02 Robustness, Resilience and Sustainability (Part I)

By NTU Complexity Institute

NANYANG TECHNOLOGICAL UNIVERSITY
SINGAPORE

Dictionary Definitions

Robust

- Dictionary.com
  - Strong and effective in all or most situations and conditions
- Merriam-Webster
  - Capable of performing without failure under a wide range of conditions
- Oxford Dictionaries
  - Able to withstand or overcome adverse conditions

Dictionary Definitions

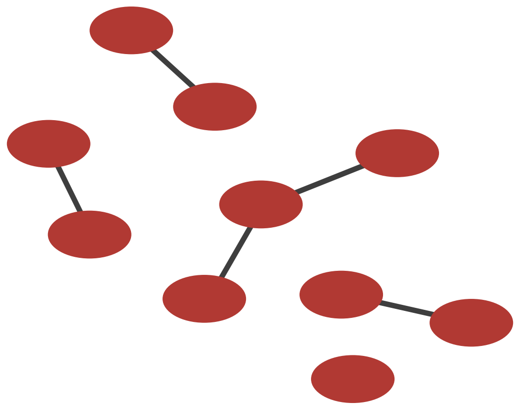
Resilient

- Dictionary.com
  - Returning to the original form or position after being bent, compressed, or stretched
- Merriam-Webster
  - Able to become strong, healthy, or successful again after something bad happens
- Oxford Dictionaries
  - Able to withstand or recover quickly from difficult conditions

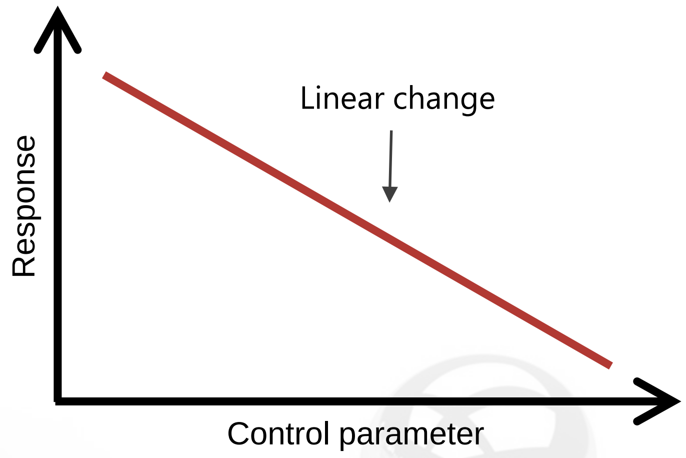
Dictionary Definitions

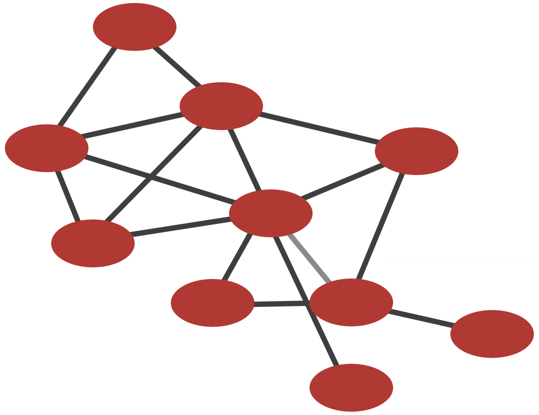
Sustainable

- Dictionary.com
  - Able to be maintained or kept going, as an action or process
- Merriam-Webster
  - Able to be used without being completely used up or destroyed
- Oxford Dictionaries
  - Able to be maintained at a certain rate or level

