Tallinn University of Technology

Department of Software Science

Exam paper:
Computer Vision ITS8030
Autumn 2020/21

Time allowed 24 hours.

The completed exam paper should be uploaded to

Answer ALL FOUR questions. You are supposed to answer the exam questions yourself. You are free to use textbooks or internet sources, but you should mention where you got the answer from, i.e. plain copying is not allowed, proper attribution is required. All text is assumed to be your own or be quoted or cited appropriately.

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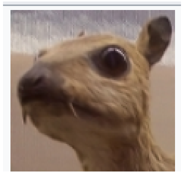
Grading result (to be fileld by staff)	

Question 1: Explain why convolution works so well for detecting various image features? Bring at least 3 different examples where convolution works really well in detecting different image features.

Answer:

Convolution is essentially a (kernel-)weighted transformation/mapping of an image. Depending on the kernel values the original values of the image patch get either highlighted or suppressed. So eg edge detection filter 3x3: by giving more weight to the centre pixel and suppressing surrounding pixels we can highlight the "edges".

Original image Kernel Result



$$\begin{bmatrix} -1 & -1 & -1 \\ -1 & 8 & -1 \\ -1 & -1 & -1 \end{bmatrix}$$

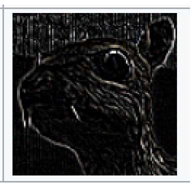
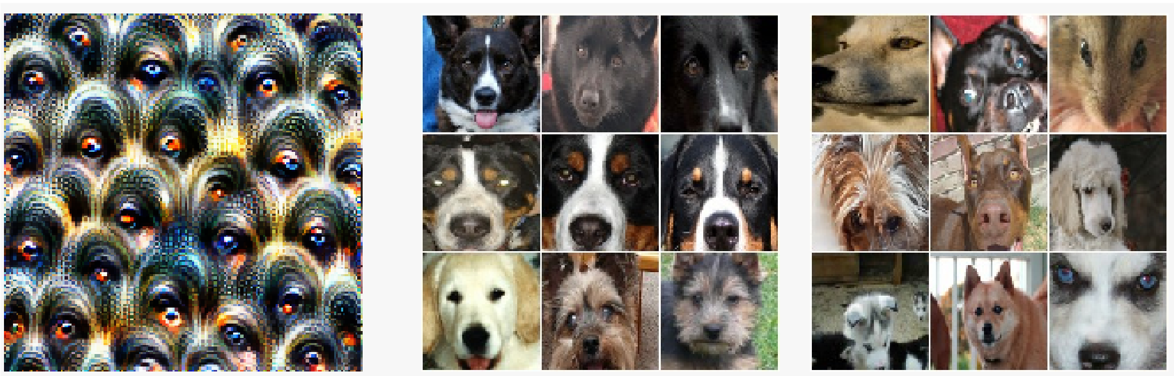


Figure 1. source: https://en.wikipedia.org/wiki/Kernel_(image_processing)

Using this marvelous property of the convolution we could devise a system that "learns" the weights, the kernel values in order to detect arbitrary shapes and/or textures. Eg. we could find a kernel that finds (1) diagonal stripes, (2) eyes, (3) wheels, (4) sharp corners, (5) faces etc.

[2] https://distill.pub/2017/feature-visualization/ has many good examples of visualizing convolutional neural networks layers after training to a particular dataset. It shows how convolution has "learned" to detect more basic features (edges, textures, patterns etc) in lower layers and more abstract features (faces, eyes, wheels etc) in higher layers.

