Why do I have to go through this ?

On the use of dimensionality reduction in neuroscience from someone who took years to come to a basic understanding of dimensionality reduction

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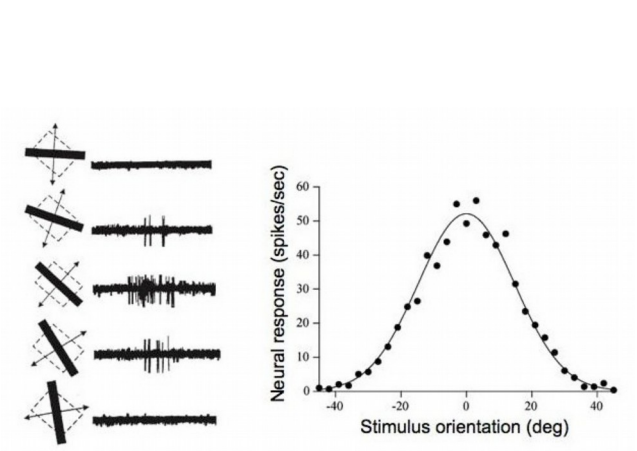
Outline

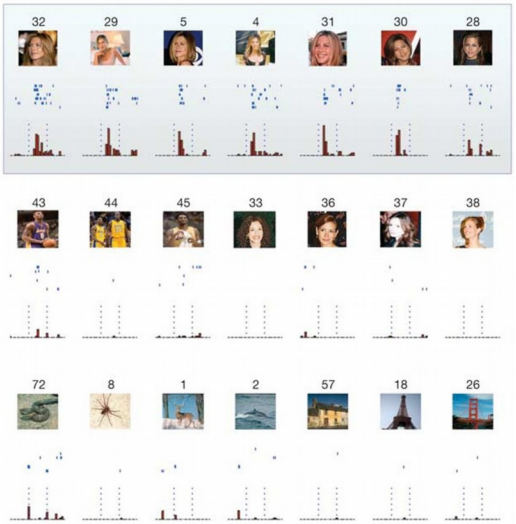
- Intro : why use dimensionality reduction methods ?
- Examples from the literature
- Dimensionality reduction methods in the field of sleep and memory
  - How I got very close to using DR but didn't, but maybe someday will
  - How others did
    - PCA/ICA for studying hippocampal assemblies (Van de Ven 2016)
    - PCA reveals hippocampus/mPFC communication (Peyrache 2009)

Why use dimensionality reduction ?

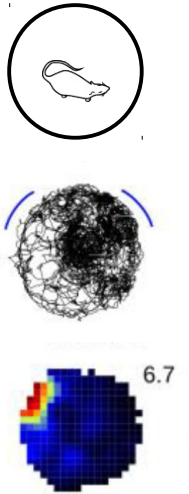
From single neurons to large-scale datasets



Hubel and Wiesel 1968



Quiroga et al. 2005



O'Keefe 1976

One stimulus type/parameter (vidual stimulus orientation, celebrity, space)

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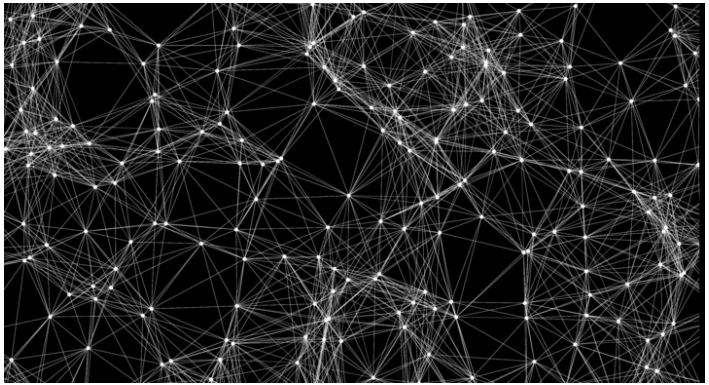

Neurons are organized in networks
- Redundancy
- Noise/Variability
→ Necessary to study coding at the population level as well

Why use dimensionality reduction ?

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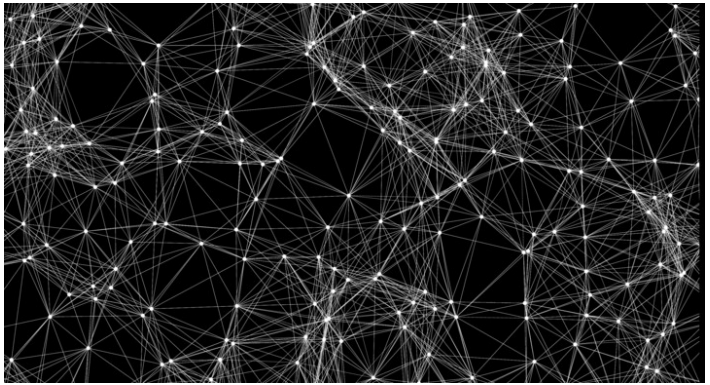
Visualize complex scenes



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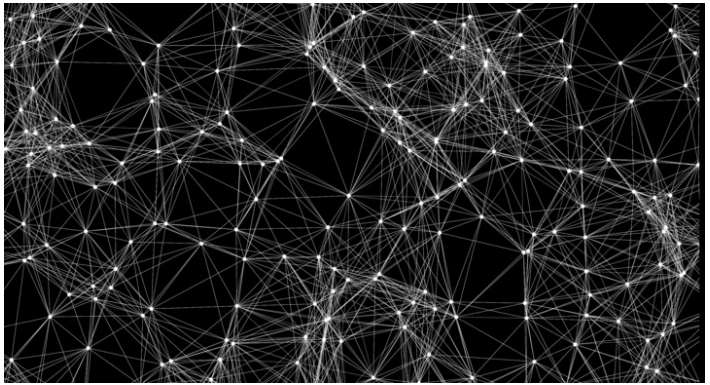

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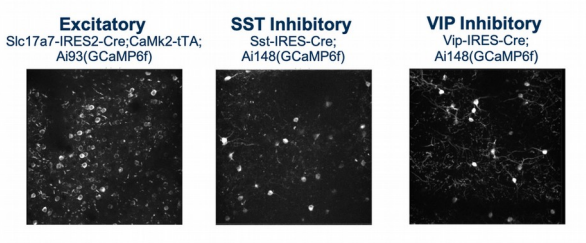
Navigate complex environments

Why use dimensionality reduction ?

From single neurons to large-scale datasets

- Tetrodes
- Silicon probes
- Neuropixel
- Arrays...



- Multi-photons imaging

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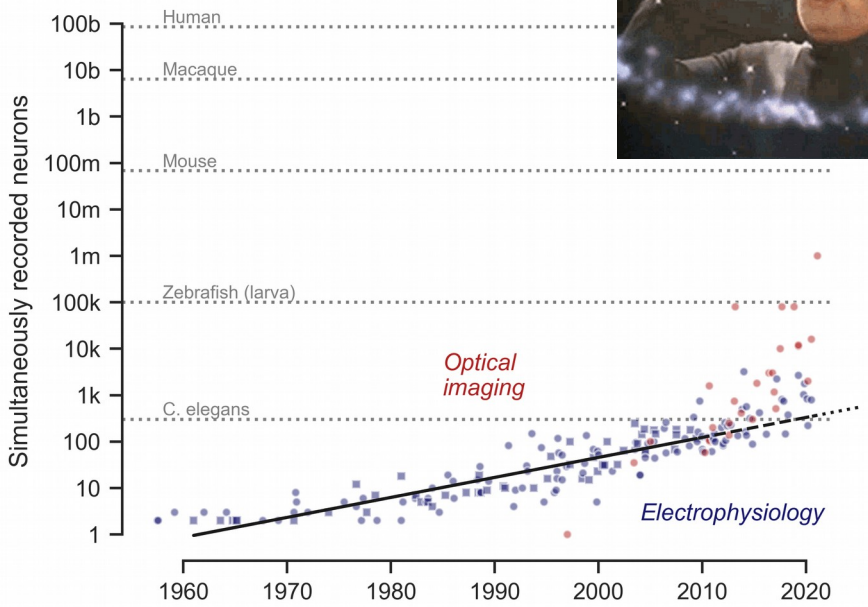

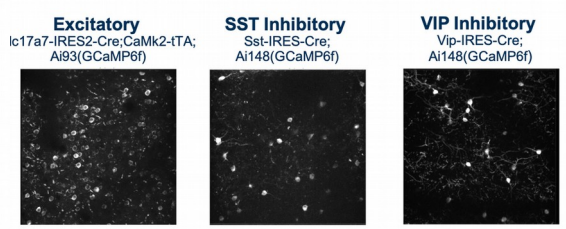

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Urai et al. 2022

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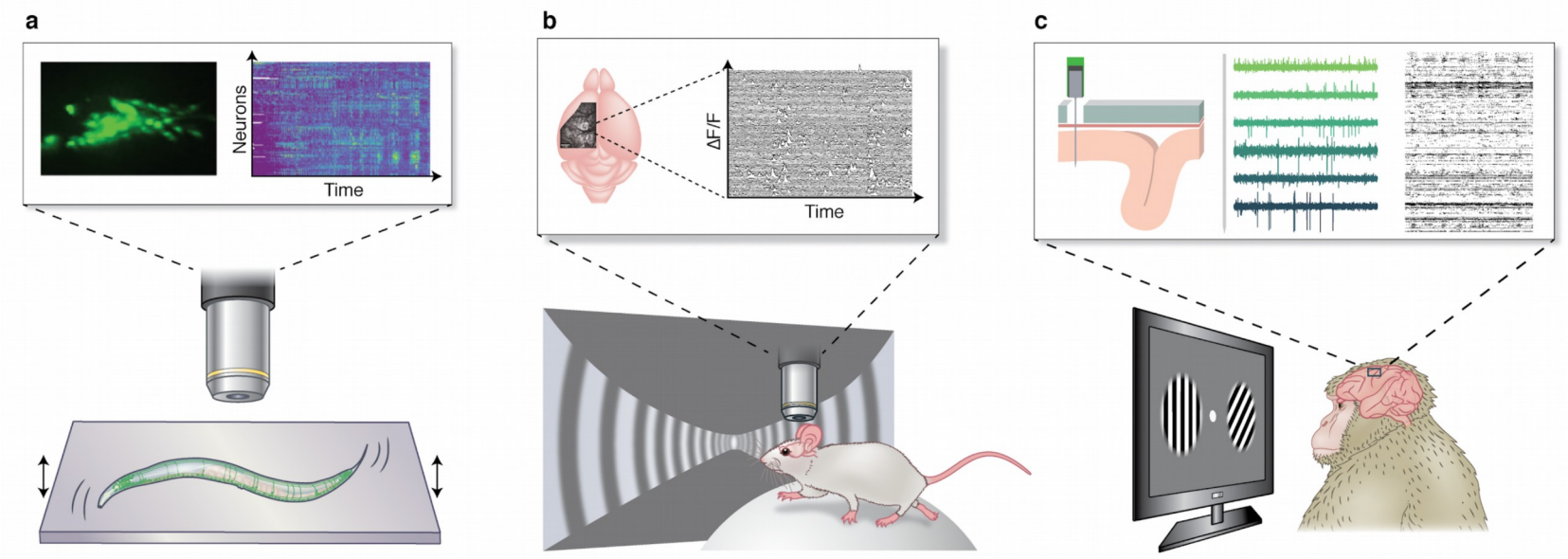


...coupled with complex behavior

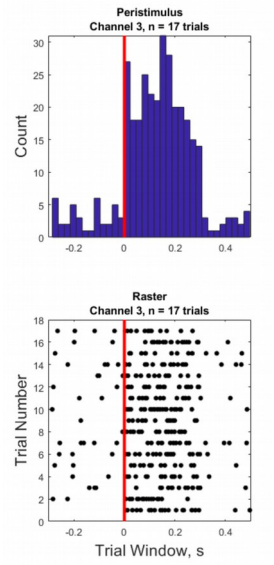
...in areas where single neuron responses are complex

Urai et al. 2022

Why use dimensionality reduction ?

From single neurons to large-scale datasets...

Single neurons
Experimenter picks the variable of interest



Peri-stimulus histogram and rasterplot

Example from Tucker-Davis Tech. website

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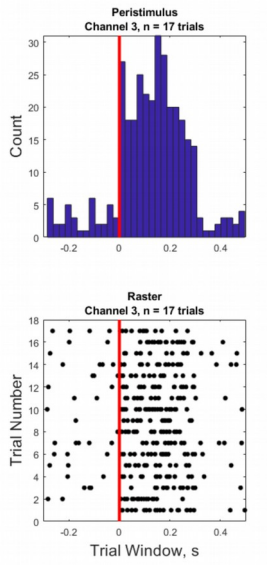

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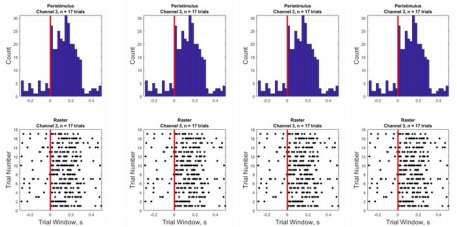
Population activity as the sum/average of multiple single neurons' responses

Experimenter still picks the variable of interest



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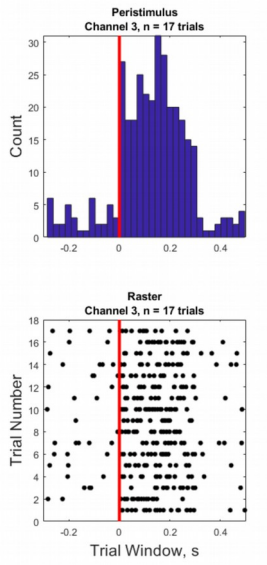

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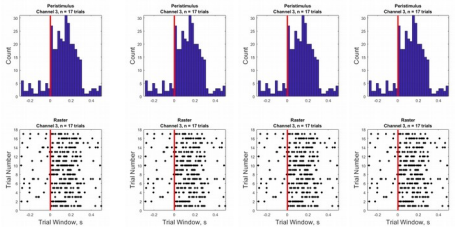
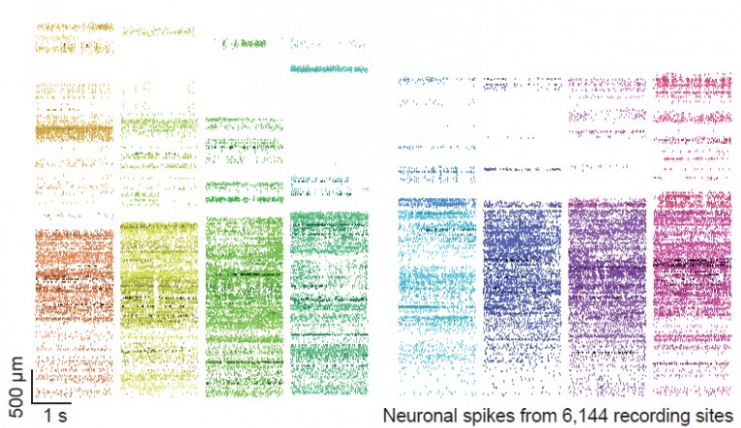


Multiple variables

Mixed selectivity, ie neurons that respond to several variables

Variables that are not easily identified (free behavior)



Human eye cannot pick regularities/patterns

It's too much/not relevant for averages of single unit patterns

Why use dimensionality reduction ?

According to ChatGPT (curated)

-
-
-
-
-
-

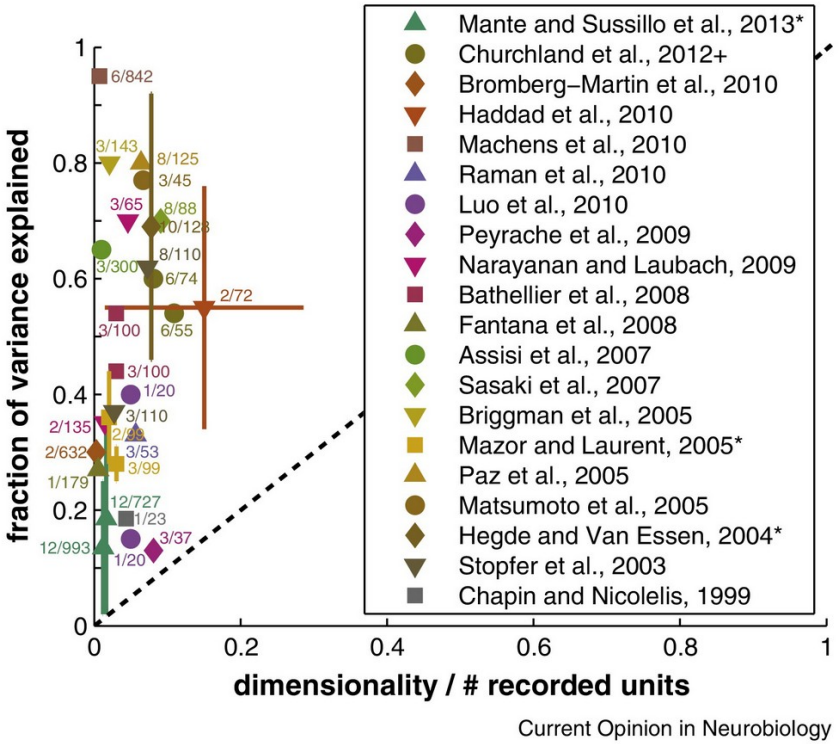
Why use dimensionality reduction ?

