Modulation of early visual processing alleviates capacity limits in solving multiple tasks

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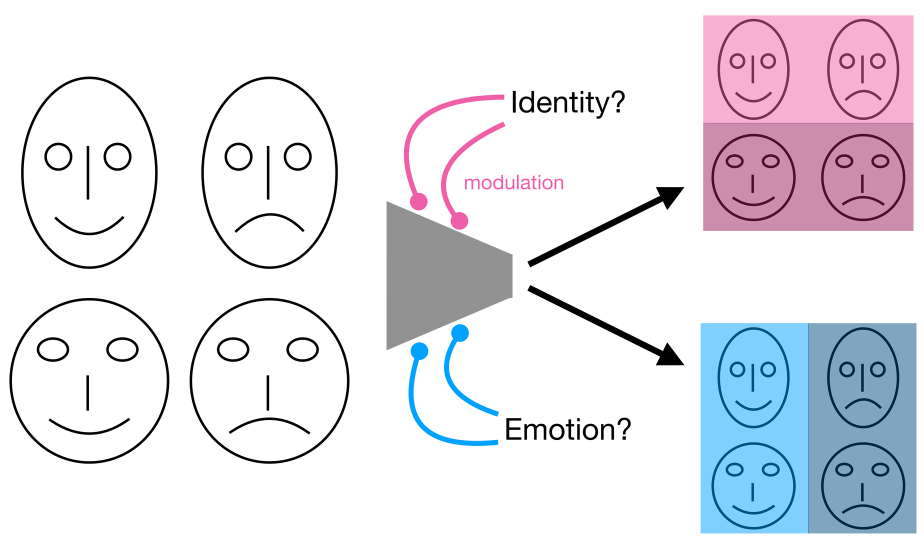
INTRODUCTION

In a multi-task scenario, extracting features common to all tasks might not always be possible.

❖ Modulating early visual processing can allow early selection of task-relevant information (Gilbert & Li, 2013)



When could early modulation be beneficial, *in addition to late modulation,* in a neural network? (i.e. overcome its wiring cost)

When there are **capacity limits**, caused by e.g.:

❖ Small number of neurons in the network

❖ Large number of tasks the network has to perform

Are the advantages of early modulation dependent on a neural network's capacity limits?

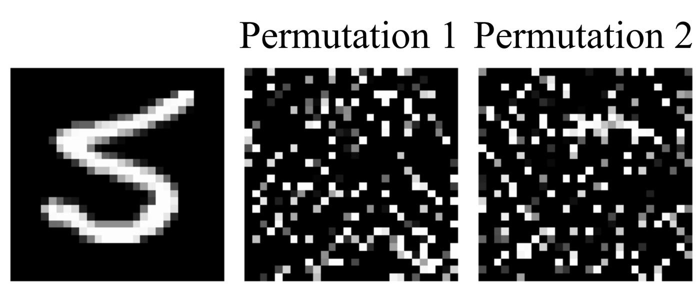
METHODS

PROBLEM DESCRIPTION

Object detection as multiple one vs. all classification tasks

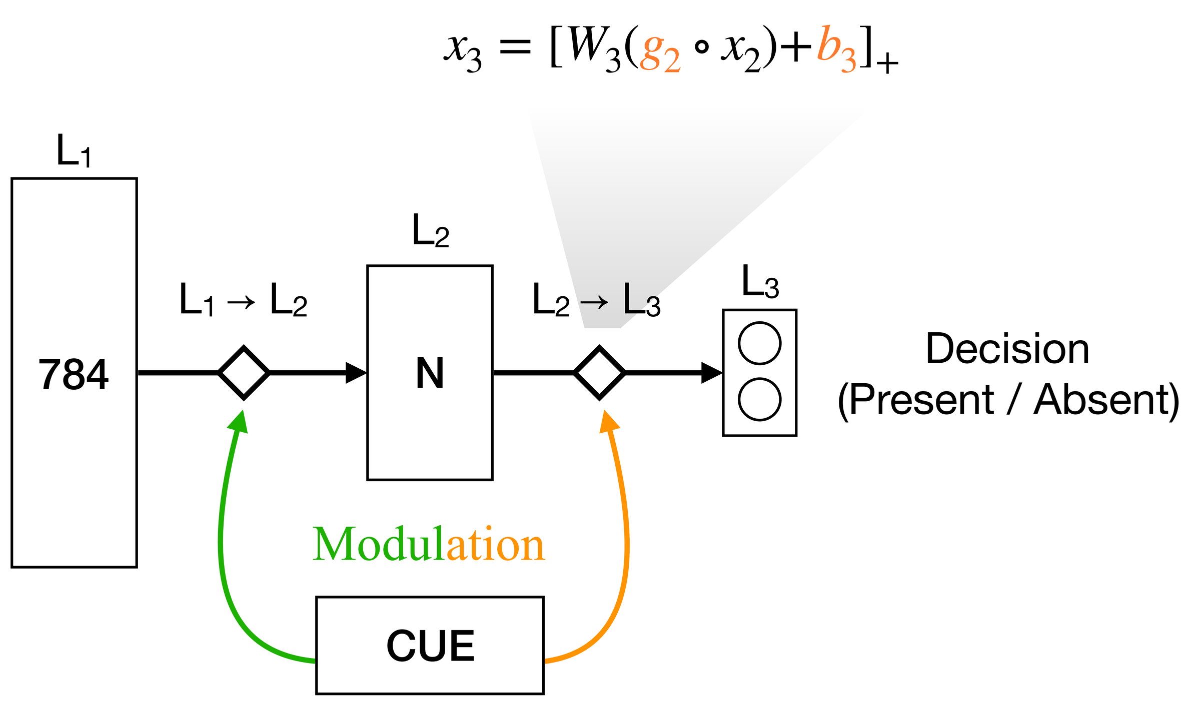
(*is this object present/absent?*)

