Workshop: Toward Glocal Control
The University of Tokyo, 2010.4.1

Idea of "Glocal Control"

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OUTLINE

1. What is “Glocal Control” ?
2. Global vs Local
3. Hierarchical Consensus
4. Toward “Glocal Control”

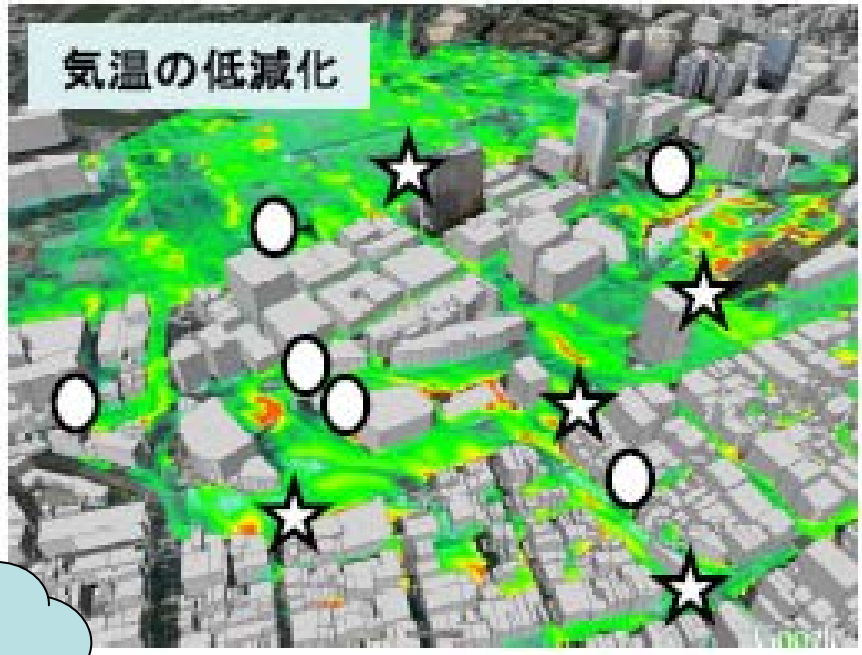
Glocal Control

Realization of Global Functions by Local Measurement and 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. We need to pay much attention to analysis and control of meteorological phenomena and bio systems as such large scale dynamical 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**.

Urban Heat Island Problem



Glocal Control

グローカル制御

☆：Fans　○：Temperature, Wind Sensors

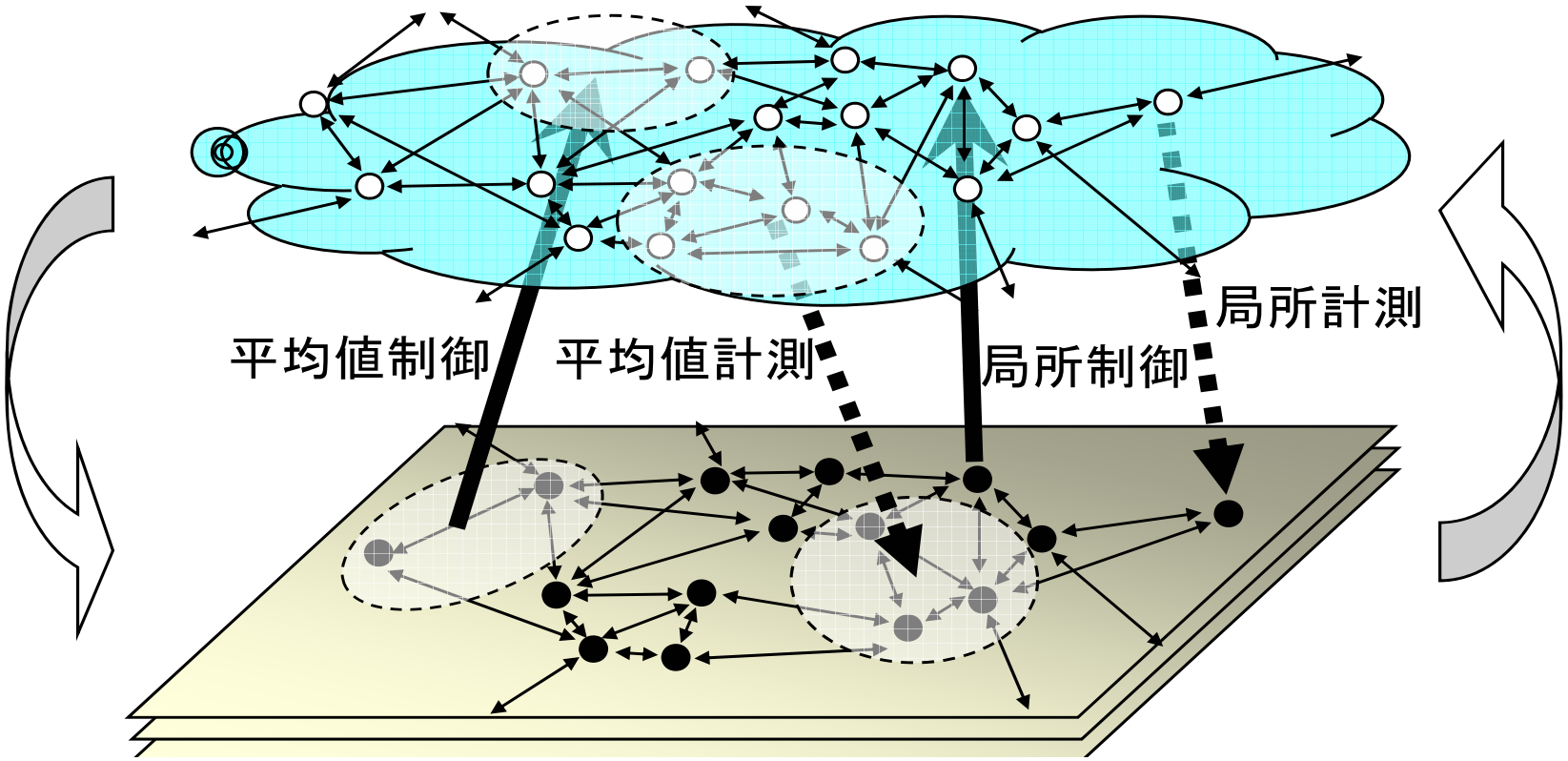
Control

Prediction

Measurement

Framework for "Glocal Control"

