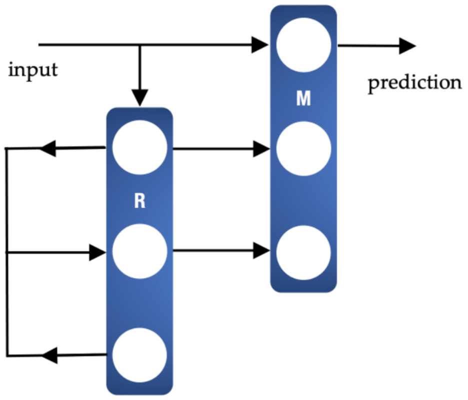
Deep Temporal Memory - Introduction

Peter Overmann, 08 Aug 2022

The most elementary temporal memory algorithm is composed of two triadic memory instances R and M, wired together in the following circuit:



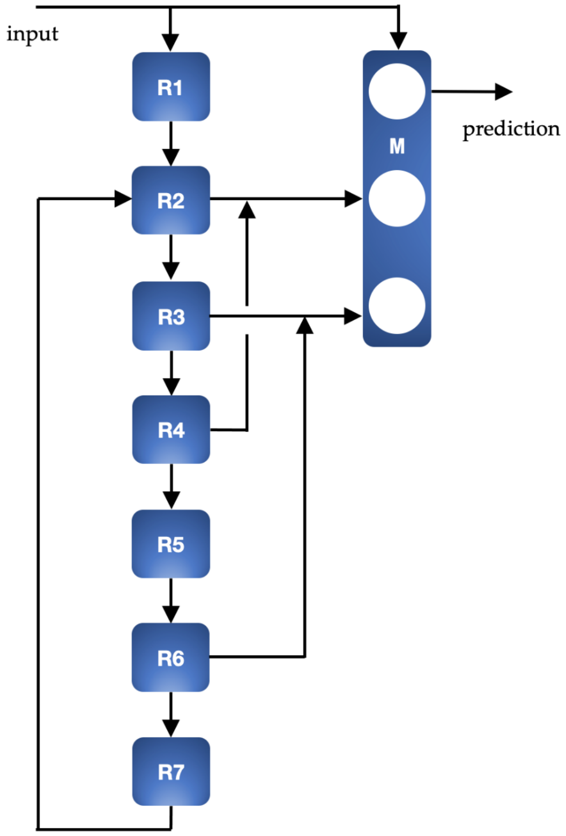
In this circuit, triadic memory R creates a random context vector for a consecutive pair of inputs, and feeds it back to the delayed input. This element effectively creates context-dependent bigrams from consecutive inputs.
Triadic memory M learns the association of the current input, and the readout from triadic memory R.

The elementary temporal memory circuit is capable of learning simple repeating patterns, such as 60 digits of pi.

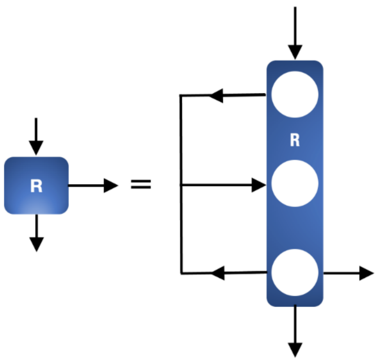
A circuit able to learn more complex patterns requires multiple feedback lines. There are infinitely many ways to design such circuits from triadic memory components. The following circuit diagram shows a simple example built from eight triadic memory units. The units R1 to R7 encode values to bigrams, bigrams to 3grams, and so on. At each step, feedback from the previous step is added to the inputs. There is an additional feedback loop from the output of R7 to the input of R2.

A readout memory M takes the state of selected bigram encoders (here chosen to be R2, R3, R4 and R6) to learn the predicted value at each step.

This circuit design resembles an architecture known as reservoir computing, where a network involving multiple feedback loops propagates a series of inputs, and a readout component attaches predictions to the state of the reservoir.



In the above diagram, the bigram encoders R represent triadic memory units with feedback loops.



Temporal Bigram Memory

TemporalBigramMemory is a circuit component consisting of a single triadic memory. It processes a stream of SDRs, returning an SDR which encodes the current input SDR and the previous SDR plus feedback from the previous step.

Therefore in encodes two consecutive SDRs into bigrams (or higher-level representations).

