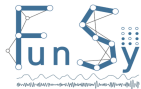


Dynamic Functional Connectivity Resolves Integration–Segregation Trade-off Under Costly Links

Simachew Mengiste

July 15, 2026

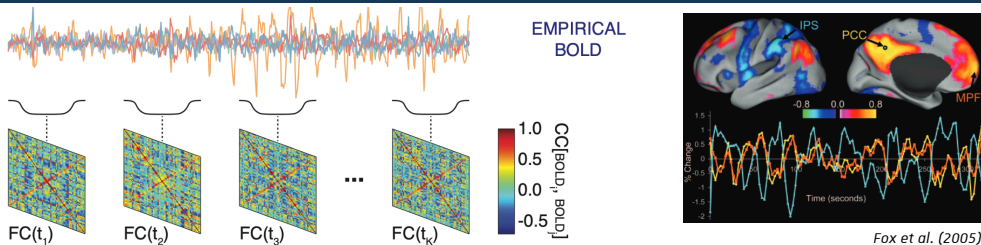


PROGRAMME
DE RECHERCHE
SANTÉ
NUMÉRIQUE

CNS 2026

Workshop on Methods of Information Theory in Computational Neuroscience

From brain activity to dynamic functional connectivity



Ordered output: $dFC = \{FC(t_1), FC(t_2), \dots, FC(t_K)\}$

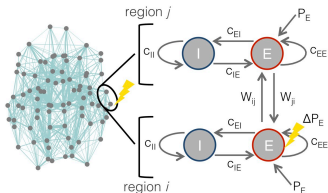
FC reveals coordinated functional systems that can span distant brain regions; dFC tracks how their interaction map reconfigures over time.

Why could FC be treated as a communication channel?

$$FC_{ij} = \rho_{ij} \implies I(X_i; X_j) = -\frac{1}{2} \log(1 - FC_{ij}^2) \quad (\text{Gaussian signals})$$

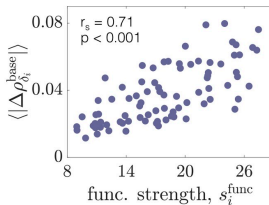
Focal stimulation

inject a local perturbation



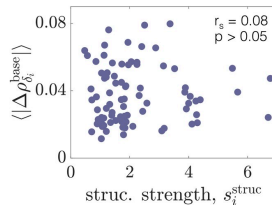
FC

coupling predicts the response



SC

coupling does not predict it

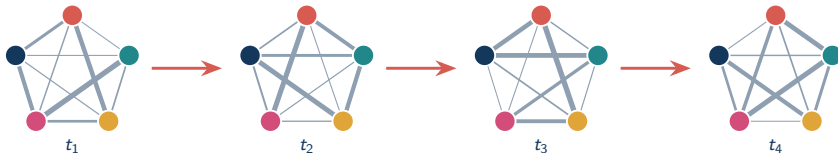


Papadopoulos et al., *PLoS Comput. Biol.* (2020)

FC captures currently expressed communication opportunities that anatomy alone cannot specify.

The question

The brain never holds still—why?



Functional connectivity changes continuously—even at rest.

Is this variability...

Noise / by-product

incidental fluctuation

Trace of computation

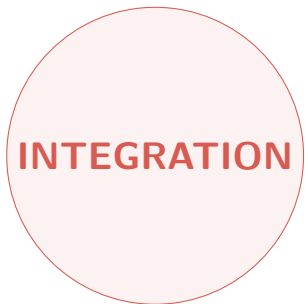
reflects ongoing processing

Communication strategy

dynamicity is itself useful

The strong hypothesis: dynamicity itself can be functional.

One budget, two competing demands



reach distant regions
combine information



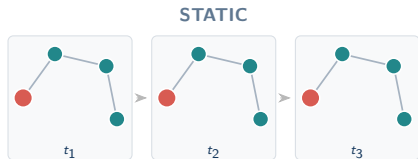
preserve local processing
and specialization

CONSTRAINT

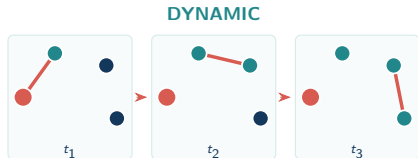
Maintaining an active functional link has a cost.

How could dynamicity help?

Same target efficiency

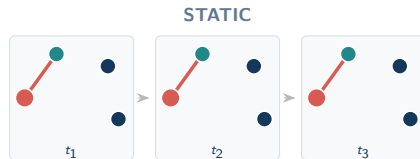


9 edge activations

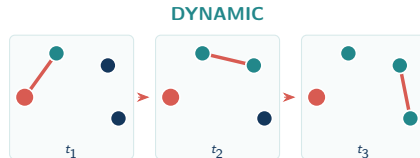


3 edge activations

Same limited budget



2 of 4 nodes reached

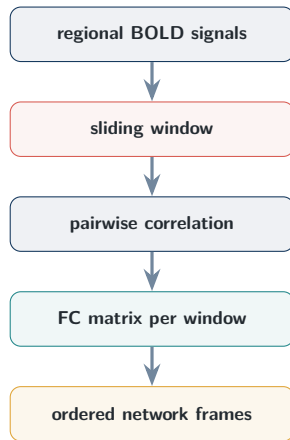
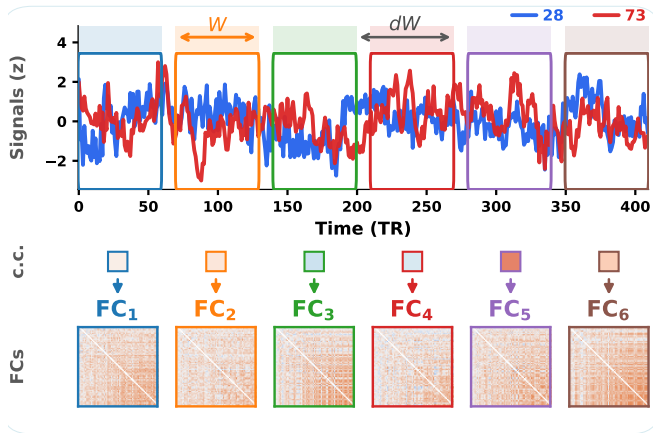


4 of 4 nodes reached

Reconfiguration delivers the same efficiency at lower cost—or greater efficiency for the same budget.

Framework

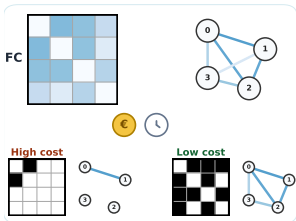
From resting-state fMRI to a temporal network



Each thresholded FC window defines the communication opportunities available at that moment.

How do we impose equal cost?

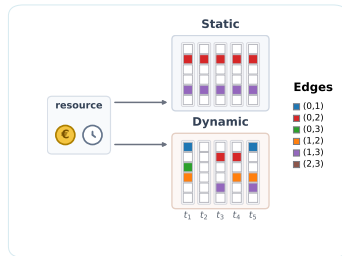
Instantaneous sparsity



Strict threshold $\rightarrow$ sparse frames $\rightarrow$ high effective cost

$$\text{total cost} = \sum_t |E_t| \quad \text{one unit per active edge per frame}$$

Allocation across time



Static: repeat edges

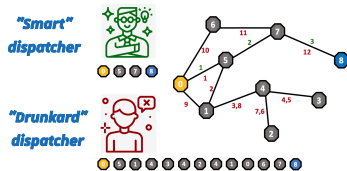
Dynamic: renew edges

Static and dynamic networks receive the same edge–time budget; only its temporal allocation changes.

Information dispatch: fixed routes or changing opportunities?

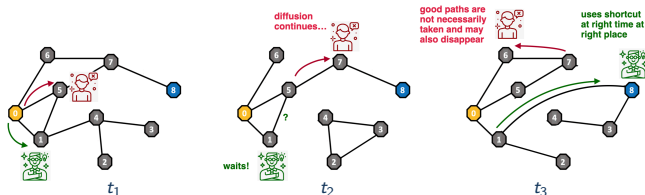
Static tNet

The same routes are available at every step.



Dynamic tNet

Routes appear in sequence: move, wait, or exploit a later shortcut.



SMART

0 → 1 → 1 → 8

DRUNK

0 → 5 → 7 → 6

On a dynamic temporal network, successful communication depends on both topology and timing.

How do we measure integration *and* segregation?

INTEGRATION

Can information spread globally?

Irrigation $\uparrow$ destinations reached within T

Resistance $\downarrow$ arrival time, penalizing unreachable pairs

s. clustering



t. clustering

SEGREGATION

Can information remain locally organized?

Return latency $\downarrow$ rapid recirculation to the source

Retention $\uparrow$ reuse of neighborhood partners

Clustering $\uparrow$ cohesive spatial and temporal neighborhoods



t



$t + 1$



$t + 2$

Success means global accessibility without immediately dissolving local structure.

How are the null models built?

Empirical dFC



Match network size and edge-time cost; selectively remove structure.

STATIC CONTROLS

One graph is repeated
through every frame.

REMOVES temporal change

Does dynamicity help?

RANDOM TEMPORAL

Edges or frames order are
randomized.

REMOVES timing/topology

Is any variability sufficient?

STRUCTURED TEMPORAL

Activation rates, hubs, or
neighborhoods are retained.

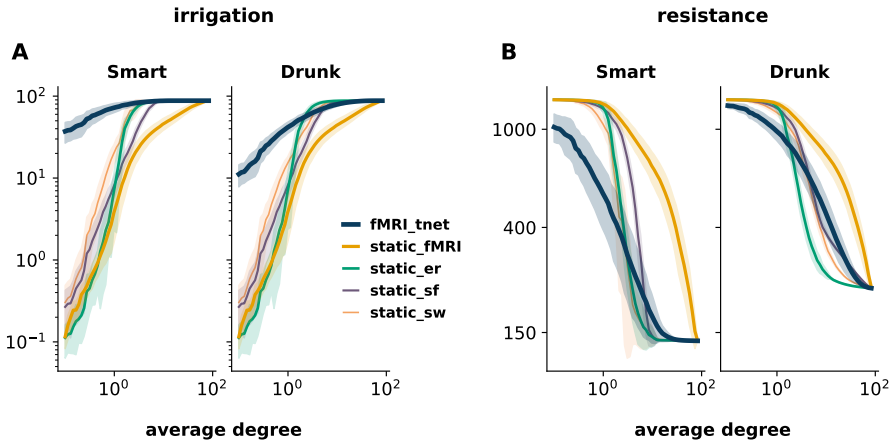
PRESERVES chosen persistence

Which structure matters?

Each null changes one aspect of temporal organization while keeping the communication budget comparable.

