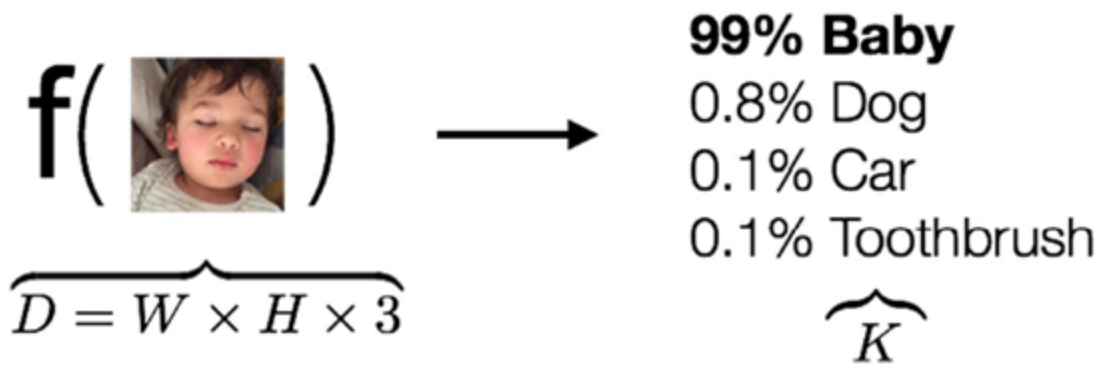# Konwolucyjne sieci neuronowe

Dziś spróbujemy stworzyć i wytrenować prostą sieć konwolucyjną do rozpoznawania, co znajduje się na obrazie. Następnie omówimy kwestię identyfikowania obiektów na obrazie, oraz porozmawiamy o wykorzystaniu gotowej już sieci.

Problem klasyfikacji obrazów

Jak się za to zabrać? Naiwnym podejściem byłaby próba ręcznej specyfikacji pewnych cech (niemowlęta mają duże głowy, szczoteczki są długie, etc.). Szybko jednak stwierdziliśmy, że nawet dla niewielkiego zbioru kategorii jest to tytaniczna praca bez gwarancji sukcesu. Co więcej, istnieje wiele czynników zniekształcających zawartość naszych zdjęć. Obiekty mogą być przedstawiane z różnych ujęć, w różnych warunkach oświetleniowych, w różnej skali, częściowo niewidoczne, ukryte w tle...

Wszystkie wymienione problemy są skutkiem istnienia semantycznej przepaści między tym, jak reprezentowane są nasze dane wejściowe (tablica liczb), a tym, czego w nich szukamy, czyli kategorii i cech: zwierząt, nosów, głów, itp. Zamiast więc próbować samodzielnie napisać funkcję $f(x)$, spróbujemy skorzystać z dobrodziejstw uczenia maszynowego, aby automatycznie skonstruować reprezentację wejścia właściwą dla postawionego sobie zadania (a przynajmniej lepszą od pierwotnej). I tu z pomocą przychodzą nam konwolucyjne sieci neuronowe. Do tego trzeba zrozumieć, czym jest konwolucja (inaczej: splot), a do tego najlepiej nadają się ilustracje, jak to działa.

Konwolucja

Konwolucja (splot) to działanie określone dla dwóch funkcji, dające w wyniku inną, która może być postrzegana jako zmodyfikowana wersja oryginalnych funkcji.
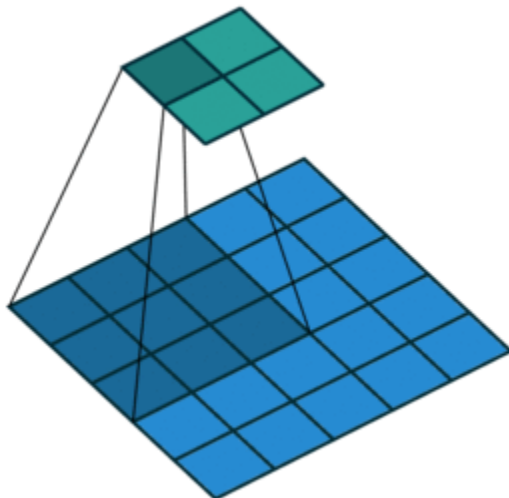
Z naszego punktu widzenia polega to na tym, że mnożymy odpowiadające sobie elementy z dwóch macierzy: obrazu, oraz mniejszej, nazywanej filtrem (lub kernelem. Następnie sumujemy wynik i zapisujemy do macierzy wynikowej na odpowiedniej pozycji. Proces powtarza się aż do momentu przeskanowania całego obrazu. Taki filtr wykrywa, czy coś do niego pasuje w danym miejscu, i z tego wynika zdolność semantycznej generalizacji sieci - uczymy się cech, a wykrywamy je potem w dowolnym miejscu. Przydatne pojęcia
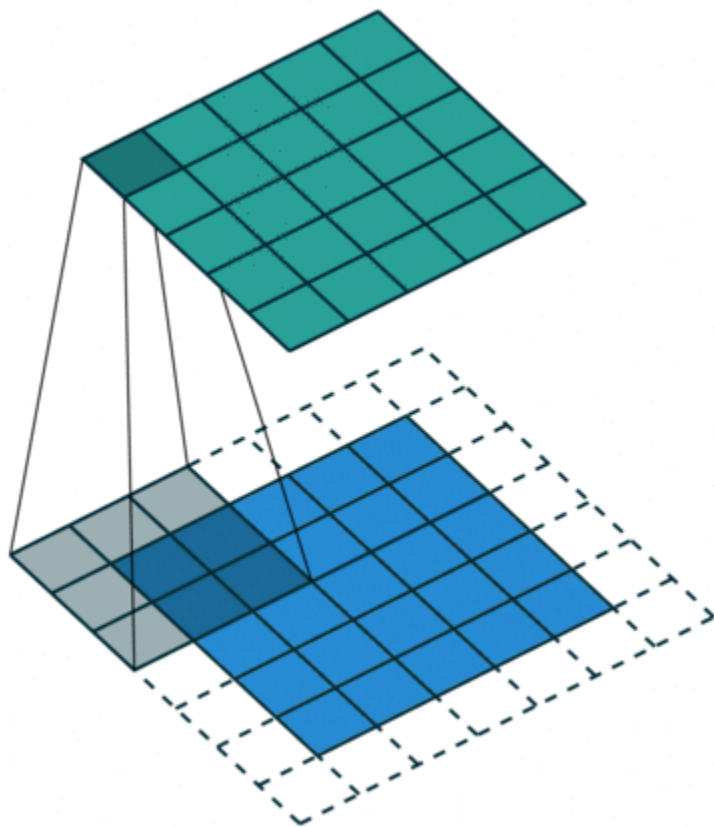
Stride

Stride to inaczej *krok algorytmu*, albo *przesunięcie*. Określa co ile komórek macierzy następuje aplikacja operatora konwolucji. Jeśli stride wynosi 1 a operator konwolucji ma rozmiar np. 3 x 3, to każdy piksel (z wyjątkiem skrajnych narożnych pikseli) będzie uczestniczył w wielu operacjach konwolucji. Jeśli natomiast krok wyniósłby 3, to każdy piksel uczestniczyłby tylko jednokrotnie w tych operacjach. Należy pamiętać, że krok stosujemy zarówno w poziomie, jak i pionie. Najczęściej w obu kierunkach wykorzystuje się ten sam krok.

Padding

Padding to inaczej *wypełnienie* krawędzi obrazu. Określa, w jaki sposób będą traktowane skrajne piksele. Jeśli padding wynosi 0, to skrajne piksele będą uczestniczyły w operacjach konwolucji rzadziej, niż pozostałe piksele (oczywiście jest to również uzależnione od wartości kroku). Aby zniwelować ten efekt, możemy dodać wypełnienie wokół całego obrazu. Te dodatkowe piksele mogą być zerami, albo mogą być również jakimiś uśrednionymi wartościami pikseli sąsiednich. Wypełnienie zerami oznacza de facto obramowanie całego obrazu czarną ramką.

[Więcej na temat wypełnienia.](#)

Pooling

Pooling jest procesem wykorzystywanym do redukcji rozmiaru obrazu. Występują 2 warianty: *max-pooling* oraz *avg-pooling*. Pozwala on usunąć zbędne dane, np. jeżeli filtr wykrywa linie, to istnieje spora szansa, że linie te ciągną się przez sąsiednie piksele, więc nie ma powodu powielać tej informacji. Dzięki temu wprowadzamy pewną inwariancję w wagach sieci i jesteśmy odporni na niewielkie wahania lokalizacji informacji, a skupiamy się na "większym obrazie".

Sposoby redukcji przeuczenia

- warstwa dropout - wyłączanie losowych neuronów w trakcie uczenia,
- regularyzacja wag - ograniczenie sumy wartości wag,
- metoda wczesnego stopu (early stopping) - zatrzymanie uczenia, jeśli proces uczenia nie poprawia wyników,
- normalizacja paczki (batch normalization) - centrowanie i skalowanie wartości wektorów *w obrębie batcha danych*,
- rozszerzanie danych (data augmentation) - generowanie lekko zaburzonych danych, na podstawie danych treningowych,
- lub... więcej danych.

Budowa sieci CNN do klasyfikacji obrazów

Sieć konwolucyjna składa się zawsze najpierw, zgodnie z nazwą, z części konwolucyjnej, której zadaniem jest wyodrębnienie przydatnych cech z obrazu za pomocą filtrów, warstw poolingowych etc.