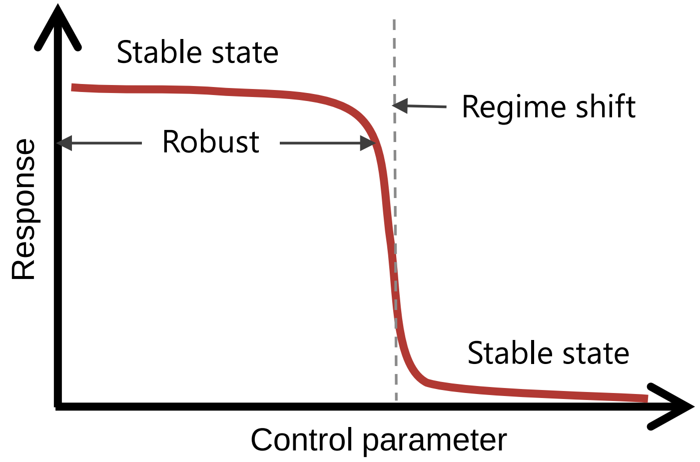


Sparse connectivity

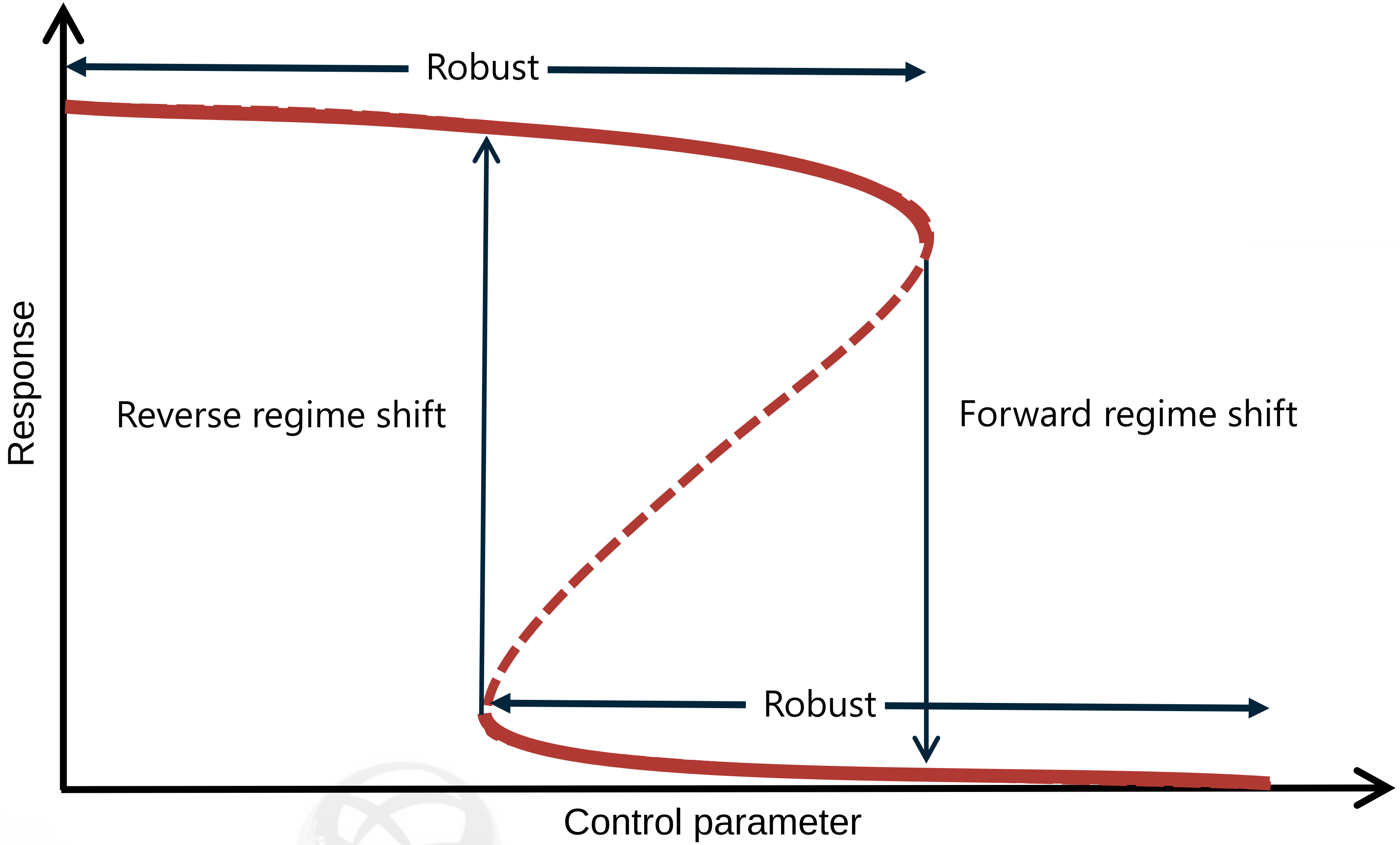




Dense connectivity

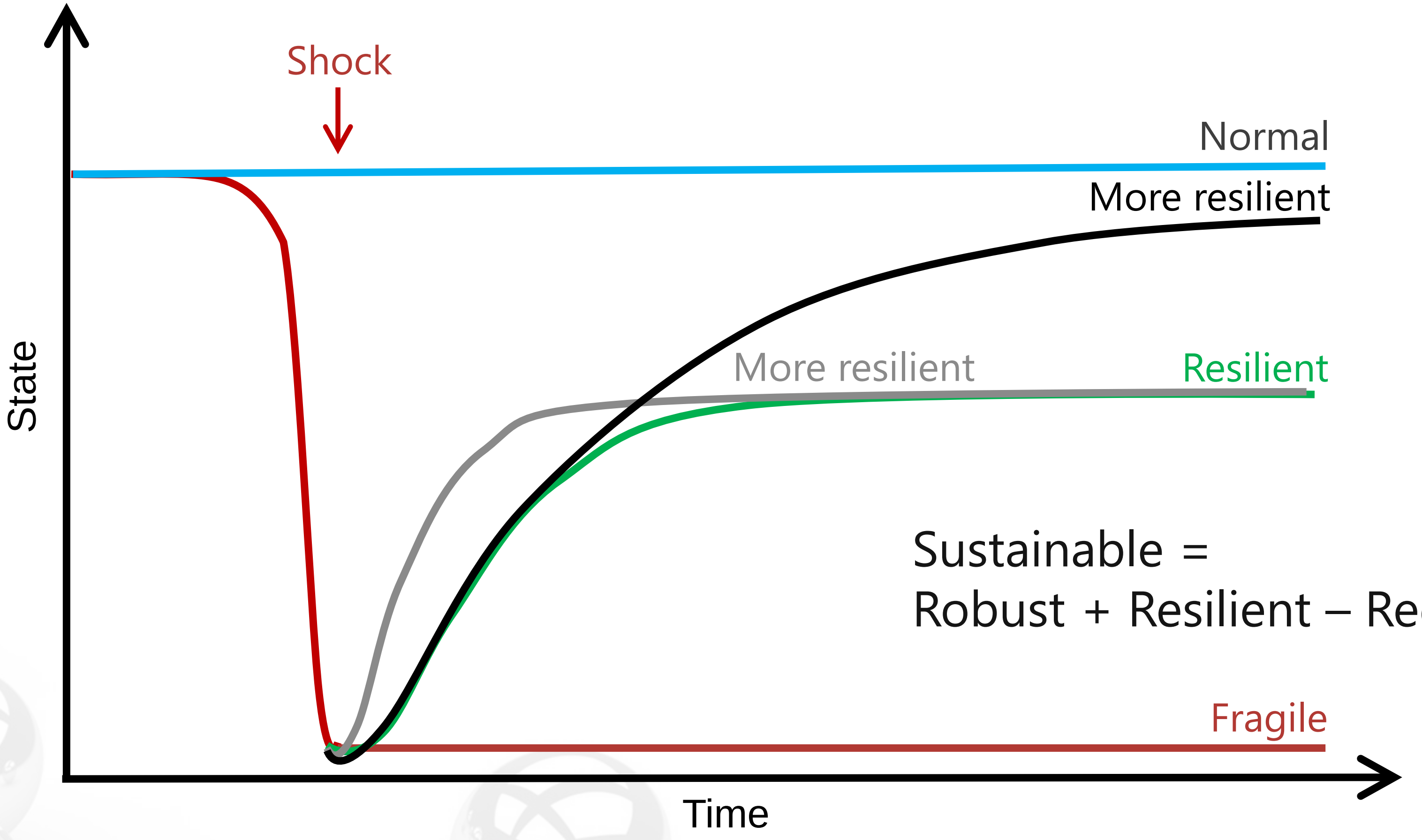


Robustness



Robust
Response
Reverse regime shift
Forward regime shift
Robust
Control parameter

Recovery From Shock



Sustainable =
Robust + Resilient – Regime Shift

William Forster Lloyd
(1794–1852)

Garrett Hardin
(1915–2003)

Tragedy of the Commons

- Grassland = Common-Pool Resource (CPR)
- Renewed at rate α, extracted at rate β
- **Sustainable vs. Unsustainable**

Modelling Considerations

- Cannot consider all variables
  - Mathematically not tractable
- Model only the most important variables
  - Results are still insightful
- Modelling choices include
  - Time-independent (equilibrium) vs. time-dependent (dynamic)
  - Deterministic vs. probabilistic
  - Continuous (differential equations) vs. discrete (agent-based models)

Toy Model of Common-Pool Resource

S (*t*) = CPR level at time *t*

L (*t*) = exploiter population at time *t*

Logistic growth

Consumption

$$\frac{dS}{dt} = \boxed{\alpha S\left(1 - \frac{S}{K}\right)} - \boxed{\beta L S}$$

Renewal rate

Extraction rate

Carrying capacity

$$\frac{dL}{dt} = L\left(\delta + \phi\beta S\right)$$

Intrinsic death rate

Conversion factor

Fixed Points of Toy Model

Fixed Point: $$\frac{dS}{dt} = 0 = \frac{dL}{dt}$$

Trivial Fixed Point: $(S, L) = (0, 0)$ No resource, no extractor **Unstable**

Trivial Fixed Point: $(S, L) = (K, 0)$ Full resource, no extractor **Unstable**

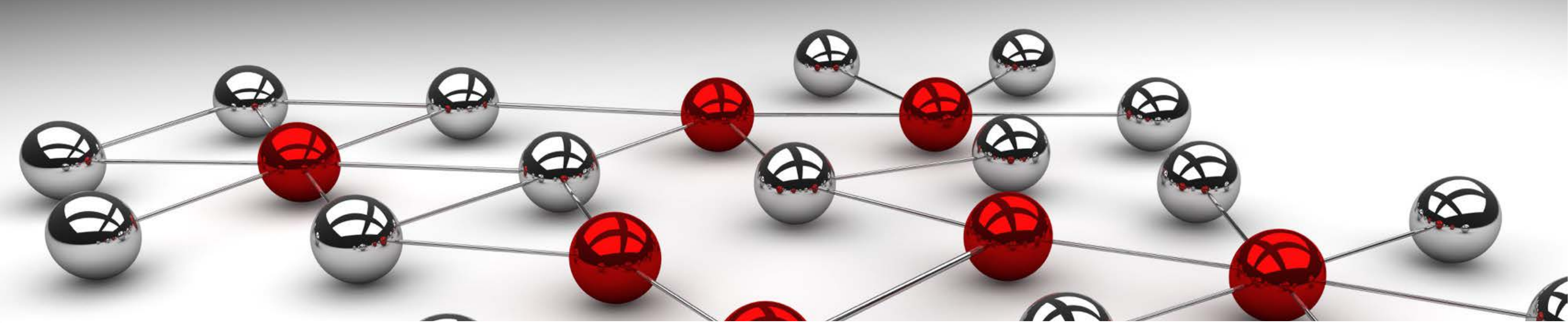
Non-Trivial Fixed Point: $$(S, L) = \left(-\frac{\delta}{\phi\beta}, \frac{\alpha}{\beta}\left(1 + \frac{\delta}{\phi\beta K}\right)\right)$$ **Stable**

Net death with no extraction

Does not always exist

Prisoner's Dilemma

- In a homogeneous group of extractors:
  - What happens if the cooperators are small, i.e. small β, and defectors are large, i.e. large β?
  - Extractors can choose to cooperate or defect
- More defectors result in smaller equilibrium, S
- Increasing proportion of defectors can drive the regime shift from finite-resource state to zero-resource state



