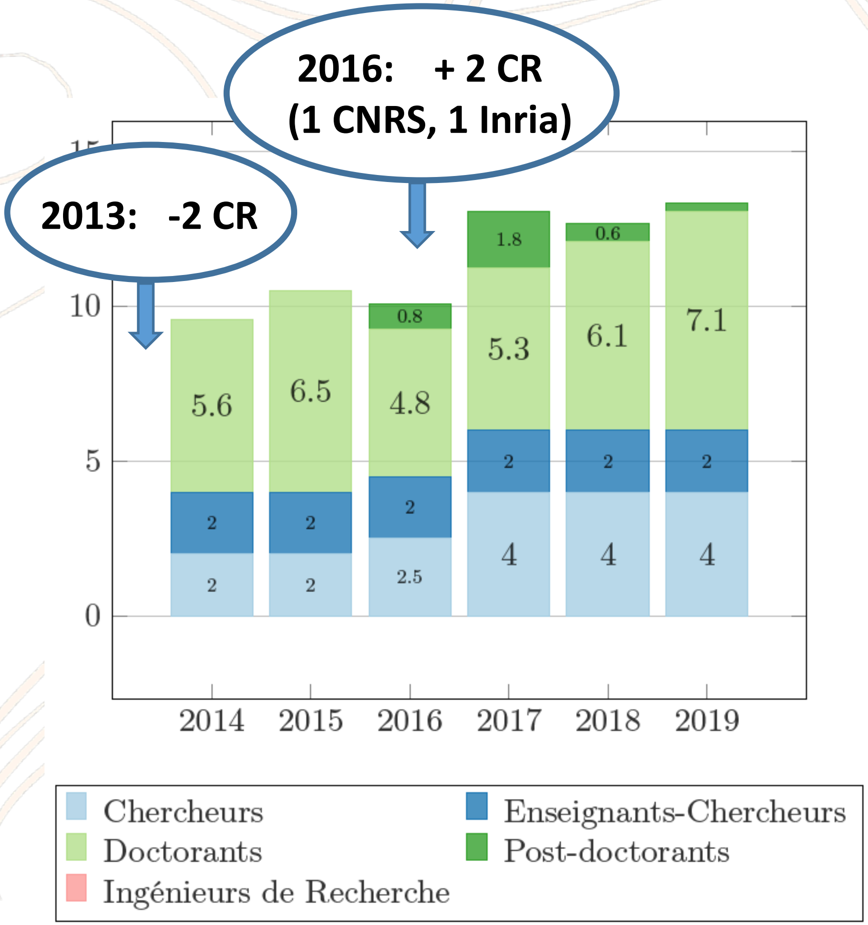
Equipe NECS
Systèmes commandés en réseaux

Carlos CANUDAS de WIT
Federica GARIN

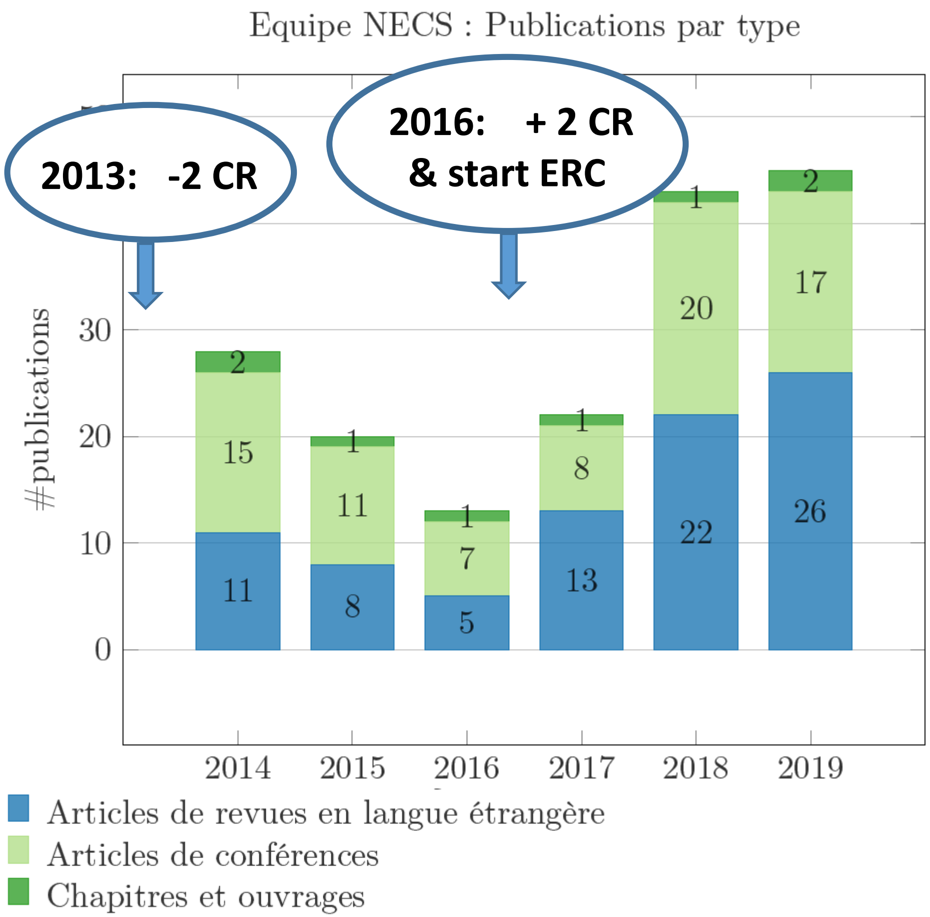
Ressources humaines

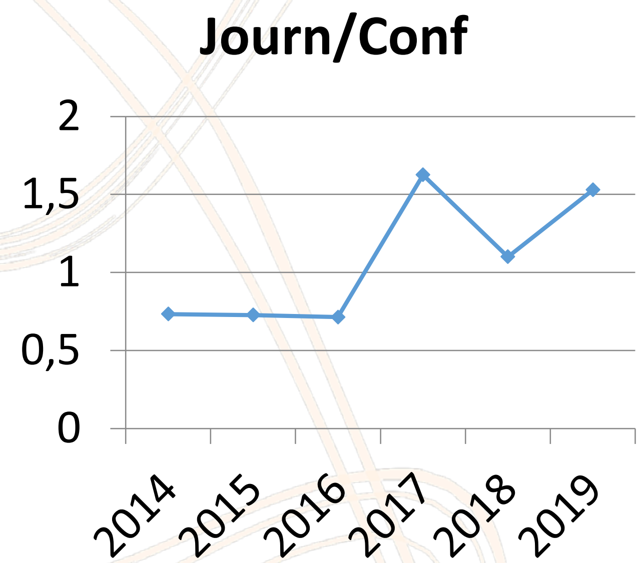


En plus : **ingénieurs CDD**
pour plateforme Grenoble Traffic Lab

1 ingénieur CNRS 2015 - 2019
(EU STREP, puis ERC)
+ 1 ingénieur Inria 2015 - 2016