Warstwa konwolucyjna sieci neuronowej składa się z wielu filtrów konwolucyjnych działających równolegle (tj. wykrywających różne cechy). Wagi kerneli, początkowo zainicjalizowane losowo, są dostrajane w procesie uczenia. Wynik działania poszczególnych filtrów jest przepuszczany przez funkcję nieliniową. Mamy tu do czynienia z sytuacją analogiczną jak w MLP: najpierw wykonujemy przekształcenie liniowe, a potem stosujemy funkcję aktywacji. Funkcji aktywacji nie stosuje się jendak po warstawch poolingowych, są to stałe operacje nie podlegające uczeniu.

W celu klasyfikacji obrazu musimy później użyć sieci MLP. Jako że wejściem do sieci MLP jest zawsze wektor, a wyjściem warstwy konwolucyjnej obraz. Musimy zatem obraz przetworzony przez filtry konwolucyjne sprowadzić do formy wektora, tzw. **embedding-u / osadzenia**, czyli reprezentacji obrazu jako punktu w pewnej ciągłej przestrzeni. Służy do tego warstwa spłaszczająca (flatten layer), rozwijająca macierze wielkowymiarowe na wektor, np $10 \times 10 \times 3$ na 300×1.

Część konwolucyjna nazywa się często **backbone**, a część MLP do klasyfikacji **head**. Głowa ma zwykle 1-2 warstwy w pełni połączone, z aktywacją softmax w ostatniej warstwie. Czasem jest nawet po prostu pojedynczą warstwą z softmaxem, bo w dużych sieciach konwolucyjnych ekstrakcja cech jest tak dobra, że taka prosta konstrukcja wystacza do klasyfikacji embeddingu.

```
In [1]:  import torch
         import torchvision
         import torchvision.transforms as transforms
```

Wybierzmy rodzaj akceleracji. Współczesne wersje PyTorch wspierają akcelerację nie tylko na kartach Nvidii i AMD, ale również na procesorach Apple z serii M. Obsługa AMD jest realizowana identycznie jak CUDA natomiast MPS (Apple) ma nieco inne API do sprawdzania dostępności i wybierania urządzenia. Zapisujemy wybrane urządzenie do zmiennej `device`, dzięki czemu w dalszych częściach kodu już nie będziemy musieli o tym myśleć.

```
In [2]:  if torch.cuda.is_available():
             device = torch.device("cuda:0")
         elif torch.backends.mps.is_available():
             device = torch.device("mps")

         print(device)
```

```
cuda:0
```

W pakiecie torchvision mamy funkcje automatycznie pobierające niektóre najbardziej popularne zbiory danych z obrazami.

W tym ćwiczeniu wykorzystamy zbiór FashionMNIST, który zawiera małe (28x28) zdjęcia ubrań w skali szarości. Zbiór ten został stworzony przez Zalando i jest "modowym" odpowiednikiem "cyferkowego" MNIST-a, jest z nim kompatybilny pod względem rozmiarów i charakterystyki danych, ale jest od MNIST-a trudniejszy w klasyfikacji.

Do funkcji ładujących zbiory danych możemy przekazać przekształcenie, które powinno zostać na nim wykonane. Przekształcenia można łączyć przy użyciu `transforms.Compose`. W tym przypadku przekonwertujemy dane z domyślnej reprezentacji PIL.Image na torch-owe tensory.

Pobrany dataset przekazujemy pod kontrolę DataLoader-a, który zajmuje się podawaniem danych w batch-ach podczas treningu.

In [3]:
```python
transform = transforms.Compose([transforms.ToTensor()])

batch_size = 32

trainset = torchvision.datasets.FashionMNIST(
    root="./data", train=True, download=True, transform=transform
)
trainloader = torch.utils.data.DataLoader(
    trainset, batch_size=batch_size, shuffle=True
)

testset = torchvision.datasets.FashionMNIST(
    root="./data", train=False, download=True, transform=transform
)
testloader = torch.utils.data.DataLoader(
    testset, batch_size=batch_size, shuffle=True
)

classes = (
    "top",
    "Trouser",
    "Pullover",
    "Dress",
    "Coat",
    "Sandal",
    "Shirt",
    "Sneaker",
    "Bag",
    "Ankle boot",
)

print(type(testset[0][0]))
```

```
Downloading http://fashion-mnist.s3-website.eu-central-1.amazonaws.com/train-images-idx3
-ubyte.gz
Downloading http://fashion-mnist.s3-website.eu-central-1.amazonaws.com/train-images-idx3
-ubyte.gz to ./data/FashionMNIST/raw/train-images-idx3-ubyte.gz
100%|██████████| 26421880/26421880 [00:02<00:00, 11086240.50it/s]
Extracting ./data/FashionMNIST/raw/train-images-idx3-ubyte.gz to ./data/FashionMNIST/raw

Downloading http://fashion-mnist.s3-website.eu-central-1.amazonaws.com/train-labels-idx1
-ubyte.gz
Downloading http://fashion-mnist.s3-website.eu-central-1.amazonaws.com/train-labels-idx1
-ubyte.gz to ./data/FashionMNIST/raw/train-labels-idx1-ubyte.gz
```

```
Extracting ./data/FashionMNIST/raw/train-labels-idx1-ubyte.gz to ./data/FashionMNIST/raw


Downloading http://fashion-mnist.s3-website.eu-central-1.amazonaws.com/t10k-images-idx3-
ubyte.gz
Downloading http://fashion-mnist.s3-website.eu-central-1.amazonaws.com/t10k-images-idx3-
ubyte.gz to ./data/FashionMNIST/raw/t10k-images-idx3-ubyte.gz
```
```
Extracting ./data/FashionMNIST/raw/t10k-images-idx3-ubyte.gz to ./data/FashionMNIST/raw


Downloading http://fashion-mnist.s3-website.eu-central-1.amazonaws.com/t10k-labels-idx1-
ubyte.gz
Downloading http://fashion-mnist.s3-website.eu-central-1.amazonaws.com/t10k-labels-idx1-
ubyte.gz to ./data/FashionMNIST/raw/t10k-labels-idx1-ubyte.gz
```
```
Extracting ./data/FashionMNIST/raw/t10k-labels-idx1-ubyte.gz to ./data/FashionMNIST/raw

<class 'torch.Tensor'>
```

Zobaczmy, co jest w naszym zbiorze danych. Poniżej kawałek kodu, który wyświetli nam kilka przykładowych obrazków. Wartości pikseli są znormalizowane do przedziału [0,1].

In [4]:
```python
import matplotlib.pyplot as plt
import numpy as np


def imshow(img):
    npimg = img.numpy()
    plt.imshow(np.transpose(npimg, (1, 2, 0)))
    plt.axis("off")
    plt.show()


dataiter = iter(trainloader)
images, labels = next(dataiter)

def grid_show(images, nrow=8):
    imshow(torchvision.utils.make_grid(images, nrow=nrow))


def print_grid(labels, nrow=8):
    rows = [labels[n : n + nrow] for n in range(0, len(labels), nrow)]
    for r in rows:
        print(" ".join(f"{classes[c]:10s}" for c in r))

grid_show(images)
print_grid(labels)
```

```
Trouser      Trouser      top        Shirt       Bag       Shirt       Pullover    top
Sneaker      Pullover     Dress      Sandal      Sneaker   Shirt       Dress       Shirt
Sandal       Trouser      Sneaker    Pullover    Coat      Trouser     Bag         Ankle boot
Dress        Bag          top        Sandal      Coat      Coat        Coat        Dress
```

LeNet

LeNet to bardzo znany, klasyczny model sieci konwolucyjnej.

Warstwy:

- obraz
- konwolucja, kernel 5×5, bez paddingu, 6 kanałów (feature maps)
- average pooling, kernel 2×2, stride 2
- konwolucja, kernel 5×5, bez paddingu, 16 kanałów (feature maps)
- average pooling, kernel 2×2, stride 2
- warstwa w pełni połączona, 120 neuronów na wyjściu
- warstwa w pełni połączona, 84 neurony na wyjściu
- warstwa w pełni połączona, na wyjściu tyle neuronów, ile jest klas

Zadanie 1 (2 punkty)

Zaimplementuj wyżej opisaną sieć, używając biblioteki PyTorch. Wprowadzimy sobie jednak pewne modyfikacje, żeby było ciekawiej:

- w pierwszej warstwie konwolucyjnej użyj 20 kanałów (feature maps)
- w drugiej warstwie konwolucyjnej użyj 50 kanałów (feature maps)
- w pierwszej warstwie gęstej użyj 300 neuronów
- w drugiej warstwie gęstej użyj 100 neuronów

Przydatne elementy z pakietu `torch.nn`:

- `Conv2d()`
- `AvgPool2d()`
- `Linear()`

Z pakietu `torch.nn.functional`:

- `relu()`

```
In [5]:   import torch.nn as nn
          import torch.nn.functional as F


          class LeNet(nn.Module):
              def __init__(self):
                  super().__init__()
                  # your code here

                  self.conv1 = nn.Conv2d(in_channels= 1, out_channels=20, kernel_size=5)
                  self.pool1 = nn.AvgPool2d(kernel_size=2, stride=2)
                  self.conv2 = nn.Conv2d(in_channels= 20, out_channels=50, kernel_size=5)
                  # self.pool2 = nn.AvgPool2d(kernel_size=2, stride=2)
                  self.flatten = nn.Flatten()

                  self.mlp1 = nn.Linear(800, 300)
                  self.mlp2 = nn.Linear(300, 120)
                  self.out = nn.Linear(120, 10)

              def forward(self, x):
                # your code here
                x = F.relu(self.conv1(x))
                x = self.pool1(x)
                x = F.relu(self.conv2(x))
                x = self.pool1(x)

                x = self.flatten(x)

                x = F.relu(self.mlp1(x))
                x = F.relu(self.mlp2(x))
                x = self.out(x)

                return x


              # def num_featres(self, x):
              #    size = x.size[1]

          # your_code
```

