Using stigmergy as a computational memory in the design of recurrent neural networks

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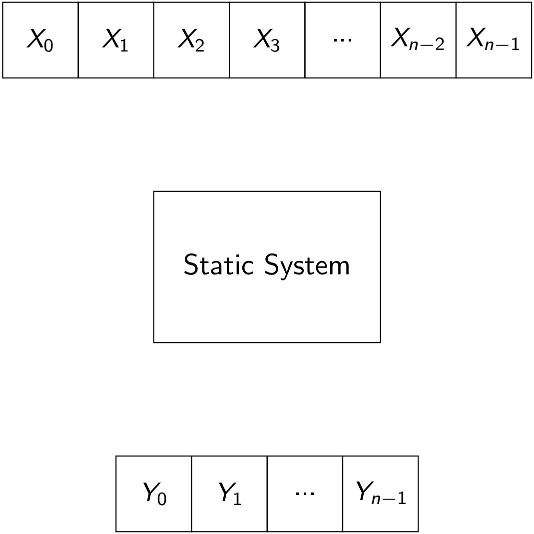
20 February 2019

Time-Series Static Classification



- MLP
- CNN
- ...

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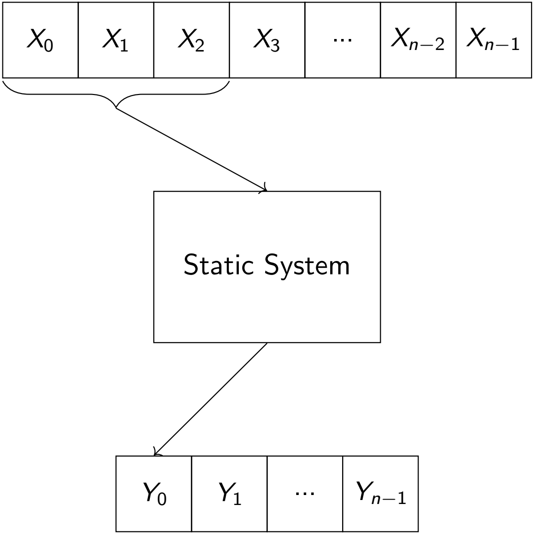

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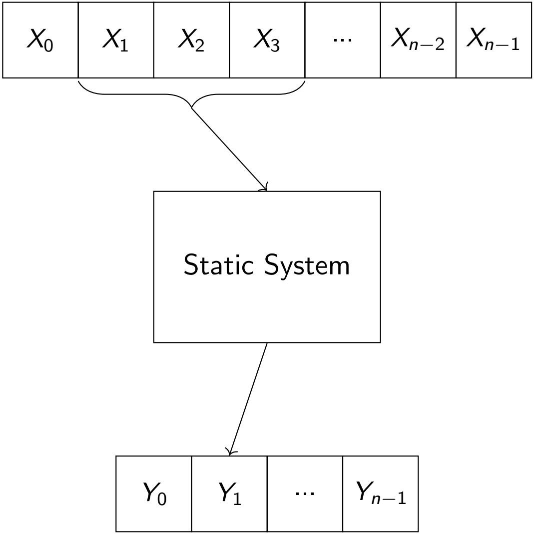

