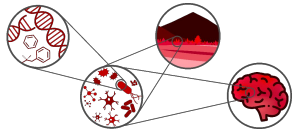
Laboratory of Interdisciplinary Physics



CoMuNe lab
COMPLEX MULTILAYER NETWORKS

PADOVA neuroscience CENTER

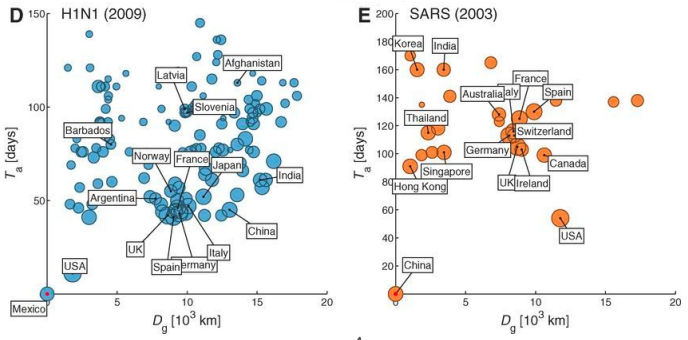
FONDAZIONE BRUNO KESSLER

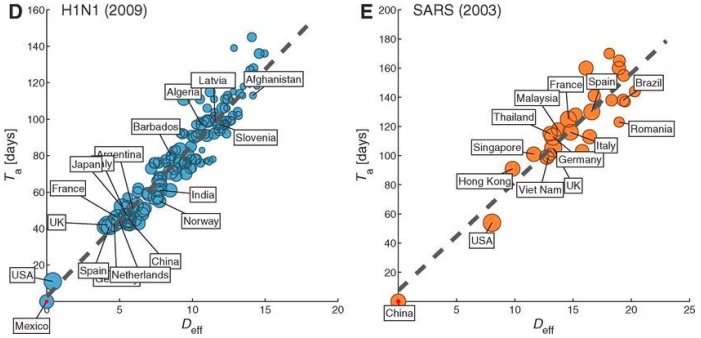
Unraveling the mesoscale organization induced by network-driven processes

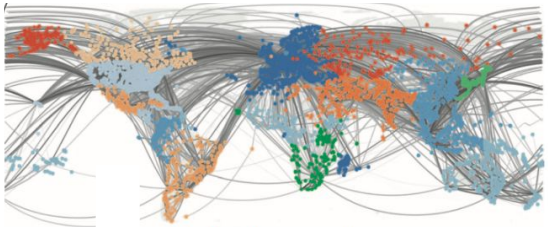
Giacomo Barzon, Oriol Artime, Samir Suweis, Manlio De Domenico

Network Days - 25 October 2024

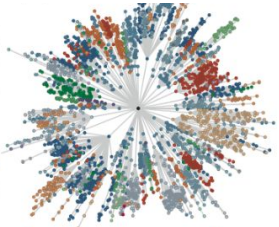
Network-driven hidden geometry of epidemics spreading