According to ChatGPT (curated)

- Vizualisation → Interpretation, intuition building, new hypotheses
- Reveal hidden structure, latent variables
- Noise reduction, improved SNR
- Efficiency : reducing the number of variables/computing time
- Pre-processing (ex : spike-sorting)
- Pattern recognition and classification, notably for BMI

Why use dimensionality reduction ?

- Both an analysis tool and a conceptual tool



Gao 2015

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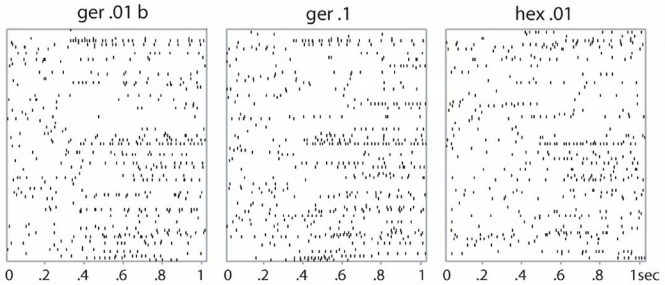

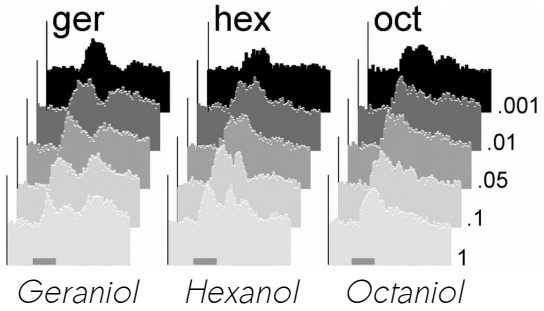

Stopfer 2003

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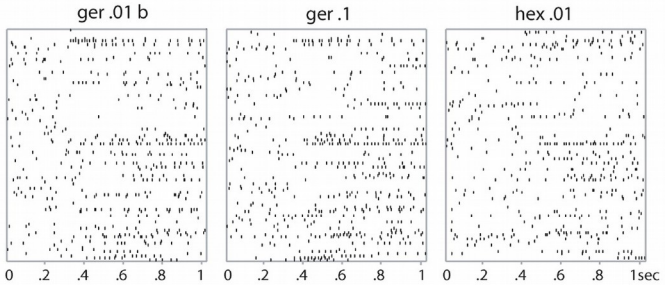

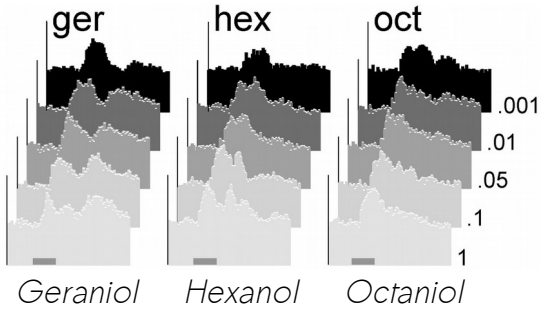

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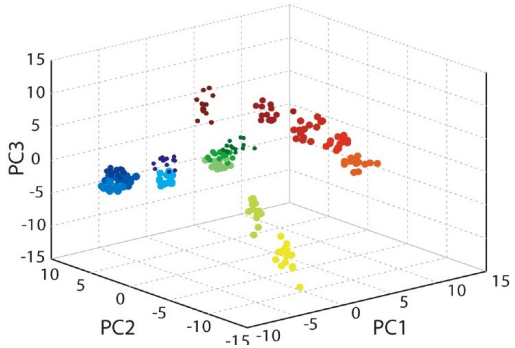

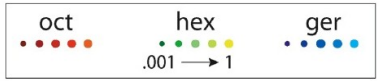

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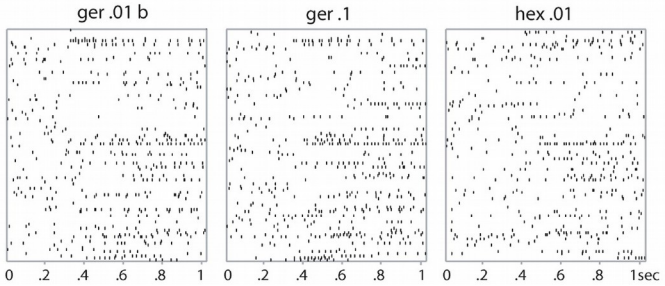

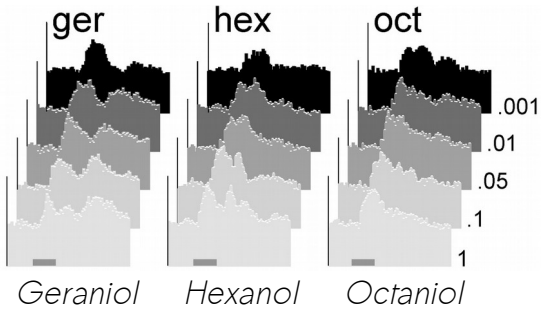

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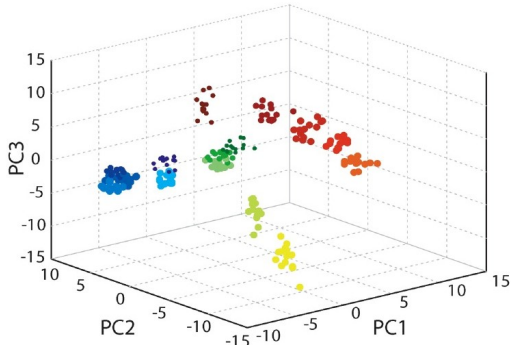

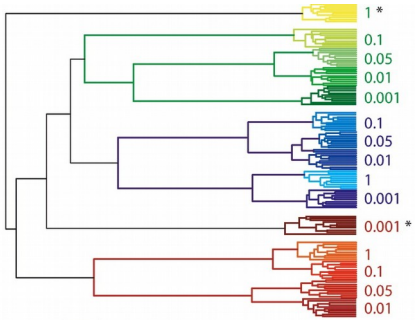

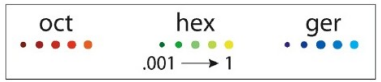

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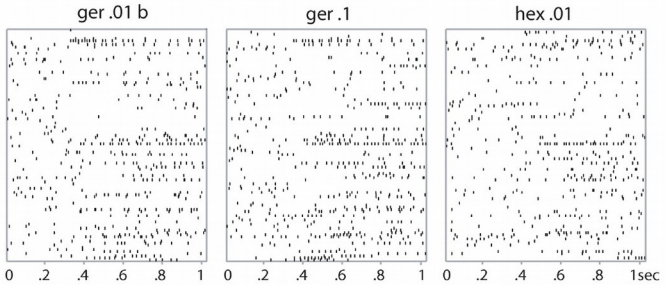

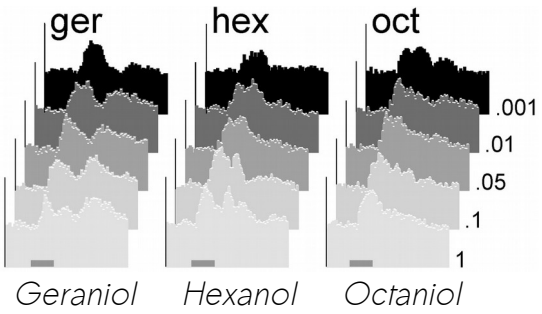

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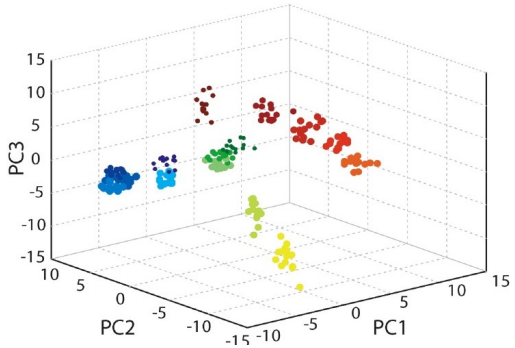
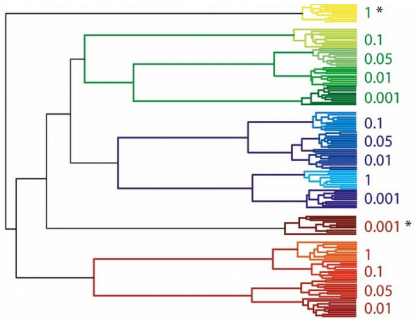
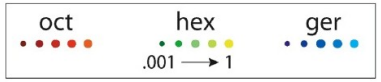
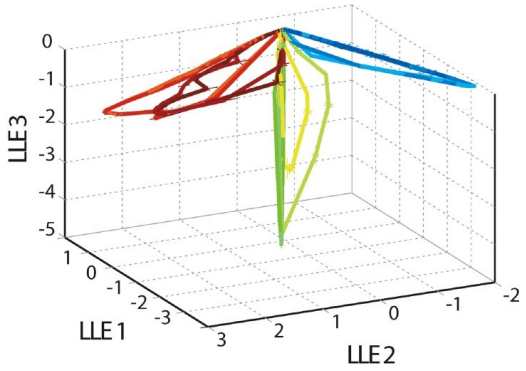
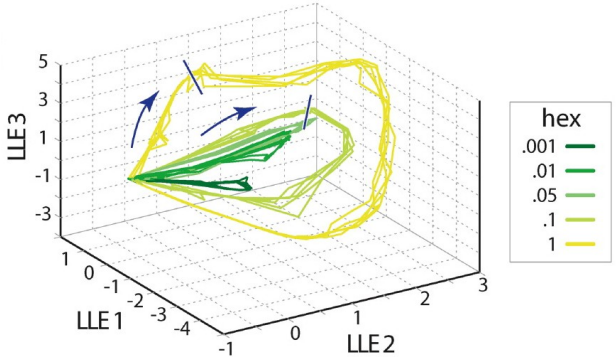






over time





Stopfer 2003

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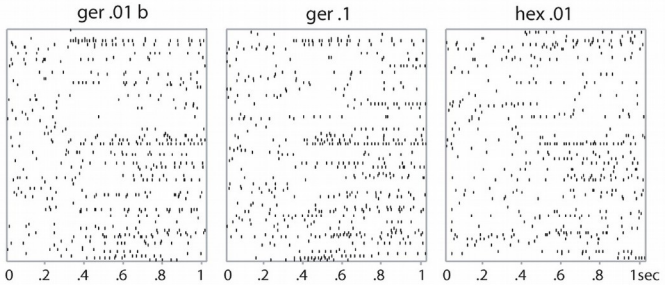

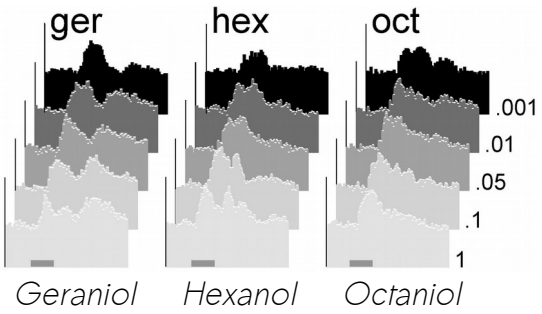

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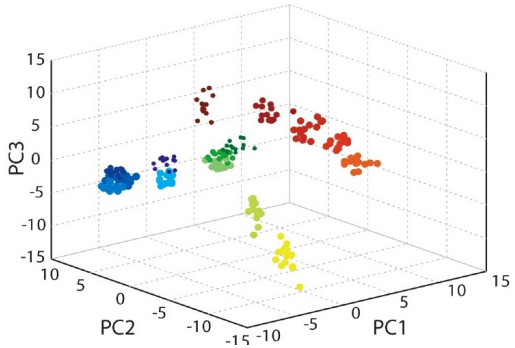

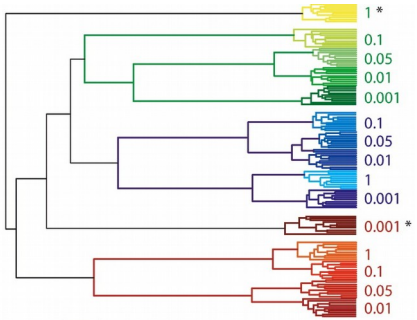

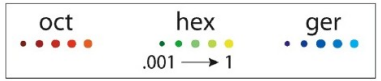

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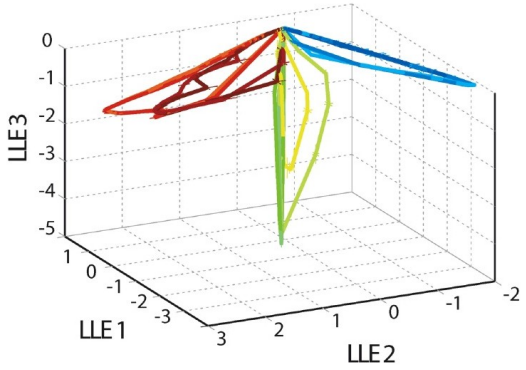
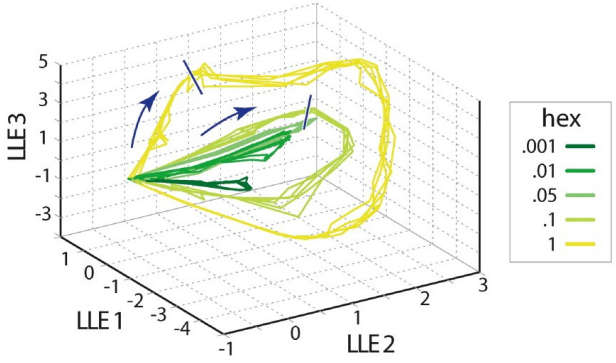
(Locally Linear Embedding)

