ImageNet Classification with Deep Convolutional Neural Networks

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Paper with same name to appear in NIPS 2012

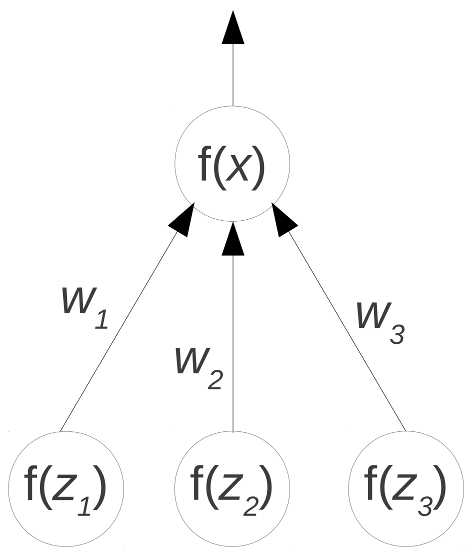
Main idea

Architecture

Technical details

Neural networks

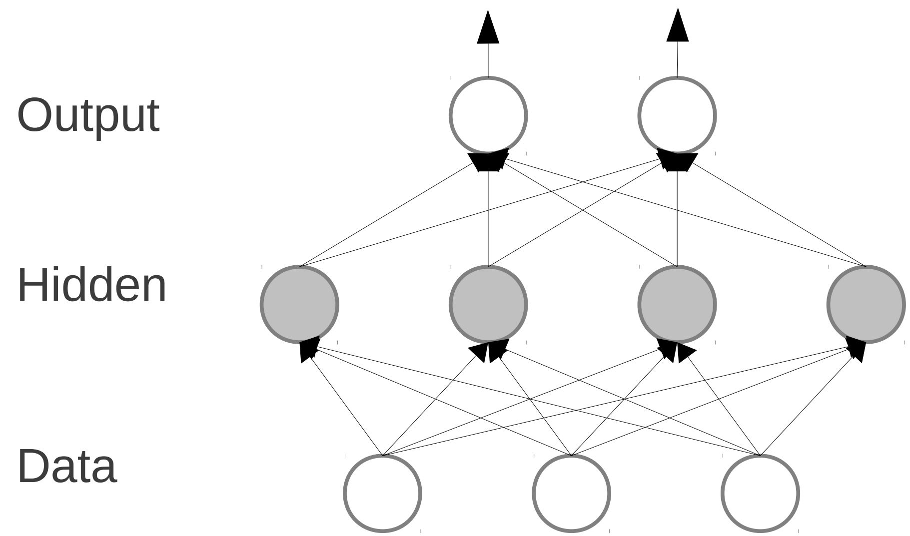
- A neuron



$x = w_1 f(z_1) + w_2 f(z_2) + w_3 f(z_3)$

x is called the total input
to the neuron, and f(*x*)
is its output

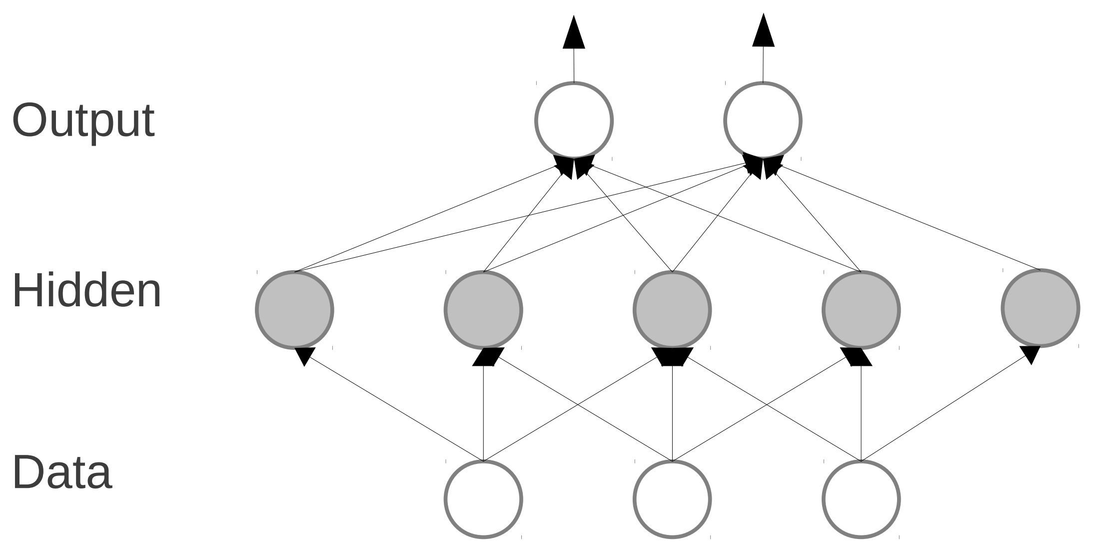
- A neural network



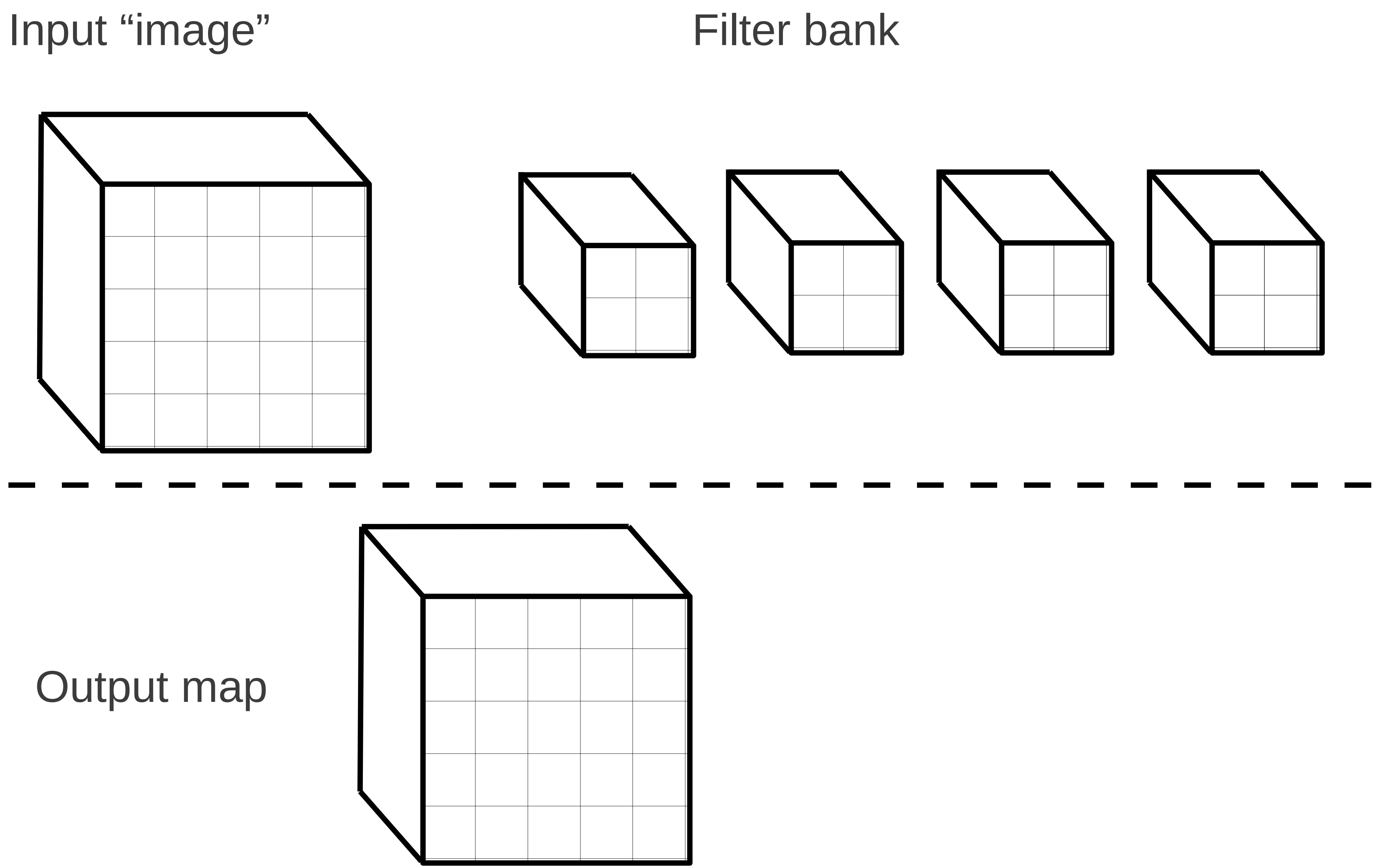
A neural network computes a differentiable function of its input. For example, ours computes: *p*(label | an input image)

