In [4]:
```python
words = open('names.txt', 'r').read().splitlines()
```

In [5]:
```python
words[:10]
```

Out[5]:
```
['emma',
 'olivia',
 'ava',
 'isabella',
 'sophia',
 'charlotte',
 'mia',
 'amelia',
 'harper',
 'evelyn']
```

In [6]:
```python
len(words)
```

Out[6]:
```
32033
```

In [7]:
```python
min(len(w) for w in words)
```

Out[7]:
```
2
```

In [8]:
```python
max(len(w) for w in words)
```

Out[8]:
```
15
```

In [9]:
```python
b = {}
for w in words:
  chs = ['<S>'] + list(w) + ['<E>']
  for ch1, ch2 in zip(chs, chs[1:]):
    bigram = (ch1, ch2)
    b[bigram] = b.get(bigram, 0) + 1
```

In [10]:
```python
sorted(b.items(), key = lambda kv: -kv[1])
```

Out[10]:
```
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```

In [11]:
```
import torch
```

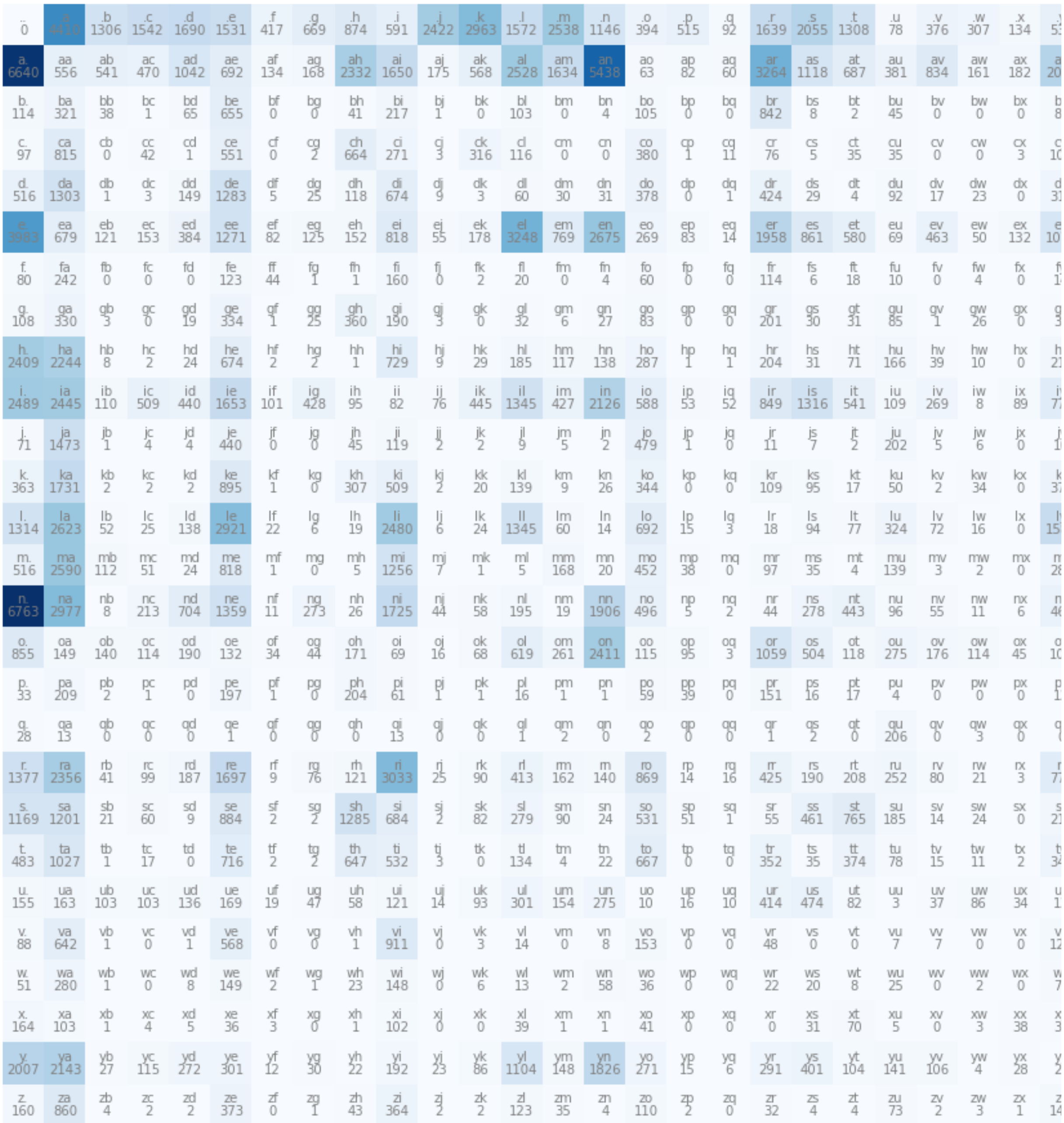
In [365…
```
N = torch.zeros((27, 27), dtype=torch.int32)
```

In [366…
```
chars = sorted(list(set(''.join(words))))
stoi = {s:i+1 for i,s in enumerate(chars)}
stoi['.'] = 0
itos = {i:s for s,i in stoi.items()}
```

In [367…
```
for w in words:
  chs = ['.'] + list(w) + ['.']
  for ch1, ch2 in zip(chs, chs[1:]):
    ix1 = stoi[ch1]
    ix2 = stoi[ch2]
    N[ix1, ix2] += 1
```

In [368…
```
import matplotlib.pyplot as plt
%matplotlib inline

plt.figure(figsize=(16,16))
plt.imshow(N, cmap='Blues')
for i in range(27):
    for j in range(27):
        chstr = itos[i] + itos[j]
        plt.text(j, i, chstr, ha="center", va="bottom", color='gray')
        plt.text(j, i, N[i, j].item(), ha="center", va="top", color='gray
plt.axis('off');
```



In [159…:
```
N[0]
```

Out[159…:
```
tensor([1., 1., 1., 1., 1., 1., 1., 1., 1., 1., 1., 1., 1., 1., 1., 1., 1.,
        1., 1., 1., 1., 1., 1., 1., 1., 1.])
```

In [17]:
```
p = N[0].float()
p = p / p.sum()
p
```

Out[17]:
```
tensor([0.0000, 0.1377, 0.0408, 0.0481, 0.0528, 0.0478, 0.0130, 0.0209, 0.02
        0.0184, 0.0756, 0.0925, 0.0491, 0.0792, 0.0358, 0.0123, 0.0161, 0.00
        0.0512, 0.0642, 0.0408, 0.0024, 0.0117, 0.0096, 0.0042, 0.0167, 0.02
```

In [18]:
```
g = torch.Generator().manual_seed(2147483647)
ix = torch.multinomial(p, num_samples=1, replacement=True, generator=g).i
itos[ix]
```

Out[18]:
```
'm'
```

In [19]:

```
g = torch.Generator().manual_seed(2147483647)
p = torch.rand(3, generator=g)
p = p / p.sum()
p
```

Out[19]:
```
tensor([0.6064, 0.3033, 0.0903])
```

In [20]:
```
torch.multinomial(p, num_samples=100, replacement=True, generator=g)
```

Out[20]:
```
tensor([1, 1, 2, 0, 0, 2, 1, 1, 0, 0, 0, 1, 1, 0, 0, 1, 1, 0, 0, 1, 0, 2, 0,
        1, 0, 0, 1, 0, 0, 0, 1, 1, 1, 0, 1, 1, 0, 0, 1, 1, 1, 0, 1, 1, 0, 1,
        0, 2, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 1,
        0, 1, 0, 0, 0, 0, 0, 0, 0, 1, 2, 0, 0, 0, 0, 0, 0, 1, 0, 0, 2, 0, 1,
        0, 1, 1, 1])
```

In [21]:
```
p.shape
```

Out[21]:
```
torch.Size([3])
```

In [30]:
```
P.shape
```

Out[30]:
```
torch.Size([27, 27])
```

In [29]:
```
P.sum(1, keepdim=True).shape
```

Out[29]:
```
torch.Size([27, 1])
```

In [24]:
```
# 27, 27
# 27,  1
```

In [28]:
```
P.sum(1).shape
```

Out[28]:
```
torch.Size([27])
```

In [26]:
```
# 27, 27
#  1, 27
```

In [310…
```
P = (N+1).float()
P /= P.sum(1, keepdims=True)
```

In [164…
```
g = torch.Generator().manual_seed(2147483647)

for i in range(5):

  out = []
  ix = 0
  while True:
    p = P[ix]
    ix = torch.multinomial(p, num_samples=1, replacement=True, generator=
    out.append(itos[ix])
    if ix == 0:
      break
  print(''.join(out))
```

