General Explanations

A run counts as a false negative in the superset sense if neither the injected assembly nor a superset of it exists in the filtered/reduced pattern set. A run counts as a false negative in the exact sense if the injected assembly does not exist exactly in the filtered/reduced pattern set. The expression “all other patterns” refers to any sets of neurons that are not identical to the injected assembly (that is, proper supersets and proper subsets of the injected assembly, sets overlapping with the injected assembly, and sets unrelated to the injected assembly).

The bar charts show (1) the decimal logarithm of the average number of patterns found in surrogate data (independent Poisson processes); (2) the fraction of runs in which an injected assembly was not detected (neither exactly nor as a superset, false negatives in the superset sense); (3) the fraction of runs in which an injected assembly was not detected (false negatives in the exact sense); and (4) the fraction of runs in which any other pattern was reported, classified according to the size and the number of coincidences of the injected assembly.

For a more detailed analysis, (non-exact) detections (that is, any patterns other than the injected assembly itself) are categorized into four classes: (1) superset patterns: the pattern is a proper superset of the injected assembly (that is, all neurons of the injected assembly are present and there is at least one additional neuron, a so-called “excess neuron”); (2) subset patterns: the pattern is a proper subset of the injected assembly (that is, at least one neuron of the assembly is missing); (3) overlap patterns: the pattern contains at least *two*, but not all neurons from the injected assembly and at least one other neuron; (4) unrelated patterns: patterns that have none or at most one neuron in common with the injected assembly. The bar charts corresponding to these pattern categories show the decimal logarithm of the average number of patterns found in a run, classified according to the size and the number of coincidences of the injected assembly. The reason for allowing unrelated patterns to share *one* neuron with the injected assembly is that the assembly activity only increases the chance of coincident spiking events of patterns that share at least two neurons with the assembly, because only then the coincidences of the assembly can have an influence on the chance of coincidences of the overlapping pattern.

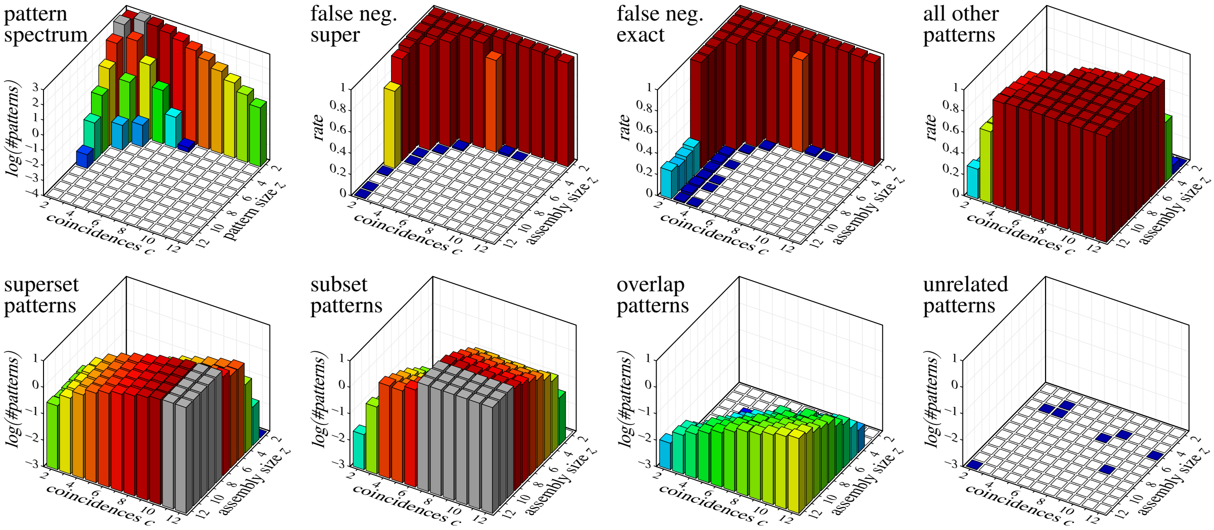
It should be noted that only the unrelated patterns are true false positives. All other pattern types are induced by the injected assembly and occur due to (1) one or more neurons outside the injected assembly accidentally firing together with a few of the coincident spiking events of the injected assembly (superset patterns); (2) neurons in a subset of the injected assembly firing together one or more times in addition to the coincident spiking events of the injected assembly due to background spiking (subset patterns); (3) like 2, but with one or more neurons outside of the injected assembly firing together with a few of the coincident spiking events of the injected assembly and at least one of the additional spiking events of the subset created by background spiking (overlap patterns).

Parameters:
20Hz firing rate for all neurons (corrected for injected coincident spikes).
3s recording period, discretized with time bins of 3, 4, or 5ms.
10,000 surrogate data sets for the frequent pattern bar chart.
1000 runs for each bar of the other bar charts.

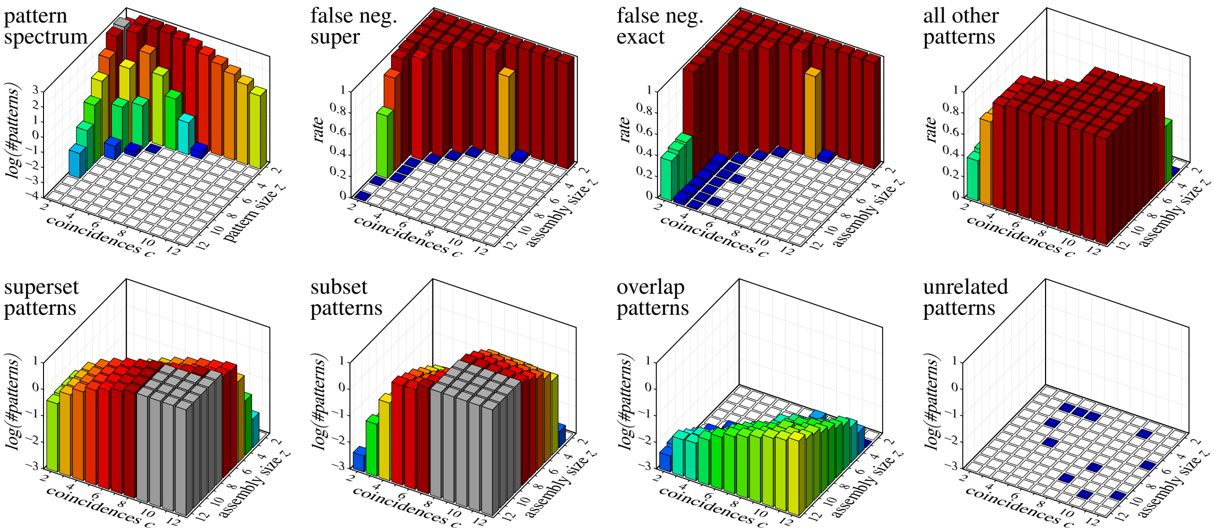
No Pattern Set Reduction

Let $\mathcal{S}$ be the set of signatures that occur in the surrogates. All patterns that are left over after primary pattern filtering are kept, that is, all patterns remaining after removing all sets I with signatures $\langle z_I, c_I \rangle = \langle |I|, s(I) \rangle \in \mathcal{S}$.

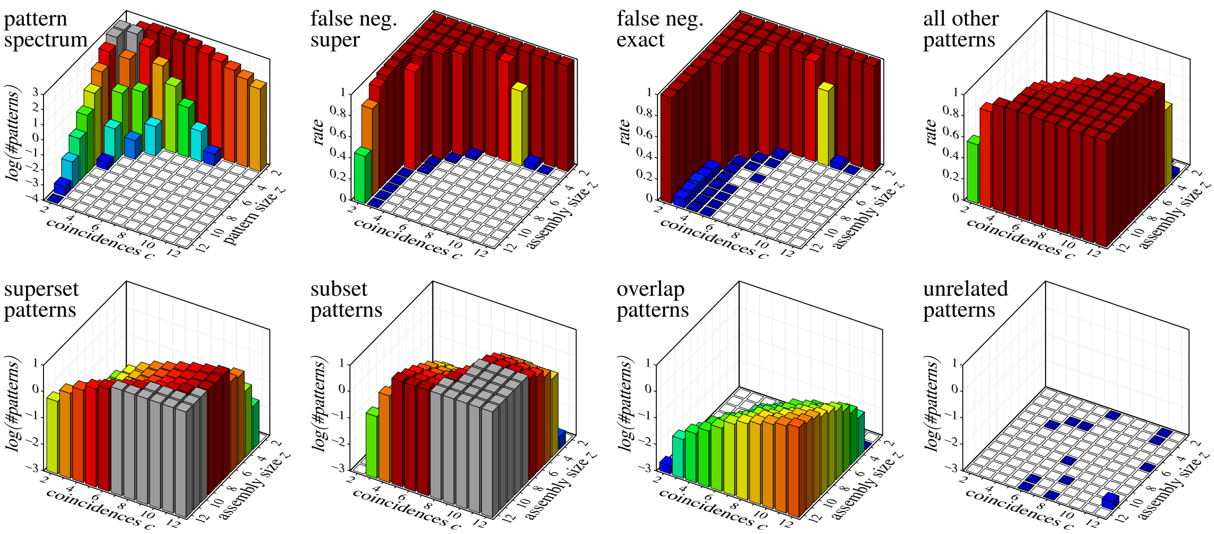
1000×3ms bins, filtered with surrogate data



750×4ms bins, filtered with surrogate data



600×5ms bins, filtered with surrogate data



Pattern Set Reduction with Excess Coincidences 1

Let $\mathcal{S}$ be the set of signatures that occur in the surrogates. Let A and B with $B \subset A$ be two sets left over after primary pattern filtering, that is, after removing all sets I with signatures $\langle z_I, c_I \rangle = \langle |I|, s(I) \rangle \in \mathcal{S}$, and therefore $\langle z_A, c_A \rangle \notin \mathcal{S}$ and $\langle z_B, c_B \rangle \notin \mathcal{S}$.

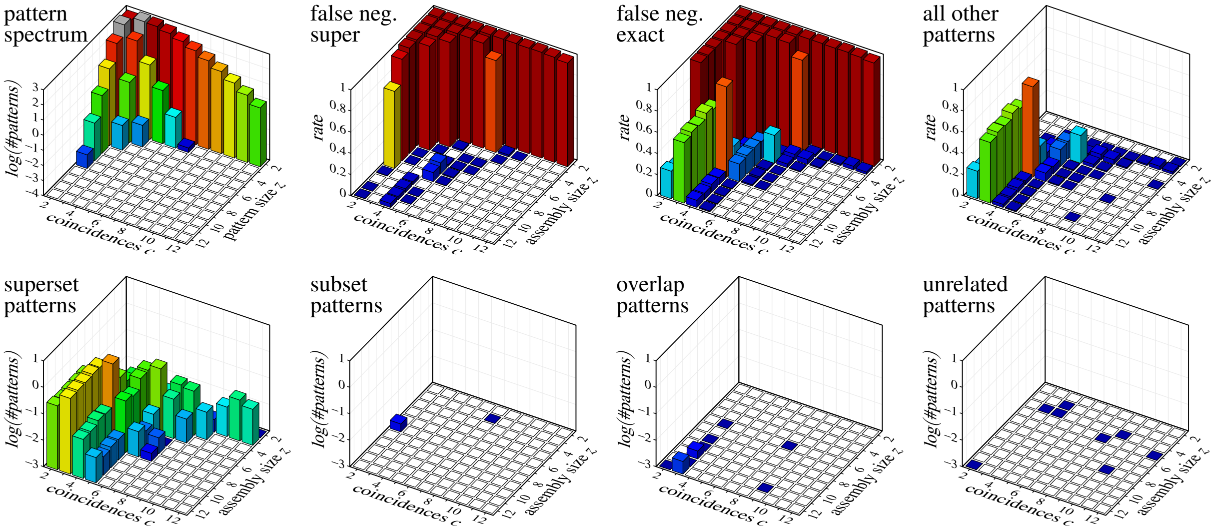
The set A is *preferred* to the set B iff

- $\langle z_B, c_B - c_A \rangle = \langle |B|, s(B) - s(A) \rangle \in \mathcal{S}$.

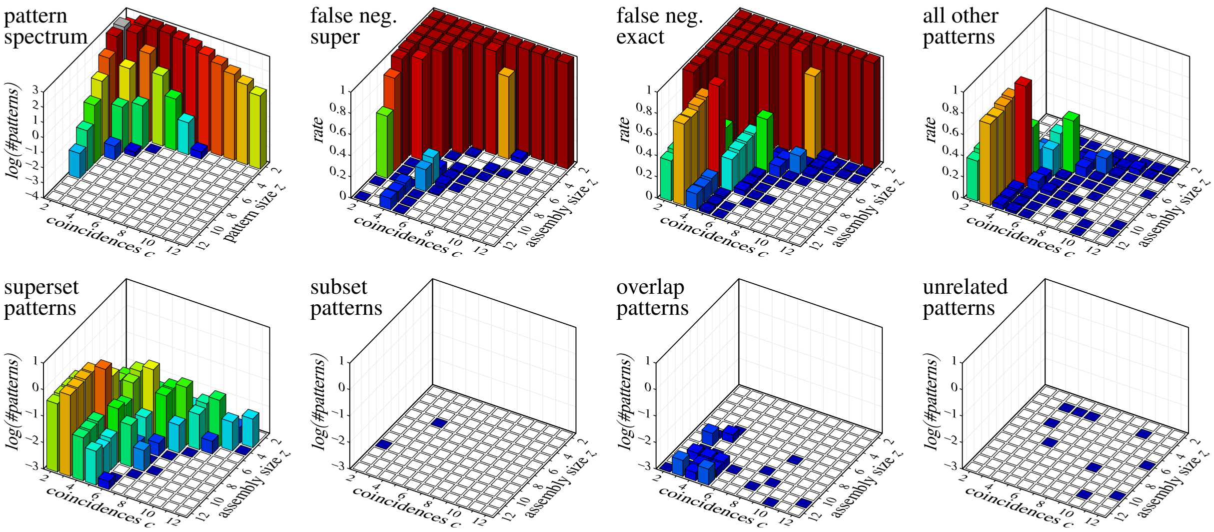
Otherwise B is preferred to A. In other words: A is preferred to B only if the excess coincidences of B can be explained (heuristically) as chance events.

Pattern set reduction keeps only sets for which there exists no subset and no superset that is preferred to them.

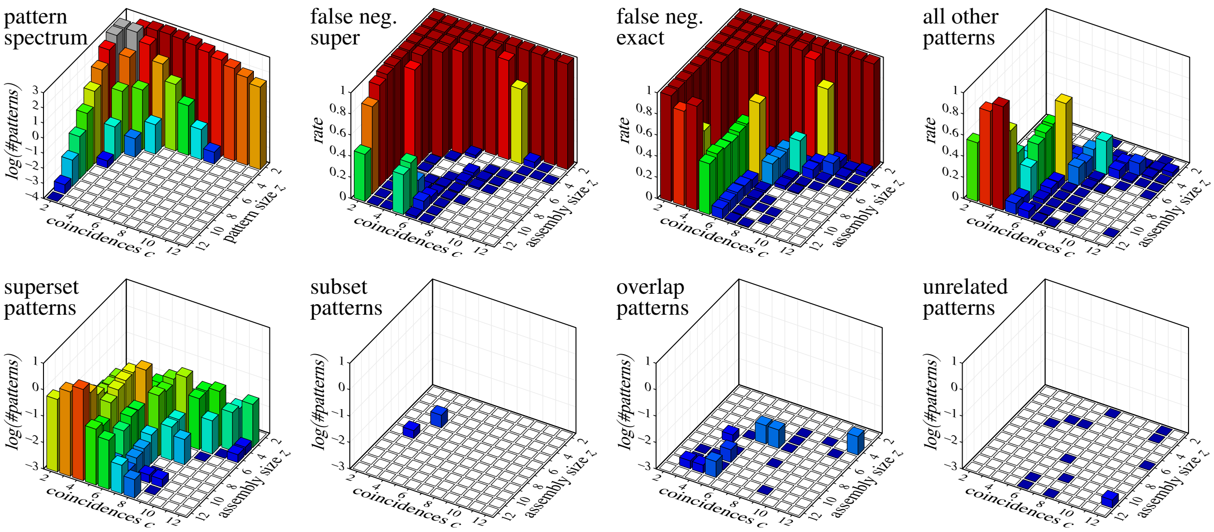
1000×3ms bins, reduced with excess coincidences 1



750×4ms bins, reduced with excess coincidences 1



600×5ms bins, reduced with excess coincidences 1



Pattern Set Reduction with Excess Coincidences 2

Let $\mathcal{S}$ be the set of signatures that occur in the surrogates. Let A and B with $B \subset A$ be two sets left over after primary pattern filtering, that is, after removing all sets I with signatures $\langle z_I, c_I \rangle = \langle |I|, s(I) \rangle \in \mathcal{S}$, and therefore $\langle z_A, c_A \rangle \notin \mathcal{S}$ and $\langle z_B, c_B \rangle \notin \mathcal{S}$.

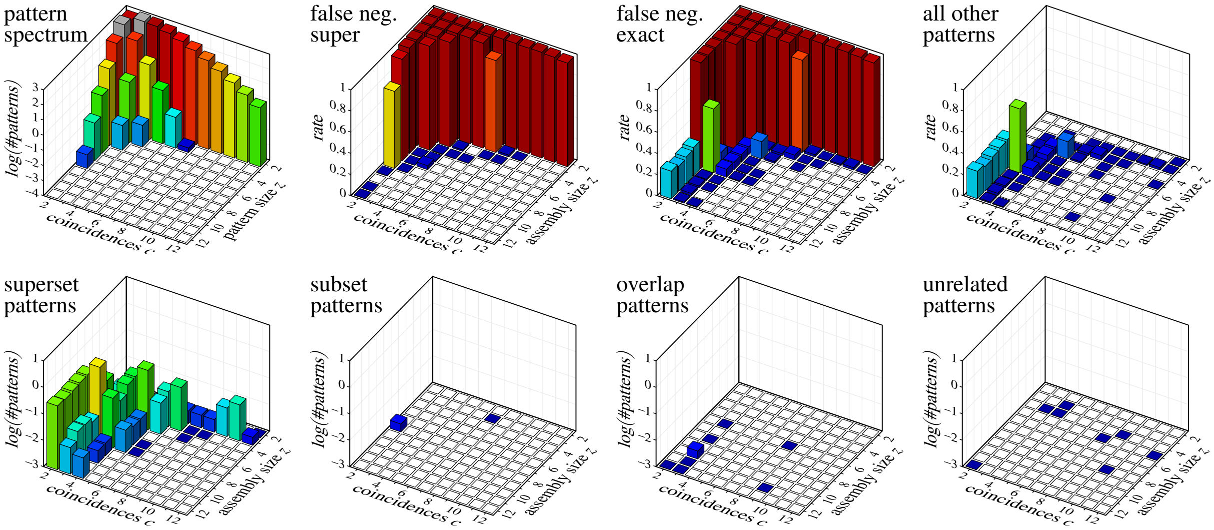
The set A is *preferred* to the set B iff

- $\langle z_B, c_B - c_A + 1 \rangle = \langle |B|, s(B) - s(A) + 1 \rangle \in \mathcal{S}$.

