Model of Intuitive Numerosity in the Human Cortex

Background:

Humans and many other animals use numerosity to guide behavior and decisions. Numerosity perception becomes less precise as the size of numbers increases and is particularly effective for small numbers. Animals, infants and tribes with no numerical language perceive numerosity although they cannot count or use symbolic representations of number. Thus, numerosity processing is an evolutionarily preserved, intuitive cognitive function, distinct from counting and humans' unique symbolic and mathematical abilities.[1]

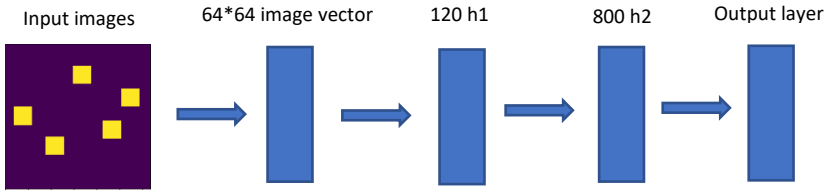
Goal:

Build up an artificial neural network model to simulate the numerosity process, which becomes less precise as the size of numbers increases and is particularly effective for small numbers.

Model:

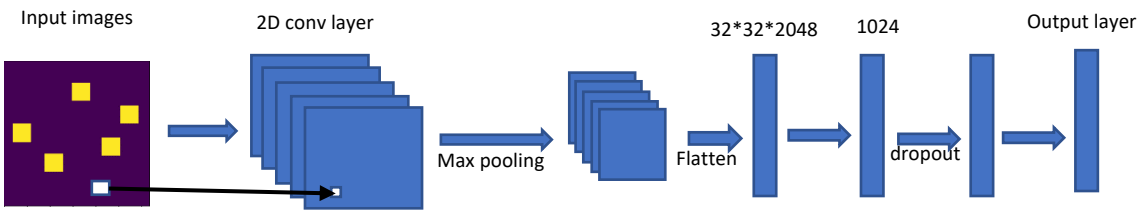
1. Model 1:

Full connected neural network: input layer (64-by-64 image) → image vector (64*64) → hidden layer 1 (120, relu) → hidden layer 2 (800, relu) → output layer (maximum numbers of patterns)



2. Model 2:

Convolution Neural network: input layer (64-by-64 image) → conv2d layer (kernel size = [5,5], relu) → max pooling (pool size = [2,2]) → flatten → dense layer (1024, relu) → dropout (rate = 0.4) → full connected output layer (maximum numbers of patterns)

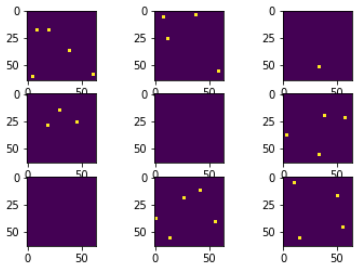
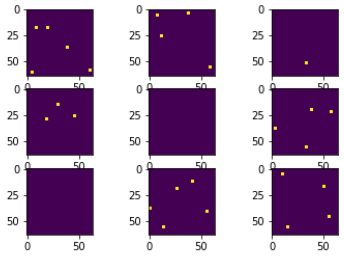
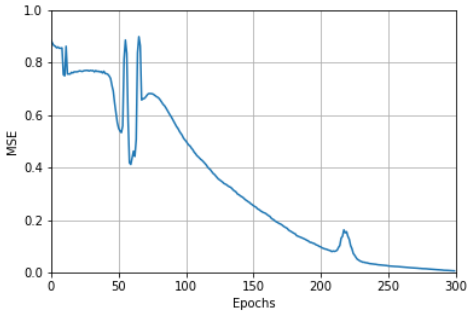
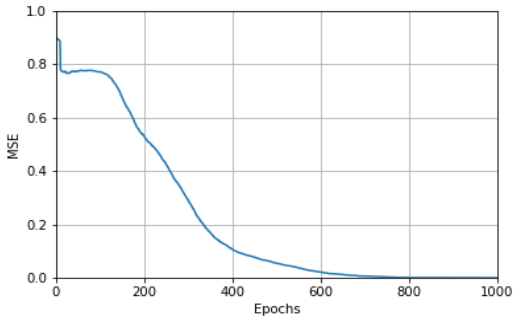
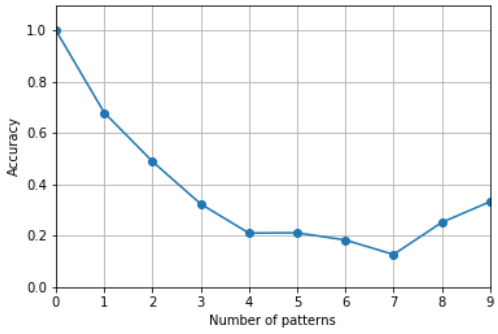
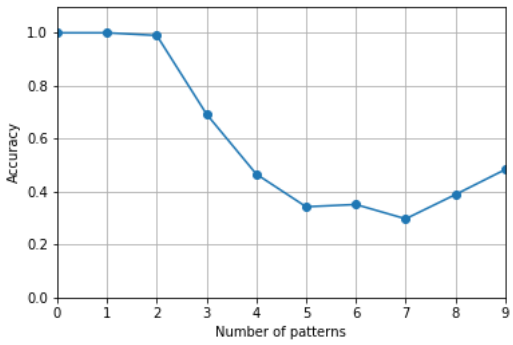