Abstract features: eyes, dogs, dog eyes



Positive optimized | **Maximum** activation examples | Slightly positive activation examples

Figure 2. source: [2] https://distill.pub/2017/feature-visualization/

Basic features: edges, textures, patterns

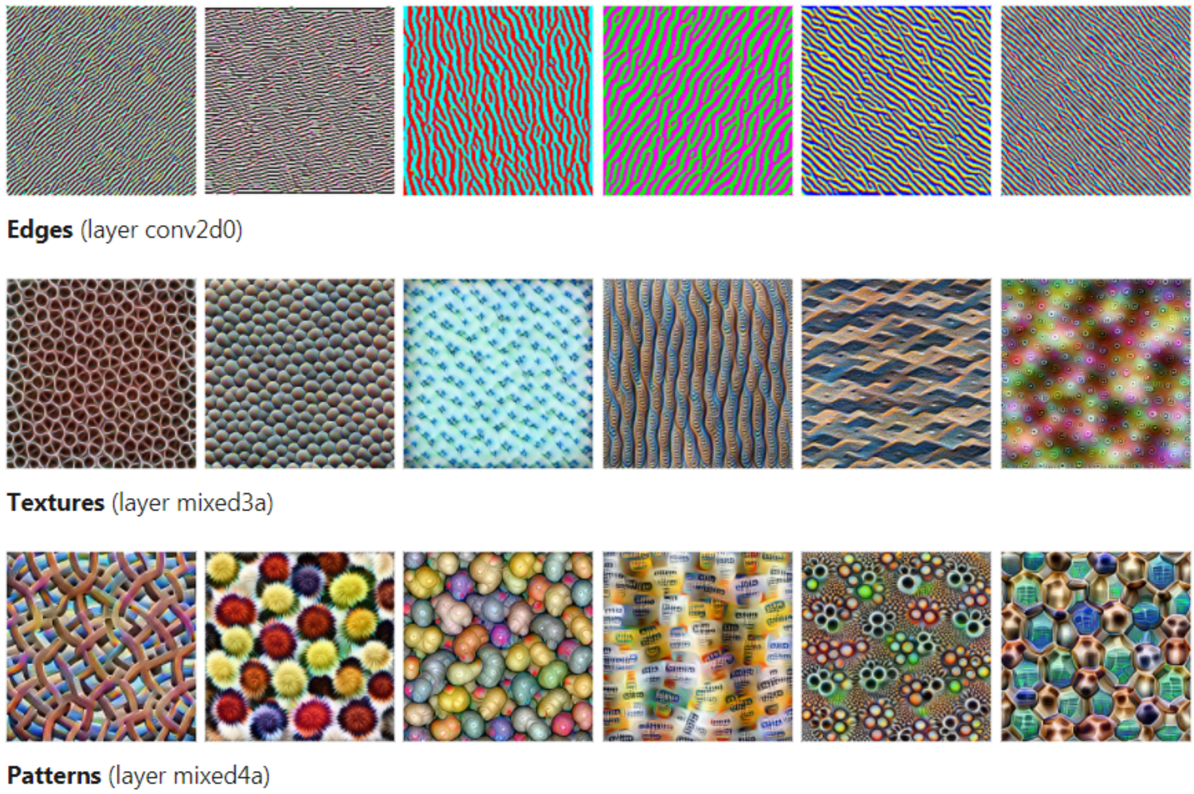


Figure 3. source: [2] https://distill.pub/2017/feature-visualization/

references:

[1] https://en.wikipedia.org/wiki/Kernel_(image_processing)

[2] https://distill.pub/2017/feature-visualization/

Question 2: When asked to apply deep convolutional networks based object detector in safety critical applications, which steps will you take and what caveats are there?

1. I would try to define as exactly as possible what are the worst case scenarios system should avoid. Eg whether we try to avoid "false positives" or "false negatives" at "any" cost.
2. Making sense of training data: is it diverse enough or imbalanced? Are we supposed to detect rare events? In case of rare events (eg. cancer prediction in medical images, as 99...% are usually non-cancer images), need to think how to generate more data for our positive event. Is it easy to generate more data or near impossible: eg too costly, impossible physically etc (eg. natural disasters, plane crashes).
3. Do we have a proper estimate of the cost of failure? Can we develop something useful here.
4. Is it possible to include human in the loop? Would it mitigate the safety problem.
5. Include confidences and uncertainties of model predictions' into the workflow. As well as predictions variances.
6. How easy is it to "trick" the system? Try to poke the system adversarily in order to reveal additional weaknesses. Do we have active adversary when system is deployed?
7. Make substantial efforts in trying to understand how the model predicts, when and how model fails. Try to understand the models inner workings as much as possible, so it would be easier to track failures and corresponding causes. Develop tooling around this kind of diagnostics.

Example cases would be:

1. Autonomous driving: detect pedestrians -> avoid collision at "any" cost.
2. Buildings, constructions, engineering: detect cracks -> avoid collapse at "any" cost because deadly or too costly.

Question 3: Please explain the difference between object detection and semantic segmentation. List the similarities and differences in the approaches.

Answer:

Object detection is something that answers the question where in the image is the object of interest. In more general case where in the image are all the objects of interest. The result of object detection is/are bounding box(es) that contain object of interest.

Usual approach is to divide input image into subsamples, grids. Sliding over the grid we can more efficiently find "region of interest", the areas where is the object of interest. Otherwise we could slide over the image and look everywhere with various receptive fields. But that would be too costly computationally.

Semantic segmentation on the other hand classifies each pixel of the image into given classes. The result of semantic segmentation is a mask (image) that is the same size as input image, so that pixel values correspond to class id-s. Eg for binary class segmentation we would have a binary mask, where pixel values are = 1 in the area of the class of interest and 0 elsewhere.

There are 2 main approaches usually:

1. Similar to object detection described above with the addition of pixel-to-pixel mask prediction from each Region-of-Interest (RoI). See [1] "Mask R-CNN".
2. U-Net: conv net with a contracting path to capture context and a symmetric expanding path that enables precise localization [2]. It is important to note that each updampling step in the expansive path is concatenated with the corresponding feature map from the contracting path.

References:

[1] He K., Gkioxari, Dollar, Girshick, "Mask R-CNN", https://arxiv.org/pdf/1703.06870.pdf

[2] Ronneberger, Fischer, Brox, "U-Net: Convolutional Networks for Biomedical Image Segmentation", https://arxiv.org/abs/1505.04597

Question 4: Please compute the eigenvalues and eigenvectors of the matrix $A = (5\ -2\ 7\ 4\ )$. Please show every step. (The use of proper formatting in the exam document is not required, you can also embed a photo of on paper solution.)

4. Eigenvalues
Eigenvectors

$$A = \begin{bmatrix} 5 & -2 \\ 7 & 4 \end{bmatrix} \begin{bmatrix} \tilde{a} \\ 6 \end{bmatrix} = \begin{bmatrix} \lambda & a \\ \lambda & 6 \end{bmatrix} \quad \lambda \cdot x$$

λ = Eigenvalue

I = Identity matrix $\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$

Determinant $|A - \lambda I|$ must be 0.

$$|A - \lambda I| = 0 \qquad \lambda \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} = \begin{bmatrix} \lambda & 0 \\ 0 & \lambda \end{bmatrix}$$

$$\left| \begin{bmatrix} 5 & -2 \\ 7 & 4 \end{bmatrix} - \lambda \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \right| = 0 \qquad \begin{vmatrix} 5-\lambda & -2 \\ 7 & 4-\lambda \end{vmatrix} = 0$$

$$(5-\lambda)(4-\lambda) + 14 = 0 \qquad \lambda^2 - 9\lambda + 20 + 14 = 0$$

$$\lambda^2 - 9\lambda + 34 = 0 \qquad \lambda = \frac{9 \pm \sqrt{81 - 136}}{2} = \frac{9 \pm \sqrt{-55}}{2}$$

$$\lambda_1 = \frac{9 \pm i\sqrt{55}}{2}$$

$$\boxed{\lambda_1 = \frac{9 + i\sqrt{55}}{2} \qquad \lambda_2 = \frac{9 - i\sqrt{55}}{2}}$$

