Australian Government
Department of Defence
Defence Science and
Technology Organisation

The J-Staff System: Network Synchronisation & Noise

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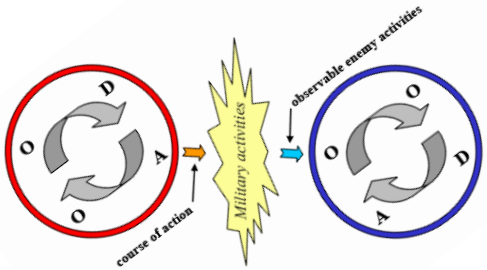
Presented by Timothy Neville

Outline

- C2 as cyclic
- The Kuramoto Model
- The J-staff system as network of phase oscillators
- Results: basic behaviours, emergence
- Conclusions

Cyclic C2 Processes

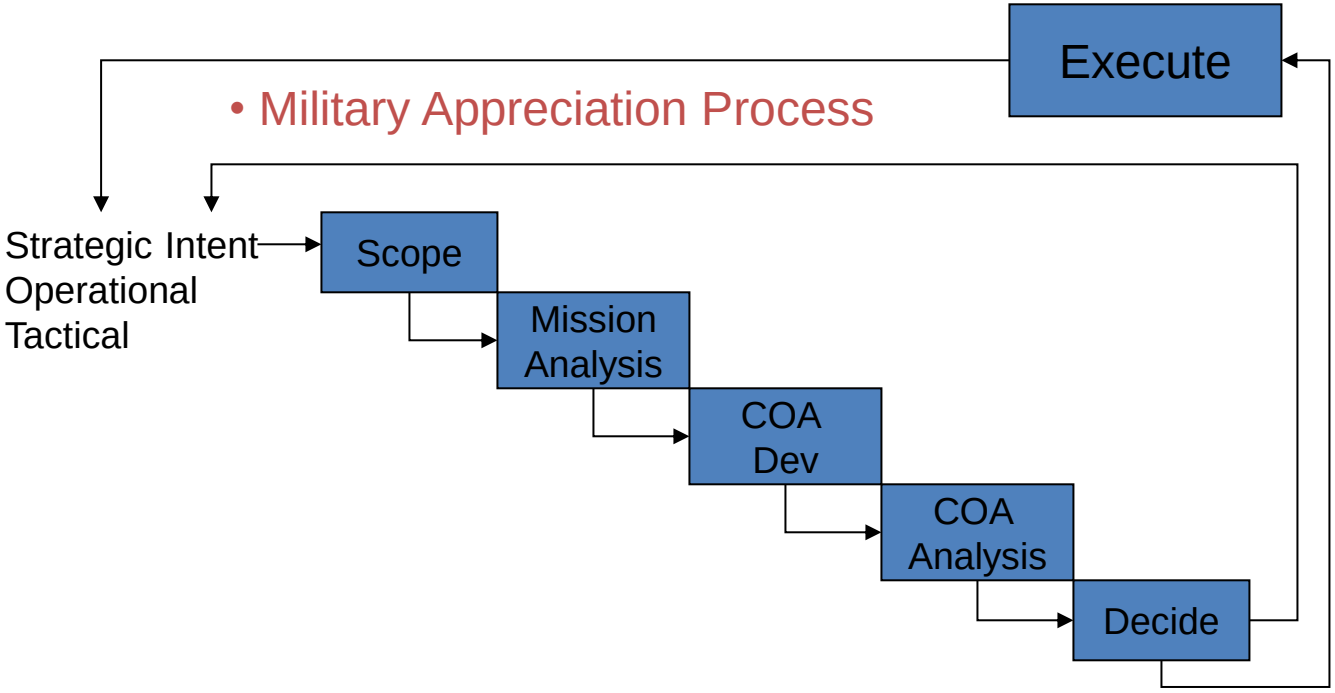
- Boyd's *O*bserve-*O*rient-*D*ecide-*A*ct Loop:



Interacting OODA:
Moon, Kruzins, Calbert 2002
'Kuramoto-Boyd Model':
Kalloniatis 2012