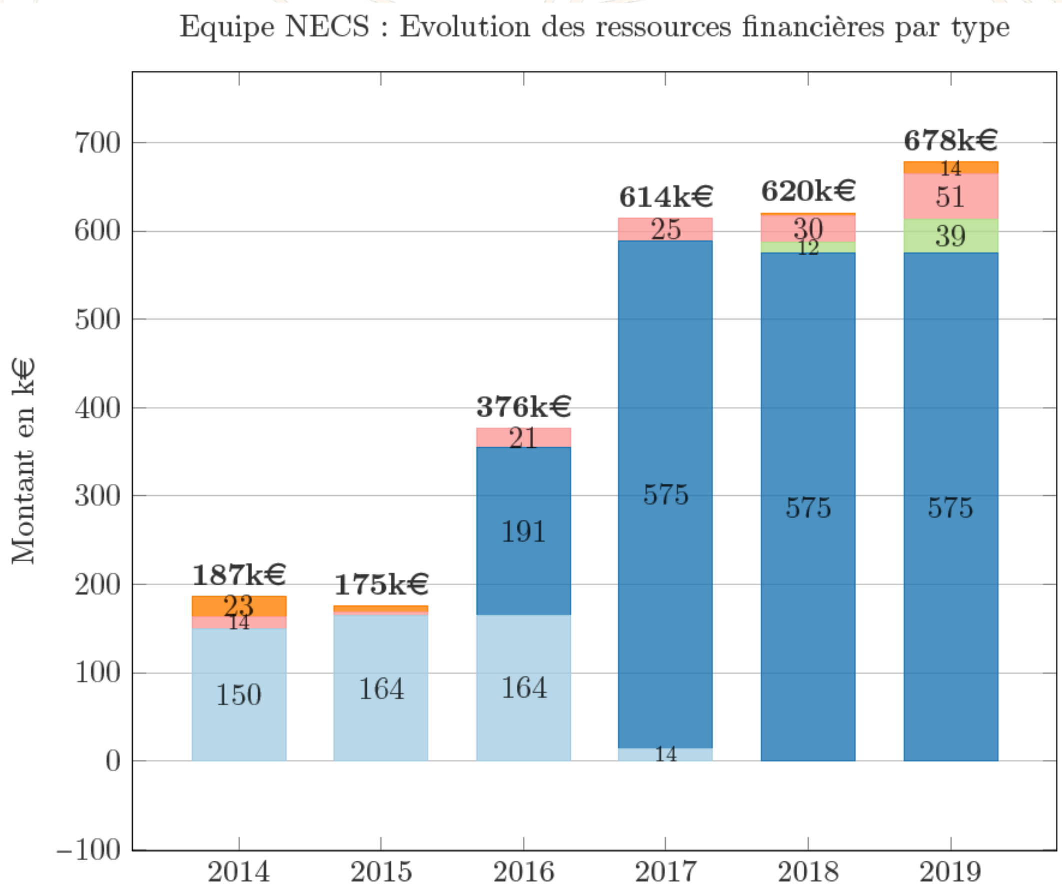
RESSOURCES BIBLIOGRAPHIQUES





Articles de revues en langue étrangère	Conférences avec actes	Chapitres d'ouvrages	Ouvrages et direction d'ouvrages	Brevets et logiciels
85	75	4	4	1

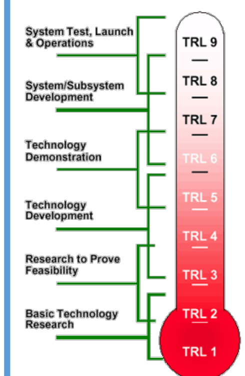
RESSOURCES FINANCIÈRES



90% du budget vient de l'<u>Europe</u>
(EU STREP, puis ERC)

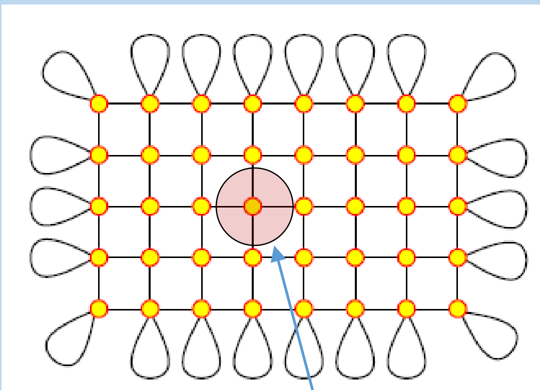
Vitrine technologique GTL: **Grenoble Traffic Lab**

Technology Readyness Level 7: Technology Demonstration



LARGE-SCALE NETWORKS—NEW VISION

From
Distributed-design for large scale systems

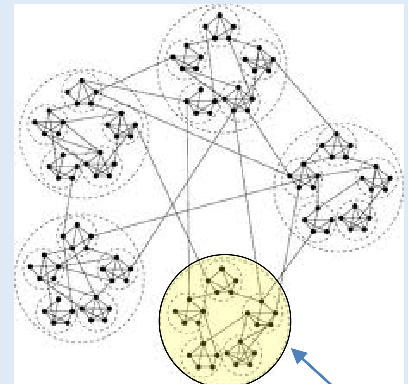


- Control/estimate **all** system states under distributed/local algorithms

$$u_i = f(x_i, x_j), j \in N_i$$

- Network analysis (graph discovering, structural properties)

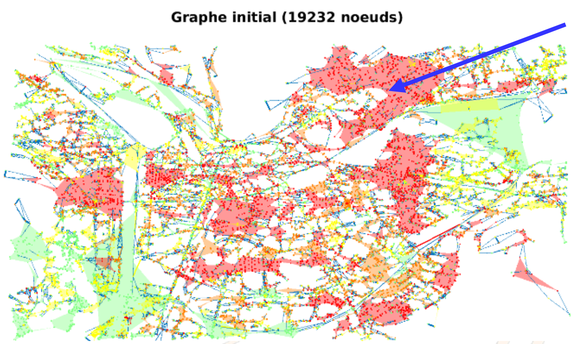
To
Scalable design for Large-scale Complex Networks



$y_i(x_j)$

- Control/estimate **an aggregate of the** system states
- Model aggregation under property preservation & Scale-Free structure
- New concepts, of Controllability, Observability

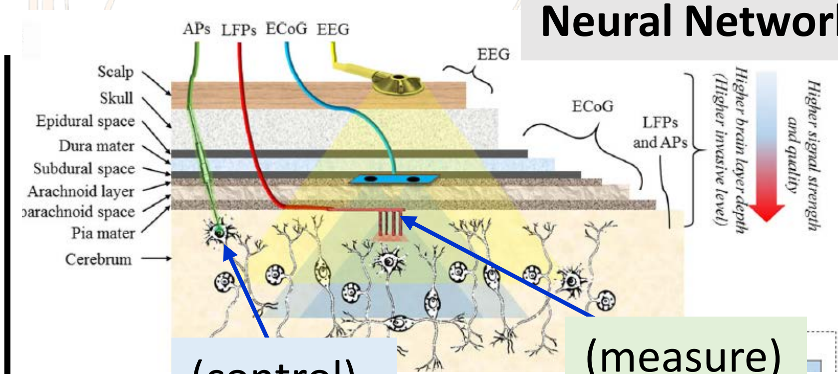
LARGE-SCALE NETWOKS: EXAMPLES—PARSIMONIOUS CONTROL & ESTIMATION



Controlling/Estimating average density in some regions by boundary actuators/sensors