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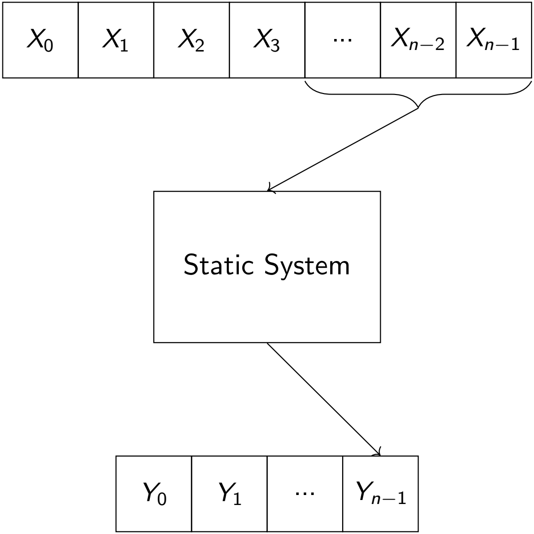
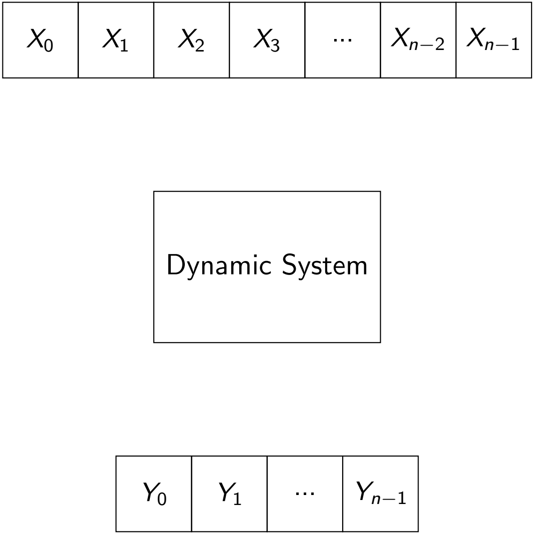


Time-Series Static Classification

- ✓ You can use any existing ML Architecture
- × Window size choice
- × Long-lived relationships are impossible to infer

Time-Series Dynamic Classification

- RNN
- LSTM
- ...



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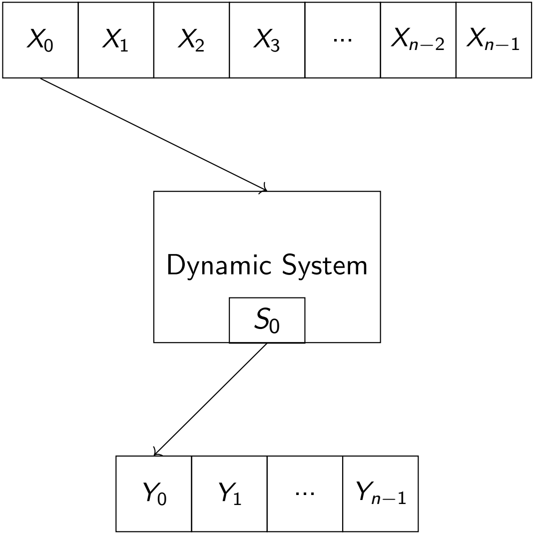

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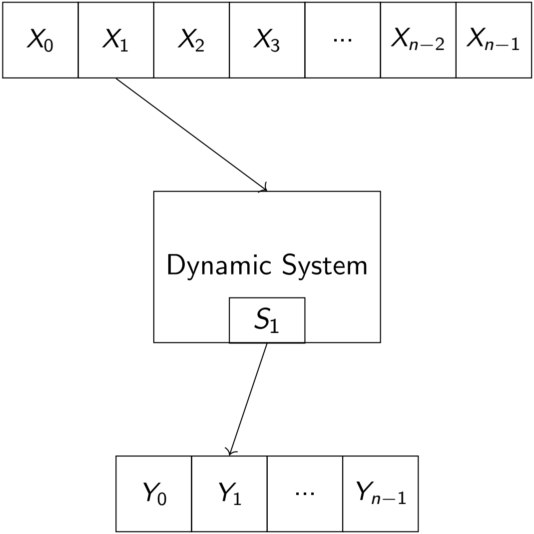
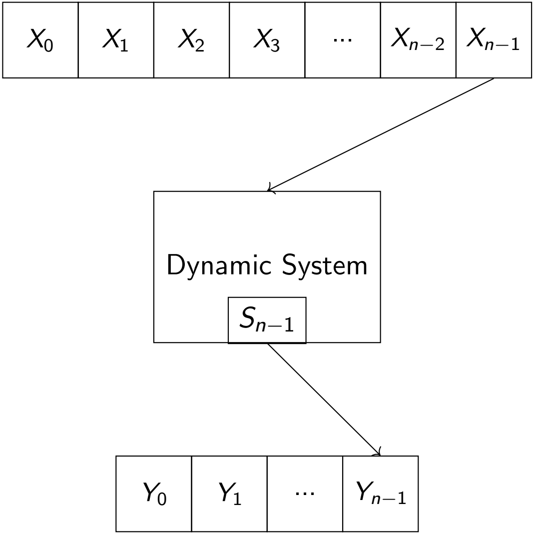