- *Elaborations:*
  Lawson's C2 Cycle; DOODA, Toroidal OODA…

- Military Appreciation Process



- Snowden's Cynefin Framework: Different loops depending on *context*

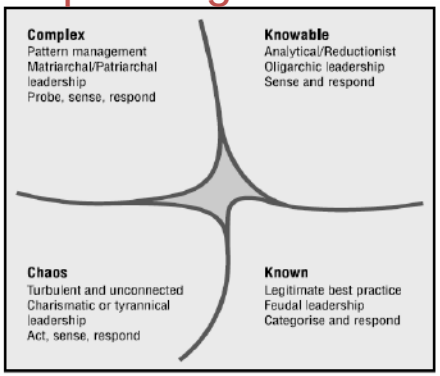


Figure 4: Cynefin Framework

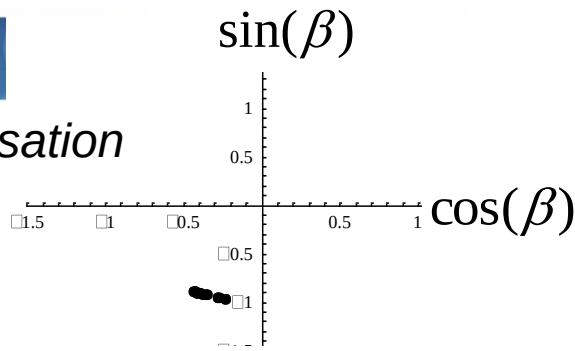
The Kuramoto* Model

1-dim Phase Oscillator:

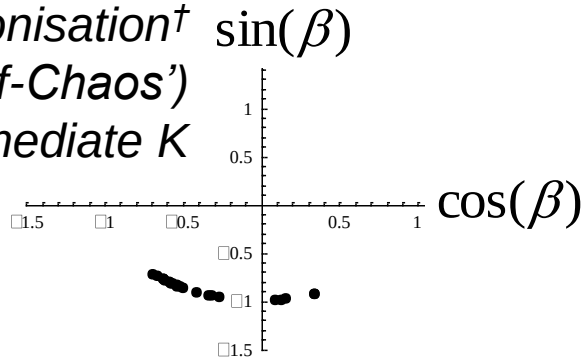
$$\dot{\beta}_i = \omega_i + \frac{K}{N}\sum_j A_{ij}\sin(\beta_j - \beta_i)$$