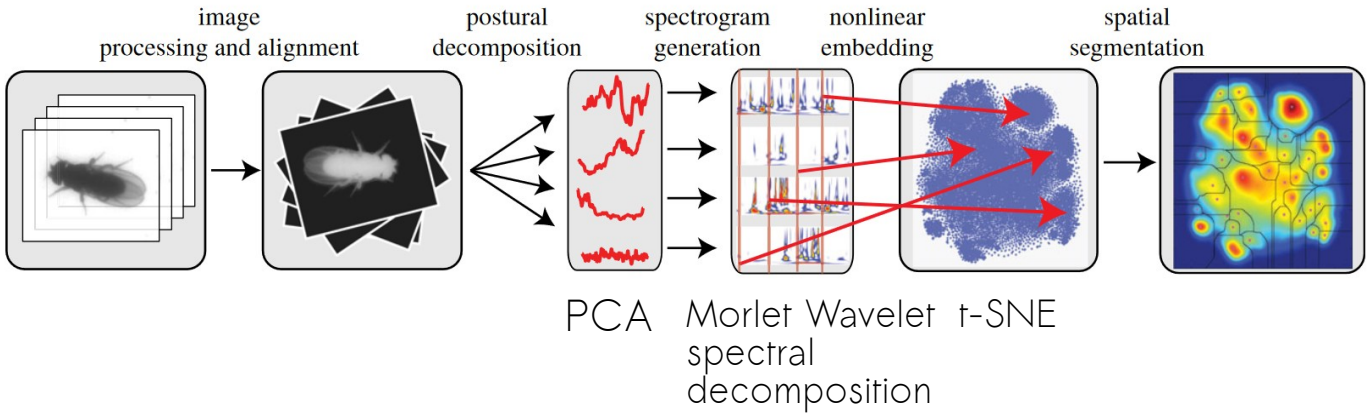


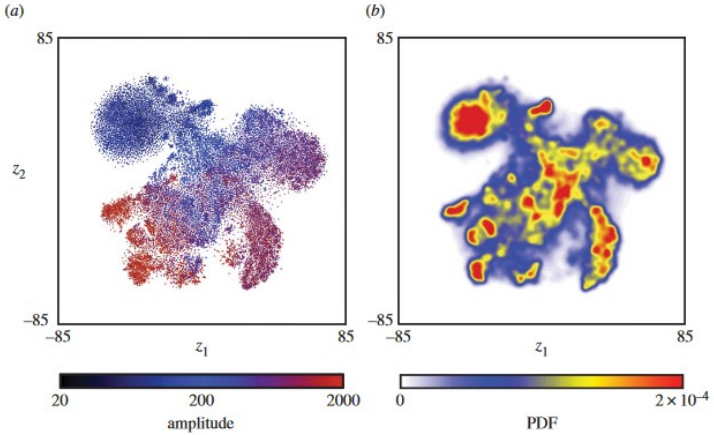


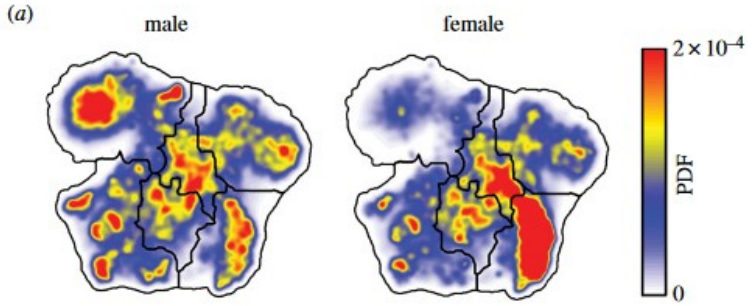
Buzzword : manifold

Stopfer 2003

Example 2 : Mapping stereotypical behavior
in the fruit fly

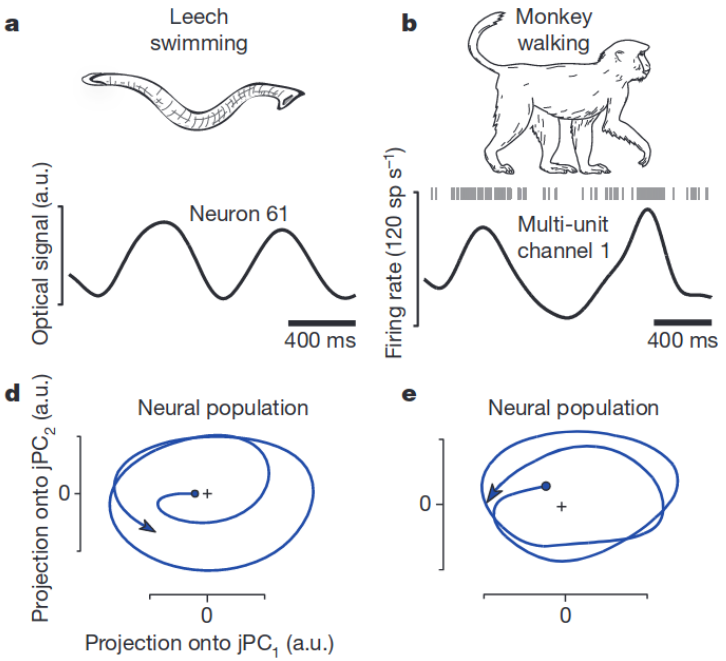






Berman 2014

Example 3 : Neural trajectories during reach in macaque



Churchland 2013

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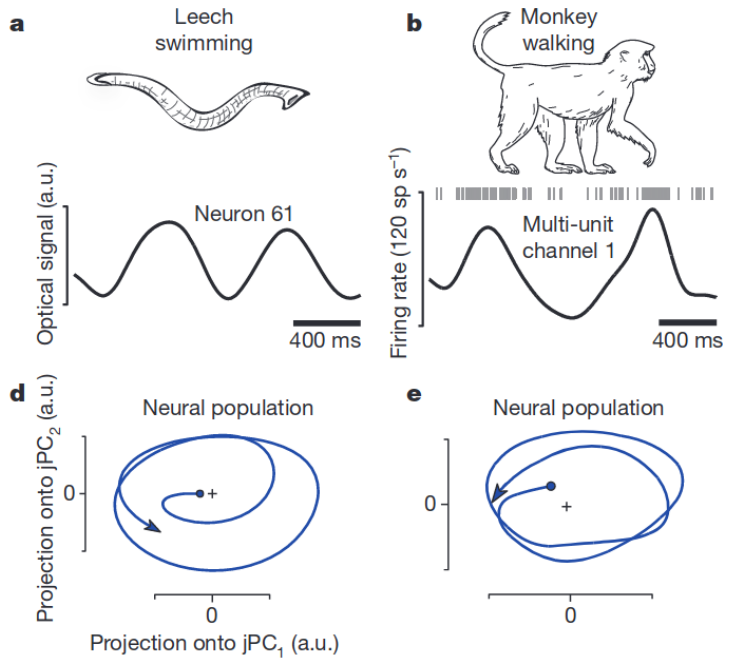

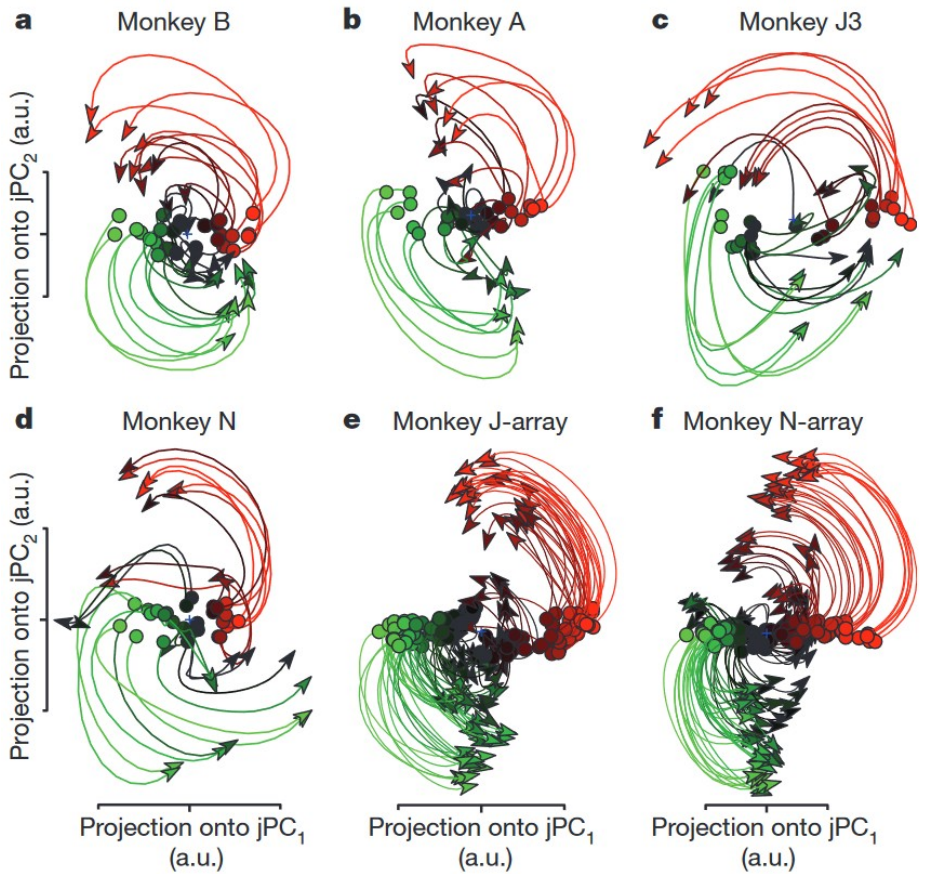

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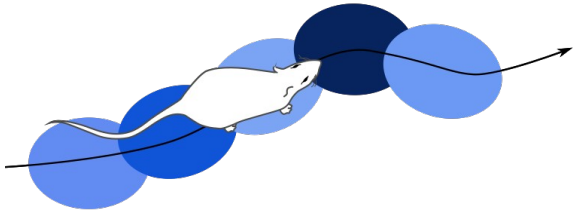
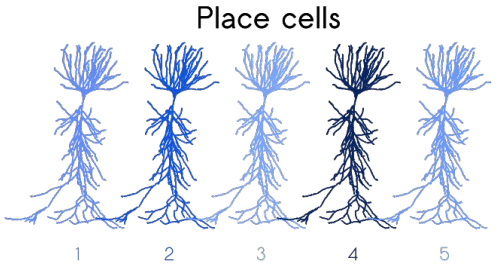
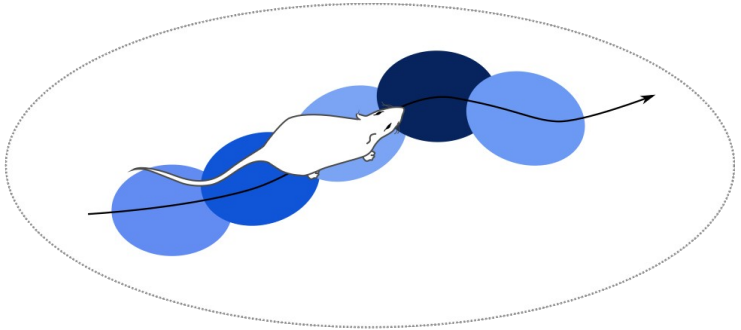
Hippocampal place cells



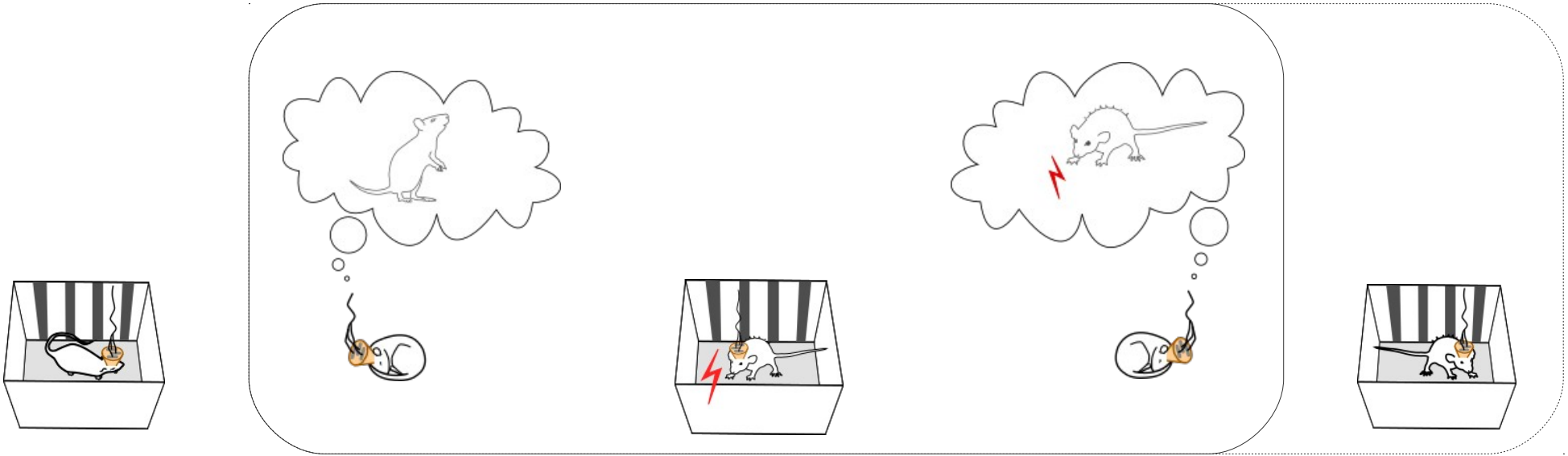




Experimental designs to study sleep and memory

Baseline Wakefulness | Pre-training sleep | Training/Exploration (Acquisition) | Post-training sleep | Test/Exploration (retrieval)

Observational/Correlational studies



Sleep Replay/Reactivations

We're looking for patterns of (co)activation during learning that are reinstated during sleep

Experimental designs to study sleep and memory

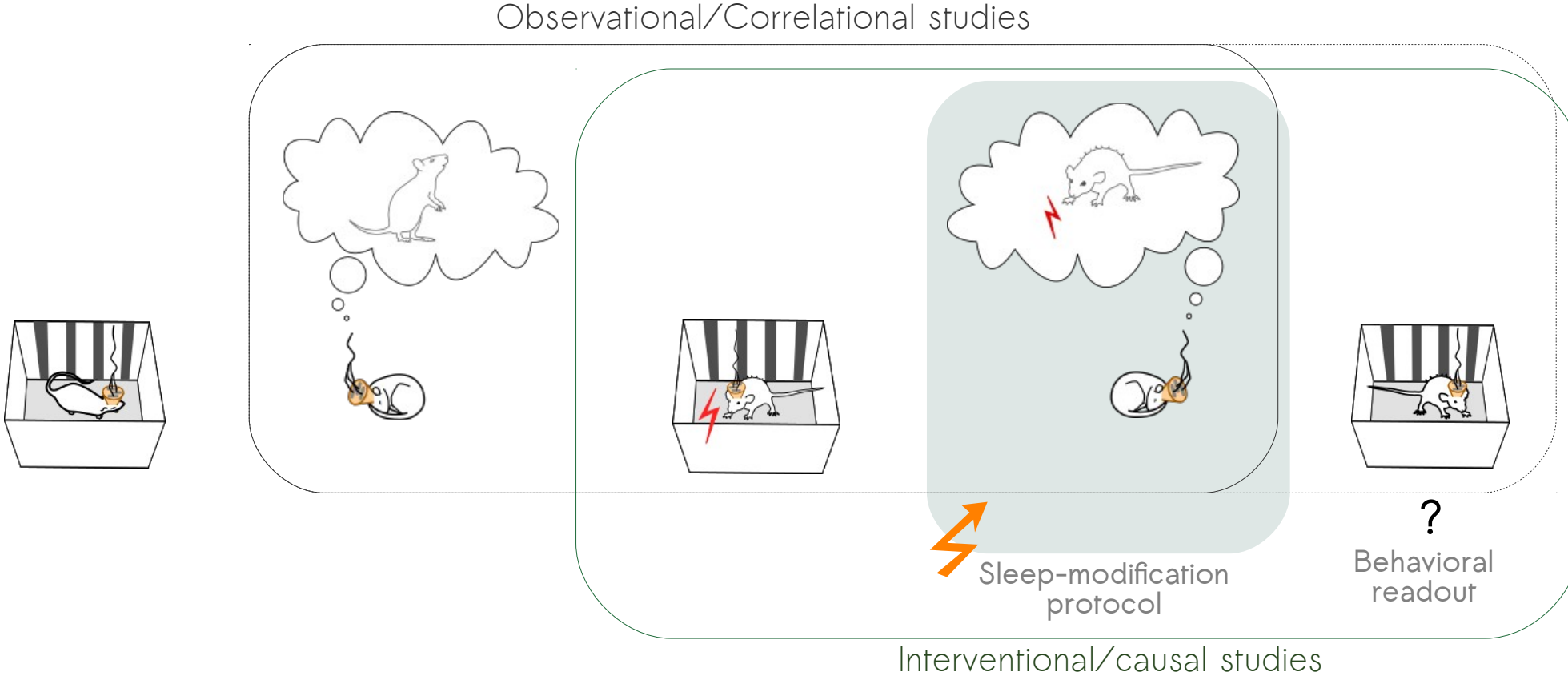
Baseline Wakefulness

Pre-training sleep

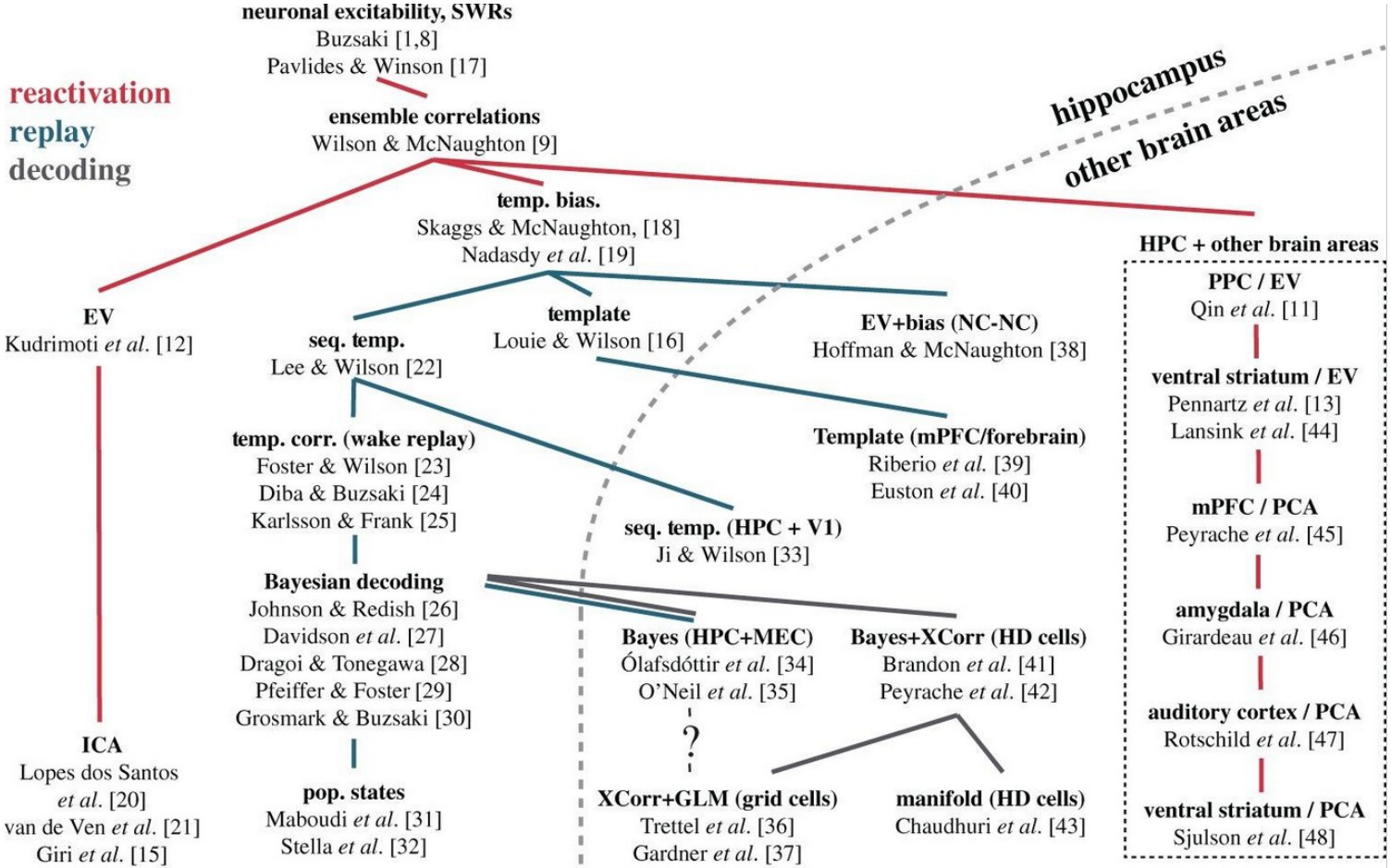
Training/Exploration (Acquisition)

