Edge event organization across temporal categories

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Josh is unable to attend OHBM this year, but is happy to field your questions *via* email!
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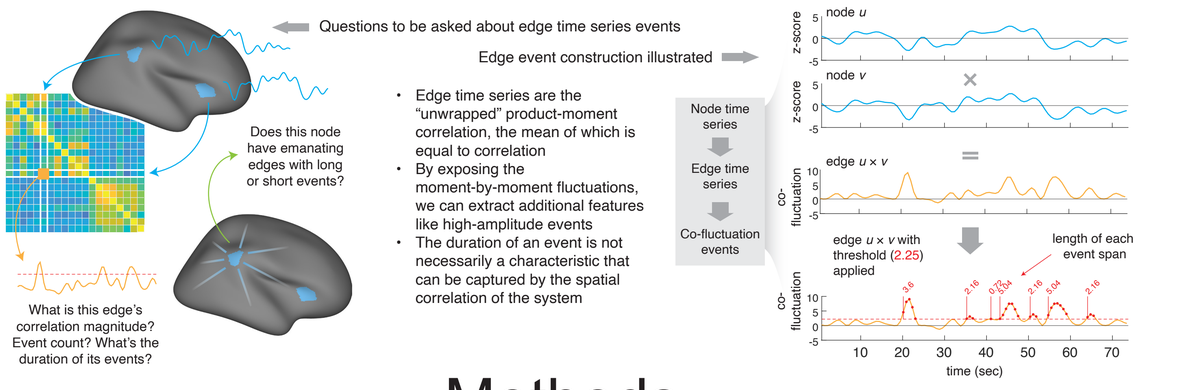
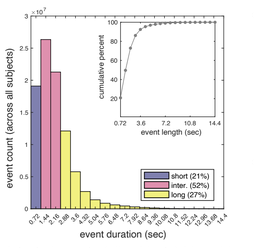
Introduction

- Functional magnetic resonance imaging (fMRI) has shown that BOLD signals will synchronize across the cortex during task-free conditions, which is used to probe functional organization (e.g. FC matrix)
  - It is often assumed that the synchrony between regions is a low-frequency phenomena
  - This assumption is implicit in time-varying FC methods, which take correlation estimates within windows spanning tens of seconds
- Prior research[1,2,7] has established that the spatial info can be pinpointed to specific fMRI frames
  - Studies also show that FC patterns can be resolved from moments of high-amplitude signal[6,7,10]
- Edge time series[3,10] render connectivity dynamics at the temporal resolution of the input time series
  - These time series are marked by high-amplitude frames, which can be used to reconstruct FC
  - By virtue of temporal resolution, edge time series can be used to identify moments of high-amplitude connectivity, which we term edge events, lasting mere seconds
  - Each edge event has a duration, which can provide added info on connectivity unfolding over time
- Here we show how the synchrony (i.e. FC) can similarly be understood through the lens of punctate events, and that this approach can enhance our understanding of FC with additional information

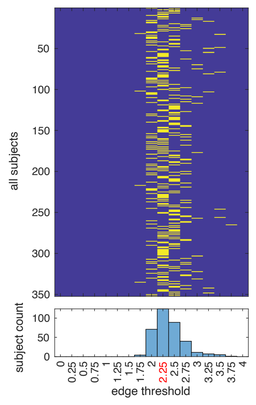


Methods

- **fMRI data**
  - Human Connectome Project[9] quality-controlled subset of 352 subjects[4]; split into train/test subsets of 176
  - Resting-state data (0.72 TR, 1200 TRs, ~15 min) minimally pre-processed, motion, distortion, ICA-FIX corrected, and projected to fsLR surface; bandpass (0.008 - 0.2 Hz) filtered, mean WM, mean CSF, linear, and quadratic drift removed via linear regression in one step using AfNI's 3dTproject
  - Time series constructed using 200 node of Schaefer parcellation (fsLR space)
- **Edge time series & edge event extraction**
  - Computed as the element-wise product of two z-scored signals
  - Edge event threshold selected in data driven manner (illustrated left): for each subject, event count matrix at various thresholds (0-4.0) constructed, then correlated to individual's FC; threshold selected as mode max across subjects = 2.25 (arbitrary units)
  - Duration of edge events were labeled as short (<1.4 sec), intermediate (>= 1.4, < 2.8 sec), long (>= 2.8 sec) categories by: setting all events detectable less than 2 TR's as short (~21% of all events), and matching as close as possible this percentage at the tail as long (4 TR's and above; ~27% of events); remaining events (52% of events) were labeled as intermediate (distri-
  - Obtain FC, event counts (overall & parsed by duration), and event durations matrices for each subject; averaged across subset (n=176) for mean matrix comparisons