Natural Frequency Coupling Network adjacency matrix

Phase Synchronisation at High K

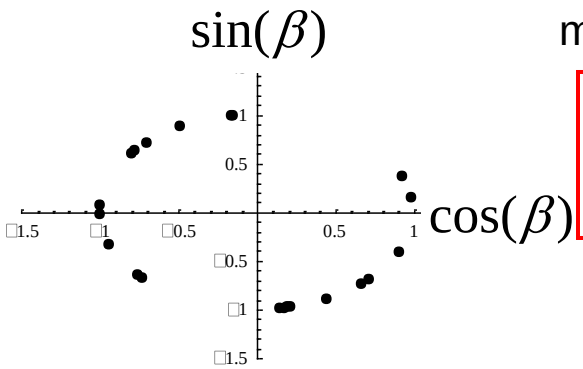


Cyclic Synchronisation† ('Edge-of-Chaos') at Intermediate K

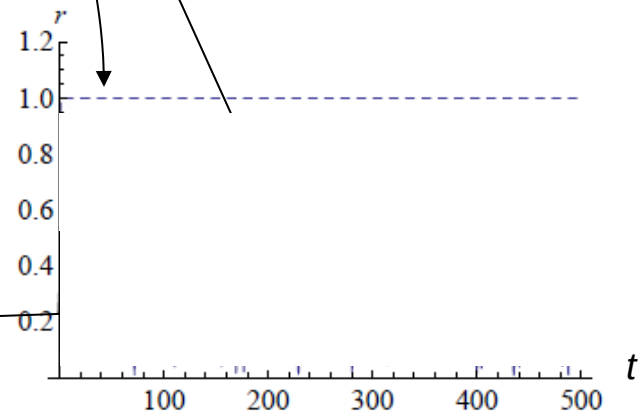


'Order Parameter'/ measure of synchronisation

$$r^2 = \frac{1}{N^2}\sum_{i,j}\cos(\beta_i - \beta_j)$$



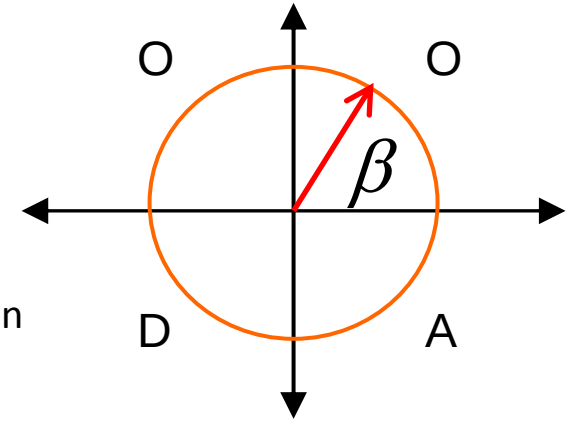
Incoherence at Low K



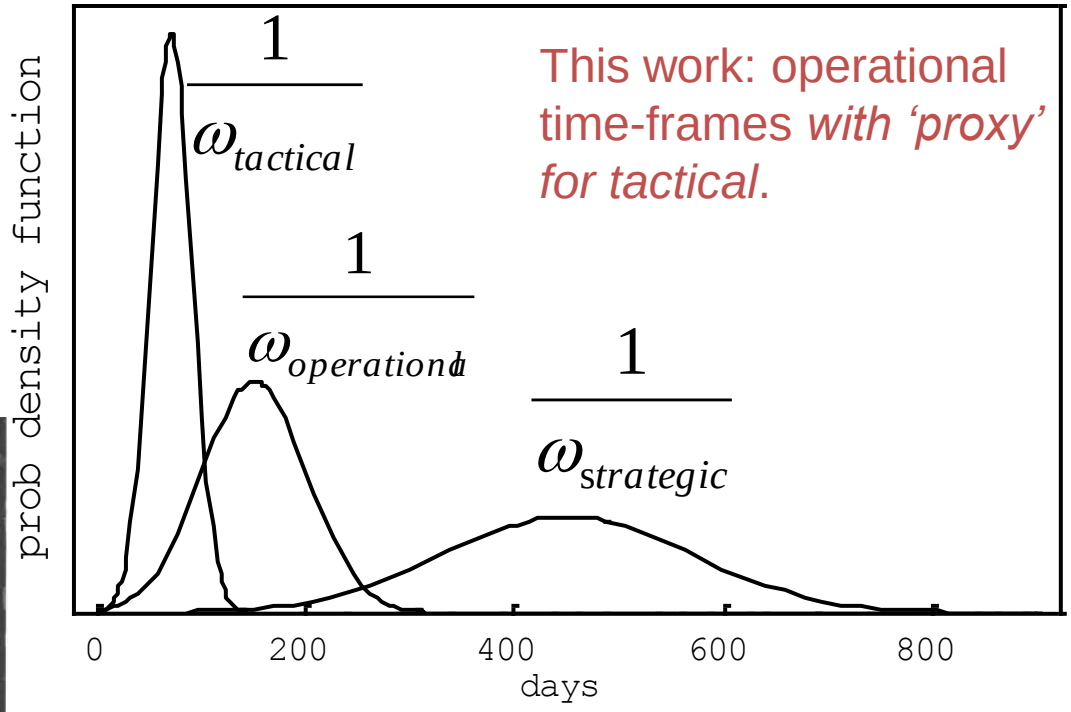
* Kuramoto, Chemical Oscillations, Waves and Turbulence, Springer, Berlin, 1984;
† Kalloniatis, Phys. Rev. E 82, 066202, 2010

Mapping Kuramoto to Boyd

- β = Point of progress in decision cycle.
- *K* = Coupling = degree of tightness of control.
- ω = *Natural* frequency of each node = inverse time period for processing appropriate information according to "environment" in order to advance through cycle.
- *A* = intra-C2 Network = not just communications connectivity, but also authority, collaborative, social, and visual networks.
  - *Who are my points of reference for my decision cycle?*
  - *With whom must I mutually adjust to progress decisions?*
- Periodicity of *sine* response function: irrelevance of "stale" information or past decisions: the *current decision cycle is all that matters*.



C2-Time Period Spectrum



This work: operational time-frames *with 'proxy' for tactical*.

Modern military operations involve diverse time scales and networking of processes.