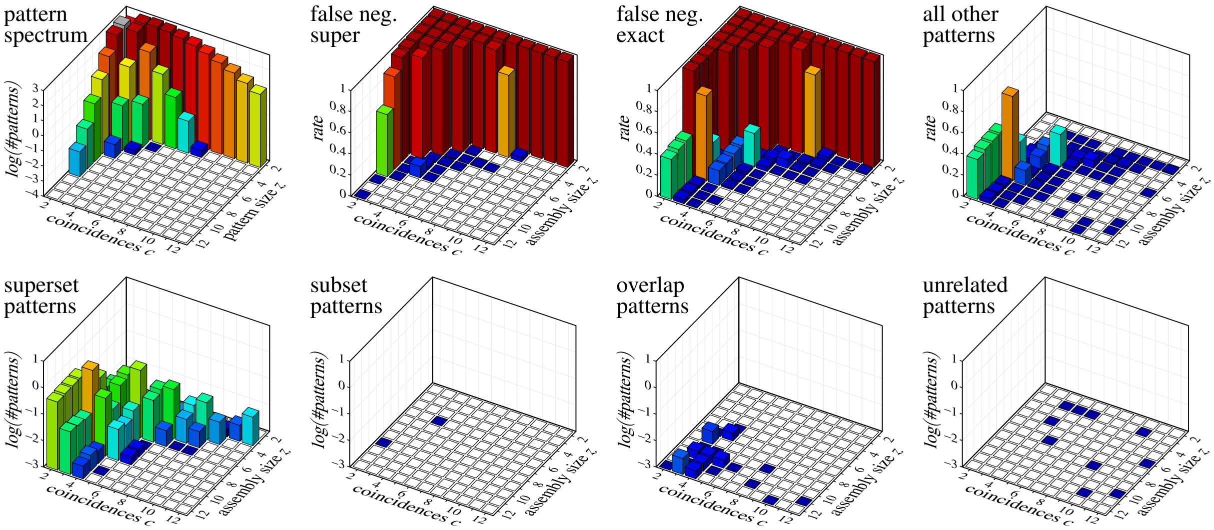
Otherwise B is preferred to A. In other words: A is preferred to B only if the excess coincidences of B can be explained (heuristically) as chance events.

Pattern set reduction keeps only sets for which there exists no subset and no superset that is preferred to them.

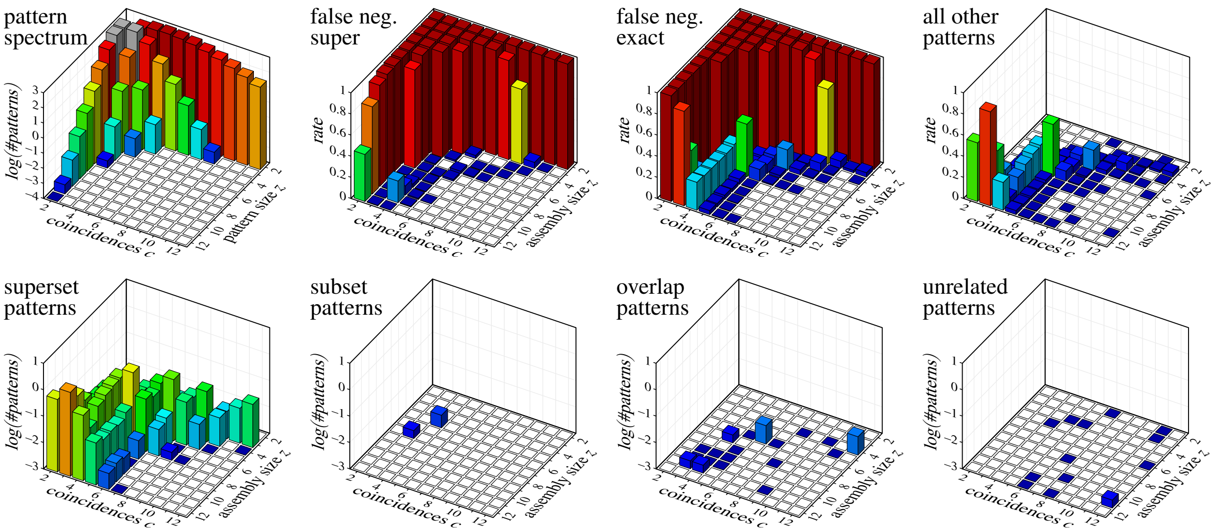
1000×3ms bins, reduced with excess coincidences 2



750×4ms bins, reduced with excess coincidences 2



600×5ms bins, reduced with excess coincidences 2



Pattern Set Reduction with Excess Neurons

Let $\mathcal{S}$ be the set of signatures that occur in the surrogates. Let A and B with $B \subset A$ be two sets left over after primary pattern filtering, that is, after removing all sets I with signatures $\langle z_I, c_I \rangle = \langle |I|, s(I) \rangle \in \mathcal{S}$, and therefore $\langle z_A, c_A \rangle \notin \mathcal{S}$ and $\langle z_B, c_B \rangle \notin \mathcal{S}$.

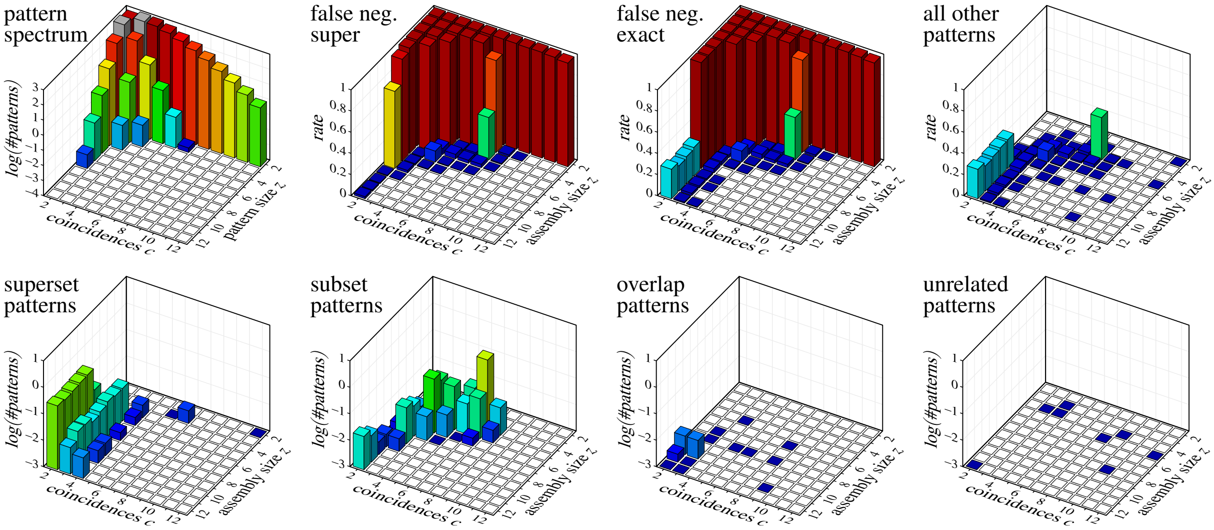
The set B is *preferred* to the set A iff

- $\langle z_A - z_B + 2, c_A \rangle = \langle |A| - |B| + 2, s(A) \rangle \in \mathcal{S}$.

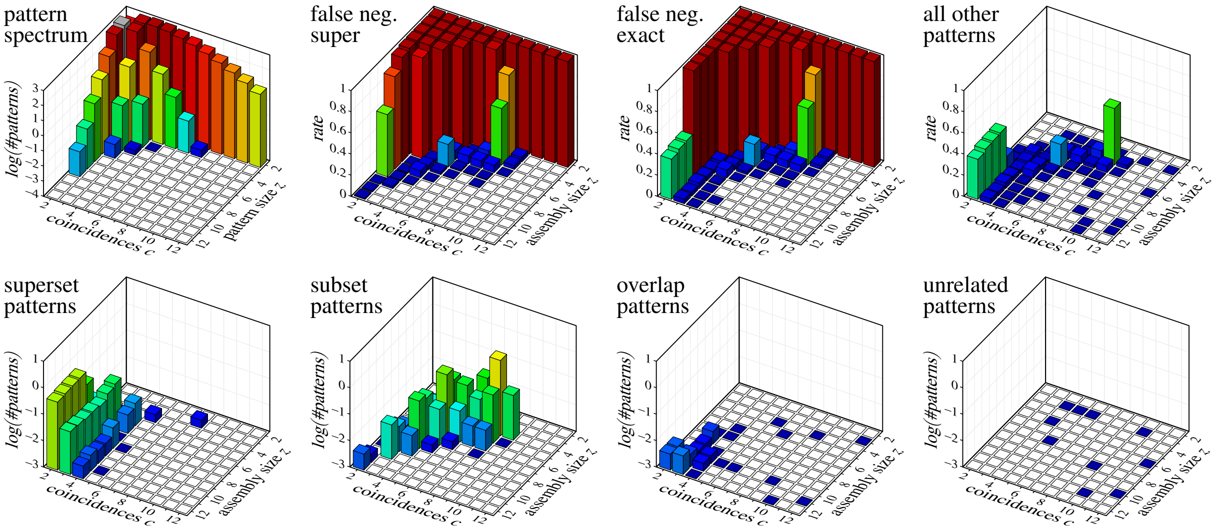
Otherwise A is preferred to B. In other words: B is preferred to A only if the excess neurons of A can be explained (heuristically) as chance events.

Pattern set reduction keeps only sets for which there exists no subset and no superset that is preferred to them.

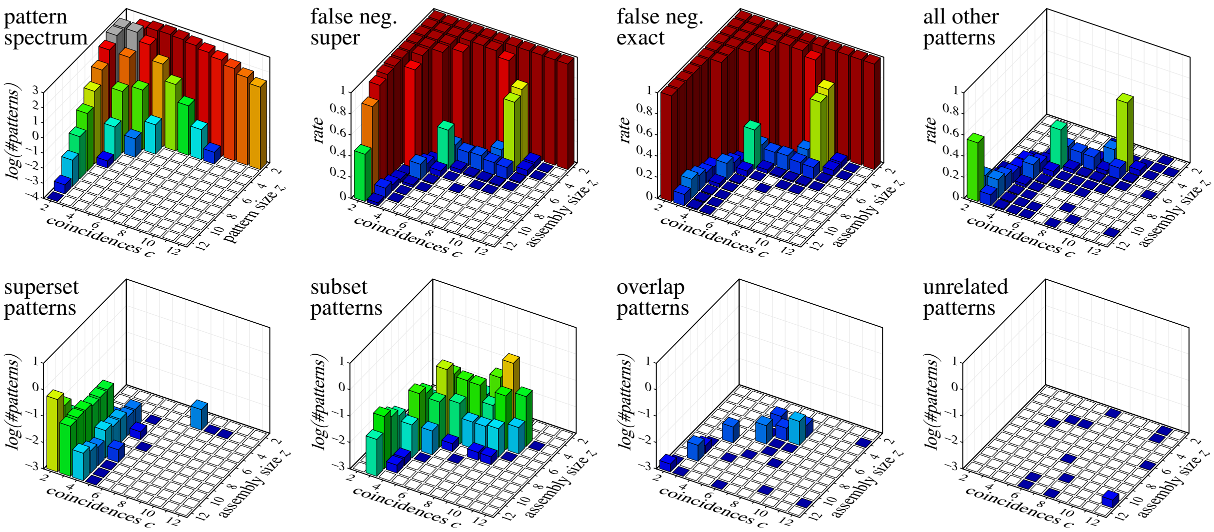
1000×3ms bins, reduced with excess neurons



750×4ms bins, reduced with excess neurons



600×5ms bins, reduced with excess neurons



Reduction with Number of Covered Spikes 1

Let $\mathcal{S}$ be the set of signatures that occur in the surrogates. Let A and B with $B \subset A$ be two sets left over after primary pattern filtering, that is, after removing all sets I with signatures $\langle z_I, c_I \rangle = \langle |I|, s(I) \rangle \in \mathcal{S}$, and therefore $\langle z_A, c_A \rangle \notin \mathcal{S}$ and $\langle z_B, c_B \rangle \notin \mathcal{S}$.

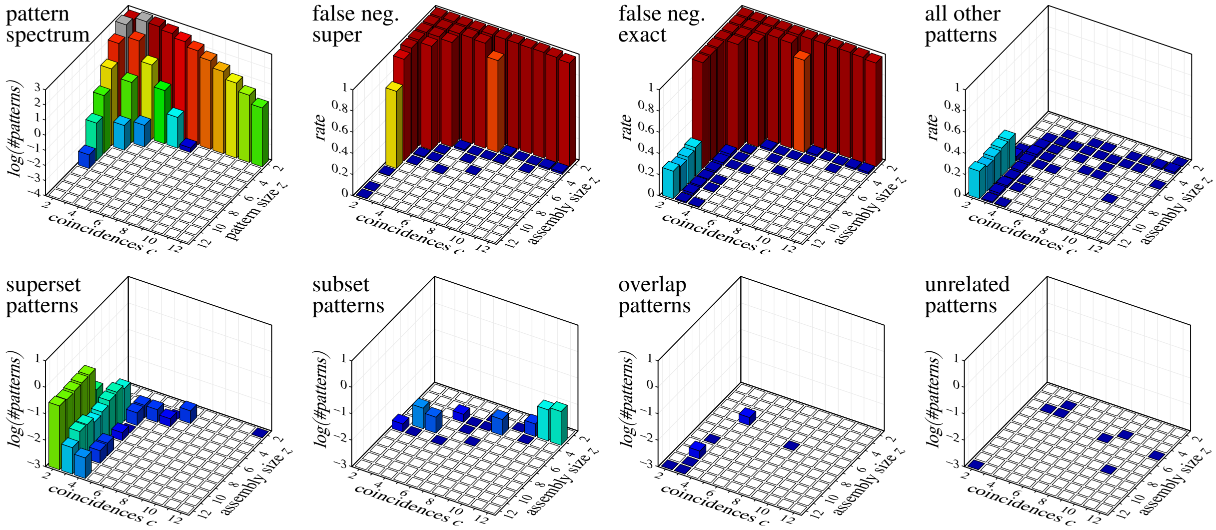
The set A is *preferred* to the set B iff

- $z_A c_A \geq z_B c_B$.

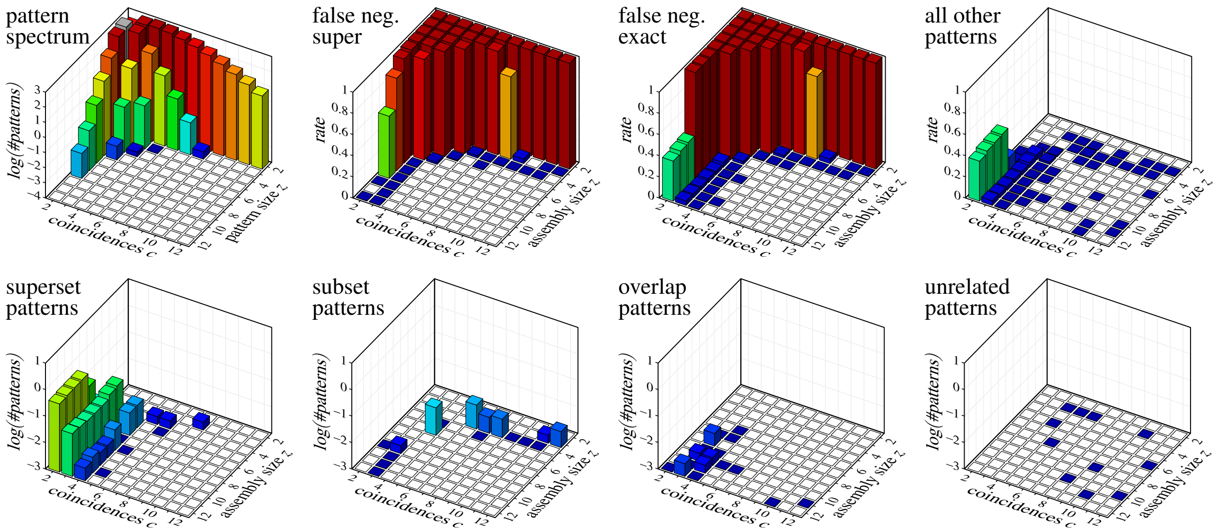
Otherwise B is preferred to A. In other words: A is preferred to B only if it covers at least as many spikes as B (assuming that more covered spikes make a pattern less likely to occur by chance).

Pattern set reduction keeps only sets for which there exists no subset and no superset that is preferred to them.

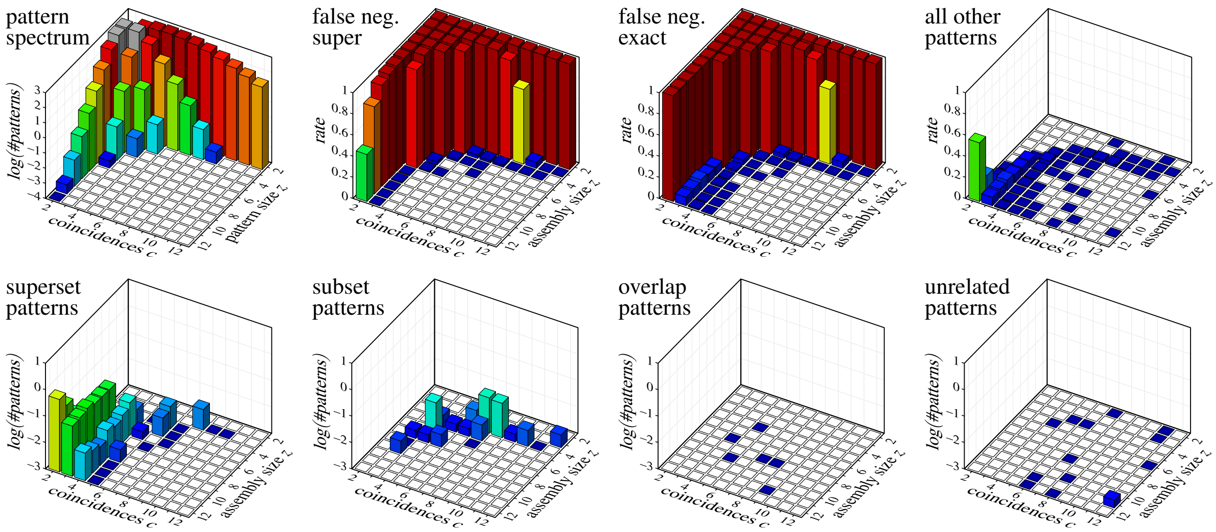
1000×3ms bins, reduced with number of covered spikes 1



750×4ms bins, reduced with number of covered spikes 1



600×5ms bins, reduced with number of covered spikes 1



Reduction with Number of Covered Spikes 2

Let $\mathcal{S}$ be the set of signatures that occur in the surrogates. Let A and B with $B \subset A$ be two sets left over after primary pattern filtering, that is, after removing all sets I with signatures $\langle z_I, c_I \rangle = \langle |I|, s(I) \rangle \in \mathcal{S}$, and therefore $\langle z_A, c_A \rangle \notin \mathcal{S}$ and $\langle z_B, c_B \rangle \notin \mathcal{S}$.

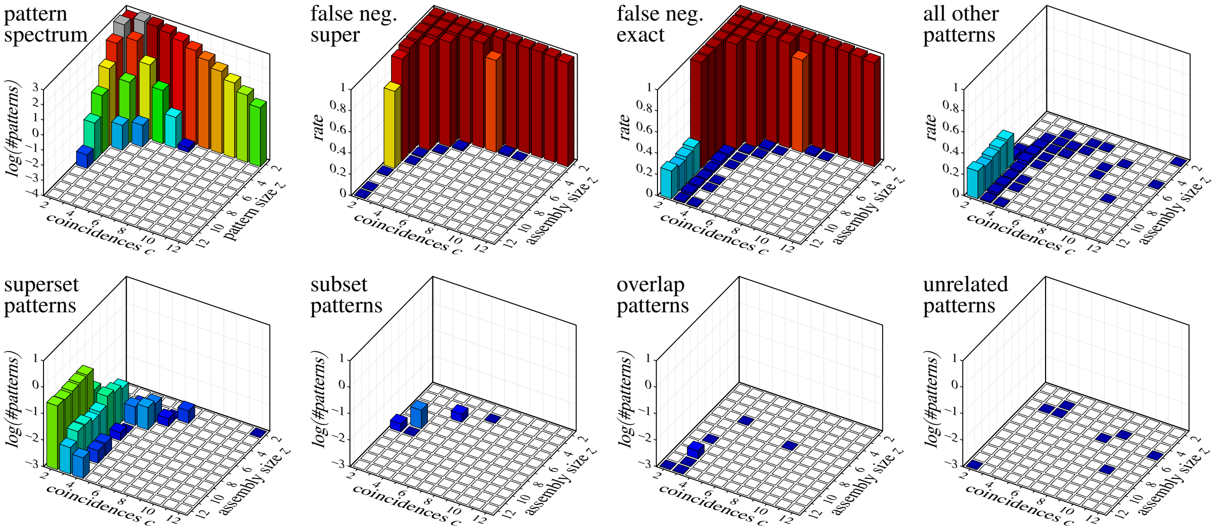
The set A is *preferred* to the set B iff

- $(z_A - 1)c_A \geq (z_B - 1)c_B$.

