Deep Temporal Memory - Introduction

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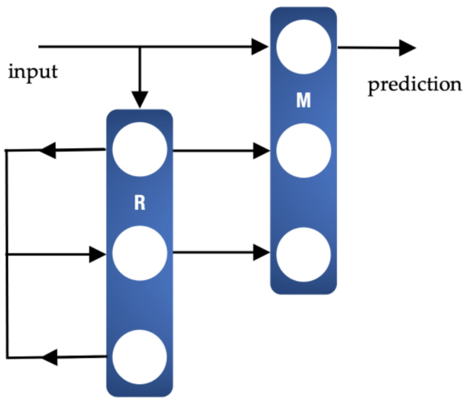
Algorithm

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



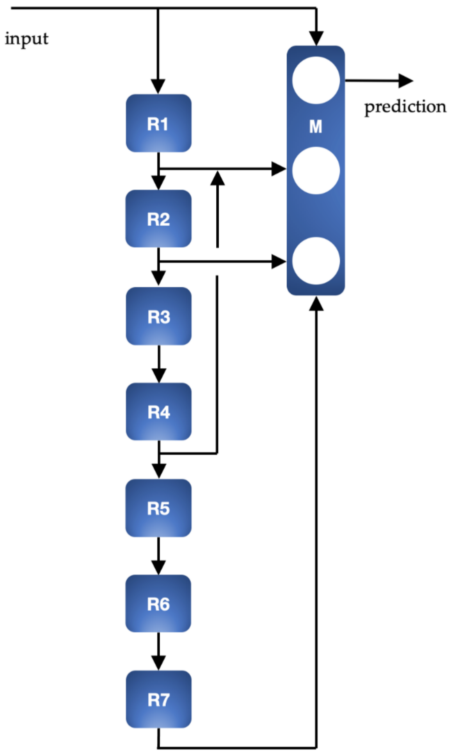
In this circuit, triadic memory R creates a random context vector for a consecutive pair of inputs, and feeds it back to the delayed input. This element effectively creates context-dependent bigrams from consecutive inputs.
Triadic memory M learns the association of the current input, and the readout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

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

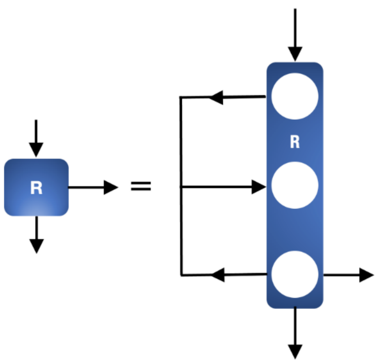
A circuit able to learn more complex patterns requires multiple feedback lines. There are infinitely many ways to design large circuits from triadic memory components. The following circuit diagram shows an example built from eight triadic memory units. The units R1 to R7 encode inputs to bigrams, bigrams 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[Total[x] > 0 && 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, t8},

   (* 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 = 1100; p = 4;

TemporalMemory[ T, {n, p}];

init  {}
```

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", 12]
```

wiriwirichiliwiriwirichiliwiriwirichiliwiriwirichiliwiriwirichiliwiriwirichiliw
iriwirichiliwiriwirichiliwiriwirichiliwiriwirichiliwiriwirichiliwiriwirichili

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

alfalfaalfalfaalfalfaalfalfaalfalfaalfalfaalfalfaalfalfaalfalfaalfalfaalfalfaal
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]], 5]
```

3.14159265358979323846264338327950288419716939937510582097494459230781640628620
899862803482534211706798214808651328230664709384460955058223172535940812848111745028410270193852110555964462294895493038196442881097566593344

61284756482337867831652712019091456485669234603486104543266482133936072
60249141273724587006606315588174881520920962829254091715364367892590360
01133053054882046652138414695194151160943305727036575959195309218611738
19326117931051185480744623799627495673518857527248912279381830119491298
33673362440656643086021394946395224737190702179860943702770539217176293
17675238467481846766940513200056812714526356082778577134275778960917363
71787214684409012249534301465495853710507922796892589235420199561121290
21960864034418159813629774771309960518707211349999998372978049951059731
73281609631859502445945534690830264252230825334468503526193118817101000
31378387528865875332083814206171776691473035982534904287554687311595628
63882353787593751957781857780532171226806613001927876611195909216420199
3.141592653589793238462643383279502884197169399375105820974944592307816
40628620899862803482534211706798214808651328230664709384460955058223172
53594081284811174502841027019385211055596446229489549303819644288109756
65933446128475648233786783165271201909145648566923460348610454326648213
39360726024914127372458700660631558817488152092096282925409171536436789
25903600113305305488204665213841469519415116094330572703657595919530921
86117381932611793105118548074462379962749567351885752724891227938183011
94912983367336244065664308602139494639522473719070217986094370277053921
71762931767523846748184676694051320005681271452635608277857713427577896
09173637178721468440901224953430146549585371050792279689258923542019956
11212902196086403441815981362977477130996051870721134999999837297804995
10597317328160963185950244594553469083026425223082533446850352619311881
71010003137838752886587533208381420617177669147303598253490428755468731
15956286388235378759375195778185778053217122680661300192787661119590921
64201993.1415926535897932384626433832795028841971693993751058209749445
9230781640628620899862803482534211706798214808651328230664709384460955
0582231725359408128481117450284102701938521105559644622948954930381964
4288109756659334461284756482337867831652712019091456485669234603486104
5432664821339360726024914127372458700660631558817488152092096282925409
1715364367892590360011330530548820466521384146951941511609433057270365
7595919530921861173819326117931051185480744623799627495673518857527248
9122793818301194912983367336244065664308602139494639522473719070217986
0943702770539217176293176752384674818467669405132000568127145263560827
7857713427577896091736371787214684409012249534301465495853710507922796
8925892354201995611212902196086403441815981362977477130996051870721134
9999998372978049951059731732816096318595024459455346908302642522308253
3446850352619311881710100031378387528865875332083814206171776691473035
9825349042875546873115956286388235378759375195778185778053217122680661
30019278766111959092164201993.1415926535897932384626433832795028841971
6939937510582097494459230781640628620899862803482534211706798214808651
3282306647093844609550582231725359408128481117450284102701938521105559
6446229489549303819644288109756659334461284756482337867831652712019091
4564856692346034861045432664821339360726024914127372458700660631558817
4881520920962829254091715364367892590360011330530548820466521384146951
9415116094330572703657595919530921861173819326117931051185480744623799
6274956735188575272489122793818301194912983367336244065664308602139494

```
6395224737190702179860943702770539217176293176752384674818467669405132
0005681271452635608277857713427577896091736371787214684409012249534301
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4771309960518707211349999998372978049951059731732816096318595024459455
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18577805321712268066130019278766111959092164201993.1415926535897932384
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5342117067982148086513282306647093844609550582231725359408128481117450
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3378678316527120190914564856692346034861045432664821339360726024914127
3724587006606315588174881520920962829254091715364367892590360011330530
5488204665213841469519415116094330572703657595919530921861173819326117
9310511854807446237996274956735188575272489122793818301194912983367336
2440656643086021394946395224737190702179860943702770539217176293176752
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```