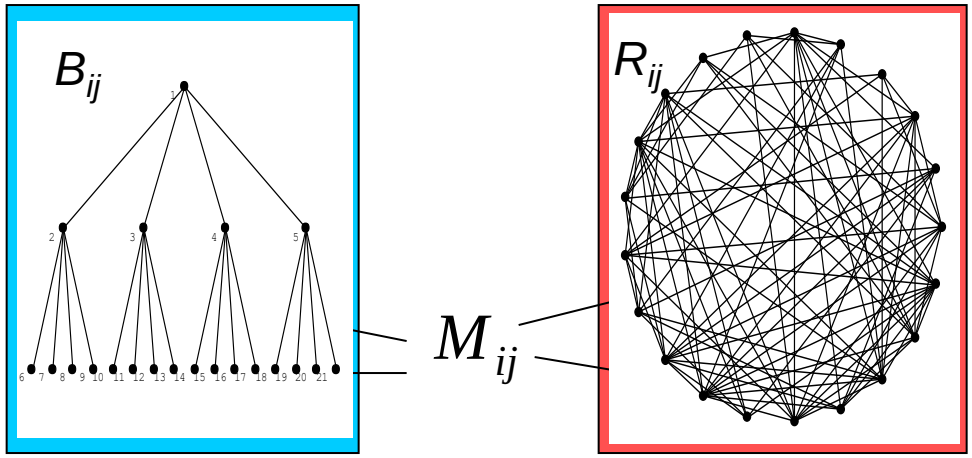
The 'Boyd-Kuramoto' Model

previous work applying networked dynamics to adversarial C2

Phase angles

Intrinsic frequencies

Adjacency matrices

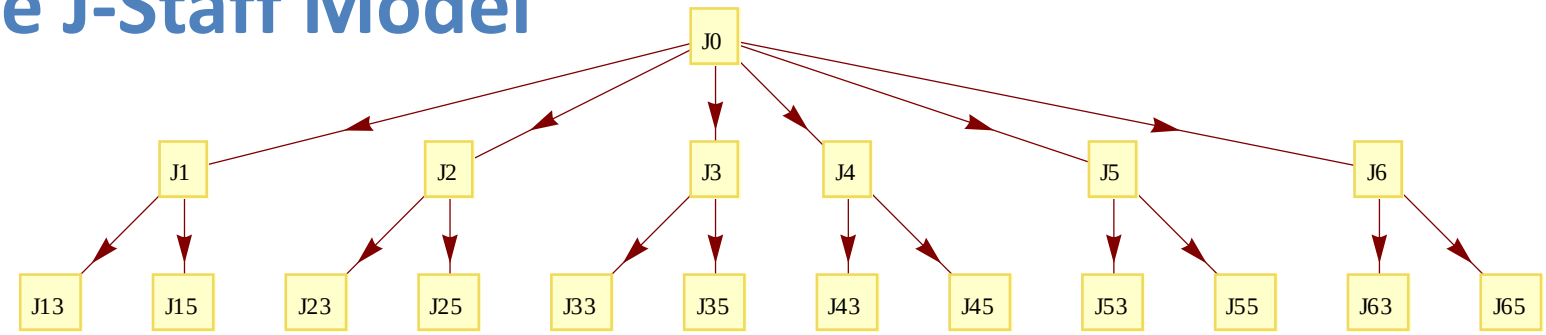


$$\dot{\beta}_i = \omega_i + \sigma_B \sum_{j=1}^{N_B} B_{ij} \sin(\beta_j - \beta_i) + \varsigma_{BR} \sum_{j=1}^{N_{BR}} M_{ij} F(\rho_j - \beta_i)$$

$$\dot{\rho}_i = \nu_i + \sigma_R \sum_{j=1}^{N_B} R_{ij} \sin(\rho_j - \rho_i) + \varsigma_{RB} \sum_{j=1}^{N_{BR}} M_{ij} G(\beta_j - \rho_i).$$

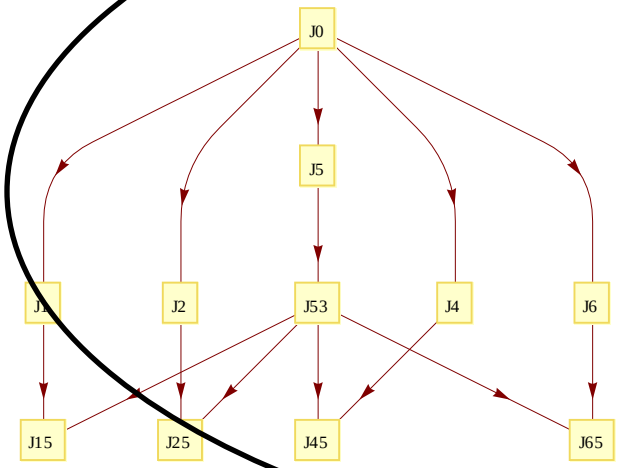
interactions only within one 'echelon'

