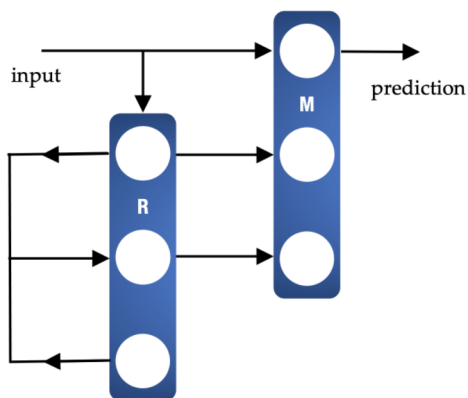# Deep Temporal Memory - Introduction

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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.
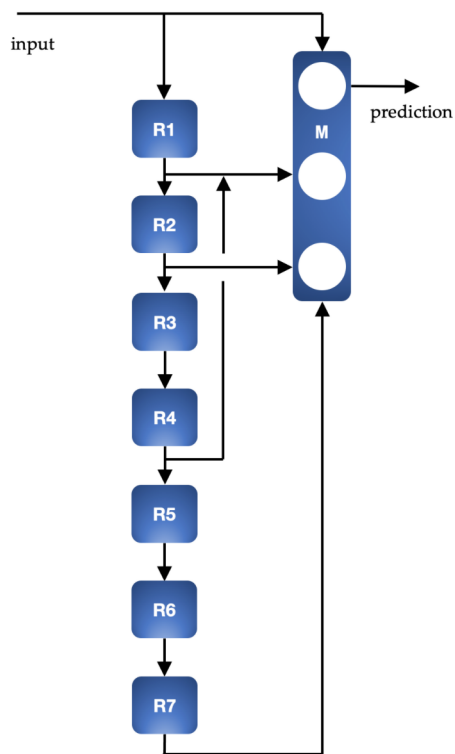
In the above diagram, the circuit components R represent triadic memory units with feedback loops as follows:
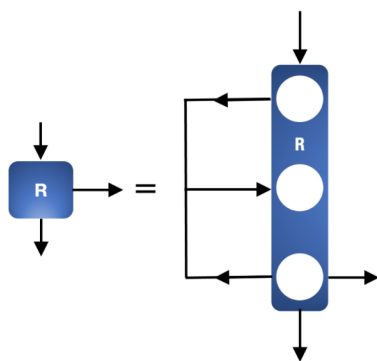
This component consists of a single triadic memory and a triple of SDRs that persist the state of the component at each time step. It processes a stream of SDRs, returning an SDR which encodes the current input SDR and the previous SDR plus feedback from the previous step.

```
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];

   Print["init  ", Sort[Flatten[t7["NonzeroPositions"]]]];

   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]

kiwikiwikiwikiwikiwikiwikiwi

temporalmemorytest ["apple", 8]

appleappleappleappleappleappleappleapple

temporalmemorytest ["pepper", 8]

pepperpepperpepperpepperpepperpepperpepperpepper

temporalmemorytest ["tomato", 8]

tomatotomatotomatotomatotomatotomatotomatotomato

temporalmemorytest ["banana", 8]

bananabananabananabananabananabananabananabanana

temporalmemorytest ["wiriwirichili", 12]

wiriwirichiliwiriwirichiliwiriwirichiliwiriwirichiliwiriwirichiliw
 iriwirichiliwiriwirichiliwiriwirichiliwiriwirichiliwiriwirichili

temporalmemorytest ["alfalfa", 20]

alfalfaalfalfaalfalfaalfalfaalfalfaalfalfaalfalfaalfalfaalfalfaal
 falfaalfalfaalfalfaalfalfaalfalfaalfalfaalfalfaalfalfaalfalfa

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]

```
3.141592653589793238462643383279502884197169399375105820974944592307816406286208998628034825342117067982148086513282306647093844609550582231725359408
12848111745028410270193852110555964462294895493038196442881097566593344
61284756482337867831652712019091456485669234603486104543266482133936072
60249141273724587006606315588174881520920962829254091715364367892590360
01133053054882046652138414695194151160943305727036575959195309218611738
19326117931051185480744623799627495673518857527248912279381830119491298
33673362440656643086021394946395224737190702179860943702770539217176293
17675238467481846766940513200056812714526356082778577134275778960917363
71787214684409012249534301465495853710507922796892589235420199561121290
21960864034418159813629774771309960518707211349999983729780499510597317
32816096318595024459455346908302642522308253344685035261931188171010003
13783875288658753320838142061717766914730359825349042875546873115956 28
63882353787593751957781857780532171226806613001927876611195909216420199
3.14159265358979323846264338327950288419716939937510582097494459230 7816
4062862089986280348253421170679821480865132823066470938446095505 8223172
535940812848111745028410270193852110555964462294895493038196442881097 56
6593344612847564823378678316527120190914564856692346034861045432664 8213
393607260249141273724587006606315588174881520920962829254091715364367 89
25903600113305305488204665213841469519415116094330572703657595919530921
861173819326117931051185480744623799627495673518857527248912279381830 11
94912983367336244065664308602139494639522473719070217986094370277053921
717629317675238467481846766940513200056812714526356082778577134275778 96
091736371787214684409012249534301465495853710507922796892589235420 19956
11212902196086403441815981362977477130996051870721134999999837297804995
1059731732816096318595024459455346908302642522308253344685035261931188 1
71010003137838752886587533208381420617177669147303598253490428755468731
15956286388235337875937519577818577805321712268066130019278766111959090921
6420199 3.141592653589793238462643383279502884197169399375105820974944 5
923078164062862089986280348253421170679821480865132823066470938446095 5
0582231725359408128481117450284102701938521105559644622948954930381964
42881097566593344612847564823378678316527120190914564856692346034861 04
5432664821339360726024914127372458700660631558817488152092096282925409
17153643678925903600113305305488204665213841469519415116094330572703 65
7595919530921861173819326117931051185480744623799627495673518857527248
91227938183011949129833673362440656643086021394946395224737190702179 86
094370277053921717629317675238467481846766940513200056812714526356082 7
785771342757789609173637178721468440901224953430146549585371050792279 6
89258923542019956112129021960864034418159813629774771309960518707211 34
999999837297804995105973173281609631859502445945534690830264252230825 3
344685035261931188171010003137838752886587533208381420617177669147303 5
982534904287554687311595628638823537875937519577818577805321712268066 1
300192787661119590921642019993.141592653589793238462643383279502884 1971
6939937510582097494459230781640628620899862803482534211706798214808651
32823066470938446095505822317253594081284811174502841027019385211055 59
644622948954930381964428810975665933446128475648233786783165271201909 1
45648566923460348610454326648213393607260249141273724587006606315588 17
```

```
4881520920962829254091715364367892590360011330530548820466521384146951
9415116094330572703657595919530921861173819326117931051185480744623799
6274956735188575272489122793818301194912983367336244065664308602139494
6395224737190702179860943702770539217176293176752384674818467669405132
0005681271452635608277857713427577896091736371787214684409012249534301
4654958537105079227968925892354201995611212902196086403441815981362977
4771309960518707211349999998372978049951059731732816096318595024459455
3469083026425222308253344685035261931188171010003137838752886587533208
8142061717766914730359825349042875546873115956286388235378759375195778
1857780532171226806613001927876611195909216420199.31415926535897932384
6264338327950288419716939937510582097494459230781640628620899862803482
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5488204665213841469519415116094330572703657595919530921861173819326117
9310511854807446237996274956735188575272489122793818301194912983367336
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