Convolutional neural networks

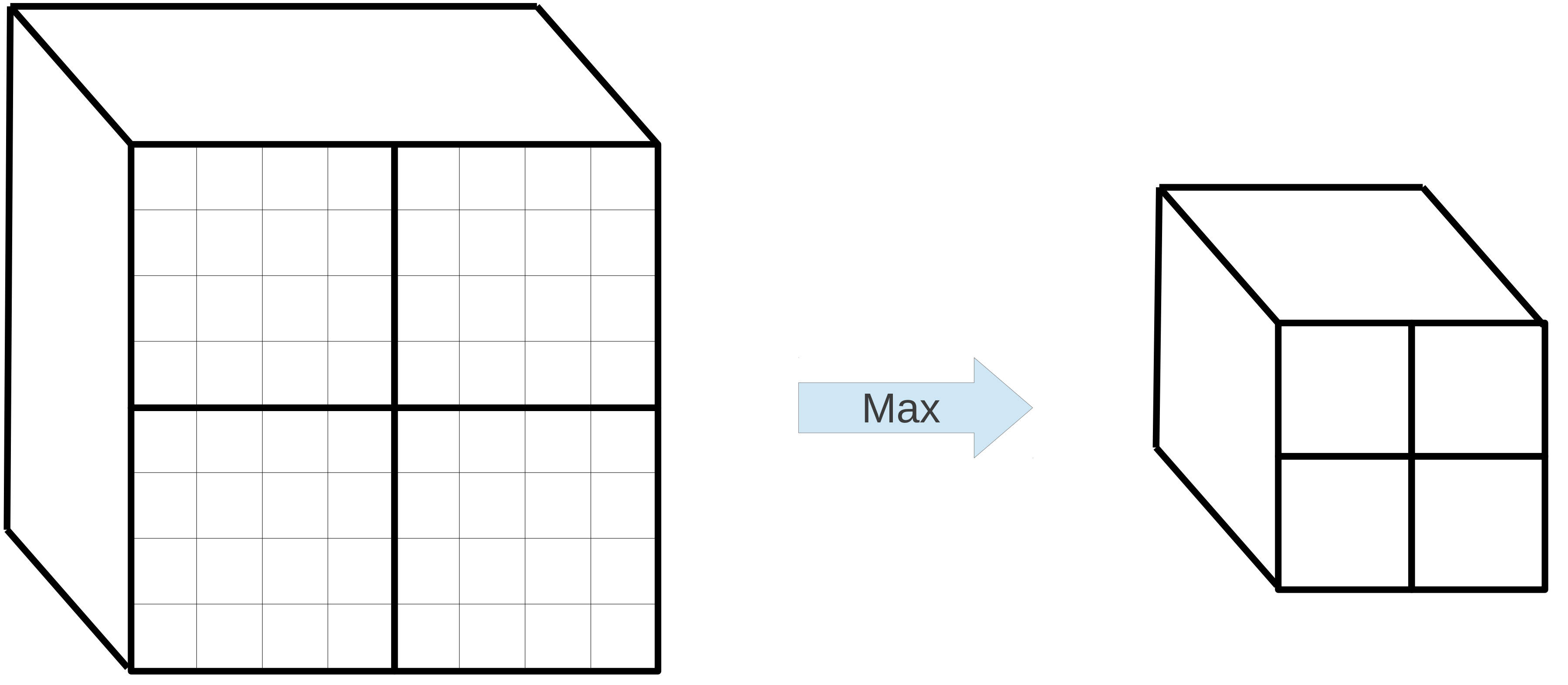
- Here's a one-dimensional convolutional neural network
- Each hidden neuron applies **the same localized, linear filter** to the input



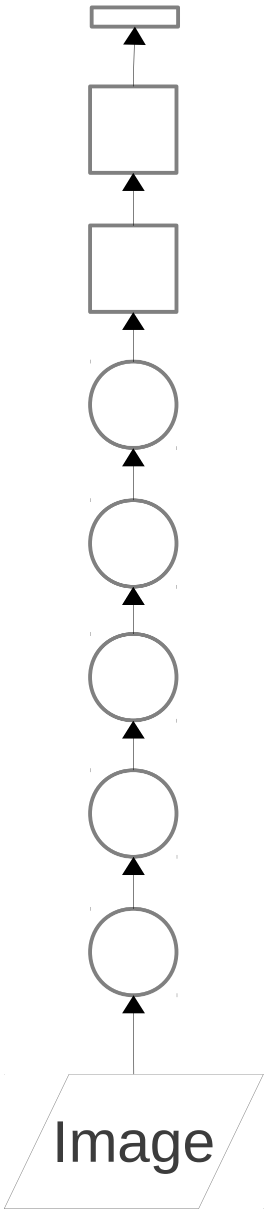
Convolution in 2D



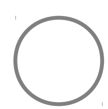
Local pooling



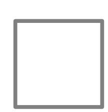
Overview of our model



- **Deep**: 7 hidden “weight” layers
- **Learned**: all feature extractors initialized at white Gaussian noise and learned from the data
- Entirely supervised
- **More data = good**

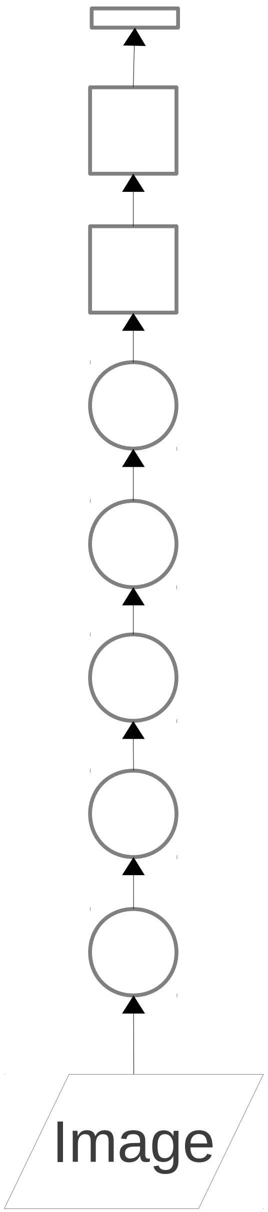


Convolutional layer: convolves its input with a bank of 3D filters, then applies point-wise non-linearity