Post-training sleep

Test/Exploration (retrieval)

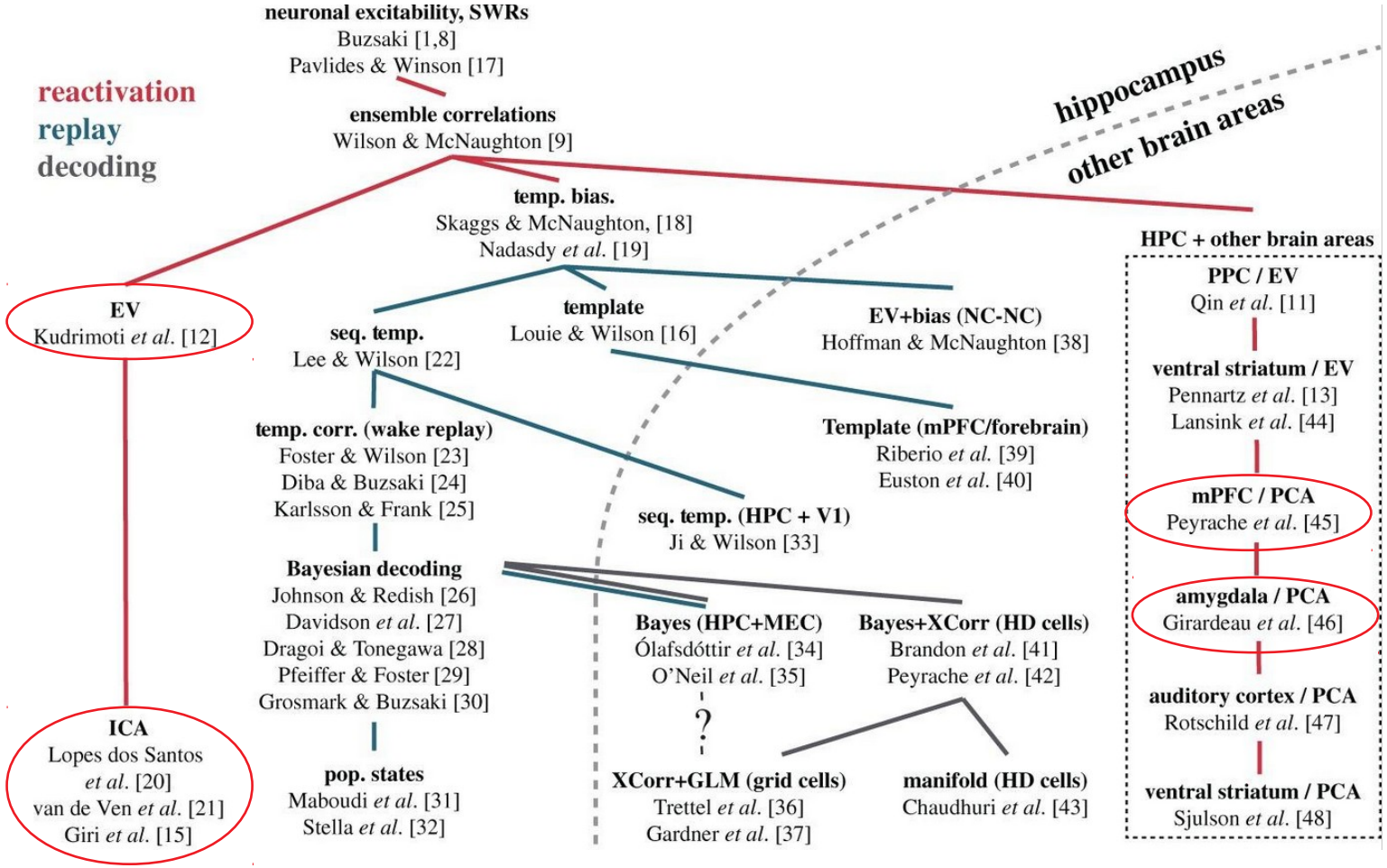


Methods for Replay Analysis



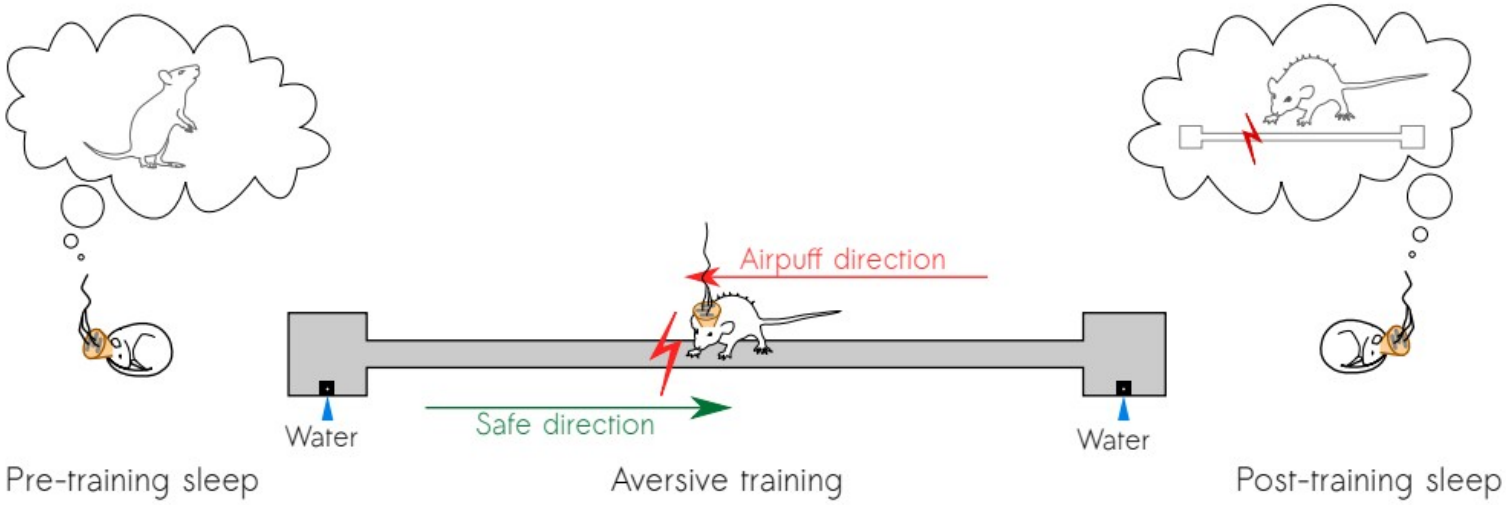
Tingley & Peyrache 2020

Methods for Replay Analysis



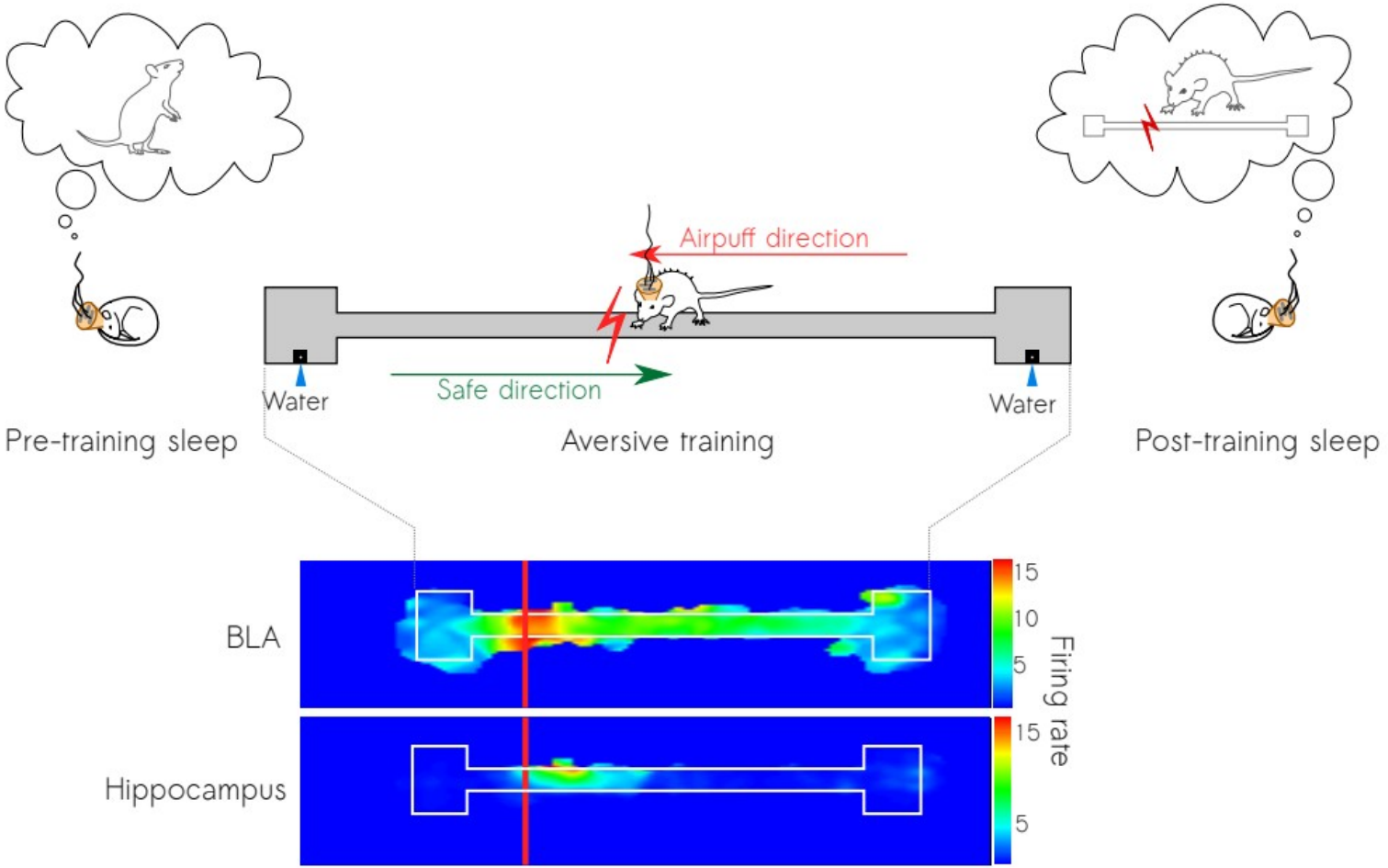
Tingley & Peyrache 2020

Hippocampus-amygdala dialogue



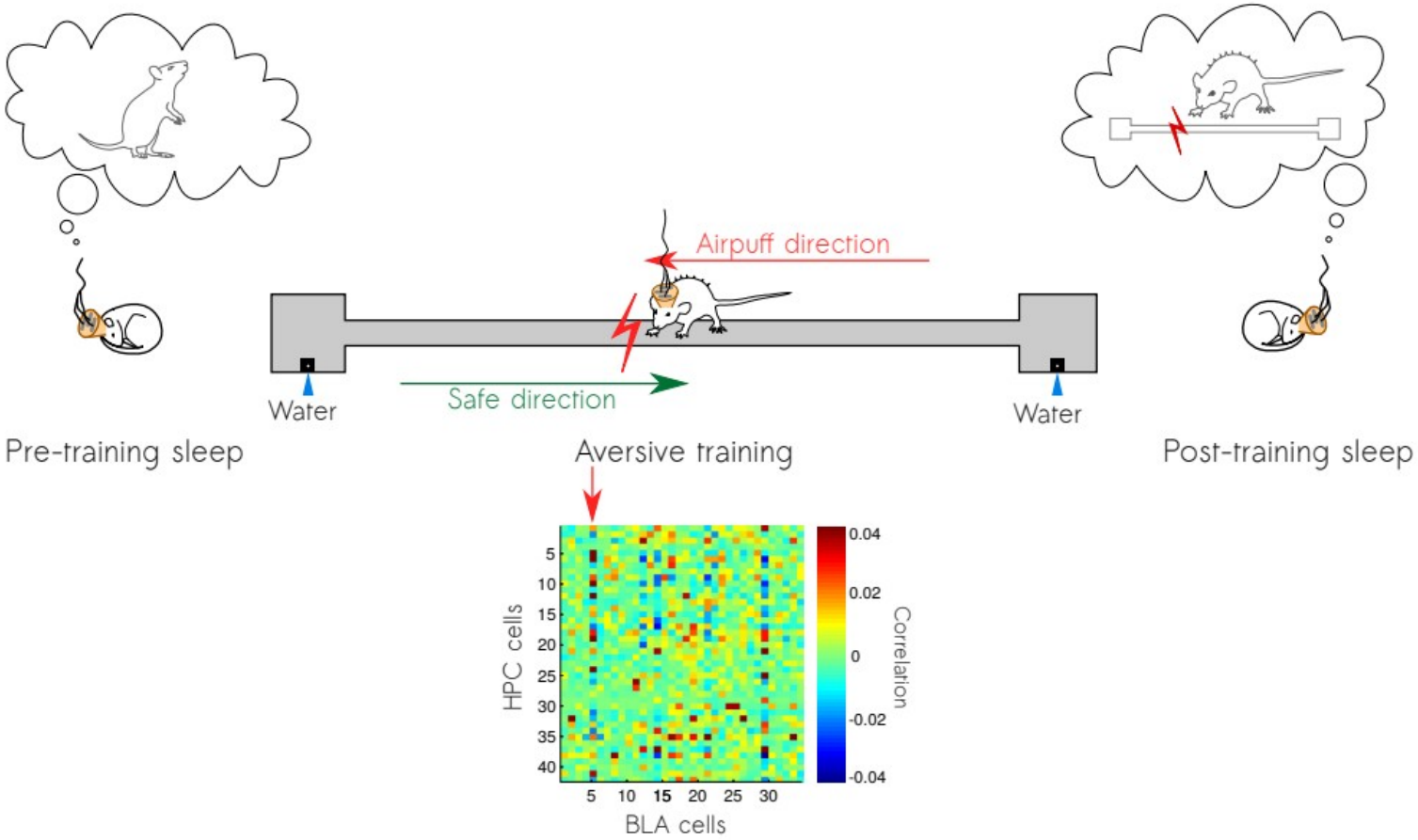
Girardeau 2017

Hippocampus-amygdala dialogue



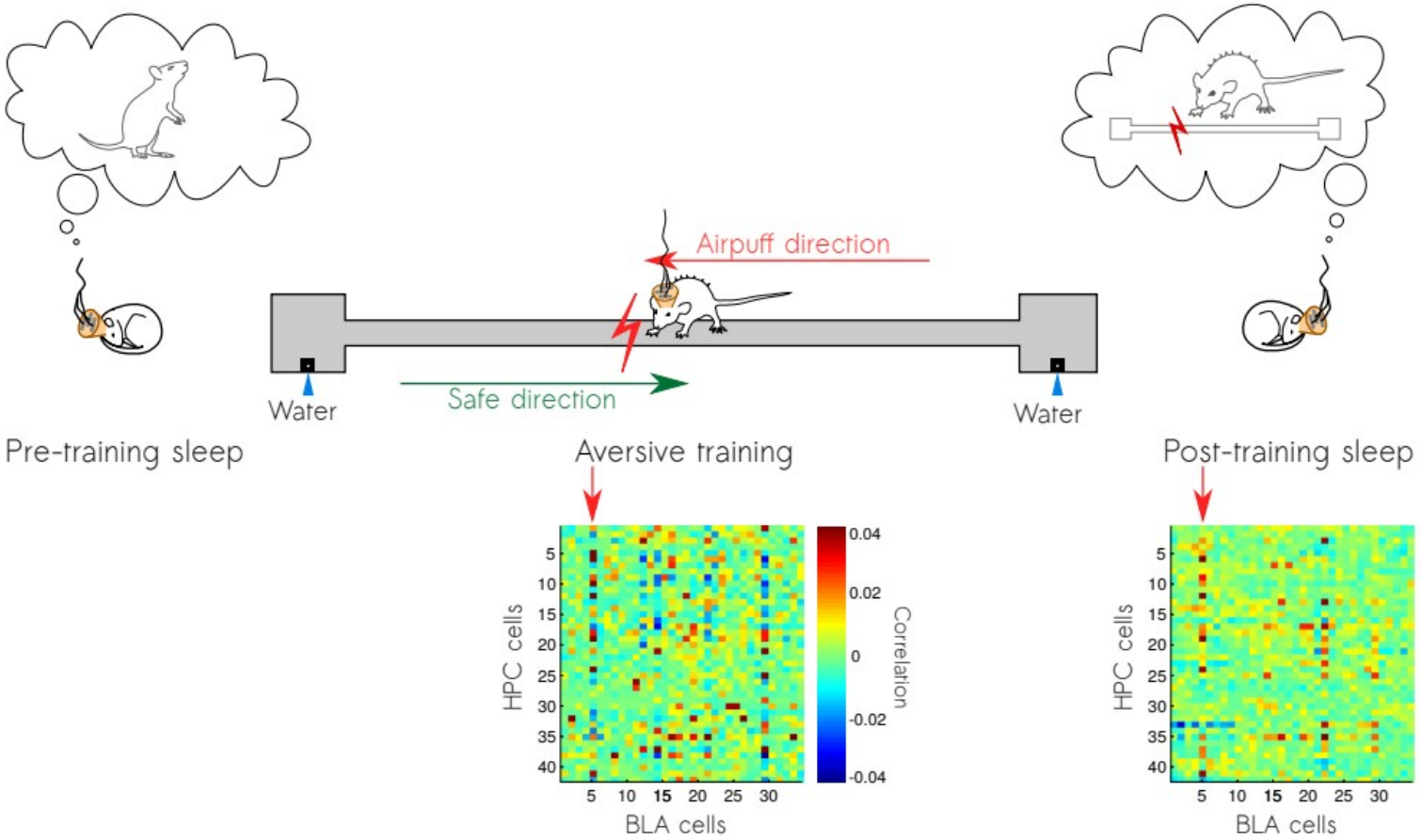
Girardeau 2017

Hippocampus-amygdala dialogue



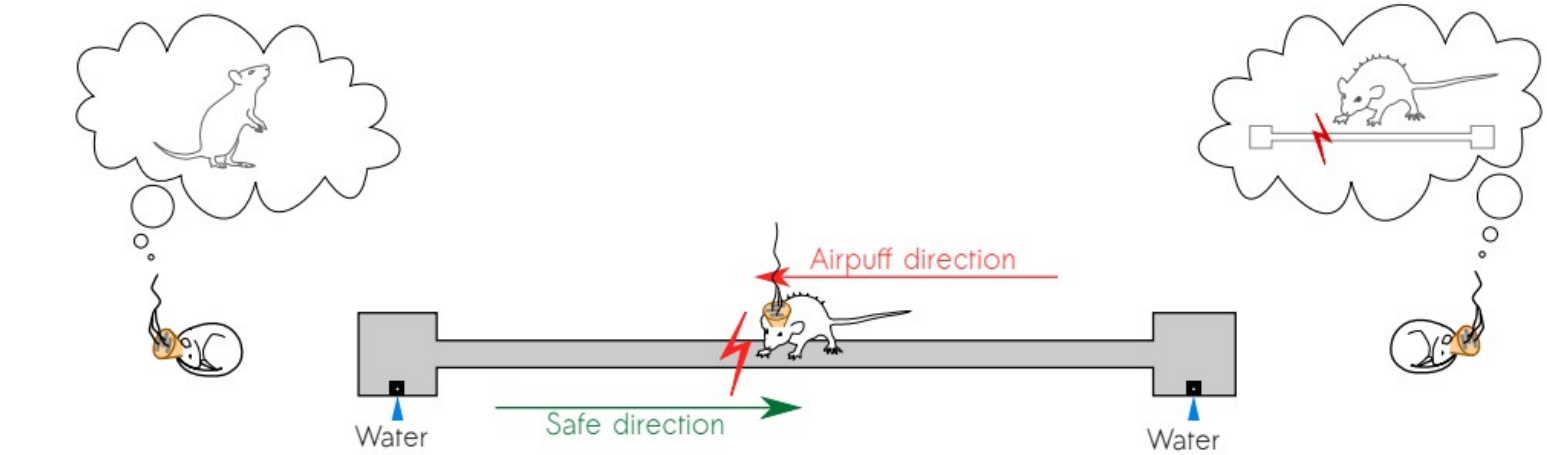
Girardeau 2017

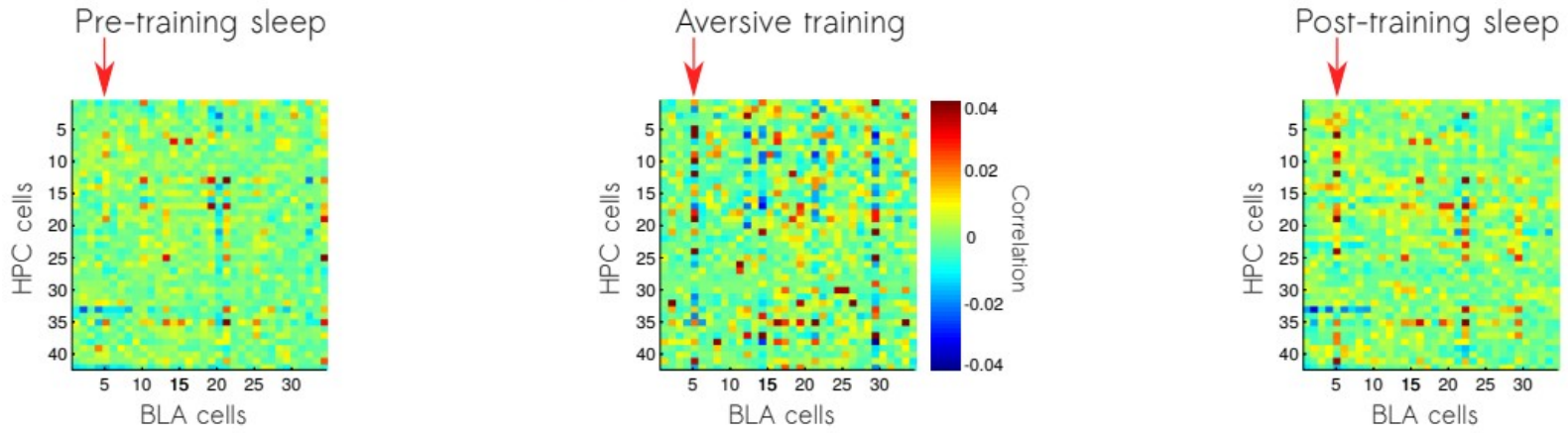
Hippocampus-amygdala dialogue



Girardeau 2017

Hippocampus-amygdala dialogue

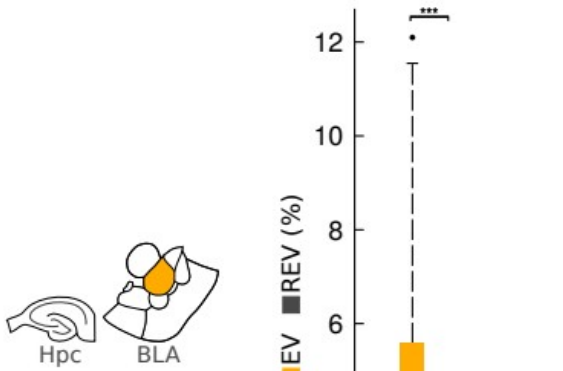




$$EV\ (\text{Explained variance}) = \left(\frac{r_{tr,post} - r_{tr,pre} \times r_{post,pre}}{\sqrt{(1-r_{tr,pre}^2)(1-r_{post,pre}^2)}} \right)^2$$

Girardeau 2017

Hippocampus-amygdala dialogue

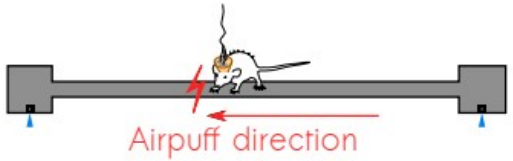


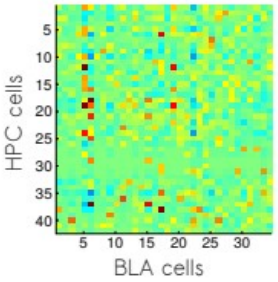
n = 3 rats, 25 sessions

Wilcoxon signed rank tests
* p<0.05
** p<0.01
*** p<0.001

Girardeau 2017

Hippocampus-amygdala dialogue



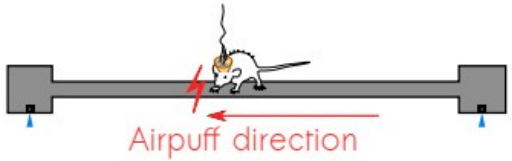


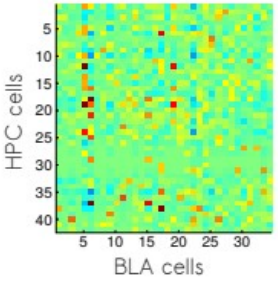
Girardeau 2017

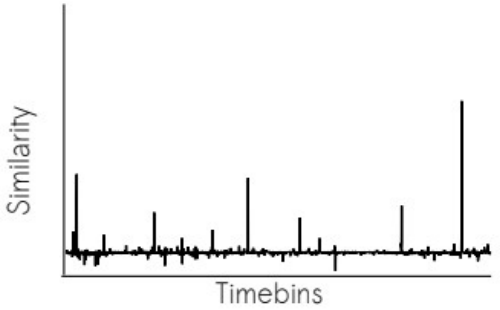
Hippocampus-amygdala dialogue

Training

Pre- or Post-training sleep







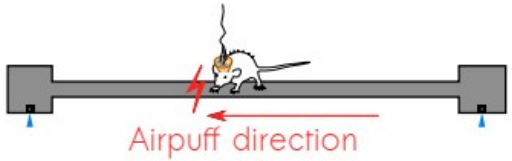
Similarity between training pattern and instantaneous pre or post-sleep patterns

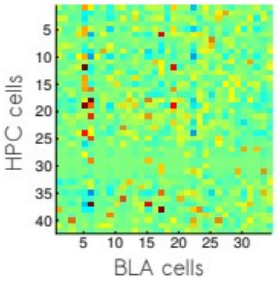
Girardeau 2017

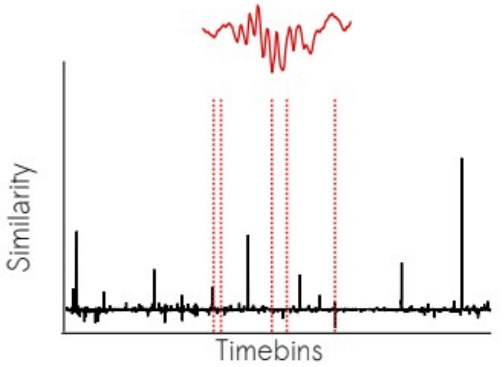
Hippocampus-amygdala dialogue