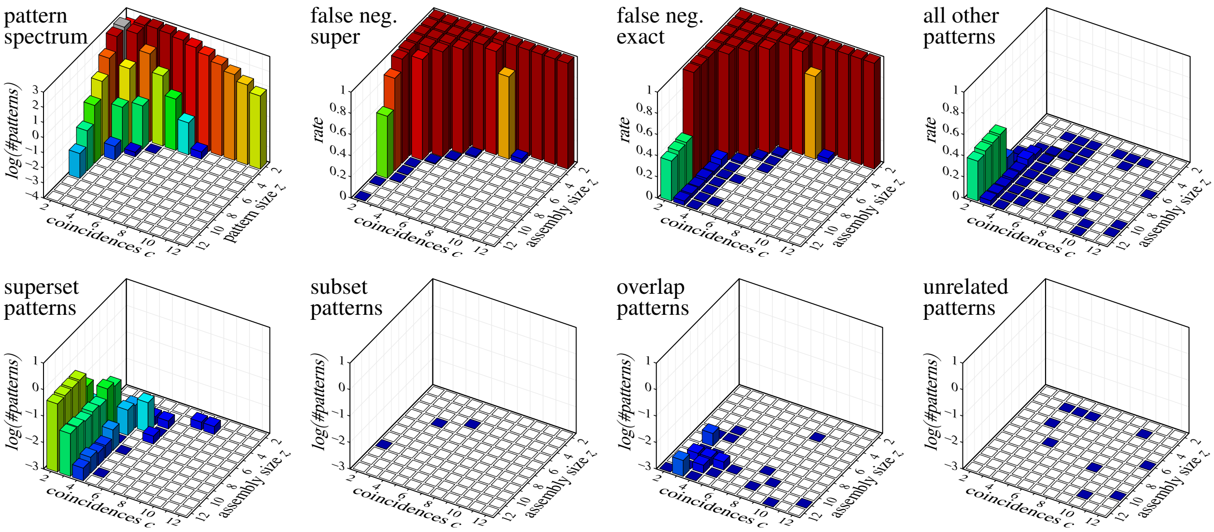
Otherwise B is preferred to A. In other words: A is preferred to B only if it covers at least as many "coincident" spikes as B (assuming that spikes, in order to be coincident, need a reference to be coincident to, which itself should not be counted).

Pattern set reduction keeps only sets for which there exists no subset and no superset that is preferred to them.

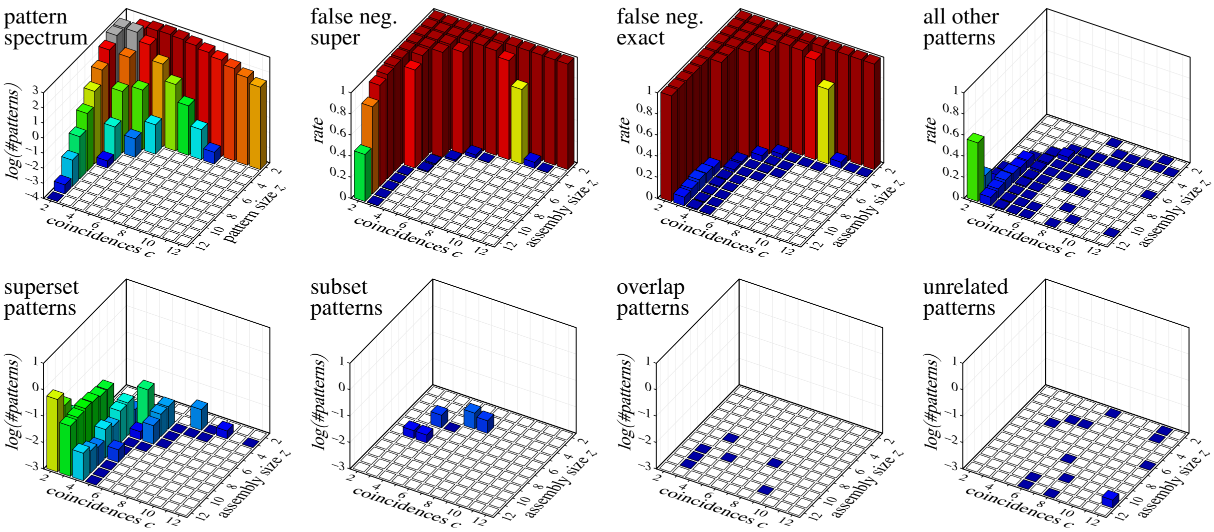
1000×3ms bins, reduced with number of covered spikes 2



750×4ms bins, reduced with number of covered spikes 2



600×5ms bins, reduced with number of covered spikes 2



Reduction with Excess Coincidences and Excess Neurons 1

Let $\mathcal{S}$ be the set of signatures that occur in the surrogates. Let A and B with $B \subset A$ be two sets left over after primary pattern filtering, that is, after removing all sets I with signatures $\langle z_I, c_I \rangle = \langle |I|, s(I) \rangle \in \mathcal{S}$, and therefore $\langle z_A, c_A \rangle \notin \mathcal{S}$ and $\langle z_B, c_B \rangle \notin \mathcal{S}$.

The set A is *preferred* to the set B iff $\langle z_B, c_B - c_A + 1 \rangle = \langle |B|, s(B) - s(A) + 1 \rangle \in \mathcal{S}$ and

- $\langle z_A - z_B + 2, c_A \rangle = \langle |A| - |B| + 2, s(A) \rangle \notin \mathcal{S}$ or $z_A c_A \geq z_B c_B$.

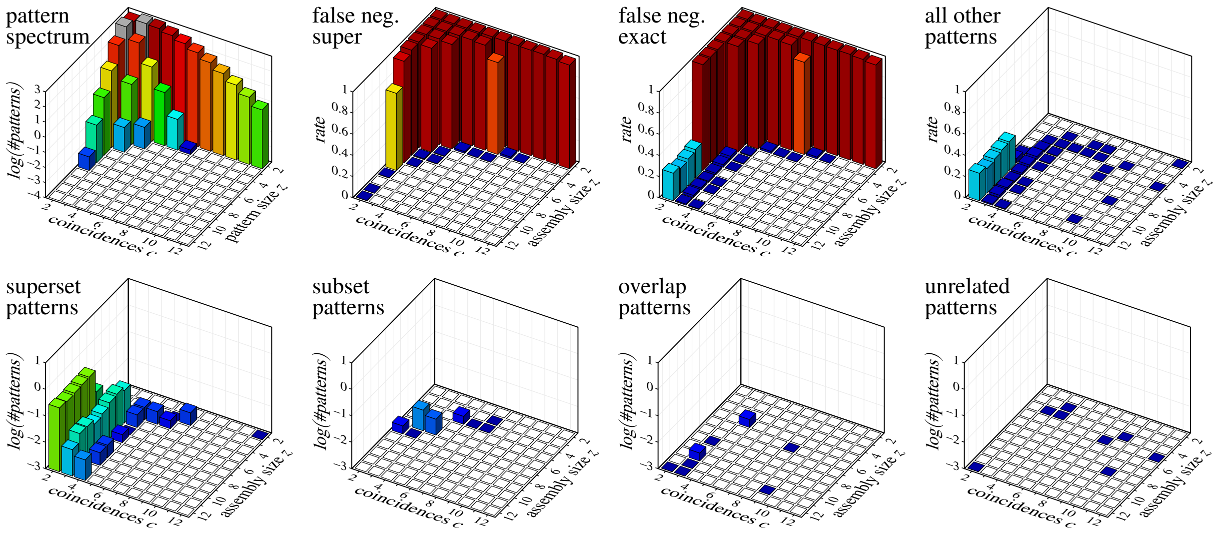
The set B is *preferred* to the set A iff $\langle z_A - z_B + 2, c_A \rangle = \langle |A| - |B| + 2, s(A) \rangle \in \mathcal{S}$ and

- $\langle z_B, c_B - c_A + 1 \rangle = \langle |B|, s(B) - s(A) + 1 \rangle \notin \mathcal{S}$ or $z_A c_A < z_B c_B$.

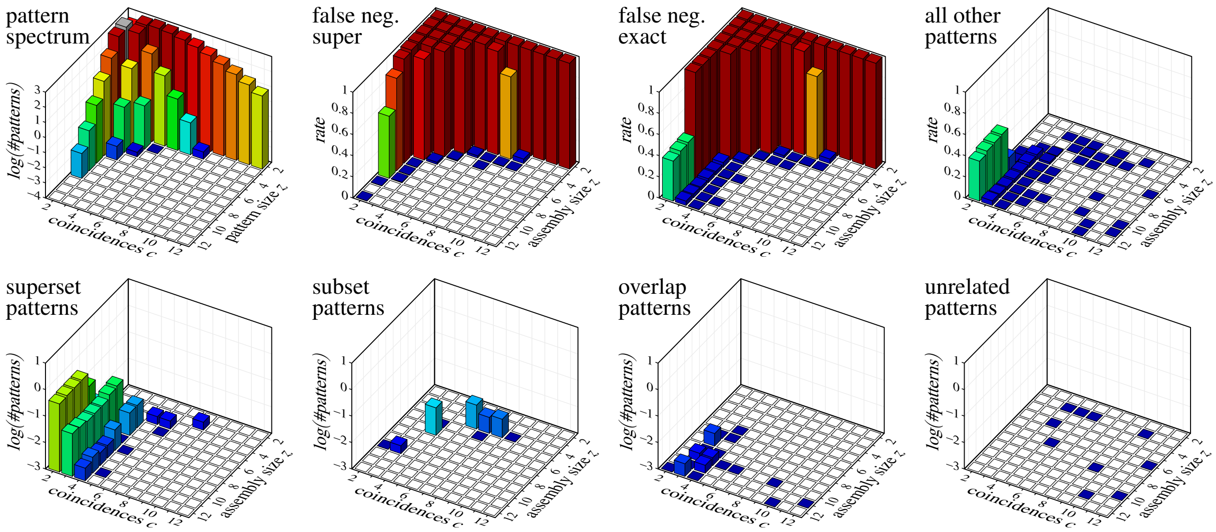
Otherwise A and B are not comparable (that is, neither is preferred to the other). In other words: A is preferred to B if the excess coincidences of B can be explained (heuristically) as chance events, but the excess neurons in A cannot be explained (heuristically) as chance events. Analogously, B is preferred to A if the excess neurons of A can be explained (heuristically) as chance events, but the excess coincidences of B cannot be explained (heuristically) as chance events. If both the excess neurons of A *and* the excess coincidences of B can be explained as chance events, the number of covered spikes is invoked as a secondary criterion to make a decision. Finally, if neither the excess neurons of A nor the excess coincidences of B can be explained (heuristically) as chance events, no preference relation is established.

Pattern set reduction keeps only sets for which there exists no subset and no superset that is preferred to them.

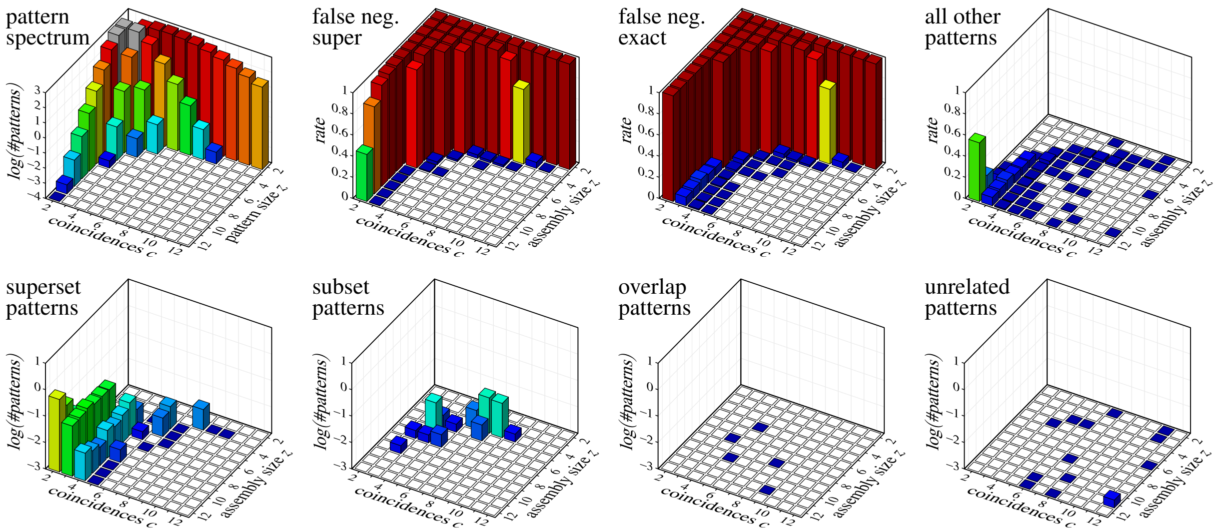
1000×3ms bins, reduced with excess coincidences and neurons 1



750×4ms bins, reduced with excess coincidences and neurons 1



600×5ms bins, reduced with excess coincidences and neurons 1



Reduction with Excess Coincidences and Excess Neurons 2

Let $\mathcal{S}$ be the set of signatures that occur in the surrogates. Let A and B with $B \subset A$ be two sets left over after primary pattern filtering, that is, after removing all sets I with signatures $\langle z_I, c_I \rangle = \langle |I|, s(I) \rangle \in \mathcal{S}$, and therefore $\langle z_A, c_A \rangle \notin \mathcal{S}$ and $\langle z_B, c_B \rangle \notin \mathcal{S}$.

The set A is *preferred* to the set B iff $\langle z_B, c_B - c_A + 1 \rangle = \langle |B|, s(B) - s(A) + 1 \rangle \in \mathcal{S}$ and

- $\langle z_A - z_B + 2, c_A \rangle = \langle |A| - |B| + 2, s(A) \rangle \notin \mathcal{S}$ or $(z_A - 1)c_A \geq (z_B - 1)c_B$.

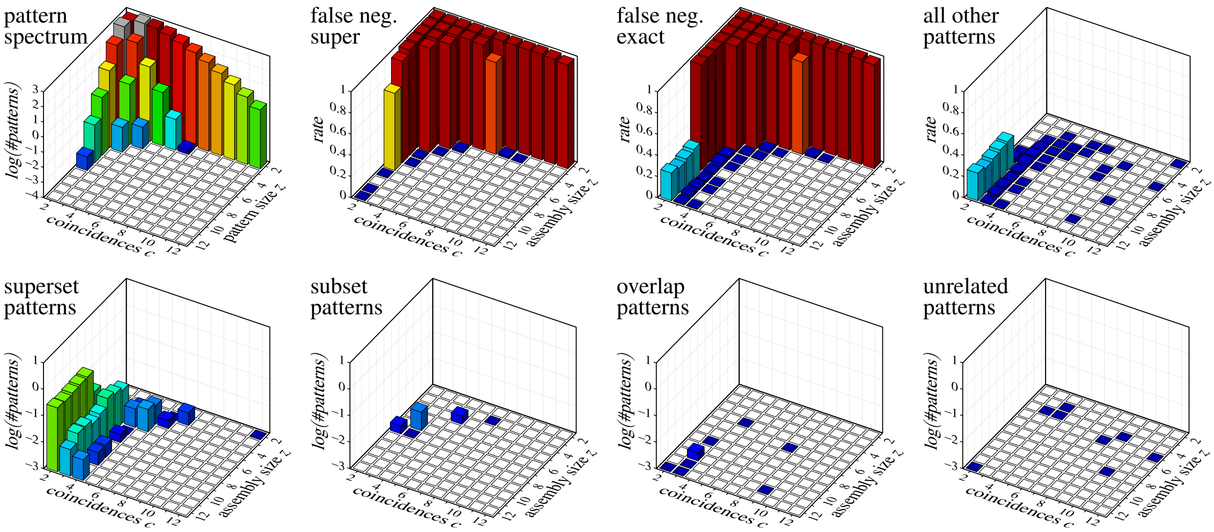
The set B is *preferred* to the set A iff $\langle z_A - z_B + 2, c_A \rangle = \langle |A| - |B| + 2, s(A) \rangle \in \mathcal{S}$ and

- $\langle z_B, c_B - c_A + 1 \rangle = \langle |B|, s(B) - s(A) + 1 \rangle \notin \mathcal{S}$ or $(z_A - 1)c_A < (z_B - 1)c_B$.

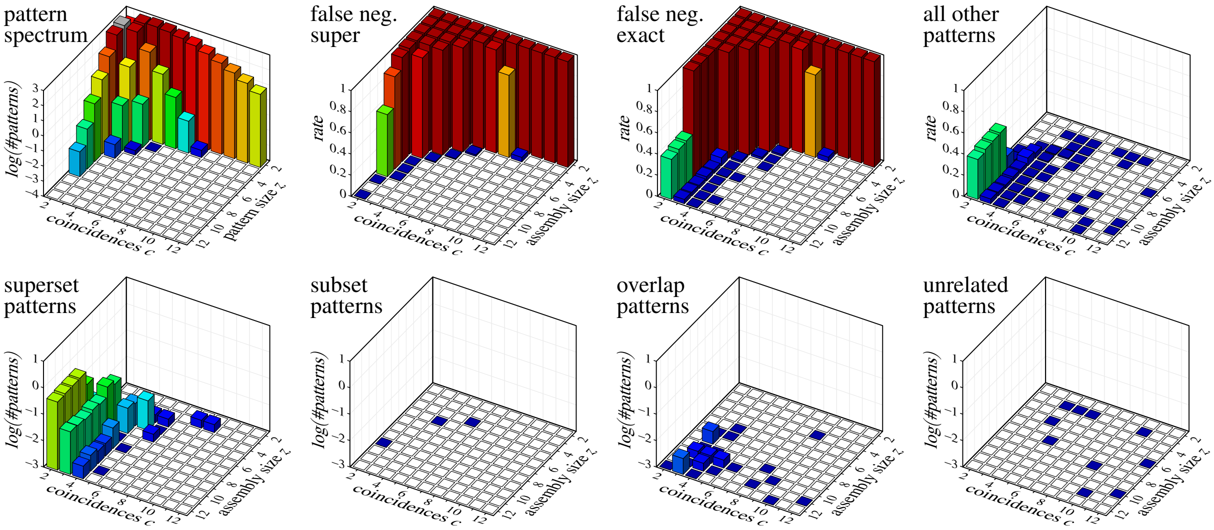
Otherwise A and B are not comparable (that is, neither is preferred to the other). In other words: A is preferred to B if the excess coincidences of B can be explained (heuristically) as chance events, but the excess neurons in A cannot be explained (heuristically) as chance events. Analogously, B is preferred to A if the excess neurons of A can be explained (heuristically) as chance events, but the excess coincidences of B cannot be explained (heuristically) as chance events. If both the excess neurons of A *and* the excess coincidences of B can be explained as chance events, the number of covered coincident spikes is invoked as a secondary criterion to make a decision. Finally, if neither the excess neurons of A nor the excess coincidences of B can be explained (heuristically) as chance events, no preference relation is established.

Pattern set reduction keeps only sets for which there exists no subset and no superset that is preferred to them.

