Australian Government
Department of Defence
Science and Technology

Modelling Multi-Domain C2 with network synchronisation: a cyber based use-case

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Overview

- Introduction: Motivation
- The “Kuramoto Model” and C2
- Applications of Kuramoto to C2 to date
- Interaction with the environment: marrying two models
- Modelling Multi-Domain C2
- Cyber attack and structural risk mitigation tests
- Conclusions

Aim and caveats

- To demonstrate that the C2 of a complex scenario of Multi-Domain Operations involving military, government, civilian and cyber activities can be mathematically modelled compactly using Differential Equations.

- The model has not yet been validated. Intention is to demonstrate ‘face validity’ through testing for reasonable behaviours.

- The scenario depicted here is fictitious drawing only upon open source information and common sense.

The Kuramoto Model (1984): application to C2 - ICCRTS 2008

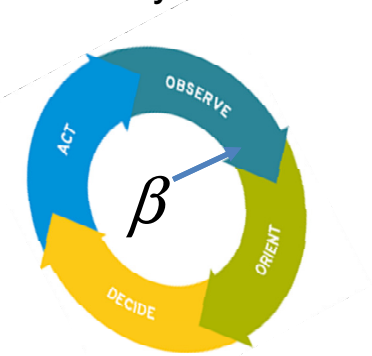
Rate of progress through decision cycle

$$\dot{\beta}_i(\mathrm{t}) = \omega_i + \sigma \sum_{i=1}^{N} A_{ij} \sin(\beta_j(t) - \beta_i(t))$$

Frequency of decision-making when left to self.

Tightness of Organisational Coupling

Organisational Interactions

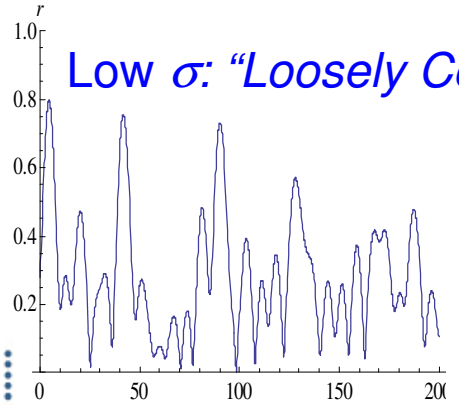


Formulation as full *stochastic* D.E. with HQ C2 data:

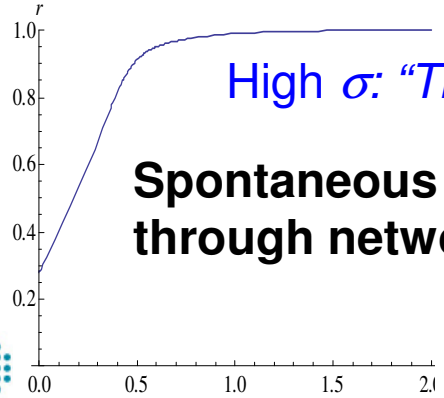
Kalloniatis, McLennan-Smith & Roberts, European J O.R. (In Press)

Measure of synchronisation:

$$r(t) = \frac{1}{N}\left|\sum_j e^{i\beta_j(t)}\right|$$



Low σ: *"Loosely Coupled"*

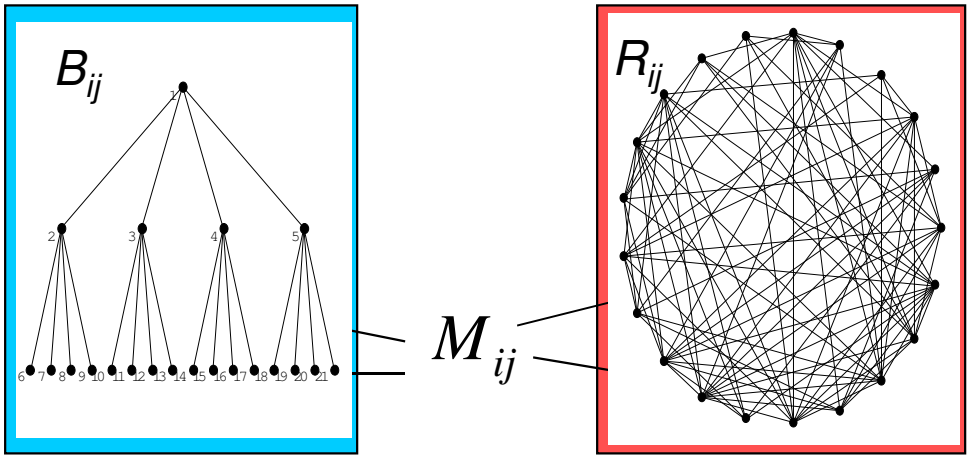


High σ: *"Tightly Coupled"*

Spontaneous synchronisation through network interactions

Kuramoto application I: Blue-vs-Red - ICCRTS 2012

- Represent adversarial C2 relationships to reflect Boyd's decision advantage strategy



'Frustrations' (cf Cond. Matt.)

