Computer Vision: Revision

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Lecture and Assignment Guide

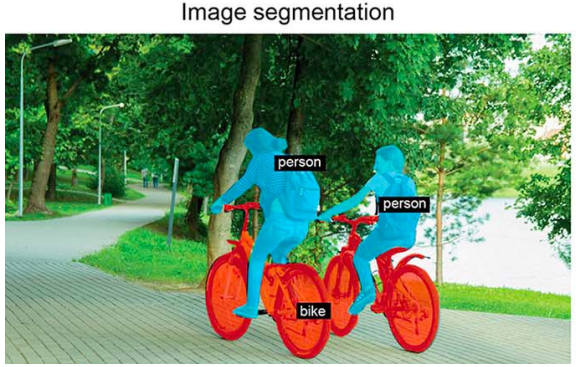
- This Slide Deck has Material for 6 hours of teaching divided into Parts 1-6
- We will go through
  - Week 01
    - Part 01 - Convolutional and Pooling Layers; AST 01
    - Part 02 - Transfer Learning and Modern CV Design Principle; AST 02
  - Week 02
    - Part 01 - Modern Convolutional Building Blocks for Image Classification; AST 03
    - Part 02 - Object Localization
    - Interpreting what convolutions learn (Advanced topic) – AST 03
  - Week 03
    - Part 01 - Object Detection (YOLO), Image Segmentation – Lec 05
    - Part 02 - Practical CVOps
    - AST04 – Object Detection with YOLO
  - Week 04
    - Revision
    - AST05 – Image Segmentation
- Additional Reading material to go in depth of math with references and code references are provided with the marking of “Additional Material” or “Additional Discussion” etc

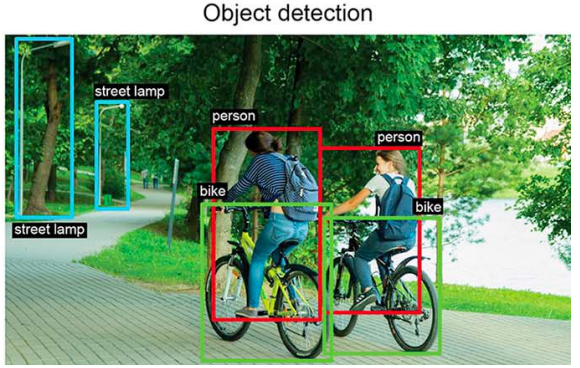
Mini Projects

- Persons with face-masks
  - load the image dataset using ImageDataGenerator from the path directory
  - perform data augmentation on the fly and create batches of the dataset
  - build the convolutional neural networks for classification problem
  - visualize & interpret what CNN layers learn
  - use the transfer learning (pre-trained models) for classification problems
- Lungs Segmentation – Biomedical Image Analytics
  - understand, prepare, and visualize the the dataset containing image and corresponding masked image used for segmentation
  - implement DeepLabV3+ architecture
  - create a masked image (prediction)

Three Essential Tasks in Computer Vision

- Image Classification
  - Single Label
    - Binary
    - Multiclass
  - Multi Label
- Image Segmentation
  - Pixel wise identify the class
  - Example: Zoom background replacement
- Object Detection
  - Bounding box around objects
  - Self-driving cars, face detection in cameras





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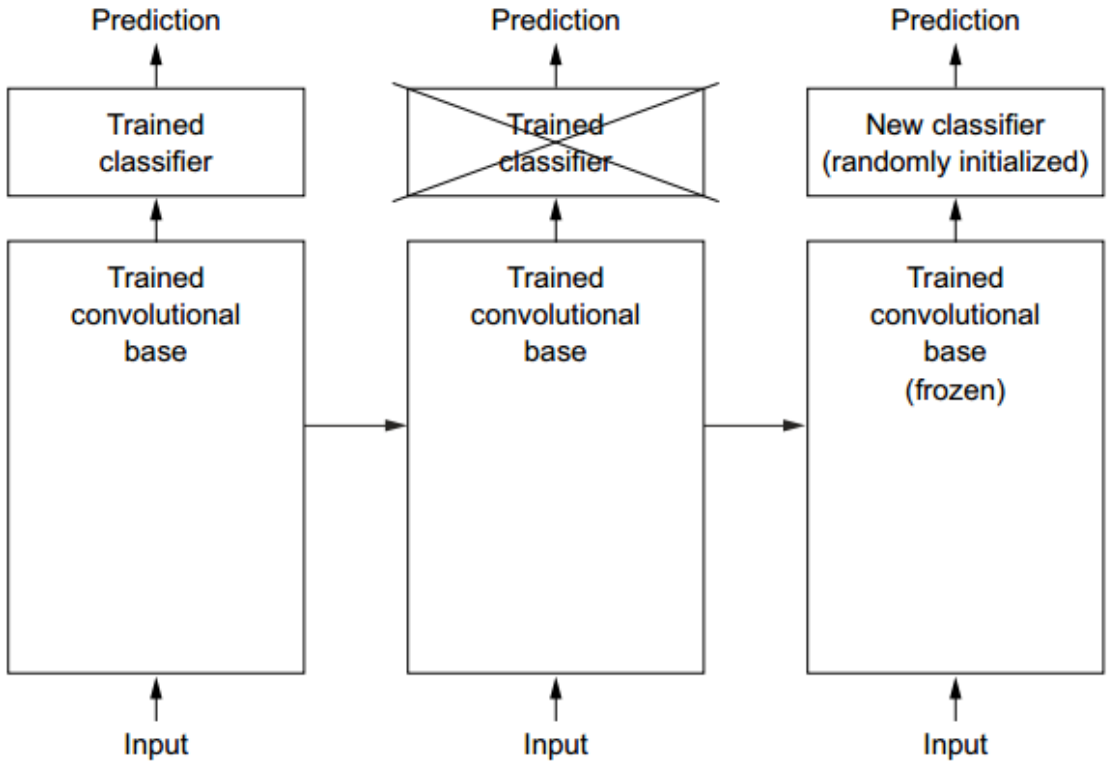
State of the Art as of Oct 2023

- https://paperswithcode.com/area/computer-vision
- Image Classification –
  - For speed: Efficient Net (CNN),
  - For accuracy: Vision Transformer
- Semantic Segmentation –
  - For speed: Unet, DeepLabv3
  - For accuracy: Deformable Convolution (InternImage), Vision Transformer (Segment Anything)
- Instance Segmentation - Mask-R-CNN, RetinaNet [Feature Pyramid]
- Object Detection –
  - For speed: YOLOv8
  - For accuracy: Deformable Convolution (InternImage)

Recommended Strategy

- Small Dataset (<1000 labelled images) – Use Transfer Learning
- Medium Dataset (Upto 5000-10000) – Use Fine Tuning
- Large Dataset (Beyond 10k) – Train from scratch
  - Rules of thumb!
- Edge Devices use MobileNet
- SoTA needed? – Use Efficient Net (or even ViT)
- Traditional firms who like time-tested methods
  - ResNet50, VGG19
- If training cost and inference time are not a concern, use all three and do an ensemble!