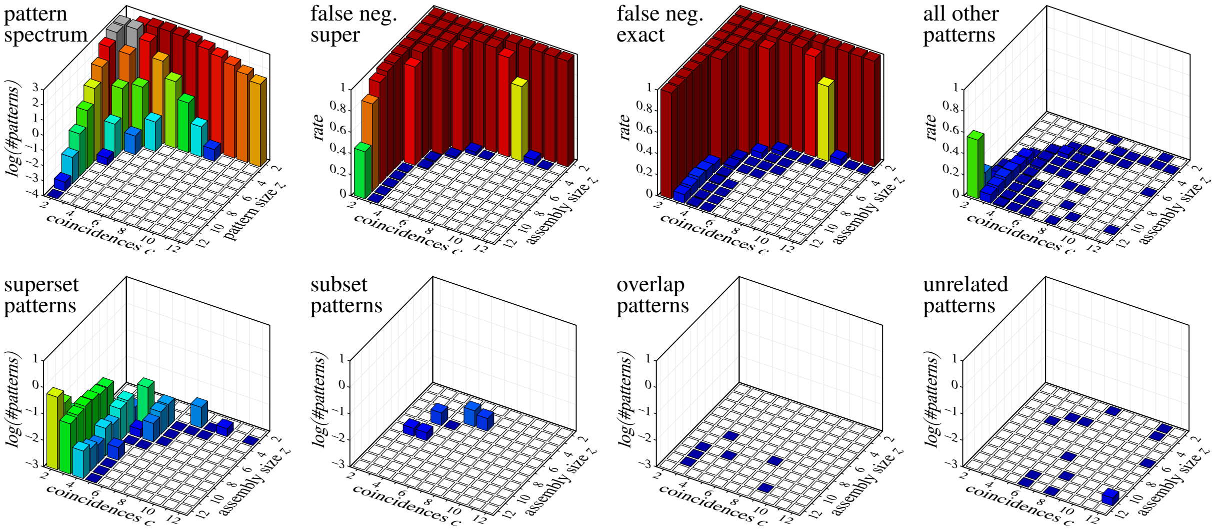
1000×3ms bins, reduced with excess coincidences and neurons 2



750×4ms bins, reduced with excess coincidences and neurons 2



600×5ms bins, reduced with excess coincidences and neurons 2



Reduction with Excess Coincidences and Excess Neurons 3

Let $\mathcal{S}$ be the set of signatures that occur in the surrogates. Let A and B with $B \subset A$ be two sets left over after primary pattern filtering, that is, after removing all sets I with signatures $\langle z_I, c_I \rangle = \langle |I|, s(I) \rangle \in \mathcal{S}$, and therefore $\langle z_A, c_A \rangle \notin \mathcal{S}$ and $\langle z_B, c_B \rangle \notin \mathcal{S}$.

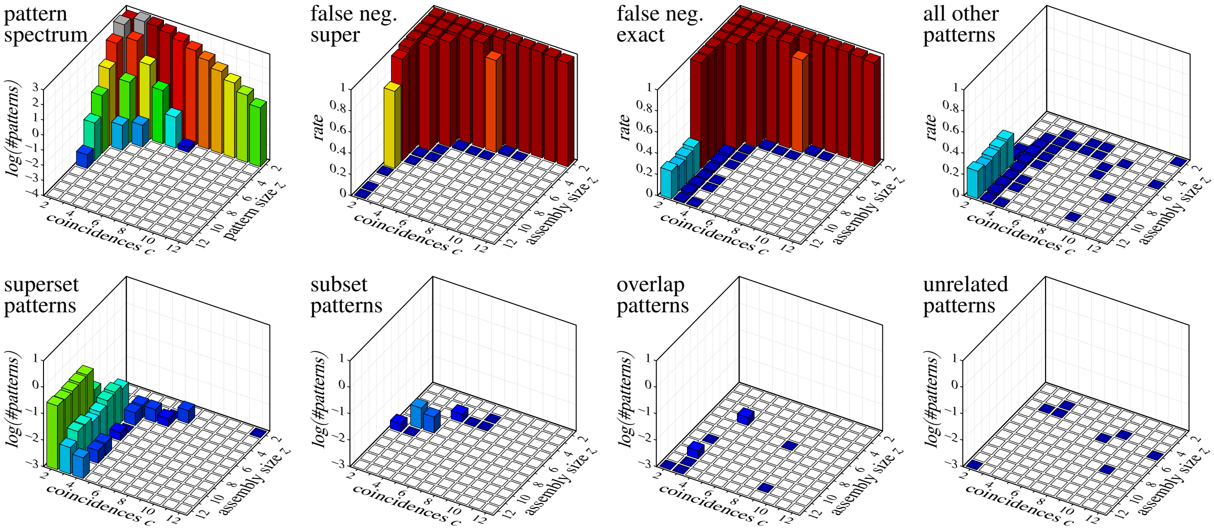
The set A is *preferred* to the set B iff

- $\langle z_B, c_B - c_A + 1 \rangle = \langle |B|, s(B) - s(A) + 1 \rangle \in \mathcal{S}$ and
  $\langle z_A - z_B + 2, c_A \rangle = \langle |A| - |B| + 2, s(A) \rangle \notin \mathcal{S}$ *or*
- $(\langle z_B, c_B - c_A + 1 \rangle \in \mathcal{S} = \langle z_A - z_B + 2, c_A \rangle \in \mathcal{S})$ and $z_A c_A \geq z_B c_B$.

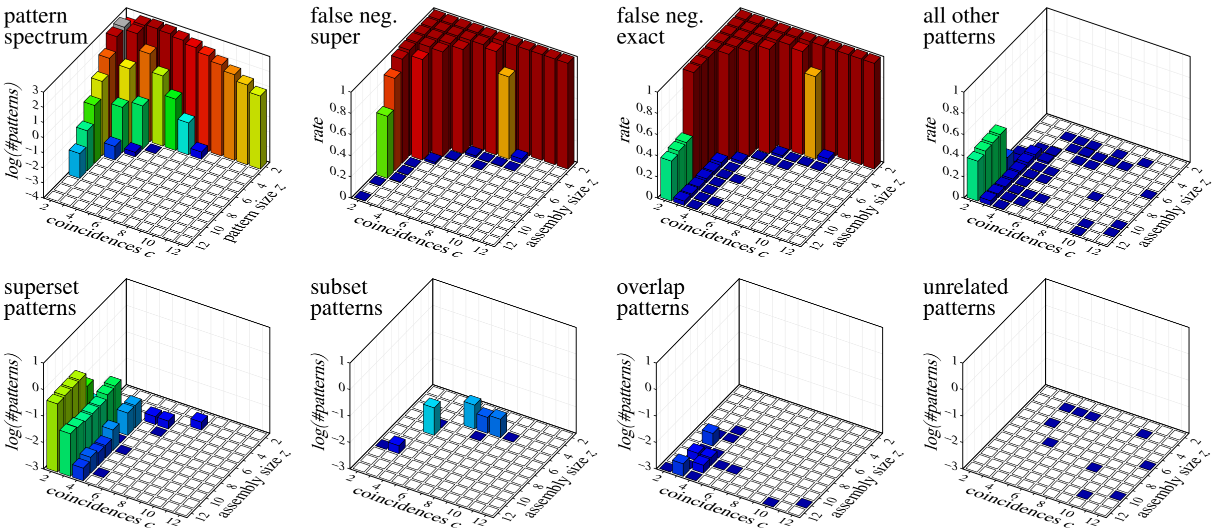
Otherwise B is preferred to A. In other words: A is preferred to B if both the excess coincidences preference relation and the excess neurons preference relation prefer A to B; and B is preferred to A if both the excess coincidences preference relation and the excess neurons preference relation prefer B to A. Finally, if the two preference relations disagree, the number of covered spikes establishes the preference. Or, more concisely: if the excess coincidences and excess neurons preference relations agree, they define the preference. If they disagree, the number of covered spikes is invoked to make a decision.

Pattern set reduction keeps only sets for which there exists no subset and no superset that is preferred to them.

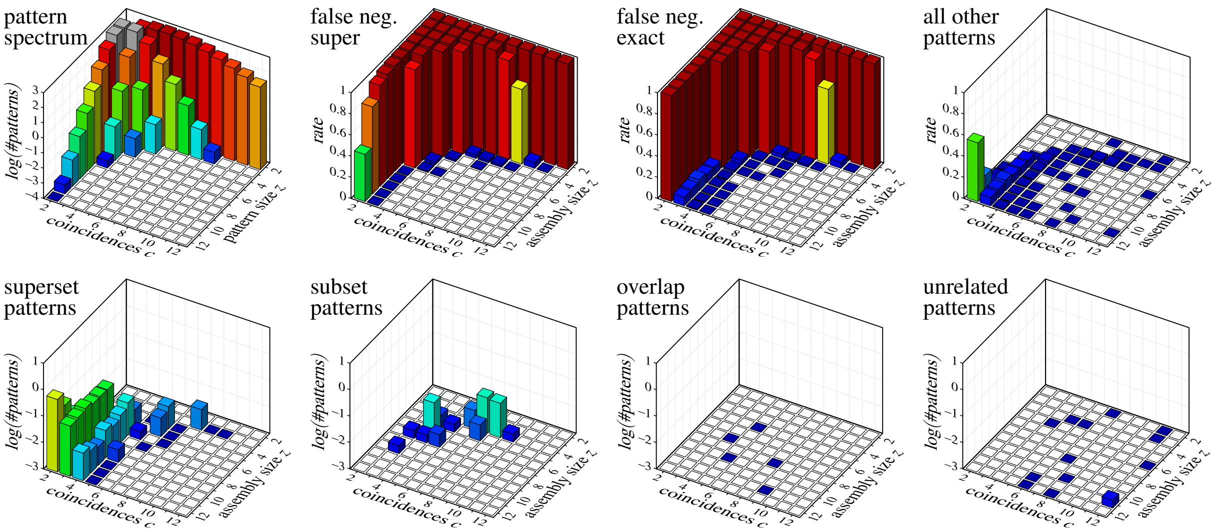
1000×3ms bins, reduced with excess coincidences and neurons 3



750×4ms bins, reduced with excess coincidences and neurons 3



600×5ms bins, reduced with excess coincidences and neurons 3



Reduction with Excess Coincidences and Excess Neurons 4

Let $\mathcal{S}$ be the set of signatures that occur in the surrogates. Let A and B with $B \subset A$ be two sets left over after primary pattern filtering, that is, after removing all sets I with signatures $\langle z_I, c_I \rangle = \langle |I|, s(I) \rangle \in \mathcal{S}$, and therefore $\langle z_A, c_A \rangle \notin \mathcal{S}$ and $\langle z_B, c_B \rangle \notin \mathcal{S}$.

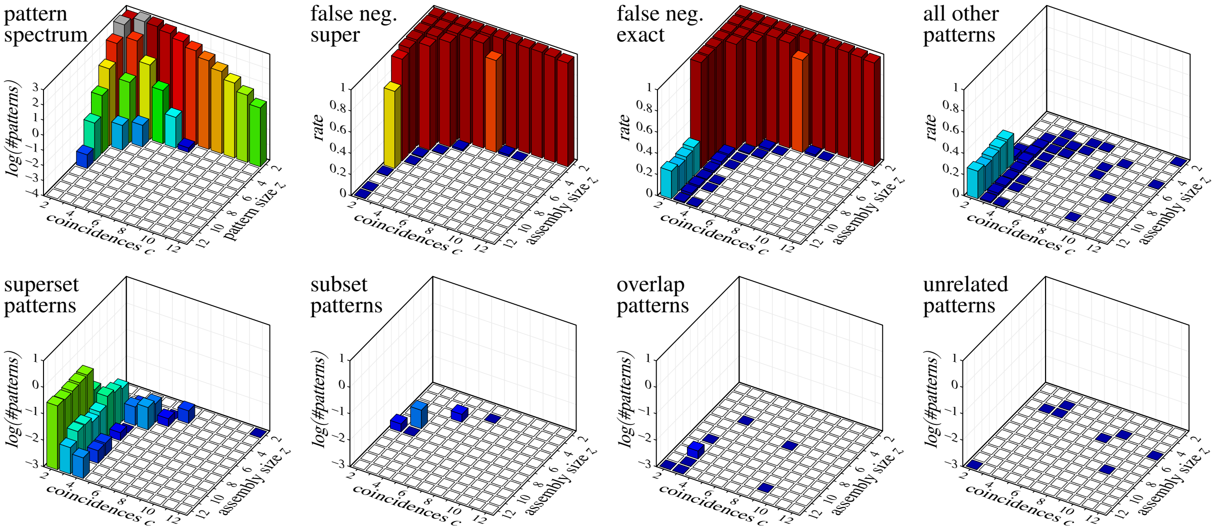
The set A is *preferred* to the set B iff

- $\langle z_B, c_B - c_A + 1 \rangle = \langle |B|, s(B) - s(A) + 1 \rangle \in \mathcal{S}$ and
  $\langle z_A - z_B + 2, c_A \rangle = \langle |A| - |B| + 2, s(A) \rangle \notin \mathcal{S}$ *or*
- $(\langle z_B, c_B - c_A + 1 \rangle \in \mathcal{S} = \langle z_A - z_B + 2, c_A \rangle \in \mathcal{S})$ and $(z_A - 1)c_A \geq (z_B - 1)c_B$.

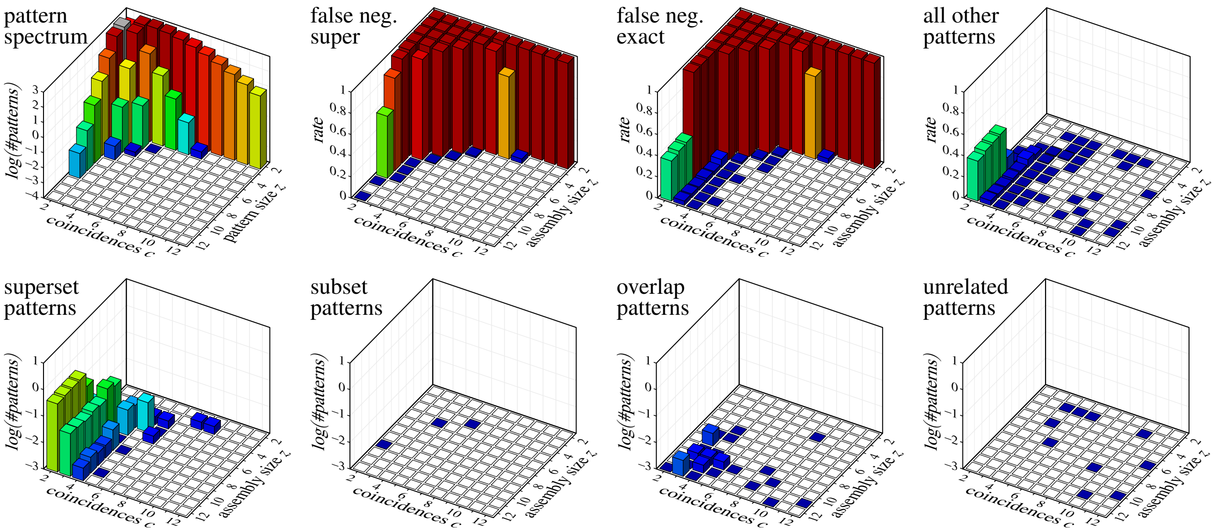
Otherwise B is preferred to A. In other words: A is preferred to B if both the excess coincidences preference relation and the excess neurons preference relation prefer A to B; and B is preferred to A if both the excess coincidences preference relation and the excess neurons preference relation prefer B to A. Finally, if the two preference relations disagree, the number of covered coincident spikes establishes the preference. Or, more concisely: if the excess coincidences and excess neurons preference relations agree, they define the preference. If they disagree, the number of covered coincident spikes is invoked to make a decision.

Pattern set reduction keeps only sets for which there exists no subset and no superset that is preferred to them.

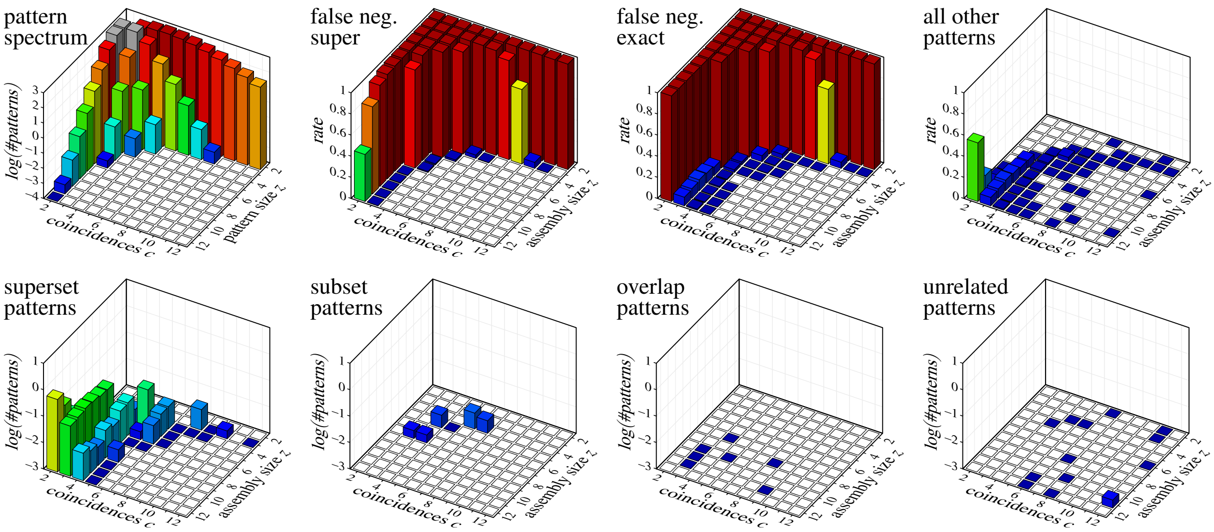
1000×3ms bins, reduced with excess coincidences and neurons 4



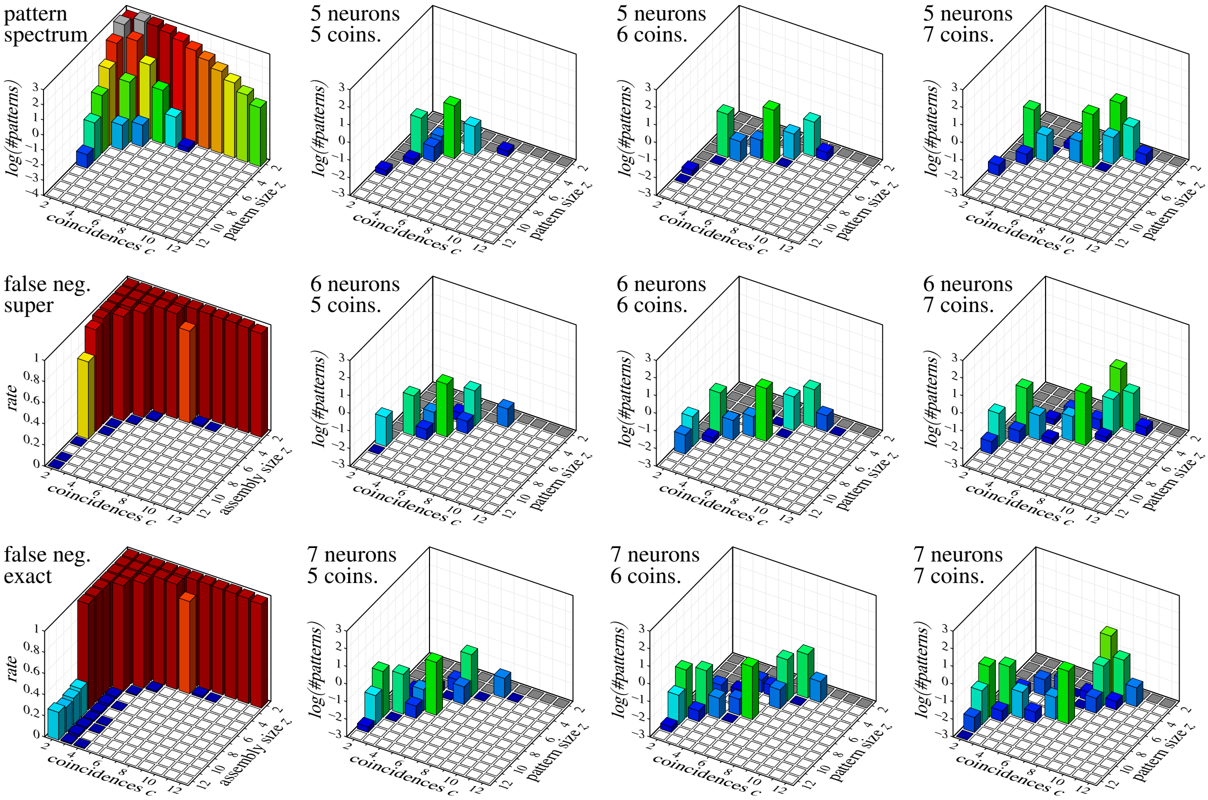
750×4ms bins, reduced with excess coincidences and neurons 4