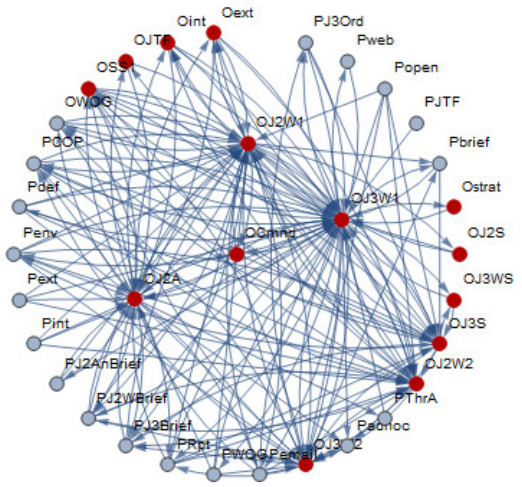
$$\dot{\beta}_i = \omega_i + \sigma_B \sum_{j \in \mathcal{B}} \mathcal{B}_{ij} \sin(\beta_j - \beta_i) + \zeta_{BR} \sum_{j \in \mathcal{R}} \mathcal{M}_{ij} \sin(\rho_j + \phi - \beta_i), \quad i \in \mathcal{B}$$

$$\dot{\rho}_i = \nu_i + \sigma_R \sum_{j \in \mathcal{R}} \mathcal{R}_{ij} \sin(\rho_j - \rho_i) + \zeta_{RB} \sum_{j \in \mathcal{B}} \mathcal{M}_{ij} \sin(\beta_j + \psi - \rho_i), \quad i \in \mathcal{R}.$$

Boyd:
Blue seeks to be ϕ ahead of Red;
Red seeks to be ψ ahead of Blue.

Kuramoto Application 2: Modelling Sociotechnical Systems - ICCRTS 2016

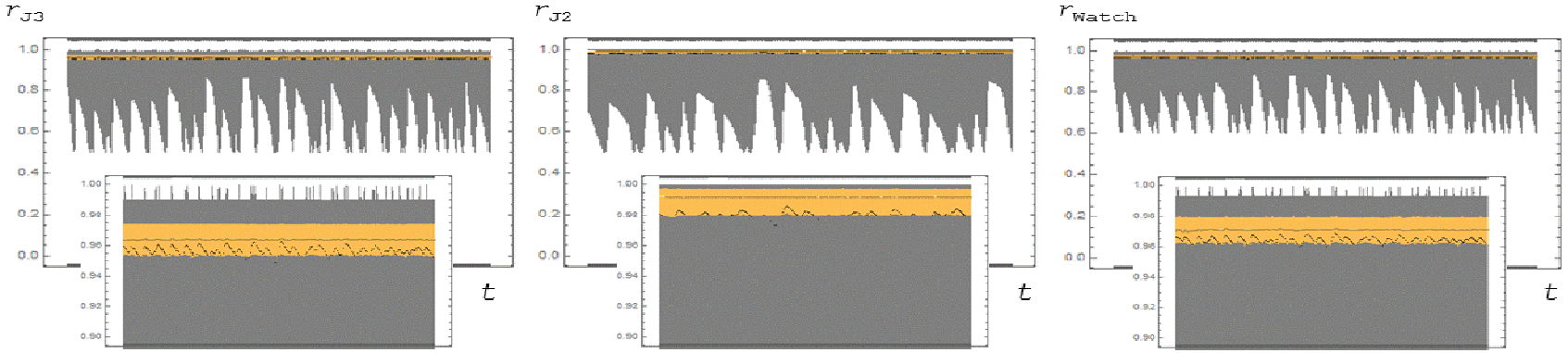
- Represent J2, J3 and Command staff interacting with information artefacts in maintaining SA and responding to crises



Based on data collected in ADF – see *Kalloniatis et al Applied Ergonomics 2017*

Measure degree of synchronisation of sub-organisations:

People
Products



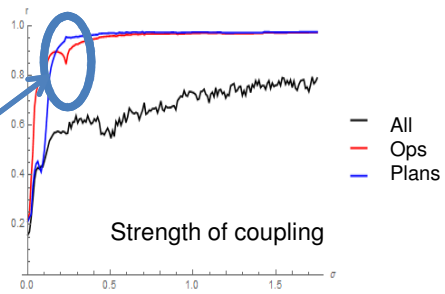
Kuramoto Application 3: Nested Decision cycles - ICCRTS 2017

- Unify slower operational planning cycles with faster reactive operational execution cycles