Time-Series Dynamic Classification



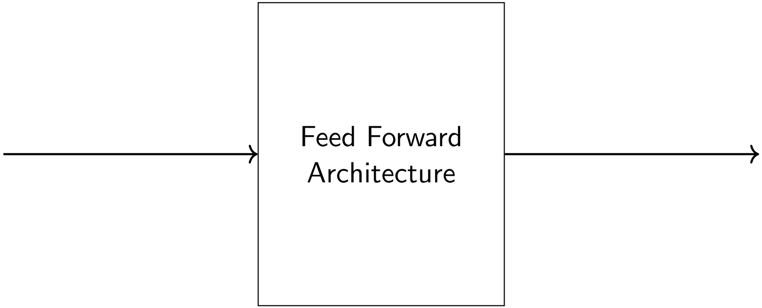
- RNN
- LSTM
- ...

Time-Series Dynamic Classification

- ✓ The system knows the concept of time
- ✓ Can autonomously decide what to remember and forget
- × Ad-Hoc solutions
- × Highly engineered

RNN $\neq$ LSTM

- RNN and LSTM are often used as synonyms in literature
- Has been proven that "Vanilla recursion" performs poorly
- LSTM are the state of the art for Time Series Classification



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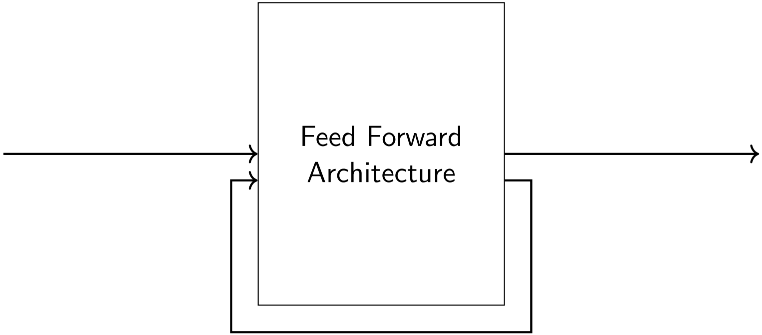