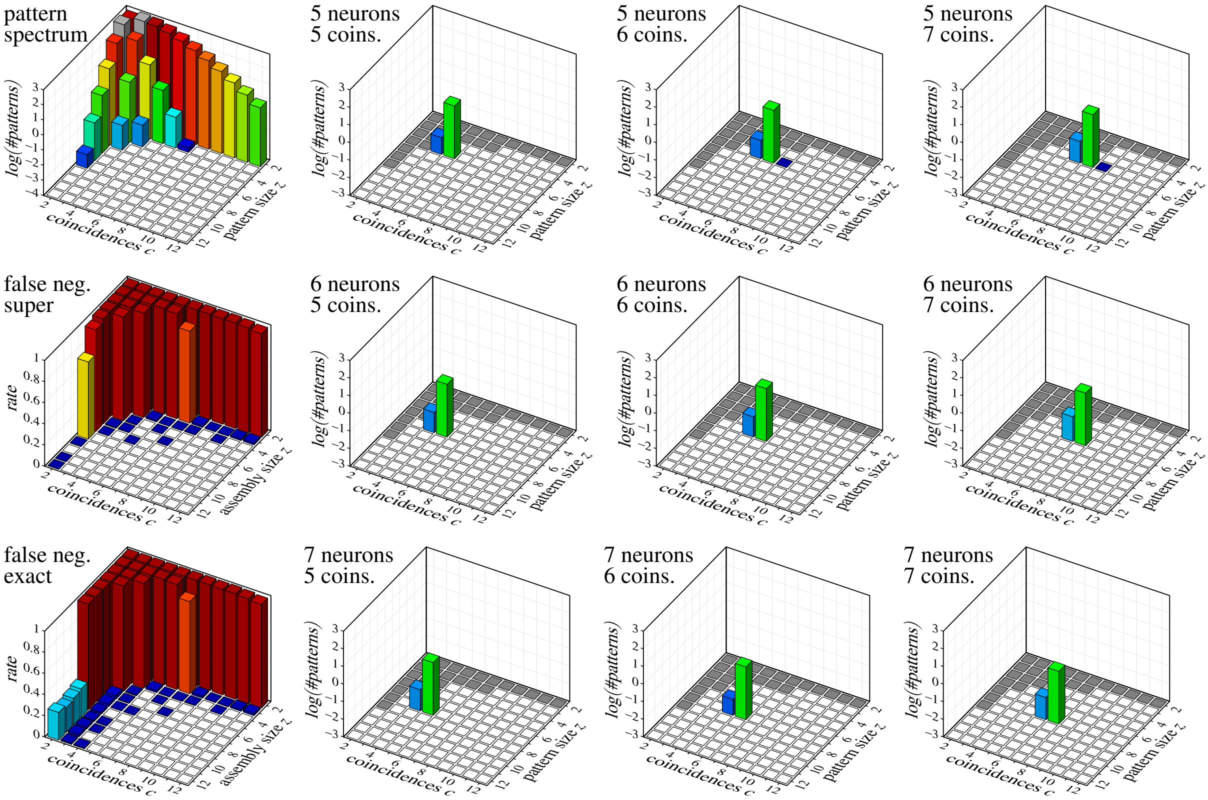
600×5ms bins, reduced with excess coincidences and neurons 4



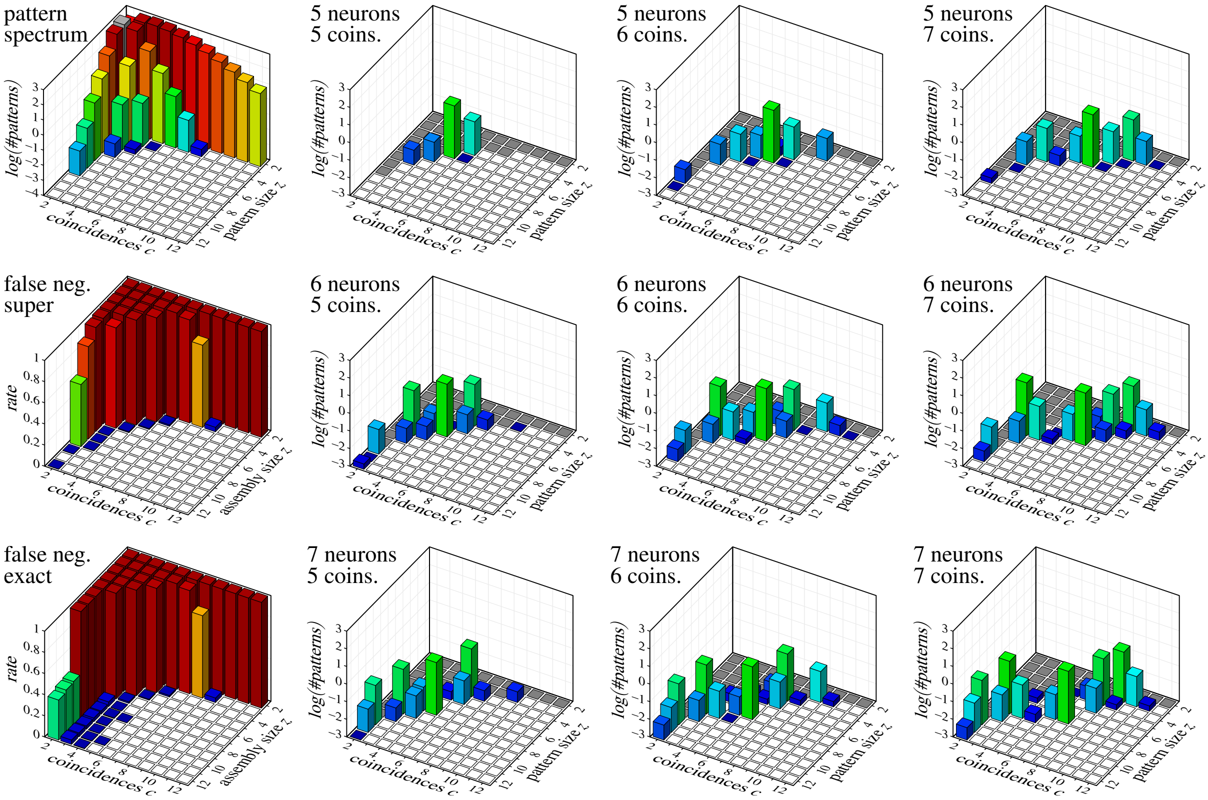
1000×3ms bins, filtered with surrogate data



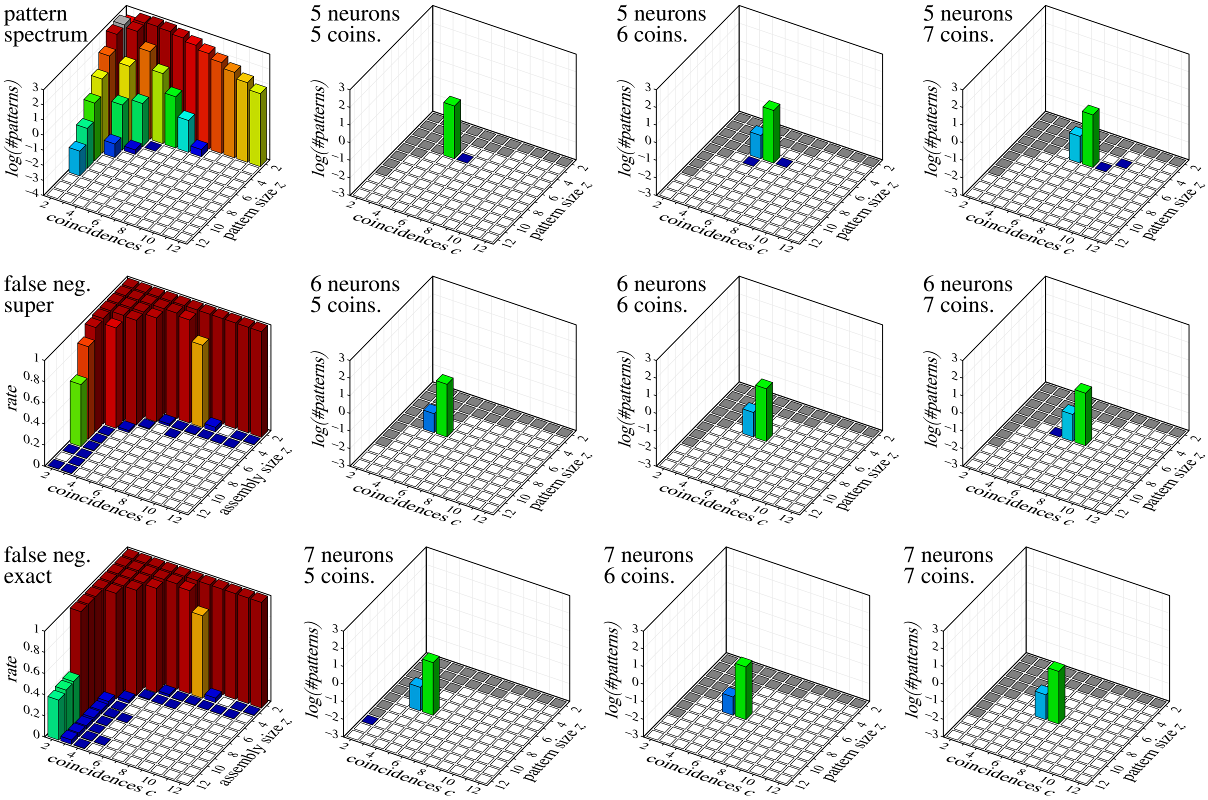
1000×3ms bins, reduced with number of covered spikes 1



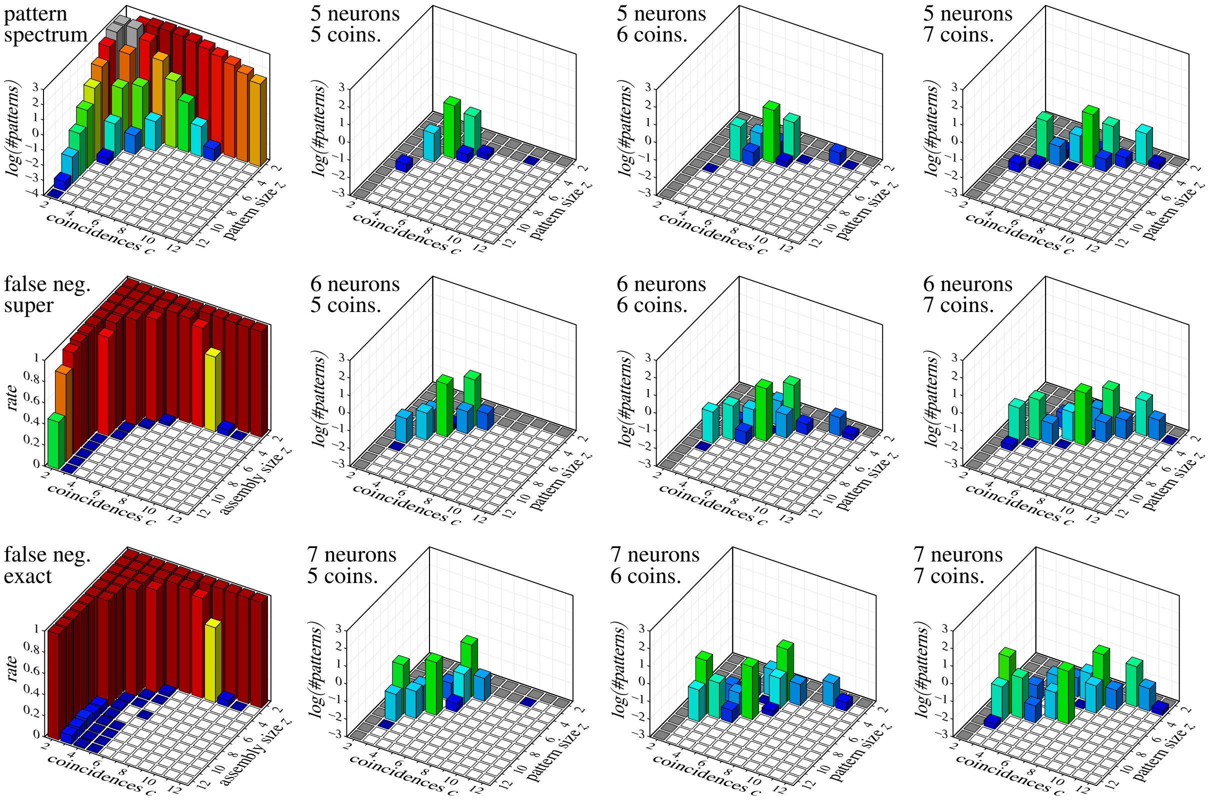
750×4ms bins, filtered with surrogate data



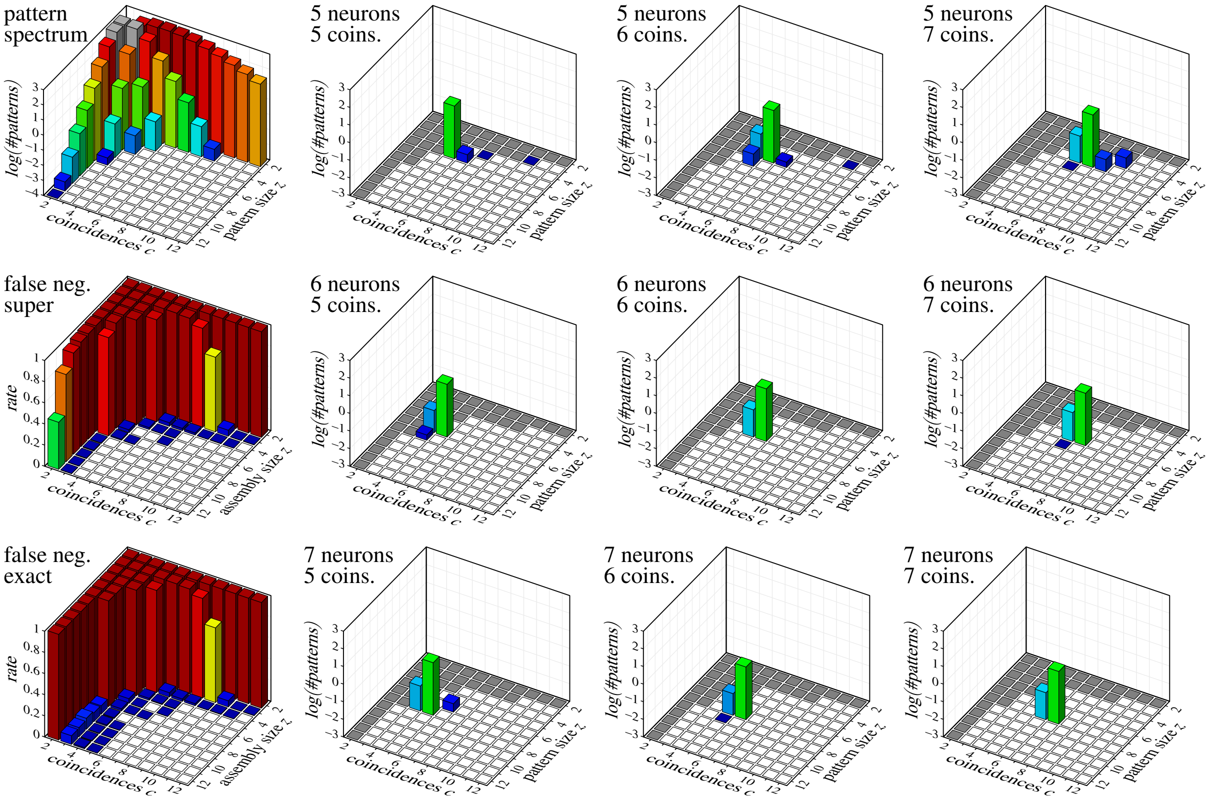
750×4ms bins, reduced with number of covered spikes 1



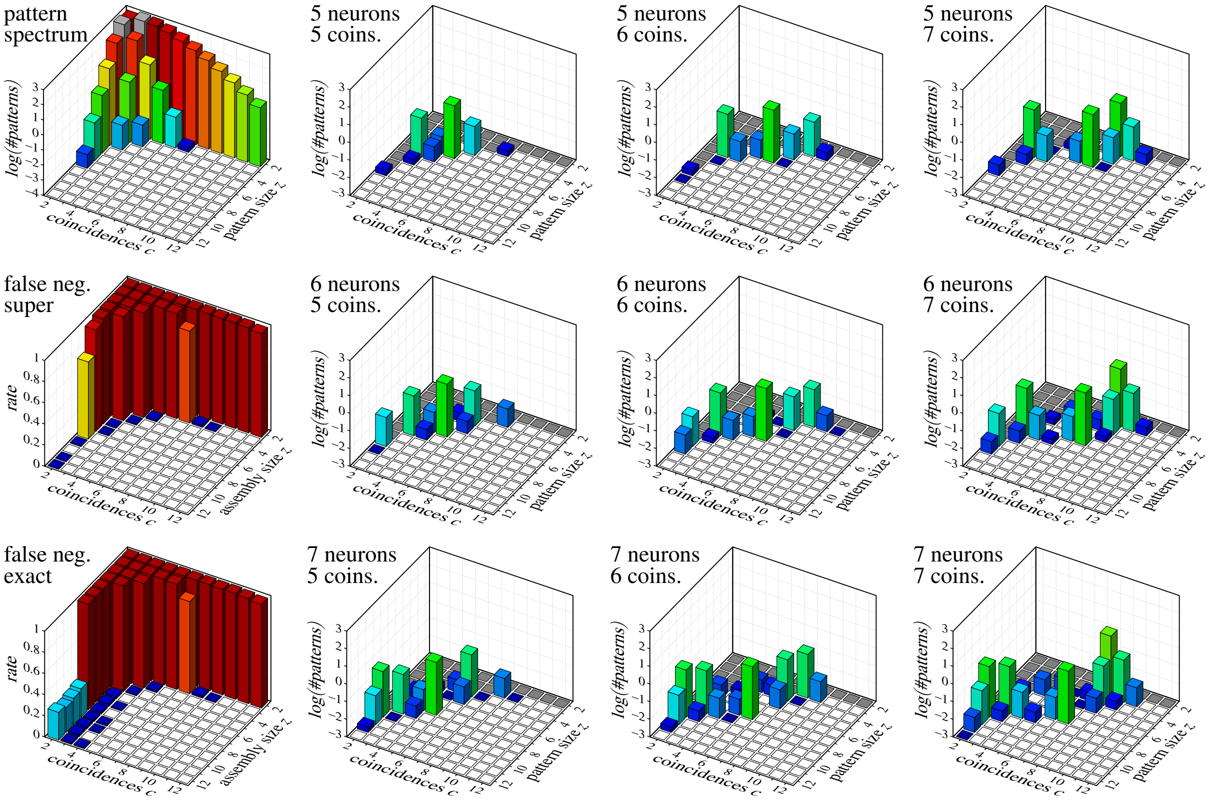
600×5ms bins, filtered with surrogate data