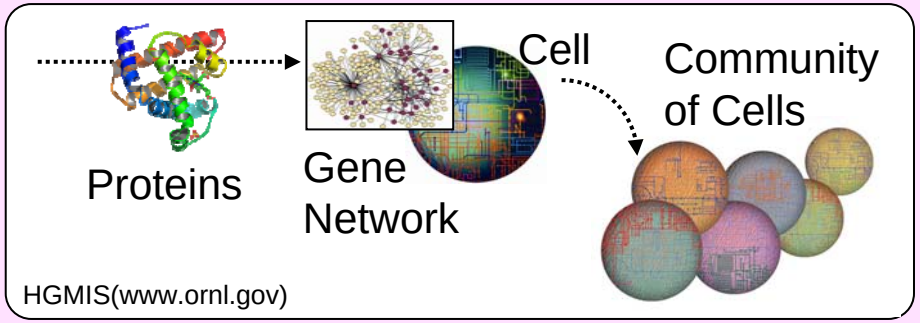
Physical Network



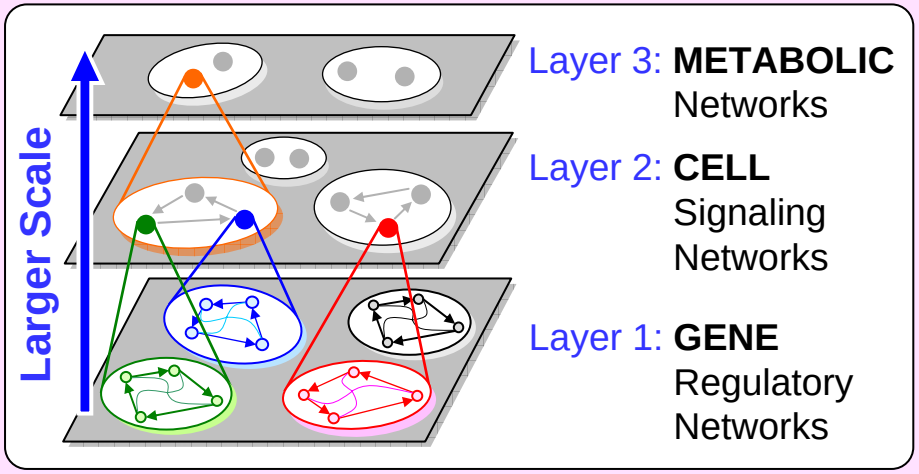
Information (Logical) Network

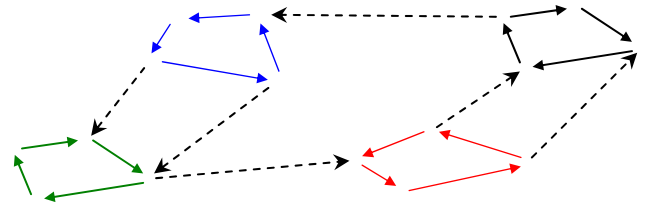
Measurement → Prediction → Control

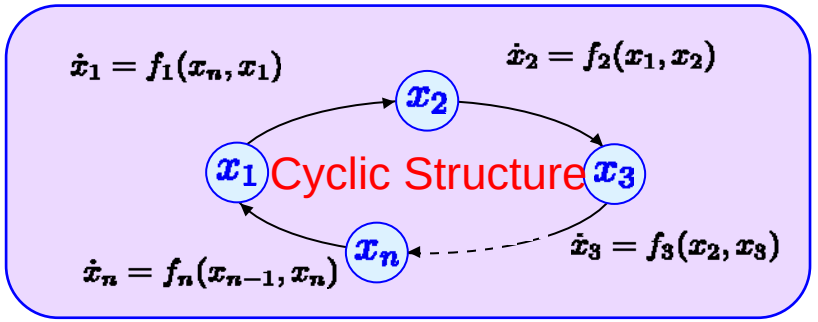
Hierarchical Bio-Network Systems

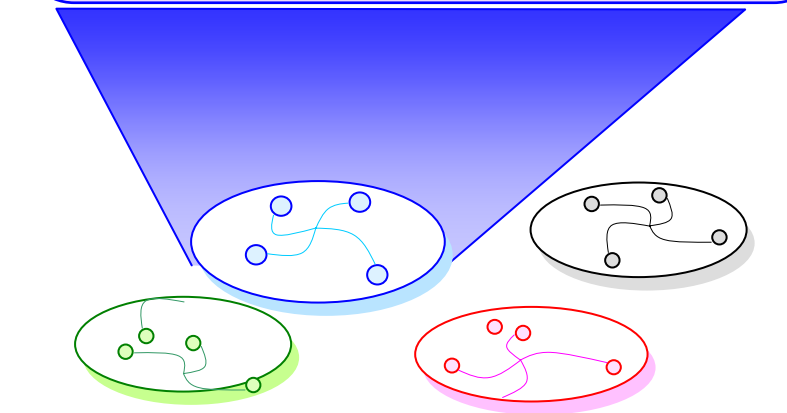


Hierarchical Bio-Network Systems



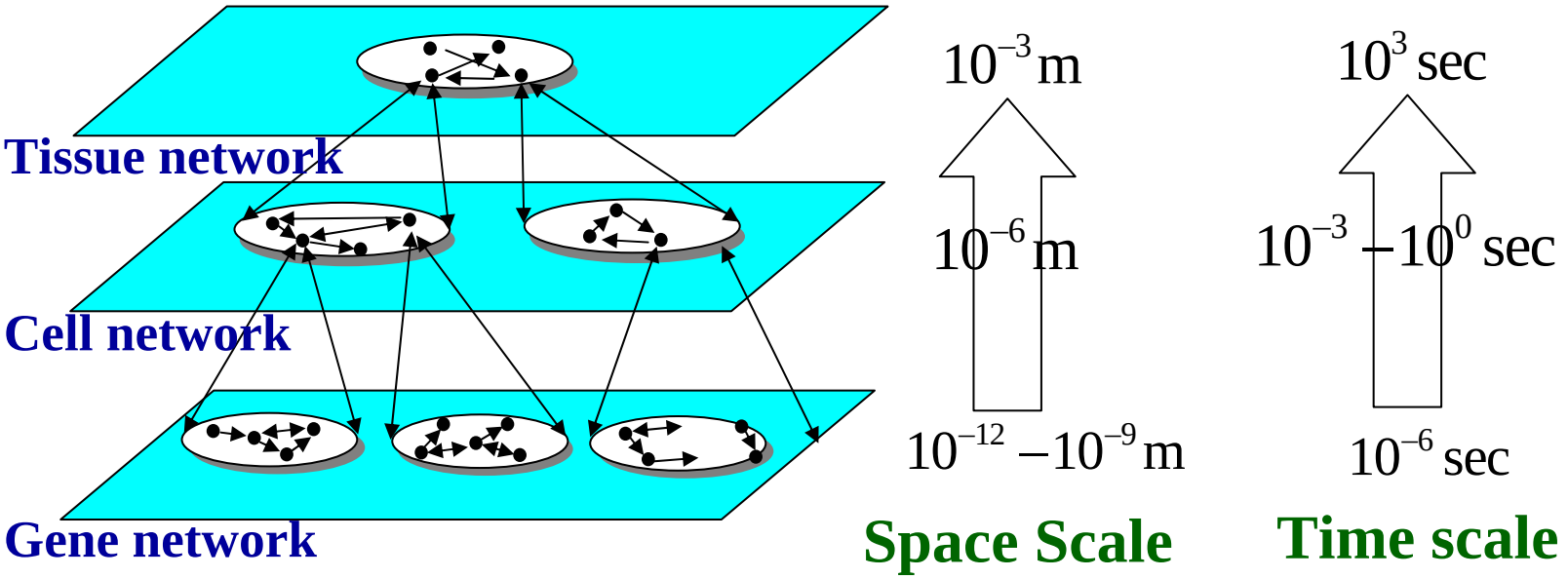






: Subsystem 1 : Subsystem 2
: Subsystem 3 : Subsystem 4