Do treningu użyjemy stochastycznego spadku po gradiencie (SGD), a jako funkcję straty Categorical Cross Entropy. W PyTorch-u funkcja ta operuje na indeksach klas (int), a nie na wektorach typu one-hot (jak w Tensorflow).

```
In [6]:   import torch.optim as optim

          net = LeNet().to(device)

          criterion = nn.CrossEntropyLoss()
          optimizer = optim.SGD(net.parameters(), lr=0.001, momentum=0.9)
```

Zadanie 2 (1 punkt)

Uzupełnij pętlę uczącą sieć na podstawie jej predykcji. Oblicz (wykonaj krok do przodu) funkcję straty, a następnie przeprowadź propagację wsteczną i wykonaj krok optymalizatora.

```
In [7]:   net.train()

          for epoch in range(5):
          # your_code
            for i, data in enumerate(trainloader):
              inputs, labels = data
```

```python
        inputs = inputs.to(device)
        labels = labels.to(device)

        optimizer.zero_grad()

        y_pred = net(inputs)

        loss = criterion(y_pred, labels)
        loss.backward()

        optimizer.step()

    print(f"Epoch {epoch} train loss: {loss.item():.4f}")

print(f"final loss: {loss.item():.4f}")
```

```
Epoch 0 train loss: 0.9801
Epoch 1 train loss: 1.0832
Epoch 2 train loss: 0.4187
Epoch 3 train loss: 0.3774
Epoch 4 train loss: 0.6432
final loss: 0.6432
```

Zobaczmy na kilku przykładach jak działa wytrenowana sieć.

In [8]:
```python
dataiter = iter(testloader)
images, labels = next(dataiter)

grid_show(images)
print("Ground Truth")
print_grid(labels)

outputs = net(images.to(device))
_, predicted = torch.max(outputs, 1)

print()
print("Predicted")
print_grid(predicted)
```



```
Ground Truth
Sandal      Bag        Pullover    Coat       Sandal      Shirt       Sneaker     Sneaker
Coat        Trouser    Pullover    Pullover   Dress       Shirt       top         Sandal
Bag         Ankle boot Ankle boot  Shirt      Sandal      Ankle boot  Sandal      top
Trouser     Bag        Sneaker     Pullover   Trouser     Coat        Sneaker     top

Predicted
Sandal      Bag        Pullover    Coat       Sandal      Shirt       Sneaker     Sneaker
Coat        Dress      Pullover    Pullover   Dress       Dress       top         Sandal
```

Bag	Ankle boot	Ankle boot	top		Sandal	Ankle boot	Sandal	top
Trouser	Bag		Sneaker	Pullover	Dress	Coat	Sneaker	top

Obliczmy dokładności (accuracy) dla zbioru danych.

In [33]:
```python
correct = 0
total = 0
net.eval()
with torch.no_grad():
    for data in testloader:
        images, labels = data
        outputs = net(images.to(device))
        _, predicted = torch.max(outputs.data, 1)
        total += labels.size(0)
        correct += (predicted == labels.to(device)).sum().item()

print(f"Accuracy of the network on the 10000 test images: {100 * correct // total} %")
print(correct)
```

```
Accuracy of the network on the 10000 test images: 79 %
7982
```

Skomentuj wyniki:

- dokładność sięga 80% co jest dobrym wynikiem jak klasyfikuje się nie binarnie a do 10 różnych klas

Znając ogólny wynik klasyfikacji dla zbioru przeanalizujmy dokładniej, z którymi klasami jest największy problem.

Zadanie 3 (1 punkt)

Oblicz dokładność działania sieci (accuracy) dla każdej klasy z osobna. Podczas oceniania skuteczności modelu nie potrzebujemy, aby gradienty się liczyły. Możemy zatem zawrzeć obliczenia w bloku `with torch.no_grad():`

In [10]:
```python
num_classes = 10

class_correct = [0] * num_classes
class_total = [0] * num_classes

net.eval()
with torch.no_grad():
    for data in testloader:
        images, labels = data
        outputs = net(images.to(device))
        _, predicted = torch.max(outputs, 1)
        c = (predicted == labels.to(device)).squeeze()
        for i in range(labels.size(0)):
            label = labels[i]
            class_correct[label] += c[i].item()
            class_total[label] += 1

for i in range(num_classes):
    accuracy = 100 * class_correct[i] / class_total[i] if class_total[i] != 0 else 0
    print(f"Accuracy of class {i}: {accuracy:.2f}%"+"  "+ classes[i])
```

```
Accuracy of class 0: 76.10%  top
Accuracy of class 1: 90.10%  Trouser
Accuracy of class 2: 68.50%  Pullover
Accuracy of class 3: 91.50%  Dress
Accuracy of class 4: 51.90%  Coat
Accuracy of class 5: 89.20%  Sandal
```

```
Accuracy of class 6: 48.80%  Shirt
Accuracy of class 7: 90.90%  Sneaker
Accuracy of class 8: 94.90%  Bag
Accuracy of class 9: 96.30%  Ankle boot
```

Skomentuj wyniki:

> klasy 2 (Pullover) i 6 (Shirt) są źle klasyfikowane. oprócz tego sieć ma problemy z podobnymi klasami jak top coat i dress.
>
> Spodnie buty i torebki są barzo dobrze rozpoznawalne

In [11]:
```python
print(classes[6])
```

```
Shirt
```

Detekcja obiektów

Problem detekcji polega na nie tylko sklasyfikowaniu obiektów na obrazie, ale również wyznaczeniu jego dokładnego położenia w postaci bounding-box-u. Choć jest to problem odmienny od klasyfikacji obrazów, to w praktyce ściśle z nim powiązany - modele do detekcji obiektów przeważnie do pewnego momentu wyglądają tak samo, jak modele klasyfikacji. Jednak pod koniec sieć jest dzielona na 2 wyjścia: jedno to standardowa klasyfikacja, a drugie to regresor określający pozycję obiektu na obrazie, tzw. bounding box. Najpopularniejszymi przykładami takich sieci są YOLO i Mask R-CNN. Zbiór danych też jest odpowiednio przygotowany do tego zadania i oprócz właściwych zdjęć zawiera również listę bounding-box-ów i ich etykiety.

Zobaczymy jak działa detekcja na przykładzie już wytrenowanej sieci neuronowej. Autorzy skutecznych sieci często udostępniają ich wagi online, dzięki czemu jeżeli mamy doczynienia z analogicznym problemem jak ten, do którego dana sieć była przygotowana możemy z niej skorzystać "prosto z pudełka".

PyTorch pozwala nam na pobranie wytrenowanych wag dla kilku najpopularniejszych modeli. Sprawdzimy jak z tego skorzystać.

In [12]:
```python
from torchvision.models import detection
import numpy as np
import cv2
from PIL import Image
import urllib
```

Poniżej znajduje się funkcja pozwalająca wczytać obraz z sieci. Przyda się do testowania działania sieci.

In [13]:
```python
def url_to_image(url):
    resp = urllib.request.urlopen(url)
    image = np.asarray(bytearray(resp.read()), dtype="uint8")
    image = cv2.imdecode(image, cv2.IMREAD_COLOR)
    return image
```

Model, którym się zajmiemy to Faster R-CNN, który był trenowany na zbiorze COCO. Poniżej znajduje się lista klas (etykiet) dla tego zbioru danych.

In [14]:
```python
classes = [
    "__background__",
    "person",
    "bicycle",
```

```
    "car",
    "motorcycle",
    "airplane",
    "bus",
    "train",
    "truck",
    "boat",
    "traffic light",
    "fire hydrant",
    "street sign",
    "stop sign",
    "parking meter",
    "bench",
    "bird",
    "cat",
    "dog",
    "horse",
    "sheep",
    "cow",
    "elephant",
    "bear",
    "zebra",
    "giraffe",
    "hat",
    "backpack",
    "umbrella",
    "handbag",
    "tie",
    "shoe",
    "eye glasses",
    "suitcase",
    "frisbee",
    "skis",
    "snowboard",
    "sports ball",
    "kite",
    "baseball bat",
    "baseball glove",
    "skateboard",
    "surfboard",
    "tennis racket",
    "bottle",
    "plate",
    "wine glass",
    "cup",
    "fork",
    "knife",
    "spoon",
    "bowl",
    "banana",
    "apple",
    "sandwich",
    "orange",
    "broccoli",
    "carrot",
    "hot dog",
    "pizza",
    "donut",
    "cake",
    "chair",
    "couch",
    "potted plant",
    "bed",
    "mirror",
    "dining table",
    "window",
```

```
        "desk",
        "toilet",
        "door",
        "tv",
        "laptop",
        "mouse",
        "remote",
        "keyboard",
        "cell phone",
        "microwave",
        "oven",
        "toaster",
        "sink",
        "refrigerator",
        "blender",
        "book",
        "clock",
        "vase",
        "scissors",
        "teddy bear",
        "hair drier",
        "toothbrush",
    ]

    colors = np.random.randint(0, 256, size=(len(classes), 3))
```

Inizjalizacja modelu ResNet50-FPN wytrenowanymi wagami. Inicjalizujemy zarówno sieć backbone jak i RCNN.