```
mor.
axx.
minaymoryles.
kondlaisah.
anchshizarie.
```

In [165…

```
# GOAL: maximize likelihood of the data w.r.t. model parameters (statisti
# equivalent to maximizing the log likelihood (because log is monotonic)
# equivalent to minimizing the negative log likelihood
# equivalent to minimizing the average negative log likelihood

# log(a*b*c) = log(a) + log(b) + log(c)
```

In [435…

```
log_likelihood = 0.0
n = 0

for w in words:
#for w in ["andrejq"]:
  chs = ['.'] + list(w) + ['.']
  for ch1, ch2 in zip(chs, chs[1:]):
    ix1 = stoi[ch1]
    ix2 = stoi[ch2]
    prob = P[ix1, ix2]
    logprob = torch.log(prob)
    log_likelihood += logprob
    n += 1
    #print(f'{ch1}{ch2}: {prob:.4f} {logprob:.4f}')

print(f'{log_likelihood=}')
nll = -log_likelihood
print(f'{nll=}')
print(f'{nll/n}')
```

```
log_likelihood=tensor(-564996.8125, grad_fn=<AddBackward0>)
nll=tensor(564996.8125, grad_fn=<NegBackward0>)
2.476470470428467
```

In [449…

```
# create the training set of bigrams (x,y)
xs, ys = [], []

for w in words[:1]:
  chs = ['.'] + list(w) + ['.']
  for ch1, ch2 in zip(chs, chs[1:]):
    ix1 = stoi[ch1]
    ix2 = stoi[ch2]
    print(ch1, ch2)
    xs.append(ix1)
    ys.append(ix2)

xs = torch.tensor(xs)
ys = torch.tensor(ys)
```

```
. e
e m
m m
m a
a .
```

In [450…

```
xs
```

Out[450…
```
tensor([ 0,  5, 13, 13,  1])
```

In [451…
```
ys
```

Out[451…
```
tensor([ 5, 13, 13,  1,  0])
```

In [487…
```
import torch.nn.functional as F
xenc = F.one_hot(xs, num_classes=27).float()
xenc
```

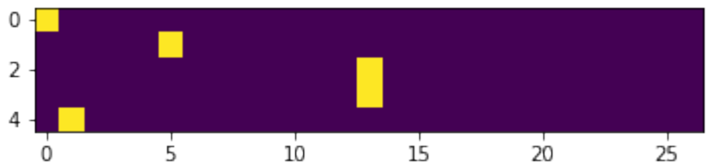
Out[487…
```
tensor([[1., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0.,
         0., 0., 0., 0., 0., 0., 0., 0., 0.],
        [0., 0., 0., 0., 0., 1., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0.,
         0., 0., 0., 0., 0., 0., 0., 0., 0.],
        [0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 1., 0., 0., 0.,
         0., 0., 0., 0., 0., 0., 0., 0., 0.],
        [0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 1., 0., 0., 0.,
         0., 0., 0., 0., 0., 0., 0., 0., 0.],
        [0., 1., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0.,
         0., 0., 0., 0., 0., 0., 0., 0., 0.]])
```

In [488…
```
xenc.shape
```

Out[488…
```
torch.Size([5, 27])
```

In [489…
```
plt.imshow(xenc)
```

Out[489…
```
<matplotlib.image.AxesImage at 0x7fa0dab44fa0>
```



In [490…
```
xenc.dtype
```

Out[490…
```
torch.float32
```

In [493…
```
W = torch.randn((27, 1))
xenc @ W
```