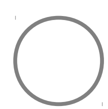


Fully-connected layer: applies linear filters to its input, then applies point-wise non-linearity

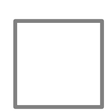
Overview of our model



- Trained with stochastic gradient descent on two NVIDIA GPUs for about a week
- 650,000 neurons
- 60,000,000 parameters
- 630,000,000 connections
- **Final feature layer:** 4096-dimensional

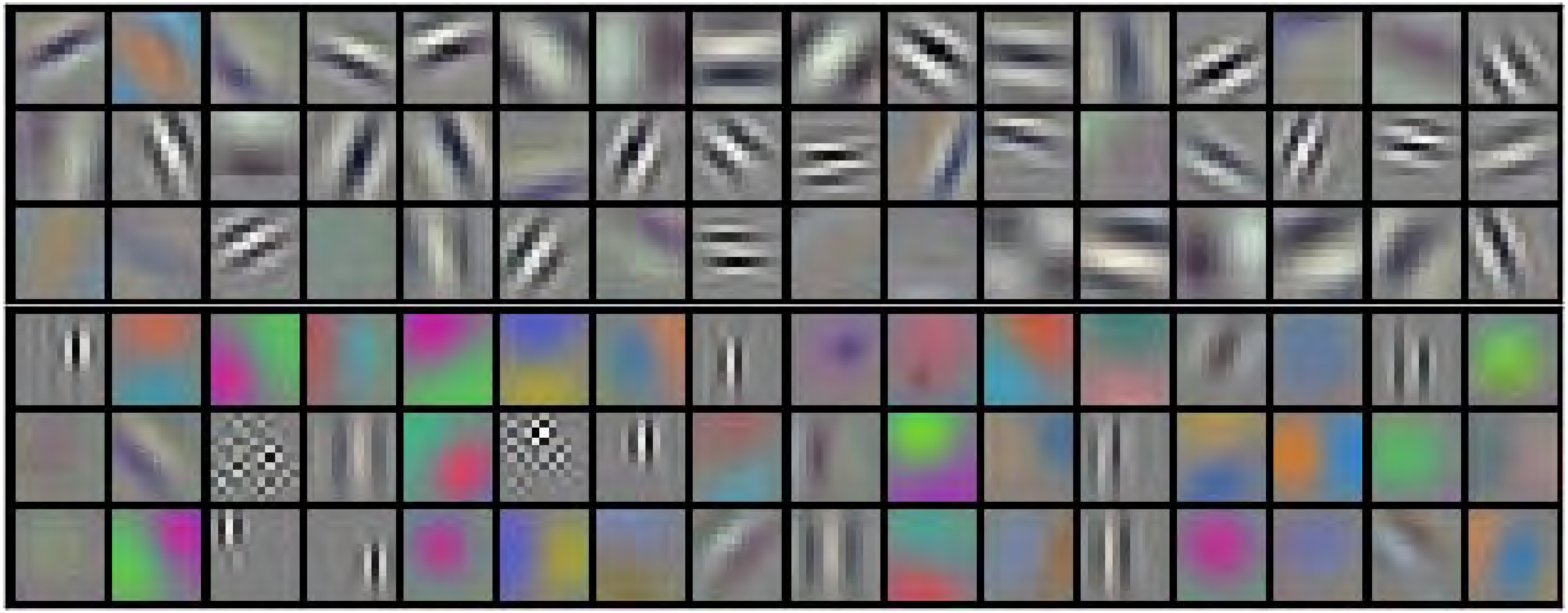


Convolutional layer: convolves its input with a bank of 3D filters, then applies point-wise non-linearity



Fully-connected layer: applies linear filters to its input, then applies point-wise non-linearity

96 learned low-level filters



Main idea

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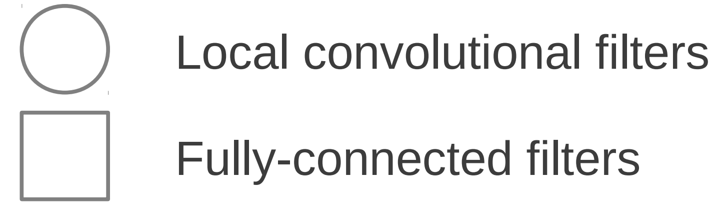
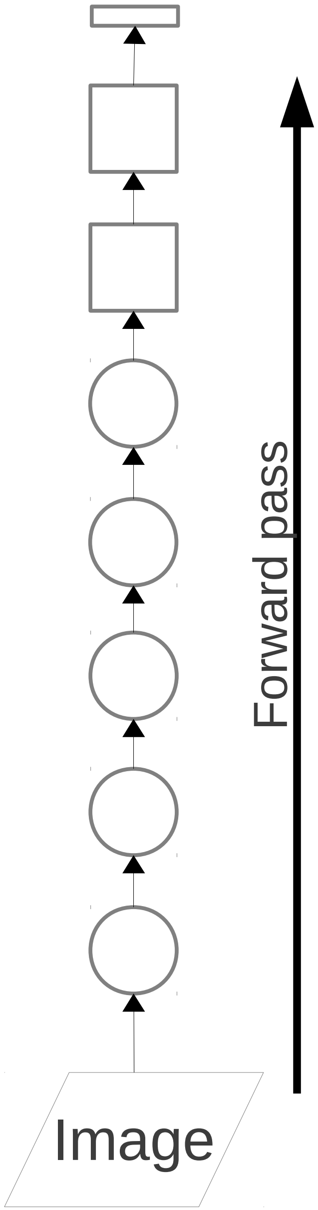


Training



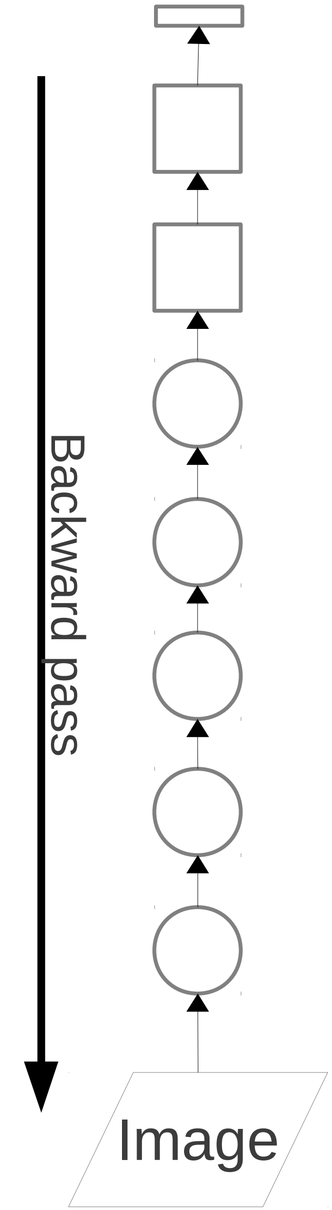
Using stochastic gradient descent and the *backpropagation algorithm* (just repeated application of the chain rule)

