APPLYING THE METHODS AND APPROACHES OF COMPLEX SYSTEMS TO COUNTER-TERRORISM

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Context

1.The Counter-terrorism (CT) environment equates to a "conflict ecosystem" [1] with multiple competing populations and individuals, which are often in conflict, seeking to maintain and improve their survivability, chance of success (which for a suicide bomber does not equate to survivability) and influence. Each individual and group of individuals in this system is a Complex System (CS) in its own right and exhibits many, if not all, of the properties and behaviours of CS. They:

- are open systems, able to exchange energy, matter and information (and with learning systems this includes memes[1]) with the external environment, for example technology, weapons and funding (Figure 1);
- exhibit emergent behaviour at multiple levels (which may only be evident through adoption of highly-abstracted viewpoints having a large scope and field of view);
- form complex social networks which may have hierarchical elements as well as dispersed control (due to inherent relationships and extant inter-dependencies);
- are dynamic and highly adaptive, but have the ability to maintain relatively stable internal conditions despite fluctuations in the external environment (*homeostasis);*
- are autopoietic[2] and able to self-organise, operating more like a self-synchronizing swarm of independent, but cooperating cells forming communities of practices, than like a formal organization and [2, 3];
- are in a dissipative non-equilibrium state and, being dependent on inputs of energy and matter from the external environment. Deny these inputs, and the feedback loops driving the insurgency lose energy, until the overall insurgency breaks down. The more energy (violence, grievances, insurgent action) circulating in the system, the more able it is to sustain itself. Once energy is drained from the system it becomes chaotic, its structure begins to collapse, inroads can be made into disrupting it, and the underlying drivers can be addressed [3].

1.Terrorists recognise that they are unable to match the Coalition Forces in a large scale confrontation so seek to prevent them from operating at the scale for which they are designed, [4] self-organising into a network of cells which are difficult to locate and target. These cells continually sense the changes in their surroundings, exploring and probing it to test new and innovative strategies, seeking feedback and sharing their information and lessons learned to increase their likelihood of success.

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[1] Memes are the basic building blocks of minds and culture (as genes are to DNA) and are therefore replicators of ideas, behaviours and culture. As with genes, memes can change in response to interactions and changing context, evolving through variation and selection.