In [15]:
```python
model = detection.fasterrcnn_resnet50_fpn(
    weights=detection.FasterRCNN_ResNet50_FPN_Weights.DEFAULT,
    weights_backbone=torchvision.models.ResNet50_Weights.DEFAULT,
    progress=True,
    num_classes=len(classes)
).to(device)
model.eval()
```

Downloading: "https://download.pytorch.org/models/fasterrcnn_resnet50_fpn_coco-258fb6c6.pth" to /root/.cache/torch/hub/checkpoints/fasterrcnn_resnet50_fpn_coco-258fb6c6.pth
100%|██████████| 160M/160M [00:01<00:00, 86.1MB/s]

Out[15]:
```
FasterRCNN(
  (transform): GeneralizedRCNNTransform(
      Normalize(mean=[0.485, 0.456, 0.406], std=[0.229, 0.224, 0.225])
      Resize(min_size=(800,), max_size=1333, mode='bilinear')
  )
  (backbone): BackboneWithFPN(
    (body): IntermediateLayerGetter(
      (conv1): Conv2d(3, 64, kernel_size=(7, 7), stride=(2, 2), padding=(3, 3), bias=False)
      (bn1): FrozenBatchNorm2d(64, eps=0.0)
      (relu): ReLU(inplace=True)
      (maxpool): MaxPool2d(kernel_size=3, stride=2, padding=1, dilation=1, ceil_mode=False)
      (layer1): Sequential(
        (0): Bottleneck(
          (conv1): Conv2d(64, 64, kernel_size=(1, 1), stride=(1, 1), bias=False)
          (bn1): FrozenBatchNorm2d(64, eps=0.0)
          (conv2): Conv2d(64, 64, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bias=False)
          (bn2): FrozenBatchNorm2d(64, eps=0.0)
          (conv3): Conv2d(64, 256, kernel_size=(1, 1), stride=(1, 1), bias=False)
          (bn3): FrozenBatchNorm2d(256, eps=0.0)
          (relu): ReLU(inplace=True)
          (downsample): Sequential(
```

```
          (0): Conv2d(64, 256, kernel_size=(1, 1), stride=(1, 1), bias=False)
          (1): FrozenBatchNorm2d(256, eps=0.0)
        )
      )
      (1): Bottleneck(
        (conv1): Conv2d(256, 64, kernel_size=(1, 1), stride=(1, 1), bias=False)
        (bn1): FrozenBatchNorm2d(64, eps=0.0)
        (conv2): Conv2d(64, 64, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bia
s=False)
        (bn2): FrozenBatchNorm2d(64, eps=0.0)
        (conv3): Conv2d(64, 256, kernel_size=(1, 1), stride=(1, 1), bias=False)
        (bn3): FrozenBatchNorm2d(256, eps=0.0)
        (relu): ReLU(inplace=True)
      )
      (2): Bottleneck(
        (conv1): Conv2d(256, 64, kernel_size=(1, 1), stride=(1, 1), bias=False)
        (bn1): FrozenBatchNorm2d(64, eps=0.0)
        (conv2): Conv2d(64, 64, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), bia
s=False)
        (bn2): FrozenBatchNorm2d(64, eps=0.0)
        (conv3): Conv2d(64, 256, kernel_size=(1, 1), stride=(1, 1), bias=False)
        (bn3): FrozenBatchNorm2d(256, eps=0.0)
        (relu): ReLU(inplace=True)
      )
    )
    (layer2): Sequential(
      (0): Bottleneck(
        (conv1): Conv2d(256, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
        (bn1): FrozenBatchNorm2d(128, eps=0.0)
        (conv2): Conv2d(128, 128, kernel_size=(3, 3), stride=(2, 2), padding=(1, 1), b
ias=False)
        (bn2): FrozenBatchNorm2d(128, eps=0.0)
        (conv3): Conv2d(128, 512, kernel_size=(1, 1), stride=(1, 1), bias=False)
        (bn3): FrozenBatchNorm2d(512, eps=0.0)
        (relu): ReLU(inplace=True)
        (downsample): Sequential(
          (0): Conv2d(256, 512, kernel_size=(1, 1), stride=(2, 2), bias=False)
          (1): FrozenBatchNorm2d(512, eps=0.0)
        )
      )
      (1): Bottleneck(
        (conv1): Conv2d(512, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
        (bn1): FrozenBatchNorm2d(128, eps=0.0)
        (conv2): Conv2d(128, 128, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), b
ias=False)
        (bn2): FrozenBatchNorm2d(128, eps=0.0)
        (conv3): Conv2d(128, 512, kernel_size=(1, 1), stride=(1, 1), bias=False)
        (bn3): FrozenBatchNorm2d(512, eps=0.0)
        (relu): ReLU(inplace=True)
      )
      (2): Bottleneck(
        (conv1): Conv2d(512, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
        (bn1): FrozenBatchNorm2d(128, eps=0.0)
        (conv2): Conv2d(128, 128, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), b
ias=False)
        (bn2): FrozenBatchNorm2d(128, eps=0.0)
        (conv3): Conv2d(128, 512, kernel_size=(1, 1), stride=(1, 1), bias=False)
        (bn3): FrozenBatchNorm2d(512, eps=0.0)
        (relu): ReLU(inplace=True)
      )
      (3): Bottleneck(
        (conv1): Conv2d(512, 128, kernel_size=(1, 1), stride=(1, 1), bias=False)
        (bn1): FrozenBatchNorm2d(128, eps=0.0)
        (conv2): Conv2d(128, 128, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), b
ias=False)
        (bn2): FrozenBatchNorm2d(128, eps=0.0)
```

```
          (conv3): Conv2d(128, 512, kernel_size=(1, 1), stride=(1, 1), bias=False)
          (bn3): FrozenBatchNorm2d(512, eps=0.0)
          (relu): ReLU(inplace=True)
        )
      )
      (layer3): Sequential(
        (0): Bottleneck(
          (conv1): Conv2d(512, 256, kernel_size=(1, 1), stride=(1, 1), bias=False)
          (bn1): FrozenBatchNorm2d(256, eps=0.0)
          (conv2): Conv2d(256, 256, kernel_size=(3, 3), stride=(2, 2), padding=(1, 1), b
ias=False)
          (bn2): FrozenBatchNorm2d(256, eps=0.0)
          (conv3): Conv2d(256, 1024, kernel_size=(1, 1), stride=(1, 1), bias=False)
          (bn3): FrozenBatchNorm2d(1024, eps=0.0)
          (relu): ReLU(inplace=True)
          (downsample): Sequential(
            (0): Conv2d(512, 1024, kernel_size=(1, 1), stride=(2, 2), bias=False)
            (1): FrozenBatchNorm2d(1024, eps=0.0)
          )
        )
        (1): Bottleneck(
          (conv1): Conv2d(1024, 256, kernel_size=(1, 1), stride=(1, 1), bias=False)
          (bn1): FrozenBatchNorm2d(256, eps=0.0)
          (conv2): Conv2d(256, 256, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), b
ias=False)
          (bn2): FrozenBatchNorm2d(256, eps=0.0)
          (conv3): Conv2d(256, 1024, kernel_size=(1, 1), stride=(1, 1), bias=False)
          (bn3): FrozenBatchNorm2d(1024, eps=0.0)
          (relu): ReLU(inplace=True)
        )
        (2): Bottleneck(
          (conv1): Conv2d(1024, 256, kernel_size=(1, 1), stride=(1, 1), bias=False)
          (bn1): FrozenBatchNorm2d(256, eps=0.0)
          (conv2): Conv2d(256, 256, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), b
ias=False)
          (bn2): FrozenBatchNorm2d(256, eps=0.0)
          (conv3): Conv2d(256, 1024, kernel_size=(1, 1), stride=(1, 1), bias=False)
          (bn3): FrozenBatchNorm2d(1024, eps=0.0)
          (relu): ReLU(inplace=True)
        )
        (3): Bottleneck(
          (conv1): Conv2d(1024, 256, kernel_size=(1, 1), stride=(1, 1), bias=False)
          (bn1): FrozenBatchNorm2d(256, eps=0.0)
          (conv2): Conv2d(256, 256, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), b
ias=False)
          (bn2): FrozenBatchNorm2d(256, eps=0.0)
          (conv3): Conv2d(256, 1024, kernel_size=(1, 1), stride=(1, 1), bias=False)
          (bn3): FrozenBatchNorm2d(1024, eps=0.0)
          (relu): ReLU(inplace=True)
        )
        (4): Bottleneck(
          (conv1): Conv2d(1024, 256, kernel_size=(1, 1), stride=(1, 1), bias=False)
          (bn1): FrozenBatchNorm2d(256, eps=0.0)
          (conv2): Conv2d(256, 256, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), b
ias=False)
          (bn2): FrozenBatchNorm2d(256, eps=0.0)
          (conv3): Conv2d(256, 1024, kernel_size=(1, 1), stride=(1, 1), bias=False)
          (bn3): FrozenBatchNorm2d(1024, eps=0.0)
          (relu): ReLU(inplace=True)
        )
        (5): Bottleneck(
          (conv1): Conv2d(1024, 256, kernel_size=(1, 1), stride=(1, 1), bias=False)
          (bn1): FrozenBatchNorm2d(256, eps=0.0)
          (conv2): Conv2d(256, 256, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), b
ias=False)
          (bn2): FrozenBatchNorm2d(256, eps=0.0)
```

```
            (conv3): Conv2d(256, 1024, kernel_size=(1, 1), stride=(1, 1), bias=False)
            (bn3): FrozenBatchNorm2d(1024, eps=0.0)
            (relu): ReLU(inplace=True)
          )
        )
        (layer4): Sequential(
          (0): Bottleneck(
            (conv1): Conv2d(1024, 512, kernel_size=(1, 1), stride=(1, 1), bias=False)
            (bn1): FrozenBatchNorm2d(512, eps=0.0)
            (conv2): Conv2d(512, 512, kernel_size=(3, 3), stride=(2, 2), padding=(1, 1), b
ias=False)
            (bn2): FrozenBatchNorm2d(512, eps=0.0)
            (conv3): Conv2d(512, 2048, kernel_size=(1, 1), stride=(1, 1), bias=False)
            (bn3): FrozenBatchNorm2d(2048, eps=0.0)
            (relu): ReLU(inplace=True)
            (downsample): Sequential(
              (0): Conv2d(1024, 2048, kernel_size=(1, 1), stride=(2, 2), bias=False)
              (1): FrozenBatchNorm2d(2048, eps=0.0)
            )
          )
          (1): Bottleneck(
            (conv1): Conv2d(2048, 512, kernel_size=(1, 1), stride=(1, 1), bias=False)
            (bn1): FrozenBatchNorm2d(512, eps=0.0)
            (conv2): Conv2d(512, 512, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), b
ias=False)
            (bn2): FrozenBatchNorm2d(512, eps=0.0)
            (conv3): Conv2d(512, 2048, kernel_size=(1, 1), stride=(1, 1), bias=False)
            (bn3): FrozenBatchNorm2d(2048, eps=0.0)
            (relu): ReLU(inplace=True)
          )
          (2): Bottleneck(
            (conv1): Conv2d(2048, 512, kernel_size=(1, 1), stride=(1, 1), bias=False)
            (bn1): FrozenBatchNorm2d(512, eps=0.0)
            (conv2): Conv2d(512, 512, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1), b
ias=False)
            (bn2): FrozenBatchNorm2d(512, eps=0.0)
            (conv3): Conv2d(512, 2048, kernel_size=(1, 1), stride=(1, 1), bias=False)
            (bn3): FrozenBatchNorm2d(2048, eps=0.0)
            (relu): ReLU(inplace=True)
          )
        )
      )
      (fpn): FeaturePyramidNetwork(
        (inner_blocks): ModuleList(
          (0): Conv2dNormActivation(
            (0): Conv2d(256, 256, kernel_size=(1, 1), stride=(1, 1))
          )
          (1): Conv2dNormActivation(
            (0): Conv2d(512, 256, kernel_size=(1, 1), stride=(1, 1))
          )
          (2): Conv2dNormActivation(
            (0): Conv2d(1024, 256, kernel_size=(1, 1), stride=(1, 1))
          )
          (3): Conv2dNormActivation(
            (0): Conv2d(2048, 256, kernel_size=(1, 1), stride=(1, 1))
          )
        )
        (layer_blocks): ModuleList(
          (0-3): 4 x Conv2dNormActivation(
            (0): Conv2d(256, 256, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
          )
        )
        (extra_blocks): LastLevelMaxPool()
      )
    )
    (rpn): RegionProposalNetwork(
```

```
      (anchor_generator): AnchorGenerator()
      (head): RPNHead(
        (conv): Sequential(
          (0): Conv2dNormActivation(
            (0): Conv2d(256, 256, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
            (1): ReLU(inplace=True)
          )
        )
        (cls_logits): Conv2d(256, 3, kernel_size=(1, 1), stride=(1, 1))
        (bbox_pred): Conv2d(256, 12, kernel_size=(1, 1), stride=(1, 1))
      )
    )
    (roi_heads): RoIHeads(
      (box_roi_pool): MultiScaleRoIAlign(featmap_names=['0', '1', '2', '3'], output_size=
(7, 7), sampling_ratio=2)
      (box_head): TwoMLPHead(
        (fc6): Linear(in_features=12544, out_features=1024, bias=True)
        (fc7): Linear(in_features=1024, out_features=1024, bias=True)
      )
      (box_predictor): FastRCNNPredictor(
        (cls_score): Linear(in_features=1024, out_features=91, bias=True)
        (bbox_pred): Linear(in_features=1024, out_features=364, bias=True)
      )
    )
  )
)
```