Training

Pre- or Post-training sleep







Similarity between training pattern and instantaneous pre or post-sleep patterns

Girardeau 2017

Hippocampus-amygdala dialogue

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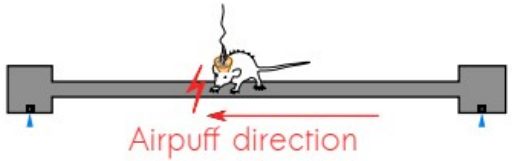
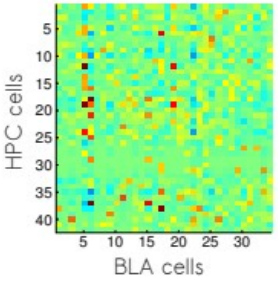
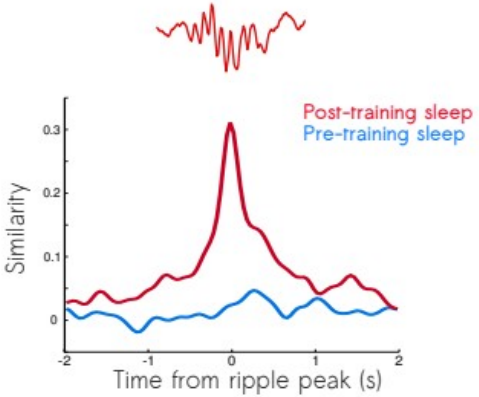
Pre- or Post-training sleep







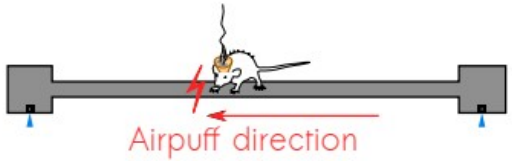
Similarity between training pattern and instantaneous pre or post-sleep patterns

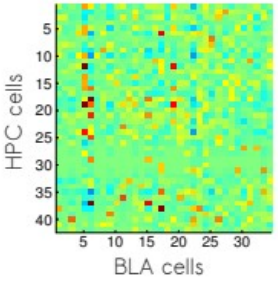
Girardeau 2017

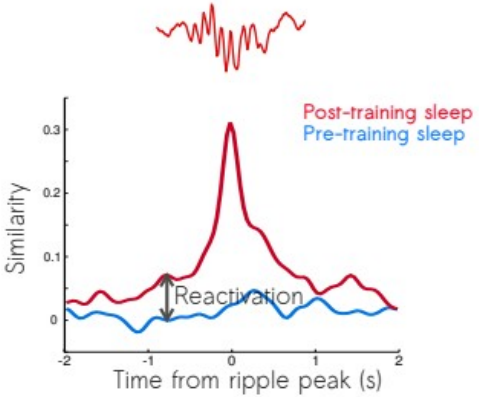
Hippocampus-amygdala dialogue

Training

Pre- or Post-training sleep







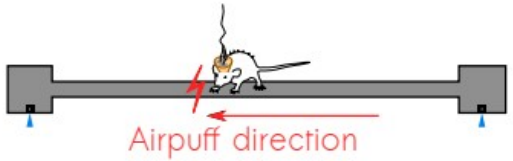
Similarity between training pattern and instantaneous pre or post-sleep patterns

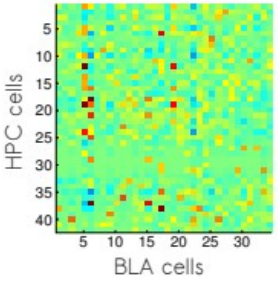
Girardeau 2017

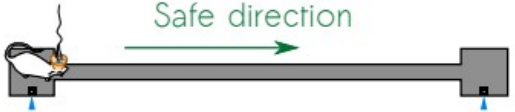
Hippocampus-amygdala dialogue

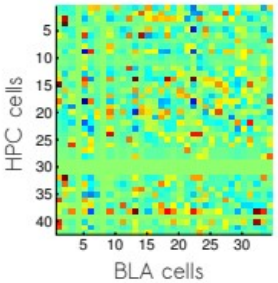
Training

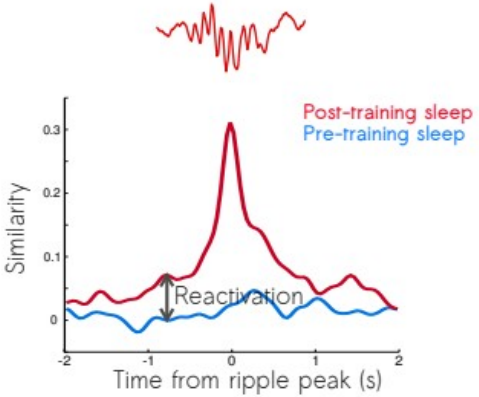
Pre- or Post-training sleep







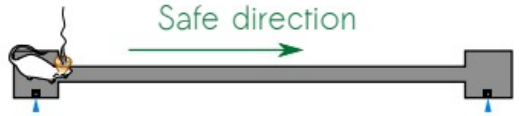


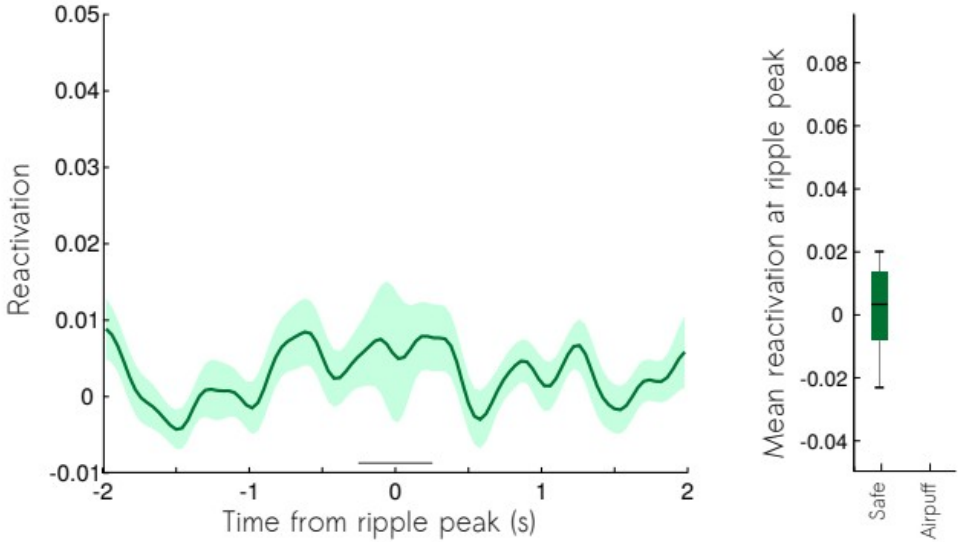


Similarity between training pattern and instantaneous pre or post-sleep patterns

Girardeau 2017

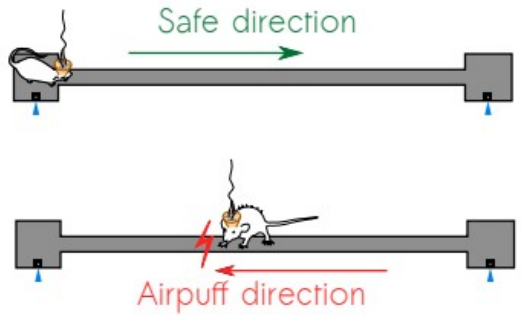
Hippocampus-amygdala dialogue

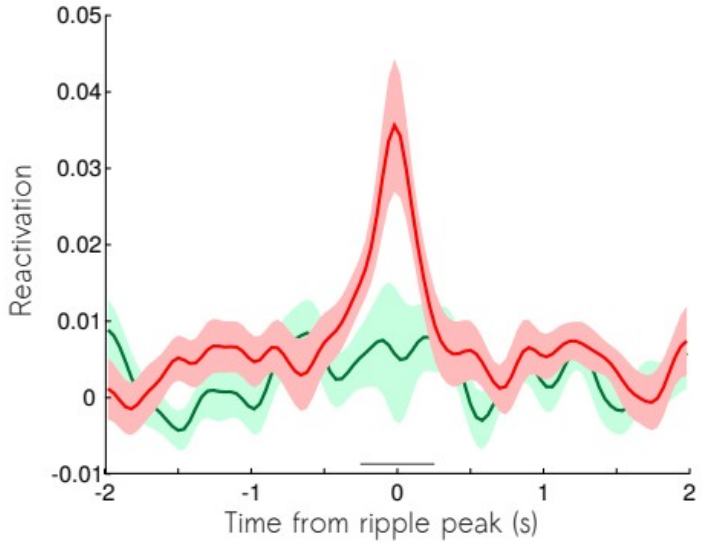


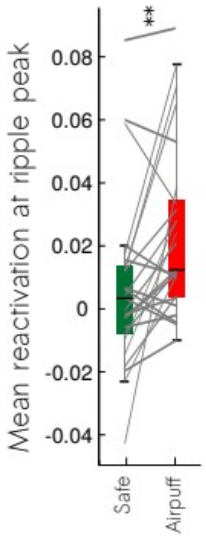


Girardeau 2017

Hippocampus-amygdala dialogue







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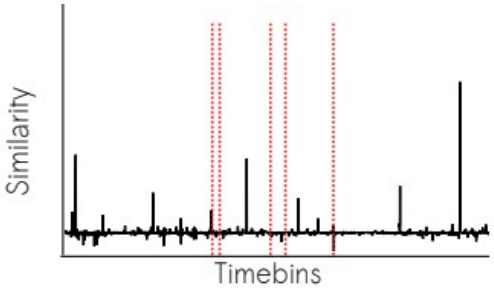
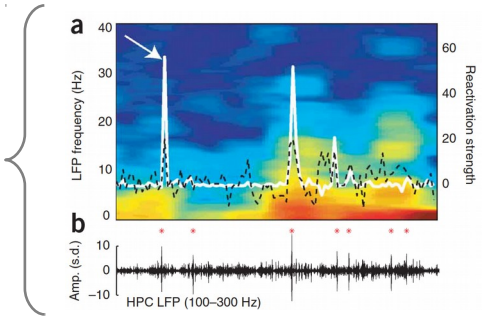
Brainstorming

