Precise Spatio-Temporal Spike Patterns in Macaque Motor Cortex during a Reach-to-Grasp Task

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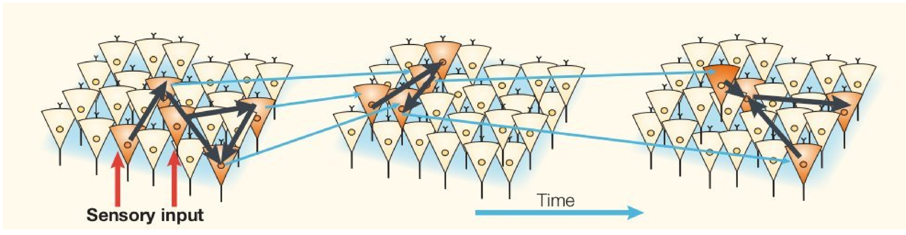
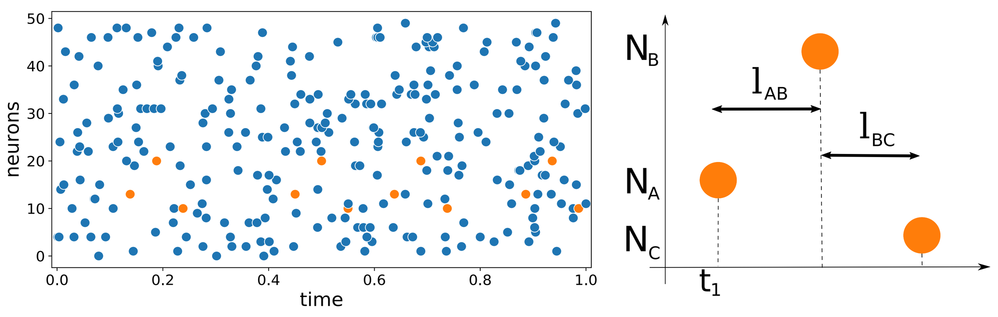
Context

Correlated activity between neurons is considered as a signature of the activation of a **cell assembly** [1], [3], thought to be responsible of the information processing in the brain.



Schematized representation of a cell assembly. Figure from [3].

We suppose that activations of a particular cell assembly are expressed by the repetitive occurrences of **precise spatio-temporal spike patterns** (STP) composed of member neurons of the cell assembly.



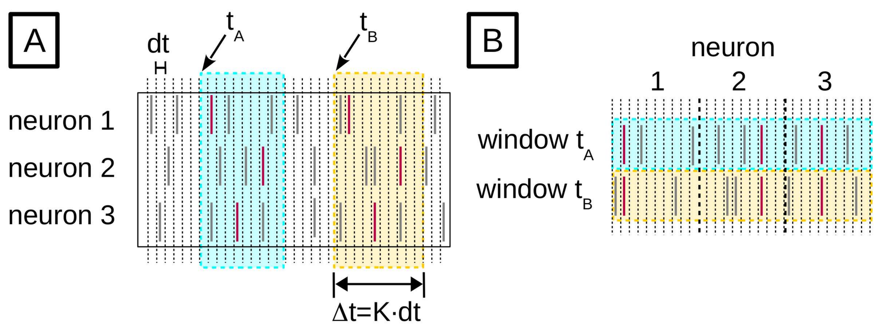
Left: Detection of STPs (in orange) among background spiking (in blue). Right: An STP is identified by the neurons spiking within the pattern, by the lags between the spikes, and by its occurrence times.

Methods

SPADE

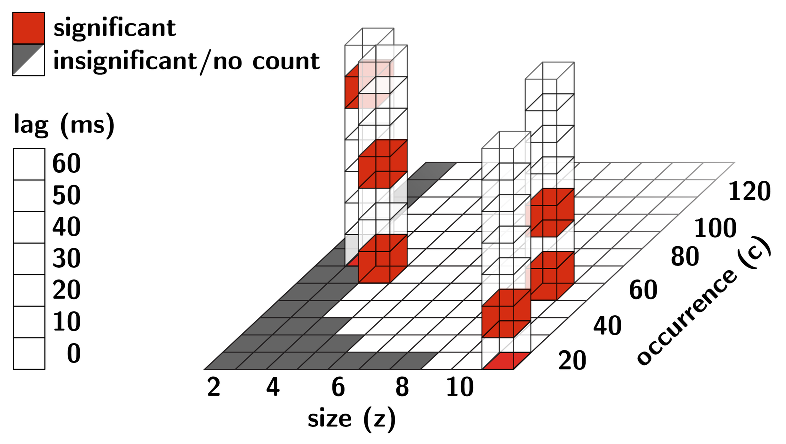
Spike PAttern Detection and Evaluation

SPADE [5], [6], [10] detects all possible repetitions of spike patterns with a mining technique called **Frequent Itemset Mining**.