One output unit per class

$x_i =$ total input to output unit i

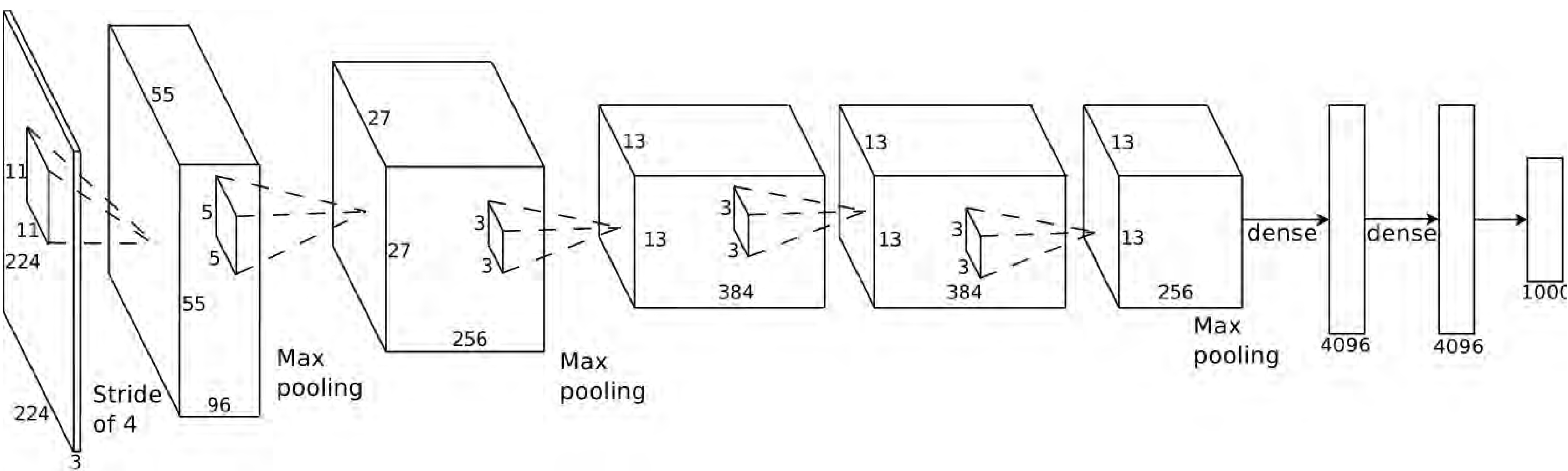
$$f(x_i) = \frac{\exp(x_i)}{\sum_{j=1}^{1000} \exp(x_j)}$$

We maximize the log-probability of the correct label, $\log f(x_t)$



Our model

- Max-pooling layers follow first, second, and fifth convolutional layers
- The number of neurons in each layer is given by 253440, 186624, 64896, 64896, 43264, 4096, 4096, 1000



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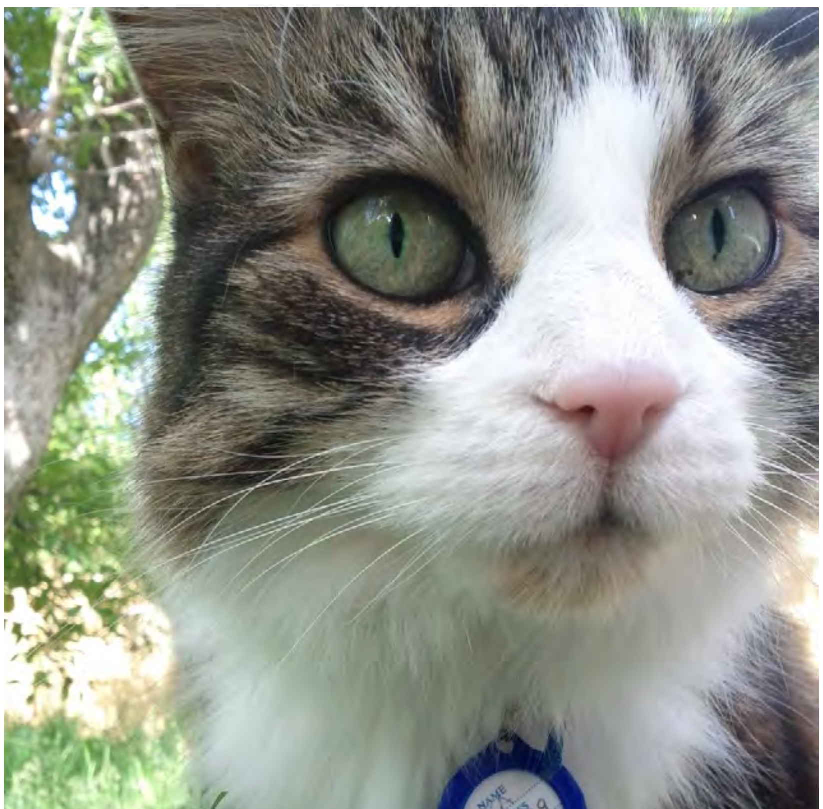
Input representation

- Centered (0-mean) RGB values.



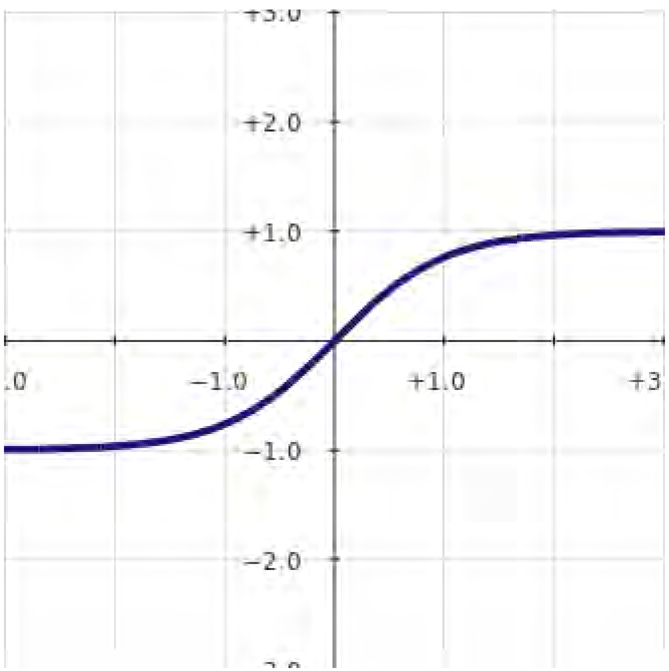
An input image (256x256)

