Deep Temporal Memory - Introduction

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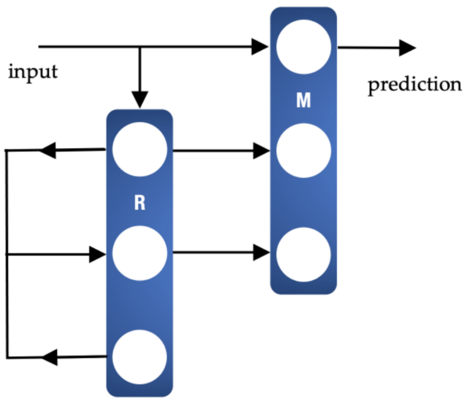
Algorithm

A simple temporal memory algorithm can be composed of two triadic memory instances, wired together in the following circuit:



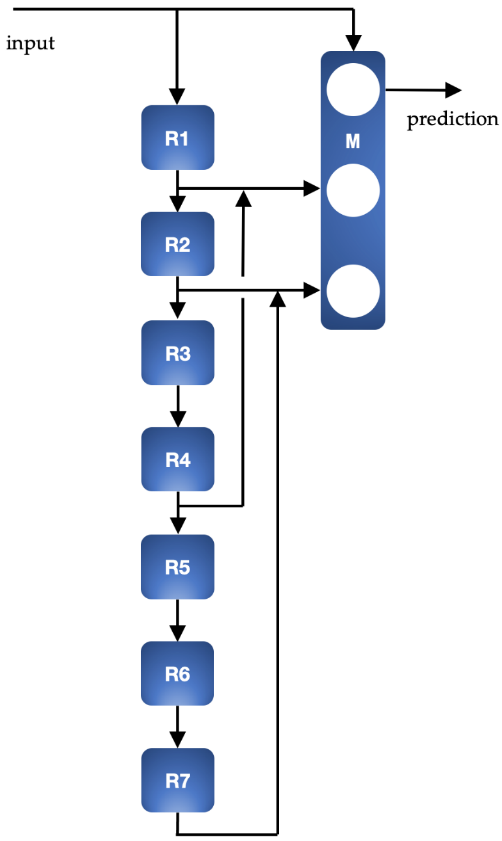
In this circuit, triadic memory R creates a random context vector for a consecutive pair of inputs, and feeds it back to the delayed input. This element effectively creates context-dependent bigrams from consecutive inputs.
Triadic memory M learns the association of the current input, and the readout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

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

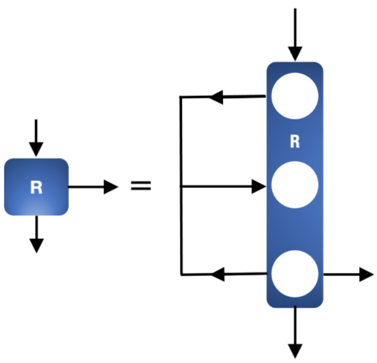
A circuit able to learn more complex patterns requires multiple feedback lines. There are infinitely many ways to design large circuits from triadic memory components. The following circuit diagram shows an example built from eight triadic memory units. The units R1 to R7 encode inputs to bigrams, bigrams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

A readout memory M aggregates the state of several encoding states 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 circuit components R represent triadic memory units with feedback loops as follows:



This component consists of a single triadic memory and a triple of SDRs that persist the state of the component at each time step. 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.

```
R[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 = BitOr[y, z];  (* binarize x and y using ranked-max algorithm *)
     y = input;

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

  ];
```

The deep temporal memory circuit includes a chain of components R, generating bigrams from the inputs, trigrams from bigrams, etc. The readout memory M learns a prediction based on the temporal state of the encoding chain.

```
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}];

   (* bigram encoder units *)
   R[#, {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]];

     (* encoding chain *)
     t1 = R1[inp];
     t2 = R2[t1];
     t3 = R3[t2];
     t4 = R4[t3];
     t5 = R5[t4];
     t6 = R6[t5];
     t7 = R7[t6];

     (* prediction readout from t1, t2, t4 and t7 *)
     z = M[x = BitOr[t1, t4], y = BitOr[t2, t7], _]

    ]

  ];
```

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]
alfalfaalfalfaalfalfaalfalfaalfalfaalfalfaalfalfaalfalfaalfalfaal
 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
 089986280348253421170679821480865132823066470938446095505822317253594081
 1284811174502841027019385211055596446229489549303819644288109756659334461
 6128475648233786783165271201909145648566923460348610454326648213393607260
 60249141273724587006606315588174881520920962829254091715364367892590360
```

0113305305488204665213841469519415116094330572703657595919530921861173819326117931051185480744623799627495673518857527248912279381830119491298336733624406566430860213949463952247371907021798609437027705392171762931767523846748184676694051320005681271452635608277857713427577896091736371787214684409012249534301465495853710507922796892589235420199561121290219608640344181598136297747713099605187072113499999983729780499510597317328160963185950244594553469083026425223082533446850352619311881710100031378387528865875332083814206171776691473035982534904287554687311595628638823537875937519577818577805321712268066130019278766111959092164201993.141592653589793238462643383279502884197169399375105820974944592307816406286208998628034825342117067982148086513282306647093844609550582231725359408128481117450284102701938521105559644622948954930381964428810975665933446128475648233786783165271201909145648566923460348610454326648213393607260249141273724587006606315588174881520920962829254091715364367892590360011330530548820466521384146951941511609433057270365759591953092186117381932611793105118548074462379962749567351885752724891227938183011949129833673362440656643086021394946395224737190702179860943702770539217176293176752384674818467669405132000568127145263560827785771342757789609173637178721468440901224953430146549585371050792279689258923542019956112129021960864034418159813629774771309960518707211349999998372978049951059731732816096318595024459455346908302642522308253344685035261931188171010003137838752886587533208381420617177669147303598253490428755468731159562863882353787593751957781857780532171226806613001927876611195909216420199

14654958537105079227968925892354201995611212902196086403441815981362977
47771309960518707211349999998372978049951059731732816096318595024459455
53469083026425223082533446850352619311881710100031378387528865875332083
81420617177669147303598253490428755468731159562863882353787593751957781
81857780532171226806613001927876611195909216420199 3.14159265358979323846
46264338327950288419716939937510582097494459230781640628620899862803482
25342117067982148086513282306647093844609550582231725359408128481117450
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63882353787593751957781857780532171226806613001927876611195909216420199
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