Transfer Learning



Tricks of the Trade

Data Augmentation

Keras – ImageDataGenerator

Batch Normalization

Fine tuning – unfreeze layer by layer

Labeling Data

- For image classification there are two manual labeling approaches
  - Move the images to a folder whose name is the label
  - Create an excel file (spreadsheet) with first column having the path of the image and the other columns having the label(s)
- Object detection
  - Needs bounding box (usually counterclockwise starting from top-left)
- Segmentation
  - Needs labels of pixels
- OpenCV Computer Vision Annotation Tool
  - https://github.com/opencv/cvat
- AI Labeling Service from Cloud Providers

Theory Concepts

- Convolution
- Pooling
- Residual Connection
- Depthwise Separable Convolution
- Inverted Residual Bottleneck (Efficient Net)
- Transpose Convolution
- Atrous Convolution
- Batch Normalization
- Fully Convolutional Network
- Evaluation Metrics (IoU, mAP)

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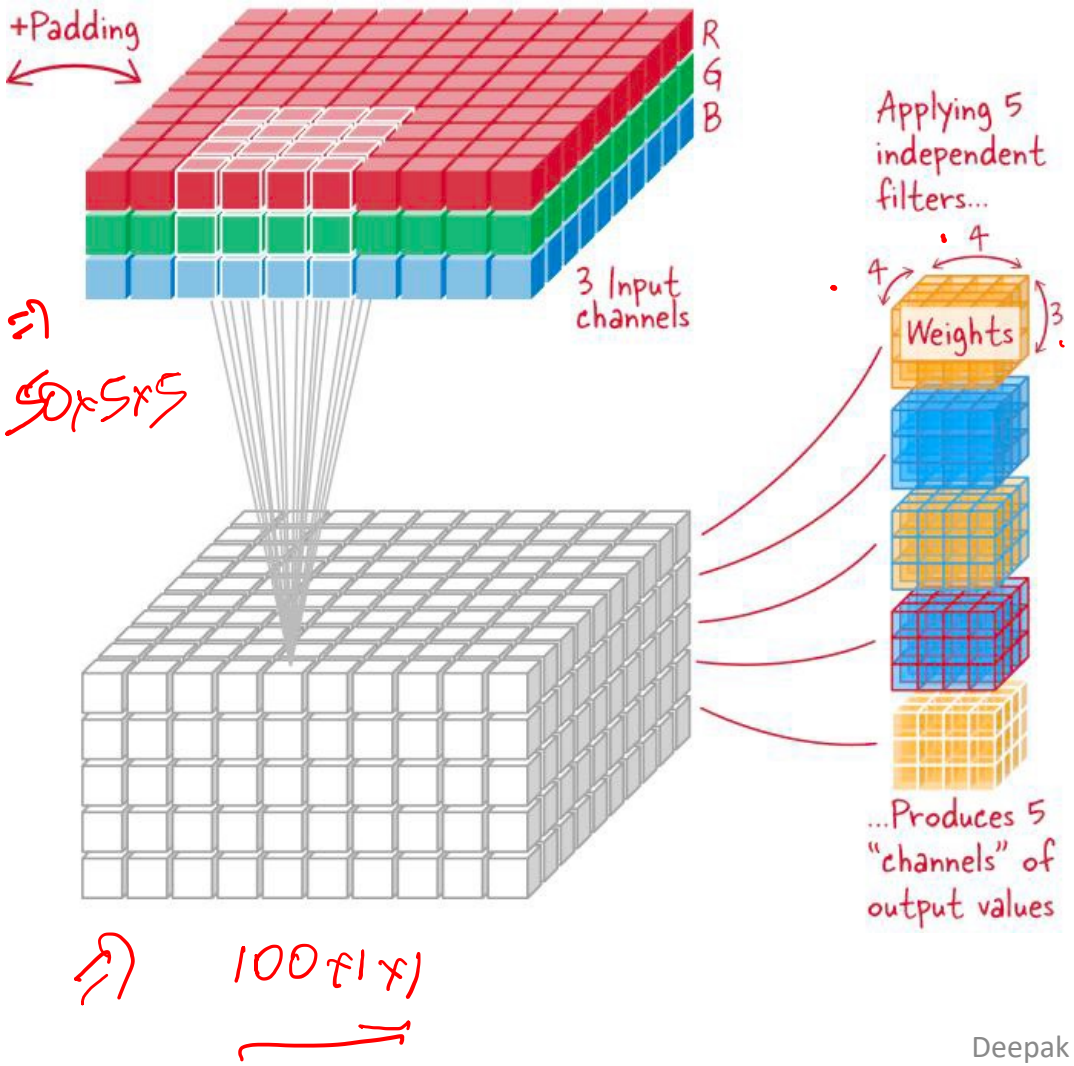
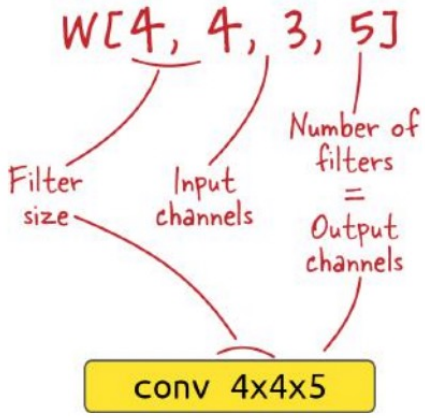
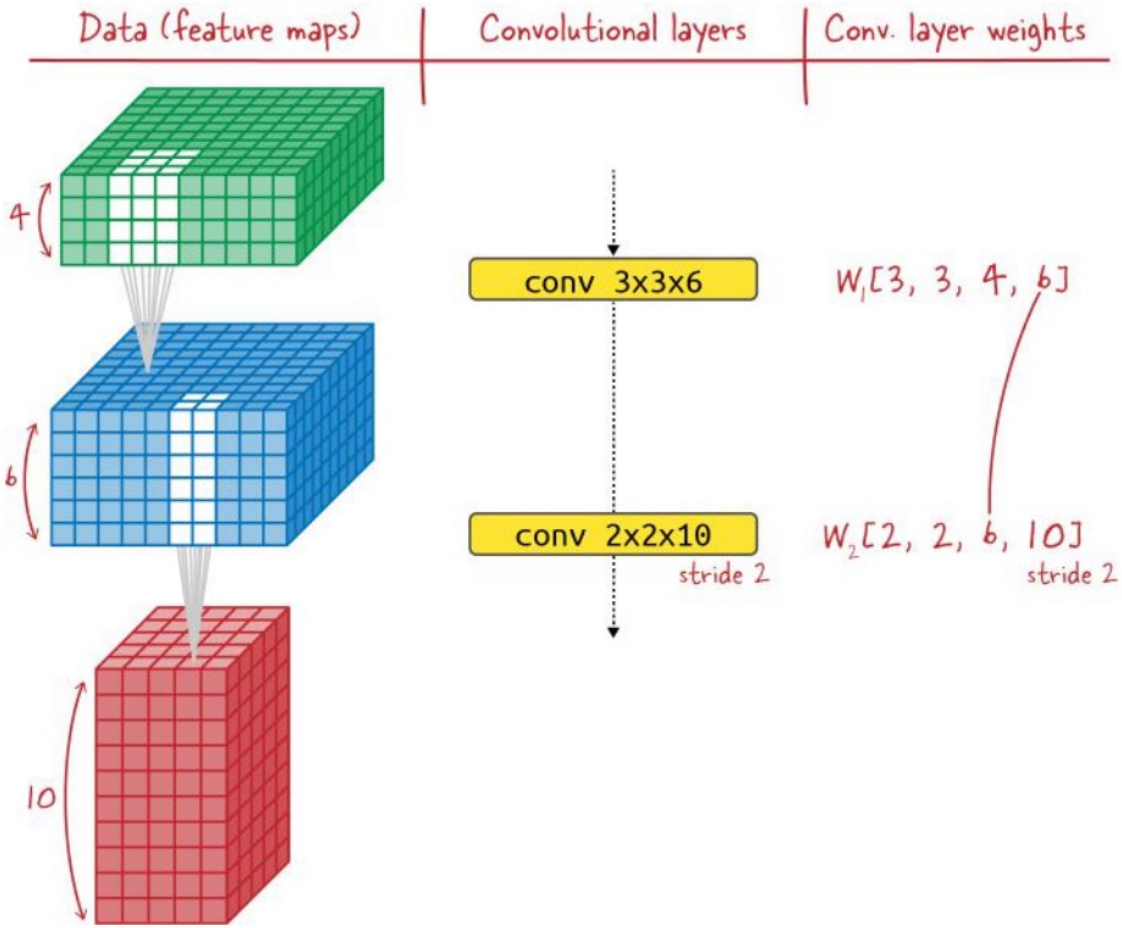
Convolutional Layer