- Objects: MNIST digits and their permutations



NETWORK DESCRIPTION

$$x_3 = [W_3(g_2 \circ x_2)+b_3]_+$$



- MLP with one hidden layer
- Variable number of units (N) in the hidden layer
- One-hot cue indicates the task (which digit to detect)
- Cue modulates transformations via bias and gain
- Main network and modulation are **trained jointly**
- **Cue either modulates only the late or both early & late transformations**

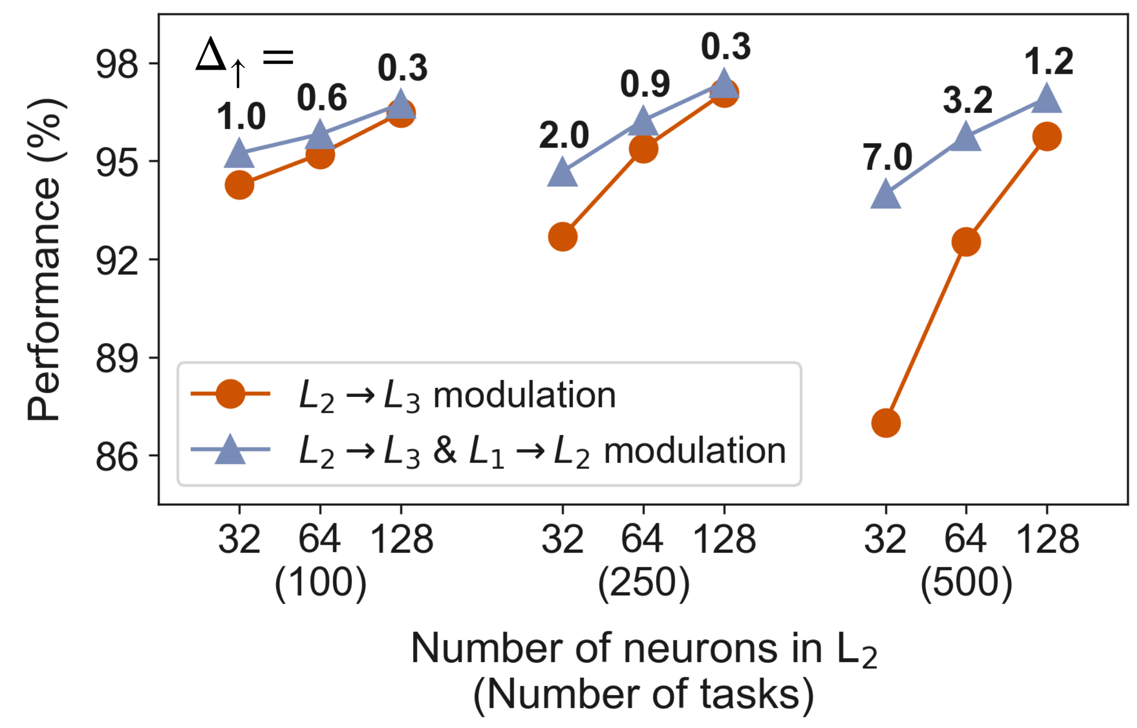
EXPERIMENTAL MANIPULATION

How does the detection performance boost provided by the addition of early modulation vary with the number of tasks and units in the network?

