Flexible inter-areal computations through low-rank communication subspaces

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Motivation

We can respond differently to similar stimuli in **different contexts** with remarkable flexibility. Understanding how different brain regions cooperate to flexibly weed out irrelevant stimuli is crucial to elucidate the neural mechanisms involved in this behavioural feat. The **communication subspace** hypothesis is particularly promising to shed light to this question, in particular if combined with **low-rank RNNs**.

Summary

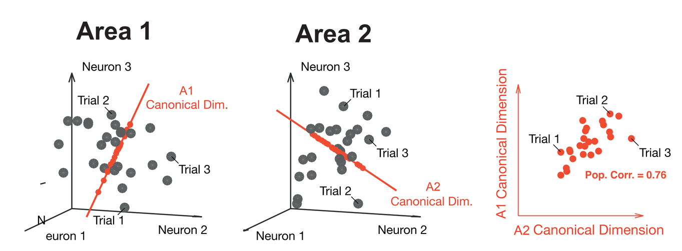
1. We found that **A1 represented both relevant and irrelevant** stimuli, but **within different subspaces**. On the other hand, PFC exclusively encoded relevant features, along one axis.

2. Recurrent neural networks (RNN) trained with back-propagation showed neural dynamics similar to those observed in A1. Reverse-engineering these networks **predicted a specific population structure** supporting these computations, with individual populations in A1, but not in PFC, gating the relevant stimuli in its preferred context.

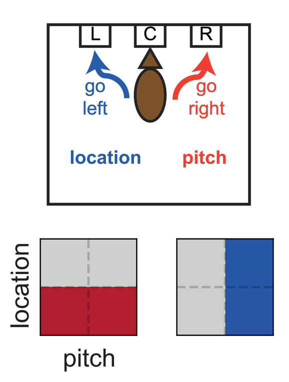
3. We modeled our empirical findings in a two-area RNN, representing A1 and PFC, as well as their potential interaction through low-rank communication subspaces. Our model is the **first neural implementation of the communication subspace hypothesis**.

Methods

Comunication subspace hypothesis



Dataset

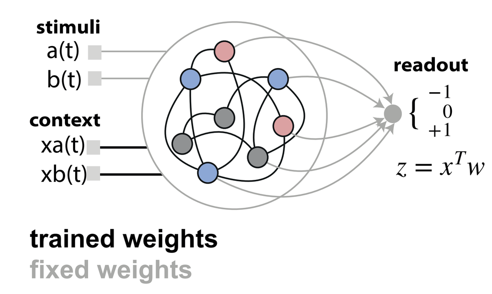


n=6 performing a context dependent task (pitch vs location)

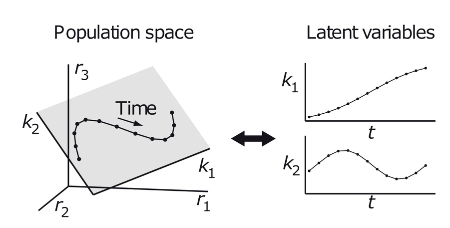
Non-simultaneous single-units recording from:
A1 (n=130)
mPFC (n=131)

data from Rodgers and deWeese, Neuron (2014)

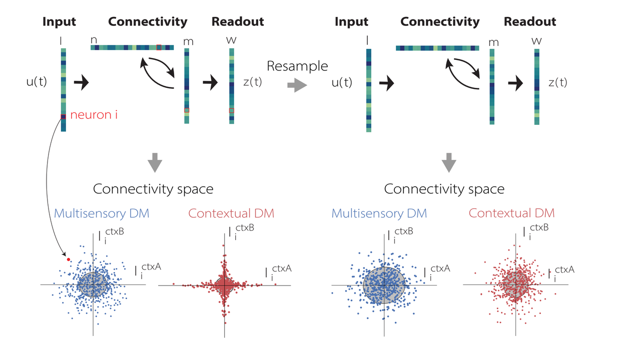
Low-rank RNN primer



High- to low-dimensional map



Mastrogiuseppe & Ostojic, Neuron 2017
Dubreuil, Valente et al., bioRxiv 2022
Beiran et al. Neural Computation, 2021