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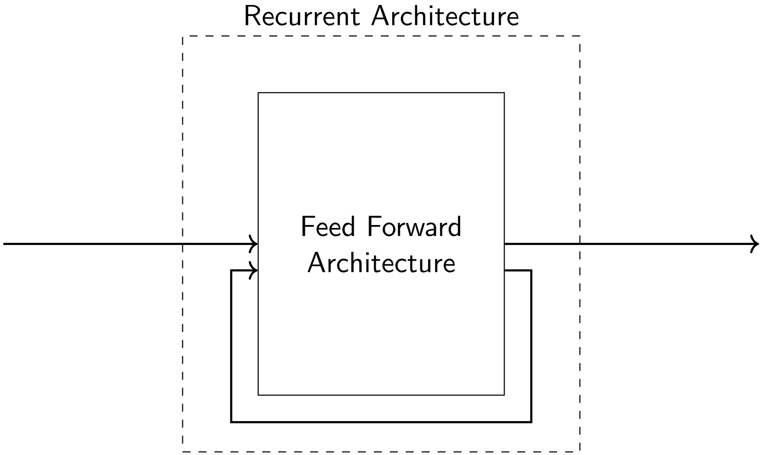
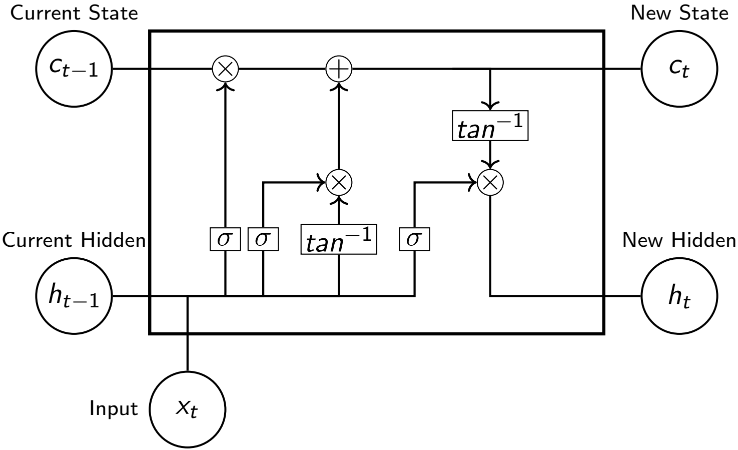


A deep look inside an LSTM cell



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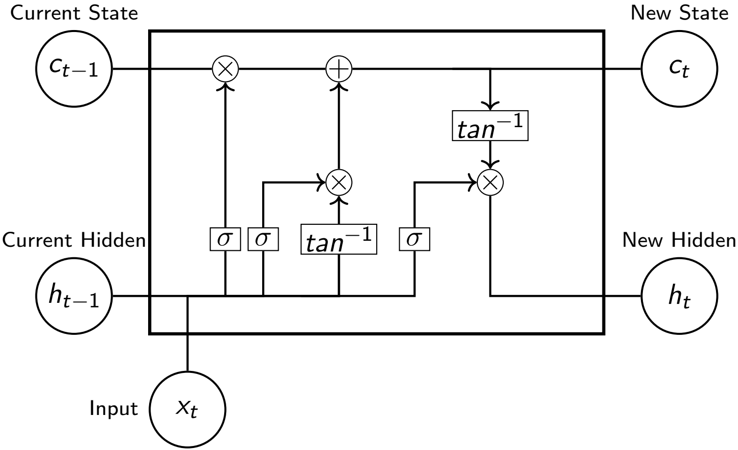

- $f_t = \sigma(W_f x_t + U_f h_t + b_f)$

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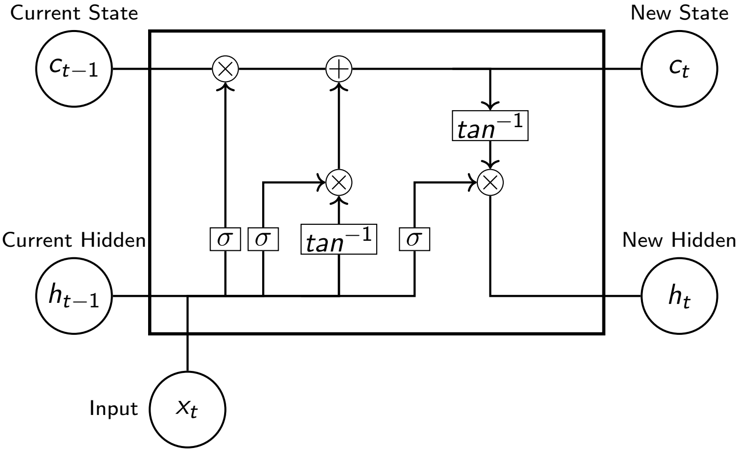

- $f_t = \sigma(W_f x_t + U_f h_t + b_f)$
- $i_t = \sigma(W_i x_t + U_i h_t + b_i)$

