Reservoir dynamics: Feedback and chaos in the network solution of a complex cognitive task

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Introduction

- Recently, recurrent microcircuits have been used to learn complex temporal computations.
- However, the effect of feedback and chaos is still poorly understood.
- Using a challenging temporal task, we show how they contribute to the performance and their effect on the network's behaviour.

Model



RLS learning [3]:

$\min_{\mathbf{W}_{out}} E = \sum_{t}$	$\mathbf{V}(\mathbf{W}_{\mathbf{out}}(t)\mathbf{r}(t) - \mathbf{W}_{\mathbf{out}}(t)\mathbf{r}(t))$	$\mathbf{y}_{target}(t))^2$
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 $\mathbf{e}_{-}(t) = \mathbf{W}_{\mathbf{out}}(t - \Delta t)\mathbf{r}(t) - \mathbf{y}_{target}(t)$

 $\mathbf{W}_{out}(t) = \mathbf{W}_{out}(t - \Delta t) - \mathbf{e}_{-}(t)\mathbf{P}(t)\mathbf{r}(t) \qquad \mathbf{P}(t) = \mathbf{P}(t - \Delta t) - \frac{\mathbf{P}(t - \Delta t)\mathbf{r}(t)\mathbf{r}^{T}(t)\mathbf{P}(t)}{1 + \mathbf{r}^{T}(t)\mathbf{P}(t - \Delta t)\mathbf{r}(t)}$

	Echo State Network	Liquid State Machine	FORCE
reference	[1]	[2]	[3]
neurons	analog	binary	analog
connectivity	random	structured	random
dynamics	stable	stable	chaotic
memory	$O(\sqrt{N})$ [7]	$O(\log N)$?

Task



- Hierarchical memory task: 12AX task [4, 5]
- In '1', respond for 'X' following a 'A'. In '2', respond for 'Y' following a 'B'.
- Identification of context critical
- Also consider shaping subtasks



- Network solves the shaping subtask perfectly.
- But Full 12AX task isn't solved properly.

12AX:	feedback		Error patterns	% errors	coverage
errors/epoch	weak	strong	$1 \cdot BY / 2 \cdot AX$	11.15	7.0 /1000
non	6.68	6.4	$1 \cdot AX \cdot BY$	7.7	6.5 /1000
chaotic			$2 \cdot AX \cdot BY$	7.5	6.1 /1000
chaotic	6.31	5.2	$2 \cdot BY \cdot AX \cdot BY$	4.4	2.4 /1000

Memory capacity



- Important measure of context memory stability and outer loop size
- Feedback stabilises memory
- Slow decay of non-chaotic reflects variety of nonlinearity work points.
- Chaos increases period of efficient recall, but reduces the stability.



• PCA analysis of reservoir activation reveals memory-state separation and feedback effect.





Computation is still localised in space.



Multiscale network

- Build a network operating with distinct multiple timescales.
- Helps with the conflicting memory scales needs of the 12AX task.



Conclusions

- Networks with temporal dynamics can solve shaping subtask, yet fail on full task
- Feedback increases relevant state separation
- Chaos improves transient memory storage
- Test case for dimensionality reduction
- 12AX Task requires multiple processing timescales, further work

References

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