1. Rank of J determines the number of latent variables

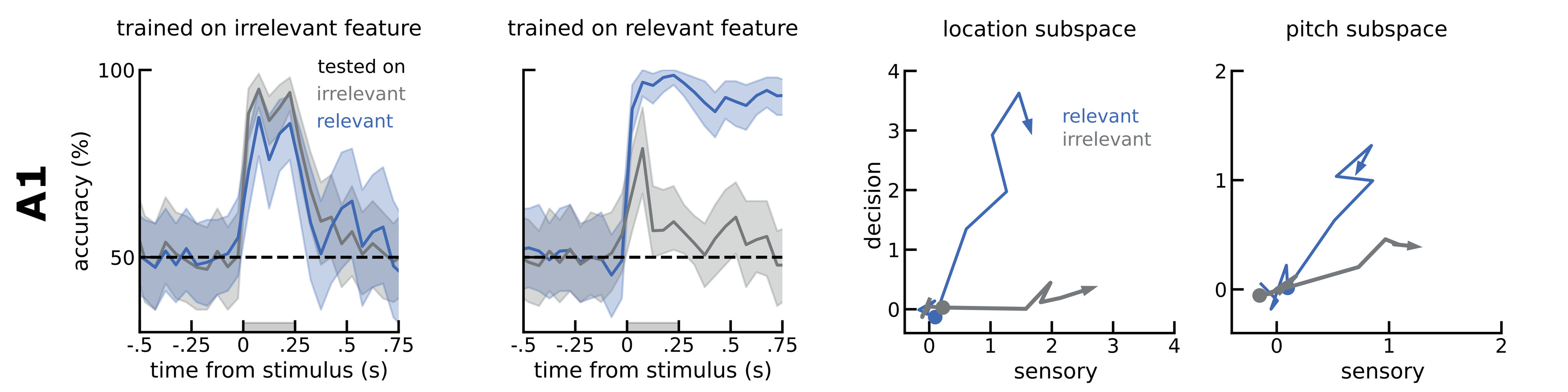
2. Correlations σ between connectivity vectors define the computations on the latent variables

3. Different populations with different correlations, allow for flexible computations on the latent variables

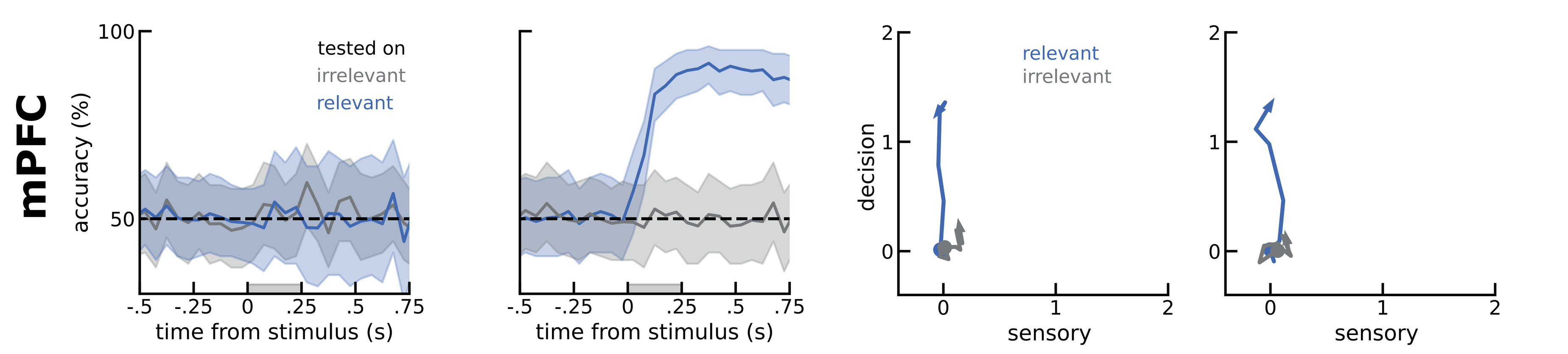
$$\dot{x} = -x + \frac{1}{N} mn^T \phi(x) + \sum_i v_i(t) I_i \quad \longleftrightarrow \quad \dot{\kappa} = -\kappa + \sum_p \tilde{\sigma}^p_{nm} \kappa + \tilde{\sigma}^p_{nI} v(t)$$