[2] Able to self-reproduce

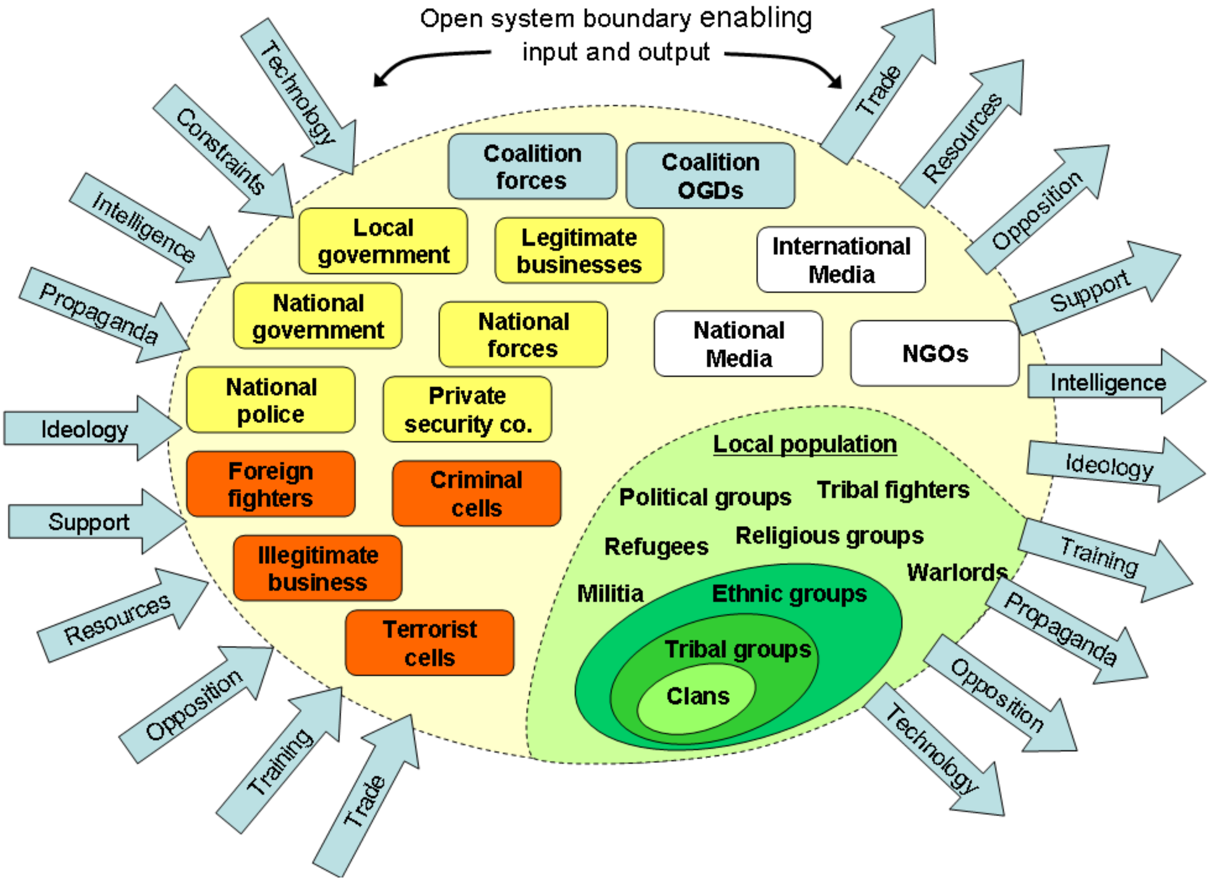

Figure 1 The counter-terrorism ecosystem with hypothetical boundary used for analytical purposes

2.Kilcullen states that:

> "*In insurgent theatres, a 'survival of the fittest' dynamic emerges. Because multiple groups compete for control over population and terrain, adaptability in changing circumstances is at a premium.*" Thus, he notes that "*the most dangerous insurgents in a theatre may not be the strongest, but rather the most adaptable, the best able to leverage an asymmetric advantage – hence the most survivable.*" [3]

3.Analysis of this ecosystem requires approaches which are capable of providing appropriate and useful insights to those who are responsible for advising and guiding actions and interventions – not so that they can solve the problem but so that they can be supported through understanding the complexity they are being faced with.

4.Any study should, therefore, adopt analytical approaches that engage in open analysis to which address the dynamic behaviour of the system and recognise the fact that "accurate" predictions are not possible. ***The reality is, there is no single 'correct', optimised solution and no single tool*** for a problem of such complexity. Analysis requires supported inquiry and exploration guided by insights from CS approach using an holistic strategy, supported by an appropriate set of hybrid methods and tools to illuminate different aspects of the problem. Analysis tools should not be used in isolation but always in a complementary way to provide insight to ways of sense-making, option-creating, decision-making and action-taking. It should be recognised that these methods and tools cannot (and are not intended to) provide any absolute predictive capability, but they can be used to provide coarse level predictions, novel insights and identify innovative possible options such as indications of likelihood and feasibility and characterisations of patterns of 'behaviour'. They also help to enable the analysis of different aspects of complex environments (which includes the organisations, individuals, groups of actors, etc) such as their stability, the 'connectedness' of the various actors and issues that may be crucially important (or not) to them.

5.This project team has chosen to take the first steps in developing two such tools: a Markov Chain model and a two dimensional cellular automata, with the aim of exploring the relationships between the population sizes of terrorists, sympathisers, and those that are neutral or against terrorism within the CT ecosystem.

Markov Chain Model

6.A simple four-state Markov Chain model is developed at the macro level to simulate the movement of individuals from one of four states to others. The model involves a starting state-vector with the initial population in each state: Anti-terrorist, Neutral, Sympathizer, and Terrorist (Figure 2).

