The 8th Asian Control Conference
Kaohsiung, Taiwan
May 16, 2011

Glocal Control

A Realization of Global Functions by Local Measurement and Control

Shinji HARA
The University of Tokyo, Japan

Why “Glocal Control” ?

Recently, systems to be treated in various fields of engineering including control have became large and complex, and more high level control such as adaptation against changes of environments for open systems is required. Typical example includes meteorological phenomena and bio systems, where our available actions of measurement and control are restricted locally although our main purpose is to achieve the desired global behaviors.

This motivates us to develop a new research area so called "Glocal Control," which means that the **desired global behaviors is achieved by only local actions**.

Advanced Science & Technology Driven by Control

Glocal Control

Realization of High Quality Products
→ Solving Social Problems such as Energy, Environments, and Medicine

Multiple Functions — **Hybrid Control**

High Performance — **Robust Control**

Automation — **Modern Control**

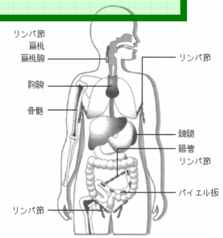
Stabilization — **Classical Control**

Steel process

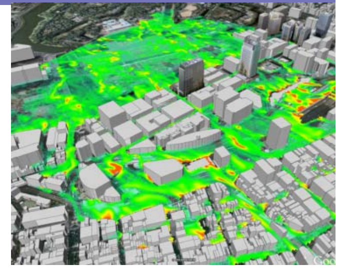
Linear motor car

Engine control

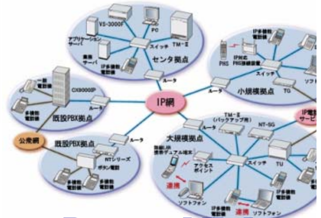
Robotics



Bio-system



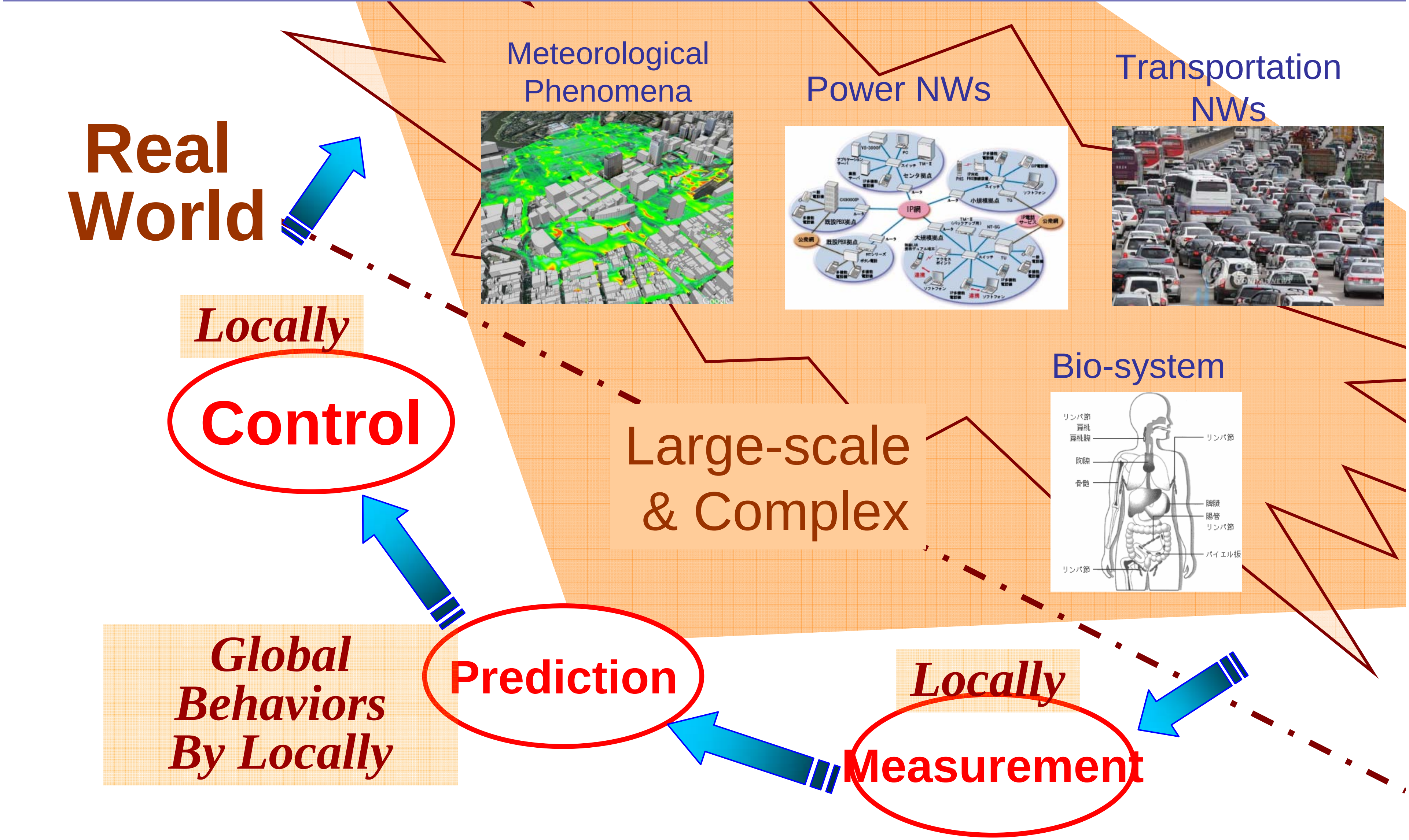
Meteorological Phenomena



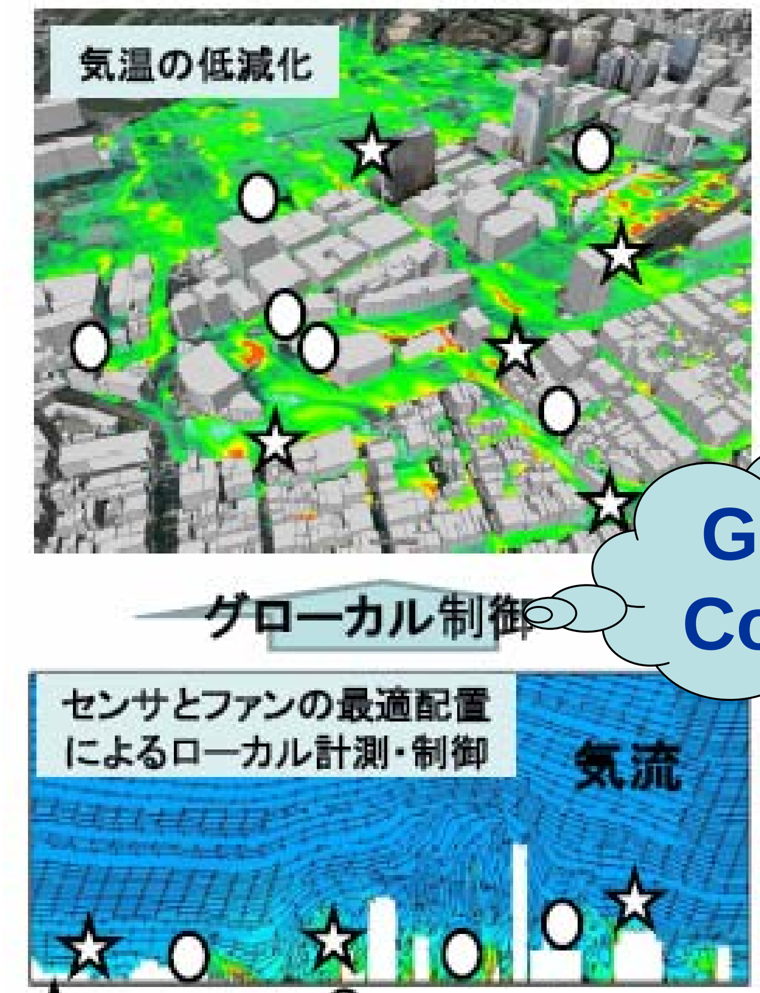
Power NWs

Transportation

Idea of "Glocal Control" ?



Urban Heat Island Problem



☆ Fans

○ Temperature, Wind Sensors

Glocal Control

Control

↑

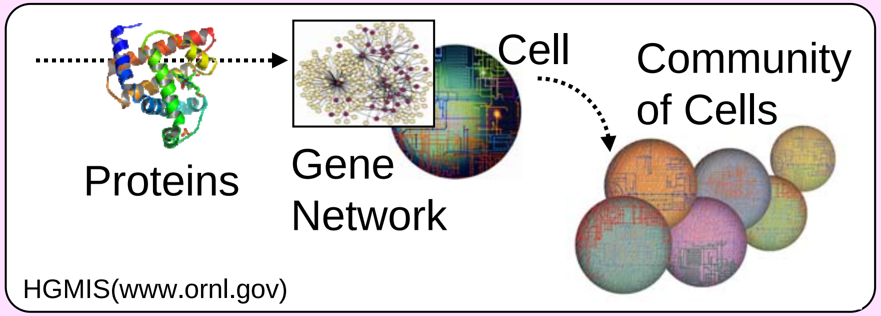
Prediction

↑

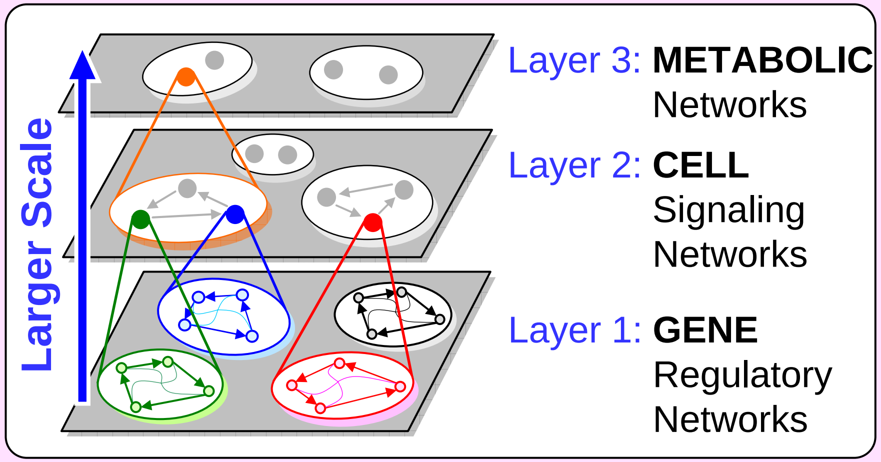
Measurement

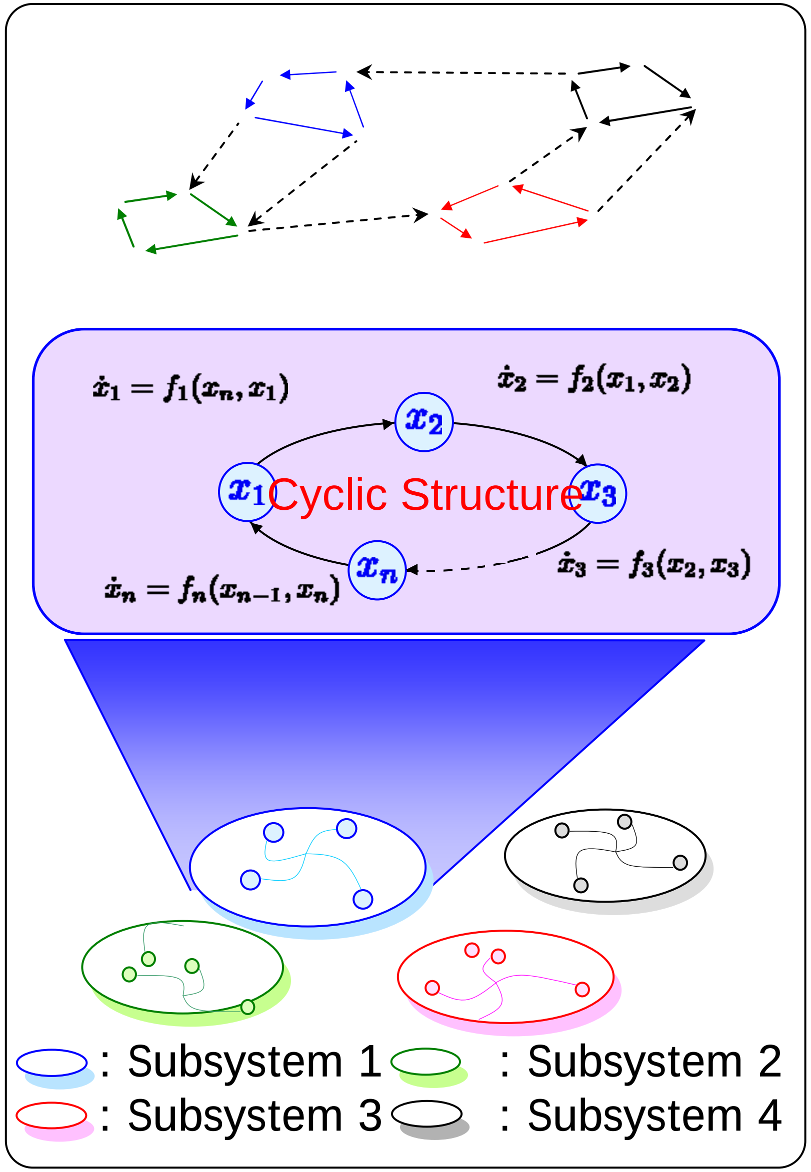
Where (space resolution)
When (time resolution)
How (level resolution)

Hierarchical Bio-Network Systems

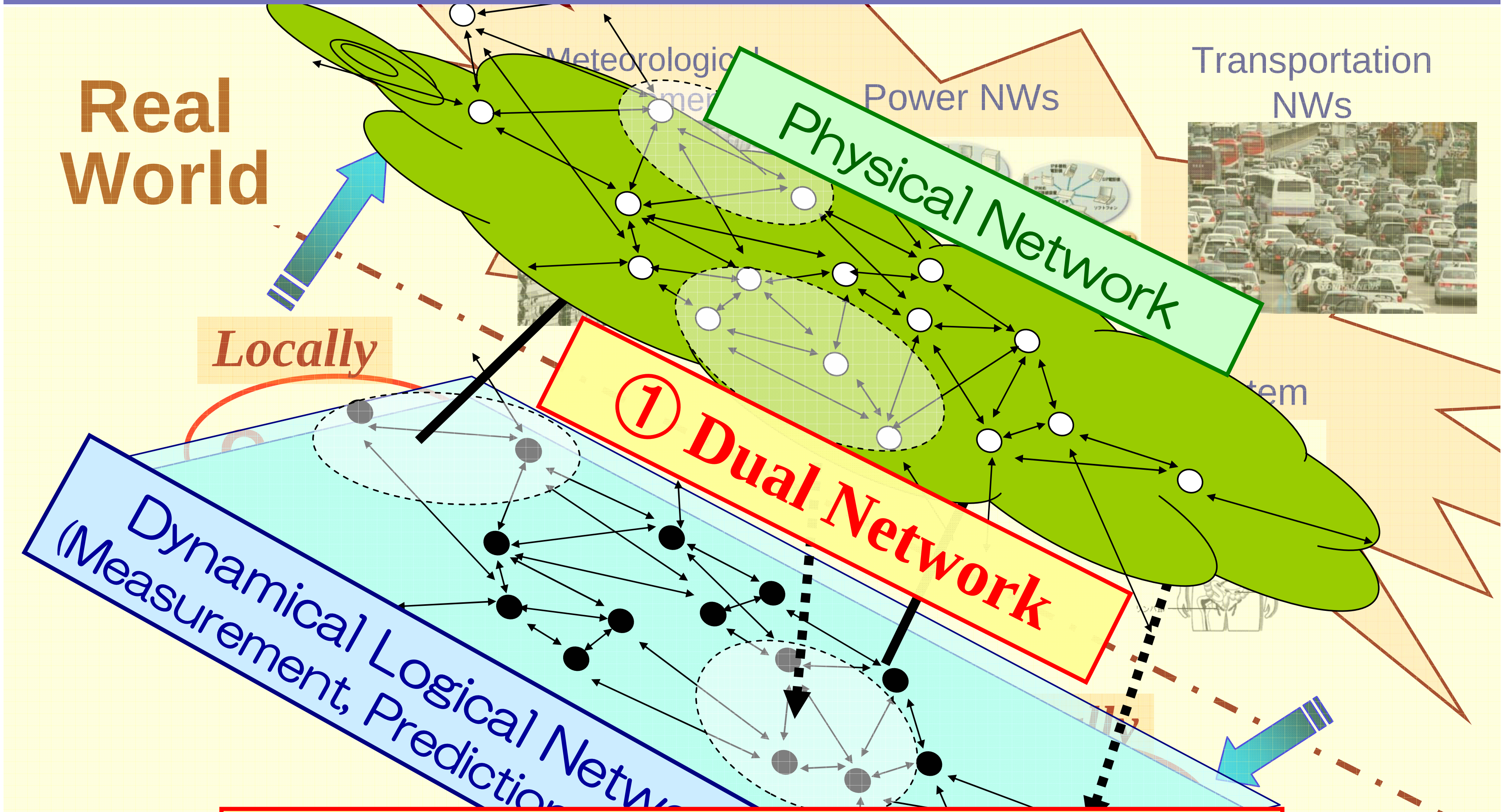


Hierarchical Bio-Network Systems





Framework for Glocal Control



② Hierarchical Dynamical Systems with Multi-resolution

Three Key Issues

① Paradigm Shift in Control

Realization of High Quality Products

→ Solving Social Problems

Glocal Control

② New Unified Framework

LTI System with Generalized Frequency Variable

→ Hierarchical Dynamical System with Multiple Resolutions

③ New Control Theory for Systematic Ways of Analysis and Synthesis

Fundamental Results & New Notions/Principles

→ Practical Applications

Three Key Issues

① **Paradigm Shift in Control**

Realization of High Quality Products

→ Solving Social Problems

Idea of ***Glocal Control***

② **New Unified Framework**

Toward ***Glocal Control***

LTI System with Generalized Frequency Variable

→ Hierarchical Dynamical System with Multiple Resolutions

③ **New Control Theory for Systematic Ways of Analysis and Synthesis**

Fundamental Results & New Notions/Principles

→ ***Practical Applications***

OUTLINE

1. Glocal Control
2. Unified Framework with Stability Conditions
3. Cooperative Stabilization
4. Robust Stability Analysis
5. Hierarchical Consensus
6. Conclusion

OUTLINE

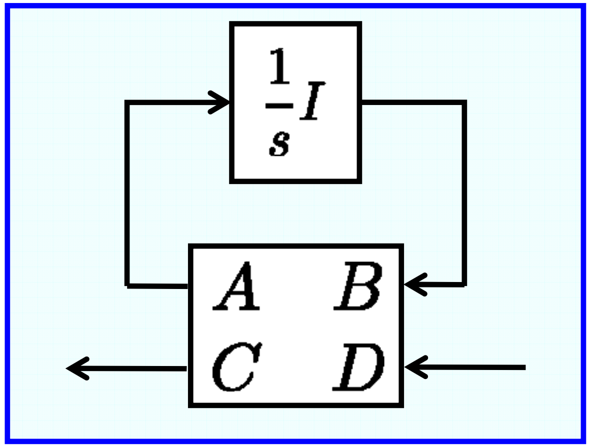
1. Glocal Control
2. **Unified Framework with Stability Conditions**
3. Cooperative Stabilization
4. Robust Stability Analysis
5. Hierarchical Consensus
6. Conclusion

(Hara et al.: CDC2007, Tanaka et al.: ASCC2009)

LTI System with Generalized Frequency Variable

A unified representation
for multi-agent dynamical systems

$C\,(sI - A)^{-1}\,B + D$

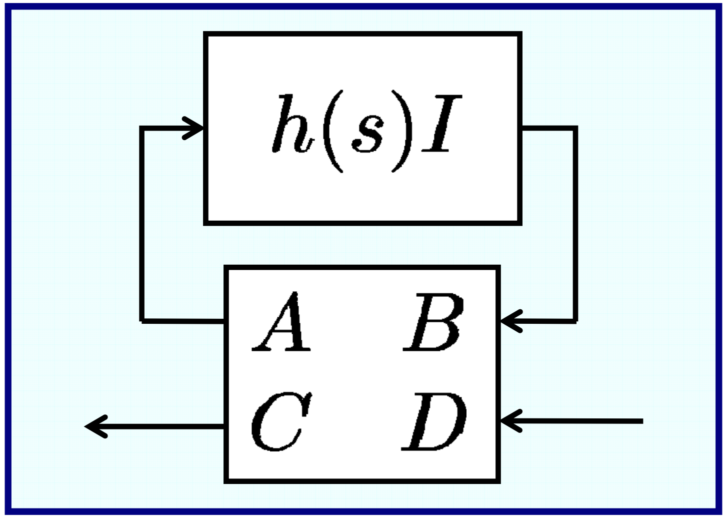


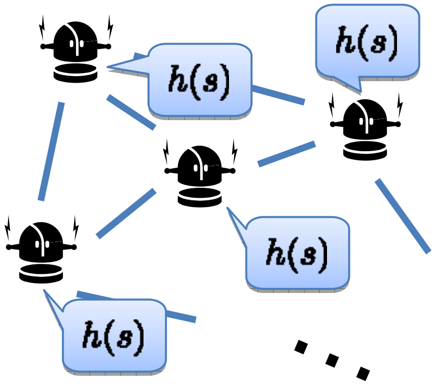
1/s → h(s)

Φ(s) = 1/h(s)

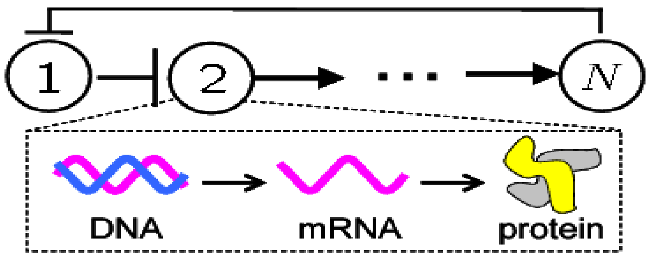
Generalized
Freq. Variable

$C\,(\phi(s)I - A)^{-1}\,B + D$





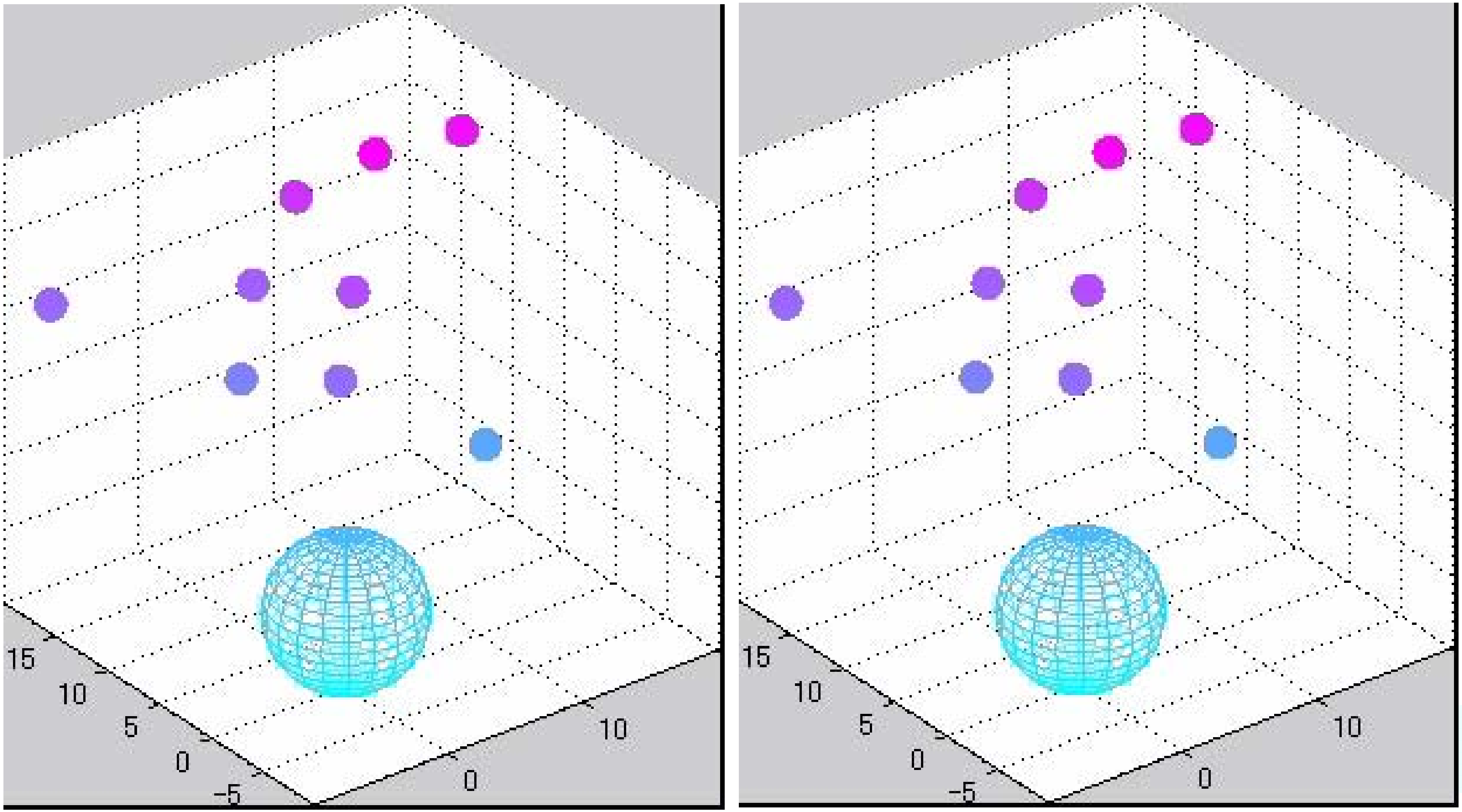
Group Robot



Gene Reg. Networks

Dynamics
+
Information
Structure

An Example : Cyclic Pursuit

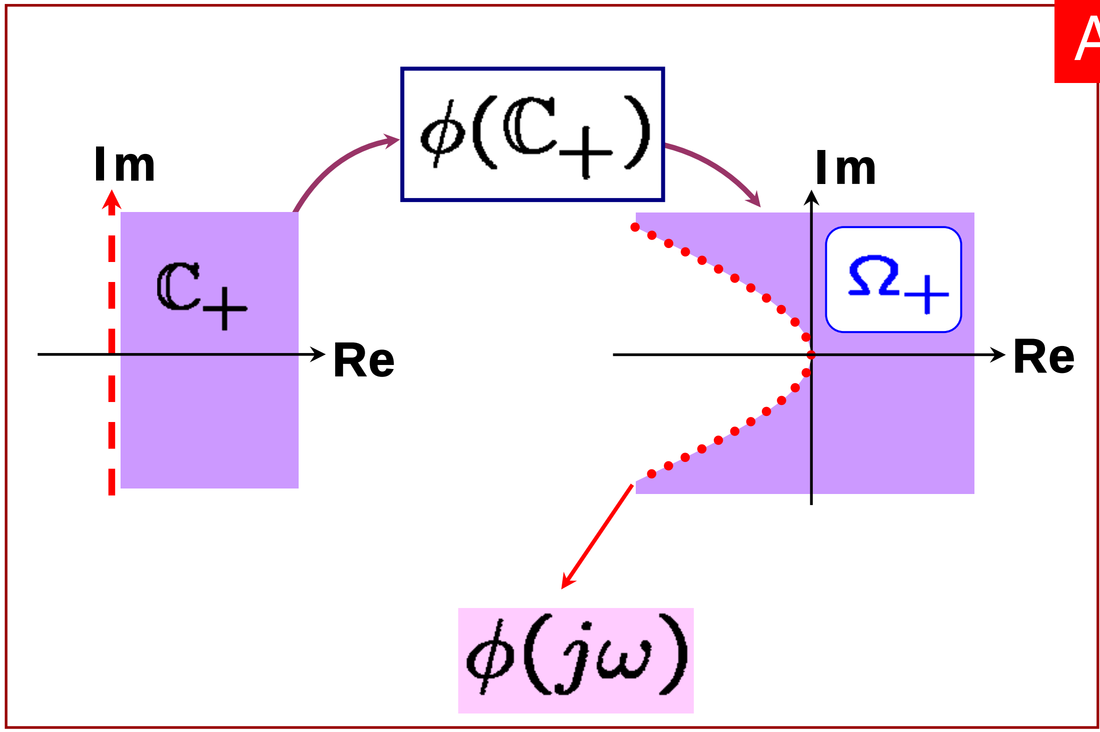


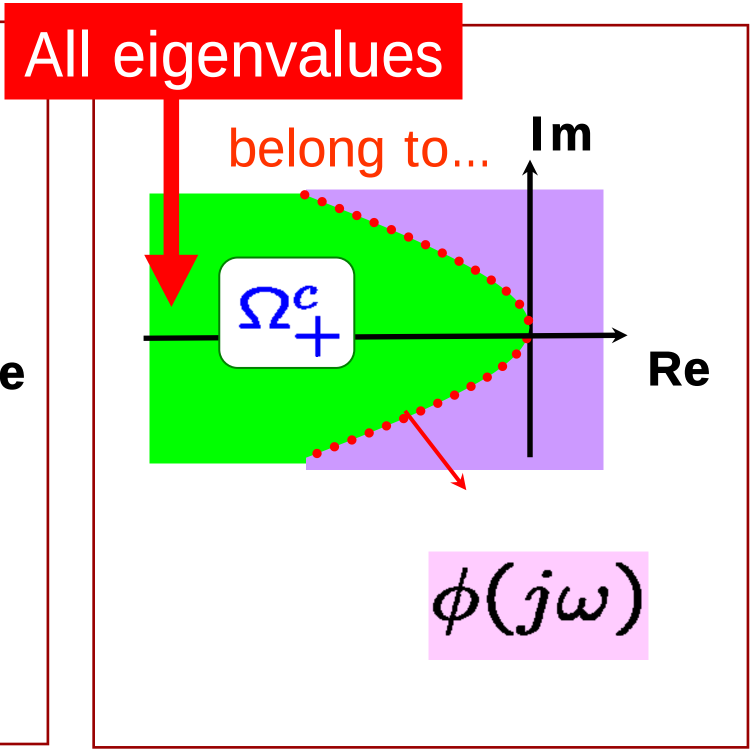
$$\delta\theta_i(t) \to 2\pi/9$$

Stability Region for LTISwGFV

(Hara et al. IEEE CDC, 2007)

❖ <u>Define</u>: Domains $\Omega_+ := \phi(\mathbb{C}_+)$, $\Omega_+^c := \mathbb{C} \backslash \Omega_+$





How to characterize the region ?
How to check the condition ?

Stability Tests for LTISwGFV

Graphical	Algebraic	Numeric (LMI)
Nyquist – type	Hurwitz – type	Lyapunov – type
Polyak & Tsypkin (1996) Fax & Murray (2004) Hara et al. (2007)	**Tanaka, Hara, Iwasaki (ASCC2009)**	**Tanaka, Hara, Iwasaki (ASCC2009)**
$h(s)$ and $\sigma(A)$	$h(s)$ and $\sigma(A)$	$h(s)$ and A

Hurwitz test for complex coefficients

Generalized Lyapunov Inequality

Stability Conditions

(Tanaka et al., ASCC, 2009)

Given $h(s) = n(s)/d(s),\ A$

$\mathcal{H}_A(s)$ is stable

$\Leftrightarrow$ Key lemma

$\sigma(A) \subset \Lambda := \{\ \lambda \in \mathbb{C} \mid d(s) - \lambda n(s) \text{ is Hurwitz stable }\}$

Extended Routh-Hurwitz Criterion [Frank,1946]

Algebraic condition

$$\sigma(A) \subset \bigcap_{k=1}^{\nu} \Sigma_k$$

$$\Sigma_k := \{\ \lambda \in \mathbb{C} \mid l_k(\lambda)^* \Phi_k l_k(\lambda) > 0\ \}$$

$$(k = 1, 2, \ldots, \nu)$$

Generalized Lyapunov inequality

$$l_\ell(\lambda) := \begin{bmatrix} 1 \\ \lambda \\ \vdots \\ \lambda^\ell \end{bmatrix},\ L_\ell(A) := \begin{bmatrix} I \\ A \\ \vdots \\ A^\ell \end{bmatrix}$$

LMI feasibility problem

$X_k = X_k^T > 0$ s.t. $L_k(A)^T(\Phi_k \otimes X_k)L_k(A) > 0$

for each $k = 1, 2, \ldots, \nu$

Numerical Example : 2nd order (1/2)

$$\text{Given } h(s) = \frac{2s+1}{s^2+s+1}, \quad A \in \mathbb{R}^{n \times n}$$

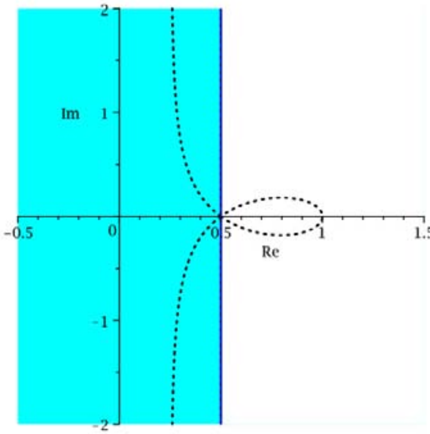
$$\sigma(A) \subset \Lambda := \{\ \lambda \in \mathbb{C} \mid (s^2+s+1) - \lambda(2s+1) \text{ is Hurwitz stable }\}$$

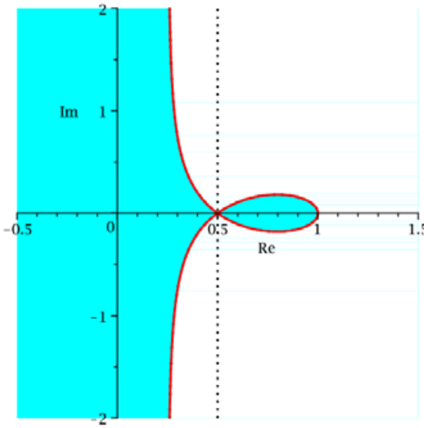
$\Updownarrow$ Extended Routh-Hurwitz Criterion

$$\sigma(A) \subset \Sigma := \{\ \lambda \in \mathbb{C} \mid \Delta_1 > 0 \text{ and } \Delta_2 > 0\ \}$$

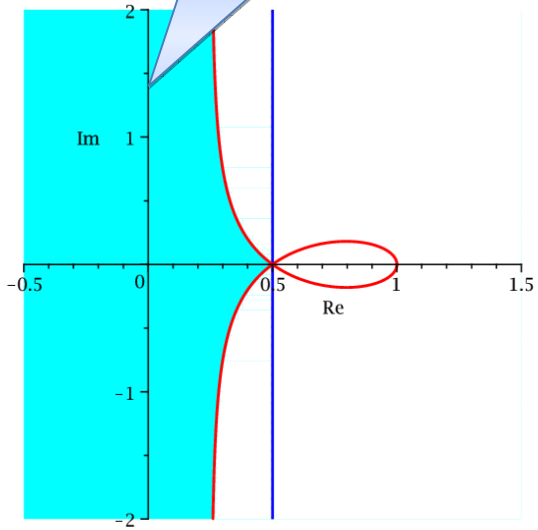
$$\Delta_1 = \begin{bmatrix} 1 \\ \lambda \end{bmatrix}^* \begin{bmatrix} 1 & -1 \\ -1 & 0 \end{bmatrix} \begin{bmatrix} 1 \\ \lambda \end{bmatrix} > 0$$

$$\Delta_2 = \frac{1}{4} \begin{bmatrix} 1 \\ \lambda \\ \lambda^2 \end{bmatrix}^* \begin{bmatrix} 4 & -10 & 7 \\ -10 & 18 & -8 \\ 7 & -8 & 0 \end{bmatrix} \begin{bmatrix} 1 \\ \lambda \\ \lambda^2 \end{bmatrix} > 0$$



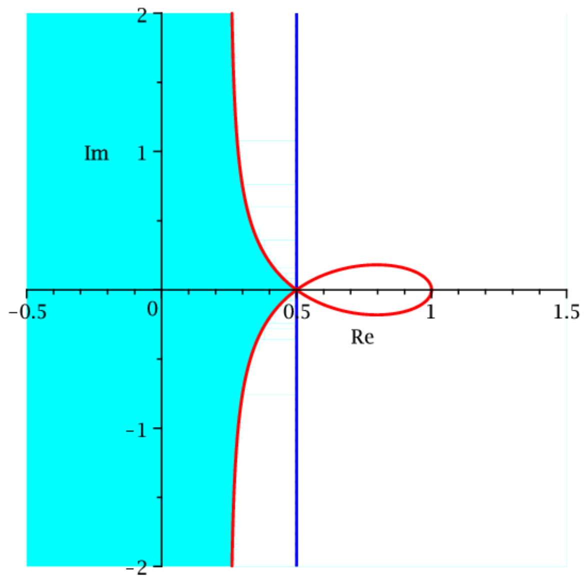


Stability region



Numerical Example : 2nd order (2/2)

Given $h(s) = \dfrac{2s+1}{s^2+s+1}$, $A \in \mathbb{R}^{n\times n}$



$$\sigma(A) \subset \Sigma := \{\ \lambda \in \mathbb{C} \mid \Delta_1 > 0 \text{ and } \Delta_2 > 0\ \}$$

$$\Delta_1 = \begin{bmatrix} 1 \\ \lambda \end{bmatrix}^* \begin{bmatrix} 1 & -1 \\ -1 & 0 \end{bmatrix} \begin{bmatrix} 1 \\ \lambda \end{bmatrix} > 0$$

$$\Delta_2 = \frac{1}{4} \begin{bmatrix} 1 \\ \lambda \\ \lambda^2 \end{bmatrix}^* \begin{bmatrix} 4 & -10 & 7 \\ -10 & 18 & -8 \\ 7 & -8 & 0 \end{bmatrix} \begin{bmatrix} 1 \\ \lambda \\ \lambda^2 \end{bmatrix} > 0$$

Generalized Lyapunov inequality

$$X_1 = X_1^T > 0 \quad \text{s.t.} \quad \begin{bmatrix} I \\ A \end{bmatrix}^T \left(\begin{bmatrix} 1 & -1 \\ -1 & 0 \end{bmatrix} \otimes X_1 \right) \begin{bmatrix} I \\ A \end{bmatrix} > 0$$

$$X_2 = X_2^T > 0 \quad \text{s.t.} \quad \begin{bmatrix} I \\ A \\ A^2 \end{bmatrix}^T \left(\begin{bmatrix} 4 & -10 & 7 \\ -10 & 18 & -8 \\ 7 & -8 & 0 \end{bmatrix} \otimes X_2 \right) \begin{bmatrix} I \\ A \\ A^2 \end{bmatrix} > 0$$

Algorithm

Given Data: all coefficients of numerator and denominator of *h(s)*

Algorithm h2Phi($h(s)$) :

Input : $h(s) = \dfrac{b_1 s^{\nu-1} + \cdots + b_\nu}{s^\nu + a_1 s^{\nu-1} + \cdots + a_\nu}$

Output : ℓ_k and Φ_k

1. $p_0 \leftarrow 1,\ q_0 \leftarrow 0$
   for $i \leftarrow 1$ **until** $2\nu - 1$ **do**
   if $i \leq \nu$ **then**
   $p_i \leftarrow a_i - b_i x,\ q_i \leftarrow -b_i y$
   else
   $p_i \leftarrow 0,\ q_i \leftarrow 0$

2 $\Delta_1 \leftarrow p_1$
for $k \leftarrow 2$ **until** 2ν **do**
$M \leftarrow O^{(2k-1)\times(2k-1)}$
for $i \leftarrow 1$ unt
if i is
$-2)/2$ **do**
$\leftarrow p_{2k-i-2(m-1)}$
until $k-(i-2)/2-1$ **do**
$(i, 2k-m) \leftarrow p_{2k-i-1-2(m-1)}$
$M^{k+1,k+2,\ldots,2k-1}_{2,3,\ldots,k} \leftarrow -M^{1,2,\ldots,k-1}_{k+1,k+2,\ldots,2k-1}$
$M^{k+1,k+2,\ldots,2k-1}_{k+1,k+2,\ldots,2k-1} \leftarrow M^{1,2,\ldots,k-1}_{1,2,\ldots,k-1}$
$\Delta_k(x,y) \leftarrow |M|$

1 **until** ν **do**
$\leftarrow \Delta_k((\lambda+\bar\lambda)/2, (\lambda-\bar\lambda)/2j)$
ntil ν **do**
imum of the degree of λ in $\Delta'_k(\lambda,\bar\lambda)$ -1
ntil $\ell_k - 1$ **do**
-0 **until** $\ell_k - 1$ **do**
$\Phi_k(m+1, l+1)$
$\leftarrow$ the coefficient of $\lambda^m \bar\lambda^l$ in $\Delta'_k(\lambda,\bar\lambda)$

5 **rerurn** ℓ_k and Φ_k.

Systematic methods for stability analysis
Hurwitz-type & LMI

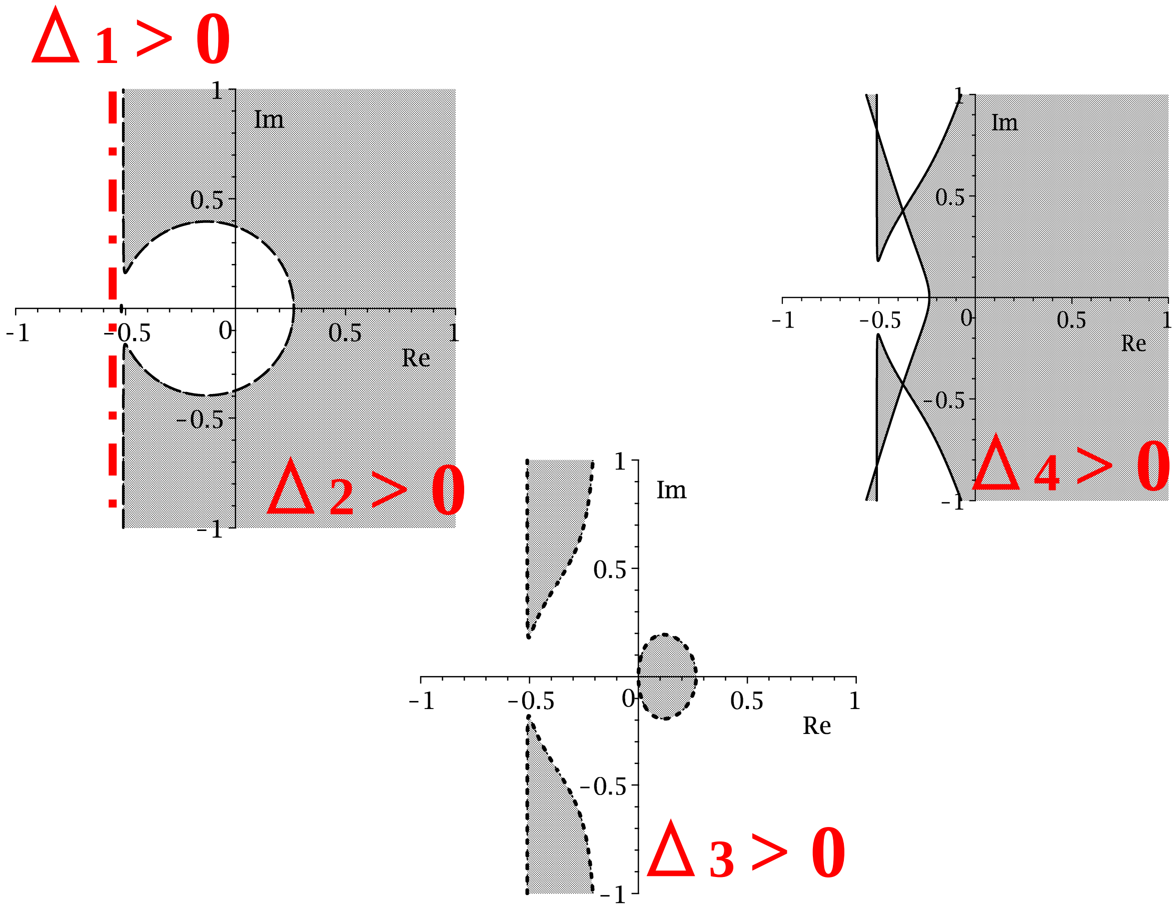
Result:

$$\Phi_k(s)\ \ (k = 1, 2, \cdots, \nu)$$

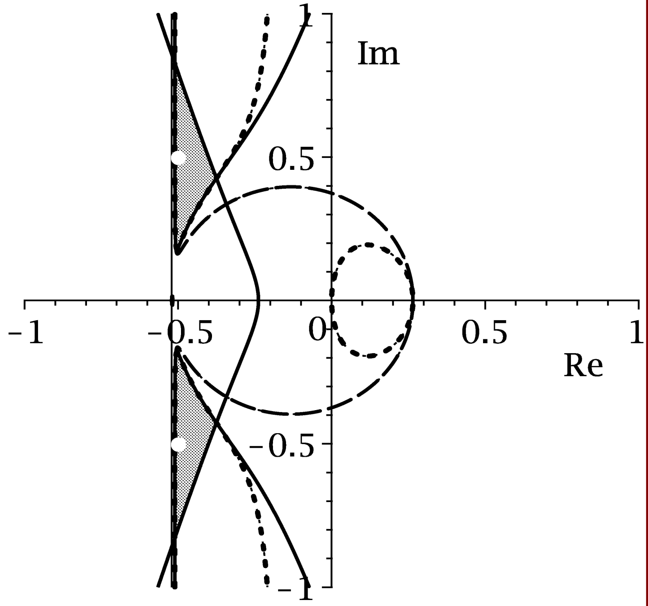
Numerical Example：4th order

$$h(s) = \frac{100(s+2)(\frac{19}{10}s^2 - \frac{1}{500000}s + \frac{21}{10})}{(s-1)^2(s+1)(s+100)}$$

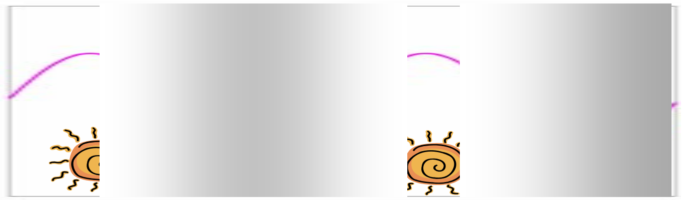
Unstable
& NMP



Stability Region



An Application : Biological rhythms

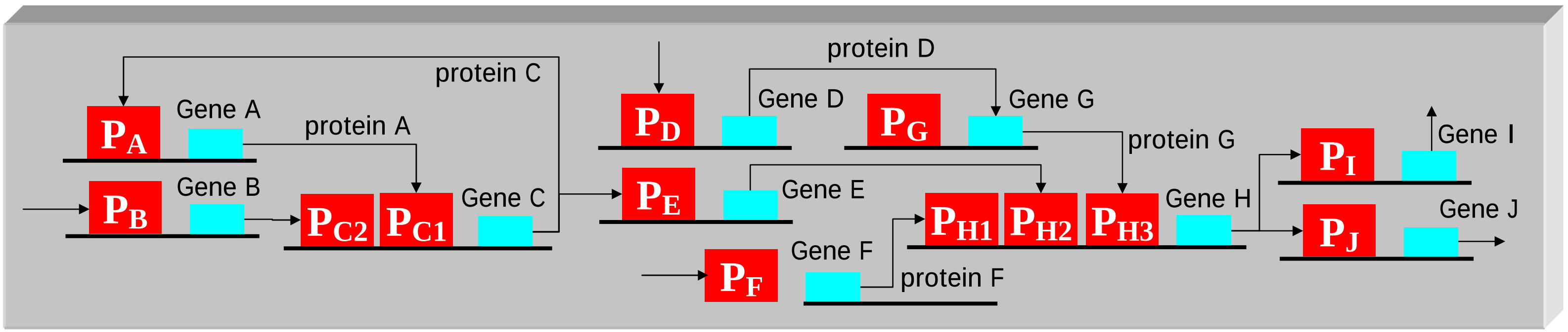


Motivation

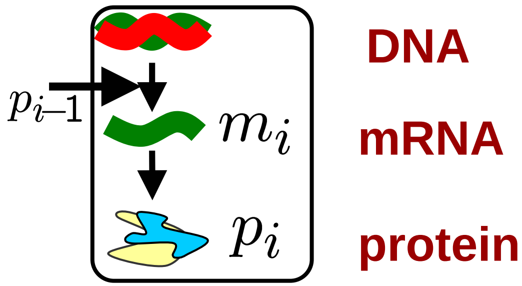
- **Biological rhythms**
  - 24h-cycle, heart beat, sleep cycle etc.
  - caused by periodic oscillations of protein concentrations in ***Gene Regulatory Networks***

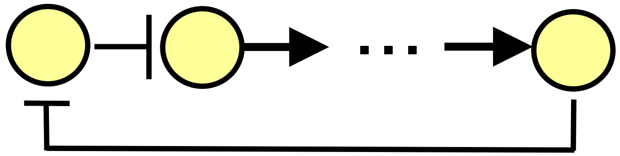
- **Medical and engineering applications**
  - Artificially engineered biological oscillators

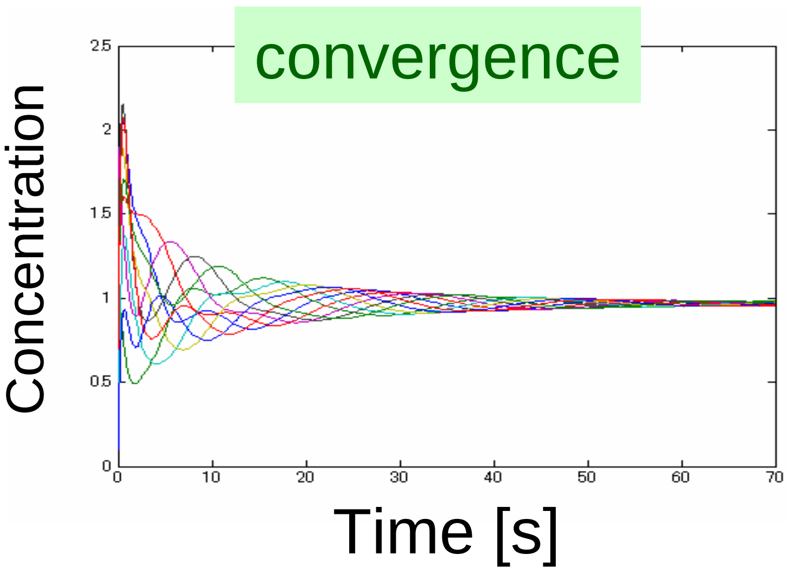
    (e.g.) Repressilator [Elowitz & Leibler, *Nature*, 2000]

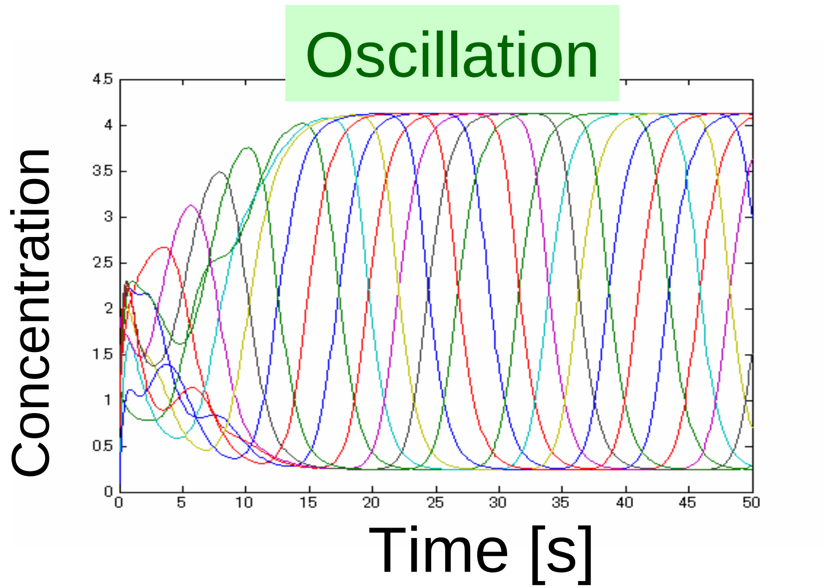


Cyclic Gene Regulatory Networks







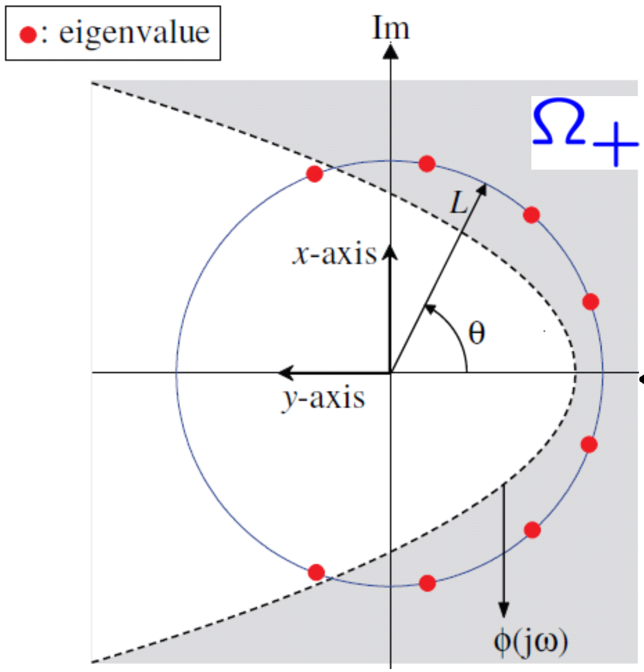


What are analytic conditions for convergence and the existence of oscillations ?

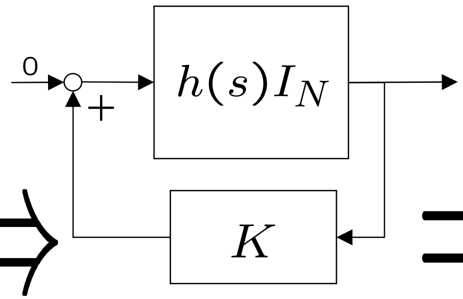
Condition for Existence of Oscillations

The cyclic GRN has periodic oscillations if at least one of eigenvalue of K lies inside Ω_+

where
$$\Omega_+ := \left\{ \lambda \in \mathbb{C} \;\middle|\; \exists s \in \mathbb{C}_+ \text{ s.t. } \lambda = \phi(s) \right\}$$

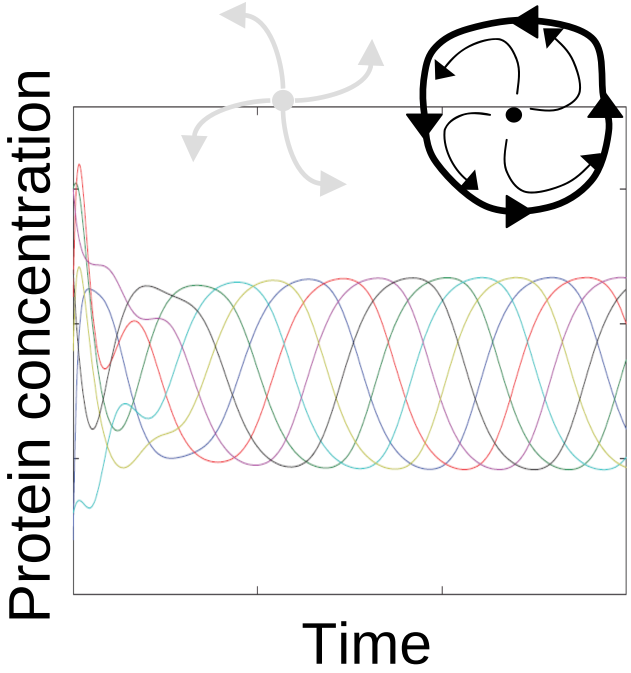


$\Leftrightarrow$



Locally unstable

$\Rightarrow$



$$\phi(s) := (T_a s + 1)(T_b s + 1)$$

Analytic Criteria

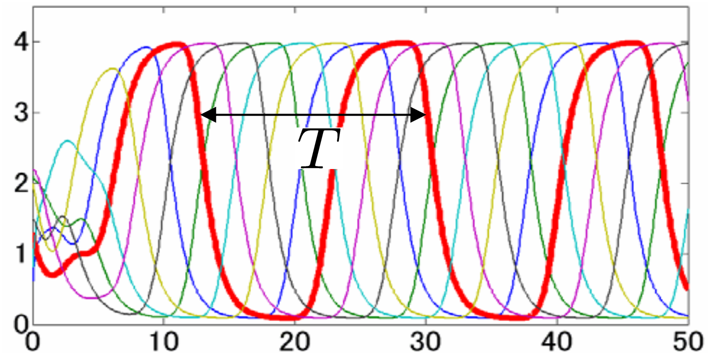
- **Assumptions:** All interactions are repressive

Theorem [Hori et al., CDC2009]

The cyclic GRN has periodic oscillations, if an analytic condition in terms of (N, ν, R, Q) is satisfied.

$R := \frac{\sqrt{c\beta}}{\sqrt{ab}}$ Raio of production and degradation rates

$Q := \frac{\sqrt{T_a T_b}}{(T_a + T_b)/2}$ Gap between two tme constants



$$T \simeq \frac{2\pi Q \tan(\frac{\pi}{N})}{\sqrt{1 + Q^2 \tan^2(\frac{\pi}{N})} - 1} \sqrt{T_a T_b}$$

(Hori, Hara: CDC2010)

Message：Framework and Stability

① **LTI system with generalized freq. variable**

a proper class of homogeneous multi-agent dynamical systems

② **Three types of stability tests, namely graphical, algebraic, and numeric (LMI)**

powerful tools for analysis

③ **Parametric stability analysis for gene regulatory networks**

new biological insight

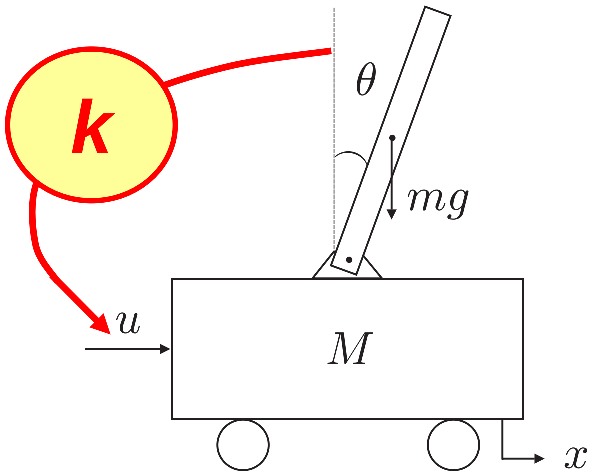
OUTLINE

1. Glocal Control
2. Unified Framework with Stability Conditions
3. **Cooperative Stabilization**
4. Robust Stability Analysis
5. Hierarchical Consensus
6. Conclusion

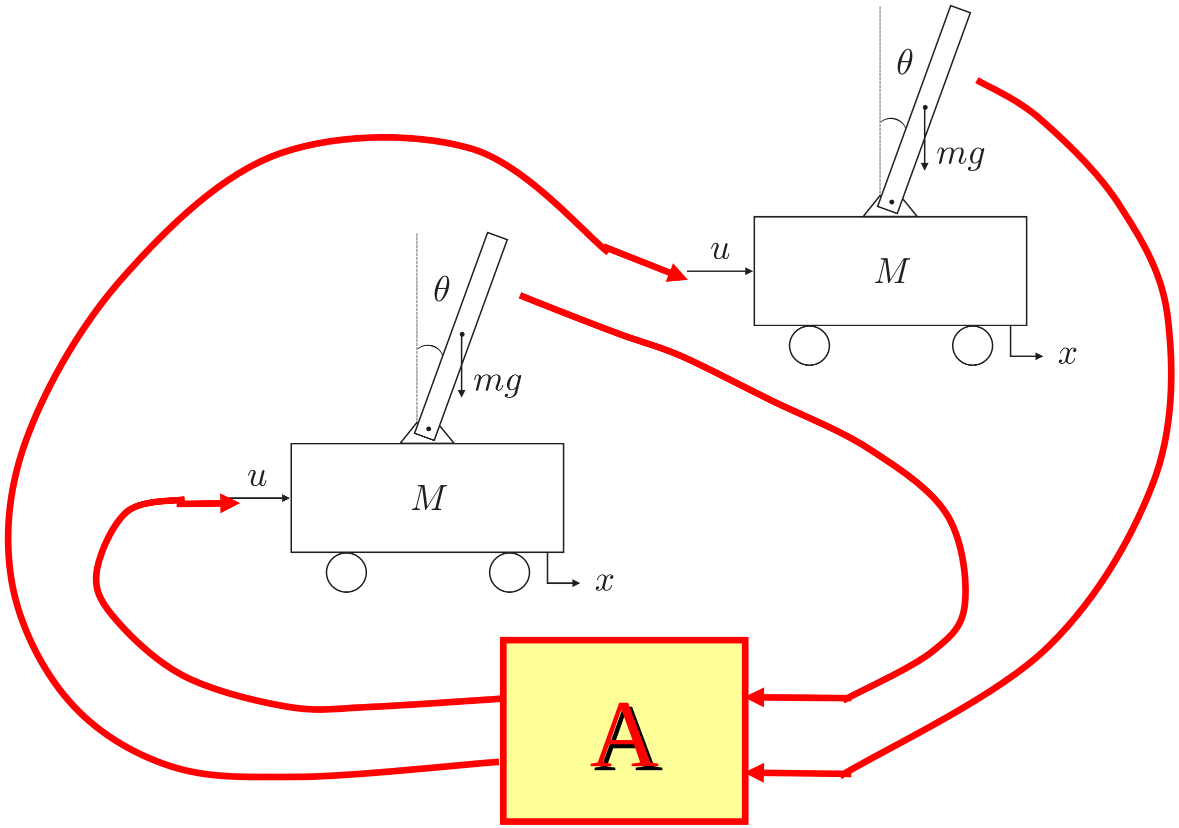
(Hara et al.: CDC-CCC2009)

An Application: Inverted Pendulum

Cooperatively stabilizable ?



Not stabilizable !



Remarks : No physical interactions
memory-less feedback

Property 1

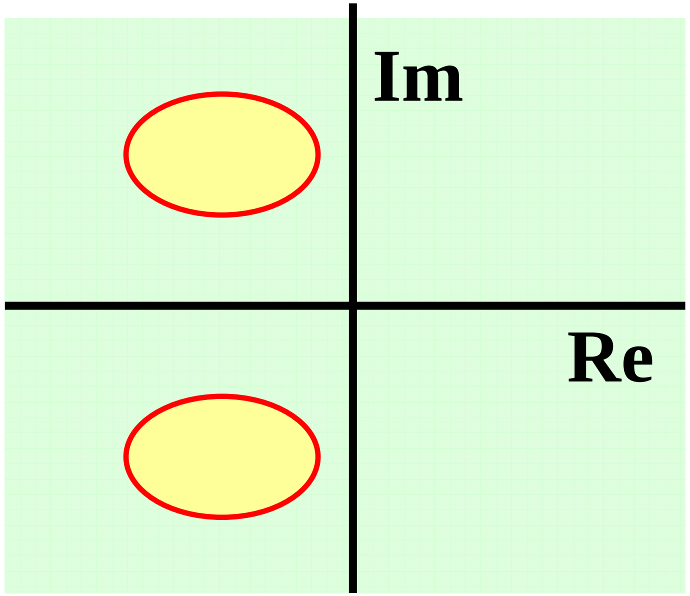
(i) $\sigma(A) \subset \Omega_+^c$

Cooperatively stabilizable：

Ω_+^c is non-empty.

<u>Solely stabilizable</u>：

Ω_+^c interacts the real axis.



N **: odd：Coop. Stab. = Solely Stab.**

N **: even：Coop Stab. (*N=2*) → any *N=2m***

Property 2

$$\mathcal{H}_A(s) := \left(\frac{d(s)}{n(s)}I - A\right)^{-1} \text{ is stable.} \quad ; \; h(s) = \frac{n(s)}{d(s)}$$

$\Updownarrow$ $$p(\lambda, s) := d(s) - \lambda\, n(s)$$

(ii) $\sigma(A) \subset \mathbf{\Lambda} \;:=\; \{\, \lambda \in \mathbb{C} \mid p(\lambda, s)$ is Hurwitz stable.$\}$

Solely Stabilizable： $\Leftrightarrow$

Stabilizable by a **real gain** output feedback

Cooperatively Stablizable： $\Leftrightarrow$

Stabilizable by a **complex gain** output feedback

Theorem: Coop. Stabliz. = Soley Stabiliz.

2nd order systems:

$$h_2(s) = \frac{cs + d}{s^2 + as + b}$$

Higher order systems:

$$\mathcal{H}_0(s) \triangleq \{\ h(s) = \frac{k}{d(s)} \mid k \neq 0\ \}$$

$$\mathcal{H}_1(s) \triangleq \{\ h(s) = \frac{ks}{d(s)} \mid k \neq 0,\ d(0) \neq 0\ \}$$

$$\mathcal{H}_2(s) \triangleq \{\ h(s) = \frac{k(s^2 - b^2)}{d(s)} \mid k \neq 0,\ d(\pm b) \neq 0\}$$

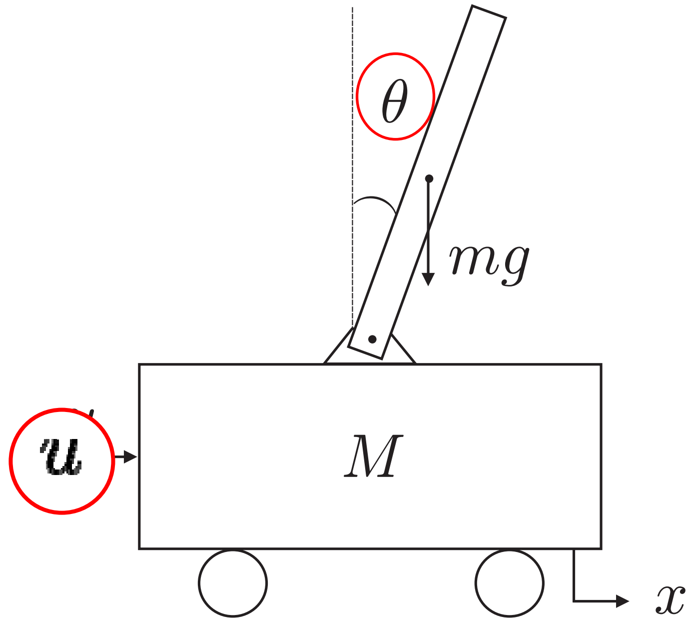
$$d(s) = s^n + a_{n-1}s^{n-1} + \cdots + a_1 s + a_0$$

Example : Inverted Pendulum

$$P_\theta(s) = \frac{-m\ell s}{D(s)} \quad \in \ \mathcal{H}_1(s)$$

$$D(s) = a_3 s^3 + a_2 s^2 + a_1 s + a_0 \ ,$$

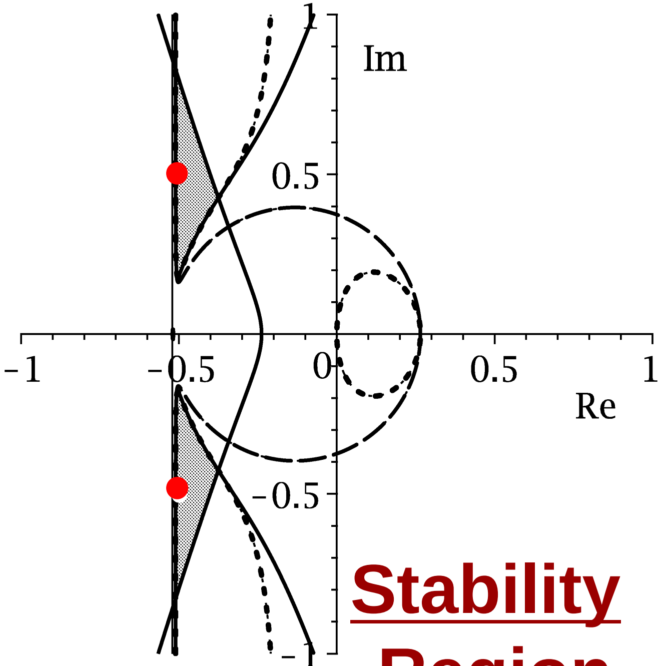
$$\begin{aligned}
a_3 &:= \frac{1}{3}(4M + m)m\ell^2 \ , \\
a_2 &:= (M + m)\mu_{\mathrm{p}} + \frac{4}{3}\mu_{\mathrm{t}} m\ell^2 \ , \\
a_1 &:= -(M + m)mg\ell + \mu_{\mathrm{p}}\mu_{\mathrm{t}} \ , \\
a_0 &:= -\mu_{\mathrm{t}} mg\ell \ .
\end{aligned}$$



An example：Cope. Stab. ≠ Soley Stab.

$$h(s) = \frac{100(s+2)(\frac{19}{10}s^2 - \frac{1}{500000}s + \frac{21}{10})}{(s-1)^2(s+1)(s+100)}$$

$$\lambda = (-1 \pm j)/2$$



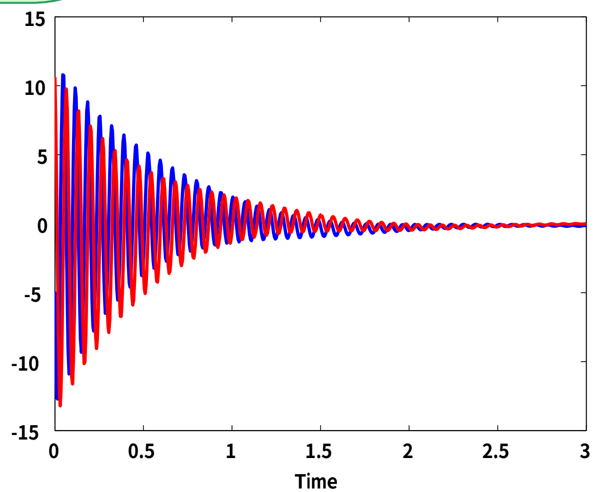
Stability Region

Control Law

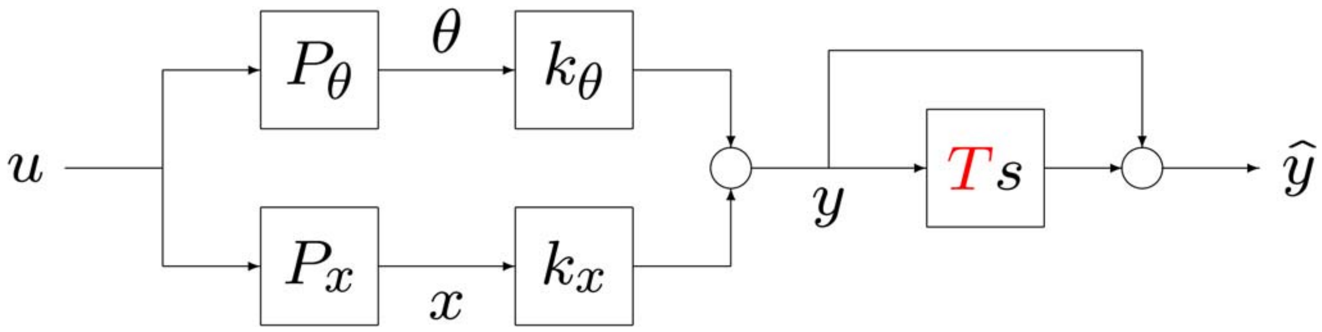
Follower

$$\begin{cases} u_1 = -(y_1 - y_2)/2 \\ u_2 = -(y_1 + y_2)/2 \end{cases}$$

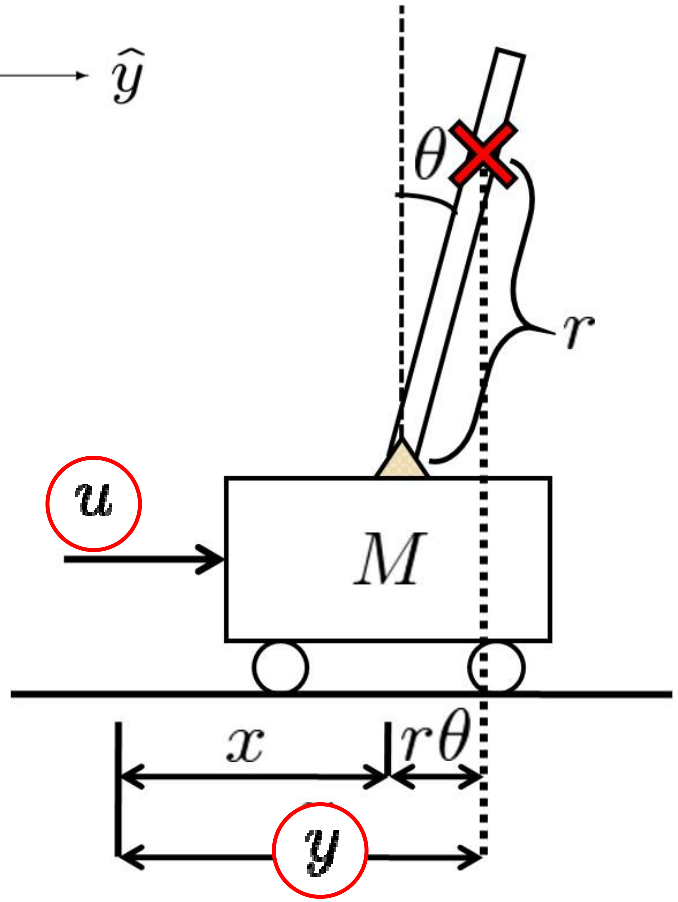
Leader



Inverted Pendulum : PD control (1/2)



$$h(s) = \frac{(Ts+1)(\frac{19}{10}s^2 - \frac{1}{500}s + \frac{21}{10})}{s(s-2)(s+1)(s+5)}$$



We can prove by a symbolic computation (QE) that the system can not be stabilized alone no matter how we choose *T>0* .

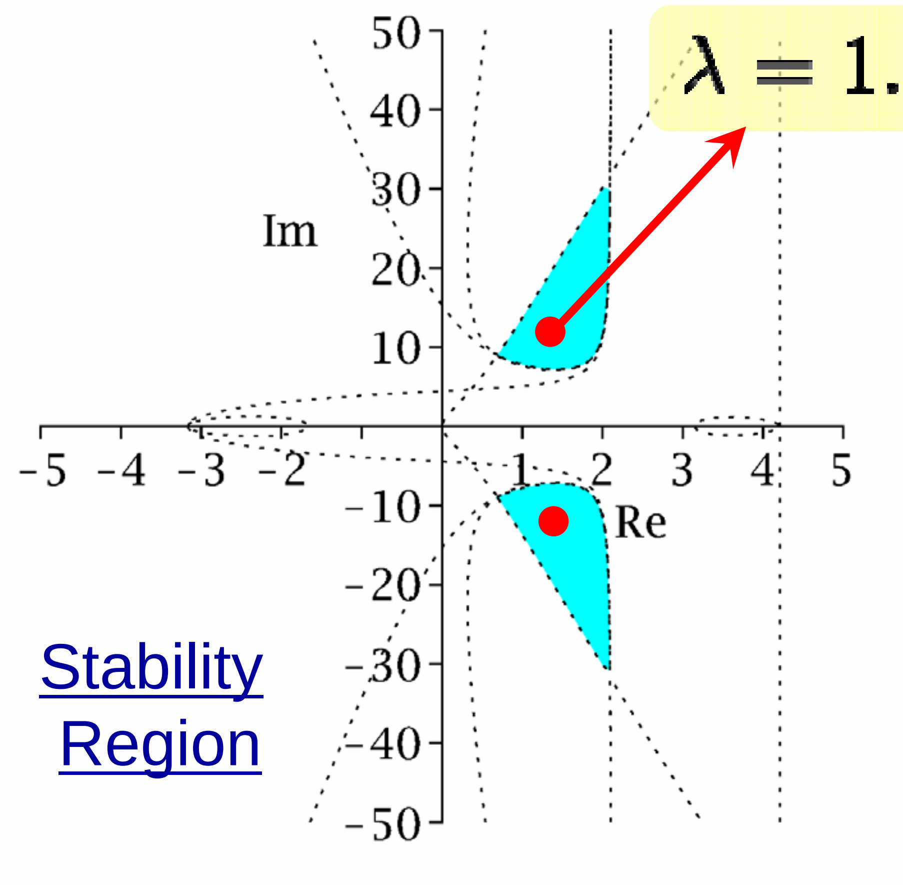
Inverted Pendulum : PD control (2/2)

T=1/2 :

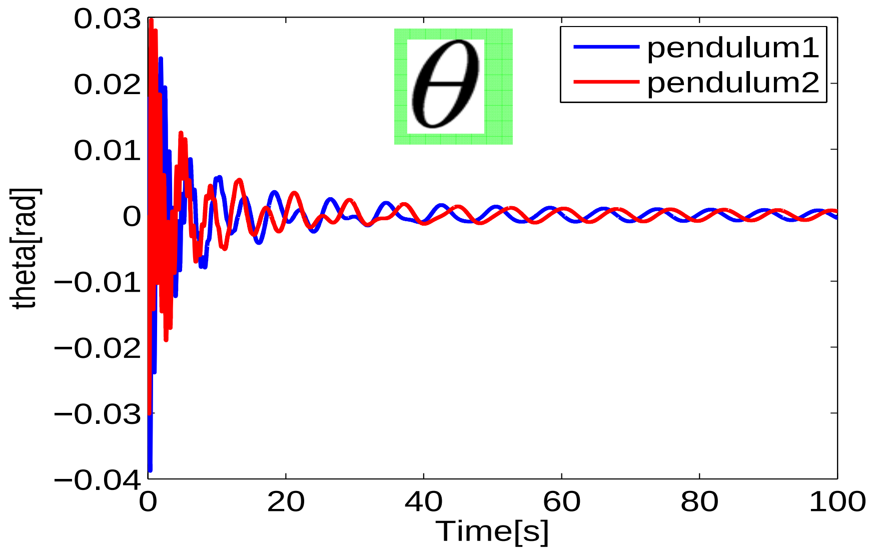
$$h(s) = \frac{(\frac{1}{2}s+1)(\frac{19}{10}s^2 - \frac{1}{500}s + \frac{21}{10})}{s(s-2)(s+1)(s+5)}$$

$$\lambda = 1.5 \pm 12j$$

$$A = \begin{bmatrix} 1.5 & -12 \\ 12 & 1.5 \end{bmatrix}$$



Stability Region



Message：Cooperative Stabilization

① **Cooperation realizes complex gain feedback virtually.**

② **Different roles of two agents are required for getting an advantage for stabilization.**

OUTLINE

1. Glocal Control
2. Unified Framework with Stability Conditions
3. Cooperative Stabilization
4. **Robust Stability Analysis**
5. Hierarchical Consensus
6. Conclusion

(Hara et al.: CDC2010)

Robust Stability for LTI Systems with GFV

Fundamental Questions in Control

From Stability to

- *Robust Stability ?*

  ** homogeneous → heterogeneous*

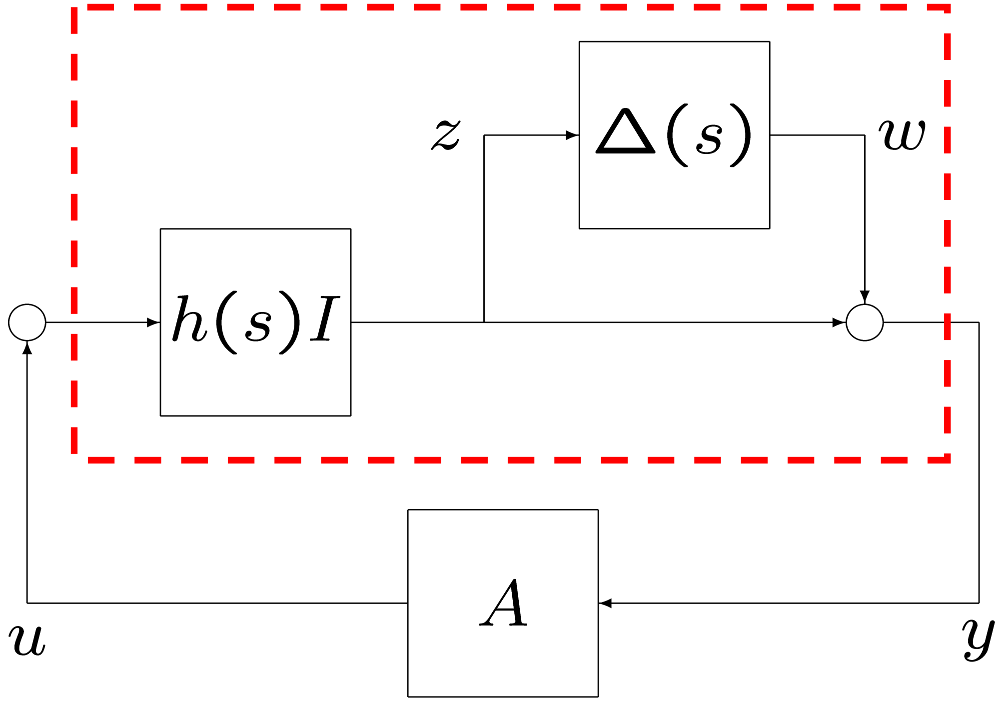
  ** physical inter-agent interactions*

- *Control Performance ?*

  H∞-norm Computation ?

Multiplicative Perturbations

$$\tilde{H}(s) = (I + \Delta(s)) \cdot h(s)$$



Nominal system: homogeneous

Independent perturbations

$$\Delta_{d\gamma} := \{ \Delta(s) \mid \Delta(s) = \mathrm{diag}\{\delta_i(s)\}, \|\Delta(s)\|_\infty \leq 1/\gamma \}$$

Robust Stability Condition for Heterogeneous Perturbations

(Hara et al.: CDC2010)

Assumption

$^{\exists}D$: diagonal s.t. DAD^{-1} is normal

Theorem: The following conditions are equivalent.

(i) The system is robustly stable for $\mathbf{\Delta}_{d\gamma}$.

(ii) $$\left\| \frac{\lambda h}{1 - \lambda h} \right\|_{\infty} < \gamma, \ \forall \ \lambda \in \sigma(A)$$

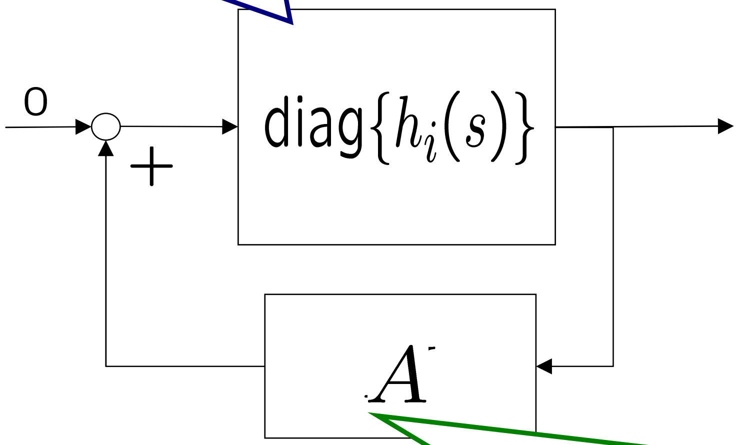
(iii) $$\left| \frac{\lambda}{\phi - \lambda} \right| < \gamma, \ \forall \ \lambda \in \sigma(A),$$

$$\forall \ \phi \in \mathbf{\Phi} := \{1/h(j\omega) | \ \omega \in \mathbb{R} \ \}.$$

Linearized Gene Network Model

Each gene's dynamics

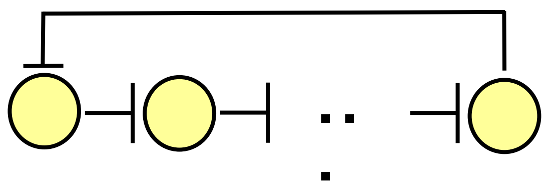
$$h_i(s) = (1 + \delta_i(s))h(s)$$



$$\begin{bmatrix} 0 & 0 & 0 & \cdots & R_1^2 f_1'(p_N^*) \\ R_2^2 f_2'(p_1^*) & 0 & 0 & \cdots & 0 \\ 0 & R_3^2 f_3'(p_2^*) & 0 & \cdots & 0 \\ \vdots & \vdots & \ddots & \ddots & \vdots \\ 0 & 0 & \cdots & R_N^2 f_N'(p_{N-1}^*) & 0 \end{bmatrix}$$

Interaction structure

$^\exists D$: diagonal s.t.
DAD^{-1} is normal



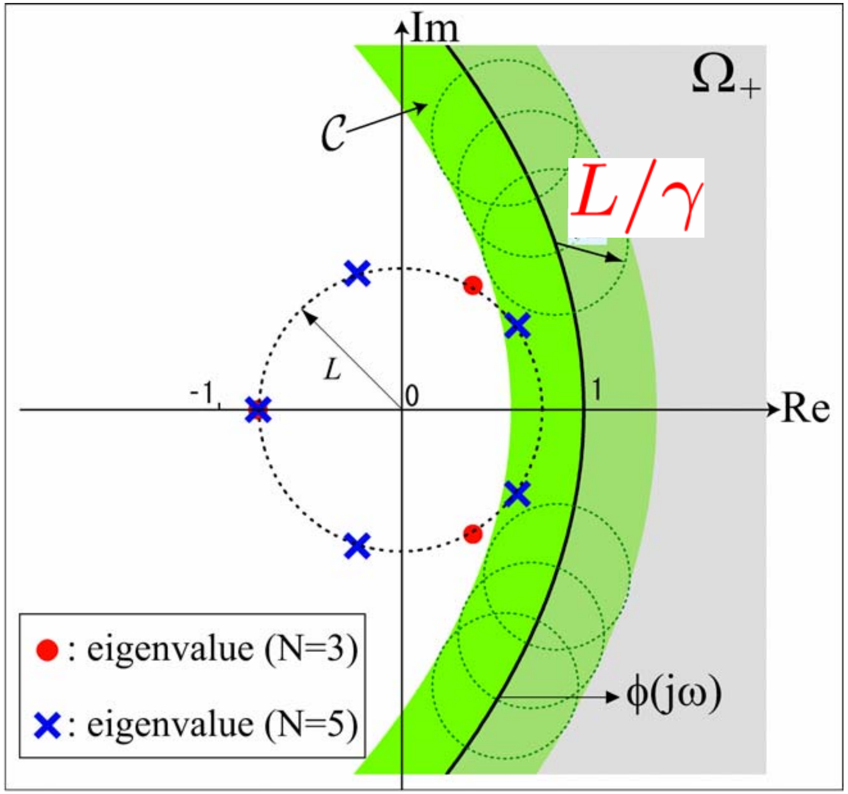
Robust Stability Test

$^{\forall}\lambda \in \sigma(A)$ and ω

$$\boxed{\left|\frac{1}{\phi(j\omega)-\lambda}\right| < \gamma/|\lambda|}$$

$$\Updownarrow \quad L := R^2 \prod_{\ell=1}^{N} |\kappa_\ell|^{\frac{1}{N}}$$

$$\boxed{|\phi(j\omega)-\lambda| > L/\gamma}$$



The smaller values of *N*, *Q*, *and*/or *R*
→ more robust for maintaining stability

(Osawa et. al., ASCC2011) tomorrow morning

Stability for Dissipative Agents

Agent Dynamics — SISO (Q, S, R)-dissipative

$$\begin{aligned} \dot{x}_i &= f_i(x_i) + g_i(x_i)u_i \\ y_i &= h_i(x_i) \end{aligned}$$

$Q = \mathrm{diag}\{Q_i\} \leq 0$,
$S = \mathrm{diag}\{S_i\}$,
$R = \mathrm{diag}\{R_i\} \geq 0$.

Theorem (LMI)

If $\exists$ a diagonal matrix $D > 0$ such that

$$A^T D R A + D S A + A^T S^T D + D Q < 0$$

holds, then the network of N interconnected (Q_i, S_i, R_i)-dissipative agents is asymptotically stable.

(Hirsch, Hara: IFAC2008)

Message：Robust Stability

① **Methods of robust stability analysis for standard systems such as *D*-scaling work well for stability analysis for heterogeneous multi-agent dynamical systems.**

② **Although the results are not complete, there are many potential practical application fields to which we can apply them.**

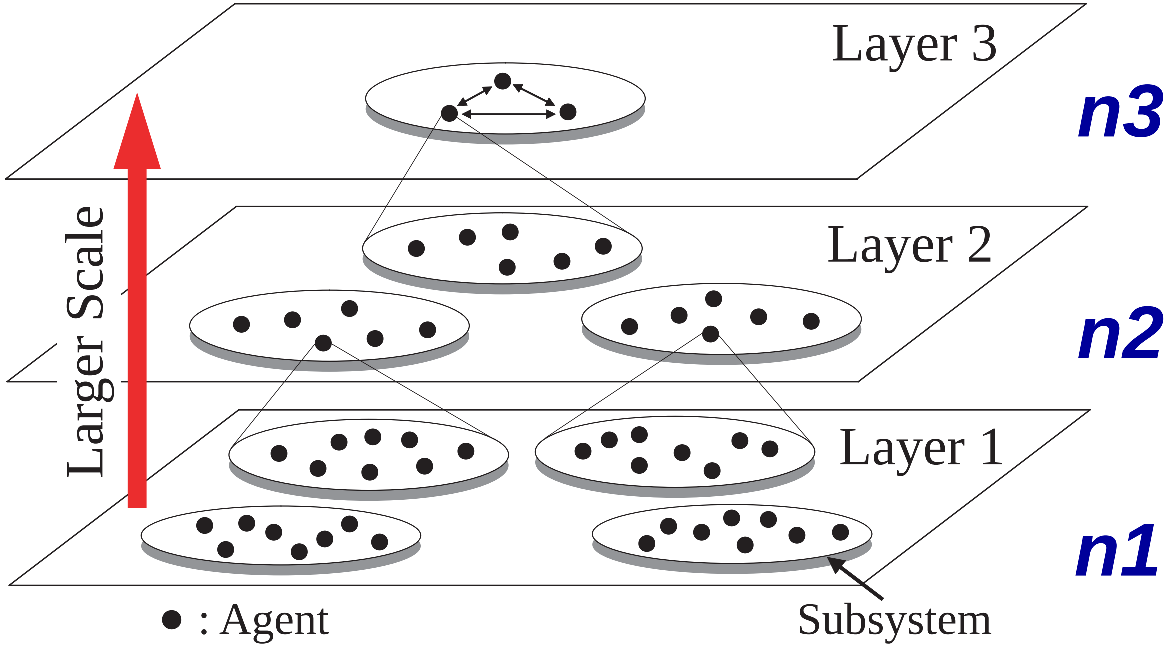
OUTLINE

1. Glocal Control
2. Unified Framework with Stability Conditions
3. Cooperative Stabilization
4. Robust Stability Analysis
5. **Hierarchical Consensus**
6. Conclusion

(Shimizu, Hara: SICE2008, Hara et al.: ACC2009)

Hierarchical Consensus Problem

$$\dot{x}(t) = Ax(t) \qquad \exists \xi\ , \quad \lim_{t \to \infty} x(t) = \xi \cdot 1$$



total agents : *n1*× *n2*× *n3*

Hierarchical Structure

$A_1 = P - I$: Cyclic Pursuit inside sub-group

$$A_l = \mathrm{diag}(\underline{\underline{A_{l-1} - I}}) + \underline{\underline{P}} \otimes \underline{\underline{\Delta}}$$

Homogeneous structure

Fractal structure

Property on Interactions

Low Rank Interaction:

$$\Delta = 1 \cdot \zeta^T$$

Share an aggregated information
Control uniformly

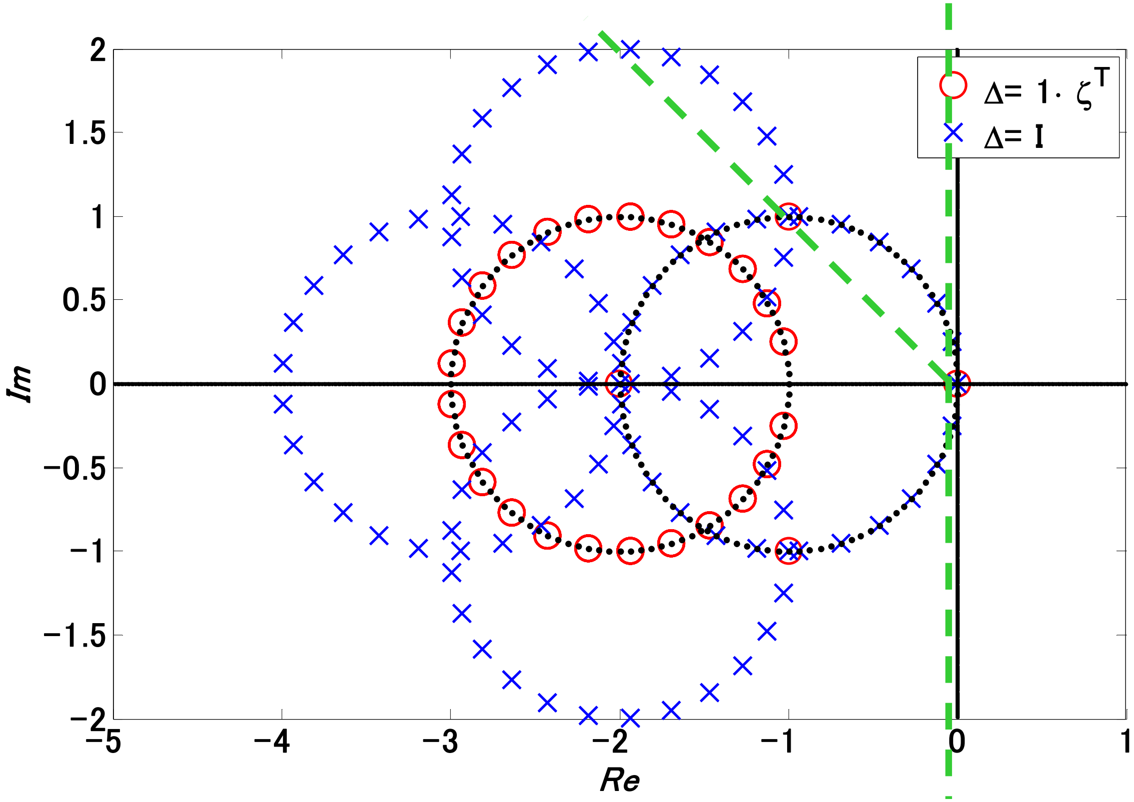
weak interaction:
Sparse
Small gain

Eigenvalue Distributions

⊿: Rank 1

$$\mathrm{eigs}(\boldsymbol{A}_1) = \bigcup_{r=1}^{n_1} \exp(2\pi j(r-1)/n_1) - 1$$

$$\mathrm{eigs}(\boldsymbol{A}_2) = \begin{cases} \bigcup_{r=1}^{n_2} \exp(2\pi j(r-1)/n_2) - 1 \\ \bigcup_{r=2}^{n_2} \exp(2\pi j(r-1)/n_1) - 2 \end{cases}$$

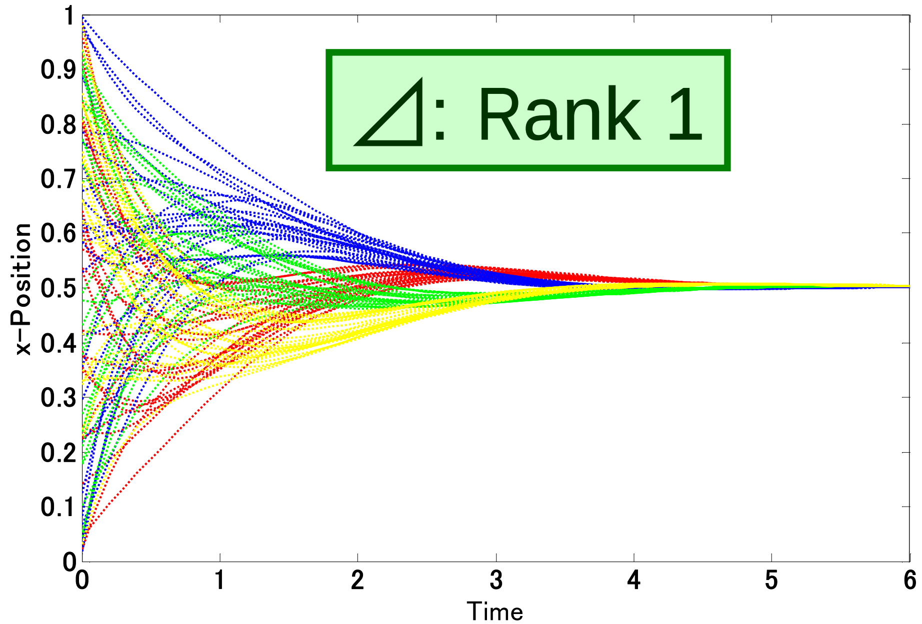


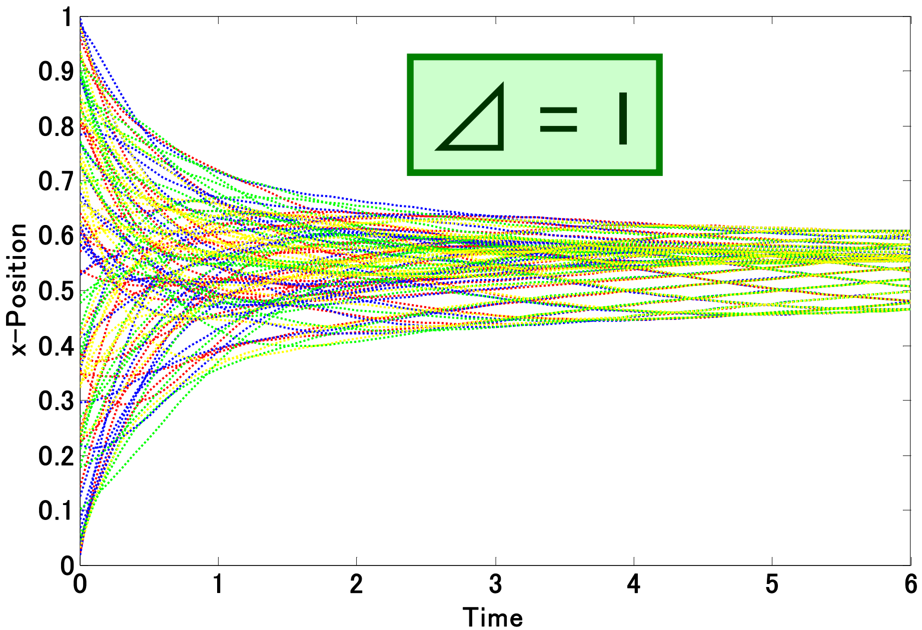
n1=25 > n2=4

○ : rank 1

× : Identity

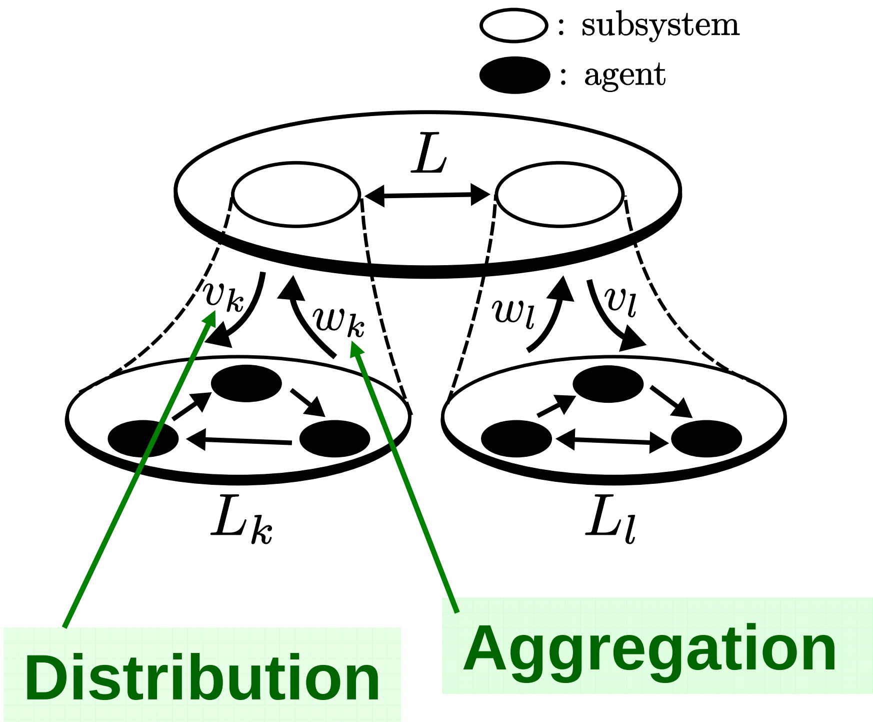
Time Responses (n1=25, n2=4)





Rapid Consensus

n1 > n2



Message：Hierarchical Consensus

① Proper ways of aggregation and distribution are important to achieve rapid consensus.

② Low rankness of interlayer connection captures them properly.

Toward "Glocal Control"

A Unified Framework for
Decentralized Cooperative Control
of Large Scale Networked Dynamical Systems

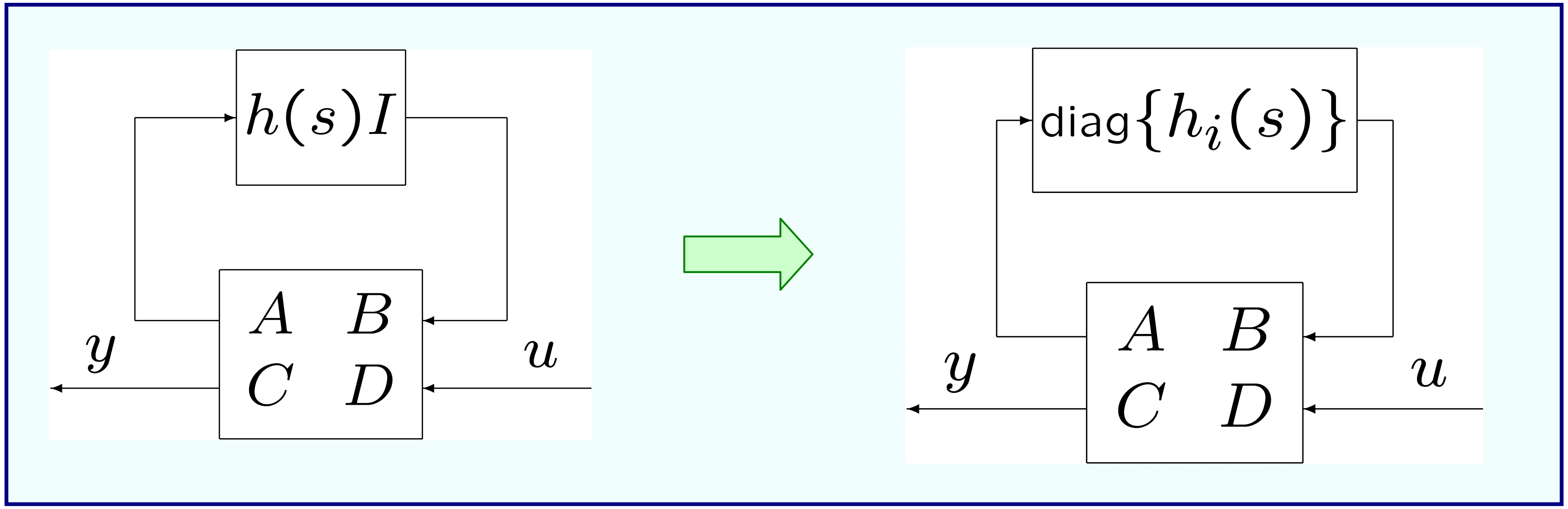
Key Idea : Dynamical System with
Generalized Frequency Variable

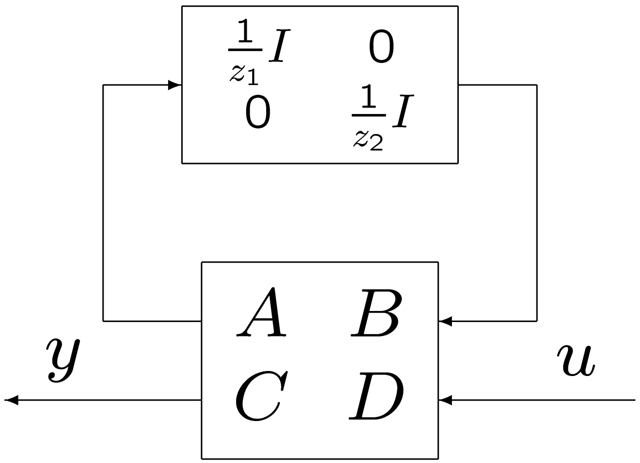
→ ***Stability & Robust Stability Analysis***
Cooperative Stabilization

Extensions :

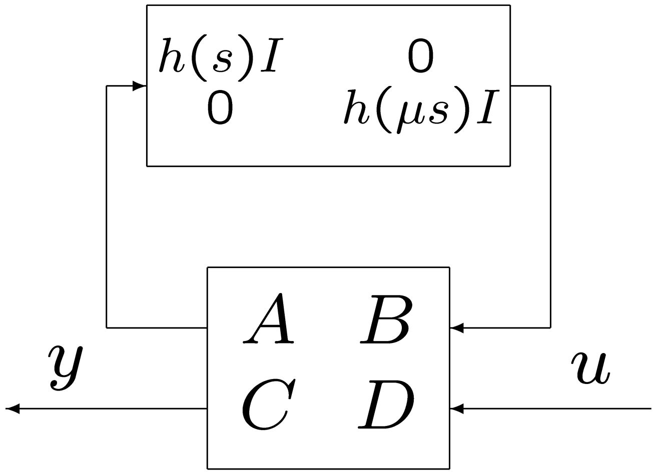
- Hierarchical case
- Non-linear case
- Control Performances, Synthesis *?*

New Framework for System Theory





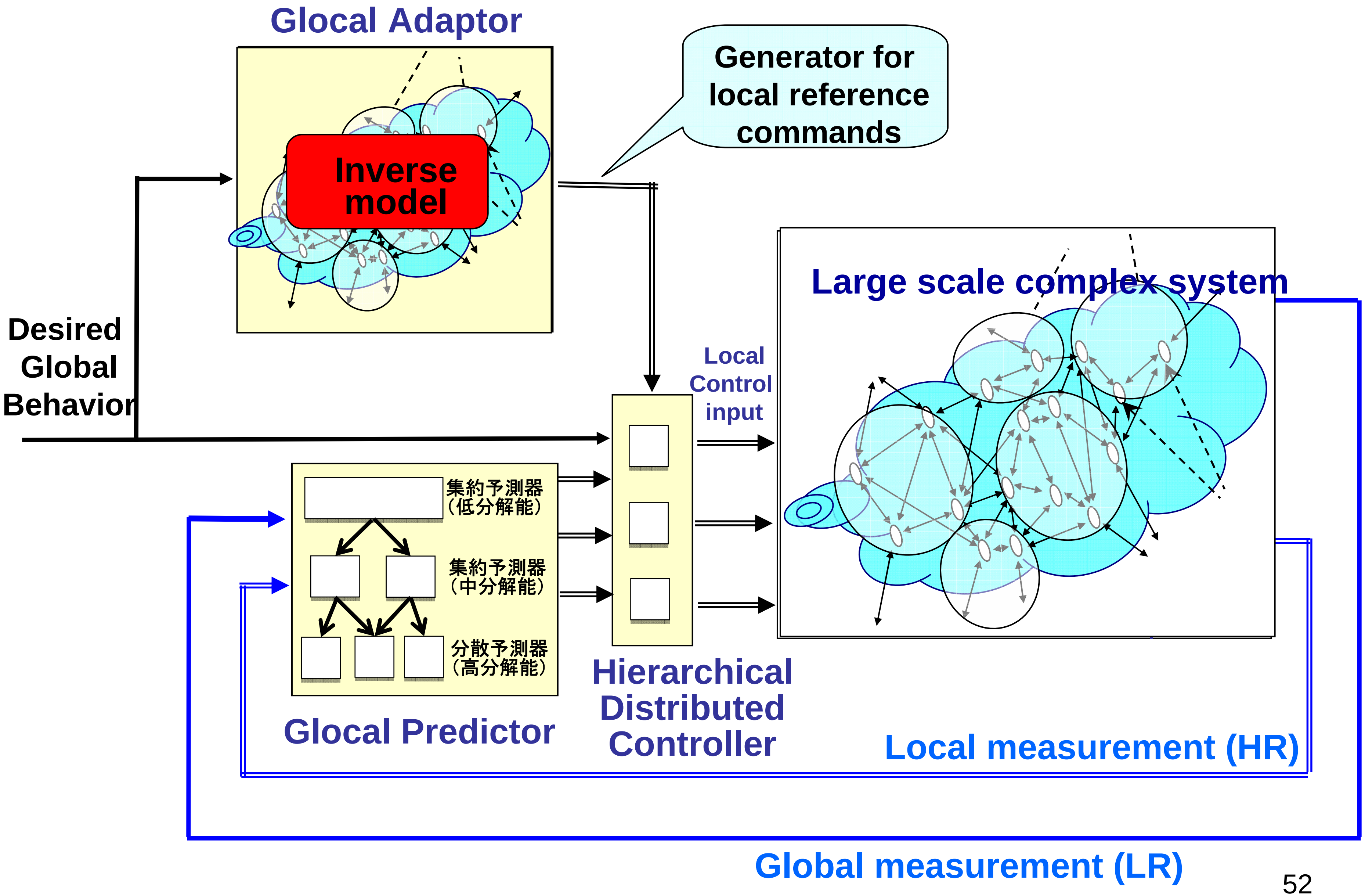
2D System



Singular Perturbed System

Multi-resolved Systems

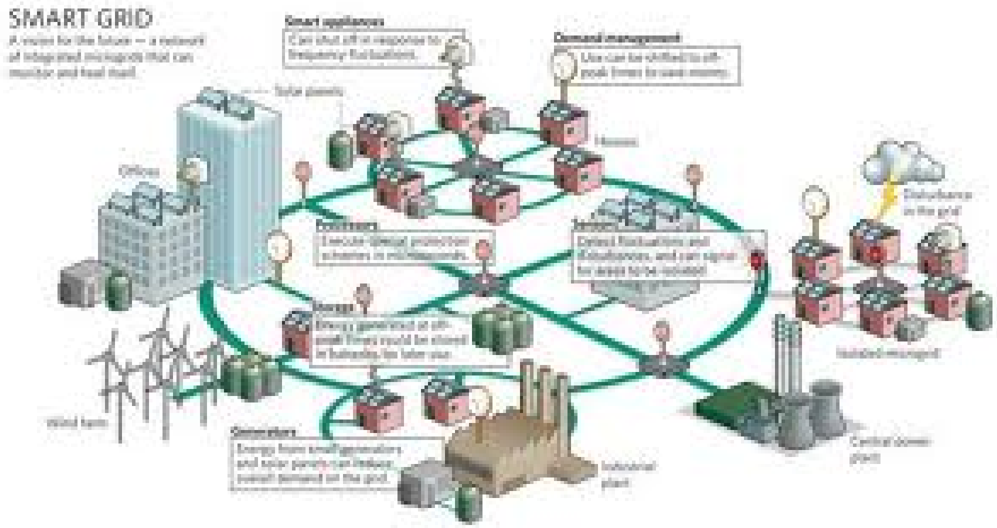
Image of Glocal Control System



Smart Energy NW and Energy Saving

Smart Energy Network

Electric power network
+ Gas energy network



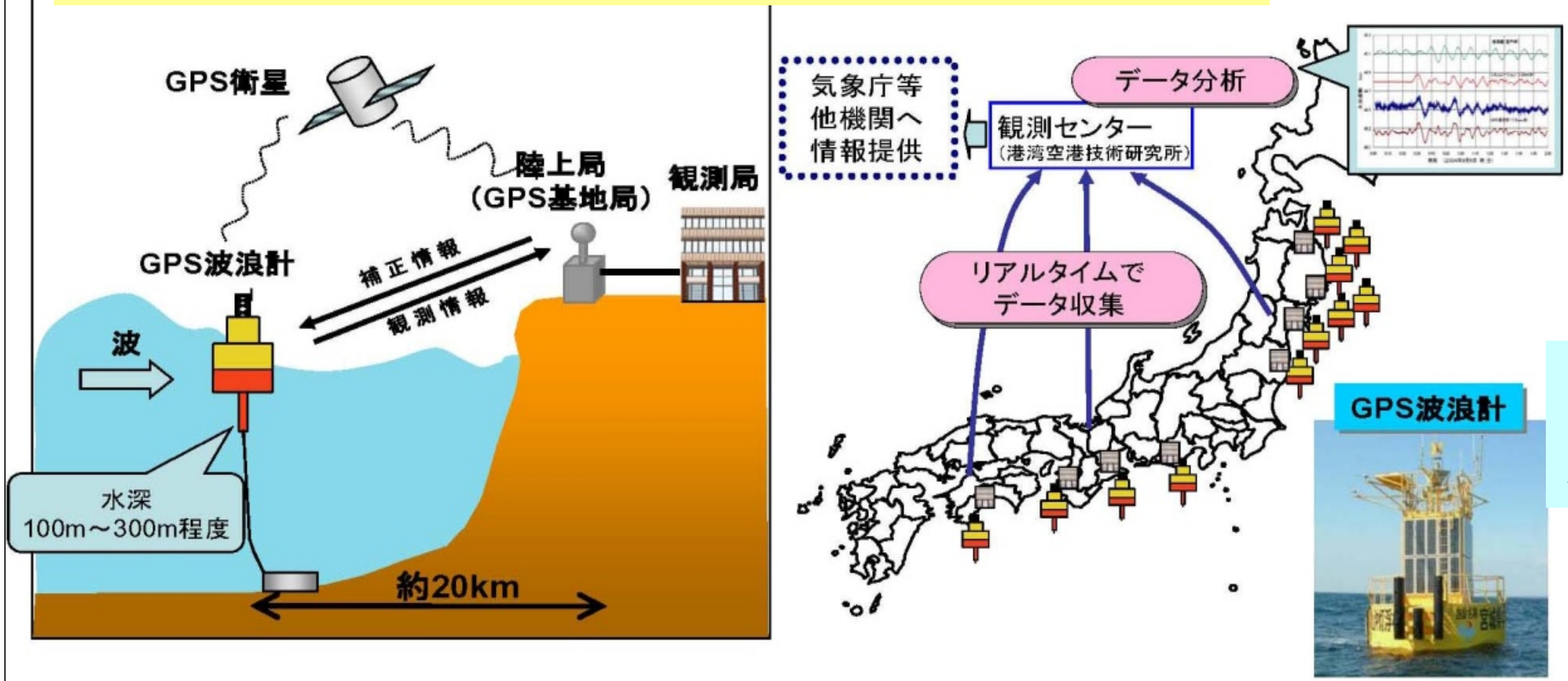
http://tinycomb.com/wp-content/uploads/2009/05/**smart-grid**.jpg

Hierarchical Air Conditioning System

Group of buildings
Set of floors
Set of rooms

Evacuation Guidance for Tsunami

Wave measurement system by GPS



GPS Wave Sensor

How to set up GPS wave sensors to predict the time and height of "tsunami" properly for effective evacuation guidance ?

Optimal time-, space-, level- resolution ?

Acknowledgements

① Glocal Control

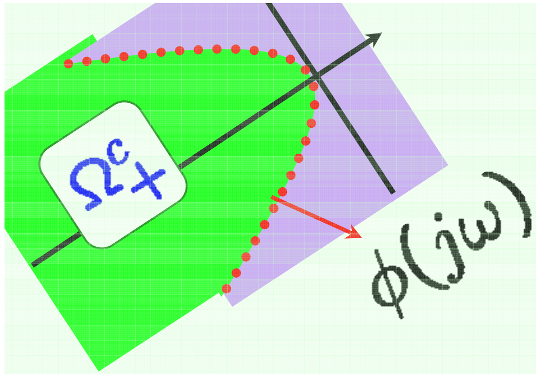
Jun-ichi Imura (Tokyo Tech.)
Koji Tsumura (U. Tokyo)
Koichiro Deguchi (Tohoku U.)

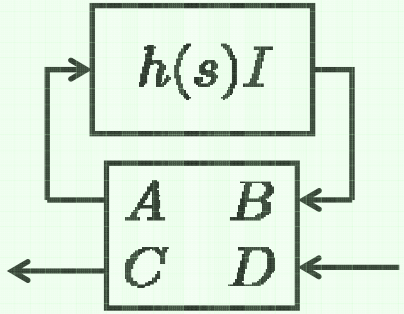
② LTI Systems with Generalized Freq. Vars.

Tetsuya Iwasaki (UCLA)
Hideaki Tanaka (U. Tokyo)
Masaaki Kanno (Niigata U.)

③ Gene Regulatory Networks

Yutaka Hori (U. Tokyo)
Tae-Hyoung Kim (Chung-Ang U.)





Please join us
to develop "Glocal Control Theory"
and to solve social problems
through "Glocal Control"

Thank you very much !