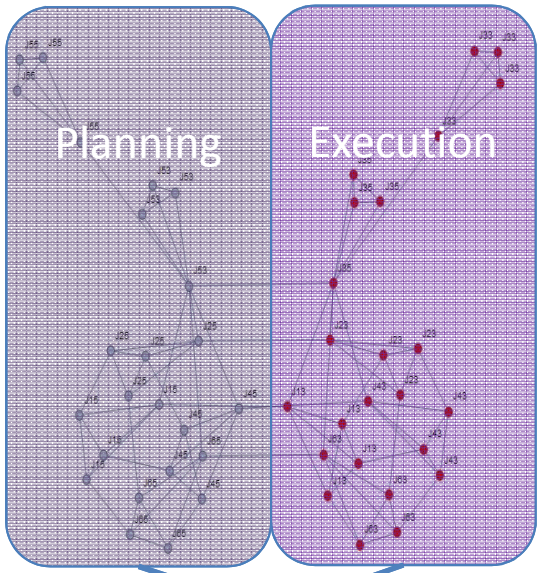
$$\dot{\theta}_i^{Ops} = \omega_i^{Ops} + \sigma \sum_{j \in fast} A_{ij} \sin(\theta_j^{Ops} - \theta_i^{Ops}) + \sigma \sum_{j \in slow} A_{ij} \sin(n\theta_j^{Plans} - \theta_i^{Ops})$$

$$\dot{\theta}_i^{Plans} = \omega_i^{Plans} + \sigma \sum_{j \in fast} A_{ij} \sin(\theta_j^{Plans} - \theta_i^{Plans}) + \sigma \sum_{j \in slow} A_{ij} \sin(\theta_j^{Ops} - n\theta_i^{Plans}).$$

Degree of Synchronisation of sub-organisations



Branches are not 'optimal' at some point – network can influence this



$$\omega_{fast} = n * \omega_{slow}$$

Unifying C2 and Combat – MORS2018

- Kuramoto

$$\dot{\beta}_i(t) = \omega_i + \sigma \sum_j B_{ij} \sin(\beta_j(t) - \beta_i(t))$$