Frequent Itemset Mining Figure adapted from [6].

The found and counted patterns are evaluated for their statistical significance by a bootstrap technique (**Pattern Spectrum Filtering**, below) employing the generation of surrogate data by spike dithering [2].



Pattern Spectrum Filtering. Figure adapted from [10].

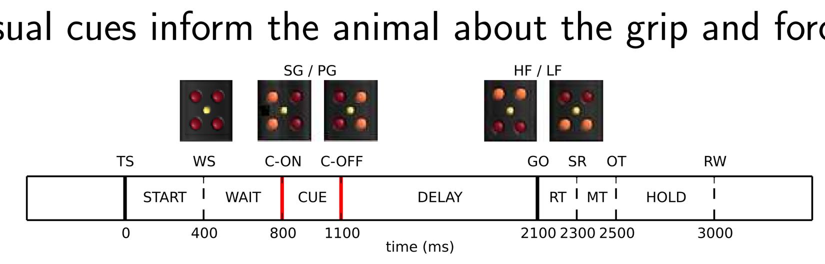
Experimental Data

Characteristics of the data set [9] analyzed by the method:

- **pre-/motor cortex** of two **macaque monkeys**
- activity recorded by a **10x10 Utah multielectrode array**
- monkeys are performing a **reach-to-grasp task**
- from **100 to 150** neurons recorded in parallel

Task:

- Reach an object and grasp it with side grip (SG) or precision grip (PG)
- Pull the object using high force (HF) or low force (LF) and hold it in a fixed position for 500ms
- Visual cues inform the animal about the grip and force



Scheme of the experimental paradigm. Figure from [8]

Conclusions

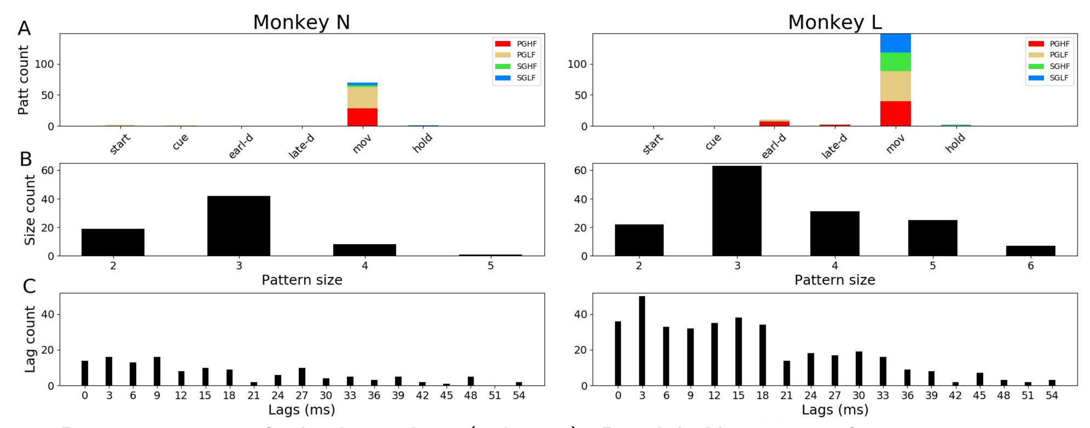
We analyzed experimental data with SPADE and detected **numerous significant STPs** occurring in relation to behavior. STPs occurred more frequently during the **movement period** than during the others. Furthermore, the patterns were **specific** to the experimental conditions (different grip and force type combinations) during movement, suggesting that **different assemblies are specifically activated during different behavioral contexts.**

Results: Spatio-Temporal Patterns in experimental data

Spatio-temporal pattern analysis:

- 4 analyzed sessions (2/monkey)
- 4 trial types (SGHF, SGLF, PGHF, PGLF)
- ~ 30 repeated trials per session
- Each trial segmented into 6 task-related epochs (500ms long) concatenated for each trial type and epoch
- Determine significant STPs for the 24 combinations of 6 epochs and 4 trial types (as previously done for synchronous patterns in [8])
- SPADE parameters: binsize $= 3ms$, window length $= 60ms$, $\alpha = 0.05$