Hierarchical Structure with Multi-resolution



- **Resolution of State Variables**
- **Resolution Converters (High ⇔ Low)**

Key Notion
Toward “Glocal Control”

(1) Combined NW:
Physical NW & Information NW
(2) Seamless Actions of
Measurement, Prediction, Control
(3) Hierarchical Dynamical Systems
with Multi-Resolution

OUTLINE

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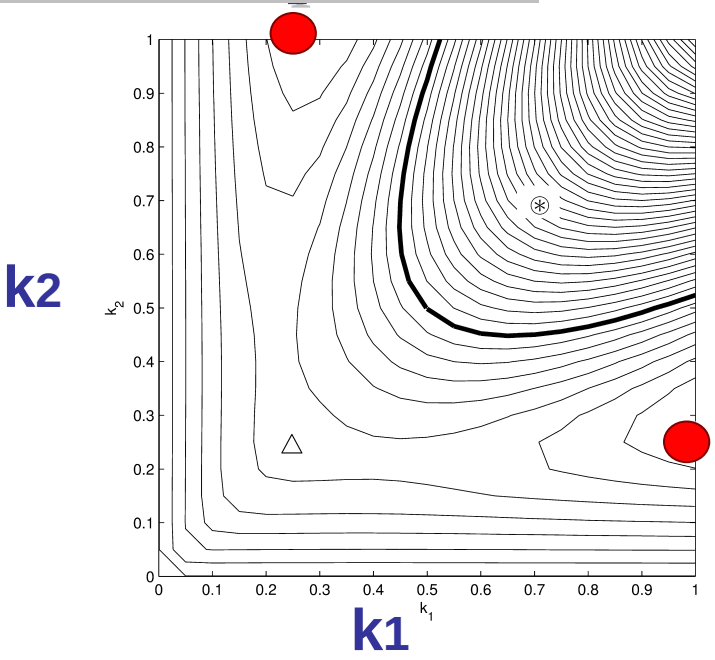
Example : Glocal vs Local Prisoners' Dilemma (1/2)

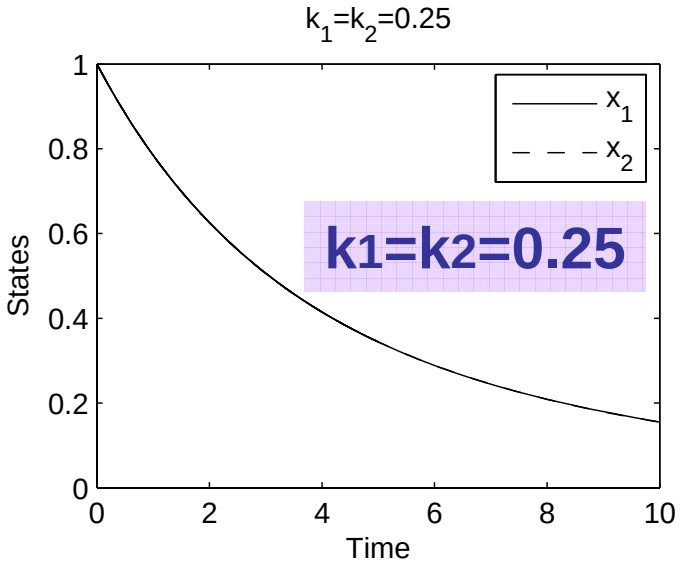
System

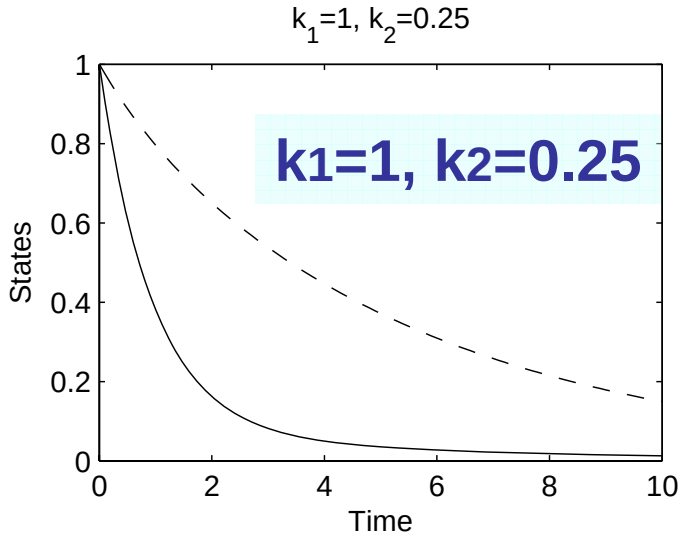
$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} = \begin{bmatrix} -k_1 & \frac{2k_2^2}{1+2(k_1-k_2)^2} \\ \frac{2k_1^2}{1+2(k_1-k_2)^2} & -k_2 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix}$$

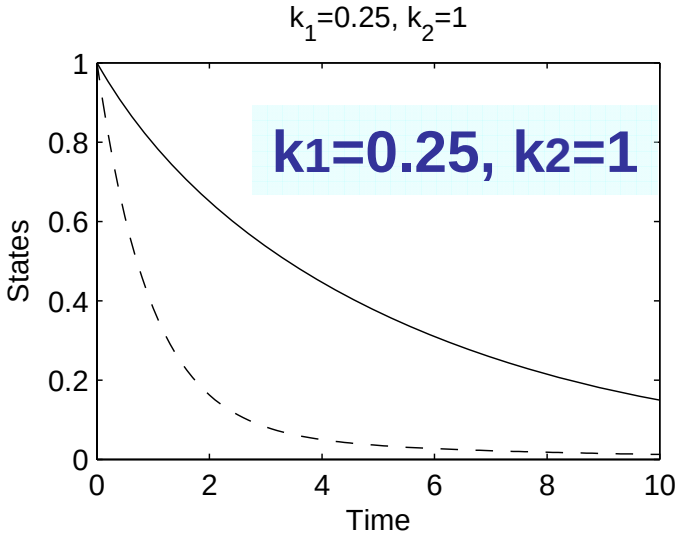
Closed-loop Poles

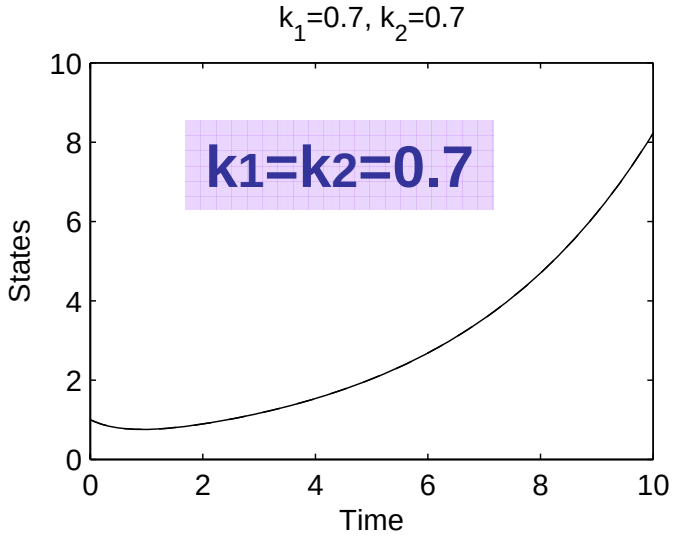


Example : Glocal vs Local Prisoners' Dilemma (2/2)









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Consensus
for multi-agent dynamical systems

$$\dot{x}_i(t) = u_i(t) = \sum_{j \neq i} a_{ij}(x_j(t) - x_i(t))$$

$$\Longleftrightarrow \quad \dot{\boldsymbol{x}}(t) = \boldsymbol{A}\boldsymbol{x}(t)$$

A : Graph Laplacian

$$\exists \xi \,, \quad \lim_{t \to \infty} \boldsymbol{x}(t) = \xi \cdot \mathbf{1}$$

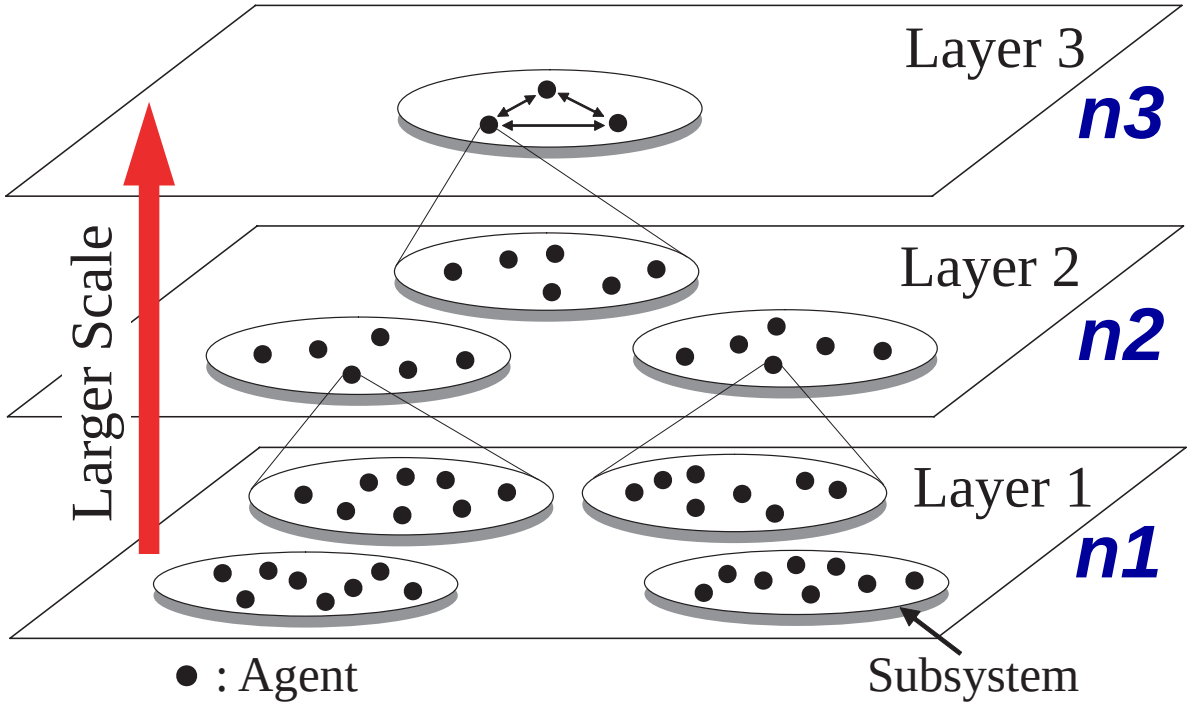
$$\boldsymbol{x} \equiv (x_1, \cdots, x_n)^T$$

$$1 \equiv (1, \cdots, 1)^T$$

Fundamental Questions

- *Consensus = Lyapunov Stability of total system, which is quite large ?*
- *Consensus Performance = Stability Degree ?*

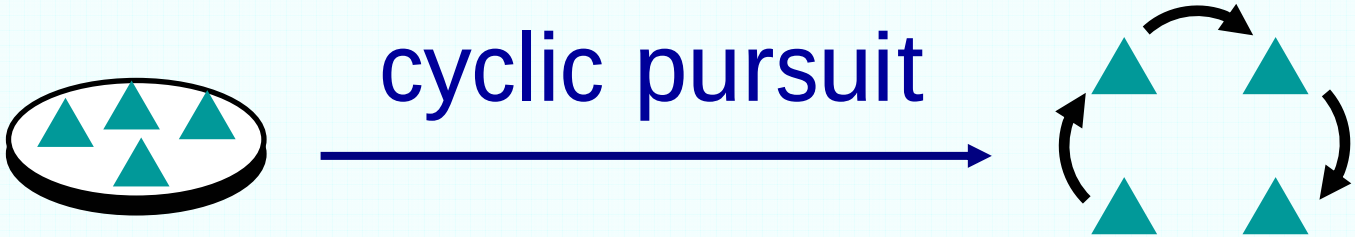
Hierarchical Multi-agent Dynamical System



total agents : *n1* × *n2* × *n3*

- *Hierarchical model with fractal structure ?*

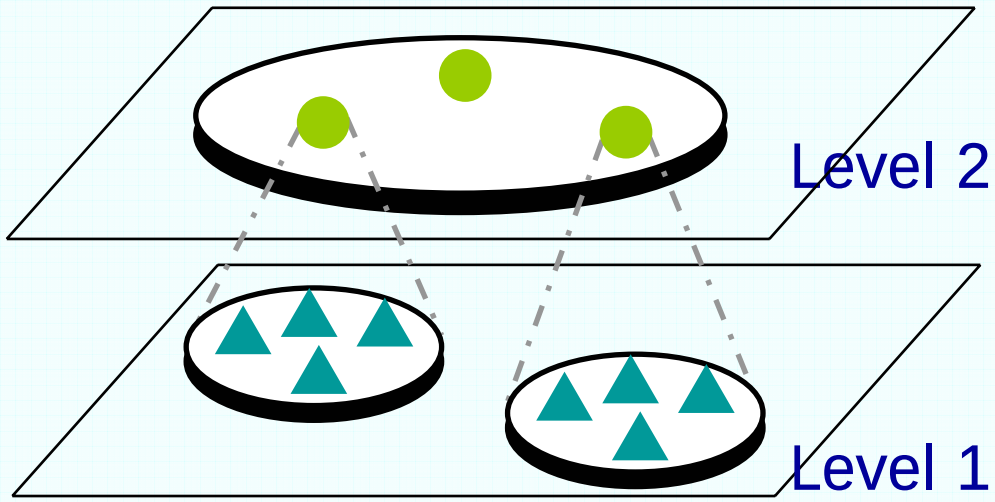
Information Structure Inside Sub-group



$$\dot{x} = A_1 x$$

$$A_1 = P - I = \underbrace{\begin{pmatrix} -1 & 1 & 0 & 0 \\ 0 & -1 & 1 & 0 \\ 0 & 0 & -1 & 1 \\ 1 & 0 & 0 & -1 \end{pmatrix}}_{\text{Graph Laplacian}} \qquad P = \underbrace{\begin{pmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \end{pmatrix}}_{\text{Circulant matrix}}$$

Hierarchical Information Structure (1/2)

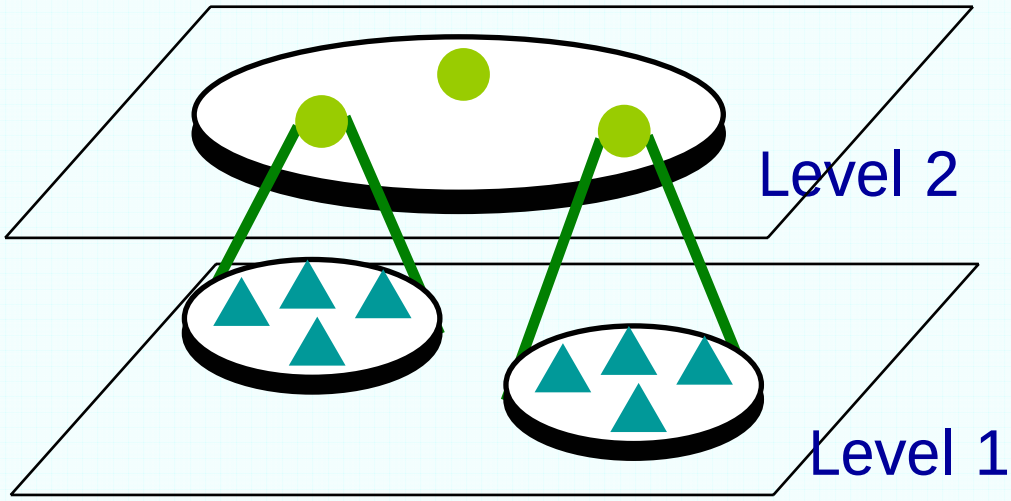


No interaction among sub-groups

$$\dot{x} = A_2 x$$

$$A_2 = \begin{pmatrix} A_1 & 0 & 0 \\ 0 & A_1 & 0 \\ 0 & 0 & A_1 \end{pmatrix}$$

Hierarchical Information Structure (2/2)



Interaction
with
Fractal Structure

$$A_2 = \begin{pmatrix} A_1 - I & \triangle & 0 \\ 0 & A_1 - I & \triangle \\ \triangle & 0 & A_1 - I \end{pmatrix}$$

General Expression for Hierarchical MADSs
- Fractal & Cyclic Structure -

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

$$\boldsymbol{A}_l = \mathrm{diag}(\boldsymbol{A}_{l-1} - \boldsymbol{I}) + \boldsymbol{P} \otimes \boldsymbol{\Delta}$$

Homogeneous structure

Fractal structure

Property on Interactions

weak interaction:
Sparse
Small gain

New Weak Interconnection Properties

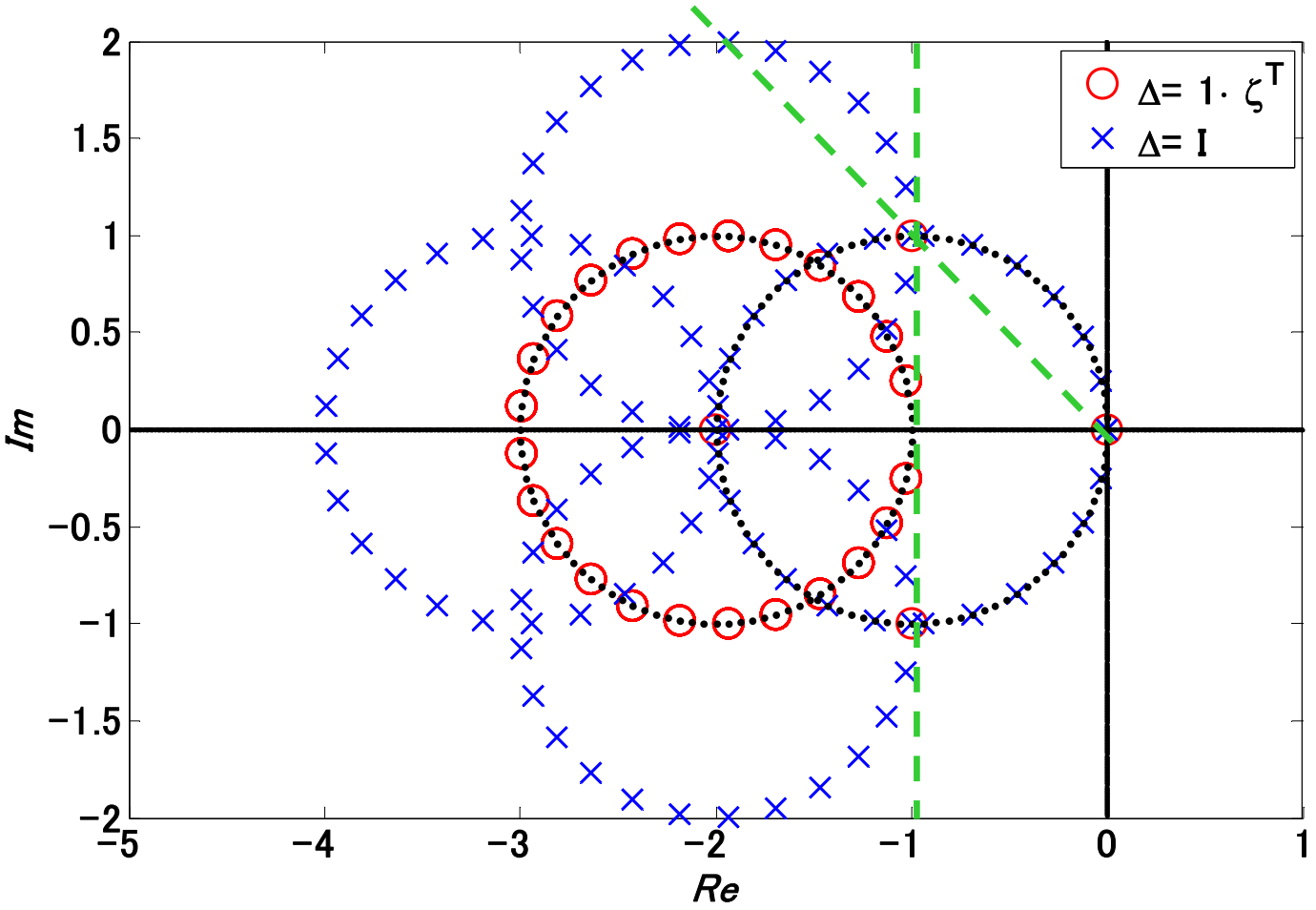
Δ	**Low-rank**	High-rank
Sparse	$\Delta = 1 \cdot \zeta^T$ $(\sum_{i=1}^{n} \zeta_i = 1, \ \ \zeta_i \geq 0)$	$\Delta = I$ (Smith)
Dense		

Share an aggregated information
Control uniformly

$\zeta^T = \begin{pmatrix} 1 & 0 & \cdots & 0 \end{pmatrix}$: sparse

$\zeta^T = \frac{1}{n}\begin{pmatrix} 1 & 1 & \cdots & 1 \end{pmatrix}$: dense

Eigenvalue Distributions (n1=25, n2=4)



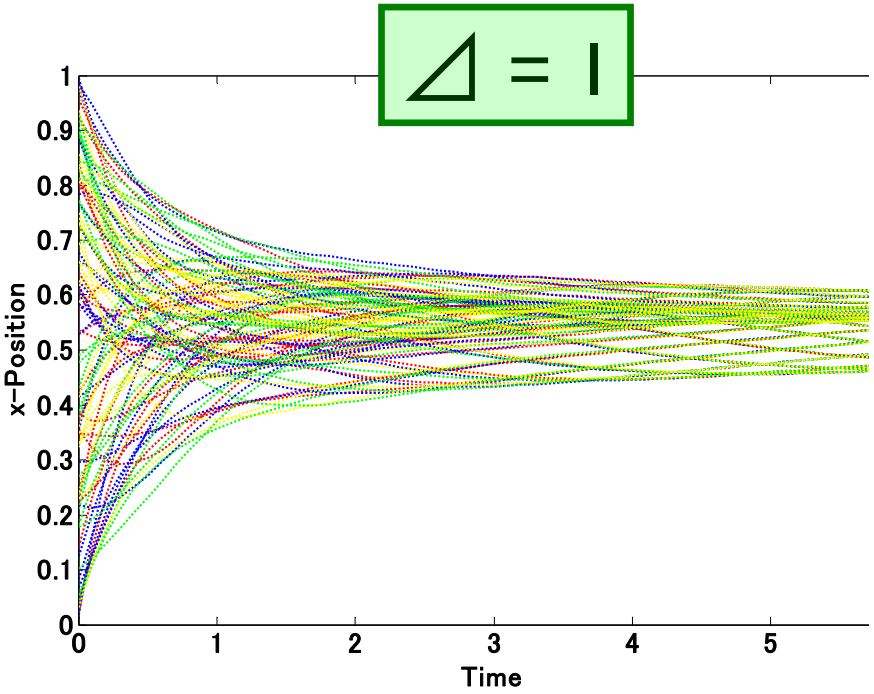
n1 > n2

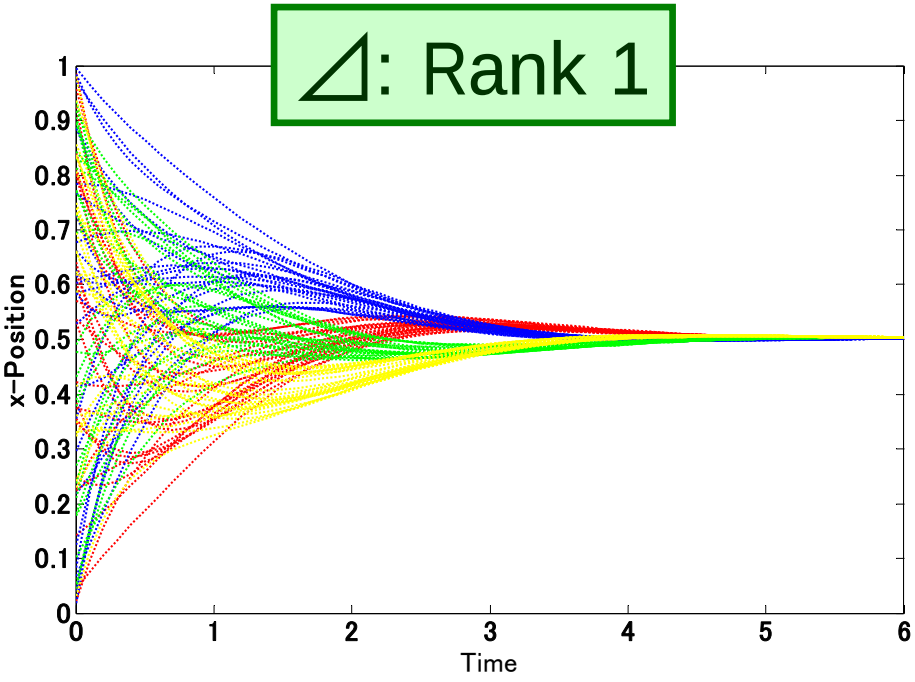
○ : rank 1

× : Identity

Time Responses (n1=25, n2=4)

n1 > n2





Rapid Consensus

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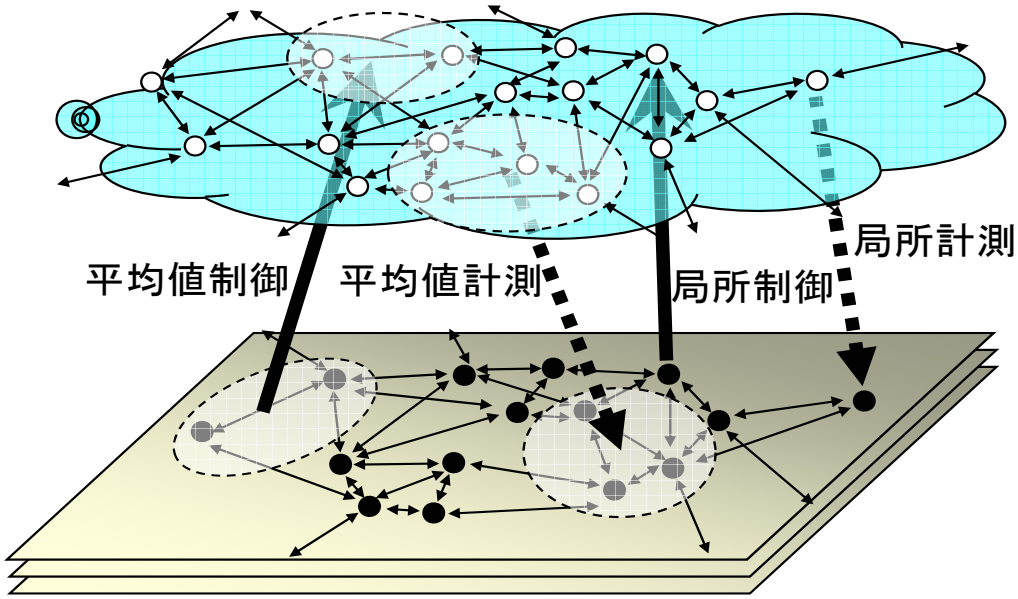
多分解能2重ネットワーク構造に基づくグローバル機能の実現

局所観測・制御による
ヒートアイランド対策

免疫系階層モデルに基づく
疾患状態の制御，．．．

物理ネットワーク（気象，生体，．．．）



グローカル制御システム論

物理NWから動的情報NWへの架け橋（適合性）

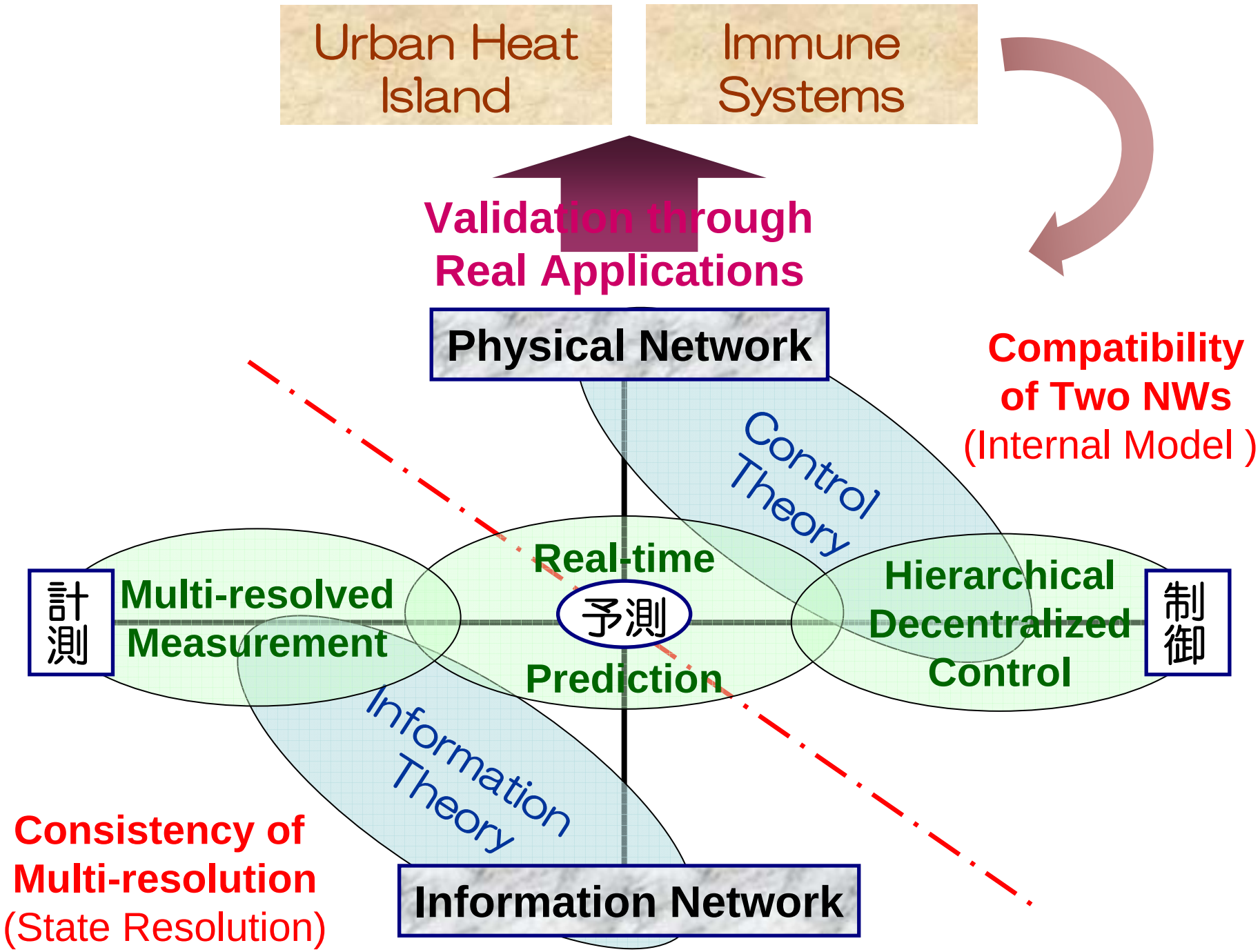
グローカル制御情報論

動的情報NWから物理NWへの架け橋（整合性）

動的情報ネットワーク（計測・予測・制御ネットワーク）

多分解能表現に基づく動的情報ネットワーク設計

- 多分解能計測　－どの分解能でいつどこの何を計測？
- リアルタイム予測－どの分解能でいつどこの何を予測？
- 分散制御　－どの分解能でいつどこの何を制御？


Urban Heat Island
Immune Systems
Validation through Real Applications
Physical Network
Compatibility of Two NWs
(Internal Model)
Control Theory
Real-time
計測
Multi-resolved Measurement
予測
Prediction
Hierarchical Decentralized Control
制御
Information Theory
Consistency of Multi-resolution
(State Resolution)
Information Network

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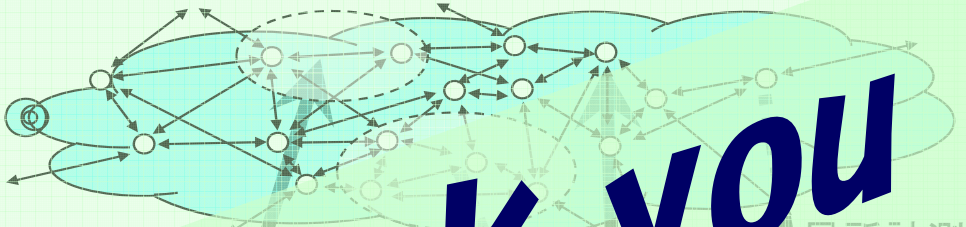

グローカル
制御
システム論

物理NWから
動的情報NW
への架け橋
（適合性）

グローカル
制御
情報論

動的情報NW
から物理NW
への架け橋
（整合性）

Thank you very much !

動的情報ネットワーク（計測・予測・制御ネットワーク）

多分解能表現に基づく動的情報ネットワーク設計

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