Traffic networks

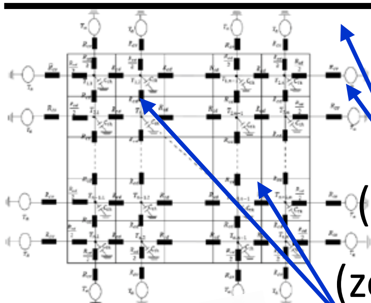
Neural Networks



(control)

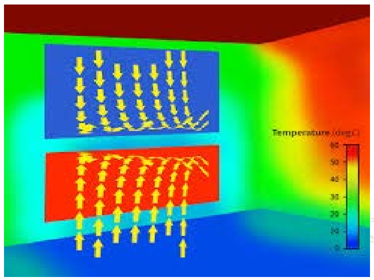
(measure)

DBS: Controlling average neural oscillations from a single electrical stimulation point



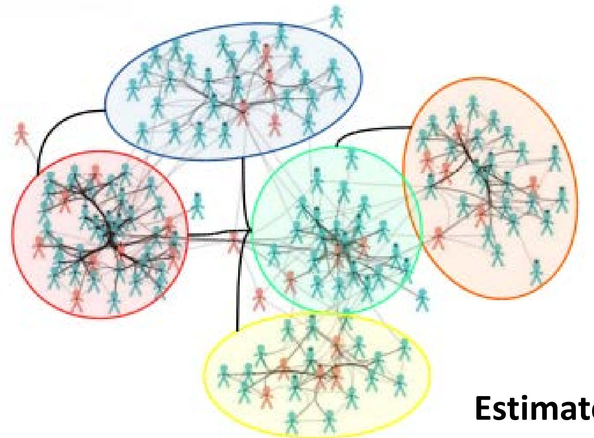
(sensor)

(zones)



Estimation & Control of average temperature from boundaries heat sensors/actuators

Heating Systems

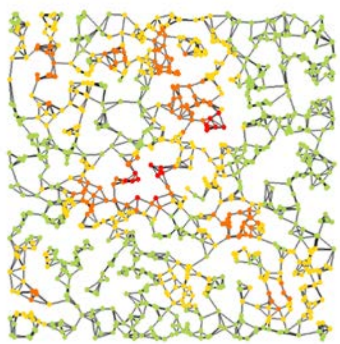


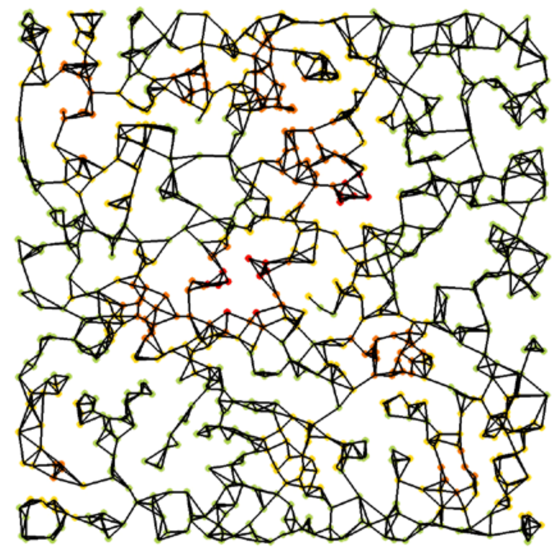
Estimate the epidemic propagation through the population (average) via few boundary samples

Epidemic spreading

THÉMATIQUES DE RECHERCHE: APPROACHES

"Class of Systems: large size, few actuators, few sensors ":

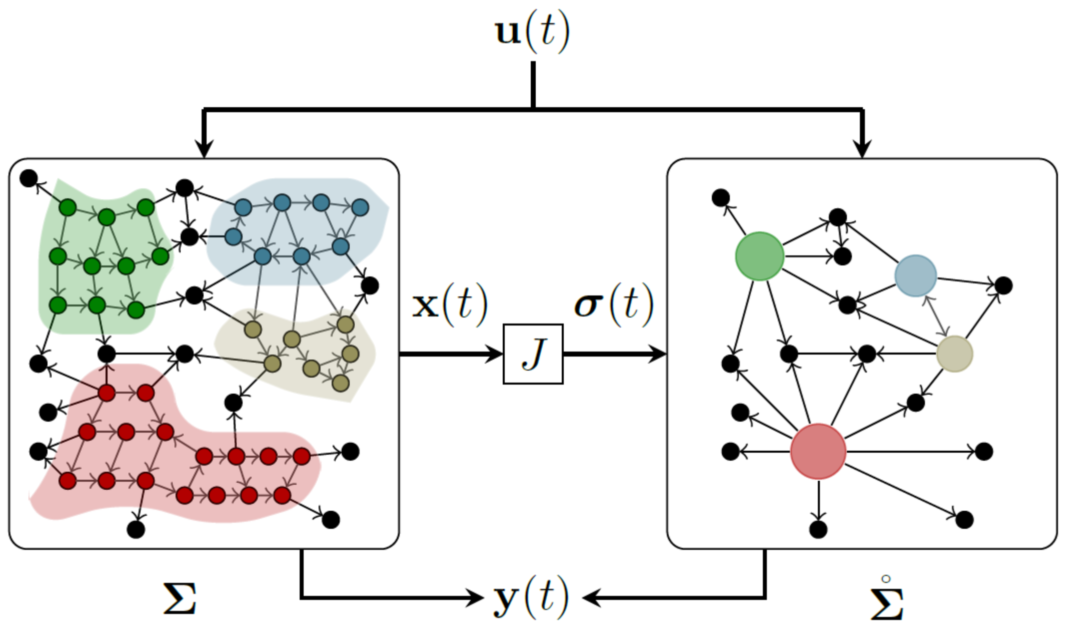




Discrete Aggregation: from a Large-Scale (Homogenous) Graph to a Reduced (Scale-Free) Graph

Continuous Aggregation: from a Large-Scale (Homogenous) Graph to a continuum (PDEs)

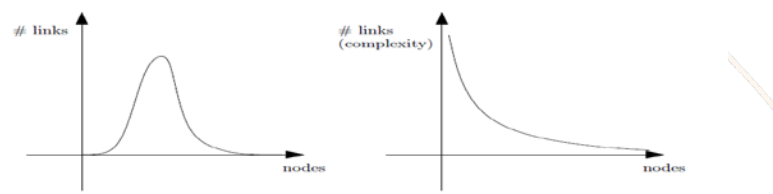
THÉMATIQUES DE RECHERCHE: FOR THE 1ST PROBLEM GROUP



- How to do Graph-Partitioning/model-reduction under:
  - Observability properties
  - Controllability properties
- Boundary Estimation and Control Design
- Applications:
  - Traffic & epidemic spreading

THÉMATIQUES DE RECHERCHE: ALGORITHMS FOR SF AGGREGATION

- **Complexity:** Scale-Free structure for the aggregate network model:
  - *Link/degree distribution → power law*