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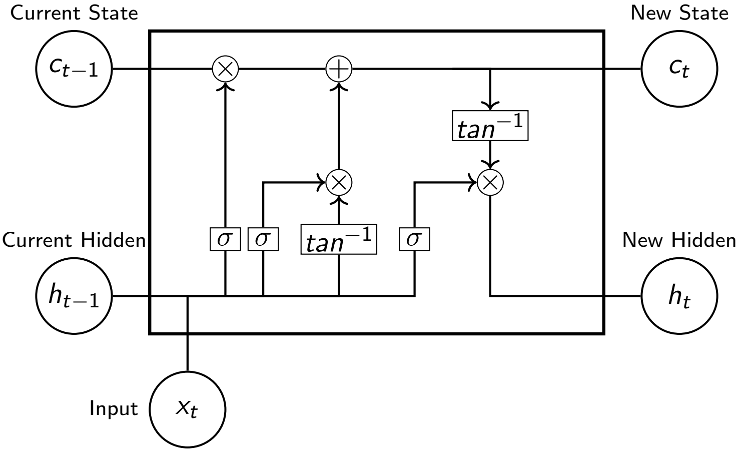

- $f_t = \sigma(W_f x_t + U_f h_t + b_f)$
- $i_t = \sigma(W_i x_t + U_i h_t + b_i)$
- $i_c = tan^{-1}(W_c x_t + U_c h_t + b_c)$

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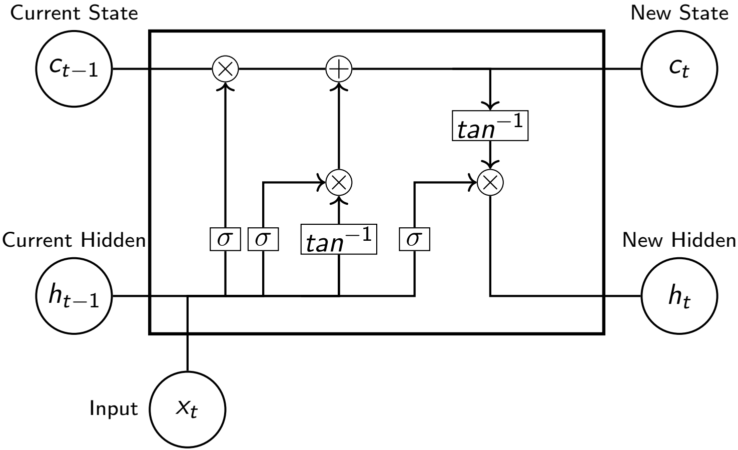

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- $c_t = f_t \circ c_{t-1}$

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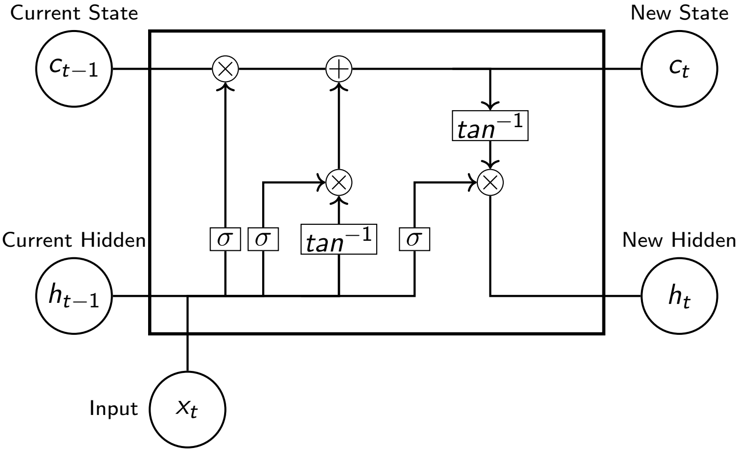