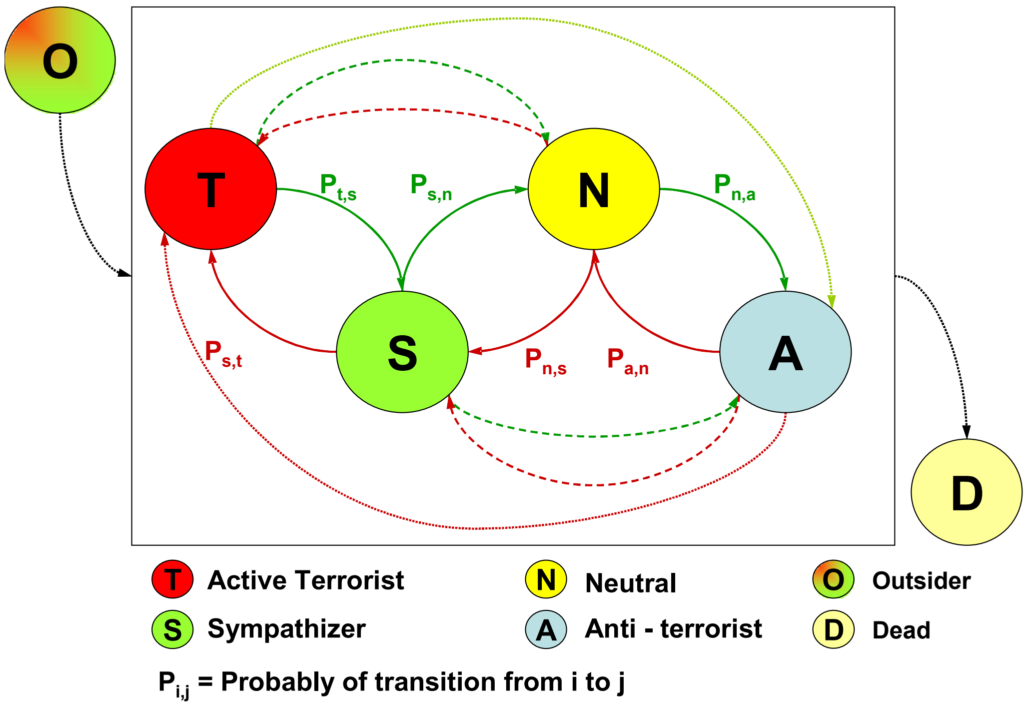

Figure 2 Markov chain showing states considered and possible transitions

Starting values	
Anti-terrorist	3000
Neutral	4500
Sympathetic	2000
Terrorist	500
Total	**10000**

Initial one-step transition probabilities					
	A	**N**	**S**	**T**	
A	0.80	0.15	0.05	0.00	**1.00**
N	0.20	0.70	0.10	0.00	**1.00**
S	0.00	0.15	0.65	0.20	**1.00**
T	0.00	0.00	0.20	0.80	**1.00**
	1.00	**1.00**	**1.00**	**1.00**	

Table 1 Starting values and 4x4 transition matrix for Markov chain model

A 4x4 transition matrix is initialized; at each time step, the number of individuals is recalculated based on the previous time step populations and the current transition matrix. The transition matrix is then updated reflecting the new distribution of the population. As expected, the Markov Chain model converges rather quickly with the population of each state becoming equal.

Time	A	N	S	T
1	4500	3000	2000	500
2	4150	3200	1850	800
3	3893	3255	1843	1010
4	3695	3241	1888	1177
5	3537	3197	1949	1319
6	3407	3140	2010	1445
7	3297	3080	2067	1558
8	3203	3022	2117	1660
9	3122	2968	2161	1751
10	3051	2918	2200	1833
				……
45	2582	2583	2590	2724
46	2583	2584	2616	2833
47	2585	2587	2655	2790
48	2589	2593	2672	2763
49	2594	2600	2678	2745
50	2599	2607	2680	2732

Table 2 Results of Markov Chain model

However, to introduce a perturbation in the model, the number of terrorists is randomly increased or decreased. The logic is simple: with probability p = 0.10, a 5% increase or decrease in the number of terrorists is triggered thus affecting the states and the transition matrix. These random events are seen as slight changes in the asymptotic convergence of the state populations.

