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# **Sparse Distributed Memory Framework Documentation**

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Welcome! This is the documentation for Sparse Distributed Memory Framework.



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## Parts of the documentation

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The documentation is organized in two parts: C API and Python Library.

It is suggested to use the Python Library. It is a facade which simplifies the creation and manipulation of SDM instances. It also works in the Jupyter Notebook.

The C API is the low level module which may be extended to add new operations to the SDM.

## 1.1 SDM Library

### 1.1.1 Bitstring

### 1.1.2 AddressSpace

### 1.1.3 Counter

### 1.1.4 SDM

## 1.2 C API

### 1.2.1 Bitstring's functions

The following functions are used to create, destroy, and manipulate bitstrings. Many of them have a parameter *len*, which is the number of bytes of the bitstring. It was a design choice which saves computing it everytime.

```
typedef uint64_t bitstring_t
```

```
void bs_init_bitcount_table ()
```

Initialize a 64kb in RAM which is used to improve performance when calculating the distance between two bitstrings.

*bitstring\_t*\* **bs\_alloc** (const unsigned int *len*)

Allocate memory for a bitstring with *len* bytes.

void **bs\_free** (*bitstring\_t* \**bs*)

Free the memory of a bitstring.

void **bs\_copy** (*bitstring\_t* \**dst*, const *bitstring\_t* \**src*, unsigned int *len*)

Copy one bitstring into another.

void **bs\_init\_zeros** (*bitstring\_t* \**bs*, unsigned int *len*, unsigned int *bits\_remaining*)

Initialize a bitstring with all bits equal to zero. The bitstring's memory must have already been allocated.

void **bs\_init\_ones** (*bitstring\_t* \**bs*, unsigned int *len*, unsigned int *bits\_remaining*)

Initialize a bitstring with all bits equal to one. The bitstring's memory must have already been allocated.

void **bs\_init\_random** (*bitstring\_t* \**bs*, unsigned int *len*, unsigned int *bits\_remaining*)

Initialize a bitstring with random bits. Each bit is sampled from Bernoulli trial with  $p=0.5$ . The bitstring's memory must have already been allocated.

void **bs\_init\_hex** (*bitstring\_t* \**bs*, unsigned int *len*, char \**hex*)

Initialize a bitstring with random bits. Each bit is sampled from Bernoulli trial with  $p=0.5$ . The bitstring's memory must have already been allocated.

void **bs\_init\_b64** (*bitstring\_t* \**bs*, char \**b64*)

Initialize a bitstring from a base64 string. The bitstring's memory must have already been allocated.

void **bs\_to\_hex** (char \**buf*, *bitstring\_t* \**bs*, unsigned int *len*)

Initialize a bitstring from a hexadecimal string. The bitstring's memory must have already been allocated.

void **bs\_to\_b64** (char \**buf*, *bitstring\_t* \**bs*, unsigned int *len*)

Generate the base64 string representation of the bitstring.

int **bs\_distance** (const *bitstring\_t* \**bs1*, const *bitstring\_t* \**bs2*, const unsigned int *len*)

Calculate the hamming distance between two bitstrings.

unsigned int **bs\_get\_bit** (*bitstring\_t* \**bs*, unsigned int *bit*)

Return a specific bit from a bitstring.

void **bs\_set\_bit** (*bitstring\_t* \**bs*, unsigned int *bit*, unsigned int *value*)

Change the value of a specific bit from a bitstring.

void **bs\_flip\_bit** (*bitstring\_t* \**bs*, unsigned int *bit*)

Flip a specific bit from a bitstring.

int **bs\_flip\_random\_bits** (*bitstring\_t* \**bs*, unsigned int *bits*, unsigned int *flips*)

Randomly choose *flips* bits of the bitstring. It is used to generate a random bitstring with a given distance from another bitstring.

void **bs\_xor** (*bitstring\_t* \**bs1*, const *bitstring\_t* \**bs2*, const unsigned int *len*)

Calculate the XOR bitwise operation between two bitstrings. The result is stored in *bs1*.

void **bs\_and** (*bitstring\_t* \**bs1*, const *bitstring\_t* \**bs2*, const unsigned int *len*)

Calculate the AND bitwise operation between two bitstrings. The result is stored in *bs1*.

void **bs\_or** (*bitstring\_t* \**bs1*, const *bitstring\_t* \**bs2*, const unsigned int *len*)

Calculate the OR bitwise operation between two bitstrings. The result is stored in *bs1*.

void **bs\_average** (*bitstring\_t* \**bs1*, const *bitstring\_t* \**bs2*, const unsigned int *len*)

Calculate average between the bitstrings. The result is stored in *bs1*.

## 1.2.2 Address Space's functions

struct **address\_space\_s** ( )

unsigned int **bits**  
SDM dimension.

unsigned int **sample**  
Number of hard-locations.

*bitstring\_t* \*\***addresses**

This approach allocates a continuous chunk of memory for all bitstring addresses. The *addresses* allows the use of array notation: *addresses*[0], *addresses*[1], ...

Let *a* be *addresses*. Then:

a[0]	a[1]	a[2]	a[3]	a[4]
v	v	v	v	v
bs_data = xxxxxx xxxxxx xxxxxx xxxxxx xxxxxx				

unsigned int **bs\_len;**

unsigned int **bs\_bits\_remaining;**

*bitstring\_t* \***bs\_data;**

int **as\_init** (struct *address\_space\_s* \**this*, unsigned int *bits*, unsigned int *sample*)  
Testing...

int **as\_init\_random** (struct *address\_space\_s* \**this*, unsigned int *bits*, unsigned int *sample*)  
Testing again..

int **as\_init\_from\_b64\_file** (struct *address\_space\_s* \**this*, char \**filename*)

int **as\_free** (struct *address\_space\_s* \**this*)

int **as\_save\_b64\_file** (const struct *address\_space\_s* \**this*, char \**filename*)

int **as\_scan\_linear** (const struct *address\_space\_s* \**this*, const *bitstring\_t* \**bs*, unsigned int *radius*,  
uint8\_t \**buf*)

int **as\_scan\_thread** (const struct *address\_space\_s* \**this*, const *bitstring\_t* \**bs*, unsigned int *radius*,  
uint8\_t \**buf*, unsigned int *thread\_count*)

void **as\_print\_summary** (struct *address\_space\_s* \**this*)

void **as\_print\_addresses\_b64** (struct *address\_space\_s* \**this*)

void **as\_print\_addresses\_hex** (struct *address\_space\_s* \**this*)

## 1.2.3 OpenCL Scanner

int **as\_scanner\_opengl\_init** (struct *opengl\_scanner\_s* \**this*, struct *address\_space\_s* \**as*,  
char \**opengl\_source*)

void **as\_scanner\_opengl\_free** (struct *opengl\_scanner\_s* \**this*)

int **as\_scan\_opengl** (struct *opengl\_scanner\_s* \**this*, *bitstring\_t* \**bs*, unsigned int *radius*, uint8\_t \**result*)

### 1.2.4 Counter's functions

```
typedef int counter_t

struct counter_s

    unsigned int bits
    unsigned int sample
    int fd
    char *filename
    counter_t **counter
    counter_t *data

int counter_init (struct counter_s *this, unsigned int bits, unsigned int sample)
int counter_init_file (char *filename, struct counter_s *this)
void counter_free (struct counter_s *this)
void counter_print_summary (struct counter_s *this)
void counter_print (struct counter_s *this, unsigned int index)
int counter_add_bitstring (struct counter_s *this, unsigned int index, bitstring_t *bs)
int counter_add_counter (struct counter_s *c1, unsigned int idx1, struct counter_s *c2, unsigned
                        int idx2)
int counter_to_bitstring (struct counter_s *this, unsigned int index, bitstring_t *bs)
int counter_create_file (char *filename, unsigned int bits, unsigned int sample)
```

### 1.2.5 SDM's functions

```
struct sdm_s

    unsigned int bits
    unsigned int sample
    unsigned int scanner_type

    SDM_SCANNER_LINEAR
    SDM_SCANNER_THREAD
    SDM_SCANNER_OPENCL

    struct opencl_scanner_s *opencl_opts
    unsigned int thread_count
    struct address_space_s *address_space
    struct counter_s *counter

int sdm_init_linear (struct sdm_s *sdm, struct address_space_s *address_space, struct
                    counter_s *counter)
```

```
int sdm_init_thread (struct sdm_s *sdm, struct address_space_s *address_space, struct
                    counter_s *counter, unsigned int thread_count)
int sdm_init_opengl (struct sdm_s *sdm, struct address_space_s *address_space, struct
                    counter_s *counter, char *opengl_source)
void sdm_free (struct sdm_s *sdm)
int sdm_write (struct sdm_s *sdm, bitstring_t *addr, unsigned int radius, bitstring_t *datum)
int sdm_read (struct sdm_s *sdm, bitstring_t *addr, unsigned int radius, bitstring_t *output)
int sdm_iter_read (struct sdm_s *sdm, bitstring_t *addr, unsigned int radius, unsigned int max_iter, bitstring_t *output)
```

## 1.3 Examples

### 1.3.1 Distance between bitstrings

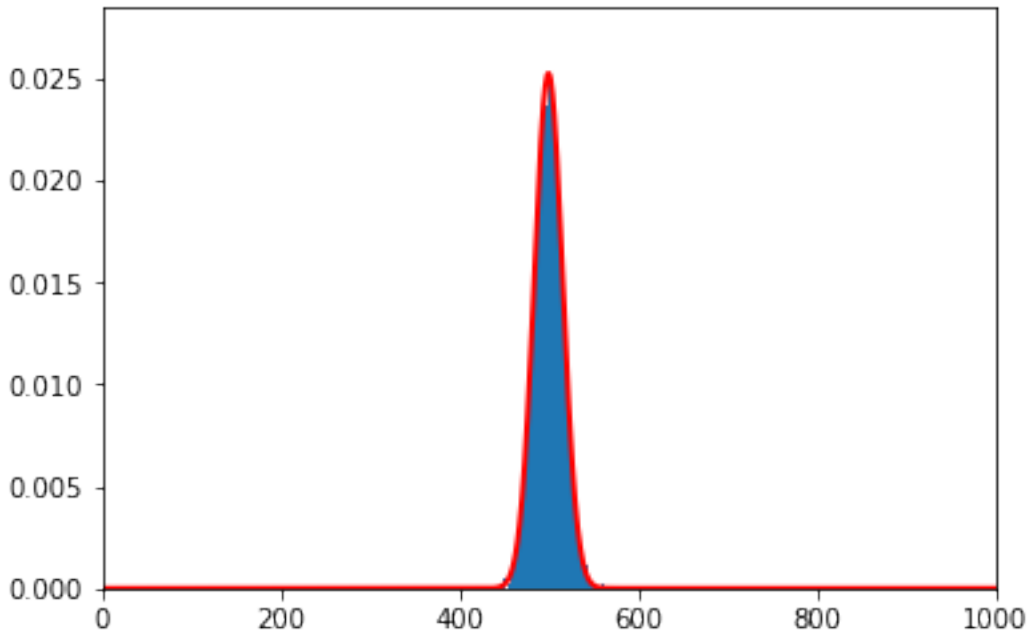
Here we will draw the histogram of the distance between two random bitstrings.

```
In [1]: import sdm as sdmlib
        import matplotlib.pyplot as plt
        import numpy as np
        import matplotlib.mlab as mlab
        %matplotlib inline

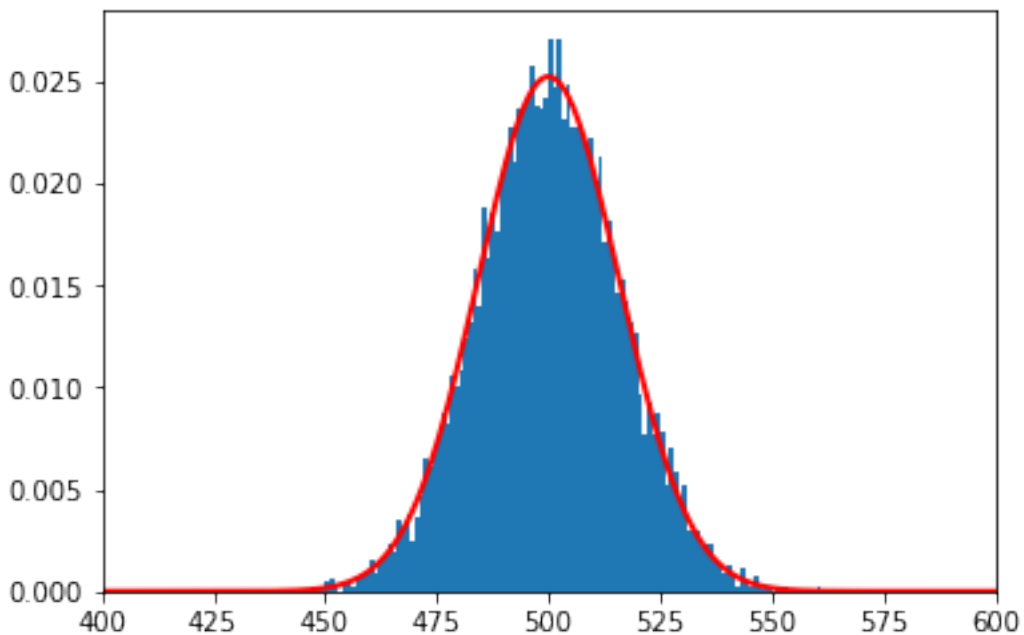
In [2]: distances = []
        for i in xrange(10000):
            b1 = sdmlib.Bitstring.init_random(1000)
            b2 = sdmlib.Bitstring.init_random(1000)
            distances.append(b1.distance_to(b2))

In [3]: mu = 500
        sigma = (1000**(0.5))/2.0
        x = np.linspace(0, 1000, 1000)
        y = mlab.normpdf(x, mu, sigma)

In [4]: plt.hist(distances, bins=range(1001), density=True)
        plt.plot(x, y, 'r', linewidth=2.0)
        plt.xlim(0, 1000)
        plt.show()
```



```
In [5]: plt.hist(distances, bins=range(1001), density=True)
plt.plot(x, y, 'r', linewidth=2.0)
plt.xlim(400, 600)
plt.show()
```



### 1.3.2 Generates a new SDM

```
In [1]: import sdm as sdmllib
In [2]: bits = 1000
sample = 1000000
```



```

scanner_type = sdmlib.SDM_SCANNER_OPENCL

In [3]: # Generate an address space with 1,000,000 random 1,000-bit bitstrings.
address_space = sdmlib.AddressSpace.init_random(bits, sample)

# Generate 1,000,000 counters initialized with value zero in the RAM memory.
counter = sdmlib.Counter.init_zero(bits, sample)

# Create a file to store the 1,000,000 counters initialized with value zero.
# You do not need to provide file extension, because it will generate two files
# and automatically included the extension for you.
#counter = sdmlib.Counter.create_file('sdm-10w', bits, sample)

# Create an SDM with the generated address space and counter.
# The scans will be performed using the OpenCL scanner.
sdm = sdmlib.SDM(address_space, counter, 451, scanner_type)

In [4]: v = []
for i in xrange(10):
    print i,
    # Generate a random 1,000-bit bitstring.
    b = sdmlib.Bitstring.init_random(1000)

    # Write the bitstring to the SDM.
    sdm.write(b, b)
    v.append(b)
print ''
print '{} bitstring wrote into memory.'.format(len(v))

0 1 2 3 4 5 6 7 8 9
10 bitstring wrote into memory.

In [5]: # Copy the bitstring from v[0].
# We have to make a copy because the flip_random_bits function changes the bitstring itself.
b = sdmlib.Bitstring.init_from_bitstring(v[0])
b.flip_random_bits(400)

# Read the bitstring from the SDM and checks the distance from the retrieved bitstring and v
c = sdm.read(b)
print 'Distance', c.distance_to(v[0])

Distance 134

In [6]: # Save the address space into the file 'sdm-10w.as'.
# The recommended extension for an address space is '.as'.

# Although we have used 10w as an indication of 10 writes to the memory, the
# address space is not affected by the writes. It is just a reference to help us
# remeber that this address space has been used together with the counters.
#address_space.save('sdm-10w.as');
```

### 1.3.3 Kanerva's Figure 1.2 (page 25)

```

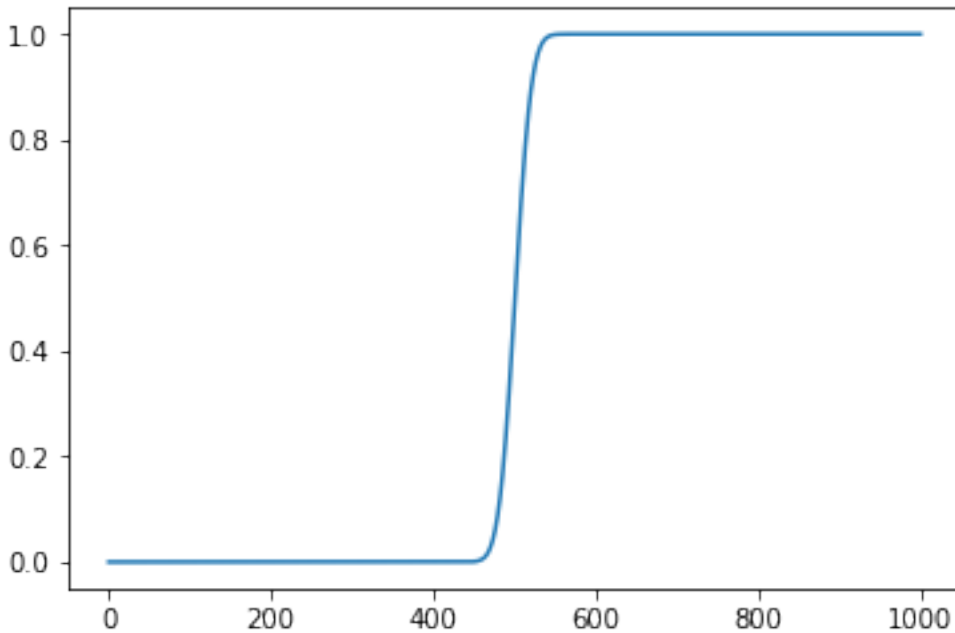
In [1]: import sdm as sdmlib
import matplotlib.pyplot as plt
from IPython.display import clear_output
%matplotlib inline

In [2]: bits = 1000
sample = 1000000
```

```
address_space = sdmlib.AddressSpace.init_random(bits, sample)
```

```
In [3]: def calculate_probabilities():
        from math import factorial
        comb = lambda a, b: factorial(a)/factorial(b)/factorial(a-b)
        acc = [0]
        for i in xrange(1001):
            acc.append(acc[-1] + comb(1000, i))
        x = range(0, 1001)
        y = [acc[i]/float(2**1000) for i in xrange(1001)]
        return x, y
```

```
In [4]: x, y = calculate_probabilities()
        plt.plot(x, y);
```



```
In [5]: def run(radius):
        x = range(0, 1001)
        y = []
        for i, dist in enumerate(x):
            clear_output(wait=True)
            print 'Distance: {:4d} ({:.2f}%)'.format(dist, 100.*(i+1)/len(x))

            b1 = sdmlib.Bitstring.init_random(bits)
            b2 = sdmlib.Bitstring.init_from_bitstring(b1)
            b2.flip_random_bits(dist)
            assert b1.distance_to(b2) == dist

            h1 = set(address_space.scan_thread(b1, radius, 4))
            h2 = set(address_space.scan_thread(b2, radius, 4))

            y.append(len(h1&h2))
        return x, y
```

```
In [6]: v = []
```

```
In [7]: v.append((451, run(451)))
```

```
Distance: 1000 (100.00%)
```

```
In [10]: v.append((480, run(480)))
```

```
Distance: 1000 (100.00%)
```

```
In [9]: v.append((500, run(500)))
```

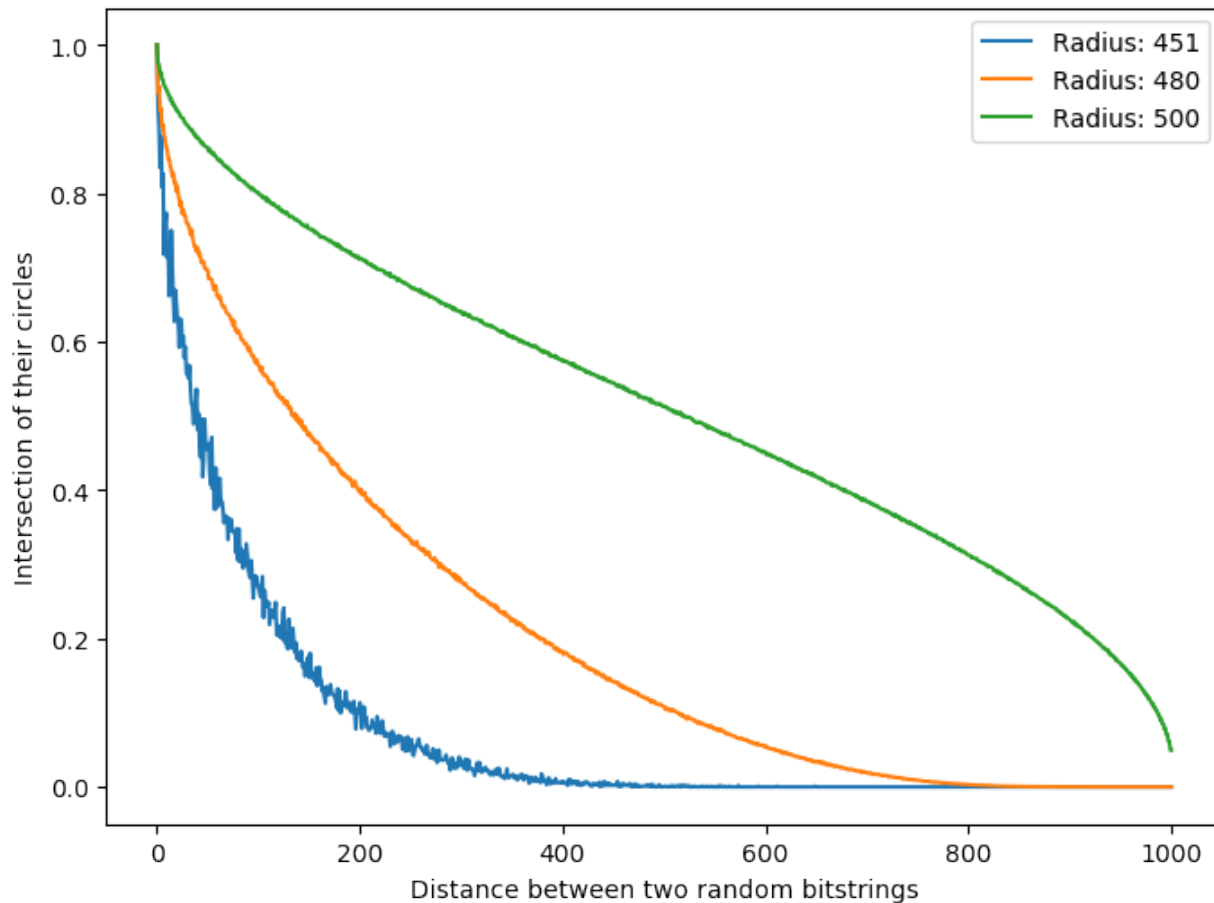
```
Distance: 1000 (100.00%)
```

```
In [14]: plt.figure(figsize=(8, 6), dpi=100)
         plt.hold(True)
         for d, points in v[:-1]:
             x, y = points
             ymax = max(y)
             y = [float(a)/ymax for a in y]
             plt.plot(x, y, label='Radius: {}'.format(d))
         plt.xlabel('Distance between two random bitstrings')
         plt.ylabel('Intersection of their circles')
         plt.legend()
         plt.hold(False)
```

```
/Library/Python/2.7/site-packages/ipykernel_launcher.py:2: MatplotlibDeprecationWarning: pyplot.hold
Future behavior will be consistent with the long-time default:
plot commands add elements without first clearing the
Axes and/or Figure.
```

```
/Library/Python/2.7/site-packages/ipykernel_launcher.py:11: MatplotlibDeprecationWarning: pyplot.hold
Future behavior will be consistent with the long-time default:
plot commands add elements without first clearing the
Axes and/or Figure.
```

```
# This is added back by InteractiveShellApp.init_path()
```



### 1.3.4 Kanerva's Table 7.3 (page 70)

```
In [1]: import sdm as sdmllib
import matplotlib.pyplot as plt
from IPython.display import clear_output
%matplotlib inline

In [2]: bits = 1000
sample = 1000000
radius = 451
scanner_type = sdmllib.SDM_SCANNER_OPENCL

In [3]: #address_space = sdmllib.AddressSpace.init_from_b64_file('sdm-10000w.as')
#counter = sdmllib.Counter.load_file('sdm-10000w')
address_space = sdmllib.AddressSpace.init_random(bits, sample)
counter = sdmllib.Counter.init_zero(bits, sample)
sdm = sdmllib.SDM(address_space, counter, radius, scanner_type)

In [4]: for i in range(10000):
clear_output(wait=True)
print i
bs = sdmllib.Bitstring.init_random(1000)
sdm.write(bs, bs)
```

9999

```
In [5]: b = sdmlib.Bitstring.init_random(1000)
        sdm.write(b, b)

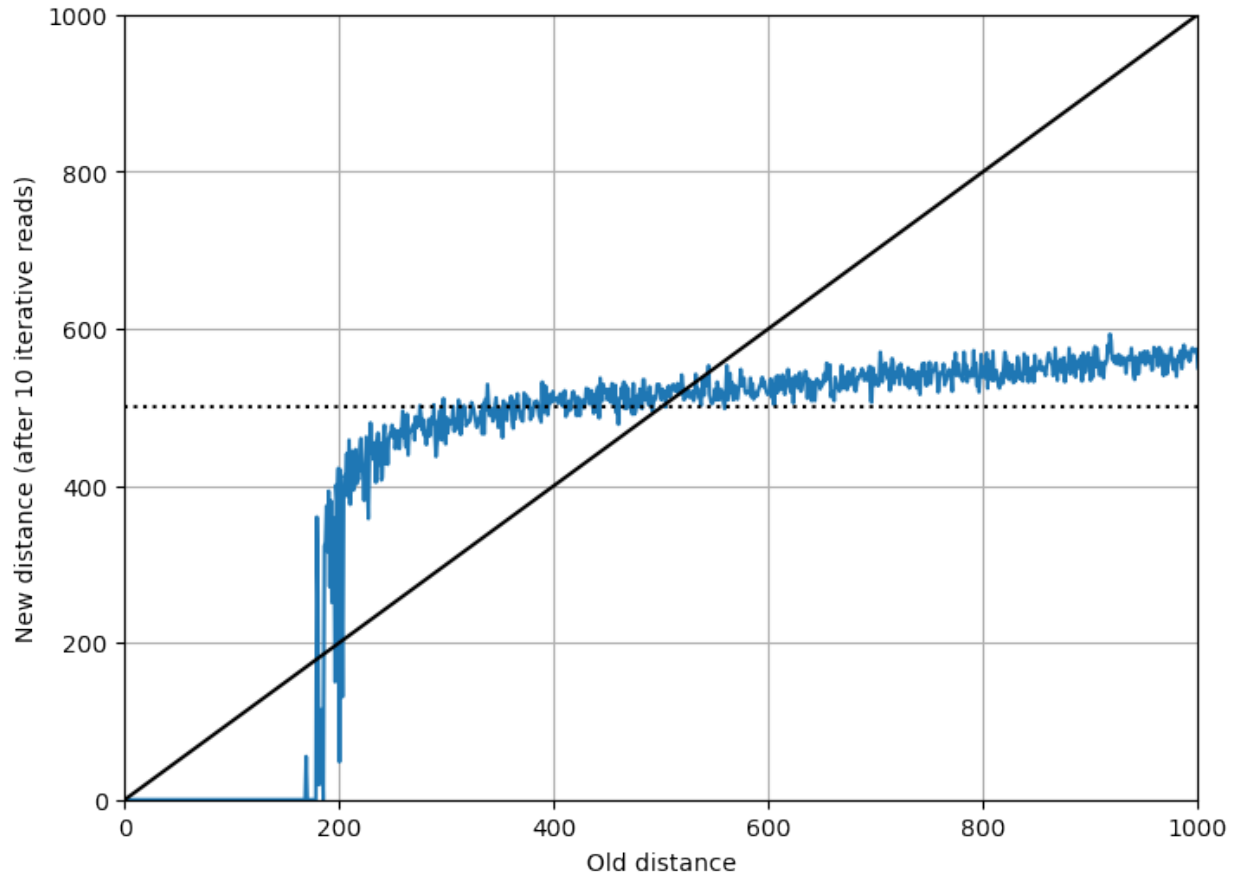
In [8]: from IPython.display import clear_output

        max_iter = 10
        samples = 1

        distances = []
        x = range(0, 1001)
        for i, dist in enumerate(x):
            clear_output(wait=True)
            print 'Distance: {:4d} ({:.2f}%)' .format(dist, 100.*(i+1)/len(x))
            v = []
            for j in range(samples):
                c = sdmlib.Bitstring.init_from_bitstring(b)
                c.flip_random_bits(dist)
                assert c.distance_to(b) == dist
                d = sdm.iter_read(c, max_iter=max_iter)
                v.append(d.distance_to(b))
            distances.append(1.0*sum(v)/len(v))
        print 'Done!'

Distance: 1000 (100.00%)
Done!

In [9]: plt.figure(figsize=(8, 6), dpi=100)
        plt.plot(x, distances)
        plt.plot(x, x, 'k')
        plt.plot(x, [500]*len(x), 'k:')
        #plt.title('Kanerva\'s Figure 7.3')
        if max_iter == 1:
            plt.ylabel('New distance (after a single read)')
        else:
            plt.ylabel('New distance (after {} iterative reads)'.format(max_iter))
        plt.xlabel('Old distance')
        plt.grid()
        #plt.axis([0, 1000, 0, 1000]);
        plt.axis([x[0], x[-1], x[0], x[-1]]);
```



```
In [ ]: c = sdmllib.Bitstring.init_from_bitstring(b)
        c.flip_random_bits(1000)
        d = c
        print 0, b.distance_to(d)
        for i in xrange(10):
            d = sdm.read(d)
            print i+1, b.distance_to(d)
```

### 1.3.5 Noise filter

```
In [1]: import sdm as sdmllib
        import matplotlib.pyplot as plt
        from PIL import Image, ImageDraw, ImageFont
        import urllib, cStringIO
        import random
        from IPython.core.display import display, Image as IPythonImage
        %matplotlib inline

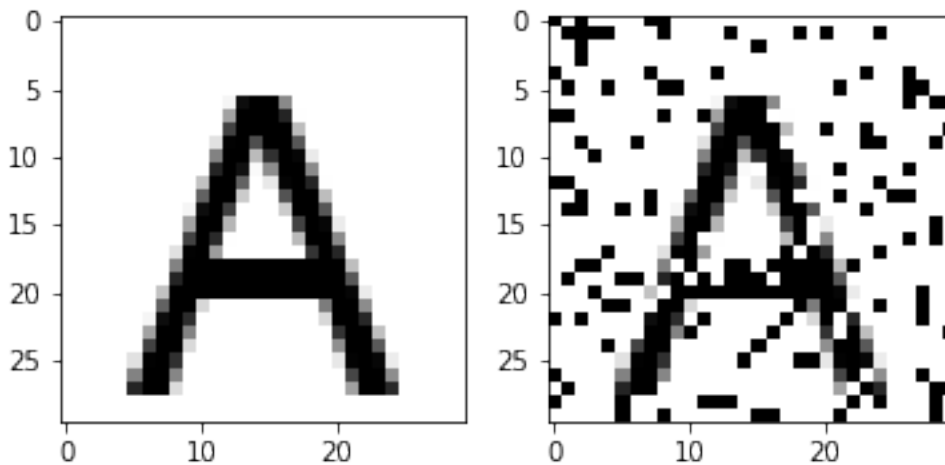
In [2]: width = 30
        height = 30
        noise_flip = True

In [3]: def gen_img(letter='A'):
        img = Image.new('RGBA', (30, 30), (255, 255, 255))
        font = ImageFont.truetype('Arial.ttf', 30)
        draw = ImageDraw.Draw(img)
```

```
draw.text((5, 0), letter, (0, 0, 0), font=font)
return img
```

```
In [4]: def gen_noise_add(img, p=0.15, flip=False):
img2 = img.copy()
draw = ImageDraw.Draw(img2)
for py in xrange(height):
    for px in xrange(width):
        if random.random() < p:
            if flip:
                pixel = img.getpixel((px, py))
                value = sum([int(x/255+0.5) for x in pixel[:3]])/3
                assert value == 0 or value == 1
                value = (1 - value)*255
                draw.point((px, py), fill=(value, value, value))
            else:
                draw.point((px, py), fill=(0, 0, 0))
return img2
```

```
In [5]: img = gen_img();
img2 = gen_noise_add(img, flip=noise_flip)
plt.subplot(1, 2, 1)
plt.imshow(img)
plt.subplot(1, 2, 2)
plt.imshow(img2);
```



```
In [6]: def to_bitstring(img):
v = []
bs = sdmlib.Bitstring.init_ones(1000)
for py in xrange(height):
    for px in xrange(width):
        pixel = img.getpixel((px, py))
        value = sum([int(x/255+0.5) for x in pixel[:3]])/3
        assert value == 0 or value == 1
        idx = px+width*py
        assert idx >= 0 and idx < 1000, 'Ops {} {} {}'.format(x, y, idx)
        bs.set_bit(idx, value)
        v.append(value)
v2 = [bs.get_bit(i) for i in xrange(height*width)]
assert v == v2
return bs
```

```
In [7]: def to_img(bs):
```

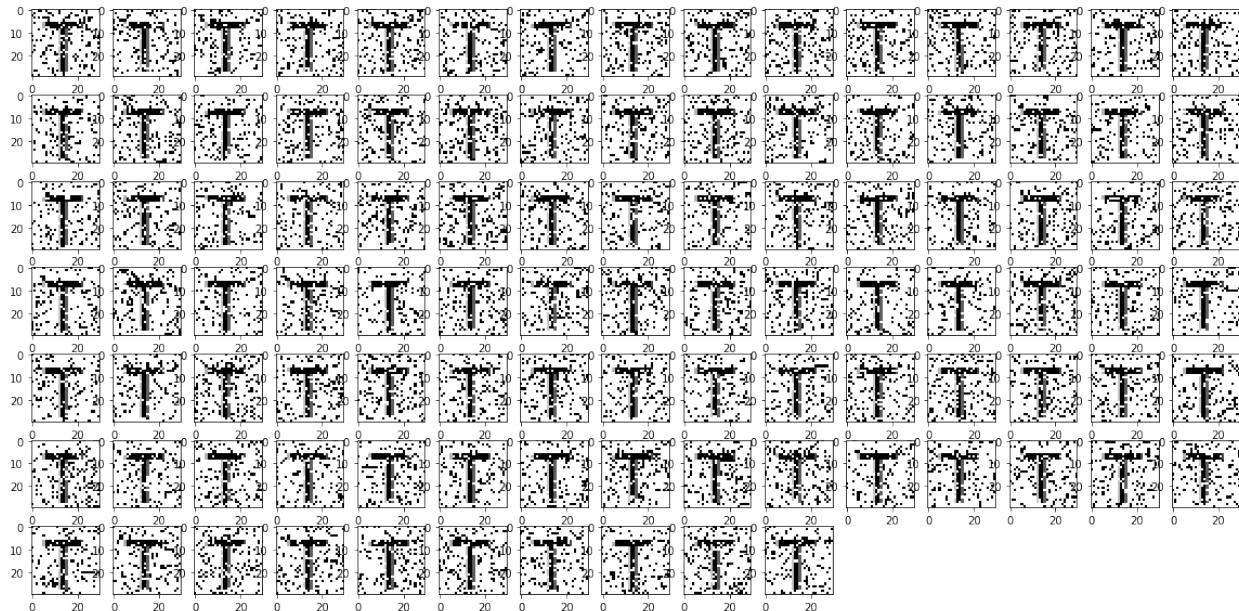
```
img = Image.new('RGBA', (30, 30), (255, 255, 255))
draw = ImageDraw.Draw(img)
for py in xrange(height):
    for px in xrange(width):
        idx = px+width*py
        assert idx >= 0 and idx < 1000, 'Ops {} {} {}'.format(x, y, idx)
        x = 255*bs.get_bit(idx)
        draw.point((px, py), fill=(x, x, x))
return img
```

```
In [8]: bits = 1000
sample = 1000000
scanner_type = sdmllib.SDM_SCANNER_OPENCL
```

```
In [9]: address_space = sdmllib.AddressSpace.init_random(bits, sample)
counter = sdmllib.Counter.init_zero(bits, sample)
sdm = sdmllib.SDM(address_space, counter, 451, scanner_type)
```

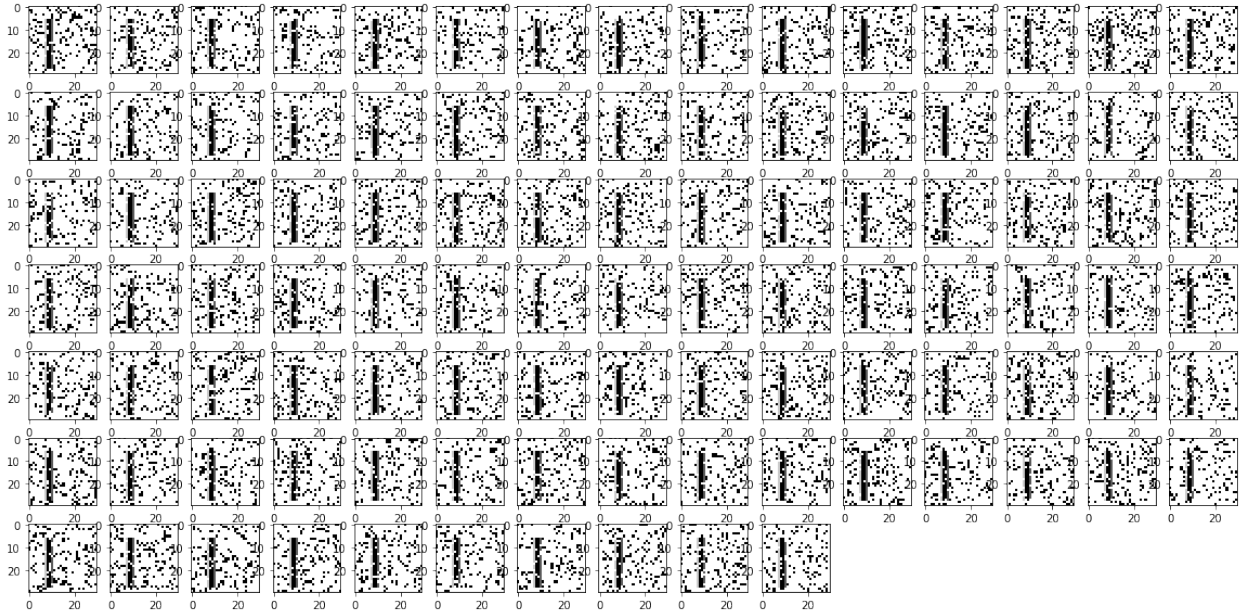
```
In [10]: def fill_memory(letter, p=0.15, n=100):
    cols = 15
    rows = n//cols + 1
    plt.figure(figsize=(20,10))
    for i in xrange(n):
        img = gen_img(letter=letter);
        img2 = gen_noise_add(img, flip=noise_flip)
        #display(img2)
        plt.subplot(rows, cols, i+1)
        plt.imshow(img2)
        bs = to_bitstring(img2)
        sdm.write(bs, bs)
```

```
In [11]: fill_memory('T')
```



```
In [12]: fill_memory('I')
```



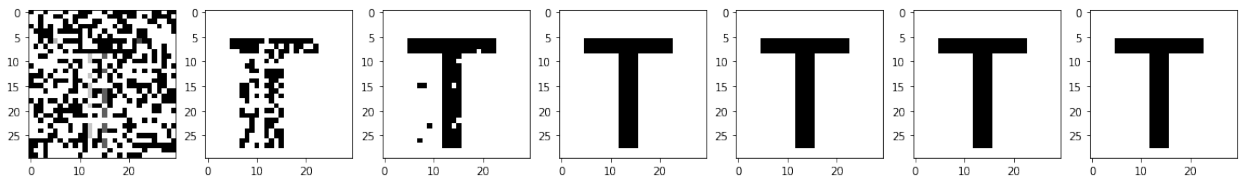


```
In [13]: def read(letter, n=6, p=0.25):
    n = 6
    cols = 7
    rows = n//cols + 1
    plt.figure(figsize=(20,10))

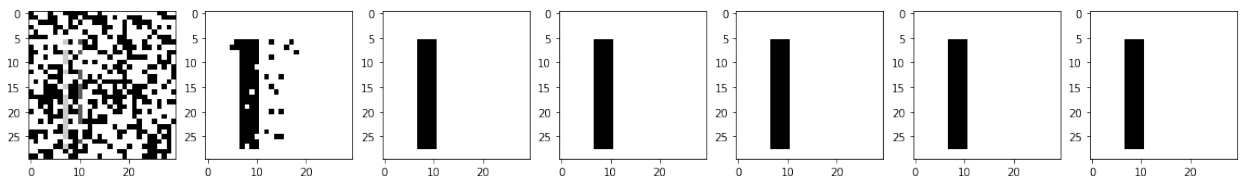
    img = gen_img(letter=letter);
    img2 = gen_noise_add(img, p=p, flip=noise_flip)
    plt.subplot(rows, cols, 1)
    plt.imshow(img2)

    for i in xrange(n):
        bs2 = to_bitstring(img2)
        bs3 = sdm.read(bs2)
        img3 = to_img(bs3)
        plt.subplot(rows, cols, i+2)
        plt.imshow(img3)
        img2 = img3
```

```
In [20]: read('T', p=0.42)
```



```
In [15]: read('I', p=0.42)
```



### 1.3.6 Classification Test #1

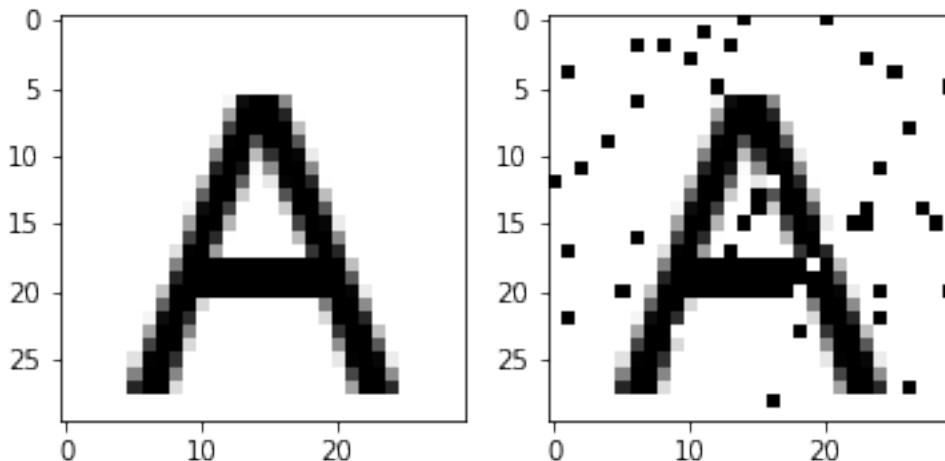
```
In [1]: import sdm as sdmllib
import matplotlib.pyplot as plt
from PIL import Image, ImageDraw, ImageFont
import urllib, cStringIO
import random
from IPython.core.display import display, Image as IPythonImage
%matplotlib inline

In [2]: width = 30
height = 30
noise_flip = True

In [3]: def gen_img(letter='A'):
    img = Image.new('RGBA', (30, 30), (255, 255, 255))
    font = ImageFont.truetype('Arial.ttf', 30)
    draw = ImageDraw.Draw(img)
    draw.text((5, 0), letter, (0, 0, 0), font=font)
    return img

In [4]: def gen_noise_add(img, p=0.15, flip=False):
    img2 = img.copy()
    draw = ImageDraw.Draw(img2)
    for py in xrange(height):
        for px in xrange(width):
            if random.random() < p:
                if flip:
                    pixel = img.getpixel((px, py))
                    value = sum([int(x/255+0.5) for x in pixel[:3]])//3
                    assert value == 0 or value == 1
                    value = (1 - value)*255
                    draw.point((px, py), fill=(value, value, value))
                else:
                    draw.point((px, py), fill=(0, 0, 0))
    return img2

In [5]: img = gen_img();
img2 = gen_noise_add(img, p=0.05, flip=noise_flip)
plt.subplot(1, 2, 1)
plt.imshow(img)
plt.subplot(1, 2, 2)
plt.imshow(img2);
```



```
In [6]: def to_bitstring(img):
        v = []
        bs = sdmlib.Bitstring.init_ones(1000)
        for py in xrange(height):
            for px in xrange(width):
                pixel = img.getpixel((px, py))
                value = sum([int(x/255+0.5) for x in pixel[:3]])//3
                assert value == 0 or value == 1
                idx = px+width*py
                assert idx >= 0 and idx < 1000, 'Ops {} {} {}'.format(x, y, idx)
                bs.set_bit(idx, value)
                v.append(value)
        v2 = [bs.get_bit(i) for i in xrange(height*width)]
        assert v == v2
        return bs
```

```
In [7]: def to_img(bs):
        img = Image.new('RGBA', (30, 30), (255, 255, 255))
        draw = ImageDraw.Draw(img)
        for py in xrange(height):
            for px in xrange(width):
                idx = px+width*py
                assert idx >= 0 and idx < 1000, 'Ops {} {} {}'.format(x, y, idx)
                x = 255*bs.get_bit(idx)
                draw.point((px, py), fill=(x, x, x))
        return img
```

```
In [8]: bits = 1000
        sample = 1000000
        scanner_type = sdmlib.SDM_SCANNER_THREAD
```

```
In [9]: address_space = sdmlib.AddressSpace.init_from_b64_file('sdm-letters.as')
        counter = sdmlib.Counter.create_file('sdm-classification', bits, sample)
        sdm = sdmlib.SDM(address_space, counter, 451, scanner_type)
```

```
In [10]: for i in xrange(100):
          print i,
          b = sdmlib.Bitstring.init_random(1000)
          sdm.write(b, b)
```

```
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36
```

```
In [11]: def fill_memory(letter, label_bs, p=0.1, n=100):
        cols = 15
        rows = n//cols + 1
        plt.figure(figsize=(20,10))
        for i in xrange(n):
            img = gen_img(letter=letter);
            img2 = gen_noise_add(img, p=p, flip=noise_flip)
            #display(img2)
            plt.subplot(rows, cols, i+1)
            plt.imshow(img2)
            bs = to_bitstring(img2)
            bs.xor(label_bs)
            sdm.write(bs, bs)
        plt.show()
```

```
In [12]: def read(letter, label_bs, n=6, p=0.2, radius=None):
        n = 7
        cols = 15
        rows = n//cols + 1
        plt.figure(figsize=(20,10))
```