02 Robustness, Resilience and Sustainability (Part II)

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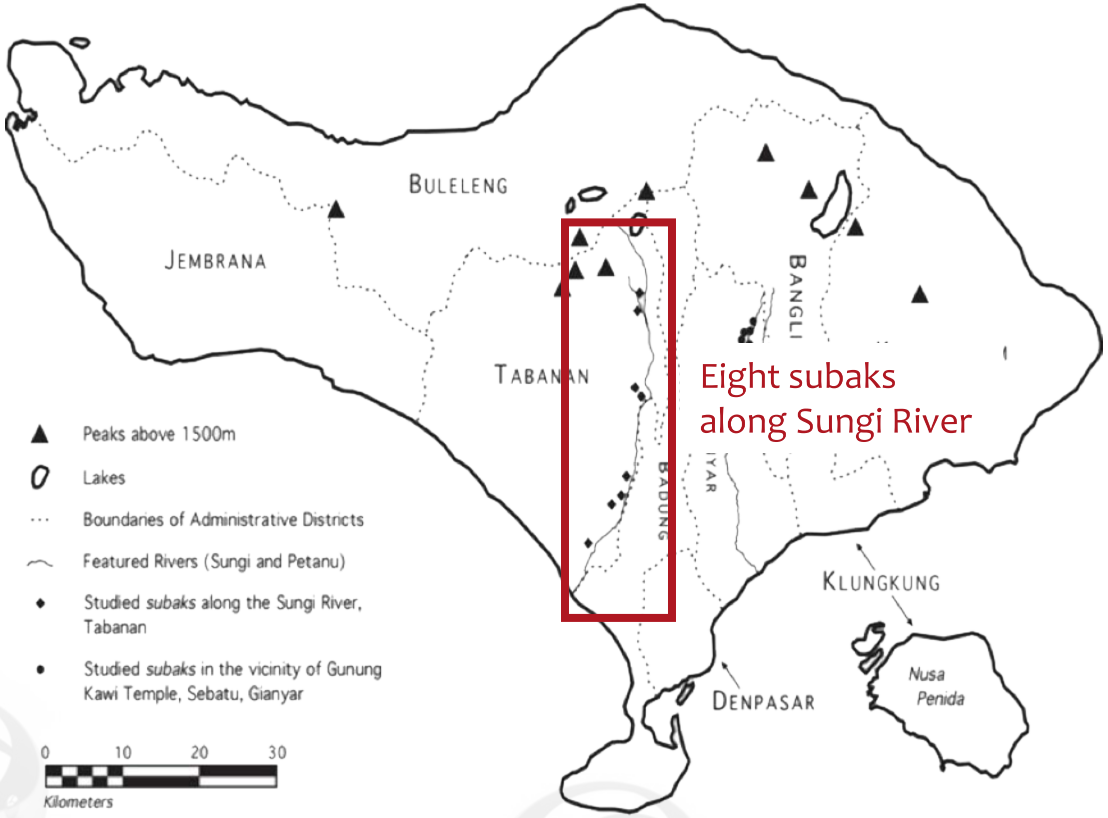
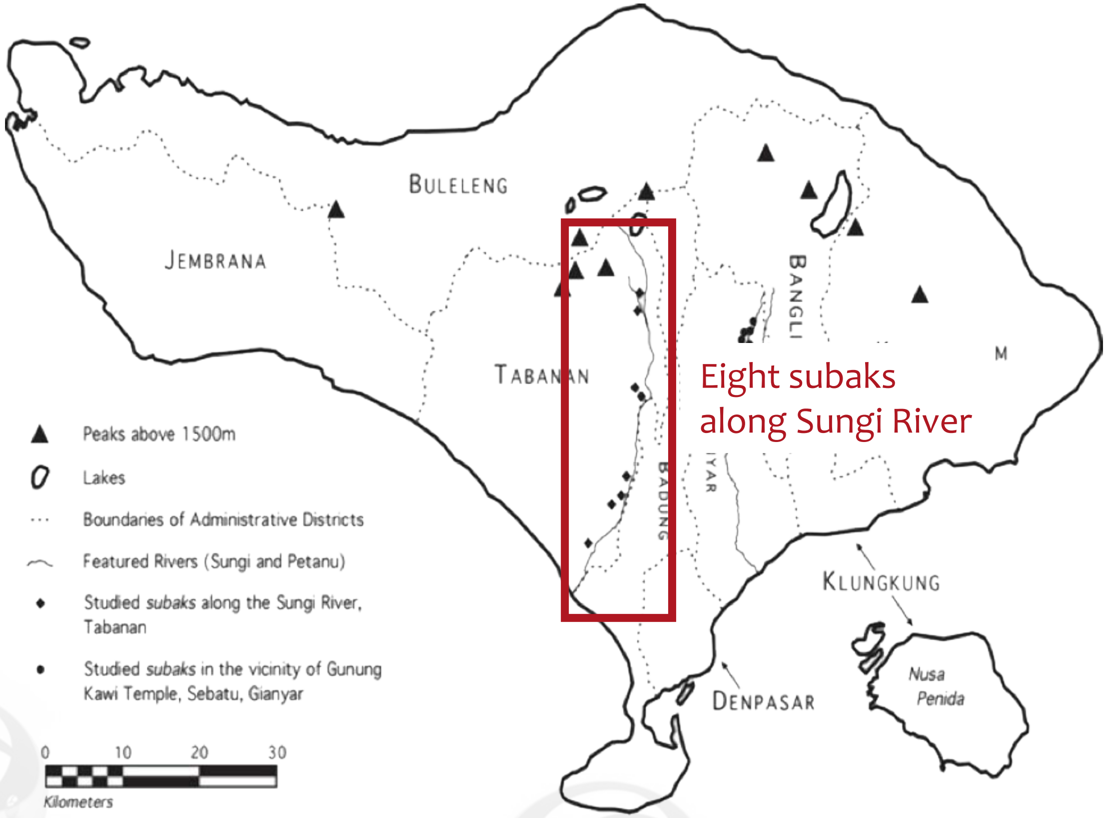
Subak System in Bali



Lansing and Fox. (2011). *Philos Trans R Soc Lond B Biol Sci, 366*(1566), 927-934.

Subak System in Bali



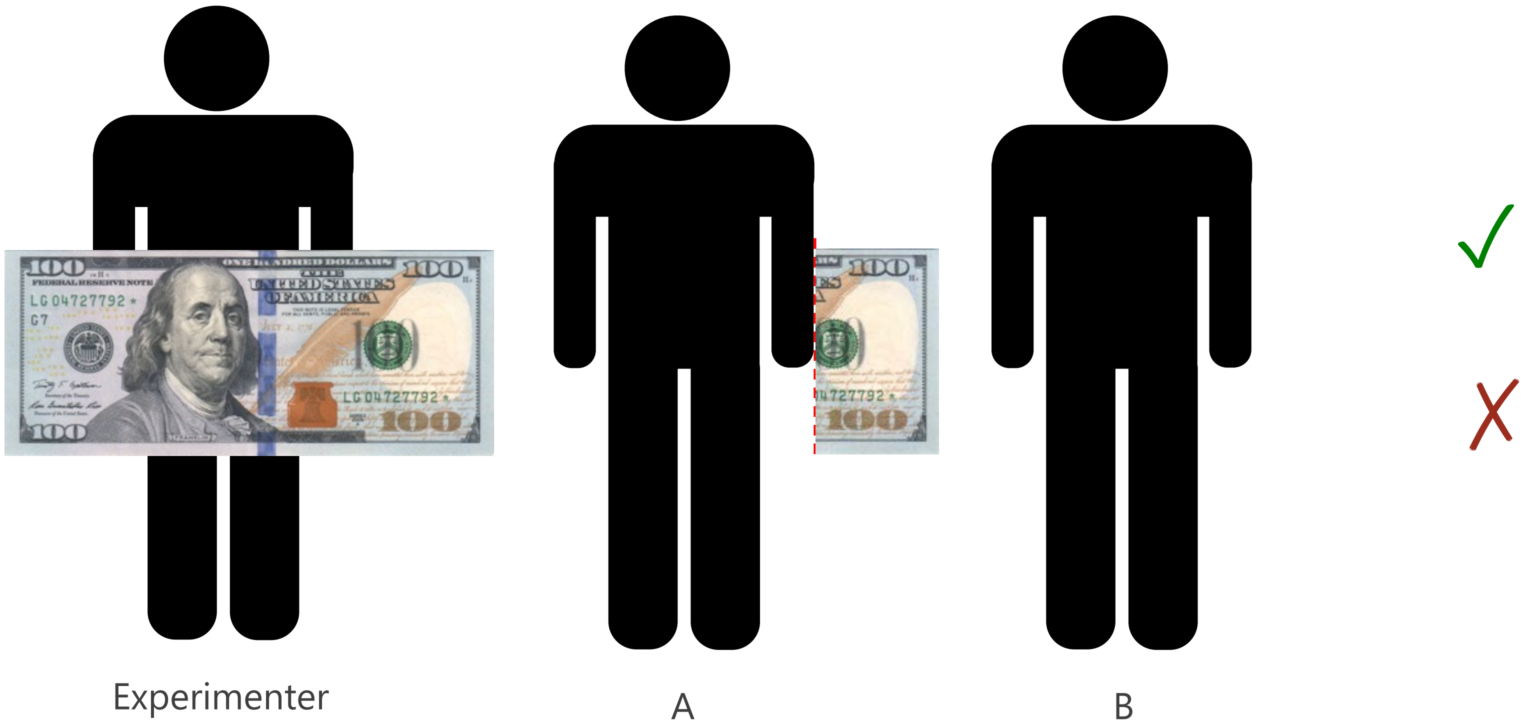
Lansing and Fox. (2011). *Philos Trans R Soc Lond B Biol Sci, 366*(1566), 927-934.

Tri Hita Karana

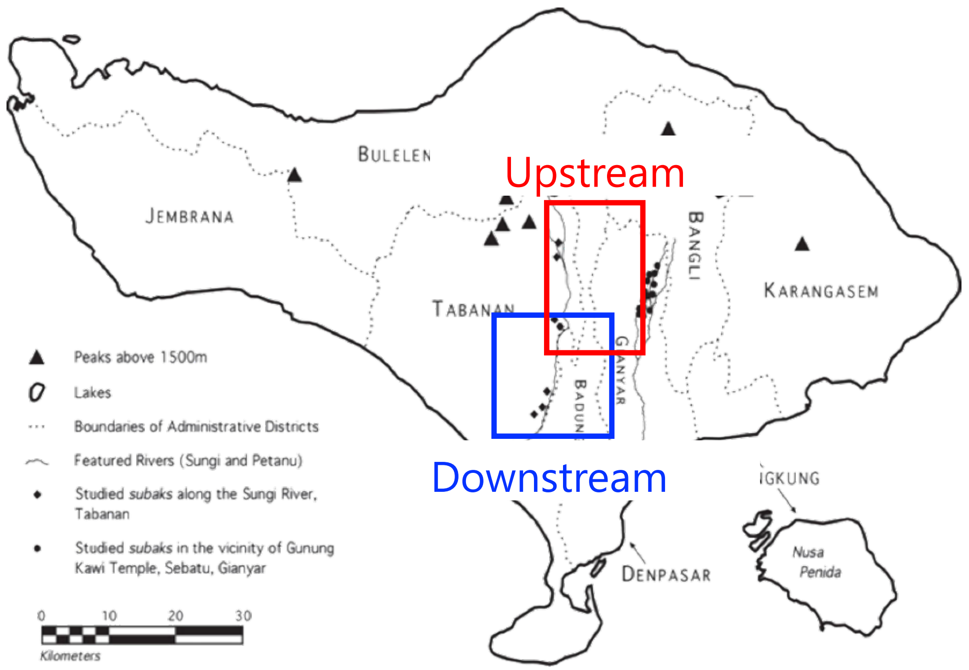
- Harmony between nature, spirit and man
- High levels of cooperation