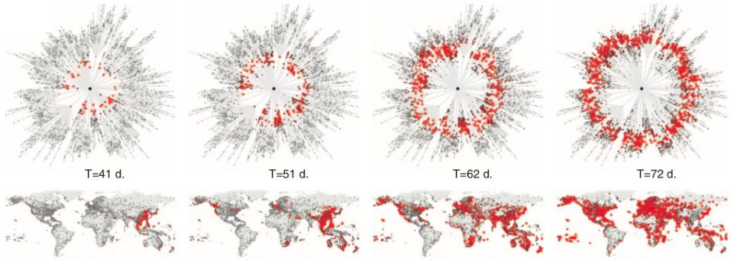




Natural geometry



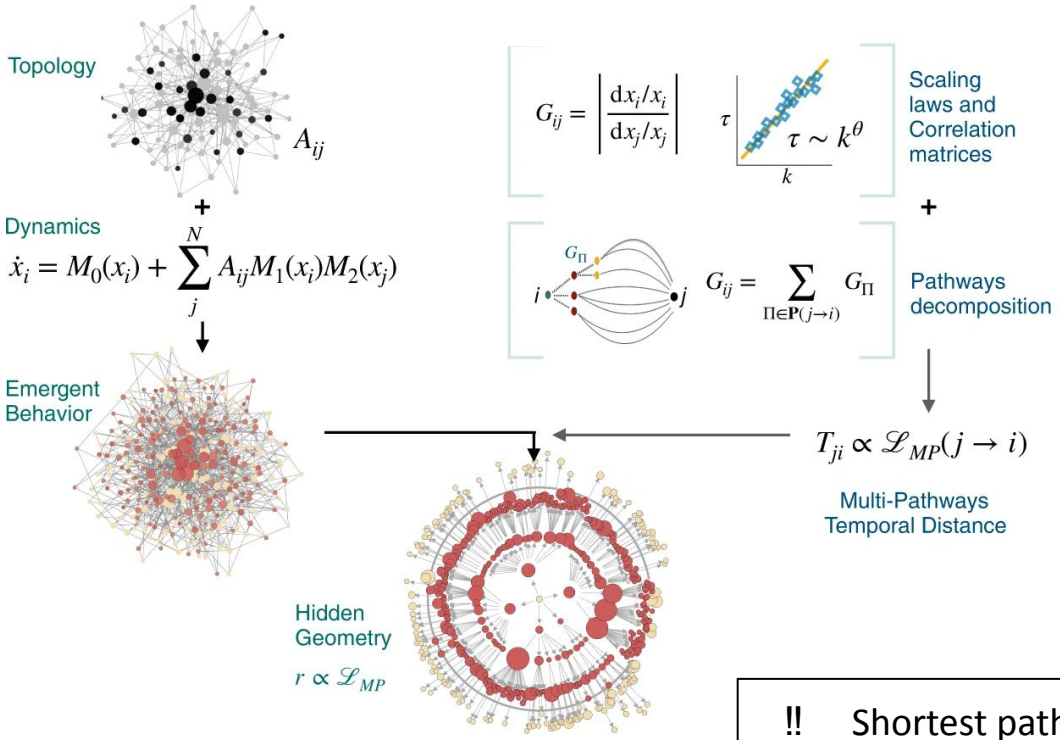
Induced geometry

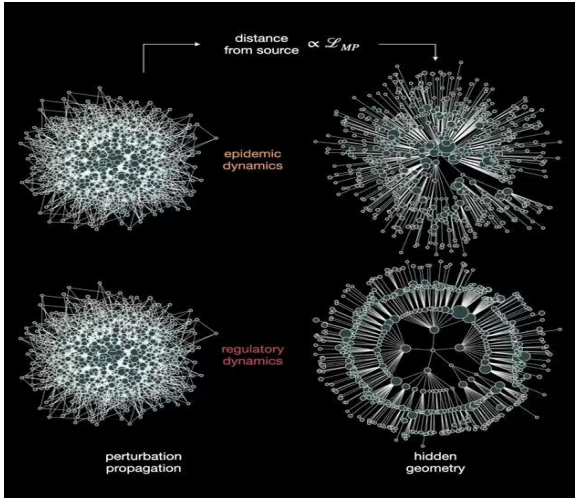


Spreading dynamics: induced (top) and natural (bottom) geometry

D. Brockmann, & D. Helbing (2013), Science

Universal temporal distance



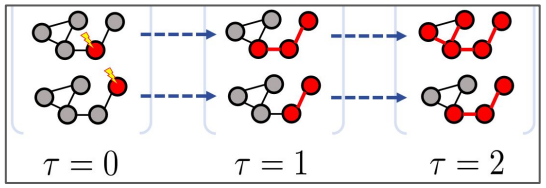


‼ Shortest path with the minimum cumulative lag time
addressed in Bontorin & De Domenico (2023), Comms Phys