IPython, z którego korzystamy w Jupyter Notebooku, ma wbudowaną funkcję `display()` do wyświetlania obrazów.

Do pobierania obrazów możemy się posłżyć wget-em.

In [16]:
```
# Pobieranie obrazka z sieci
!wget https://upload.wikimedia.org/wikipedia/commons/thumb/7/7a/Toothbrush_x3_20050716_0
```

```
--2023-11-27 17:06:04--  https://upload.wikimedia.org/wikipedia/commons/thumb/7/7a/Tooth
brush_x3_20050716_001.jpg/1280px-Toothbrush_x3_20050716_001.jpg
Resolving upload.wikimedia.org (upload.wikimedia.org)... 198.35.26.112, 2620:0:863:ed1
a::2:b
Connecting to upload.wikimedia.org (upload.wikimedia.org)|198.35.26.112|:443... connecte
d.
HTTP request sent, awaiting response... 200 OK
Length: 338300 (330K) [image/jpeg]
Saving to: 'toothbrushes.jpg'

toothbrushes.jpg    100%[===================>] 330.37K  --.-KB/s    in 0.08s

2023-11-27 17:06:05 (4.08 MB/s) - 'toothbrushes.jpg' saved [338300/338300]
```

In [17]:
```
# Wyświetlanie obrazka
image = Image.open("toothbrushes.jpg")
# make sure we have 3-channel RGB, e.g. without transparency
image = image.convert("RGB")
display(image)
```

PyTorch wymaga obrazów w kształcie [channels, height, width] (C, H, W) oraz z wartościami pikseli między 0 a 1. Pillow wczytuje obrazy z kanałami (H, W, C) oraz z wartościami pikseli między 0 a 255. Przed wykorzystaniem sieci neuronowej trzeba zatem:

- zamienić obraz na tensor
- zmienić kolejność kanałów
- podzielić wartości pikseli przez 255

```
In [18]:   image_tensor = torch.from_numpy(np.array(image))
           image_tensor = image_tensor.permute(2, 0, 1)
           image_tensor_int = image_tensor  # useful for displaying, dtype = uint8
           image_tensor = image_tensor / 255
           image_tensor.shape, image_tensor.dtype
```

```
Out[18]:   (torch.Size([3, 960, 1280]), torch.float32)
```

Zadanie 4 (1 punkt)

Użyj modelu do wykrycia obiektów na obrazie. Następnie wybierz tylko te bounding boxy, dla których mamy wynik powyżej 50%. Wypisz te bounding boxy, ich prawdopodobieństwa (w procentach) oraz nazwy klas.

Następnie wykorzystaj wyniki do zaznaczenia bounding box'a dla każdego wykrytego obiektu na obrazie oraz podpisz wykrytą klasę wraz z prawdopodobieństwem. Możesz tutaj użyć:

- OpenCV
- PyTorch - Torchvision

```
In [19]:   # torchvision.transforms.functional
           def show(imgs):
               if not isinstance(imgs, list):
                   imgs = [imgs]
               fig, axs = plt.subplots(ncols=len(imgs), squeeze=False)
               for i, img in enumerate(imgs):
                   img = img.detach()
                   img = torchvision.transforms.functional.to_pil_image(img)
                   axs[0, i].imshow(np.asarray(img))
                   axs[0, i].set(xticklabels=[], yticklabels=[], xticks=[], yticks=[])
```

```
In [20]:   from torchvision.utils import draw_bounding_boxes
           # your_code
           from PIL import ImageDraw
           image_tensor_to_eval = image_tensor.to(device)
           with torch.no_grad():
               model.eval()
               predictions = model([image_tensor_to_eval])
           # print(predictions)
           boxes = predictions[0]['boxes'].cpu().numpy()
           labels = predictions[0]['labels'].cpu().numpy()
           scores = predictions[0]['scores'].cpu().numpy()

           # Filtracja wyników powyżej 50% pewności
           confidence_threshold = 0.5
           filtered_boxes = boxes[scores > confidence_threshold]
           filtered_labels = labels[scores > confidence_threshold]
           filtered_scores = scores[scores > confidence_threshold]

           colors = [ "green", "purple", "yellow", "red", "black", "white", "pink", "orange", "brow
           # colors = ["yellow"]*4

           # Wypisz te bounding boxy, ich prawdopodobieństwa i nazwy klas
           for box, label, score, color in zip(filtered_boxes, filtered_labels, filtered_scores, co
               print(f"Label: {classes[label]}, Score: {score:.2%}")
               print(f"Bounding Box: {box} "+ color)

           filtered_boxes_tensor = torch.from_numpy(filtered_boxes)
           # print(type(filtered_boxes_tensor))
           result = draw_bounding_boxes(image_tensor_int, filtered_boxes_tensor, colors=colors, wid
           show(result)
```
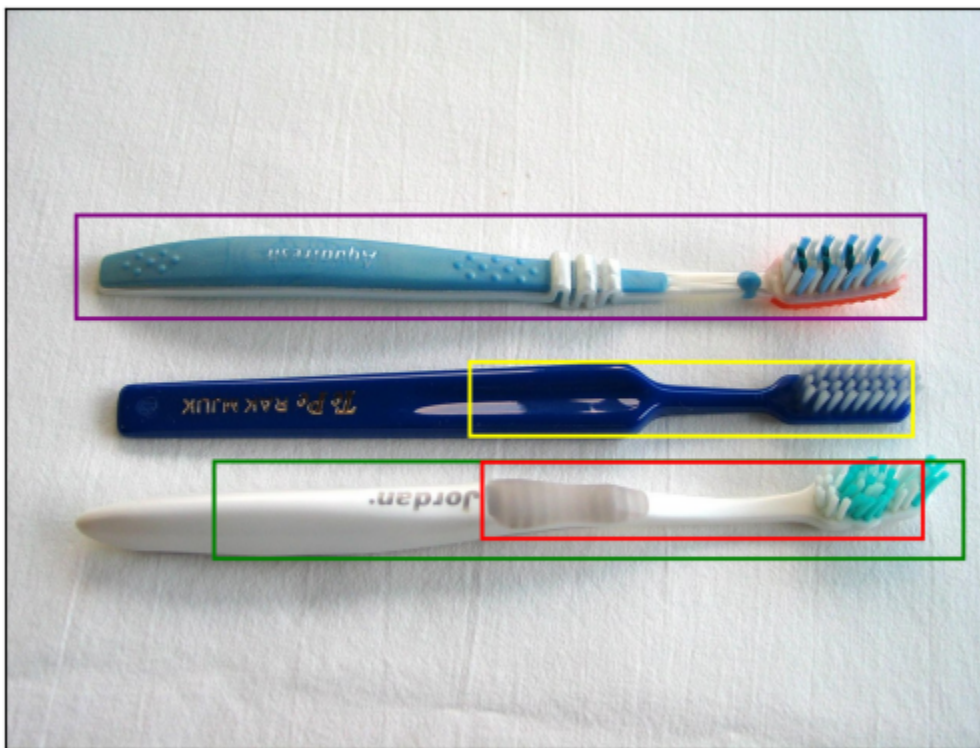
```
Label: toothbrush, Score: 94.17%
Bounding Box: [ 269.026     585.4757   1246.7506    715.89514] green
Label: toothbrush, Score: 88.41%
Bounding Box: [  90.03049  266.97845 1196.9512    404.13617] purple
Label: spoon, Score: 69.83%
Bounding Box: [ 601.2891    456.07553 1180.7574    556.1579 ] yellow
Label: toothbrush, Score: 63.00%
Bounding Box: [ 617.2332   586.1252 1193.0754   689.2256] red
```