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- $i_c = tan^{-1}(W_c x_t + U_c h_t + b_c)$
- $c_t = f_t \circ c_{t-1} + i_t \circ i_c$

A deep look inside an LSTM cell

- $f_i = \sigma(W_f x_i + U_f h_{i-1} + b_f)$
- $i_i = \sigma(W_i x_i + U_i h_{i-1} + b_i)$
- $o_i = \sigma(W_o x_i + U_o h_{i-1} + b_o)$
- $c_i = \sigma(f_i \circ c_{i-1} + i_i \circ tan^{-1}(W_c X_i + U_c h_{i-1} + b_c))$
- $h_t = o_i * tan^{-1}(c_i)$

Using

- $W_f,\ W_i,\ W_o,\ W_C \in R^{n \times h}$
- $U_f,\ U_i,\ U_o,\ U_c \in R^{h \times h}$
- $b_f,\ b_i,\ b_o,\ b_c \in R^h$

A deep look inside an LSTM cell

- $f_i = \sigma(W_f x_i + U_f h_{i-1} + b_f)$
- $i_i = \sigma(W_i x_i + U_i h_{i-1} + b_i)$
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Can we do better?

A deep look inside an LSTM cell

- $f_i = \sigma(W_f x_i + U_f h_{i-1} + b_f)$
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- $h_t = o_i * tan^{-1}(c_i)$

Using

- $W_f,\ W_i,\ W_o,\ W_C \in R^{n \times h}$
- $U_f,\ U_i,\ U_o,\ U_c \in R^{h \times h}$
- $b_f,\ b_i,\ b_o,\ b_c \in R^h$

Can we do better?

Can we do **simpler**?

Let's take a step back

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- Complex behaviors can **emerge** from simple ones
- Emergence is a key phenomenon in nature
- **Stigmergy** is one of the tools nature uses to achieve emergence

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- Complex behaviors can **emerge** from simple ones
- Emergence is a key phenomenon in nature
- **Stigmergy** is one of the tools nature uses to achieve emergence

Can we **emerge** a computational memory using the **stigmergy**?

Biological Stigmergy

Implemented in nature via pheromonic marks

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Mark

Biological Stigmergy

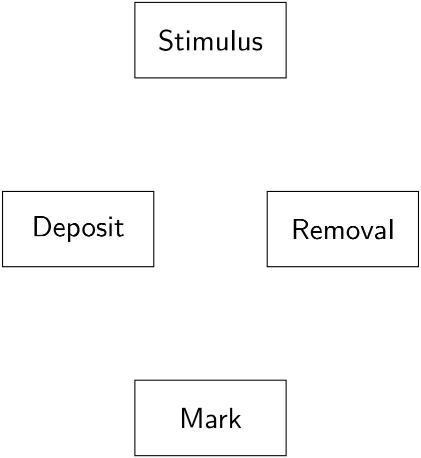
Implemented in nature via pheromonic marks

Stimulus

Mark

Biological Stigmergy

Implemented in nature via pheromonic marks



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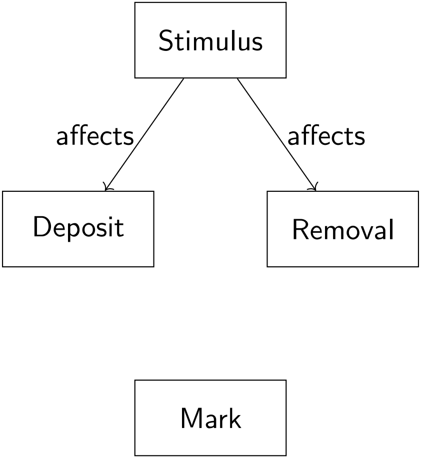