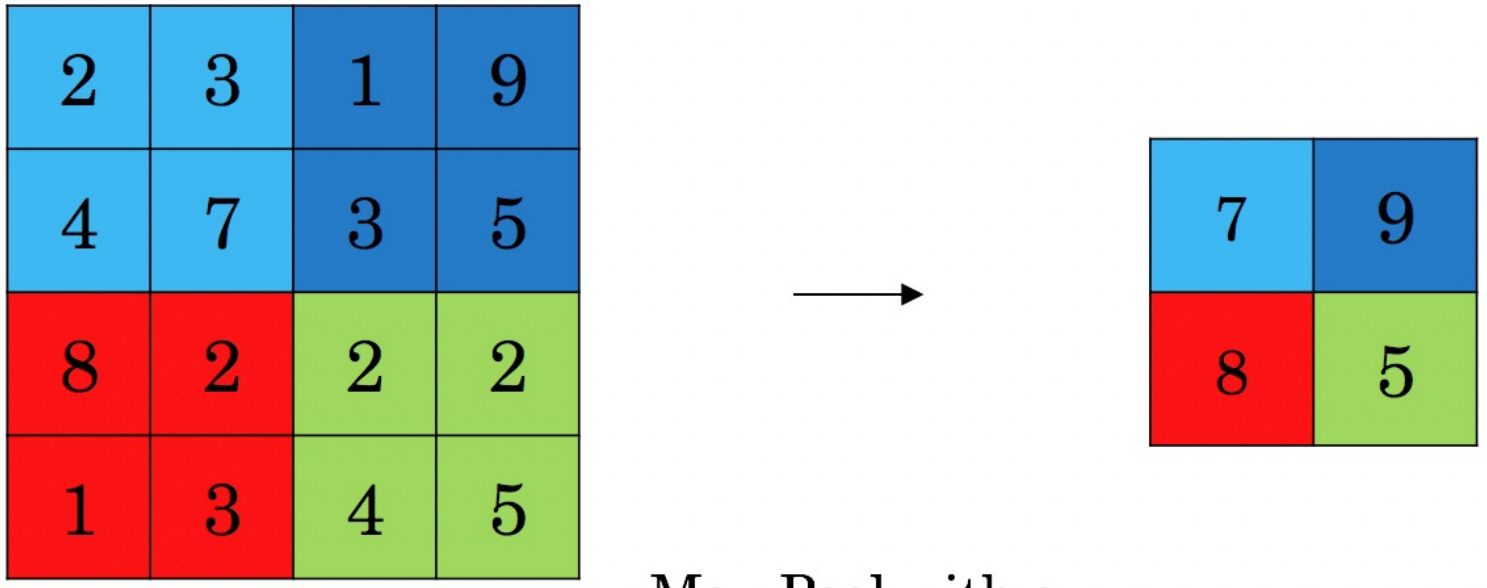






Pooling Layer

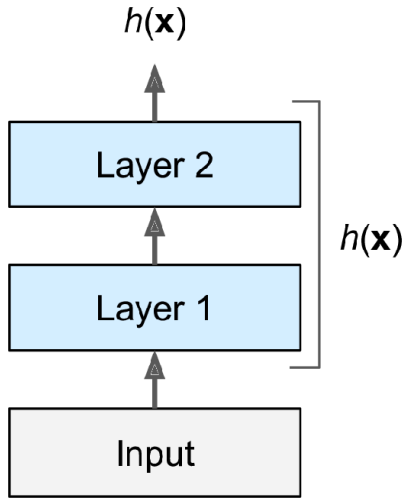
Max Pool

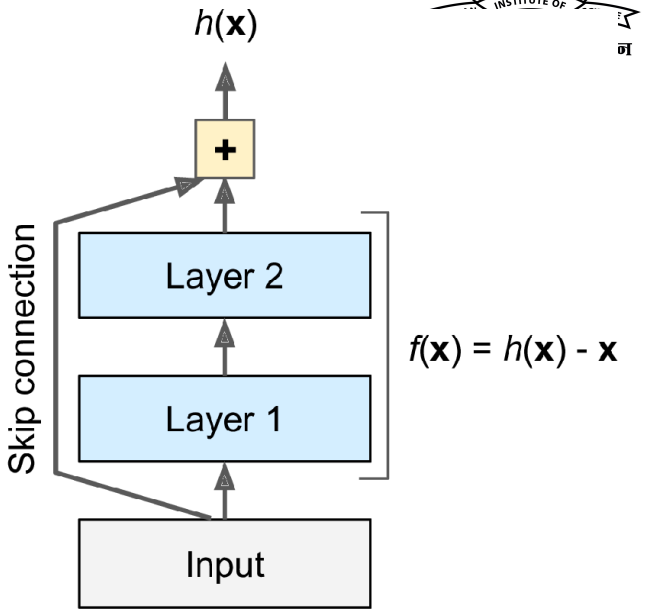


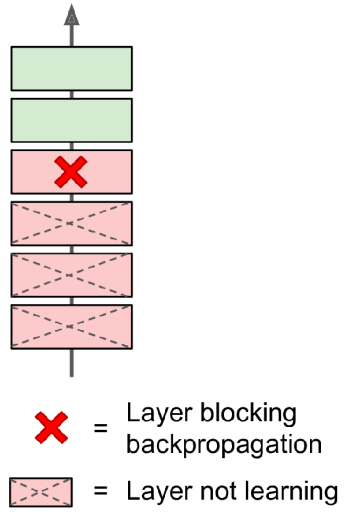
Max-Pool with a 2 by 2 filter and stride 2.

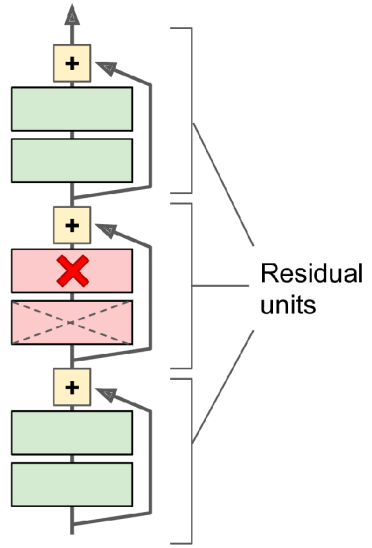
Residual Block

- 2015 winner is ResNet that used a residual block
- Networks were being deeper and residual (or skip connections) enabled training such deeper networks
- Usually networks are trained to learn a function $h(x)$
- By adding a skip connection, we are forcing the network to learn $f(x) = h(x) - x$
- When stacking several Residual Units, the signal can make its way to all the parts of network even if some layers experience a vanishing gradient