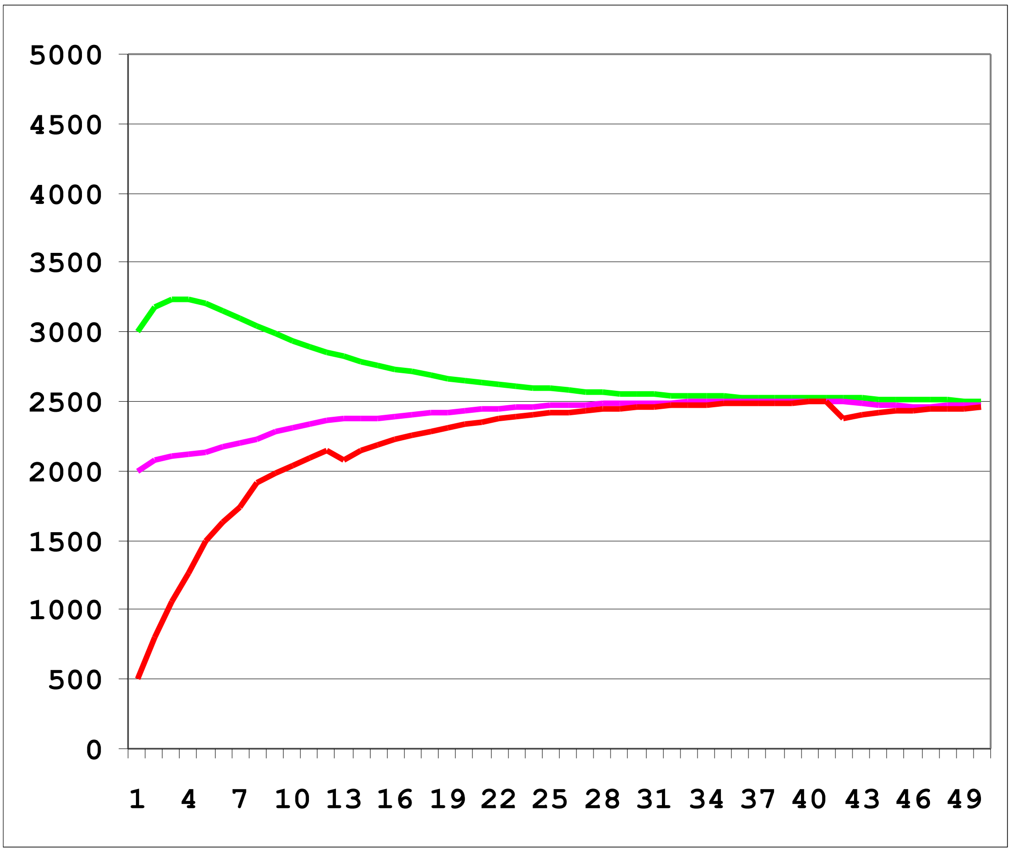

Figure 3 Graphical output from Markov Chain model

Cellular Automata

7.The second tool is a two dimensional cellular automata based on a tool developed in *Mathematica* by Dr Hiroki Sayama (State Univeristy of New York). The structure of the model was modified to enable the effects of perturbations to be studied, by changing the states of particular groups e.g. a sudden influx of distributed or co-located terrorists, at a certain point in time during the simulation. The ability to generate a list plot, which shows the real time population levels of the four states, was also added to the model in order to provide a more quantitative form of analysis.

8.We ran the model three times. The initial conditions were:

- 100x100 cell matrix (giving 10,000 population)
- Spatial distribution is totally random but with weighted probabilities of (5% terrorists, 20% sympathisers, 30% chance of anti-terrorist, 45% chance of neutrals
- Spatial model where each cell is aware of its Moore neighbourhood with a radius of one cell
- Periodic boundaries

1.The rule used is the customised majority rule which examines the number of each state of the cells neighbours and changes to match the majority; but if there is no clear majority the cell remains in the same state.