Fine-tuning i pretrening

Trenowanie głębokich sieci neuronowych do przetwarzania obrazów jest zadaniem wymagającym bardzo dużych zbiorów danych i zasobów obliczeniowych. Często jednak, nie musimy trenować takich sieci od nowa, możemy wykorzystać wytrenowane modele i jedynie dostosowywaać je do naszych problemów. Działanie takie nazywa się transfer learning-iem.

Przykładowao: mamy już wytrenowaną sieć na dużym zbiorze danych (pretrening) i chcemy, żeby sieć poradziła sobie z nową klasą obiektów (klasyfikacja), albo lepiej radziła sobie z wybranymi obiektami, które już zna (fine-tuning). Możemy usunąć ostatnią warstwę sieci i na jej miejsce wstawić nową, identyczną, jednak z losowo zainicjalizowanymi wagami, a następnie dotrenować sieć na naszym nowym, bardziej specyficznym zbiorze danych. Przykładowo, jako bazę weźmiemy model wytrenowany na zbiorze ImageNet i będziemy chcieli użyć go do rozpoznawania nowych, nieznanych mu klas, np. ras psów.

Dla przećwiczenia takiego schematu działania wykorzystamy zbiór danych z hotdogami. Będziemy chcieli stwierdzić, czy na obrazku jest hotdog, czy nie. Jako sieci użyjemy modelu ResNet-18, pretrenowanej na zbiorze ImageNet.

In [21]:
```
# Download the hotdog dataset
!wget http://d2l-data.s3-accelerate.amazonaws.com/hotdog.zip
!unzip -n hotdog.zip
```

```
--2023-11-27 17:06:06--  http://d2l-data.s3-accelerate.amazonaws.com/hotdog.zip
Resolving d2l-data.s3-accelerate.amazonaws.com (d2l-data.s3-accelerate.amazonaws.com)...
3.163.169.121
Connecting to d2l-data.s3-accelerate.amazonaws.com (d2l-data.s3-accelerate.amazonaws.co
m)|3.163.169.121|:80... connected.
HTTP request sent, awaiting response... 200 OK
Length: 261292301 (249M) [application/zip]
Saving to: 'hotdog.zip'

hotdog.zip          100%[===================>] 249.19M  23.7MB/s    in 9.8s

2023-11-27 17:06:16 (25.5 MB/s) - 'hotdog.zip' saved [261292301/261292301]
```

```
Archive:  hotdog.zip
  creating: hotdog/
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 extracting: hotdog/train/hotdog/164.png
 extracting: hotdog/train/hotdog/623.png
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 extracting: hotdog/train/hotdog/766.png
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```

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  extracting: hotdog/train/hotdog/203.png
  extracting: hotdog/train/hotdog/970.png
  extracting: hotdog/train/hotdog/625.png
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  extracting: hotdog/train/hotdog/710.png
   inflating: hotdog/train/hotdog/218.png
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   inflating: hotdog/train/hotdog/552.png
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  extracting: hotdog/train/hotdog/95.png
   inflating: hotdog/train/hotdog/144.png
   inflating: hotdog/train/hotdog/779.png
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   inflating: hotdog/train/hotdog/915.png
```

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  inflating: hotdog/train/hotdog/82.png
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  inflating: hotdog/train/hotdog/894.png
  inflating: hotdog/train/hotdog/116.png
 extracting: hotdog/train/hotdog/626.png
  inflating: hotdog/train/hotdog/794.png
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  inflating: hotdog/train/hotdog/397.png
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  inflating: hotdog/train/hotdog/223.png
  inflating: hotdog/train/hotdog/522.png
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   creating: hotdog/test/not-hotdog/
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  inflating: hotdog/test/not-hotdog/1114.png
  inflating: hotdog/test/not-hotdog/1186.png
  inflating: hotdog/test/not-hotdog/1200.png
  inflating: hotdog/test/not-hotdog/1380.png
  inflating: hotdog/test/not-hotdog/1247.png
 extracting: hotdog/test/not-hotdog/1206.png
 extracting: hotdog/test/not-hotdog/1246.png
  inflating: hotdog/test/not-hotdog/1227.png
  inflating: hotdog/test/not-hotdog/1079.png
 extracting: hotdog/test/not-hotdog/1297.png
 extracting: hotdog/test/not-hotdog/1378.png
  inflating: hotdog/test/not-hotdog/1286.png
 extracting: hotdog/test/not-hotdog/1045.png
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  inflating: hotdog/test/not-hotdog/1299.png
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  inflating: hotdog/test/not-hotdog/1047.png
  inflating: hotdog/test/not-hotdog/1303.png
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 extracting: hotdog/test/not-hotdog/1033.png
 extracting: hotdog/test/not-hotdog/1205.png
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  inflating: hotdog/test/not-hotdog/1305.png
  inflating: hotdog/test/not-hotdog/1195.png
  inflating: hotdog/test/not-hotdog/1371.png
  inflating: hotdog/test/not-hotdog/1392.png
  inflating: hotdog/test/not-hotdog/1024.png
  inflating: hotdog/test/not-hotdog/1319.png
  inflating: hotdog/test/not-hotdog/1287.png
 extracting: hotdog/test/not-hotdog/1048.png
```