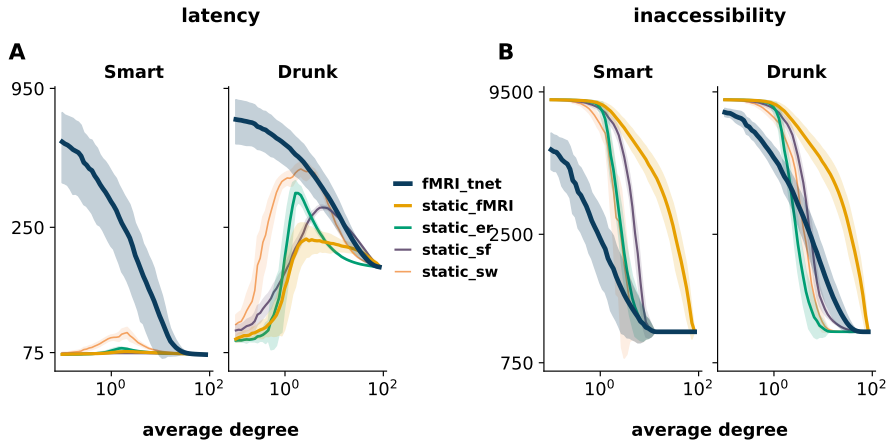
Results

Dynamicity pays when links are costly



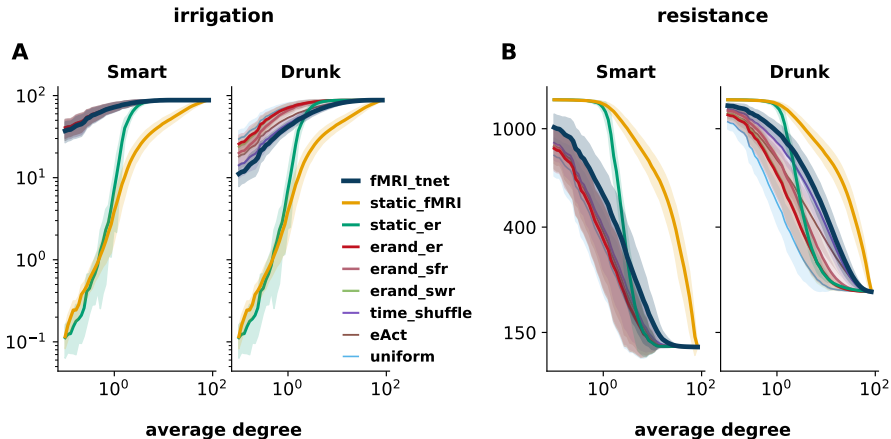
Sparse empirical dFC reaches more nodes than equal-cost static networks.

The gain is reachability—not faster realized paths



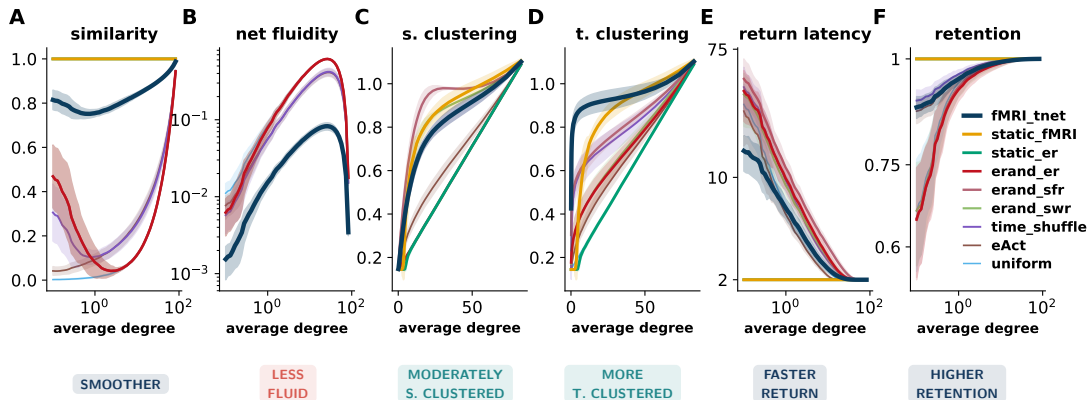
Temporal reconfiguration lowers resistance mainly by reducing inaccessible pairs.

Random reconfiguration integrates even better



Temporal variability generically promotes integration.

Does empirical dFC trade maximal integration for other objectives?



Empirical links reconfigure smoothly while sustaining cohesive neighborhoods and rapid recirculation.

The trade-off is managed across temporal scales

WITHIN SHORT WINDOWS

cohesive neighborhoods

high retention • rapid return • clustering

local segregation is preserved

ACROSS MANY WINDOWS

neighborhoods gradually renew

changing edges • time-respecting paths • reach

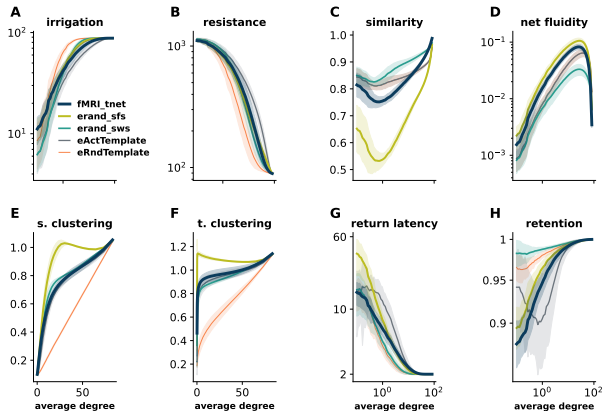
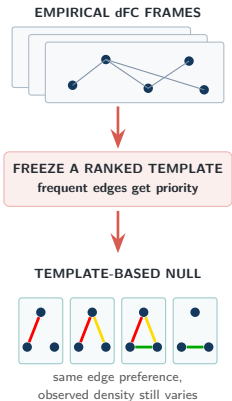
global integration becomes possible

CONTROLLED RENEWAL local neighborhoods persist while their membership gradually changes

Structured reconfiguration of dFC preserves local cohesion over short windows while building global reach across longer timescales.

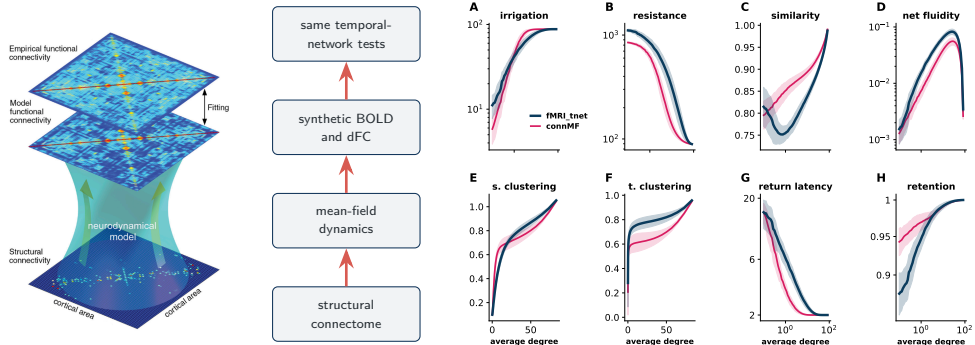
Explanation

Can persistent empirical structure explain the balance?



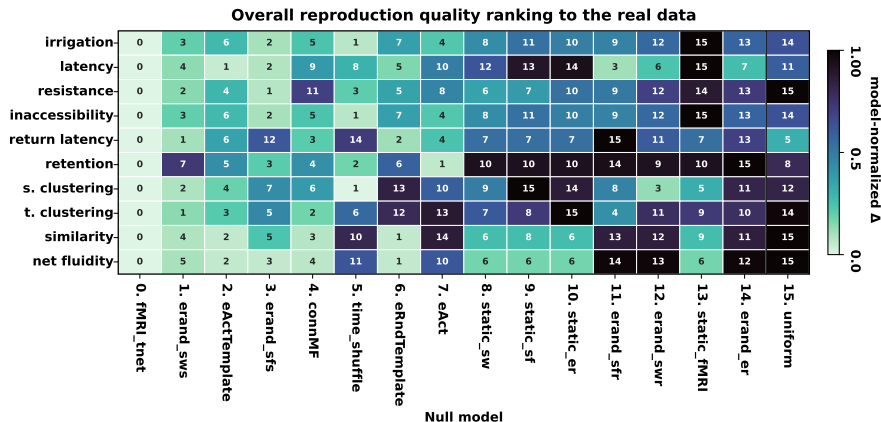
Freezing edge priorities, hubs, or neighborhoods recovers selected features
—but not the full empirical signature.

Can the empirical balance emerge mechanistically?



Connectome-constrained dynamics can generate integration and local cohesion without an imposed empirical edge template.

No model captures the full empirical signature



ConnMF is the strongest physiologically interpretable candidate, but the match remains qualitative.

Interpretation

What the results establish

REACH

Dynamic links reduce inaccessible pairs when links are costly.

COHESION

Empirical dFC preserves local organization beyond random temporal nulls.

BALANCE

Segregation is maintained locally while integration accumulates over time.

Empirical dFC occupies a controlled middle regime between static persistence and unconstrained temporal randomization.

Limitations define the next steps

Limitation

Propagation and reconfiguration share one timescale

Binary, undirected links

Slow BOLD-fMRI dynamics

Link cost is assumed, not measured

Next step

→ Decouple the two clocks

→ Test weighted and directed temporal networks

→ Probe faster EEG and LFP dFC

→ Relate dFC organization directly to metabolic cost

Thank you