Note: the input SDR need not be binary. The algorithm reduces it to binary using the ranked-max method from the triadic memory algorithm.

```
TemporalBigramMemory[f_Symbol, {n_Integer, p_Integer} ] :=
  Module[ {T, x, y, z, overlap},

   (* instantiate a triadic memory unit *)
   TriadicMemory[ T, {n, p}];

   overlap[a_SparseArray, b_SparseArray] := Total[BitAnd[a, b]];

   x = y = z = SparseArray[{0}, {n}];

   (* reset x, y, z *)
   f[SparseArray[{0}, {n}]] := x = y = z = SparseArray[{0}, {n}];

   f[input_SparseArray] := Module[ {},

     x = T[y + z];  (* binarize x and y using ranked-max algorithm *)
     y = T[input];

     If[overlap[T[_, y, z = T[x, y, _]], x] < p, T[x, y, z = T[]]];
     z
    ];

  ];
```

Deep Temporal Memory Algorithm

```
TemporalMemory[t_Symbol, {n_Integer, p_Integer}] :=

  Module[{M, R1, R2, R3, R4, R5, R6, R7,  x, y, z, t1, t2, t3, t4, t5, t6, t7},

   (* predictions / readout memory *)
   TriadicMemory[M, {n, p}];

   (* reservoir units *)
   TemporalBigramMemory[#, {n, p}] & /@ {R1, R2, R3, R4, R5, R6, R7};

   (* initialize state variables with null vectors *)
   x = y = z = t1 = t2 = t3 = t4 = t5 = t6 = t7 =  M[0];

   t[inp_] := Module[{},

     (* flush state if input is zero - needed when used
       as a sequence memory *)If[Total[inp] == 0, x = y = z = M[0]];

     (* store new prediction if necessary *)
     If[z ≠ inp, M[x, y, inp]];

     t1 = R1[inp];
     t2 = R2[t1 + t7]; (* feedback from the output of R7 *)
     t3 = R3[t2];
     t4 = R4[t3];
     t5 = R5[t4];
     t6 = R6[t5];
     t7 = R7[t6];

     (* prediction readout from t1, t4, t2 and t6 *)
     z = M[x = M[t1 + t4], y = M[t2 + t6], _]

     (* Note: the function M[x+y]
       binarizes the sum of two binary vectors. BitOr[x,y] would
       give the same result if x and y don't overlap *)

    ]

  ];
```

Configuration

```
Get[ $UserBaseDirectory <> "/TriadicMemory/triadicmemoryC.m"]
```

```
n = 1000; p = 5;
TemporalMemory[ T, {n, p}];
```

Encoder / Decoder

Test function

Tests

The following tests are run in a single session. The temporal memory processes a stream of characters with repeating patterns, at each step making a prediction for the next character. Correct predictions are shown in black, mispredictions in red. All characters are test input -- the temporal memory is not used to auto-continue a sequence in this setup.

```
temporalmemorytest [ "ABC", 8 ]
```

ABCABCABCABCABCABCABCABC

```
temporalmemorytest [ "kiwi", 8]
```

kiwikiwikiwikiwikiwikiwikiwikiwi

```
temporalmemorytest [ "apple", 8]
```

appleappleappleappleappleappleappleapple

```
temporalmemorytest [ "pepper", 8]
```

pepperpepperpepperpepperpepperpepperpepperpepper

```
temporalmemorytest [ "tomato", 8]
```

tomatotomatotomatotomatotomatotomatotomatotomato

```
temporalmemorytest [ "banana", 8]
```

bananabananabananabananabananabananabananabanana

```
temporalmemorytest [ "wiriwirichili", 8]
```

wiriwirichiliwiriwirichiliwiriwirichiliwiriwiric
hiliwiriwirichiliwiriwirichiliwiriwirichiliwiriwirichili

```
temporalmemorytest [ "alfalfa", 20]
```

alfalfaalfalfaalfalfaalfalfaalfalfaalfalfaalfalfaalfalfaalfalfaalfalfaal
falfaalfalfaalfalfaalfalfaalfalfaalfalfaalfalfaalfalfaalfalfaalfalfa

```
temporalmemorytest ["A quick brown fox jumps over the lazy dog. ", 4]
```

A quick brown fox jumps over the lazy dog. A quick bro
wn fox jumps over the lazy dog. A quick brown fox jumps ove
r the lazy dog. A quick brown fox jumps over the lazy dog.

1000 digits of pi:

```
temporalmemorytest [ ToString[N[Pi, 1000]], 8]
```

3.1415926535897932384626433832795028841971693993751058209749445923078164062862
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