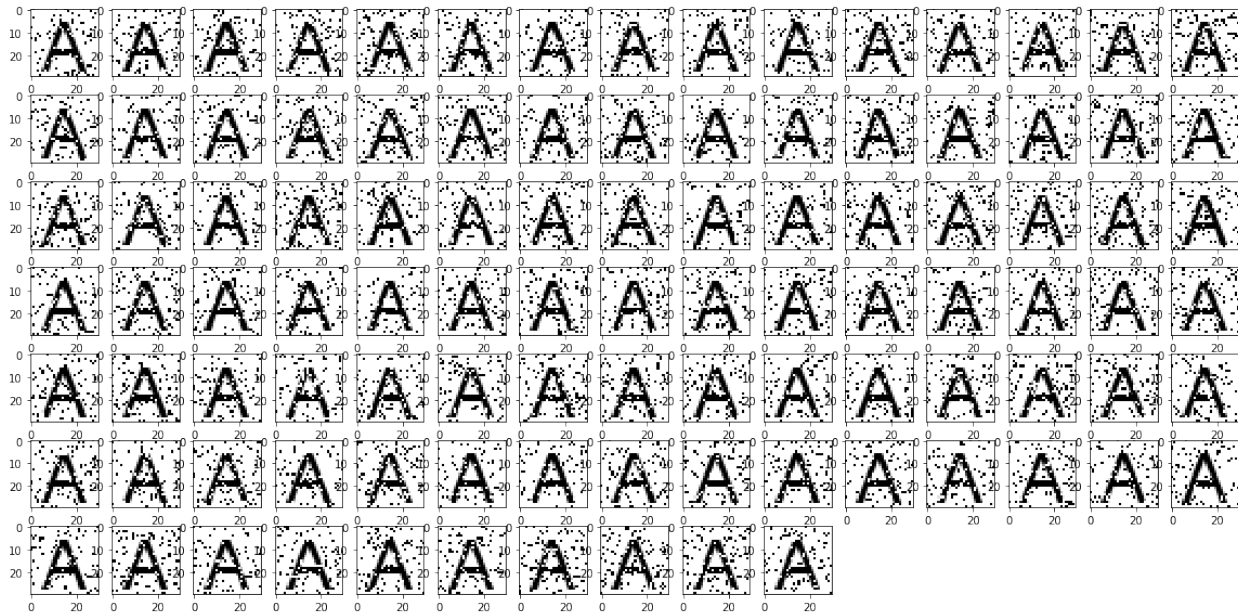
```
img = gen_img(letter=letter);
img2 = gen_noise_add(img, p=p, flip=noise_flip)
plt.subplot(rows, cols, 1)
plt.imshow(img2)
```

```
for i in xrange(n):
    bs2 = to_bitstring(img2)
    bs2.xor(label_bs)
    bs3 = sdm.read(bs2, radius=radius)
    if bs3 == bs2:
        break
    bs3.xor(label_bs)
    img3 = to_img(bs3)
    plt.subplot(rows, cols, i+2)
    plt.imshow(img3)
    img2 = img3
```

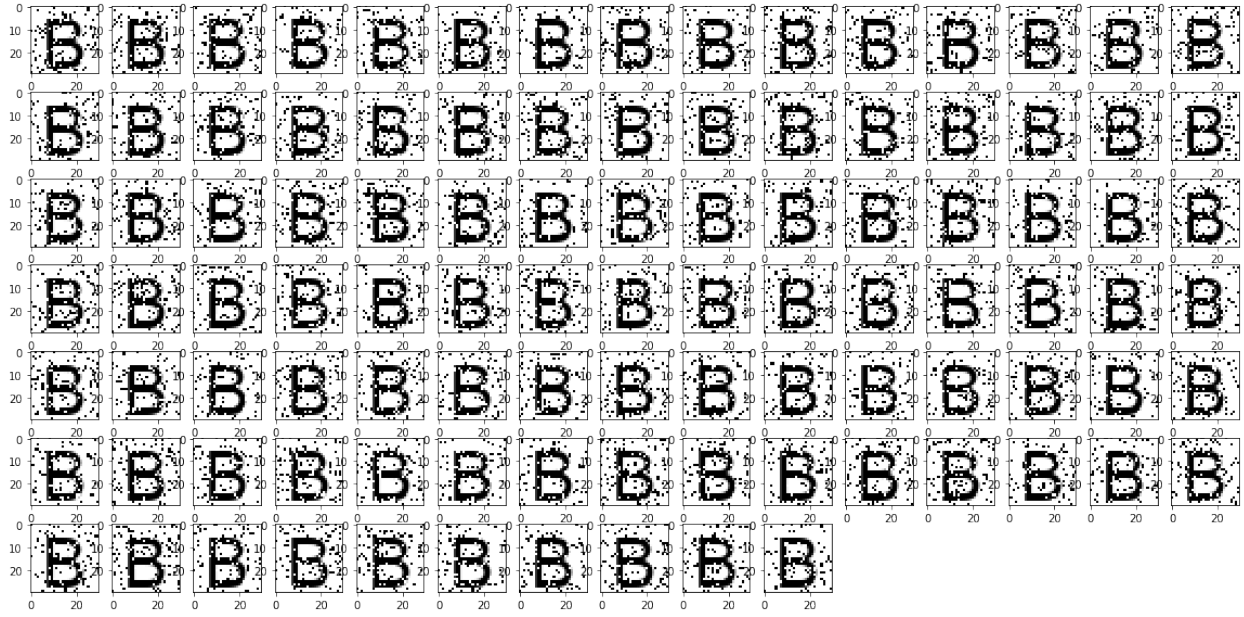
```
In [13]: labels = list('ABCD8OQ')
        label_to_bs = {}
        for x in labels:
            label_to_bs[x] = sdmlib.Bitstring.init_random(1000)
```

```
In [14]: for x in labels:
        print 'Training for label {}'.format(x)
        fill_memory(x, label_to_bs[x])
```

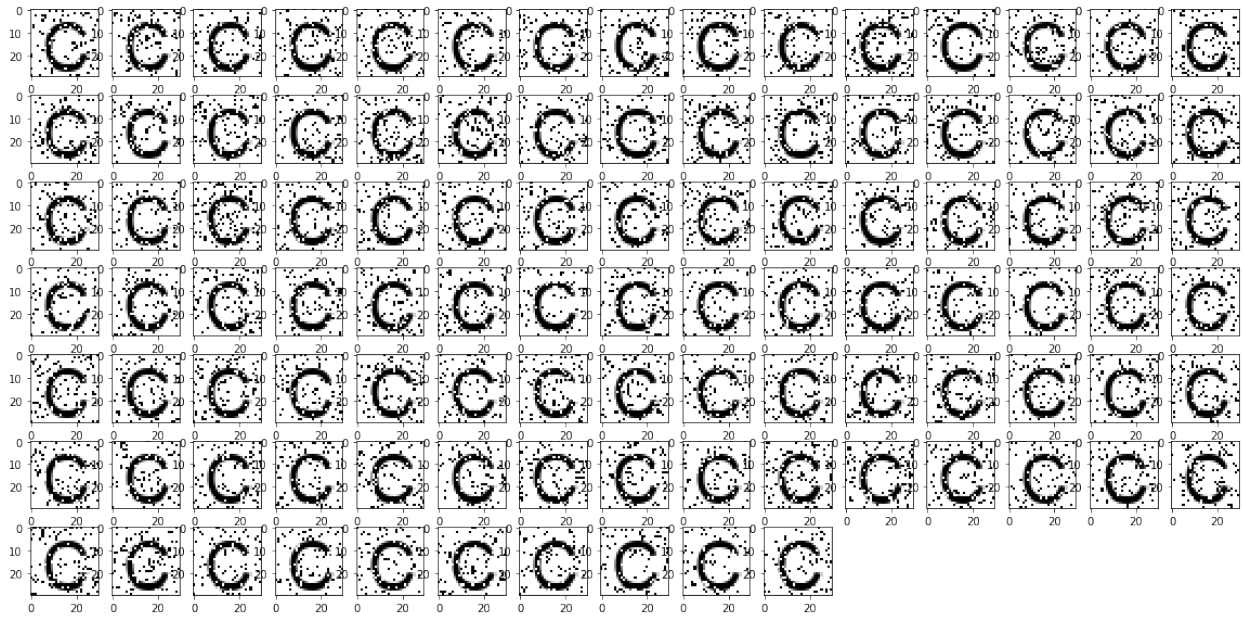
Training for label A...



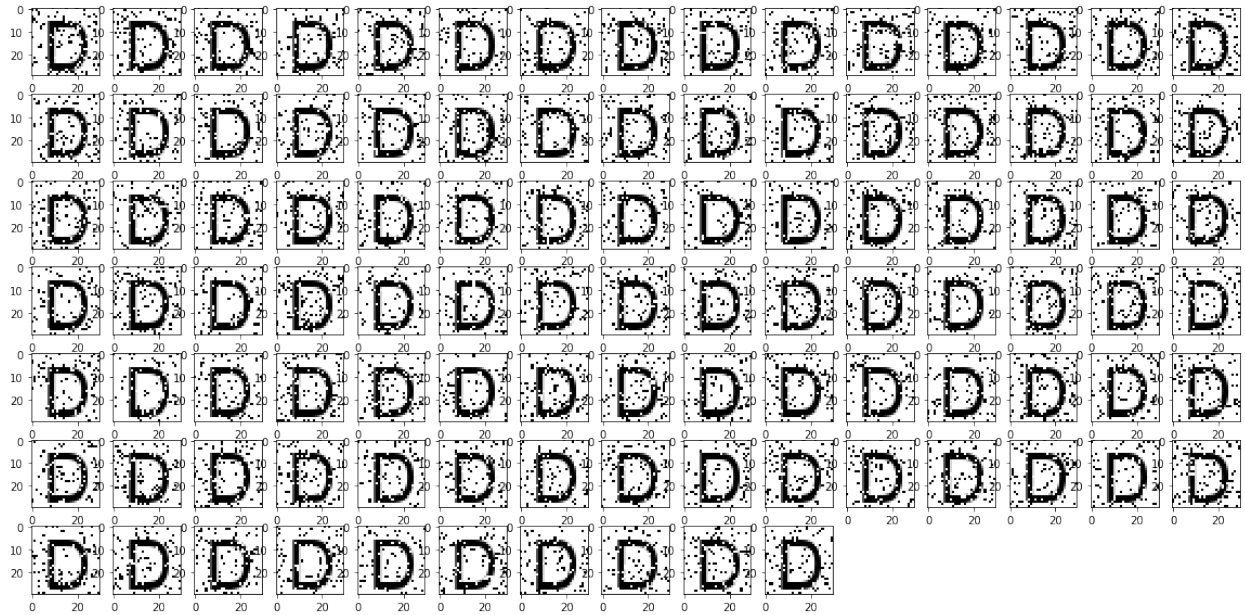
Training for label B...



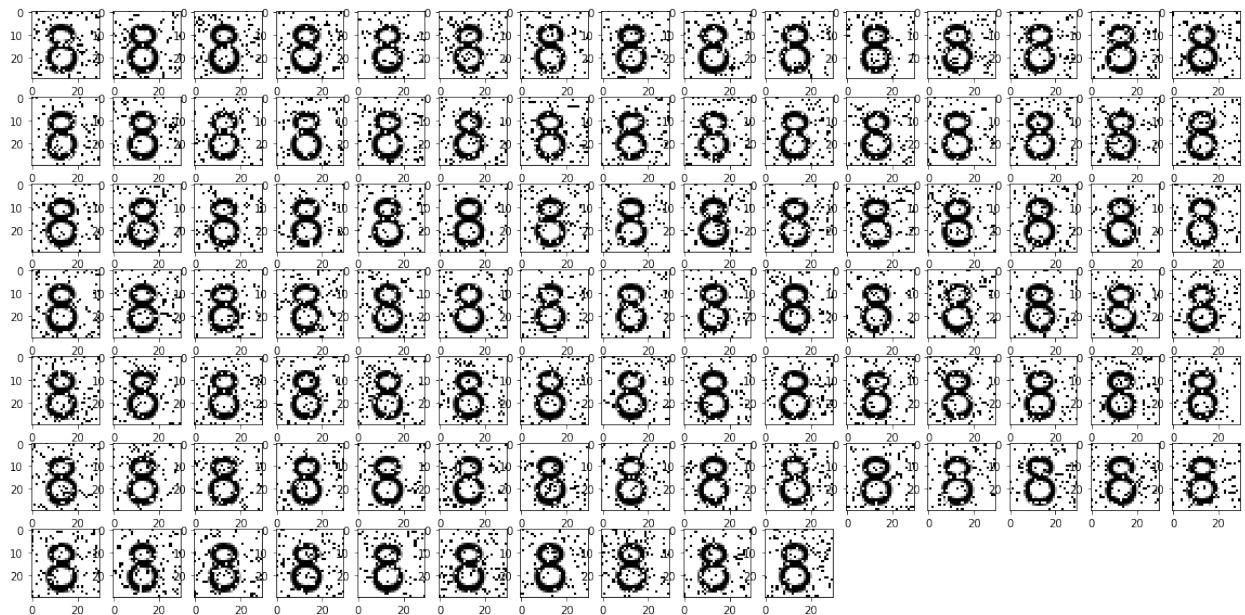
Training for label C...



Training for label D...

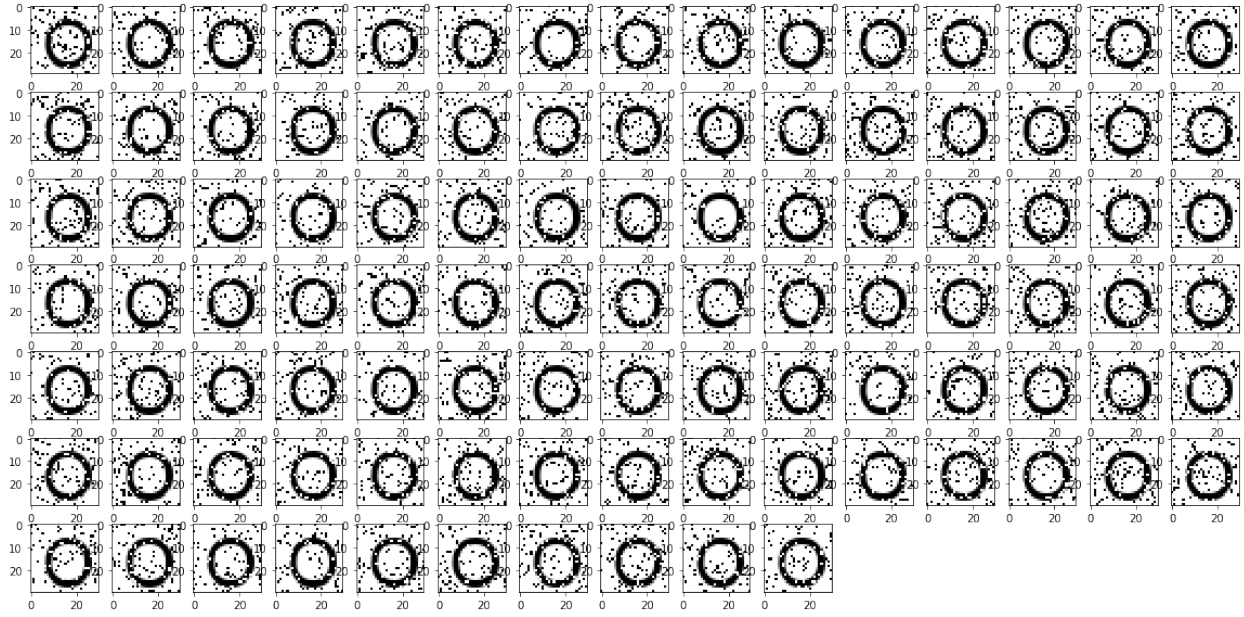


Training for label 8...

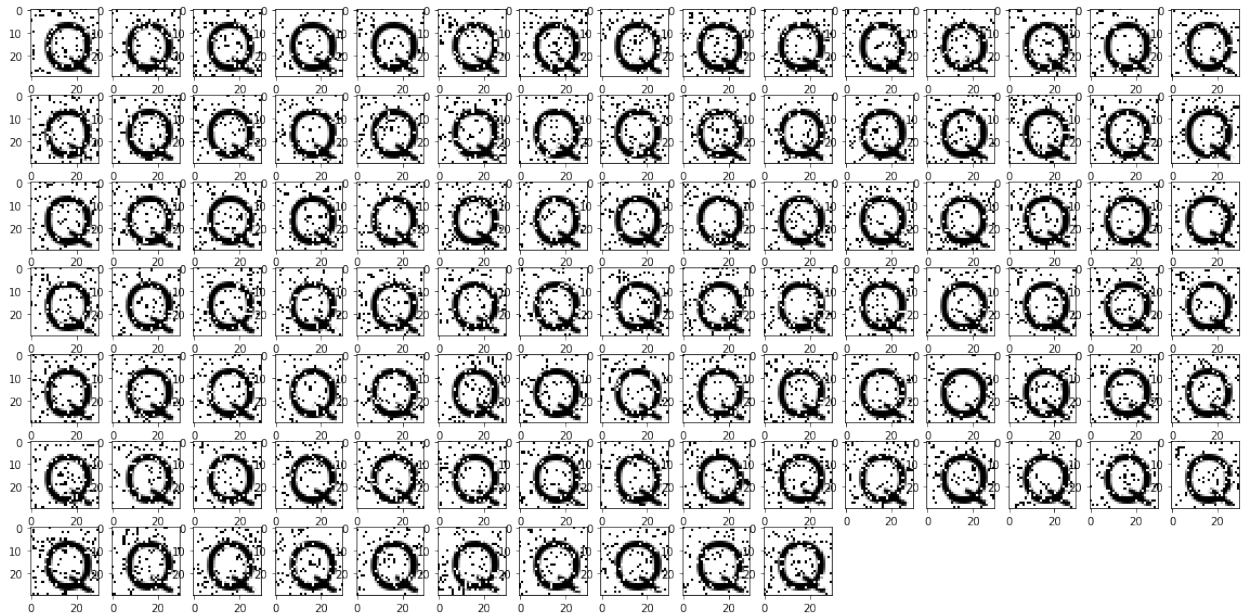


Training for label 0...

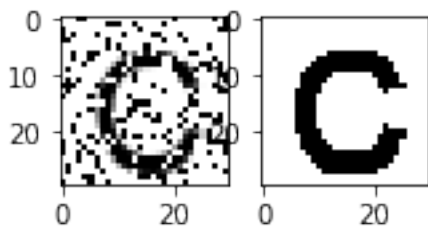


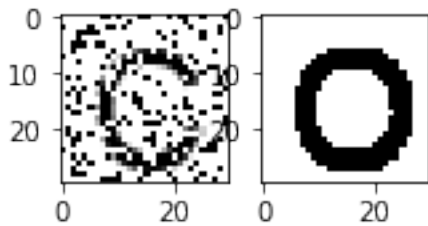
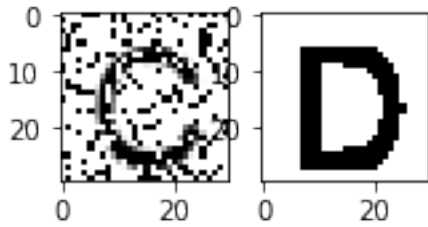


Training for label Q...

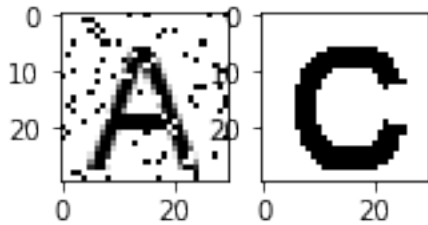


```
In [15]: read('C', label_to_bs['C'])
         read('C', label_to_bs['D'])
         read('C', label_to_bs['O'])
```





```
In [16]: read('A', label_to_bs['C'], p=0.1)
```



```
In [17]: read('A', sdmllib.Bitstring.init_random(1000), p=0)
```



```
In [18]: def intersection(a, b):
          bs1 = to_bitstring(gen_img(letter=a))
          bs2 = to_bitstring(gen_img(letter=b))
          h11 = set(address_space.scan_thread(bs1, 451, 4))
          h12 = set(address_space.scan_thread(bs2, 451, 4))
          return len(h11 & h12)
          print intersection('B', '8')
```

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### 1.3.7 Classification Test #2

```
In [1]: import sdm as sdmllib
import matplotlib.pyplot as plt
from PIL import Image, ImageDraw, ImageFont
import urllib, cStringIO
import random
from IPython.core.display import display, Image as IPythonImage
%matplotlib inline
```



```

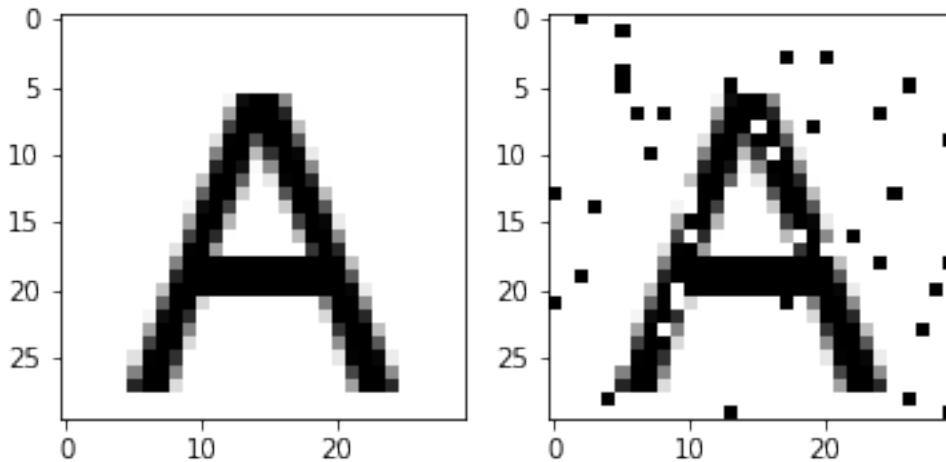
In [2]: width = 30
        height = 30
        noise_flip = True

In [3]: def gen_img(letter='A'):
        img = Image.new('RGBA', (30, 30), (255, 255, 255))
        font = ImageFont.truetype('Arial.ttf', 30)
        draw = ImageDraw.Draw(img)
        draw.text((5, 0), letter, (0, 0, 0), font=font)
        return img

In [4]: def gen_noise_add(img, p=0.15, flip=False):
        img2 = img.copy()
        draw = ImageDraw.Draw(img2)
        for py in xrange(height):
            for px in xrange(width):
                if random.random() < p:
                    if flip:
                        pixel = img.getpixel((px, py))
                        value = sum([int(x/255+0.5) for x in pixel[:3]])//3
                        assert value == 0 or value == 1
                        value = (1 - value)*255
                        draw.point((px, py), fill=(value, value, value))
                    else:
                        draw.point((px, py), fill=(0, 0, 0))
        return img2

In [5]: img = gen_img();
        img2 = gen_noise_add(img, p=0.05, flip=noise_flip)
        plt.subplot(1, 2, 1)
        plt.imshow(img)
        plt.subplot(1, 2, 2)
        plt.imshow(img2);

```



```

In [6]: def to_bitstring(img):
        v = []
        bs = sdmlib.Bitstring.init_ones(1000)
        for py in xrange(height):
            for px in xrange(width):
                pixel = img.getpixel((px, py))
                value = sum([int(x/255+0.5) for x in pixel[:3]])//3
                assert value == 0 or value == 1
                idx = px+width*py

```

```

        assert idx >= 0 and idx < 1000, 'Ops {} {} {}'.format(x, y, idx)
        bs.set_bit(idx, value)
        v.append(value)
    v2 = [bs.get_bit(i) for i in xrange(height*width)]
    assert v == v2
    return bs

In [7]: def to_img(bs):
    img = Image.new('RGBA', (30, 30), (255, 255, 255))
    draw = ImageDraw.Draw(img)
    for py in xrange(height):
        for px in xrange(width):
            idx = px*width*py
            assert idx >= 0 and idx < 1000, 'Ops {} {} {}'.format(x, y, idx)
            x = 255*bs.get_bit(idx)
            draw.point((px, py), fill=(x, x, x))
    return img

In [8]: bits = 1000
    sample = 1000000
    scanner_type = sdmllib.SDM_SCANNER_OPENCL

In [9]: address_space = sdmllib.AddressSpace.init_from_b64_file('sdm-letters.as')
    counter = sdmllib.Counter.create_file('sdm-classification-2', bits, sample)
    sdm = sdmllib.SDM(address_space, counter, 451, scanner_type)

In [10]: def fill_memory(letter, label_bs, p=0.1, n=100):
    cols = 15
    rows = n//cols + 1
    plt.figure(figsize=(20,10))
    for i in xrange(n):
        img = gen_img(letter=letter);
        img2 = gen_noise_add(img, p=p, flip=noise_flip)
        #display(img2)
        plt.subplot(rows, cols, i+1)
        plt.imshow(img2)
        bs = to_bitstring(img2)
        sdm.write(bs, label_bs)
    plt.show()

In [11]: def read(letter, n=6, p=0.2, radius=None):
    n = 7
    cols = 15
    rows = n//cols + 1
    plt.figure(figsize=(20,10))

    img = gen_img(letter=letter);
    img2 = gen_noise_add(img, p=p, flip=noise_flip)
    plt.subplot(rows, cols, 1)
    plt.imshow(img2)

    bs2 = to_bitstring(img2)
    bs3 = sdm.read(bs2, radius=radius)

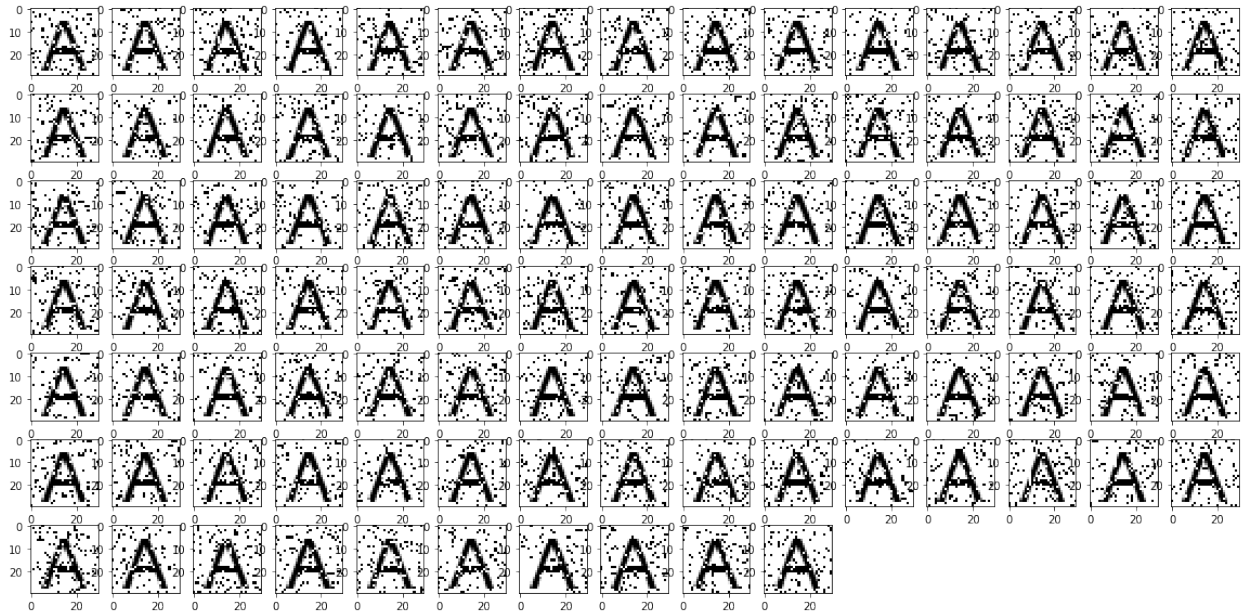
    label = min(label_to_bs.items(), key=lambda v: bs3.distance_to(v[1]))
    return label[0]

In [12]: labels = list('ABCD80Q0')
    label_to_bs = {}
    for x in labels:
        label_to_bs[x] = sdmllib.Bitstring.init_random(1000)

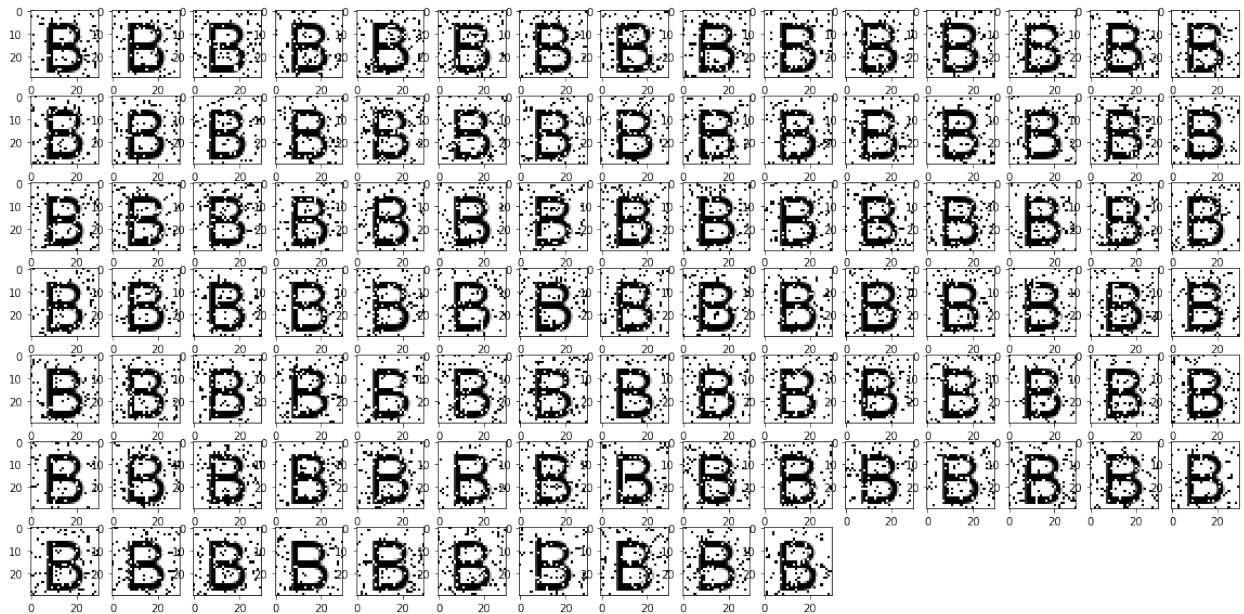
```

```
In [13]: for x in labels:
        print 'Training for label {}'.format(x)
        fill_memory(x, label_to_bs[x])
```

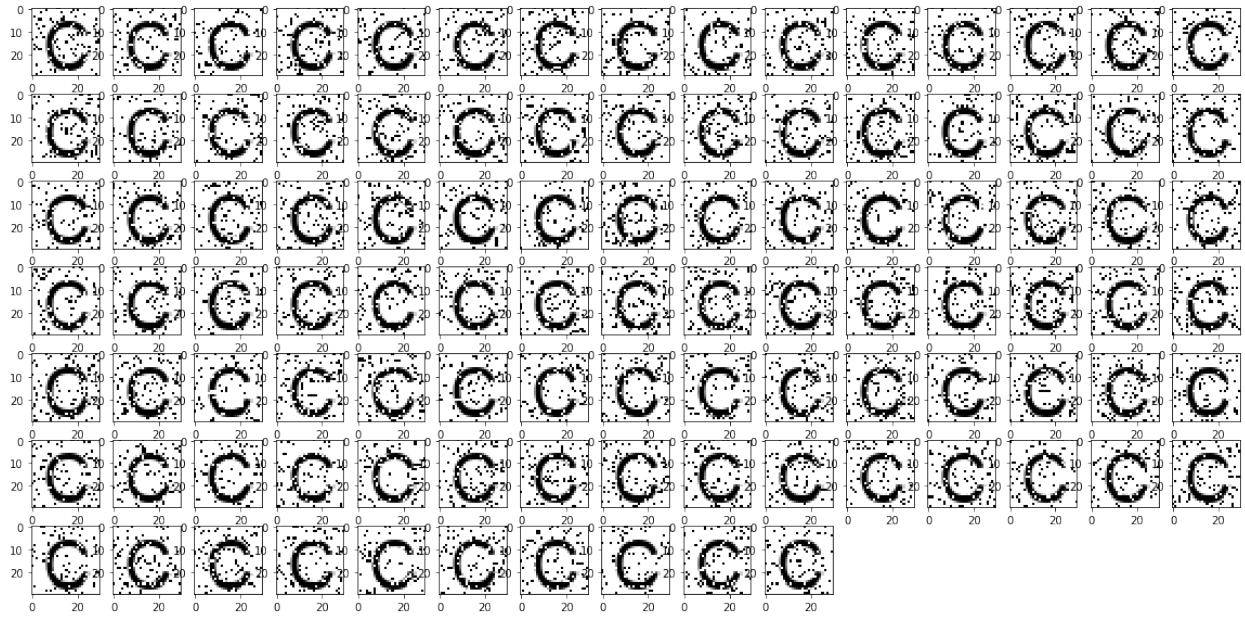
Training for label A...



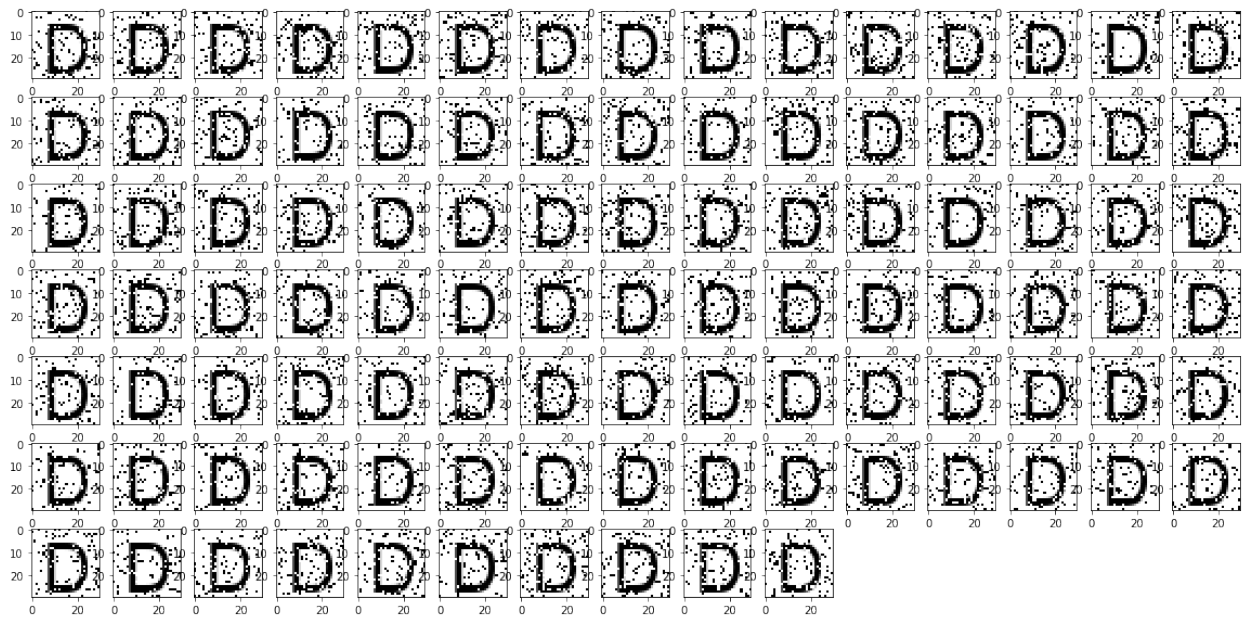
Training for label B...



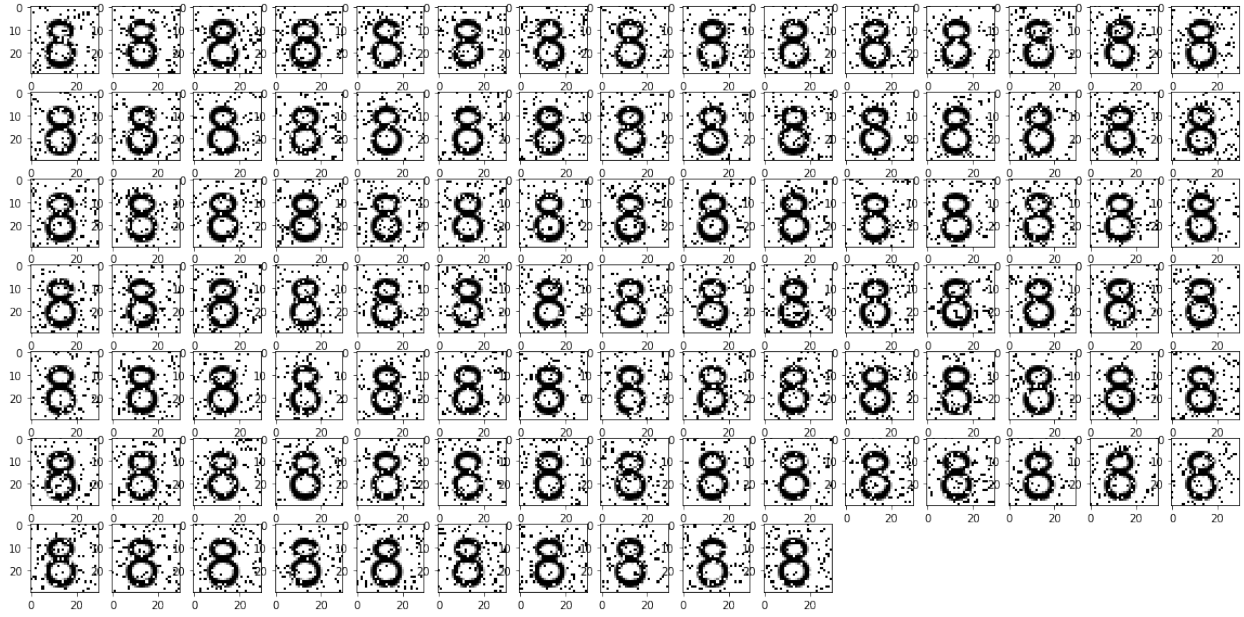
Training for label C...



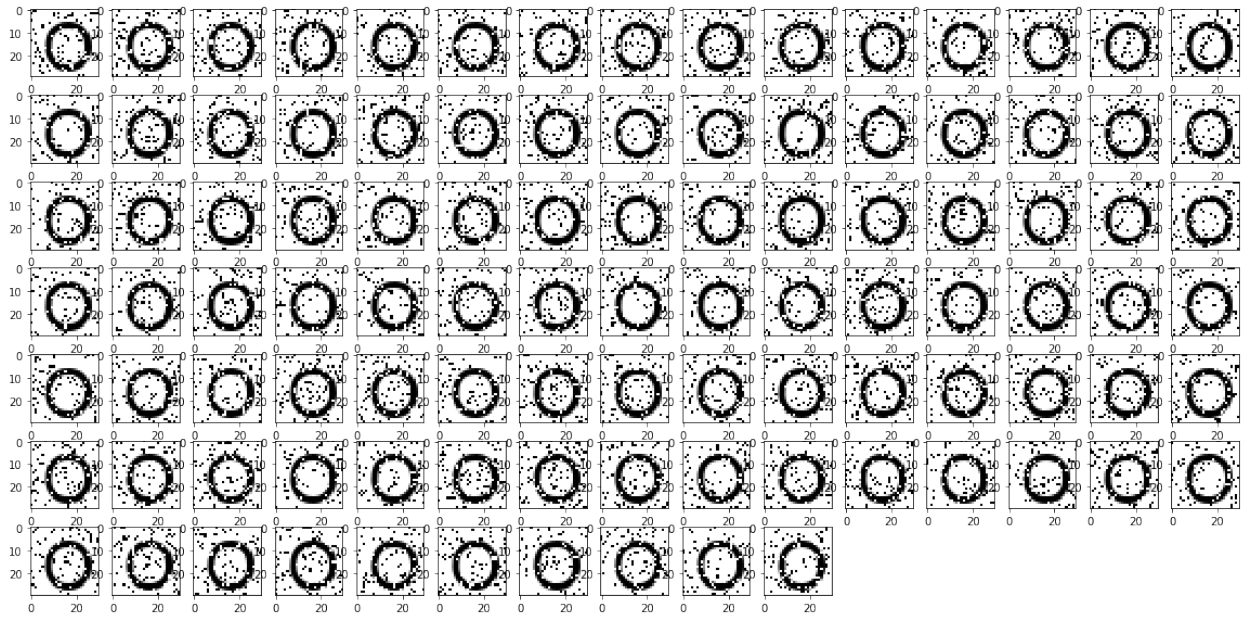
Training for label D...



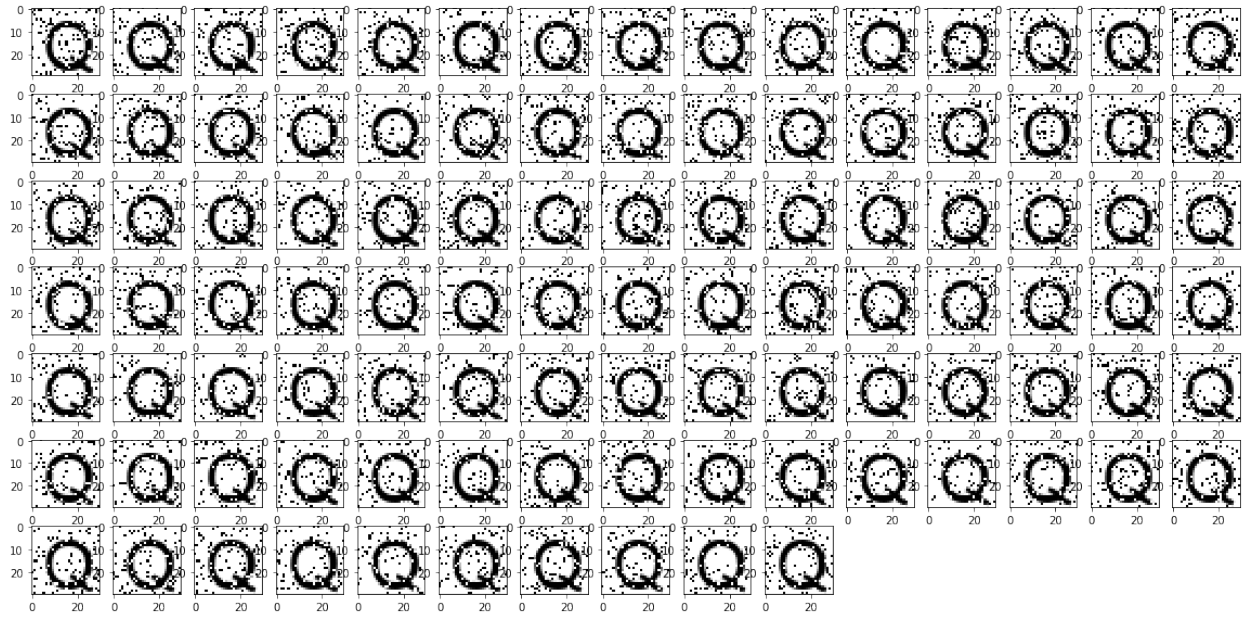
Training for label 8...