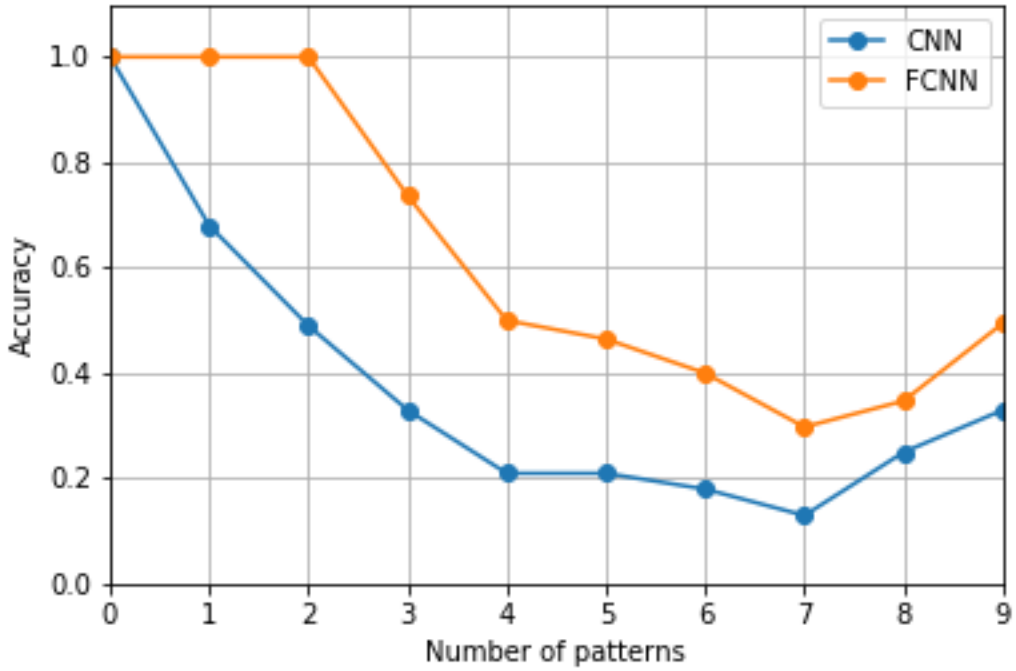
Common parameters:

- Learning rate = 0.1
- cost function = reduce mean of softmax cross entropy
- training with gradient descent method
- epochs ~300-1000.

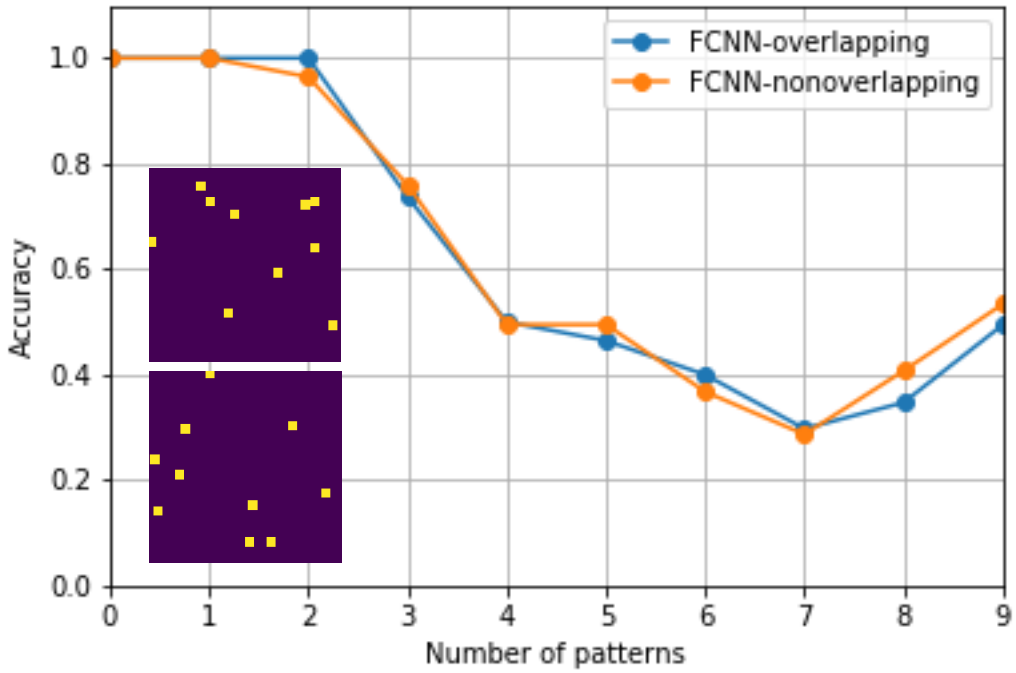
Results:

1. FCNN vs. CNN

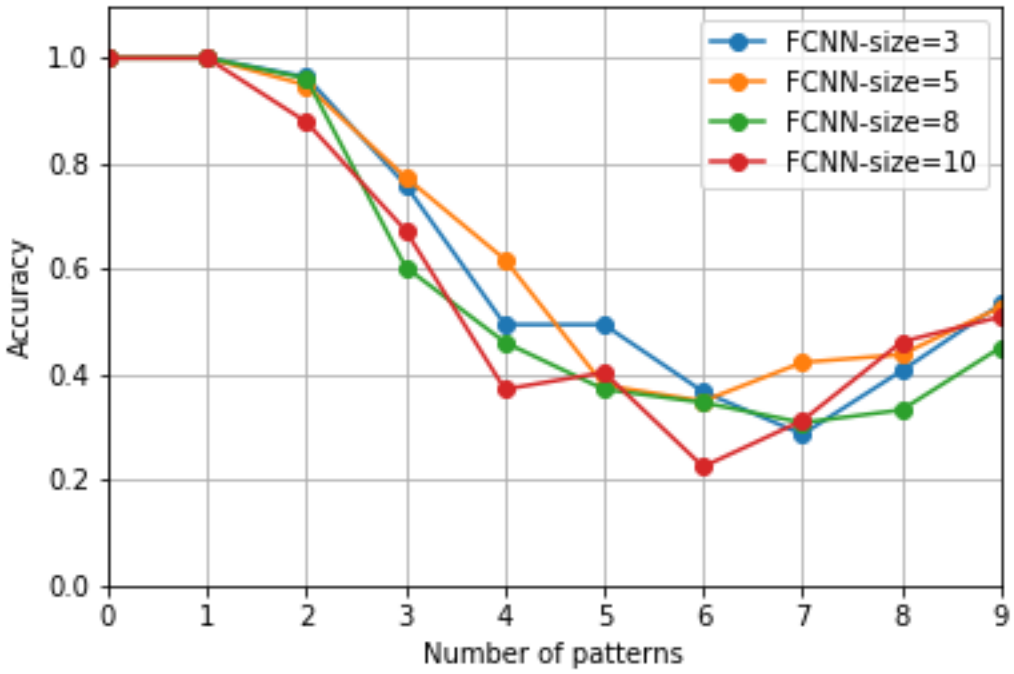
	CNN	FCNN
Input images		
MSE - learning curve		
Accuracy -Number of patterns		



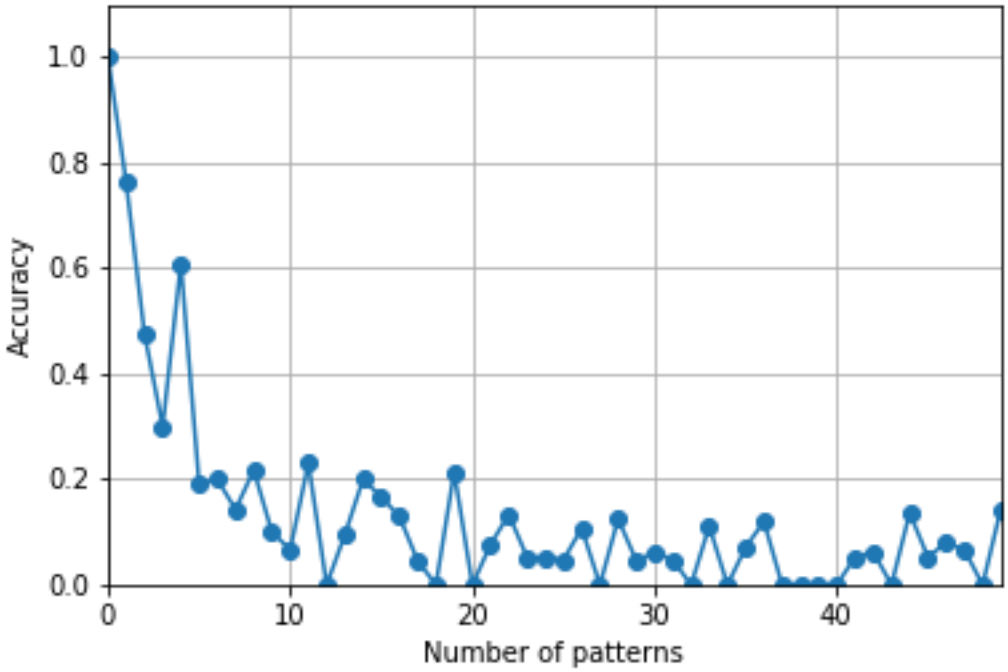
2. Overlapping vs. Non-overlapping images



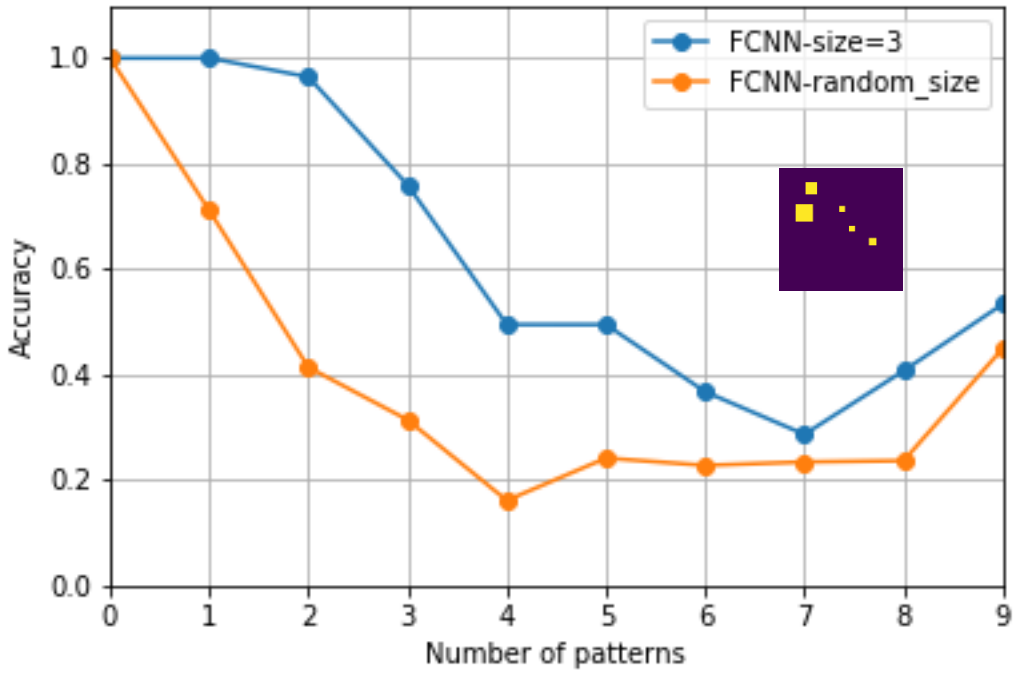
3. Accuracy vs. Size of patterns



4. Accuracy for large number of patterns



5. Random size vs. Constant size



Conclusion:

- Both FCNN & CNN can reproduce the numerosity process, which becomes less precise as the size of numbers increases and is particularly effective for small numbers.
- FCNN works with higher accuracy than CNN, and less training time and expense.
- FCNN works with higher accuracy on small size of patterns than large size of patterns.
- FCNN works with higher accuracy on constant size of patterns than random size of patterns.
- Can't explain the rising tail: why the accuracy of 9 patterns are higher than 6-8 patterns.

Future:

1. Predicting fMRI response

Experimental result shows that: the neural representation of numerosity resides in higher-order association cortices, including the posterior parietal cortex. Human fMRI consistently identifies this region as particularly responsive to numerosity manipulations. Is it possible to predict the fMRI response with the FCNN or CNN model above? And reproduce the number of patterns with the fMRI signals?[1]

2. Unsupervised model

Numerosity perception is an intuitive process, without the knowledge of counting or mathematical abilities. Would an unsupervised model be more reasonable to simulate numerosity perception process?[2]

Ref:

[1]: Topographic Representation of Numerosity in the Human Parietal Cortex. B. M. Harvey, et al.

[2]: Emergence of a ‘visual number sense’ in hierarchical generative models. Ivilin Stoianov & Marco Zorzi.