1. Relevant stimuli are integrated along an additional axis

irrelevant decoders work well on irrelevant and relevant trials — *relevant decoder stronger in relevant than irrelevant trials* — *common axis across contexts (sensory), but decision integrated only in relevant context*



irrelevant stimuli are not encoded in PFC — *activity along only one axis (decision)*

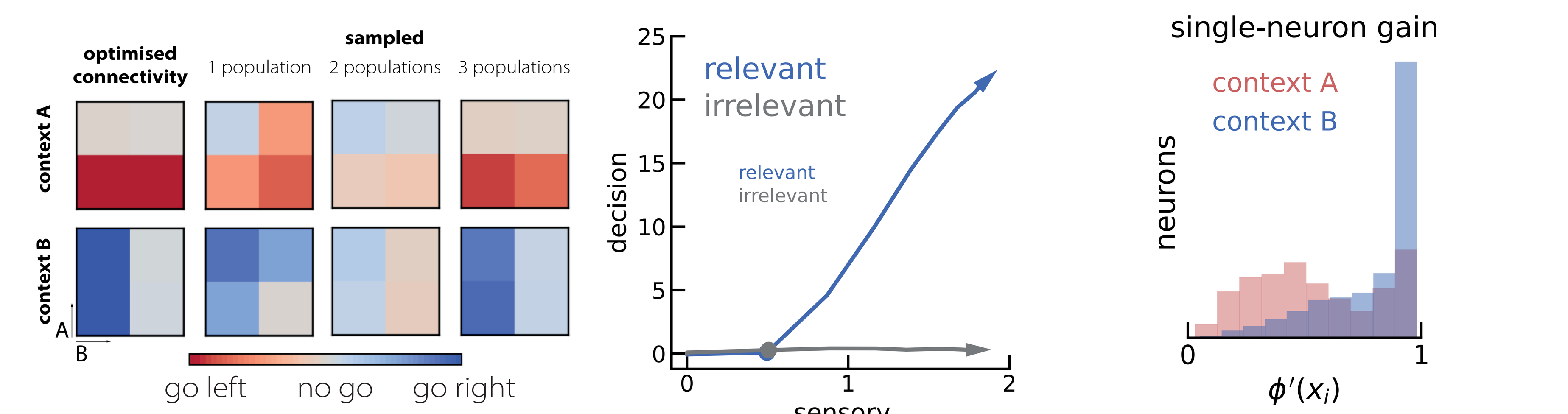


context encoded in both areas, Rodgers & deWeese, Neuron (2014)