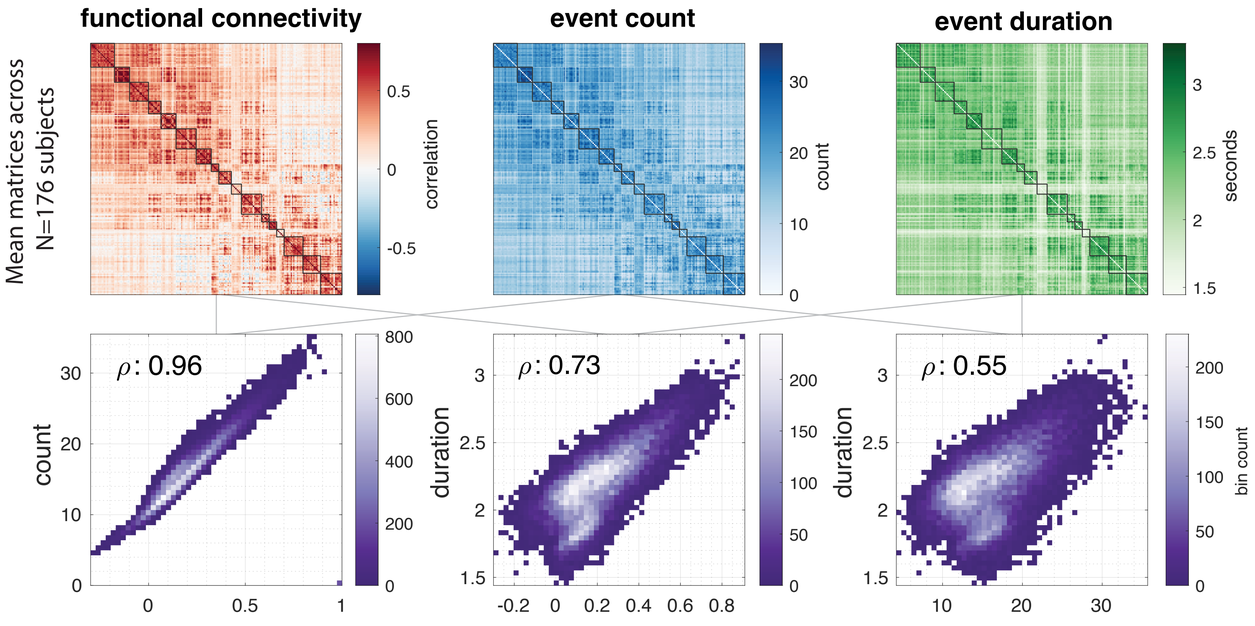


All detected events (all subjects) binned by duration, forming a heavy-tailed distribution; bins are colored by assigned duration category; cumulative distribution in inset



Results

FC correlated with event count & duration provides alternative information



Group average FC matrix provide nearly the same information, as the upper triangle of these matrices are highly correlated (Spearman rho: 0.96). This indicates that FC is driven, or overwhelmingly influenced, by the number of high-amplitude connectivity events occurring over the course of a resting-state scan. FC and event duration are also highly correlated (rho: 0.73), but the attenuated correlation and shape of the distribution suggest that event duration might provide different information about functional connections between regions of the cortex.

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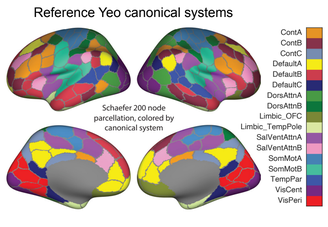

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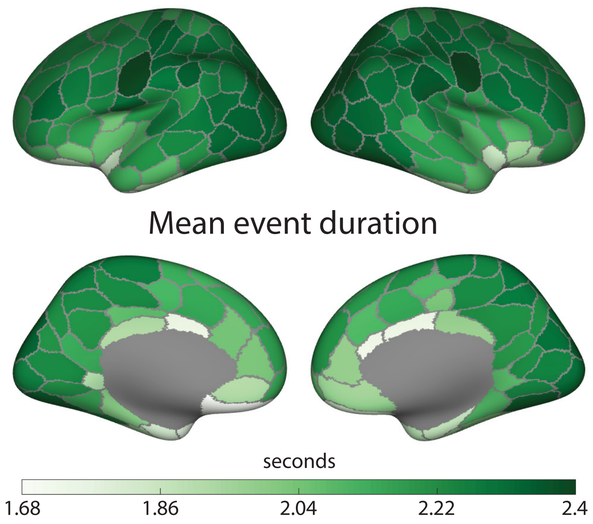
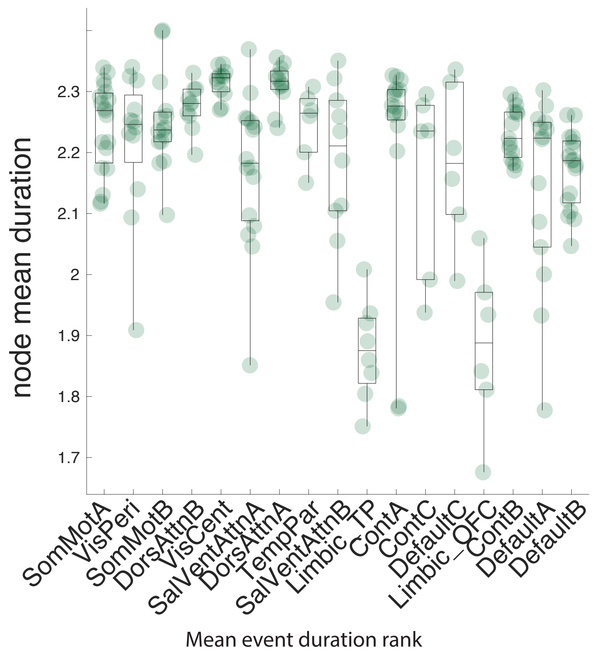
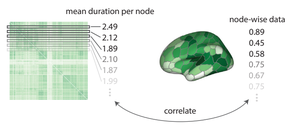
- Checkout github.com/nimh-sfim/edgeevents for code in MATLAB
- Thanks to NIMH SFIM lab for their support; especially Dan Handwerker (who transported this poster cross-continent) and Peter Bandettini for representing us at OHBM.

Edge event duration differs across cortex & is not explainable by common artifacts or physiological factors

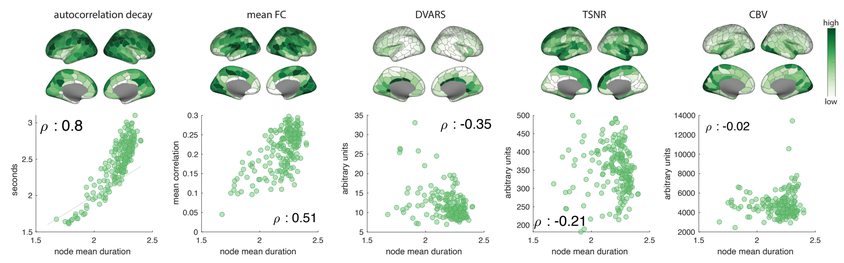


For each node, we compute the duration of its emanating edge events on average, and display this data on the inflated cortex (top). Edge events have different durations, depending on their cortical location - longer events are found in primary sensory areas (VisCent system & L&R SomMotB nodes), whereas the shortest events fall along the mid-line and ventral surface. This pattern is clarified even more when rank ordering duration data (right).

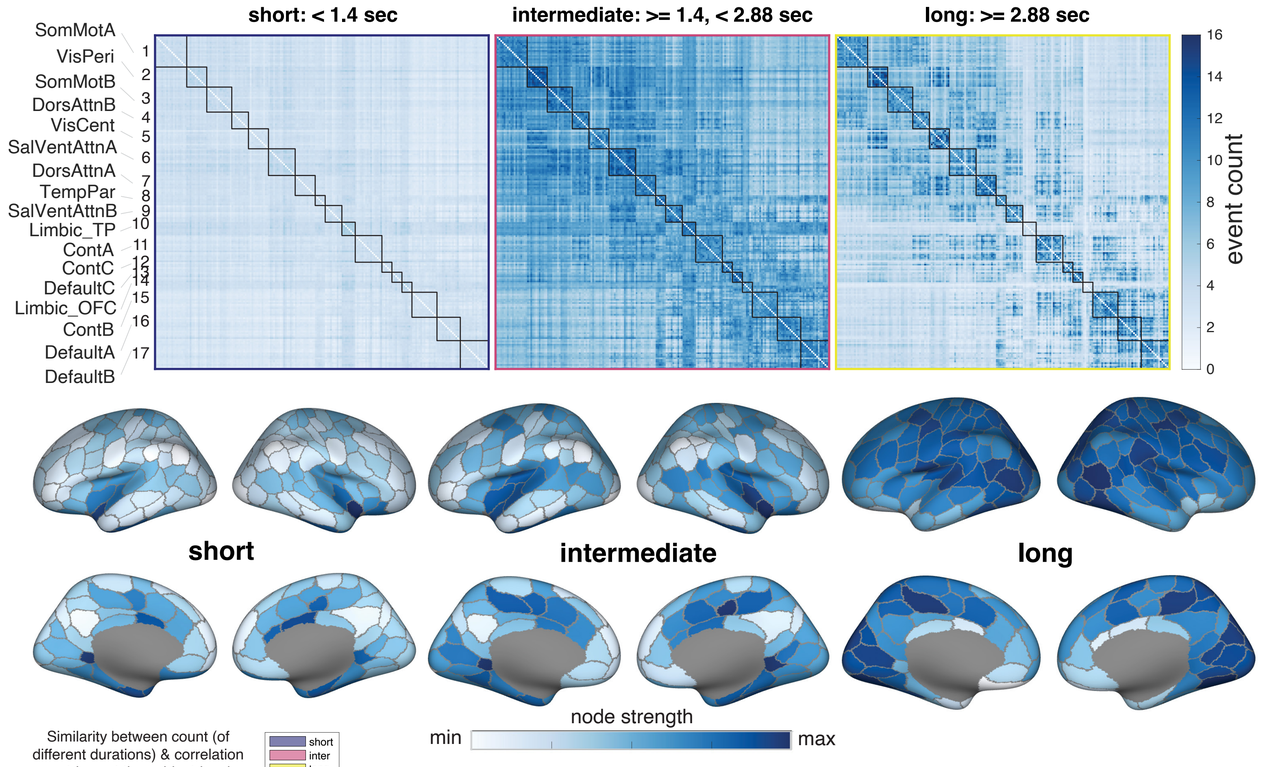


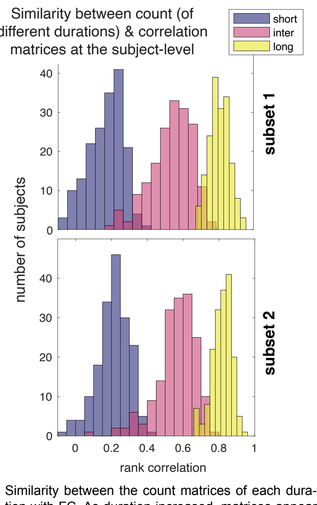


Here, we compared duration data to other cortical maps. Edge event duration is highly correlated with time series autocorrelation decay, indicating that the 'timescale' of node time series contributes to the duration of edge events. However, this map does not align with the spatial pattern of event duration, suggesting non-redundant information. Duration does not seem to be a byproduct of mean FC, nor does it seem to be highly influenced by nodal data quality (DVARS, TSNR) or the blood volume at specific cortical locations (CBV).



Functional organization differs when parsing events by duration

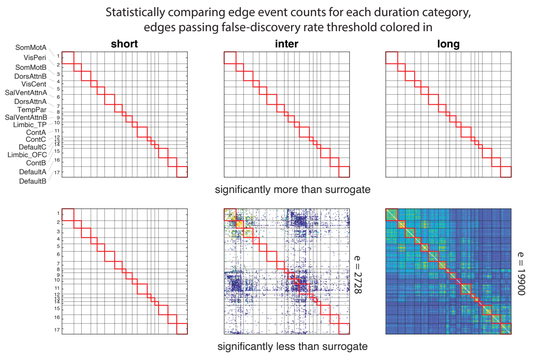




Similarity between the count matrices of each duration with FC. As duration increased, matrices appear to be more similar to FC (within-subject). This relationship is highly similar across dataset subset.

Illustration of the count matrices, organized by canonical system, when parsing edge events by duration category. Short and intermediate events load heavily onto mid-line and insular areas, whereas the long events form a matrix that is very similar to FC matrix at both the group level (rho=0.96) and subject level (see histogram, left). Thus, FC can be framed as a phenomenon driven primarily by long events that occur sparsely (less than 16 times on average) throughout the resting state scan.

Event count matrices at each duration were compared to data from phase randomized (preserving spatial correlation) and frequency-matched surrogate time series[5] were created and edge event durations were recorded. Surrogate data consistently overestimated the number of intermediate and long edge events. This demonstrates that basic system properties (spatial correlation & frequency spectra) can result in edge events, but not with the sparsity observed in empirical data.



Discussion

- We show that connectivity can be cast as a series of punctate events rather than slow oscillations, at level of edges.
  - Whereas previous time-varying FC methods demonstrate the ebb and flow of connectivity patterns, our approach shows the expression of this information in moments generally < 5 sec (but also: shorter events relate less to FC)
  - As FC can be thought of as counts of sparse events, begs question about timing of these events and if there are relevant patterns in-between events
- Edge event duration is not redundant with FC, and thus, is a candidate to uncover novel cortical organization
  - Longest edge events emanate from primary sensory regions, which are thought to be fast-acting, responsive to the environment; prolonged events could be signature of feedback from areas higher on functional hierarchy
- Given the bursty nature of FC when 'unrolled' at the edge level, suggests future prospects for statistically differentiating functional relationships using techniques sensitive to these sparse features.