i = WHM$, $P_i = K^2CM$, $U_i = WHK^2CM$ For the fully connected layers, again let N_i , P_i , and U_i be the number of output units, parameters (weights), and connections of layer L_i .

- Layer L₆: 4096 units. (Max pooling: input 13/2 = 6.)
 N₆ = 4096; P₆ = U₆ = 6 × 6 × 256 × 4096 = 37,748,736
- Layer L₇: N₇ = 4096 units. P₇ = U₇ = 4096 × 4096 = 16,777,216
- Layer *L*₈: *N*₈ =1000 units. *P*₈ = *U*₈ = 4096 × 1000 = 4,096,000

Notice that the number of parameters is much larger for the dense layers than the convolutional ones.

Summary of Results

Layer	Units	Weights	Connections
L ₁ (Conv)	290,400	34,848	105,415,200
L ₂ (Conv)	186,624	307,200	111,974,400
L ₃ (Conv)	64,896	884,736	149,520,384
L ₄ (Conv)	64,869	663,552	112,140,288
L ₅ (Conv)	43,264	442,368	74,760,192
L ₆ (Dense)	4096	37,748,736	37,748,736
L7 (Dense)	4096	16,777,216	16,777,216
L ₈ (Dense)	1000	4,096,000	4,096,000
Conv Subtotal	650,080	2,332,704	553,810,464
Dense Subtotal	9192	58,621,952	58,621,952
Total	659,272	60,954,656	612,432,416

Overall, AlexNet has about 660K units, 61M parameters, and over 600M connections.

Notice: the convolutional layers comprise most of the units and connections, but the fully connected layers are responsible for most of the weights.

More modern networks can do better with fewer parameters (e.g. GoogLeNet).

The original paper:

• Krizhevsky, Alex, Ilya Sutskever, and Geoffrey E. Hinton. "Imagenet classification with deep convolutional neural networks." *Advances in neural information processing systems.* 2012.

It's possible to reduce the number of parameters of AlexNet by 9x without losing accuracy:

• Han, Song, et al. "Learning both weights and connections for efficient neural network." *Advances in neural information processing systems.* 2015.