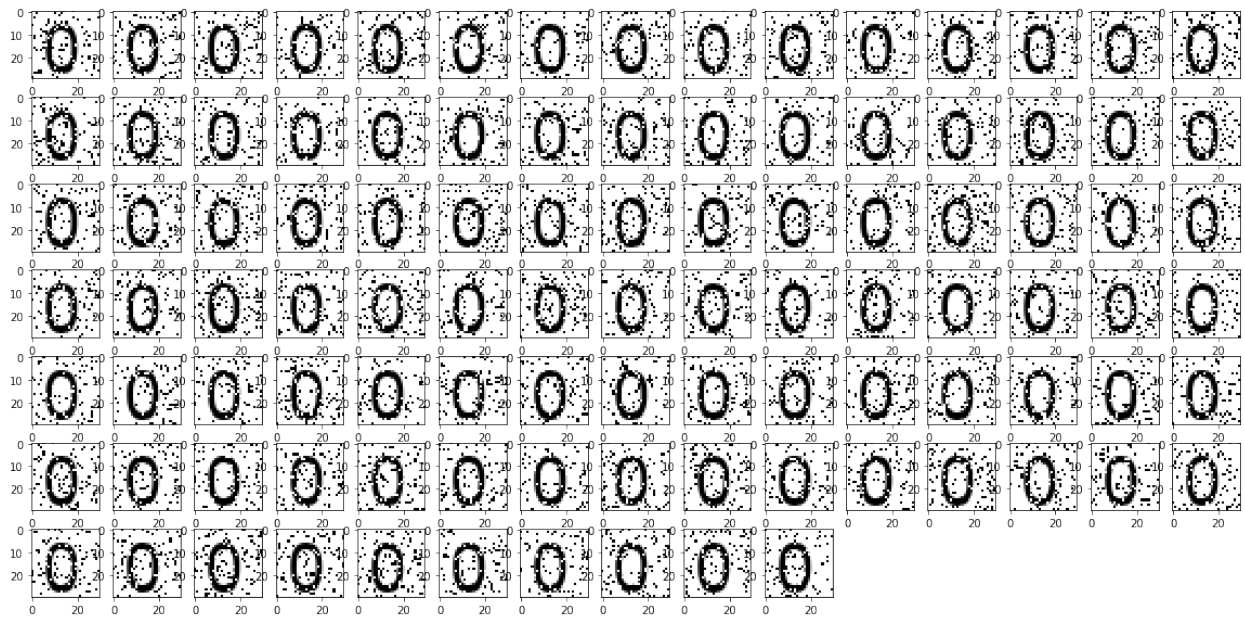
Training for label 0...



Training for label Q...

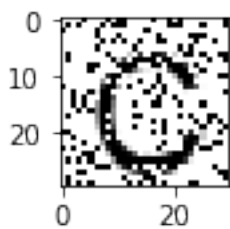


Training for label 0...



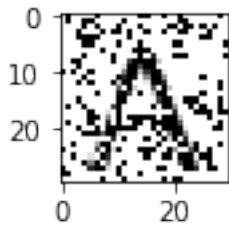
```
In [14]: read('C')
```

```
Out[14]: 'C'
```



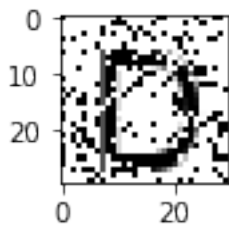
```
In [15]: read('A')
```

Out[15]: 'A'



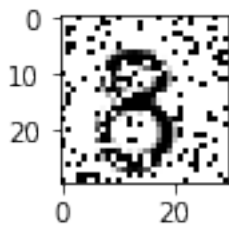
In [16]: read('D')

Out[16]: 'D'



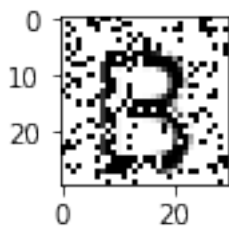
In [17]: read('8')

Out[17]: '8'



In [18]: read('B')

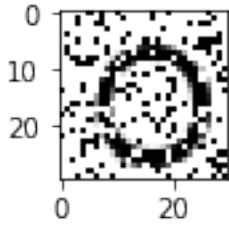
Out[18]: 'B'



In [19]: read('O')

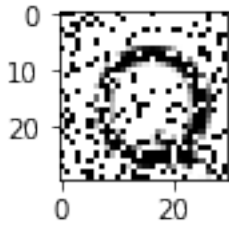
Out[19]: 'O'





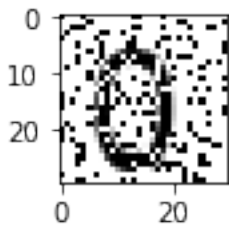
```
In [35]: read('Q')
```

```
Out[35]: 'Q'
```



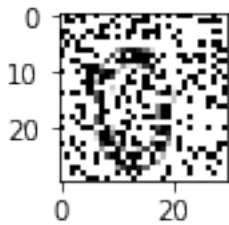
```
In [25]: read('0')
```

```
Out[25]: '0'
```



```
In [45]: read('0', p=0.3)
```

```
Out[45]: '0'
```



### 1.3.8 Classification Test #3

- *Generating labels*
- *Training the SDM*
- *Testing with high noise*
- *Testing with low noise*
- *Testing with no noise*



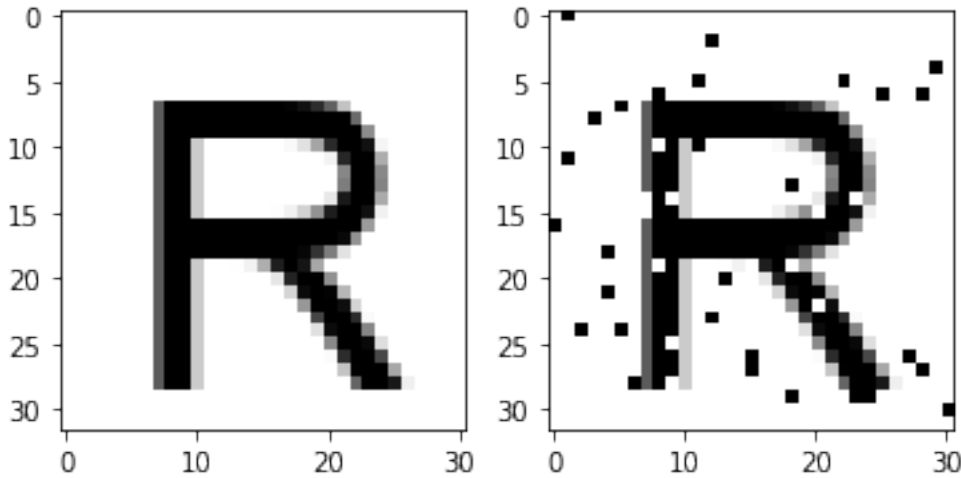
```
In [1]: import sdm as sdmlib
import matplotlib.pyplot as plt
from PIL import Image, ImageDraw, ImageFont
import urllib, cStringIO
import random
from IPython.core.display import display, Image as IPythonImage
%matplotlib inline

In [2]: width = 31
height = 32
noise_flip = True

In [3]: def gen_img(letter='A'):
    img = Image.new('RGBA', (width, height), (255, 255, 255))
    font = ImageFont.truetype('Arial.ttf', 30)
    draw = ImageDraw.Draw(img)
    w, h = draw.textsize(letter, font=font)
    top = (height-w)//2
    left = (width-h)//2 if h <= 30 else 30-2-h
    draw.text((top, left), letter, (0, 0, 0), font=font)
    return img

In [4]: def gen_noise_add(img, p=0.15, flip=False):
    img2 = img.copy()
    draw = ImageDraw.Draw(img2)
    for py in xrange(height):
        for px in xrange(width):
            if random.random() < p:
                if flip:
                    pixel = img.getpixel((px, py))
                    value = sum([int(x/255+0.5) for x in pixel[:3]])//3
                    assert value == 0 or value == 1
                    value = (1 - value)*255
                    draw.point((px, py), fill=(value, value, value))
                else:
                    draw.point((px, py), fill=(0, 0, 0))
    return img2

In [5]: img = gen_img(letter='R');
img2 = gen_noise_add(img, p=0.05, flip=noise_flip)
plt.subplot(1, 2, 1)
plt.imshow(img)
plt.subplot(1, 2, 2)
plt.imshow(img2);
```



```
In [6]: def to_bitstring(img):
        v = []
        bs = sdmllib.Bitstring.init_ones(1000)
        for py in xrange(height):
            for px in xrange(width):
                pixel = img.getpixel((px, py))
                value = sum([int(x/255+0.5) for x in pixel[:3]])/3
                assert value == 0 or value == 1
                idx = px+width*py
                assert idx >= 0 and idx < 1000, 'Ops {} {} {}'.format(x, y, idx)
                bs.set_bit(idx, value)
                v.append(value)
        v2 = [bs.get_bit(i) for i in xrange(height*width)]
        assert v == v2
        return bs
```

```
In [7]: def to_img(bs):
        img = Image.new('RGBA', (30, 30), (255, 255, 255))
        draw = ImageDraw.Draw(img)
        for py in xrange(height):
            for px in xrange(width):
                idx = px+width*py
                assert idx >= 0 and idx < 1000, 'Ops {} {} {}'.format(x, y, idx)
                x = 255*bs.get_bit(idx)
                draw.point((px, py), fill=(x, x, x))
        return img
```

```
In [8]: bits = 1000
        sample = 1000000
        scanner_type = sdmllib.SDM_SCANNER_OPENCL
```

```
In [9]: address_space = sdmllib.AddressSpace.init_from_b64_file('sdm-letters.as')
```

```
In [10]: counter = sdmllib.Counter.create_file('sdm-classification-3', bits, sample)
        sdm = sdmllib.SDM(address_space, counter, 451, scanner_type)
```

```
In [11]: def fill_memory(letter, label_bs, p=0.1, n=100):
        cols = 15
        rows = n//cols + 1
        plt.figure(figsize=(20,10))
        for i in xrange(n):
            img = gen_img(letter=letter);
            img2 = gen_noise_add(img, p=p, flip=noise_flip)
```

```

        #display(img2)
        plt.subplot(rows, cols, i+1)
        plt.imshow(img2)
        bs = to_bitstring(img2)
        sdm.write(bs, label_bs)
    plt.show()

In [12]: def read(letter, n=6, p=0.2, radius=None):
    img = gen_img(letter=letter);
    img2 = gen_noise_add(img, p=p, flip=noise_flip)
    plt.imshow(img2)

    bs2 = to_bitstring(img2)
    bs3 = sdm.read(bs2, radius=radius)

    label = min(label_to_bs.items(), key=lambda v: bs3.distance_to(v[1]))
    return label[0]

In [13]: def iter_read(letter, n=10, p=0.2):
    cols = 15
    rows = n//cols + 1
    plt.figure(figsize=(20,10))

    wrong = 0
    correct = 0
    answers = []
    for i in xrange(n):
        plt.subplot(rows, cols, i+1)
        y = read(x, p=p)
        answers.append(y)
        if x == y:
            correct += 1
        else:
            wrong += 1
    plt.show()
    print '!! {} correct={:2d} wrong={:2d} answers={}'.format(x, correct, wrong, answers)

```

## Generating labels

```

In [14]: labels = list('ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz0123456789')
    label_to_bs = {}
    for x in labels:
        label_to_bs[x] = sdmlib.Bitstring.init_random(1000)

```

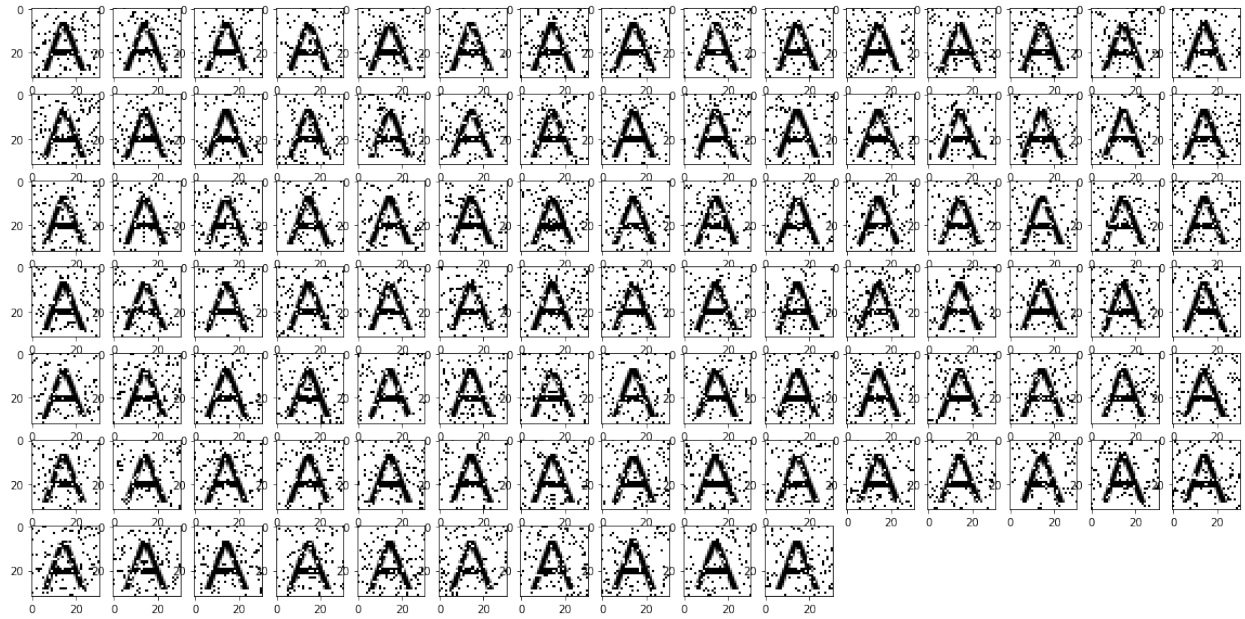
## Training the SDM

```

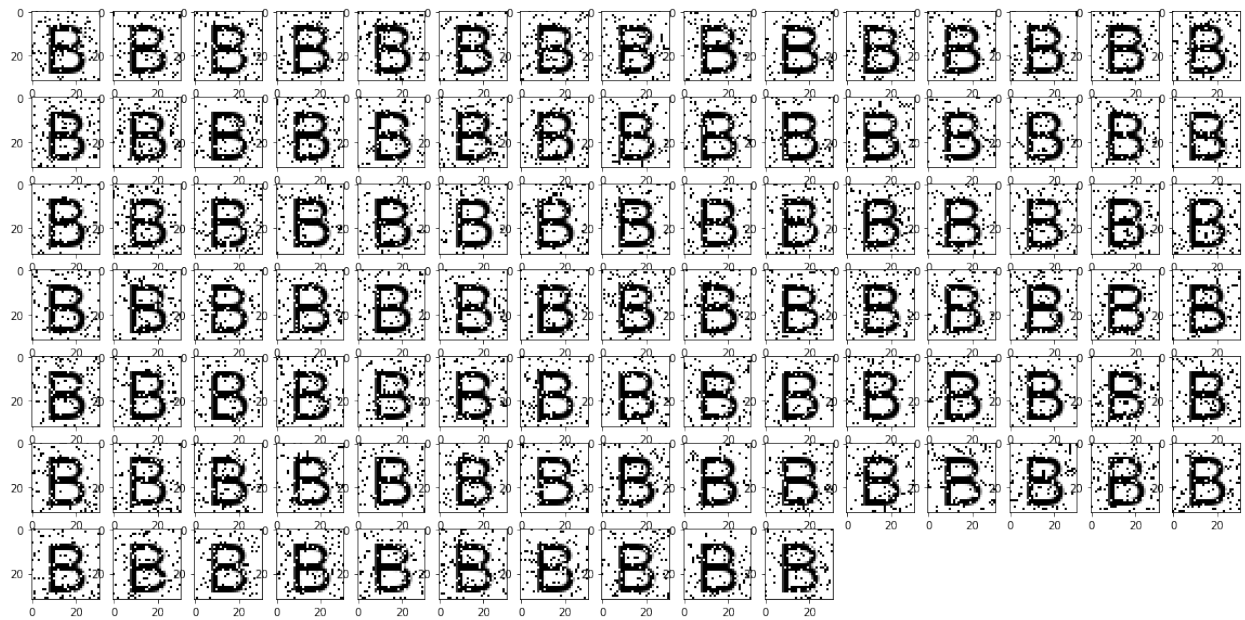
In [15]: for x in labels:
    print 'Training for label {}'.format(x)
    fill_memory(x, label_to_bs[x])

```

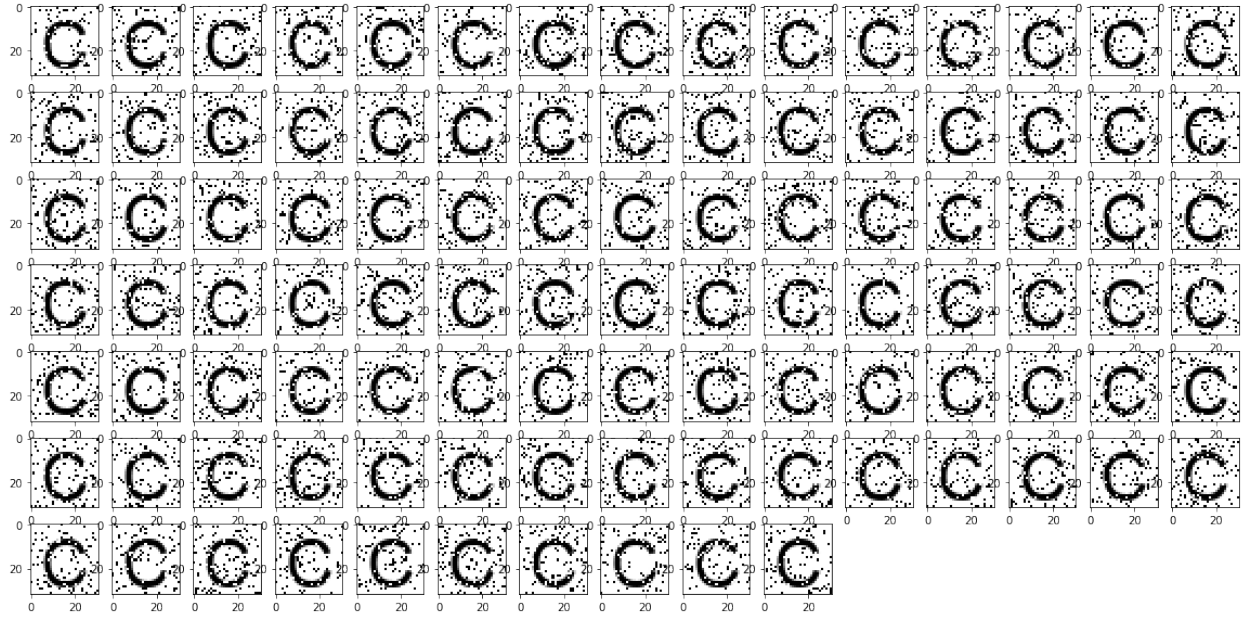
Training for label A...



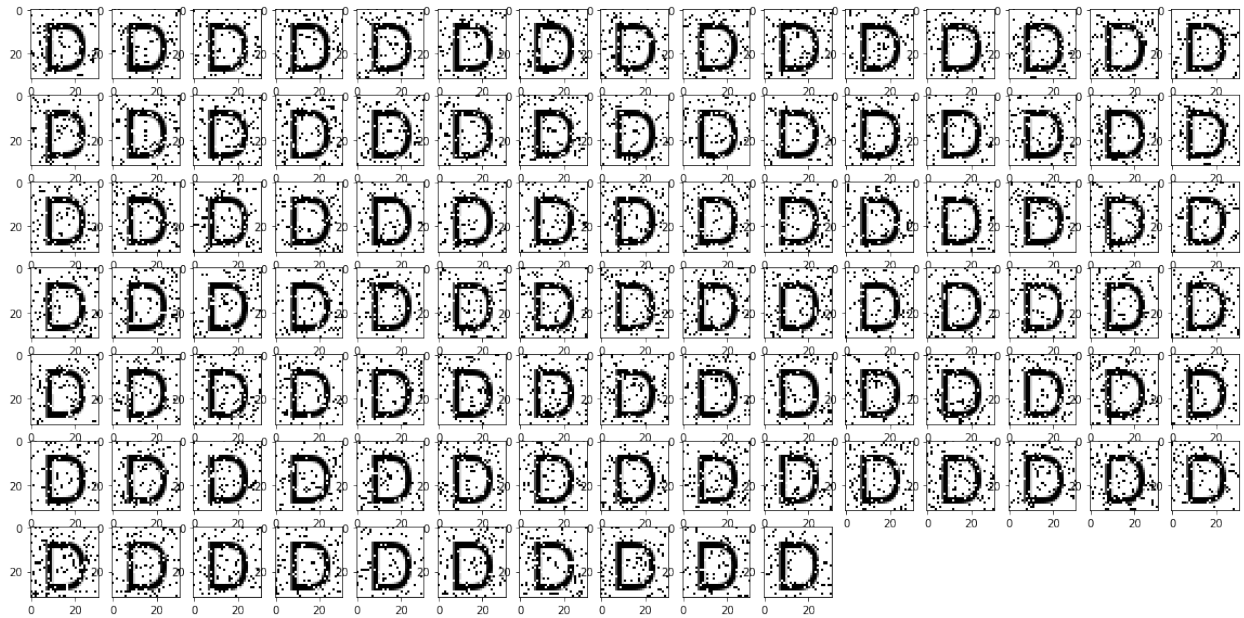
Training for label B...



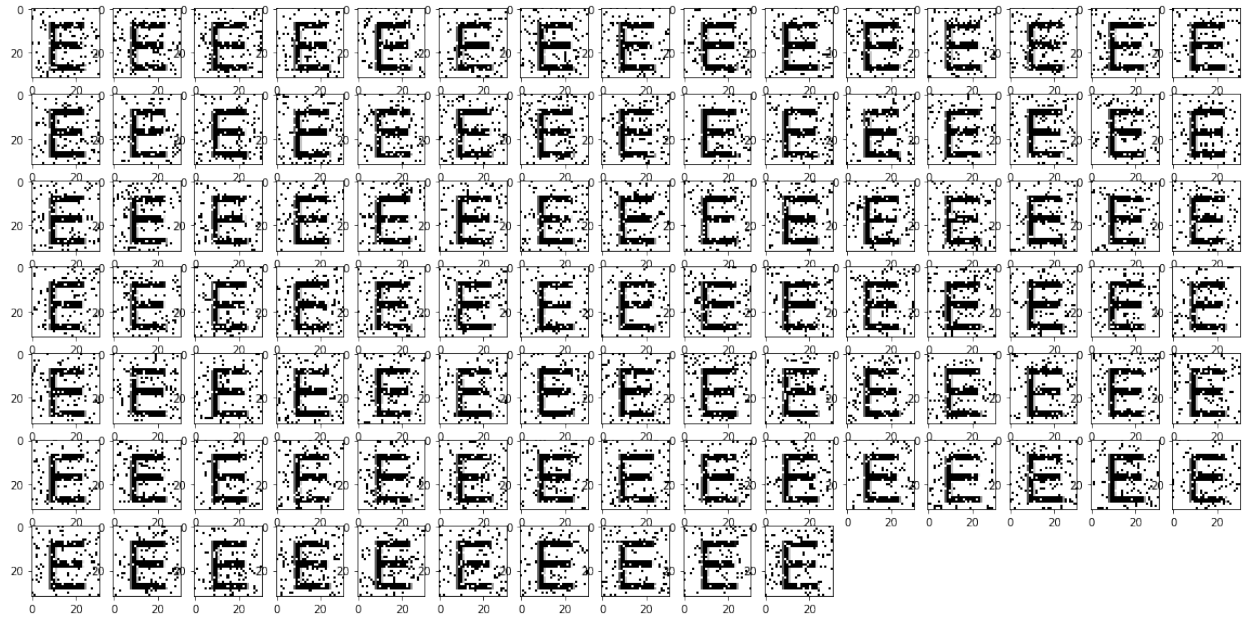
Training for label C...



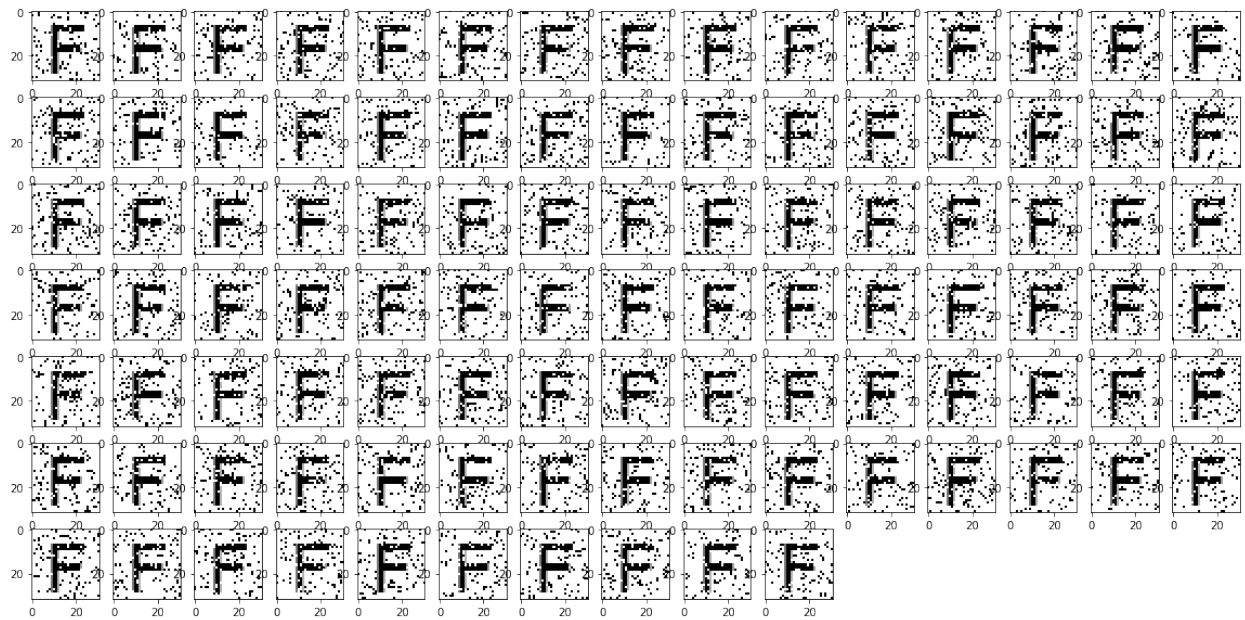
Training for label D...



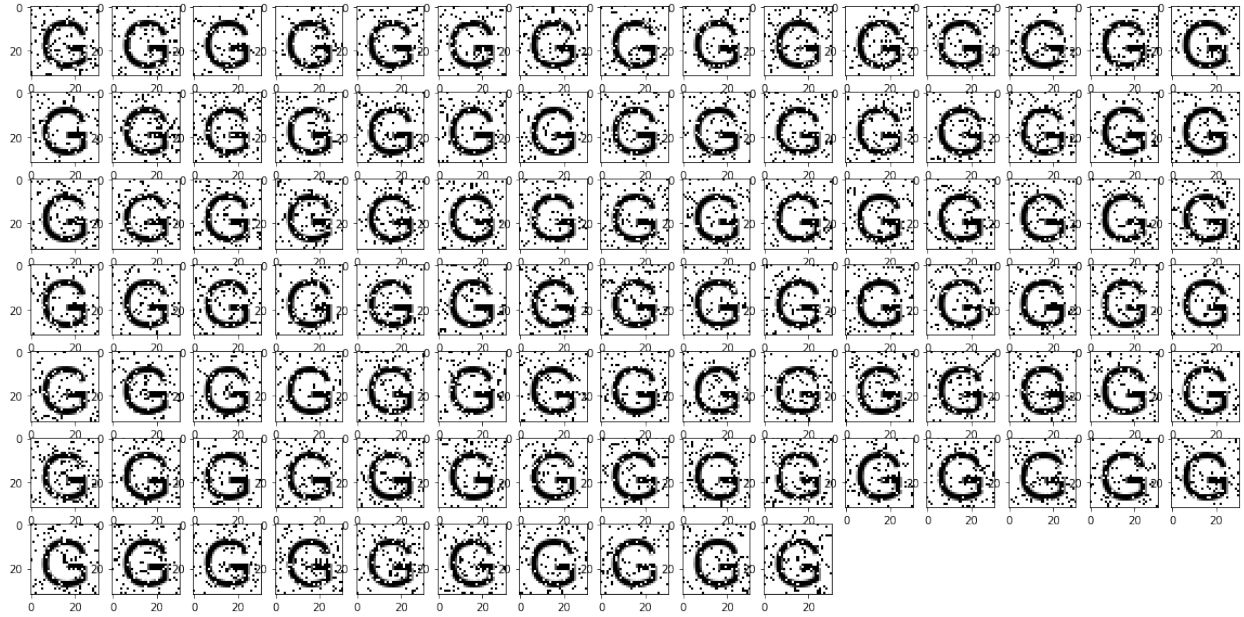
Training for label E...



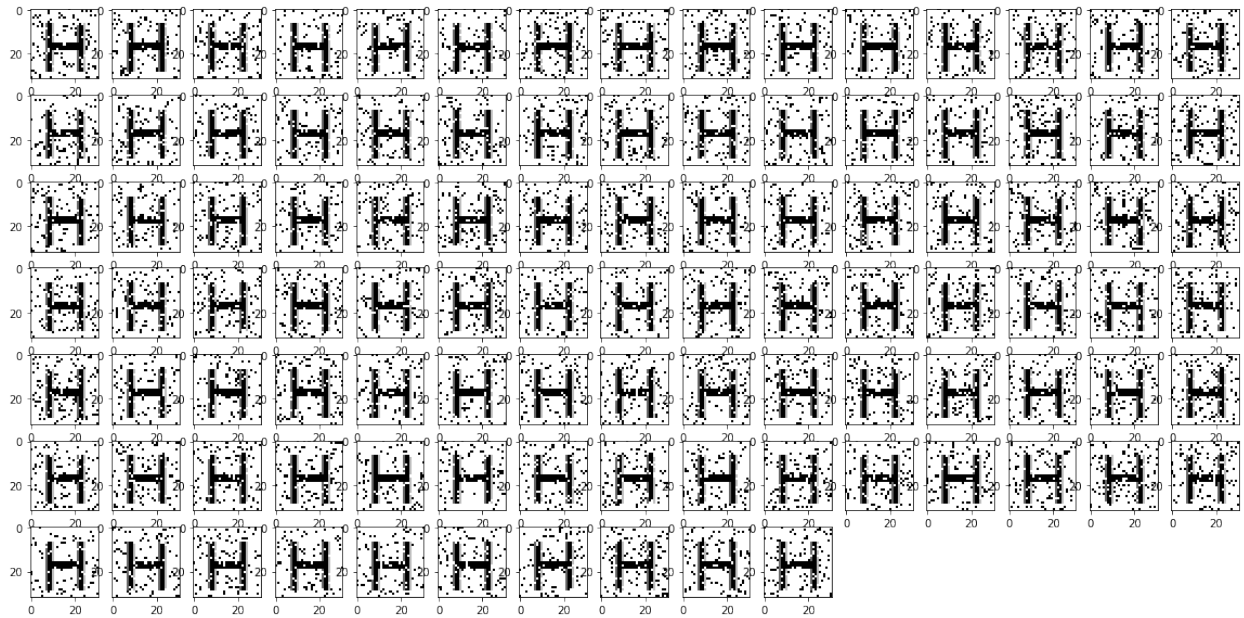
Training for label F...



Training for label G...



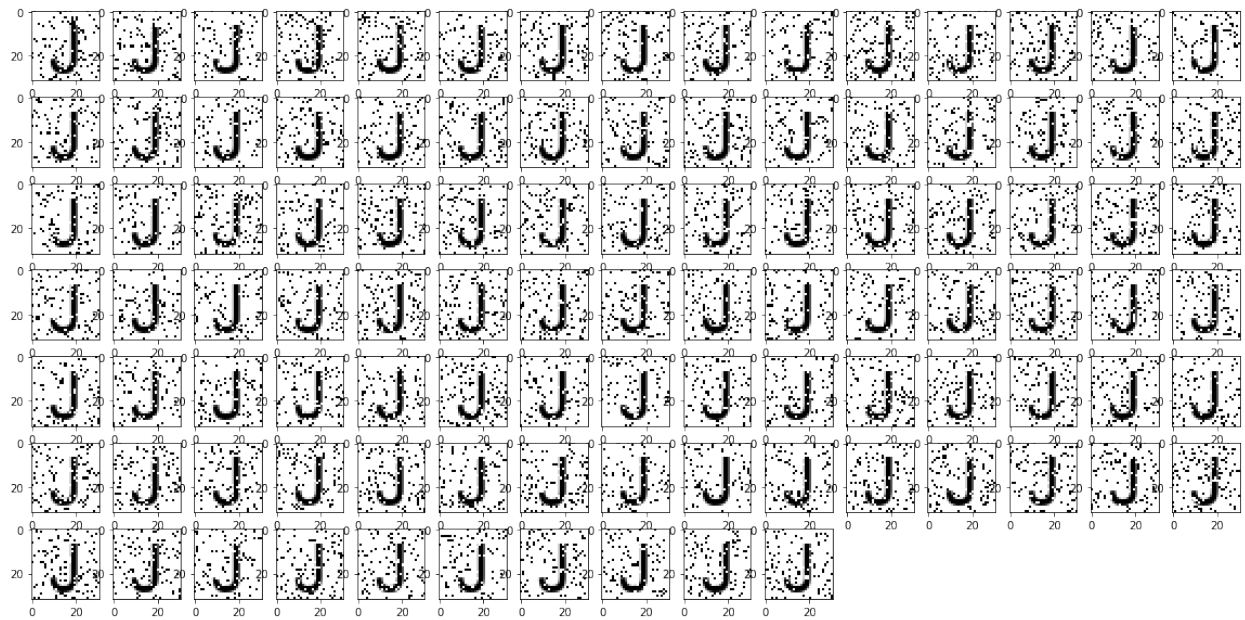
Training for label H...



Training for label I...

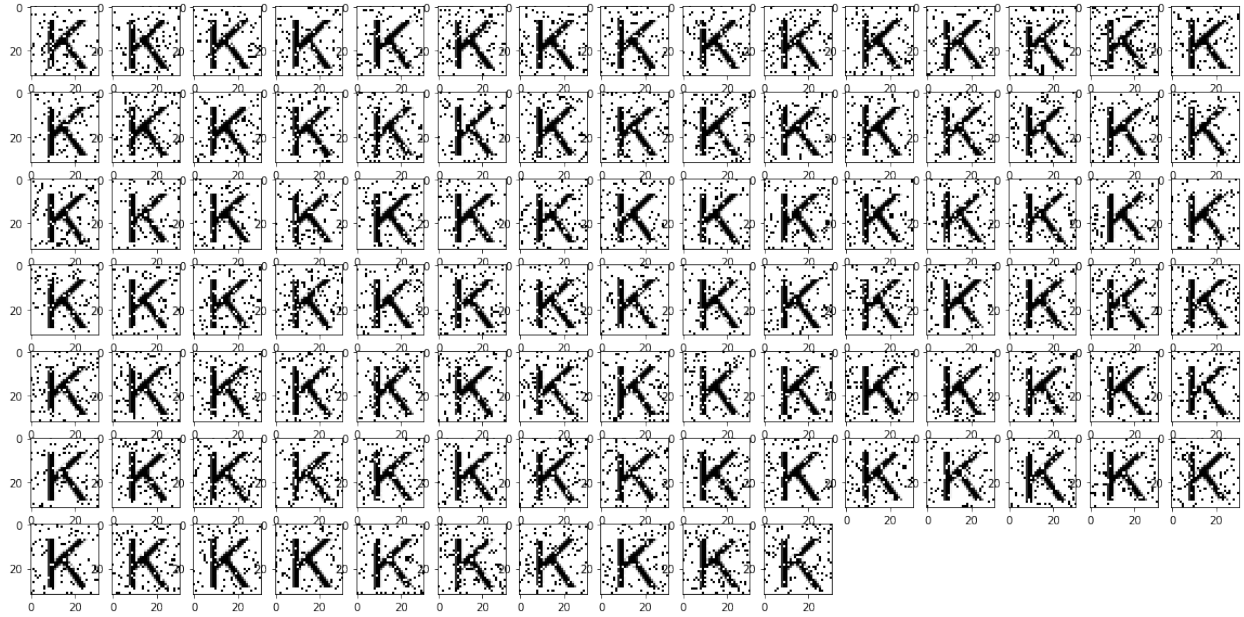


Training for label J...

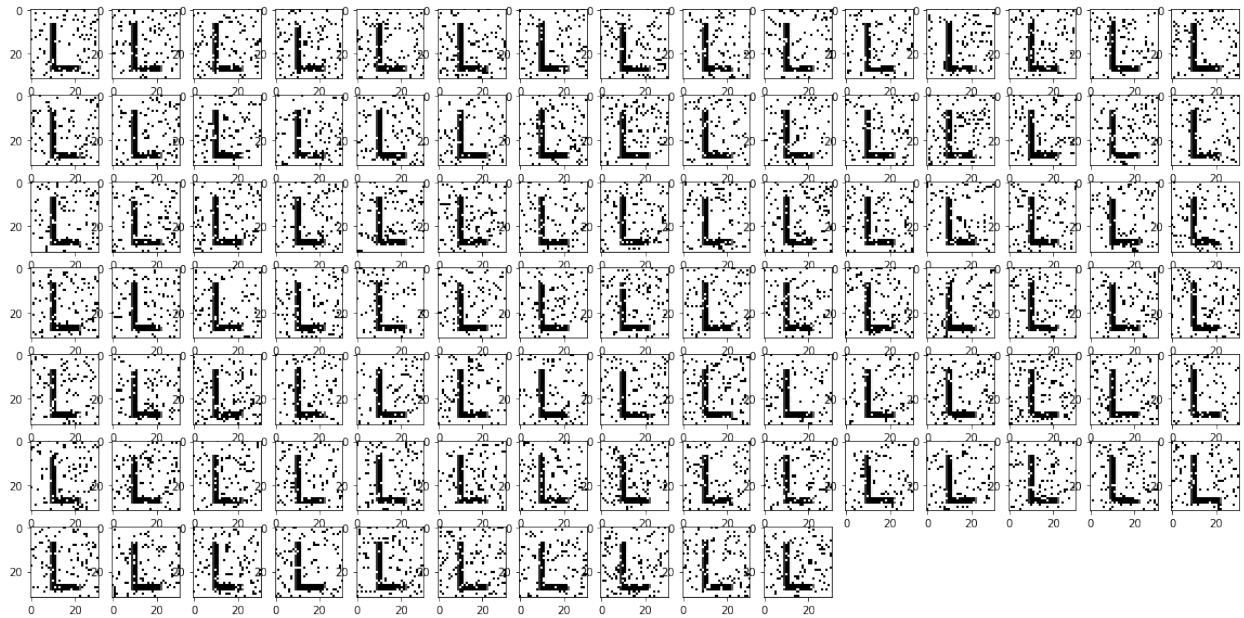


Training for label K...

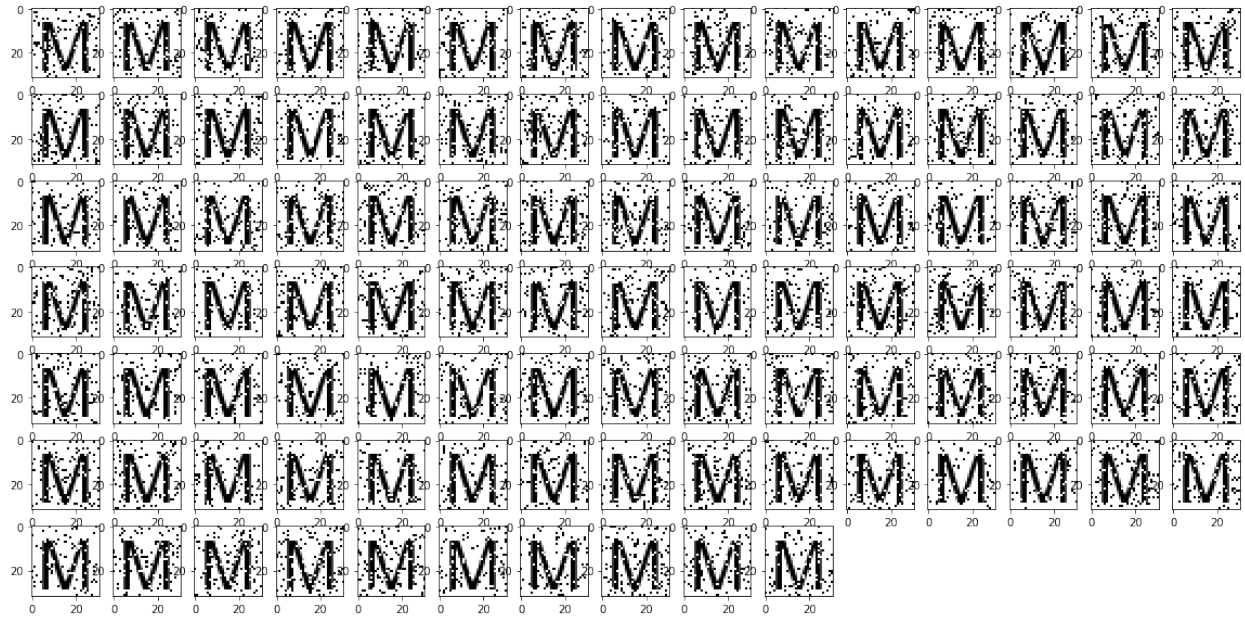




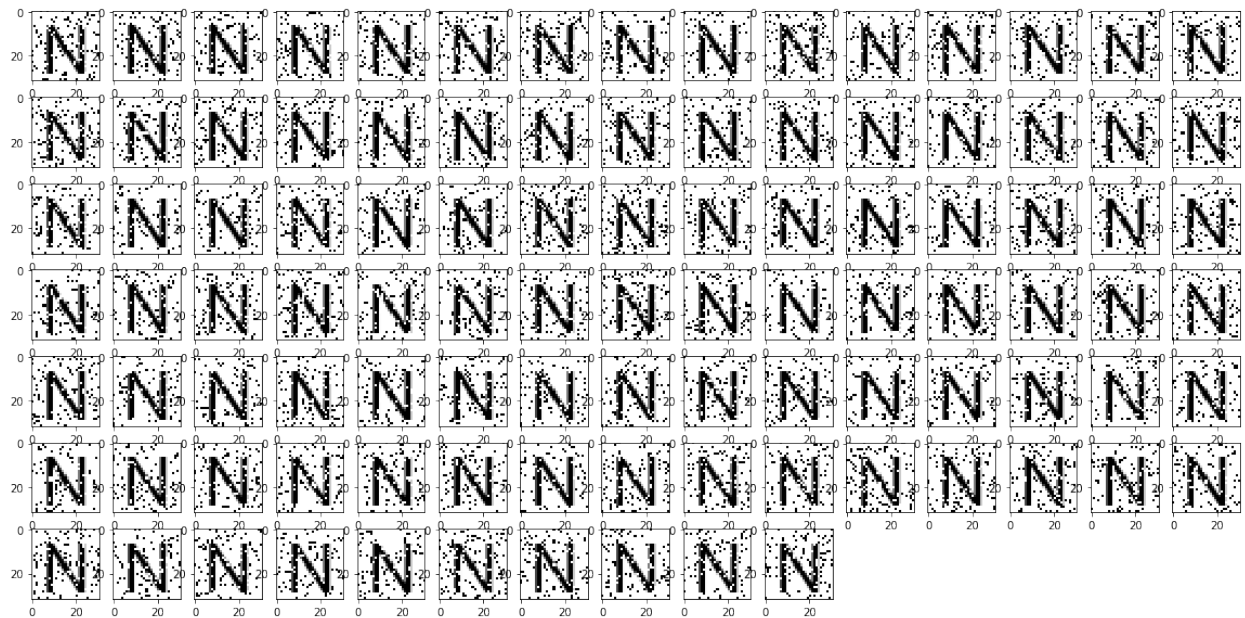
Training for label L...