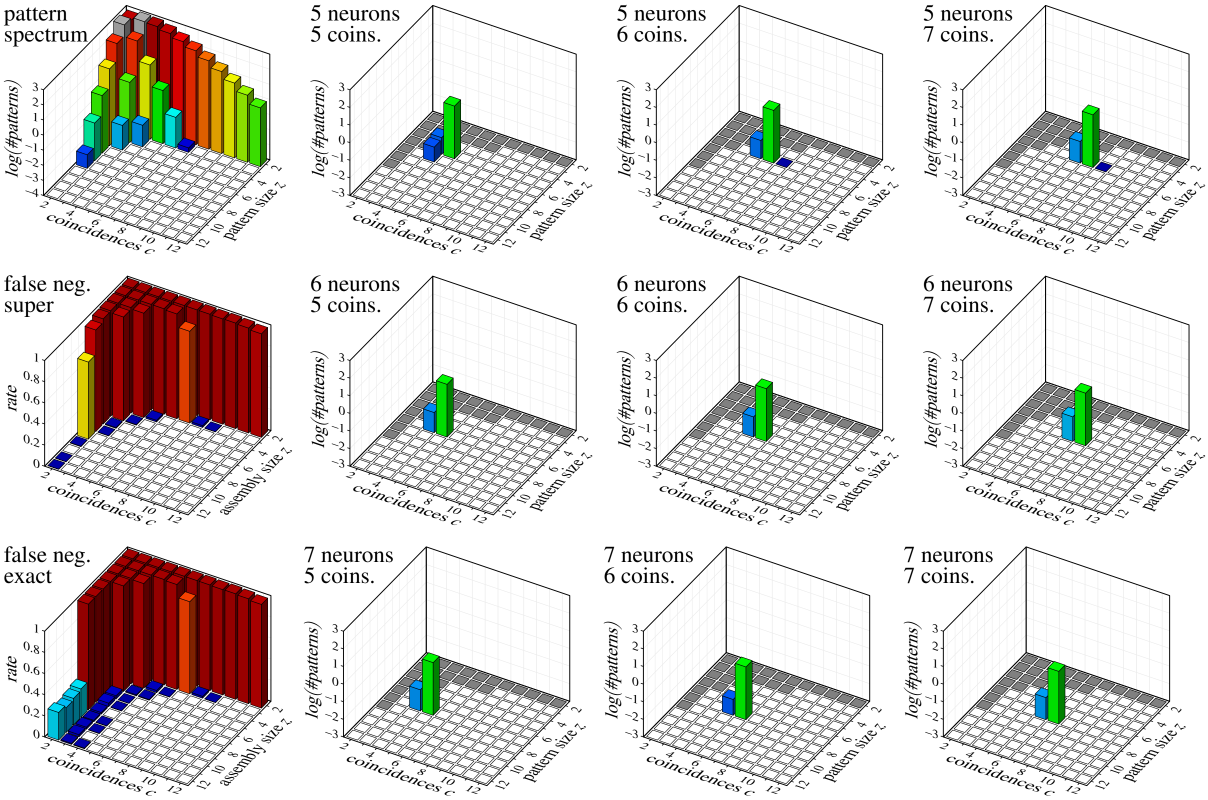
600×5ms bins, reduced with number of covered spikes 1



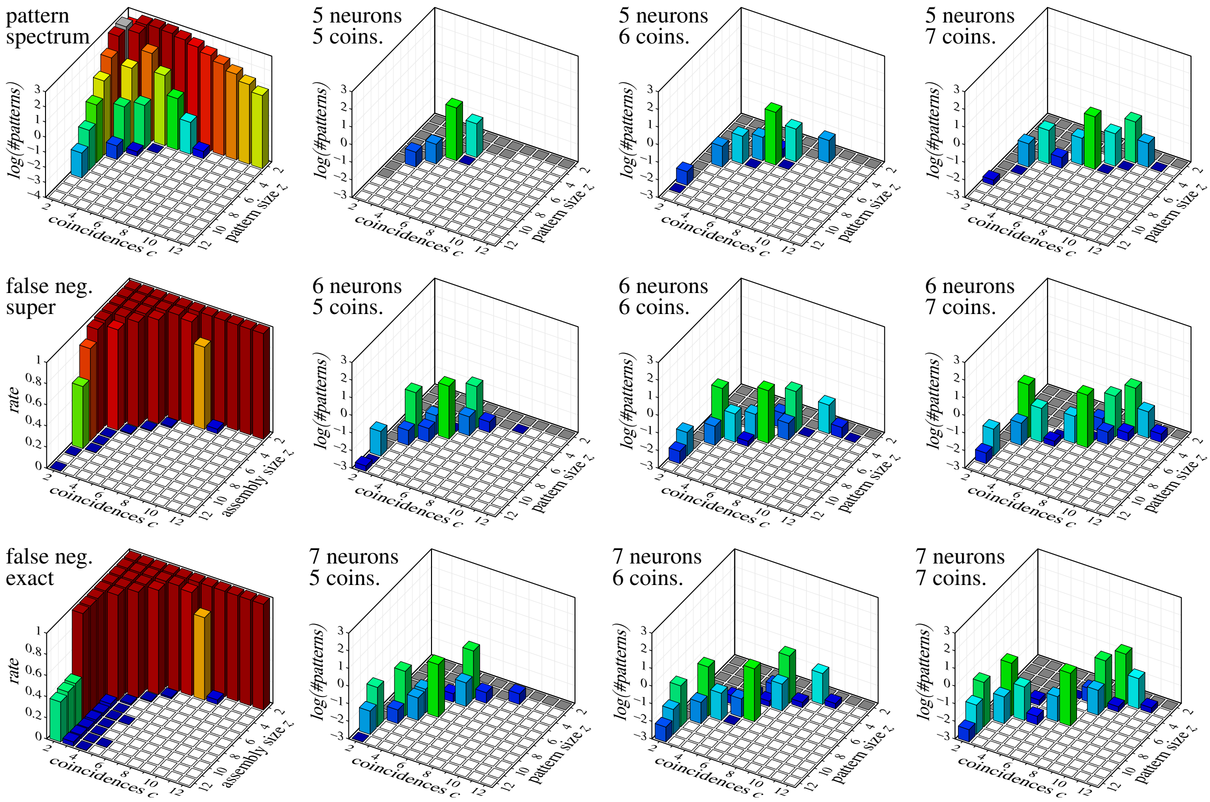
1000×3ms bins, filtered with surrogate data



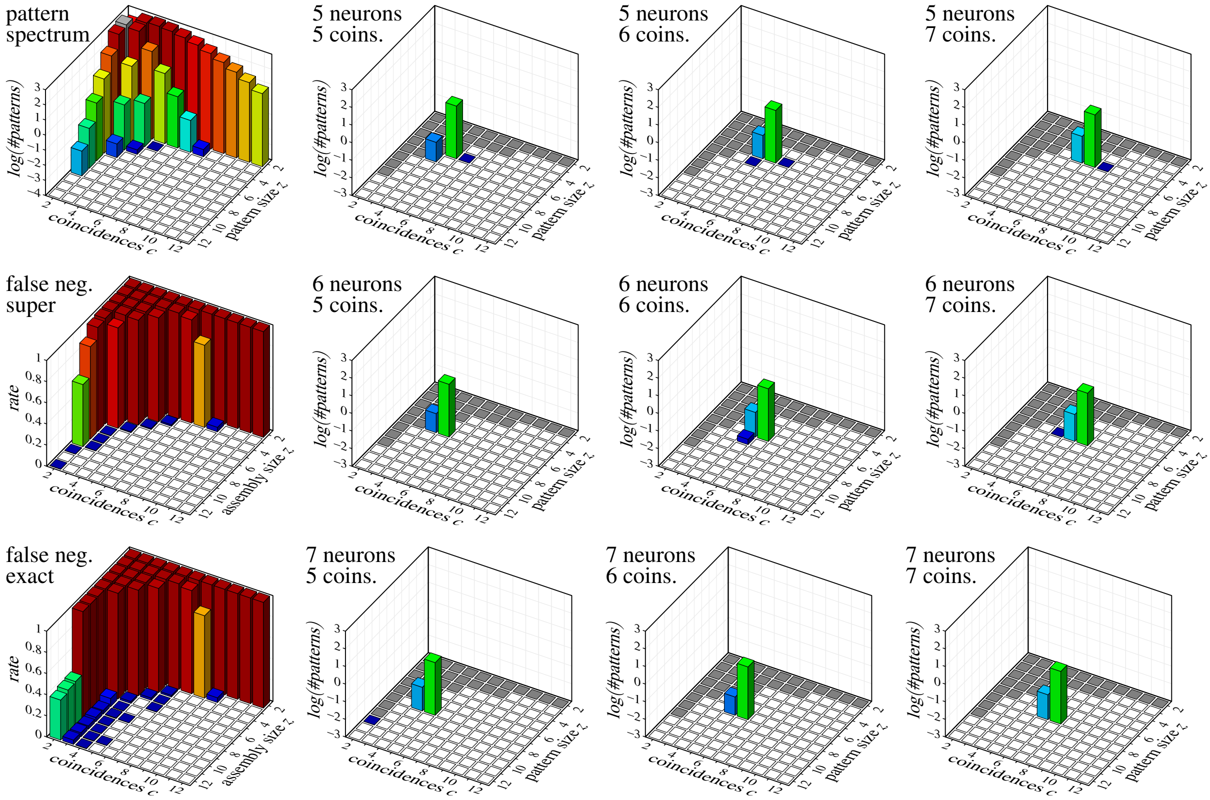
1000×3ms bins, reduced with number of covered spikes 2



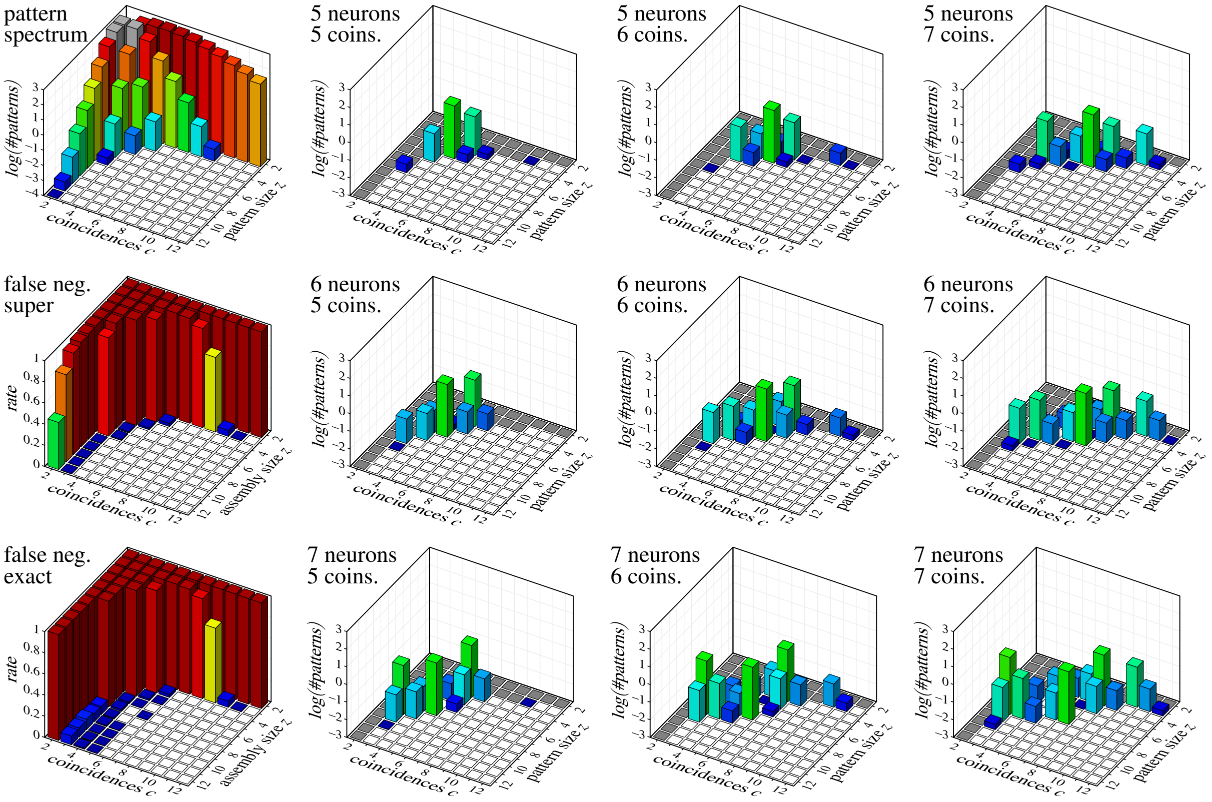
750×4ms bins, filtered with surrogate data



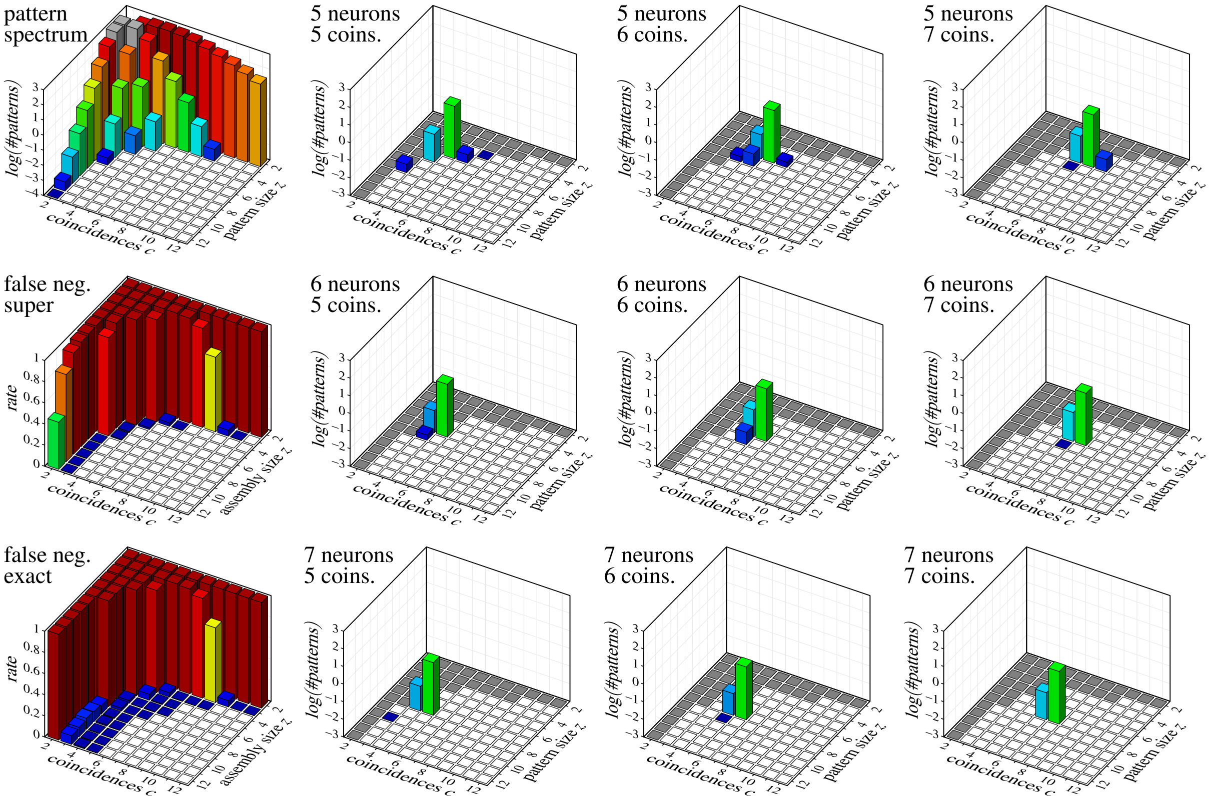
750×4ms bins, reduced with number of covered spikes 2



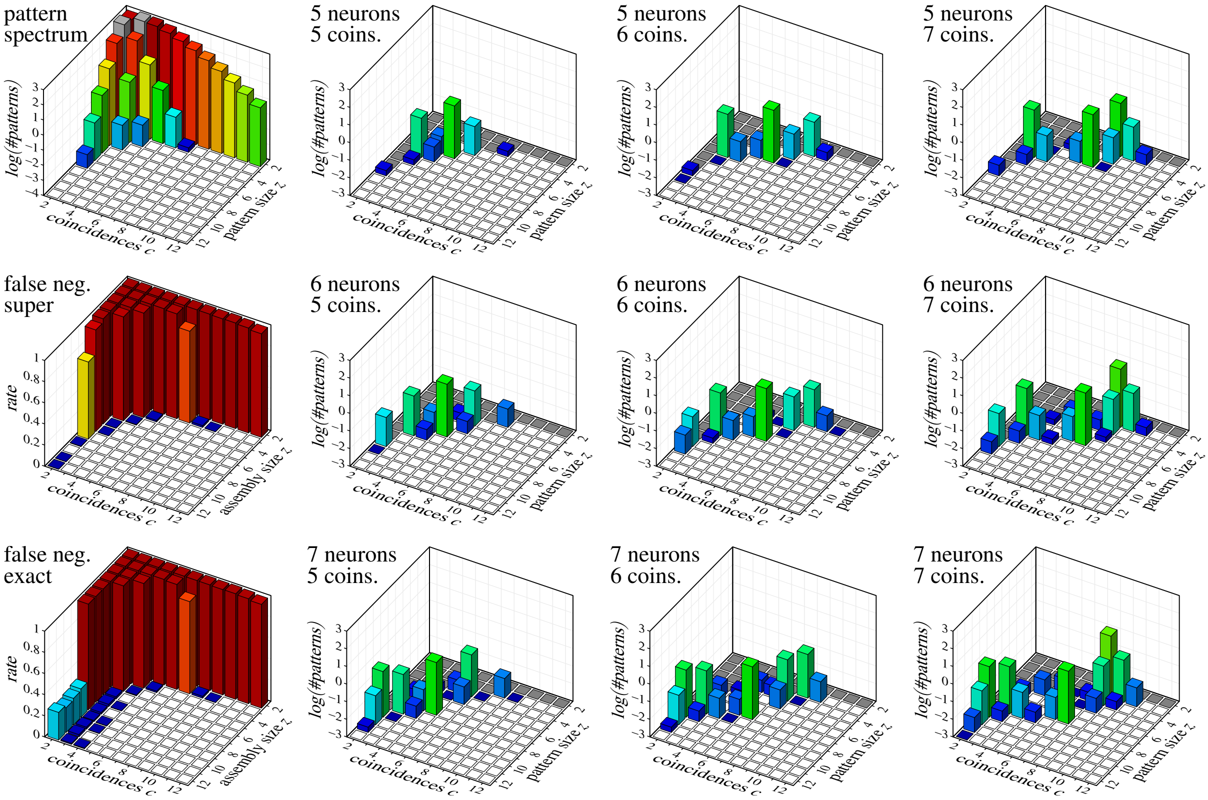
600×5ms bins, filtered with surrogate data



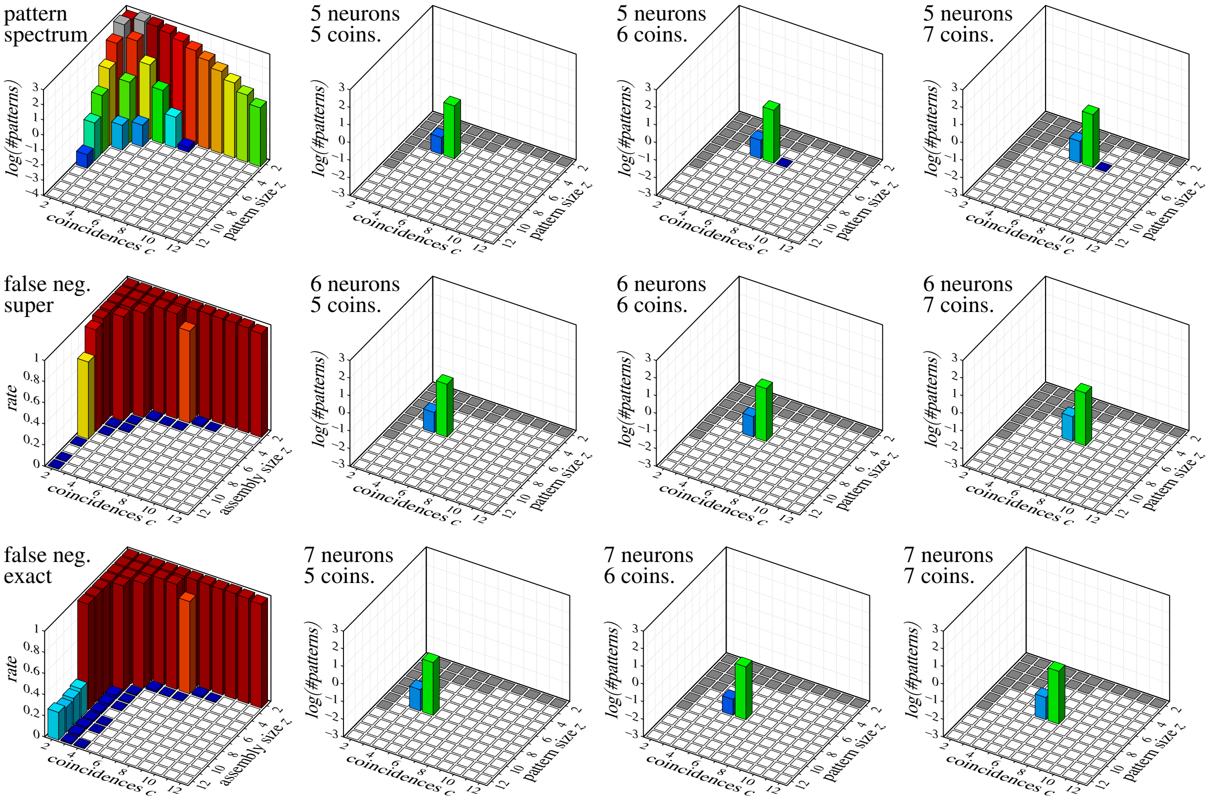
600×5ms bins, reduced with number of covered spikes 2