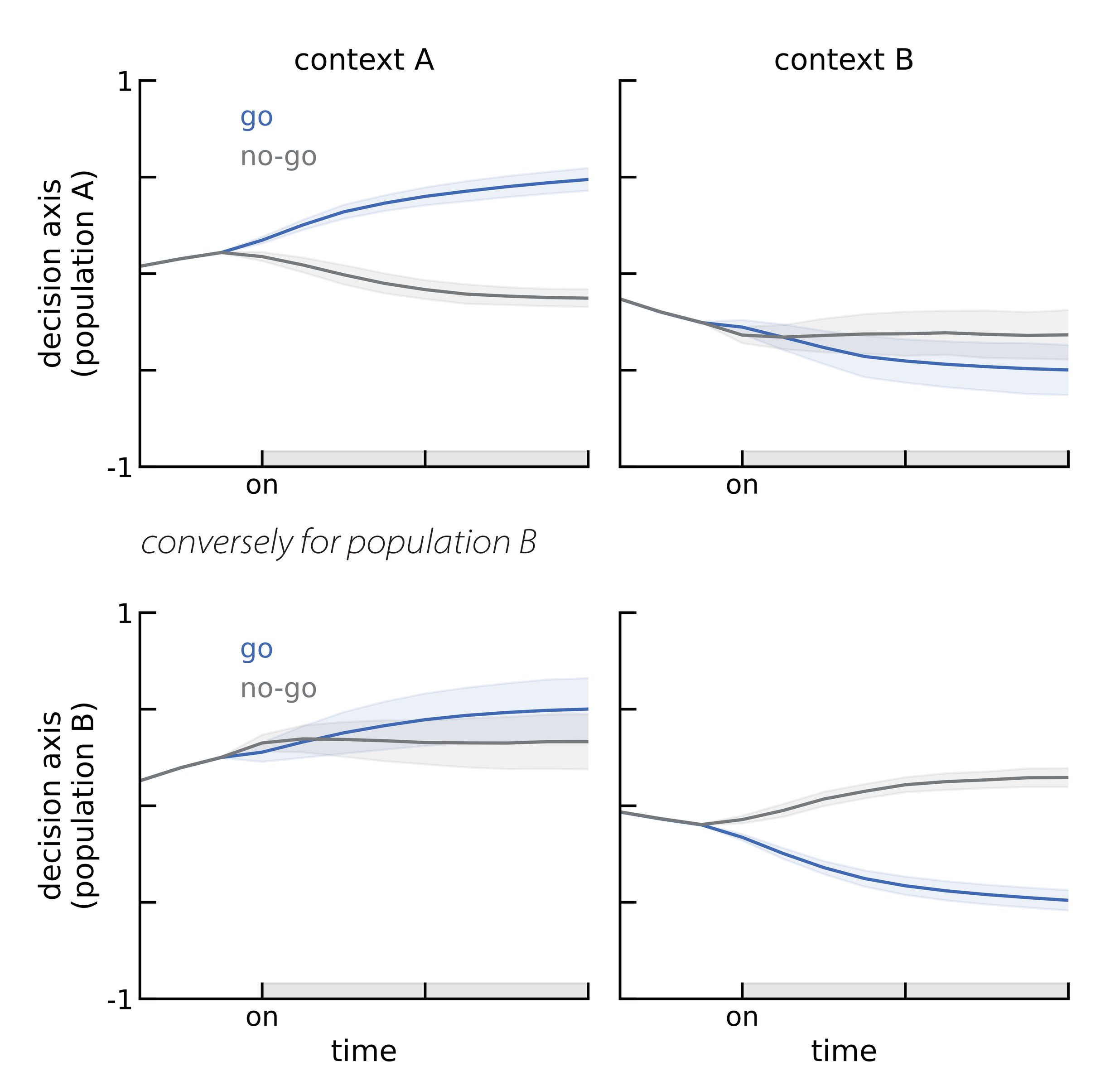
→ ***Question:*** *How does A1 selectively integrate the relevant stimulus?*

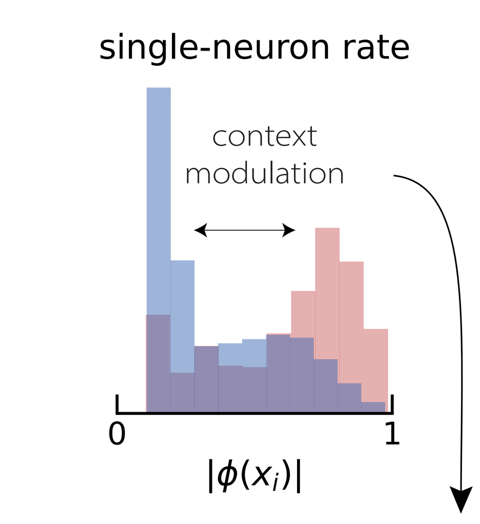
2. Trained RNNs predict that population gating supports flexible integration of relevant stimuli in A1.

3 populations are necessary for high performance context-dependent behavior — *both stimuli are represented and integrated into decision if relevant* — *population B (A) has low gain in context A (B)*

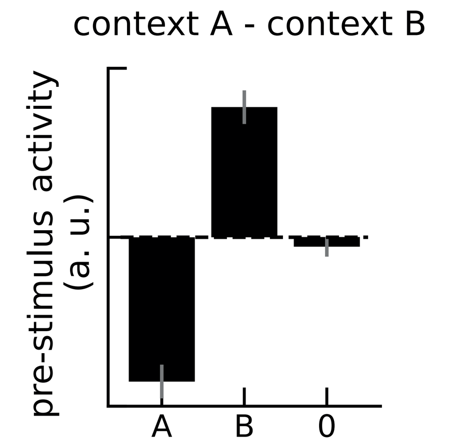


population A integrates the relevant stimuli in context A — *population A is silent in context B* — *gain modulation reflected in prestimulus acti vity modulation*





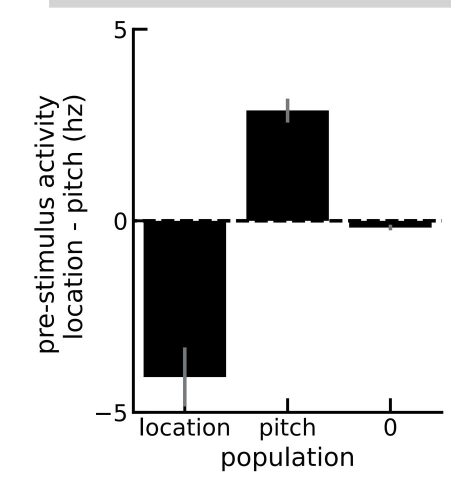
model prediction: *populations identified by pre-stimulus activity*

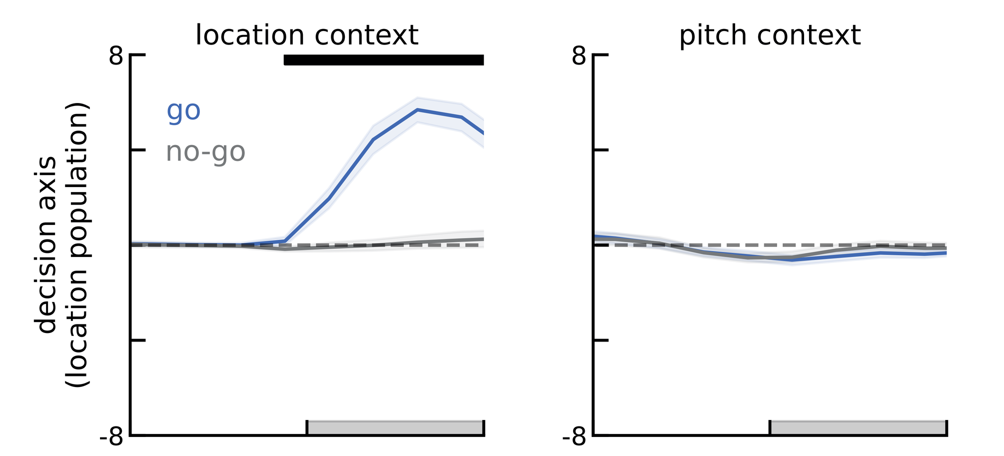


DATA

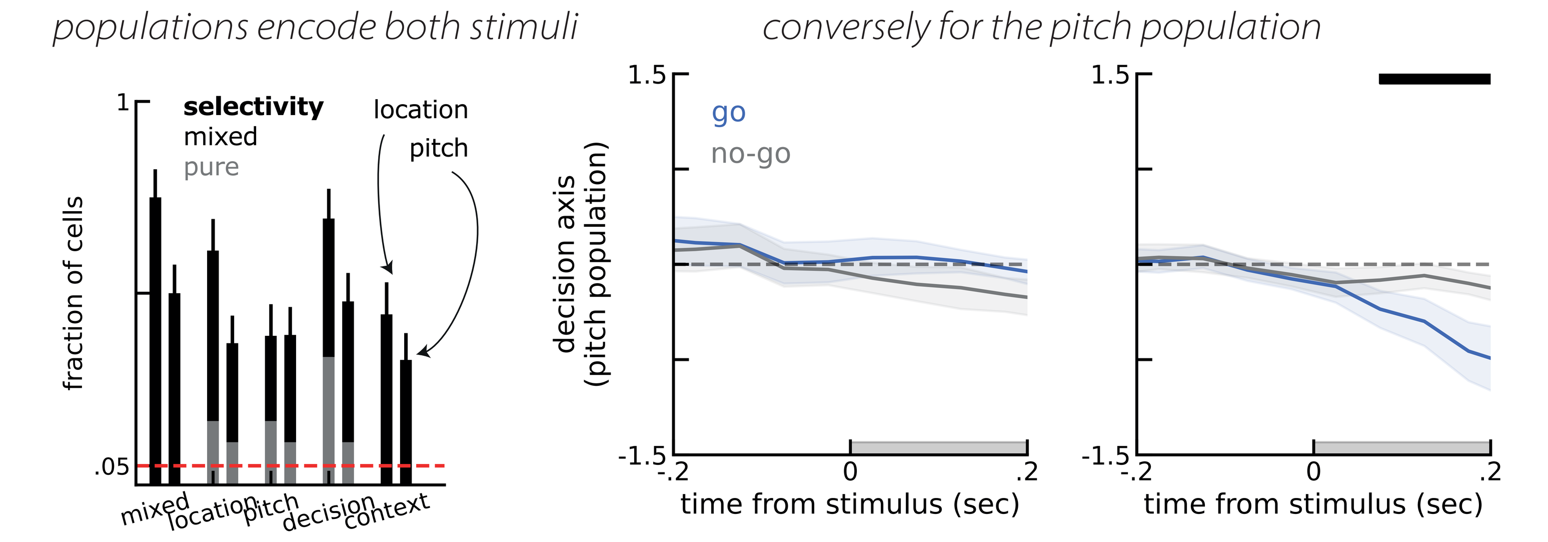
3. Pre-stimulus activity reveals a subpopulation structure in A1, as predicted by the trained RNNs.

model prediction: *populations identified by pre-stimulus activity* — *location population integrates the relevant stimuli in the location context* — *location population is silent in the pitch context*





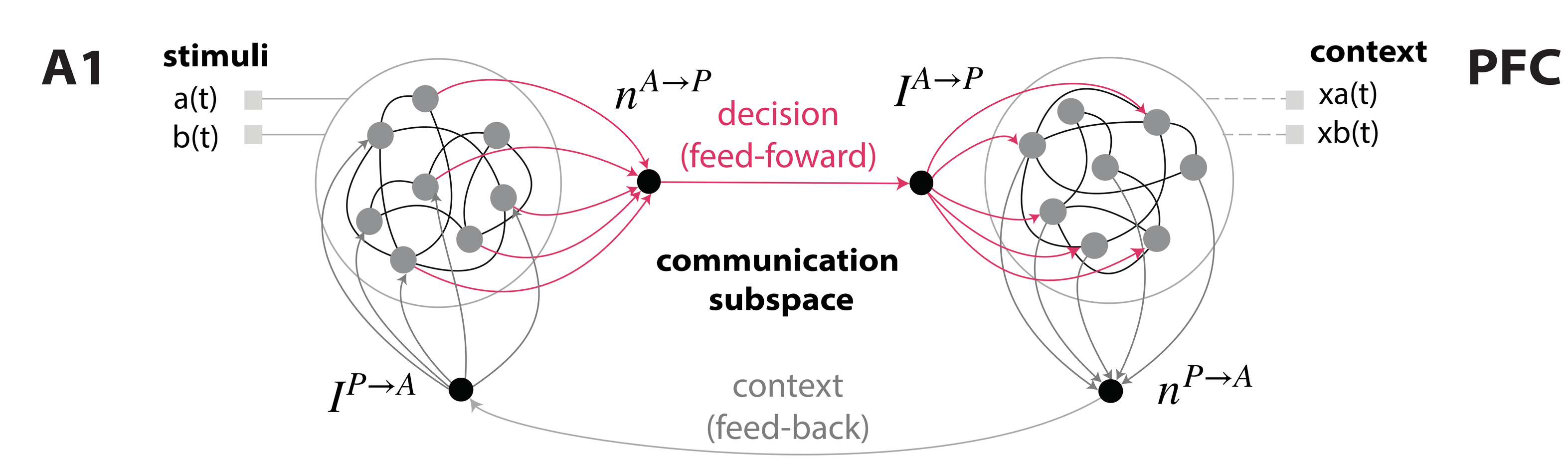
populations encode both stimuli — *conversely for the pitch population*



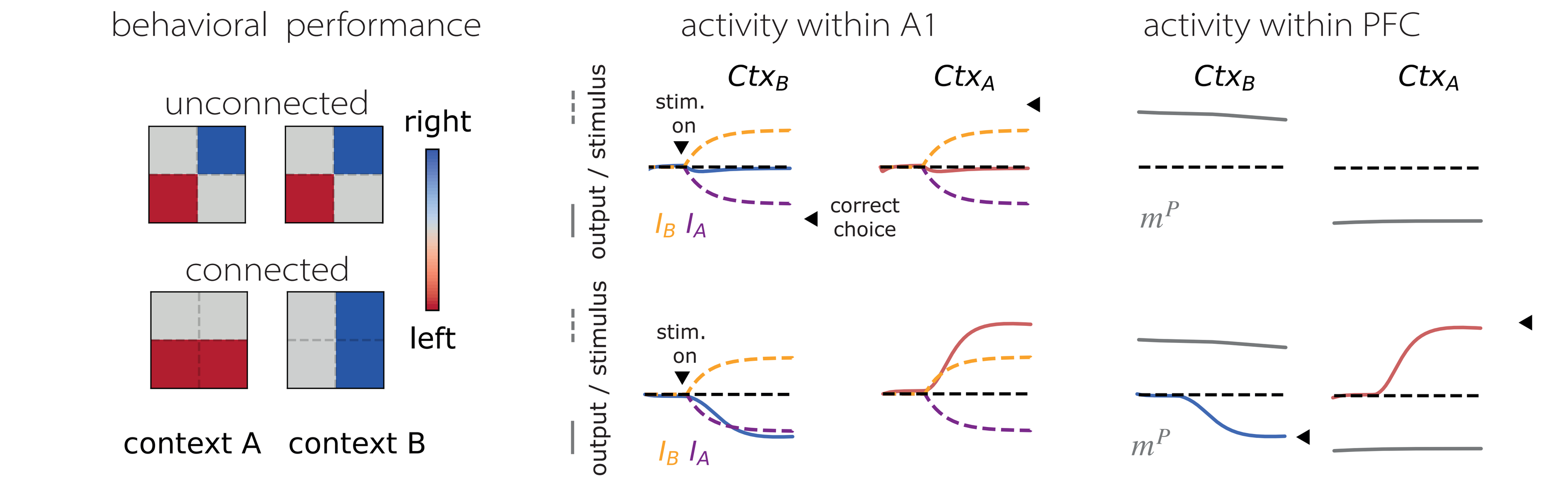
MODEL

4. Computations through communication subspaces in a multi-area model

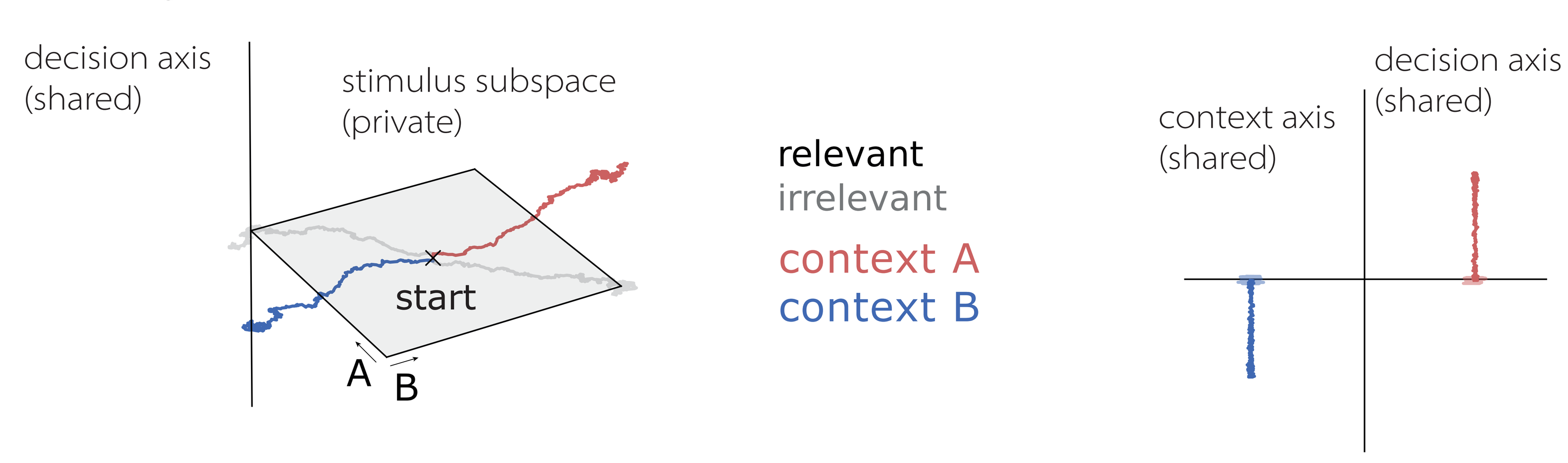
→ ***Question:*** *Can context stored in PFC drive selective gating in A1?*



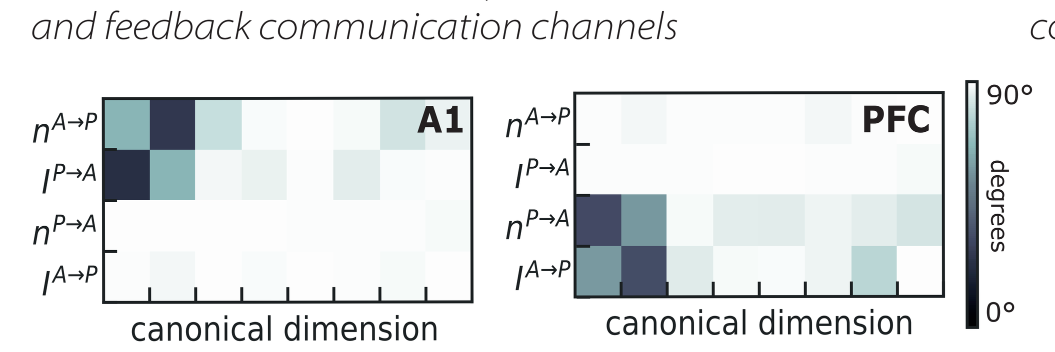
unconnected networks cannot perform context-dependent computations, but connected do

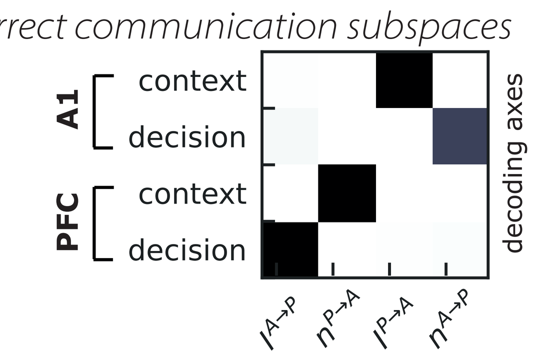


A1 *integrates relevant stimulus* — **PFC** *stores current context in WM*



Cannonical correlation analyses mixes feedforward and feedback communication channels — *LDA of task variables estimates the correct communication subspaces*





References

Dubreuil, Valente et al. The role of population structure in computations through neural dynamics. bioRxiv, 2021, 10.1101/2020.07.03.185942
Mante, Susillo et al. Context-dependent computation by recurrent dynamics in prefrontal cortex. Nature, 2013, 10.1038/nature12742
Rodgers & deWeese. Neural correlates of task switching in prefrontal cortex and primary auditory cortex in a novel stimulus selection task for rodents. Neuron, 2014, 10.1016/j.neuron.2014.04.031
Semedo et al. Cortical Areas Interact through a Communication Subspace. Neuron, 2019, 10.1016/j.neuron.2019.01.026