The J-Staff Model



J-staff hierarchy

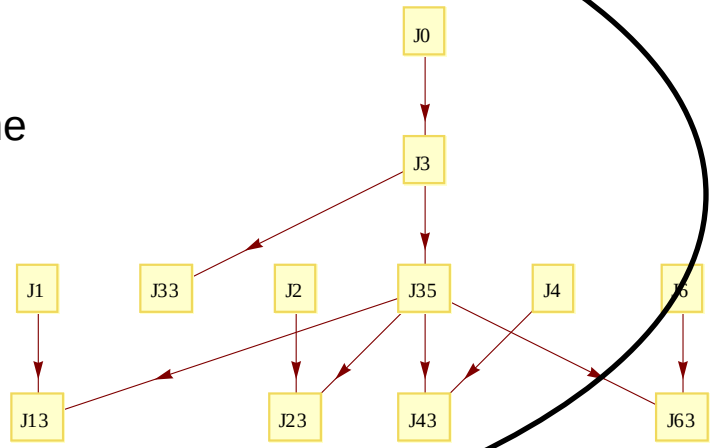
J staff units	Natural Period (time units)
J33	0.5
J0, J1, J2, J3, J4, J6, J13, J23, J35, J43, J63	1
J15, J25, J45, J5, J53, J65	15
J55	30



Planning (J5) network

The ‘processes’ for the dynamical model

And then …

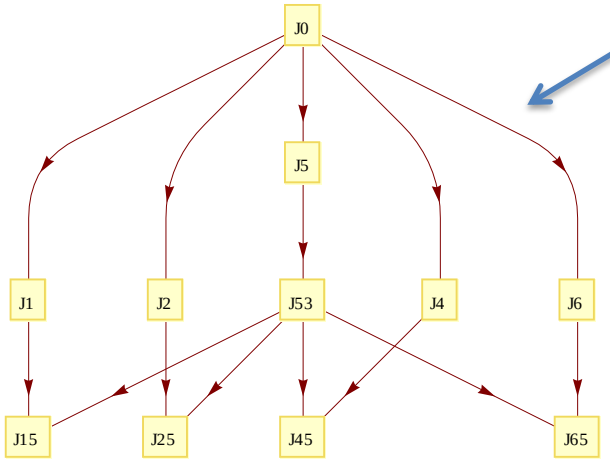


Operations (J3) network

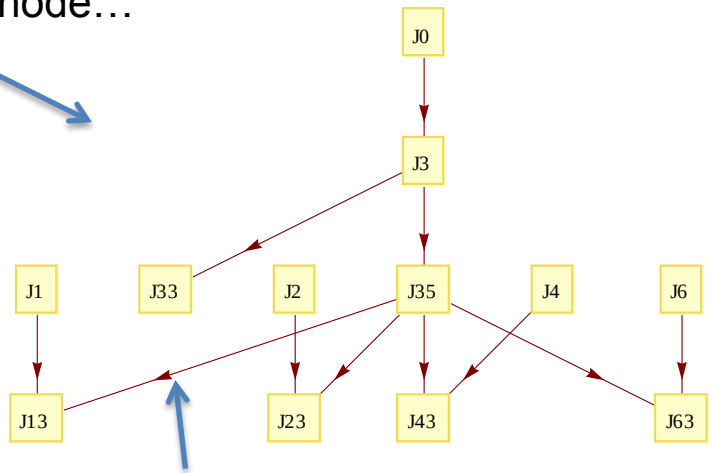
Applying Noise = erratic behaviour in time

Here:
Gaussian White Noise

Additive noise on each node…



Simulates individual internal factors (mood, health etc)



M*ultiplicative* noise on each *link*

Simulates lack of clarity in agent interactions during heightened activity (hence applied to operators).

Heightened activity = onset of a crisis to which HQ must respond.

As many crises are short lived, noise applied over finite time periods.

Some math …

$$\dot{\beta}_i = \omega_i + \gamma_a \Gamma_i^a + \sigma \sum_{j=1}^{N} A_{ij} \sin(\beta_j - \beta_i) + \gamma_m \sum_{j=1}^{N} R_{ij} \beta_j \Gamma_i^m \ .$$

OODA phase rate of change

Natural frequency

Additive noise for all

Routine OODA interactions for planners

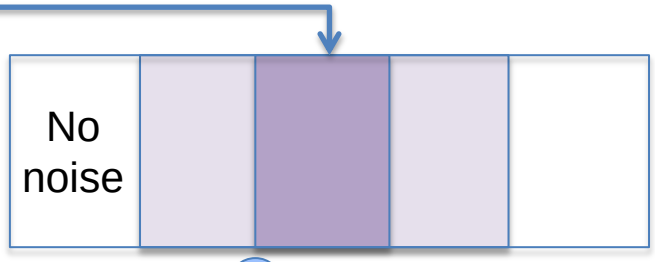
Multiplicative noise for operators

We solve this system numerically

Basic Behaviours

Multiplicative noise (operators)