```
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  inflating: hotdog/test/not-hotdog/1217.png
 extracting: hotdog/test/not-hotdog/1060.png
 extracting: hotdog/test/not-hotdog/1203.png
  inflating: hotdog/test/not-hotdog/1090.png
  inflating: hotdog/test/not-hotdog/1304.png
  inflating: hotdog/test/not-hotdog/1063.png
  inflating: hotdog/test/not-hotdog/1387.png
 extracting: hotdog/test/not-hotdog/1267.png
  inflating: hotdog/test/not-hotdog/1219.png
 extracting: hotdog/test/not-hotdog/1182.png
  inflating: hotdog/test/not-hotdog/1012.png
  inflating: hotdog/test/not-hotdog/1139.png
 extracting: hotdog/test/not-hotdog/1257.png
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  inflating: hotdog/test/not-hotdog/1105.png
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  inflating: hotdog/test/not-hotdog/1249.png
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 extracting: hotdog/test/not-hotdog/1347.png
 extracting: hotdog/test/not-hotdog/1005.png
 extracting: hotdog/test/not-hotdog/1361.png
  inflating: hotdog/test/not-hotdog/1038.png
  inflating: hotdog/test/not-hotdog/1357.png
 extracting: hotdog/test/not-hotdog/1070.png
  inflating: hotdog/test/not-hotdog/1399.png
  inflating: hotdog/test/not-hotdog/1113.png
  inflating: hotdog/test/not-hotdog/1167.png
  inflating: hotdog/test/not-hotdog/1112.png
  inflating: hotdog/test/not-hotdog/1384.png
 extracting: hotdog/test/not-hotdog/1213.png
  inflating: hotdog/test/not-hotdog/1342.png
 extracting: hotdog/test/not-hotdog/1362.png
  inflating: hotdog/test/not-hotdog/1085.png
  inflating: hotdog/test/not-hotdog/1131.png
  inflating: hotdog/test/not-hotdog/1027.png
  inflating: hotdog/test/not-hotdog/1002.png
 extracting: hotdog/test/not-hotdog/1254.png
 extracting: hotdog/test/not-hotdog/1291.png
  inflating: hotdog/test/not-hotdog/1259.png
  inflating: hotdog/test/not-hotdog/1121.png
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  inflating: hotdog/test/not-hotdog/1279.png
 extracting: hotdog/test/not-hotdog/1044.png
 extracting: hotdog/test/not-hotdog/1314.png
  inflating: hotdog/test/not-hotdog/1087.png
  inflating: hotdog/test/not-hotdog/1311.png
  inflating: hotdog/test/not-hotdog/1095.png
 extracting: hotdog/test/not-hotdog/1056.png
  inflating: hotdog/test/not-hotdog/1289.png
  inflating: hotdog/test/not-hotdog/1351.png
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 extracting: hotdog/test/not-hotdog/1352.png
  inflating: hotdog/test/not-hotdog/1046.png
```

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extracting: hotdog/test/not-hotdog/1127.png
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 inflating: hotdog/test/not-hotdog/1098.png
extracting: hotdog/test/not-hotdog/1298.png
extracting: hotdog/test/not-hotdog/1296.png
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 inflating: hotdog/test/not-hotdog/1025.png
 inflating: hotdog/test/not-hotdog/1294.png
 inflating: hotdog/test/not-hotdog/1117.png
extracting: hotdog/test/not-hotdog/1062.png
```

```
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  inflating: hotdog/test/not-hotdog/1280.png
  inflating: hotdog/test/not-hotdog/1158.png
  inflating: hotdog/test/not-hotdog/1128.png
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```

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 extracting: hotdog/test/not-hotdog/1094.png
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  inflating: hotdog/test/not-hotdog/1332.png
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  inflating: hotdog/test/not-hotdog/1004.png
  inflating: hotdog/test/not-hotdog/1316.png
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  inflating: hotdog/test/not-hotdog/1156.png
  inflating: hotdog/test/not-hotdog/1192.png
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  inflating: hotdog/test/not-hotdog/1255.png
  inflating: hotdog/test/not-hotdog/1026.png
  inflating: hotdog/test/not-hotdog/1110.png
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  inflating: hotdog/test/not-hotdog/1160.png
  inflating: hotdog/test/not-hotdog/1282.png
 extracting: hotdog/test/not-hotdog/1285.png
 extracting: hotdog/test/not-hotdog/1032.png
  inflating: hotdog/test/not-hotdog/1133.png
  inflating: hotdog/test/not-hotdog/1049.png
  inflating: hotdog/test/not-hotdog/1162.png
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  inflating: hotdog/test/not-hotdog/1271.png
  inflating: hotdog/test/not-hotdog/1006.png
  inflating: hotdog/test/not-hotdog/1326.png
  inflating: hotdog/test/not-hotdog/1143.png
  inflating: hotdog/test/not-hotdog/1236.png
 extracting: hotdog/test/not-hotdog/1272.png
  inflating: hotdog/test/not-hotdog/1244.png
  inflating: hotdog/test/not-hotdog/1367.png
  inflating: hotdog/test/not-hotdog/1277.png
 extracting: hotdog/test/not-hotdog/1381.png
 extracting: hotdog/test/not-hotdog/1389.png
  inflating: hotdog/test/not-hotdog/1372.png
 extracting: hotdog/test/not-hotdog/1093.png
 extracting: hotdog/test/not-hotdog/1069.png
  inflating: hotdog/test/not-hotdog/1385.png
  inflating: hotdog/test/not-hotdog/1209.png
 extracting: hotdog/test/not-hotdog/1177.png
  inflating: hotdog/test/not-hotdog/1324.png
  inflating: hotdog/test/not-hotdog/1224.png
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  inflating: hotdog/test/not-hotdog/1100.png
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  inflating: hotdog/test/not-hotdog/1284.png
  inflating: hotdog/test/not-hotdog/1208.png
 extracting: hotdog/test/not-hotdog/1078.png
 extracting: hotdog/test/not-hotdog/1334.png
  inflating: hotdog/test/not-hotdog/1019.png
  inflating: hotdog/test/not-hotdog/1141.png
  inflating: hotdog/test/not-hotdog/1130.png
 extracting: hotdog/test/not-hotdog/1265.png
  inflating: hotdog/test/not-hotdog/1229.png
  inflating: hotdog/test/not-hotdog/1175.png
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  inflating: hotdog/test/not-hotdog/1268.png
  inflating: hotdog/test/not-hotdog/1350.png
  inflating: hotdog/test/not-hotdog/1232.png
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  inflating: hotdog/test/not-hotdog/1140.png
  inflating: hotdog/test/not-hotdog/1230.png
  inflating: hotdog/test/not-hotdog/1099.png
  inflating: hotdog/test/not-hotdog/1104.png
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  inflating: hotdog/test/not-hotdog/1178.png
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  inflating: hotdog/test/not-hotdog/1201.png
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  inflating: hotdog/test/not-hotdog/1345.png
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  inflating: hotdog/test/not-hotdog/1211.png
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  inflating: hotdog/test/not-hotdog/1349.png
  inflating: hotdog/test/not-hotdog/1198.png
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  inflating: hotdog/test/not-hotdog/1091.png
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  inflating: hotdog/test/hotdog/1195.png
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  inflating: hotdog/test/hotdog/1368.png
  inflating: hotdog/test/hotdog/1233.png
  inflating: hotdog/test/hotdog/1309.png
  inflating: hotdog/test/hotdog/1147.png
 extracting: hotdog/test/hotdog/1119.png
  inflating: hotdog/test/hotdog/1016.png
  inflating: hotdog/test/hotdog/1199.png
  inflating: hotdog/test/hotdog/1001.png
  inflating: hotdog/test/hotdog/1201.png
  inflating: hotdog/test/hotdog/1293.png
  inflating: hotdog/test/hotdog/1108.png
  inflating: hotdog/test/hotdog/1071.png
 extracting: hotdog/test/hotdog/1169.png
  inflating: hotdog/test/hotdog/1058.png
  inflating: hotdog/test/hotdog/1345.png
  inflating: hotdog/test/hotdog/1068.png
  inflating: hotdog/test/hotdog/1135.png
  inflating: hotdog/test/hotdog/1211.png
 extracting: hotdog/test/hotdog/1275.png
  inflating: hotdog/test/hotdog/1336.png
 extracting: hotdog/test/hotdog/1040.png
 extracting: hotdog/test/hotdog/1142.png
  inflating: hotdog/test/hotdog/1101.png
  inflating: hotdog/test/hotdog/1197.png
  inflating: hotdog/test/hotdog/1036.png
  inflating: hotdog/test/hotdog/1170.png
  inflating: hotdog/test/hotdog/1373.png
  inflating: hotdog/test/hotdog/1082.png
```

```
 extracting: hotdog/test/hotdog/1000.png
  inflating: hotdog/test/hotdog/1171.png
 extracting: hotdog/test/hotdog/1065.png
  inflating: hotdog/test/hotdog/1349.png
  inflating: hotdog/test/hotdog/1198.png
 extracting: hotdog/test/hotdog/1222.png
  inflating: hotdog/test/hotdog/1077.png
  inflating: hotdog/test/hotdog/1335.png
  inflating: hotdog/test/hotdog/1080.png
  inflating: hotdog/test/hotdog/1091.png
  inflating: hotdog/test/hotdog/1184.png
  inflating: hotdog/test/hotdog/1327.png
 extracting: hotdog/test/hotdog/1358.png
  inflating: hotdog/test/hotdog/1061.png
 extracting: hotdog/test/hotdog/1179.png
  inflating: hotdog/test/hotdog/1329.png
  inflating: hotdog/test/hotdog/1274.png
  inflating: hotdog/test/hotdog/1344.png
 extracting: hotdog/test/hotdog/1221.png
  inflating: hotdog/test/hotdog/1374.png
 extracting: hotdog/test/hotdog/1029.png
  inflating: hotdog/test/hotdog/1395.png
  inflating: hotdog/test/hotdog/1310.png
  inflating: hotdog/test/hotdog/1397.png
  inflating: hotdog/test/hotdog/1243.png
  inflating: hotdog/test/hotdog/1292.png
  inflating: hotdog/test/hotdog/1010.png
 extracting: hotdog/test/hotdog/1187.png
 extracting: hotdog/test/hotdog/1223.png
 extracting: hotdog/test/hotdog/1041.png
  inflating: hotdog/test/hotdog/1253.png
  inflating: hotdog/test/hotdog/1168.png
  inflating: hotdog/test/hotdog/1183.png
  inflating: hotdog/test/hotdog/1382.png
 extracting: hotdog/test/hotdog/1124.png
  inflating: hotdog/test/hotdog/1097.png
  inflating: hotdog/test/hotdog/1072.png
```

Kiedy korzystamy z sieci pretrenowanej na zbiorze ImageNet, zgodnie z dokumentacją trzeba dokonać standaryzacji naszych obrazów, odejmując średnią i dzieląc przez odchylenie standardowe każdego kanału ze zbioru ImageNet.

```
All pre-trained models expect input images normalized in the same way,
i.e. mini-batches of 3-channel RGB images of shape (3 x H x W), where H
and W are
expected to be at least 224. The images have to be loaded in to a range
of [0, 1] and then normalized using mean = [0.485, 0.456, 0.406] and std
= [0.229,
0.224, 0.225]. You can use the following transform to normalize:

normalize = transforms.Normalize(mean=[0.485, 0.456, 0.406],
                                 std=[0.229, 0.224, 0.225])
```

In [22]:
```python
torch.manual_seed(17)

normalize = transforms.Normalize(
    mean=[0.485, 0.456, 0.406],
    std=[0.229, 0.224, 0.225]
)

train_augs = torchvision.transforms.Compose(
    [
        torchvision.transforms.RandomResizedCrop(224),
```

```python
        torchvision.transforms.RandomHorizontalFlip(),
        torchvision.transforms.ToTensor(),
        normalize,
    ]
)

test_augs = torchvision.transforms.Compose(
    [
        torchvision.transforms.Resize(256),
        torchvision.transforms.CenterCrop(224),
        torchvision.transforms.ToTensor(),
        normalize,
    ]
)
```

In [23]:
```python
pretrained_net = torchvision.models.resnet18(weights=torchvision.models.ResNet18_Weights
```

Downloading: "https://download.pytorch.org/models/resnet18-f37072fd.pth" to /root/.cach
e/torch/hub/checkpoints/resnet18-f37072fd.pth
100%|████████████| 44.7M/44.7M [00:01<00:00, 35.2MB/s]

In [24]:
```python
pretrained_net.fc
```

Out[24]:
```
Linear(in_features=512, out_features=1000, bias=True)
```

Zadanie 5 (1 punkt)

Dodaj warstwę liniową do naszej fine-fune'owanej sieci oraz zainicjuj ją losowymi wartościami.