Actual dimensionality reduction case studies



PCA - Reactivation strength

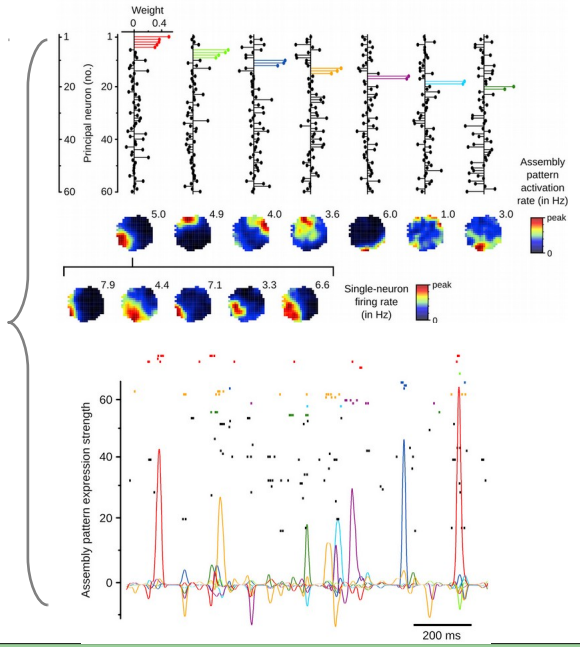
Peyrache 2009



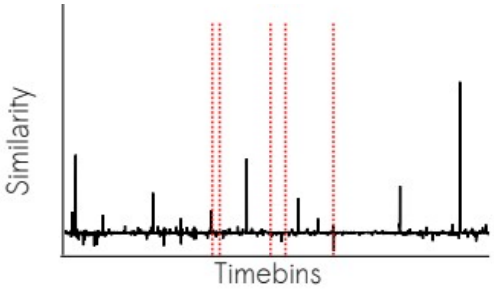
PCA/ICA

Neuronal assembly tracking

Van de Ven 2016



Actual dimensionality reduction case studies



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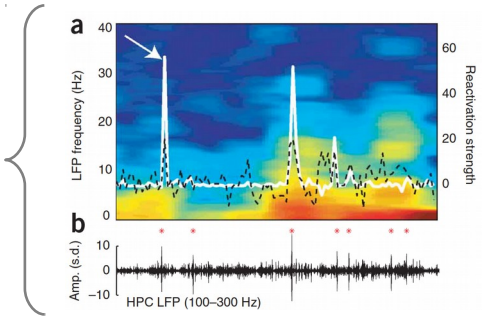
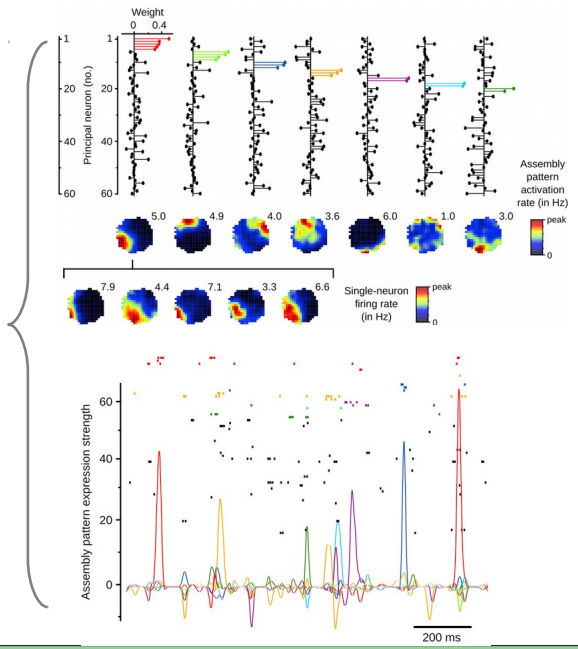
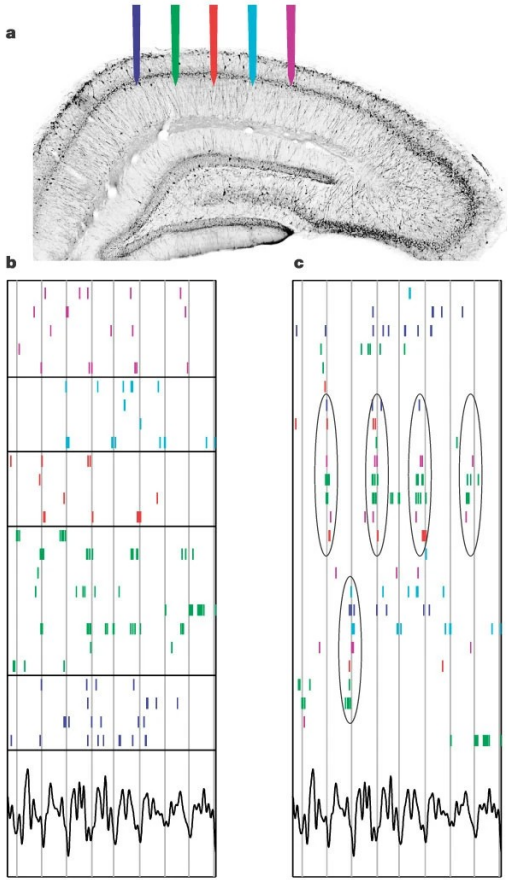




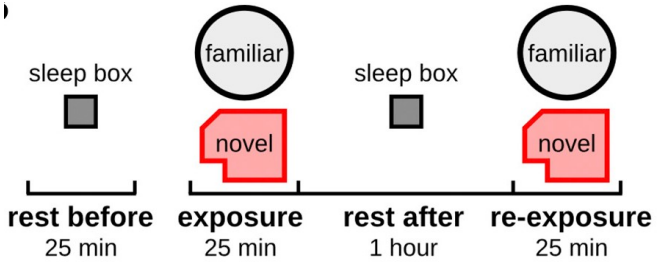
DR for cell assemblies : PCA/ICA



Optimal time-window for cell assembly formation : 25ms

Harris 2003

DR for cell assemblies : PCA/ICA



Van de Ven 2016

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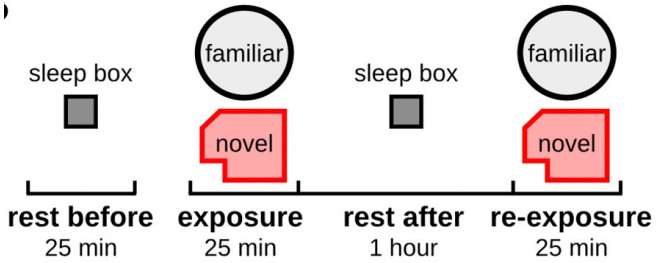

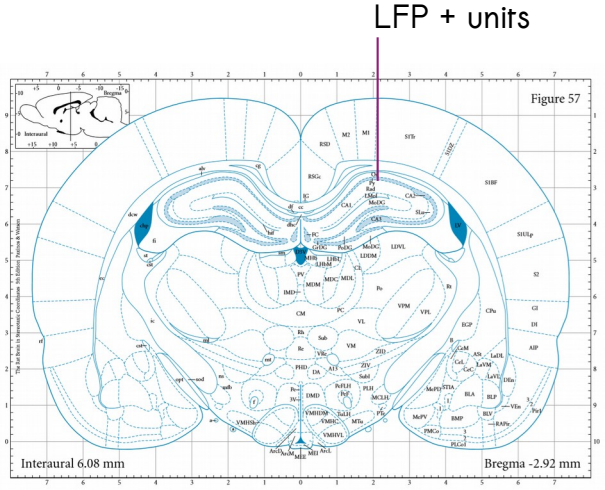

Van de Ven 2016

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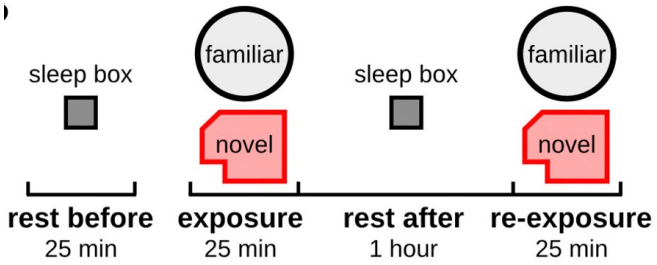