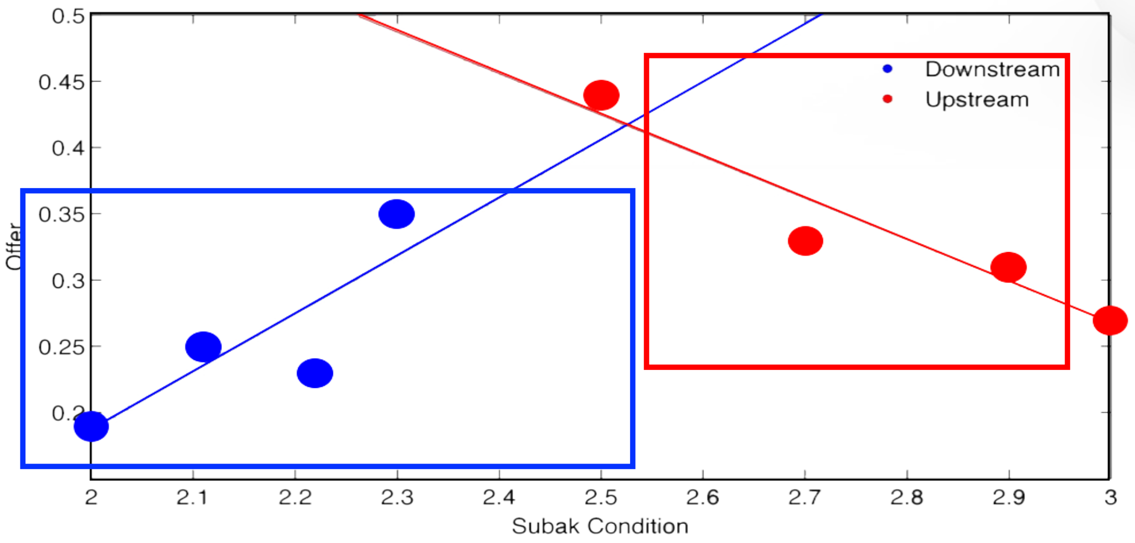
Stephen J Lansing

Ultimatum Game



Ultimatum Game





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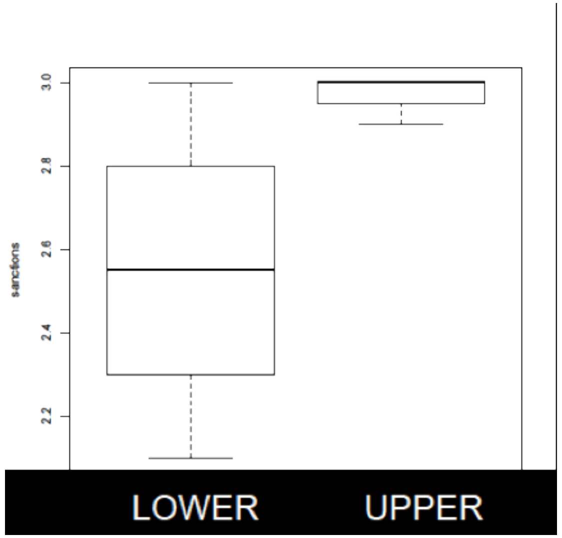
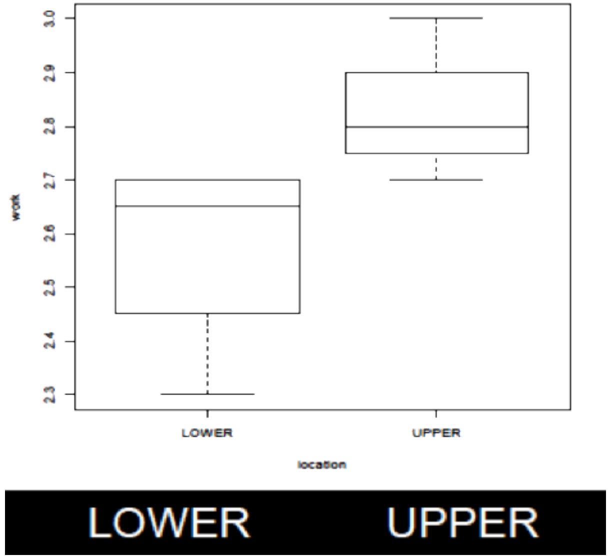
Large-Scale Survey

- 83 farmers, *N*, from each Subak
- Eleven questions on the following were posed:
  - Community structure
  - Farming practices
  - Religious practices
  - Conflict management