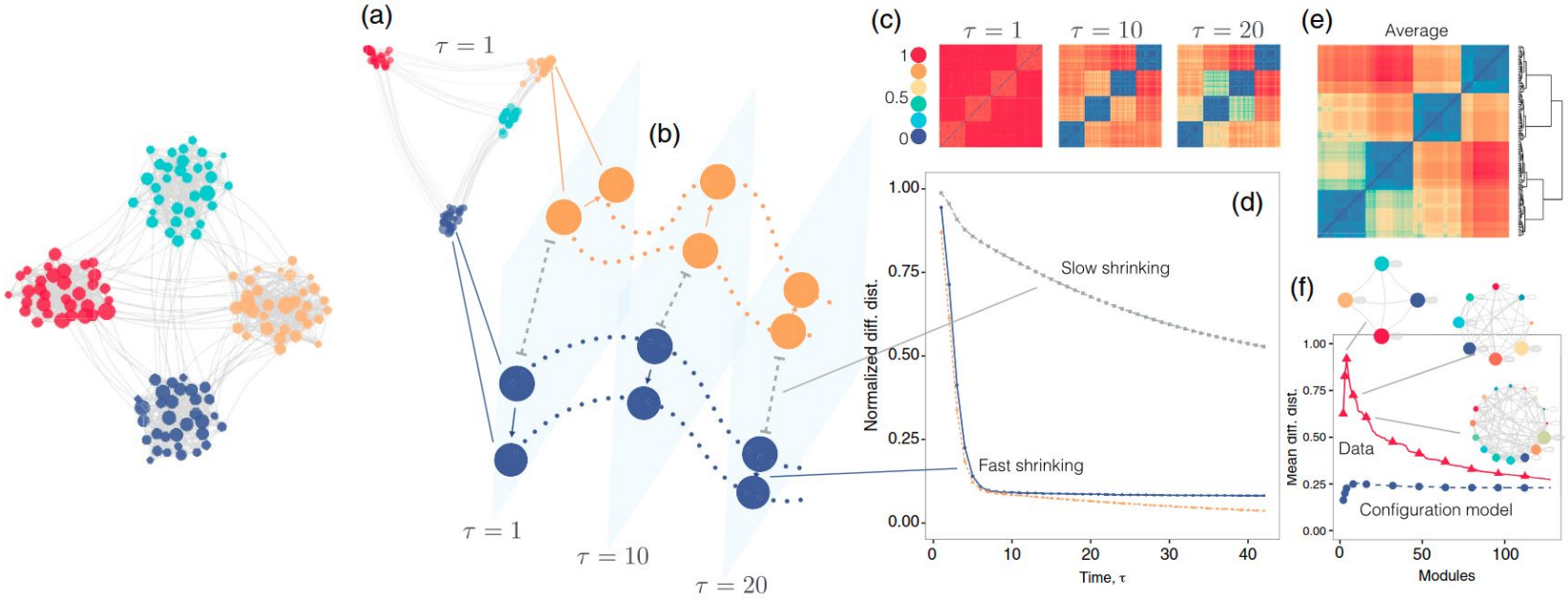
‼ Configuration model

C. Hens, et al. (2019), Nature Physics

Diffusion geometry

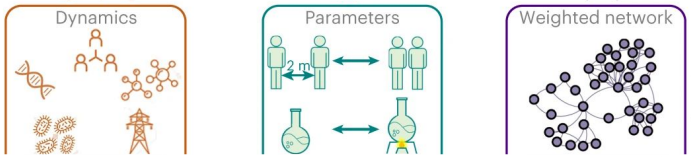


$$d_\tau^2(i,j) = [\mathbf{p}(\tau|i) - \mathbf{p}(\tau|j)]^2$$



M. De Domenico (2017), PRL

Jacobian geometry



$$\delta \mathbf{x}_{(k)}(0) \equiv \mathrm{d}x_k \mathbf{e}_{(k)}$$

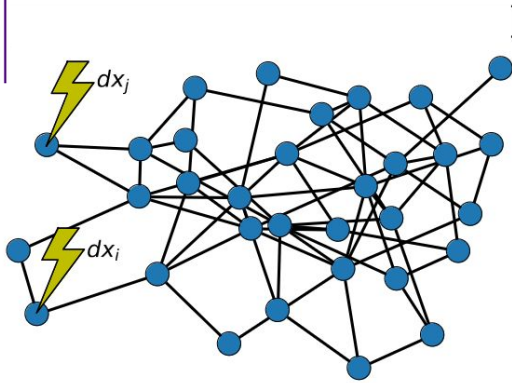
$$\delta \dot{\mathbf{x}}_{(k)}(t) \approx \mathrm{J}(\mathbf{x}^*)\delta_{(k)}\mathbf{x}(t)$$

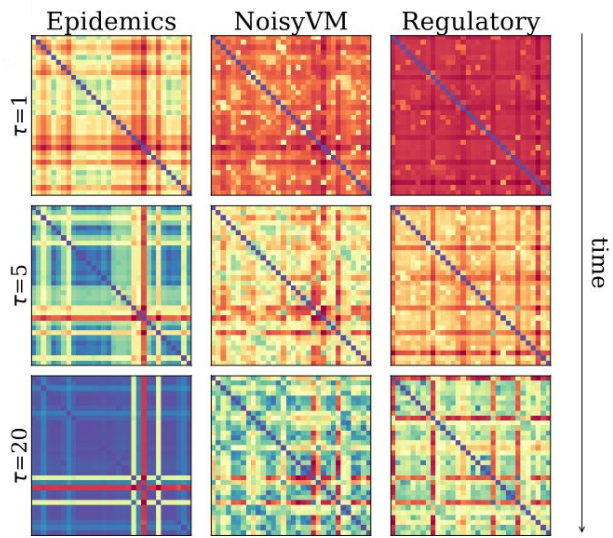
$$\delta_{(k)}\mathbf{x}(t) = e^{\mathrm{J}(\mathbf{x}^*)t}\delta_{(k)}\mathbf{x}(0)$$

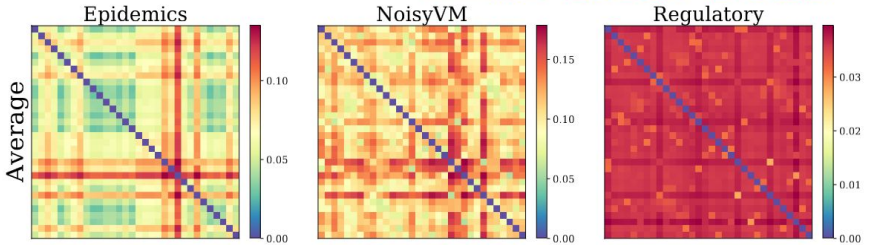
Jacobian distance

$$d_\tau(i,j) = ||e^{\mathrm{J}(\mathbf{x}^*)\tau}[dx_i e_{(i)} - dx_j e_{(j)}]||$$

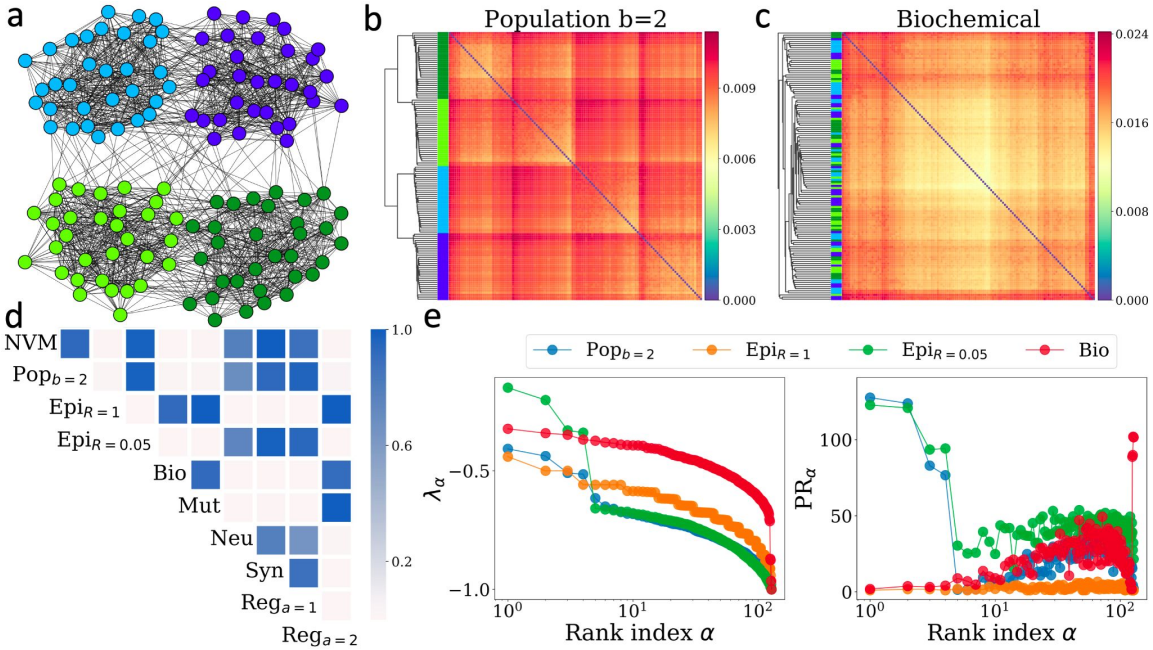
Dynamics	$\partial_\tau x_i =$
Biochemical	$F - Bx_i - R\sum_j A_{ij}x_i x_j$
Epidemics	$-Bx_i + R\sum_j A_{ij}(1-x_i)x_j$
Mutualistic	$Bx_i(1-x_i) + R\sum_j A_{ij}x_i \frac{x_j^b}{1+x_j^b}$
Neuronal	$-Bx_i + C\tanh x_i + R\sum_j A_{ij}\tanh x_j$
Noisy voter model	$A - Bx_i + \frac{C}{k_i}\sum_j A_{ij}x_j$
Population	$-Bx_i^b + R\sum_j A_{ij}x_j^a$
Regulatory	$-Bx_i^a + R\sum_j A_{ij}\frac{x_j^h}{1+x_j^h}$
Synchronization	$\omega_i + R\sum_j A_{ij}\sin(x_j - x_i)$







Structural vs functional hierarchy

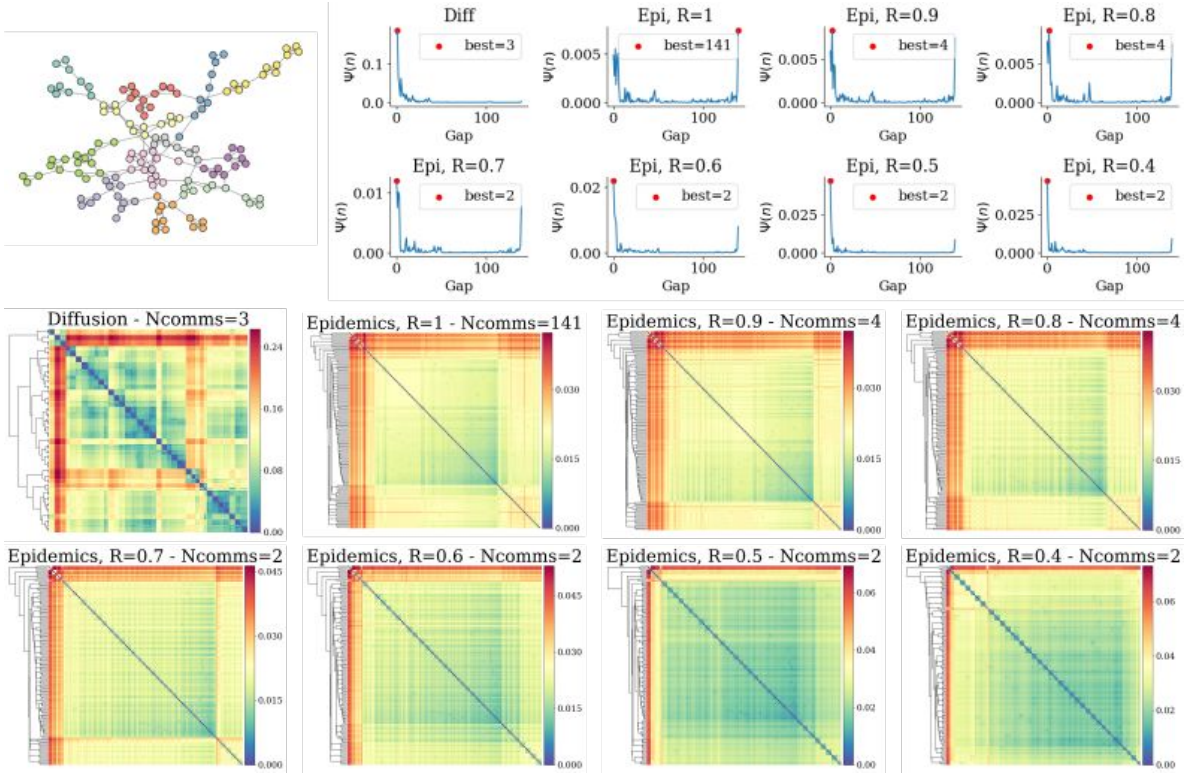


$$\delta \mathbf{x}_{(k)}(t) = \mathrm{d}x_{(k)} \sum_{\alpha} \frac{\mathbf{e}_{(k)} \cdot \mathbf{u}_\alpha}{\mathbf{u}_\alpha \cdot \mathbf{v}_\alpha} e^{\lambda_\alpha t} \mathbf{v}_\alpha$$

$$PR_\alpha = \frac{\left(\sum_i v_{i,\alpha} u_{i,\alpha}\right)^2}{\sum_i \left(v_{i,\alpha} u_{i,\alpha}\right)^2}$$

- Effective hierarchy may diverge from structural hierarchy
- Functional regimes unraveled by the Jacobian spectrum

Transitions in emergent communities



- Environmental conditions may lead to a continuous transition between regimes

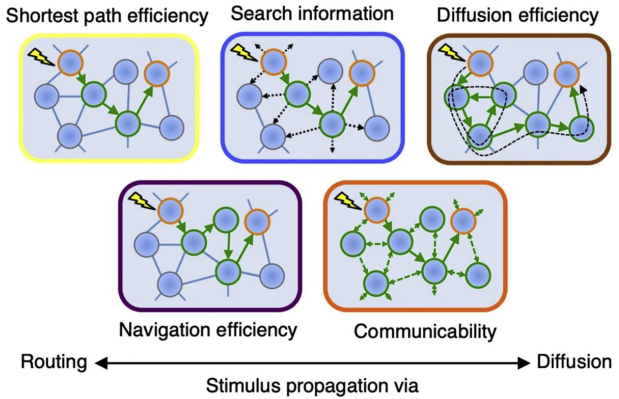
Linking brain structure and function

Published: 14 December 2017

Communication dynamics in complex brain networks

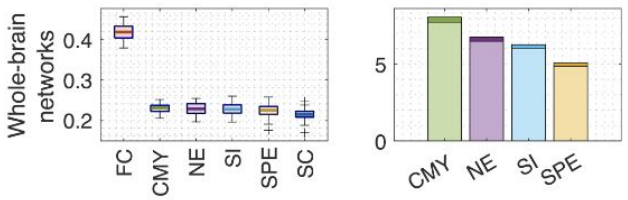
Andrea Avena-Koenigsberger, Bratislav Misic & Olaf Sporns

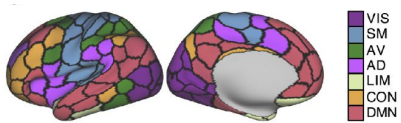
Nature Reviews Neuroscience **19**, 17–33 (2018) | Cite this article



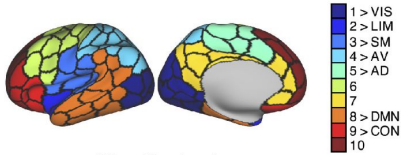
Network communication models narrow the gap between the modular organization of structural and functional brain networks

Caio Seguin [a b c], Sina Mansour L [a g], Olaf Sporns [c d e f], Andrew Zalesky [1 a g], Fernando Calamante [1 b h i]

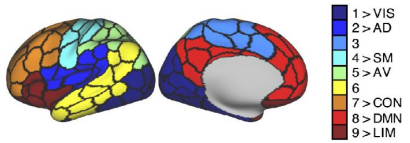




Reference functional partition (Yeo7)

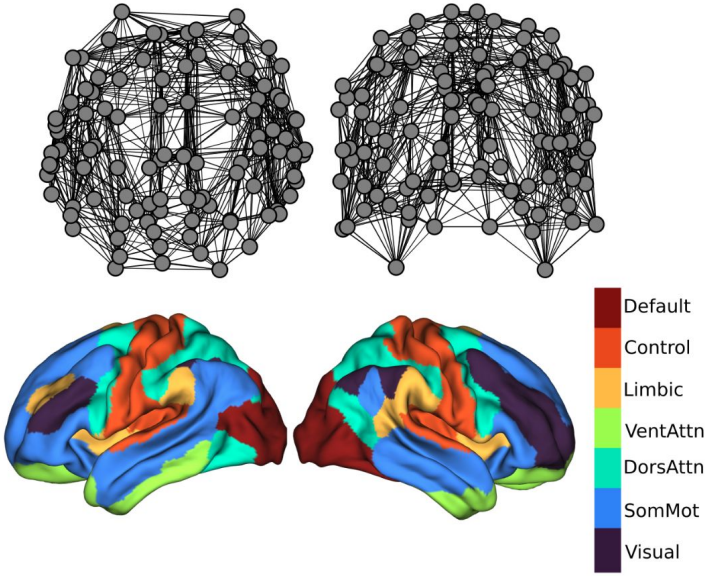


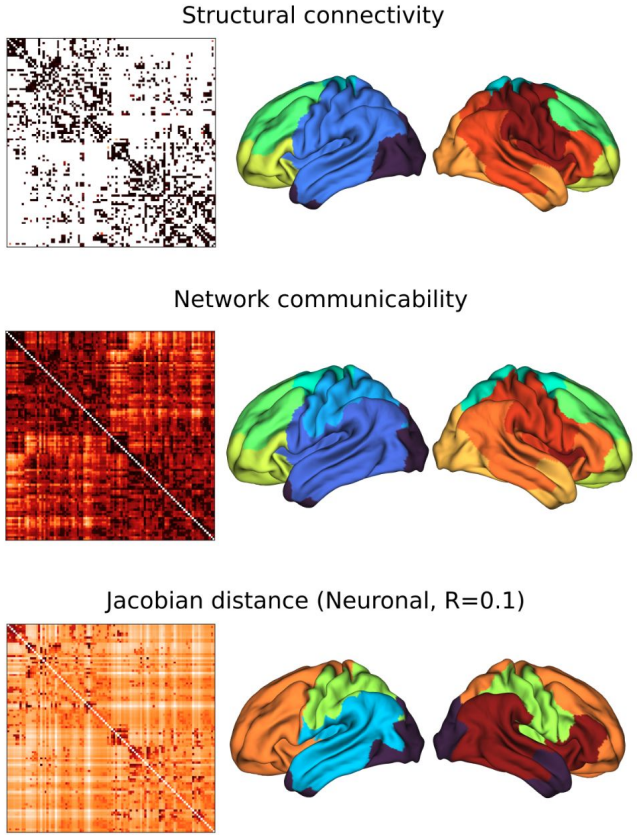
SC partition (γ_{492})



CMY partition (γ_{492})

Process-driven geometry of brain networks





Summary

- Perturbation-based geometry of any nonlinear processes unfolding on a network
- Interplay between physical dynamical rules, environmental parameters and network topology
- Effective emergent interactions explained by the spectrum of the Jacobian
- Relax the linearization around a steady-state

Thank you for your attention!

RESEARCH ARTICLE | APPLIED PHYSICAL SCIENCES

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Giacomo Barzon, Oriol Artime, Samir Suweis, and Manlio De Domenico Authors Info & Affiliations

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