Blue C2 system

$$\dot{\rho}_i(t) = \nu_i + \sigma \sum_j R_{ij} \sin(\rho_j(t) - \rho_i(t))$$

Red C2 system

- Synchronisation

$$r_B(t) = \frac{1}{N}\left|\sum_j e^{i\beta_j(t)}\right|$$

$$r_R(t) = \frac{1}{N}\left|\sum_j e^{i\rho_j(t)}\right|$$

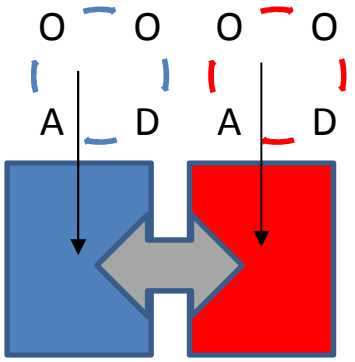
- Lanchester

$$\dot{B}(t) = r_B(t)B(t) - r_R(t)R(t)$$

$$\dot{R}(t) = r_R(t)R(t) - r_B(t)B(t)$$

Resupply

Attrition



C2 capability ***sits over*** the combat force

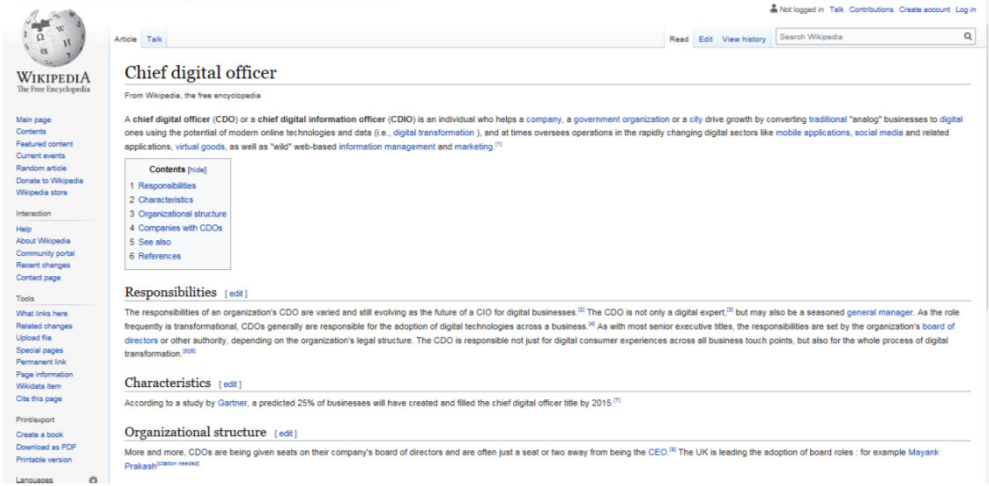
C2 as Force Multiplier

Good C2 ⇒ Good resupply of own and good firepower on adversary

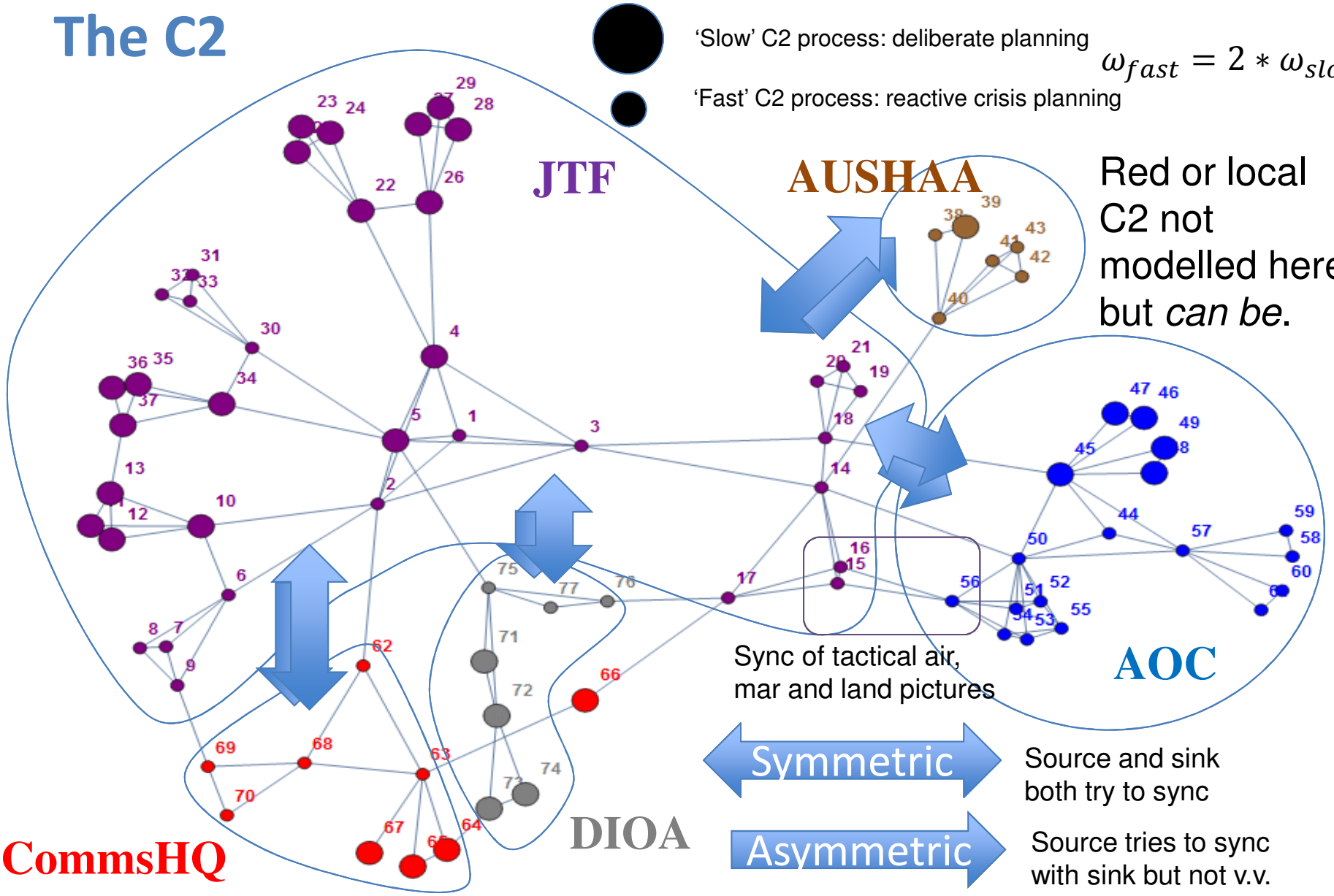
The organisations -

- Joint Task Force (JTF) – organised on Common Joint Staff System lines
- Air Operations Center (AOC) – see Wikipedia
- Communications HQ (CommsHQ) – fictitious NSA/GCHQ like
- Digital Information Officer Agency (DIOA)
- Australian Humanitarian Assistance Agency (AUSHAA) – fictitious

The scenario depicted here is a work of fiction; organisations, roles and processes are either the products of the author's imagination or used in a fictitious manner; any resemblance to actual organisations, roles or processes is purely coincidental



The C2



'Slow' C2 process: deliberate planning

'Fast' C2 process: reactive crisis planning

$$\omega_{fast} = 2 * \omega_{slow}$$

Red or local C2 not modelled here, but *can be*.

Modelling the civil-military dimension

- Blue and Red engage militarily: internal synchronisation enhances performance in combat.

$$\begin{cases} \dot{B}(t) = -\kappa_R r_R R(t), \\ \dot{R}(t) = -\kappa_B r_{Tact}(t) B(t), \end{cases}$$

$$\dot{L}(t) = \rho_L r_{MD}(t) L(t) - \kappa_B (1 - r_{Tact}(t)) B(t)$$

- Humanitarian assistance agency supports local population: synchronisation with military authorities enables deconfliction between humanitarian and military activities.

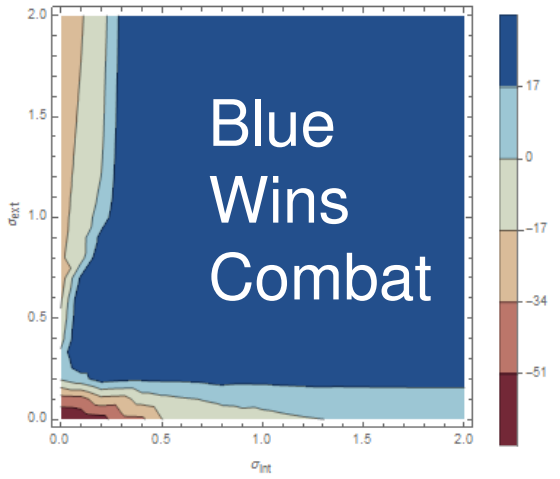
- Poor Blue force military synchronisation inflicts collateral damage.