Pattern statistics

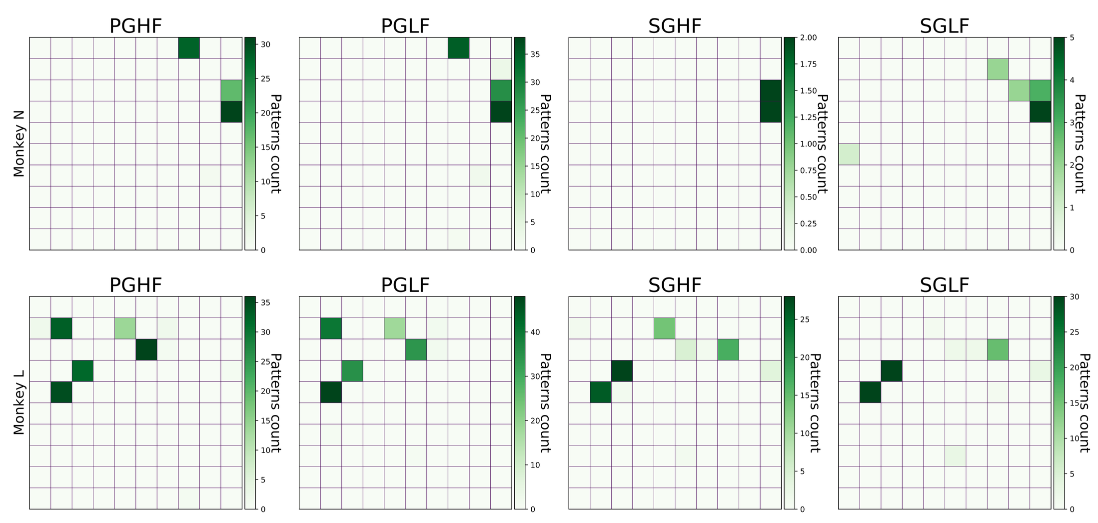


Pattern statistics for both monkeys (columns). Panel A. Histogram of pattern count in all behavioral epochs. Panel B, C Distribution of pattern size and pattern lags during the movement epoch.

Results of the analysis:

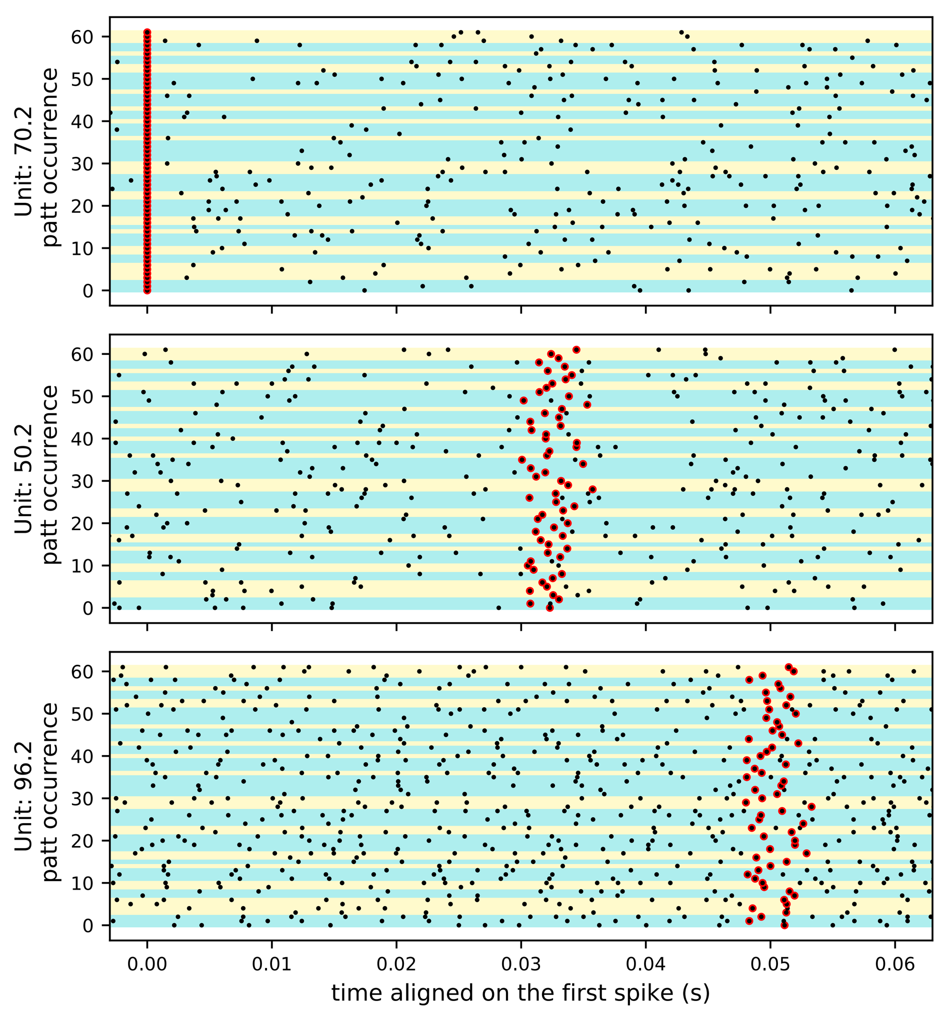
- Pattern statistics:
  - Significant patterns detected mostly during movement epoch
  - Significant patterns of different sizes (2 - 6)
  - Patterns exhibit a variety of lags
- Pattern occurrences:
  - Individual neurons often participate in multiple patterns
  - Individual spikes participate in different patterns
  - Patterns have strong overlap of participating neurons
  - Pattern rate is different for different grip types, but not for different force types
- Pattern spike alignment:
  - Pattern occurrences are equally distributed in time across trials in a single session