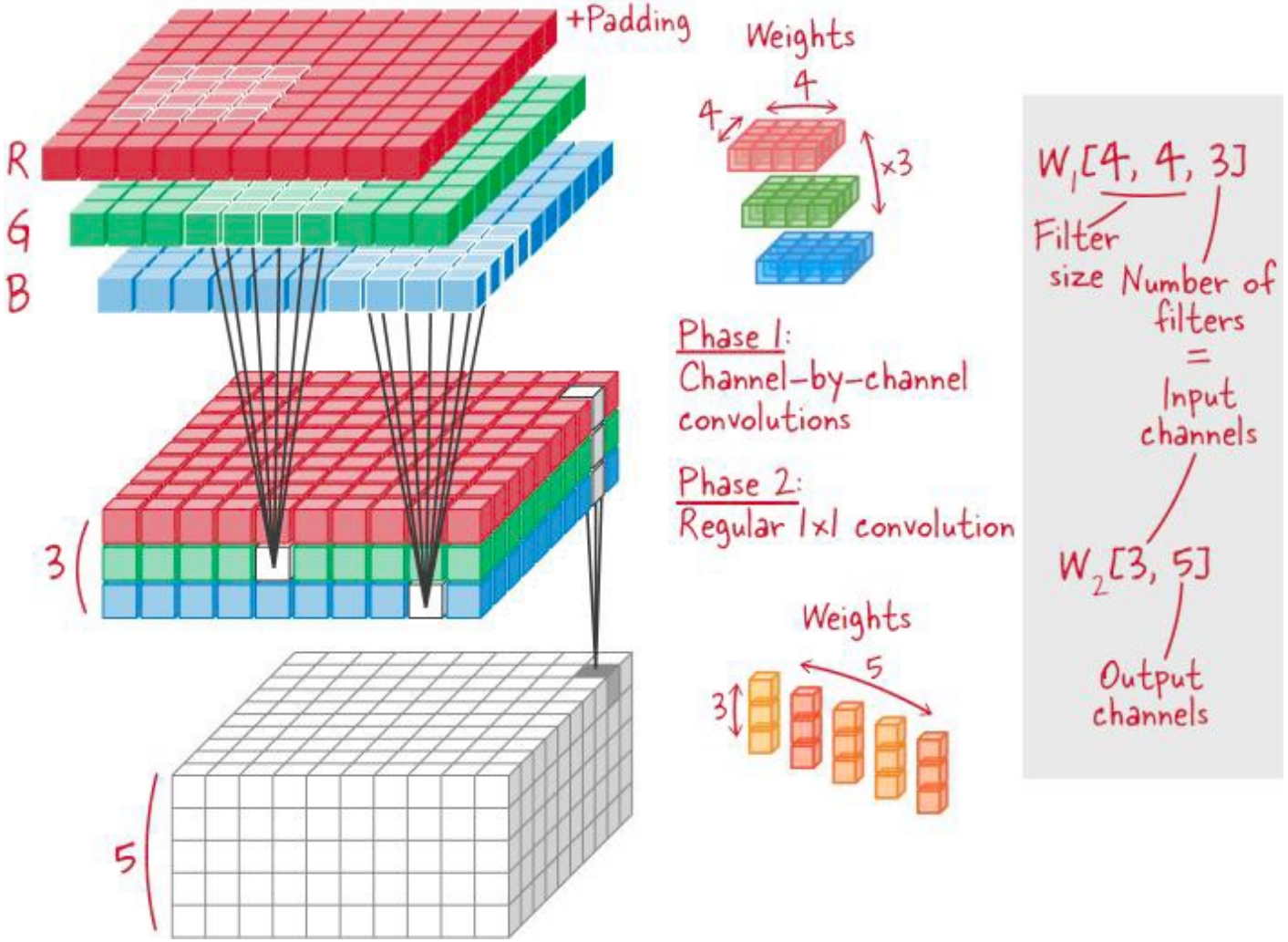






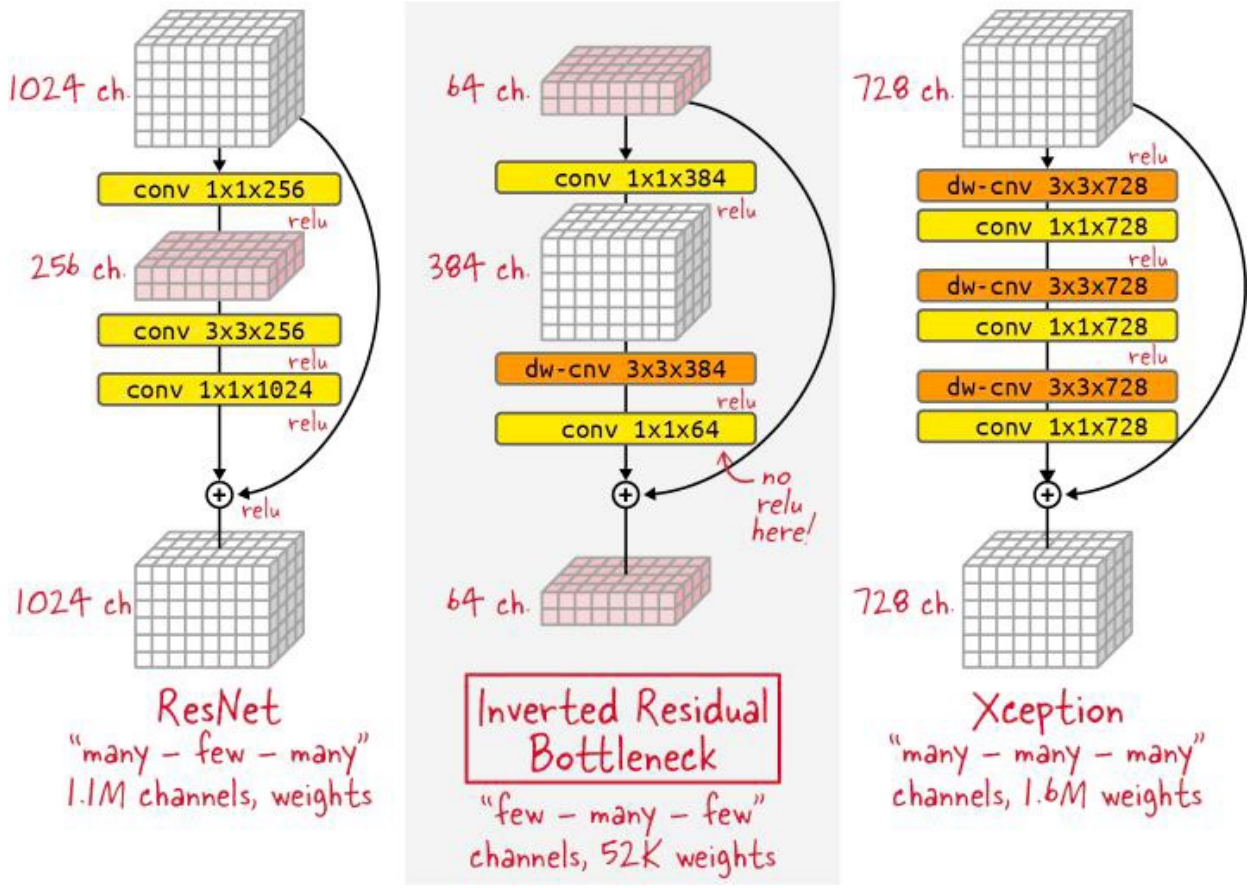
Depthwise Separable Convolutions

- Channel-by-channel convolutions followed by 1x1 Conv



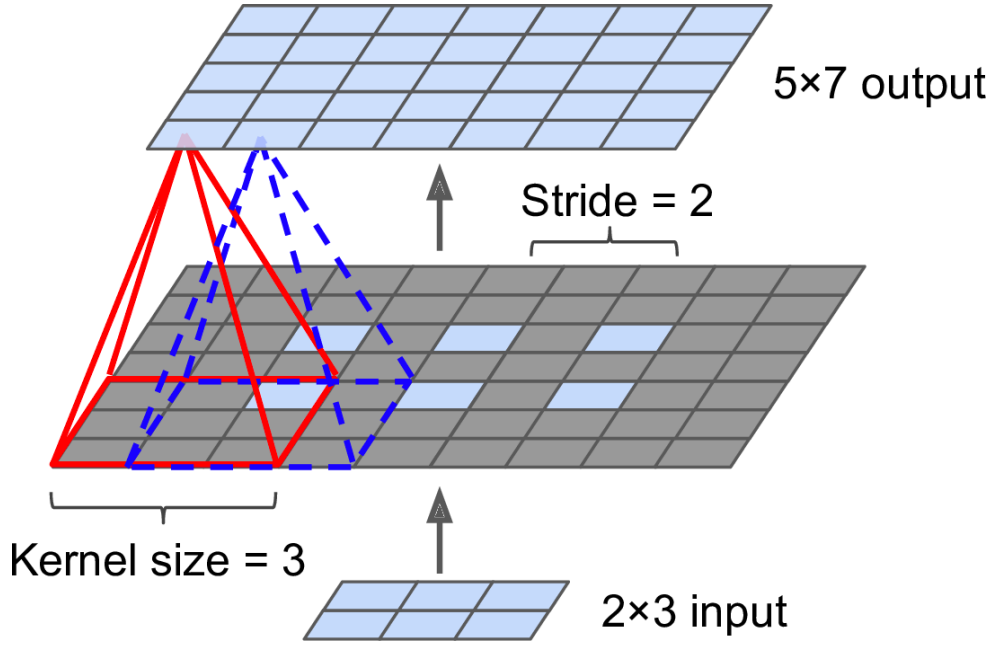
Inverted Residual Bottleneck

- Goal: Same expressivity as ResNet, Xception but with a dramatically reduced weight count and inference time
- Designed to be used on mobile phone where resources are scarce
- Argument: Information flow between residual blocks is low-dim in nature and can be represented by limited number of channels
- Important: Last 1x1 doesn't have any nonlinear activation as ReLU would destroy too much information



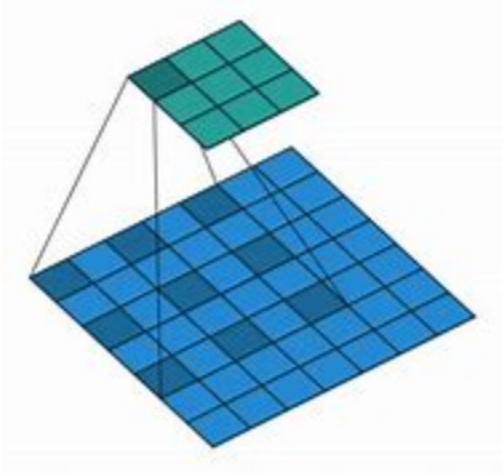
Transposed Convolution

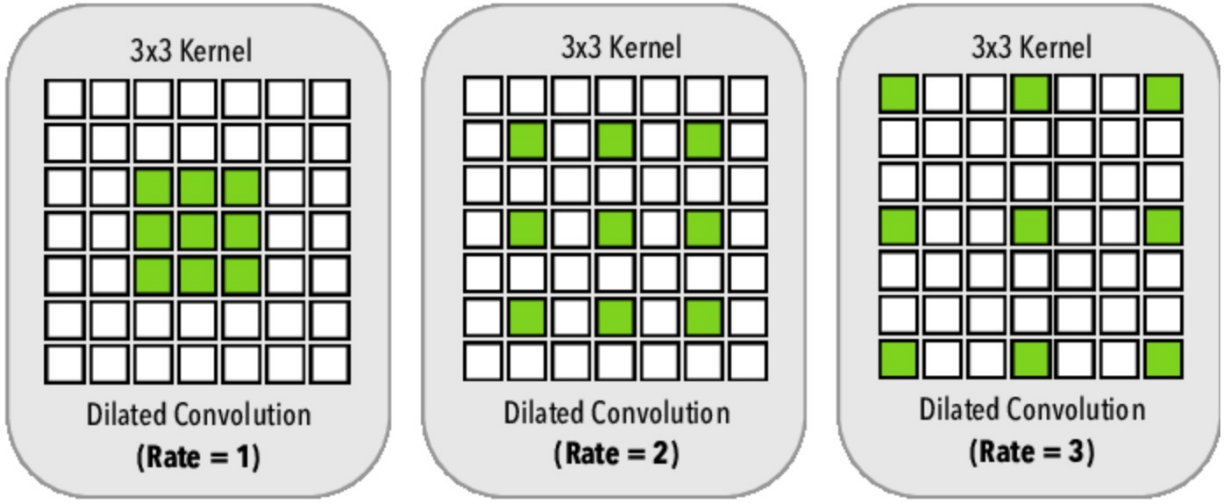
- Think of stretching an image by adding empty rows and columns
- Then on the stretched image do a regular convolution
- Initialize these kernels to do a linear interpolation
- But as the weights are learnable, it does better!



Atrous Convolution

- The convolution field of view is modified by considering a larger area with zeros added to the filter itself
- Number of learnable parameters is the same as regular convolution, but now the field of view has changed
- This is used in Deep Lab



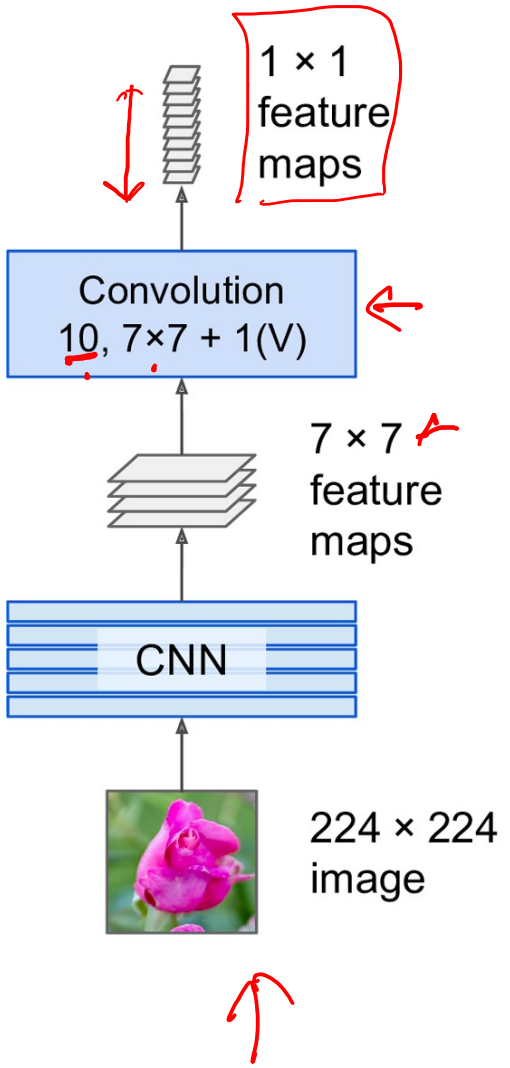


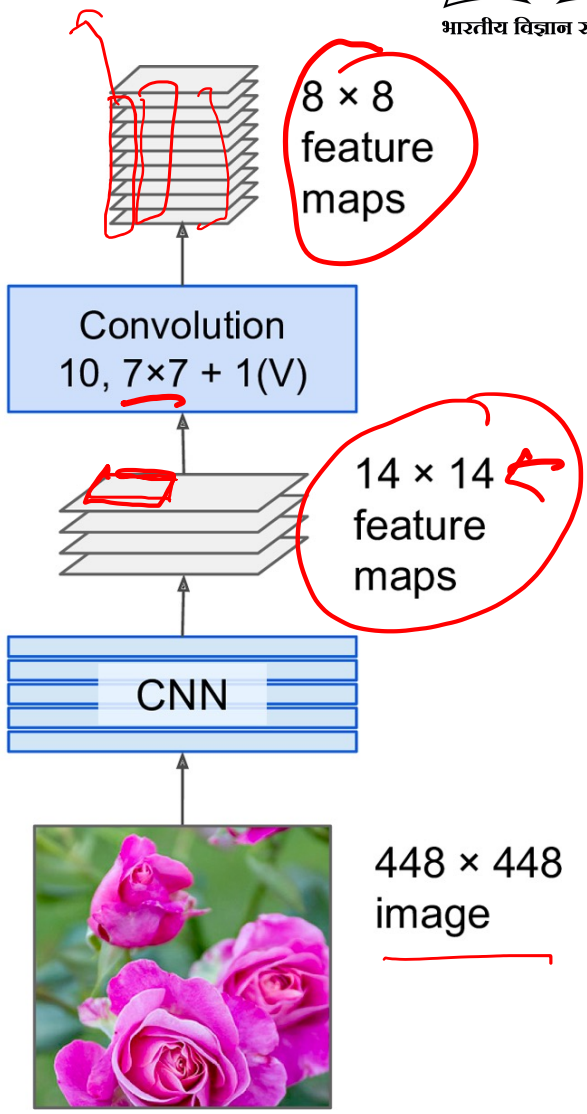
Batch Normalization

- He initialization + ELU can reduce vanishing/exploding gradient problem at the beginning, but problems can recur later during training
- Batch Normalization (Ioffe and Szegedy 2015) solves this problem
- Idea:
  - Zero center and normalize before or after activation function of every layer
  - Learn two parameter vectors (one set for every input) – output scaling and output shift – i.e., learn the optimal mean and scale of each of the layer's inputs!
- Question:
  - Need a batch to calculate the mean and std for scaling
  - Use the current mini batch to get the mean and std
- Note:
  - Add BN after input layer, then it is almost equivalent to applying StandardScaler, but only on the mini-batch and not the full train set

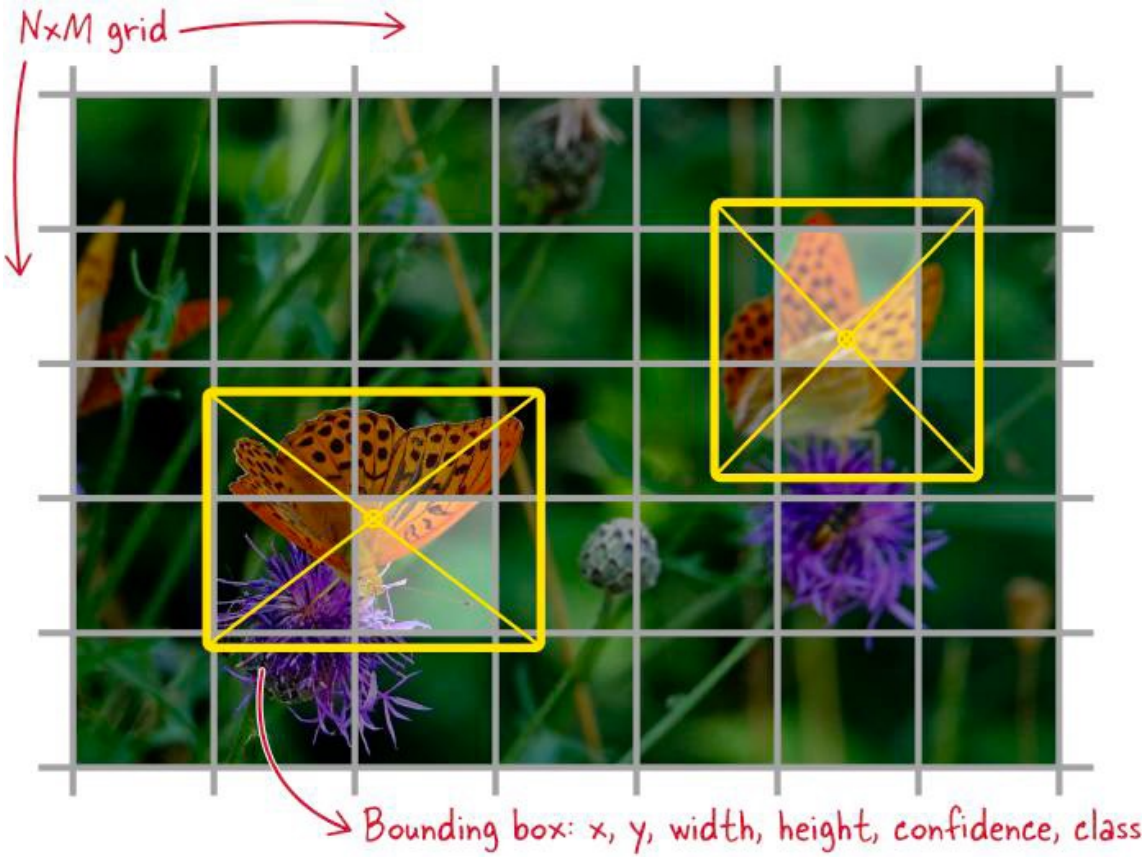
FCN Example (Cont)

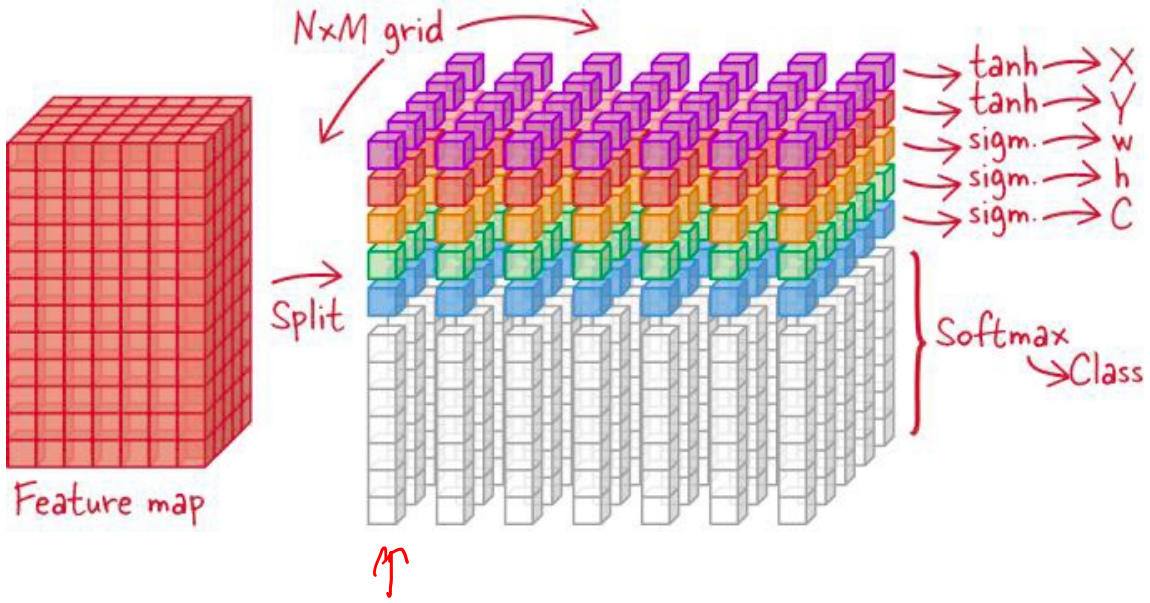
- What happens if we feed 448x448 images to this FCN?
  - Last conv layer is 14x14, and it will produce a 8x8 map
  - What is this 8x8 map? – It is equivalent to sliding the original CNN across the image
- Now the network has to be run only once
- You Only Look Once (YOLO)