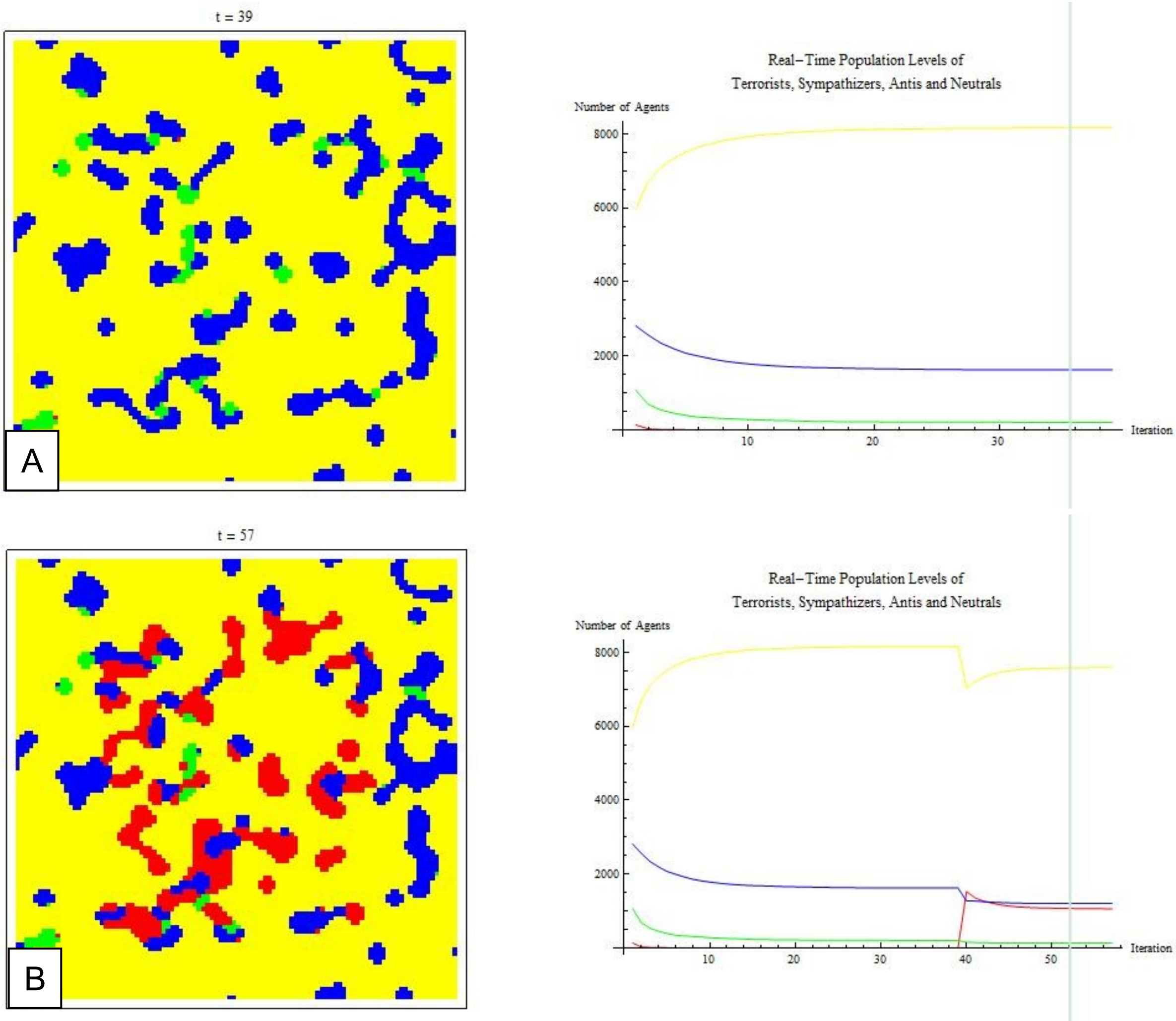

Figure 4 Output from CA model (A) first run (B) second run

2.In the first run the system achieves equilibrium after 20 time steps, the population remains dominated by the neutrals (yellow in Figure 3) with patches of sympathisers forming anti-terrorists developing and a small number of terrorists remaining. The population f the neutrals increased at the expense of all the other states. In the second run at t=40 the system was perturbed by changing the state of 1000 cells to terrorists (spread randomly throughout the CA). After the perturbation the simulation was continued – but because of the majority rule the system fell back almost to the previous equilibrium state. With the third run the system was perturbed in the same manner but the terrorists were concentrated in a square at the centre of the CA (but with some element of dispersion). On this occasion large stable islands of terrorists formed.

3.The question is how well does this model represent real world behaviour as it can only provide a limited insight (particularly in the limited time we have had to build it!)? This tool only scrapes the tip of the iceberg of the potential parameters and their inter-relationships to be considered, it looks at only a single scale. However, it may provide guidance into where to focus future analytical work and the validity of our some of our assumptions. The next steps would be to test the effects on the behaviour of model of changing it to have non-periodic values, empty spaces, initial space distributions where clusters exist, long range neighbourhoods to mimic network connectivity rather than spatial connectivity.

4.Most events or properties within this dynamic system can be ascribed to the result of many preceding interacting causal and influence processes, not one of which can be unambiguously defined as *the* cause (although there may be triggers when result in a change of behaviour state). Similarly, the consequences of any single event or property unfold through many interacting pathways and may have ramifications well beyond the sphere of the single event. Grisogono and Ryan describe this feature as a complex Causal and Influence Network (C&IN) [5] and it is a multi-scale phenomena. The potential list of causes and influences possible is enormous, but any future work would need to consider which of these are key and should be incorporated incrementally into future models.

REFERENCES

[1] Kilcullen D., Counterinsurgency Redux, Small Wars Journal, http://smallwarsjournal.com/documents/kilcullen1.pdf

[2] Vos Fellman P., Wright R., Modeling Terrorist Networks - Complex Systems at the Mid-Range, A Dual International Conference on Ethics, Complexity, and Organisations, 2001, URL: http://www.psych.lse.ac.uk/complexity/Conference/FellmanWright.pdf

[3] Kilcullen D., Countering Global Insurgency, November 2004, Small Wars Journal, URL: http://smallwarsjournal.com/documents/kilcullen.pdf

[4] Ryan A, The Bears and the Bees, Presentation at the 6th International Conference on Complex Systems (ICCS), June 25-30, 2006; Boston, MA. http://necsi.org/events/iccs6/viewpaper.php?id=60

[5] Grisogono A., Ryan A., Operationalising Adaptive Campaigning, 12th CCRTS, 2007, URL: http://www.dodccrp.org/events/12th_ICCRTS/CD/html/papers/198.pdf