EIGENVALUES λ_1, λ_2

EIGENVECTORS FOR EIGENVALUES λ_1, λ_2

$$v^1_{\lambda_1} = \left[\frac{4}{1 - i\sqrt{55}}, 1\right] \qquad v^1_{\lambda_2} = \left[\frac{4}{1 + i\sqrt{55}}, 1\right]$$

$$v^2_{\lambda_1} = \left[\frac{1 + i\sqrt{55}}{14}, 1\right] \qquad v^2_{\lambda_2} = \left[-\frac{-1 + i\sqrt{55}}{14}, 1\right]$$

Solution for eigenvectors on the next page.

According to definition

$A \cdot x = \lambda x$, where x is eigenvector.

$$(A - \lambda_1 I)\, x = 0$$

$$\left(\begin{bmatrix} 5 & -2 \\ 7 & 4 \end{bmatrix} - \begin{bmatrix} \lambda_1 & 0 \\ 0 & \lambda_1 \end{bmatrix} \right) \cdot x = 0$$

$$\begin{bmatrix} 5 - \frac{9 + i\sqrt{55}}{2} & -2 \\ 7 & 4 - \frac{9 + i\sqrt{55}}{2} \end{bmatrix} \cdot \underbrace{\begin{bmatrix} x_1 \\ x_2 \end{bmatrix}}_{x} = 0$$

Case λ_1

$$\begin{cases} \frac{1 - i\sqrt{55}}{2} \cdot x_1 - 2x_2 = 0 \\ 7x_1 + \frac{-1 - i\sqrt{55}}{2} x_2 = 0 \end{cases}$$

choose: $\boxed{x_2 = 1}$

$$\frac{1 - i\sqrt{55}}{2} \cdot x_1 = 2 \cdot 1 \Rightarrow \boxed{x_1 = \frac{4}{1 - i\sqrt{55}}}$$

$$7x_1 = -\frac{-1 - i\sqrt{55}}{2} \Rightarrow \boxed{x_1 = \frac{1 + i\sqrt{55}}{14}}$$

Case λ_2

$$\begin{bmatrix} 5 - \frac{9 - i\sqrt{55}}{2} & -2 \\ 7 & 4 - \frac{9 - i\sqrt{55}}{2} \end{bmatrix} \cdot \underbrace{\begin{bmatrix} x_1 \\ x_2 \end{bmatrix}}_{x} = 0$$

$$\begin{cases} \frac{1 + i\sqrt{55}}{2} x_1 - 2x_2 = 0 \\ 7x_1 + \frac{-1 + i\sqrt{55}}{2} = 0 \end{cases}$$

choose: $\boxed{x_2 = 1}$

$$\frac{1 + i\sqrt{55}}{2} \cdot x_1 = 2 \Rightarrow \boxed{x_1 = \frac{4}{1 + i\sqrt{55}}}$$

$$7x_1 = -\frac{-1 + i\sqrt{55}}{2} \Rightarrow \boxed{x_1 = -\frac{-1 + i\sqrt{55}}{14}}$$

ANSWER:

EIGENVECTORS FOR EIGENVALUES λ_1, λ_2

$$v^1_{\lambda_1} = \left[\frac{4}{1-i\sqrt{55}}, 1\right] \qquad v^1_{\lambda_2} = \left[\frac{4}{1+i\sqrt{55}}, 1\right]$$

$$v^2_{\lambda_1} = \left[\frac{1+i\sqrt{55}}{14}, 1\right] \qquad v^2_{\lambda_2} = \left[-\frac{-1+i\sqrt{55}}{14}, 1\right]$$

WOLFRAM ALFA:

$$v_1 = \left[\frac{1+i\sqrt{55}}{14}, 1\right] \qquad v_2 = \left[-\frac{-1+i\sqrt{55}}{14}, 1\right]$$