YOLO Visually





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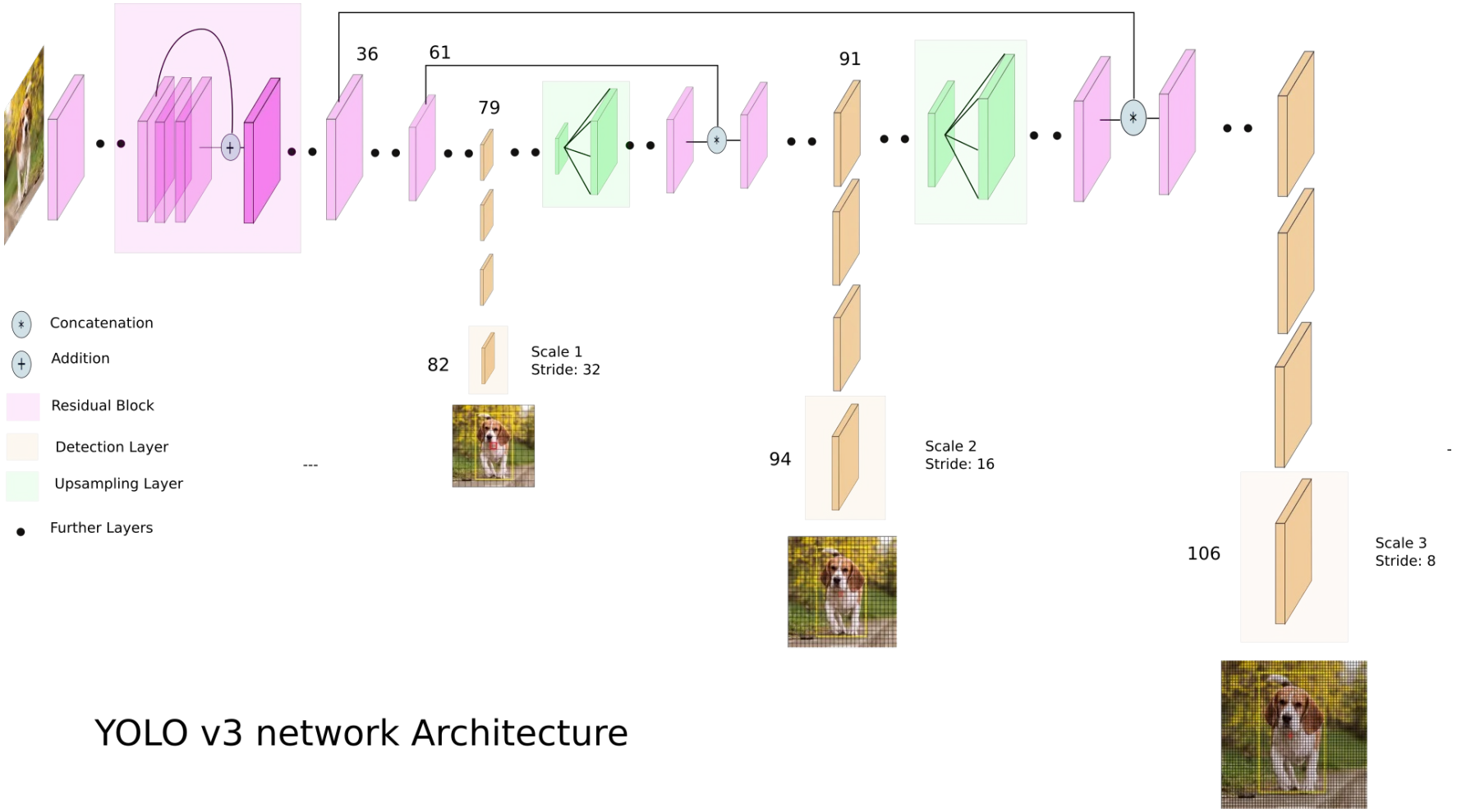
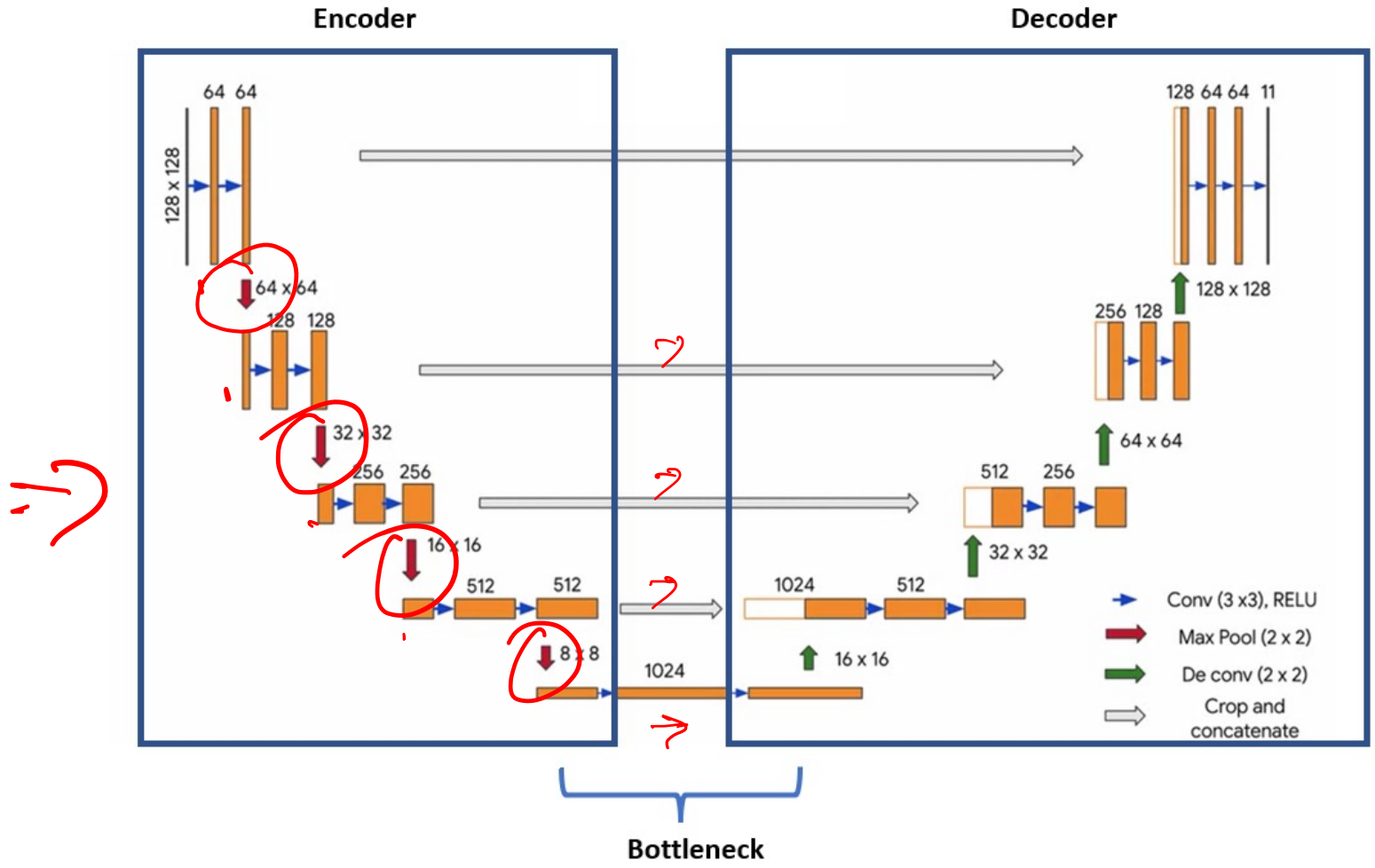
YOLO v3