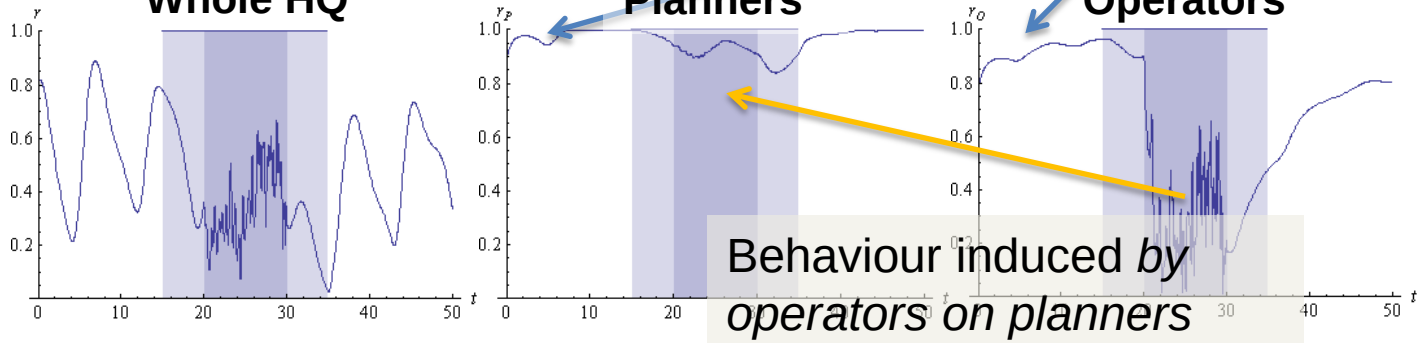
Additive noise (all)



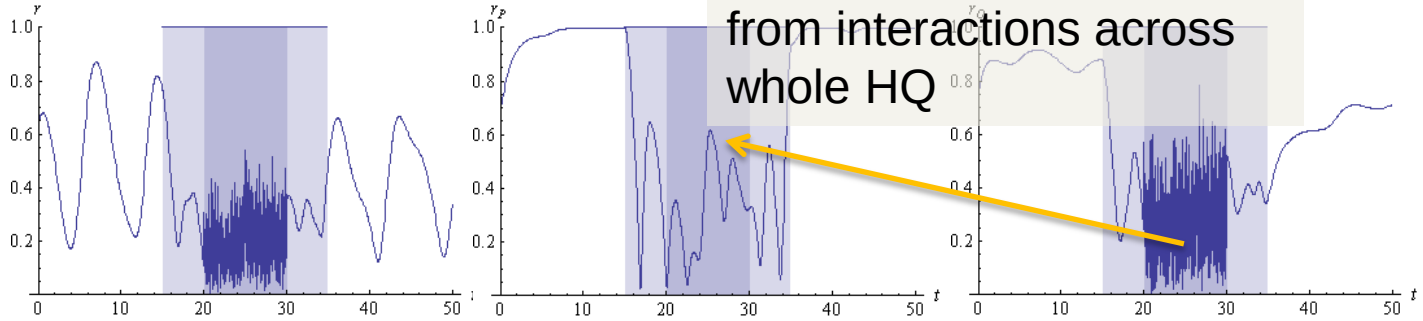
Calibrate couplings to achieve near sync in absence of noise

Whole HQ | **Planners** | **Operators**

Low noise



High noise

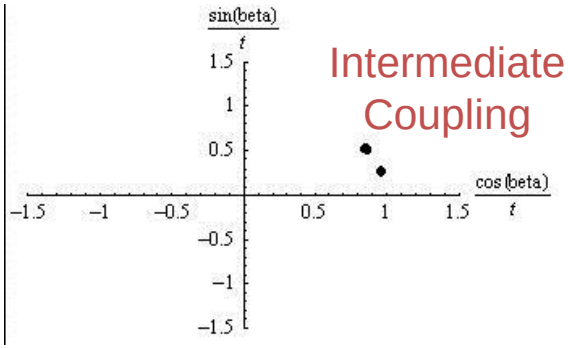


Behaviour induced *by operators on planners* from interactions across whole HQ

Emergence: Agile Headquarters

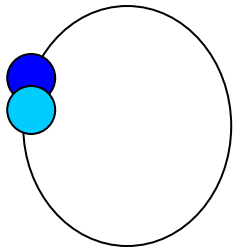
Laughlin: ‘system qualities or *behaviours* not reducible to the system components but arise from their interactions.”

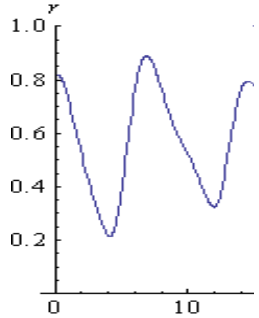
Recall the intermediate regime of coupling where two independent clusters form.



Intermediate Coupling

Zero noise





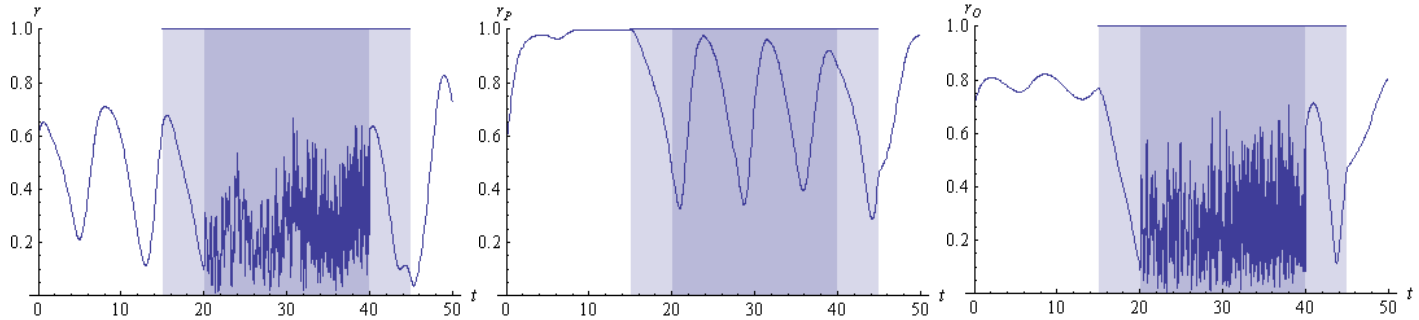
Here: planners and operators have formed their own clusters because of two sets of time-periods (slow and fast).

Can we generate similar behaviour with noise?

Spoiler: YES!

Emergence: Multi-speed Planners

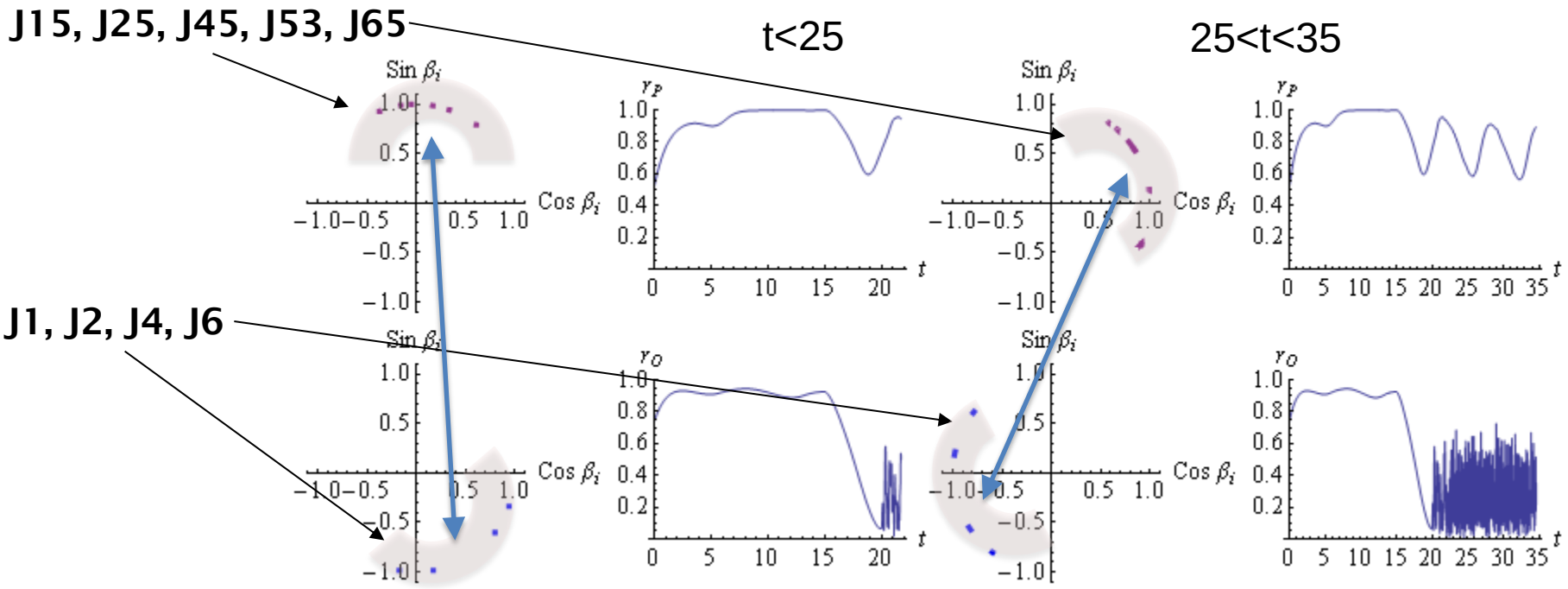
Consider the network with ***intermediate*** noise



Periodicity of planners *induced by noise*:
robust – appearing in many instances.

Two clusters of planners form, each with their own frequency.

Agile HQ: in Depth

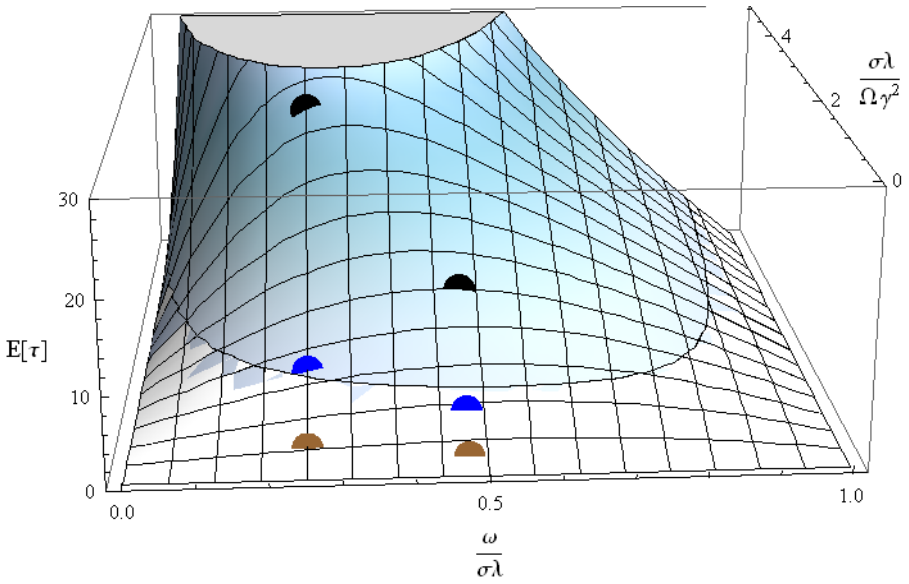


- 'Accidental' herding of planners *anti-correlated* with formal hierarchy.
- Double role of hierarchy at intermediate noise: path to disrupt planners but indirectly generates a *phase shifted convergence* of those same planners.

More math …

Instead of performing large sweeps of parameter ranges over many instances:

- Approximate close to fixed point for phase synchronisation;
- Solve for probability distribution (via ‘Fokker-Planck equation’);
- Extract steady-state distribution;
- Pose question: how long for system to leave basin of attraction of fixed point for phase synchronisation?
- Compute *mean time* for variables to cross basin boundary in state space *first time (‘MFPT’, vertical axis)*



Equi-MFPT slices give estimate of time for which planners with specific frequency/coupling (x-axis) can tolerate noise of specific strength (y-axis) before driven out of cyclic planning.

Conclusions

- Proof of concept that mathematical formulation of Kuramoto model can represent structure and dynamics of a military staff headquarters, including cyclic and chaotic activity.
- Demonstrated basic behaviours of the model may be recognised in a poorly functioning headquarters: planners either reactive or unresponsive to external environment.
- Found an intermediate regime of behaviour where order and chaos are finely balanced: planners routinely achieve near synchronisation.
- We propose this is the regime of an *agile organisation*, able to achieve ordered behaviour that is *responsive* to the fluctuations in its environment.
- Not quite ready to model a real HQ.
- Future work: nested loops to represent OODA loops of individuals within OODA loops of units, time-dependent network links, non-Gaussian noise.