Spatial arrangement on the Utah Array



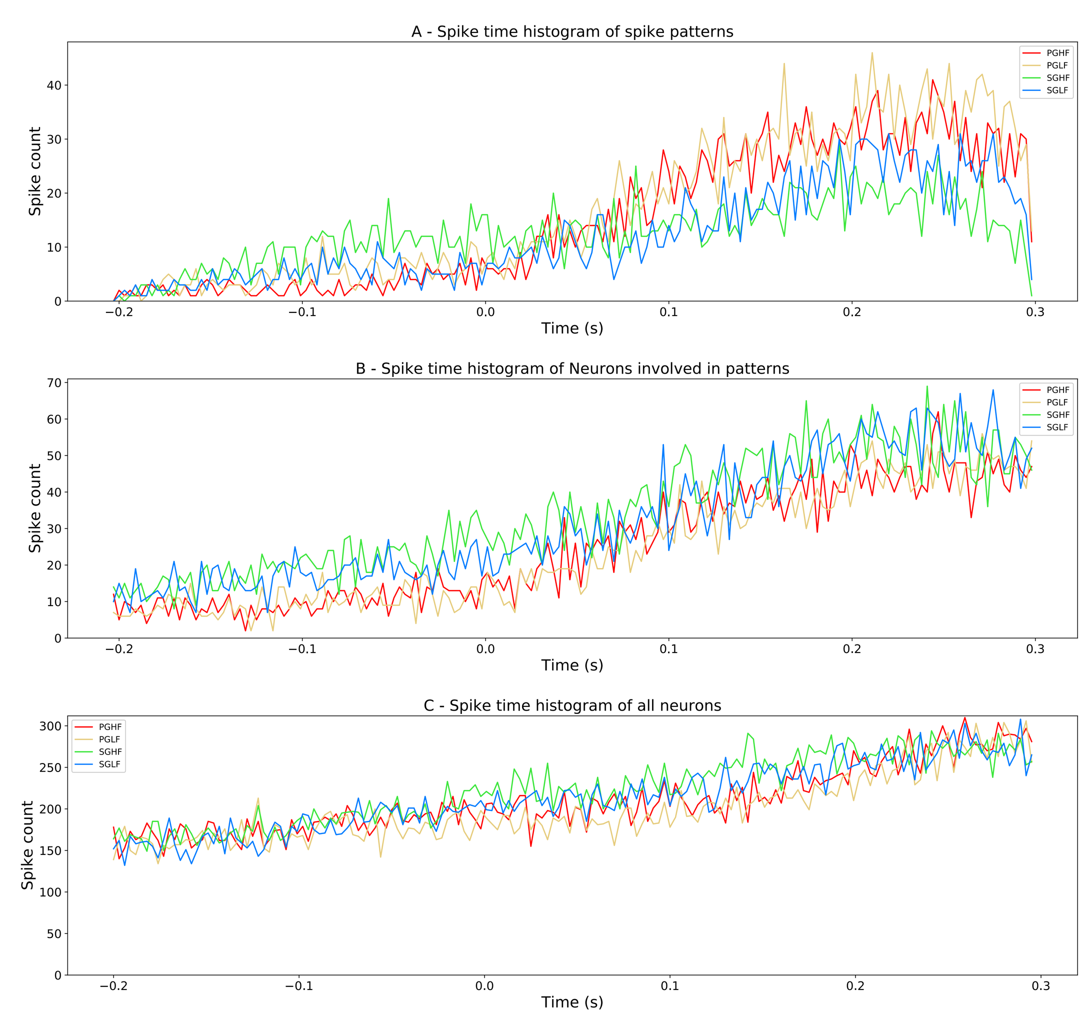
Count of number of patterns for each electrode in the Utah Array, for each monkey (rows) and trial type (columns).

Pattern spike alignment raster plot



Raster plot of one specific pattern of size 3 detected during the selected trial type and epoch (movement, PGHF) for monkey N. Pattern occurrences are aligned to the first spike of the pattern. Spikes belonging to the pattern are marked in red. Different colored bands represent the pattern occurrence within one trial. Trials are ordered along the y-axis.

PSTH of all and STP spikes



Spike count time histograms across the movement epoch for cases of A) spike belonging only to patterns, B) all spikes of neurons involved in patterns, C) all spikes from all neurons for session i140627-001.

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