Main contrast: modulating early & late neural processing (**$L_1 \rightarrow L_2$ & $L_2 \rightarrow L_3$**) vs. modulating late only (**$L_2 \rightarrow L_3$**)

- Measure of interest: detection performance
- Manipulation: number of tasks (100, 250, 500), and number of units in the hidden layer (32, 64, 128)

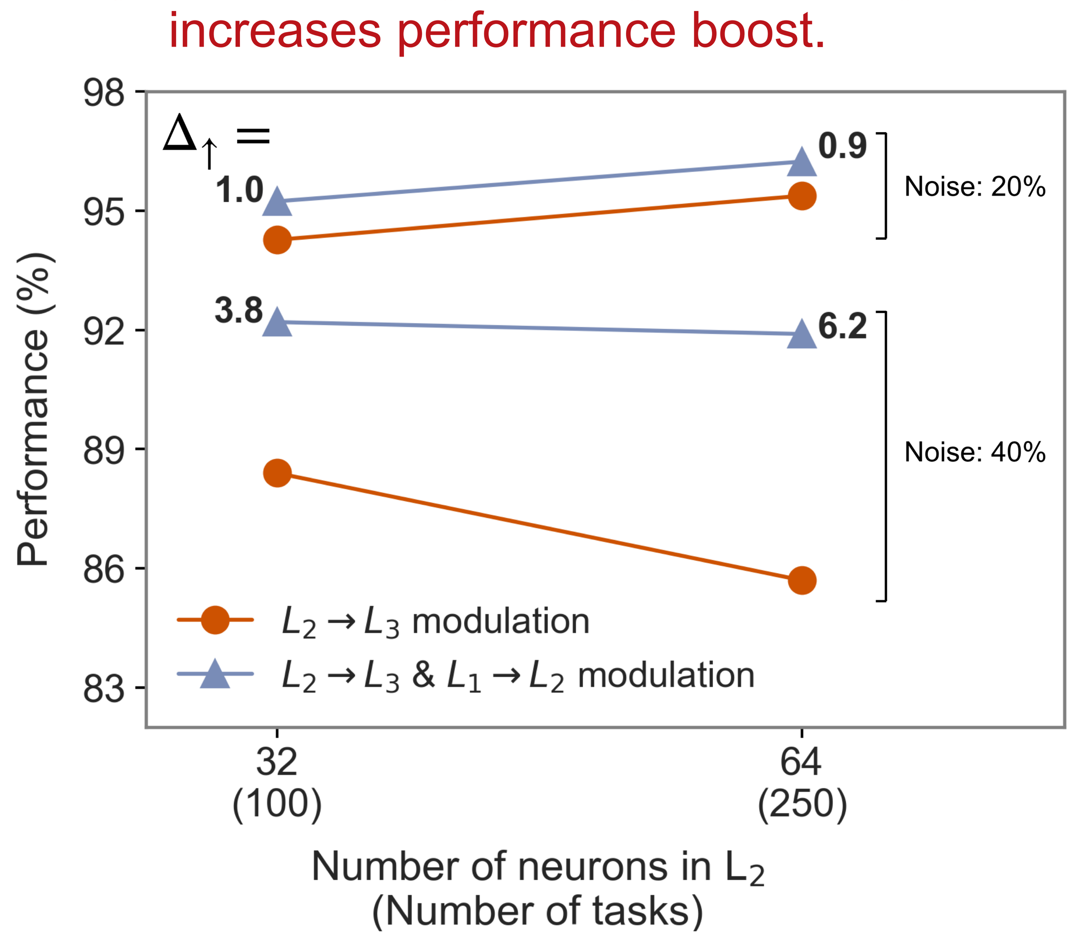
RESULTS



The performance boost provided by additionally modulating early processing is

- ***directly*** **proportional to the number of tasks**
- ***inversely*** **proportional to number of units in hidden layer**

Increasing **task difficulty** (adding noise to digits) also increases performance boost.



Bias modulation does not aid performance on top of gain modulation.

e.g. Network (32 units, 25 tasks, early+late) trained with:

- gain only modulation: 94.8%
- bias only modulation: 90.9%
- bias & gain modulation: 94.7%

CONCLUSIONS

Modulation of early neural processing increases multi-tasking performance in conditions of limited network capacity.

❖ Capacity limits can be a result of there being limited number of neurons in the network and/or too many (difficult) tasks.

❖ Is this the role of early sensory modulation in biological brains?

❖ Forgoing wiring costs in favour of optimality?

Further work should look at more natural datasets and tasks:

❖ Permuted-MNIST limits the sharing of early visual features

❖ In a naturalistic dataset (CIFAR, ImageNet) the effect of early modulation might be different because low-level features are shared across categories

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