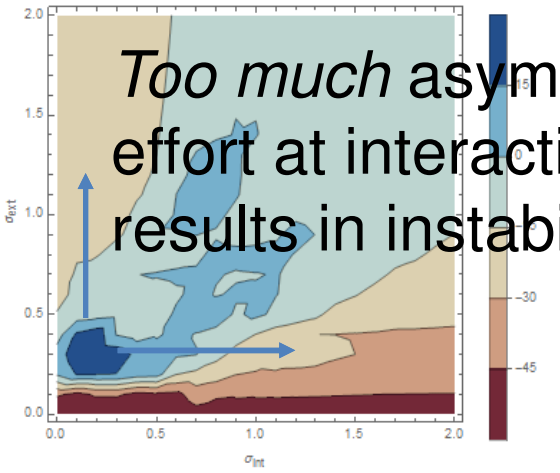
Model outputs – baseline performance

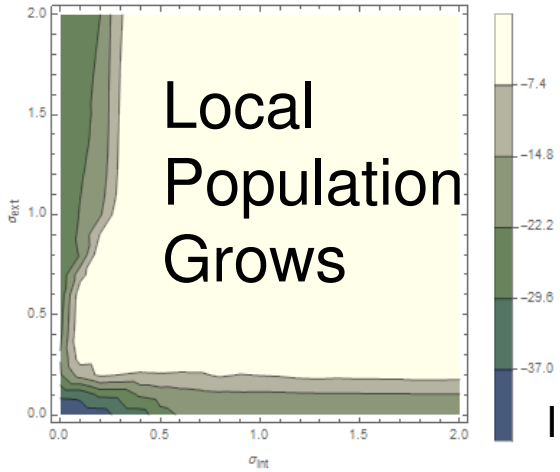
Compute solution until one of Blue or Red hit zero.