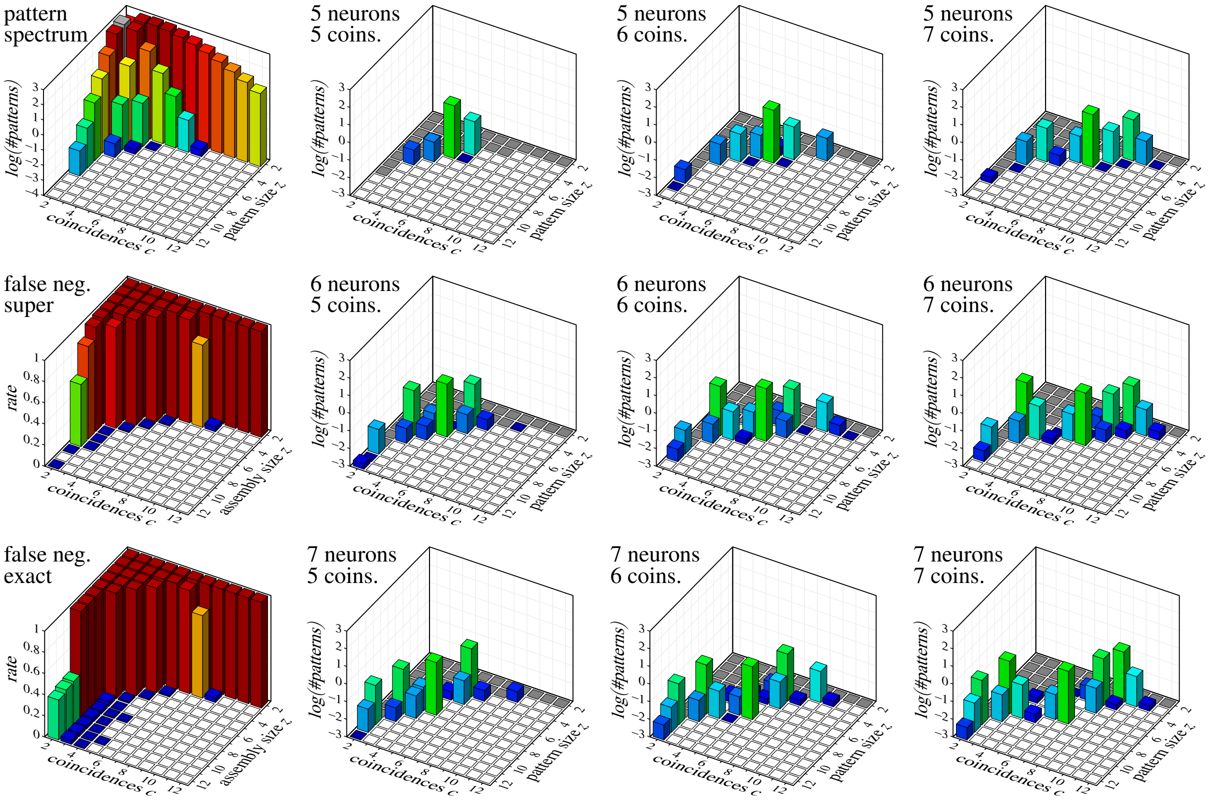
1000$\times$3ms bins, filtered with surrogate data



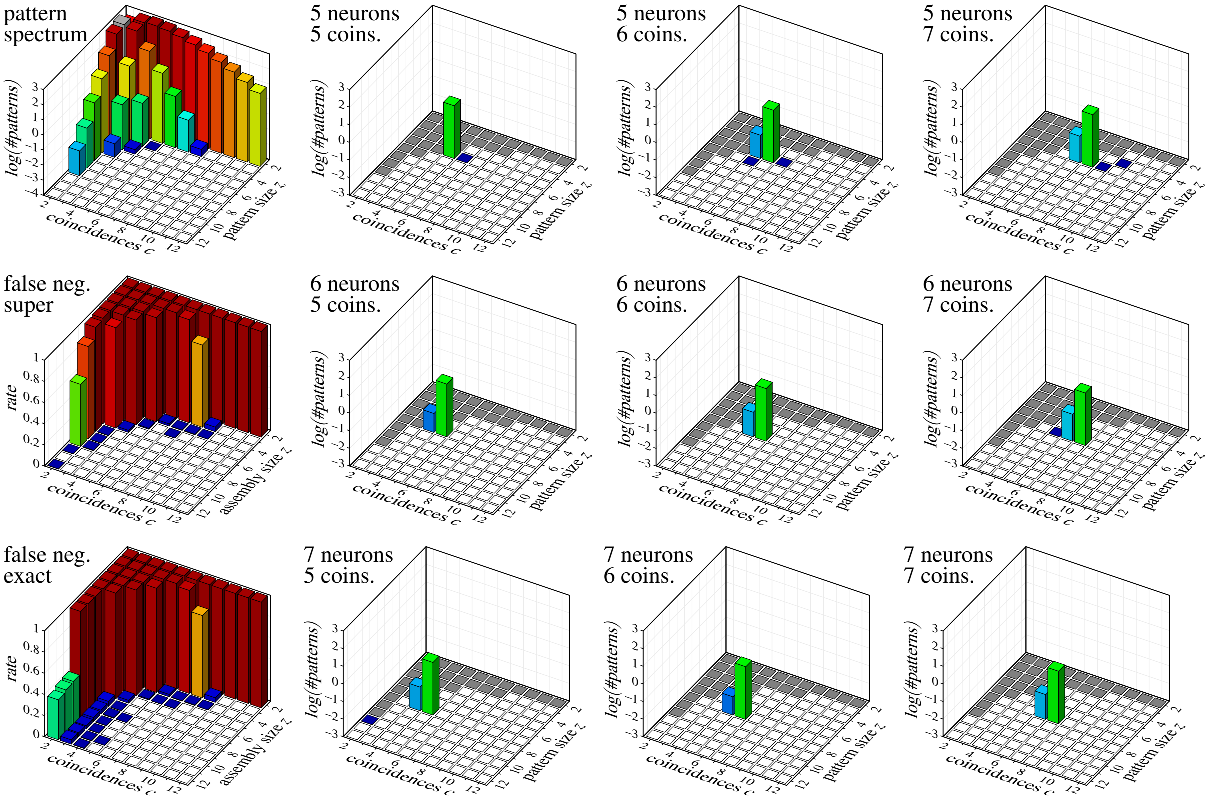
1000$\times$3ms bins, reduced with excess coincidences and neurons 1



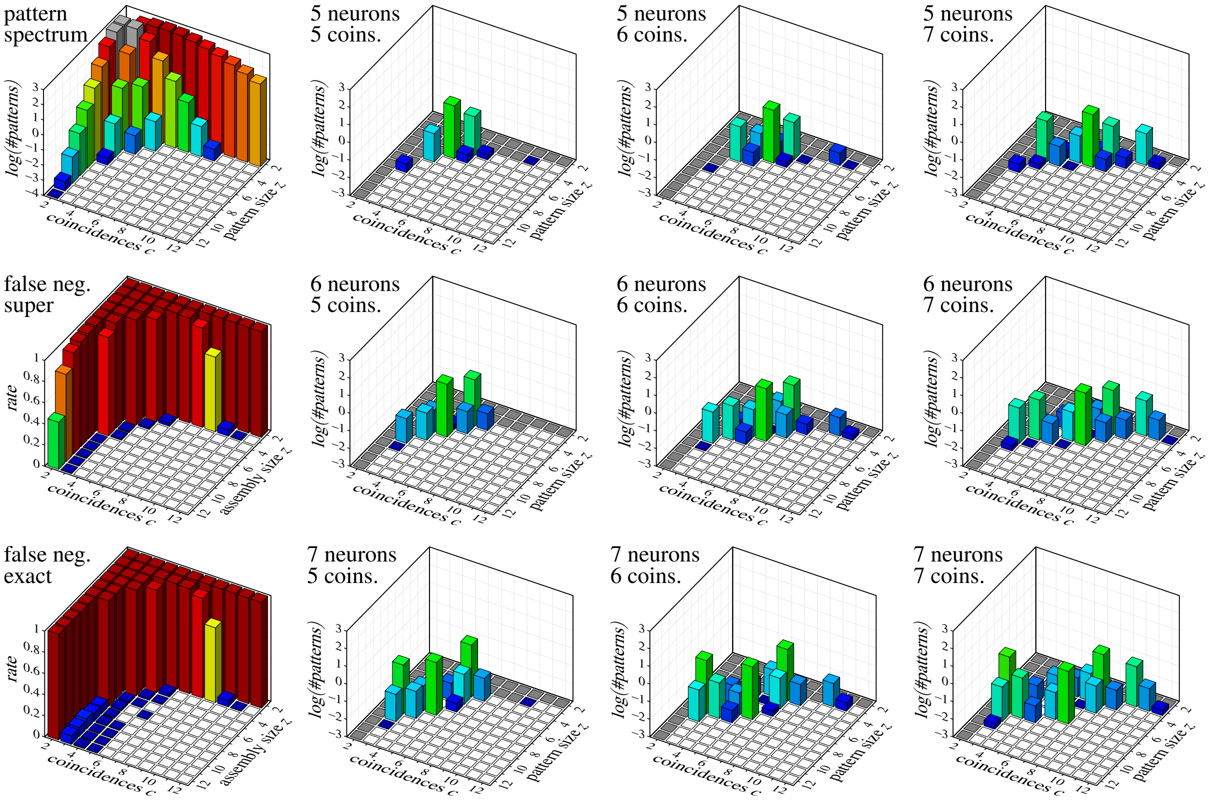
750×4ms bins, filtered with surrogate data



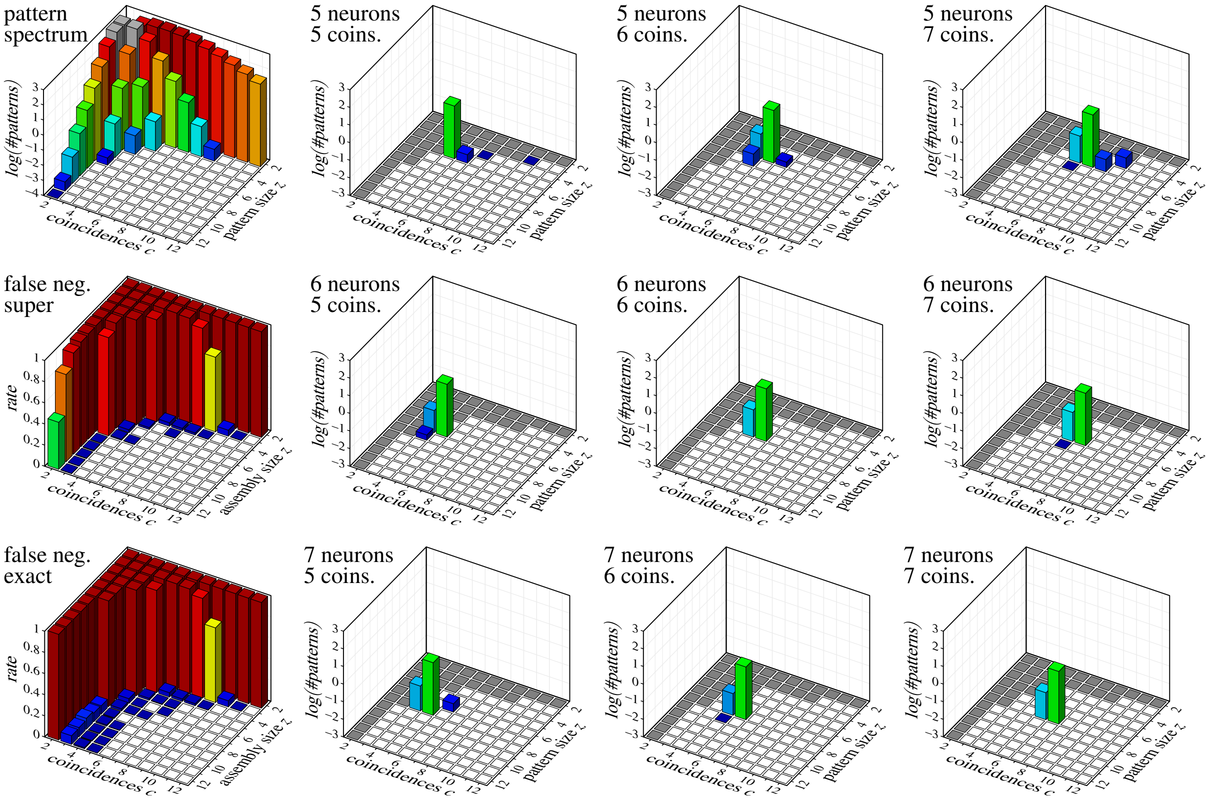
750×4ms bins, reduced with excess coincidences and neurons 1



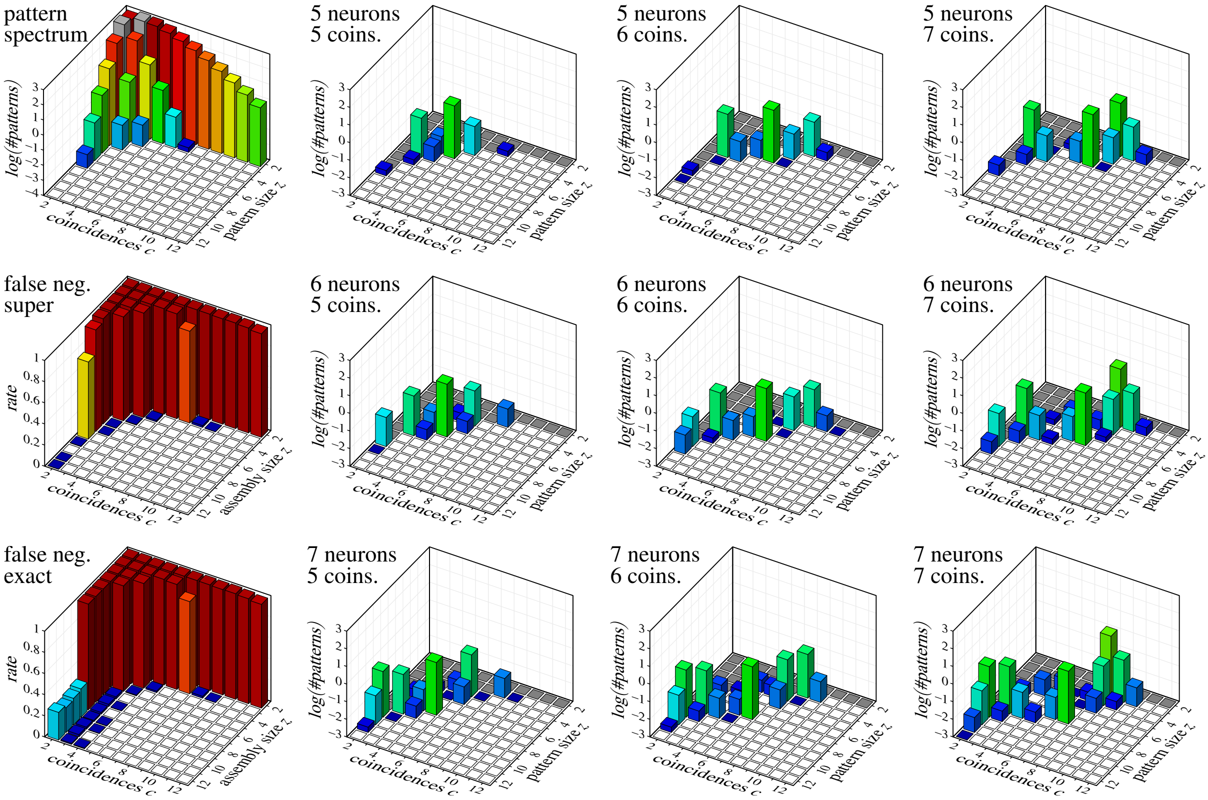
600×5ms bins, filtered with surrogate data



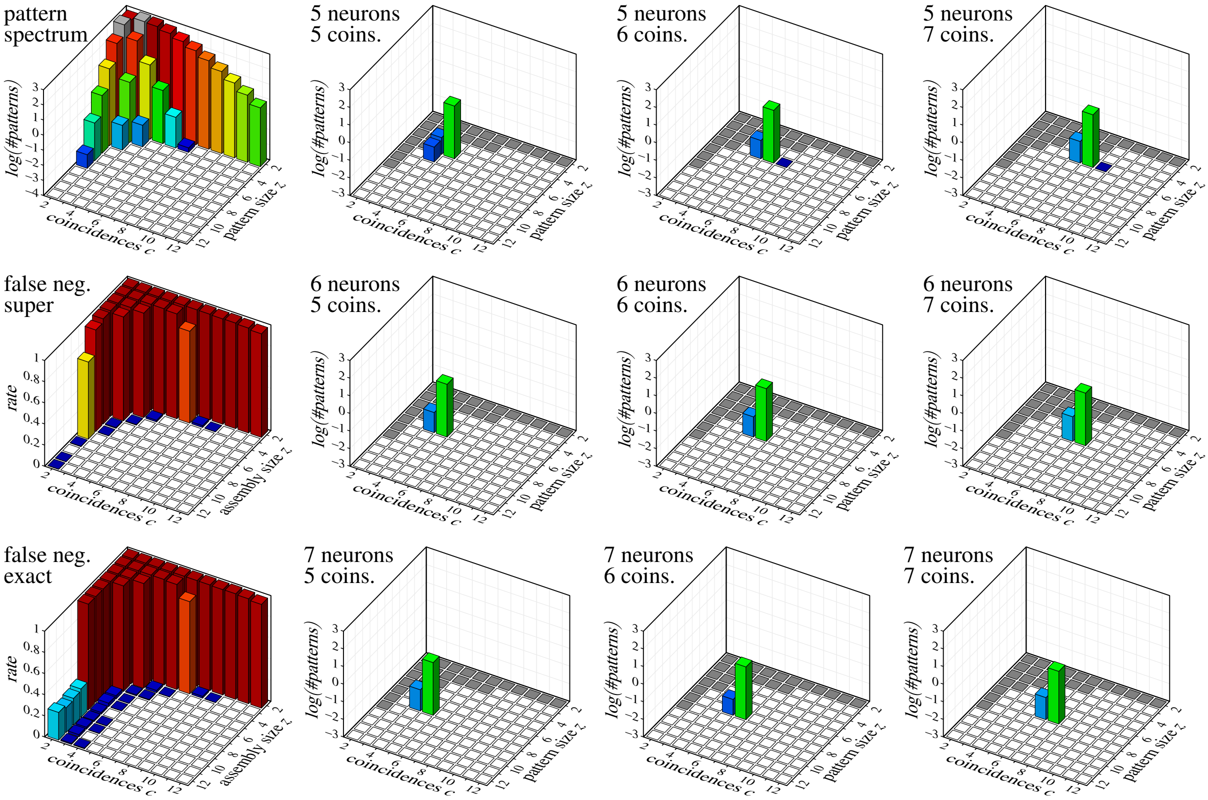
600×5ms bins, reduced with excess coincidences and neurons 1



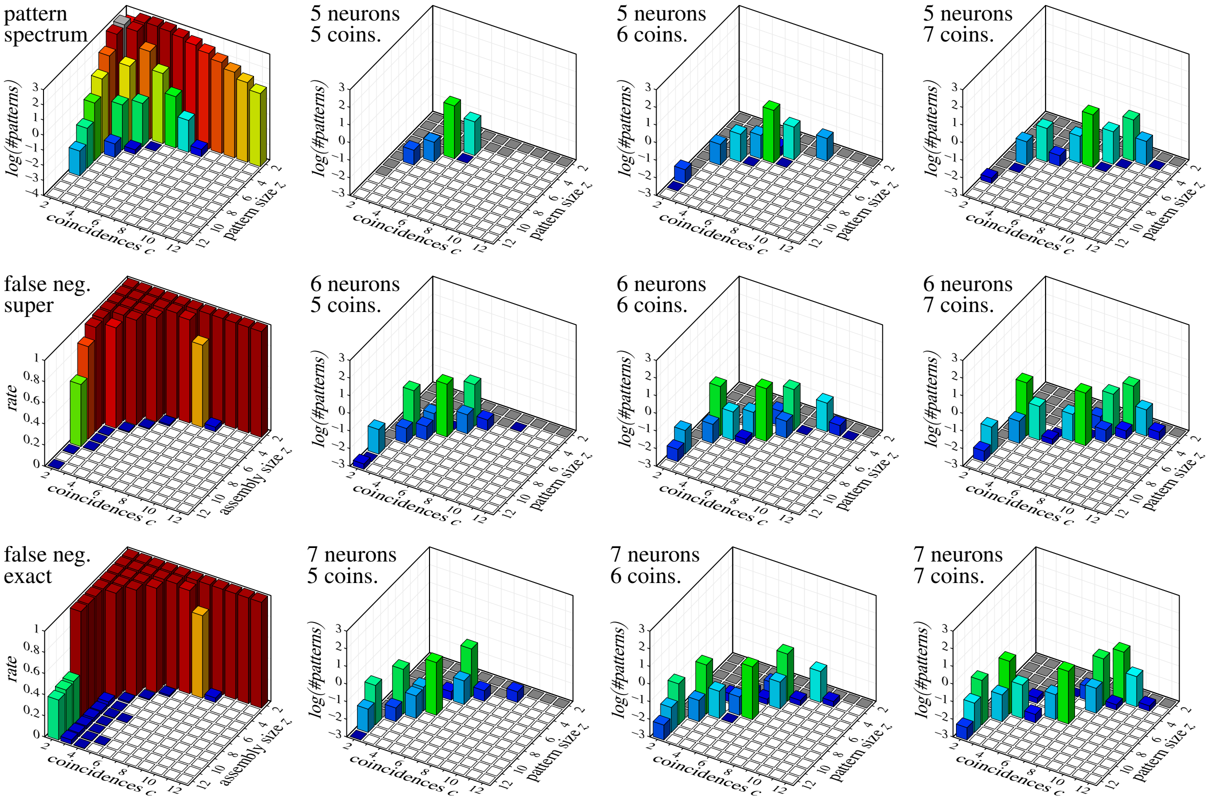
1000×3ms bins, filtered with surrogate data



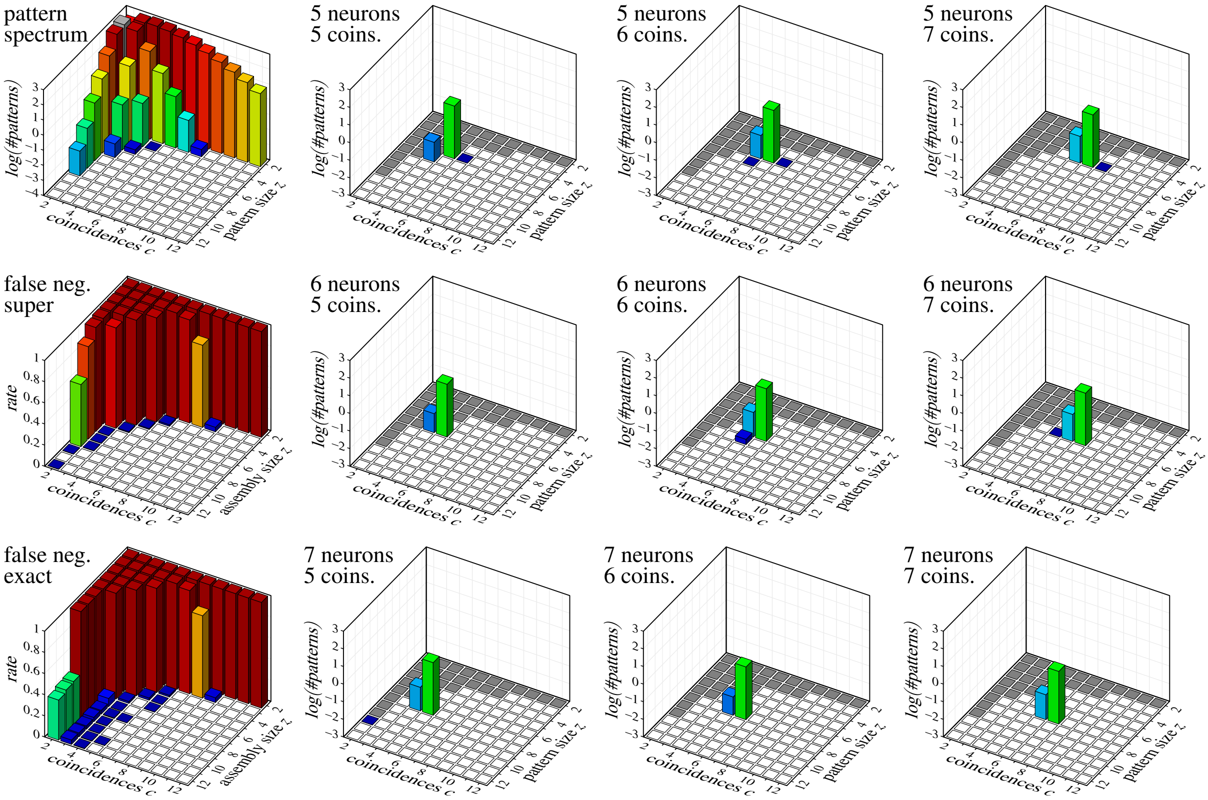
1000×3ms bins, reduced with excess coincidences and neurons 2



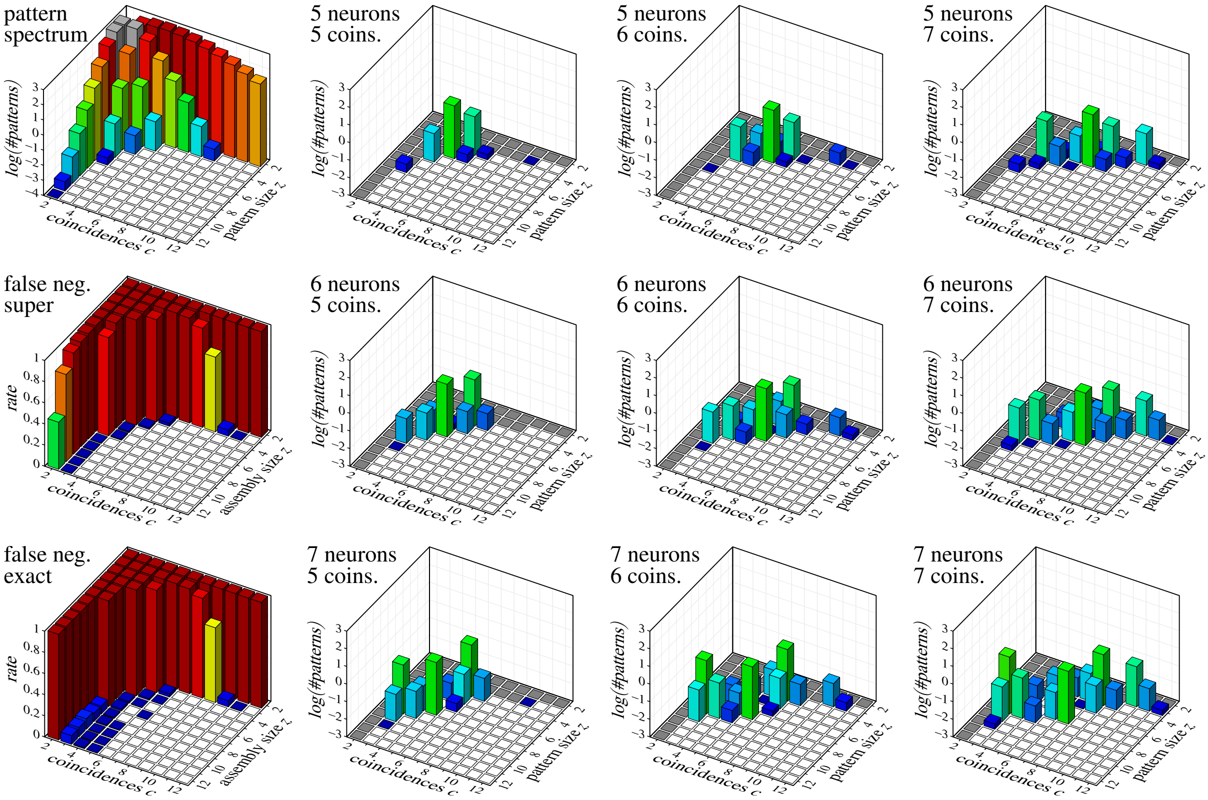
750×4ms bins, filtered with surrogate data



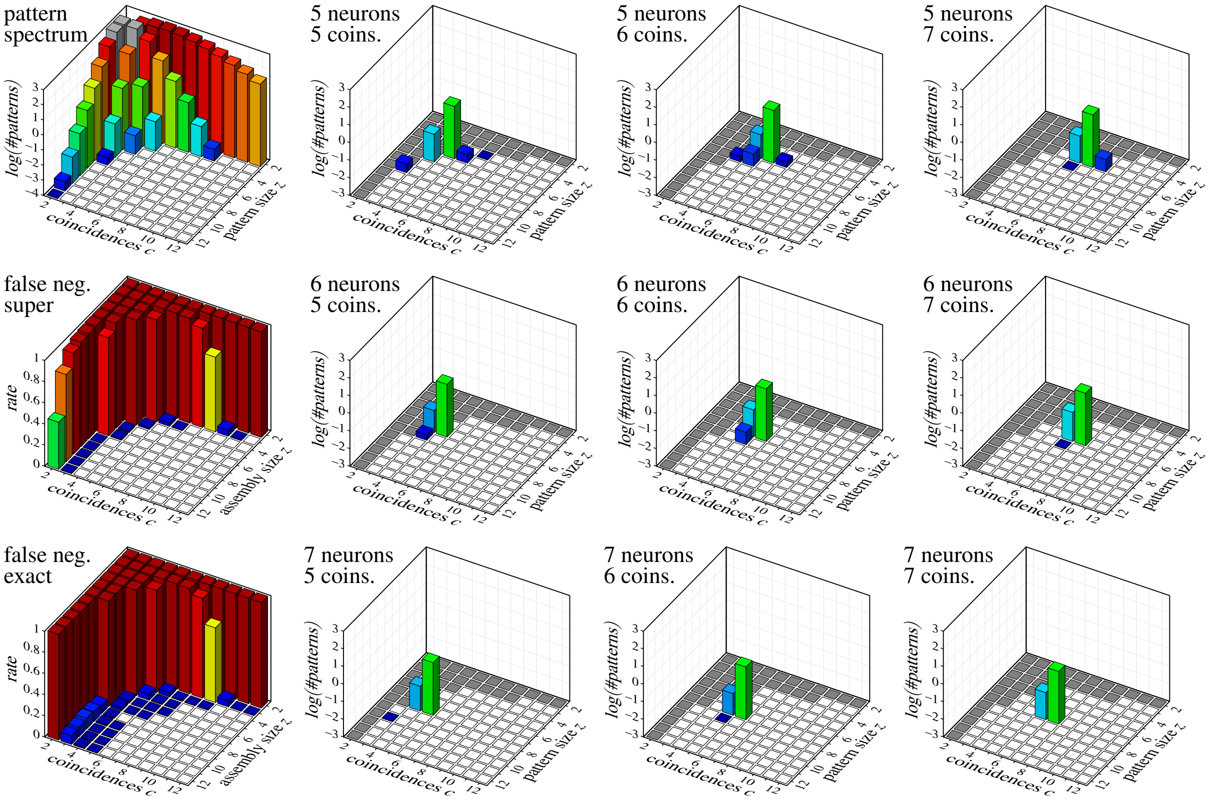
750×4ms bins, reduced with excess coincidences and neurons 2



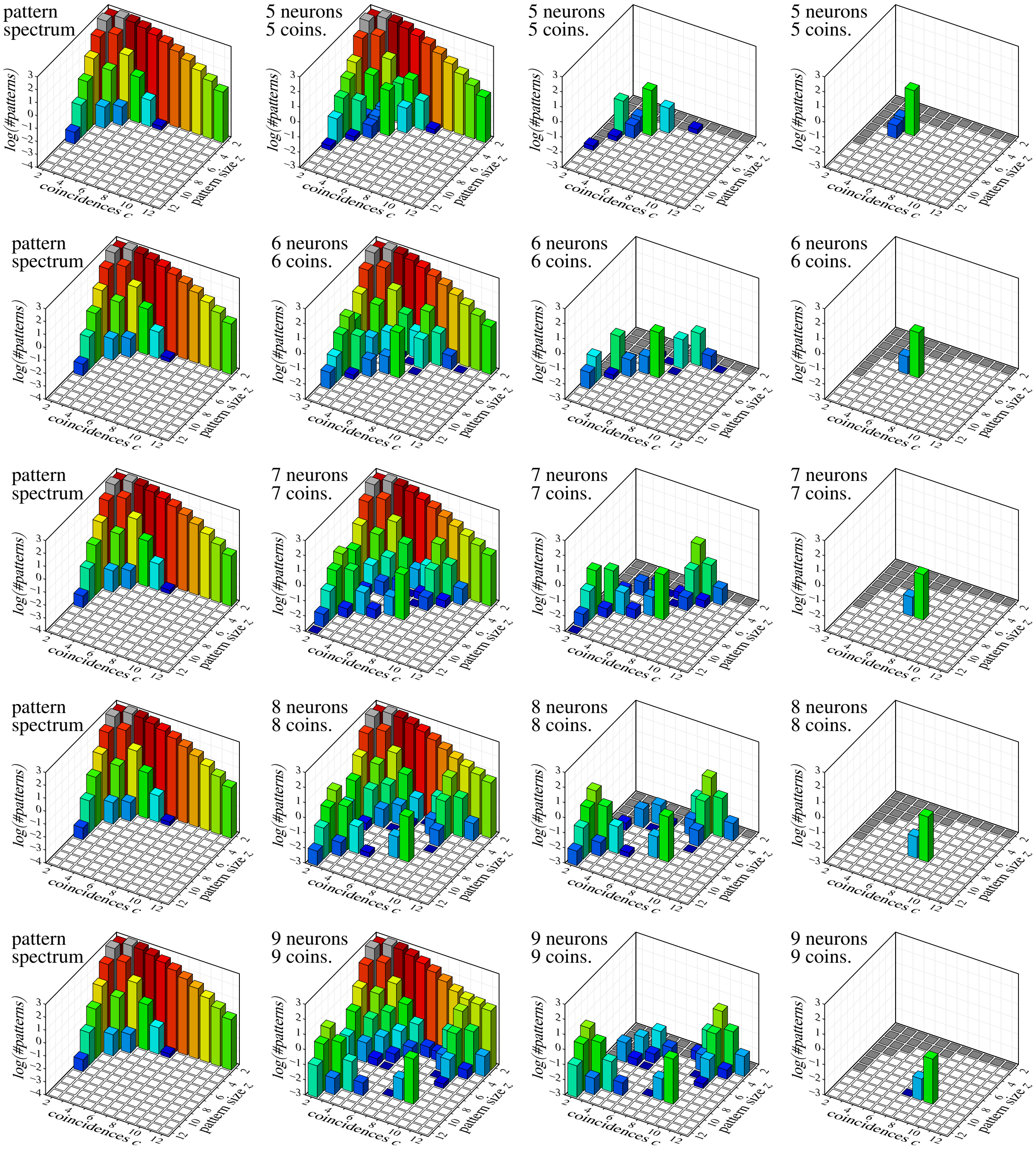
600×5ms bins, filtered with surrogate data



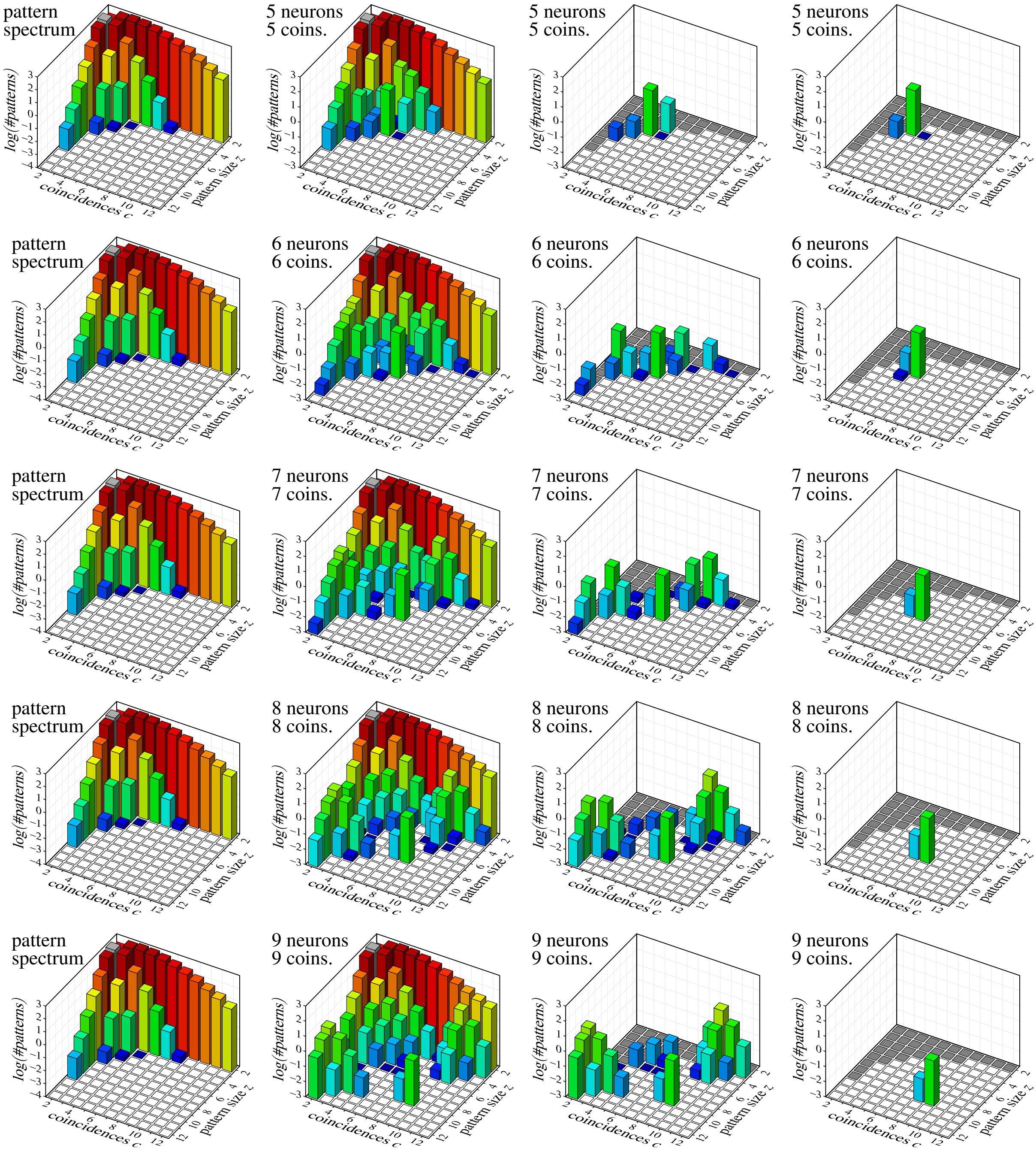
600×5ms bins, reduced with excess coincidences and neurons 2



1000×3ms bins, reduced with number of covered spikes 2



750×4ms bins, reduced with number of covered spikes 2



600×5ms bins, reduced with number of covered spikes 2