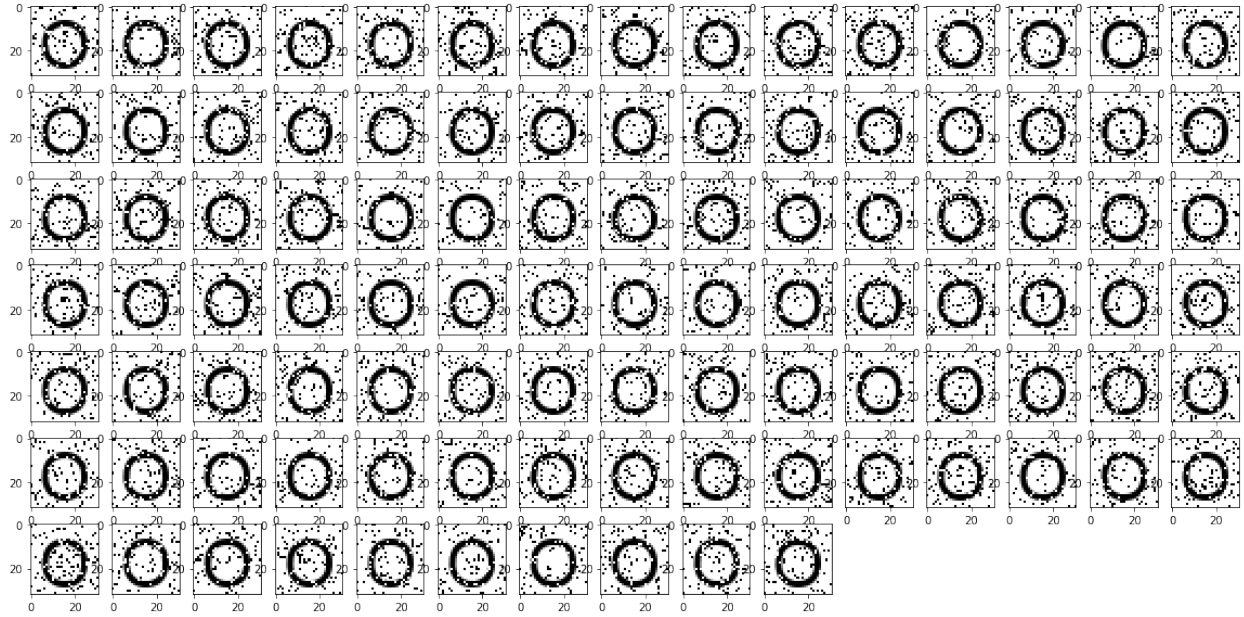
Training for label M...



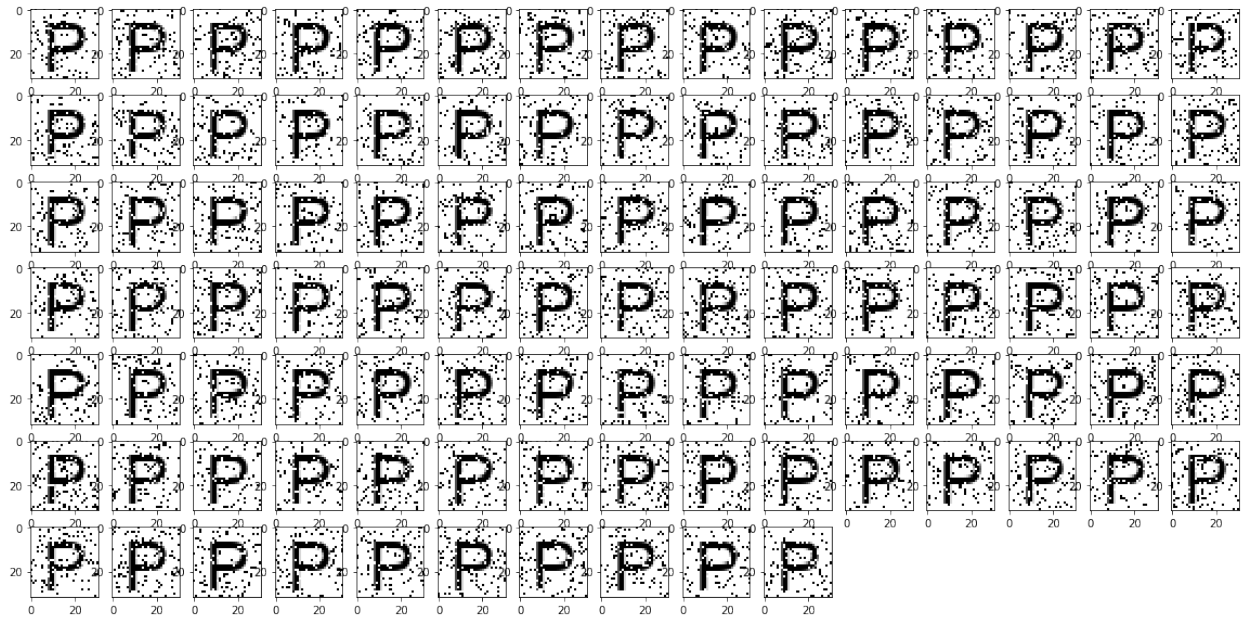
Training for label N...



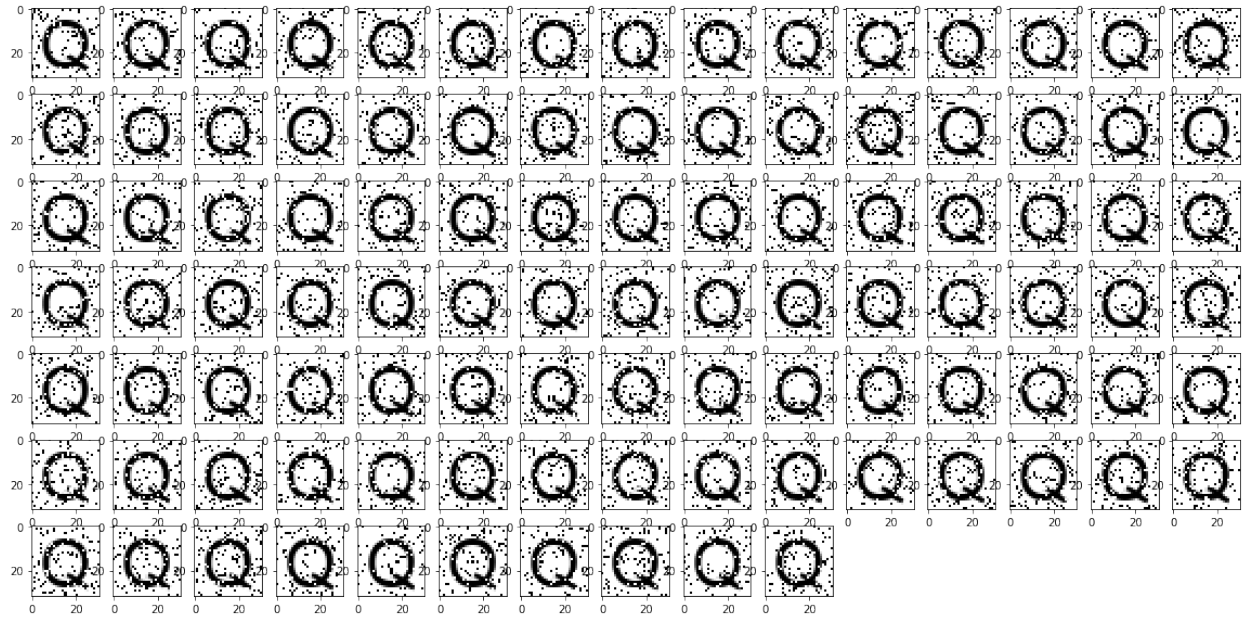
Training for label O...



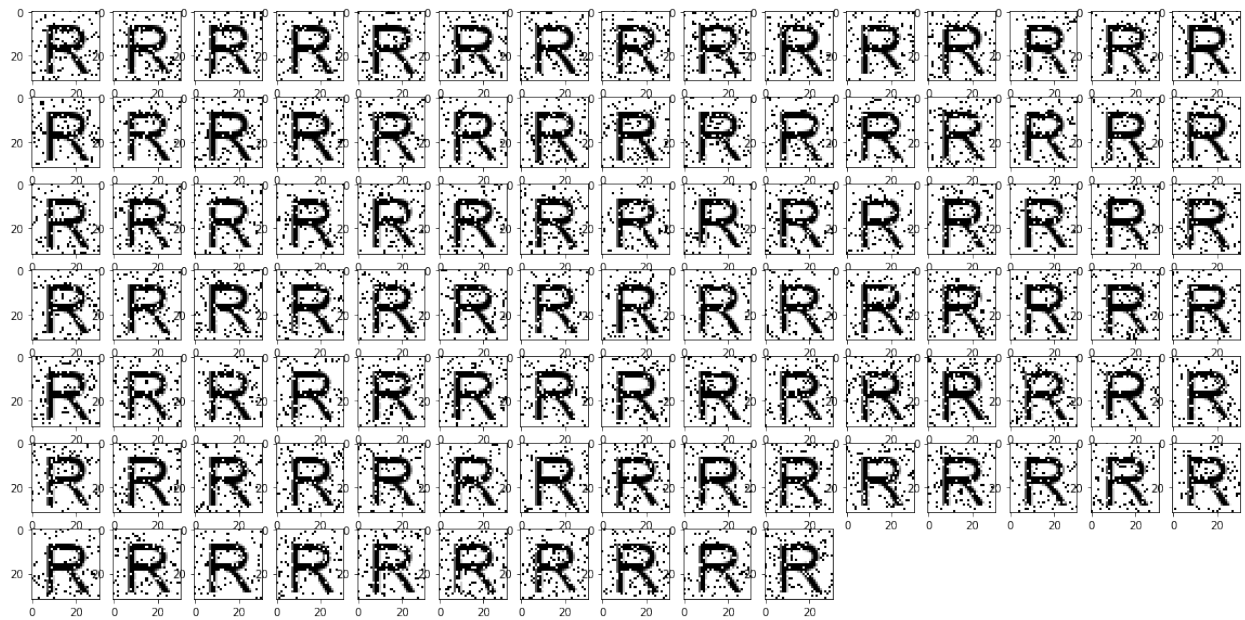
Training for label P...



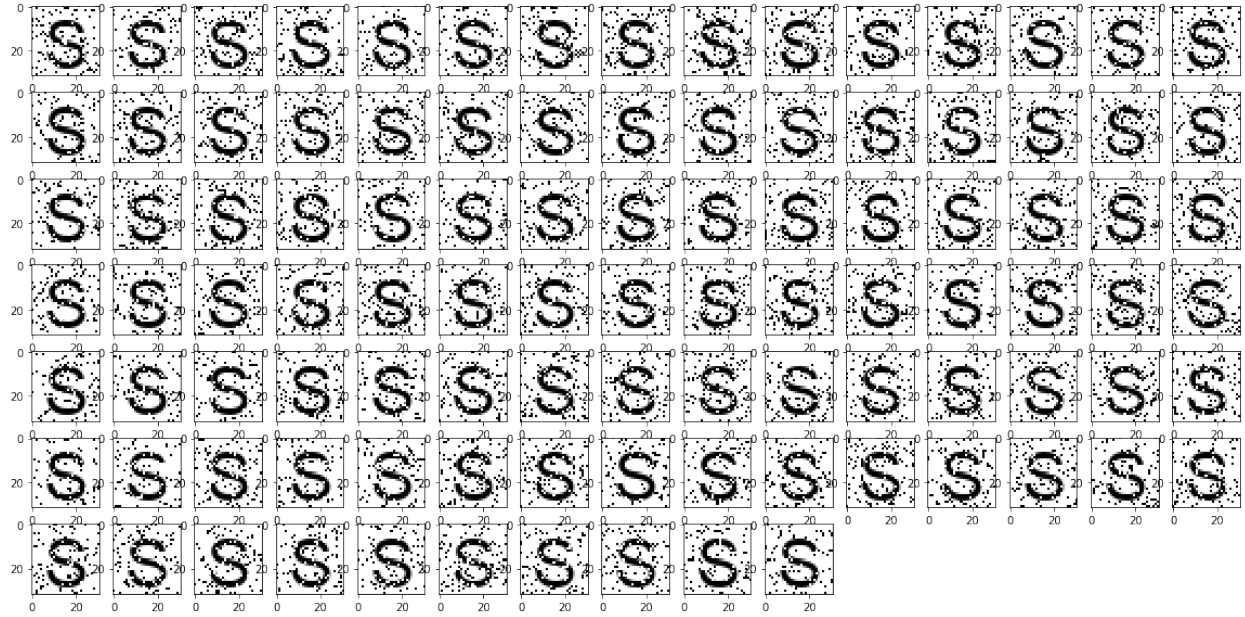
Training for label Q...



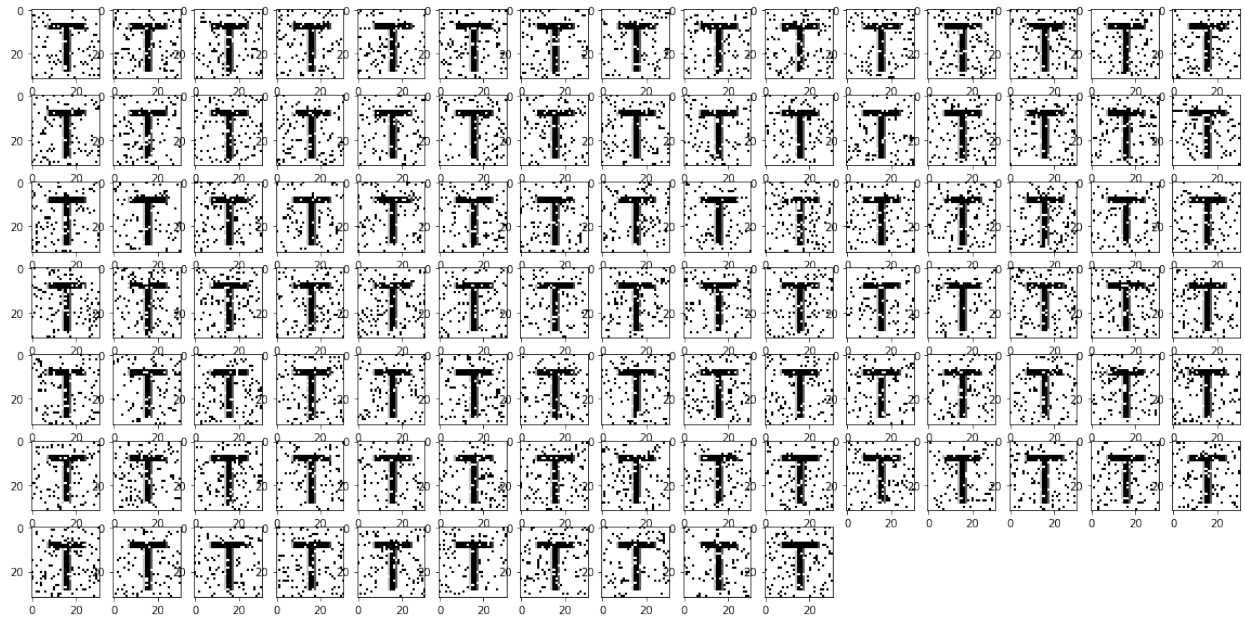
Training for label R...



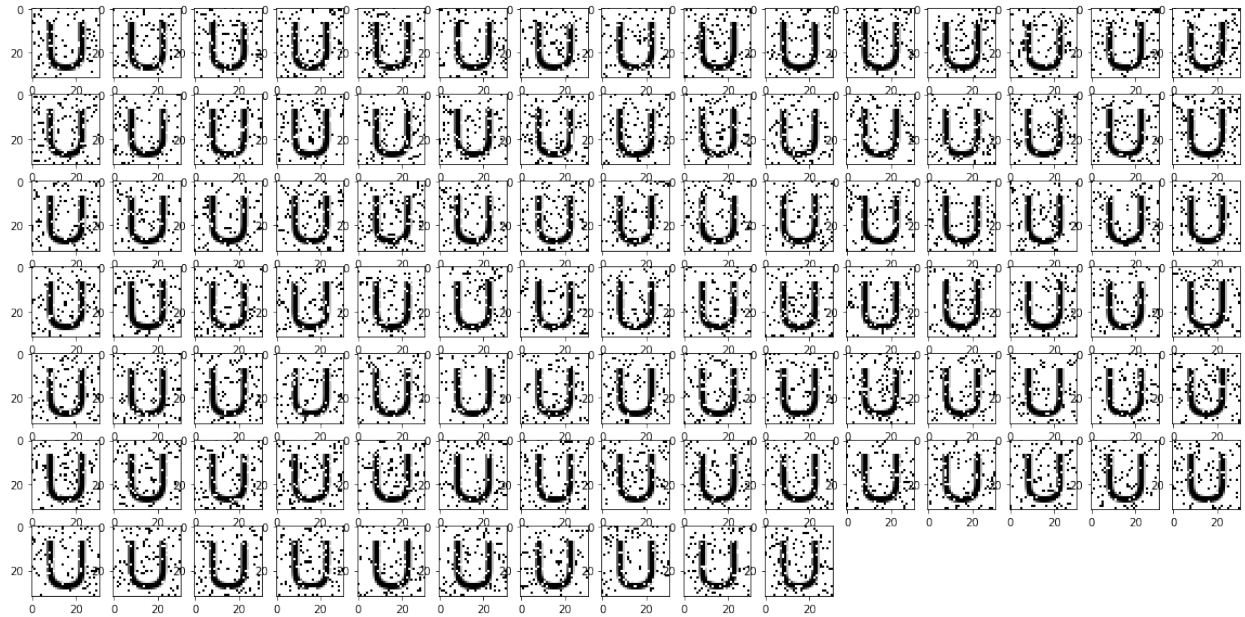
Training for label S...



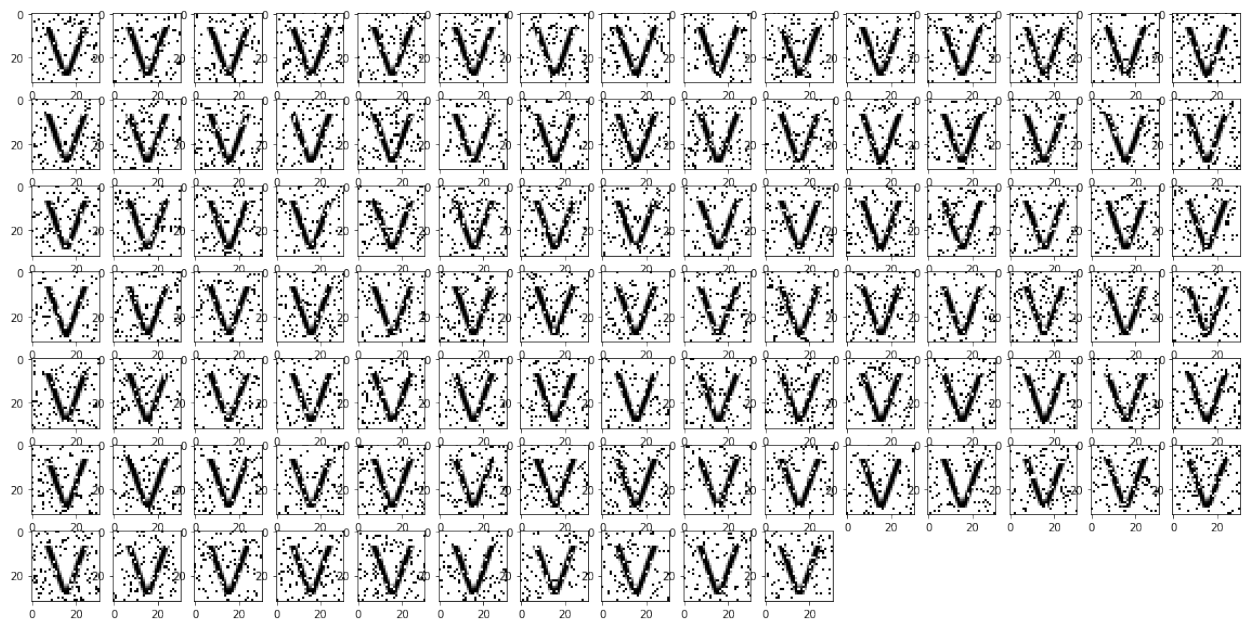
Training for label T...



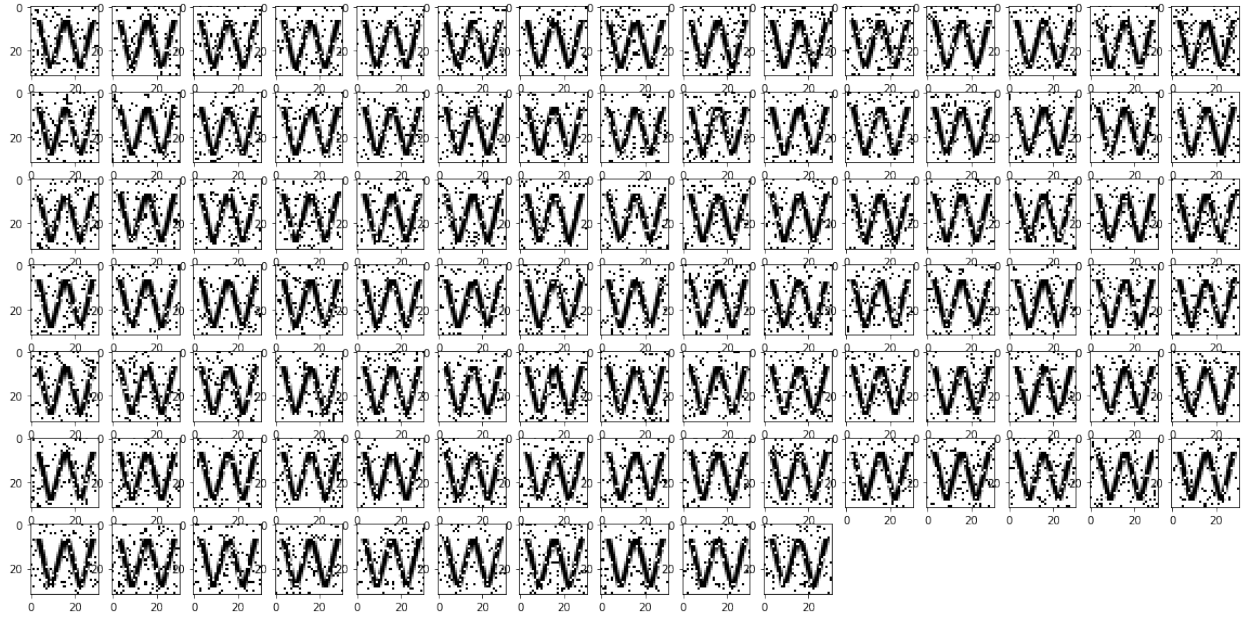
Training for label U...



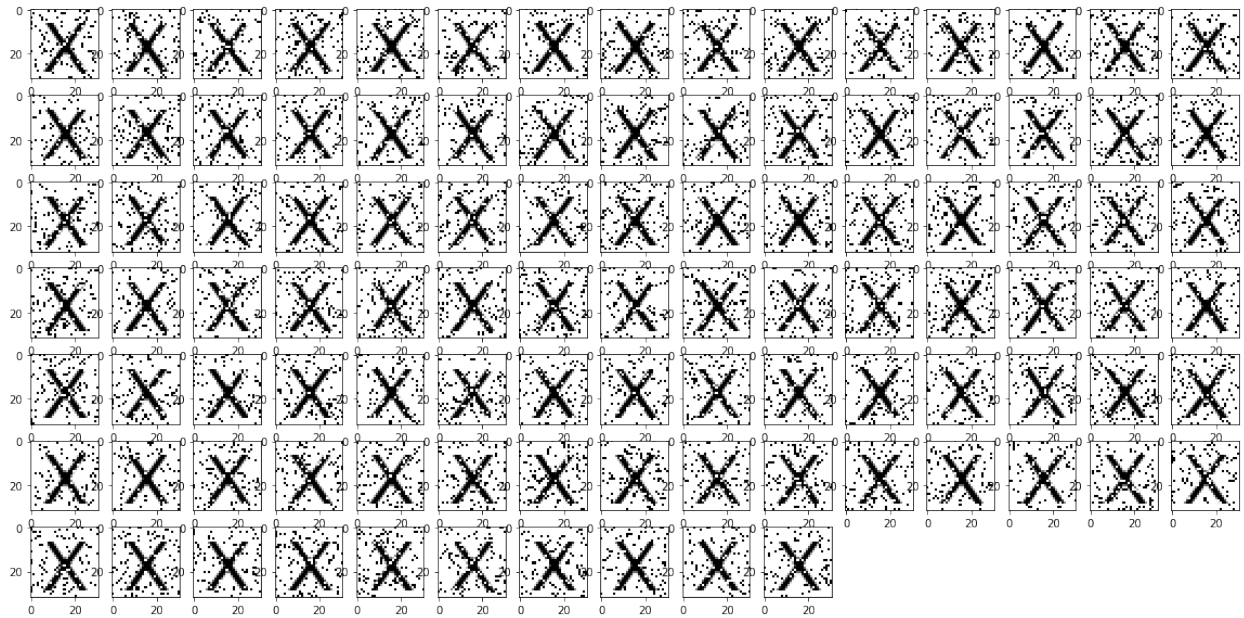
Training for label V...



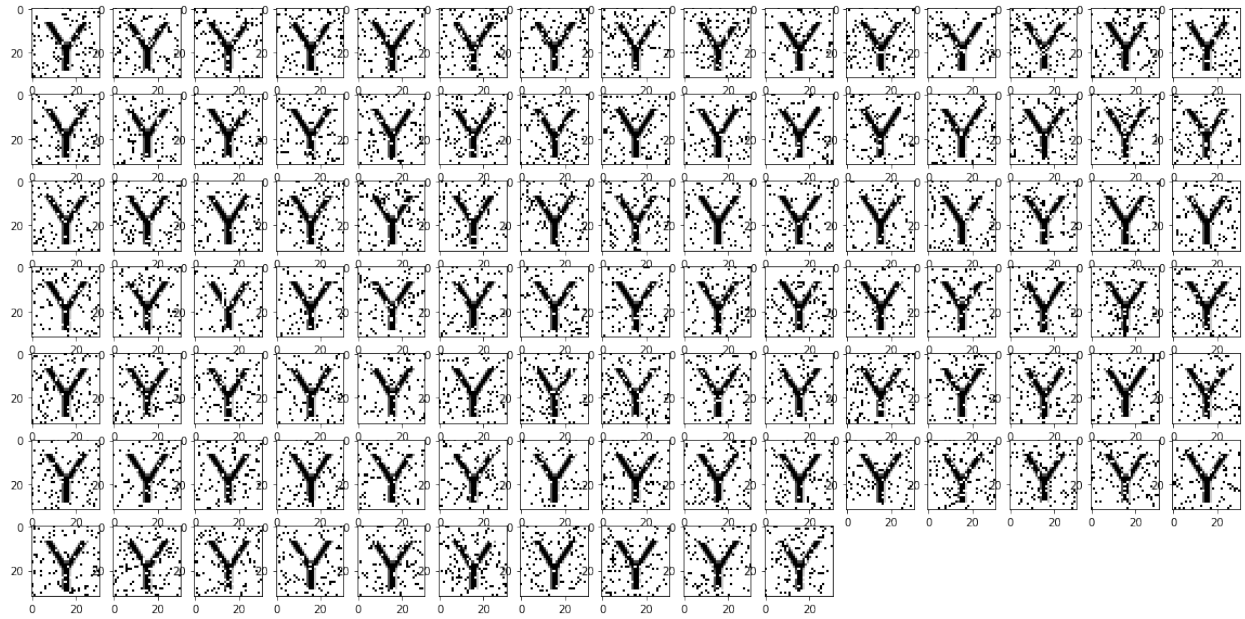
Training for label W...



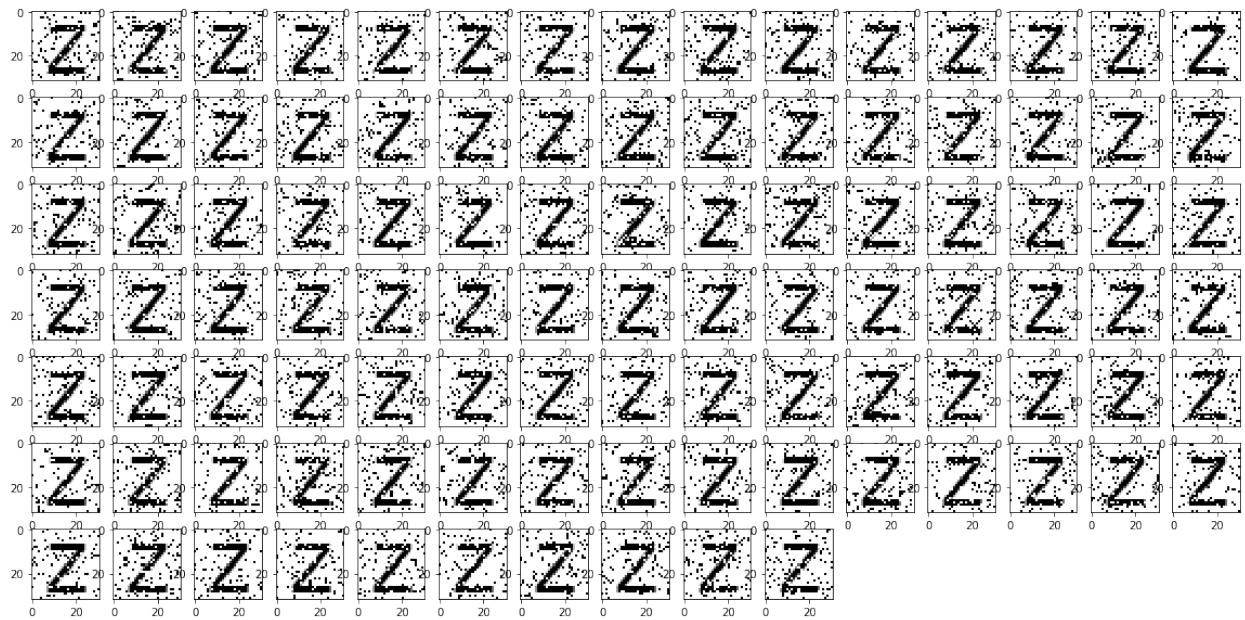
Training for label X...



Training for label Y...

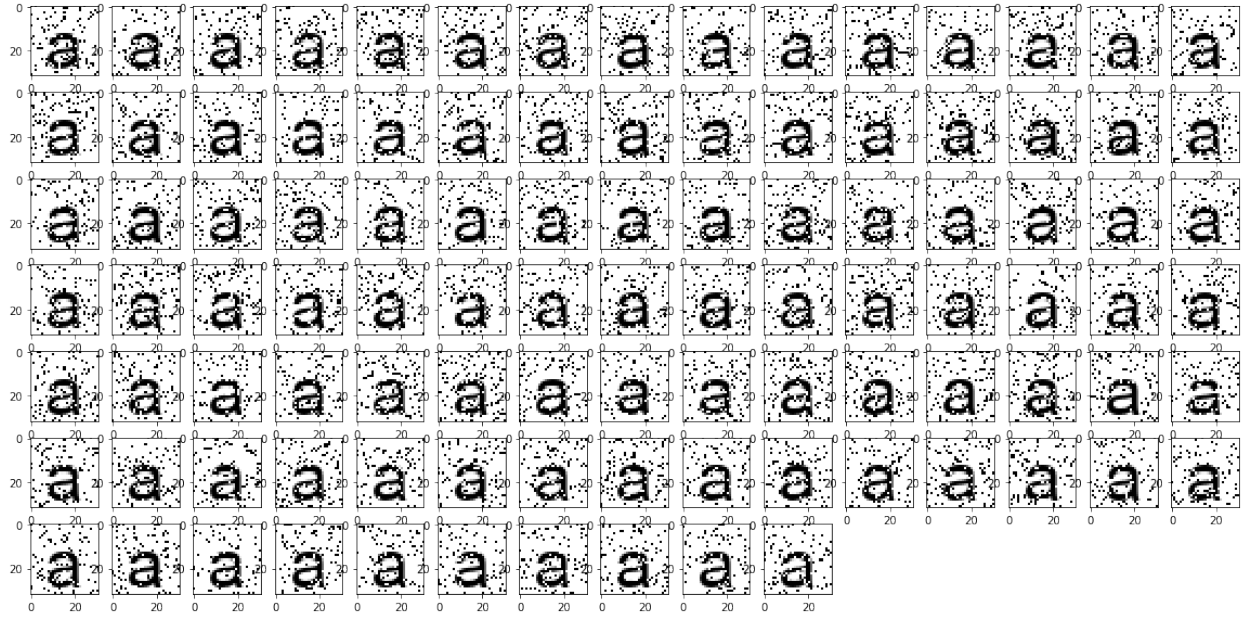


Training for label Z...

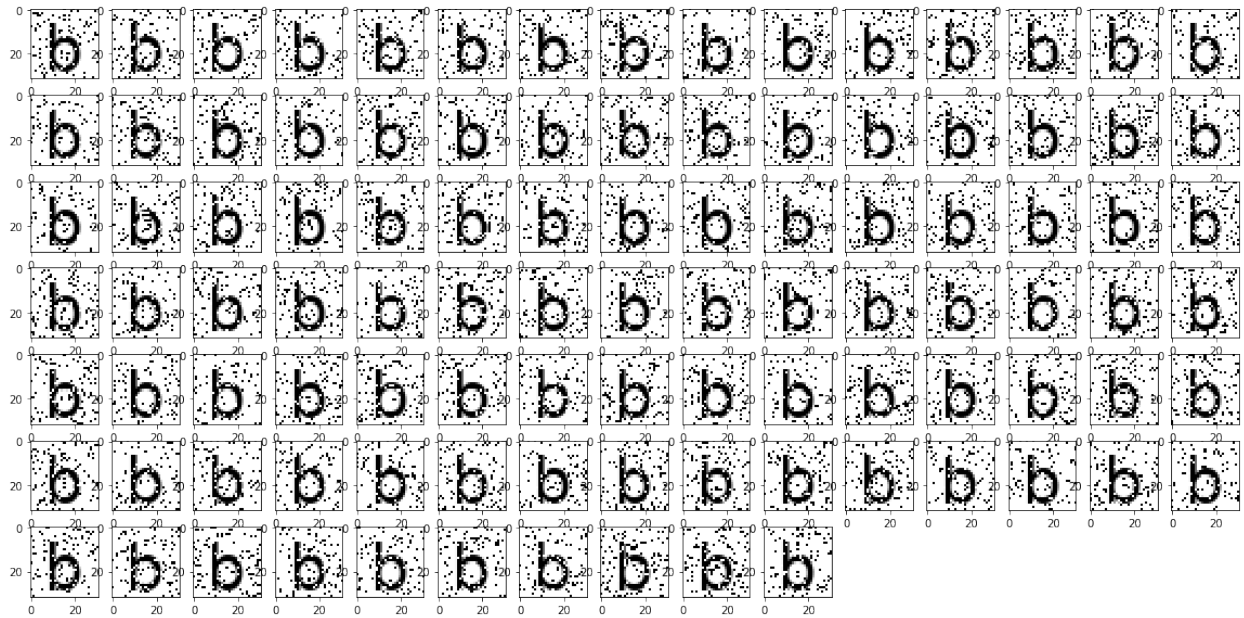


Training for label a...

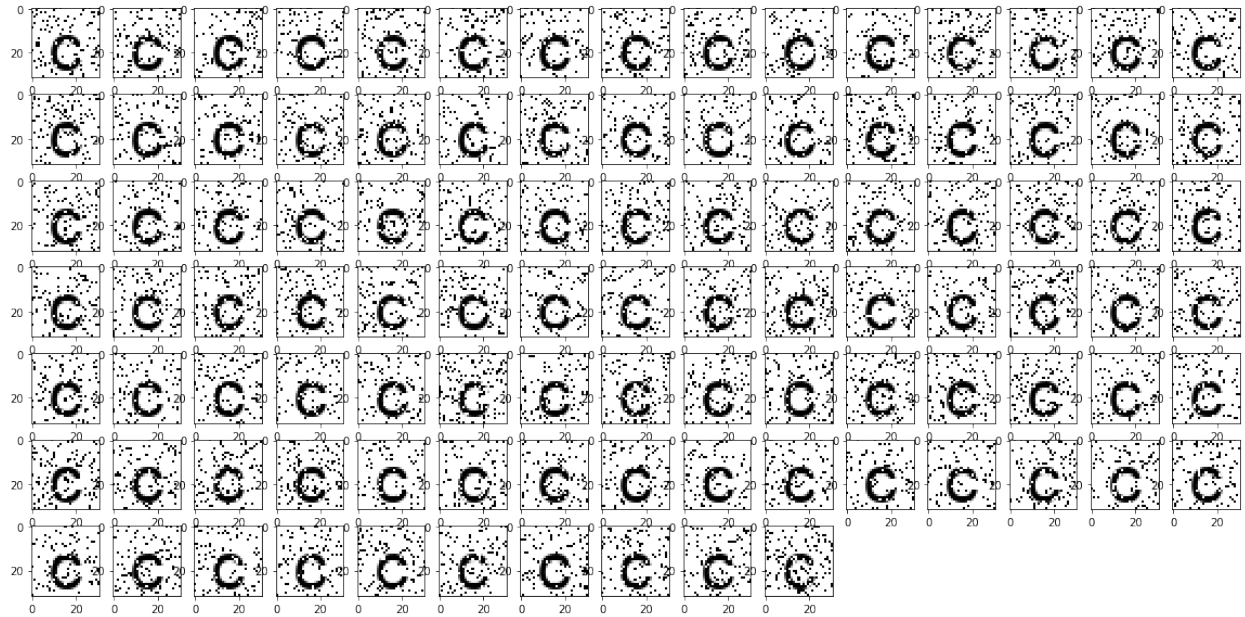




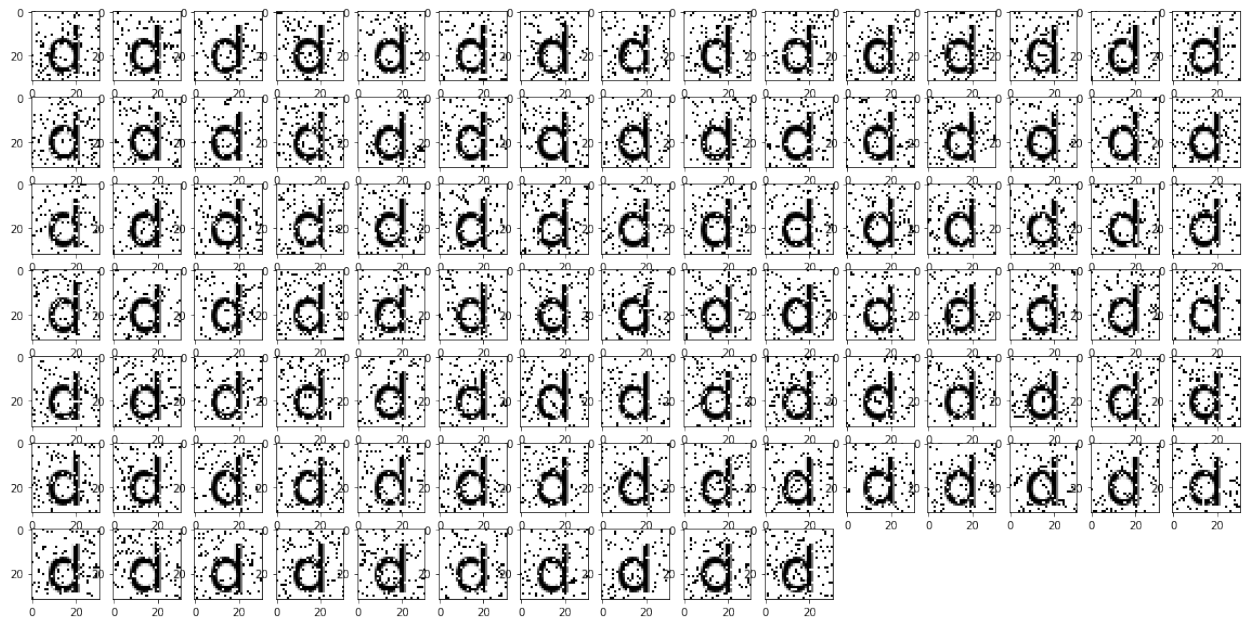
Training for label b...



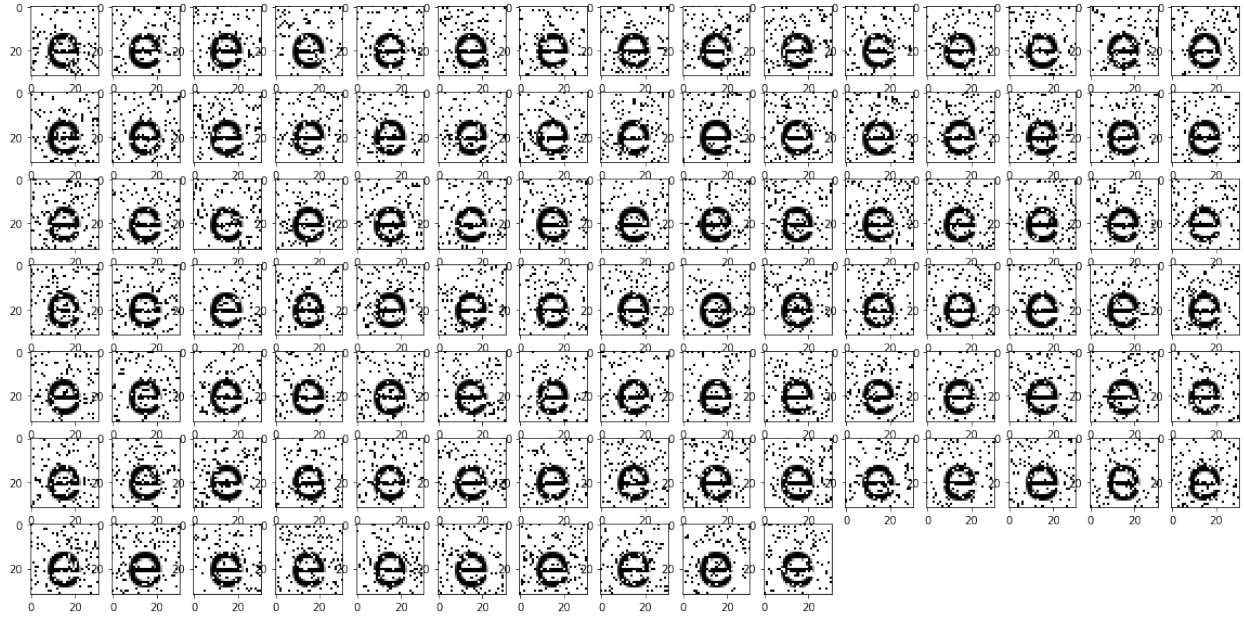
Training for label c...



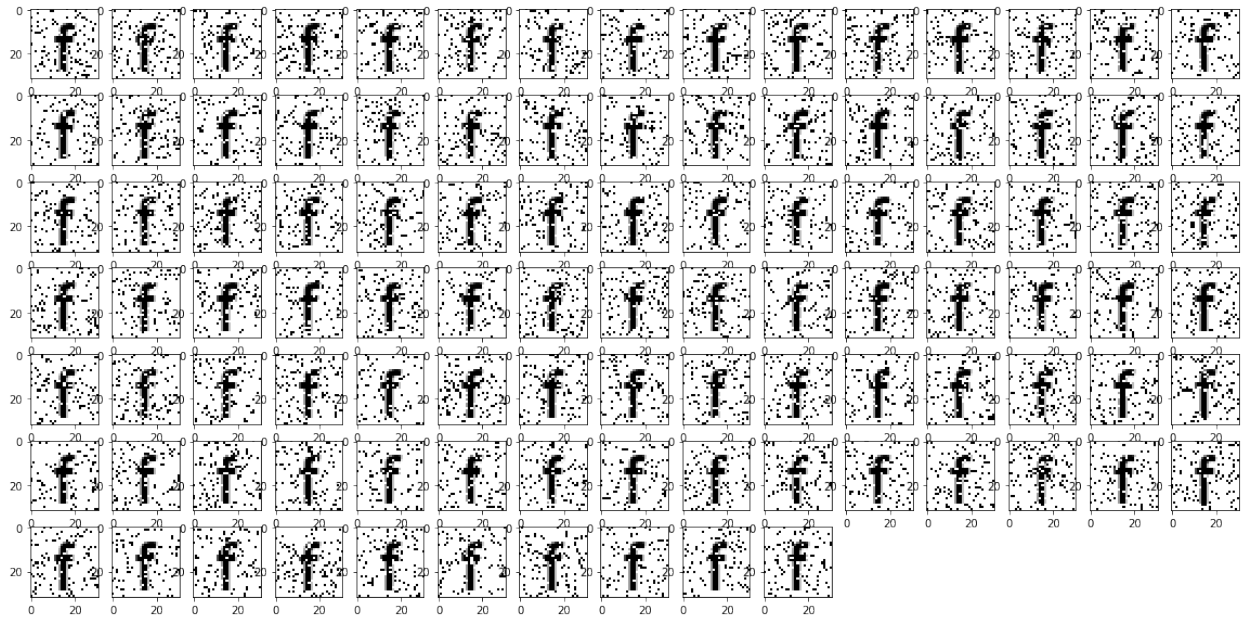
Training for label d...



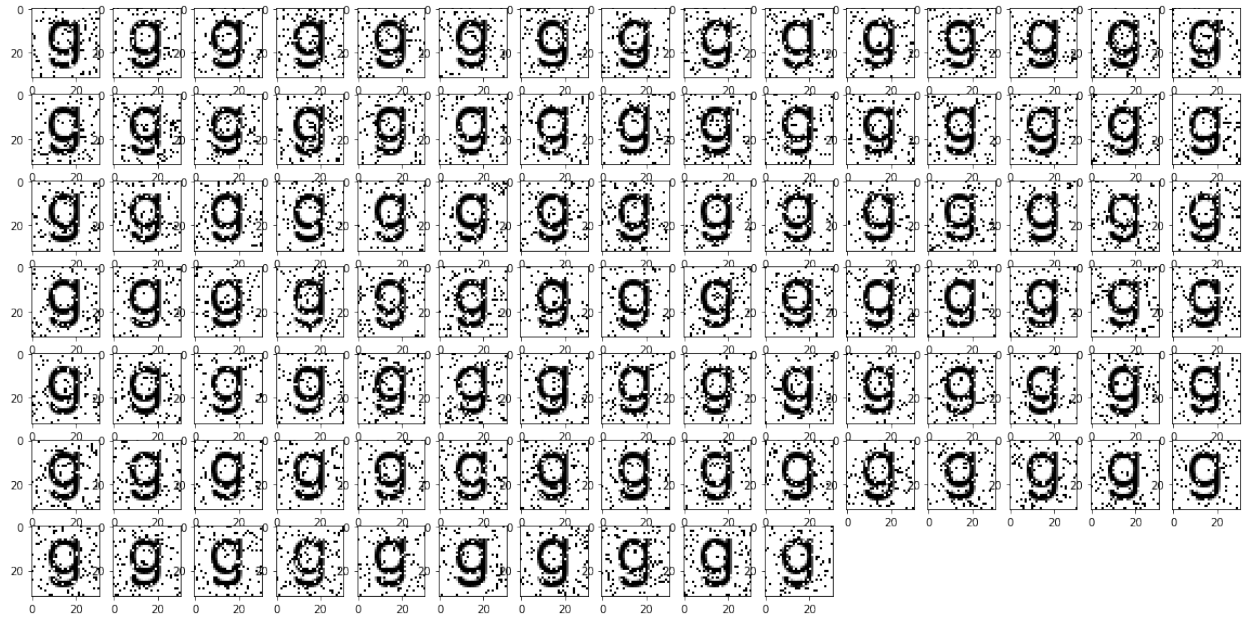
Training for label e...



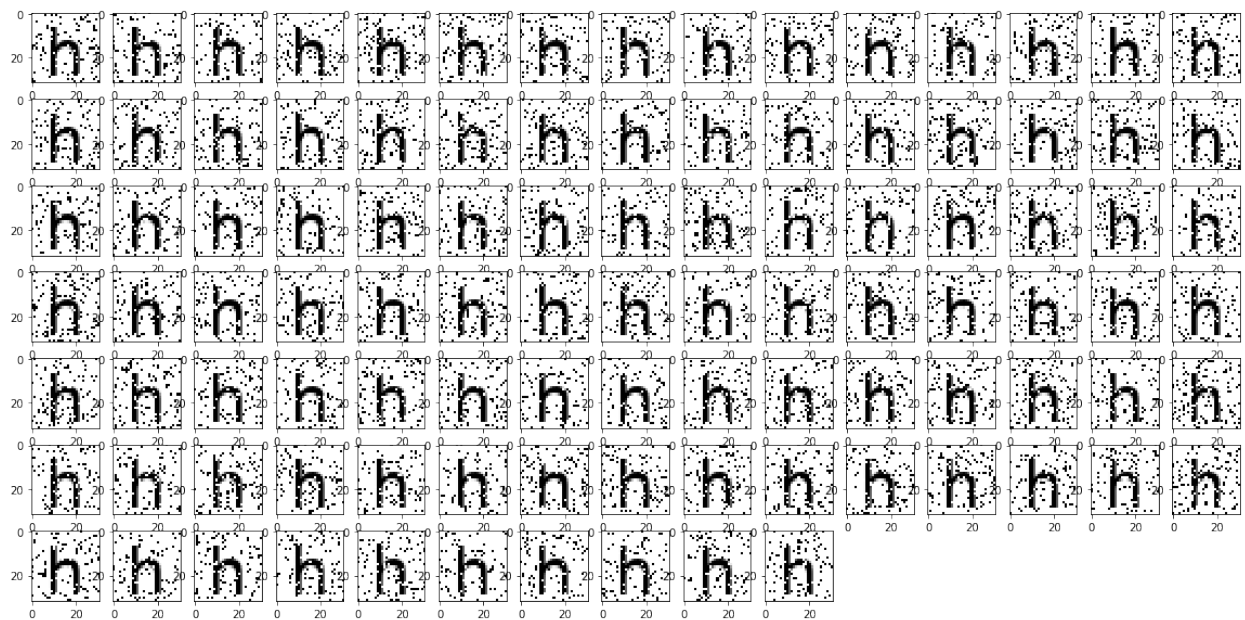
Training for label f...



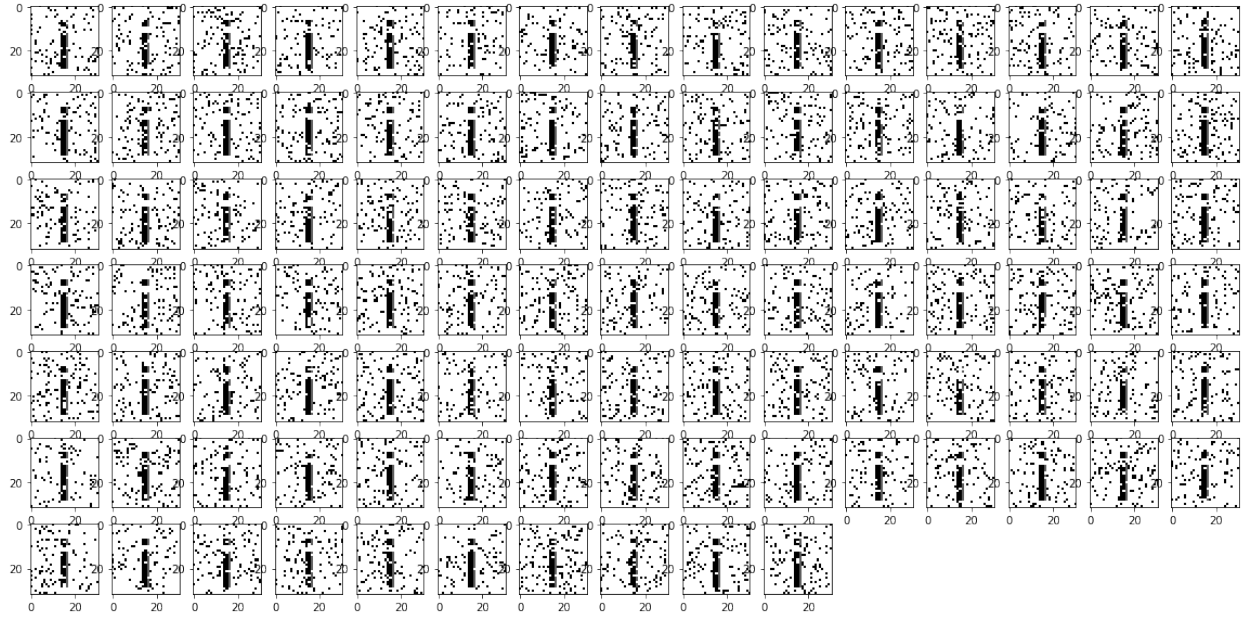
Training for label g...



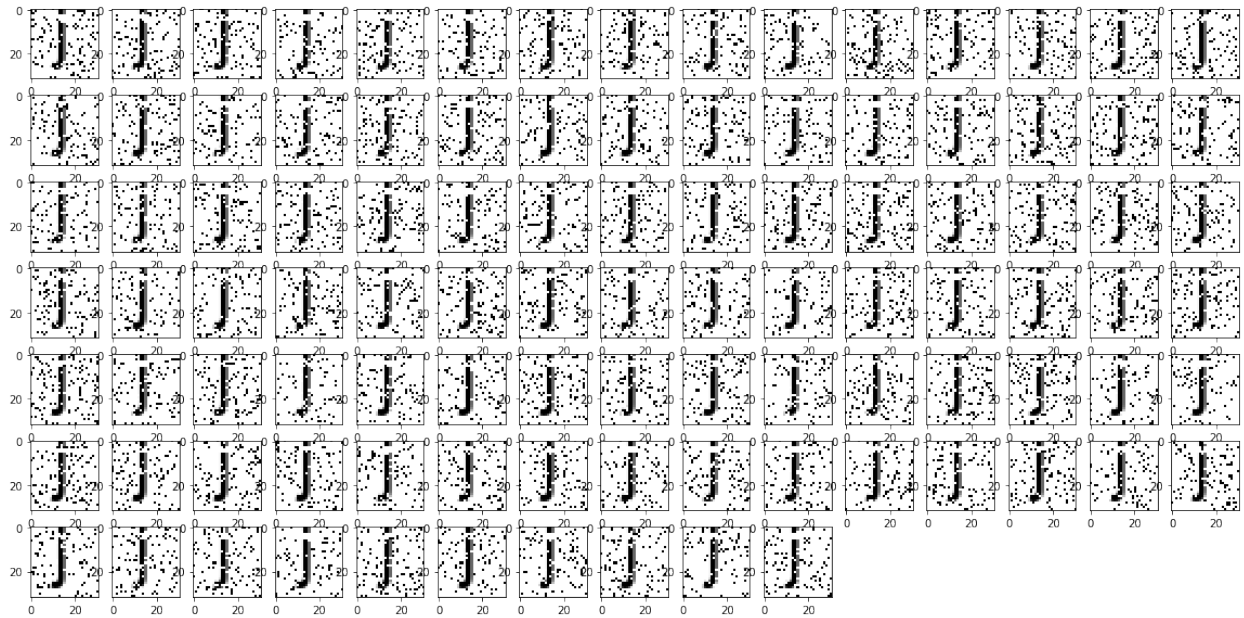
Training for label h...



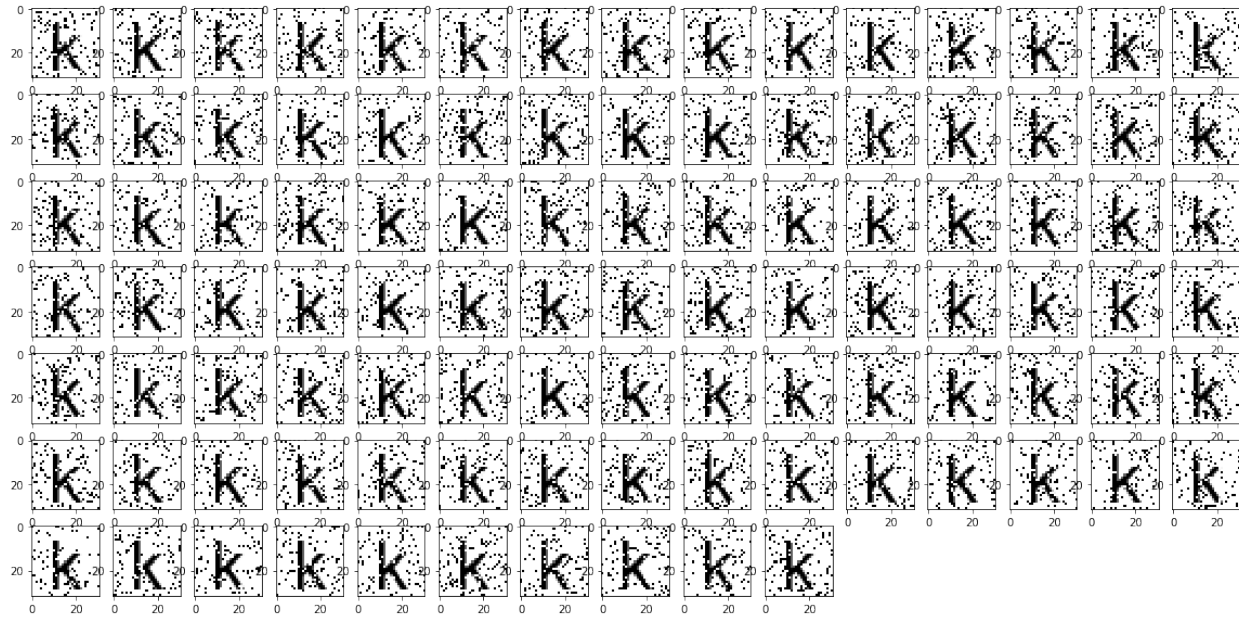
Training for label i...



Training for label j...



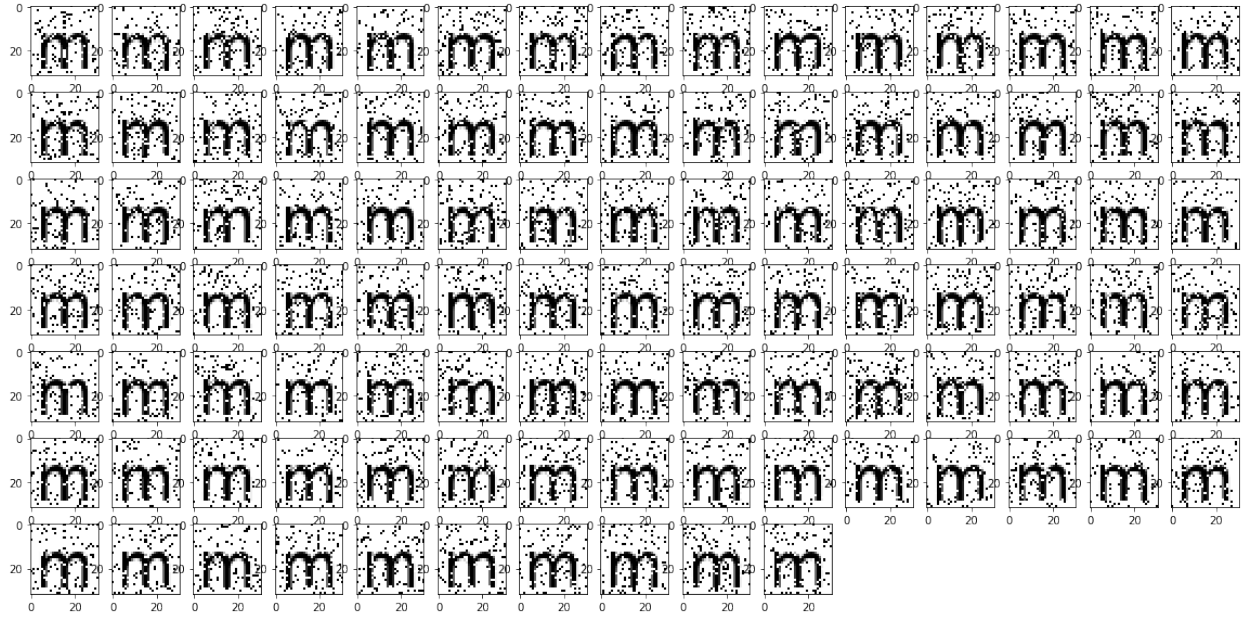
Training for label k...



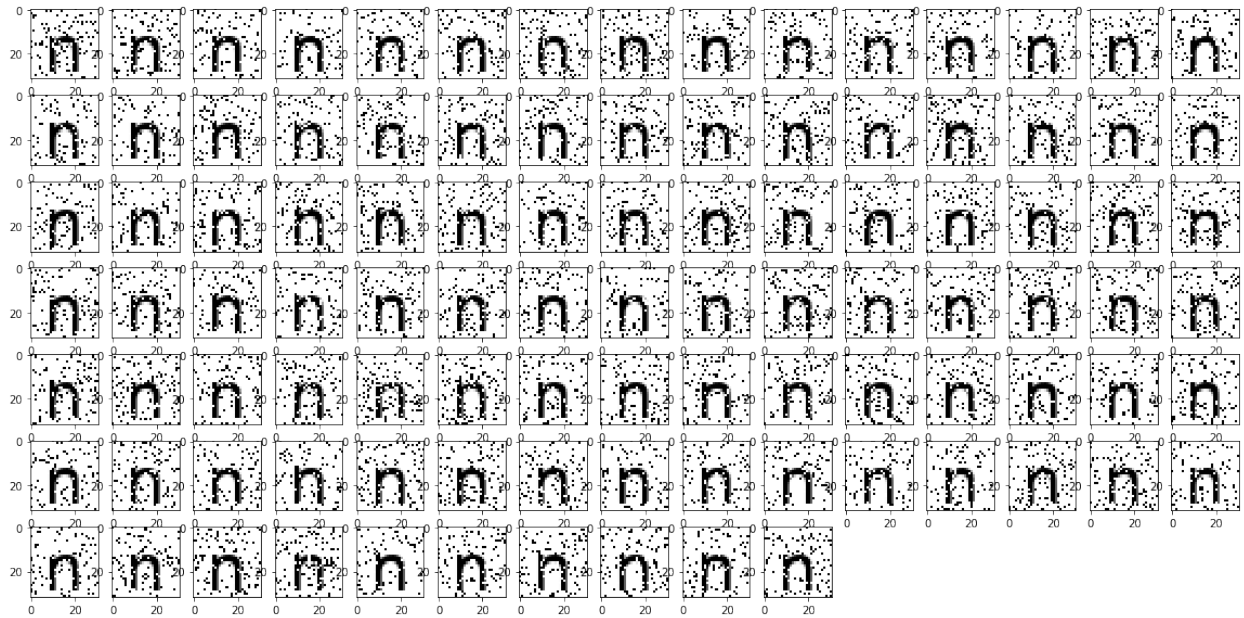
Training for label l...



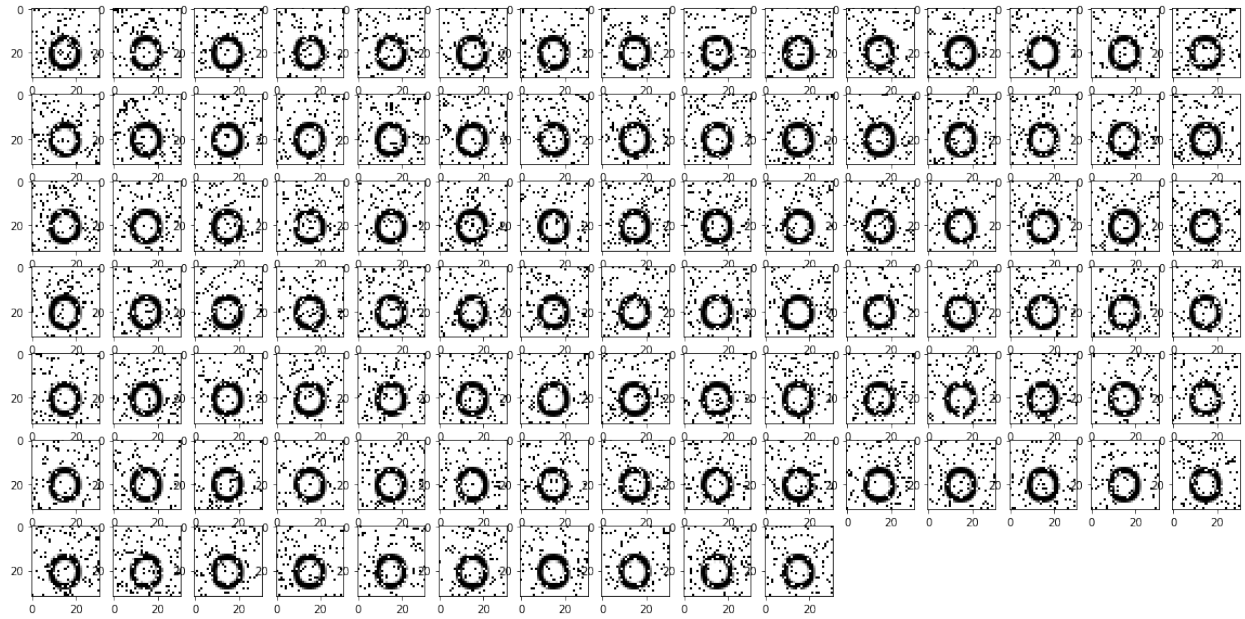
Training for label m...



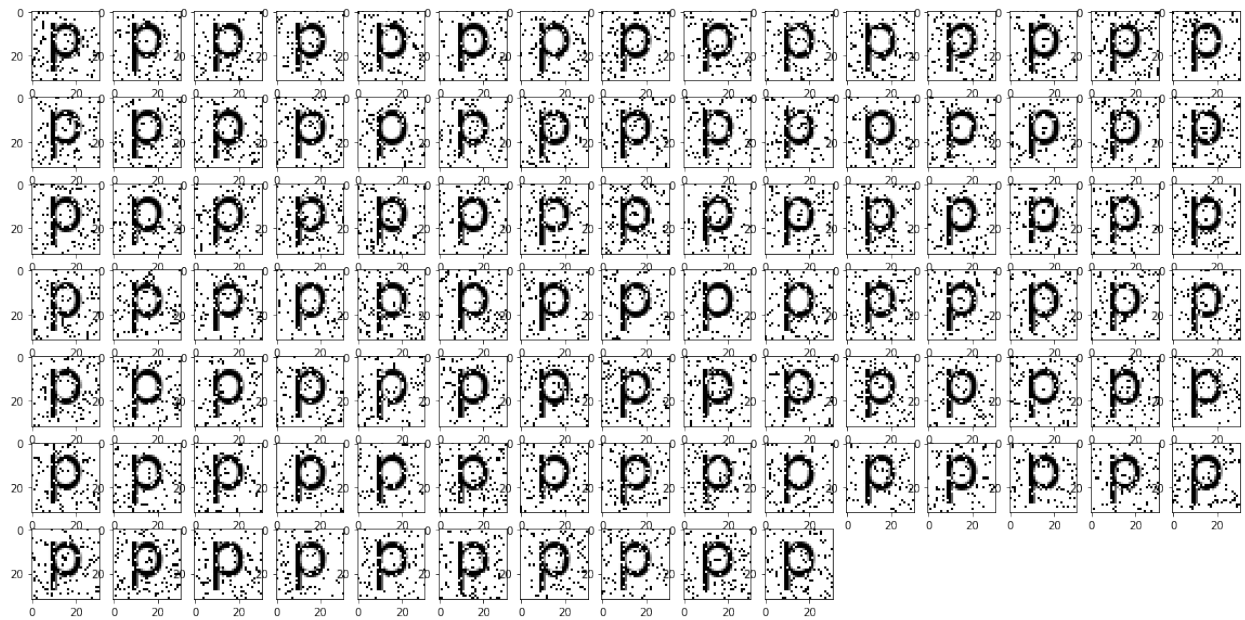
Training for label n...



Training for label o...

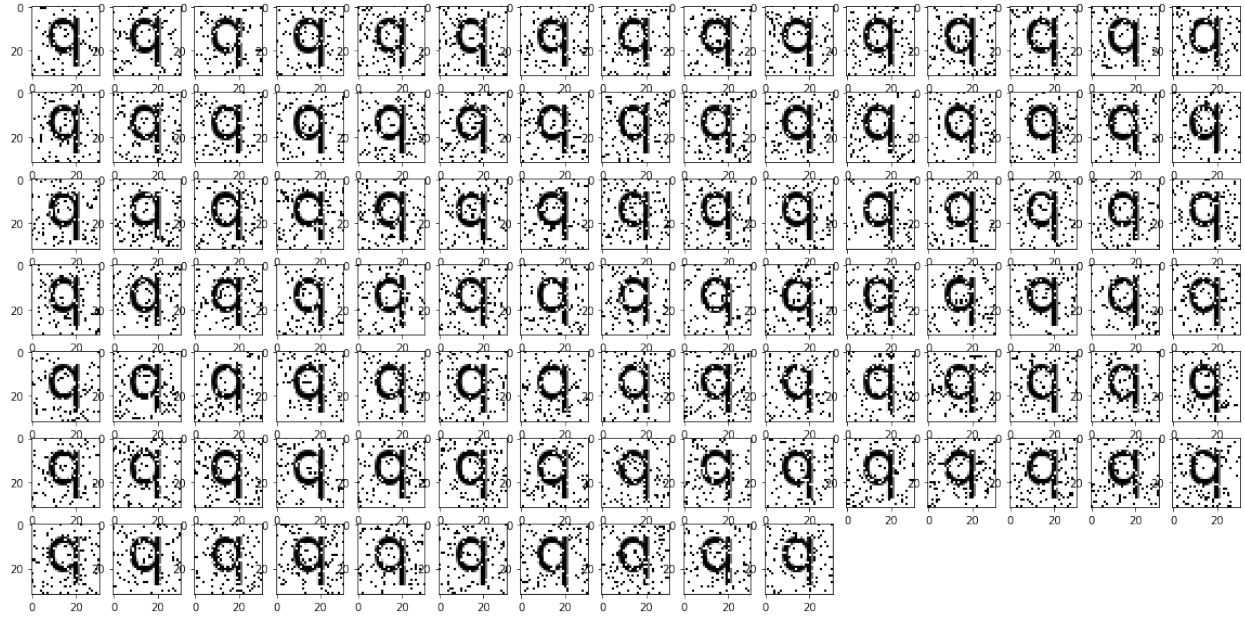


Training for label p...

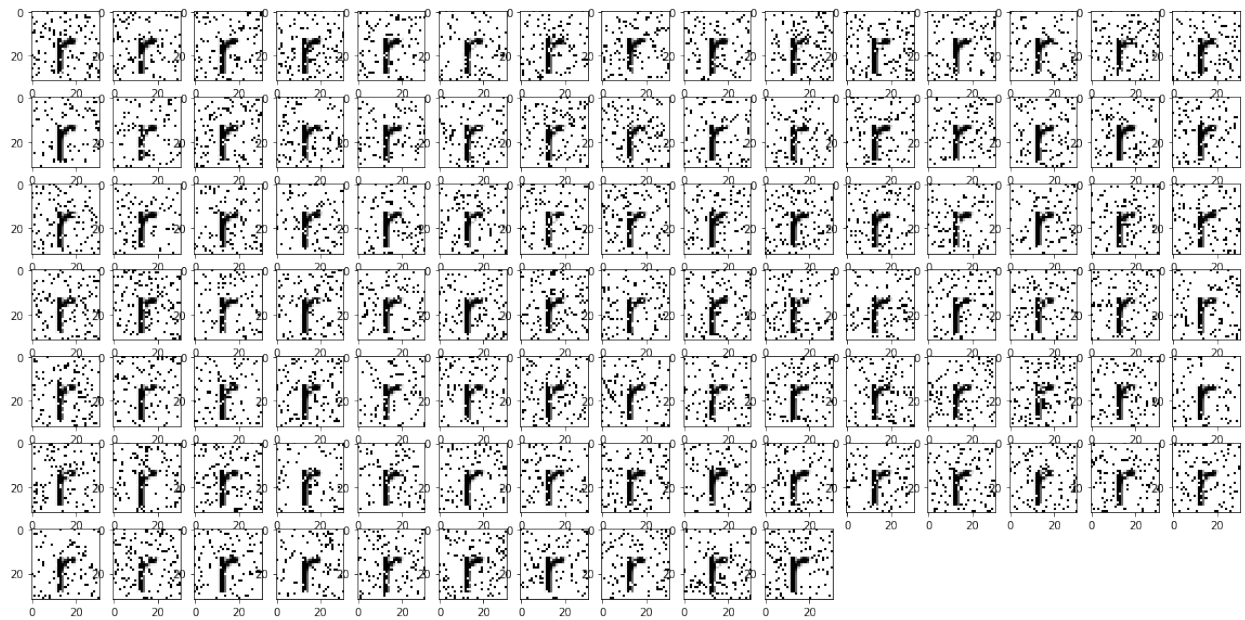


Training for label q...

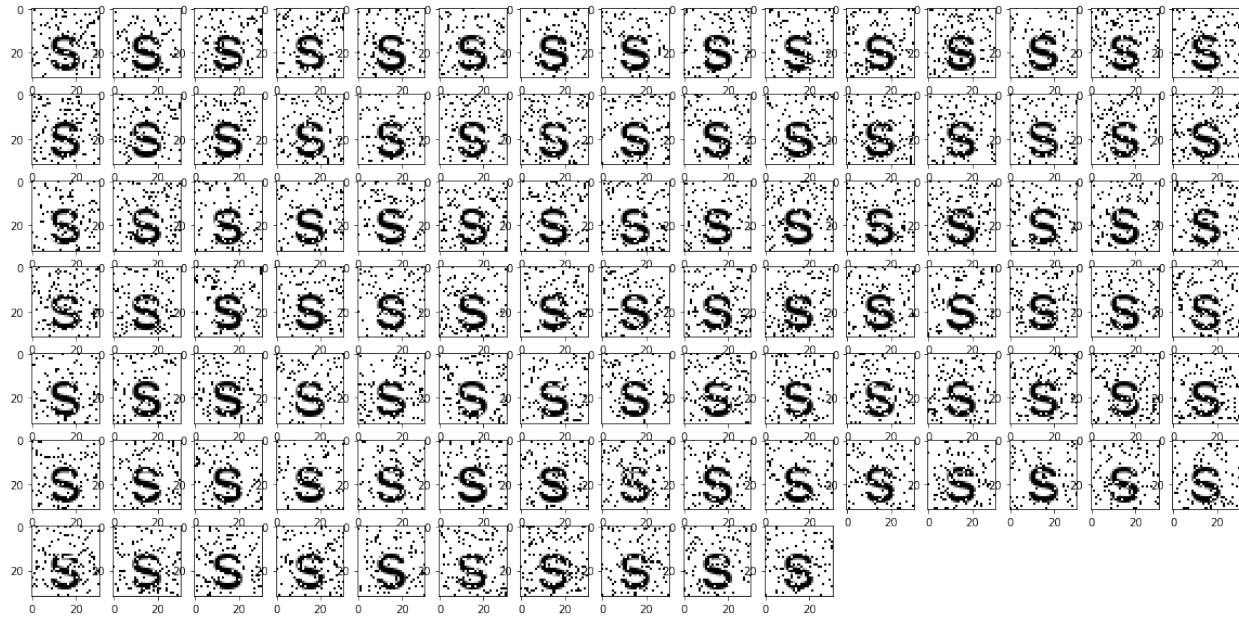




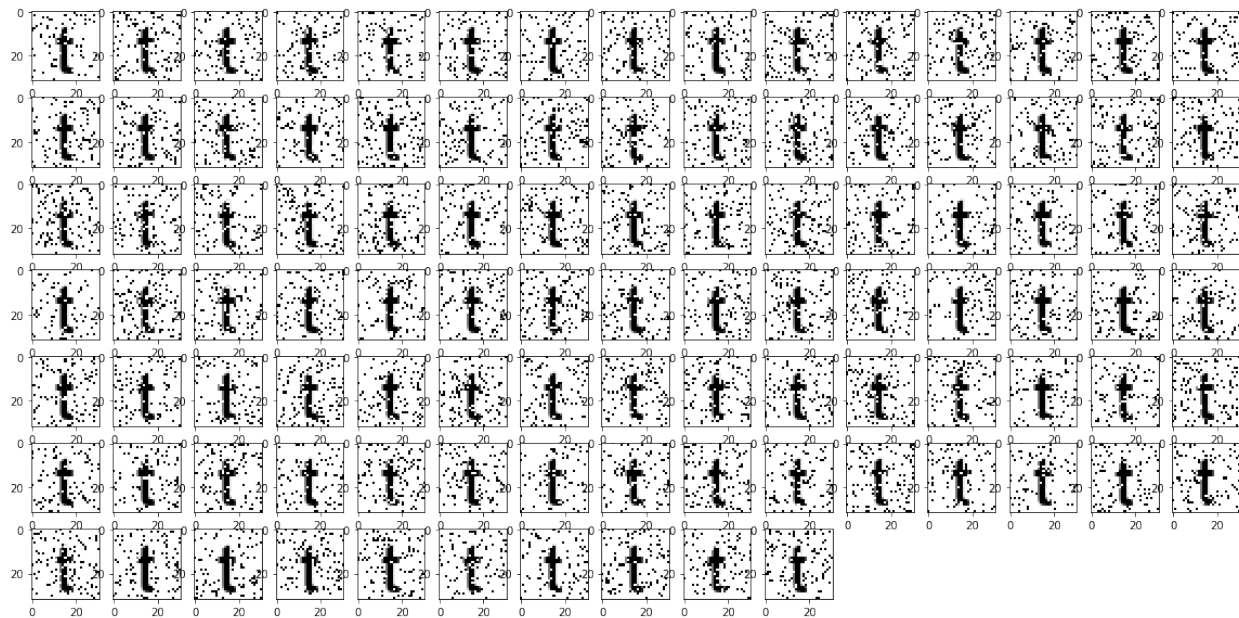
Training for label r...



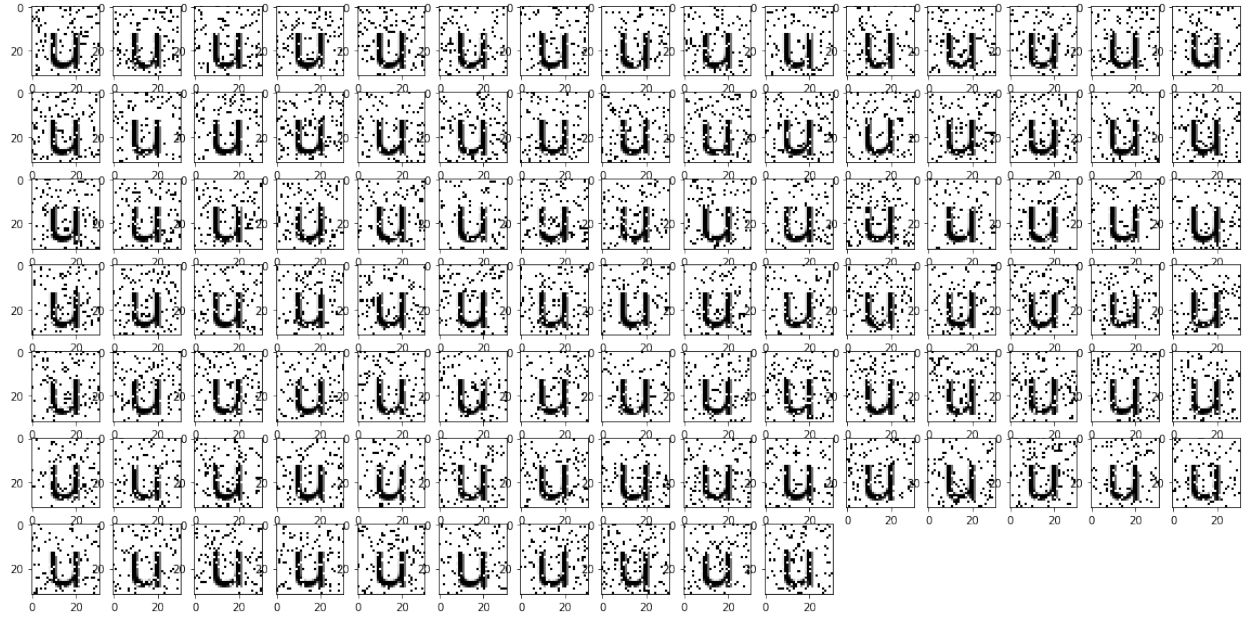
Training for label s...



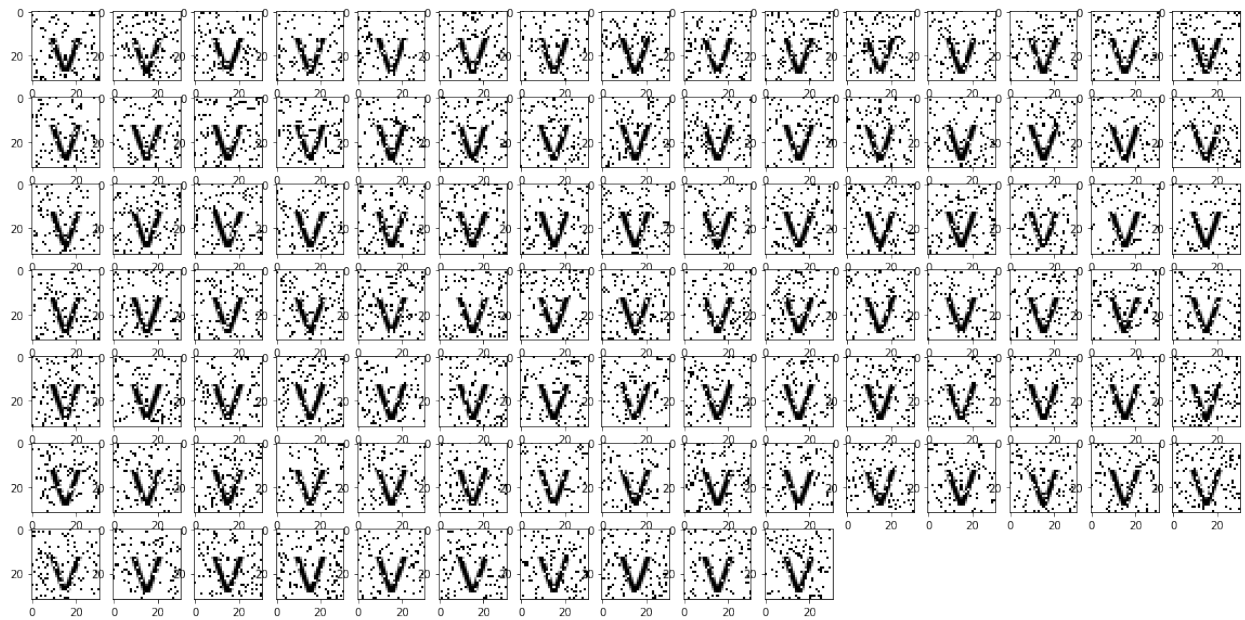
Training for label t...



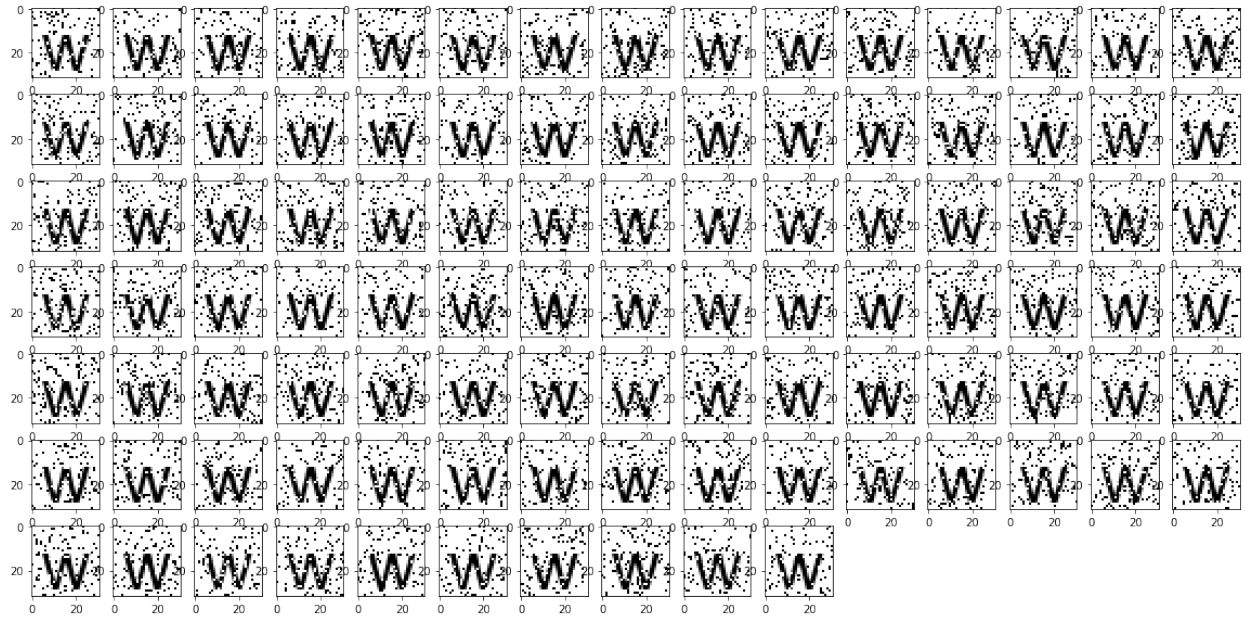
Training for label u...



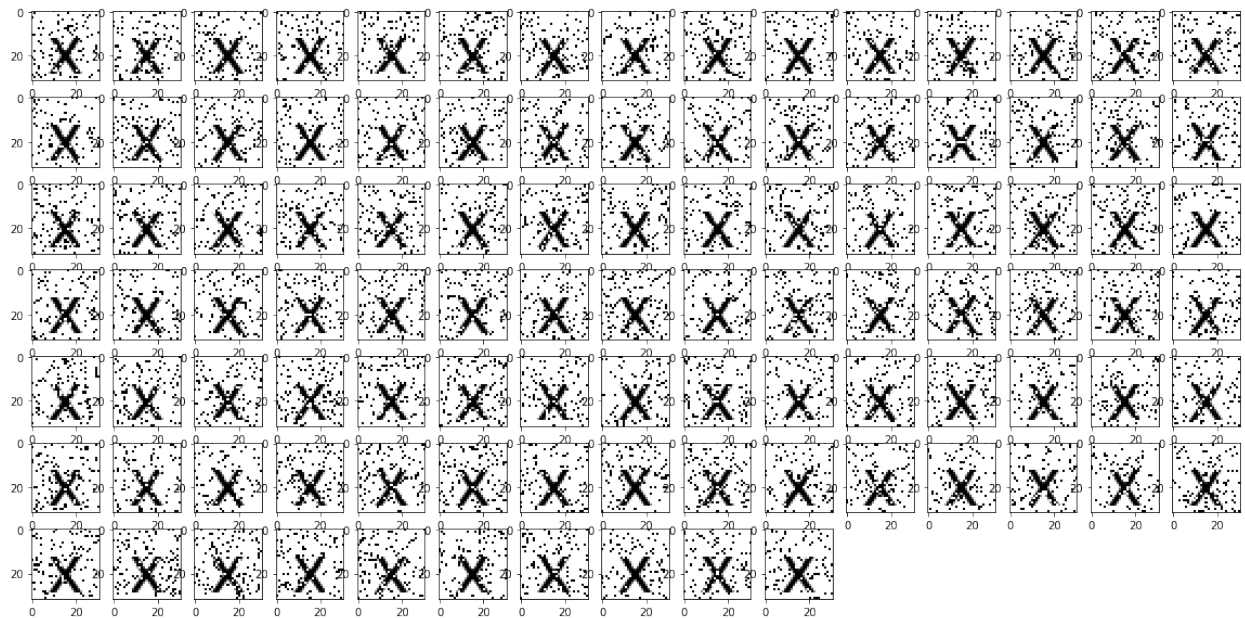
Training for label v...



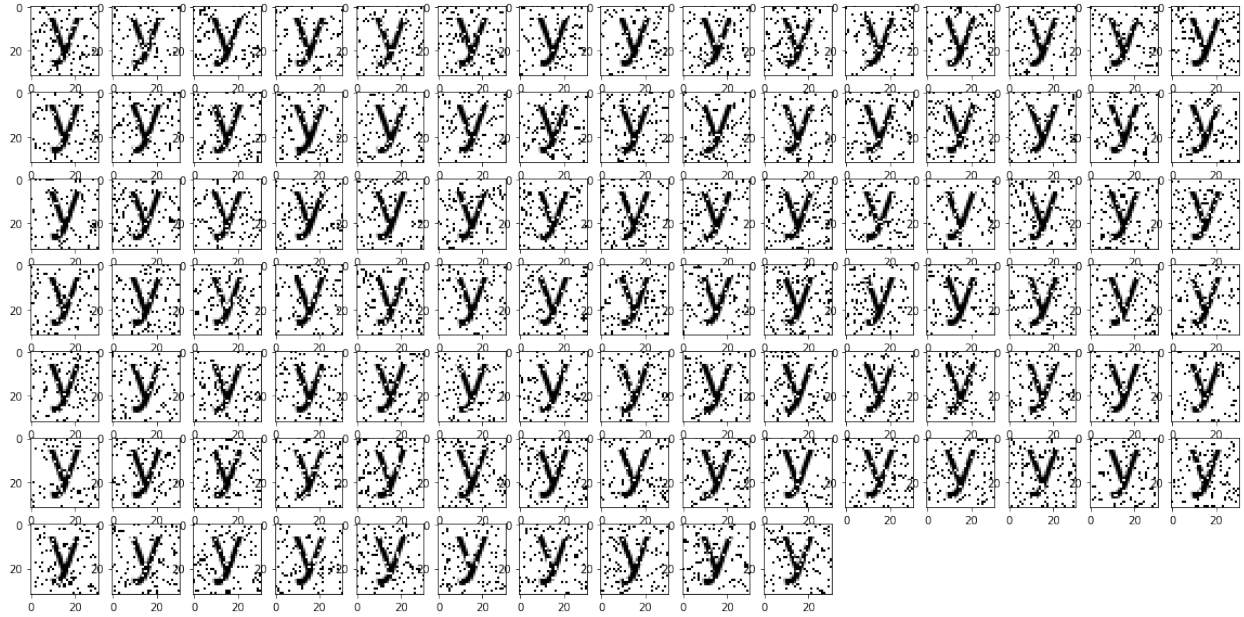
Training for label w...