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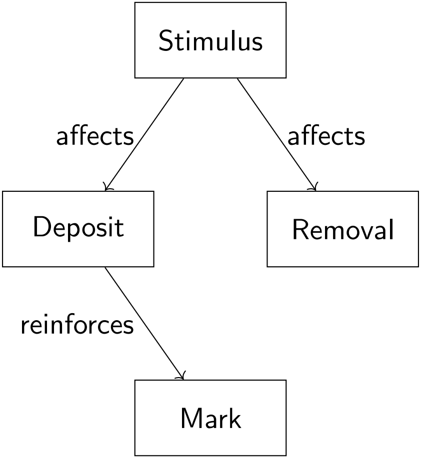

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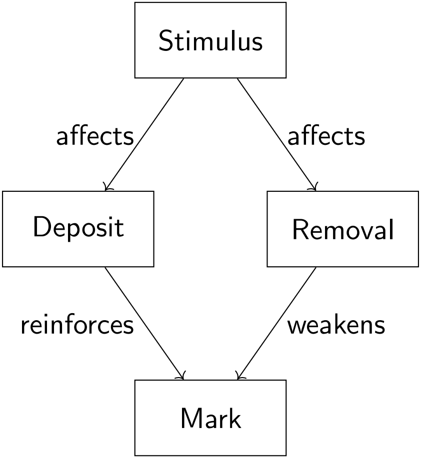

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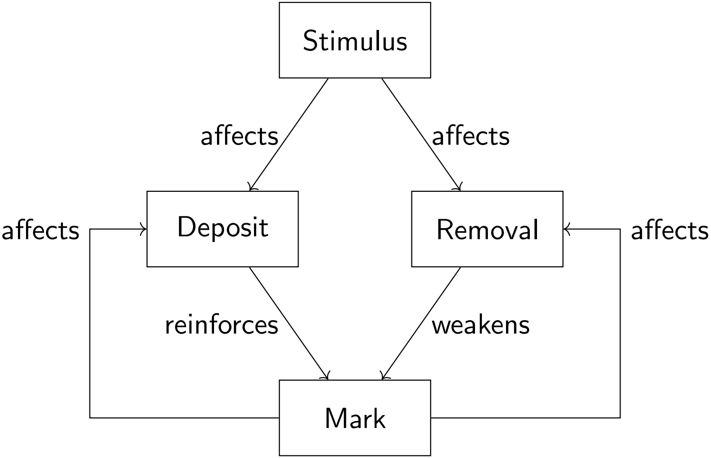
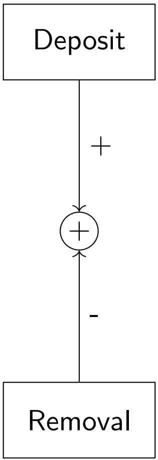


Computational Stigmergy

Deposit

Removal

Computational Stigmergy



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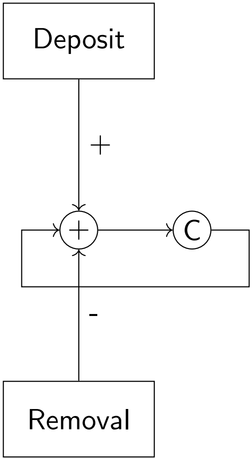

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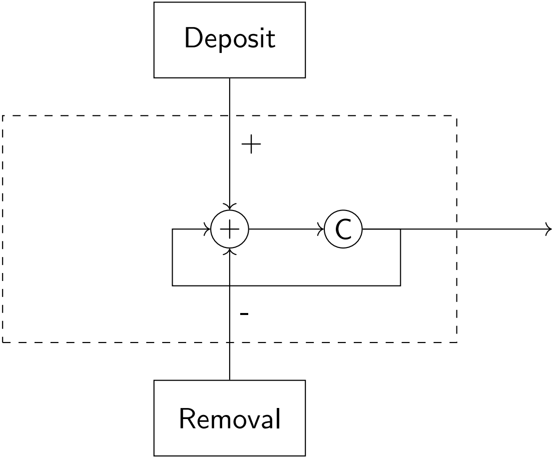

Stigmergic Memory Neural Network