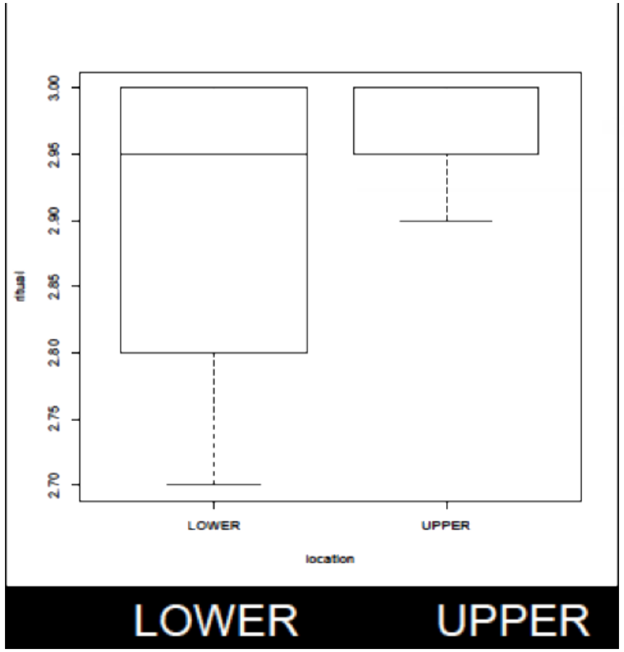
Large-Scale Survey



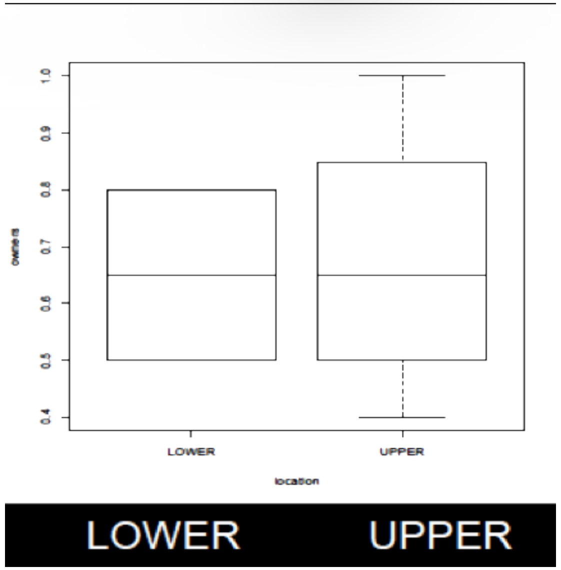
Sanctions



Collective labour

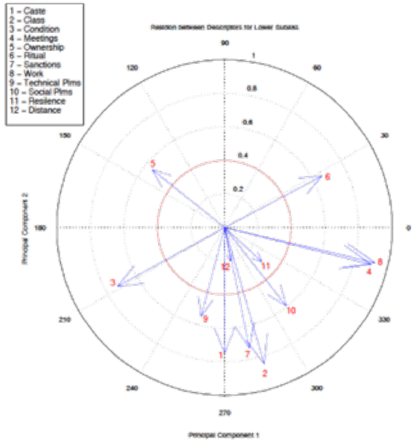


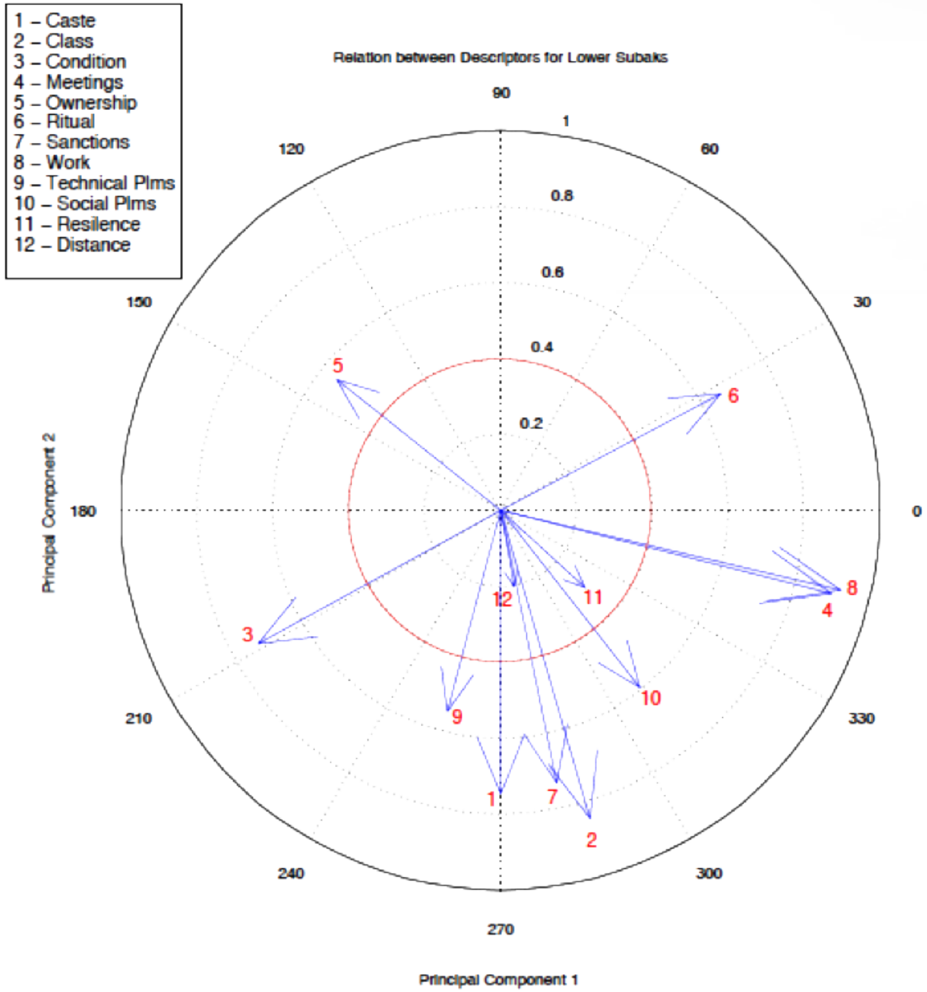
Temple rituals



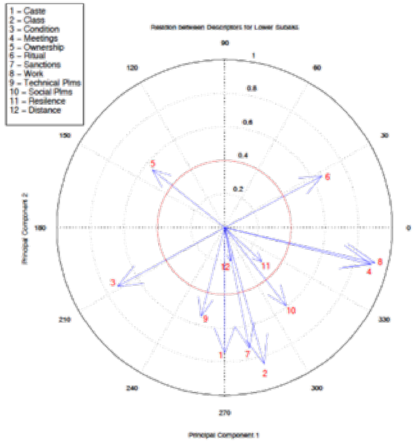
Land ownership

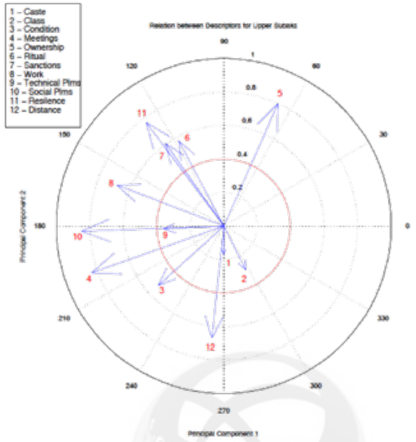
Principal Component Analysis

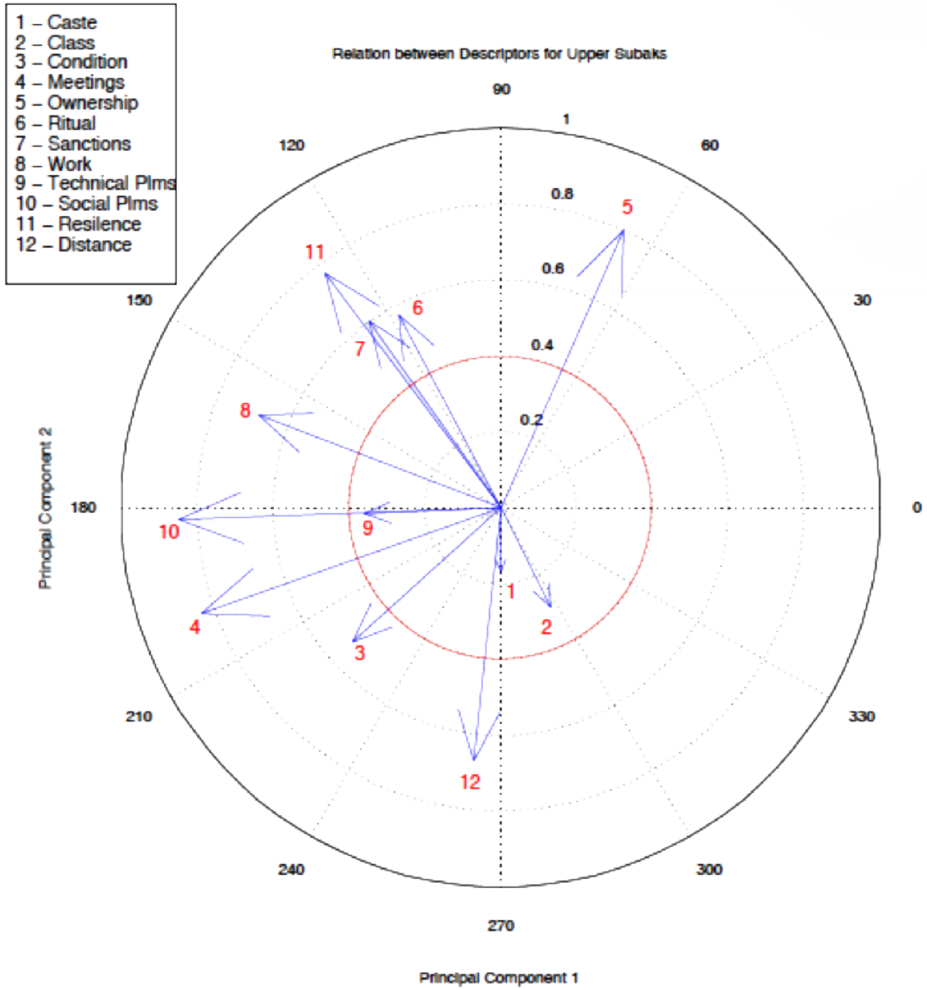




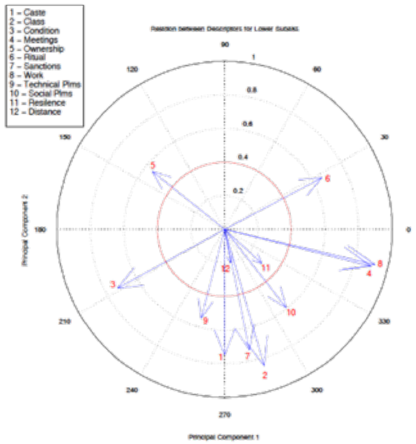
Principal Component Analysis

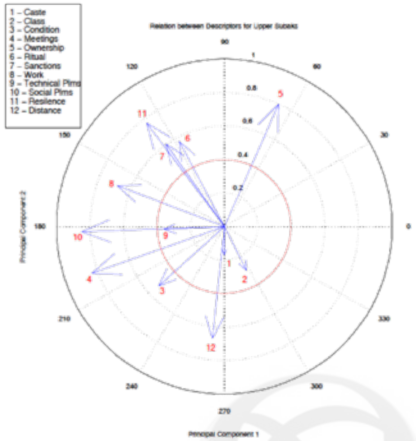


