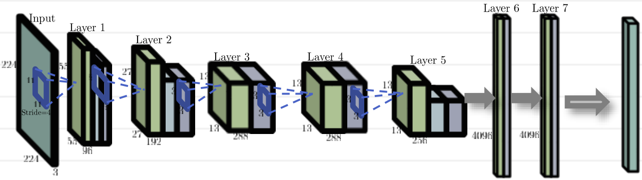
# Lecture 6: Convolutional Networks in Computer Vision

# Haven't it all been about computer vision?

*(in fact, No)*

***What*** is this? Ostrich




What is this? Cat

# The art of asking right questions

***What*** *is this?*

It is a car (and a road and a building)

A lot of applications need to answer ***Where?***

# The art of asking right questions


***What*** is this?

It is a human!

A lot of applications need to answer ***Who? / Is it the same person as X?***

# Questions answered by computer vision

- ***What*** is this?
- ***Where*** are the things?
  - ..in the image
  - ..in the 3D world
- ***Who*** is this?
- ***How far*** is this thing?
- ***What is*** he/she/they ***doing***?
- *What is the shape*?
- ....


"Excuse me, is this the Society for Asking Stupid Questions?"

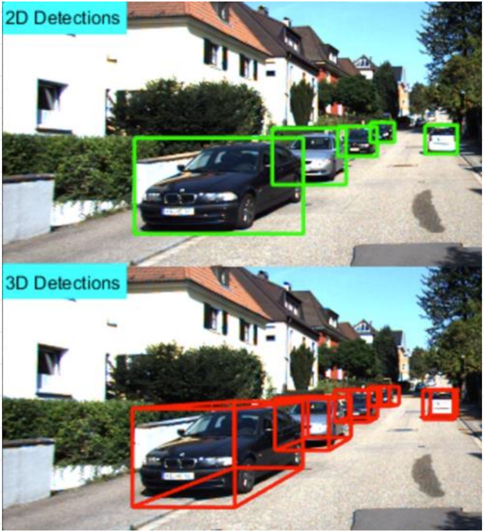
# Answering the where question

## Format 1: semantic segmentation

# Answering the where question

## Format 2: object detection

Today



# Answering the where question

## Format 3: instance segmentation

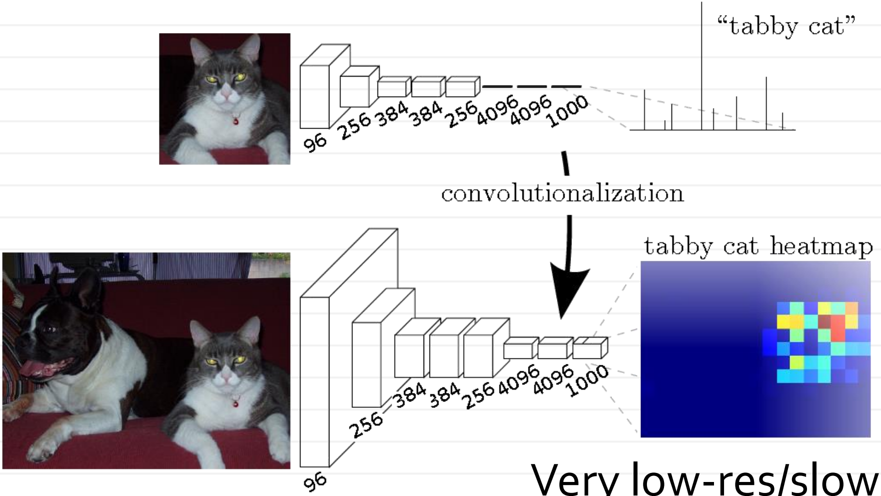
*Images from Chaosmail Blog*

# Answering the where question

- Semantic segmentaion:
  - Relatively fast/easy
  - Allows “complete” explanation
  - Merges instances
- Object detection
  - Relatively fast/easy
  - Distinguishes instances
  - Inaccurate for some classes
  - Incomplete
- Instance segmentation
  - Complete
  - Distinguish instances
  - Accurate
  - Slow/hard

Today

# From classification to Segmentation

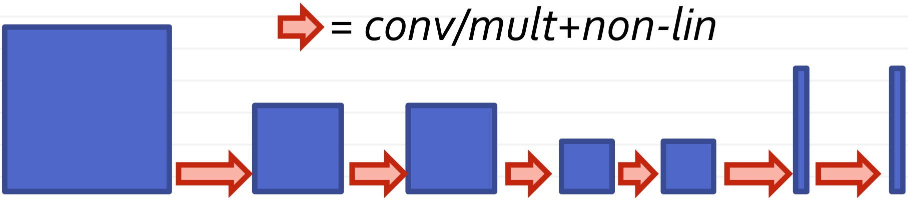



Very low-res/slow!

[Long et al. 2015]

# From classification to segmentation

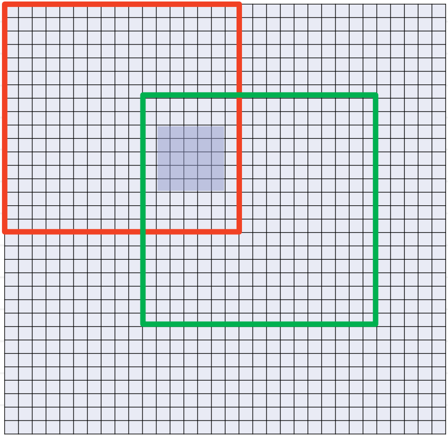
Consider a classification net *without* max-poolings:




Can we make an equivalent network that computes the result of this network for all window locations?

Answer: yes

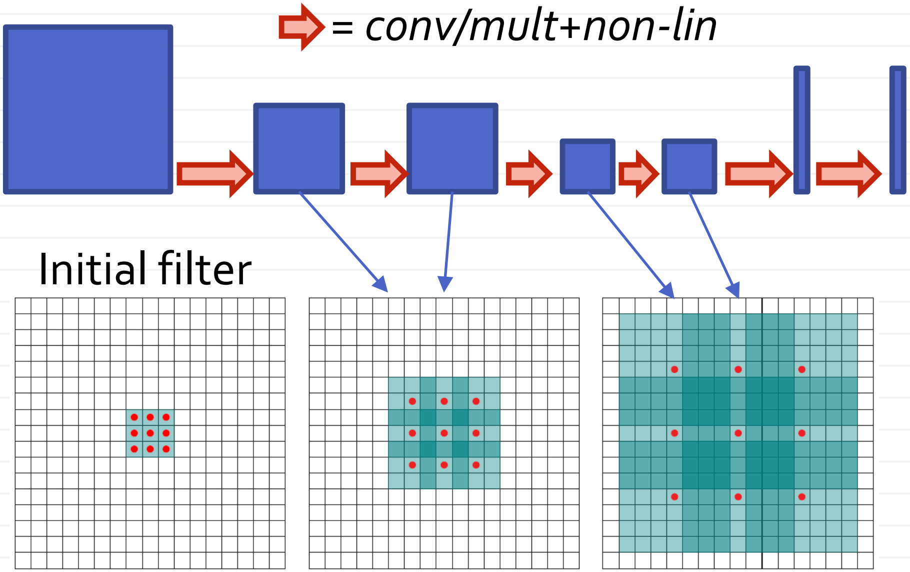
# "Convolutionization"



- Classifying overlapping patches incur shared convolutions
- We can convolve the entire map with a kernel straight away ("fully-convolutional")
- Slight difference (non-zero padding)

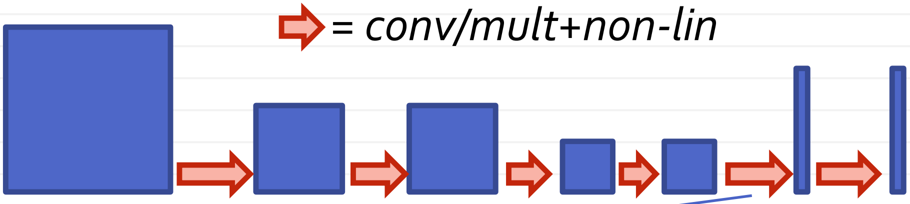
Things get more complicated with strides > 1 and maxpoolings

# Dilated convolutions




[Yu & Koltun ICLR16]

# Dilated convolutions

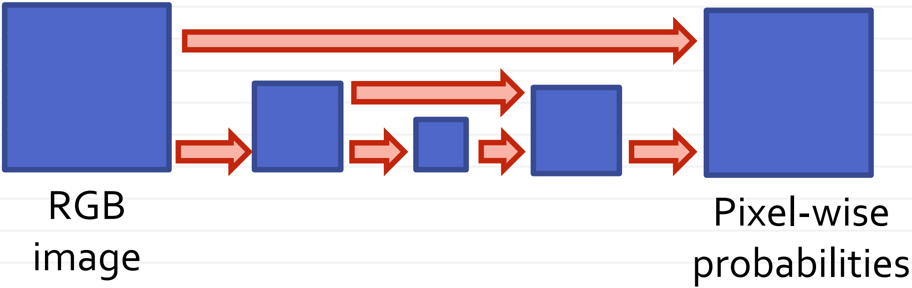



- Reshape+mult → conv filter
- Mult → 1x1 conv filter

Max-pooling in classification can be approximated with max-filtering + dilation increase in the segmentation network

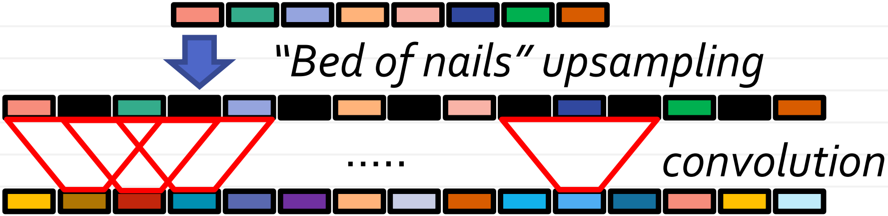
# Downsampling-upsampling architectures

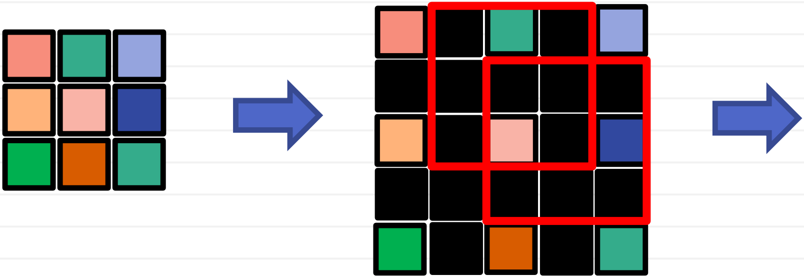
These architectures look approximately like:



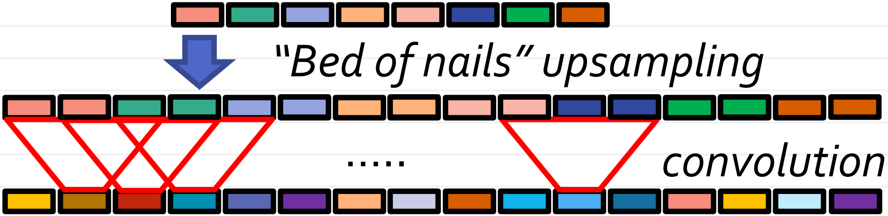

- Are not equivalent to classification
- Need to define upsampling/upconvolution

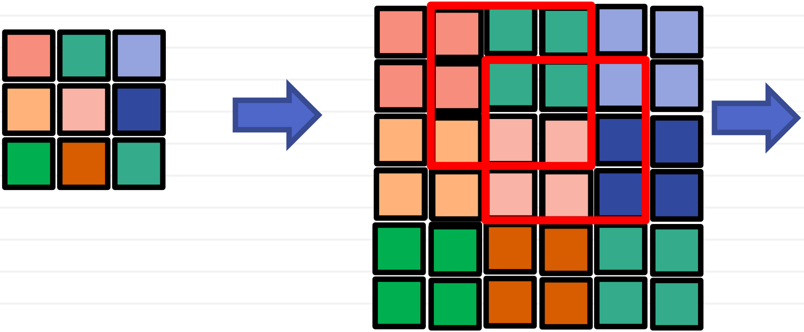
# Bed-of-nails upsampling operation



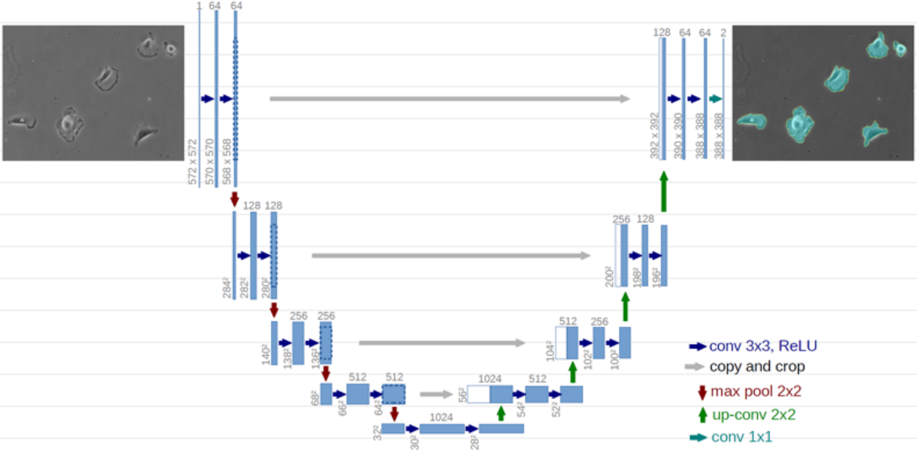
# Nearest upsampling operation



# U-Net

## An example of non-equivalent formulation

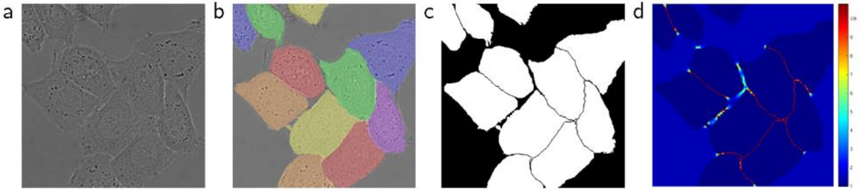



[Ronnerberger et al. MICCAI15]

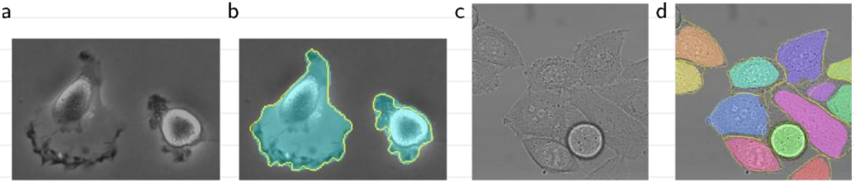
# U-Net

[Ronnerberger et al. MICCAI15]

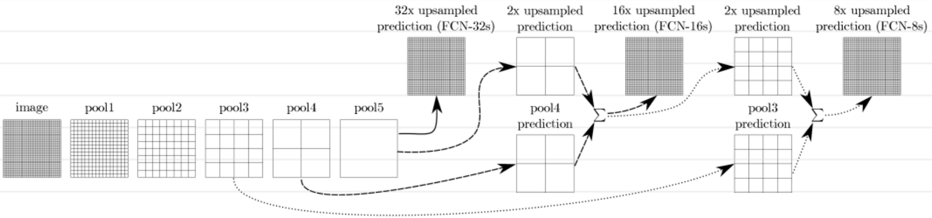
Upweighting thin borders:

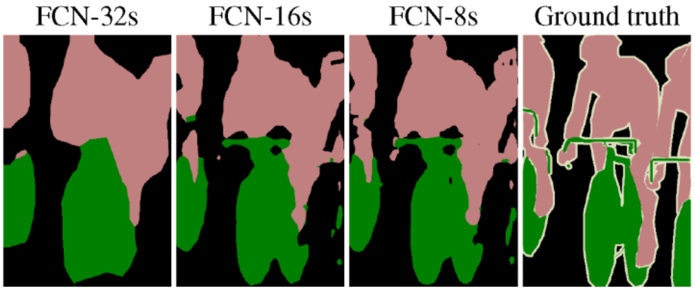



Result:



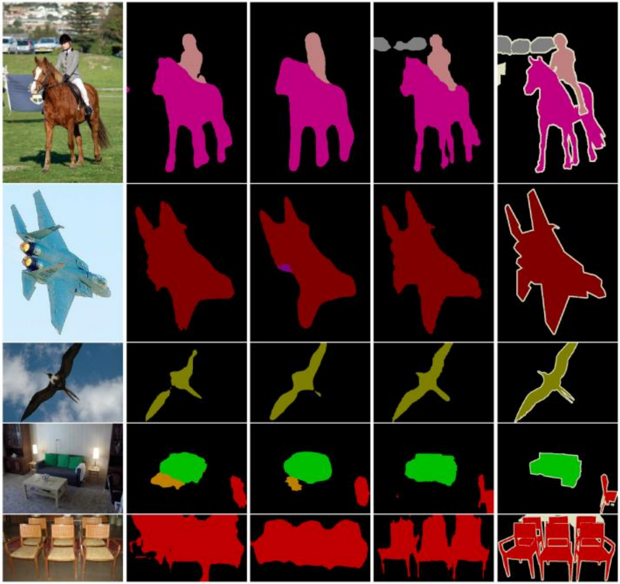
# “Fully-convolutional networks”




[Long et al. 2015]

# Dilated convolutions



FCN Dilated [Yu & Koltun ICLR16]

# Recap: ideas in semantic segmentation

- Dilated convolutions
- Upsampling layers/upconvolution layers (aka *transposed convolution/deconvolution*)
- Skip connections (to retain fine-details)
- We can mix and match all of the above

# Detection vs classification


Detection is harder than classification:

- Localization errors
- Huge class disbalance
- Variation in scale and aspect ratio's
- Tricky occlusions, including "intra"-occlusions

# Intersection-over-Union measure

Common criterion for correct boxes:

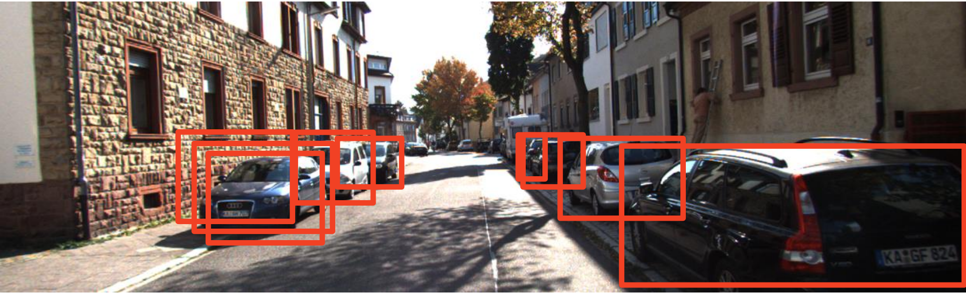
Intersection / Union > threshold (e.g. 0.5)

# Double detection


Double detection of the same object is penalized as false positive

# Non-maximum suppression

Almost invariably used in detection algorithms:

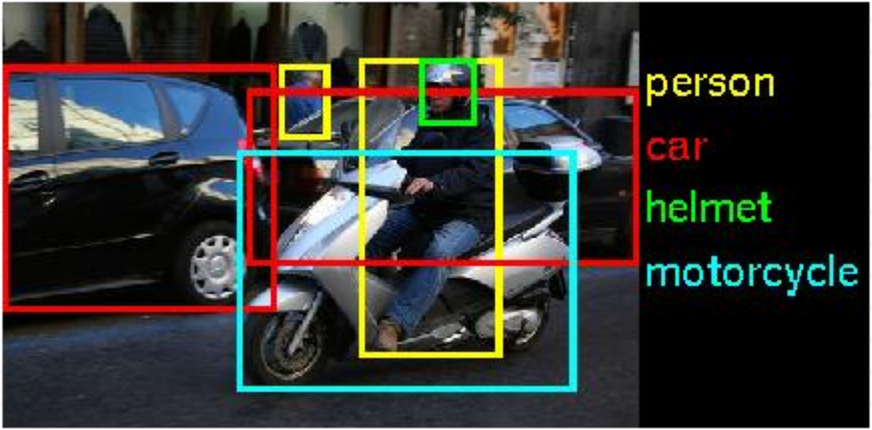



*Input: set of detections ($\{B_i, s_i\}$)*

- *Sort in the descending order of $s_i$*
- *For i = 1 to N*
- *Pick the bounding box i*
- *Suppress all subsequent boxes with IoU > 50%*

# Multi-class detection

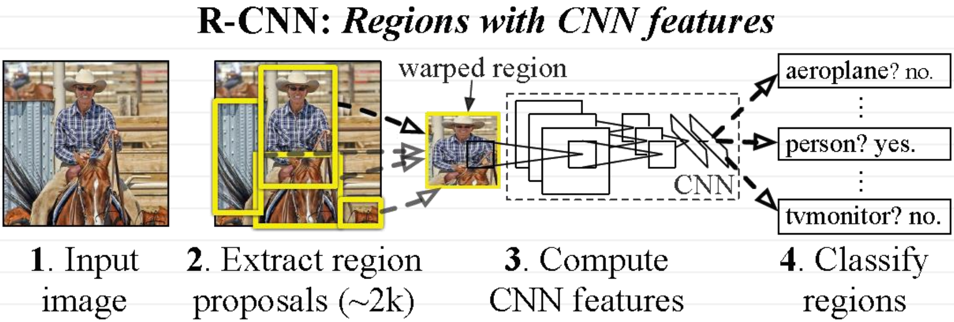
- Lots of research is going towards object detection for a large number of classes:



# General ideas for object detection


- **Sliding-window:** use binary classification to classify every possible subwindow (infeasible with DL)
- **Region proposal:** pick a subset of prospective regions and score them with a binary classifier
- **Bounding box regression:** predict the coordinates of the boxes as real-valued variables

# R-CNN framework

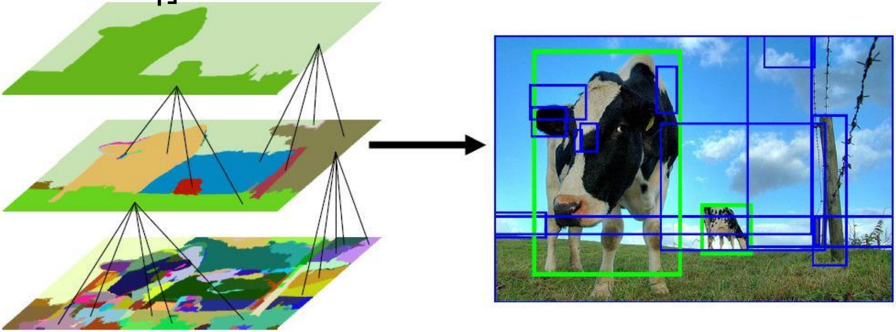



- Use an external box proposal method
- Fine-tune a CNN to score proposal

[Girshik et al. CVPR14]

# Example source of external proposals

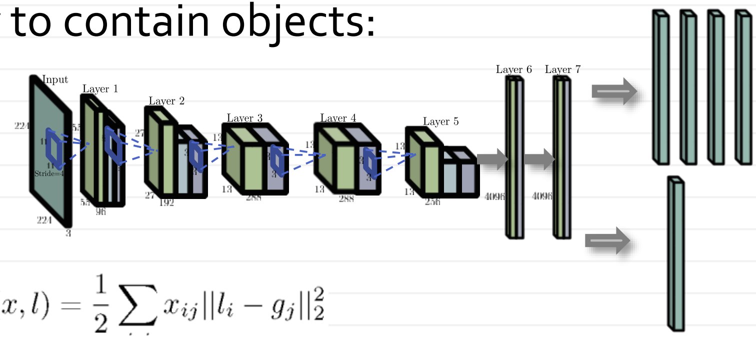
Graph-based hierarchical segmentation based on maximum-spanning trees [Felsenszwalb & Huttenlocher IJCV2004] :



[Uijlings et al. ICCV11]

# Bounding box regression

Goal: predicting 100 boxes that are likely to contain objects:




$$F_{\text{match}}(x, l) = \frac{1}{2} \sum_{i,j} x_{ij} \|l_i - g_j\|_2^2$$

$$F_{\text{conf}}(x, c) = -\sum_{i,j} x_{ij} \log(c_i) - \sum_i \Big(1 - \sum_j x_{ij}\Big) \log(1 - c_i)$$

$$F(x, l, c) = \alpha F_{\text{match}}(x, l) + F_{\text{conf}}(x, c)$$

[Szegedy et al. 2013]

# Optimization for bounding box regression

[Szegedy et al. 2014]

$$F_{\text{match}}(x,l) = \frac{1}{2}\sum_{i,j} x_{ij}||l_i - g_j||_2^2$$

$$F_{\text{conf}}(x,c) = -\sum_{i,j} x_{ij}\log(c_i) - \sum_i \Big(1 - \sum_j x_{ij}\Big)\log(1-c_i)$$

$$F(x,l,c) = \alpha F_{\text{match}}(x,l) + F_{\text{conf}}(x,c)$$

Alternate:

- Optimize x (optimal matching)

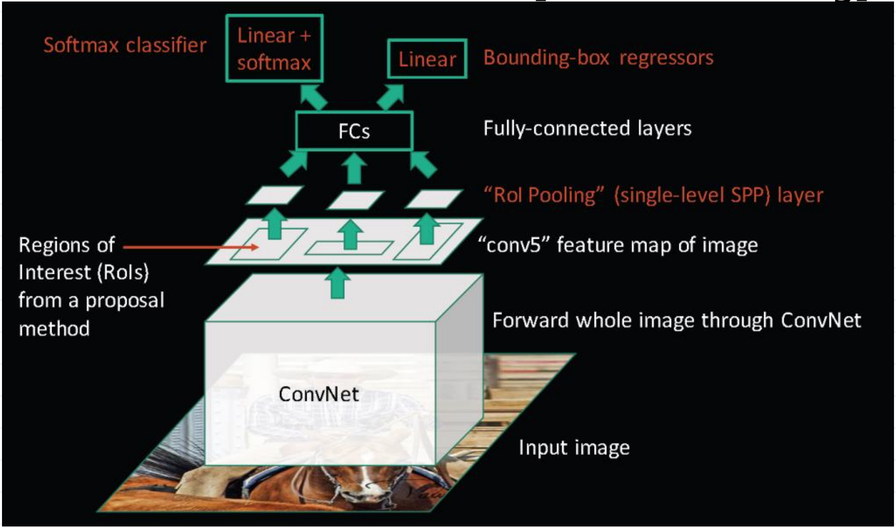
$$\begin{aligned} x^* &= \arg\min_x F(x,l,c) \\ \text{subject to} \quad & x_{ij} \in \{0,1\}, \sum_i x_{ij} = 1 \end{aligned}$$

- Optimize network params (backprop)

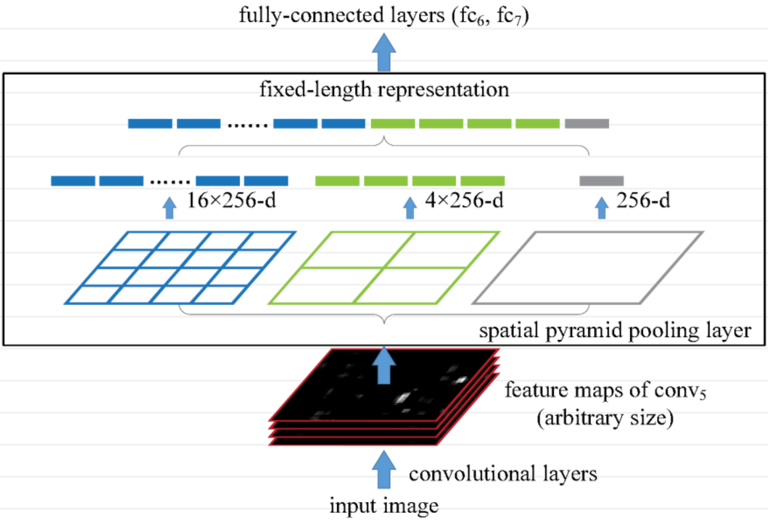
# Fast R-CNN

- Processing lots of overlapping boxes is inefficient
- Alternative:

[Girshick ICCV15]



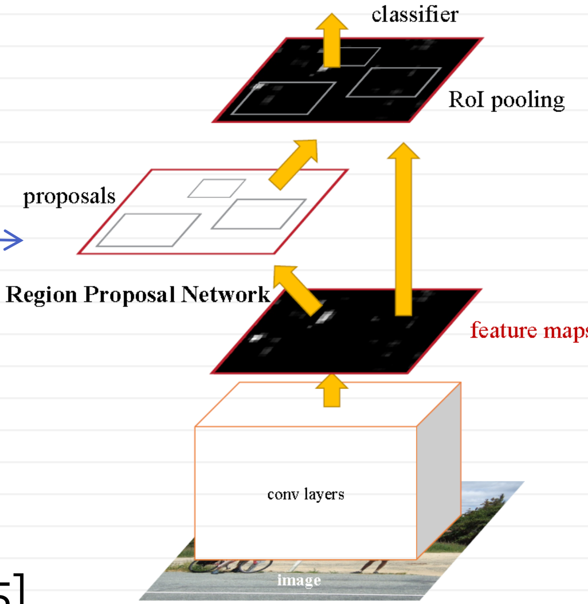
# Spatial pyramid pooling




[He et al. ECCV14]

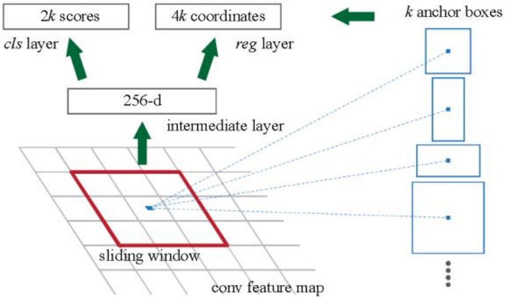
# Faster CNN

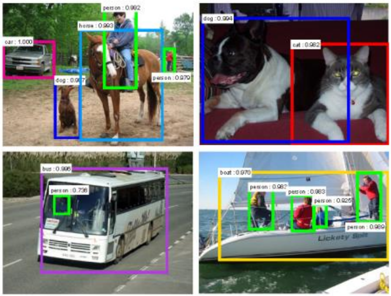
Key novelty: the proposals come from "sparse sliding window search"

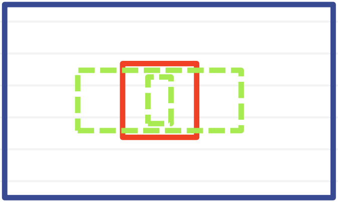



[Ren et al. NIPS15]

# Faster CNN: Region-proposal network



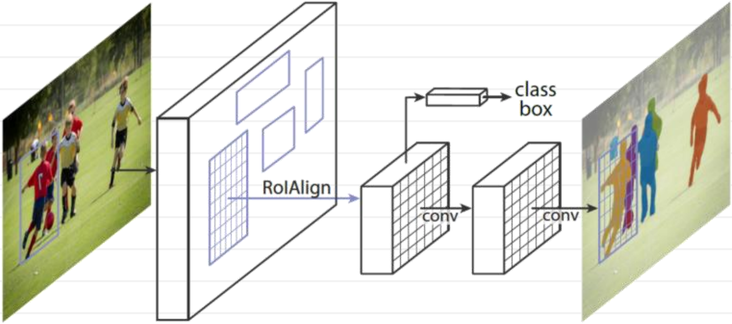


[Ren et al. NIPS15]

- Sparse set of positions
- At each positions, 9 centered "anchor" windows
- Each anchor is adjusted and scored for each class

# Extension for Instance Segmentation

Mask R-CNN: adding  mask prediction



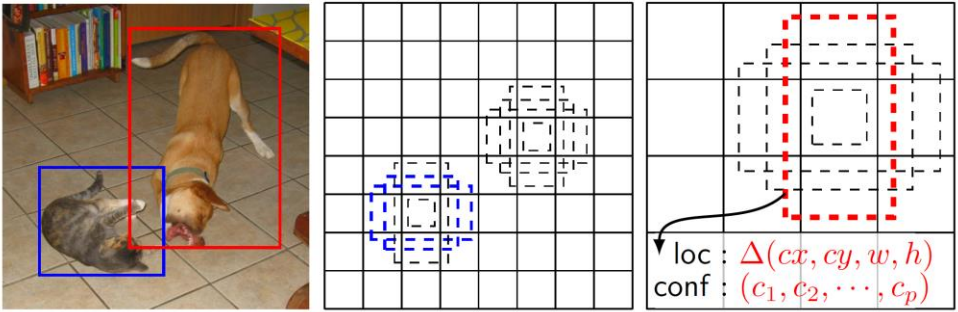

Masks for different classes are predicted and scored independently (decoupling classification and segmentation)

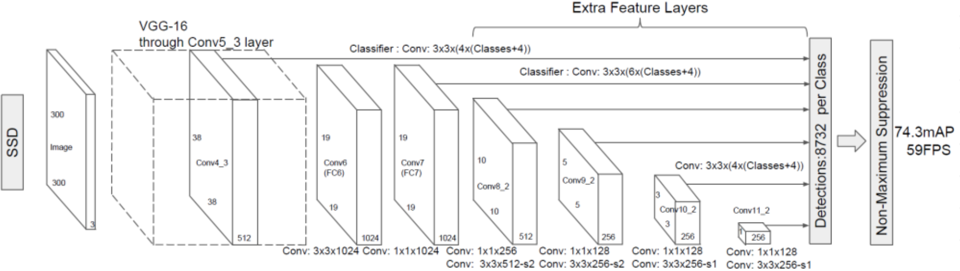
[He et al. 2017]

# Mask R-CNN results


[He et al. 2017]

# Latest king of the hill: SSD detector

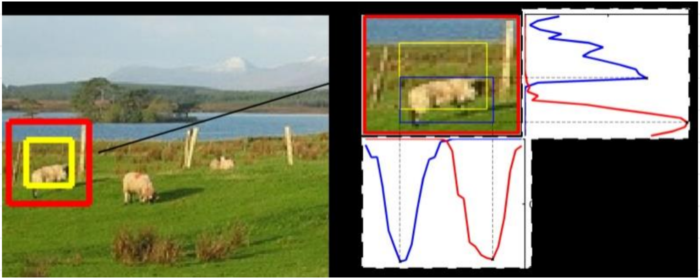


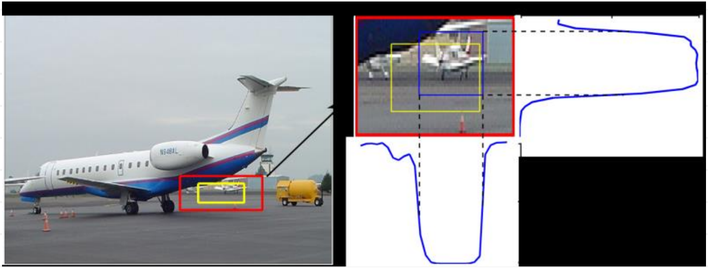




[Liu et al. ECCV16]

# Examples: SSD detection

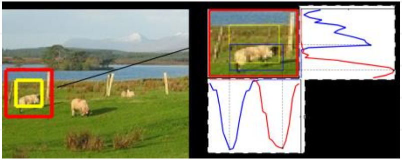
# Localization Network

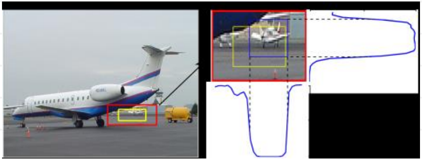


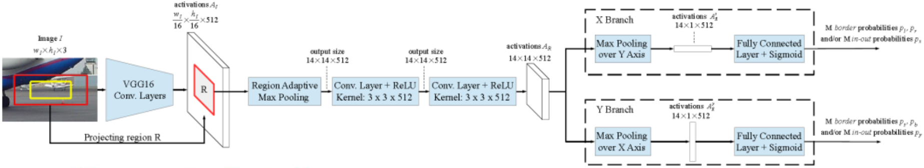


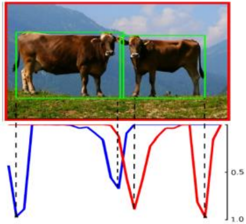
[Gidaris & Komodakis 2015]

# Localization Network








[Gidaris & Komodakis 2015]

# Recap: ideas for detection

- **ROI-pooling:** sharing convolutional features
- **Anchor+Regression:** “fast sliding window”
- **External proposals:** can be better if there is a good external source

# Verification problems in vision

Key question: do two photos show the same object/subject? (*verification)*

Face recognition datasets (e.g. *MSRA-CF*):