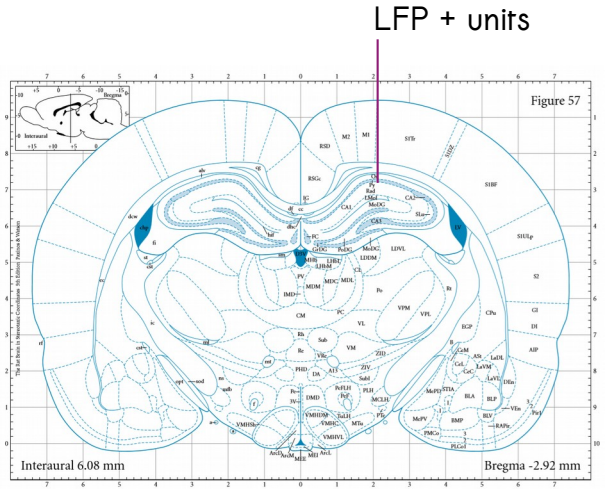

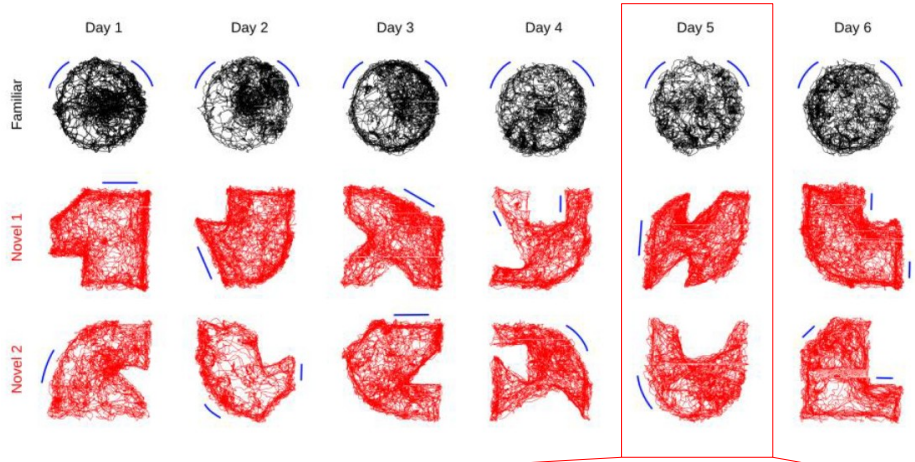

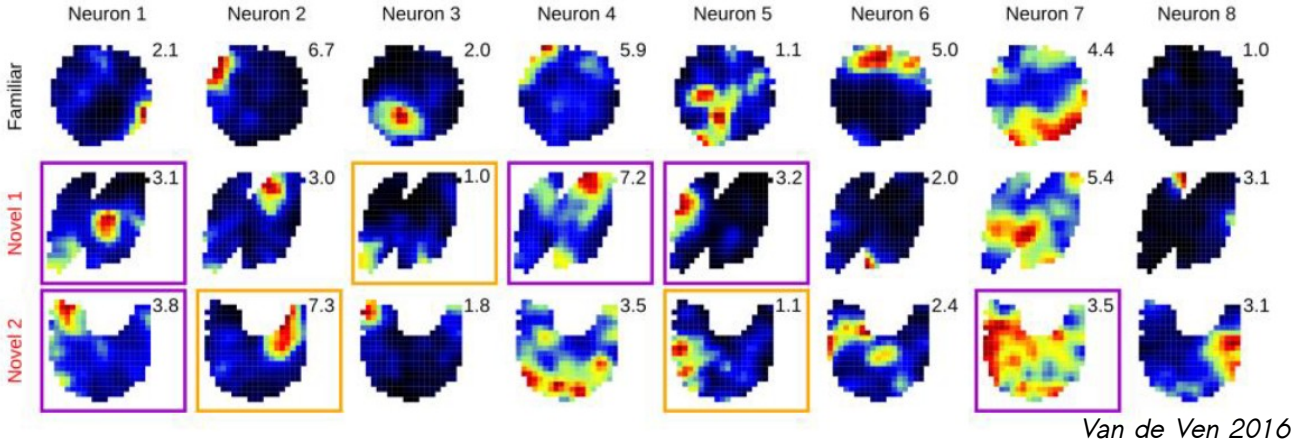

Van de Ven 2016

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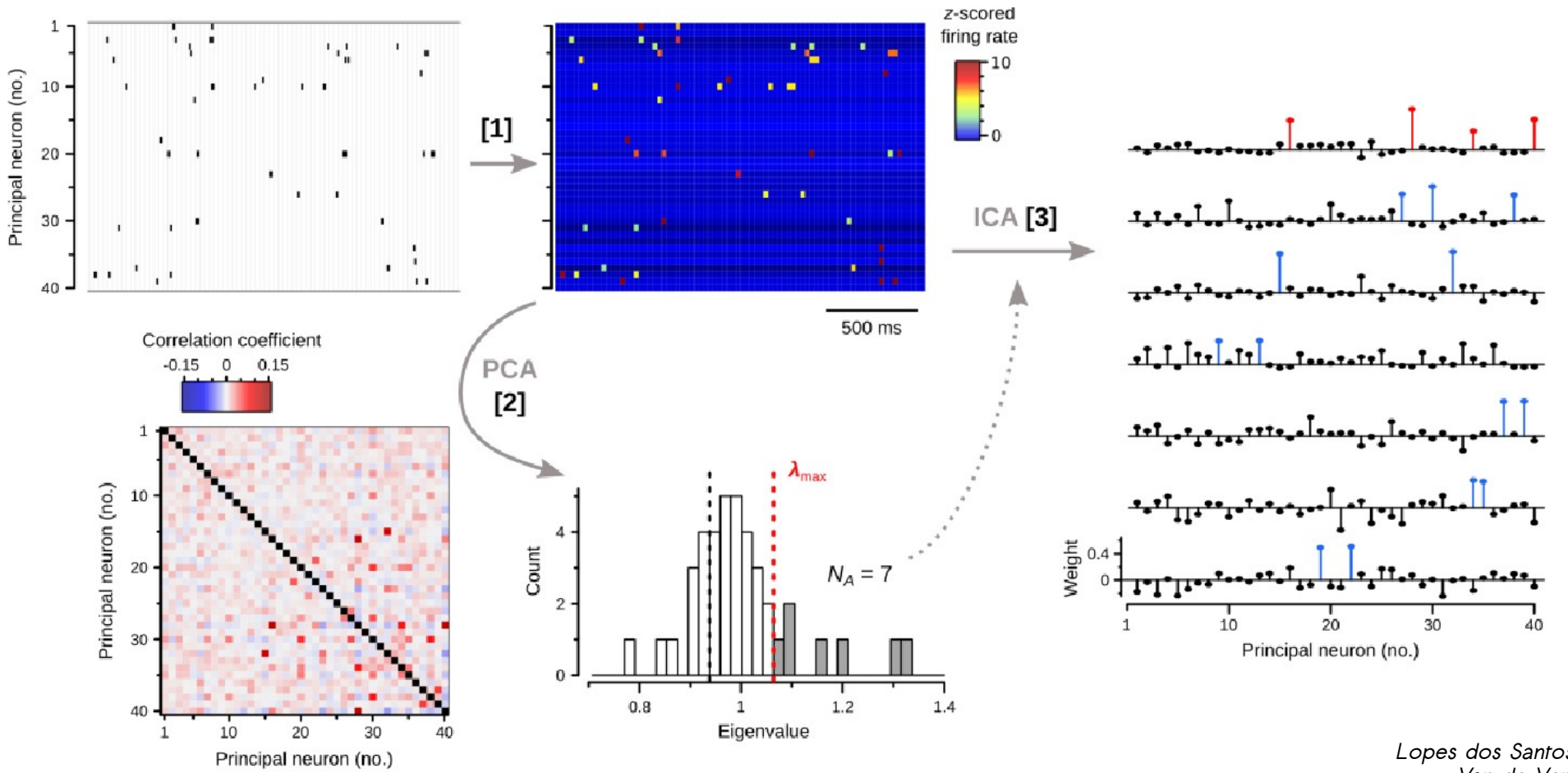
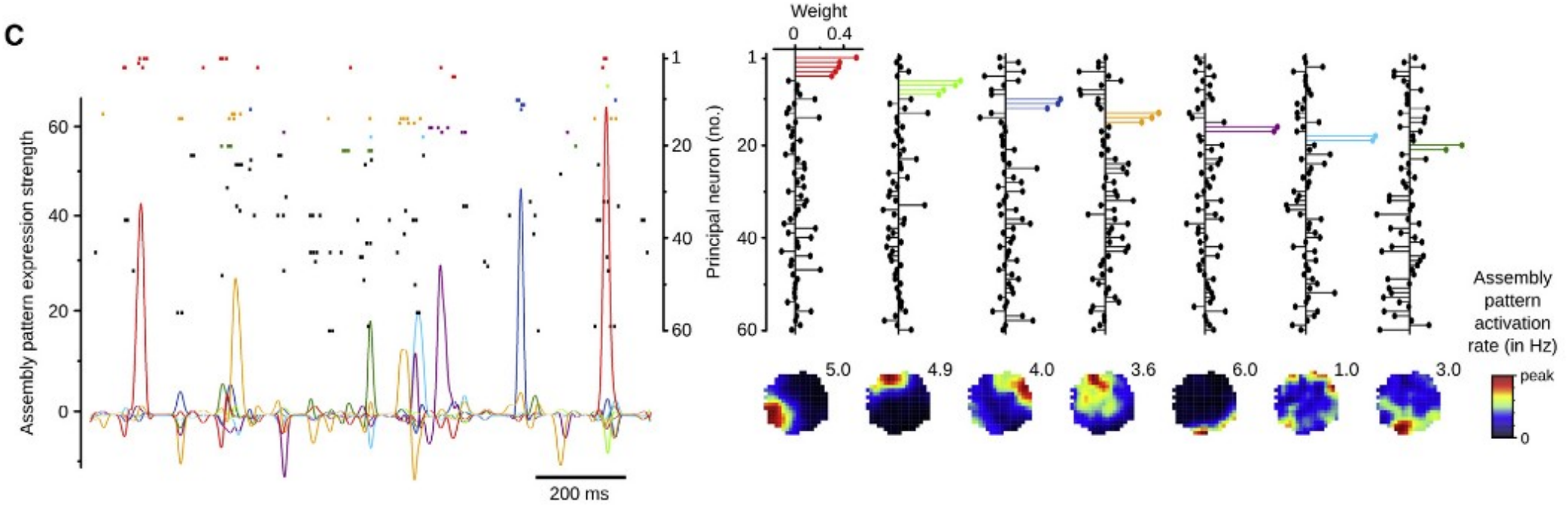


Lopes dos Santos 2013
Van de Ven 2016

DR for cell assemblies : PCA/ICA



Van de Ven 2016

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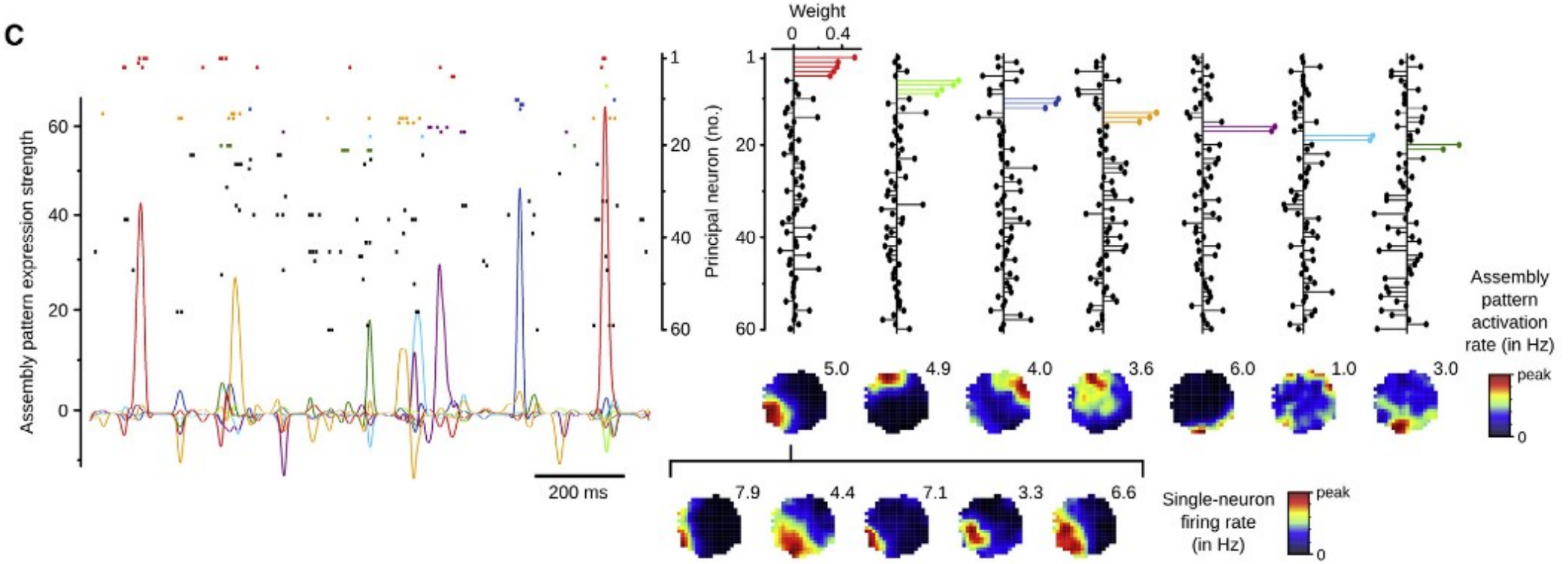
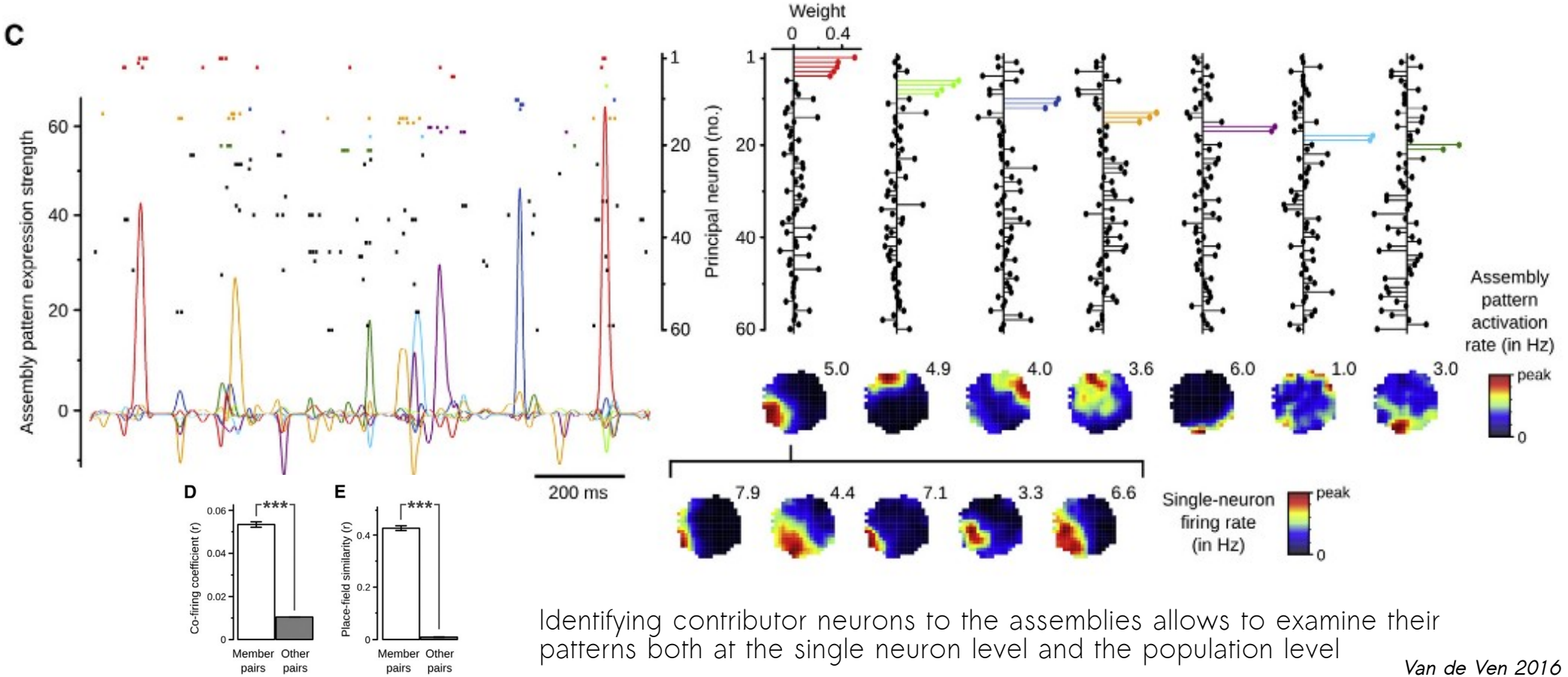


Identifying contributor neurons to the assemblies allows to examine their patterns both at the single neuron level and the population level

Van de Ven 2016

DR for cell assemblies : PCA/ICA



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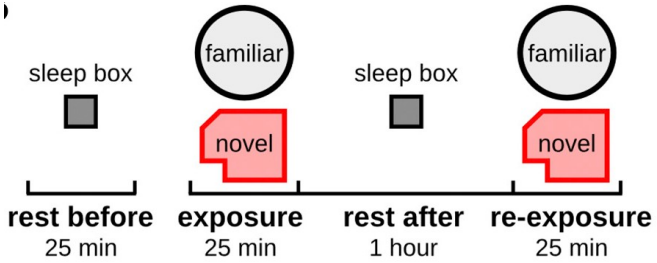
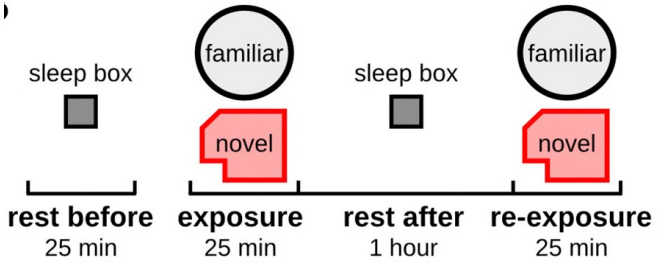


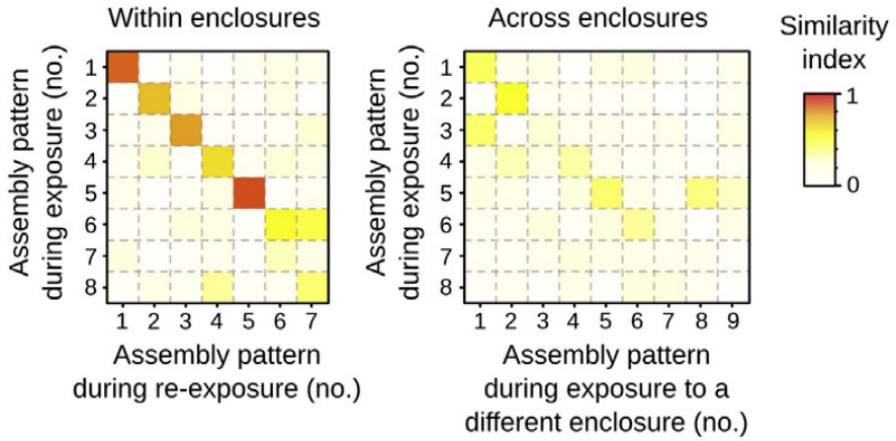
What are the dynamics of hippocampal cell assemblies of familiar or novel environments across initial exploration, sleep and re-exposure ?

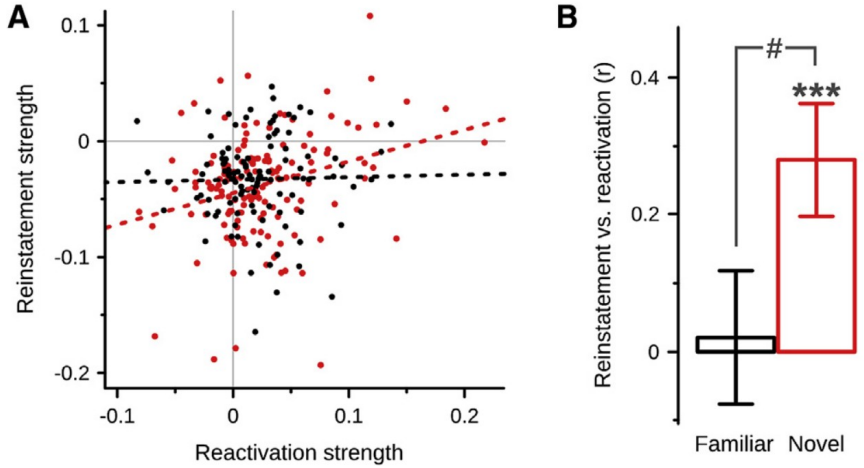
Van de Ven 2016

DR for cell assemblies : PCA/ICA



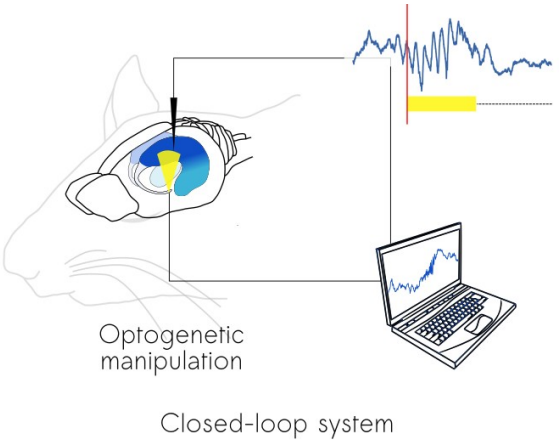
What are the dynamics of hippocampal cell assemblies of familiar or novel environments across initial exploration, sleep and re-exposure ?





Van de Ven 2016

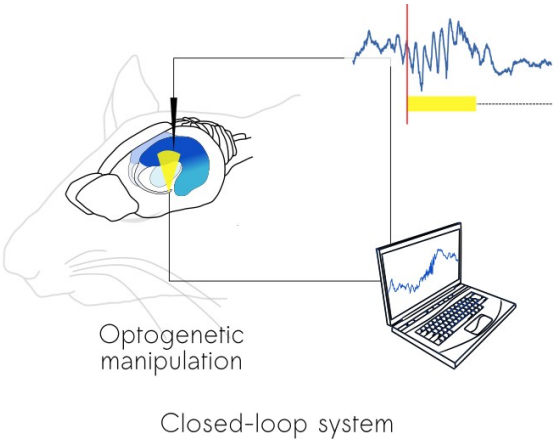
Assembly reactivation during sleep

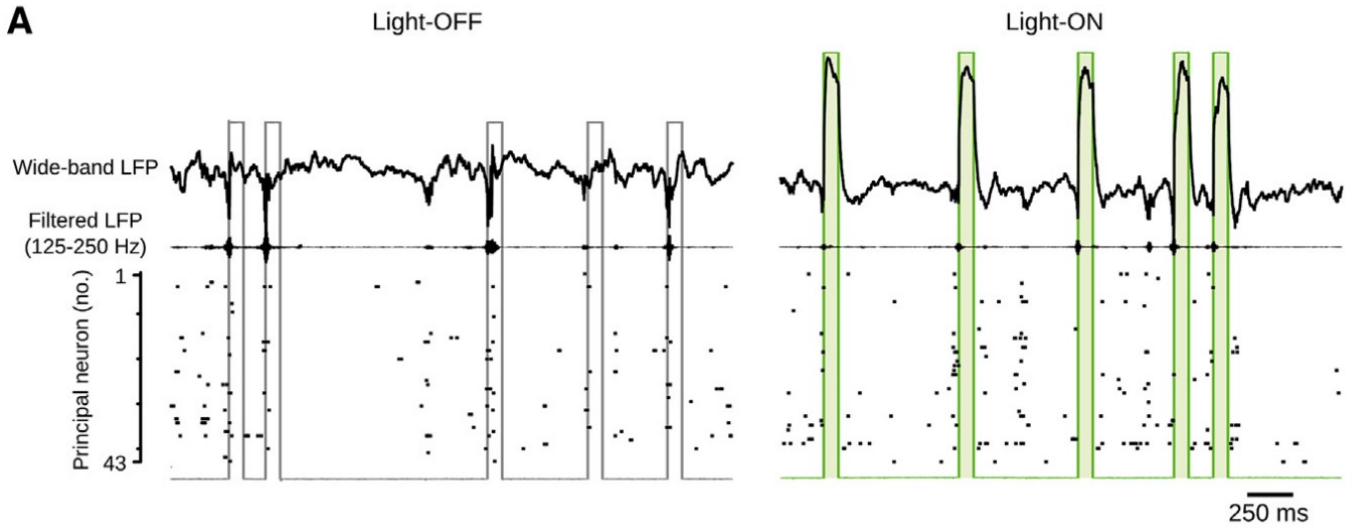


Closed-loop system

Van de Ven 2016

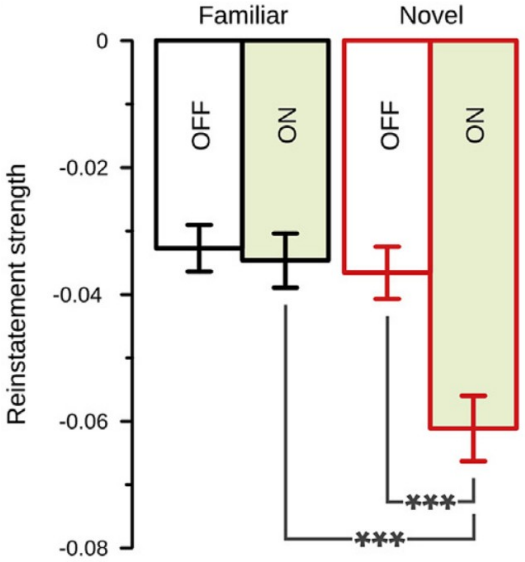
Assembly reactivation during sleep

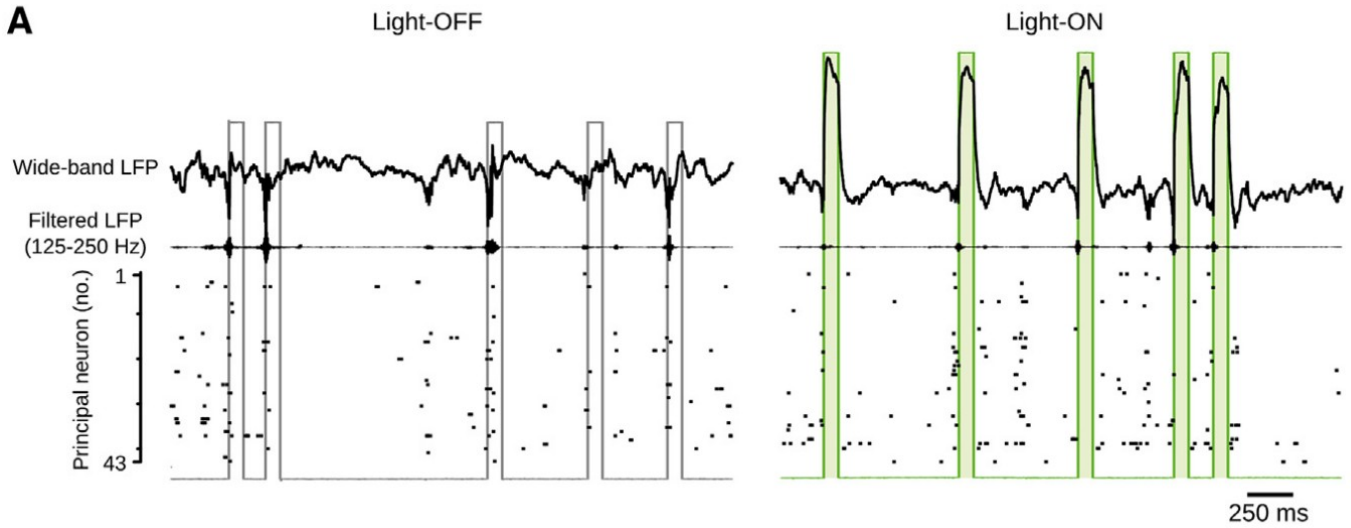




Van de Ven 2016

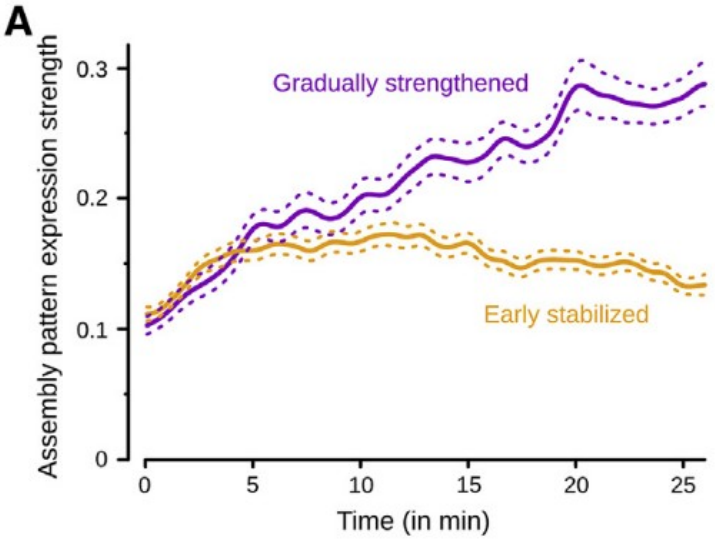
Assembly reactivation during sleep





Van de Ven 2016

Assembly dynamics over exposure to a new environment



Van de Ven 2016

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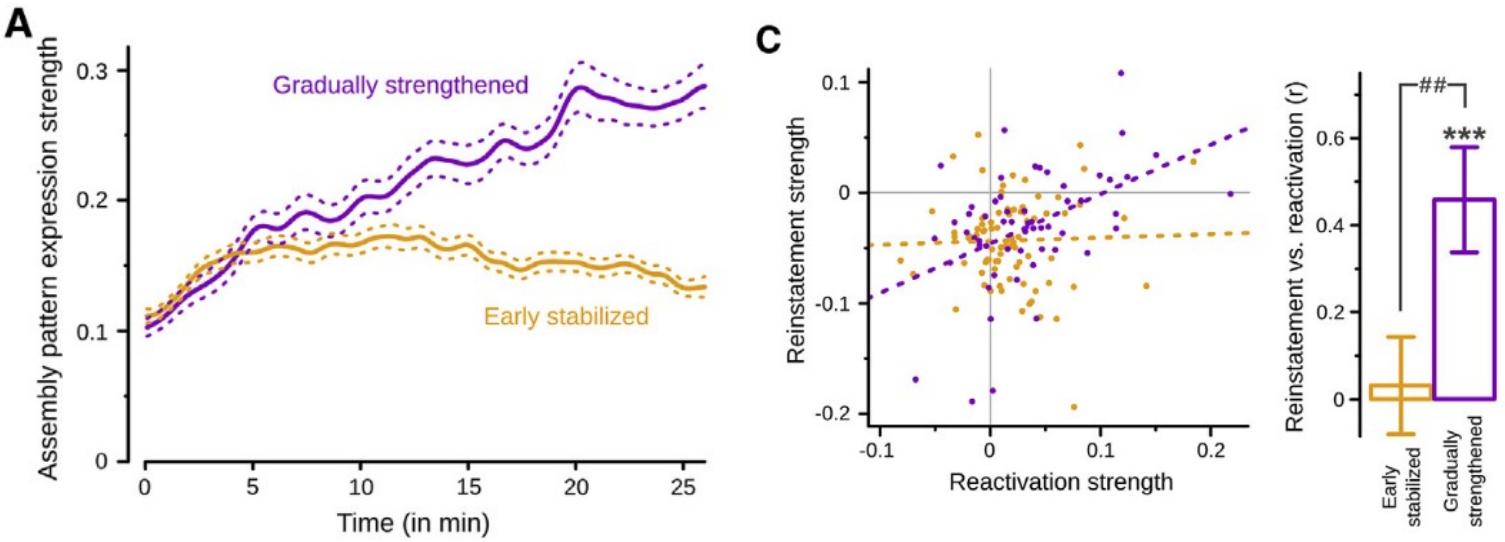
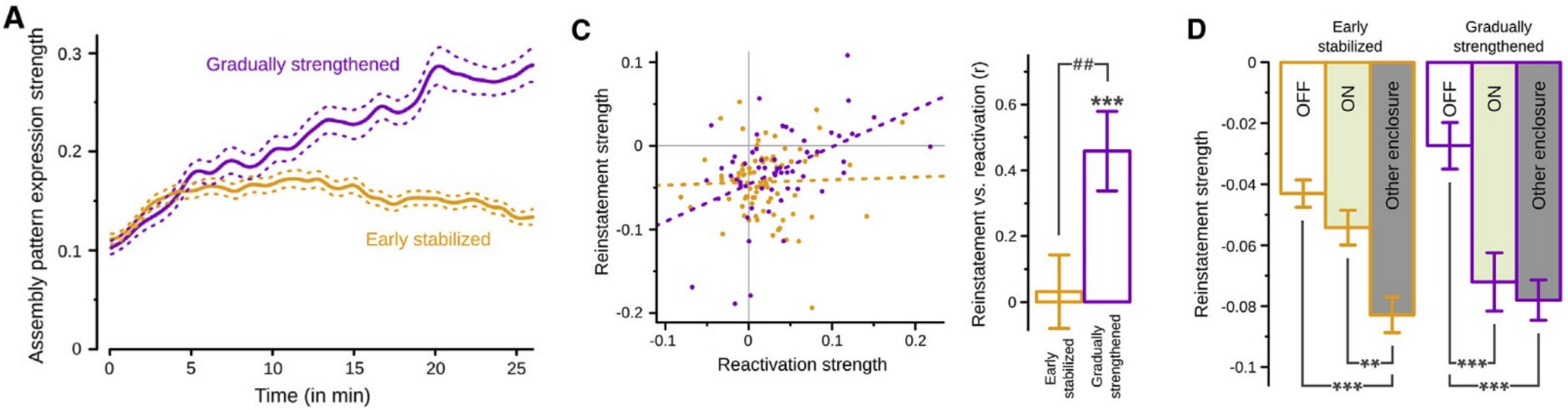


Track assembly early and reinstatement dynamics and link them to sleep reactivation

→ Functional heterogeneity in the representation space

Van de Ven 2016

Assembly dynamics over exposure to a new environment



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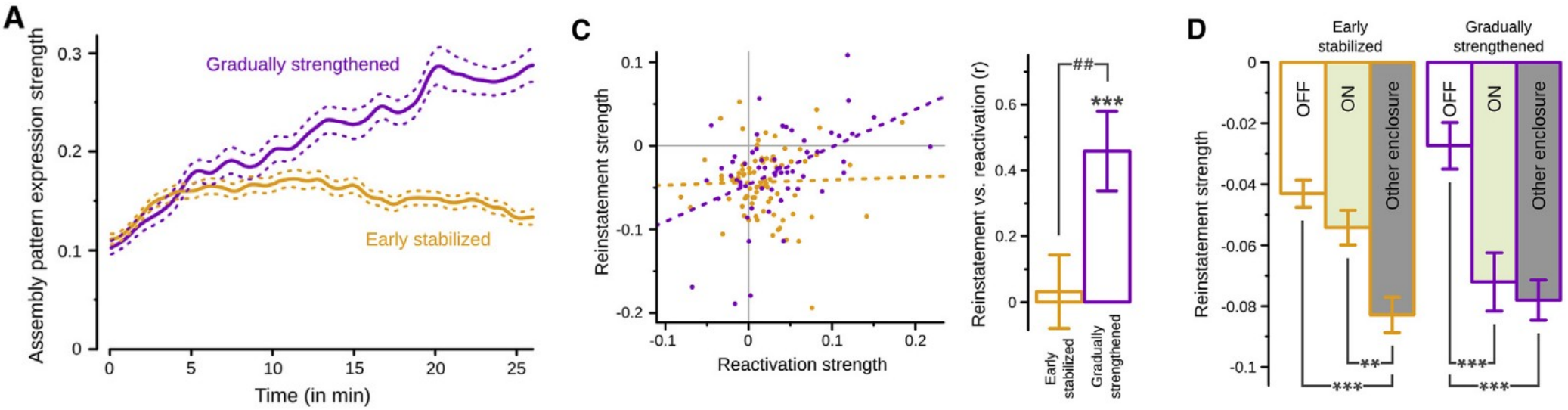
Van de Ven 2016

Assembly dynamics over exposure to a new environment



Track assembly early and reinstatement dynamics and link them to sleep reactivation

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Van de Ven 2016

Conclusion

- Dimensionality reduction is a powerful way to reveal and analyze hidden structure in large scale neural data
- It can also give us cues as to « how the brain works » i.e. how the information is encoded within neuronal networks
- Don't get over-enthusiastic and try to « kill a mosquito with a gun » : sometimes simple analysis are sufficient/best. The importance is to know what tools are available and choose the best one for your question
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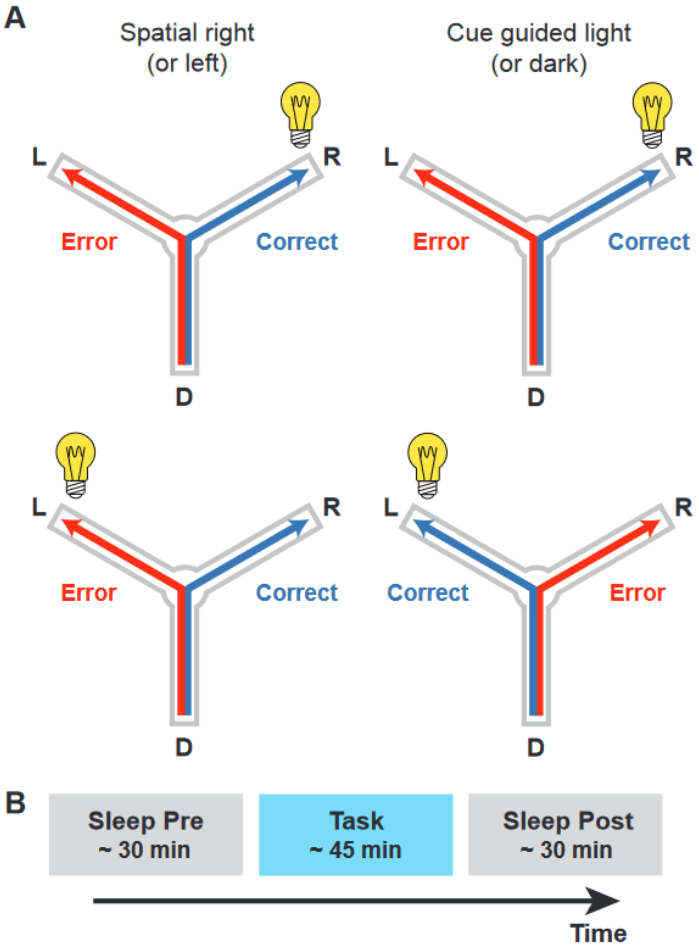
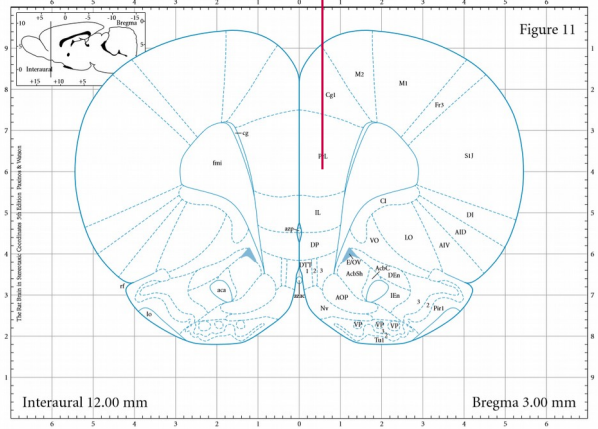
Thank you

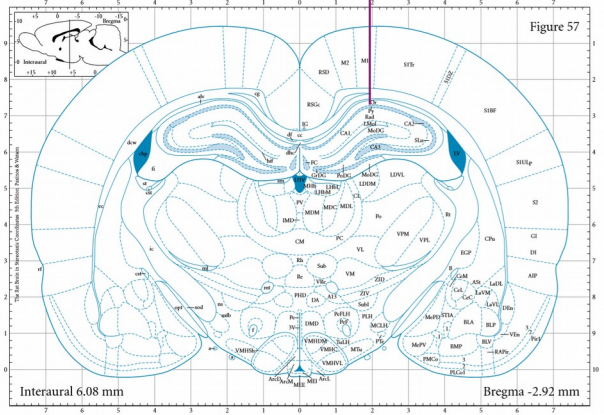
Methods for multi-structure reactivation : hippocampo-cortical coordination



LFP + units (n=1692)



LFP



Supplementaries