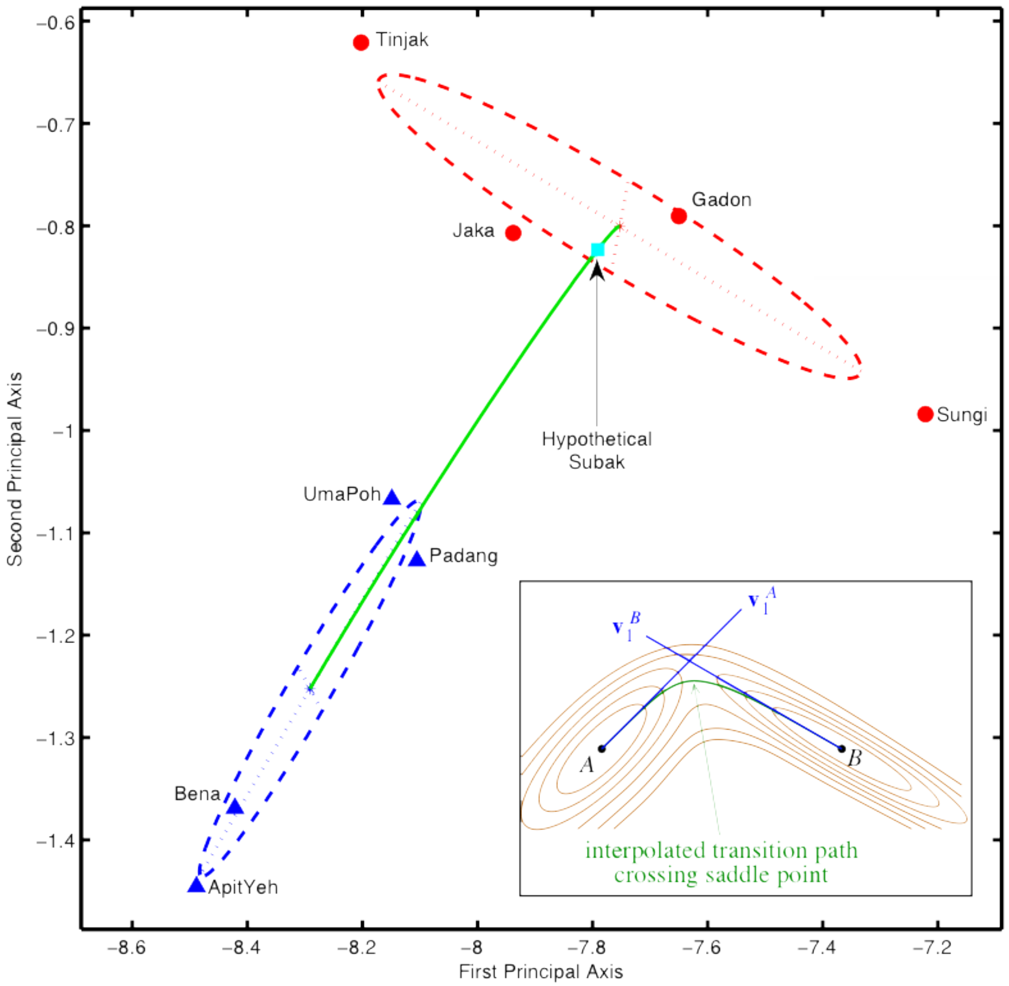




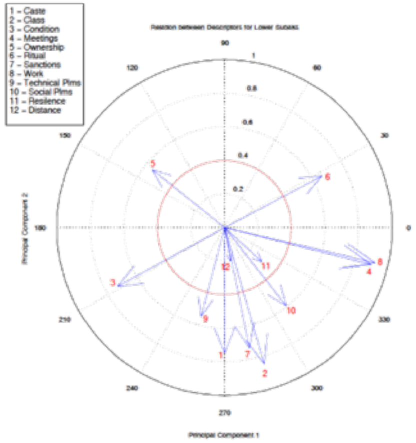
Principal Component Analysis

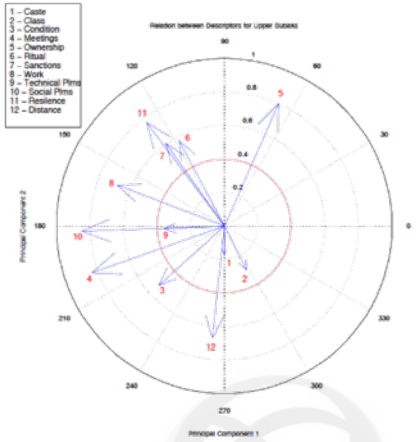


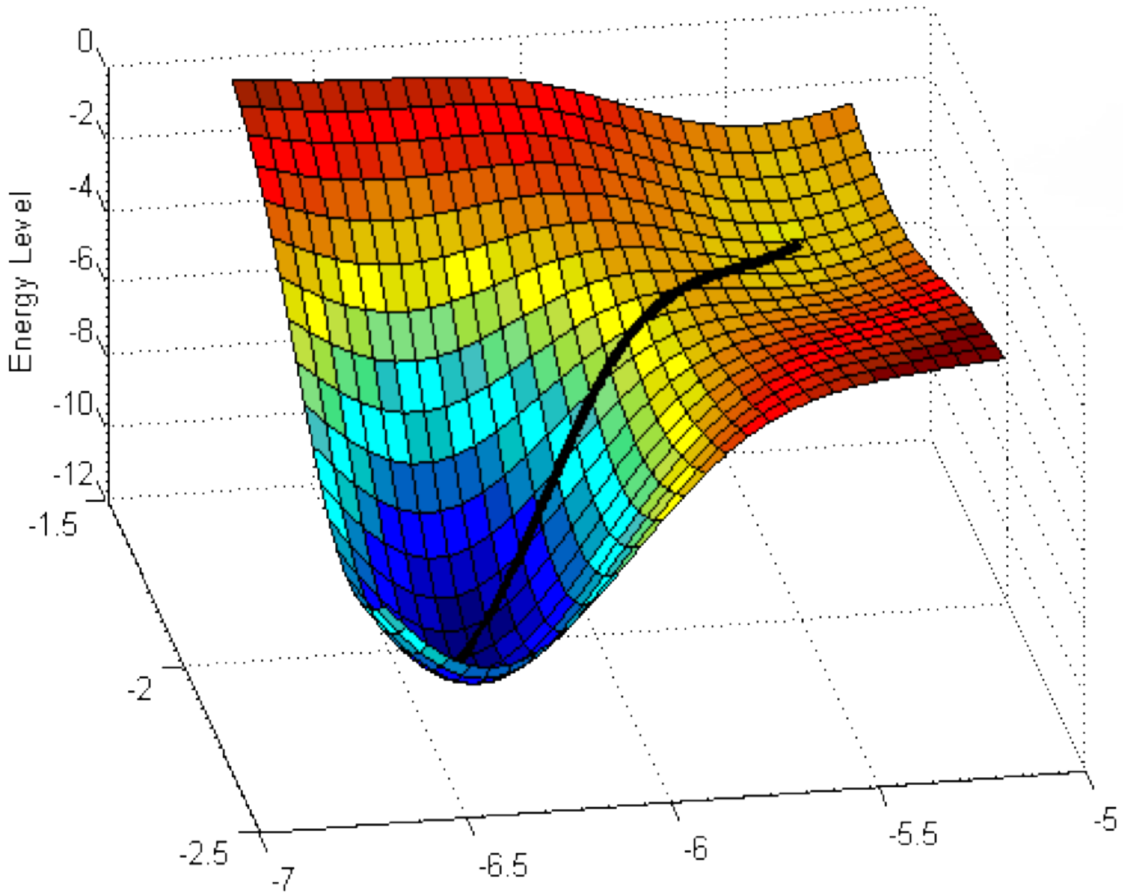




Principal Component Analysis







Tavoni-Schlüter-Levin Model

Hendrik Santoso Sugiarto

Chew Lock Yue

Tavoni-Schlüter-Levin Model

Resource: $R_{t+1} = R_t + c - d\left[\frac{R_t}{R_{\max}}\right]^2 - qE_tR_t$

Resource level

Logistic renewal

Extraction rate

Communal effort: $E = N_c e_c + N_d e_d = N[f_c e_c + (1-f_c)e_d]$

Cooperator effort

Defector effort

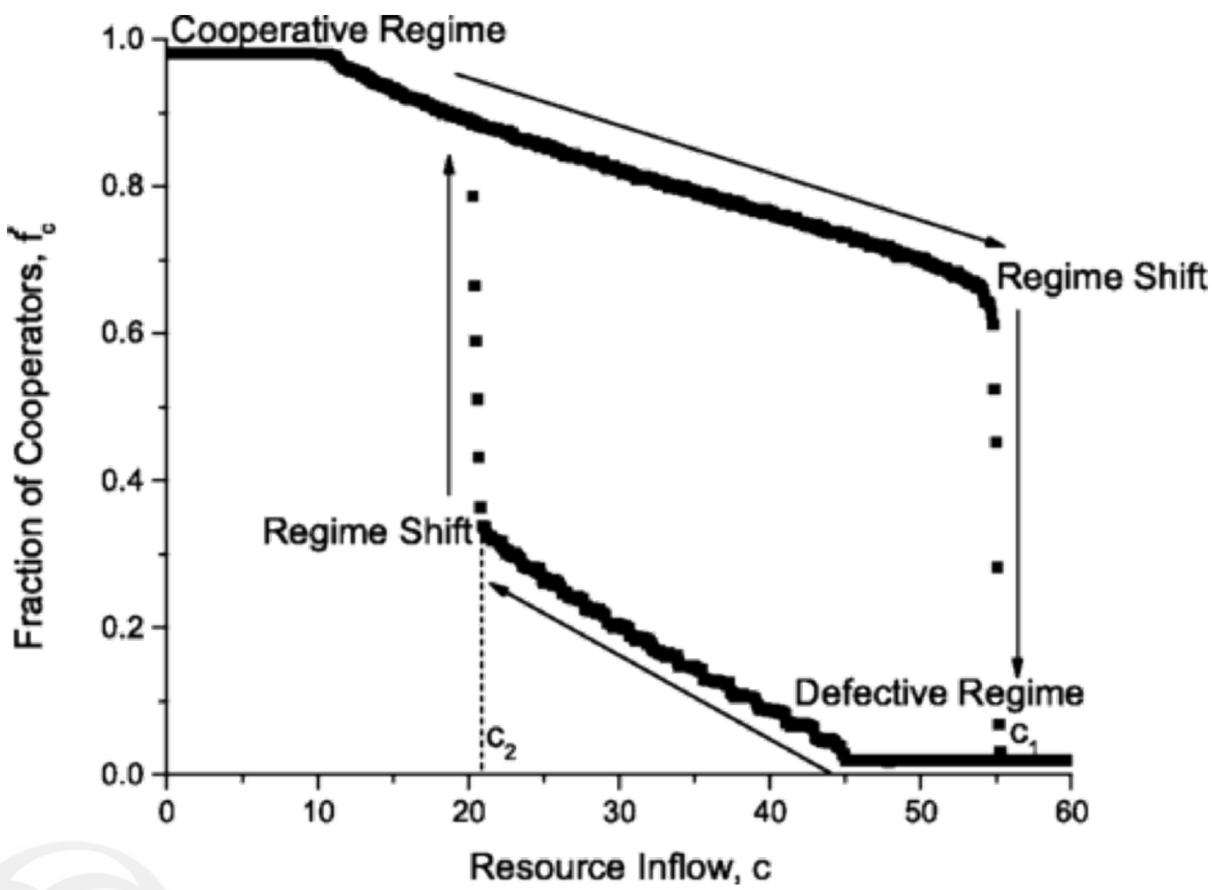
Fraction of cooperators

Payoff: $\pi_c = \frac{e_c}{E}F(E,R) - we_c,$

$$\pi_d = \frac{e_d}{E}F(E,R) - we_d,$$

$$F = \gamma E^\alpha R^\beta, \quad \alpha + \beta < 1$$

Results



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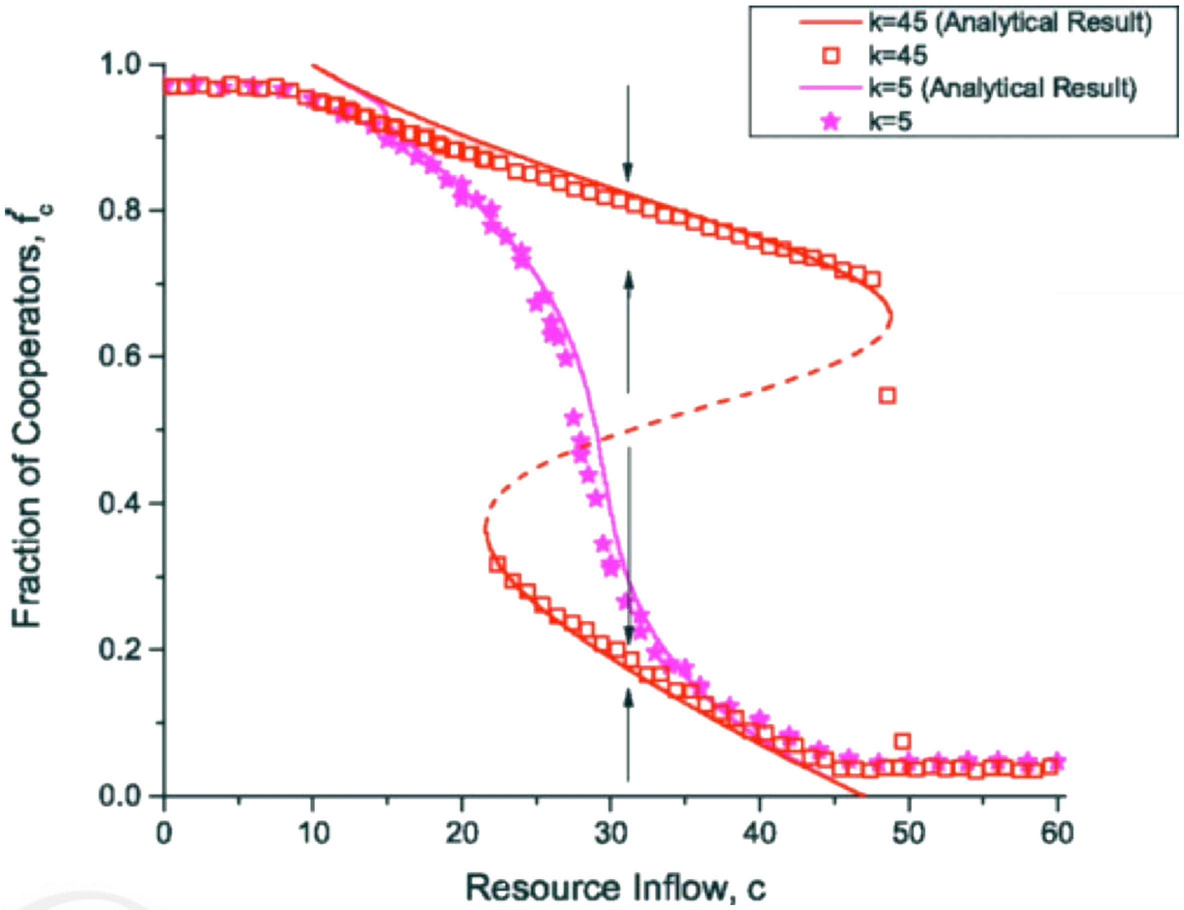
Results



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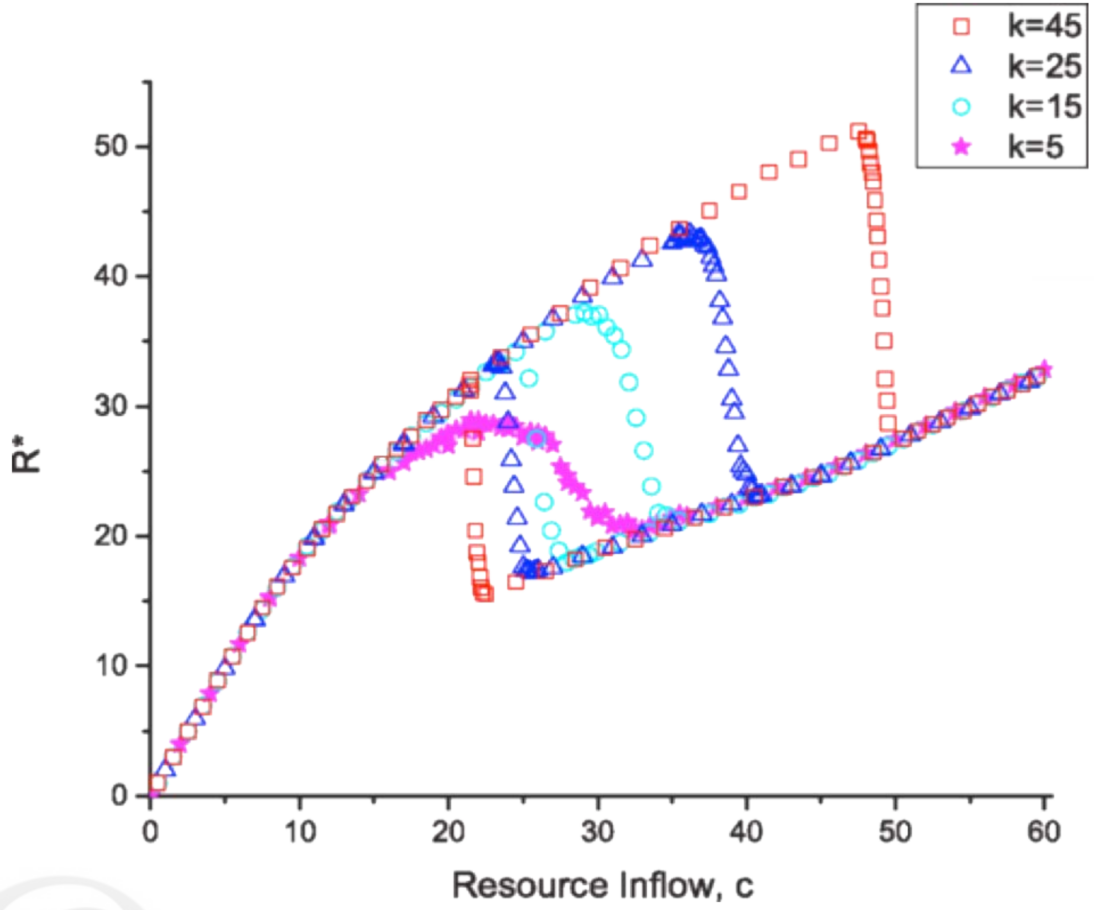

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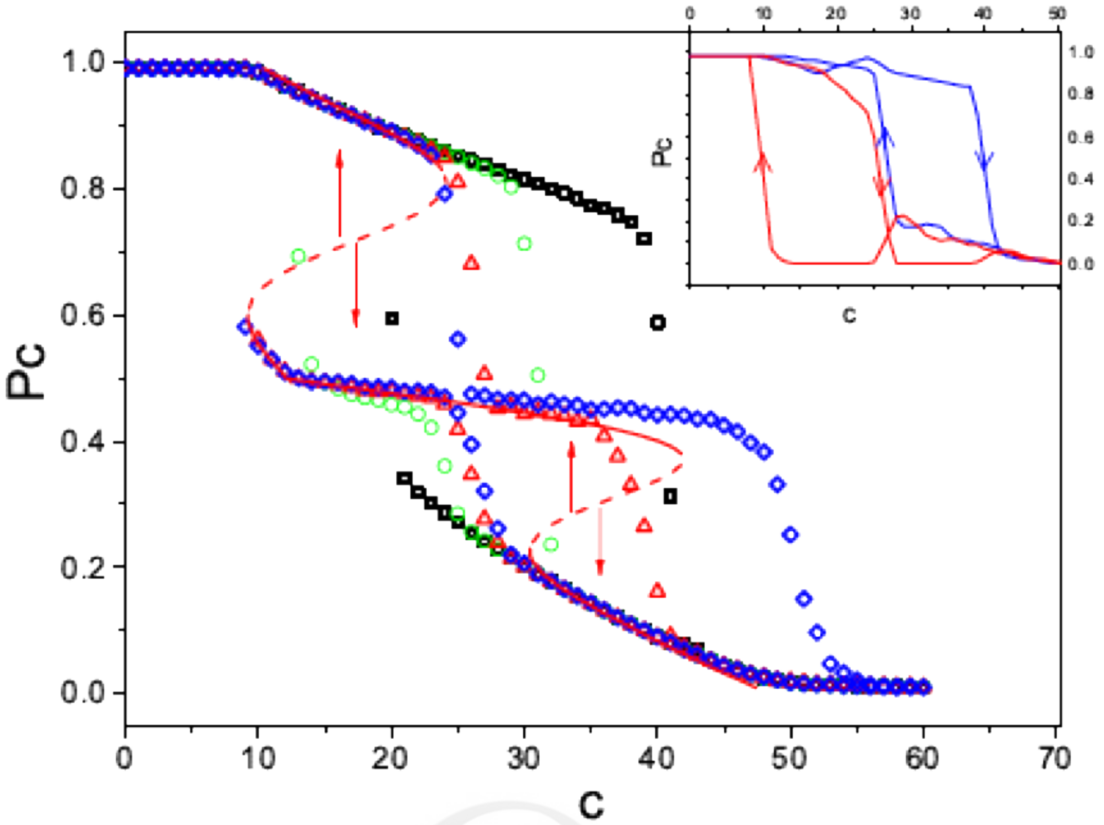