```
Out[493… tensor([[-0.2003, -2.3711, -0.9466,  0.5369, -0.0949, -1.7872, -0.9038,  0.8
           0.6926,  0.0114, -1.5301,  0.6077, -1.2056,  1.8605, -1.3012, -0.0
          -2.1611, -0.0538, -0.0133, -0.3629,  0.5254, -0.0080,  1.1602,  1.9
           0.4976,  0.7351, -0.6373],
         [-0.4422,  0.5024,  1.3514, -0.4085, -0.7854, -1.2568, -0.4558,  0.1
          -0.4460,  1.2748, -0.6367,  0.6403, -0.5617, -0.3060,  1.6771, -1.4
          -2.7395,  0.3876,  0.3970,  1.5577, -0.1995, -0.1397, -1.3045,  0.4
           1.2557,  0.8007,  0.5450],
         [-0.2680, -0.2640,  0.4591,  0.0338,  0.7478,  1.2757, -0.9842,  0.1
           0.0824, -0.5646, -0.3657, -0.8358, -1.7654,  0.5008, -1.7455, -0.8
          -2.2721,  0.9713, -1.0734,  0.3115, -0.2506,  0.0757,  0.9332,  1.6
           1.2306,  0.1231, -0.2530],
         [-0.2680, -0.2640,  0.4591,  0.0338,  0.7478,  1.2757, -0.9842,  0.1
           0.0824, -0.5646, -0.3657, -0.8358, -1.7654,  0.5008, -1.7455, -0.8
          -2.2721,  0.9713, -1.0734,  0.3115, -0.2506,  0.0757,  0.9332,  1.6
           1.2306,  0.1231, -0.2530],
         [ 0.1949, -1.1315,  0.9479, -0.6382, -0.4422, -0.6489,  0.6576, -1.9
           2.0254,  1.2617, -1.7238,  1.2971, -0.6925, -0.3873,  0.7874, -0.8
           0.5746, -0.5263, -0.5928,  0.1419,  1.0683, -0.1760, -0.3507, -0.5
           0.1470,  1.5682, -1.0393]])
```

```
In [506…
logits = xenc @ W # log-counts
counts = logits.exp() # equivalent N
probs = counts / counts.sum(1, keepdims=True)
probs
```

```
Out[506… tensor([[0.0205, 0.0023, 0.0097, 0.0428, 0.0228, 0.0042, 0.0101, 0.0568, 0.0
          0.0253, 0.0054, 0.0460, 0.0075, 0.1609, 0.0068, 0.0243, 0.0029, 0.0
          0.0247, 0.0174, 0.0423, 0.0248, 0.0799, 0.1822, 0.0412, 0.0522, 0.0
         [0.0154, 0.0397, 0.0928, 0.0160, 0.0110, 0.0068, 0.0152, 0.0278, 0.0
          0.0860, 0.0127, 0.0456, 0.0137, 0.0177, 0.1286, 0.0055, 0.0016, 0.0
          0.0357, 0.1141, 0.0197, 0.0209, 0.0065, 0.0369, 0.0844, 0.0535, 0.0
         [0.0212, 0.0213, 0.0439, 0.0287, 0.0586, 0.0994, 0.0104, 0.0332, 0.0
          0.0158, 0.0192, 0.0120, 0.0047, 0.0458, 0.0048, 0.0123, 0.0029, 0.0
          0.0095, 0.0379, 0.0216, 0.0299, 0.0705, 0.1450, 0.0950, 0.0314, 0.0
         [0.0212, 0.0213, 0.0439, 0.0287, 0.0586, 0.0994, 0.0104, 0.0332, 0.0
          0.0158, 0.0192, 0.0120, 0.0047, 0.0458, 0.0048, 0.0123, 0.0029, 0.0
          0.0095, 0.0379, 0.0216, 0.0299, 0.0705, 0.1450, 0.0950, 0.0314, 0.0
         [0.0289, 0.0077, 0.0613, 0.0126, 0.0153, 0.0124, 0.0459, 0.0036, 0.1
          0.0839, 0.0042, 0.0869, 0.0119, 0.0161, 0.0522, 0.0106, 0.0422, 0.0
          0.0131, 0.0274, 0.0692, 0.0199, 0.0167, 0.0139, 0.0275, 0.1140, 0.0
```

```
In [509…
probs[0]
```

```
Out[509… tensor([0.0205, 0.0023, 0.0097, 0.0428, 0.0228, 0.0042, 0.0101, 0.0568, 0.05
         0.0253, 0.0054, 0.0460, 0.0075, 0.1609, 0.0068, 0.0243, 0.0029, 0.02
         0.0247, 0.0174, 0.0423, 0.0248, 0.0799, 0.1822, 0.0412, 0.0522, 0.01
```