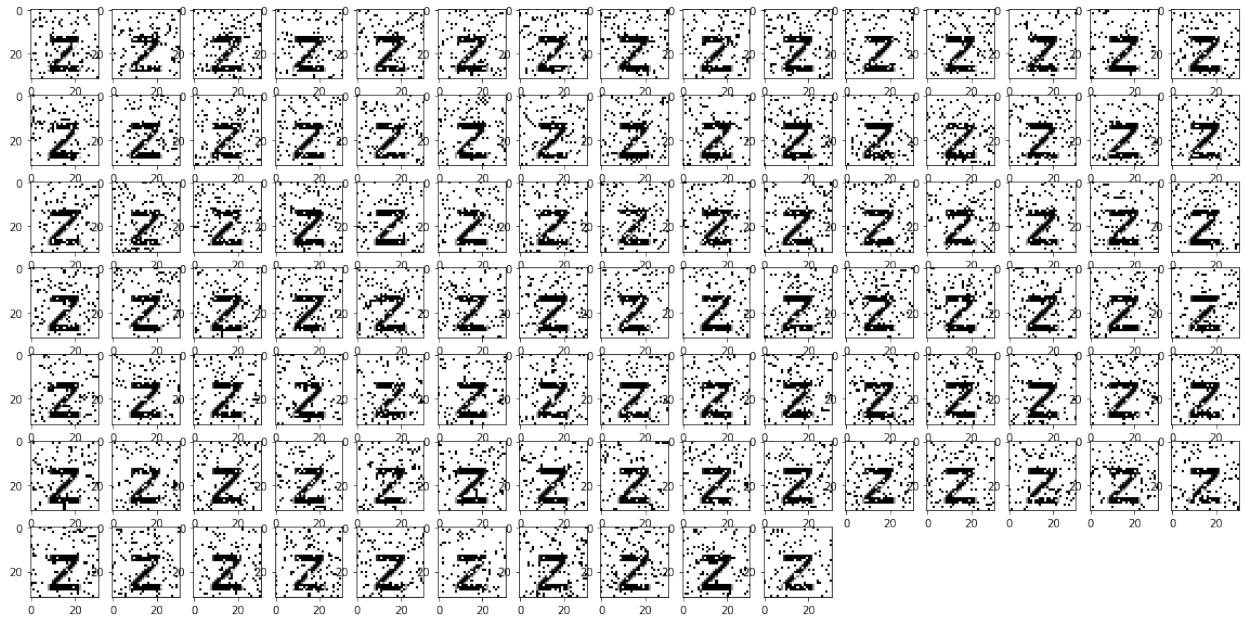
Training for label x...



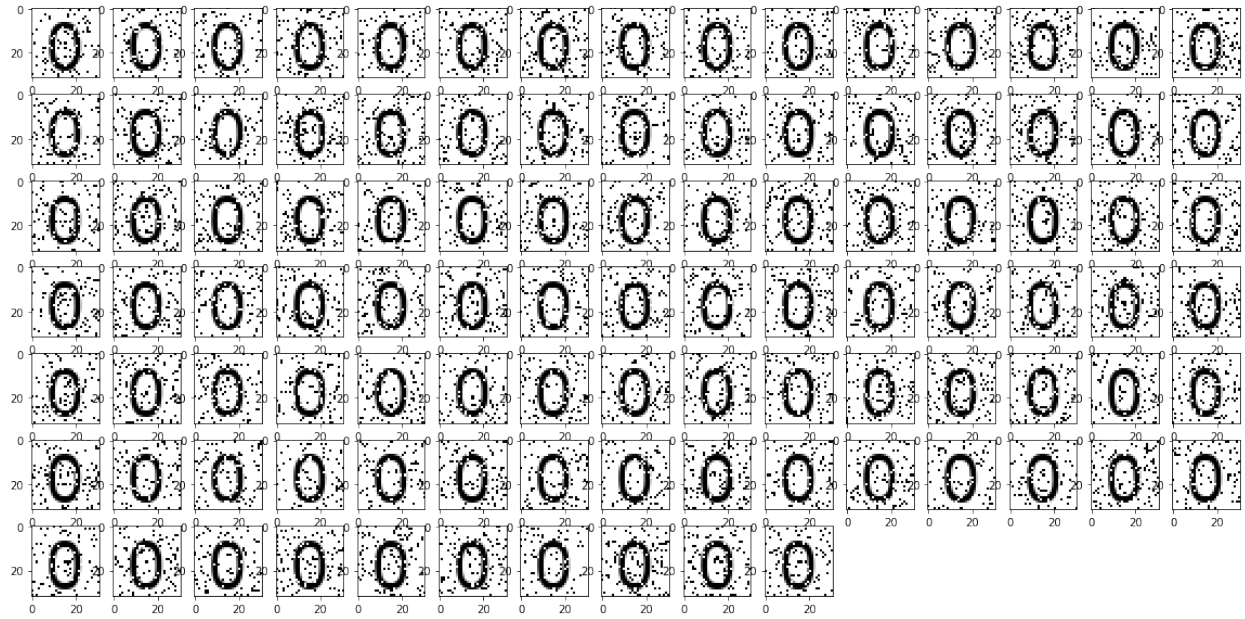
Training for label y...



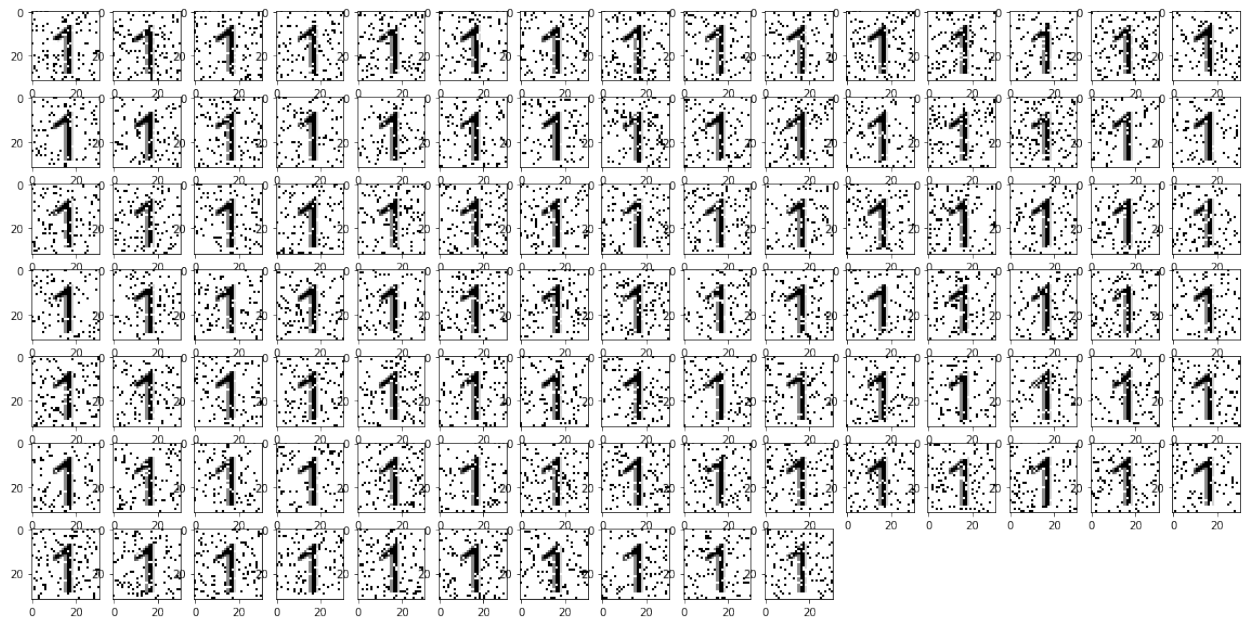
Training for label z...



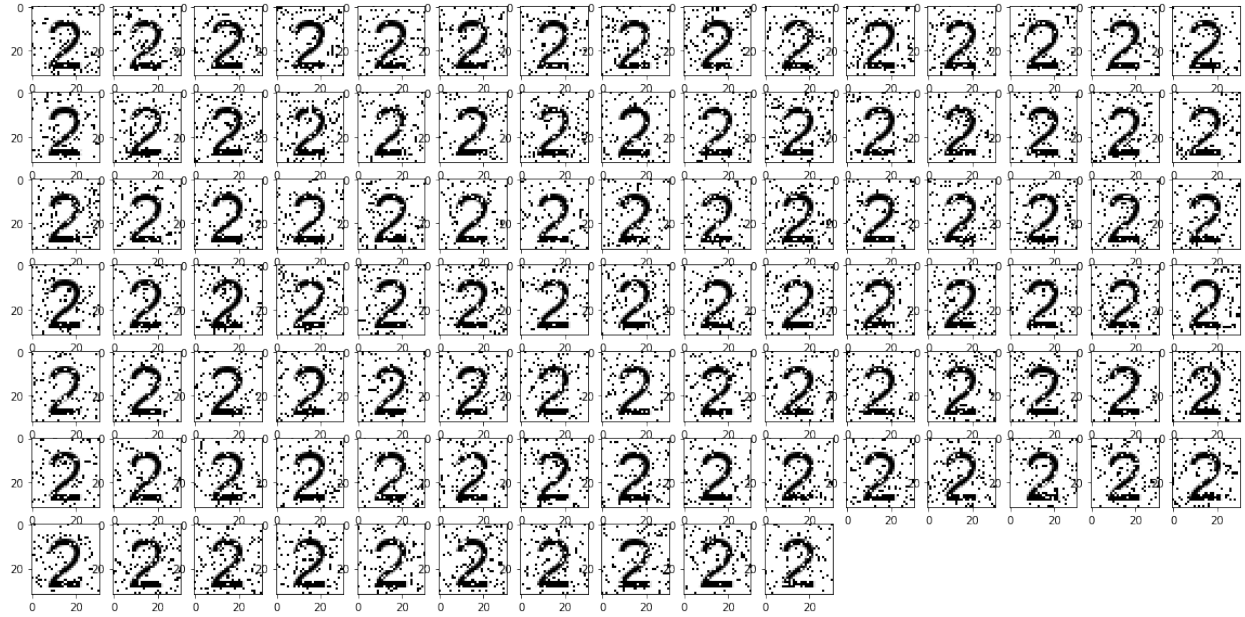
Training for label 0...



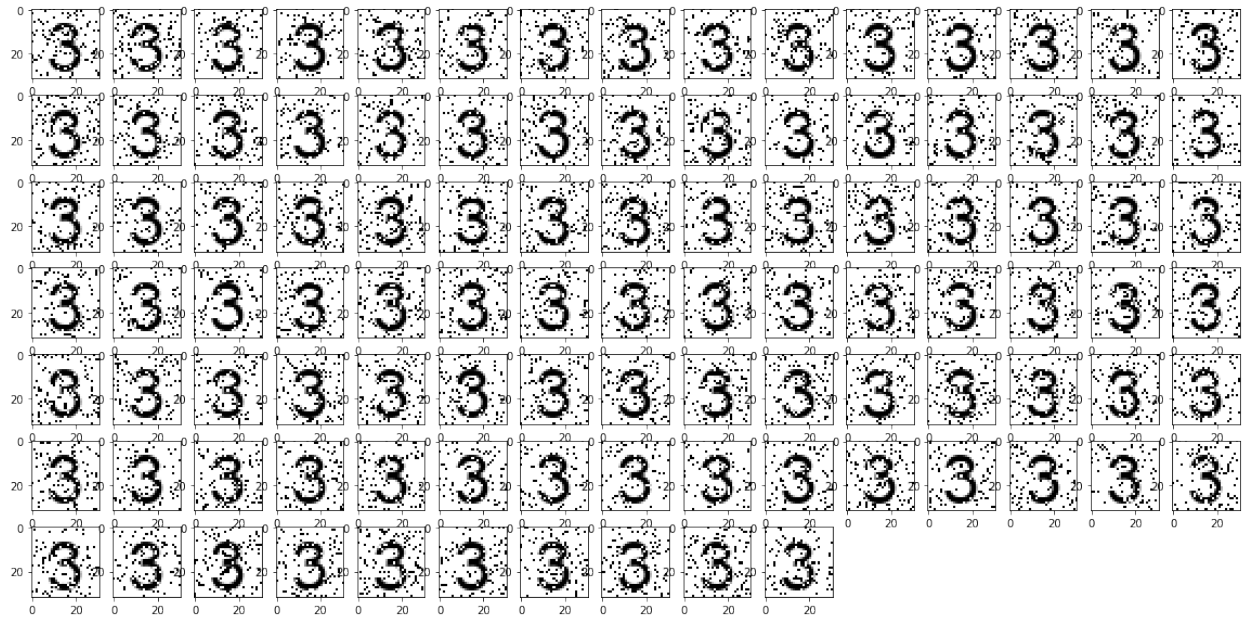
Training for label 1...



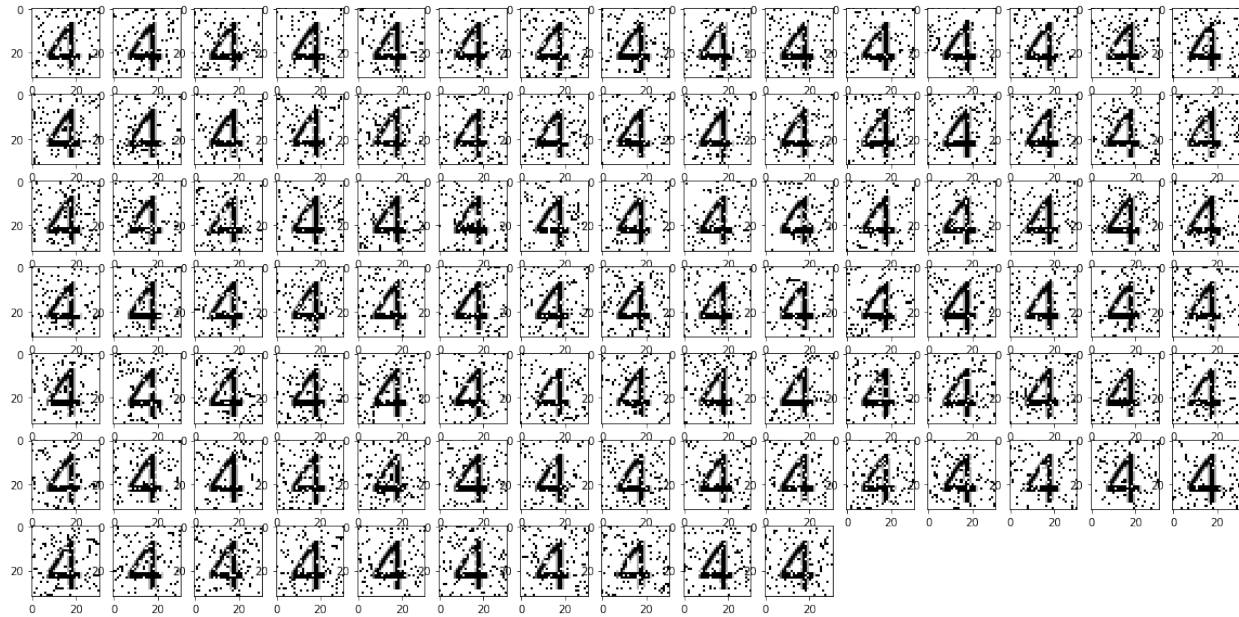
Training for label 2...



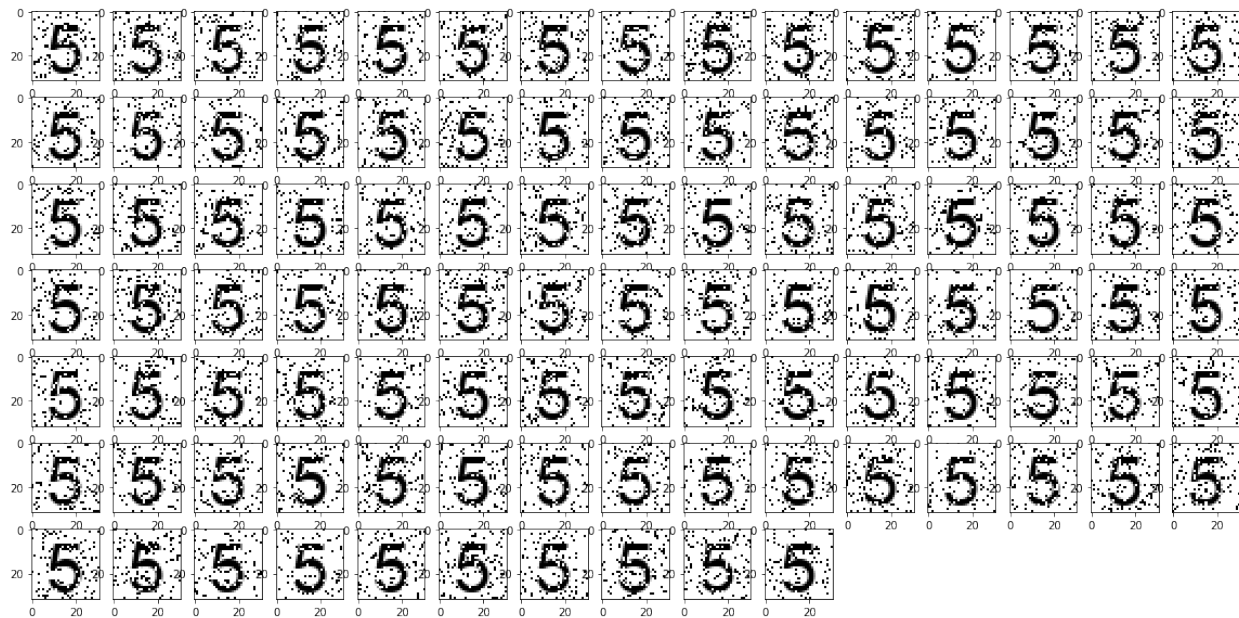
Training for label 3...



Training for label 4...

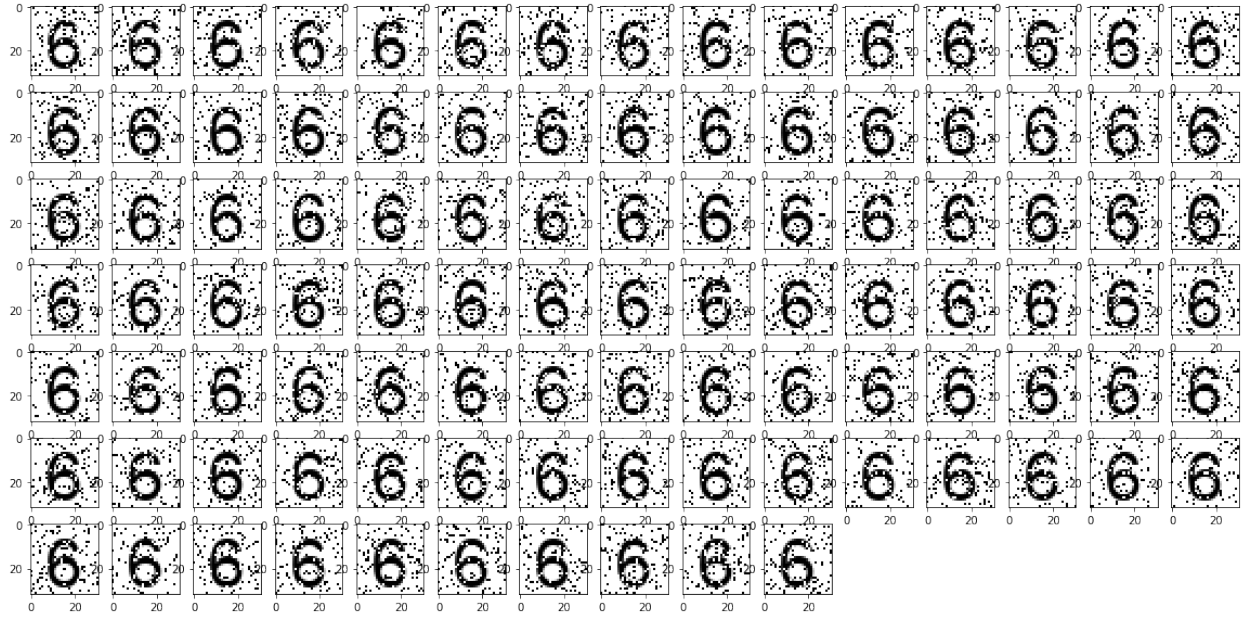


Training for label 5...

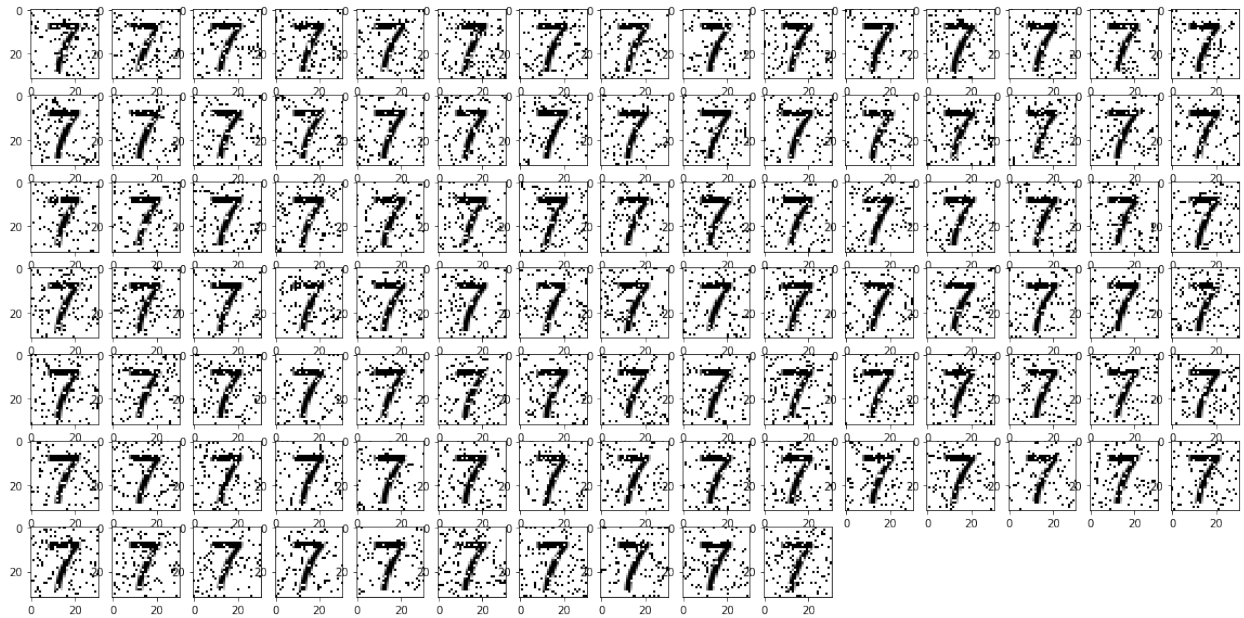


Training for label 6...

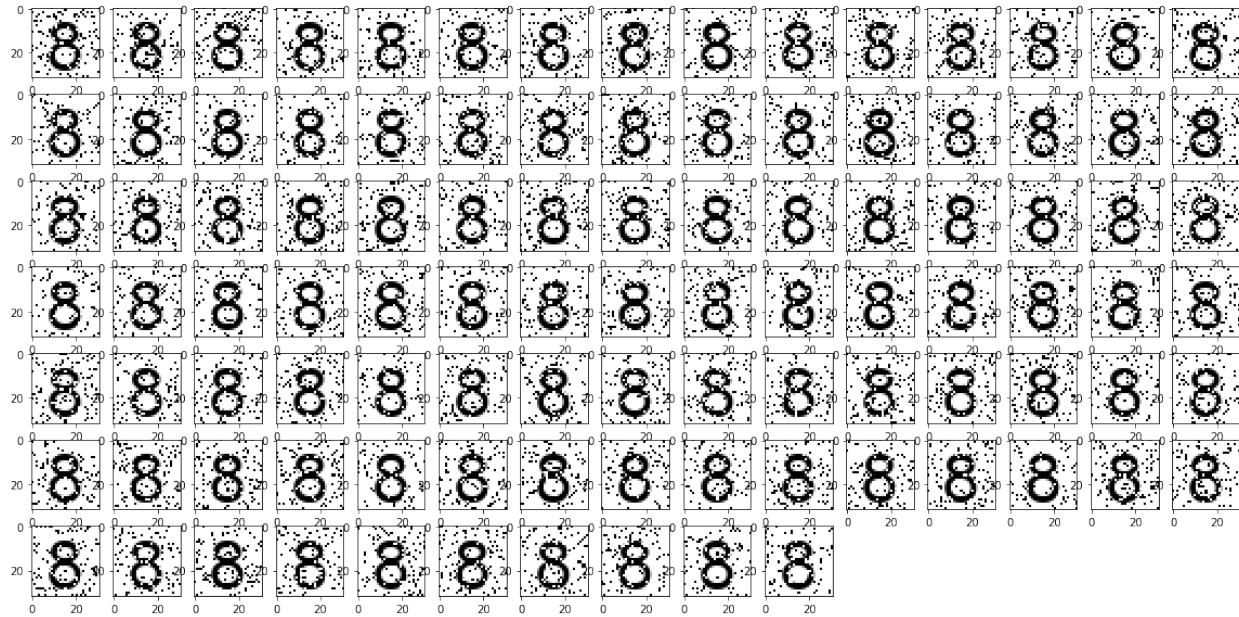




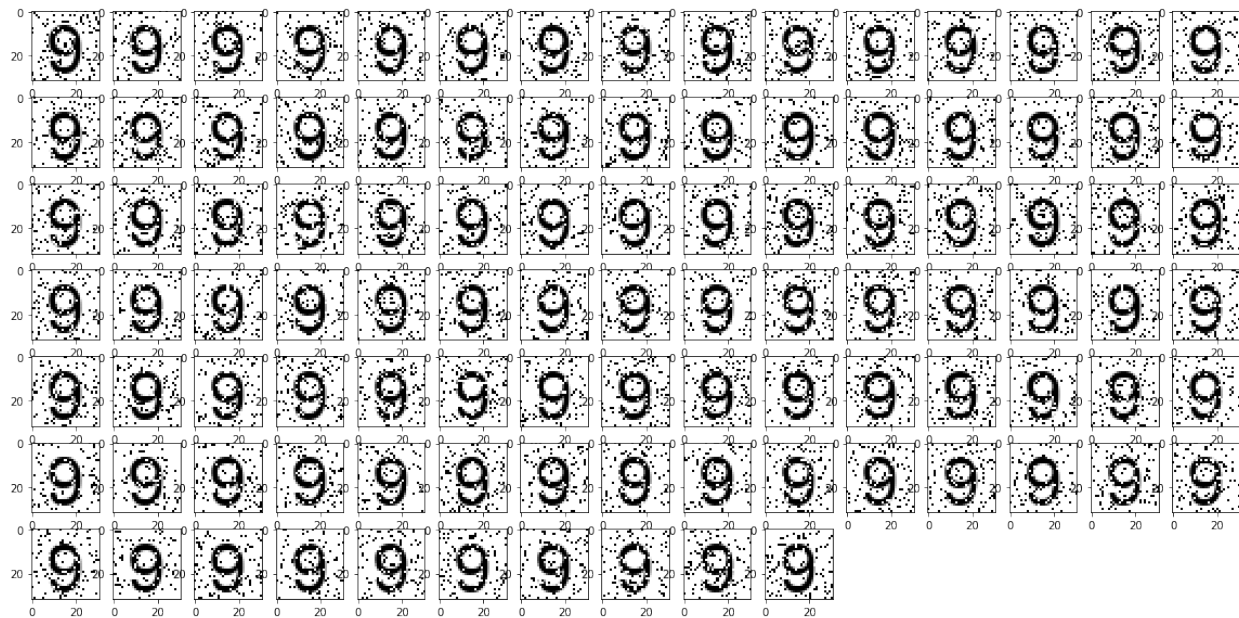
Training for label 7...



Training for label 8...

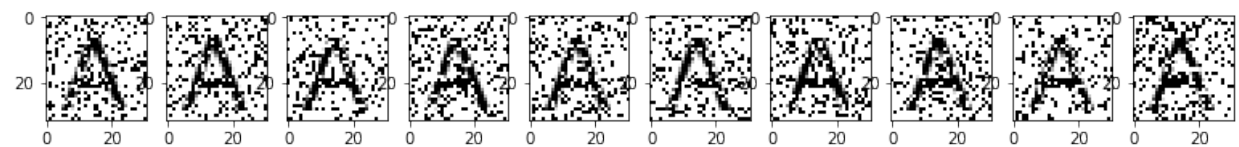


Training for label 9...



## Testing with high noise

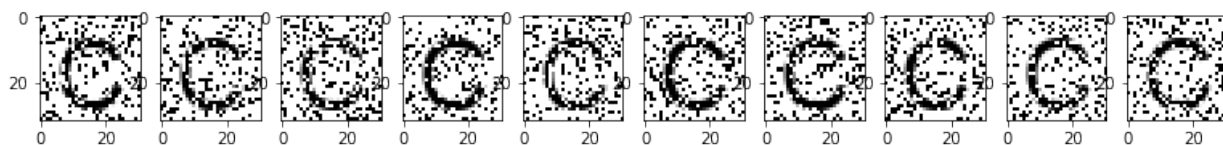
```
In [16]: for x in 'ABCDEFGHJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz0123456789':
         iter_read(x)
```



```
!! A correct=10 wrong= 0 answers=['A', 'A', 'A', 'A', 'A', 'A', 'A', 'A', 'A', 'A']
```



```
!! B correct= 9 wrong= 1 answers=['S', 'B', 'B', 'B', 'B', 'B', 'B', 'B', 'B', 'B']
```



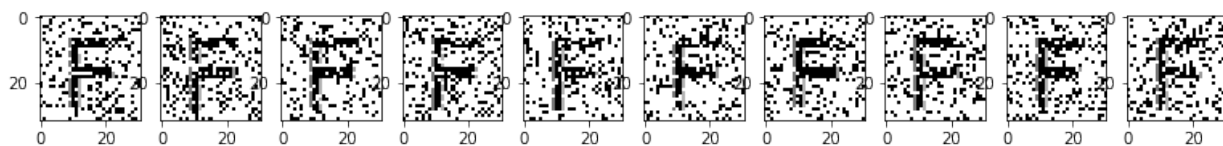
```
!! C correct=10 wrong= 0 answers=['C', 'C', 'C', 'C', 'C', 'C', 'C', 'C', 'C', 'C']
```



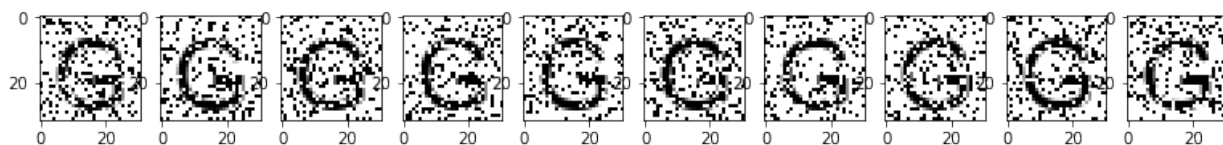
```
!! D correct=10 wrong= 0 answers=['D', 'D', 'D', 'D', 'D', 'D', 'D', 'D', 'D', 'D']
```



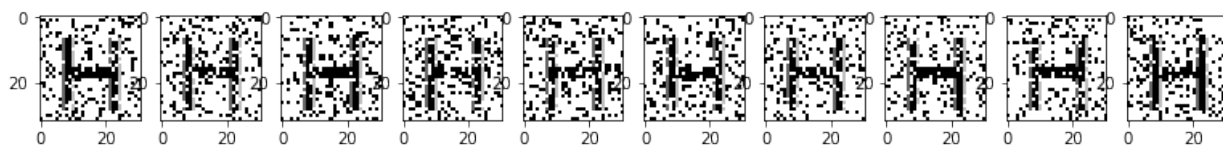
```
!! E correct=10 wrong= 0 answers=['E', 'E', 'E', 'E', 'E', 'E', 'E', 'E', 'E', 'E']
```



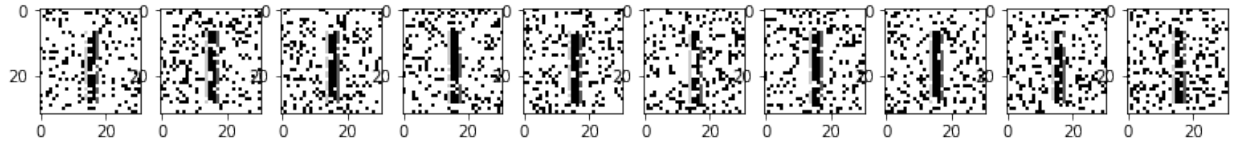
```
!! F correct=10 wrong= 0 answers=['F', 'F', 'F', 'F', 'F', 'F', 'F', 'F', 'F', 'F']
```



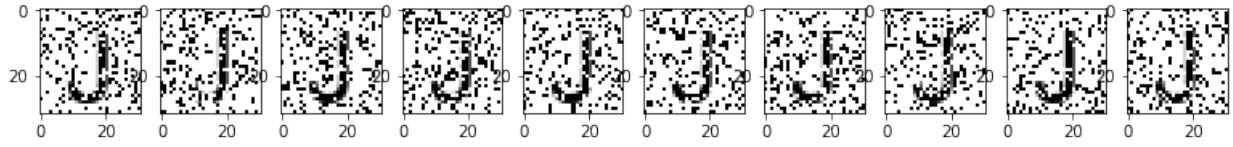
```
!! G correct=10 wrong= 0 answers=['G', 'G', 'G', 'G', 'G', 'G', 'G', 'G', 'G', 'G']
```



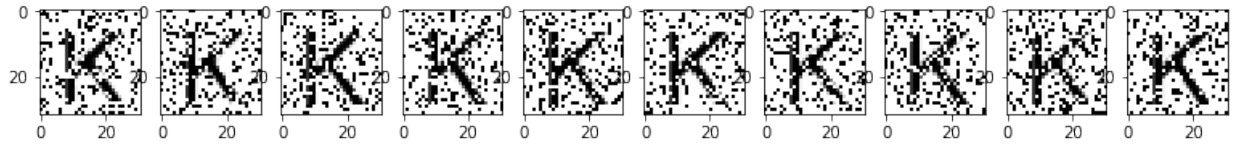
```
!! H correct=10 wrong= 0 answers=['H', 'H', 'H', 'H', 'H', 'H', 'H', 'H', 'H', 'H']
```



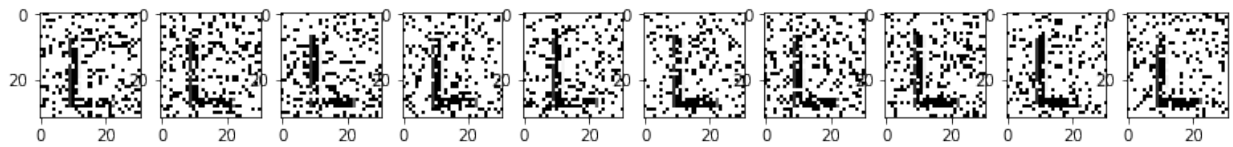
!! I correct=10 wrong= 0 answers=['I', 'I', 'I', 'I', 'I', 'I', 'I', 'I', 'I', 'I']



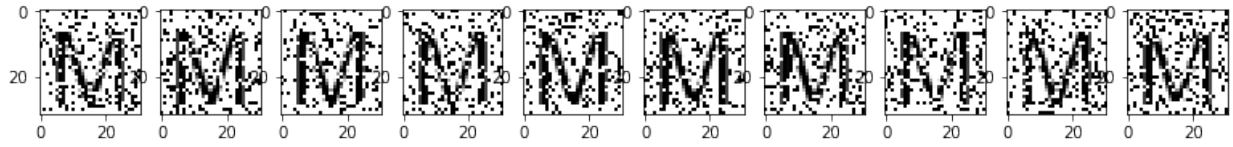
!! J correct=10 wrong= 0 answers=['J', 'J', 'J', 'J', 'J', 'J', 'J', 'J', 'J', 'J']



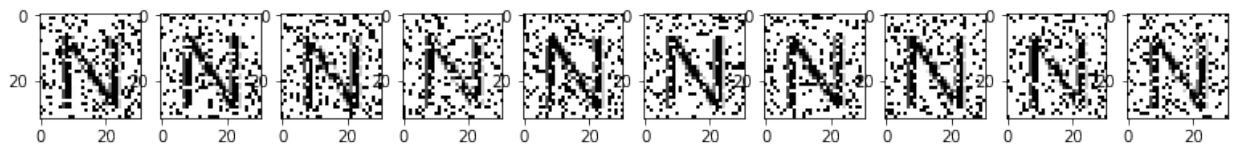
!! K correct=10 wrong= 0 answers=['K', 'K', 'K', 'K', 'K', 'K', 'K', 'K', 'K', 'K']



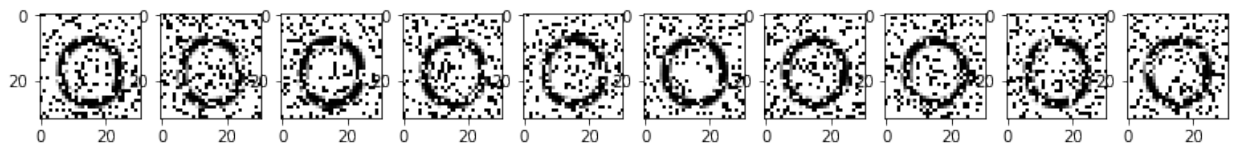
!! L correct=10 wrong= 0 answers=['L', 'L', 'L', 'L', 'L', 'L', 'L', 'L', 'L', 'L']



!! M correct=10 wrong= 0 answers=['M', 'M', 'M', 'M', 'M', 'M', 'M', 'M', 'M', 'M']



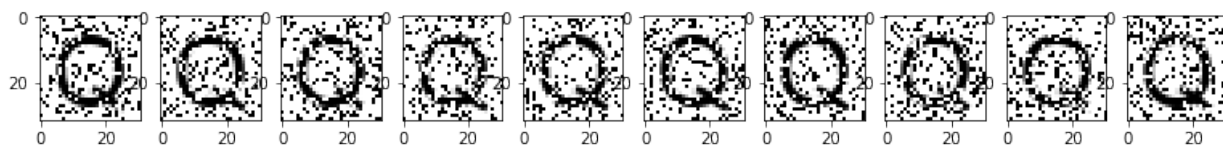
!! N correct=10 wrong= 0 answers=['N', 'N', 'N', 'N', 'N', 'N', 'N', 'N', 'N', 'N']



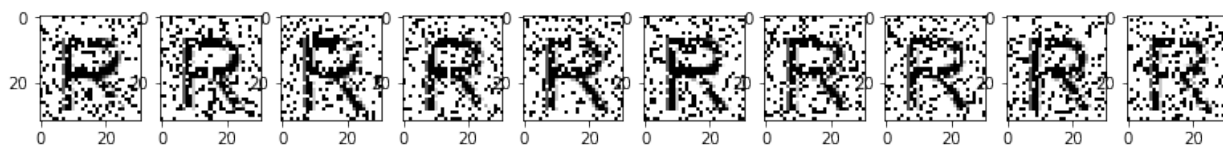
!! O correct= 8 wrong= 2 answers=['G', 'G', 'O', 'O', 'O', 'O', 'O', 'O', 'O', 'O']



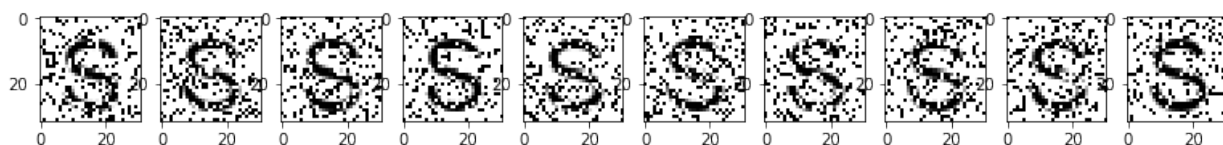
!! P correct=10 wrong= 0 answers=['P', 'P', 'P', 'P', 'P', 'P', 'P', 'P', 'P', 'P']



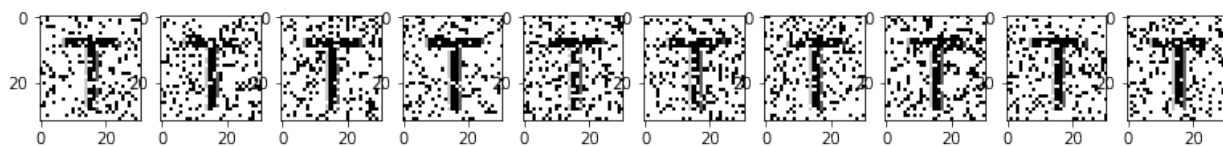
!! Q correct=10 wrong= 0 answers=['Q', 'Q', 'Q', 'Q', 'Q', 'Q', 'Q', 'Q', 'Q', 'Q']



!! R correct=10 wrong= 0 answers=['R', 'R', 'R', 'R', 'R', 'R', 'R', 'R', 'R', 'R']



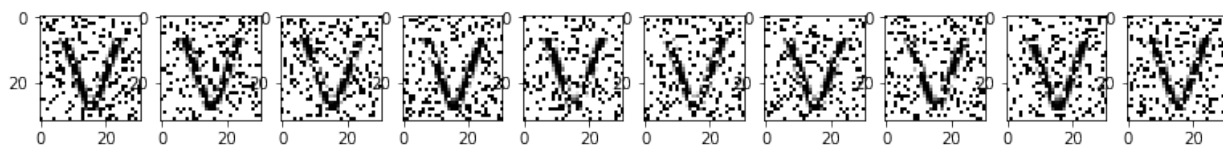
!! S correct=10 wrong= 0 answers=['S', 'S', 'S', 'S', 'S', 'S', 'S', 'S', 'S', 'S']



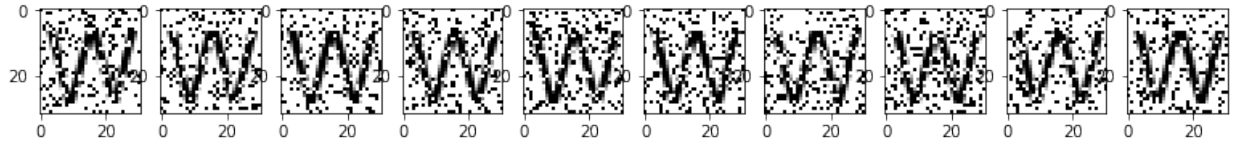
!! T correct= 9 wrong= 1 answers=['T', 'T', 'T', 'T', 'T', 'I', 'T', 'T', 'T', 'T']



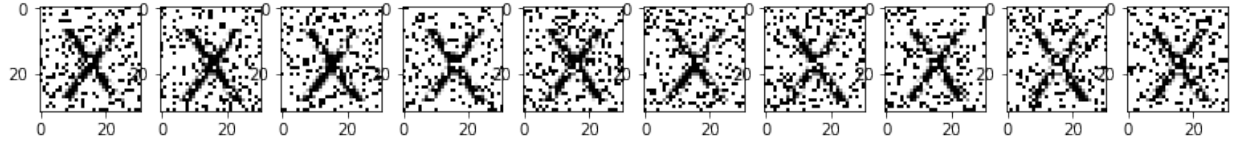
!! U correct=10 wrong= 0 answers=['U', 'U', 'U', 'U', 'U', 'U', 'U', 'U', 'U', 'U']



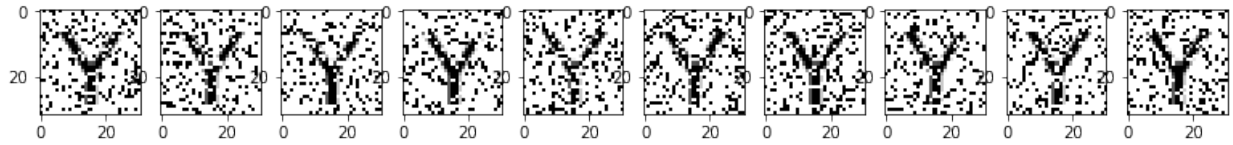
!! V correct=10 wrong= 0 answers=['V', 'V', 'V', 'V', 'V', 'V', 'V', 'V', 'V', 'V']



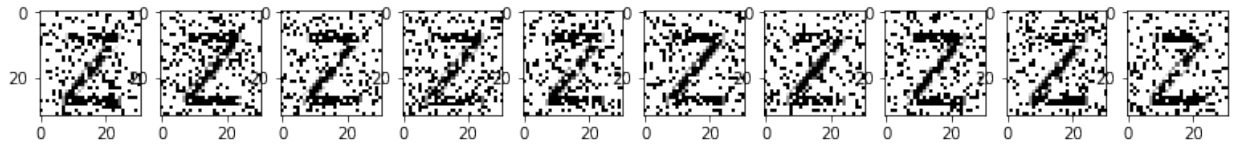
!! W correct=10 wrong= 0 answers=['W', 'W', 'W', 'W', 'W', 'W', 'W', 'W', 'W', 'W']



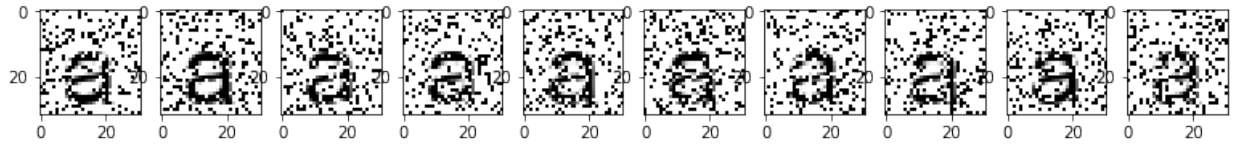
!! X correct=10 wrong= 0 answers=['X', 'X', 'X', 'X', 'X', 'X', 'X', 'X', 'X', 'X']



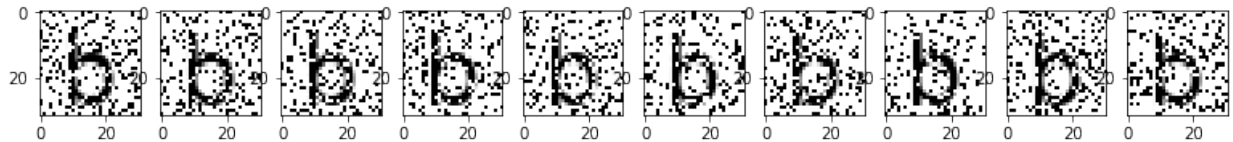
!! Y correct= 9 wrong= 1 answers=['Y', 'I', 'Y', 'Y', 'Y', 'Y', 'Y', 'Y', 'Y', 'Y']



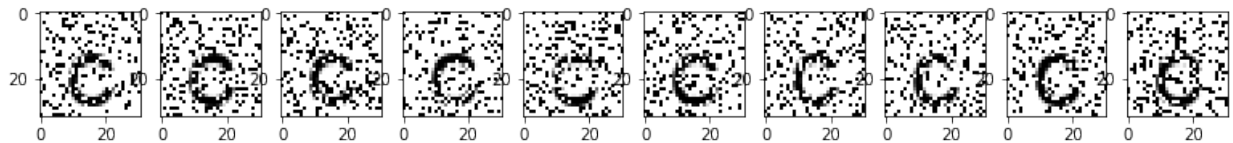
!! Z correct=10 wrong= 0 answers=['Z', 'Z', 'Z', 'Z', 'Z', 'Z', 'Z', 'Z', 'Z', 'Z']



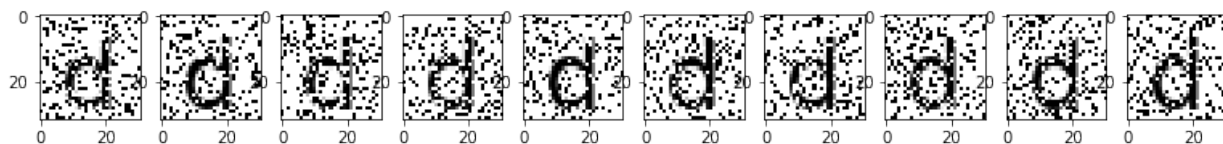
!! a correct=10 wrong= 0 answers=['a', 'a', 'a', 'a', 'a', 'a', 'a', 'a', 'a', 'a']



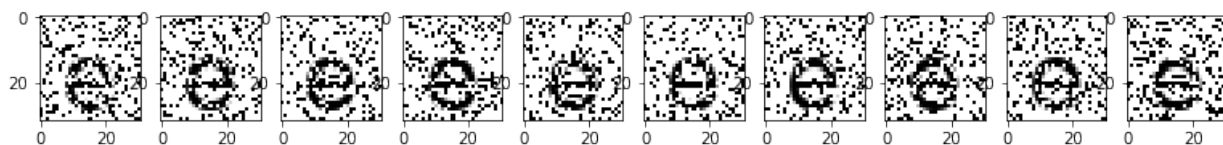
!! b correct= 3 wrong= 7 answers=['o', 'o', 'o', 'b', 'o', 'h', 'h', 'b', 'b', 'o']



!! c correct= 8 wrong= 2 answers=['c', 'c', 'c', 'c', 'c', 'o', 'c', 'c', 'c', 'o']



!! d correct=10 wrong= 0 answers=['d', 'd', 'd', 'd', 'd', 'd', 'd', 'd', 'd', 'd']



!! e correct= 4 wrong= 6 answers=['e', 'o', 'e', 'o', 'o', 'o', 'e', 'o', 'o', 'e']



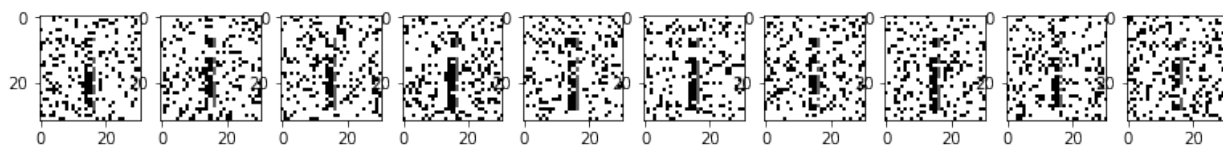
!! f correct= 0 wrong=10 answers=['I', 'I', 'I', 'I', 'i', 'I', 'I', 'I', 'I', 'I']



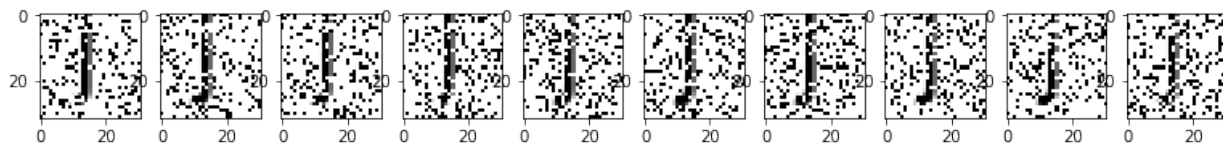
!! g correct=10 wrong= 0 answers=['g', 'g', 'g', 'g', 'g', 'g', 'g', 'g', 'g', 'g']



!! h correct=10 wrong= 0 answers=['h', 'h', 'h', 'h', 'h', 'h', 'h', 'h', 'h', 'h']

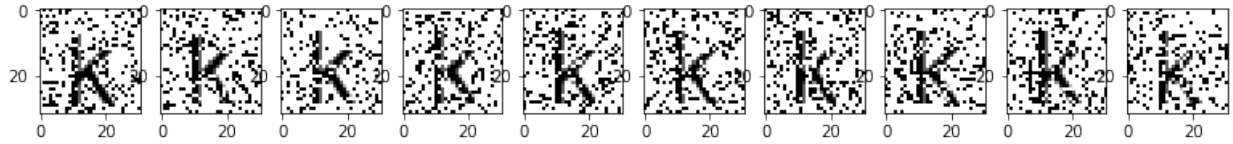


!! i correct= 8 wrong= 2 answers=['i', 'i', 'i', 'I', 'i', 'i', 'i', 'i', 'I', 'i']

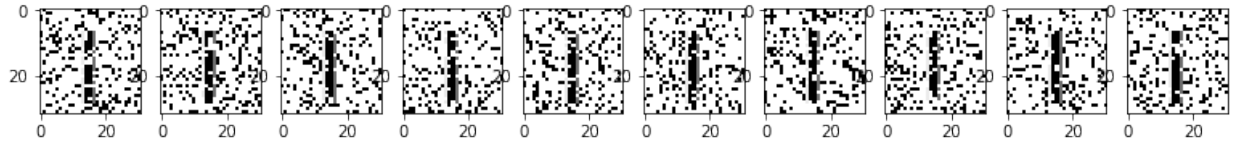


!! j correct= 7 wrong= 3 answers=['j', 'j', 'j', 'I', 'I', 'j', 'j', 'j', 'j', 'I']

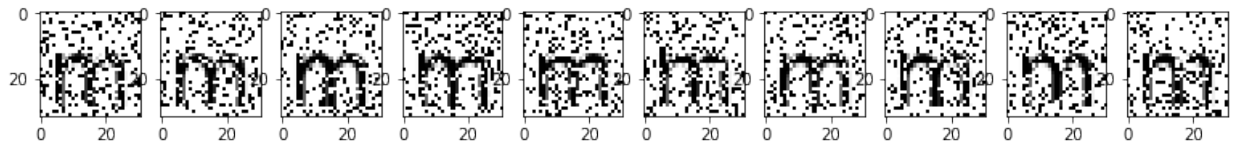




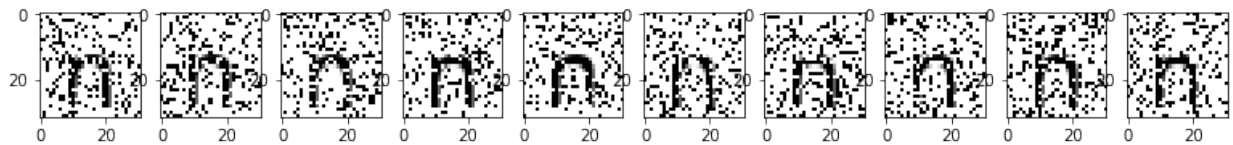
```
!! k correct=10 wrong= 0 answers=['k', 'k', 'k', 'k', 'k', 'k', 'k', 'k', 'k', 'k']
```



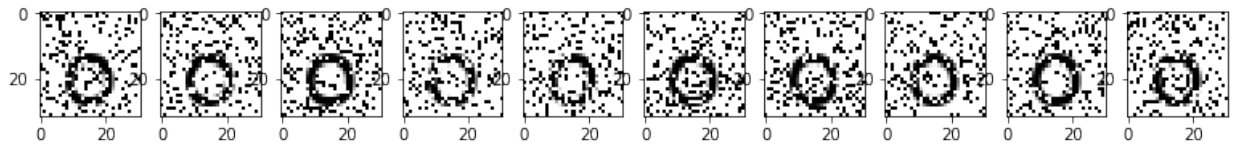
```
!! l correct= 0 wrong=10 answers=['I', 'i', 'I', 'I', 'I', 'I', 'i', 'I', 'I', 'i']
```



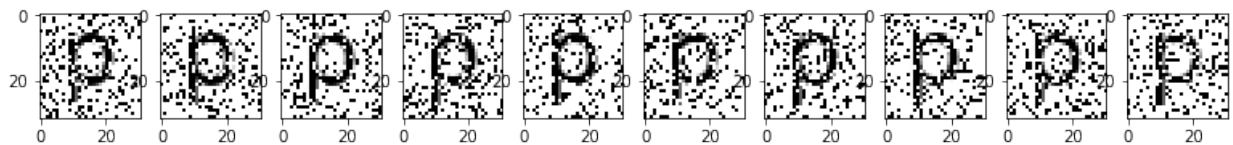
```
!! m correct=10 wrong= 0 answers=['m', 'm', 'm', 'm', 'm', 'm', 'm', 'm', 'm', 'm']
```



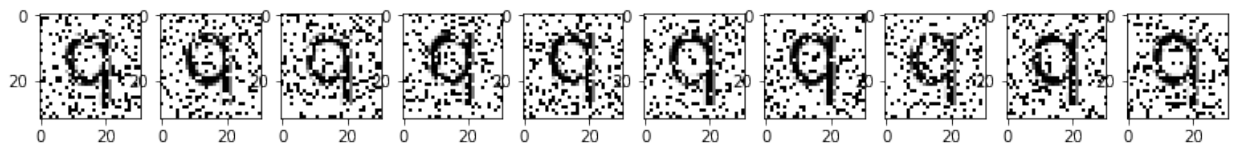
```
!! n correct= 5 wrong= 5 answers=['u', 'n', 'n', 'n', 'n', 'n', 'u', 'u', 'u', 'h']
```



```
!! o correct=10 wrong= 0 answers=['o', 'o', 'o', 'o', 'o', 'o', 'o', 'o', 'o', 'o']
```



```
!! p correct=10 wrong= 0 answers=['p', 'p', 'p', 'p', 'p', 'p', 'p', 'p', 'p', 'p']
```

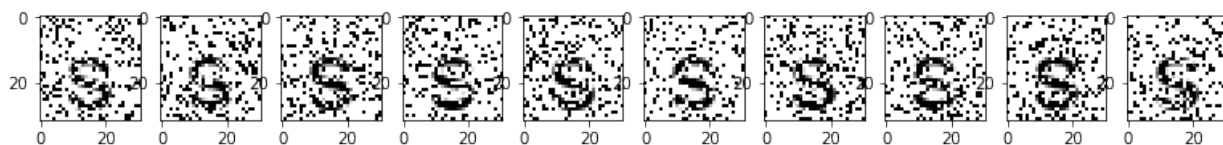


```
!! q correct= 9 wrong= 1 answers=['q', 'q', 'q', 'q', 'q', 'q', 'q', 'q', 'q', 'g']
```

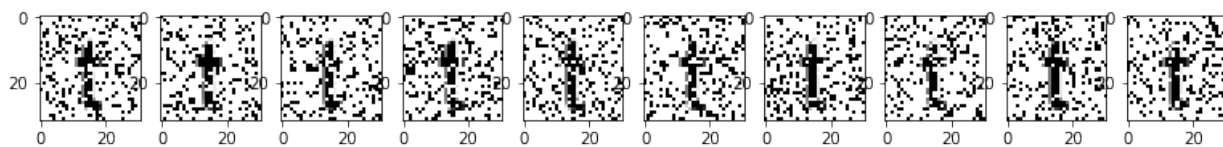




!! r correct=10 wrong= 0 answers=['r', 'r', 'r', 'r', 'r', 'r', 'r', 'r', 'r', 'r']



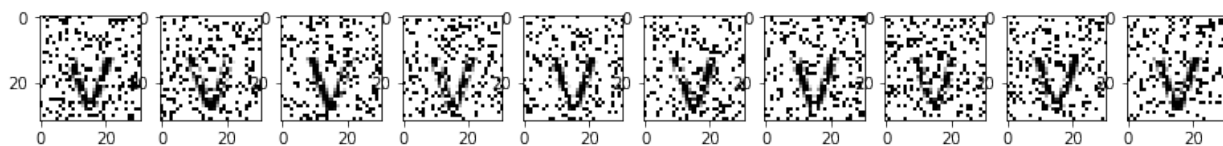
!! s correct=10 wrong= 0 answers=['s', 's', 's', 's', 's', 's', 's', 's', 's', 's']



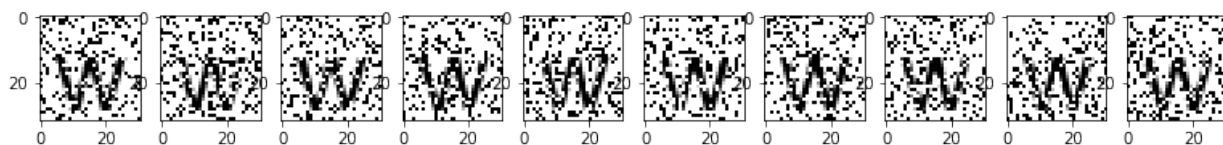
!! t correct= 0 wrong=10 answers=['I', 'r', 'I', 'i', 'I', 'i', 'i', 'i', 'I', 'i']



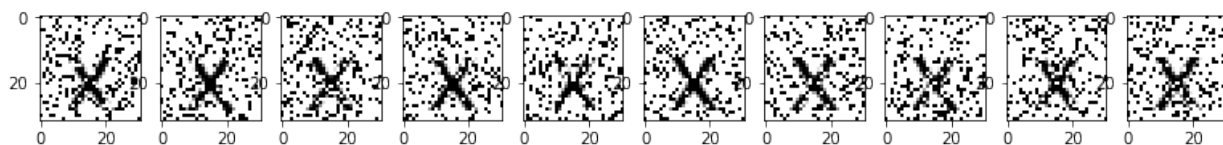
!! u correct=10 wrong= 0 answers=['u', 'u', 'u', 'u', 'u', 'u', 'u', 'u', 'u', 'u']



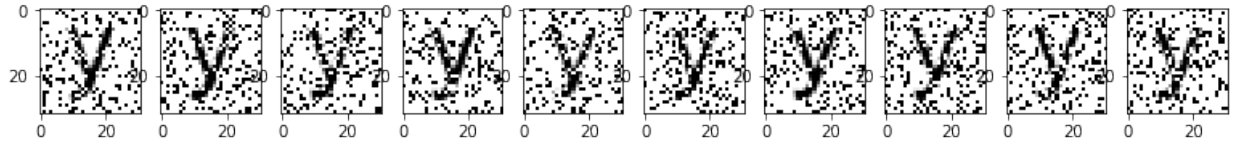
!! v correct=10 wrong= 0 answers=['v', 'v', 'v', 'v', 'v', 'v', 'v', 'v', 'v', 'v']



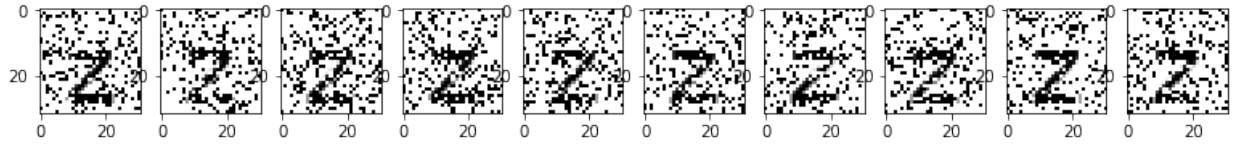
!! w correct=10 wrong= 0 answers=['w', 'w', 'w', 'w', 'w', 'w', 'w', 'w', 'w', 'w']



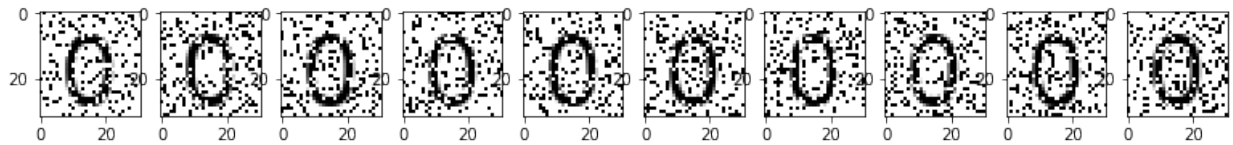
!! x correct=10 wrong= 0 answers=['x', 'x', 'x', 'x', 'x', 'x', 'x', 'x', 'x', 'x']



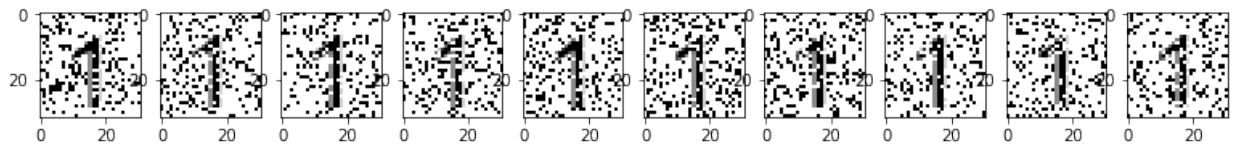
```
!! y correct=10 wrong= 0 answers=['y', 'y', 'y', 'y', 'y', 'y', 'y', 'y', 'y', 'y']
```



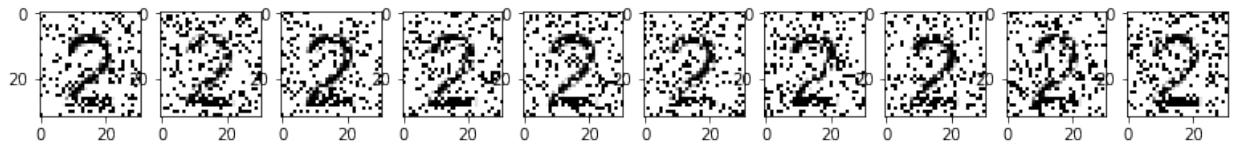
```
!! z correct=10 wrong= 0 answers=['z', 'z', 'z', 'z', 'z', 'z', 'z', 'z', 'z', 'z']
```



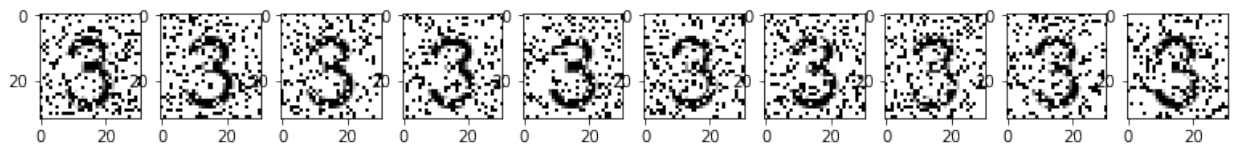
```
!! 0 correct=10 wrong= 0 answers=['0', '0', '0', '0', '0', '0', '0', '0', '0', '0']
```



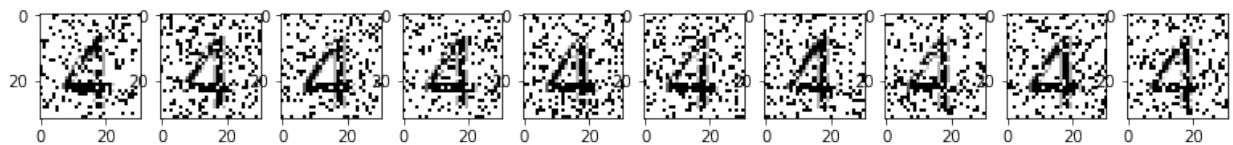
```
!! 1 correct= 5 wrong= 5 answers=['1', 'I', '1', 'I', '1', '1', 'I', 'I', '1', 'I']
```



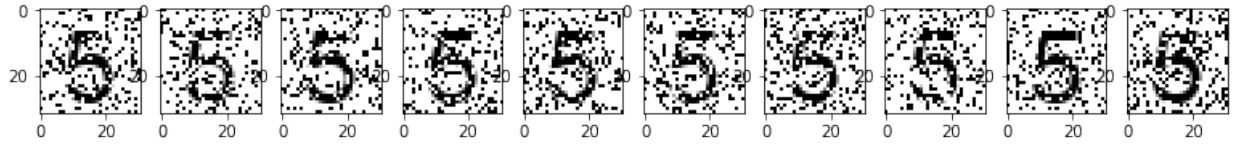
```
!! 2 correct=10 wrong= 0 answers=['2', '2', '2', '2', '2', '2', '2', '2', '2', '2']
```



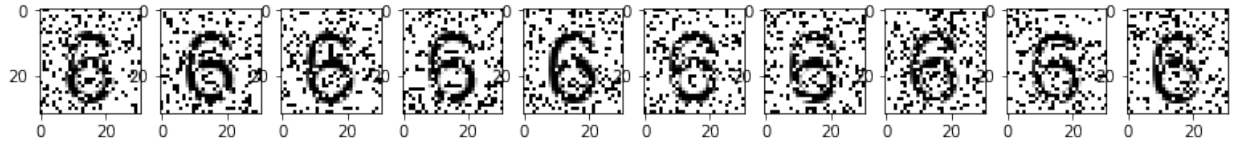
```
!! 3 correct=10 wrong= 0 answers=['3', '3', '3', '3', '3', '3', '3', '3', '3', '3']
```



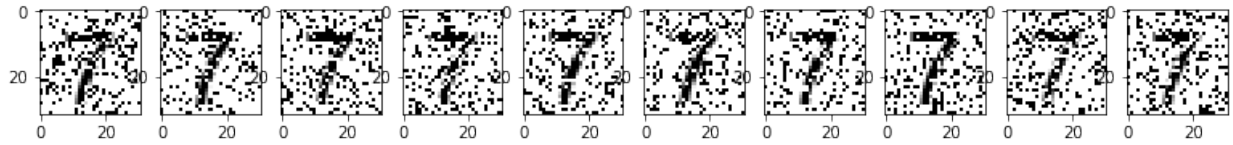
```
!! 4 correct=10 wrong= 0 answers=['4', '4', '4', '4', '4', '4', '4', '4', '4', '4']
```



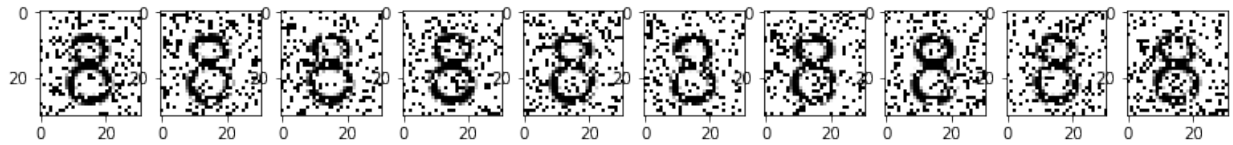
!! 5 correct=10 wrong= 0 answers=['5', '5', '5', '5', '5', '5', '5', '5', '5', '5']



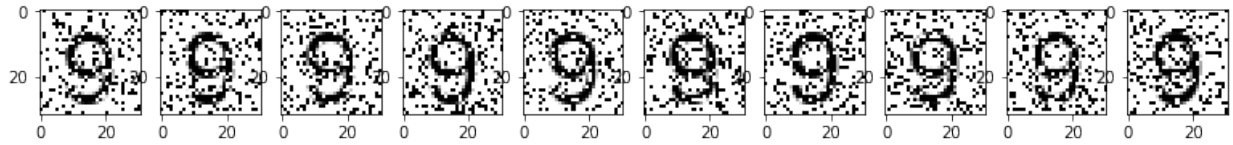
!! 6 correct=10 wrong= 0 answers=['6', '6', '6', '6', '6', '6', '6', '6', '6', '6']



!! 7 correct= 7 wrong= 3 answers=['7', '7', '7', 'I', '7', 'I', 'I', '7', '7', '7']



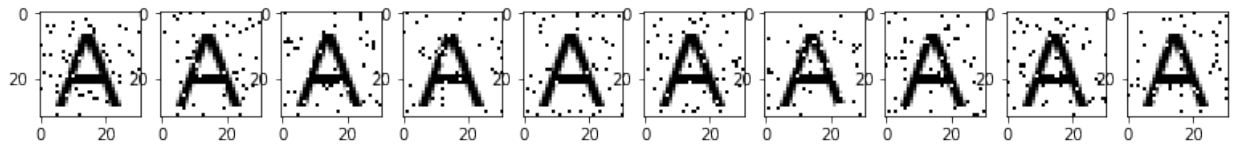
!! 8 correct= 4 wrong= 6 answers=['8', '6', '6', '6', '8', 'd', '8', '8', 'd', '6']



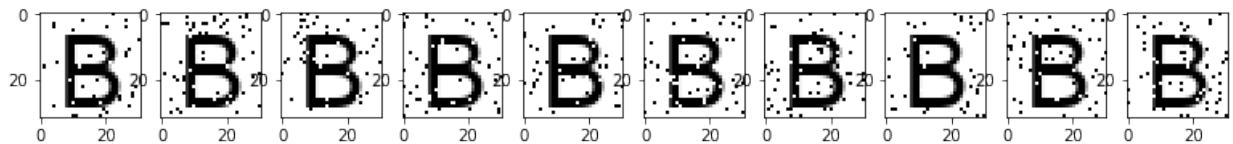
!! 9 correct= 3 wrong= 7 answers=['9', '0', '6', '0', '9', '0', '0', '9', '0', '0']

### Testing with low noise

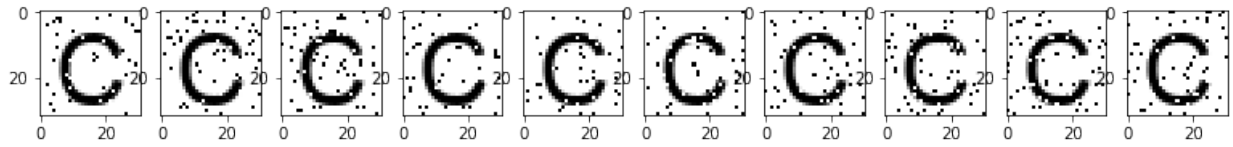
```
In [17]: for x in 'ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz0123456789':
          iter_read(x, p=0.05)
```



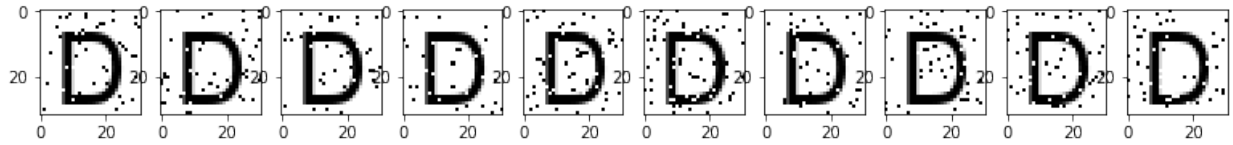
!! A correct=10 wrong= 0 answers=['A', 'A', 'A', 'A', 'A', 'A', 'A', 'A', 'A', 'A']



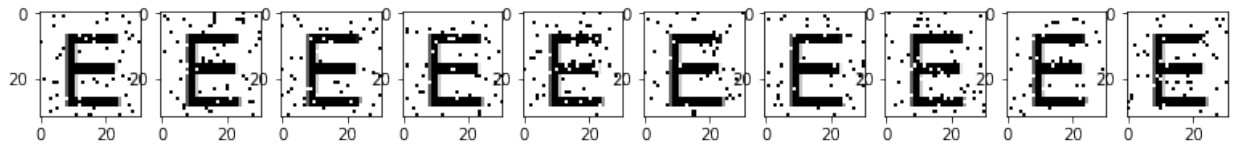
!! B correct=10 wrong= 0 answers=['B', 'B', 'B', 'B', 'B', 'B', 'B', 'B', 'B', 'B']



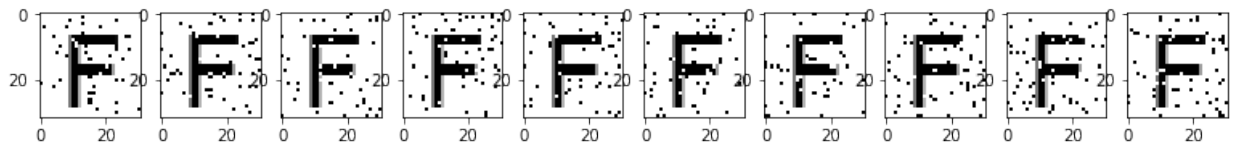
!! C correct=10 wrong= 0 answers=['C', 'C', 'C', 'C', 'C', 'C', 'C', 'C', 'C', 'C']



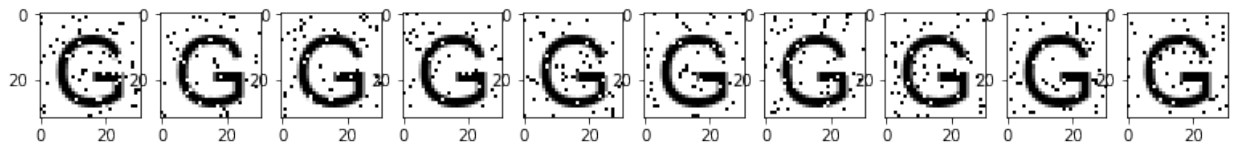
!! D correct=10 wrong= 0 answers=['D', 'D', 'D', 'D', 'D', 'D', 'D', 'D', 'D', 'D']



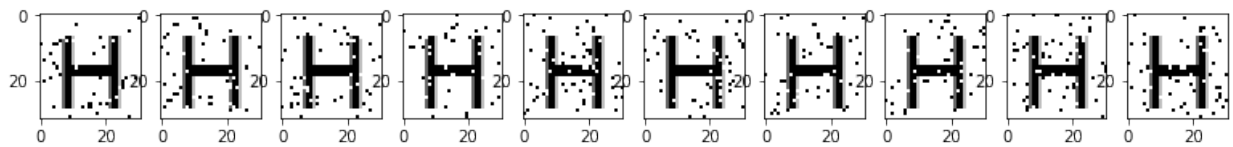
!! E correct=10 wrong= 0 answers=['E', 'E', 'E', 'E', 'E', 'E', 'E', 'E', 'E', 'E']



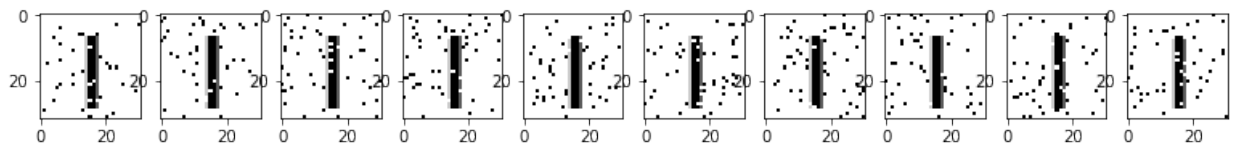
!! F correct=10 wrong= 0 answers=['F', 'F', 'F', 'F', 'F', 'F', 'F', 'F', 'F', 'F']



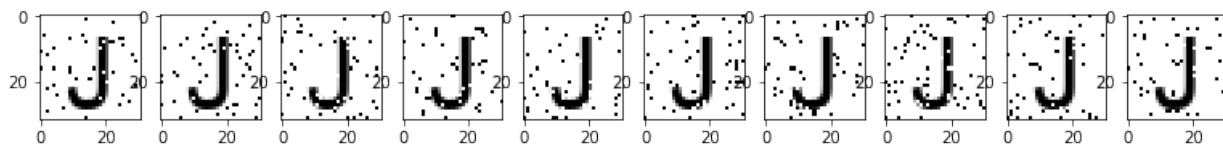
!! G correct=10 wrong= 0 answers=['G', 'G', 'G', 'G', 'G', 'G', 'G', 'G', 'G', 'G']



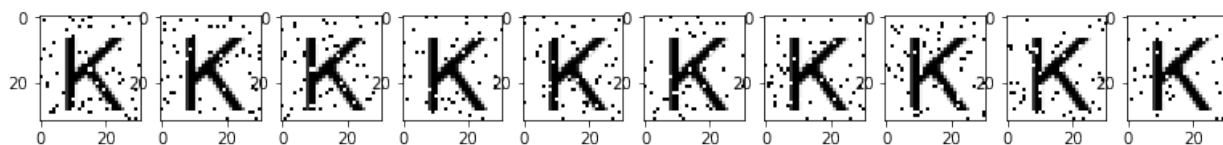
!! H correct=10 wrong= 0 answers=['H', 'H', 'H', 'H', 'H', 'H', 'H', 'H', 'H', 'H']



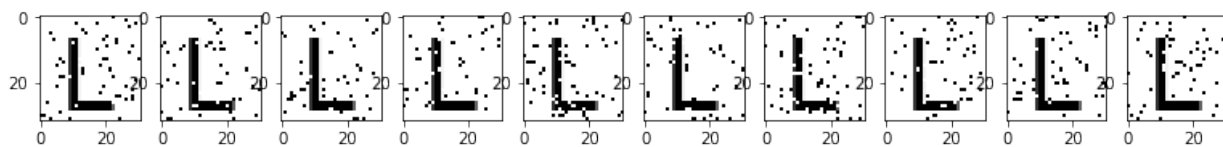
!! I correct=10 wrong= 0 answers=['I', 'I', 'I', 'I', 'I', 'I', 'I', 'I', 'I', 'I']



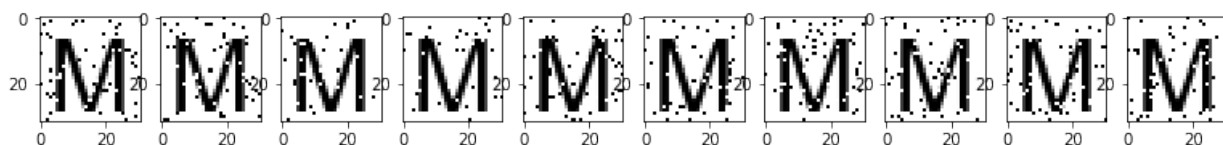
```
!! J correct=10 wrong= 0 answers=['J', 'J', 'J', 'J', 'J', 'J', 'J', 'J', 'J', 'J']
```



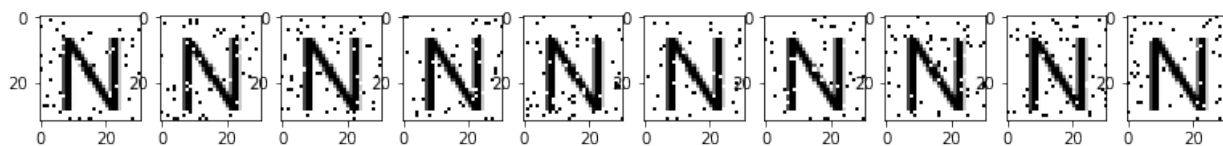
```
!! K correct=10 wrong= 0 answers=['K', 'K', 'K', 'K', 'K', 'K', 'K', 'K', 'K', 'K']
```



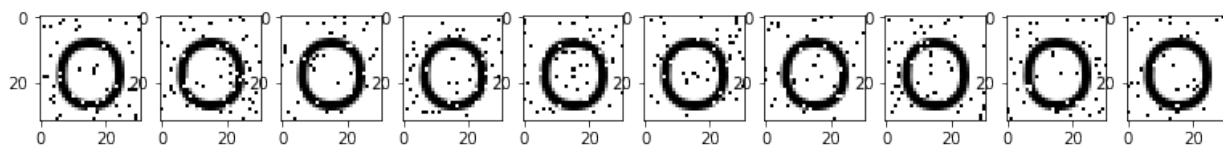
```
!! L correct=10 wrong= 0 answers=['L', 'L', 'L', 'L', 'L', 'L', 'L', 'L', 'L', 'L']
```



```
!! M correct=10 wrong= 0 answers=['M', 'M', 'M', 'M', 'M', 'M', 'M', 'M', 'M', 'M']
```



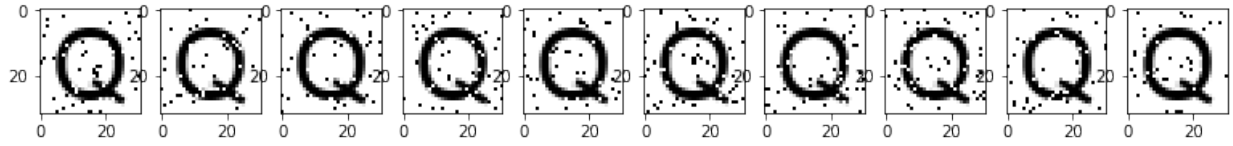
```
!! N correct=10 wrong= 0 answers=['N', 'N', 'N', 'N', 'N', 'N', 'N', 'N', 'N', 'N']
```



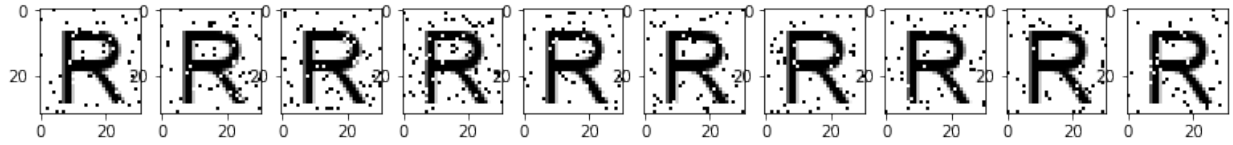
```
!! O correct=10 wrong= 0 answers=['O', 'O', 'O', 'O', 'O', 'O', 'O', 'O', 'O', 'O']
```



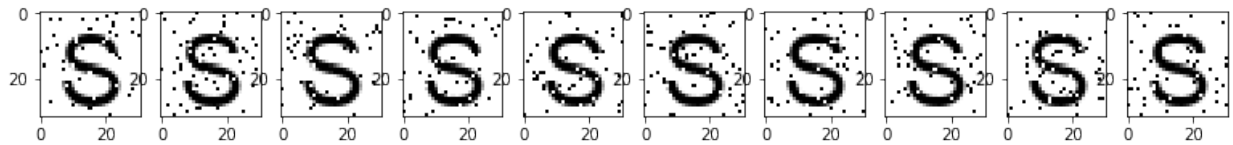
```
!! P correct=10 wrong= 0 answers=['P', 'P', 'P', 'P', 'P', 'P', 'P', 'P', 'P', 'P']
```



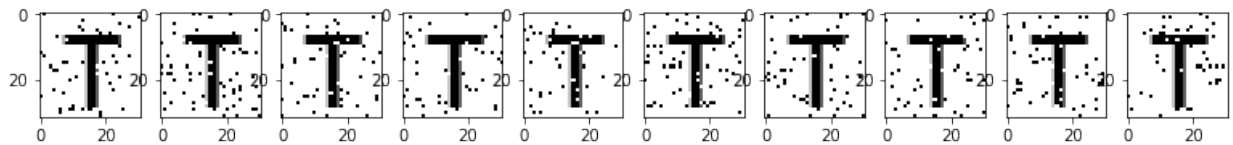
!! Q correct=10 wrong= 0 answers=['Q', 'Q', 'Q', 'Q', 'Q', 'Q', 'Q', 'Q', 'Q', 'Q']



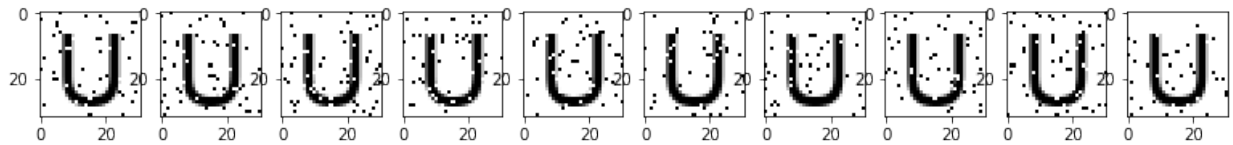
!! R correct=10 wrong= 0 answers=['R', 'R', 'R', 'R', 'R', 'R', 'R', 'R', 'R', 'R']



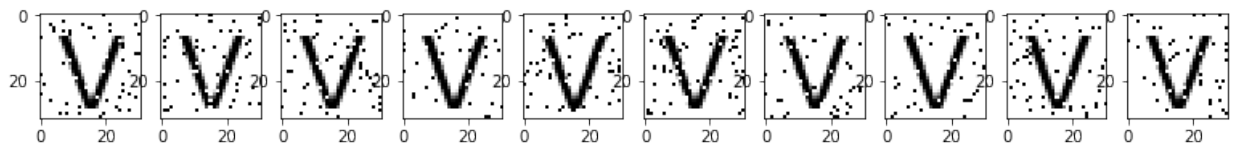
!! S correct=10 wrong= 0 answers=['S', 'S', 'S', 'S', 'S', 'S', 'S', 'S', 'S', 'S']



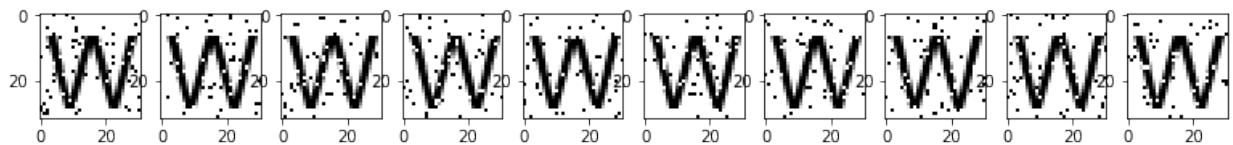
!! T correct=10 wrong= 0 answers=['T', 'T', 'T', 'T', 'T', 'T', 'T', 'T', 'T', 'T']



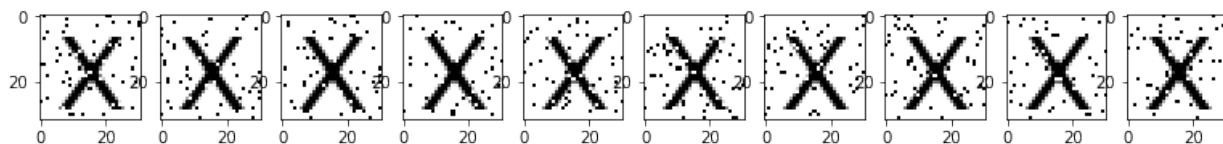
!! U correct=10 wrong= 0 answers=['U', 'U', 'U', 'U', 'U', 'U', 'U', 'U', 'U', 'U']



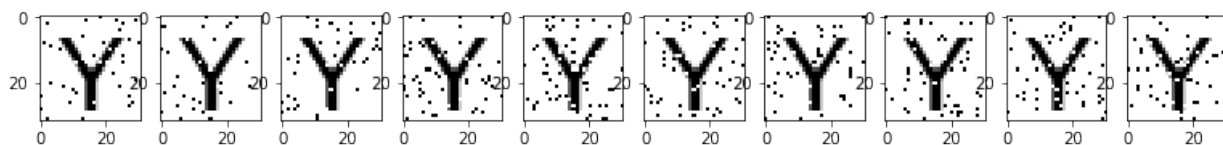
!! V correct=10 wrong= 0 answers=['V', 'V', 'V', 'V', 'V', 'V', 'V', 'V', 'V', 'V']



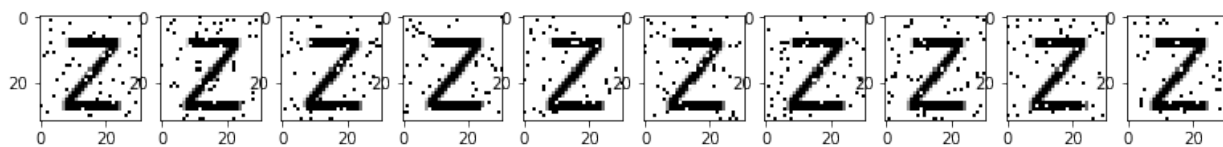
!! W correct=10 wrong= 0 answers=['W', 'W', 'W', 'W', 'W', 'W', 'W', 'W', 'W', 'W']



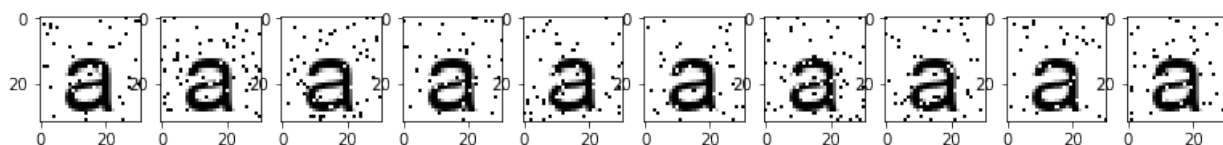
!! X correct=10 wrong= 0 answers=['X', 'X', 'X', 'X', 'X', 'X', 'X', 'X', 'X', 'X']



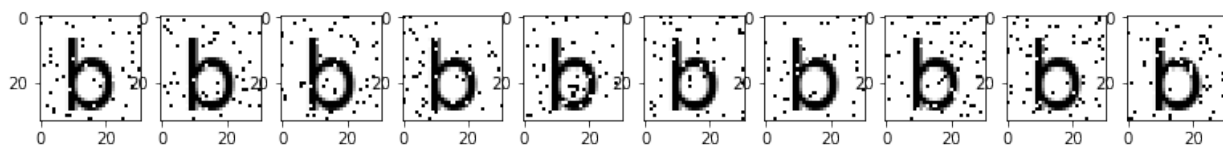
!! Y correct=10 wrong= 0 answers=['Y', 'Y', 'Y', 'Y', 'Y', 'Y', 'Y', 'Y', 'Y', 'Y']



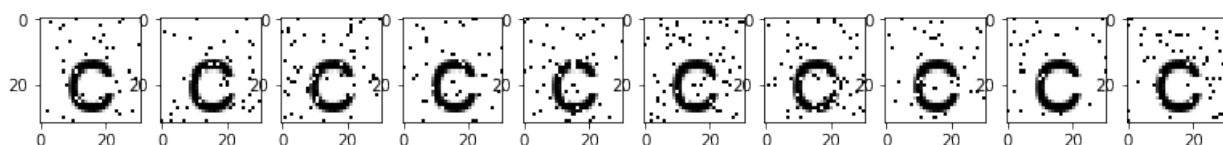
!! Z correct=10 wrong= 0 answers=['Z', 'Z', 'Z', 'Z', 'Z', 'Z', 'Z', 'Z', 'Z', 'Z']



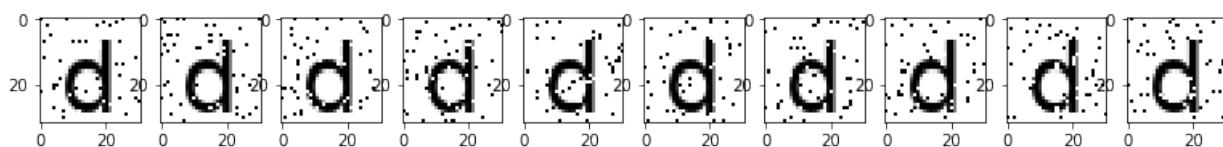
!! a correct=10 wrong= 0 answers=['a', 'a', 'a', 'a', 'a', 'a', 'a', 'a', 'a', 'a']



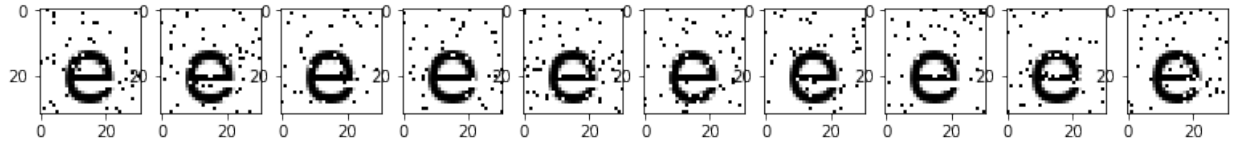
!! b correct= 7 wrong= 3 answers=['b', 'b', 'b', 'h', 'b', 'o', 'b', 'h', 'b', 'b']



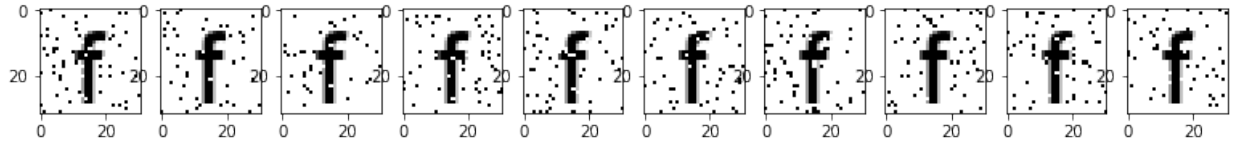
!! c correct=10 wrong= 0 answers=['c', 'c', 'c', 'c', 'c', 'c', 'c', 'c', 'c', 'c']



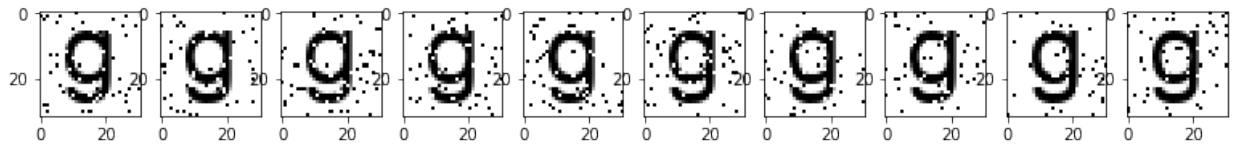
!! d correct=10 wrong= 0 answers=['d', 'd', 'd', 'd', 'd', 'd', 'd', 'd', 'd', 'd']



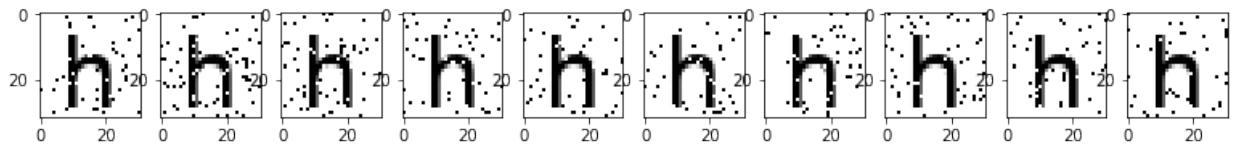
!! e correct= 9 wrong= 1 answers=['e', 'e', 'e', 'e', 'e', 'e', 'e', 'e', 'o', 'e']



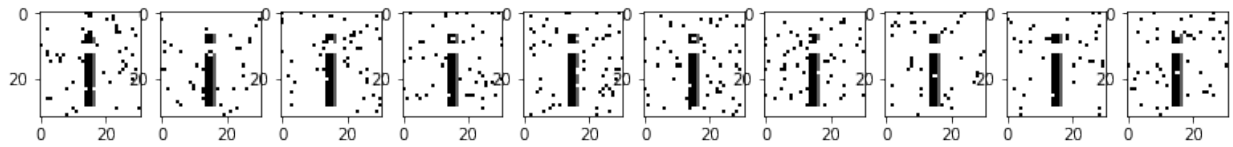
!! f correct= 6 wrong= 4 answers=['i', 'f', 'f', 'I', 'I', 'I', 'f', 'f', 'f', 'f']



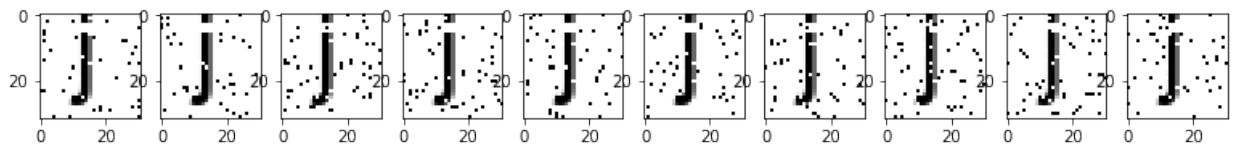
!! g correct=10 wrong= 0 answers=['g', 'g', 'g', 'g', 'g', 'g', 'g', 'g', 'g', 'g']



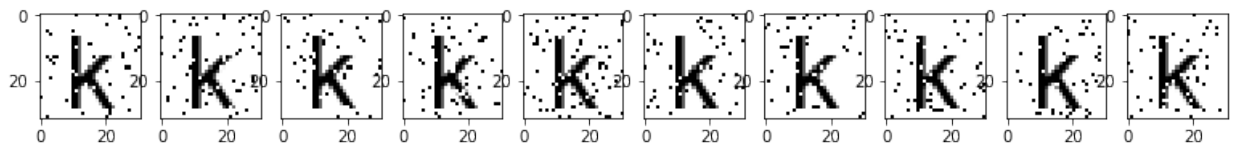
!! h correct=10 wrong= 0 answers=['h', 'h', 'h', 'h', 'h', 'h', 'h', 'h', 'h', 'h']



!! i correct=10 wrong= 0 answers=['i', 'i', 'i', 'i', 'i', 'i', 'i', 'i', 'i', 'i']

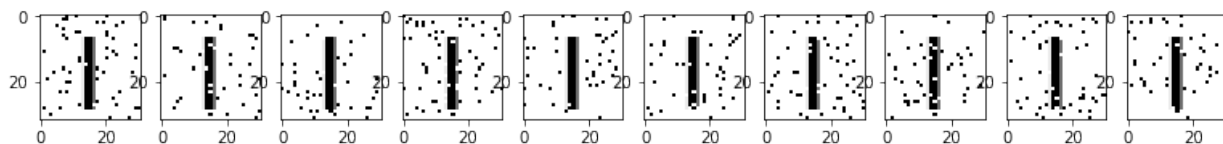


!! j correct=10 wrong= 0 answers=['j', 'j', 'j', 'j', 'j', 'j', 'j', 'j', 'j', 'j']

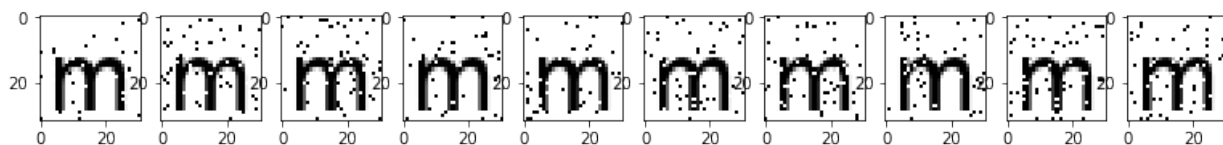


!! k correct=10 wrong= 0 answers=['k', 'k', 'k', 'k', 'k', 'k', 'k', 'k', 'k', 'k']

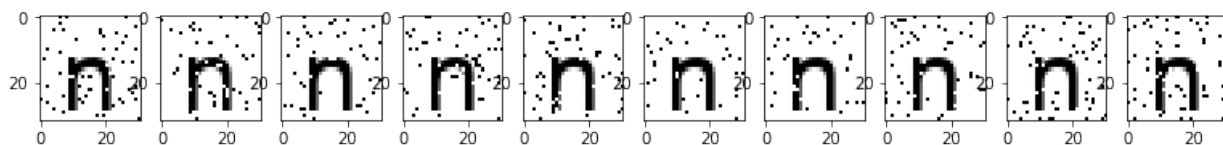




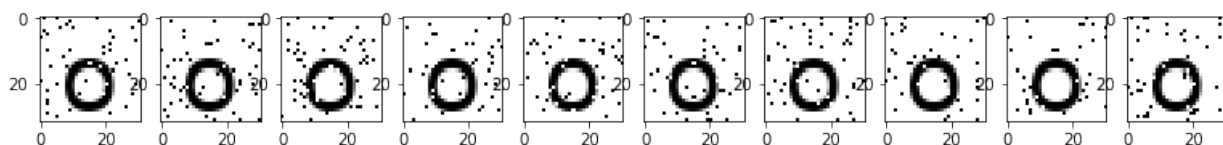
!! i correct= 0 wrong=10 answers=['i', 'i', 'i', 'i', 'i', 'i', 'i', 'i', 'i', 'i']



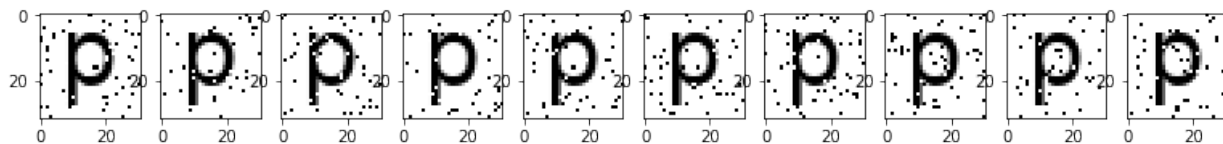
!! m correct=10 wrong= 0 answers=['m', 'm', 'm', 'm', 'm', 'm', 'm', 'm', 'm', 'm']



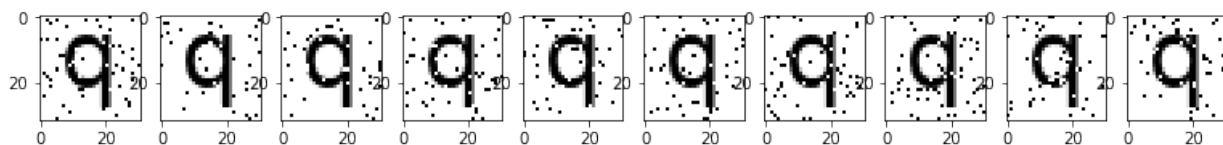
!! n correct=10 wrong= 0 answers=['n', 'n', 'n', 'n', 'n', 'n', 'n', 'n', 'n', 'n']



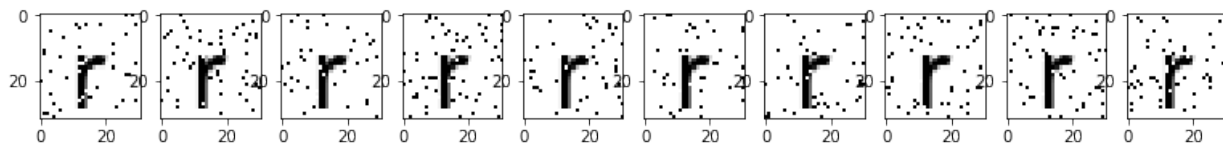
!! o correct=10 wrong= 0 answers=['o', 'o', 'o', 'o', 'o', 'o', 'o', 'o', 'o', 'o']



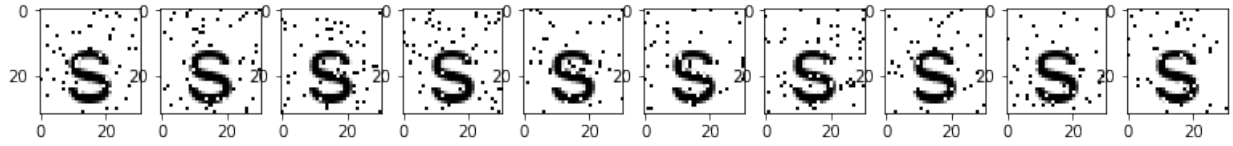
!! p correct=10 wrong= 0 answers=['p', 'p', 'p', 'p', 'p', 'p', 'p', 'p', 'p', 'p']



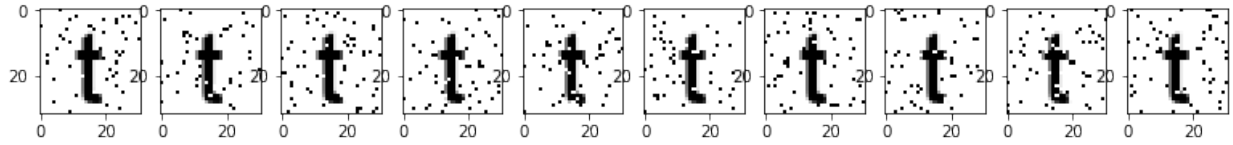
!! q correct=10 wrong= 0 answers=['q', 'q', 'q', 'q', 'q', 'q', 'q', 'q', 'q', 'q']



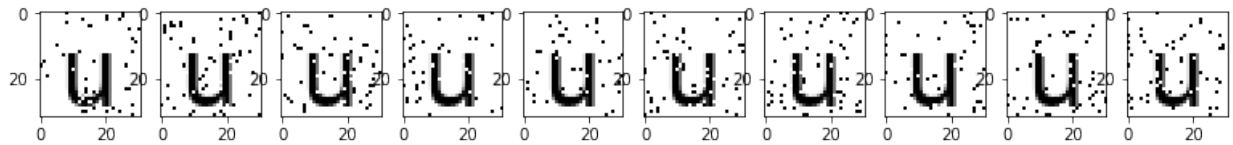
!! r correct=10 wrong= 0 answers=['r', 'r', 'r', 'r', 'r', 'r', 'r', 'r', 'r', 'r']



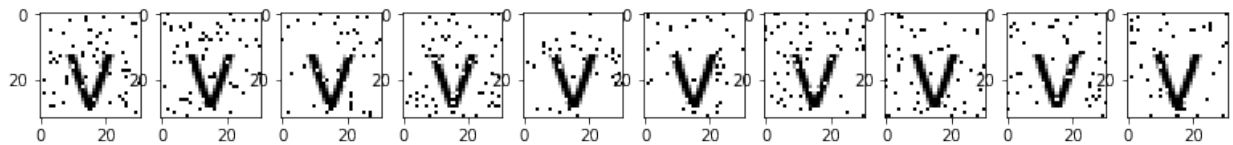
```
!! s correct=10 wrong= 0 answers=['s', 's', 's', 's', 's', 's', 's', 's', 's', 's']
```



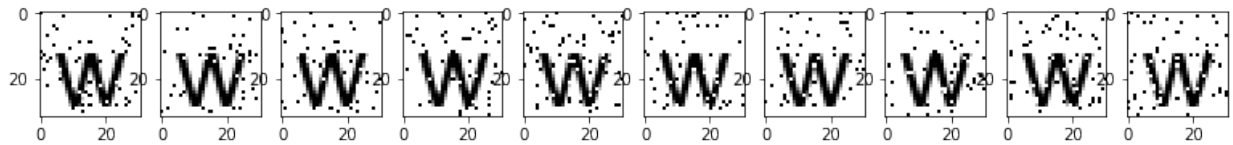
```
!! t correct= 9 wrong= 1 answers=['t', 't', 't', 't', 't', 't', 't', 'i', 't', 't']
```



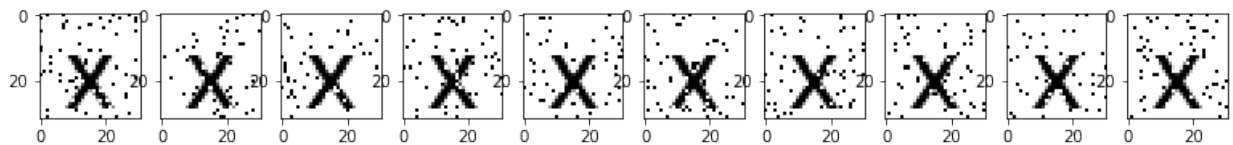
```
!! u correct=10 wrong= 0 answers=['u', 'u', 'u', 'u', 'u', 'u', 'u', 'u', 'u', 'u']
```



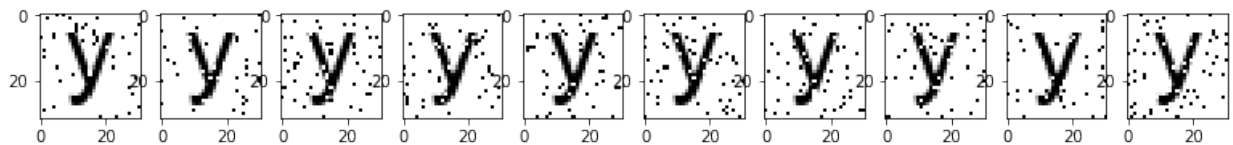
```
!! v correct=10 wrong= 0 answers=['v', 'v', 'v', 'v', 'v', 'v', 'v', 'v', 'v', 'v']
```



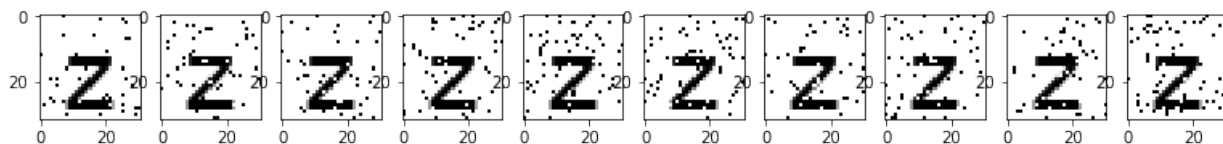
```
!! w correct=10 wrong= 0 answers=['w', 'w', 'w', 'w', 'w', 'w', 'w', 'w', 'w', 'w']
```



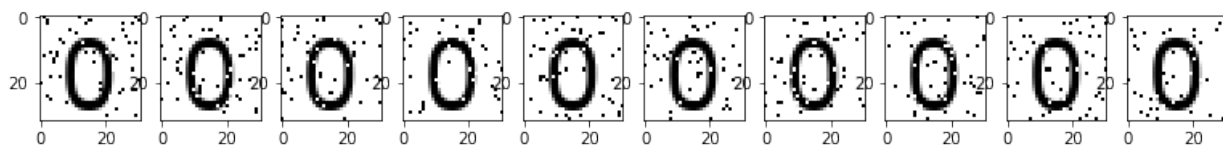
```
!! x correct=10 wrong= 0 answers=['x', 'x', 'x', 'x', 'x', 'x', 'x', 'x', 'x', 'x']
```



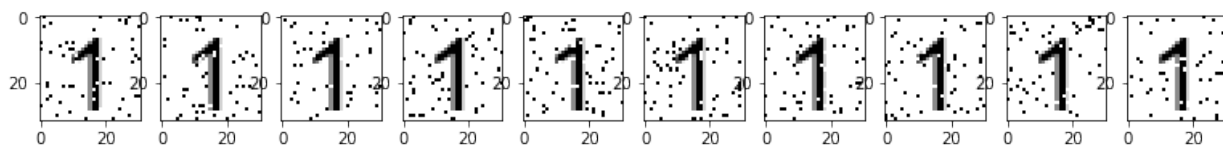
```
!! y correct=10 wrong= 0 answers=['y', 'y', 'y', 'y', 'y', 'y', 'y', 'y', 'y', 'y']
```



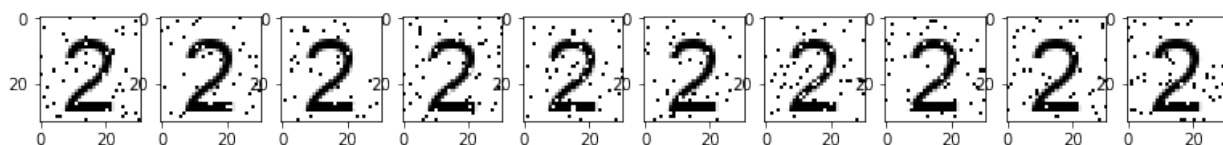
```
!! z correct=10 wrong= 0 answers=['z', 'z', 'z', 'z', 'z', 'z', 'z', 'z', 'z', 'z']
```



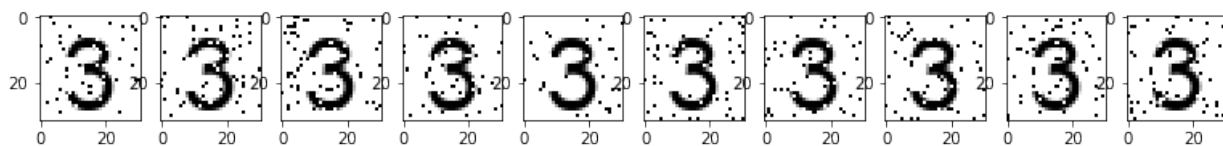
```
!! 0 correct=10 wrong= 0 answers=['0', '0', '0', '0', '0', '0', '0', '0', '0', '0']
```



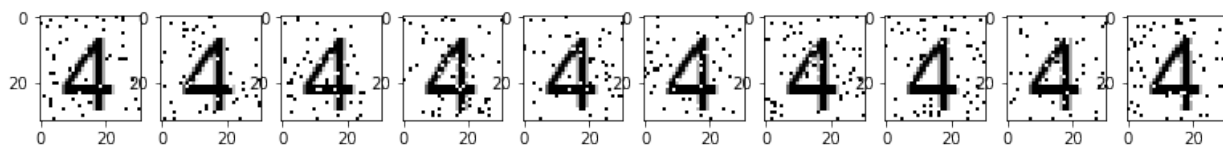
```
!! 1 correct=10 wrong= 0 answers=['1', '1', '1', '1', '1', '1', '1', '1', '1', '1']
```



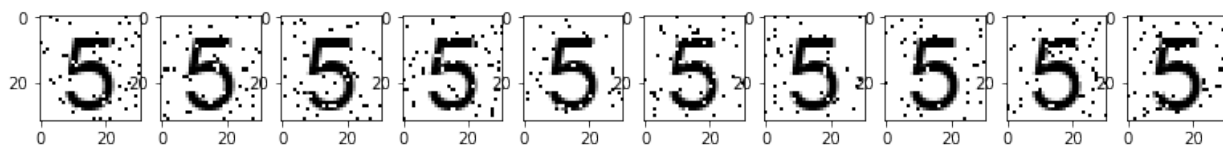
```
!! 2 correct=10 wrong= 0 answers=['2', '2', '2', '2', '2', '2', '2', '2', '2', '2']
```



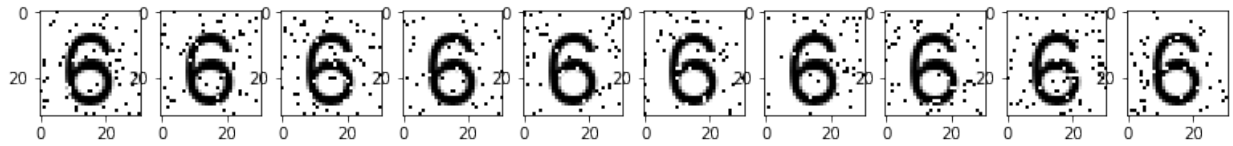
```
!! 3 correct=10 wrong= 0 answers=['3', '3', '3', '3', '3', '3', '3', '3', '3', '3']
```



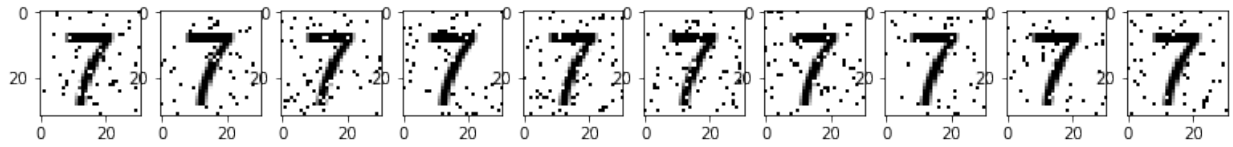
```
!! 4 correct=10 wrong= 0 answers=['4', '4', '4', '4', '4', '4', '4', '4', '4', '4']
```



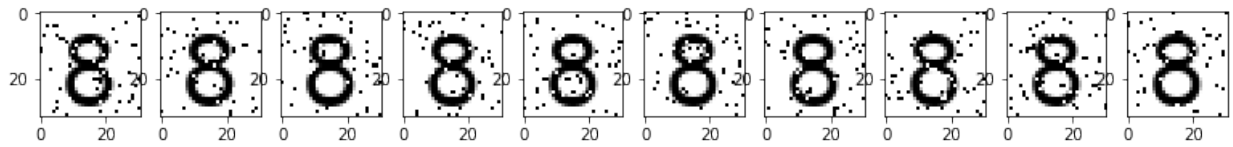
```
!! 5 correct=10 wrong= 0 answers=['5', '5', '5', '5', '5', '5', '5', '5', '5', '5']
```



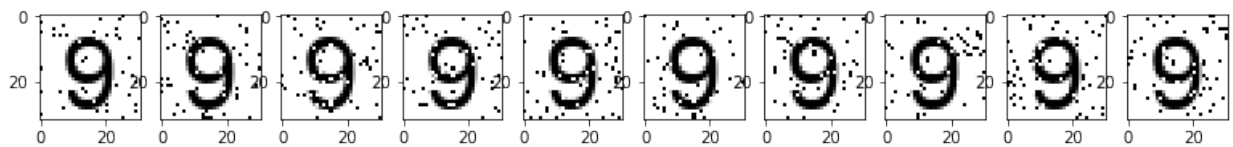
```
!! 6 correct=10 wrong= 0 answers=['6', '6', '6', '6', '6', '6', '6', '6', '6', '6']
```



```
!! 7 correct=10 wrong= 0 answers=['7', '7', '7', '7', '7', '7', '7', '7', '7', '7']
```



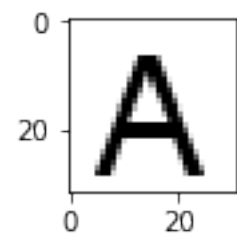
```
!! 8 correct= 9 wrong= 1 answers=['8', '6', '8', '8', '8', '8', '8', '8', '8', '8']
```



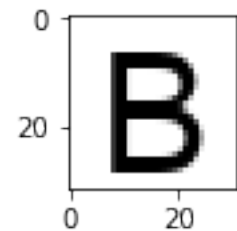
```
!! 9 correct= 7 wrong= 3 answers=['9', '9', '0', '9', '9', '9', '0', '0', '9', '9']
```

### Testing with no noise

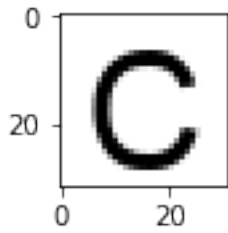
```
In [18]: for x in 'ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz0123456789':
          iter_read(x, p=0, n=1)
```



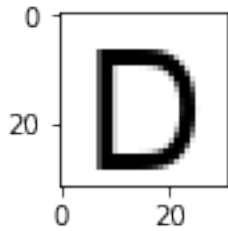
```
!! A correct= 1 wrong= 0 answers=['A']
```



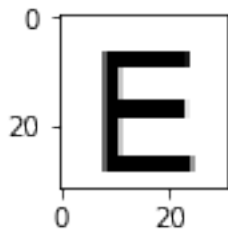
```
!! B correct= 1 wrong= 0 answers=['B']
```



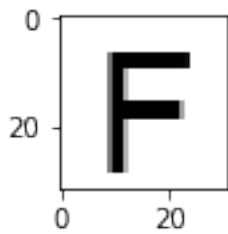
```
!! C correct= 1 wrong= 0 answers=['C']
```



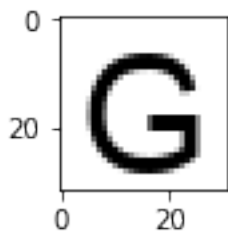
```
!! D correct= 1 wrong= 0 answers=['D']
```



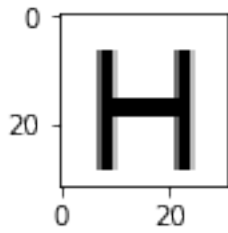
```
!! E correct= 1 wrong= 0 answers=['E']
```



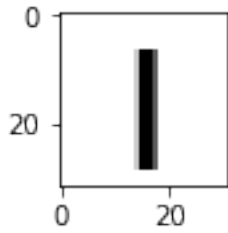
```
!! F correct= 1 wrong= 0 answers=['F']
```



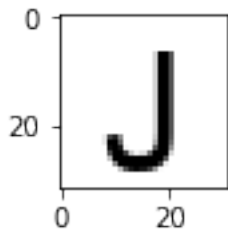
```
!! G correct= 1 wrong= 0 answers=['G']
```



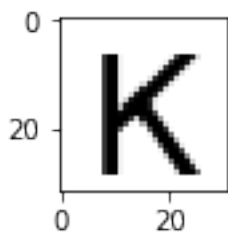
```
!! H correct= 1 wrong= 0 answers=['H']
```



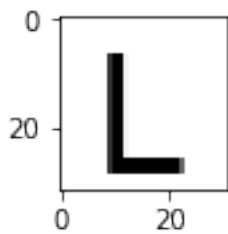
```
!! I correct= 1 wrong= 0 answers=['I']
```



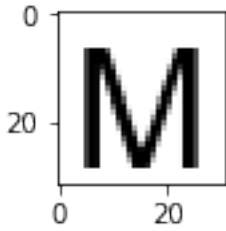
```
!! J correct= 1 wrong= 0 answers=['J']
```



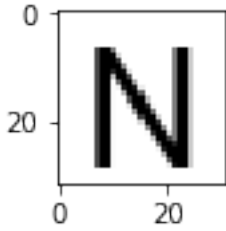
```
!! K correct= 1 wrong= 0 answers=['K']
```



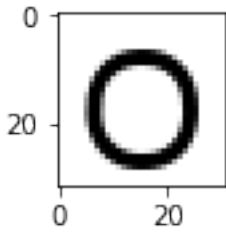
```
!! L correct= 1 wrong= 0 answers=['L']
```



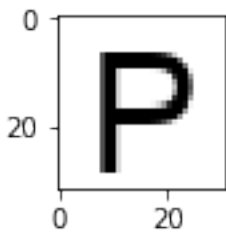
```
!! M correct= 1 wrong= 0 answers=['M']
```



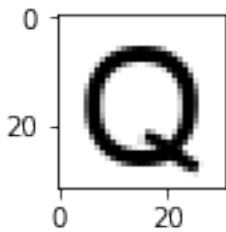
```
!! N correct= 1 wrong= 0 answers=['N']
```



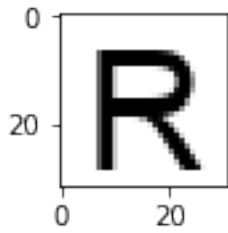
```
!! O correct= 1 wrong= 0 answers=['O']
```



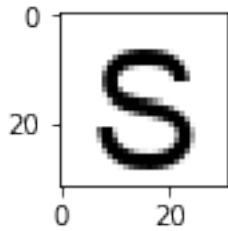
```
!! P correct= 1 wrong= 0 answers=['P']
```



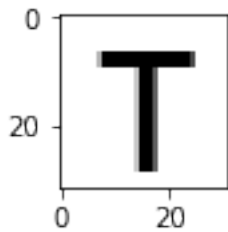
```
!! Q correct= 1 wrong= 0 answers=['Q']
```



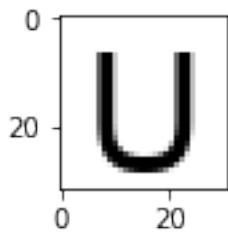
```
!! R correct= 1 wrong= 0 answers=['R']
```



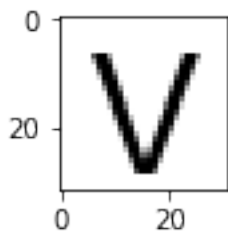
```
!! S correct= 1 wrong= 0 answers=['S']
```



```
!! T correct= 1 wrong= 0 answers=['T']
```

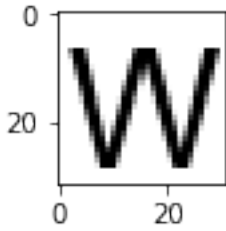


```
!! U correct= 1 wrong= 0 answers=['U']
```

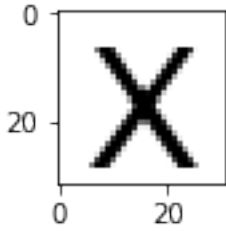


```
!! V correct= 1 wrong= 0 answers=['V']
```

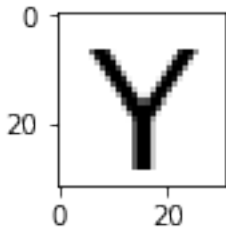




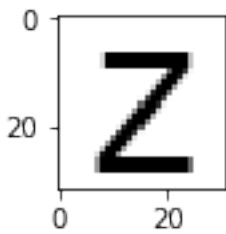
```
!! W correct= 1 wrong= 0 answers=['W']
```



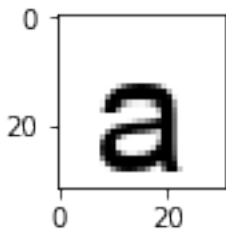
```
!! X correct= 1 wrong= 0 answers=['X']
```



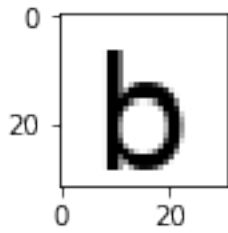
```
!! Y correct= 1 wrong= 0 answers=['Y']
```



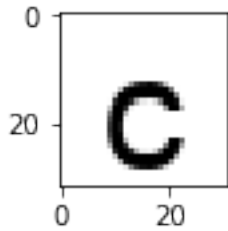
```
!! Z correct= 1 wrong= 0 answers=['Z']
```



```
!! a correct= 1 wrong= 0 answers=['a']
```



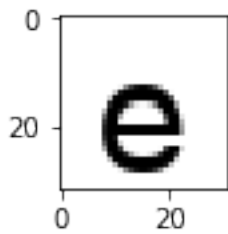
```
!! b correct= 1 wrong= 0 answers=['b']
```



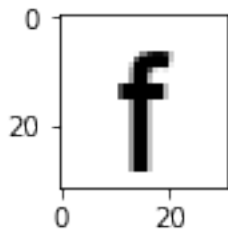
```
!! c correct= 1 wrong= 0 answers=['c']
```



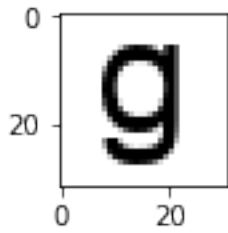
```
!! d correct= 1 wrong= 0 answers=['d']
```



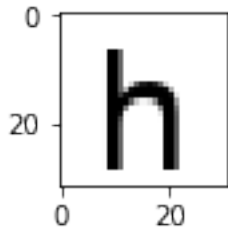
```
!! e correct= 1 wrong= 0 answers=['e']
```



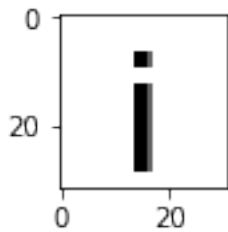
```
!! f correct= 1 wrong= 0 answers=['f']
```



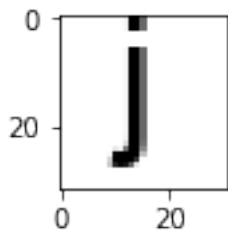
```
!! g correct= 1 wrong= 0 answers=['g']
```



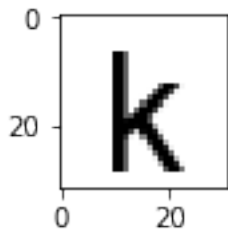
```
!! h correct= 1 wrong= 0 answers=['h']
```



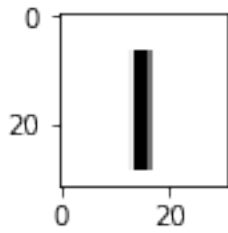
```
!! i correct= 1 wrong= 0 answers=['i']
```



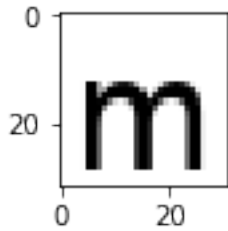
```
!! j correct= 1 wrong= 0 answers=['j']
```



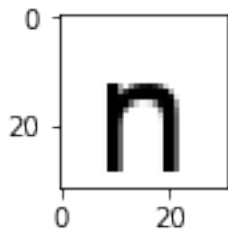
```
!! k correct= 1 wrong= 0 answers=['k']
```



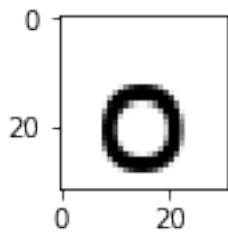
```
!! 1 correct= 0 wrong= 1 answers=['i']
```



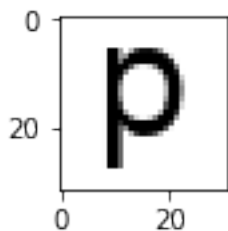
```
!! m correct= 1 wrong= 0 answers=['m']
```



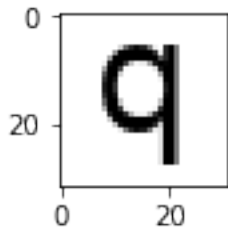
```
!! n correct= 1 wrong= 0 answers=['n']
```



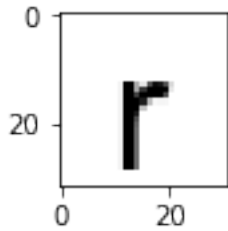
```
!! o correct= 1 wrong= 0 answers=['o']
```



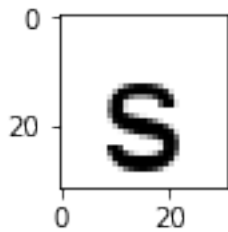
```
!! p correct= 1 wrong= 0 answers=['p']
```



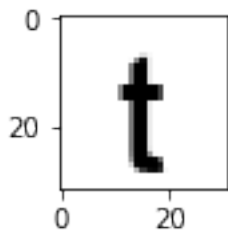
```
!! q correct= 1 wrong= 0 answers=['q']
```



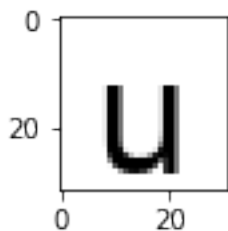
```
!! r correct= 1 wrong= 0 answers=['r']
```



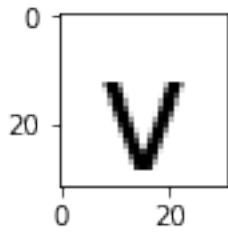
```
!! s correct= 1 wrong= 0 answers=['s']
```



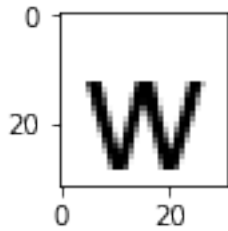
```
!! t correct= 1 wrong= 0 answers=['t']
```



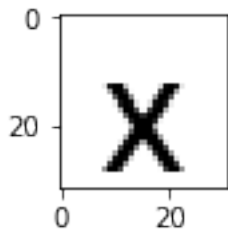
```
!! u correct= 1 wrong= 0 answers=['u']
```



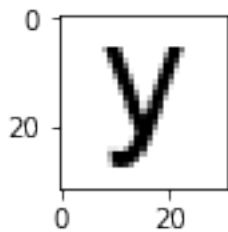
```
!! v correct= 1 wrong= 0 answers=['v']
```



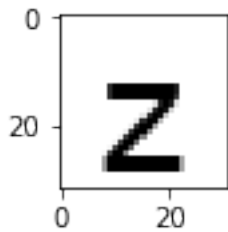
```
!! w correct= 1 wrong= 0 answers=['w']
```



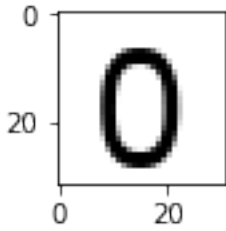
```
!! x correct= 1 wrong= 0 answers=['x']
```



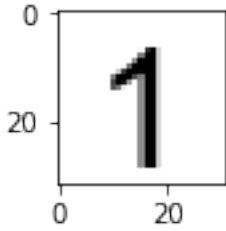
```
!! y correct= 1 wrong= 0 answers=['y']
```



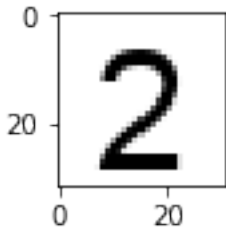
```
!! z correct= 1 wrong= 0 answers=['z']
```



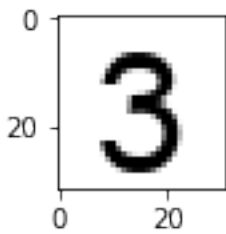
```
!! 0 correct= 1 wrong= 0 answers=['0']
```



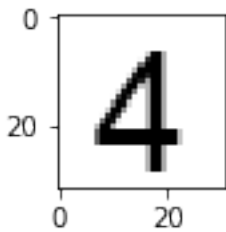
```
!! 1 correct= 1 wrong= 0 answers=['1']
```



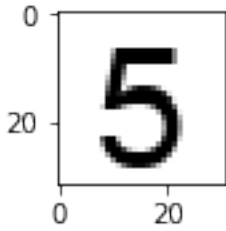
```
!! 2 correct= 1 wrong= 0 answers=['2']
```



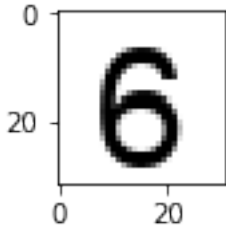
```
!! 3 correct= 1 wrong= 0 answers=['3']
```



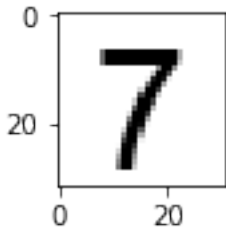
```
!! 4 correct= 1 wrong= 0 answers=['4']
```



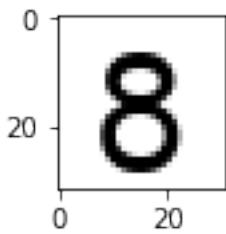
```
!! 5 correct= 1 wrong= 0 answers=['5']
```



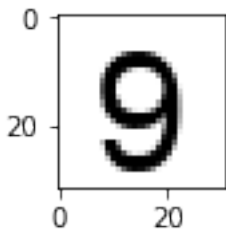
```
!! 6 correct= 1 wrong= 0 answers=['6']
```



```
!! 7 correct= 1 wrong= 0 answers=['7']
```



```
!! 8 correct= 1 wrong= 0 answers=['8']
```



```
!! 9 correct= 1 wrong= 0 answers=['9']
```



## CHAPTER 2

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---

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