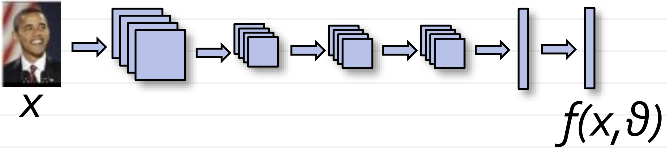
Re-identification datasets (e.g. *ViPER*):

# Verification vs Classification

Key question: do two photos show the same object/subject? (*verification*)

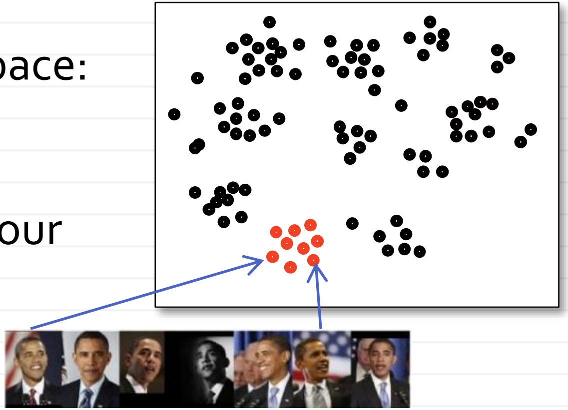
- System must be able to handle unseen "classes"
- During training classes can be numerous, small-sized, imbalanced, etc.
- Example from last lecture: retrieval

# Verification as embedding learning

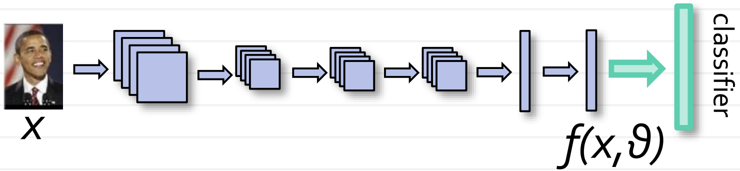



Semantic space:

NB: always normalize your descriptors!



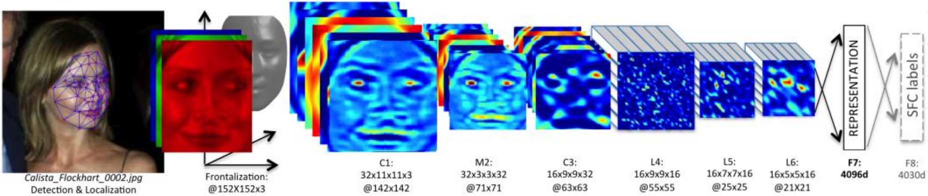
# Approach 1: classification-based




- Same idea as "Train on ImageNet, use for retrieval"
- The bigger the classification dataset, the better is the performance
- Training-time classes can be seen as prototypes for test-time classes

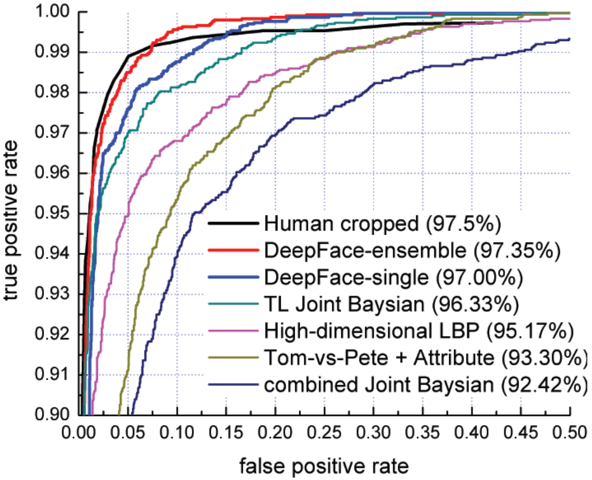
# Face verification: "Deep face"

[Taigman et al. 2014]



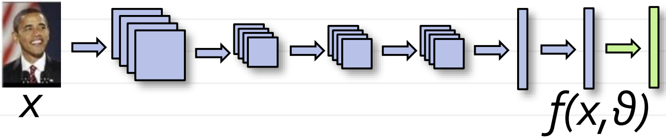

- *Classification* network trained on 4030 people x ~1000 images.
- Target problem: *verification* (same vs different)

# Face verification: "Deep face"




Different CNNs combined using SVM-learned weights on validation set

# Pair-based learning (*aka Siamese*)




Example distances:

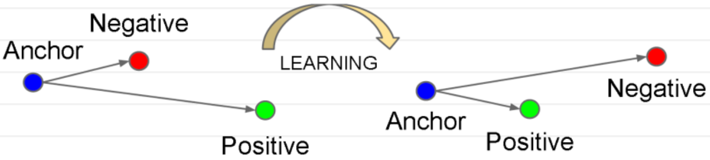
- 1 – cos
- L2 (equivalent if normalization is added)
- Separate network (verification network)

NB: all embedding-based systems work better with normalized descriptors

[Chopra et al. CVPR05]

# Google "FaceNet"

[Schroff et al. CVPR15]




Simple **triplet loss**: $$\sum_i^N \left[ \|f(x_i^a) - f(x_i^p)\|_2^2 - \|f(x_i^a) - f(x_i^n)\|_2^2 + \alpha \right]_+$$

- Use large mini-batches (1800, 40 images for several classes + lots of random)
- Take all positives from the batch
- Mine "*semi-hard*" negatives

$$\|f(x_i^a) - f(x_i^p)\|_2^2 < \|f(x_i^a) - f(x_i^n)\|_2^2$$

# Google "FaceNet" results


[Schroff et al. CVPR15]

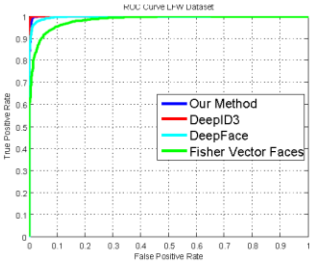
- Upto 99.63% on LFW (human is ~97%)

Performance vs training data:

| #images | VAL |
|---|---|
| 2.6M | 76.3% |
| 26M | 85.1% |
| 52M | 85.1% |
| 260M | 86.2% |

# Oxford Face Recognition

| No. | Method | Images | Networks | Acc. |
|---|---|---|---|---|
| 1 | Fisher Vector Faces [21] | - | - | 93.10 |
| 2 | DeepFace [29] | 4M | 3 | 97.35 |
| 3 | Fusion [30] | 500M | 5 | 98.37 |
| 4 | DeepID-2,3 | | 200 | 99.47 |
| 5 | FaceNet [17] | 200M | 1 | 98.87 |
| 6 | FaceNet [17] + Alignment | 200M | 1 | 99.63 |
| 7 | Ours | 2.6M | 1 | 98.95 |

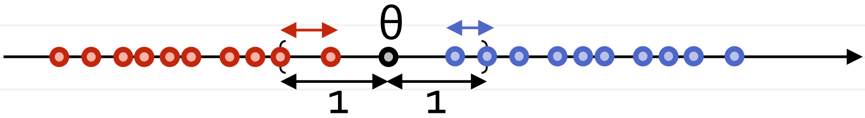


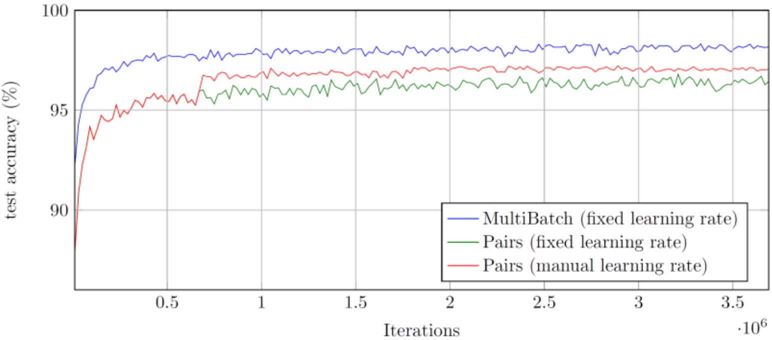

- Start with classification
- Fine-tune **last layers only** with moderately hard triplets
- Dataset publicly available
- Models are available in Caffe zoo and MatConvNet zoo

[Parkhi et al. BMVC15]

# Quadruplet losses: multi-batch loss

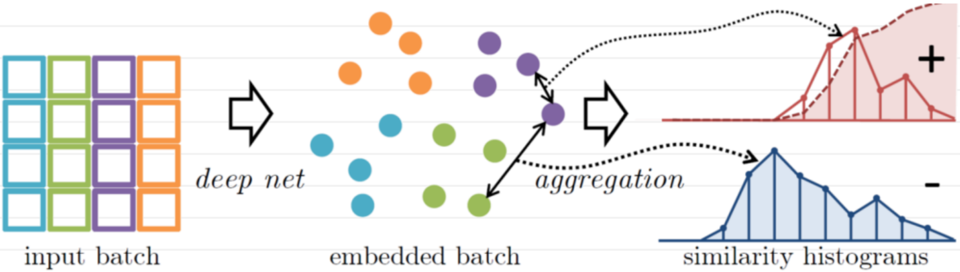
$$l(w,\theta;\ x_i,x_j,y_{ij}) = \left(1 - y_{ij}\left(\theta - \|f_w(x_i) - f_w(x_j)\|^2\right)\right)_+$$




[Tadmor et al, NIPS16]

# Quadruplet losses: histogram loss

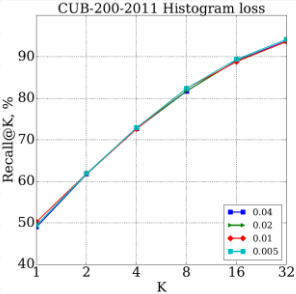


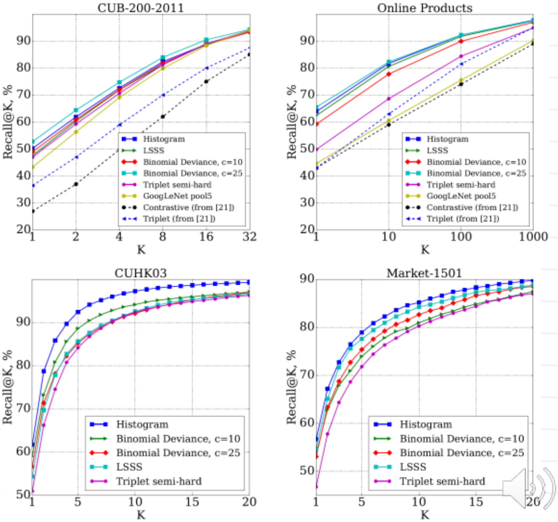

$$p_{\text{reverse}} = \int_{-1}^{1} p^{-}(x) \left[ \int_{-1}^{x} p^{+}(y)\, dy \right] dx = \int_{-1}^{1} p^{-}(x)\, \Phi^{+}(x)\, dx$$

[Ustinova & Lempitsky NIPS16]

# Quadruplet losses: histogram loss

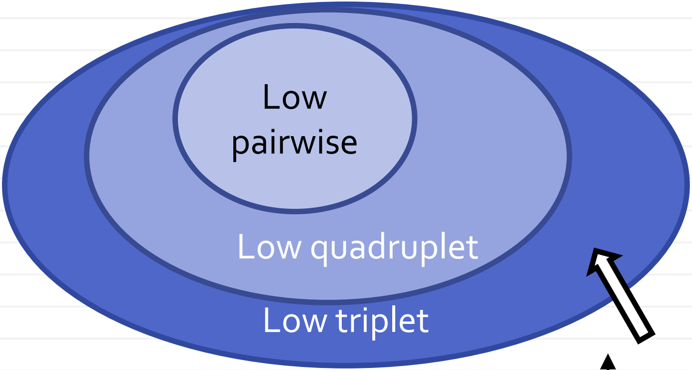
Sensitivity to the bin size:

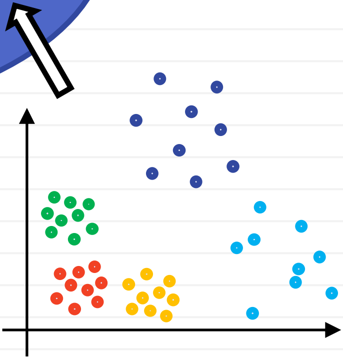



[Ustinova & Lempitsky NIPS16]

# Embedding learning: recap



*Recommendation:* use quadruplet, or soft pairwise (binomial loss)

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