```
In [510…
probs[0].shape
```

```
Out[510… torch.Size([27])
```

```
In [507…
probs[0].sum()
```

```
Out[507… tensor(1.)
```

```
In [ ]:
# (5, 27) @ (27, 27) -> (5, 27)
```

```
# SUMMARY ------------------------------>>>>
```

In [ ]:

```

```

In [528…

```
xs
```

Out[528…

```
tensor([ 0,  5, 13, 13,  1])
```

In [529…

```
ys
```

Out[529…

```
tensor([ 5, 13, 13,  1,  0])
```

In [557…

```
# randomly initialize 27 neurons' weights. each neuron receives 27 inputs
g = torch.Generator().manual_seed(2147483647)
W = torch.randn((27, 27), generator=g)
```

In [558…

```
xenc = F.one_hot(xs, num_classes=27).float() # input to the network: one-
logits = xenc @ W # predict log-counts
counts = logits.exp() # counts, equivalent to N
probs = counts / counts.sum(1, keepdims=True) # probabilities for next ch
# btw: the last 2 lines here are together called a 'softmax'
```

In [559…

```
probs.shape
```

Out[559…

```
torch.Size([5, 27])
```

In [560…

```
nlls = torch.zeros(5)
for i in range(5):
  # i-th bigram:
  x = xs[i].item() # input character index
  y = ys[i].item() # label character index
  print('--------')
  print(f'bigram example {i+1}: {itos[x]}{itos[y]} (indexes {x},{y})')
  print('input to the neural net:', x)
  print('output probabilities from the neural net:', probs[i])
  print('label (actual next character):', y)
  p = probs[i, y]
  print('probability assigned by the net to the the correct character:',
  logp = torch.log(p)
  print('log likelihood:', logp.item())
  nll = -logp
  print('negative log likelihood:', nll.item())
  nlls[i] = nll

print('=========')
print('average negative log likelihood, i.e. loss =', nlls.mean().item())
```

```
--------
bigram example 1: .e (indexes 0,5)
input to the neural net: 0
output probabilities from the neural net: tensor([0.0607, 0.0100, 0.0123, 0.0
0.0168, 0.0123, 0.0027, 0.0232, 0.0137,
        0.0313, 0.0079, 0.0278, 0.0091, 0.0082, 0.0500, 0.2378, 0.0603, 0.002
        0.0249, 0.0055, 0.0339, 0.0109, 0.0029, 0.0198, 0.0118, 0.1537, 0.145
label (actual next character): 5
probability assigned by the net to the the correct character: 0.0122862532734
log likelihood: -4.3992743492126465
negative log likelihood: 4.3992743492126465
--------
bigram example 2: em (indexes 5,13)
input to the neural net: 5
output probabilities from the neural net: tensor([0.0290, 0.0796, 0.0248, 0.0
0.1989, 0.0289, 0.0094, 0.0335, 0.0097,
        0.0301, 0.0702, 0.0228, 0.0115, 0.0181, 0.0108, 0.0315, 0.0291, 0.004
        0.0916, 0.0215, 0.0486, 0.0300, 0.0501, 0.0027, 0.0118, 0.0022, 0.047
label (actual next character): 13
probability assigned by the net to the the correct character: 0.0180507022887
log likelihood: -4.014570713043213
negative log likelihood: 4.014570713043213
--------
bigram example 3: mm (indexes 13,13)
input to the neural net: 13
output probabilities from the neural net: tensor([0.0312, 0.0737, 0.0484, 0.0
0.0674, 0.0200, 0.0263, 0.0249, 0.1226,
        0.0164, 0.0075, 0.0789, 0.0131, 0.0267, 0.0147, 0.0112, 0.0585, 0.012
        0.0650, 0.0058, 0.0208, 0.0078, 0.0133, 0.0203, 0.1204, 0.0469, 0.012
label (actual next character): 13
probability assigned by the net to the the correct character: 0.0266915336251
log likelihood: -3.623408794403076
negative log likelihood: 3.623408794403076
--------
bigram example 4: ma (indexes 13,1)
input to the neural net: 13
output probabilities from the neural net: tensor([0.0312, 0.0737, 0.0484, 0.0
0.0674, 0.0200, 0.0263, 0.0249, 0.1226,
        0.0164, 0.0075, 0.0789, 0.0131, 0.0267, 0.0147, 0.0112, 0.0585, 0.012
        0.0650, 0.0058, 0.0208, 0.0078, 0.0133, 0.0203, 0.1204, 0.0469, 0.012
label (actual next character): 1
probability assigned by the net to the the correct character: 0.0736768469214
log likelihood: -2.6080667972564697
negative log likelihood: 2.6080667972564697
--------
bigram example 5: a. (indexes 1,0)
input to the neural net: 1
output probabilities from the neural net: tensor([0.0150, 0.0086, 0.0396, 0.0
0.0606, 0.0308, 0.1084, 0.0131, 0.0125,
        0.0048, 0.1024, 0.0086, 0.0988, 0.0112, 0.0232, 0.0207, 0.0408, 0.007
        0.0899, 0.0531, 0.0463, 0.0309, 0.0051, 0.0329, 0.0654, 0.0503, 0.009
label (actual next character): 0
probability assigned by the net to the the correct character: 0.0149775305762
log likelihood: -4.201204299926758
negative log likelihood: 4.201204299926758
=========
average negative log likelihood, i.e. loss = 3.7693049907684326
```

In [561…

```
# --------- !!! OPTIMIZATION !!! yay --------------
```

In [565…

```
xs
```

Out[565…

```
tensor([ 0,  5, 13, 13,  1])
```

In [566…

```
ys
```

Out[566…

```
tensor([ 5, 13, 13,  1,  0])
```

In [580…

```
# randomly initialize 27 neurons' weights. each neuron receives 27 inputs
g = torch.Generator().manual_seed(2147483647)
W = torch.randn((27, 27), generator=g, requires_grad=True)
```

In [602…

```
# forward pass
xenc = F.one_hot(xs, num_classes=27).float() # input to the network: one-
logits = xenc @ W # predict log-counts
counts = logits.exp() # counts, equivalent to N
probs = counts / counts.sum(1, keepdims=True) # probabilities for next ch
loss = -probs[torch.arange(5), ys].log().mean()
```

In [603…

```
print(loss.item())
```

```
3.6891887187957764
```

In [604…

```
# backward pass
W.grad = None # set to zero the gradient
loss.backward()
```

In [605…

```
W.data += -0.1 * W.grad
```

In [606…

```
# --------- !!! OPTIMIZATION !!! yay, but this time actually ------------
```

In [682…

```
# create the dataset
xs, ys = [], []
for w in words:
  chs = ['.'] + list(w) + ['.']
  for ch1, ch2 in zip(chs, chs[1:]):
    ix1 = stoi[ch1]
    ix2 = stoi[ch2]
    xs.append(ix1)
    ys.append(ix2)
xs = torch.tensor(xs)
ys = torch.tensor(ys)
num = xs.nelement()
print('number of examples: ', num)

# initialize the 'network'
g = torch.Generator().manual_seed(2147483647)
W = torch.randn((27, 27), generator=g, requires_grad=True)
```

```
number of examples:  228146
```

In [716…

```
# gradient descent
for k in range(1):

  # forward pass
  xenc = F.one_hot(xs, num_classes=27).float() # input to the network: on
  logits = xenc @ W # predict log-counts
  counts = logits.exp() # counts, equivalent to N
```

```
  probs = counts / counts.sum(1, keepdims=True) # probabilities for next
  loss = -probs[torch.arange(num), ys].log().mean() + 0.01*(W**2).mean()
  print(loss.item())

  # backward pass
  W.grad = None # set to zero the gradient
  loss.backward()

  # update
  W.data += -50 * W.grad
```

```
2.481828451156616
```

In [725…

```
# finally, sample from the 'neural net' model
g = torch.Generator().manual_seed(2147483647)

for i in range(5):

  out = []
  ix = 0
  while True:

    # ----------
    # BEFORE:
    #p = P[ix]
    # ----------
    # NOW:
    xenc = F.one_hot(torch.tensor([ix]), num_classes=27).float()
    logits = xenc @ W # predict log-counts
    counts = logits.exp() # counts, equivalent to N
    p = counts / counts.sum(1, keepdims=True) # probabilities for next ch
    # ----------

    ix = torch.multinomial(p, num_samples=1, replacement=True, generator=
    out.append(itos[ix])
    if ix == 0:
      break
  print(''.join(out))
```

```
mor.
axx.
minaymoryles.
kondlaisah.
anchthizarie.
```

In [ ]: