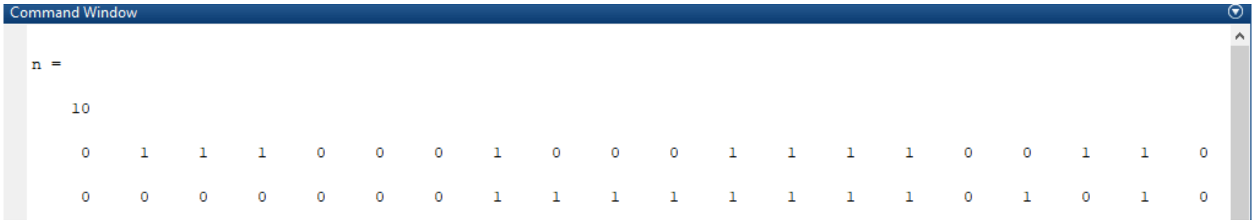
Fall 2017 - Mini project on sequence learning in a cerebellum-like model

Part 1

1a) The longest sequence the weighted network can learn.

In the command window below first pattern is A and the second pattern is B.

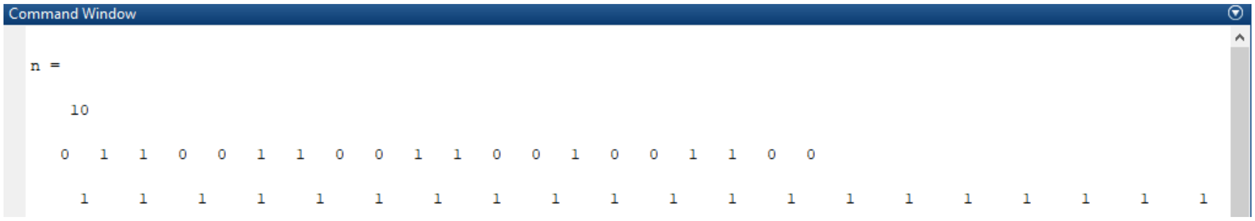


```
n =

    10

     0     1     1     1     0     0     0     1     0     0     0     1     1     1     1     0     0     1     1     0

     0     0     0     0     0     0     0     1     1     1     1     1     1     1     1     0     1     0     1     0
```

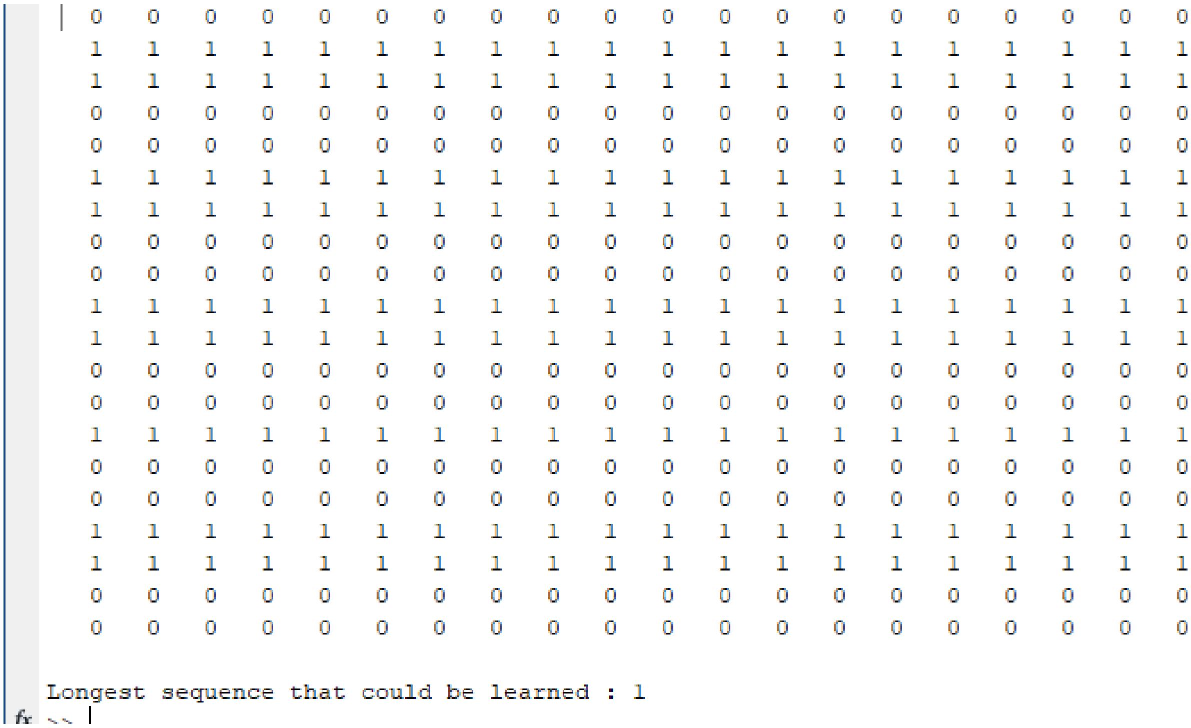
W=

```
     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1
     1     0     1     0     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     0
     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1
     1     0     1     0     0     1     1     1     1     1     1     1     1     1     1     1     1     1     1     0
     0     1     1     1     0     0     0     1     0     0     0     1     1     1     1     0     0     1     1     0
     1     1     1     1     1     1     0     1     1     1     1     1     1     1     1     0     0     1     1     1
     1     1     1     1     0     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1
     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1
     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     0     1     1     1
     1     0     1     0     1     1     1     1     1     0     1     0     0     1     1     1     1     1     1     0
     1     1     1     1     0     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1
     1     0     1     0     1     1     0     1     1     1     1     1     1     1     1     0     1     1     1     0
     1     0     1     0     0     1     1     1     1     1     1     1     1     1     1     1     1     1     1     0
     1     1     1     1     0     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1
     1     1     1     1     0     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1
     1     1     1     1     0     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1
     1     1     1     0     0     1     1     1     1     1     1     1     0     1     1     1     0     1     1     1
     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1
     1     1     1     1     0     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1
     1     0     1     0     1     1     1     1     1     0     1     0     0     1     1     1     1     1     1     0

Longest sequence that could be learned : 7
```

1b)Example of a sequence of the same length that can’t be learned:



```
n =

    10

   0   1   1   0   0   1   1   0   0   1   1   0   0   1   0   0   1   1   0   0

     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1
```



```
    0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
    1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1
    1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1
    0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
    0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
    1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1
    1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1
    0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
    0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
    1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1
    1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1
    0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
    0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
    1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1
    0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
    0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
    1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1
    1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1
    0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
    0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

Longest sequence that could be learned : 1
fx >> 
```

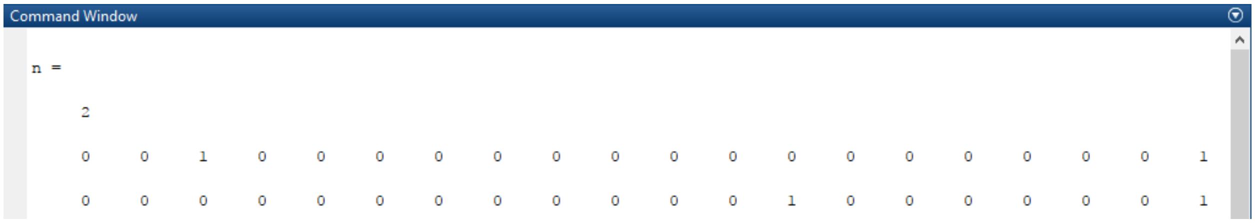
1c)What is it that makes one sequence easier or harder to learn than another? I think it’s the complexity of Patterns generated (i.e. depends on the number of 1s in the patterns while learning process is going on), and the length of the pattern generated.

In the command window below first pattern is A and the second pattern is B. Here we can make the pattern B more complicated by making it all 1s instead of initializing to 0 and randomly generating it to get 1’s and 0’s.

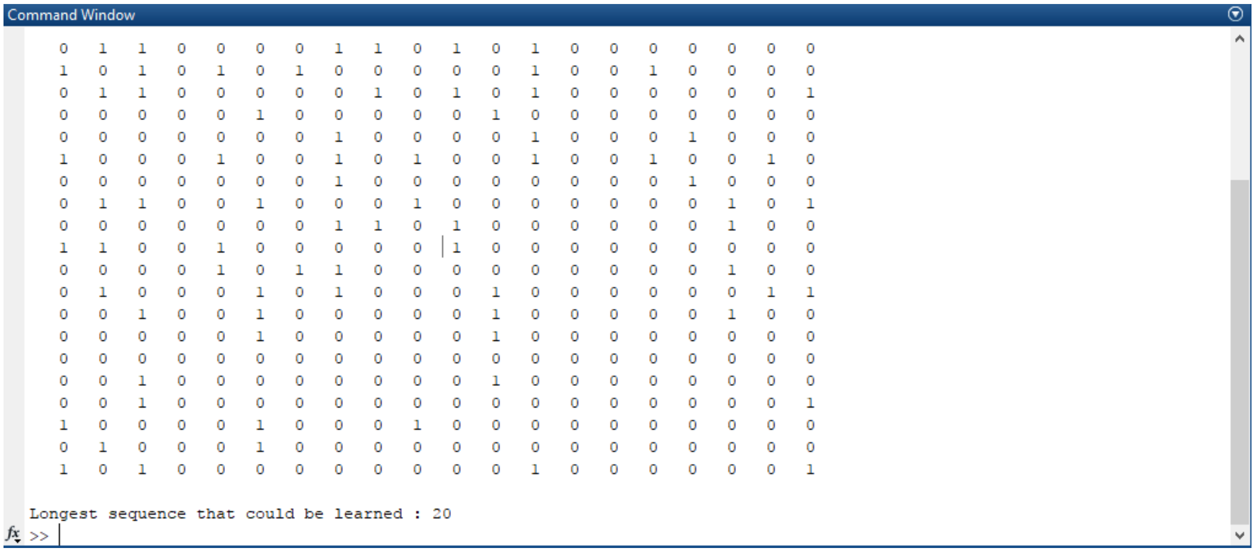
Part 2)

Consider a Range of values for *f* and to find out which value of f lets you learn the most.

2a) At f=0.1

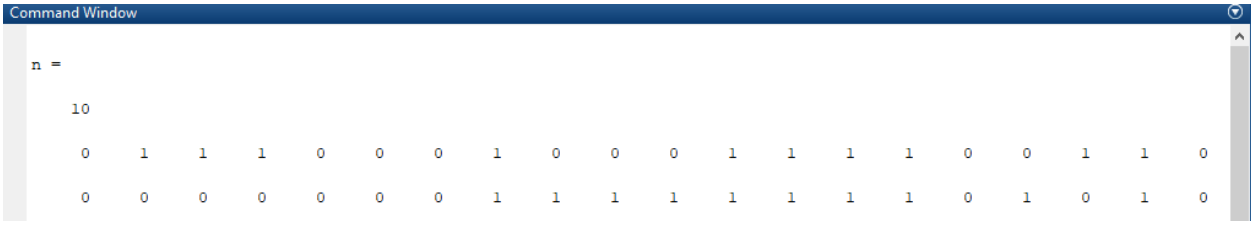


```
n =

     2

     0     0     1     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     1

     0     0     0     0     0     0     0     0     0     0     0     0     1     0     0     0     0     0     0     1
```

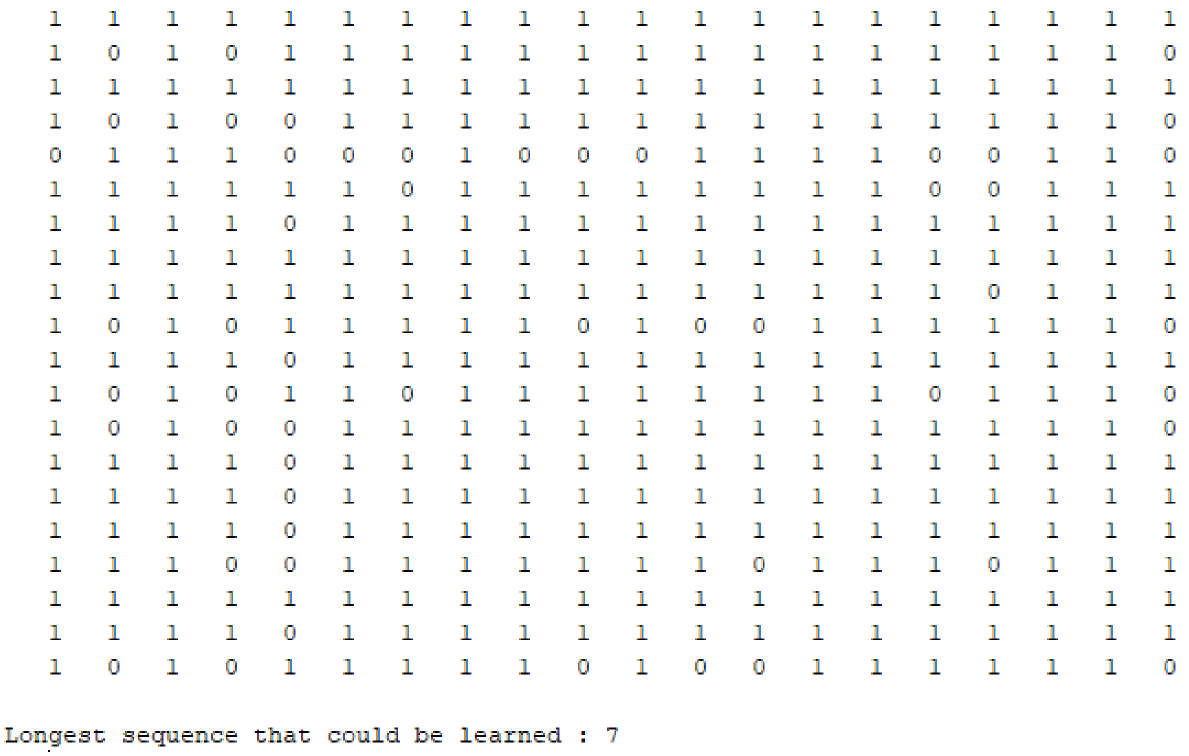


```
     0     1     1     0     0     0     0     1     1     0     1     0     1     0     0     0     0     0     0     0
     1     0     1     0     1     0     1     0     0     0     0     0     1     0     0     1     0     0     0     0
     0     1     1     0     0     0     0     0     1     0     1     0     1     0     0     0     0     0     0     1
     0     0     0     0     0     1     0     0     0     0     0     1     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     1     0     0     0     0     1     0     0     0     1     0     0     0
     1     0     0     0     1     0     0     1     0     1     0     0     1     0     0     1     0     0     1     0
     0     0     0     0     0     0     0     1     0     0     0     0     0     0     0     0     1     0     0     0
     0     1     1     0     0     1     0     0     0     1     0     0     0     0     0     0     0     1     0     1
     0     0     0     0     0     0     0     1     1     0     1     0     0     0     0     0     0     1     0     0
     1     1     0     0     1     0     0     0     0     0     1     0     0     0     0     0     0     0     0     0
     0     0     0     0     1     0     1     1     0     0     0     0     0     0     0     0     0     1     0     0
     0     1     0     0     0     1     0     1     0     0     0     1     0     0     0     0     0     0     1     1
     0     0     1     0     0     1     0     0     0     0     0     1     0     0     0     0     0     1     0     0
     0     0     0     0     0     1     0     0     0     0     0     1     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     1     0     0     0     0     0     0     0     0     1     0     0     0     0     0     0     0     0
     0     0     1     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     1
     1     0     0     0     0     1     0     0     0     1     0     0     0     0     0     0     0     0     0     0
     0     1     0     0     0     1     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     1     0     1     0     0     0     0     0     0     0     0     0     1     0     0     0     0     0     0     1

Longest sequence that could be learned : 20
>> 
```

At f=0.5

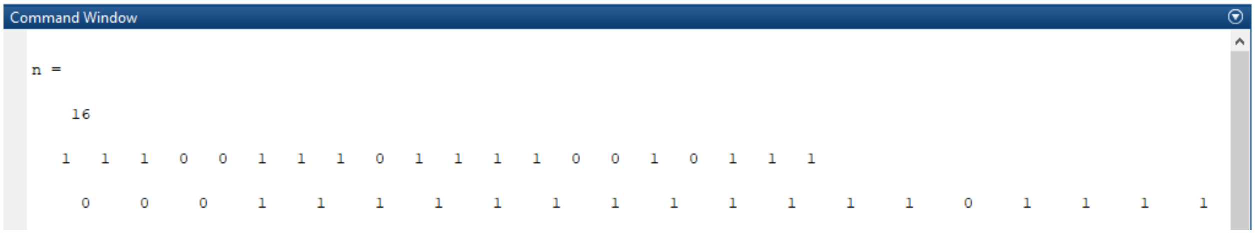


```
n =

    10

      0     1     1     1     0     0     0     1     0     0     0     1     1     1     1     0     0     1     1     0

      0     0     0     0     0     0     0     1     1     1     1     1     1     1     1     0     1     0     1     0
```

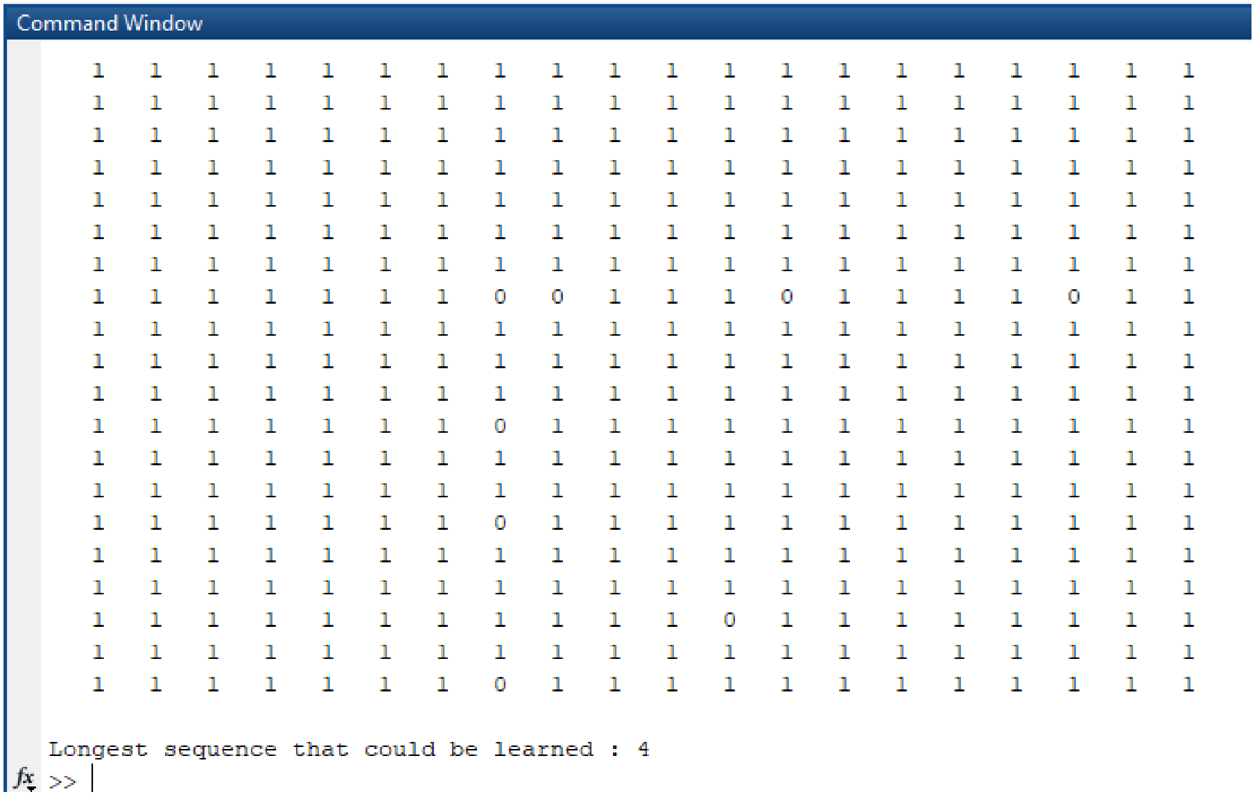


```
     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1
     1     0     1     0     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     0
     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1
     1     0     1     0     0     1     1     1     1     1     1     1     1     1     1     1     1     1     1     0
     0     1     1     1     0     0     0     1     0     0     0     1     1     1     1     0     0     1     1     0
     1     1     1     1     1     1     0     1     1     1     1     1     1     1     1     0     0     1     1     1
     1     1     1     1     0     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1
     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1
     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     0     1     1     1
     1     0     1     0     1     1     1     1     1     0     1     0     0     1     1     1     1     1     1     0
     1     1     1     1     0     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1
     1     0     1     0     1     1     0     1     1     1     1     1     1     1     1     0     1     1     1     0
     1     0     1     0     0     1     1     1     1     1     1     1     1     1     1     1     1     1     1     0
     1     1     1     1     0     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1
     1     1     1     1     0     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1
     1     1     1     1     0     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1
     1     1     1     0     0     1     1     1     1     1     1     1     0     1     1     1     0     1     1     1
     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1
     1     1     1     1     0     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1
     1     0     1     0     1     1     1     1     1     0     1     0     0     1     1     1     1     1     1     0

Longest sequence that could be learned : 7
```

At f=0.8



```
n =

    16

  1   1   1   0   0   1   1   1   0   1   1   1   1   0   0   1   0   1   1   1

     0     0     0     1     1     1     1     1     1     1     1     1     1     1     1     0     1     1     1     1
```

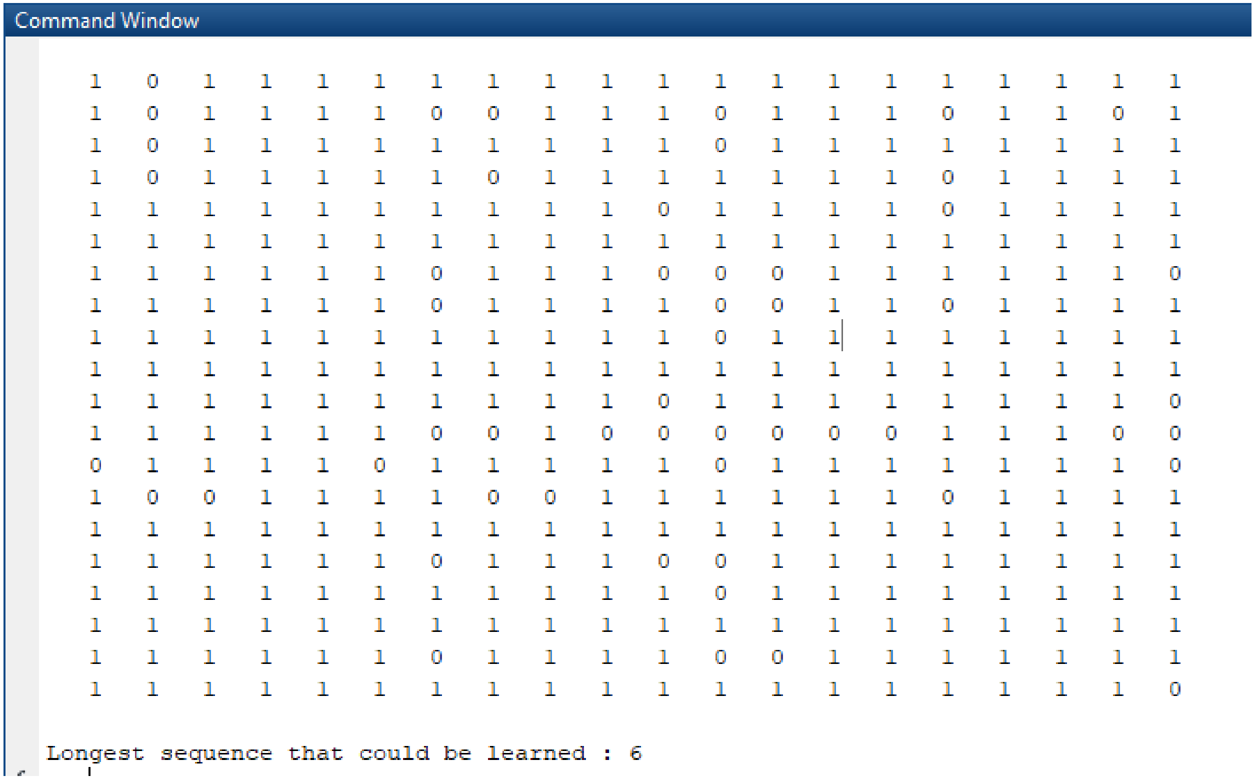


```
     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1
     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1
     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1
     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1
     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1
     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1
     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1
     1     1     1     1     1     1     1     0     0     1     1     1     0     1     1     1     1     0     1     1
     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1
     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1
     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1
     1     1     1     1     1     1     1     0     1     1     1     1     1     1     1     1     1     1     1     1
     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1
     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1
     1     1     1     1     1     1     1     0     1     1     1     1     1     1     1     1     1     1     1     1
     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1
     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1
     1     1     1     1     1     1     1     1     1     1     1     0     1     1     1     1     1     1     1     1
     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1
     1     1     1     1     1     1     1     0     1     1     1     1     1     1     1     1     1     1     1     1

Longest sequence that could be learned : 4
>> 
```

We can see from the results obtained above that as the frequency increases the ability of the network to learn decreases. That means as the number of 1’s increases in the patterns it gets complicated and the system seizes to learn after some particular frequency.

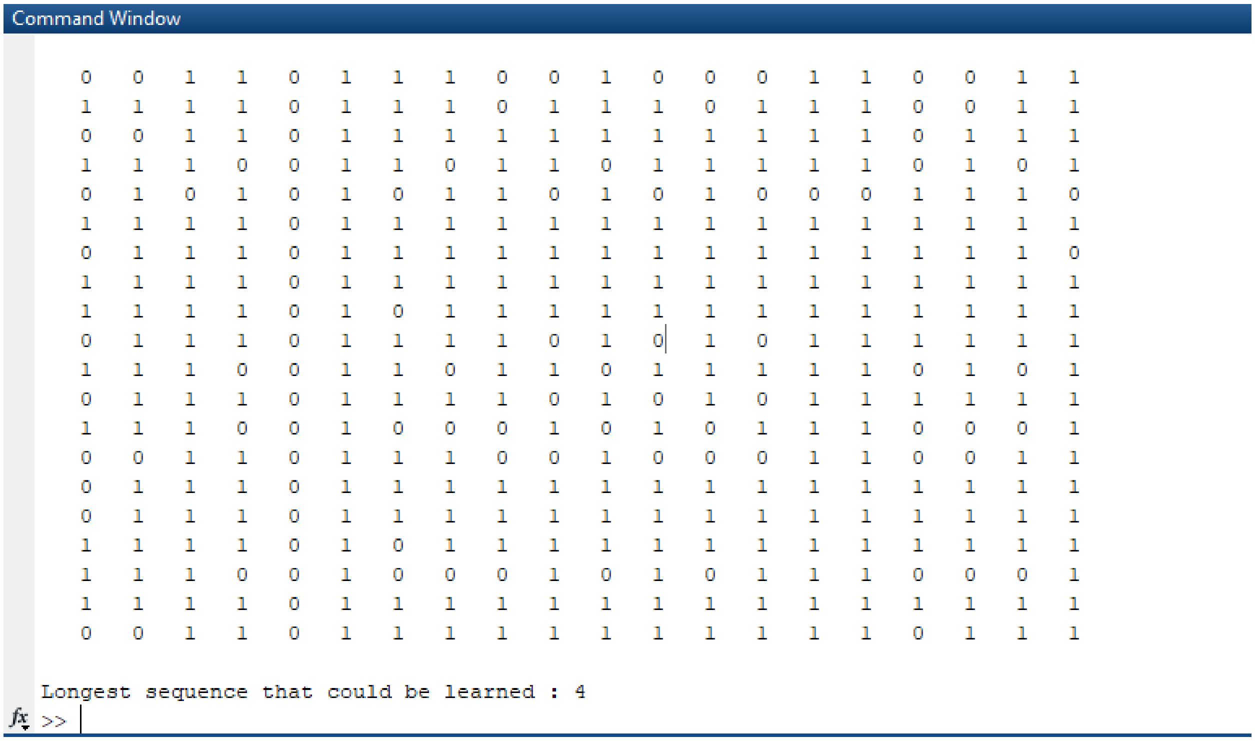
Part 3

Alternate way of forming patterns: f is the exact fraction of bits set to 1. In each pattern rather than having f be the probability that each bit is set.



```
     1     0     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1
     1     0     1     1     1     1     0     0     1     1     1     0     1     1     1     0     1     1     0     1
     1     0     1     1     1     1     1     1     1     1     1     0     1     1     1     1     1     1     1     1
     1     0     1     1     1     1     1     0     1     1     1     1     1     1     1     0     1     1     1     1
     1     1     1     1     1     1     1     1     1     1     0     1     1     1     1     0     1     1     1     1
     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1
     1     1     1     1     1     1     0     1     1     1     0     0     0     1     1     1     1     1     1     0
     1     1     1     1     1     1     0     1     1     1     1     0     0     1     1     0     1     1     1     1
     1     1     1     1     1     1     1     1     1     1     1     0     1     1     1     1     1     1     1     1
     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1
     1     1     1     1     1     1     1     1     1     1     0     1     1     1     1     1     1     1     1     0
     1     1     1     1     1     1     0     0     1     0     0     0     0     0     0     1     1     1     0     0
     0     1     1     1     1     0     1     1     1     1     1     0     1     1     1     1     1     1     1     0
     1     0     0     1     1     1     1     0     0     1     1     1     1     1     1     0     1     1     1     1
     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1
     1     1     1     1     1     1     0     1     1     1     0     0     1     1     1     1     1     1     1     1
     1     1     1     1     1     1     1     1     1     1     1     0     1     1     1     1     1     1     1     1
     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1
     1     1     1     1     1     1     0     1     1     1     1     0     0     1     1     1     1     1     1     1
     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1     0

Longest sequence that could be learned : 6
```

Previously :



```
     0     0     1     1     0     1     1     1     0     0     1     0     0     0     1     1     0     0     1     1
     1     1     1     1     0     1     1     1     0     1     1     1     0     1     1     1     0     0     1     1
     0     0     1     1     0     1     1     1     1     1     1     1     1     1     1     1     0     1     1     1
     1     1     1     0     0     1     1     0     1     1     0     1     1     1     1     1     0     1     0     1
     0     1     0     1     0     1     0     1     1     0     1     0     1     0     0     0     1     1     1     0
     1     1     1     1     0     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1
     0     1     1     1     0     1     1     1     1     1     1     1     1     1     1     1     1     1     1     0
     1     1     1     1     0     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1
     1     1     1     1     0     1     0     1     1     1     1     1     1     1     1     1     1     1     1     1
     0     1     1     1     0     1     1     1     1     0     1     0     1     0     1     1     1     1     1     1
     1     1     1     0     0     1     1     0     1     1     0     1     1     1     1     1     0     1     0     1
     0     1     1     1     0     1     1     1     1     0     1     0     1     0     1     1     1     1     1     1
     1     1     1     0     0     1     0     0     0     1     0     1     0     1     1     1     0     0     0     1
     0     0     1     1     0     1     1     1     0     0     1     0     0     0     1     1     0     0     1     1
     0     1     1     1     0     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1
     0     1     1     1     0     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1
     1     1     1     1     0     1     0     1     1     1     1     1     1     1     1     1     1     1     1     1
     1     1     1     0     0     1     0     0     0     1     0     1     0     1     1     1     0     0     0     1
     1     1     1     1     0     1     1     1     1     1     1     1     1     1     1     1     1     1     1     1
     0     0     1     1     0     1     1     1     1     1     1     1     1     1     1     1     0     1     1     1

Longest sequence that could be learned : 4
>>
```

From the above examples we can see that the longest sequence that could be learned is greater when f is the exact fraction of bits set to 1. Neural circuit that could provide this type of normalization is the one which has a low frequency. It helps provide a better learning efficiency.

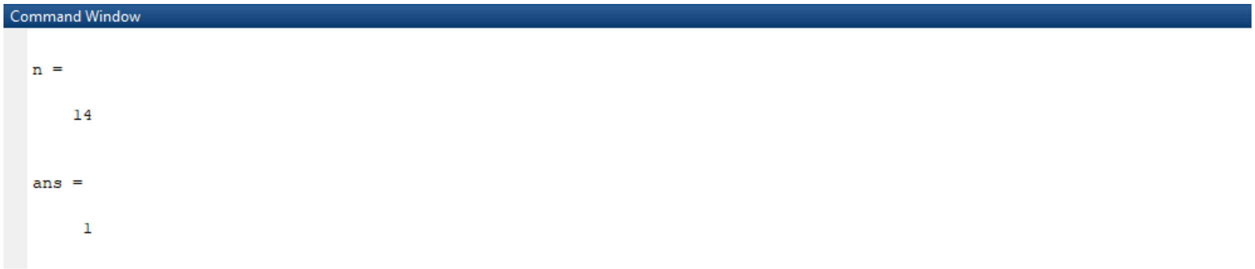
Matlab Code:

```
%Neural Sequence Learning
clear
clc
close all

%the frequency of 1's in a single pattern
f = 0.8;

% no. of elements in a pattern
%the number of 1's in a given pattern
N = 20;
n = N*f

%sequence consists of a collection of binary patterns
Q=0;

%  Weighted Matrix
W = zeros(N); %initialise to Zero

% Input pattern

A=rand(1,20)<f;

%Output pattern
B = zeros(1,N);%initialise to Zero
%B = ones(1,N);
B(randperm(N,n))=1; % Permuted variable

W_T = zeros(N);
%Pattern C
C = zeros(1,N);%initialise to zero
```

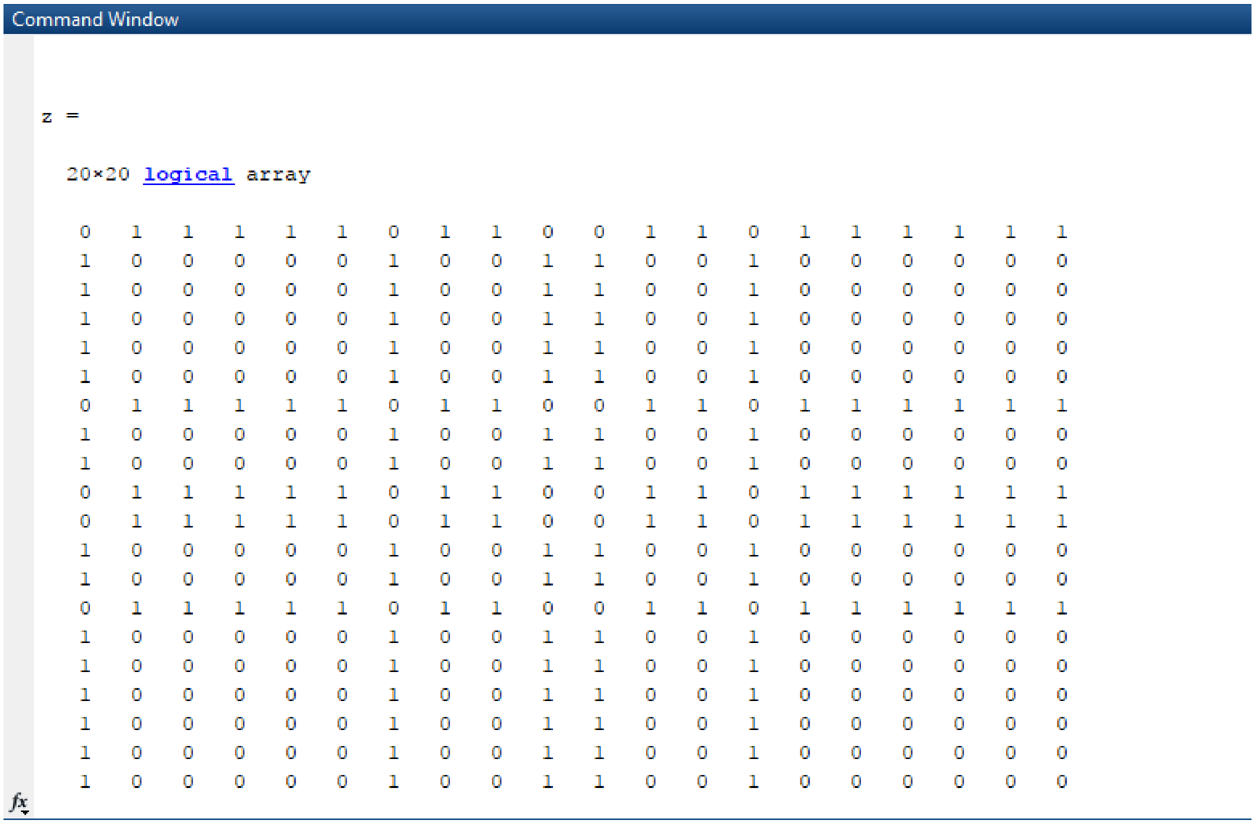
```
%GIVEN: 100 ITERATIONS
for t = 1:100
Q = Q + 1; % to generate a sequence of Q+1 patterns
for i=1:N
W(i,:) = A(i).*B';
end
W_T = W_T + W;
W = W_T >= 1;

% plug the values of A and B in the sequence of patterns and compare it
patterns(t,:) = A;
patterns(t+1,:) = B;


for j = 1:N
C(j) = sum(A'.*W(:,j)) >= N*f;
end

comapare(t,:) = C;
% Now Check if both B and C are euqal
check = isequal(B,C);
if check == 0
break % Loop breaks if there is an error in the sequence
end

A = B;
B = zeros(1,N);
B(randperm(N,N*f)) = 1;

end
disp([A])
disp([B])
disp([W])

disp(['Longest sequence that could be learned : ' num2str(Q)])
```

Extra credit

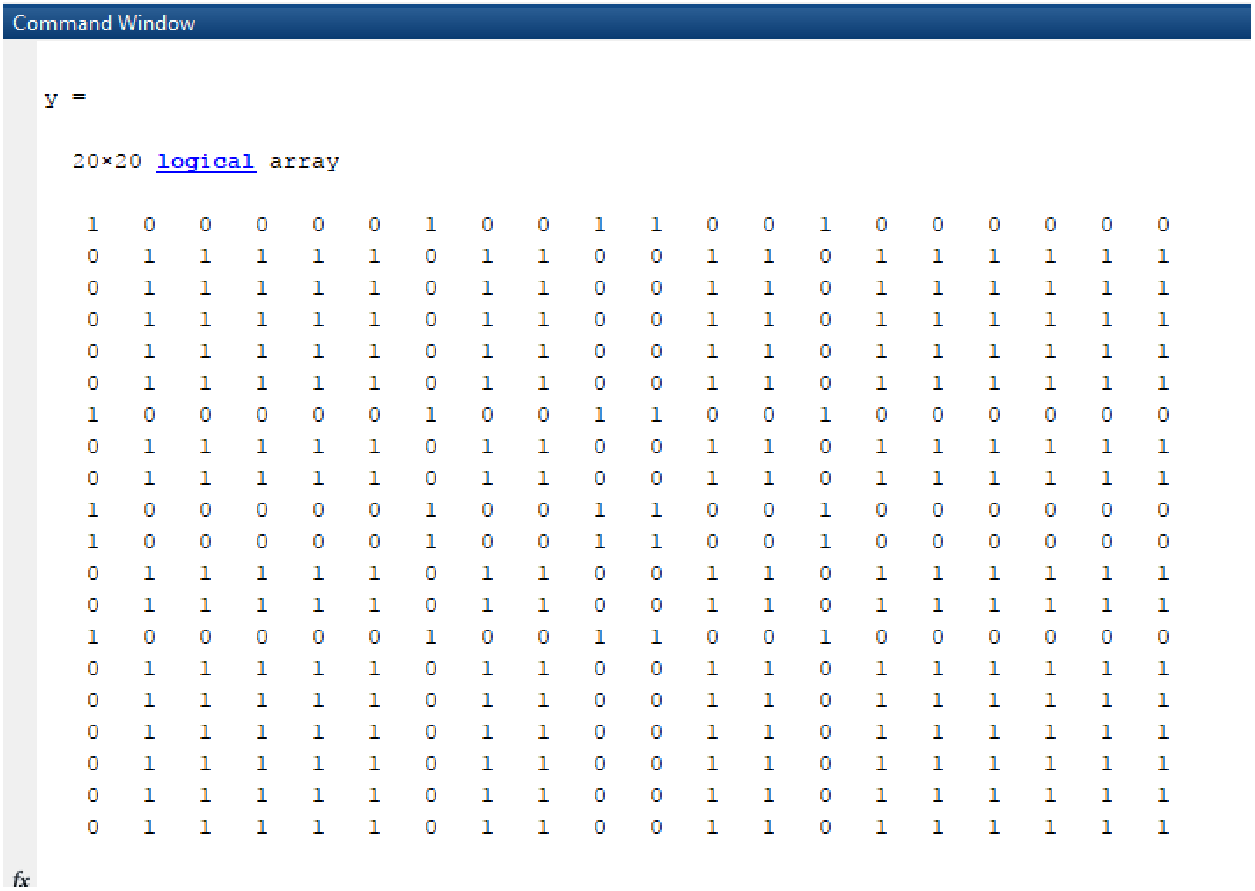
To explore the advantage of a high-dimensional recoding of the patterns analogous to that performed by the granule cells in the cerebellum



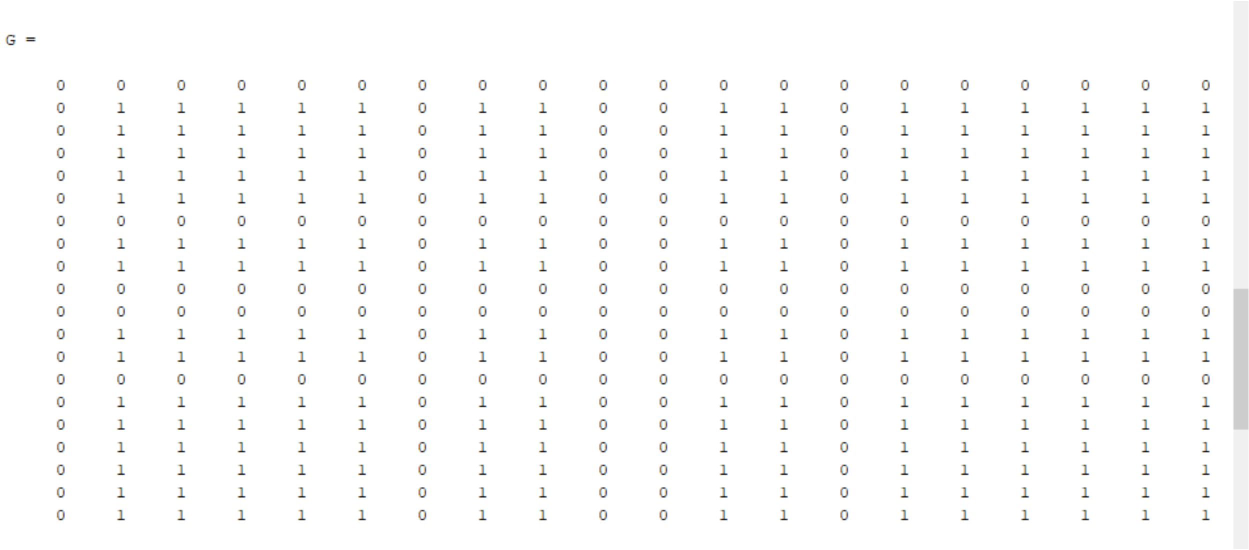
```
n =

    14


ans =

     1
```



```
z =

  20×20 logical array

   0   1   1   1   1   1   0   1   1   0   0   1   1   0   1   1   1   1   1   1
   1   0   0   0   0   0   1   0   0   1   1   0   0   1   0   0   0   0   0   0
   1   0   0   0   0   0   1   0   0   1   1   0   0   1   0   0   0   0   0   0
   1   0   0   0   0   0   1   0   0   1   1   0   0   1   0   0   0   0   0   0
   1   0   0   0   0   0   1   0   0   1   1   0   0   1   0   0   0   0   0   0
   1   0   0   0   0   0   1   0   0   1   1   0   0   1   0   0   0   0   0   0
   0   1   1   1   1   1   0   1   1   0   0   1   1   0   1   1   1   1   1   1
   1   0   0   0   0   0   1   0   0   1   1   0   0   1   0   0   0   0   0   0
   1   0   0   0   0   0   1   0   0   1   1   0   0   1   0   0   0   0   0   0
   0   1   1   1   1   1   0   1   1   0   0   1   1   0   1   1   1   1   1   1
   0   1   1   1   1   1   0   1   1   0   0   1   1   0   1   1   1   1   1   1
   1   0   0   0   0   0   1   0   0   1   1   0   0   1   0   0   0   0   0   0
   1   0   0   0   0   0   1   0   0   1   1   0   0   1   0   0   0   0   0   0
   0   1   1   1   1   1   0   1   1   0   0   1   1   0   1   1   1   1   1   1
   1   0   0   0   0   0   1   0   0   1   1   0   0   1   0   0   0   0   0   0
   1   0   0   0   0   0   1   0   0   1   1   0   0   1   0   0   0   0   0   0
   1   0   0   0   0   0   1   0   0   1   1   0   0   1   0   0   0   0   0   0
   1   0   0   0   0   0   1   0   0   1   1   0   0   1   0   0   0   0   0   0
   1   0   0   0   0   0   1   0   0   1   1   0   0   1   0   0   0   0   0   0
   1   0   0   0   0   0   1   0   0   1   1   0   0   1   0   0   0   0   0   0
```



```
y =

  20×20 logical array

   1   0   0   0   0   0   1   0   0   1   1   0   0   1   0   0   0   0   0   0
   0   1   1   1   1   1   0   1   1   0   0   1   1   0   1   1   1   1   1   1
   0   1   1   1   1   1   0   1   1   0   0   1   1   0   1   1   1   1   1   1
   0   1   1   1   1   1   0   1   1   0   0   1   1   0   1   1   1   1   1   1
   0   1   1   1   1   1   0   1   1   0   0   1   1   0   1   1   1   1   1   1
   0   1   1   1   1   1   0   1   1   0   0   1   1   0   1   1   1   1   1   1
   1   0   0   0   0   0   1   0   0   1   1   0   0   1   0   0   0   0   0   0
   0   1   1   1   1   1   0   1   1   0   0   1   1   0   1   1   1   1   1   1
   0   1   1   1   1   1   0   1   1   0   0   1   1   0   1   1   1   1   1   1
   1   0   0   0   0   0   1   0   0   1   1   0   0   1   0   0   0   0   0   0
   1   0   0   0   0   0   1   0   0   1   1   0   0   1   0   0   0   0   0   0
   0   1   1   1   1   1   0   1   1   0   0   1   1   0   1   1   1   1   1   1
   0   1   1   1   1   1   0   1   1   0   0   1   1   0   1   1   1   1   1   1
   1   0   0   0   0   0   1   0   0   1   1   0   0   1   0   0   0   0   0   0
   0   1   1   1   1   1   0   1   1   0   0   1   1   0   1   1   1   1   1   1
   0   1   1   1   1   1   0   1   1   0   0   1   1   0   1   1   1   1   1   1
   0   1   1   1   1   1   0   1   1   0   0   1   1   0   1   1   1   1   1   1
   0   1   1   1   1   1   0   1   1   0   0   1   1   0   1   1   1   1   1   1
   0   1   1   1   1   1   0   1   1   0   0   1   1   0   1   1   1   1   1   1
   0   1   1   1   1   1   0   1   1   0   0   1   1   0   1   1   1   1   1   1
```



```
G =

     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     0     1     1     1     1     1     0     1     1     0     0     1     1     0     1     1     1     1     1     1
     0     1     1     1     1     1     0     1     1     0     0     1     1     0     1     1     1     1     1     1
     0     1     1     1     1     1     0     1     1     0     0     1     1     0     1     1     1     1     1     1
     0     1     1     1     1     1     0     1     1     0     0     1     1     0     1     1     1     1     1     1
     0     1     1     1     1     1     0     1     1     0     0     1     1     0     1     1     1     1     1     1
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     0     1     1     1     1     1     0     1     1     0     0     1     1     0     1     1     1     1     1     1
     0     1     1     1     1     1     0     1     1     0     0     1     1     0     1     1     1     1     1     1
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     0     1     1     1     1     1     0     1     1     0     0     1     1     0     1     1     1     1     1     1
     0     1     1     1     1     1     0     1     1     0     0     1     1     0     1     1     1     1     1     1
     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
     0     1     1     1     1     1     0     1     1     0     0     1     1     0     1     1     1     1     1     1
     0     1     1     1     1     1     0     1     1     0     0     1     1     0     1     1     1     1     1     1
     0     1     1     1     1     1     0     1     1     0     0     1     1     0     1     1     1     1     1     1
     0     1     1     1     1     1     0     1     1     0     0     1     1     0     1     1     1     1     1     1
     0     1     1     1     1     1     0     1     1     0     0     1     1     0     1     1     1     1     1     1
     0     1     1     1     1     1     0     1     1     0     0     1     1     0     1     1     1     1     1     1
```

Matlab Code:

```
clear
clc
close all

%the frequency of 1's in a single pattern
f = 0.8;

% no. of elements in a pattern
%the number of 1's in a given pattern
N = 20;
n = N*f

%sequence consists of a collection of binary patterns
Q=0;

%  Weighted Matrix
W = zeros(N); %initialise to Zero

A=rand(1,20)<f; % Random input variable
z = xor(A,A')
y = ~z
G = A.*y'

B = zeros(1,N);
B(randperm(N,n))=1;
W_T = zeros(N);
C = zeros(1,N);


for t = 1:100
Q = Q + 1;

for i=1:N
W(i,:) = G(i).*B';
end
W_T = W_T + W;
W = W_T >= 1;


for j = 1:N
C(j) = sum(A'.*G(:,j)) >= N*f;
```

```
end
compare(t,:) = C;
tf = isequal(B,C);
if tf == 0
break
end
G = B;
B = zeros(1,N);
B(randperm(N,N*f)) = 1;
end
disp([W])

disp(['The longest sequence that can be learned is' num2str(Q)])
```