In [25]:
```python
finetuned_net = pretrained_net # your code here
# your_code

# Freeze all the layers in the pre-trained ResNet18
# for param in finetuned_net.parameters():
#     param.requires_grad = False

# Modify the architecture by appending a new linear layer
in_features = finetuned_net.fc.in_features
finetuned_net.fc = nn.Linear(in_features, 2)

# Initialize the new linear layer with random values
finetuned_net.fc.reset_parameters()
```

In [26]:
```python
import time
import copy


def train_model(
    model, dataloaders, criterion, optimizer, num_epochs=25
):
    since = time.time()

    val_acc_history = []

    best_model_wts = copy.deepcopy(model.state_dict())
    best_acc = 0.0

    for epoch in range(1, num_epochs + 1):
        print("Epoch {}/{}".format(epoch, num_epochs))
        print("-" * 10)

        # Each epoch has a training and validation phase
        for phase in ["train", "val"]:
```

```python
            if phase == "train":
                model.train()  # Set model to training mode
            else:
                model.eval()  # Set model to evaluate mode

            running_loss = 0.0
            running_corrects = 0

            # Iterate over data.
            for inputs, labels in dataloaders[phase]:
                inputs = inputs.to(device)
                labels = labels.to(device)

                # zero the parameter gradients
                optimizer.zero_grad()

                # forward
                # track history if only in train
                with torch.set_grad_enabled(phase == "train"):
                    # Get model outputs and calculate loss

                    outputs = model(inputs)
                    loss = criterion(outputs, labels)
                    _, preds = torch.max(outputs, 1)

                    # backward + optimize only if in training phase
                    if phase == "train":
                        loss.backward()
                        optimizer.step()

                # statistics
                running_loss += loss.item() * inputs.size(0)
                running_corrects += torch.sum(preds == labels.data)

            epoch_loss = running_loss / len(dataloaders[phase].dataset)
            epoch_acc = running_corrects.float() / len(dataloaders[phase].dataset)

            print("{} Loss: {:.4f} Acc: {:.4f}".format(phase, epoch_loss, epoch_acc))

            # deep copy the model
            if phase == "val" and epoch_acc > best_acc:
                best_acc = epoch_acc
                best_model_wts = copy.deepcopy(model.state_dict())
            if phase == "val":
                val_acc_history.append(epoch_acc)

        print()

    time_elapsed = time.time() - since
    print(
        "Training complete in {:.0f}m {:.0f}s".format(
            time_elapsed // 60, time_elapsed % 60
        )
    )
    print("Best val Acc: {:4f}".format(best_acc))

    # load best model weights
    model.load_state_dict(best_model_wts)
    return model, val_acc_history
```

In [27]:
```python
import os

data_dir = "hotdog"
batch_size = 32
```

```python
model_ft = finetuned_net.to(device)
train_iter = torch.utils.data.DataLoader(
    torchvision.datasets.ImageFolder(
        os.path.join(data_dir, "train"), transform=train_augs
    ),
    batch_size=batch_size,
    shuffle=True,
)
test_iter = torch.utils.data.DataLoader(
    torchvision.datasets.ImageFolder(
        os.path.join(data_dir, "test"), transform=test_augs
    ),
    shuffle=True,
    batch_size=batch_size,
)
loss = nn.CrossEntropyLoss(reduction="none")
```

Zadanie 6 (1 punkt)

Zmodyfikuj tak parametry sieci, aby learning rate dla ostatniej warstwy był 10 razy wyższy niż dla
pozostałych.

Trzeba odpowiednio podać pierwszy parametr `torch.optim.SGD` tak, aby zawierał parametry normalne,
oraz te z `lr * 10`. Paramety warstw niższych to takie, które mają nazwę inną niż `fc.weight` albo
`fc.bias` - może się przydać metoda sieci `named_parameters()`.

In [28]:
```python
def train_fine_tuning(net, learning_rate, num_epochs=15):

    params_to_update = []
    for name, param in net.named_parameters():
        if "fc" in name:  # Last layer parameters
            params_to_update.append({"params": param, "lr": learning_rate * 10})
        else:
            params_to_update.append({"params": param})

    trainer = torch.optim.SGD(params_to_update, learning_rate) #, momentum = 0.9) # your

    dataloaders_dict = {"train": train_iter, "val": test_iter}
    criterion = nn.CrossEntropyLoss()
    model_ft, hist = train_model(
        net, dataloaders_dict, criterion, trainer, num_epochs=num_epochs
    )
    return model_ft, hist


    # your_code
```

In [29]:
```python
model_ft, hist = train_fine_tuning(model_ft, learning_rate=5e-5)
```

```
Epoch 1/15
----------
train Loss: 0.6585 Acc: 0.6095
val Loss: 0.5865 Acc: 0.6850

Epoch 2/15
----------
train Loss: 0.5790 Acc: 0.6990
val Loss: 0.5129 Acc: 0.7662

Epoch 3/15
----------
train Loss: 0.5186 Acc: 0.7615
val Loss: 0.4663 Acc: 0.8100
```

```
Epoch 4/15
----------
train Loss: 0.4770 Acc: 0.8130
val Loss: 0.4295 Acc: 0.8400

Epoch 5/15
----------
train Loss: 0.4456 Acc: 0.8300
val Loss: 0.4000 Acc: 0.8475

Epoch 6/15
----------
train Loss: 0.4265 Acc: 0.8440
val Loss: 0.3786 Acc: 0.8687

Epoch 7/15
----------
train Loss: 0.4008 Acc: 0.8585
val Loss: 0.3612 Acc: 0.8775

Epoch 8/15
----------
train Loss: 0.3826 Acc: 0.8620
val Loss: 0.3398 Acc: 0.8875

Epoch 9/15
----------
train Loss: 0.3689 Acc: 0.8700
val Loss: 0.3290 Acc: 0.8862

Epoch 10/15
----------
train Loss: 0.3558 Acc: 0.8645
val Loss: 0.3194 Acc: 0.8912

Epoch 11/15
----------
train Loss: 0.3473 Acc: 0.8780
val Loss: 0.3088 Acc: 0.8925

Epoch 12/15
----------
train Loss: 0.3458 Acc: 0.8680
val Loss: 0.2993 Acc: 0.8975

Epoch 13/15
----------
train Loss: 0.3301 Acc: 0.8790
val Loss: 0.2932 Acc: 0.8950

Epoch 14/15
----------
train Loss: 0.3159 Acc: 0.8845
val Loss: 0.2818 Acc: 0.9038

Epoch 15/15
----------
train Loss: 0.3069 Acc: 0.8880
val Loss: 0.2758 Acc: 0.9050

Training complete in 4m 52s
Best val Acc: 0.905000
```

skomentuj wyniki:

- Dokładność jest dość dobra. Na zbiorze treningowym model osiąga podobne ale gorsze wyniki niż na testowym. Występuje underfitting którego powodem jest to że sieć była oryginalnie treniwana do czego innego.

Przy wyświetlaniu predykcji sieci musimy wykonać operacje odwrotne niż te, które wykonaliśmy, przygotowując obrazy do treningu:

- zamienić kolejność kanałów z (C, H, W) na (H, W, C)
- zamienić obraz z tensora na tablicę Numpy'a
- odwrócić normalizację (mnożymy przez odchylenie standardowe, dodajemy średnią) i upewnić się, że nie wychodzimy poza zakres [0, 1] (wystarczy proste przycięcie wartości)

In [30]:
```python
def imshow(img, title=None):
    img = img.permute(1, 2, 0).numpy()
    means = np.array([0.485, 0.456, 0.406])
    stds = np.array([0.229, 0.224, 0.225])
    img = stds * img + means
    img = np.clip(img, 0, 1)

    plt.imshow(img)
    if title is not None:
        plt.title(title)

    plt.pause(0.001)
```

In [31]:
```python
import matplotlib.pyplot as plt
plt.ion()


def visualize_model(model, num_images=6):
    class_names = ["hotdog", "other"]
    model.eval()
    images_so_far = 0
    fig = plt.figure()
    with torch.no_grad():
        for i, (inputs, labels) in enumerate(test_iter):
            inputs = inputs.to(device)
            labels = labels.to(device)

            outputs = model(inputs)
            _, preds = torch.max(outputs, 1)

            for j in range(inputs.size()[0]):
                images_so_far += 1
                ax = plt.subplot(num_images // 2, 2, images_so_far)
                ax.axis('off')
                ax.set_title(f'predicted: {class_names[preds[j]]}')

                imshow(inputs.data[j].cpu())

                if images_so_far == num_images:
                    return
```
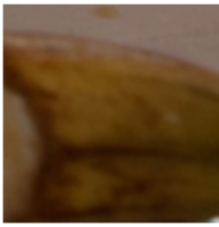
In [32]:
```python
visualize_model(model_ft)
```

predicted: other

predicted: other

predicted: hotdog

predicted: other

predicted: hotdog

predicted: other

Zadanie dla chętnych (3 punkty)

W zadaniach dotyczących klasyfikacji obrazu wykorzystywaliśmy prosty zbiór danych i sieć LeNet. Teraz zamień zbiór danych na bardziej skomplikowany, np. ten lub ten (lub inny o podobnym poziomie trudności) i

zamiast prostej sieci LeNet użyj bardziej złożonej, np. AlexNet, ResNet, MobileNetV2.

In [32]: