

Classifying galaxies with deep learning

Sander Dieleman – March 12th, 2015

PhD student at Ghent University

Working on audio-based music classification,
recommendation, ...

Graduating this summer



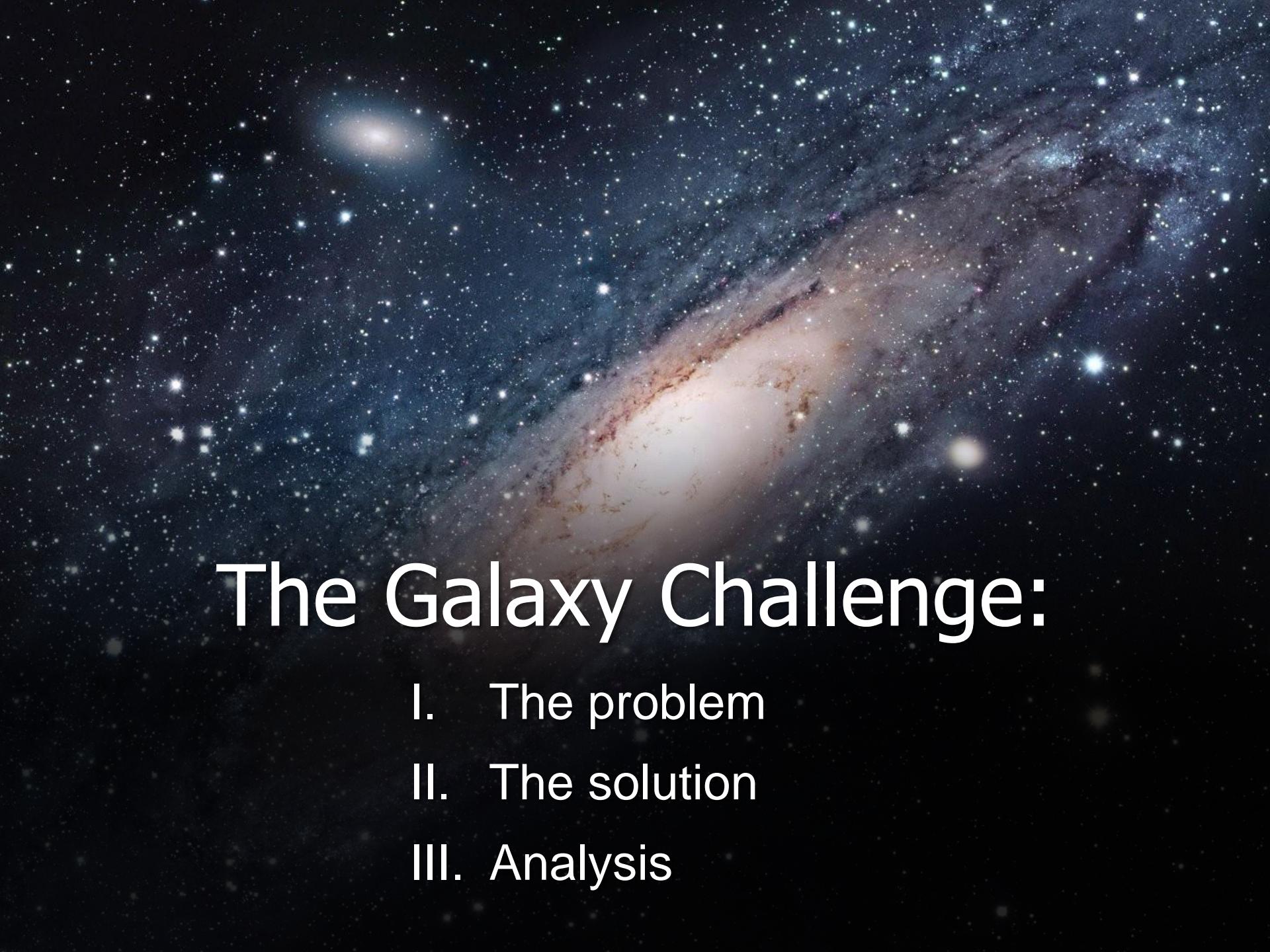
<http://benanne.github.io>

<http://github.com/benanne>

<http://reslab.elis.ugent.be>

sanderdieleman@gmail.com





The Galaxy Challenge:

- I. The problem
- II. The solution
- III. Analysis

I. The problem

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GALAXY ZOO

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Few have witnessed what you're about to see

Experience a privileged glimpse of the distant universe as observed by the SDSS, the Hubble Space Telescope, and UKIRT

Classify Galaxies

To understand how galaxies formed we need your help to classify them according to their shapes. If you're quick, you may even be the first person to see the galaxies you're asked to classify.

[Begin Classifying](#)

How Do Galaxies Form?

Roughly one hundred billion galaxies are scattered throughout our observable Universe, each a glorious system that might contain billions of stars. Many are remarkably beautiful, and the aim of Galaxy Zoo is to study them, assisting astronomers in attempting to understand how the galaxies we see around us formed, and what their stories can tell us about the past, present and future of our Universe as a whole. [MORE](#)

History of Galaxy Zoo

The launch of this new version of Galaxy Zoo, the 4th, comes just a few weeks after the site's 5th birthday. It all started back in July 2007, with a data set made up of a million galaxies imaged by the Sloan Digital Sky Survey, who still provide some of the images in the site today. With so many galaxies, we'd assumed it would take years for visitors to the site to work through them all, but within 24 hours of launch we were stunned to be

<http://www.galaxyzoo.org>

Is the galaxy simply smooth and rounded,
with no sign of a disk?

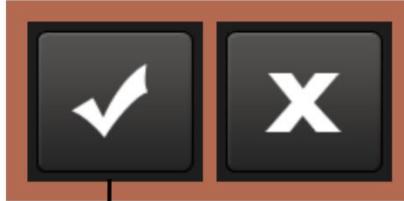
How rounded is it?



Could this be a disk viewed edge-on?



Is there anything odd?



Is the odd feature a ring, or is the
galaxy disturbed or irregular?



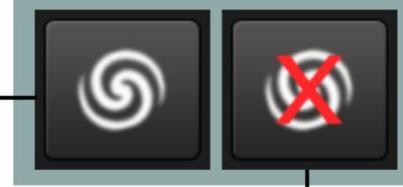
Does the galaxy have a bulge at its centre?
If so, what shape?



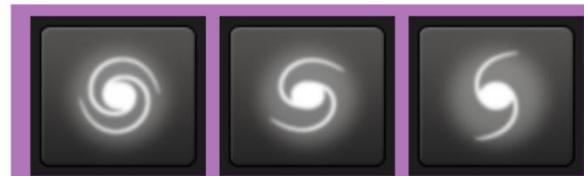
Is there a sign of a bar feature through
the centre of the galaxy?



Is there any sign of a spiral
arm pattern?



How tightly wound do the spiral arms appear?



How many spiral arms are there?

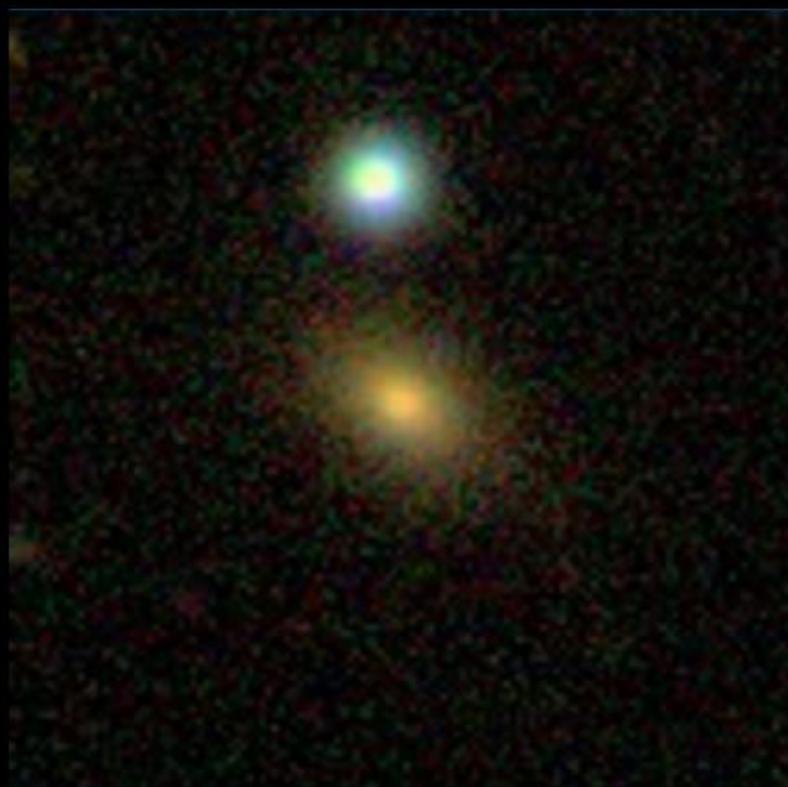


How prominent is the central bulge,
compared to the rest of the galaxy?



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Classify



SDSS



Invert

[Examples](#)[Restart](#)

SHAPE

Is the galaxy simply smooth and rounded, with no sign of a disk?



Smooth



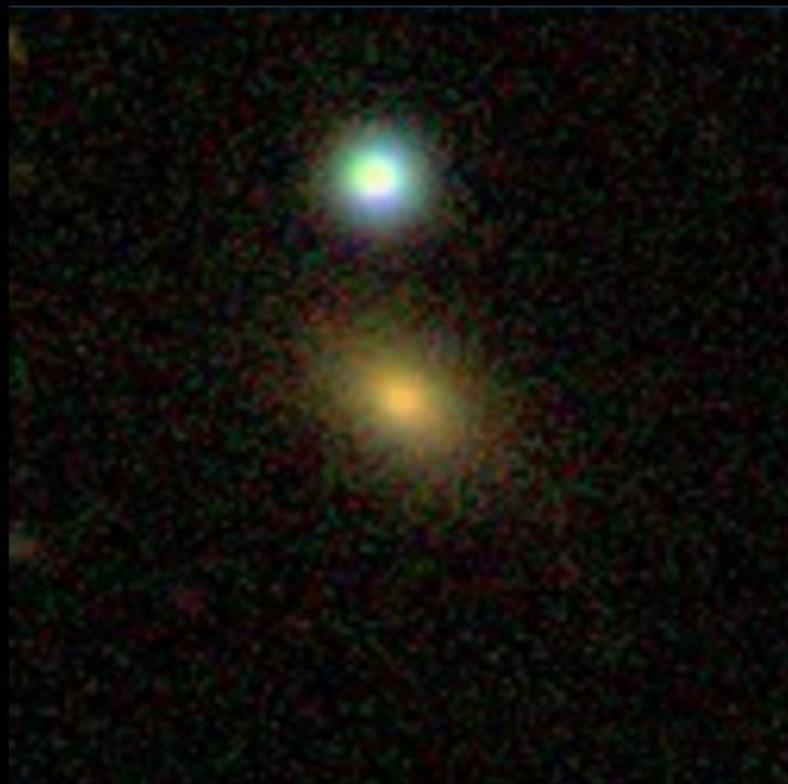
Features or disk



Star or artifact

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ROUND

How rounded is it?



Completely round



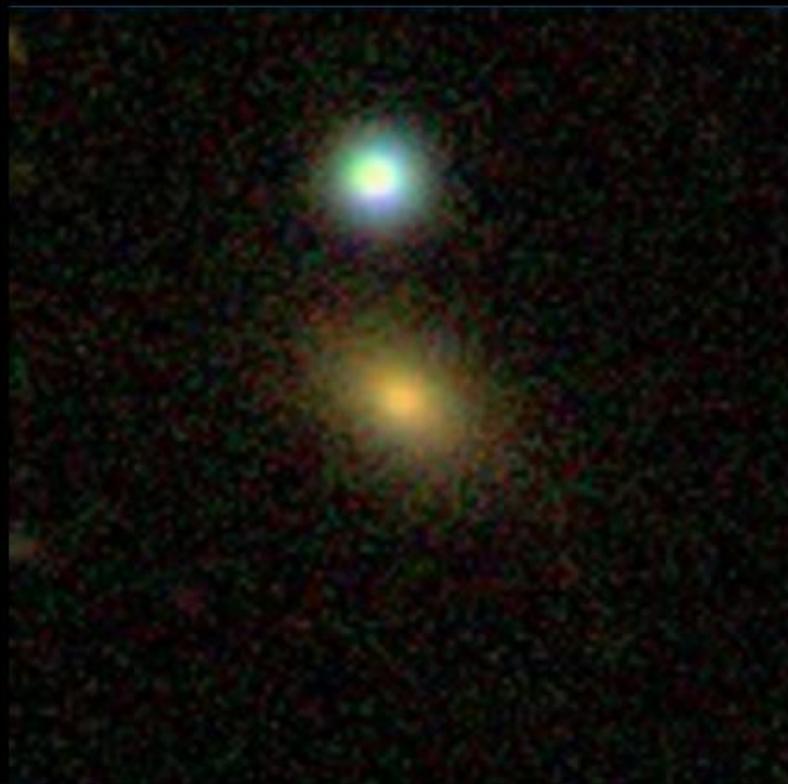
In between



Cigar shaped

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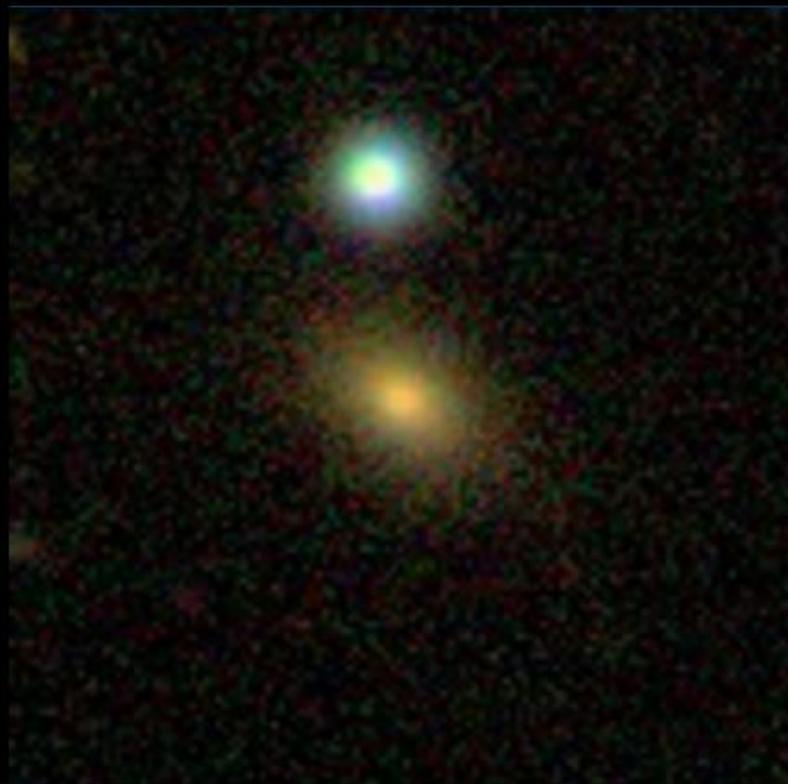
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ODD

Is there anything odd?



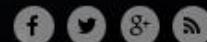
Yes



No

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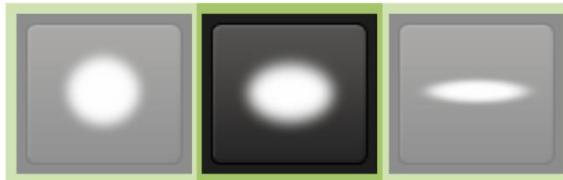
Yes



No

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How rounded is it?



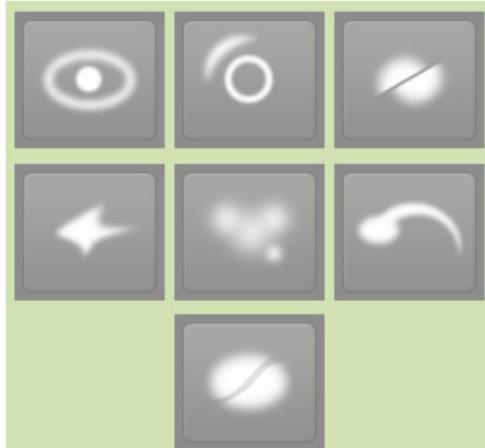
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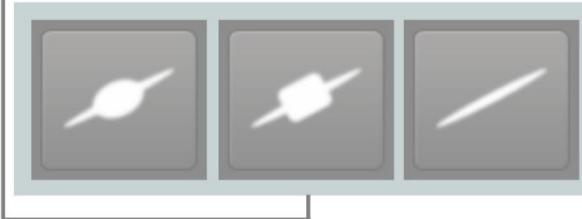
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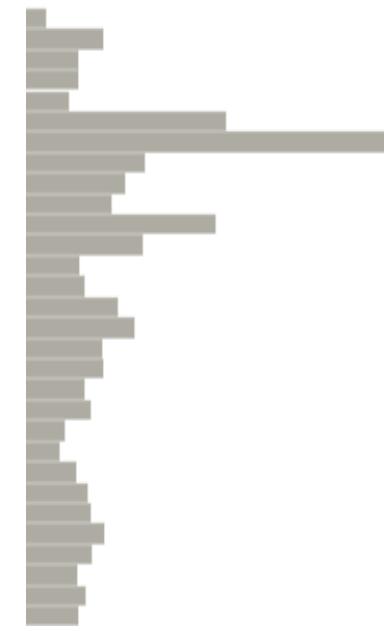
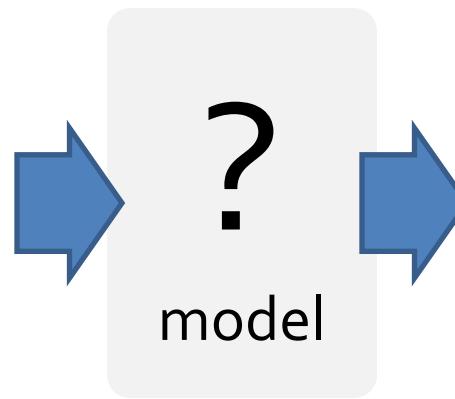


The Galaxy Challenge: automate this classification process

Competition on **kaggle**[™]

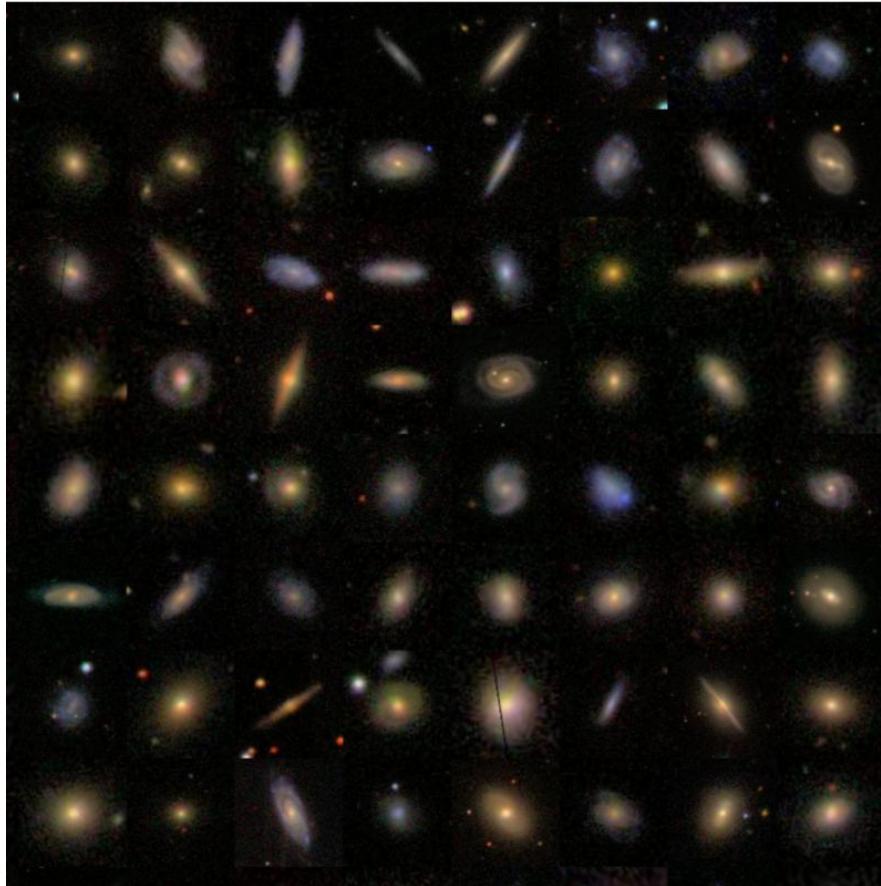


colour image



predictions

The data: 140 000 JPEG colour images

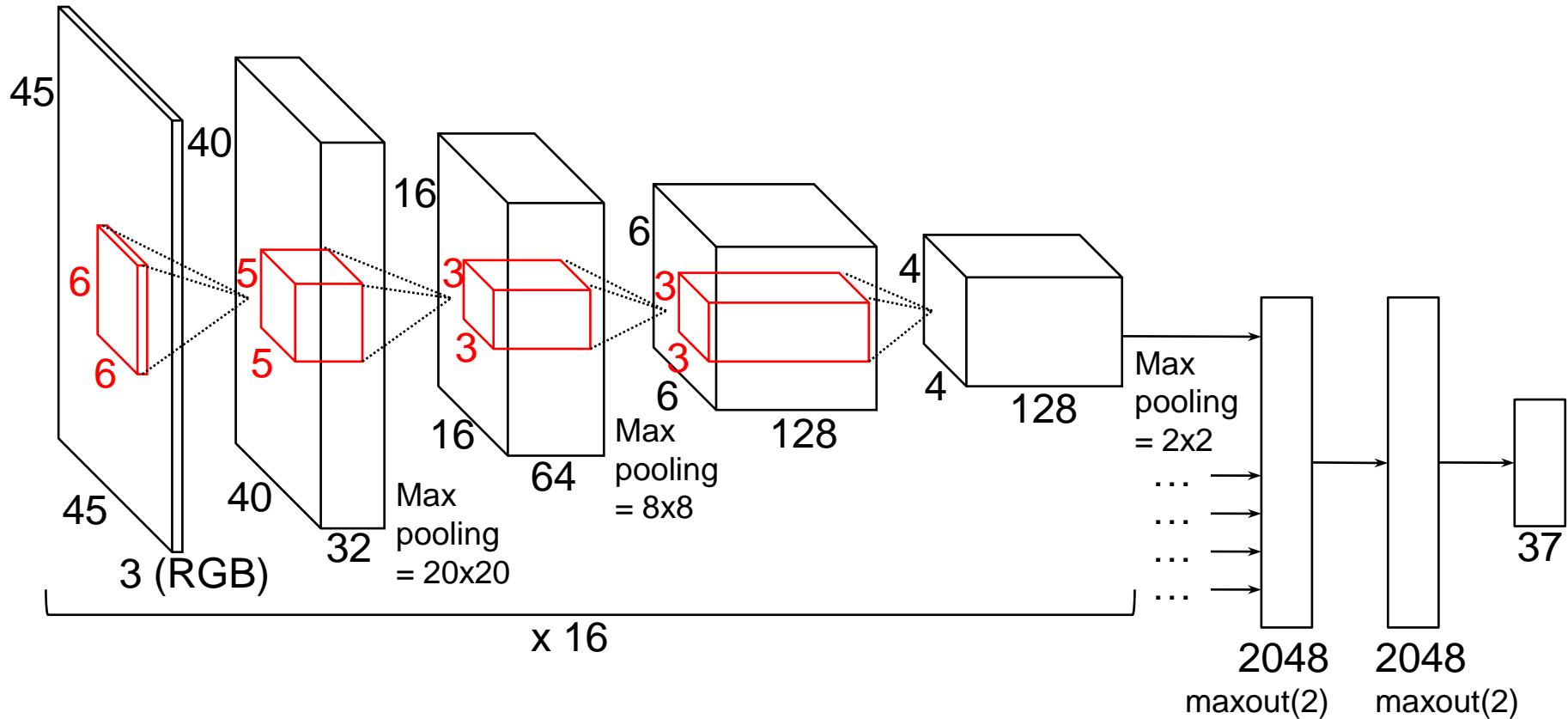


dimensions: 424 x 424

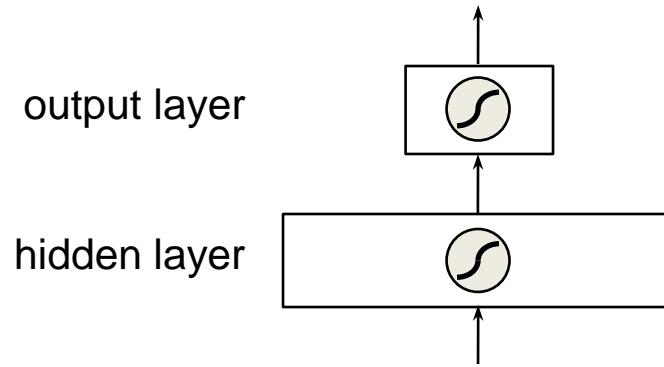
train: 61 578 images
test: 79 975 images

II. The solution

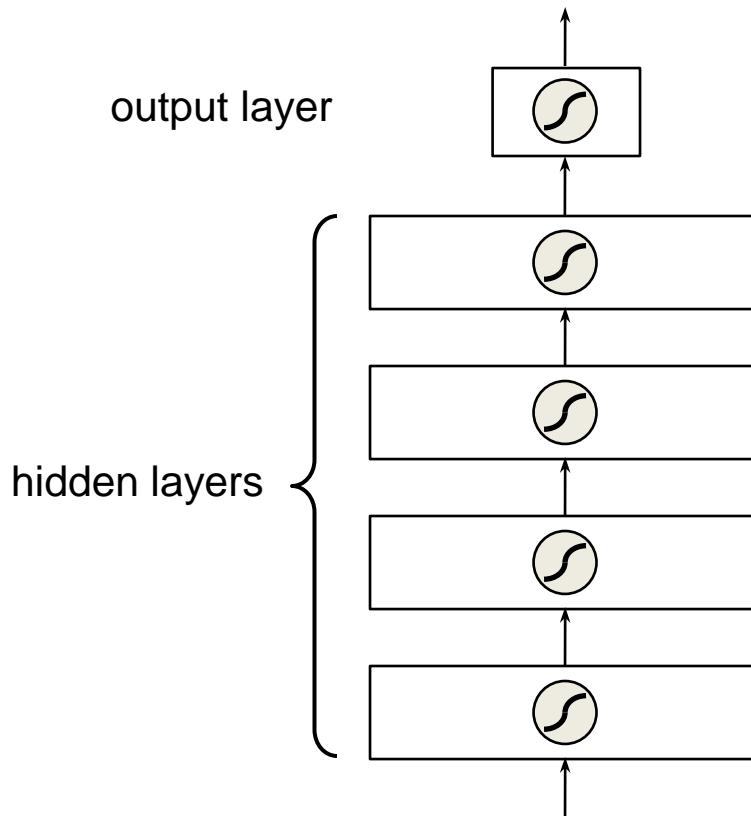
The solution: a **convnet** with 7 layers



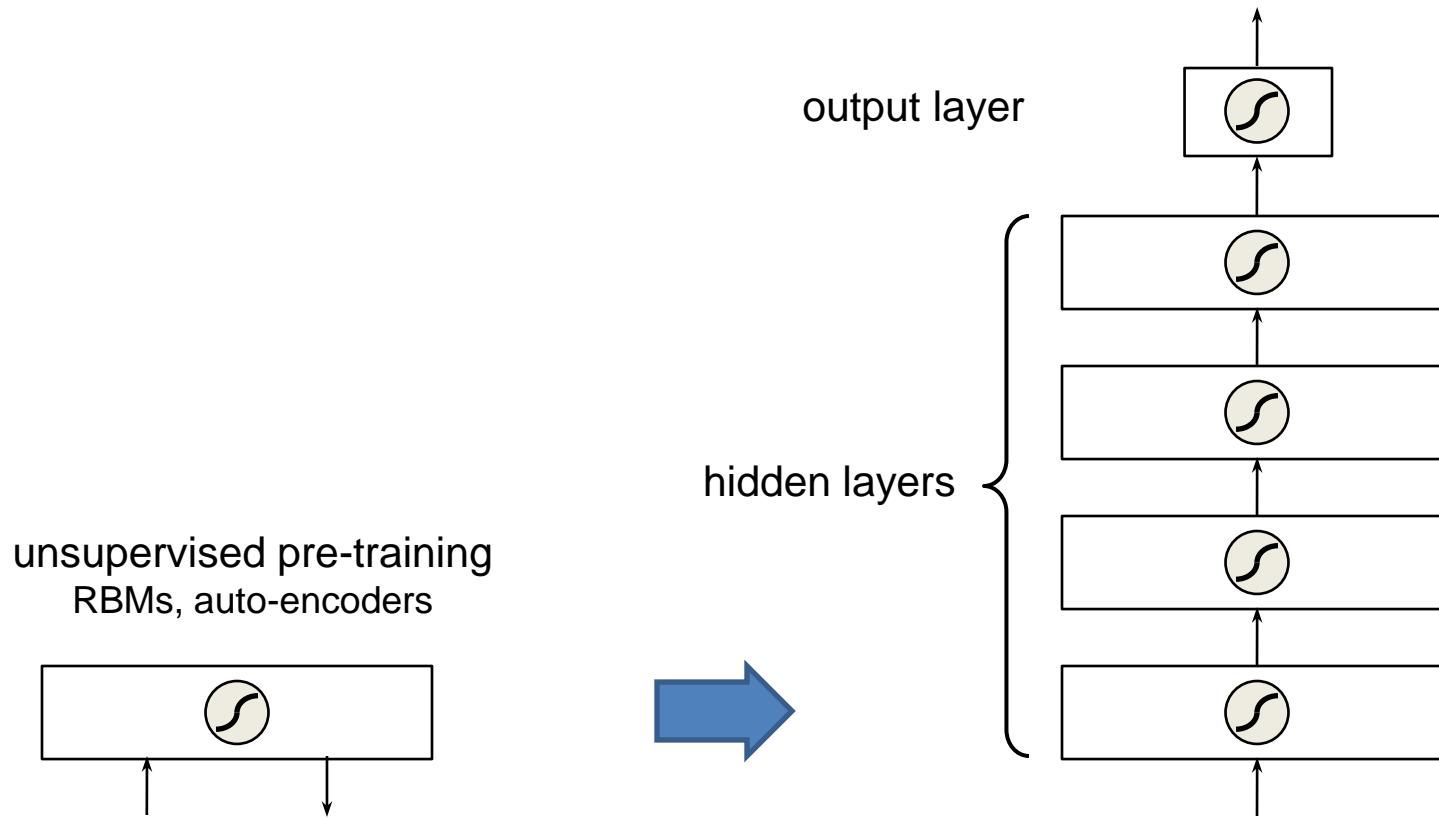
Deep learning vs. traditional neural networks



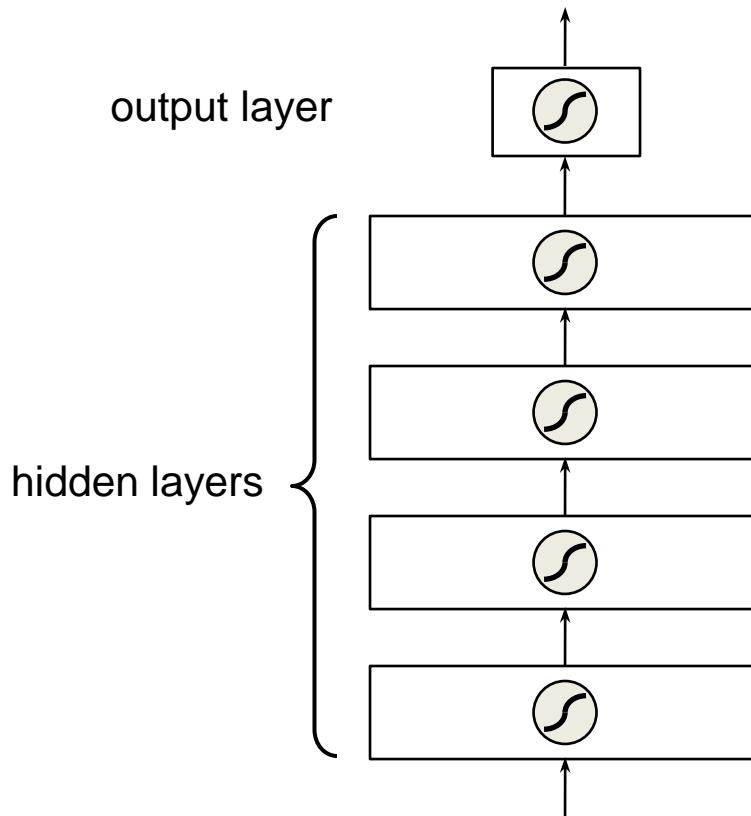
Deep learning vs. traditional neural networks



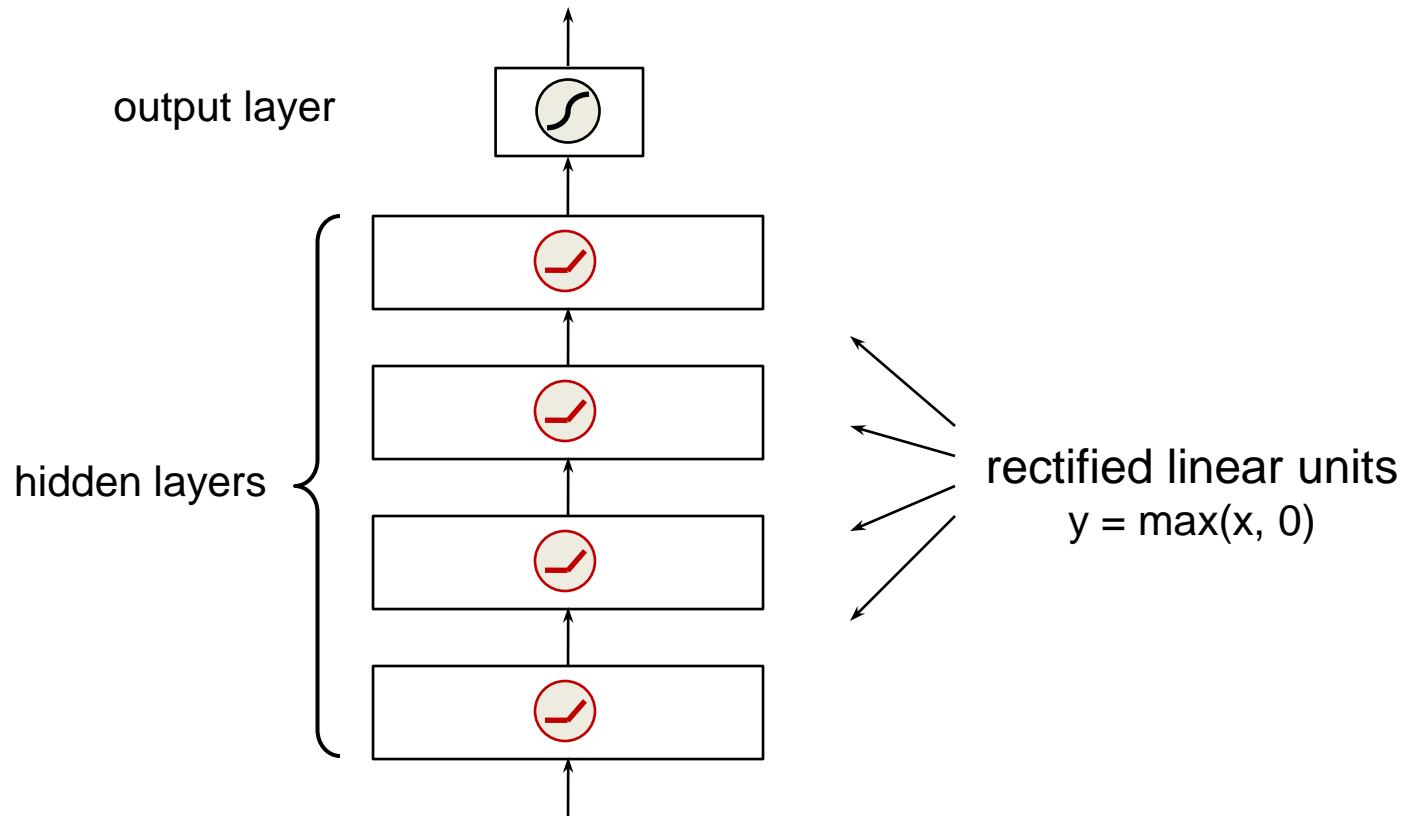
Deep learning vs. traditional neural networks



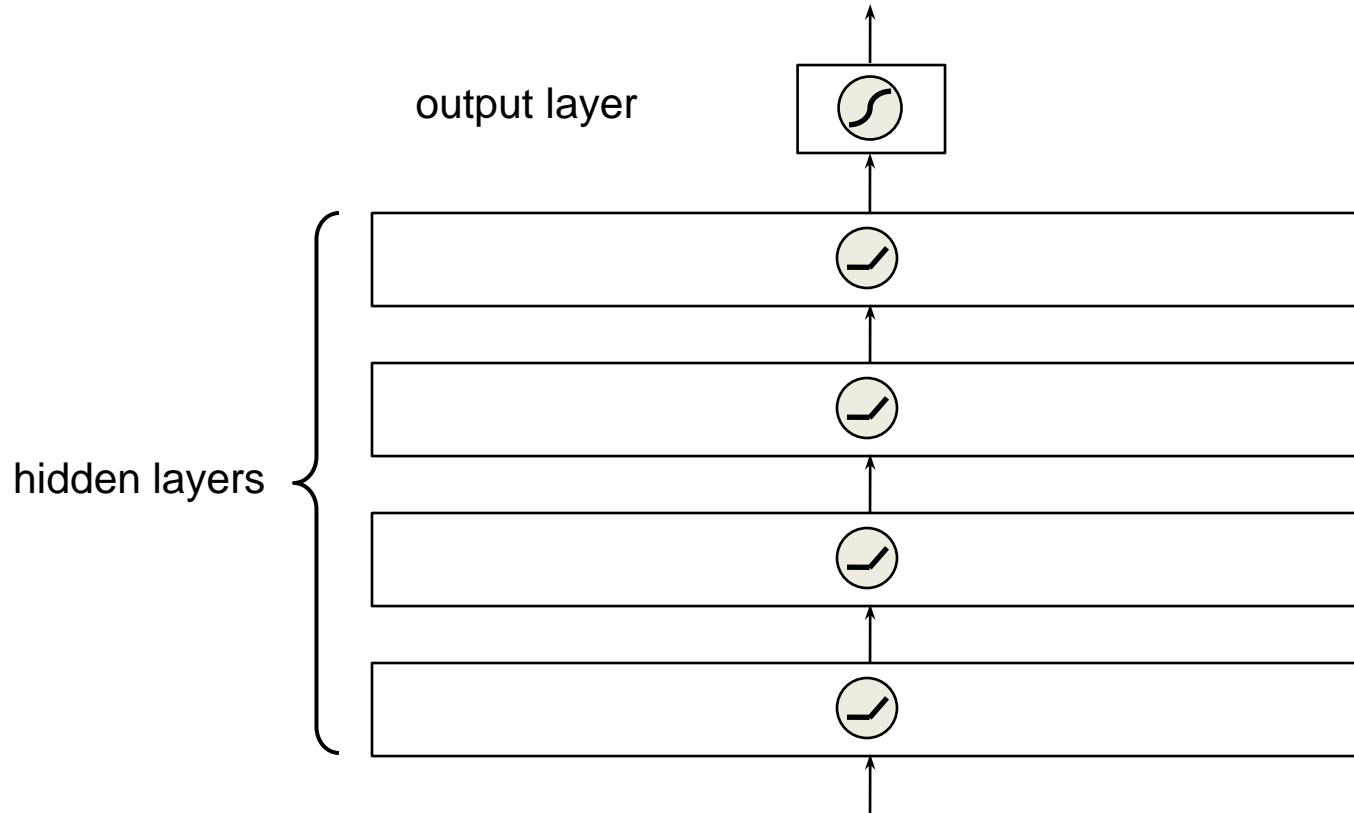
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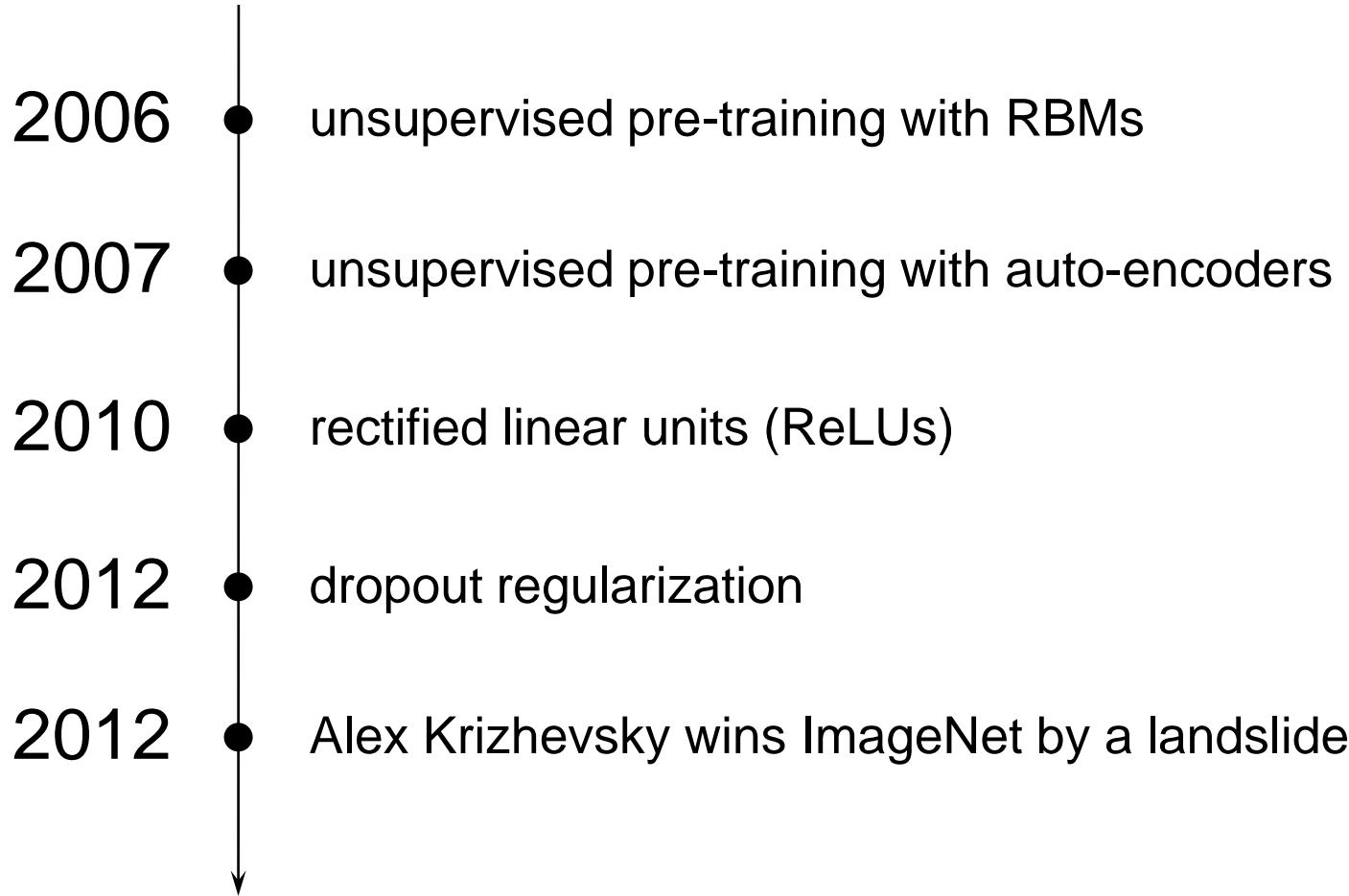
Deep learning vs. traditional neural networks



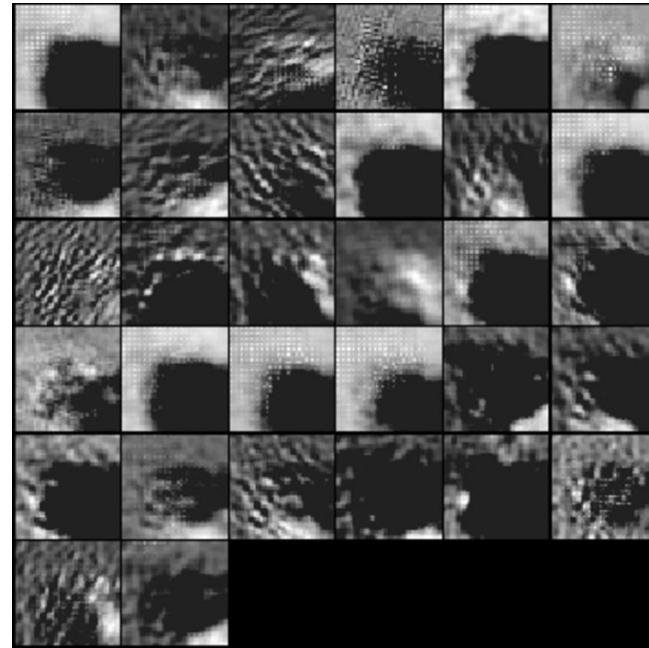
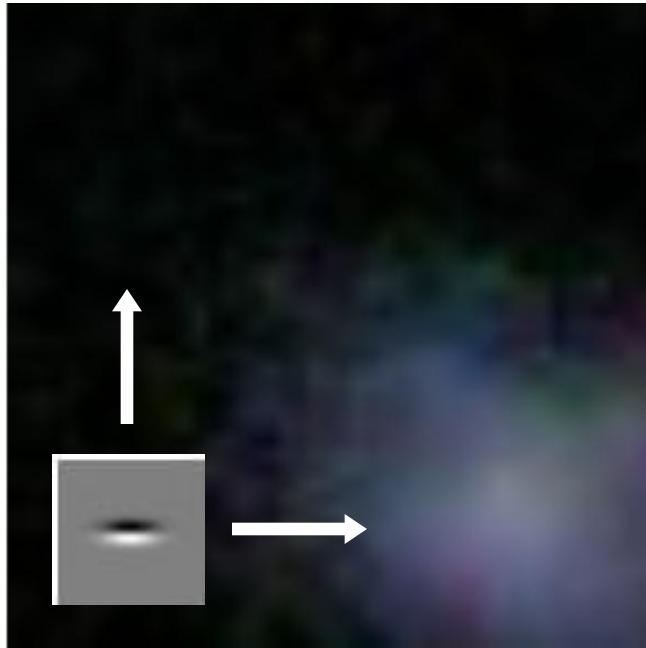
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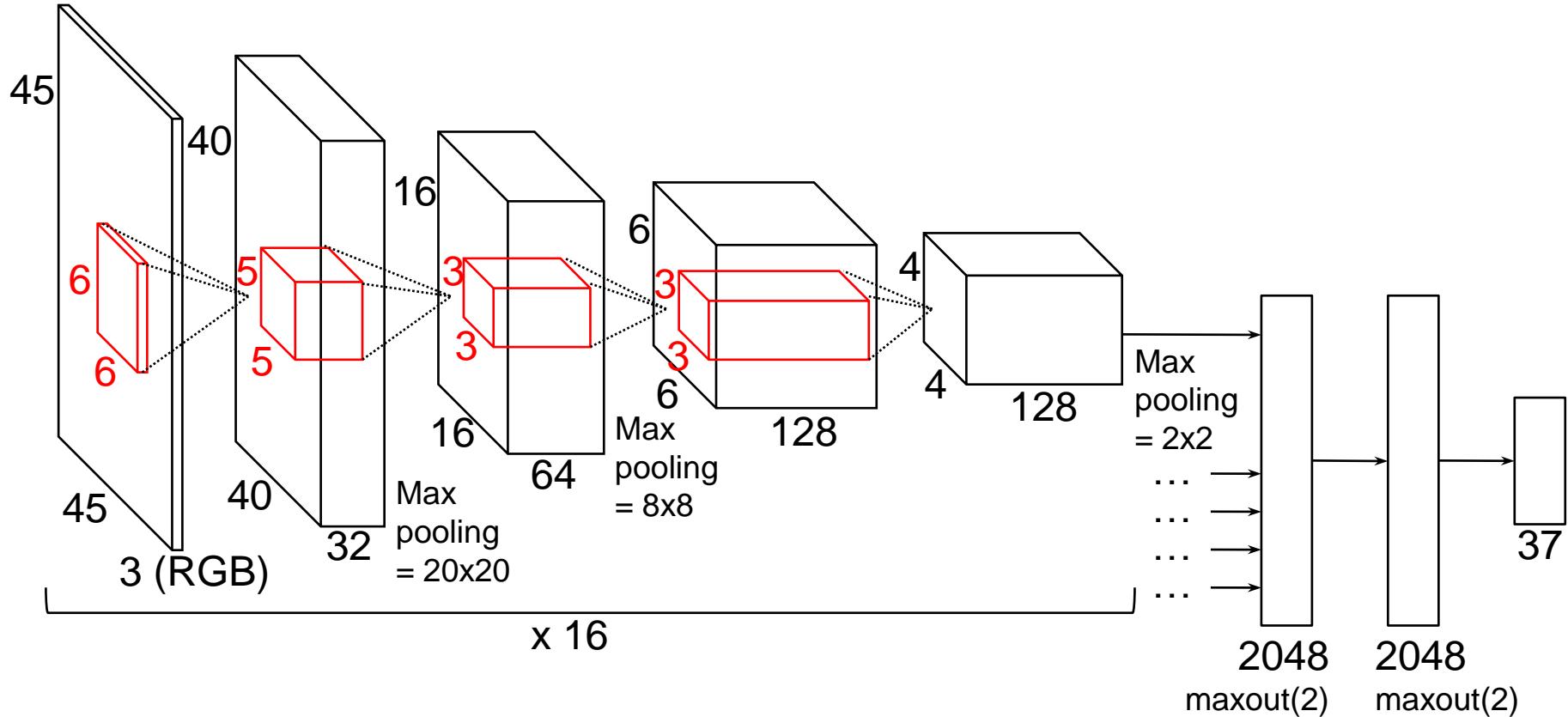
A brief history of deep learning



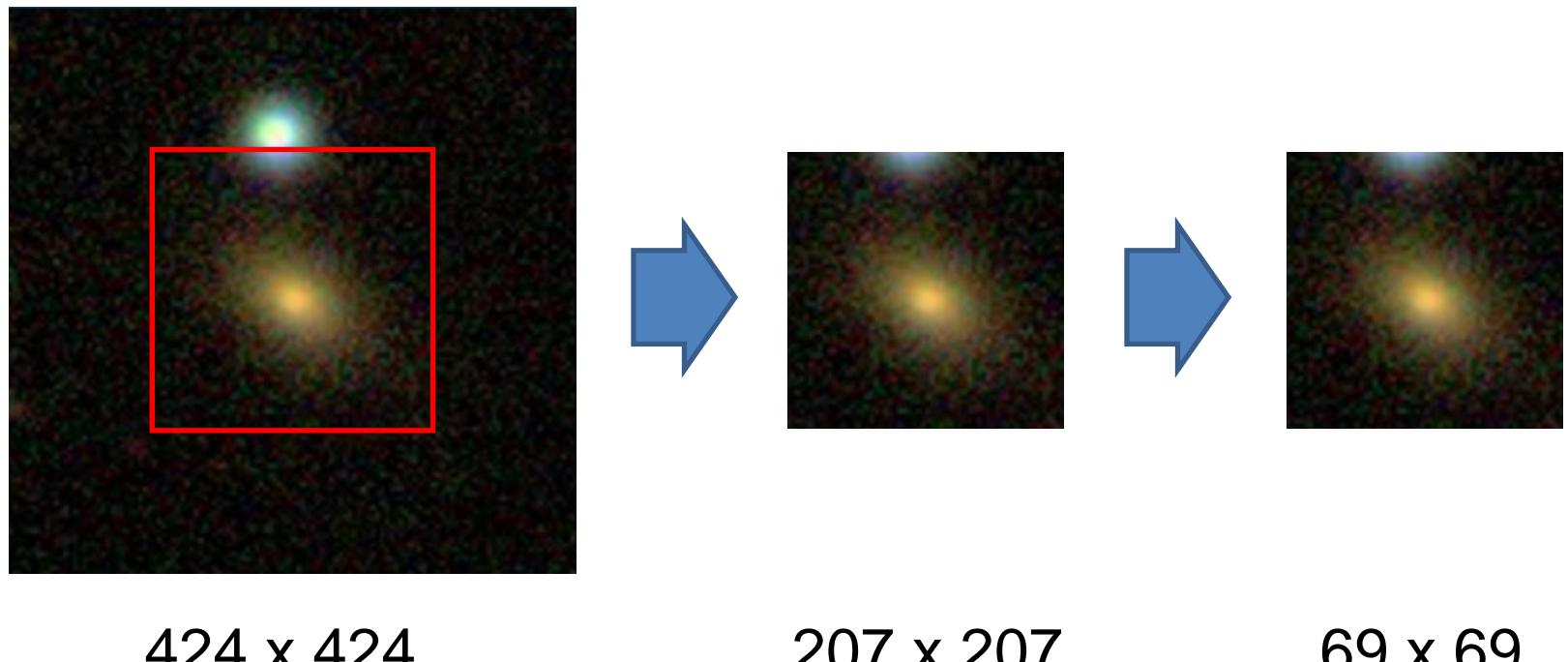
Convolutional neural networks exploit spatial structure



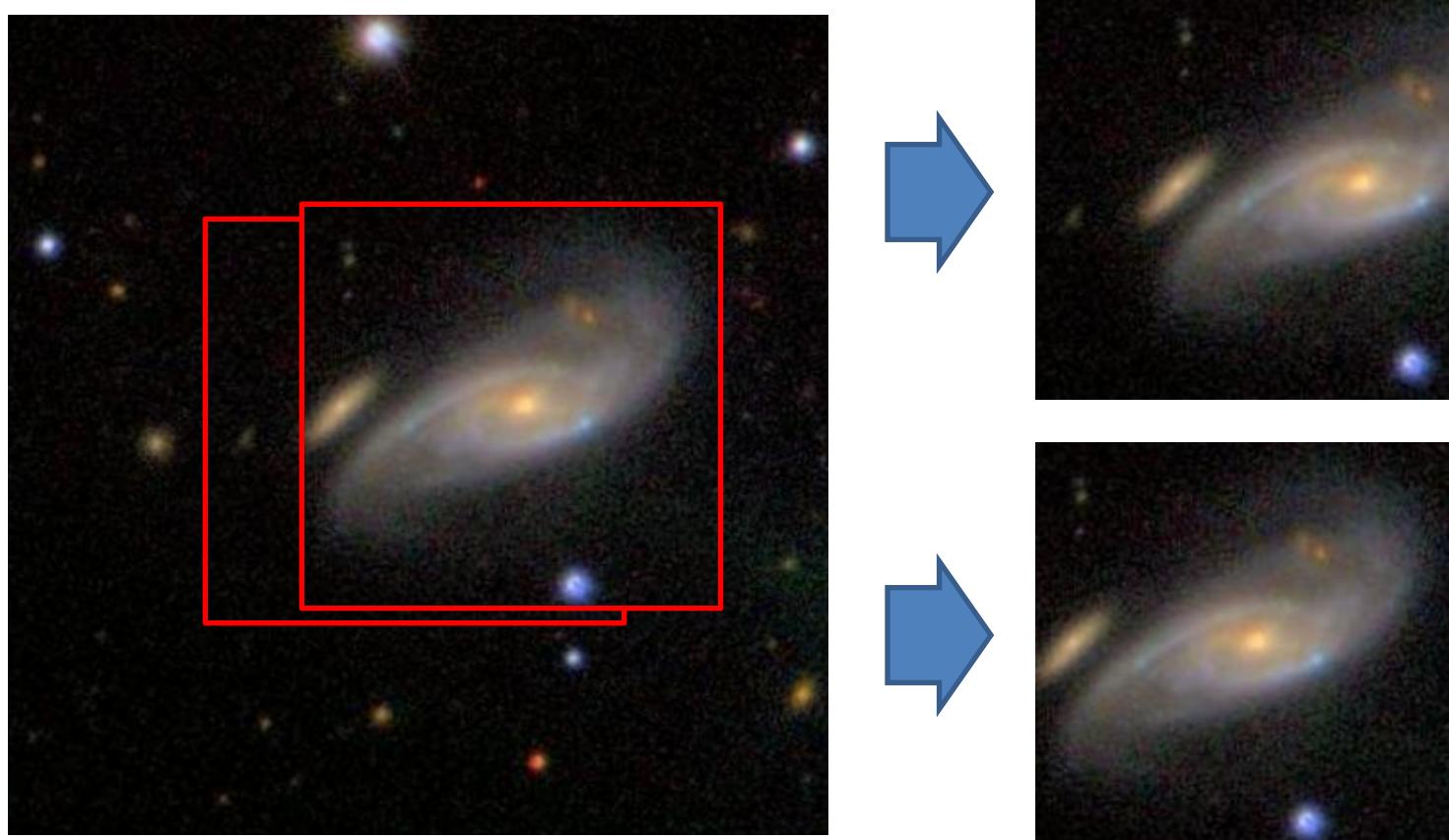
The solution: a **convnet** with 7 layers



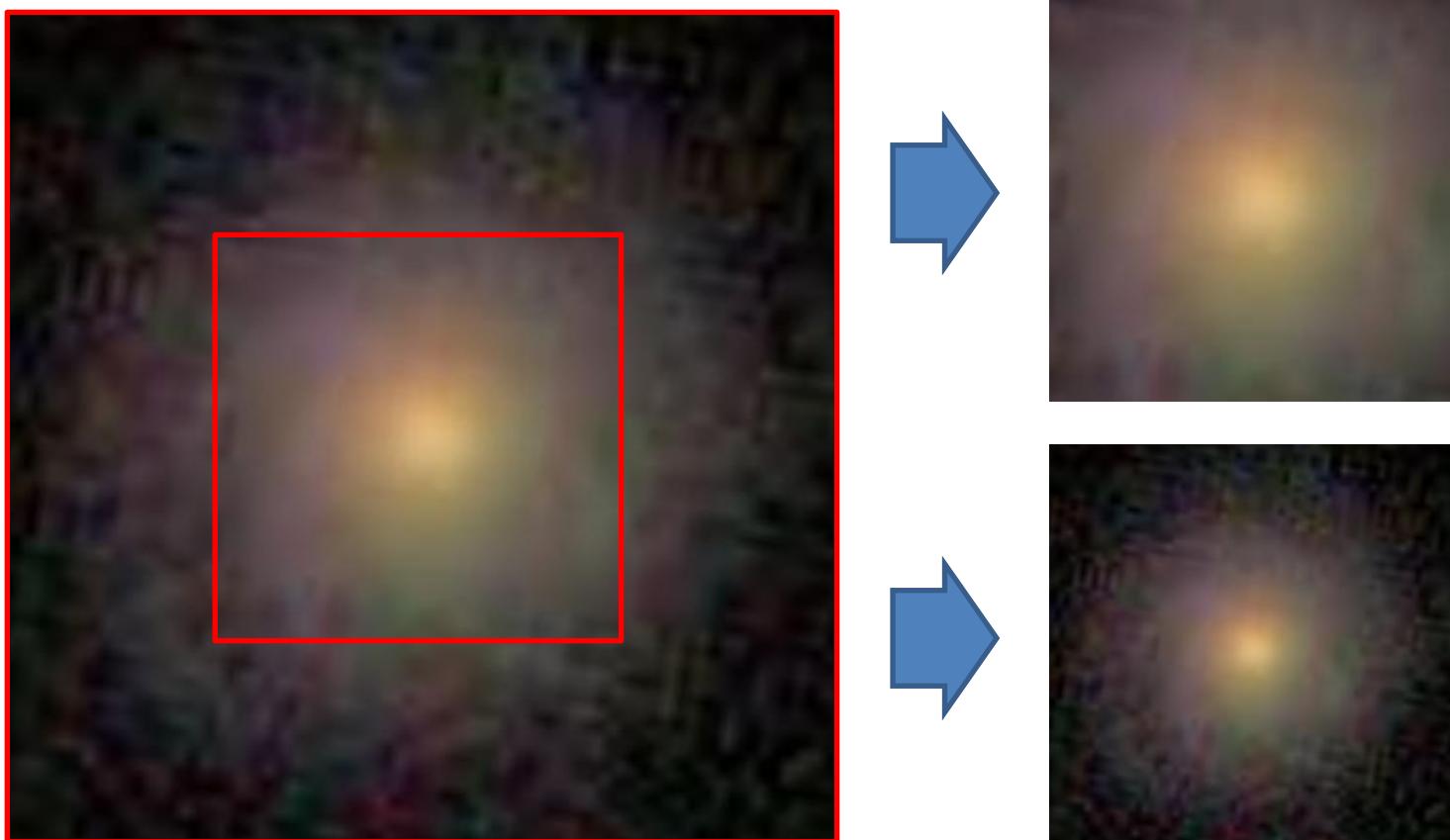
Preprocessing: cropping and downsampling



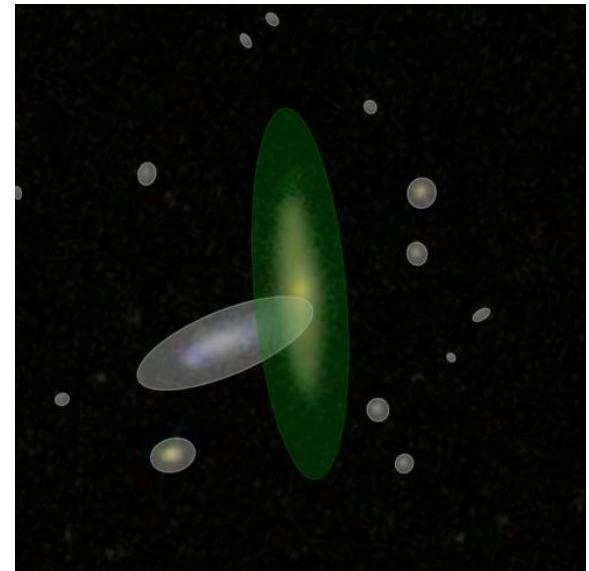
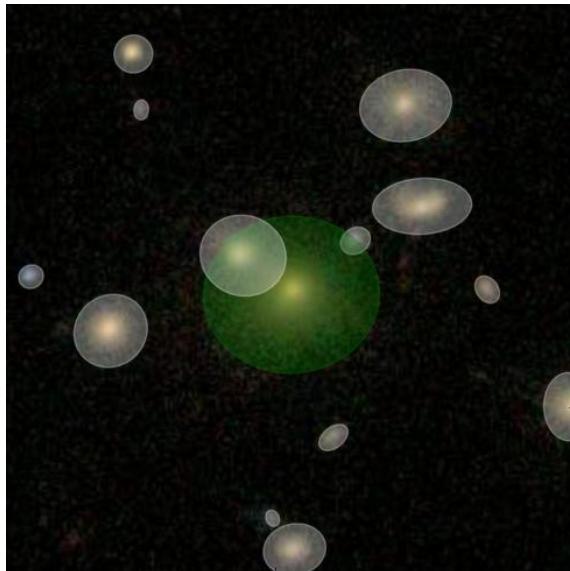
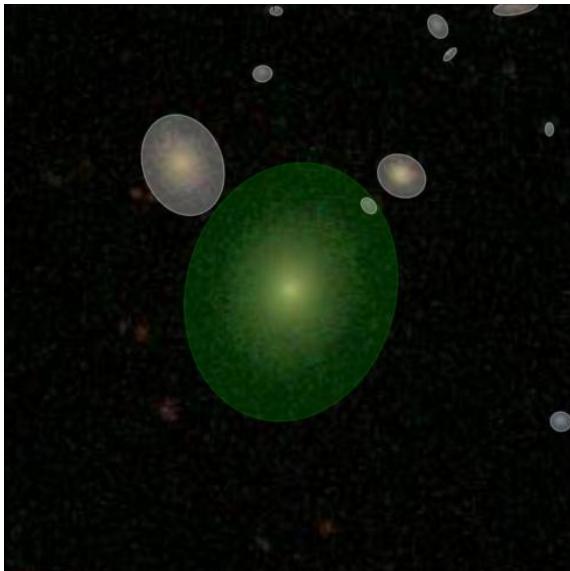
Optional preprocessing: re-center and rescale



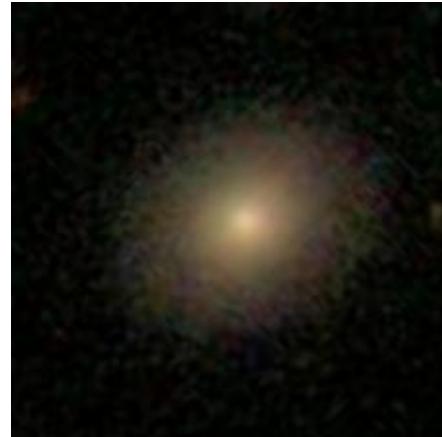
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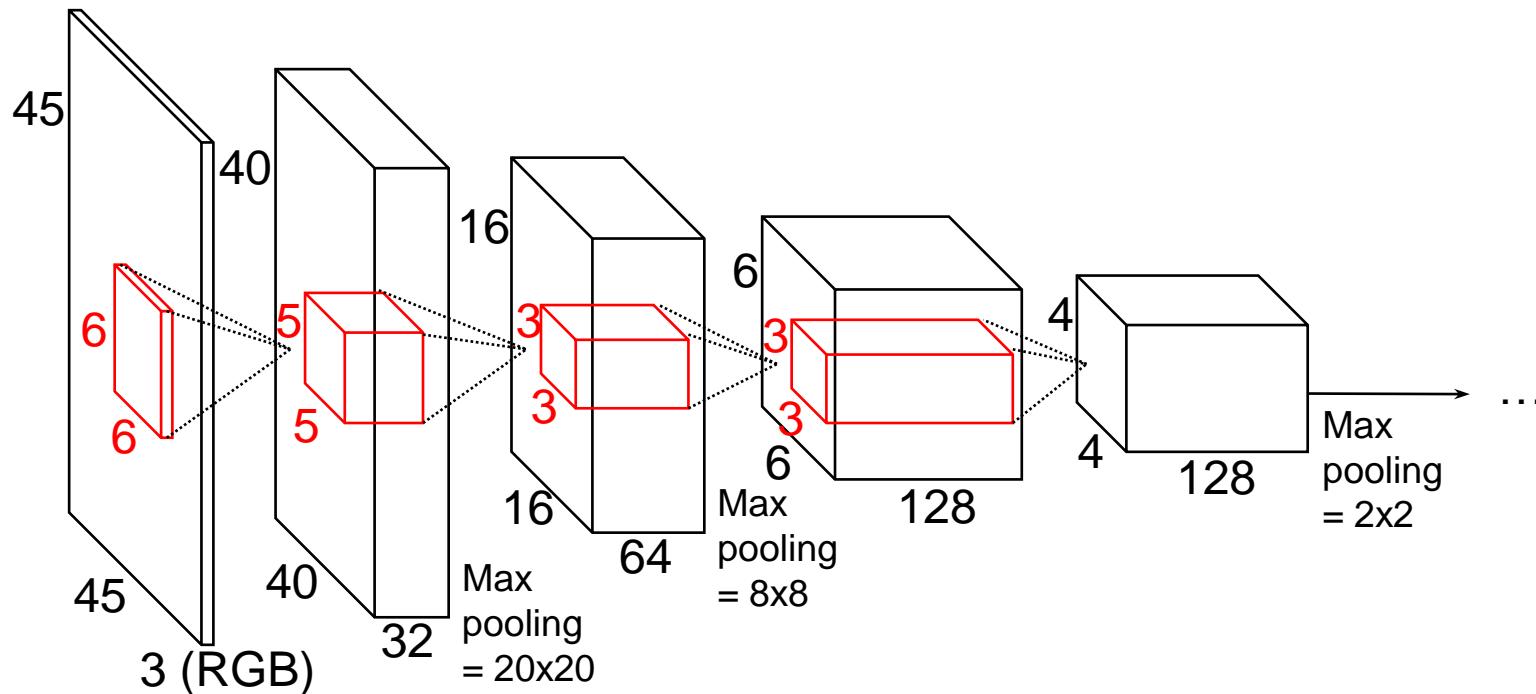
Source extractor estimates galaxy centers and Petrosian radii



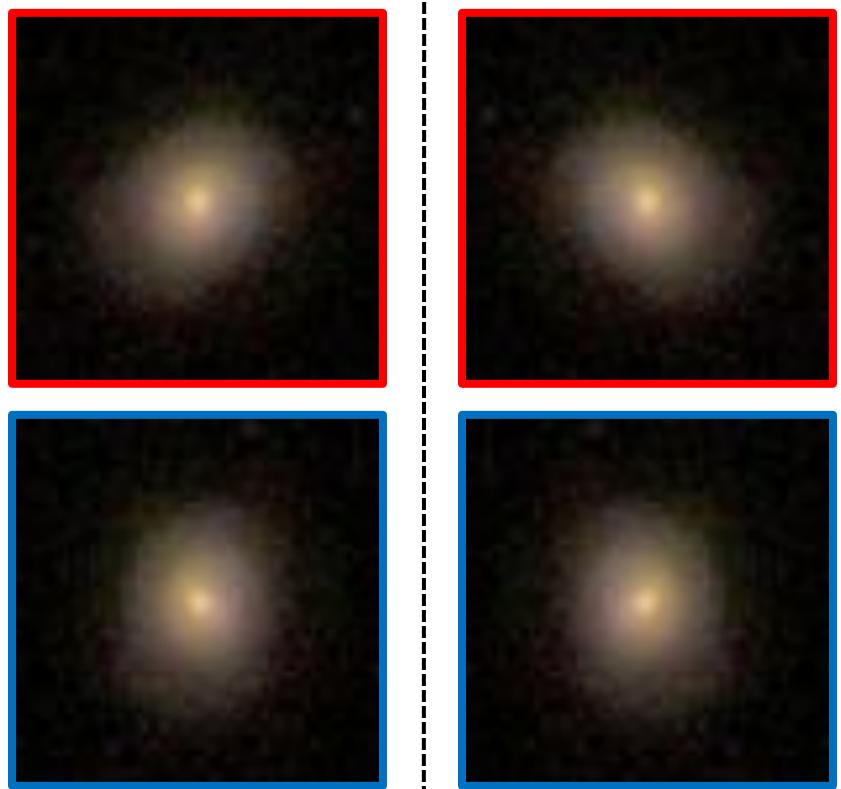
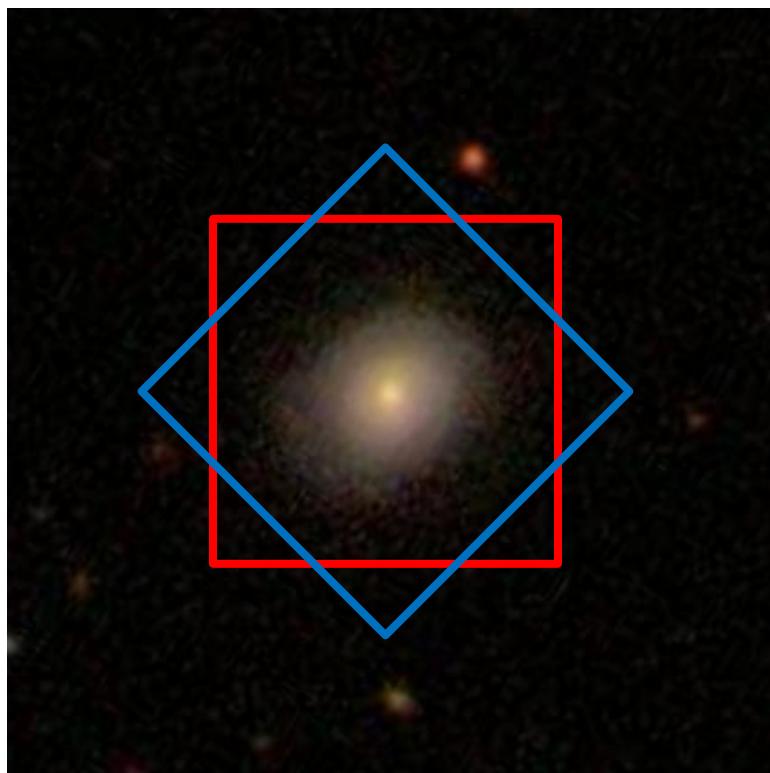
Data augmentation: rotation, translation, rescaling, flipping, ...



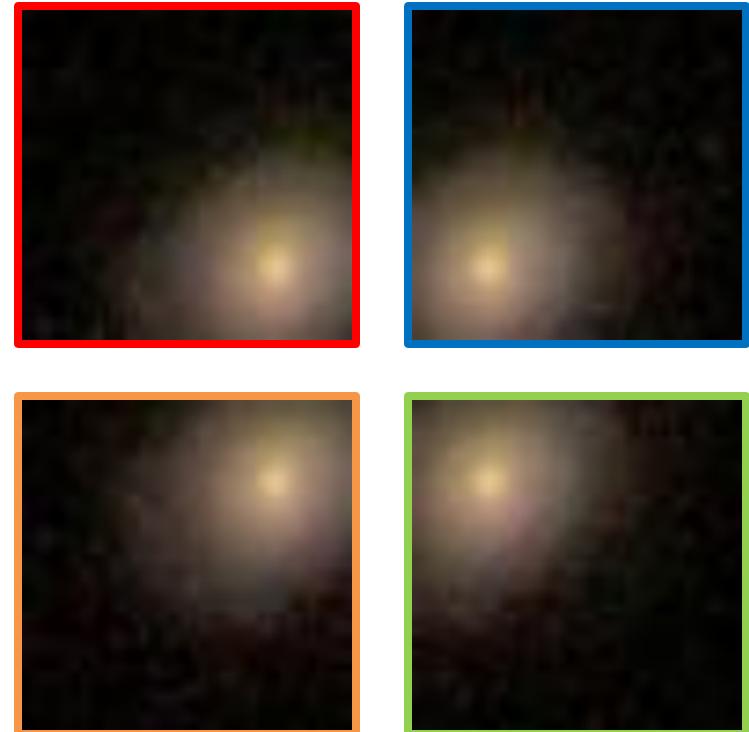
Network architecture: convolutions and pooling



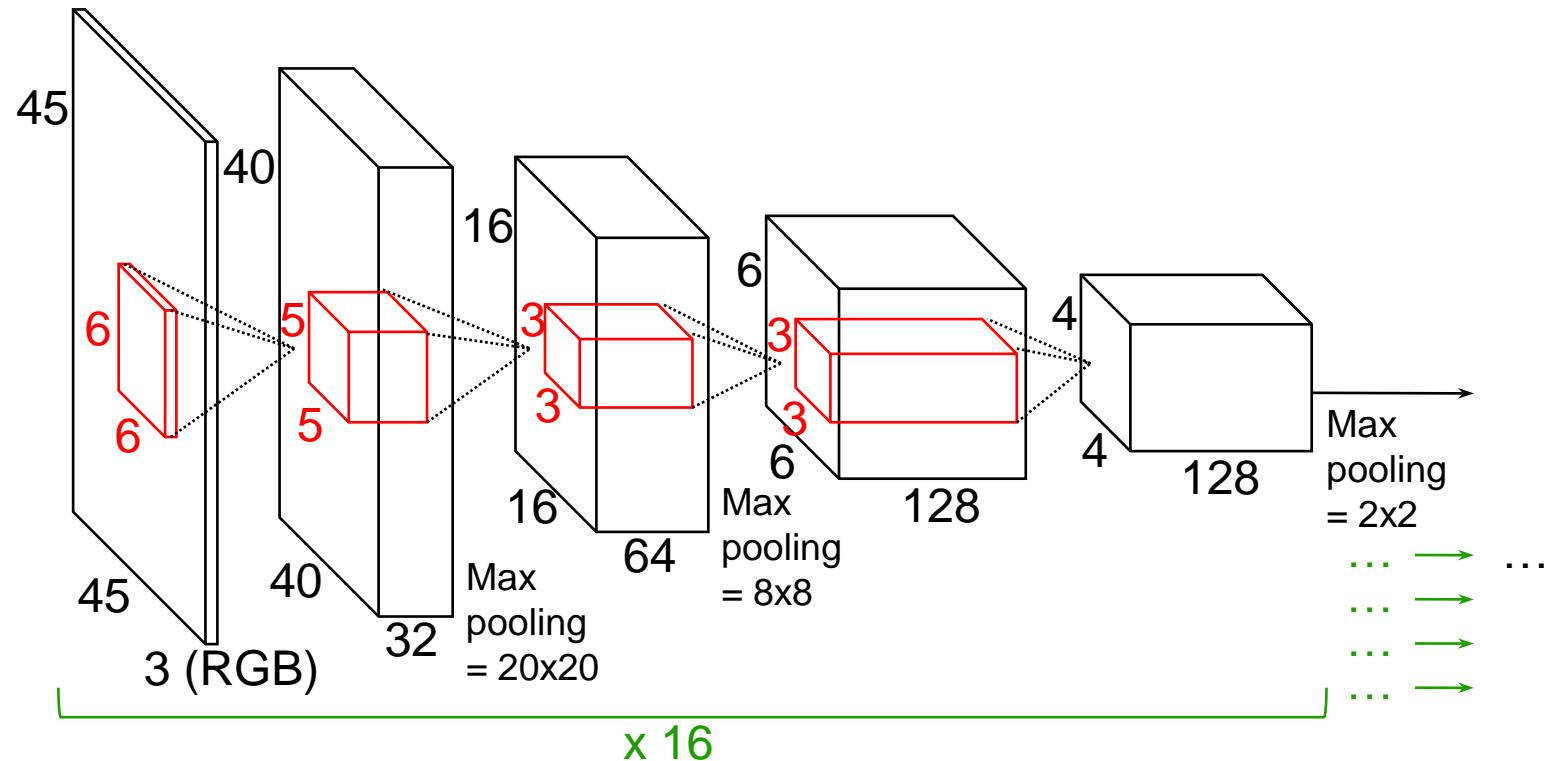
Network architecture: exploiting **rotation invariance**



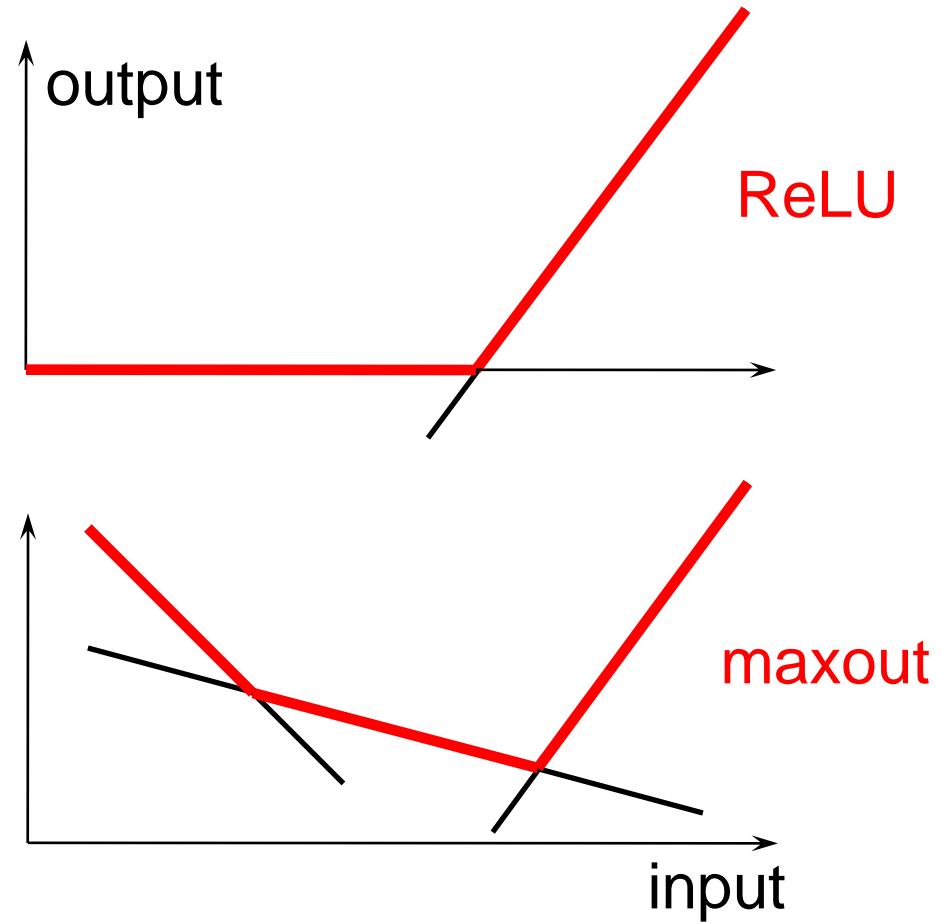
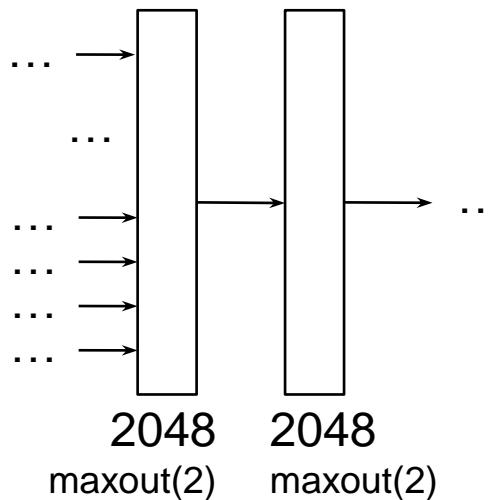
Network architecture: exploiting **rotation invariance**



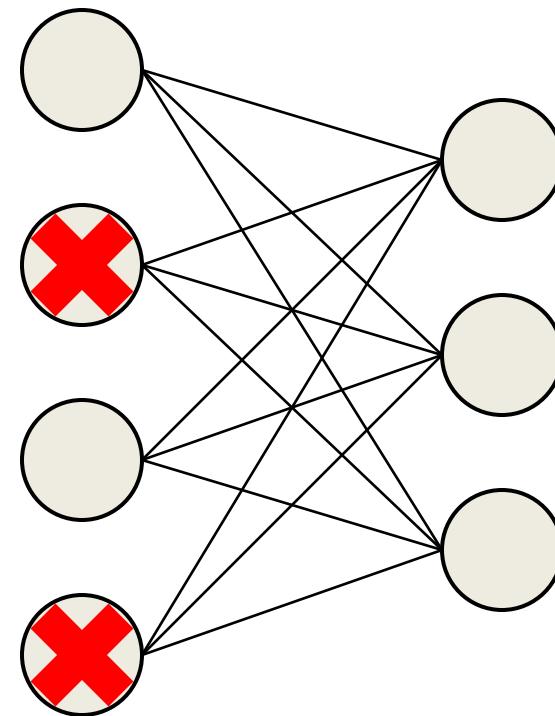
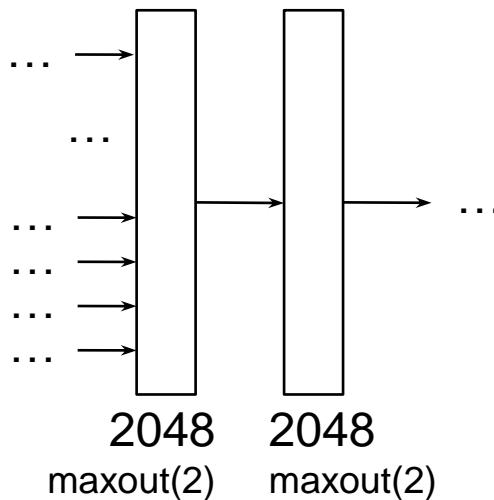
Network architecture: exploiting **rotation invariance**



Network architecture: **maxout** layers

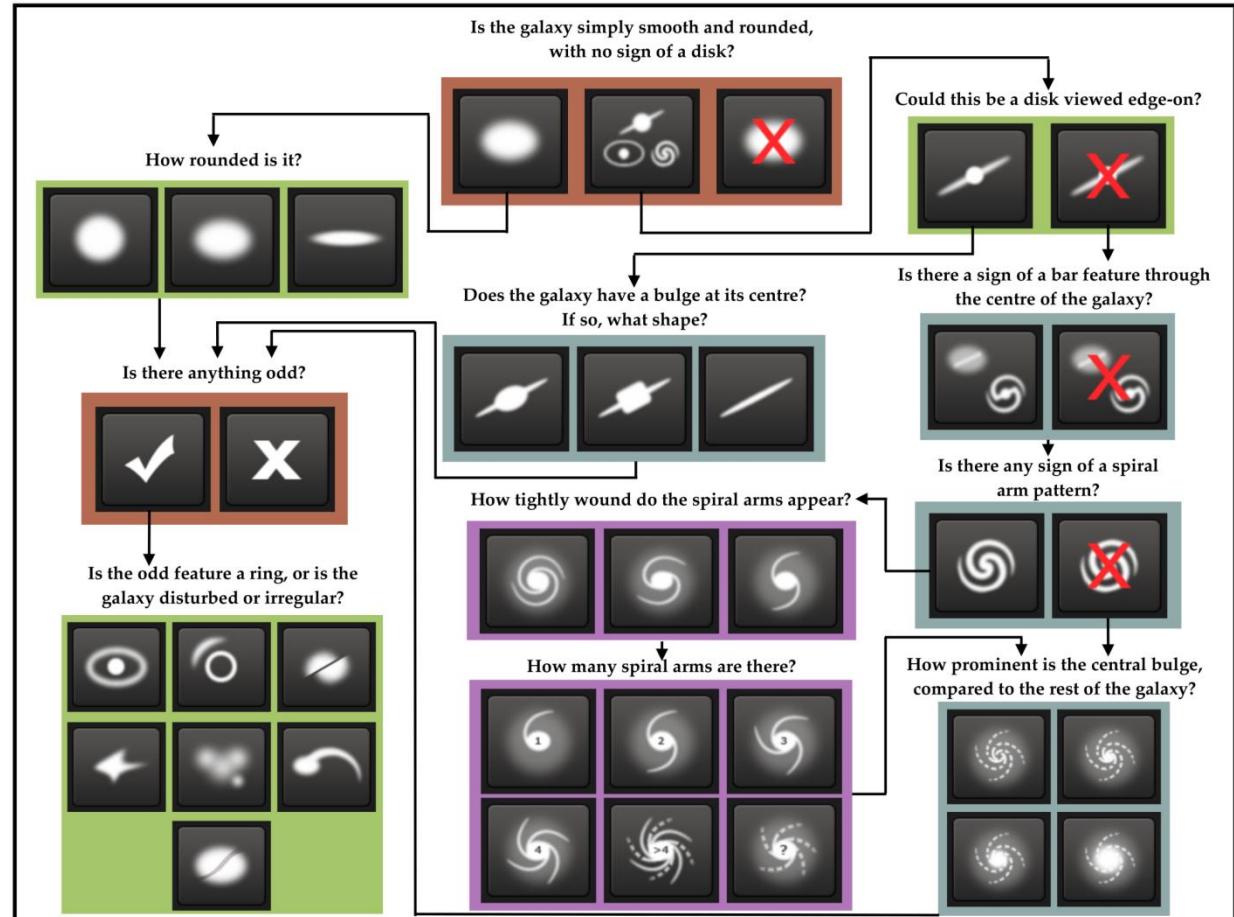


Network architecture: **dropout** regularisation

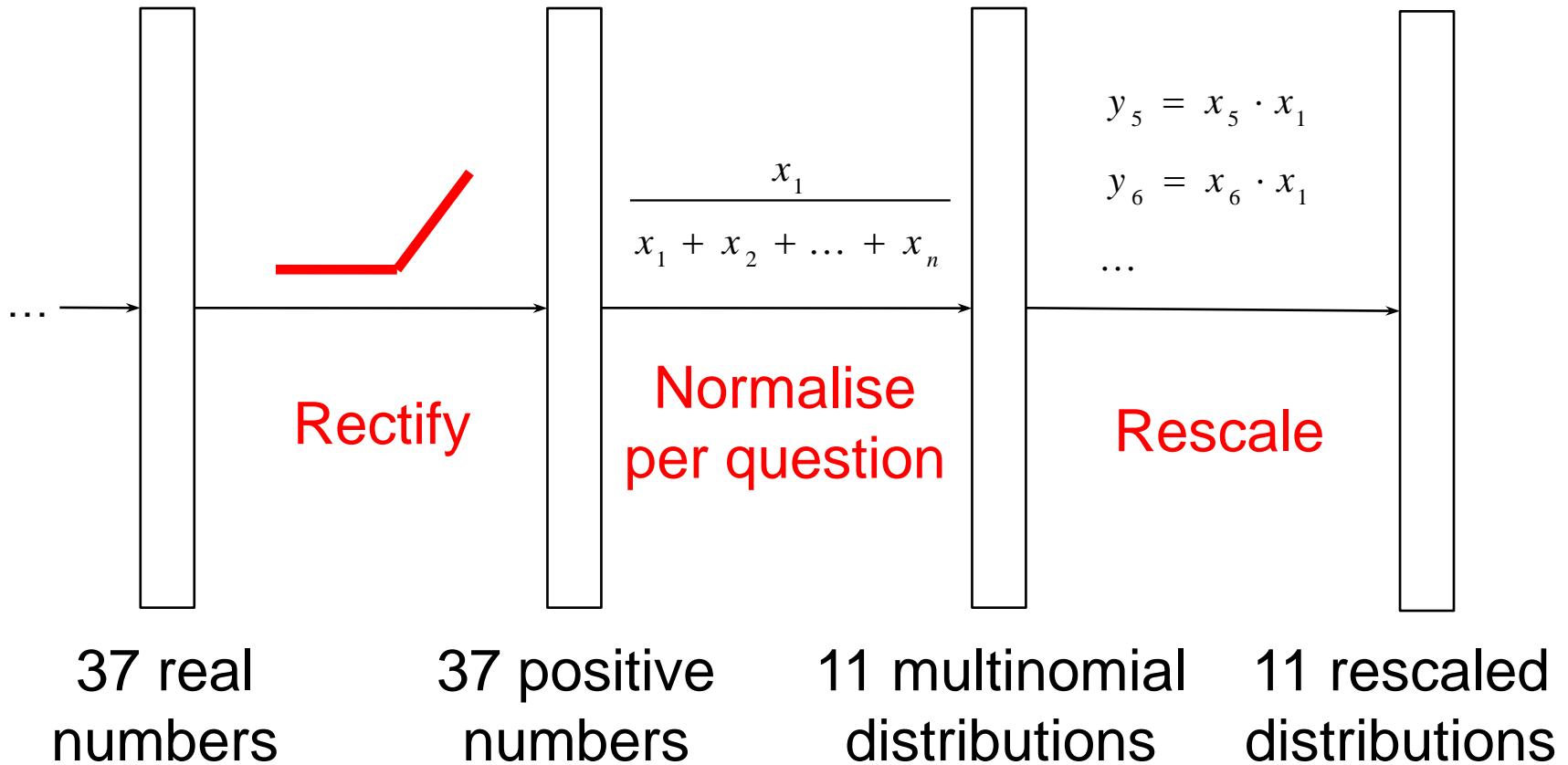


Network architecture: incorporating output constraints

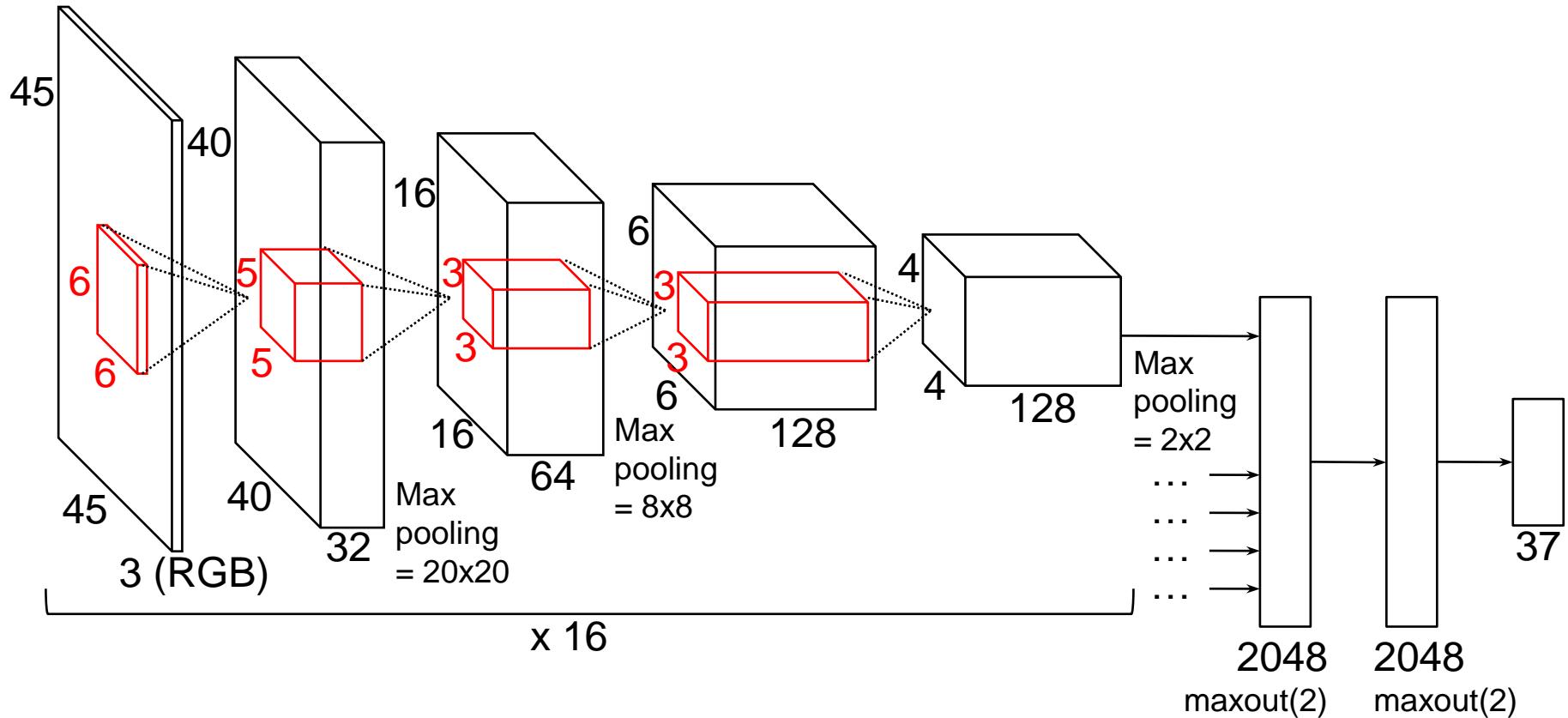
... → 37



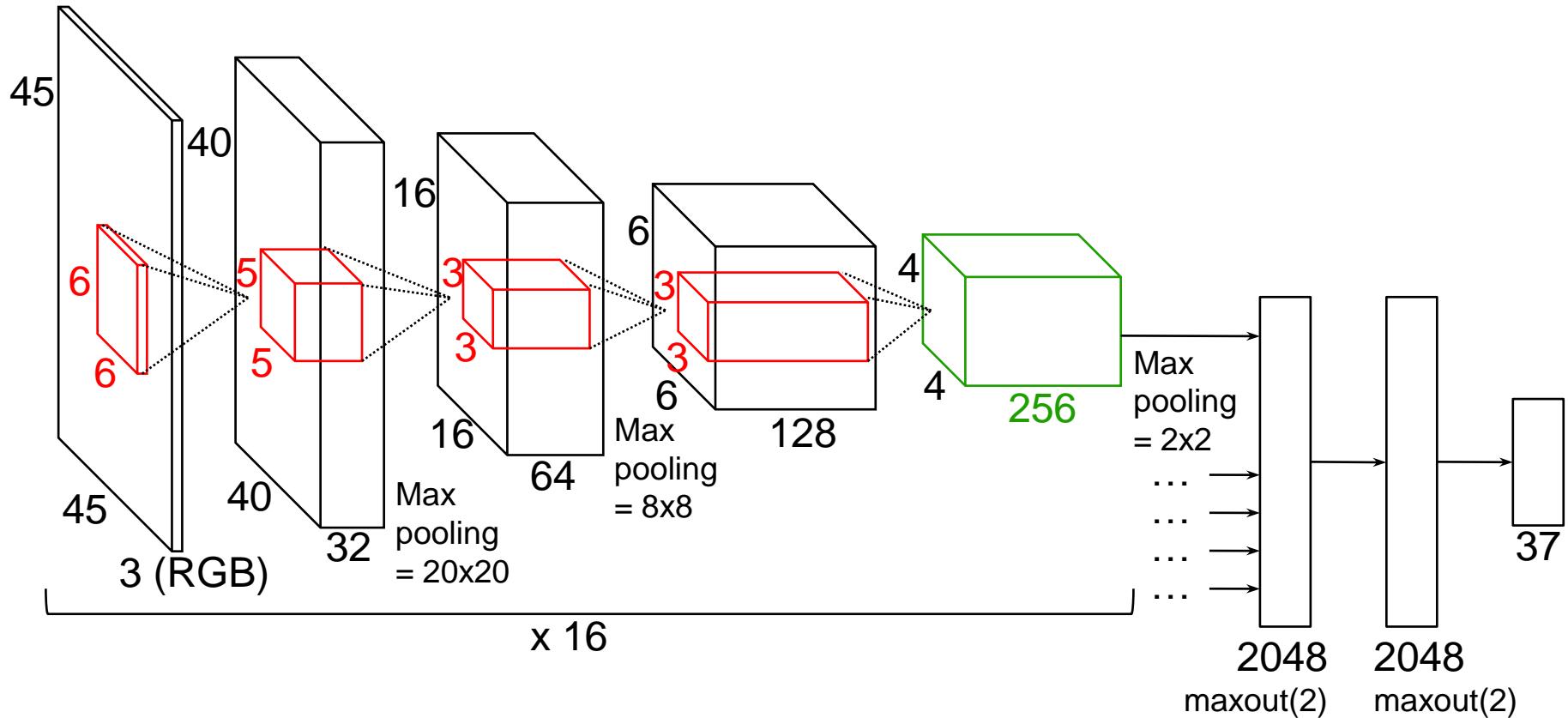
Network architecture: incorporating **output constraints**



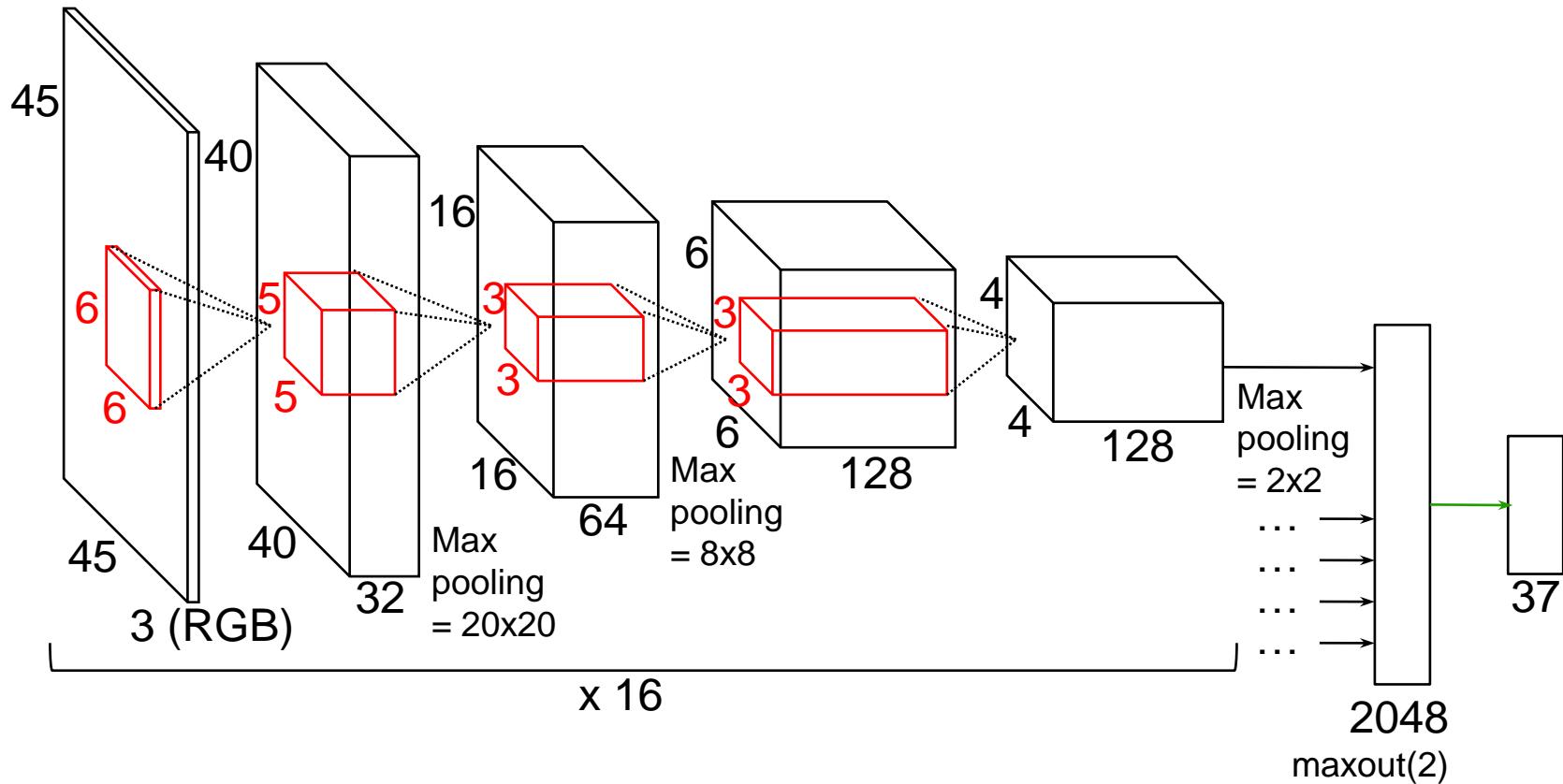
Model averaging: across architectures



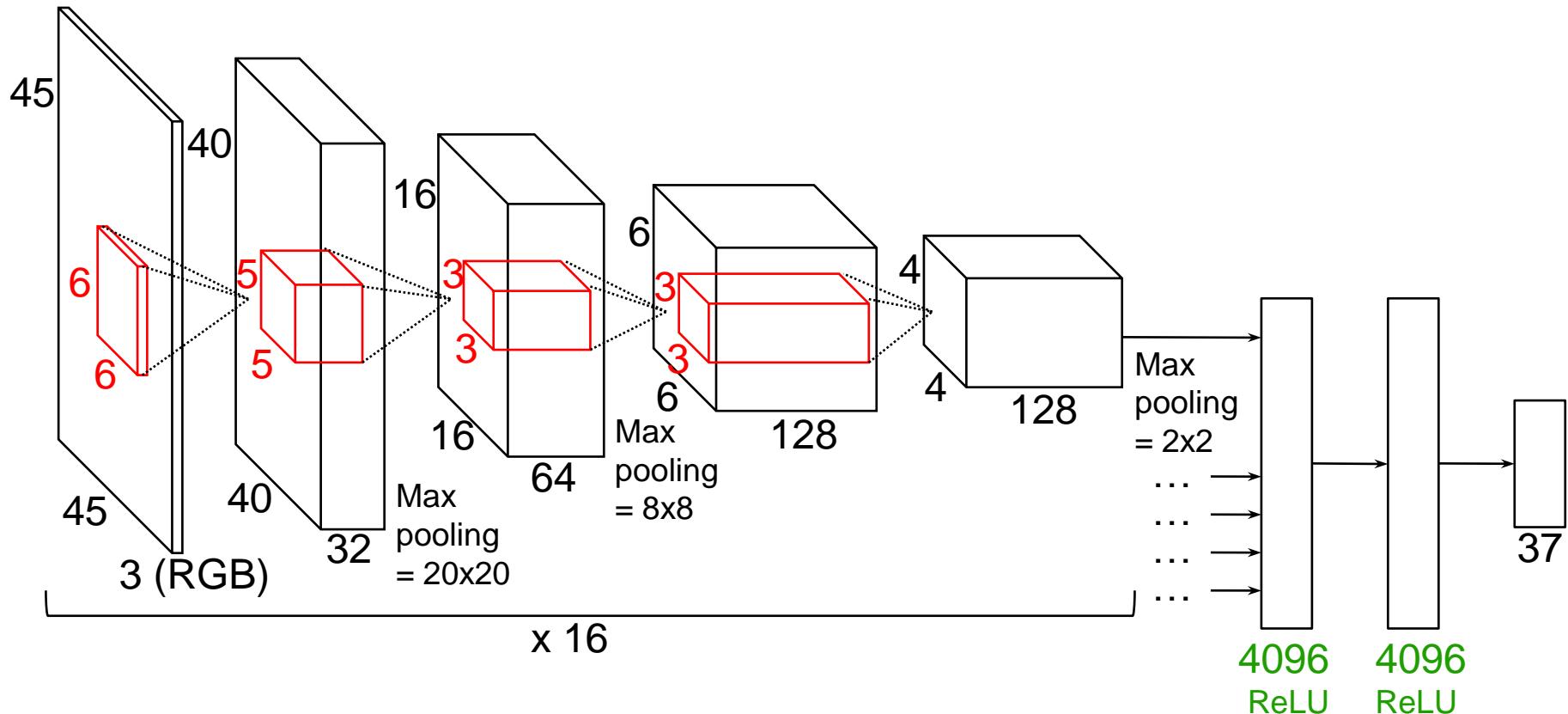
Model averaging: across architectures



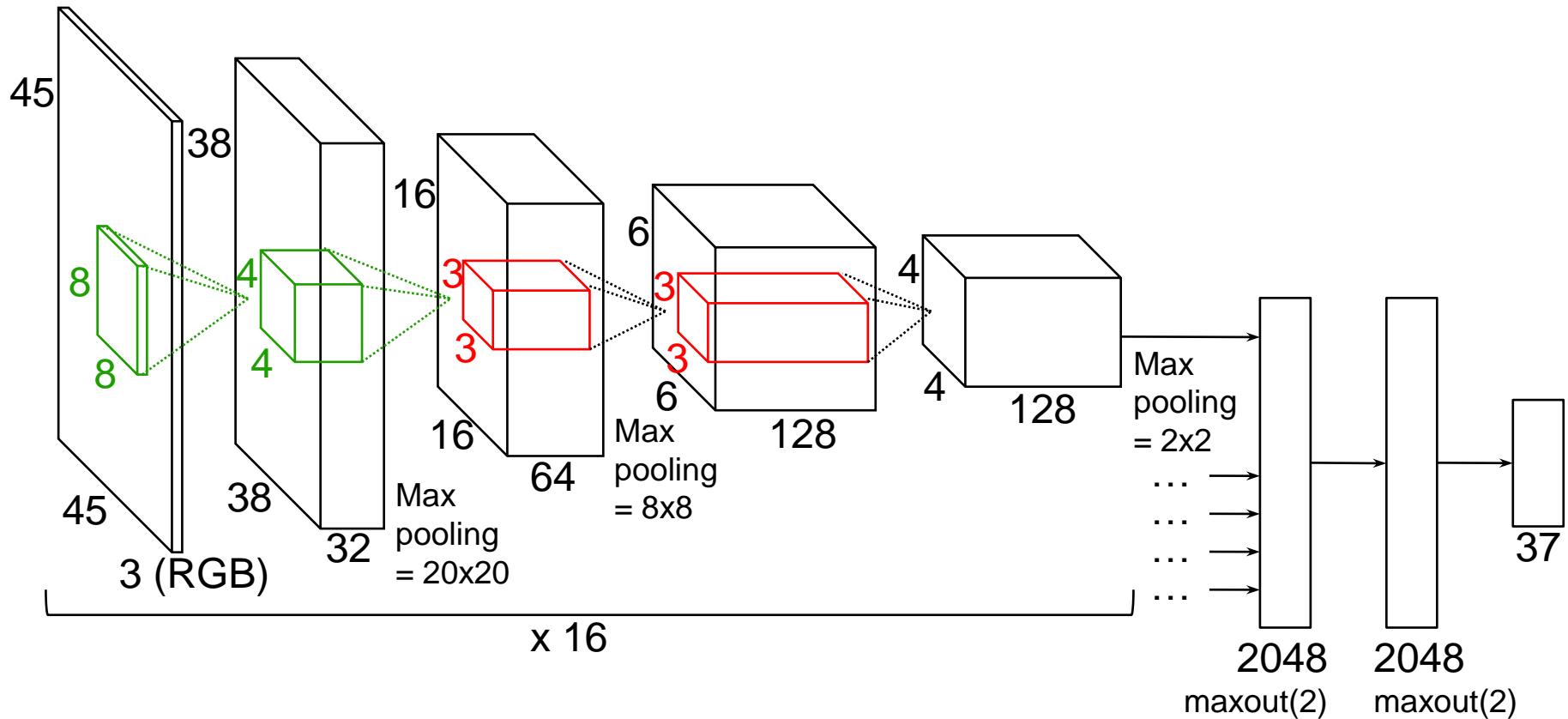
Model averaging: across architectures



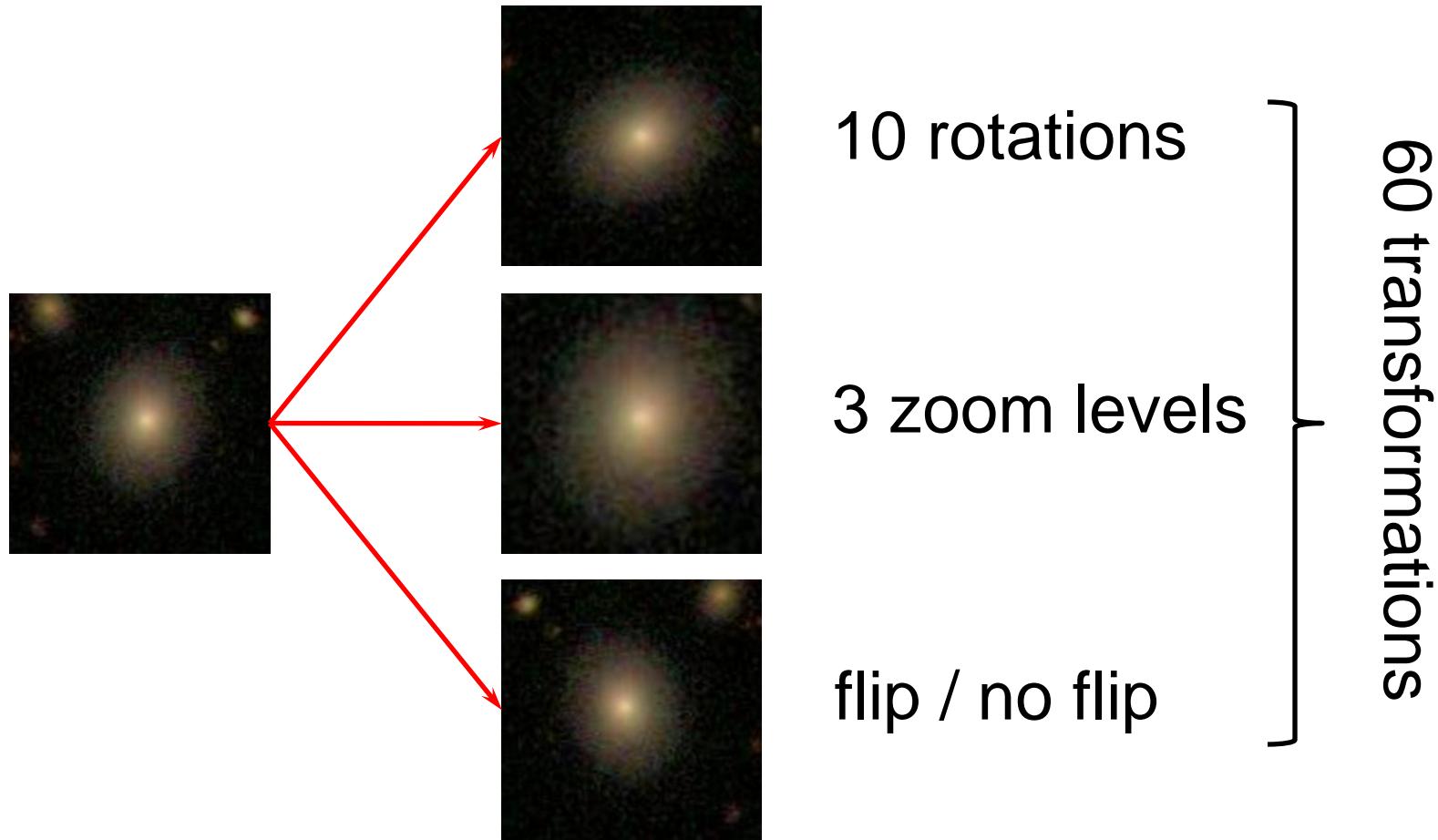
Model averaging: across architectures



Model averaging: across architectures



Model averaging: across **transformations**



Reducing **overfitting**

Data augmentation

Rotation invariant architecture

Model averaging

Dropout

Maxout

Training large CNNs requires **GPU acceleration**



Intel Core i7 3930K at 3.2 GHz, **6 cores**

32GB RAM

NVIDIA **GeForce GTX 680** 2GB / 4GB (2x)

theano

Implementation: **Python + Theano**
+ **cuda-convnet** wrappers from **pylearn2**

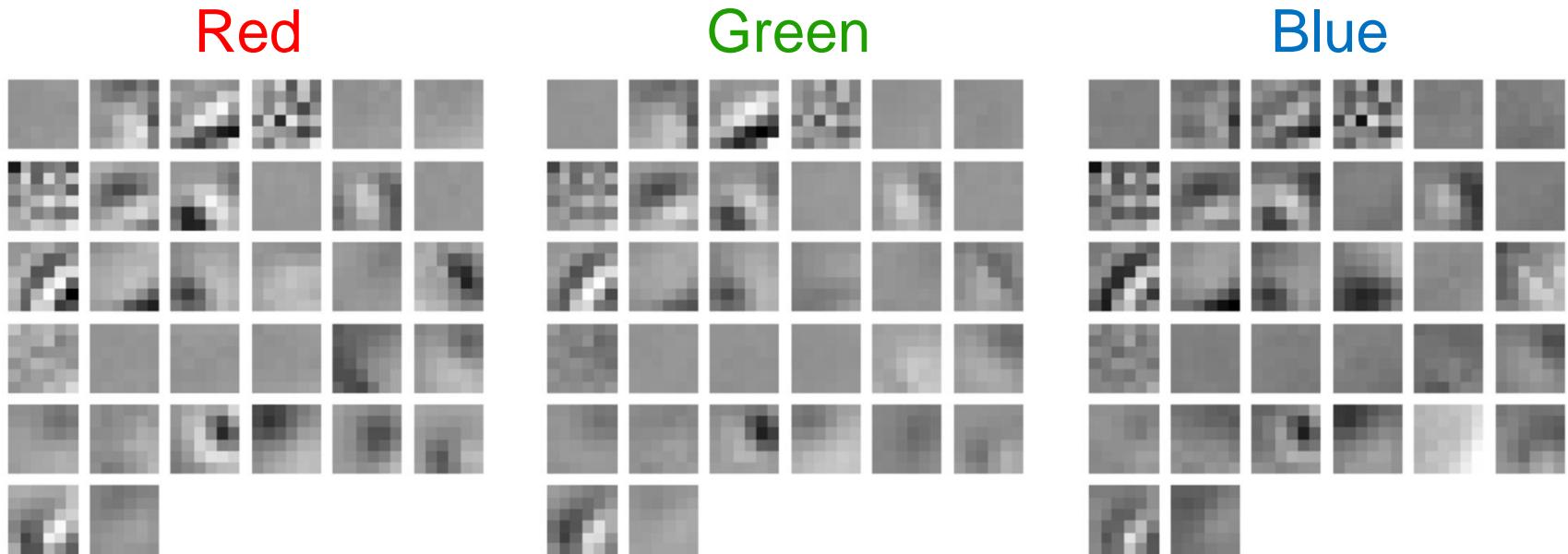


scikit-image
image processing in python

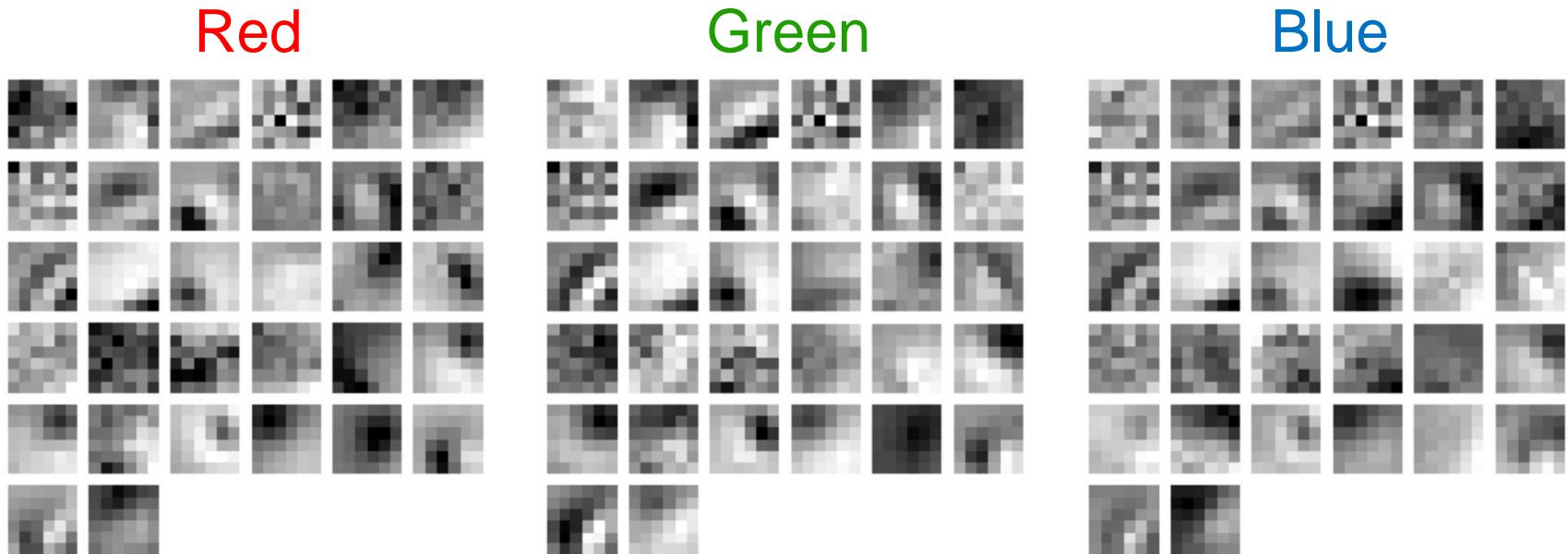
Realtime pre-processing and
augmentation: **scikit-image**

III. Analysis

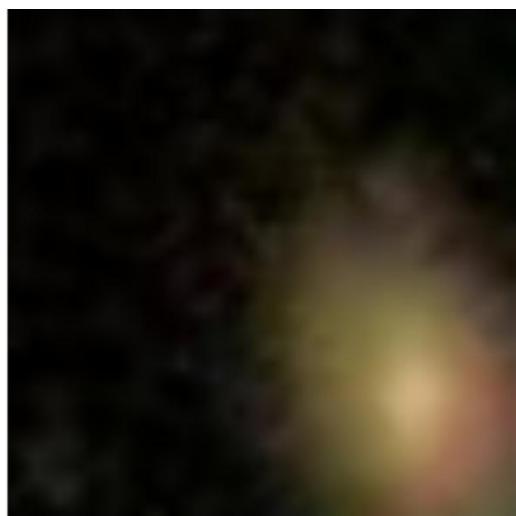
The filters learned in the first convolutional layer



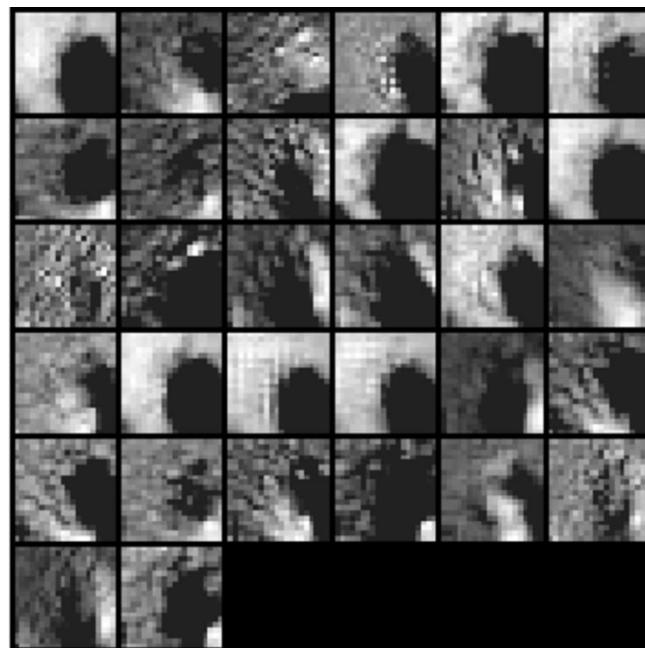
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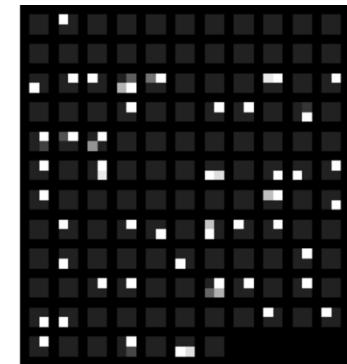
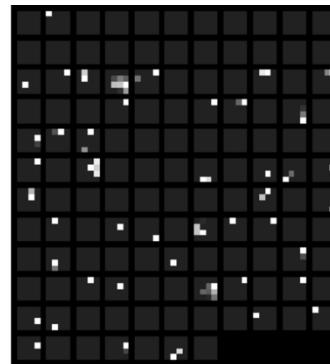
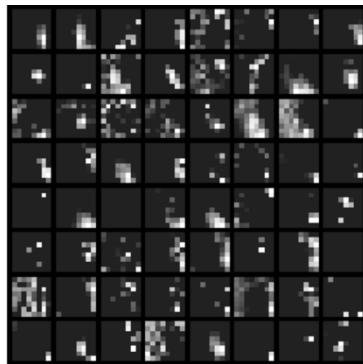
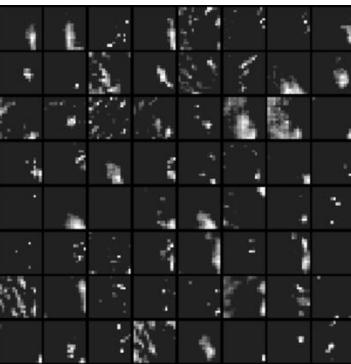
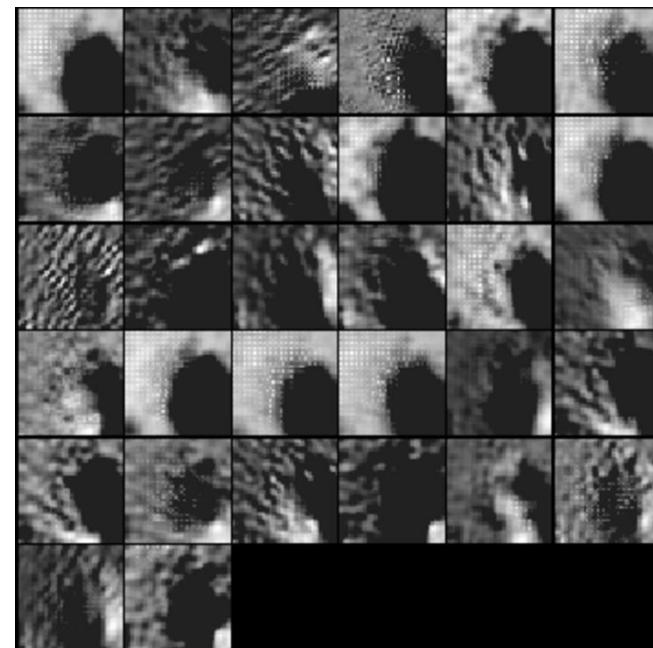
input



layer 1 – 40x40



pooling 1 – 20x20



layer 2 – 16x16

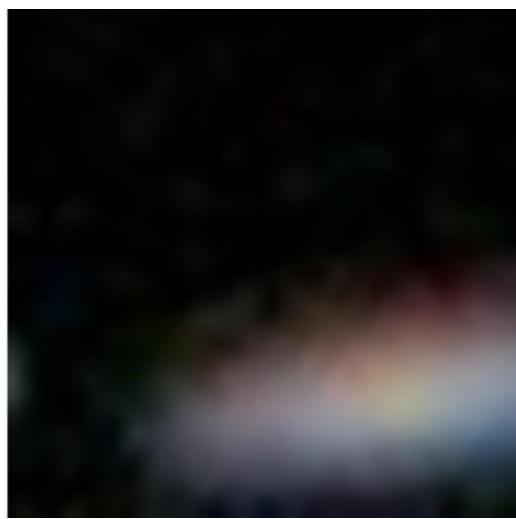
pooling 2 – 8x8

layer 3 – 6x6

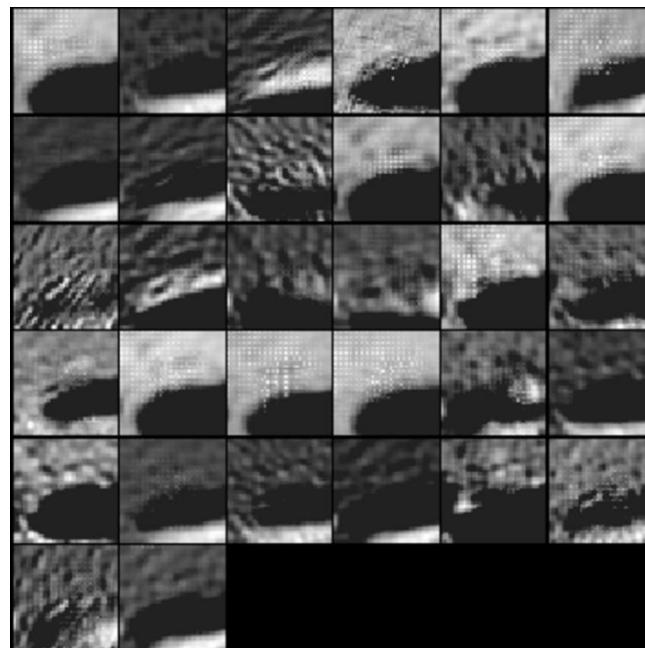
layer 4 – 4x4

pooling 4 – 2x2

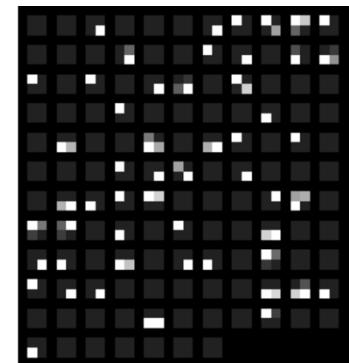
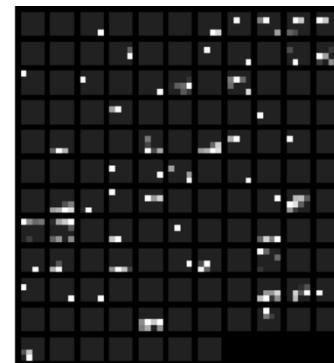
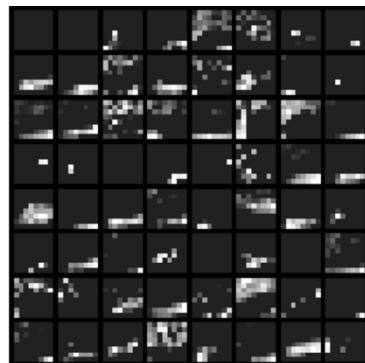
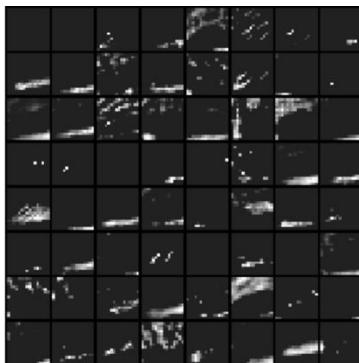
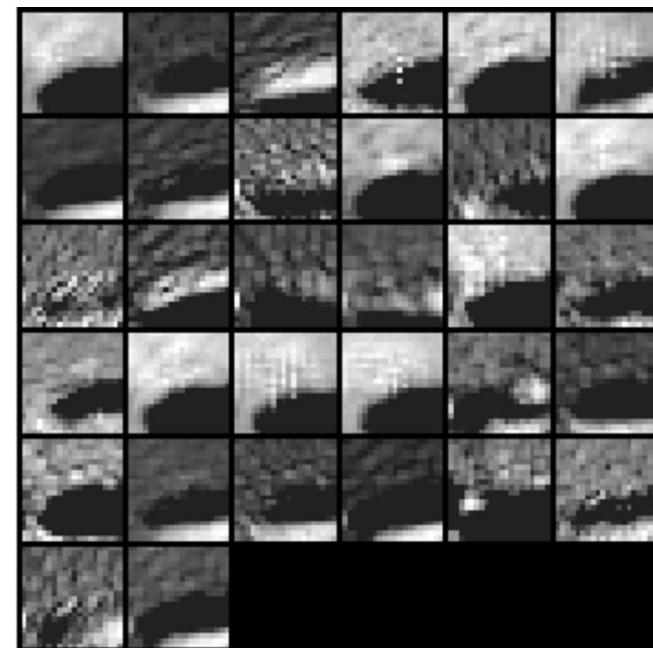
input



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pooling 2 – 8x8

layer 3 – 6x6

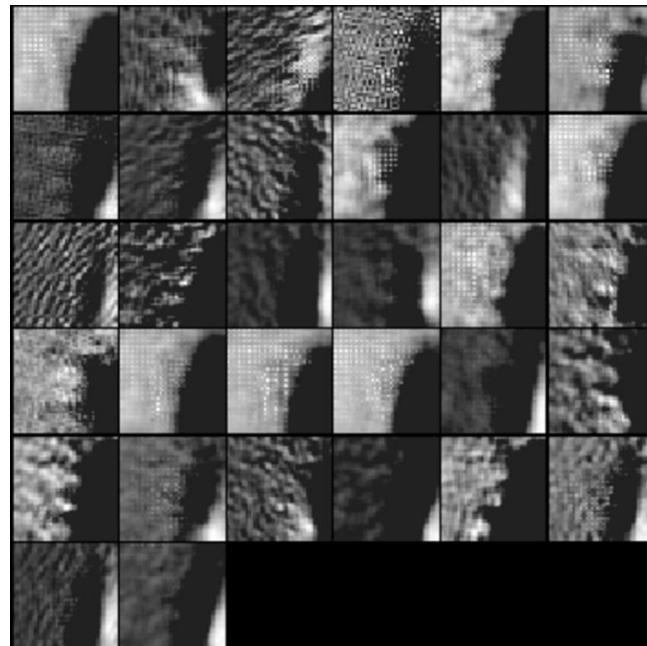
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pooling 4 – 2x2

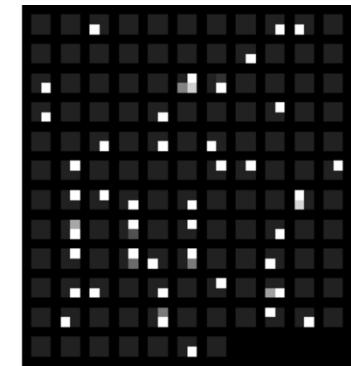
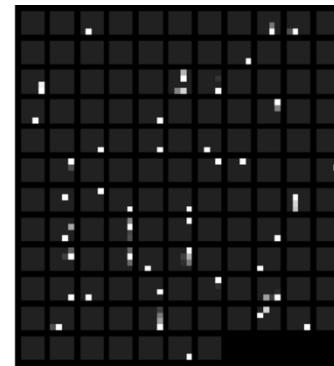
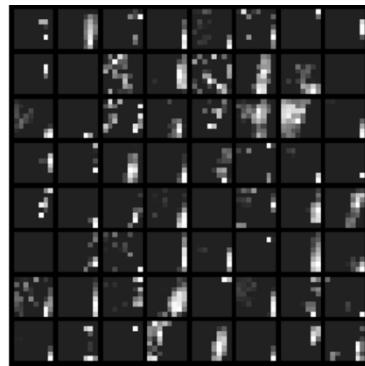
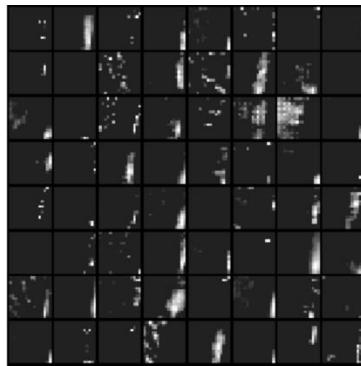
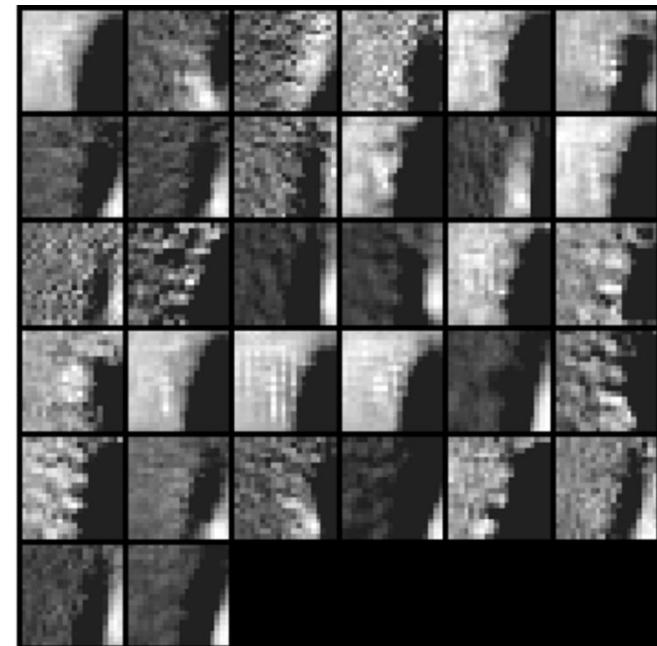
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pooling 2 – 8x8

layer 3 – 6x6

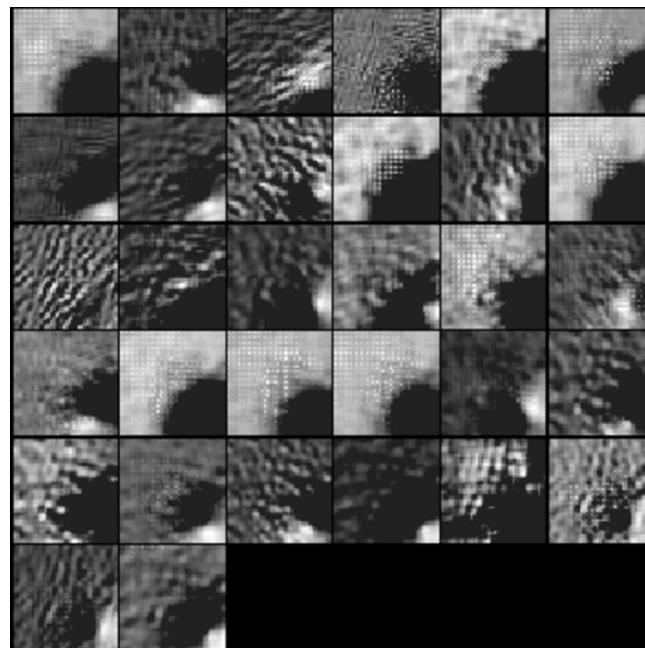
layer 4 – 4x4

pooling 4 – 2x2

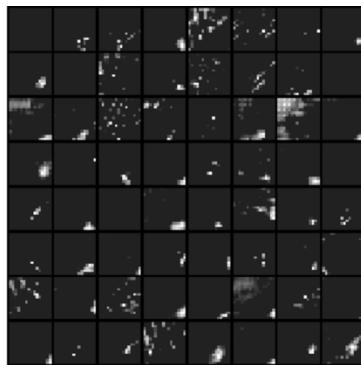
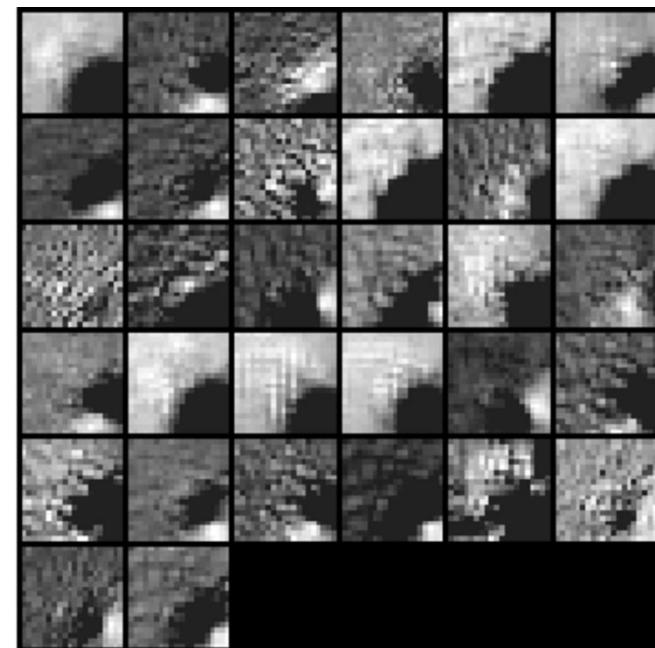
input



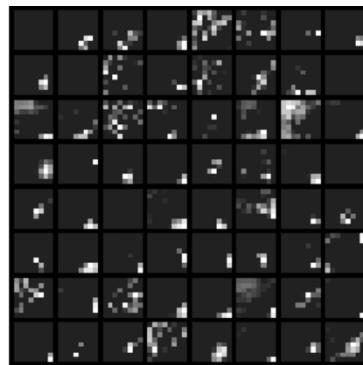
layer 1 – 40x40



pooling 1 – 20x20



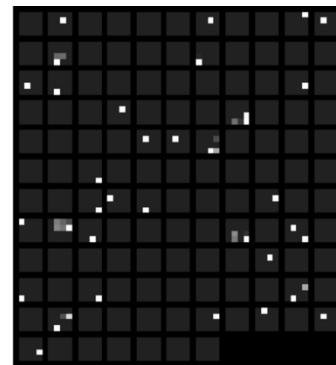
layer 2 – 16x16



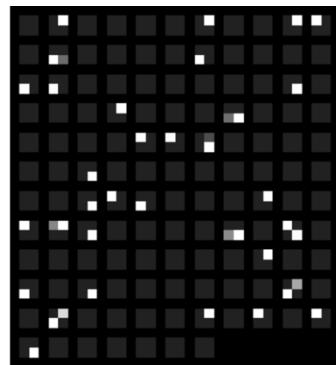
pooling 2 – 8x8



layer 3 – 6x6

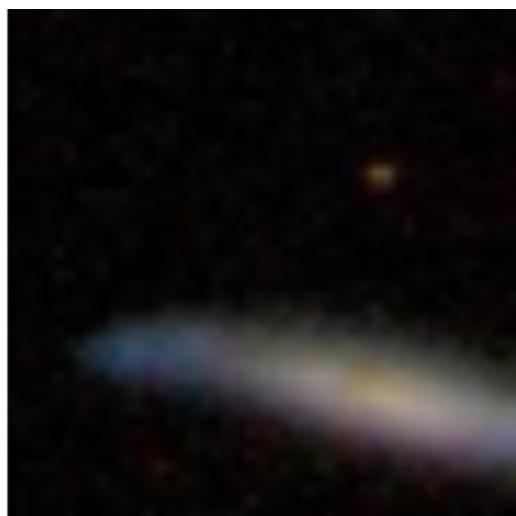


layer 4 – 4x4

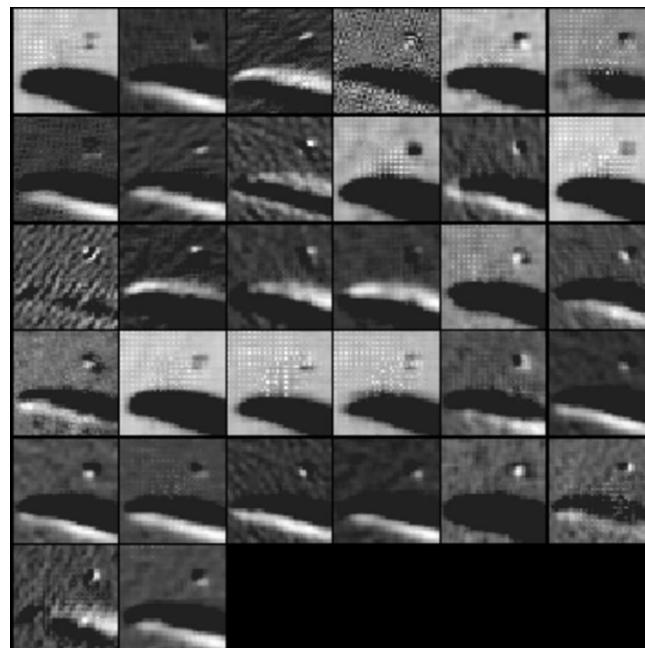


pooling 4 – 2x2

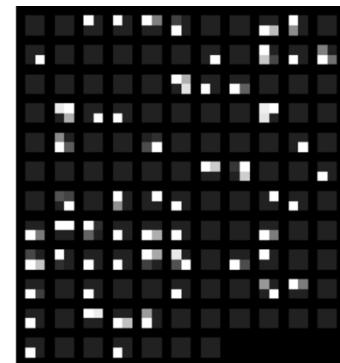
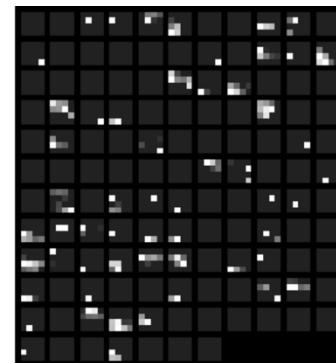
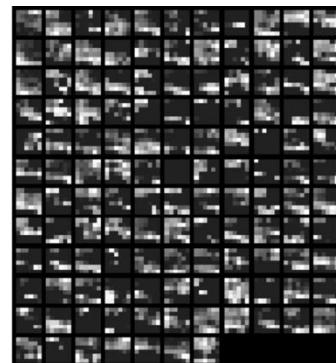
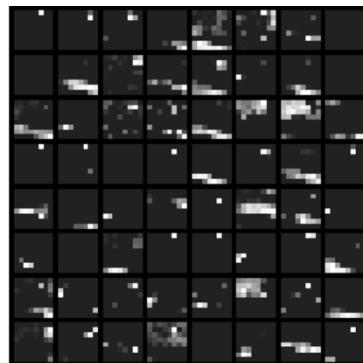
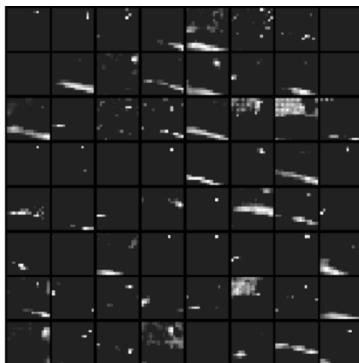
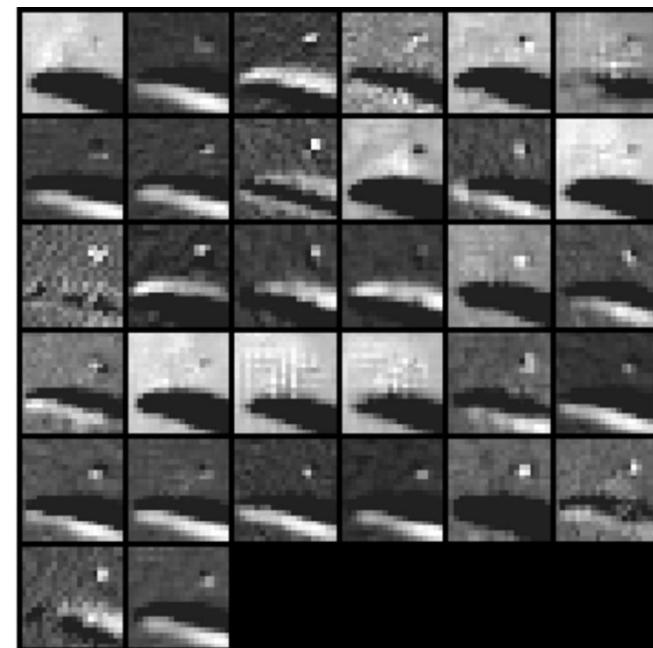
input



layer 1 – 40x40



pooling 1 – 20x20



layer 2 – 16x16

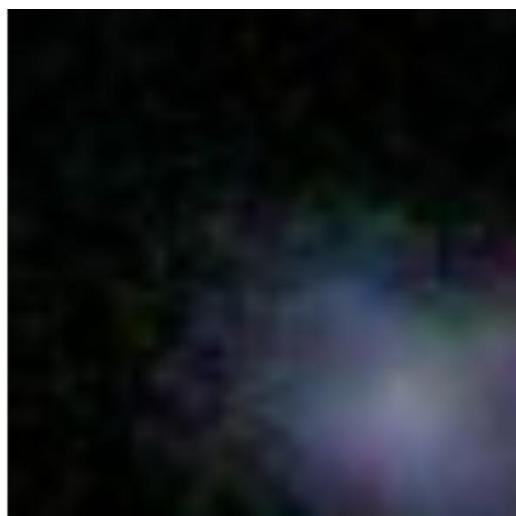
pooling 2 – 8x8

layer 3 – 6x6

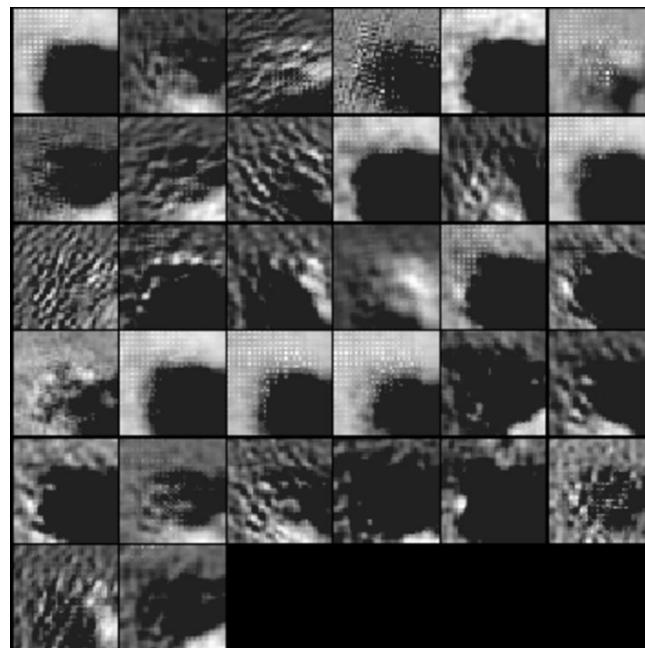
layer 4 – 4x4

pooling 4 – 2x2

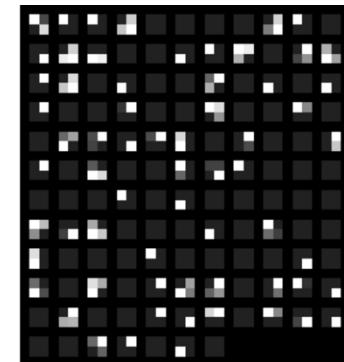
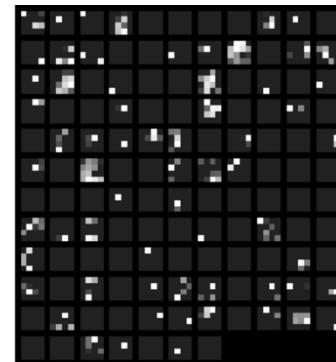
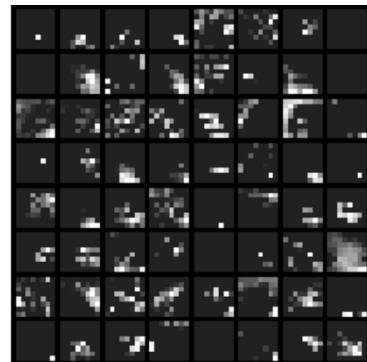
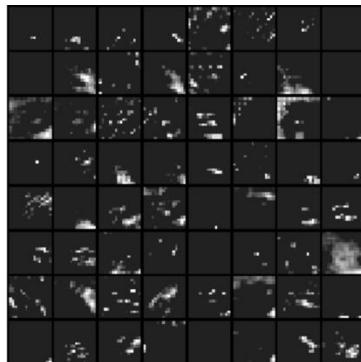
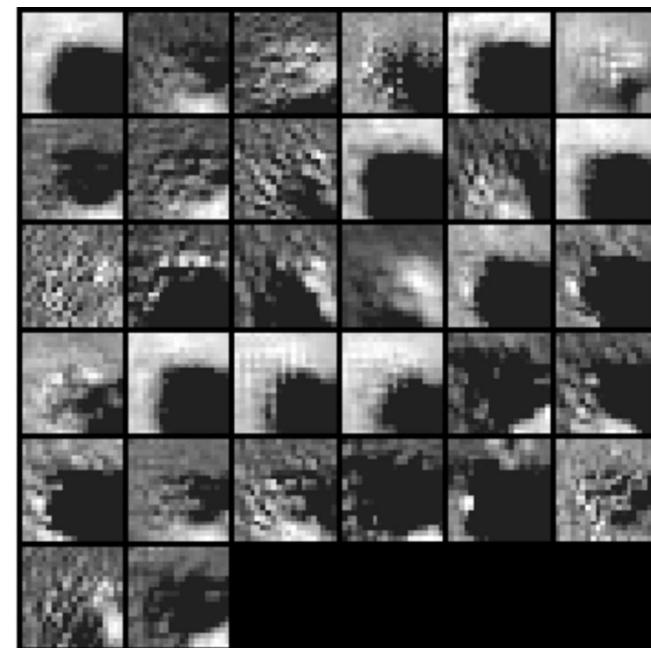
input



layer 1 – 40x40



pooling 1 – 20x20



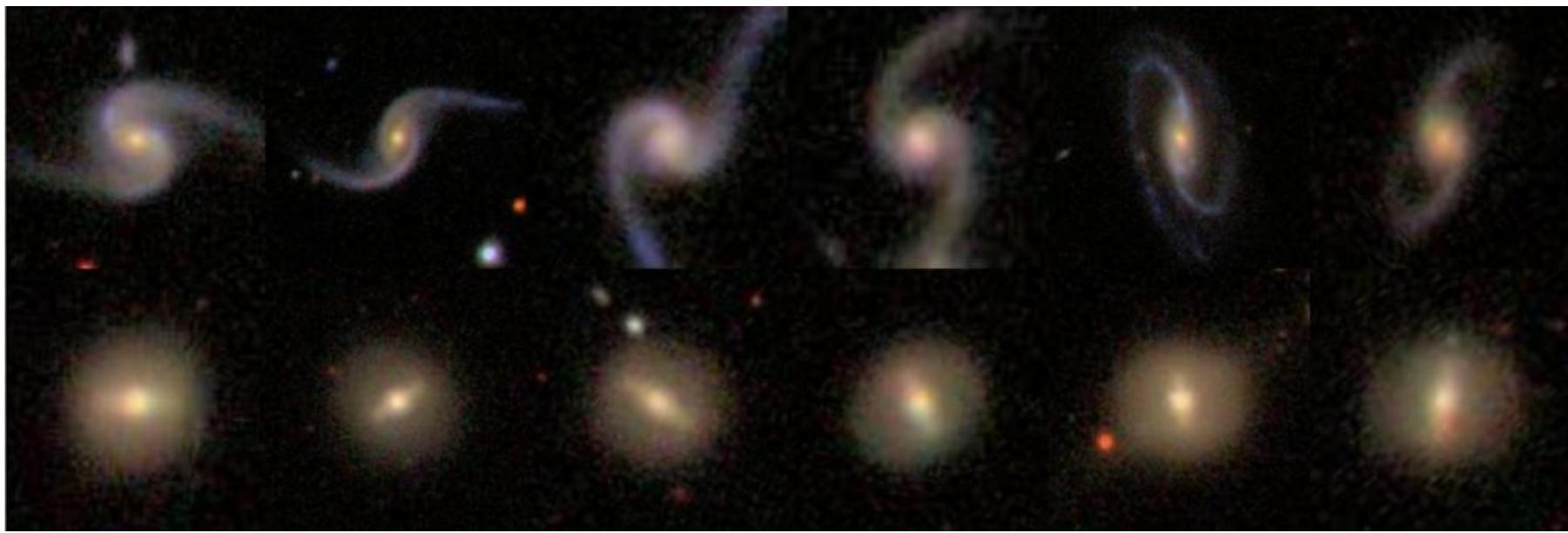
layer 2 – 16x16

pooling 2 – 8x8

layer 3 – 6x6

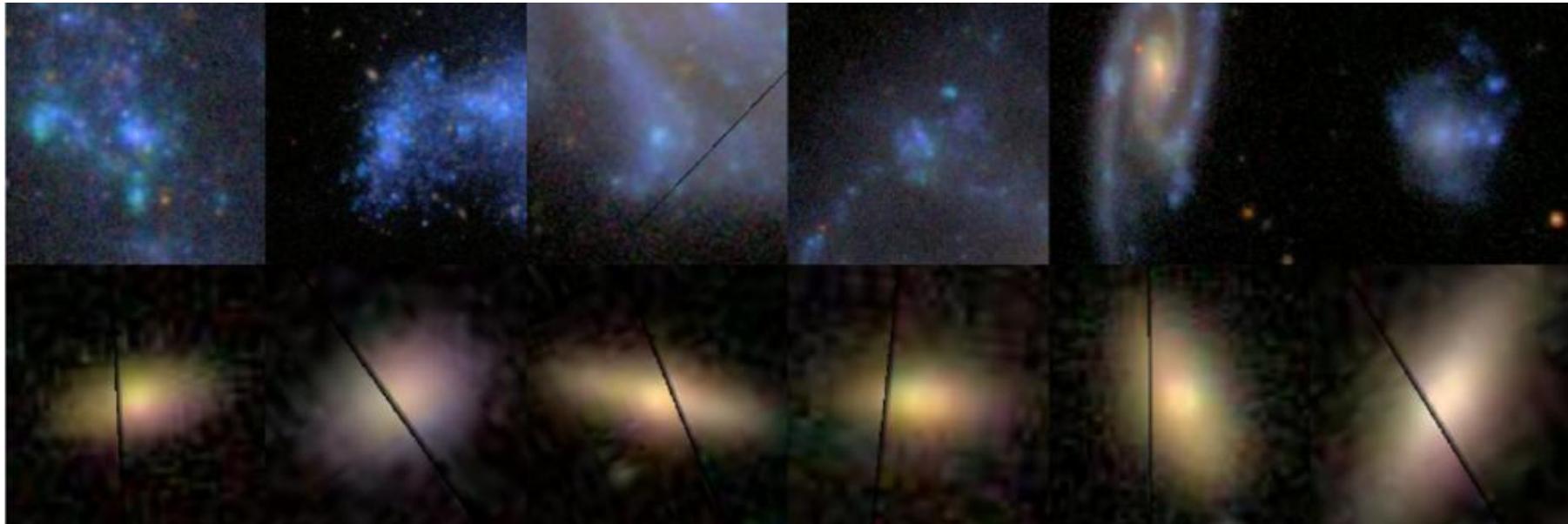
layer 4 – 4x4

pooling 4 – 2x2



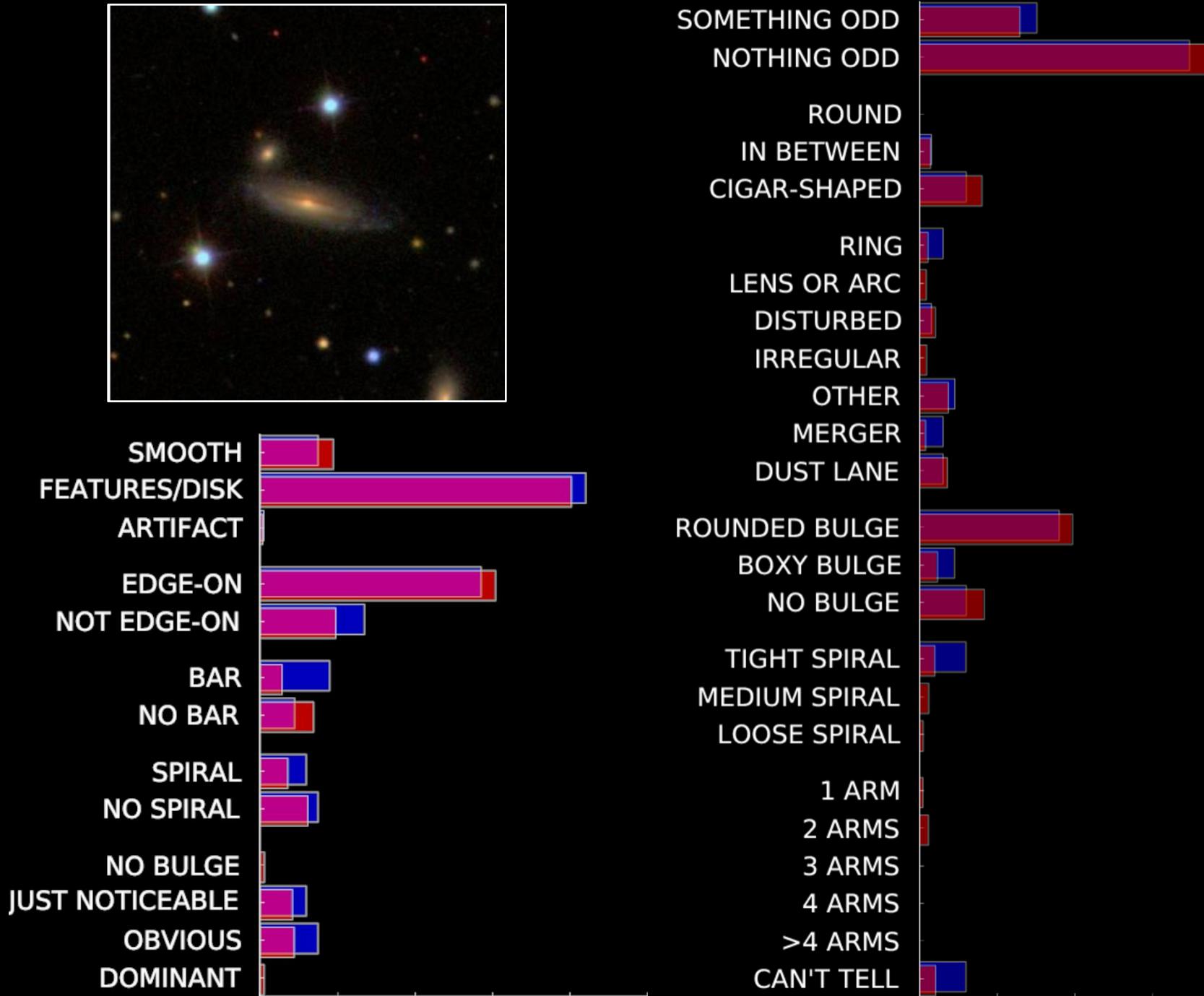
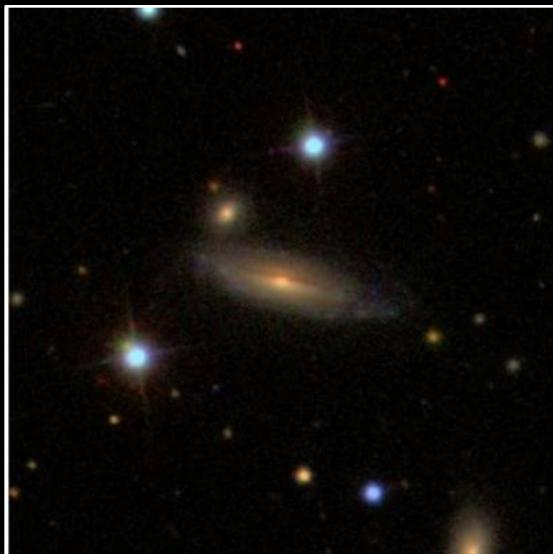


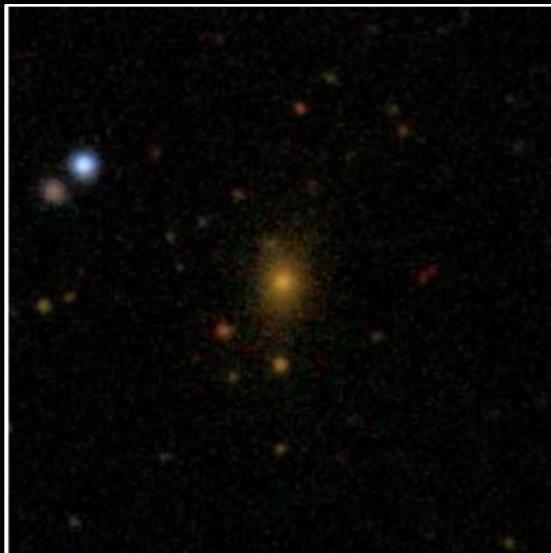


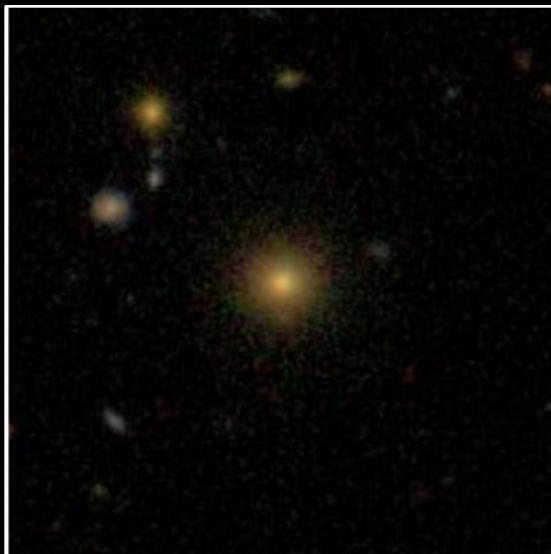


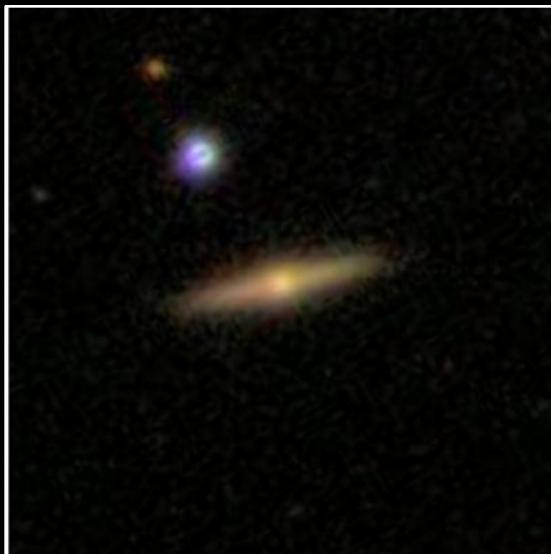


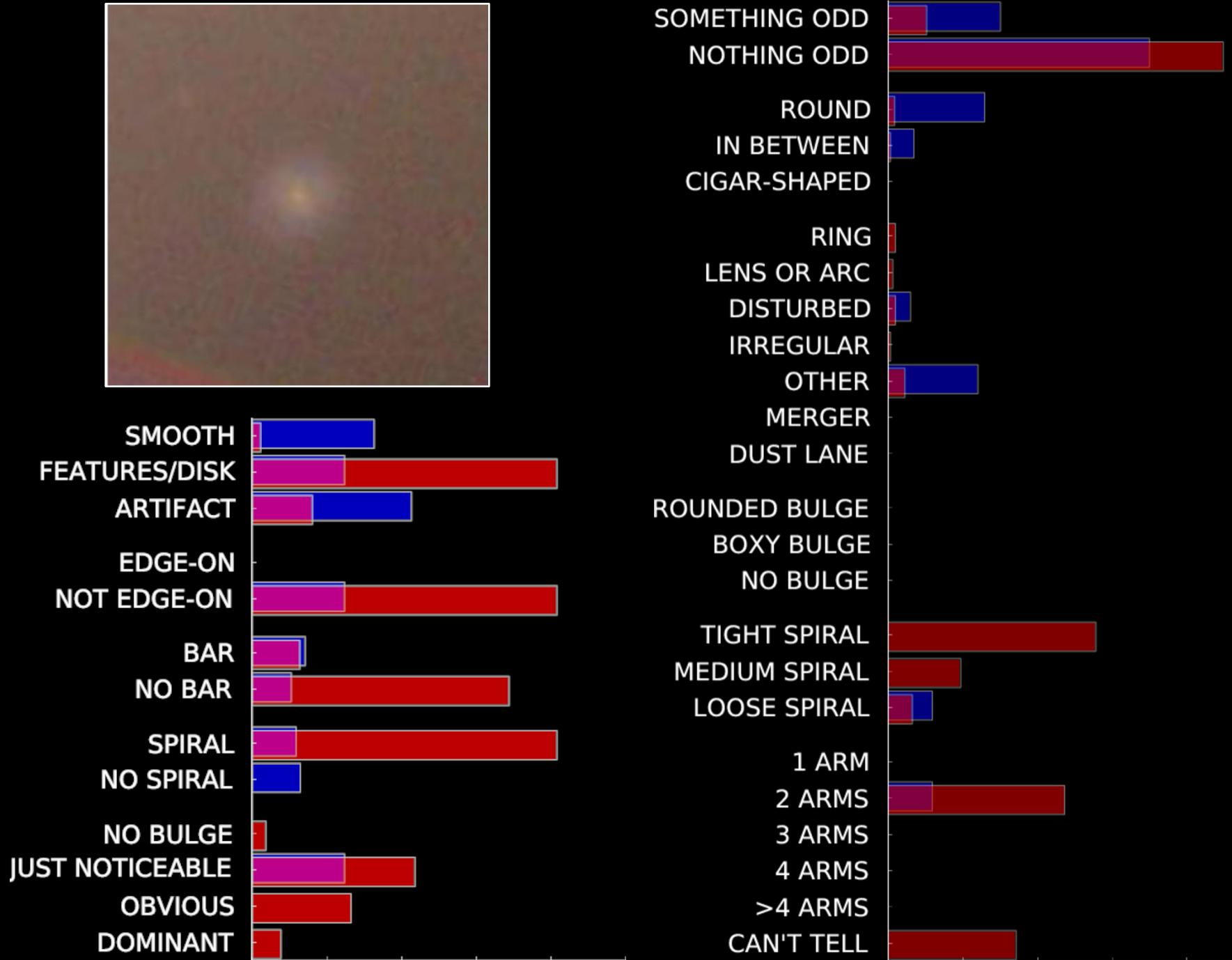


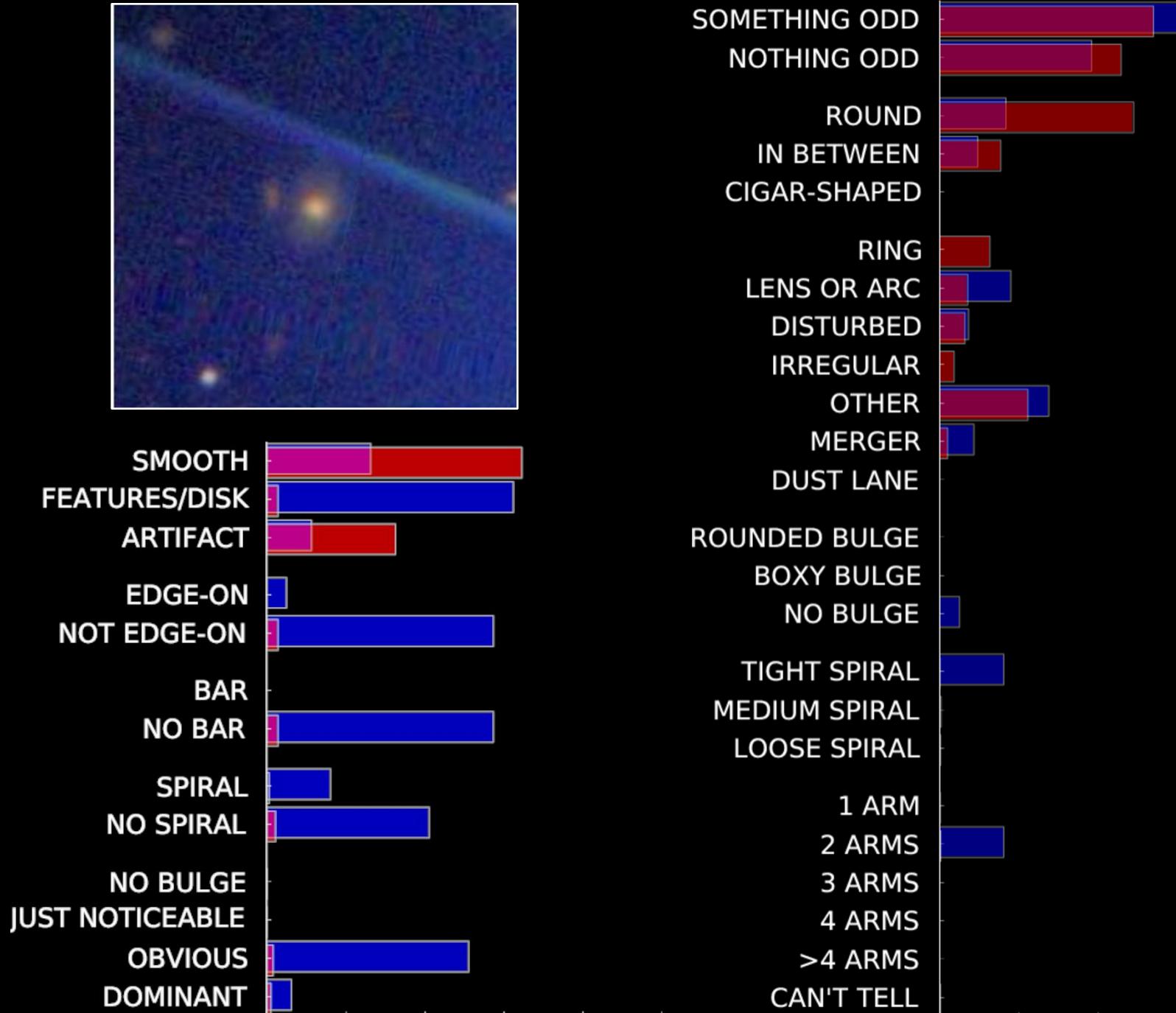


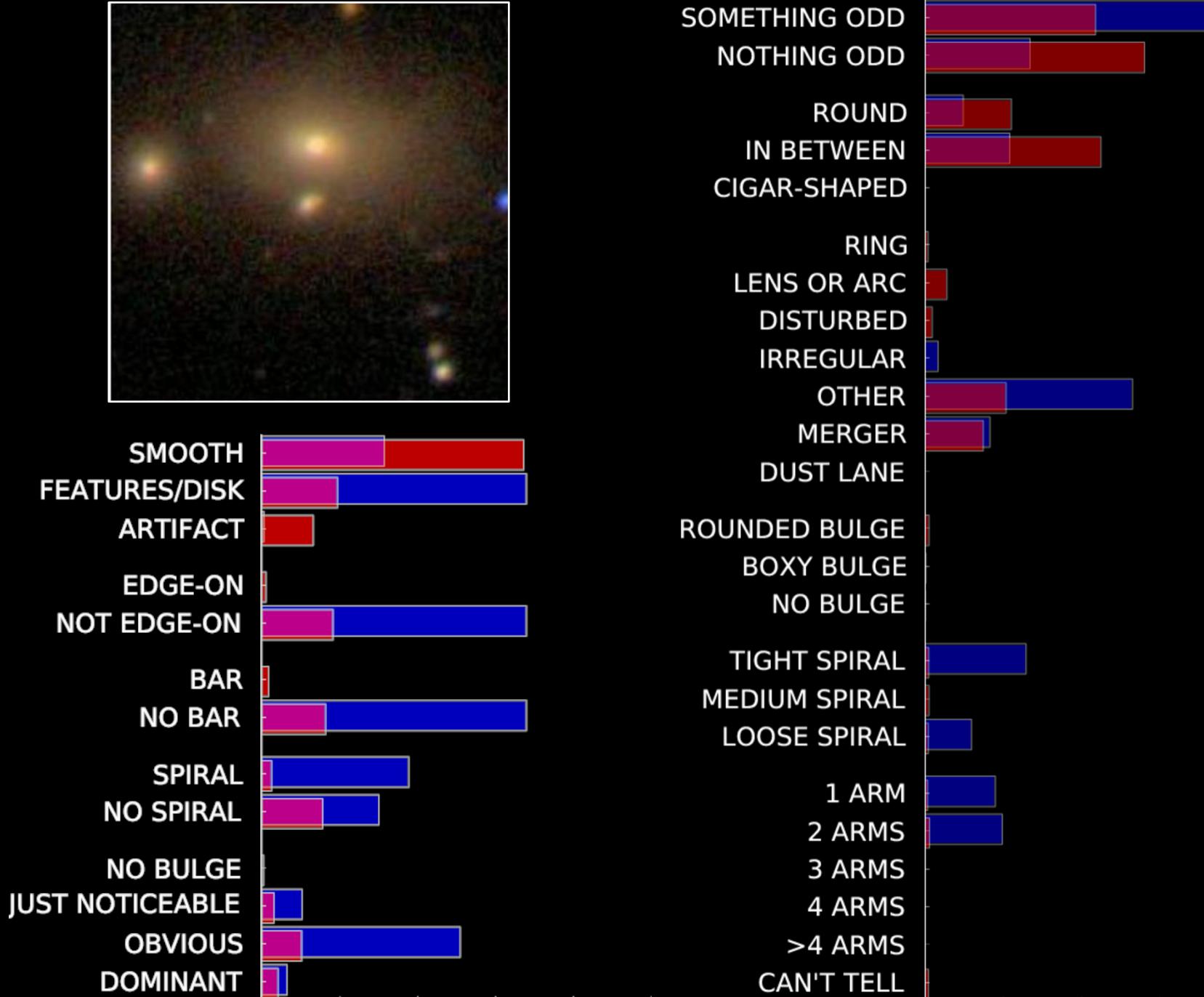
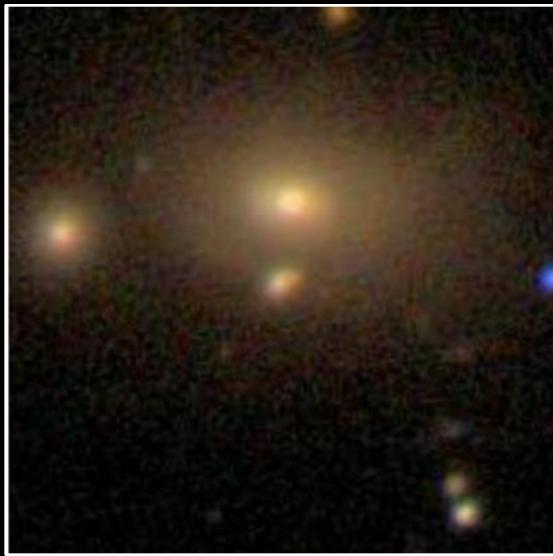


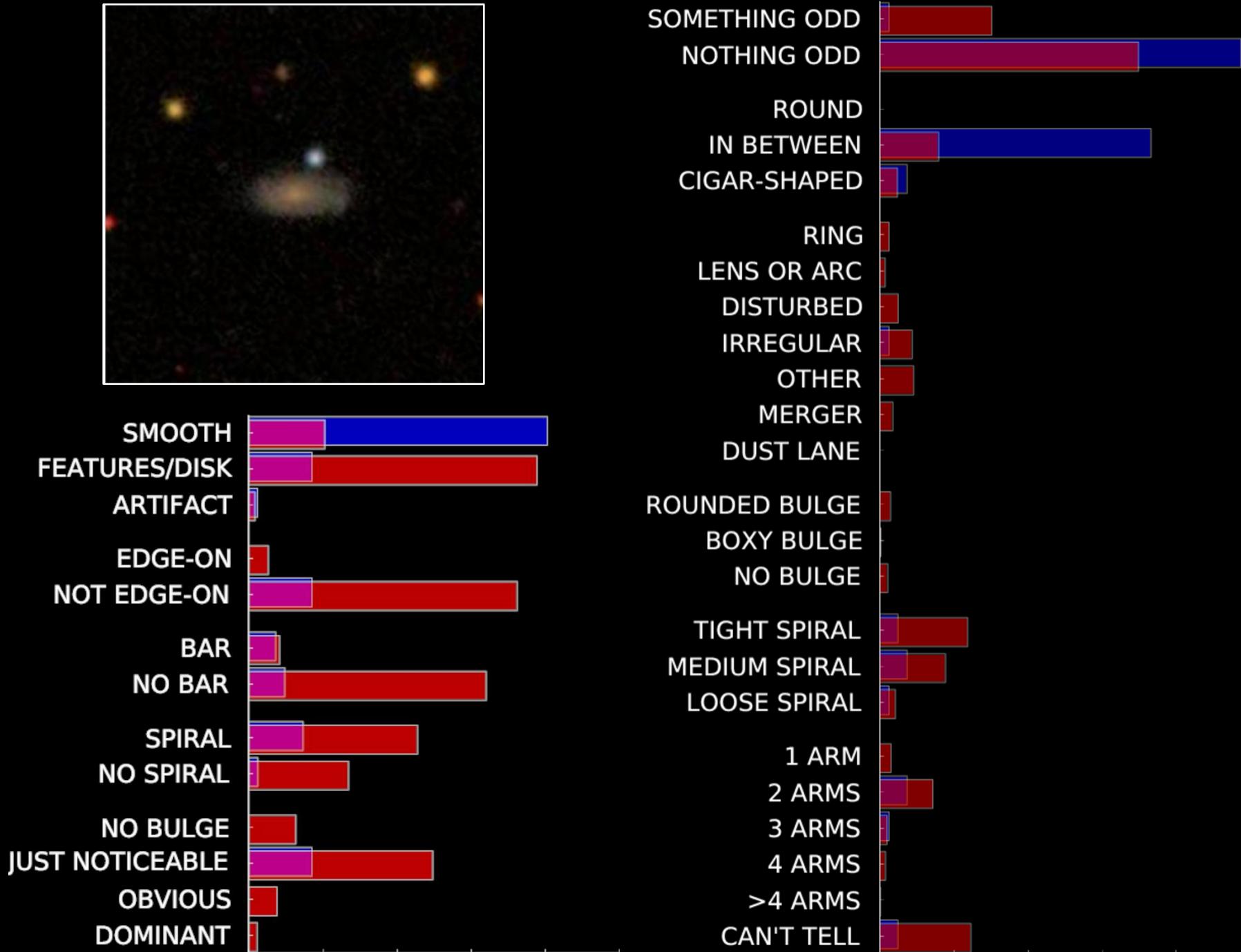
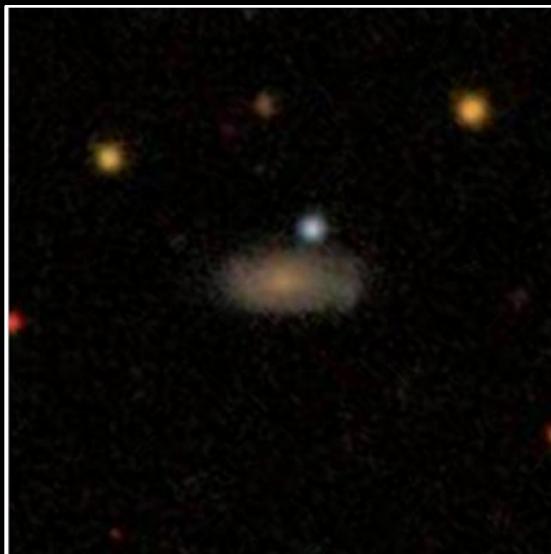


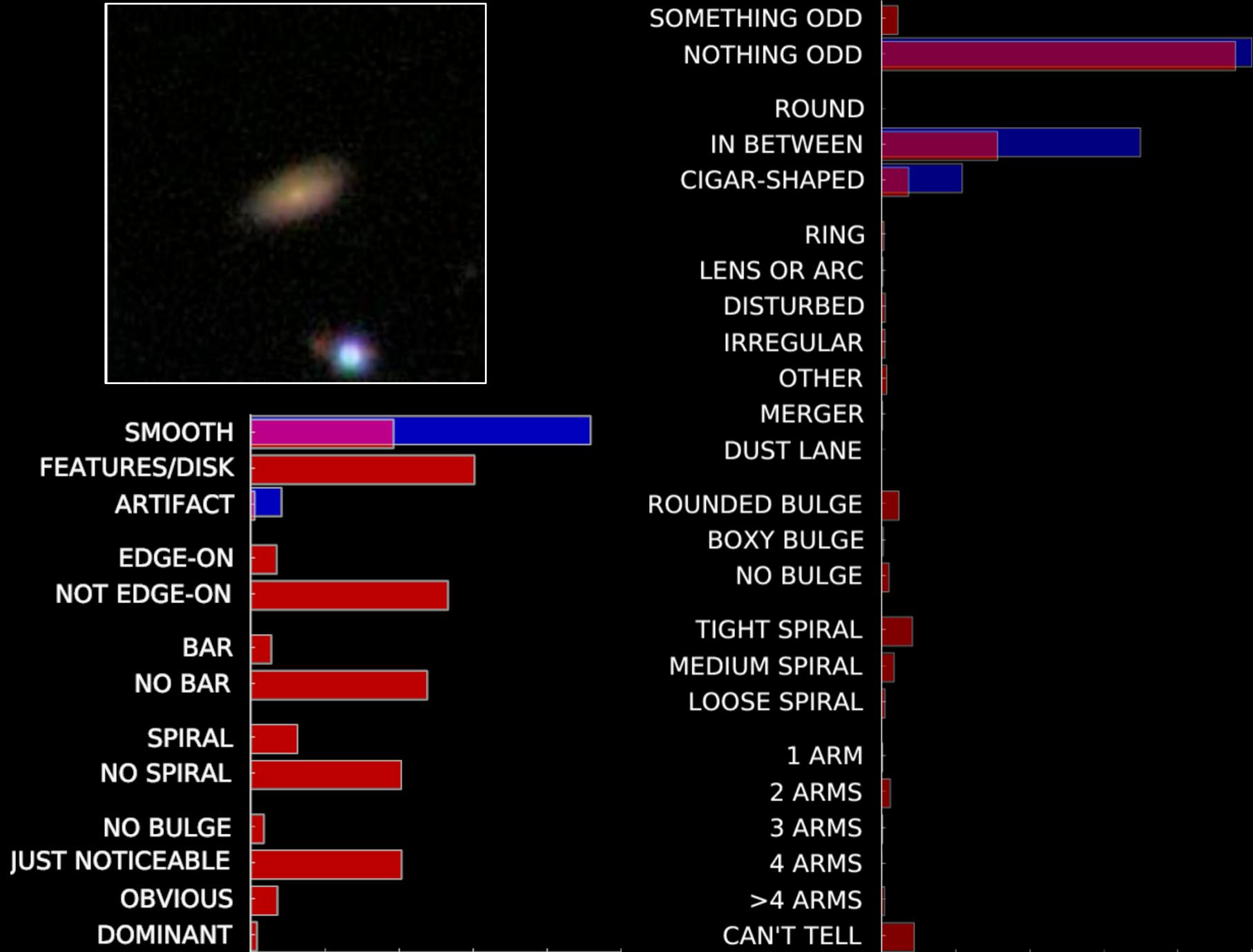


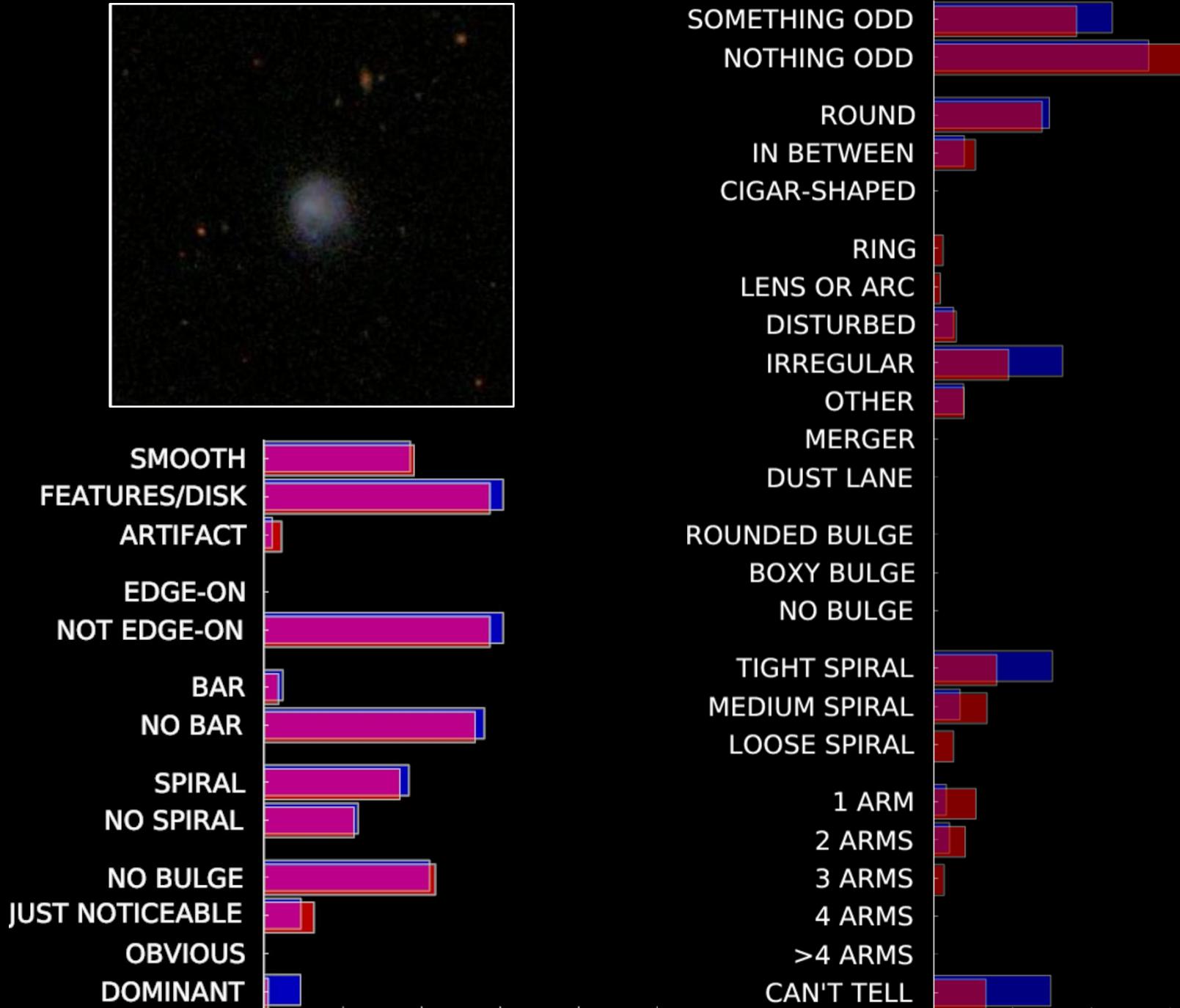
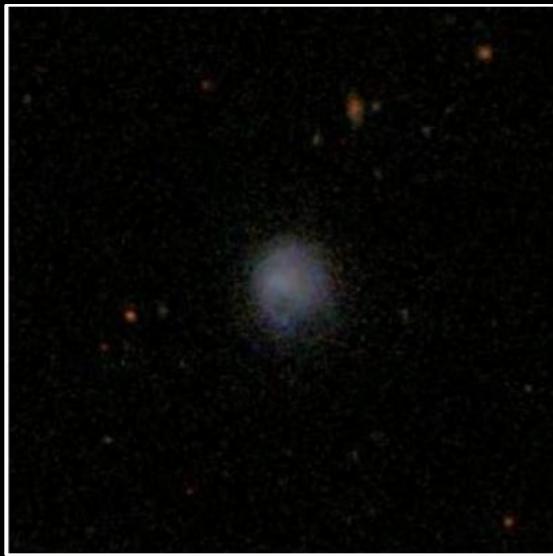


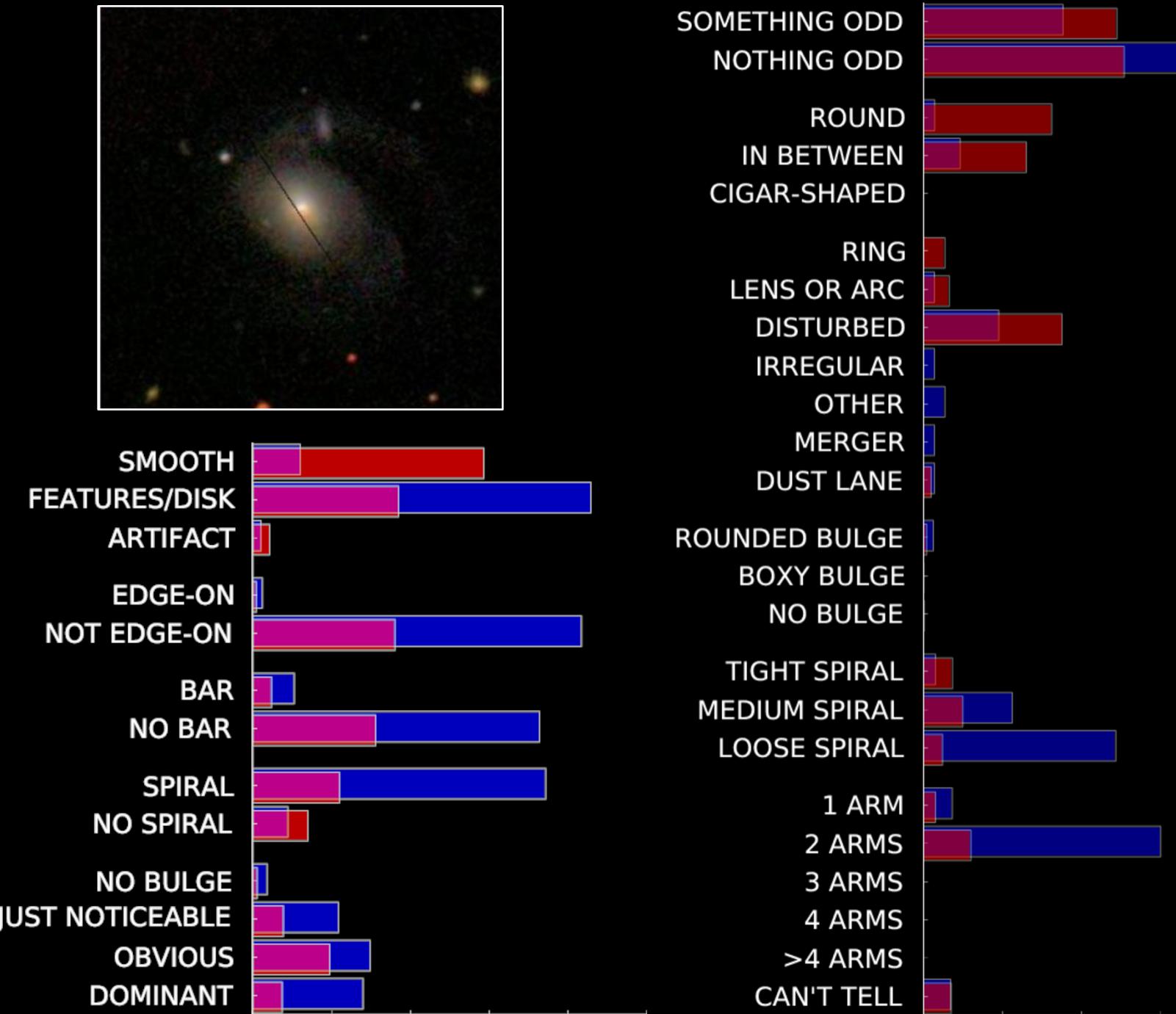


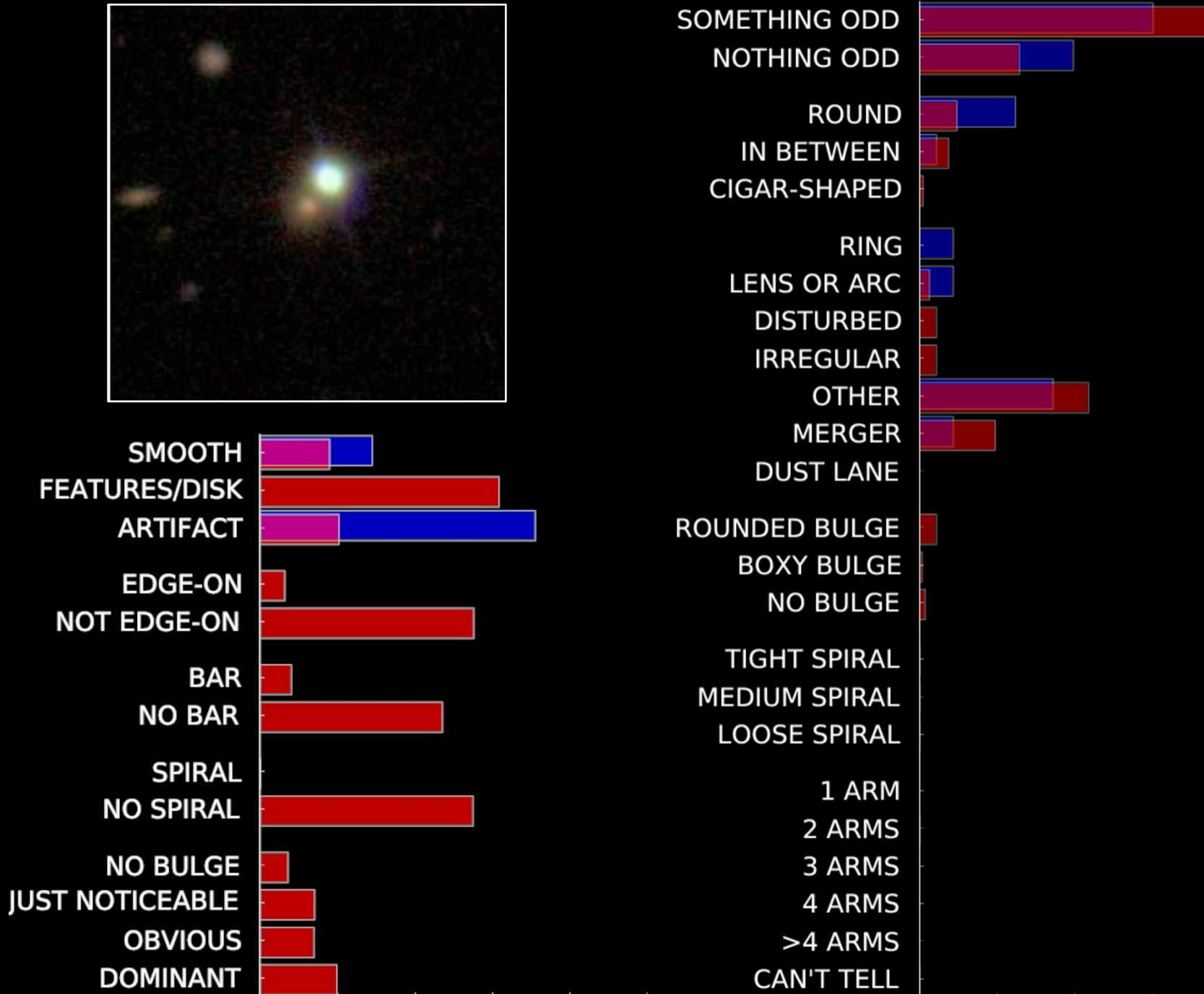












Things that didn't work

Adding Gaussian noise

Multiple image scales

Strided convolution

Shearing

Overlapping pooling

Conclusion

Convnets

Reduce overfitting

Prior knowledge is useful

Incorporate constraints

Use GPUs

Code is on **GitHub**

<https://github.com/benanne/kaggle-galaxies>

Blog post describing the solution

<http://benanne.github.io/2014/04/05/galaxy-zoo.html>

Interview on the **kaggle** blog

<http://blog.kaggle.com/2014/04/18/submitting-to-the-galaxy-challenge-with-convnets/>

A close-up photograph of a whale breaching. The whale's dark, textured skin is visible as it cuts through the deep blue ocean. A massive splash of white and light blue water erupts from its body, creating a dynamic and powerful scene. The whale's tail is partially submerged in the background.

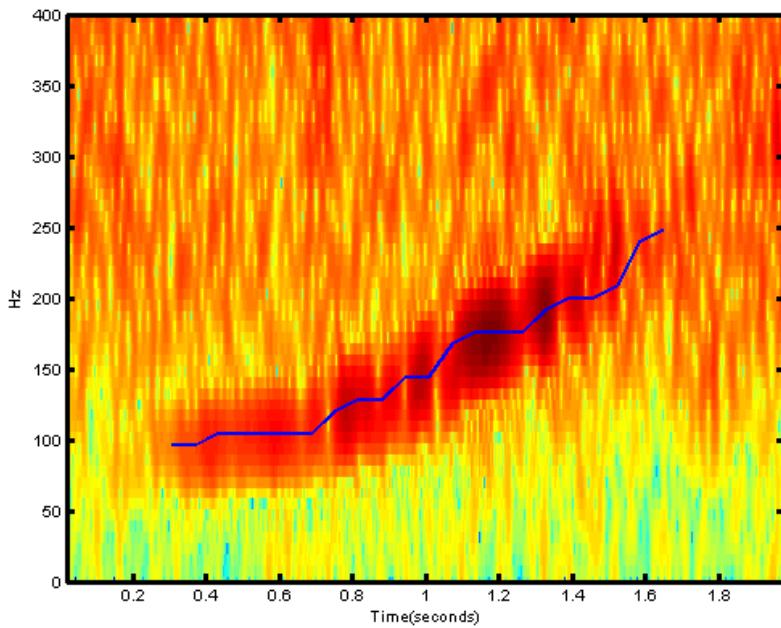
Detecting whales with unsupervised feature learning

Sander Dieleman – March 12th, 2015

The whale detection challenge (2013)

2 second audio clips (2 kHz)
+ labels

train: 30 000 clips
test: 54 503 clips



1. Downsample
2. Normalize volume
3. Extract spectrograms
4. Local contrast normalization
5. PCA whitening
6. Spherical K-means
7. Max pooling
8. Train classifier (SVM / RF / GBM)

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K-means for feature learning: cluster centers are features

Spherical K-means:

means lie on the unit sphere, have a **unit L2 norm**

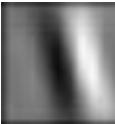
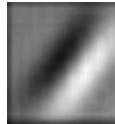
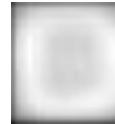
+ conceptually very **simple**

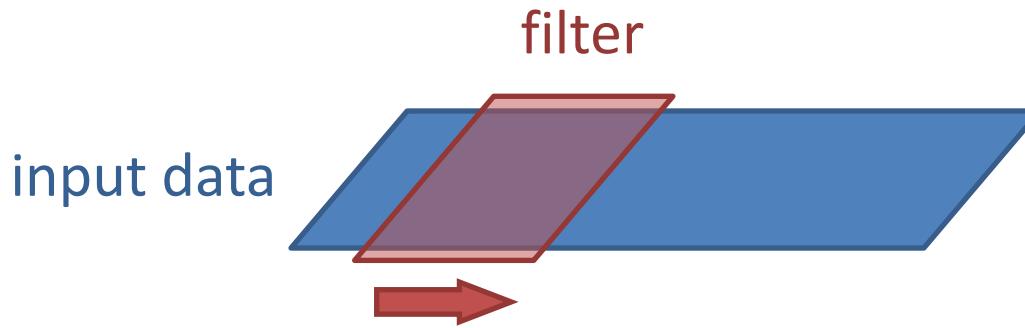
+ **only one parameter** to tune: number of means

+ **orders of magnitude faster** than RBMs, autoencoders, sparse coding

(Coates and Ng, 2012)

Spherical K-means features work well with **linear feature encoding**

					
During training:	0	0	1.7	0	One-of-K
During feature extraction:	-0.2	2.3	1.7	0.7	Linear



Feature extraction is a **convolution** operation

(Coates and Ng, 2012)

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6. Spherical K-means
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- 8. Train classifier (SVM / RF / GBM)**

Fast iteration

- About 30 mins per ‘run’ on 30 machines
- Random search across hyperparameters
- Hyperparameter ranges periodically refined

Final submission

- Blend of ~30 model instances with best CV AUC scores
- Data leak: temporal smoothing improved the score slightly

<https://github.com/benanne/kaggle-whales>

Winning a Kaggle competition

Look at the data

Analyze your models

Iterate fast

Tree-based models / neural networks

Don't overfit the leaderboard

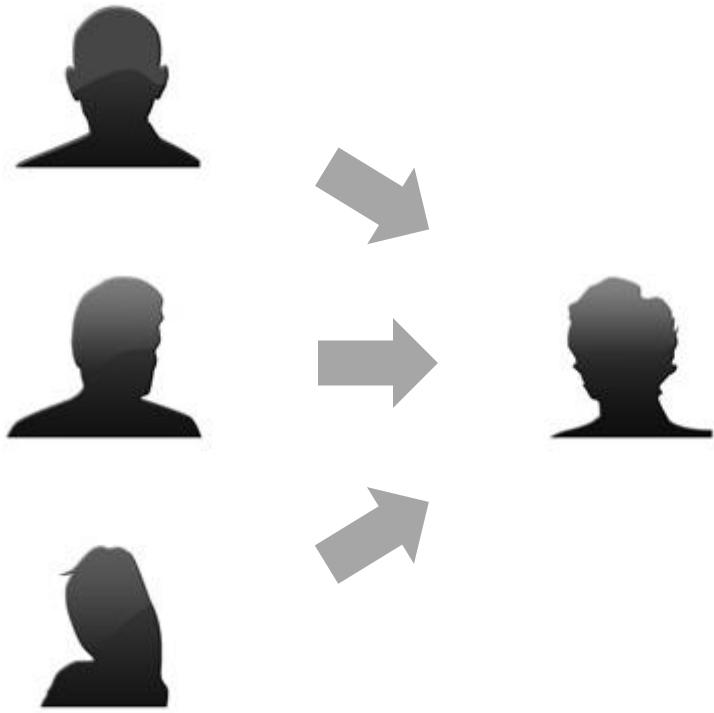
Model averaging



Content-based music recommendation

Sander Dieleman – March 12th, 2015

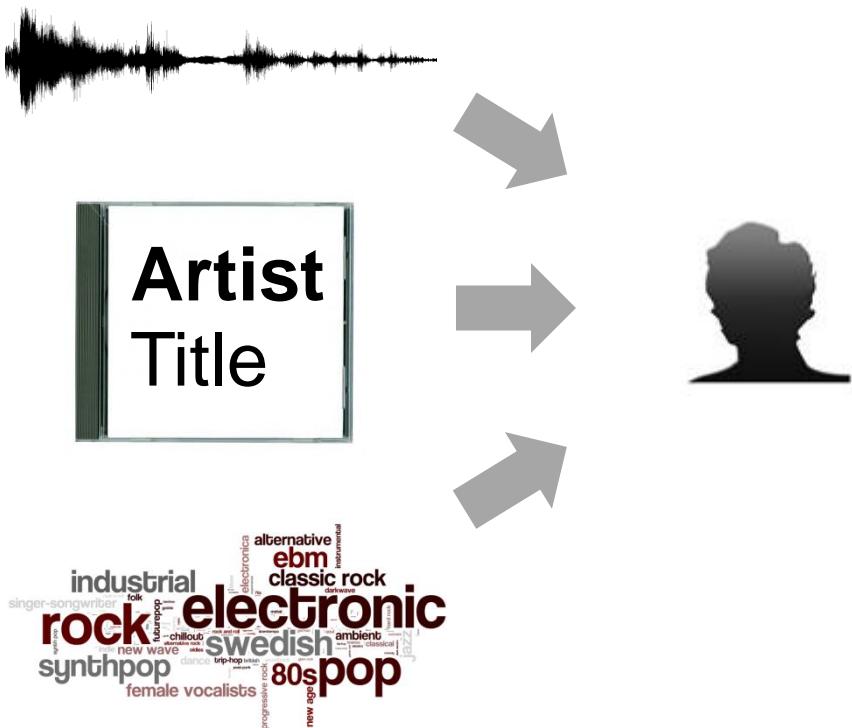
Collaborative filtering: use listening patterns for recommendation



+ good performance
- cold start problem

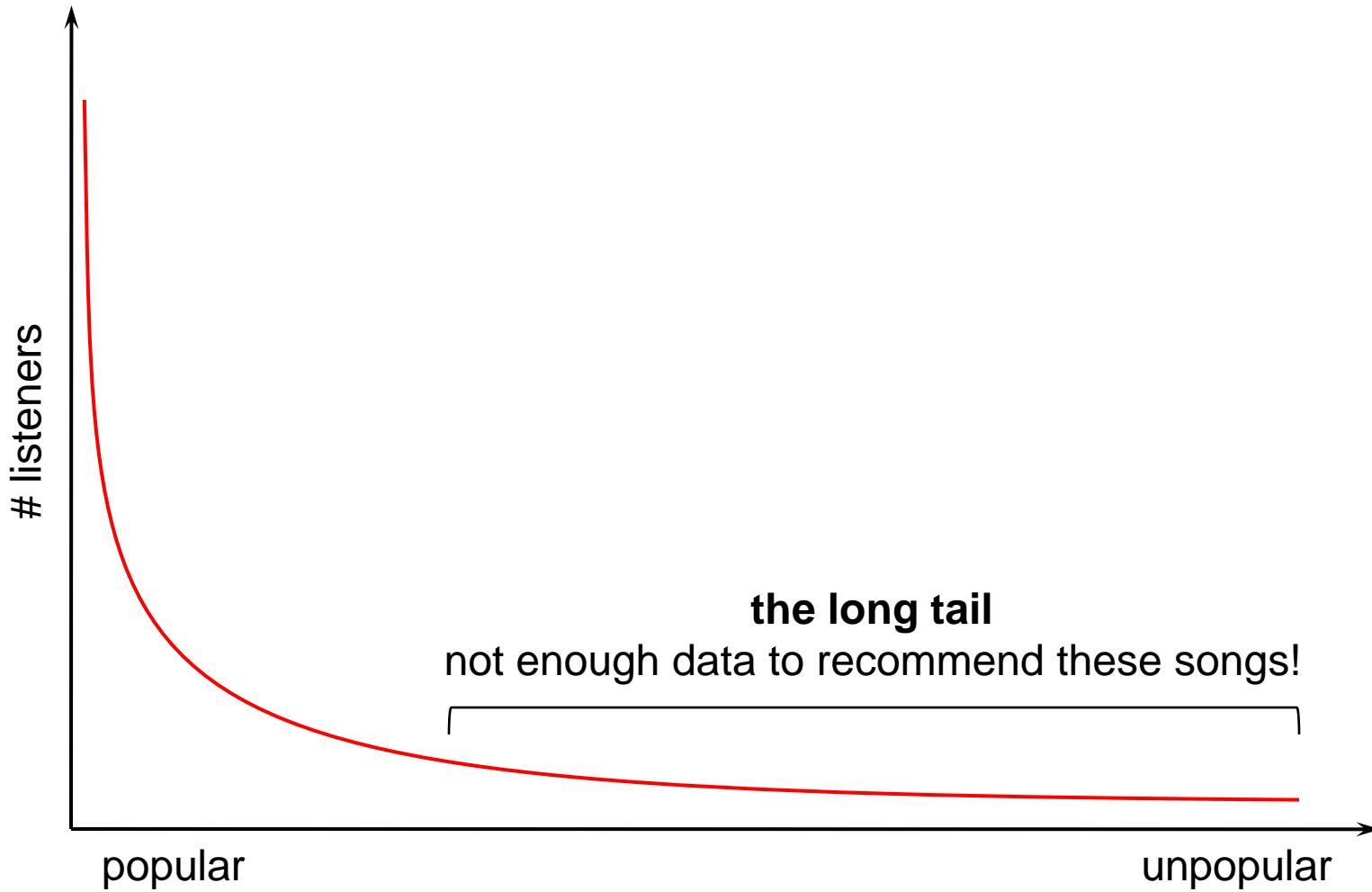
many **niche items** that
only appeal to a small
audience

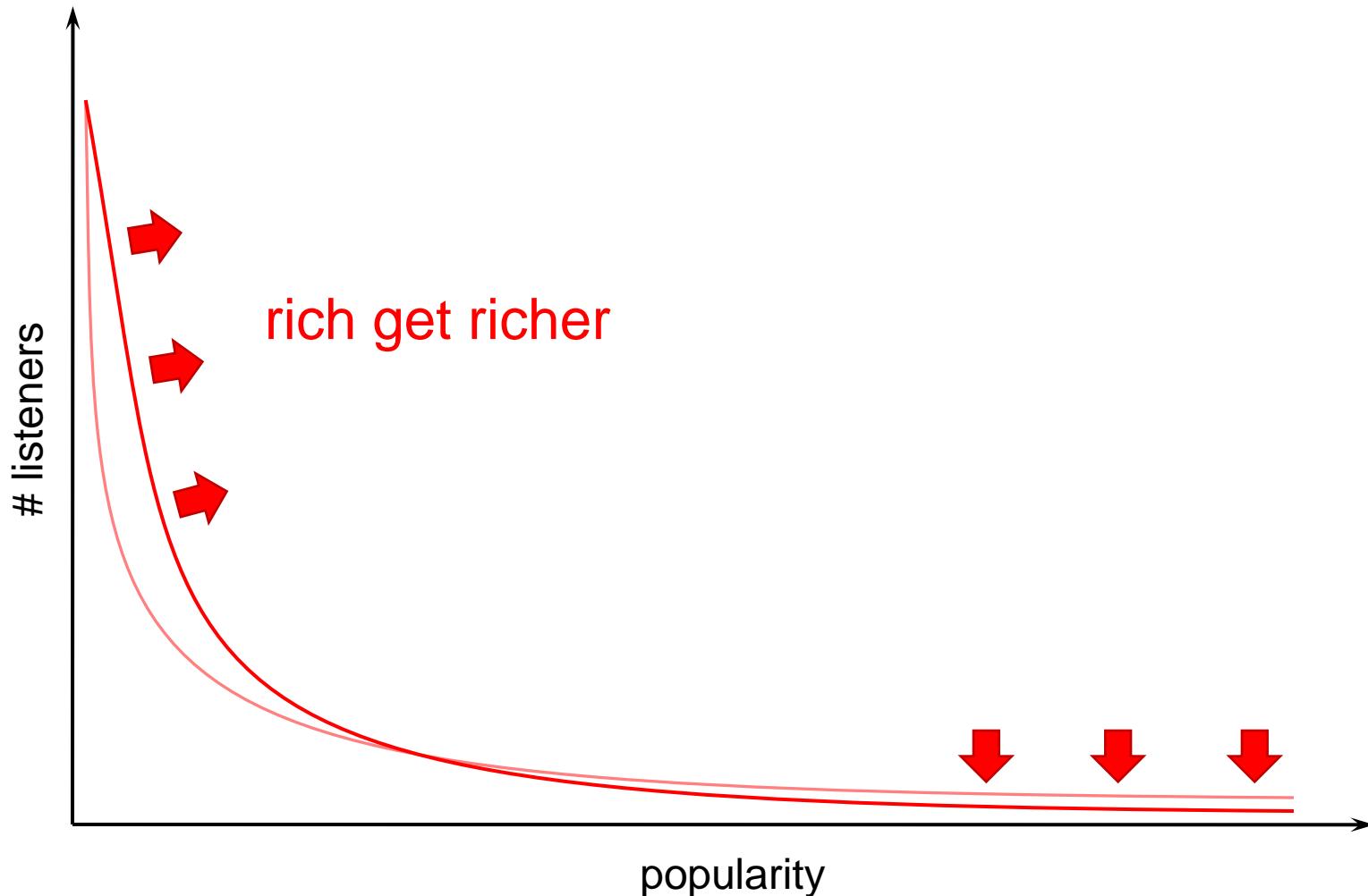
Content-based: use audio content and/or metadata for recommendation



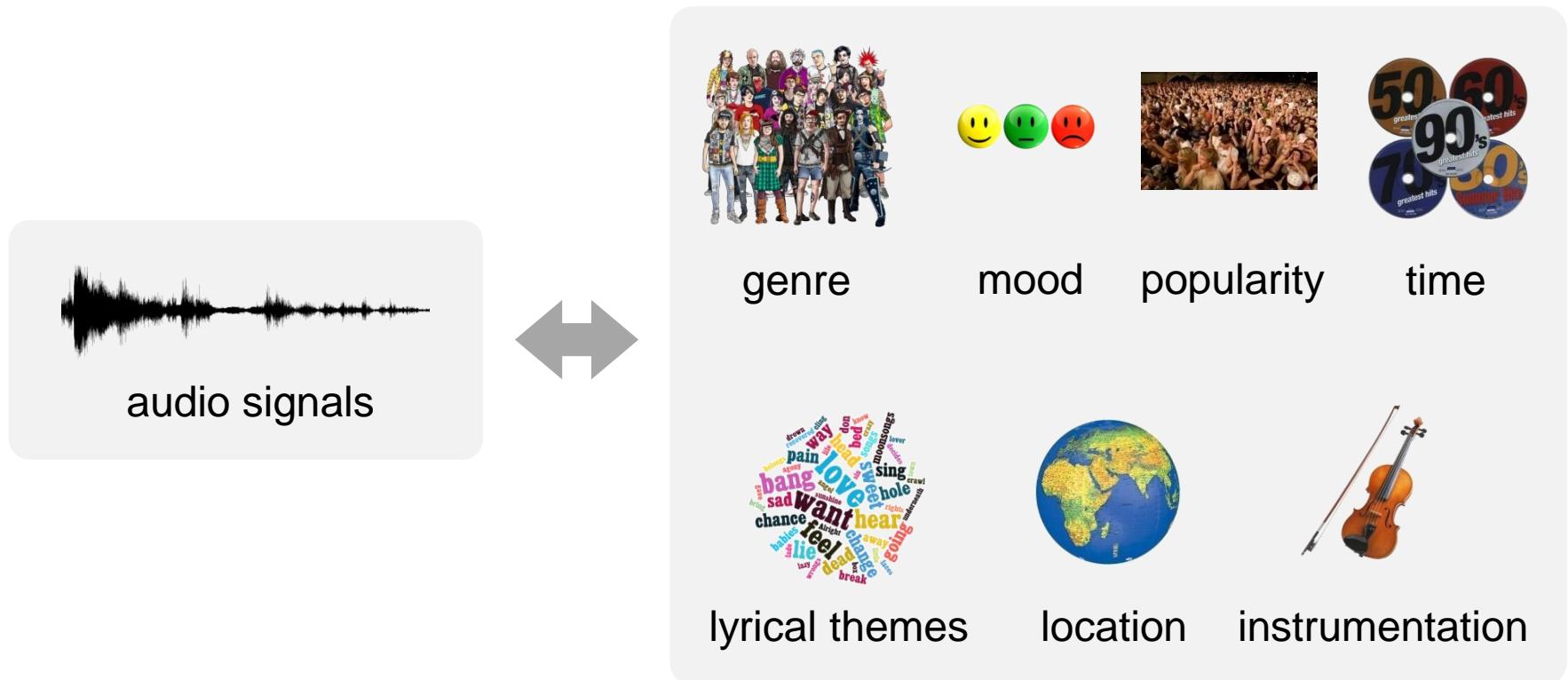
- worse performance
+ no usage data required

allows for all items to
be recommended
regardless of popularity

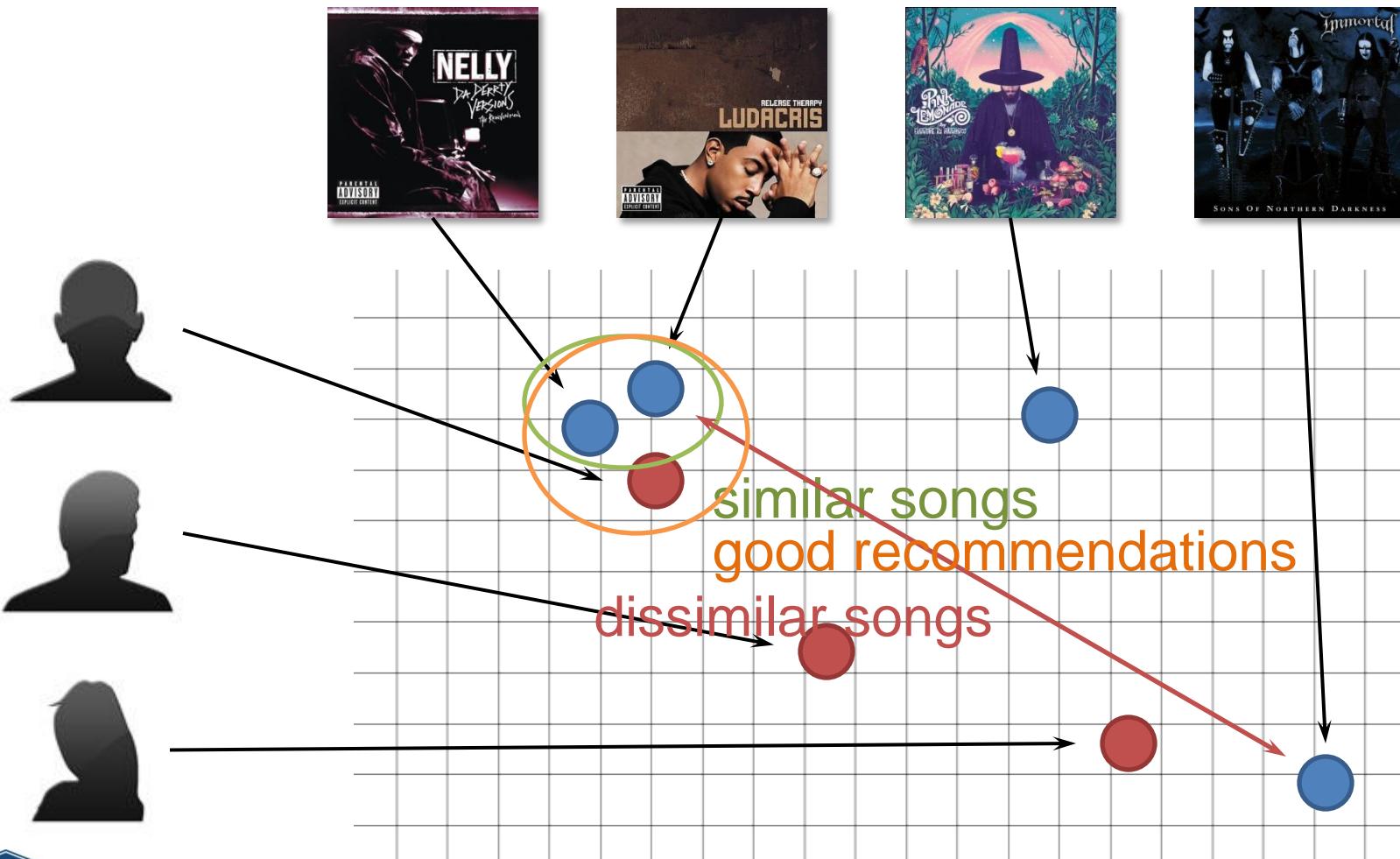




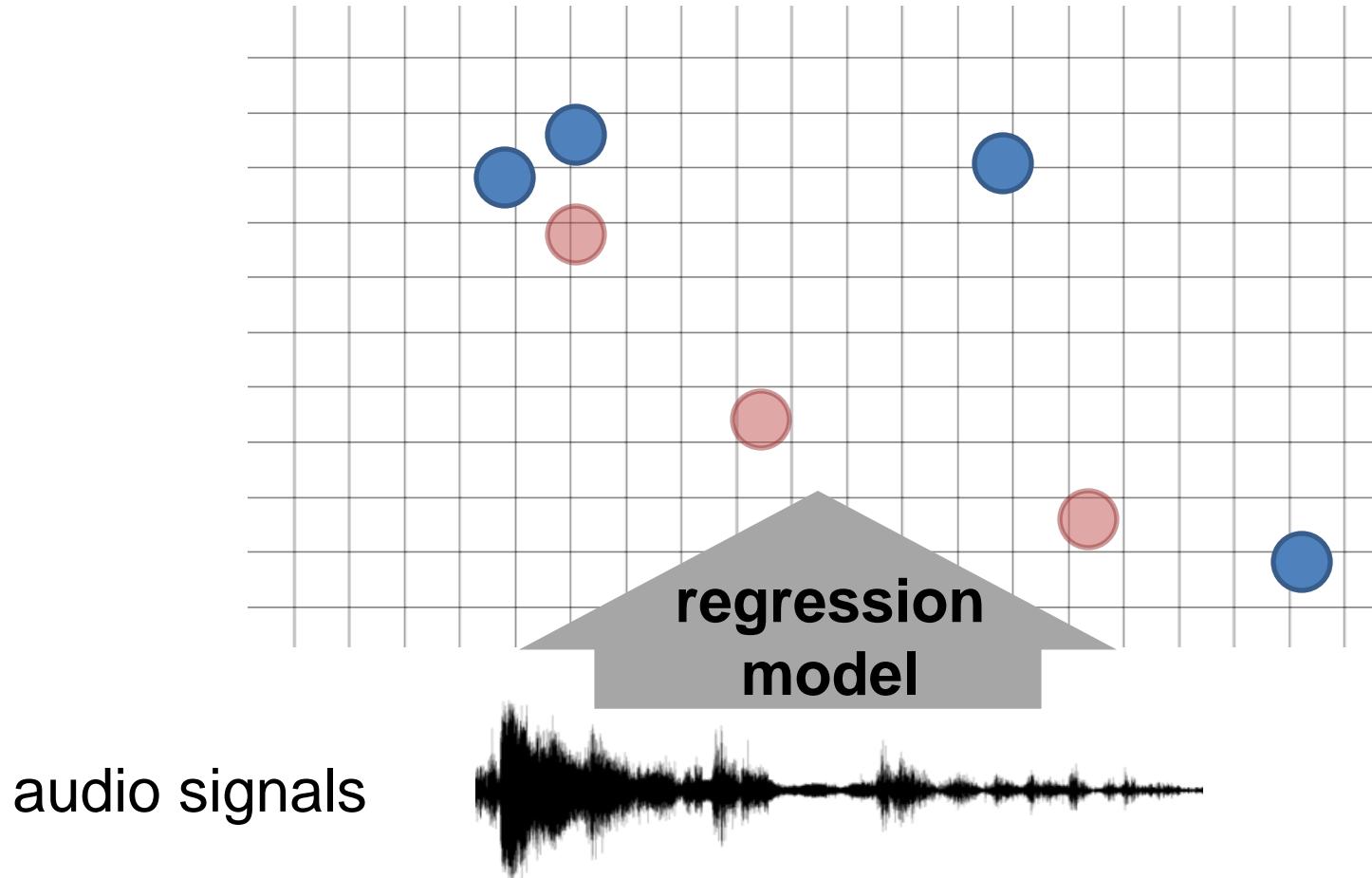
There is a large **semantic gap** between audio signals and listener preference



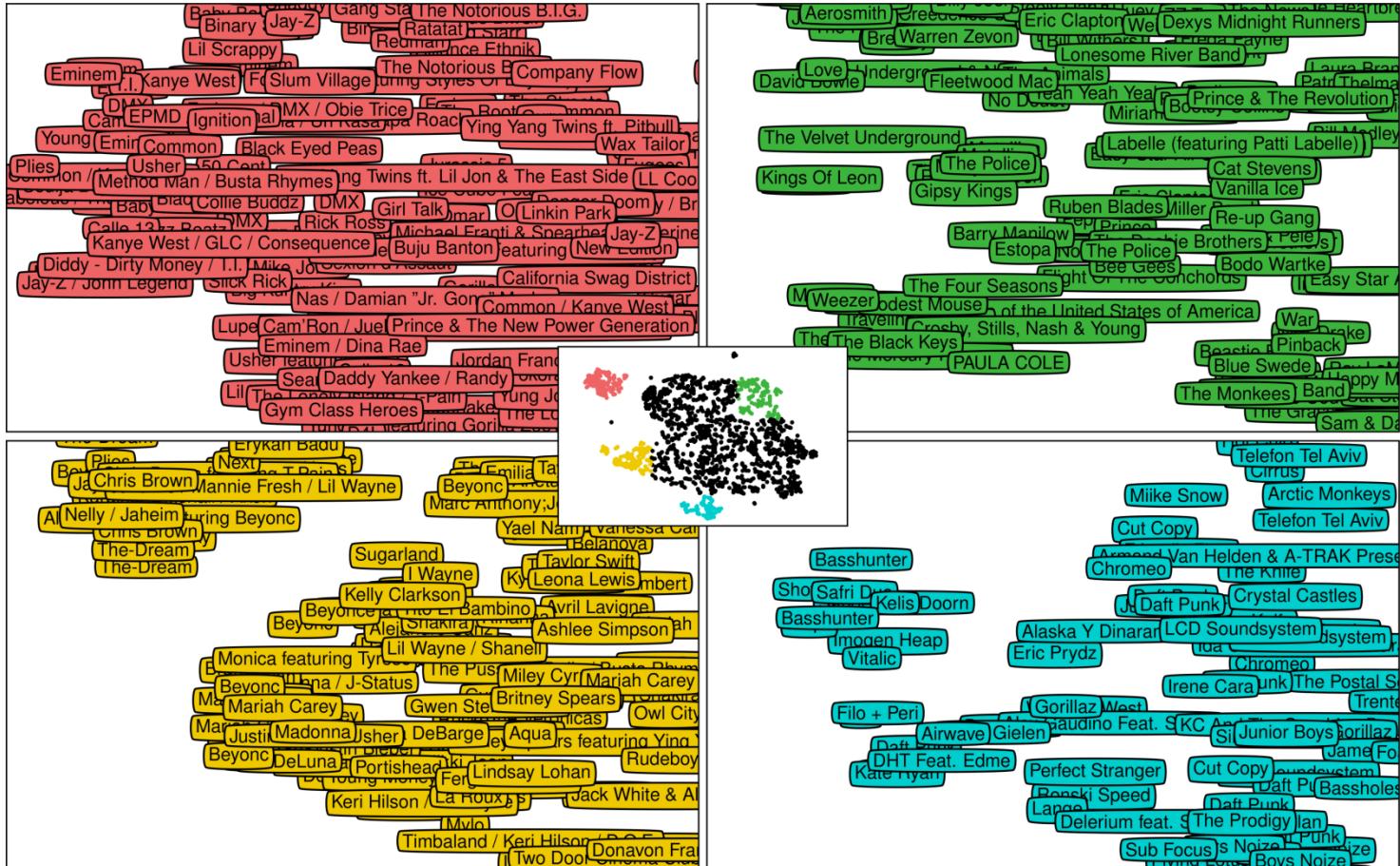
Latent factor models: project users and songs into the same latent space



Predict latent factors from music audio signals



Qualitative evaluation: visualisation of predicted usage patterns (t-SNE)



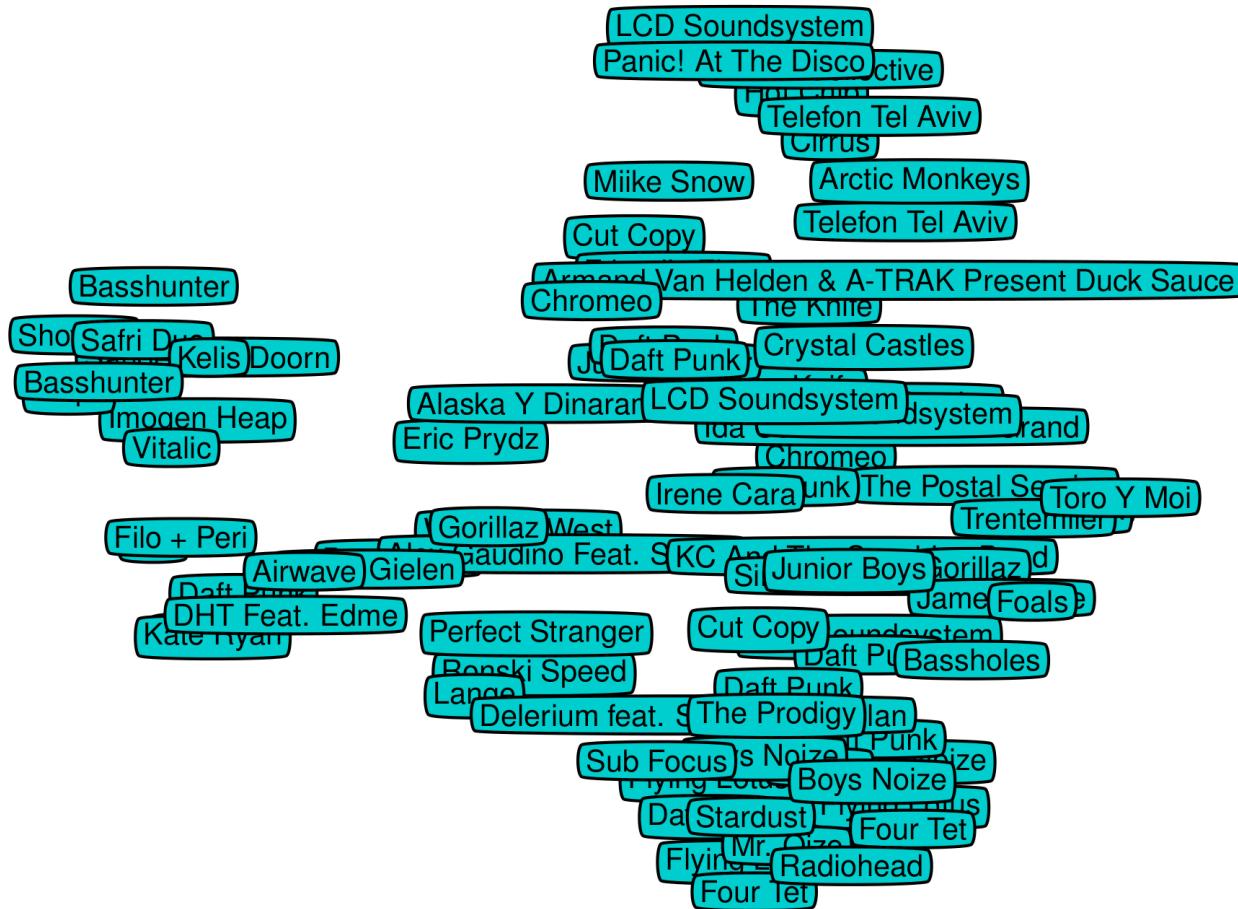
Qualitative evaluation: visualisation of predicted usage patterns (t-SNE)



Qualitative evaluation: visualisation of predicted usage patterns (t-SNE)

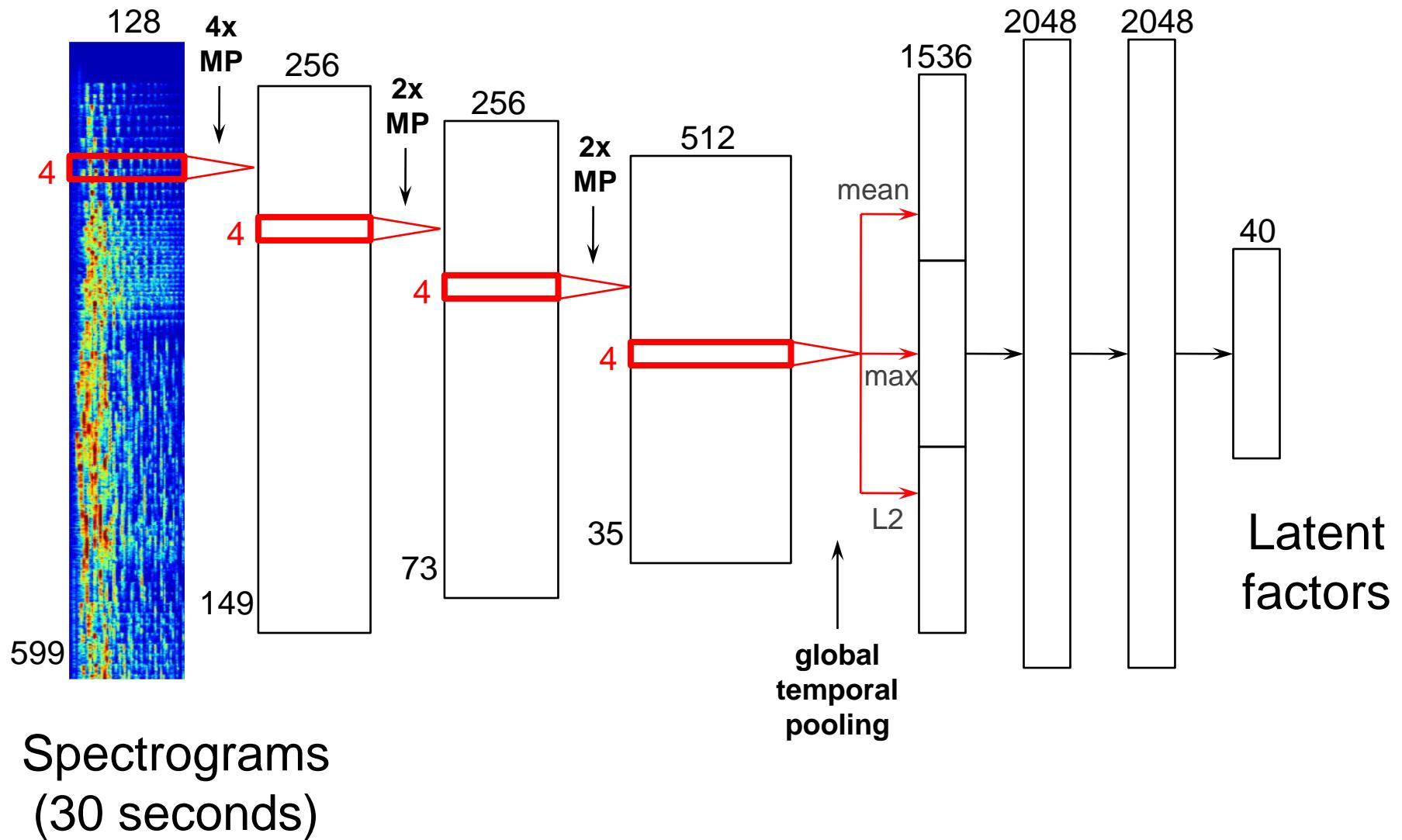


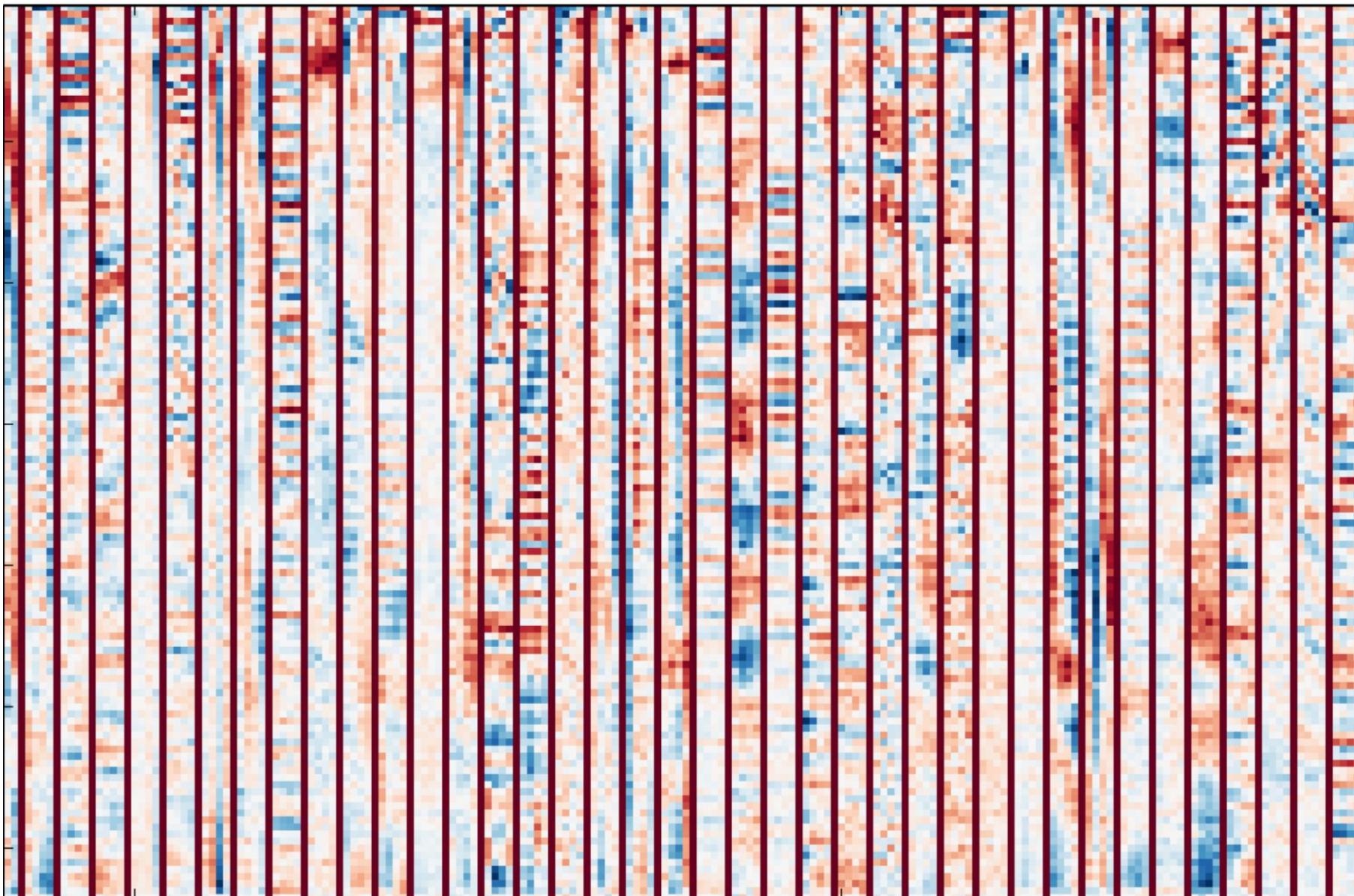
Qualitative evaluation: visualisation of predicted usage patterns (t-SNE)



Qualitative evaluation: visualisation of predicted usage patterns (t-SNE)







DEMO