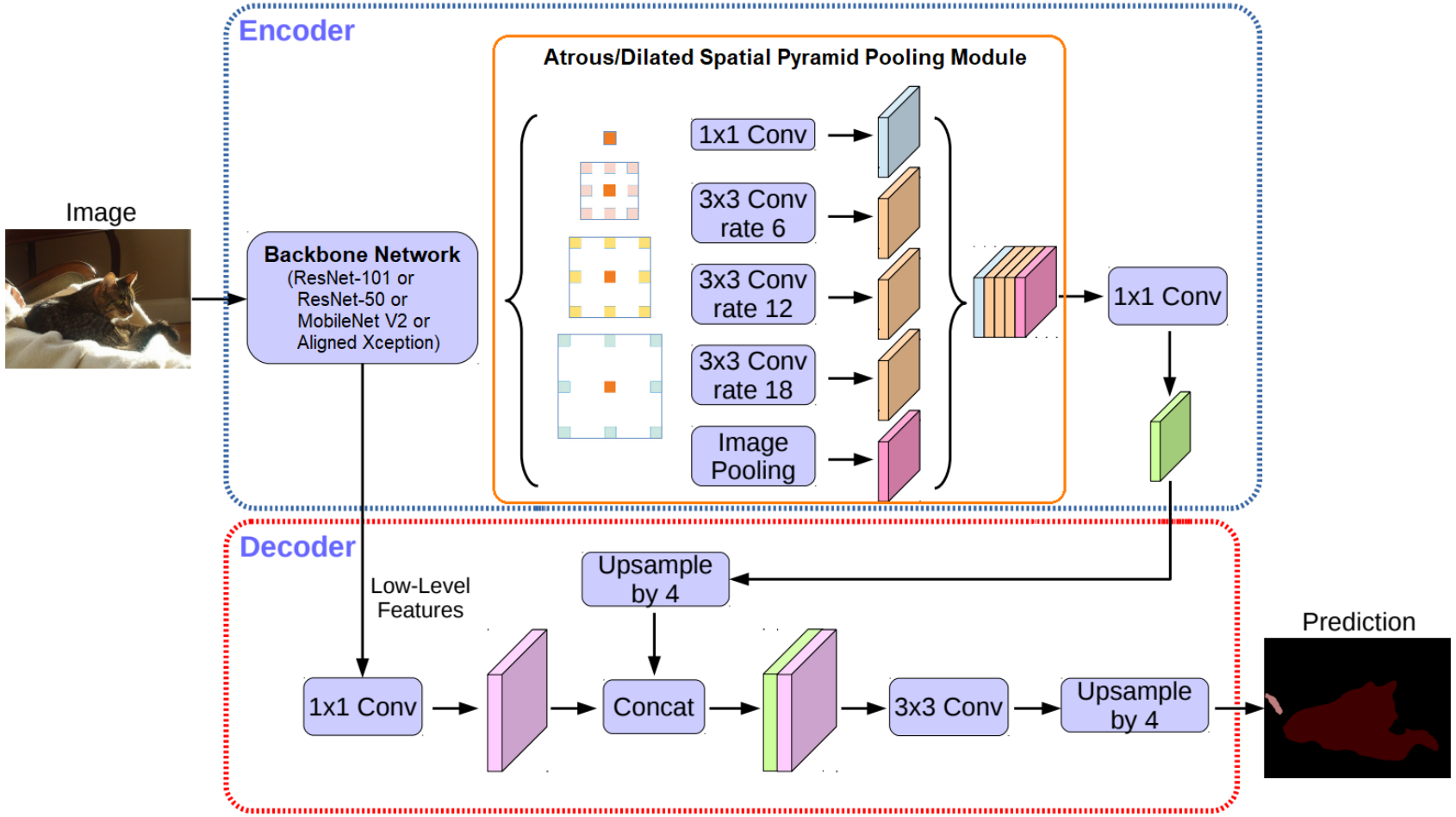


YOLO v3 network Architecture

U-Net


Encoder
Decoder
64 64
128 x 128
64 x 64
128 128
32 x 32
256 256
16 x 16
512 512
8 x 8
1024
128 64 64 11
128 x 128
256 128
64 x 64
512 256
32 x 32
1024 512
16 x 16
Conv (3 x3), RELU
Max Pool (2 x 2)
De conv (2 x 2)
Crop and concatenate
Bottleneck

DeepLabv3



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Evaluation Metric

- IoU – Intersection over union
- mAP - Mean Average Precision

Other Tasks in CV

- Pose Estimation
- Object Tracking
- Action Recognition
- Motion Estimation
- Monocular Depth
- Content-aware Image Editing
- Scene Reconstruction (NeRF Neural Radiance Fields)
  - novel views of complex scenes

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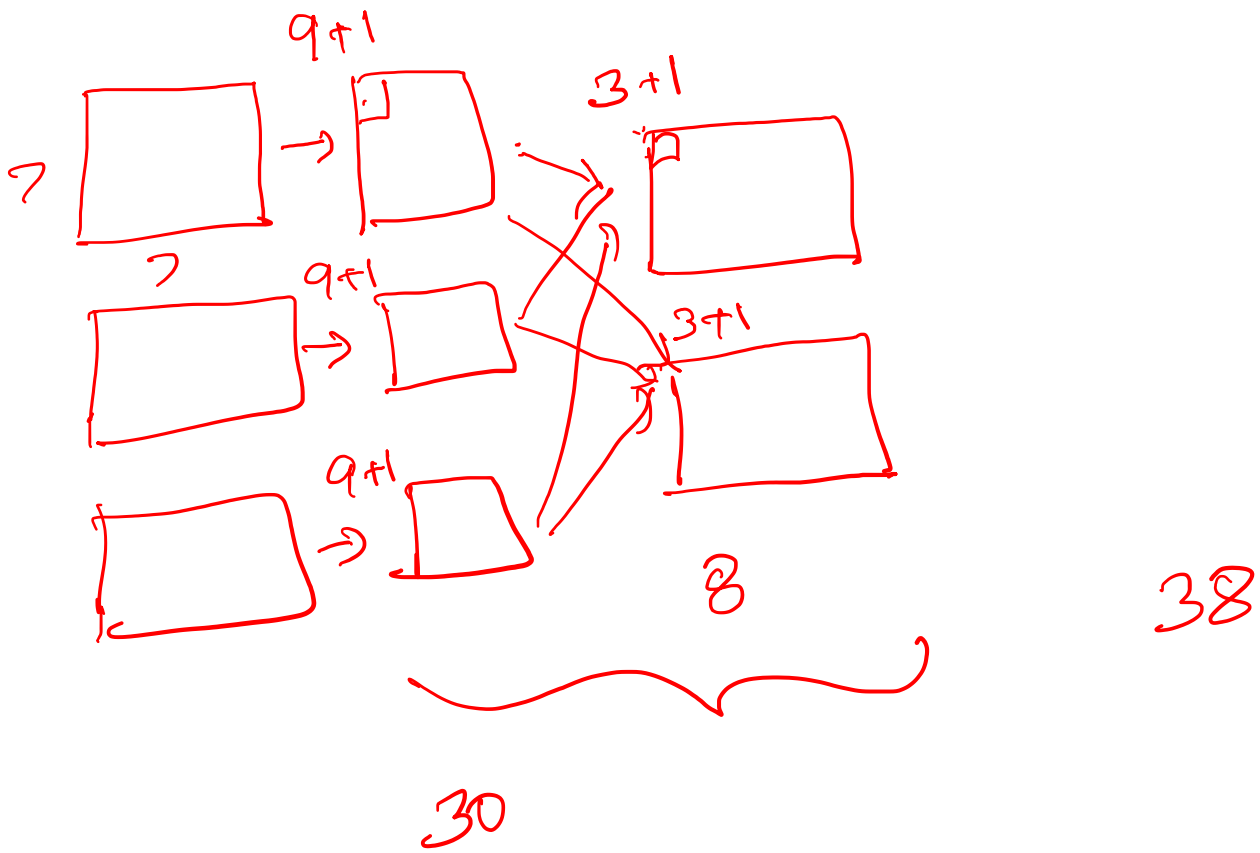
DW Separable

7x7x3 2 filters 3x3



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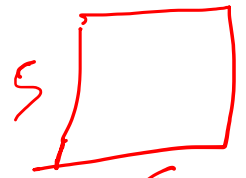
DL 100

50 × 5 × 5 → 100

50 × 5 × 5

1 5 → 25 × 50



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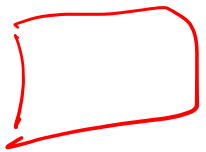
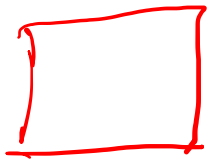


50



100 × 1 × 1

0
0
0
100

5 × 5 × 50 × 100

→ 100

GT P

0 → 0 48%

1 52%

2

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