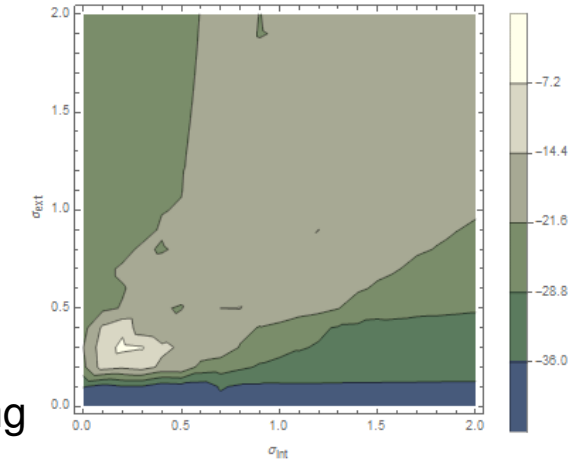
Symmetric

Asymmetric







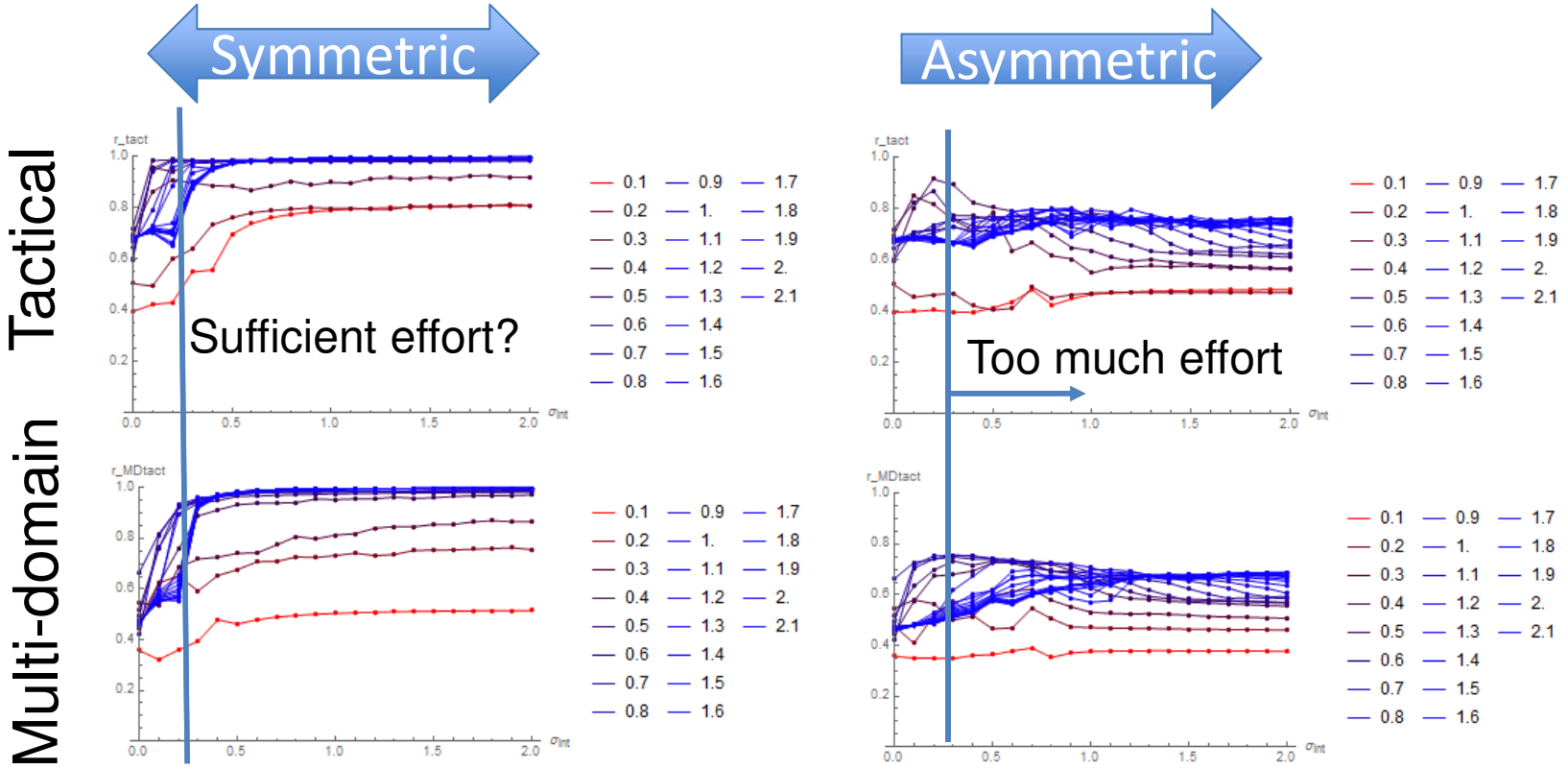


Ext. Coupling

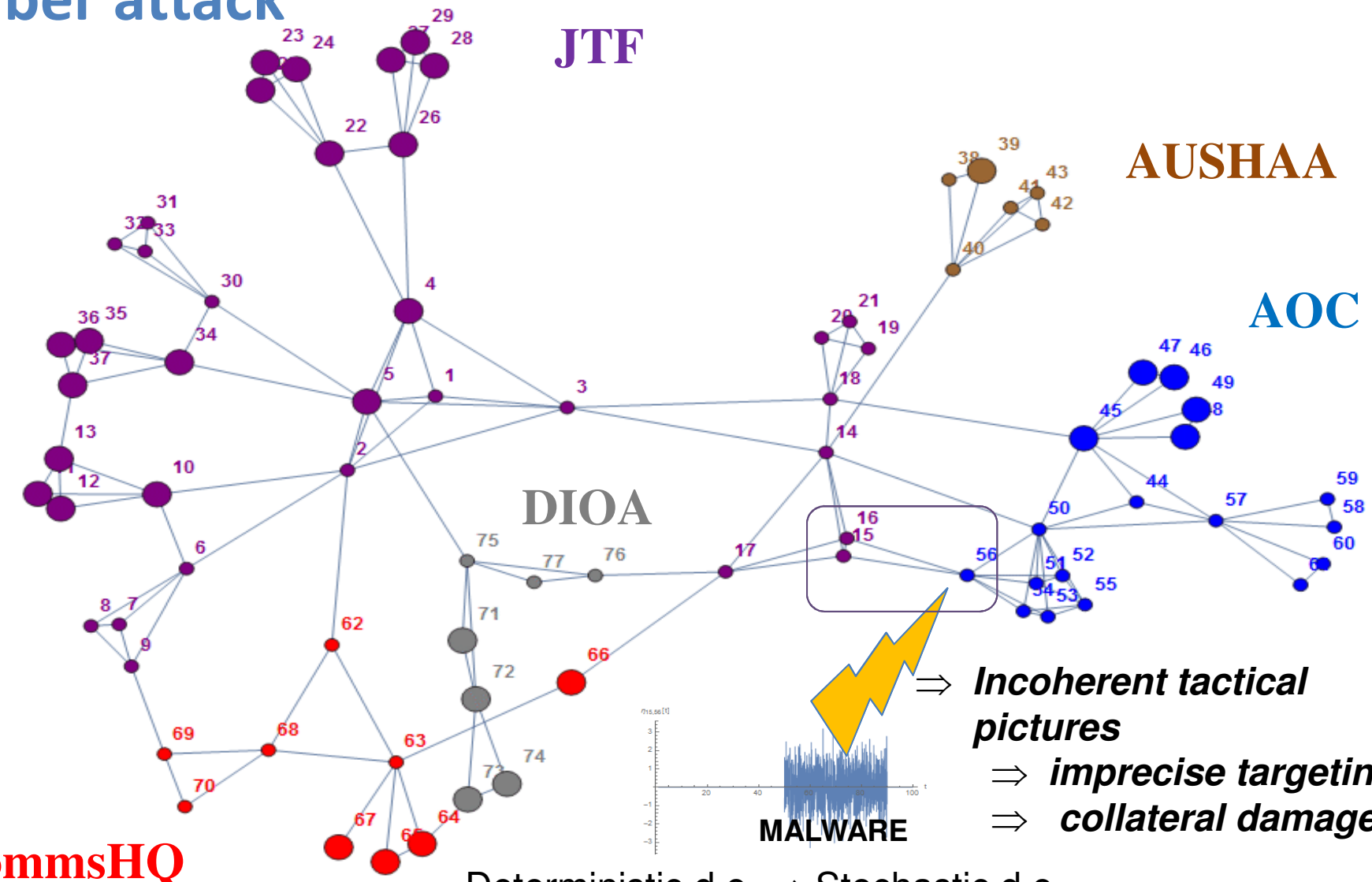
Int. Coupling

‘C2 Harmony’ (NATO SAS-143) – a Synchronisation definition

… the regions in coupling where <u>all</u> C2 actors across their domains of interaction have <u>mutually</u> <u>high</u> levels of (time-av) <u>synchronisation</u>

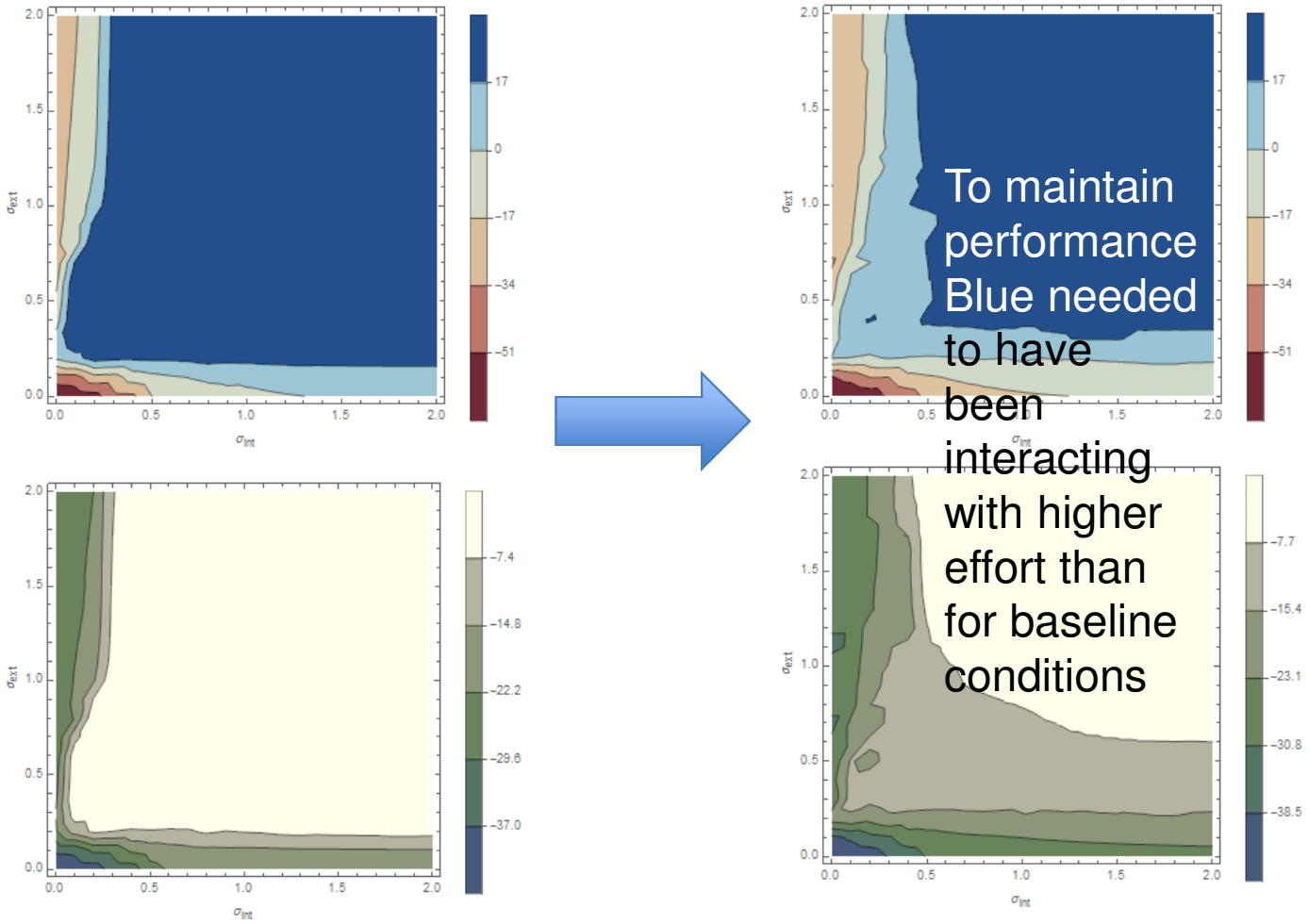


Cyber attack



Deterministic d.e. → Stochastic d.e.