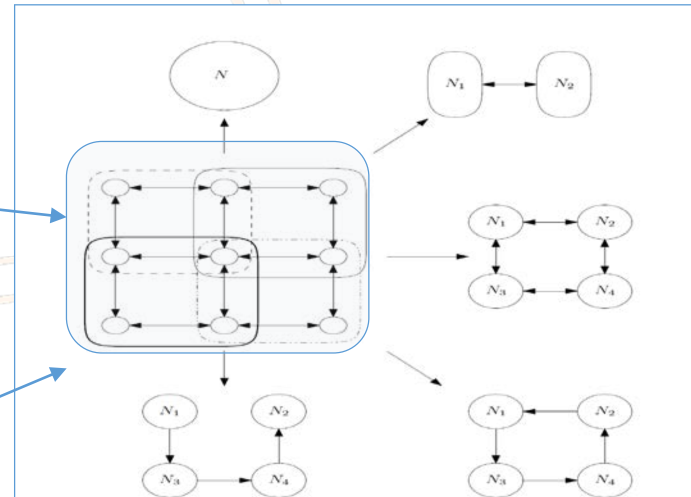


Homogenous → Scale-Free

- **Physical properties:** keep the original physical properties:
  - *Physical preserving properties*

Mass conservation → Mass conservation
Passivity → Passivity

- **Control properties:** controllability, observability:
  - *New conditions (boundary/averaged controllability & observability, etc.)*



Multiple solutions

- **Unicity:** discriminate solutions via optimization.

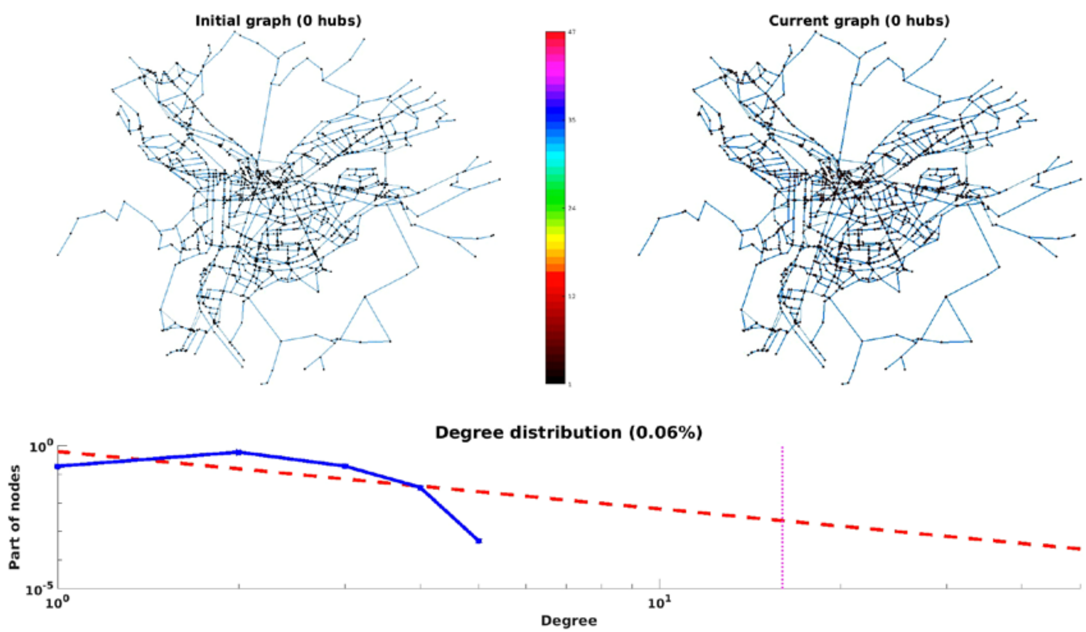
Grenoble Sub-Network (2 000 nodes) Densities

Given a graph $G_0 \in \Gamma \cap \Psi$, find a graph G solution of:

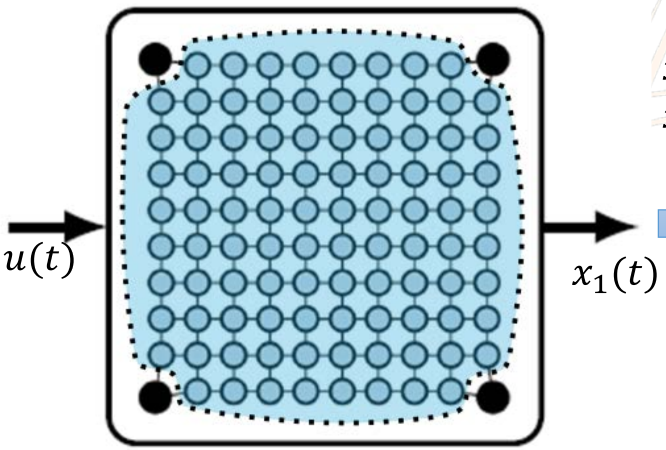
$$min_G \; \{ \; J_{\{SF_\alpha\}}(G) + J_{\{cont\}}(G) \; \}$$

$$subject\ to: \qquad G_0 > G, \quad G \in \Psi$$

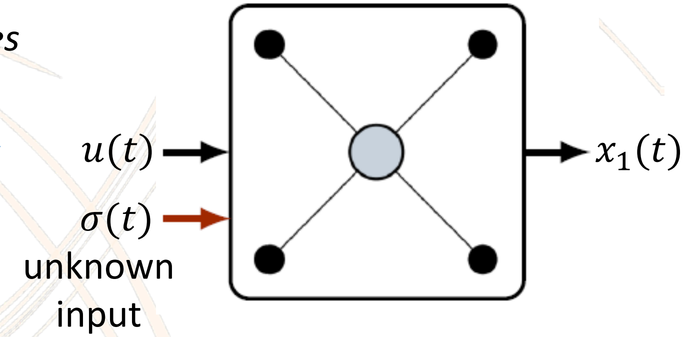
- $J_{\{SF_\alpha\}}(G)$ distant to a desired scale-free distribution
- $J_{\{contr\}}(G)$ desired control properties
- Ψ physical constraints (i.e. mass conservation)



THÉMATIQUES DE RECHERCHE: AVERAGE STATE ESTIMATION



x_1: State of k *measured nodes*
x_2: State of m *unmeasured nodes*



$$x = \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} \longrightarrow z = \begin{bmatrix} x_1 \\ x_2^{av} \end{bmatrix}$$

$$\Sigma: \begin{aligned} \dot{x}(t) &= Ax(t) + Bu(t) \\ y(t) &= Cx(t) = x_1(t) \end{aligned}$$

$$\Pi: \begin{aligned} \dot{z}(t) &= Ez(t) + F\sigma(t) + Gu(t) \\ 0 &= 1^T\sigma(t) \\ y(t) &= Hz(t) = x_1(t) \end{aligned}$$

$$x_2^{av} = \frac{1}{m} 1^T x_2$$

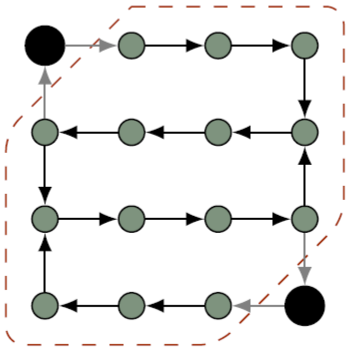
$$\sigma = x_2 - \mathbf{1} x_2^{av}$$

THÉMATIQUES DE RECHERCHE: DETECTABILITY

$$x = \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} \longrightarrow z = \begin{bmatrix} x_1 \\ x_2^{av} \end{bmatrix}$$

$$\Sigma: \begin{aligned} \dot{x}(t) &= Ax(t) + Bu(t) \\ y(t) &= Cx(t) = x_1(t) \end{aligned} \quad \Longrightarrow \quad \Pi: \begin{aligned} \dot{z}(t) &= Ez(t) + F\sigma(t) + Gu(t) \\ 0 &= 1^T\sigma(t) \\ y(t) &= Hz(t) = x_1(t) \end{aligned}$$

Graph-theoretic interpretation:
The induced (undirected/directed) subgraph formed by unmeasured nodes should be regular/out-regular and stable.



Example (directed graph): each green node has out-degree equal to 1 w.r.t. green nodes group.

Average Detectability (Multiple Clusters Case)

$$x = \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_r \end{bmatrix} \longrightarrow z = \begin{bmatrix} x_1 \\ x_2^{av} \\ \vdots \\ x_r^{av} \end{bmatrix}$$

$$\Sigma: \quad \begin{aligned} \dot{x}(t) &= Ax(t) + Bu(t) \\ y(t) &= Cx(t) = x_1(t) \end{aligned}$$

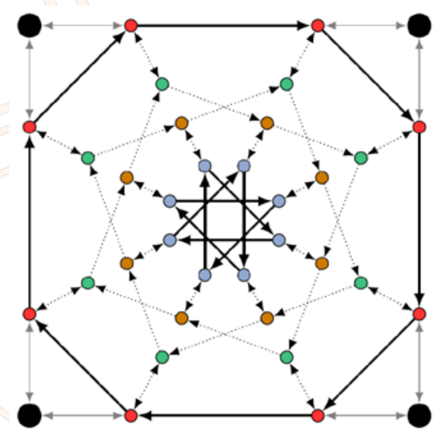
$$\Pi: \quad \begin{aligned} \dot{z}(t) &= Ez(t) + F\sigma(t) + Gu(t) \\ 0 &= Q^T\sigma(t) \\ y(t) &= Hz(t) = x_1(t) \end{aligned}$$

$$Q^T = diag[\mathbf{1}^T, \dots, \mathbf{1}^T]$$

$$\sigma = \begin{bmatrix} x_2 \\ \vdots \\ x_r \end{bmatrix} - Q \begin{bmatrix} x_2^{av} \\ \vdots \\ x_r^{av} \end{bmatrix}$$

Σ is average detectable if and only if 1) and 2):

1) Each cluster forms an undirected/directed **subgraph** that is regular/out-regular and stable.
2) The set of clusters form an **almost equitable partition**.



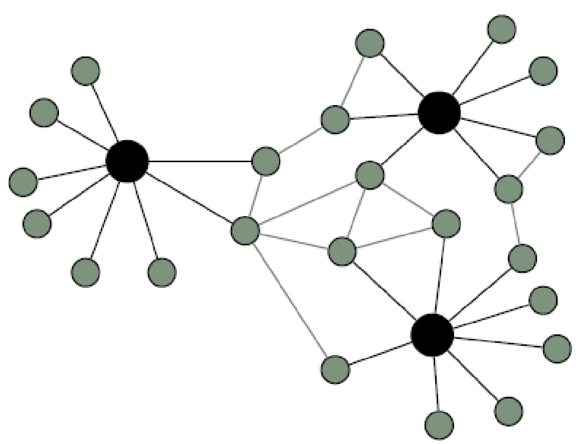
Average Observability (Single Cluster Case)

$$x = \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} \longrightarrow z = \begin{bmatrix} x_1 \\ x_2^{av} \end{bmatrix}$$

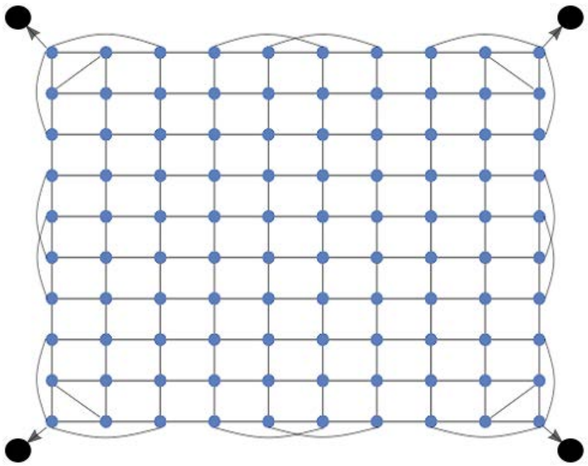
$$\Sigma: \begin{aligned} \dot{x}(t) &= Ax(t) + Bu(t) \\ y(t) &= Cx(t) = x_1(t) \end{aligned}$$

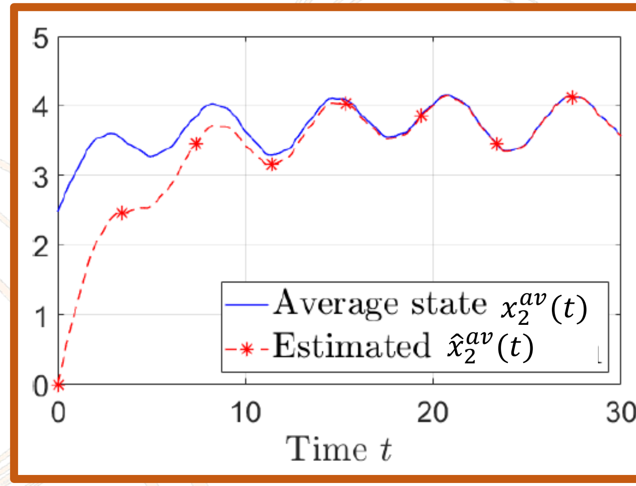
$$\Pi: \begin{aligned} \dot{z}(t) &= Ez(t) + F\sigma(t) + Gu(t) \\ 0 &= 1^T\sigma(t) \\ y(t) &= Hz(t) = x_1(t) \end{aligned}$$

Sufficient Condition for average observability:
Σ is average observable if the measured nodes span all the unmeasured nodes.

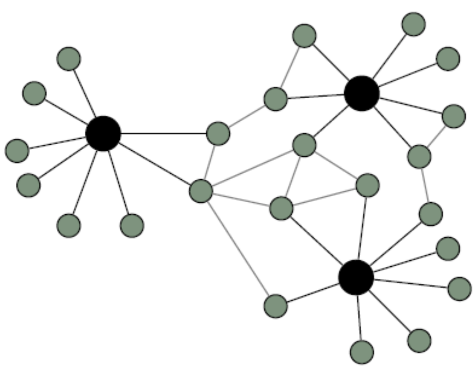


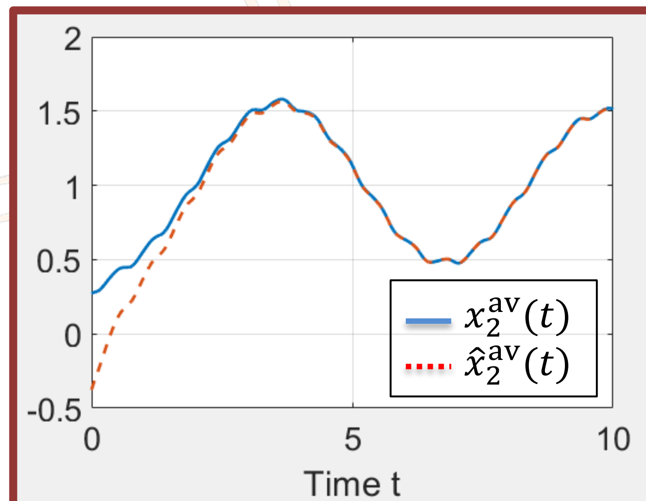
Average Detectable System (Single Cluster Case)

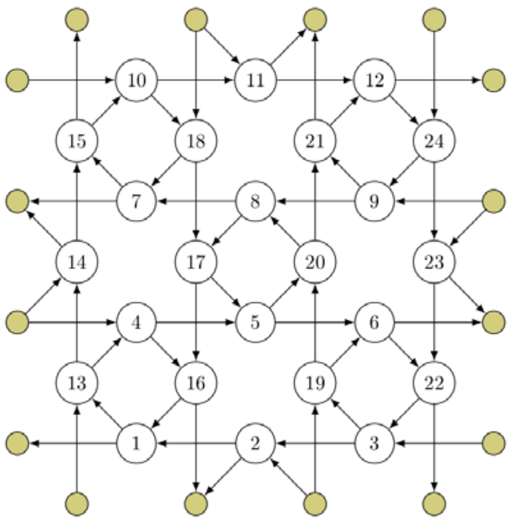




Average Observable system (Single Cluster Case)



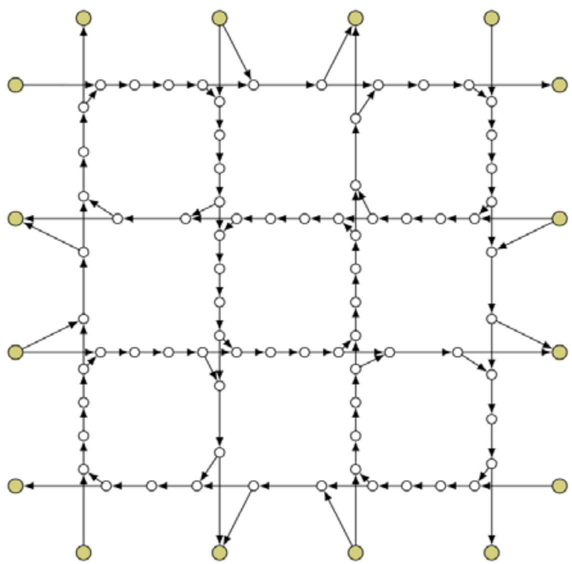


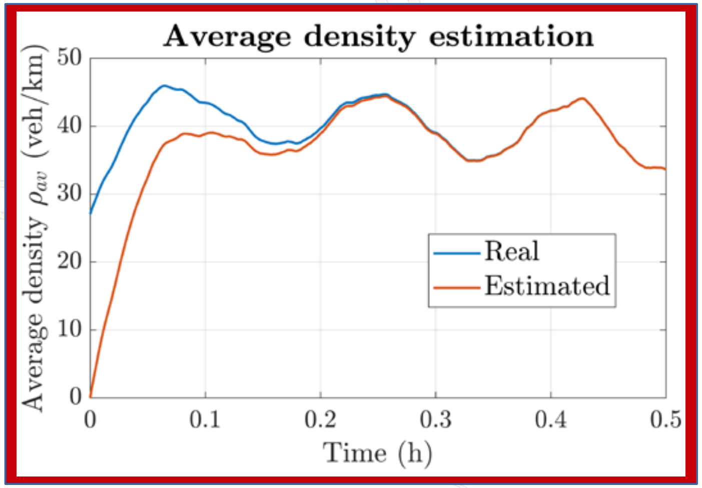


Traffic Network Example
(not Average Detectable)

Split the network in such a way that it is average detectable!

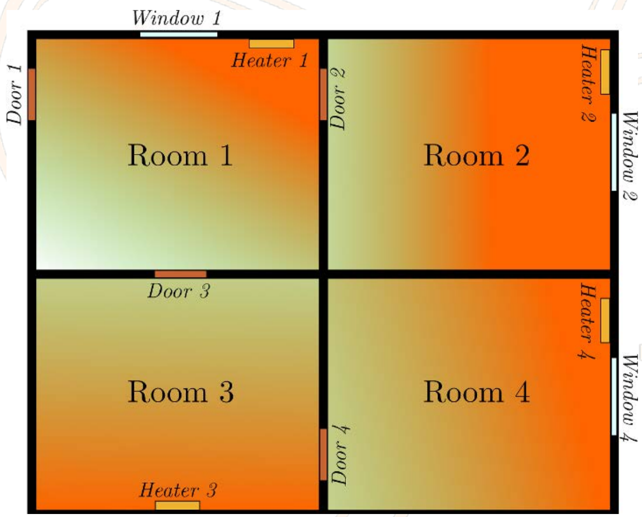
Splitted Virtual network (average detectable)

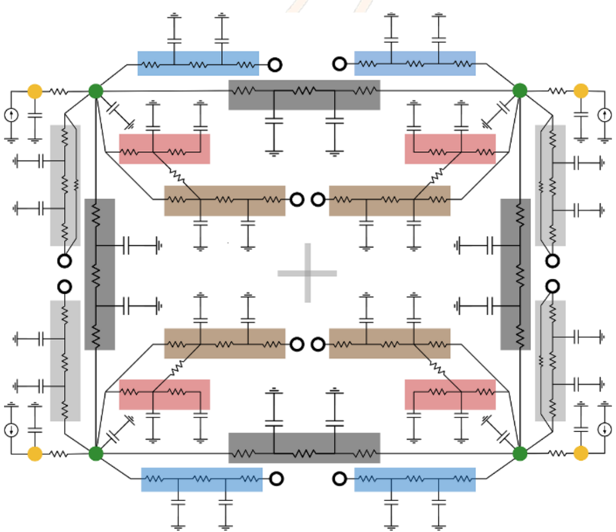


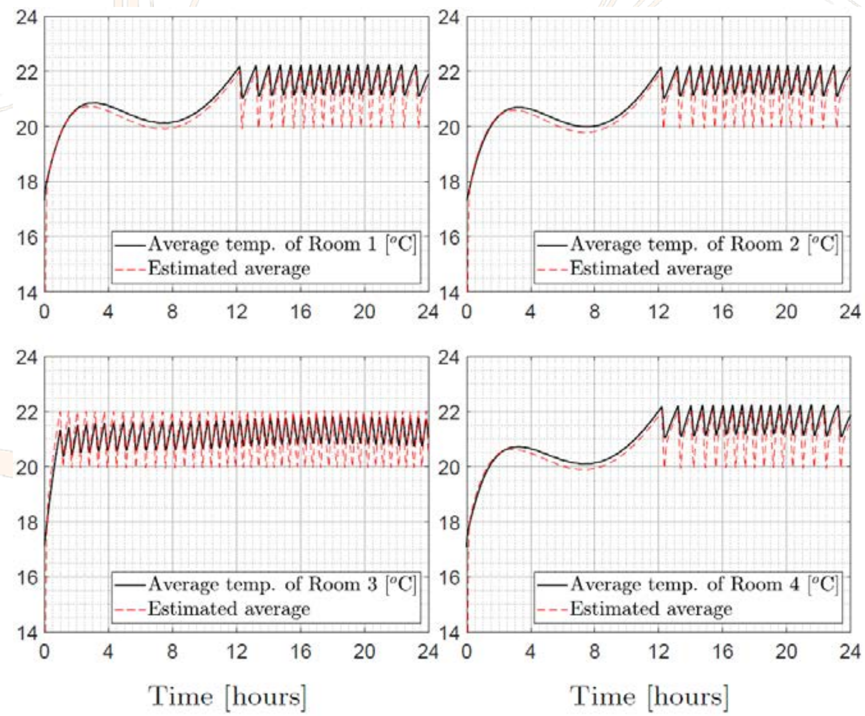


Building Thermal Model Example

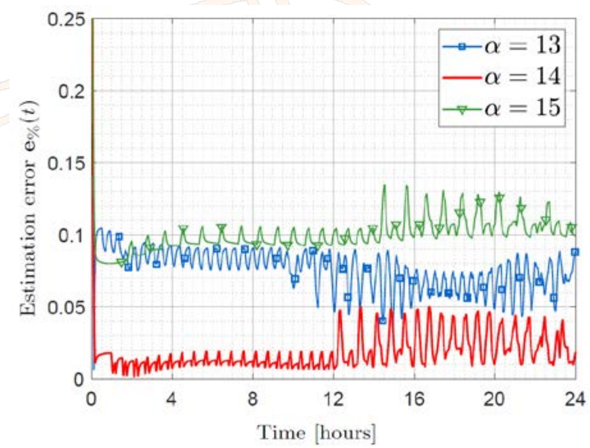
(neither avg. observable nor avg. detectable)





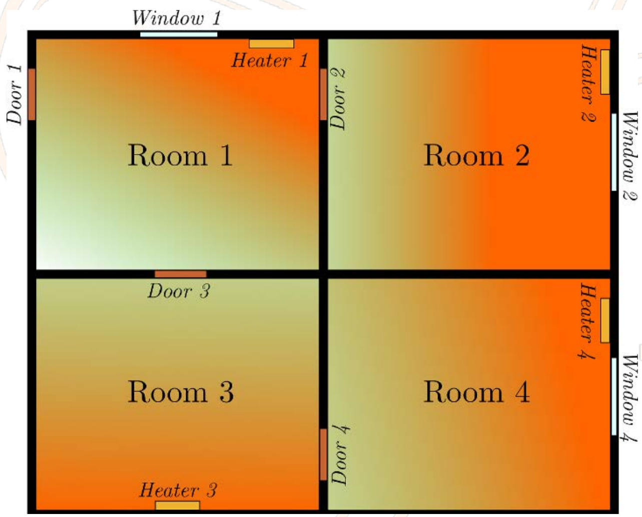


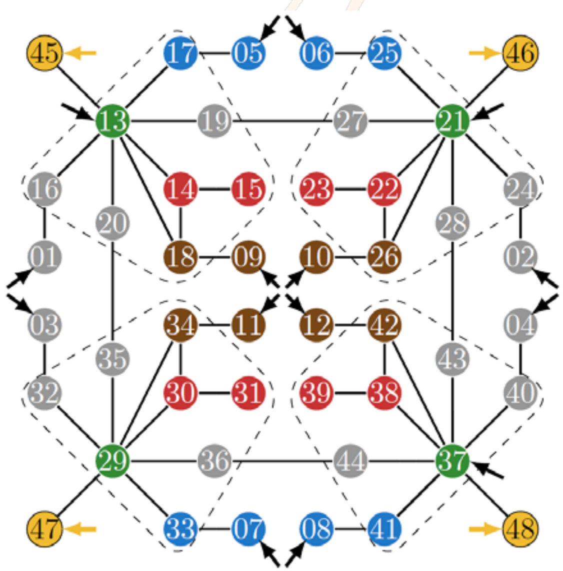
Minimize estimation error by designing an optimal observer!

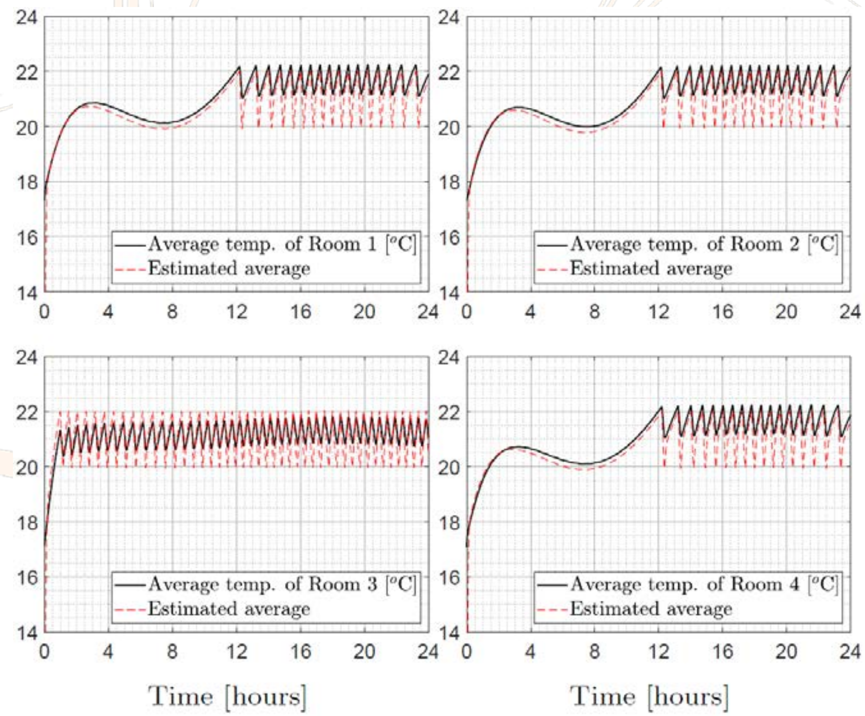


Building Thermal Model Example

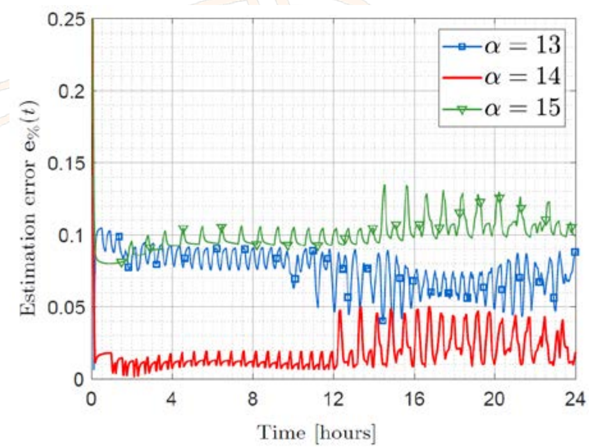
(neither avg. observable nor avg. detectable)







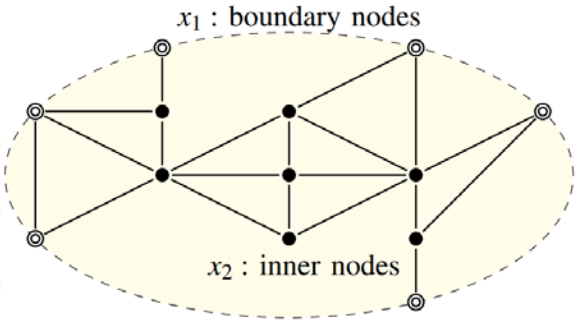
Minimize estimation error by designing an optimal observer!



THÉMATIQUES DE RECHERCHE: CONTROL OF AVERAGE

$$\Sigma: \begin{aligned} \dot{x}(t) &= Ax(t) + Bu(t) \\ y(t) &= Cx(t) \end{aligned}$$

$x = \begin{bmatrix} x_1 \\ x_2 \end{bmatrix}$ $\quad B = \begin{bmatrix} I \\ 0 \end{bmatrix}$



Control goal: $\lim_{t \to \infty} y(t) = y_d$

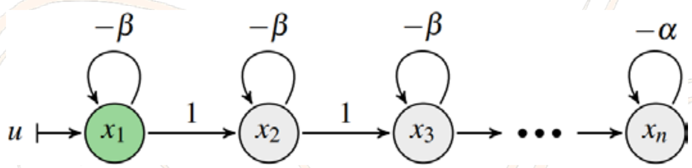
Example: control of the average $y(t) = \frac{1}{n} 1^T x(t)$

Σ is said to be *positive* if all links have non-negative weights

Theorem: if Σ is stable, positive and $CA^2 > 0$, then the goal is achieved by integral controller $u(t) = \gamma \int_0^t (y_d - y(\tau))\, d\tau$ with arbitrary $\gamma > 0$

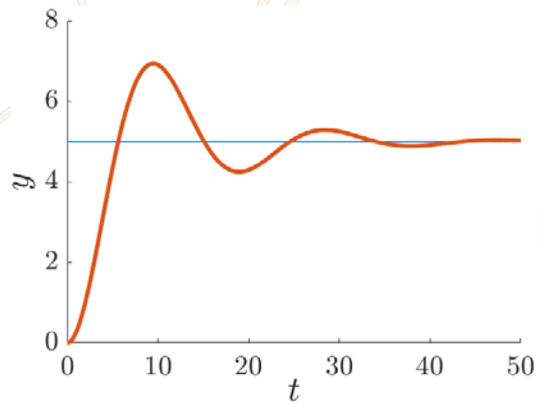
Example: Damped consensus:
If $A = -L - \alpha I$ with L being a Laplacian matrix of some network, $\alpha > 0$ and $C = \frac{1}{n} 1^T$, then the system is stable, positive and $CA^2 > 0$

THÉMATIQUES DE RECHERCHE: CONTROL OF AVERAGE AND VARIANCE

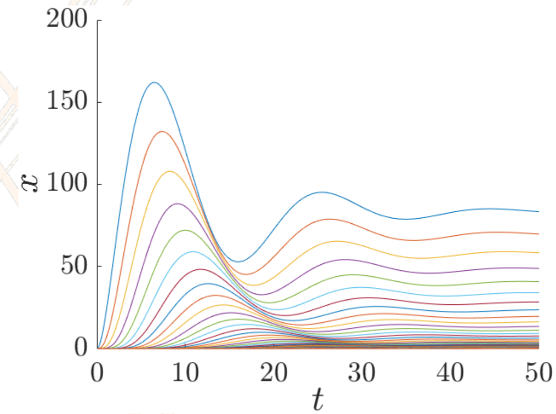


$$CA^2 > 0 \Rightarrow \sqrt{\alpha + \frac{1}{4}} - \frac{1}{2} \leq \beta \leq \alpha + \alpha^2$$

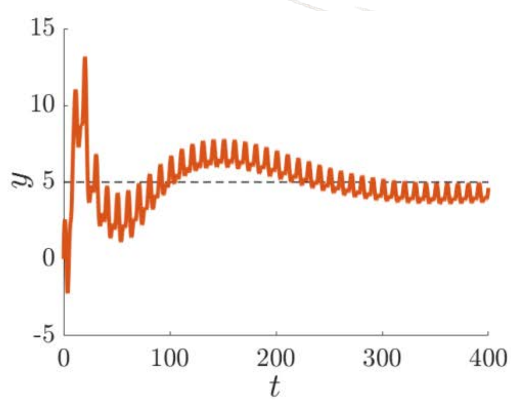
Average state:

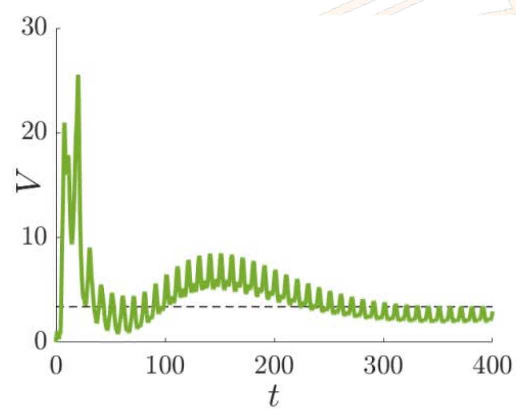


Spread of states:



The constrained extremum seeking algorithm is used to minimize the variance while driving the average to the desired state





Faits marquants

Awards:

- C. Canudas de Wit: Fellow of the IEEE & IFAC. Scale-FreeBack ERC AdG 2016-2021, IEEE-CSS distinguished lecturer in 2013-15.
- G. De Nunzio: “Prix de thèse 2016 de UGA” (C. Canudas de Wit and Ph. Moulin).
- M. L. Delle Monache: France-Berkeley award in 2018.

Activities/Responsabilities:

- 2 Int. workshops (2017 & 18): Large-scale systems (Grenoble)
- Grenoble Summer school (2016): “Traffic prediction & Control”
- General chair CDC’19 Nice, President of EUCA, BoG IEEE-CSS (Carlos)
- Pôle MSTIC UGA (Alain), LabEx Persyval-Lab (Alain & Federica), Comité de Direction du GdR MACS (Paolo), CNU61 (Hassen)

Projects:

- *Europe:* Scale-FreeBack (ERC),Speedd (EU), HYCON2
- *Industry:* Alstom,2x IFP-EN, SysNav
- *Others:* HANDY, AgileWord, MOB, C2S2, COMFORT, MEMENTO…

ANALYSE SWOT

Forces

- Balanced mix: expertise, gender, theory/applications
- Collaborations within & outside the team
- Editorial boards, societies
- Experimental platforms
- Publication record: 1.5 (journals/conf)

Faiblesses

- Unbalanced seniority
  (1 full rank *vs* 5 junior rank)

Opportunités

- Possibility to apply for "young researcher" grants, including ERCs
- Using GTL as attractor for collaborative projects in traffic systems
- Cross-domain opportunities: Social networks, Brain neural networks

Menaces

- Lack of full professor position in local universities
- After ERC ends:
  - Risk to lack engineering support for GTL
  - Reduction of research funds