Pc
c
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0.8
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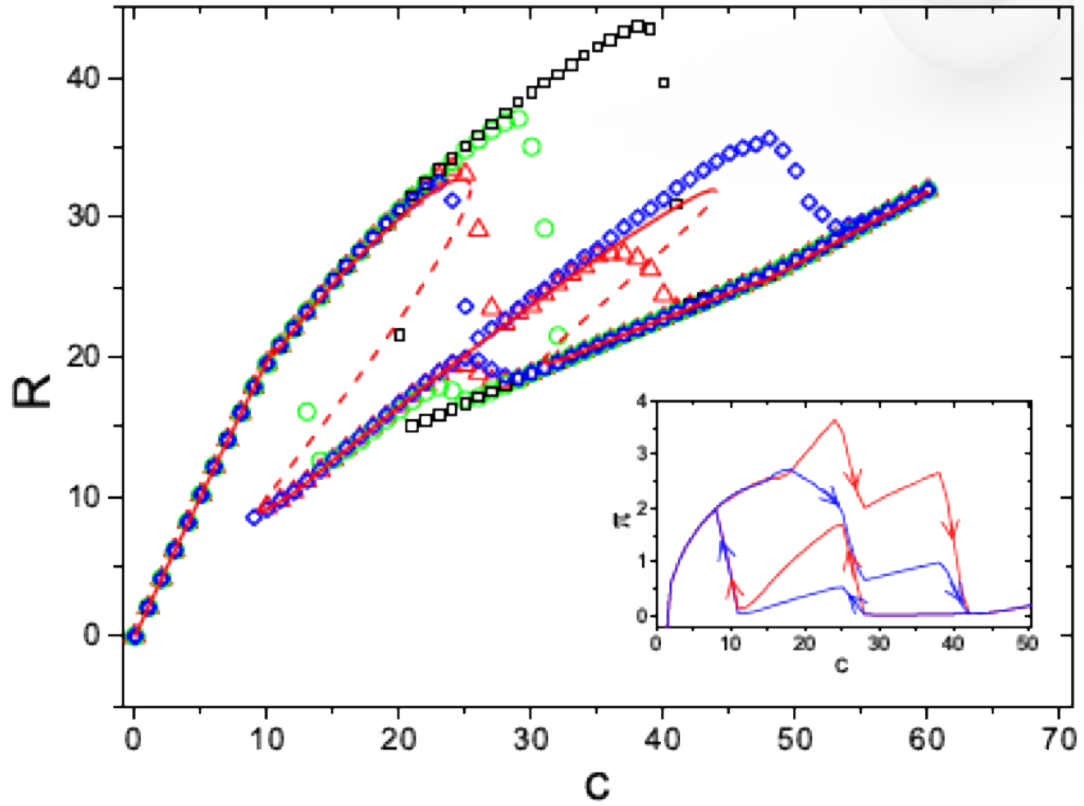

R
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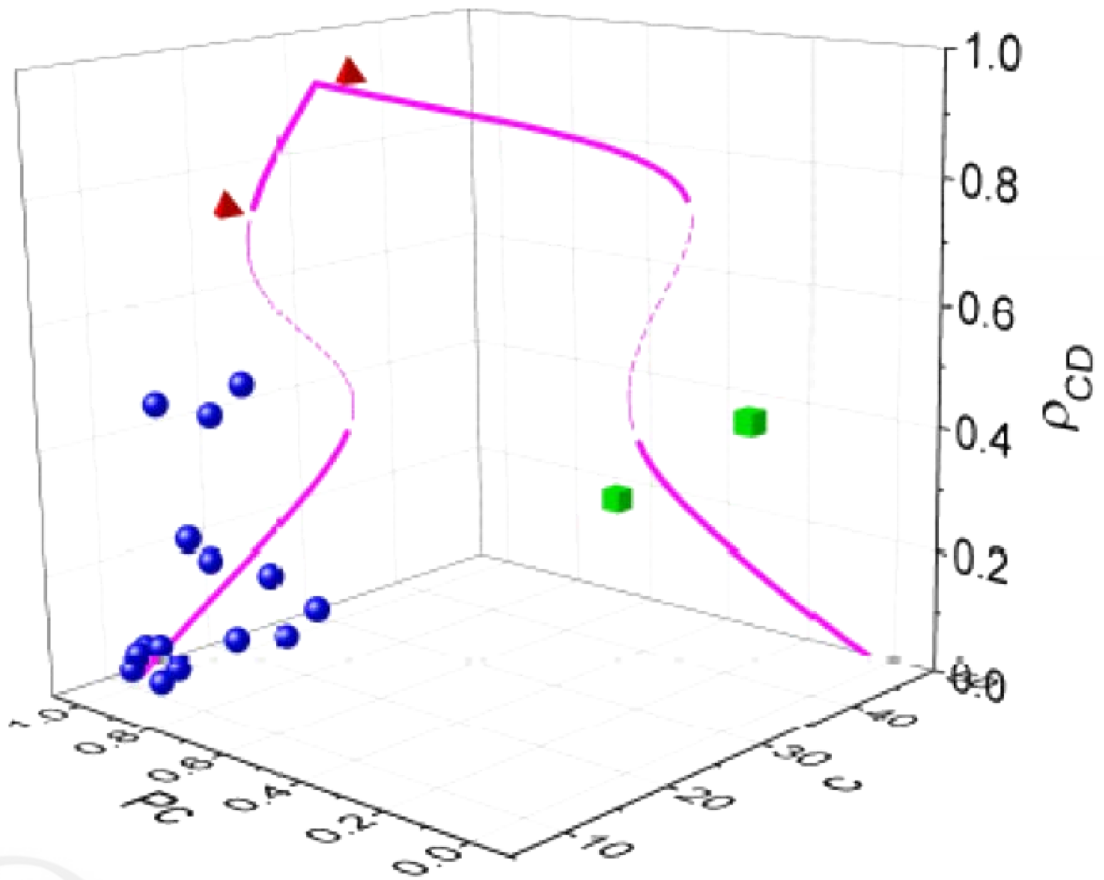
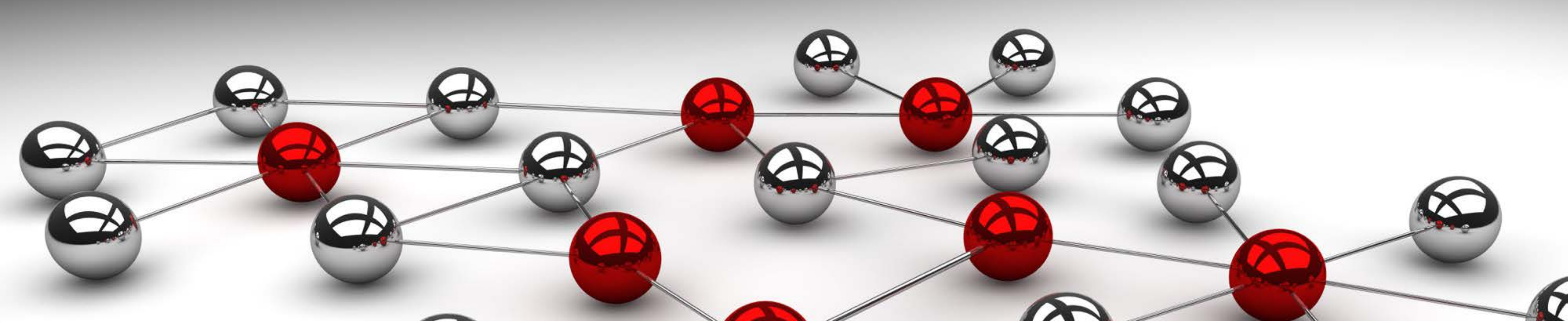
Results





02 Robustness, Resilience and Sustainability (Part III)

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NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE

Resilience of a Swarm

- Reynolds and Boids
  - Swarming is produced by three simple rules:
    - Moving in the same direction as neighbours
    - Staying close to neighbours
    - Avoiding collision with neighbours
- Work by Roland Bouffanais (Assistant Professor, SUTD)
  - Who are neighbours?
  - How big is a neighbourhood?
  - What is *k*-nearest neighbours?

Resilience of a Swarm

- When *k* is small, no swarming is produced. When *k* is large, there is no recovery from shocks.
- In real swarms, *k* is determined by the adaptation to achieve maximum recovery rate, i.e. real swarms are resilient.

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- Slides 22-26: Lansing, J.S., Cheong, S.A., Chew, L.Y., Cox, M.P., Ho, M-H.R. and Arthawiguna, W.A. (2014). *Current Anthropology*, *55*(2), 232-239. doi:10.1086/605344
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