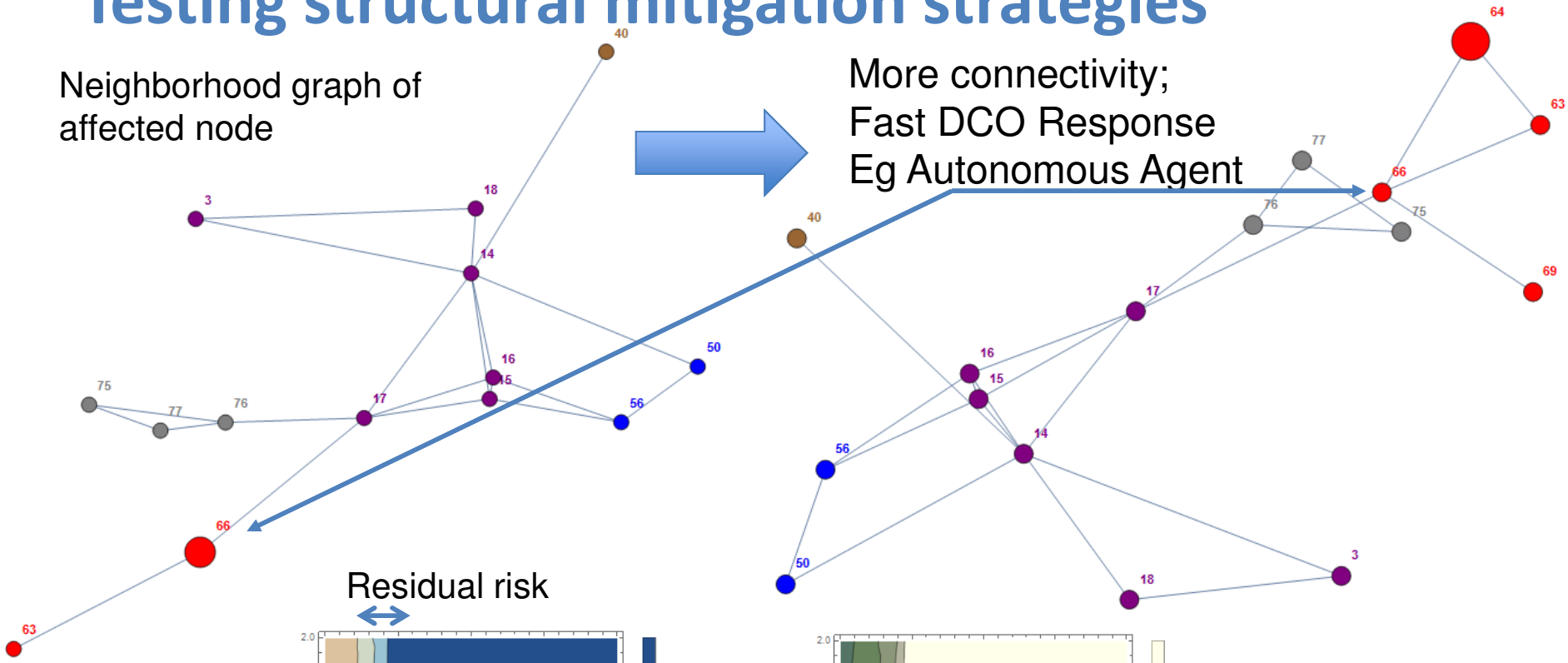
Impact (symmetric shown only)



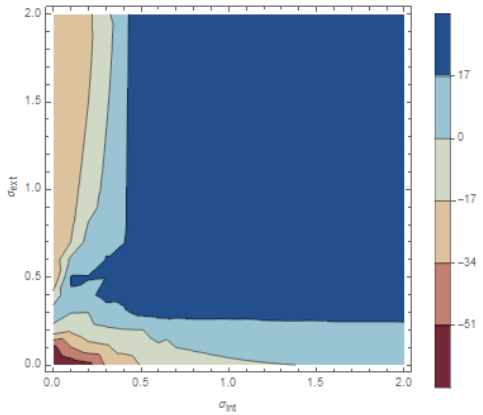
Testing structural mitigation strategies

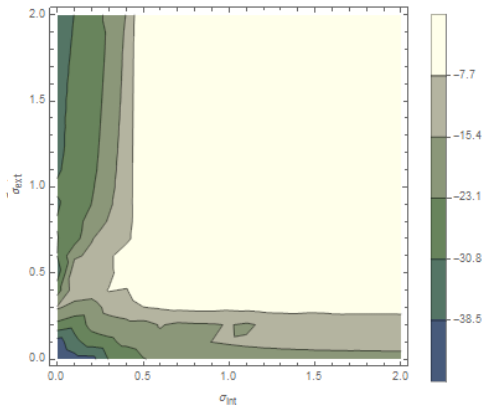
Neighborhood graph of affected node

More connectivity;
Fast DCO Response
Eg Autonomous Agent



Residual risk





Conclusions

- The Kuramoto Model is flexible enough to extend to modelling C2 in Multi-domain Operations.
- There is a natural way to measure C2 harmony in this approach – and to measure it's impact on operational performance.
- Autonomous ("faster than human") entities can be represented in such an approach.
- Scenarios for Cyber Risk Mitigation can be explored in this approach.
- Key insight: *Some cyber tasks are intrinsically slow, eg attribution, however appropriate structural change around such nodes with insertion of autonomy to speed up other processes can mitigate cyber risk*.
- Red force C2 and local population governance can be straightforwardly modelled here.