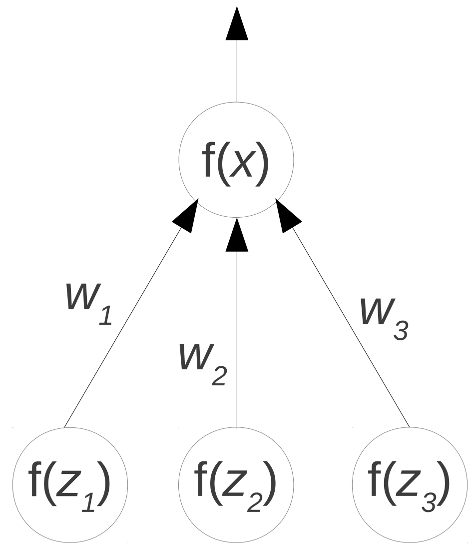
Minus sign

The mean input image

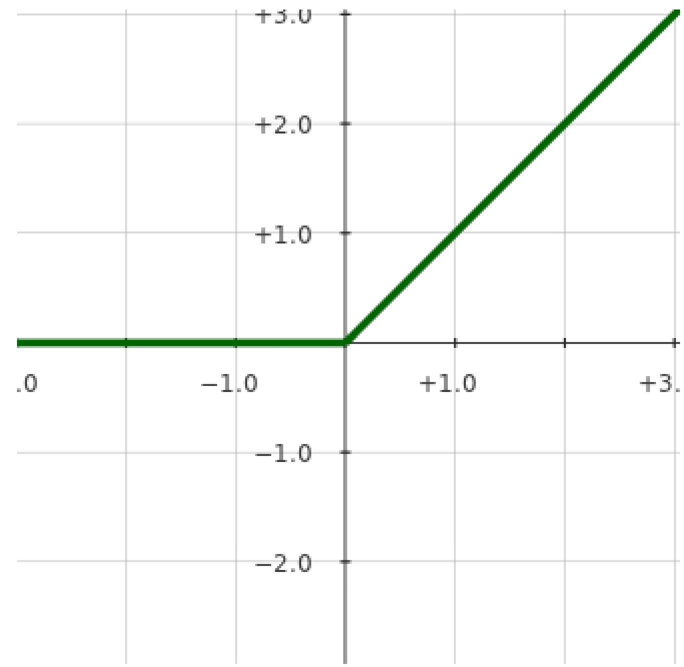
Neurons

$f(x) = \tanh(x)$





$f(x) = \max(0, x)$



$x = w_1 f(z_1) + w_2 f(z_2) + w_3 f(z_3)$

x is called the total input to the neuron, and $f(x)$ is its output

Very bad (slow to train)

Very good (quick to train)

Data augmentation

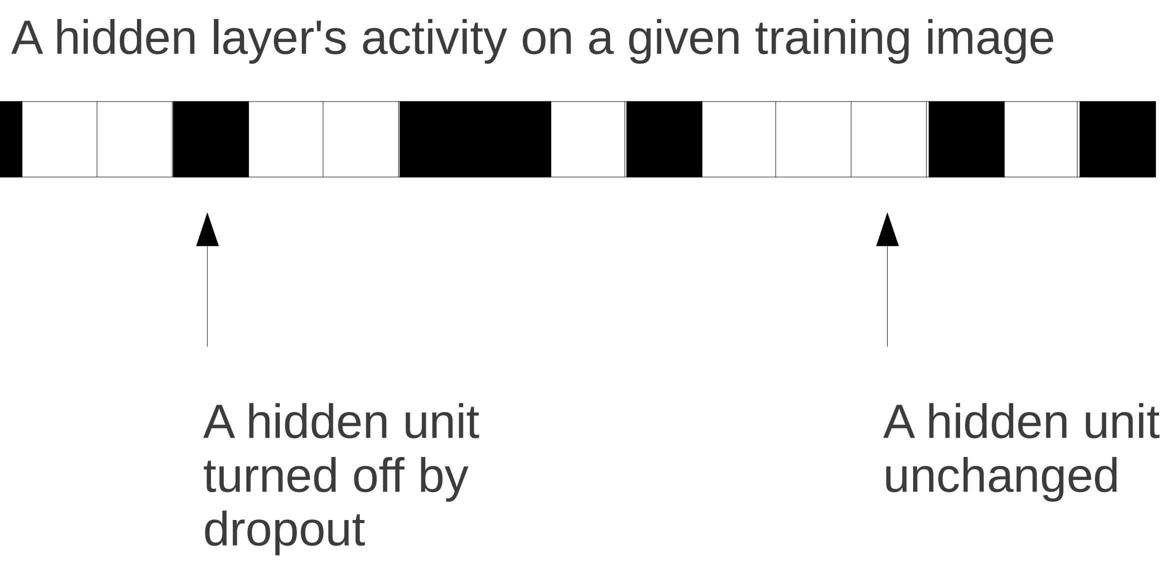
- Our neural net has 60M real-valued parameters and 650,000 neurons
- It overfits a lot. Therefore we train on 224x224 patches extracted randomly from 256x256 images, and also their horizontal reflections.

Testing

- Average predictions made at five 224x224 patches and their horizontal reflections (four corner patches and center patch)
- Logistic regression has the nice property that it outputs a probability distribution over the class labels
- Therefore no score normalization or calibration is necessary to combine the predictions of different models (or the same model on different patches), as would be necessary with an SVM.

Dropout

- Independently set each hidden unit activity to zero with 0.5 probability
- We do this in the two globally-connected hidden layers at the net's output



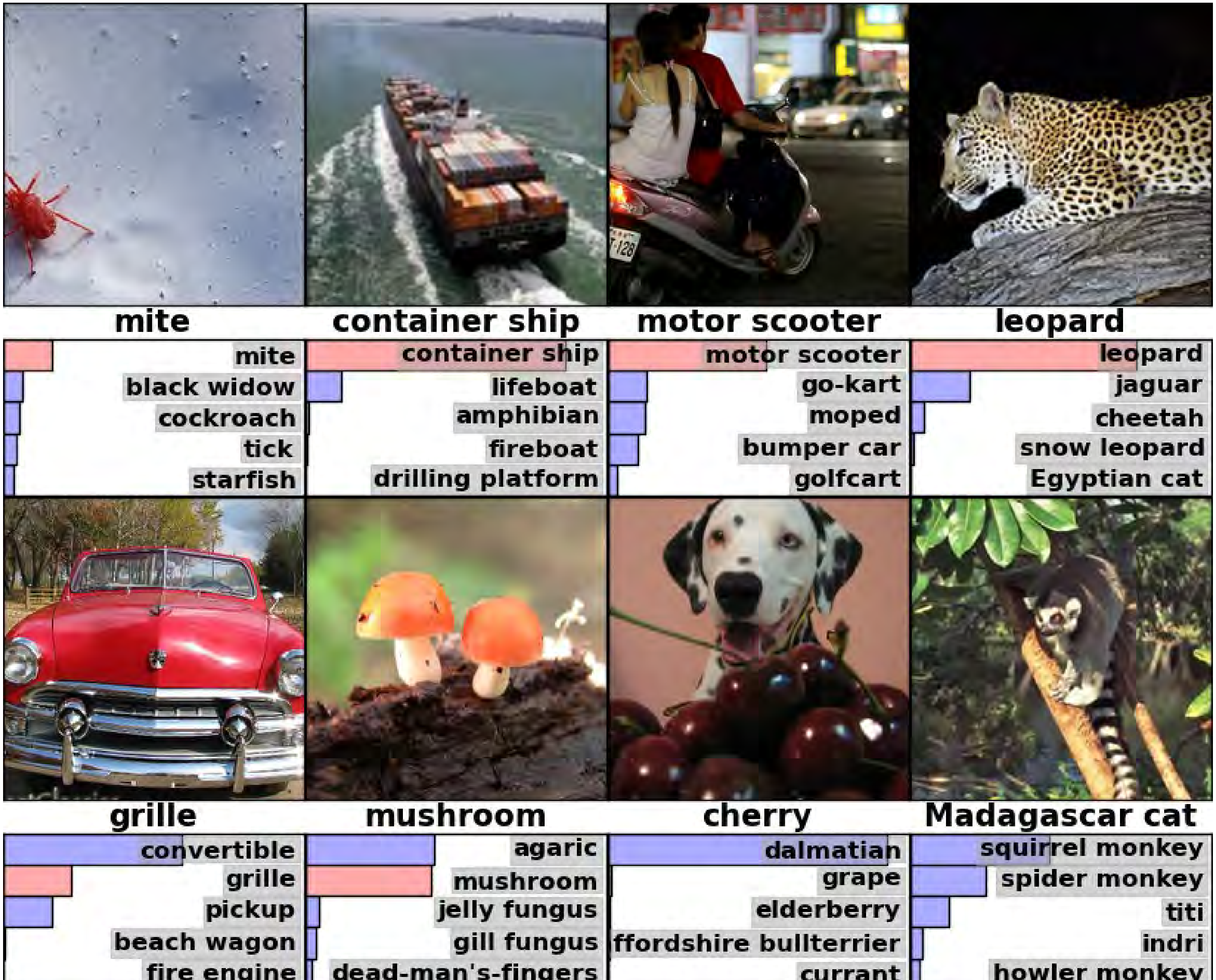
Implementation

- The only thing that needs to be stored on disk is the raw image data
- We stored it in JPEG format. It can be loaded and decoded entirely in parallel with training.
- Therefore only 27GB of disk storage is needed to train this system.
- Uses about 2GB of RAM on each GPU, and around 5GB of system memory during training.

Implementation

- Written in Python/C++/CUDA
- Sort of like an instruction pipeline, with the following 4 instructions happening in parallel:
  - Train on batch *n* (on GPUs)
  - Copy batch *n*+1 to GPU memory
  - Transform batch *n*+2 (on CPU)
  - Load batch *n*+3 from disk (on CPU)

Validation classification



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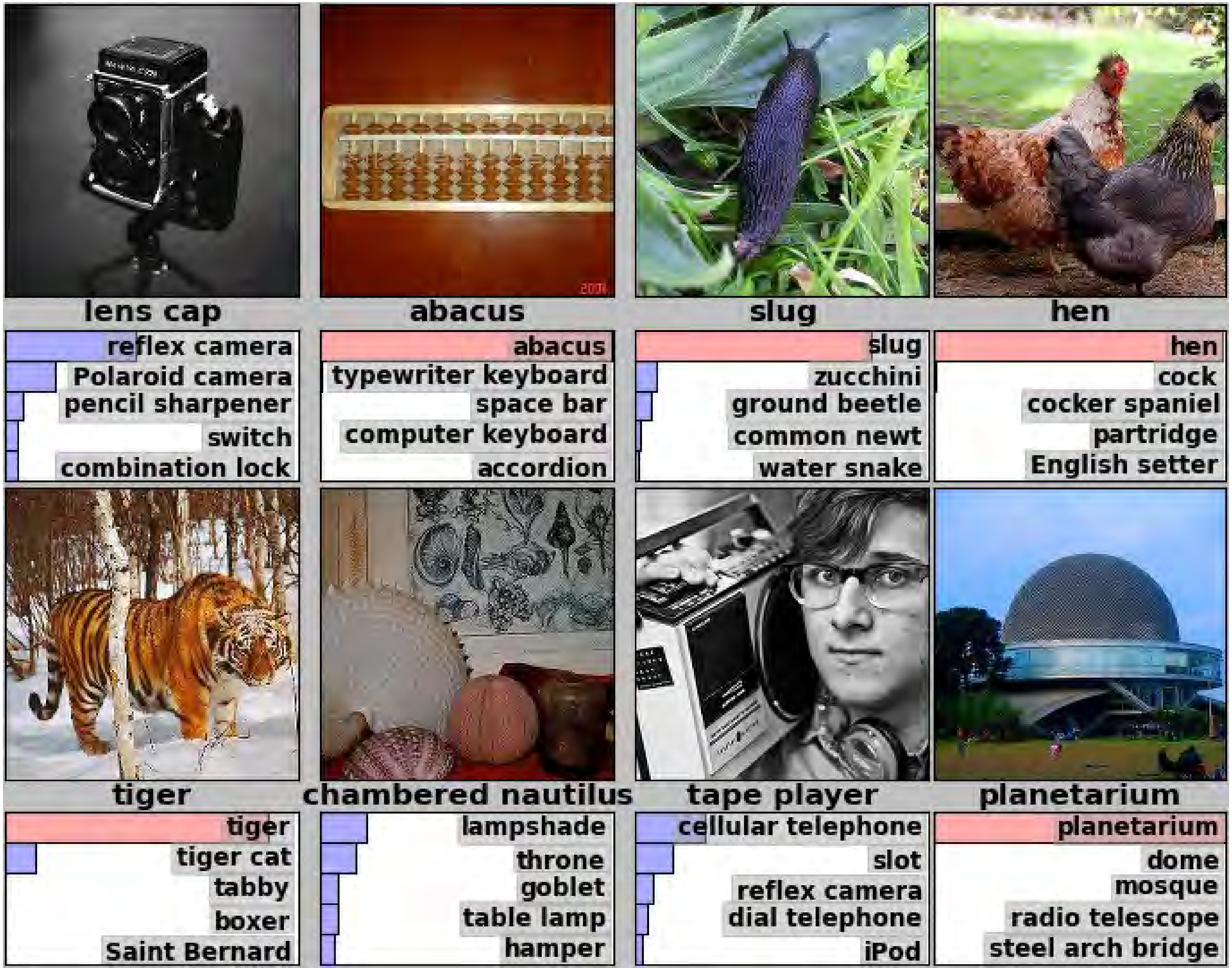

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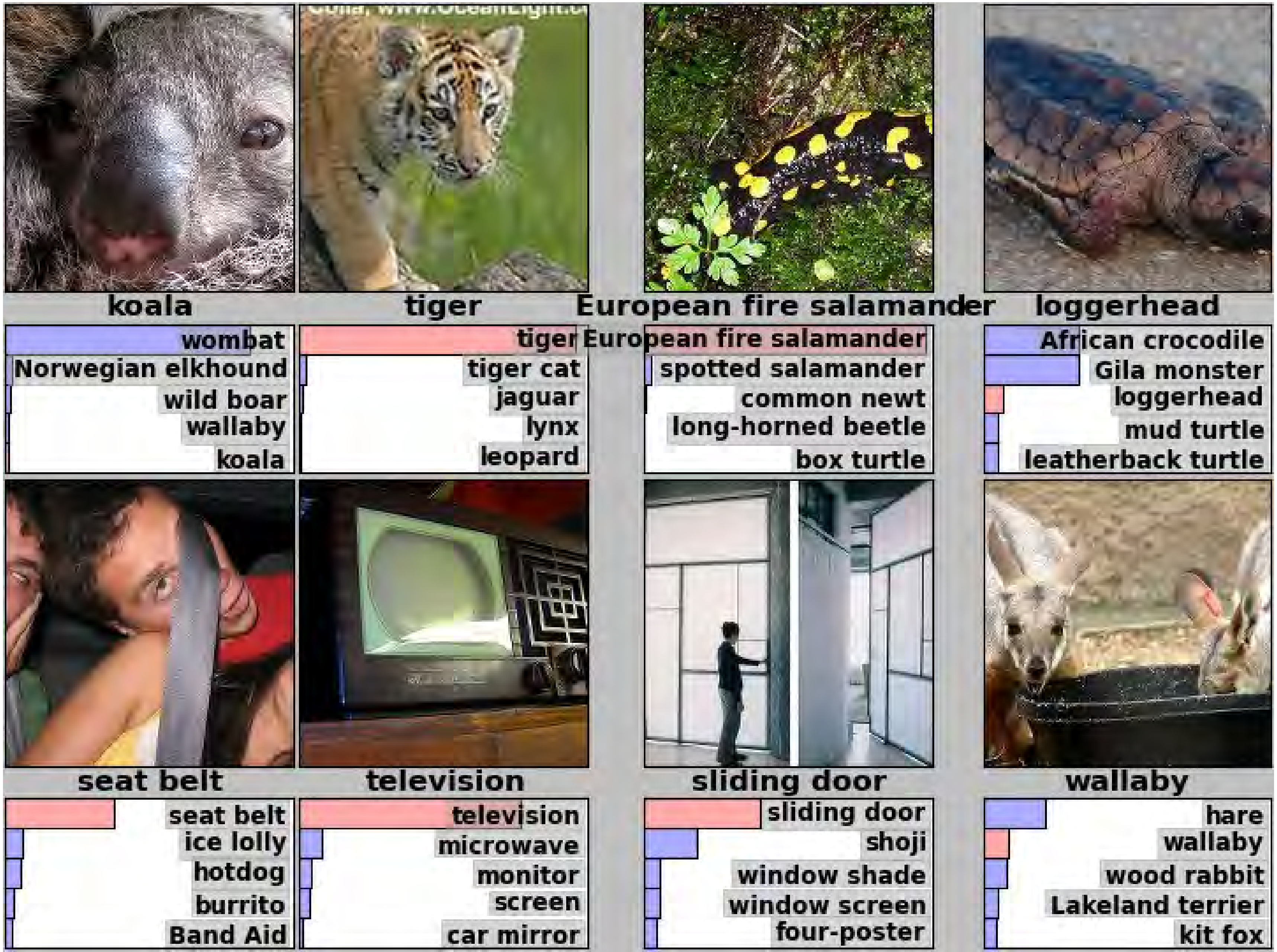
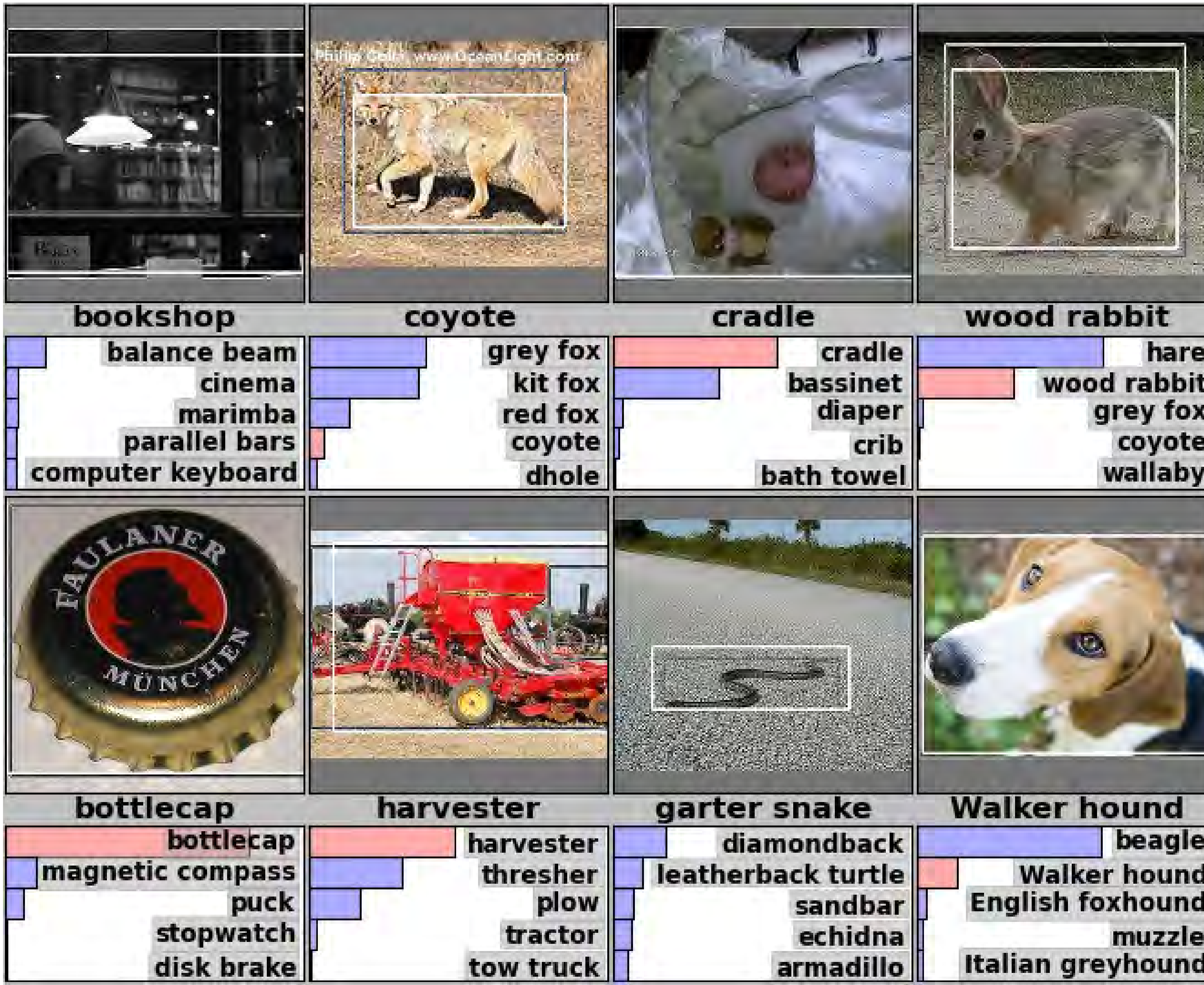
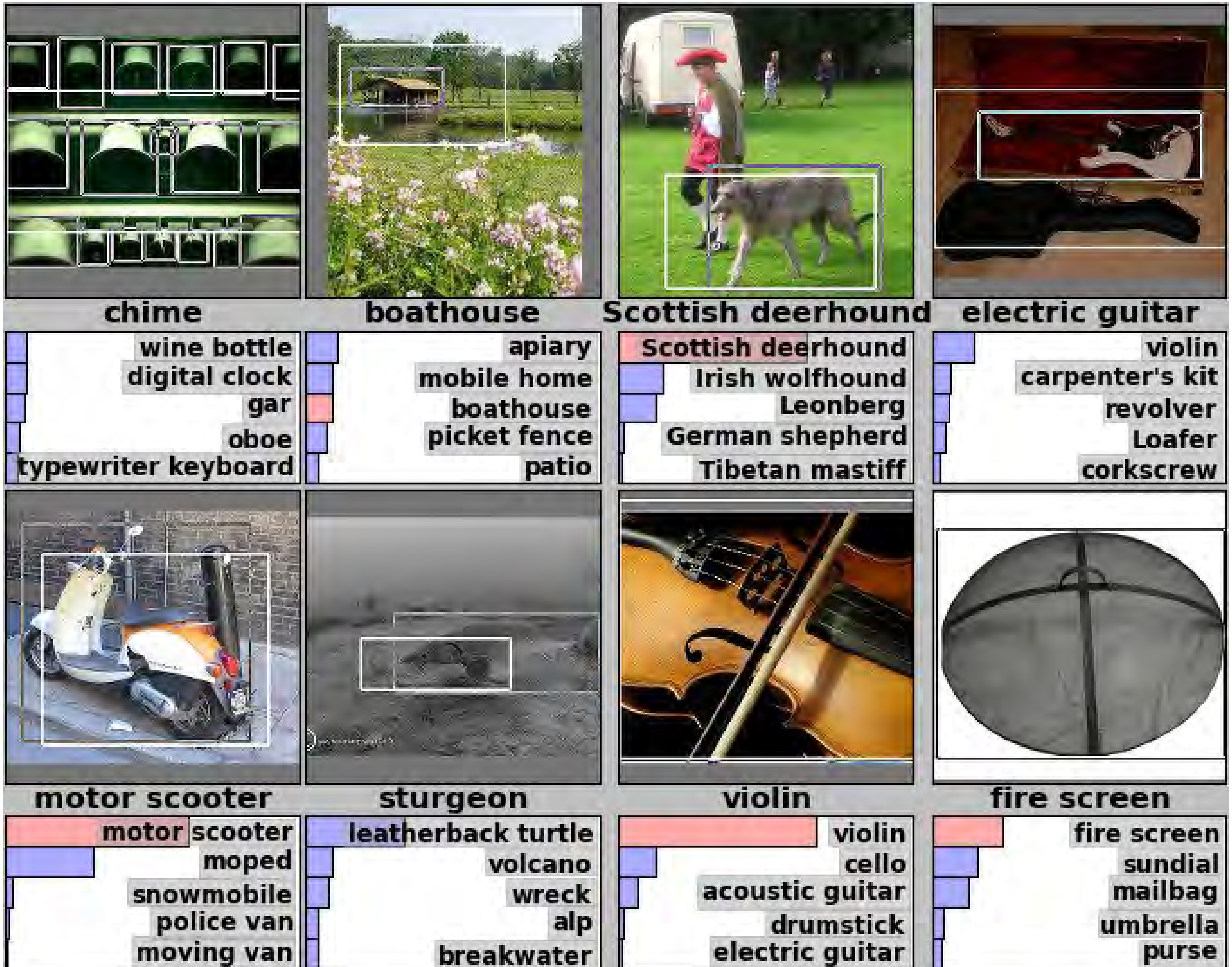


Validation localizations

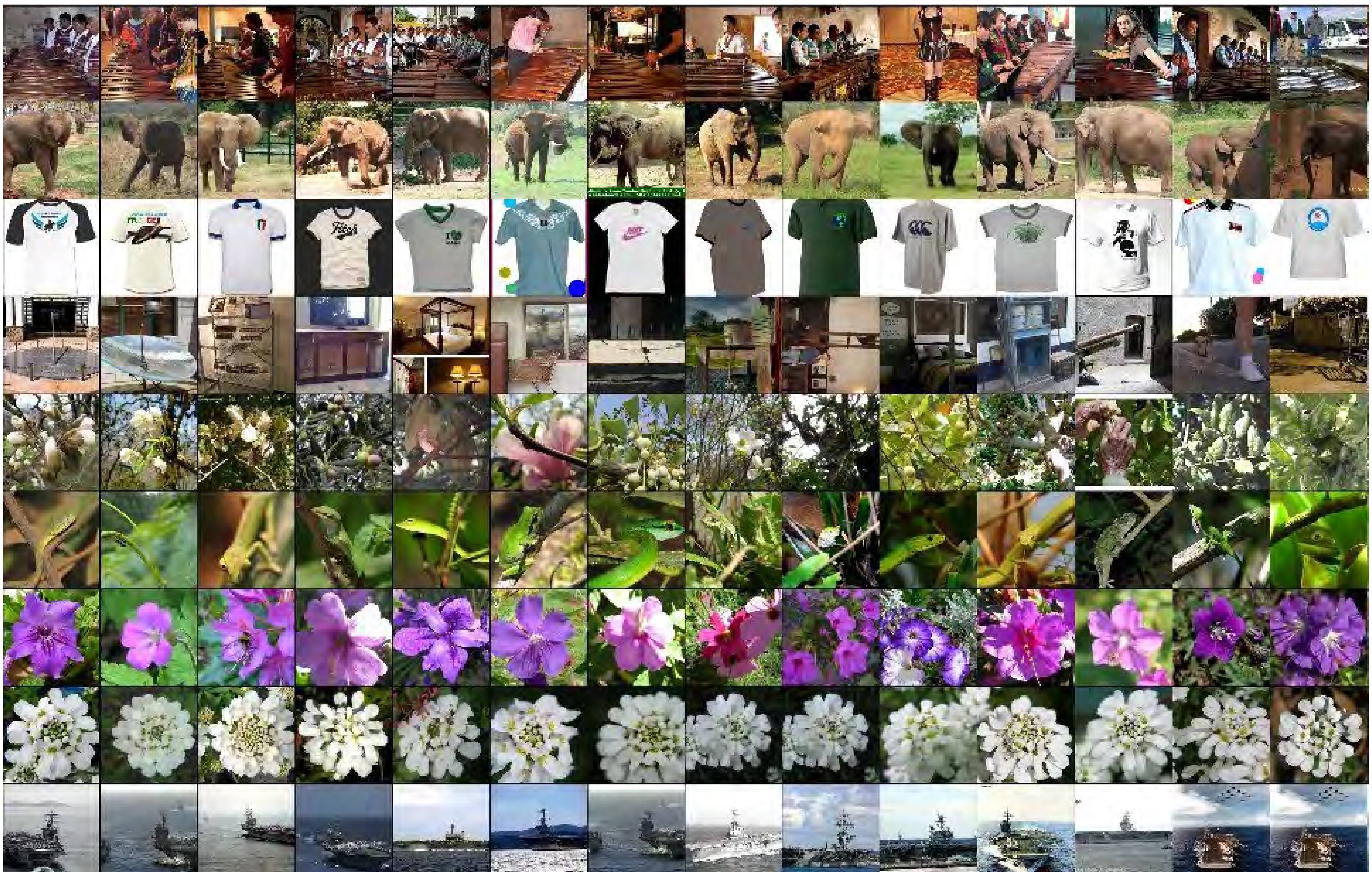


Validation localizations



Retrieval experiments

First column contains query images from ILSVRC-2010 test set, remaining columns contain retrieved images from training set.



Retrieval experiments