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Computational models of emergent organisation in conflict environments

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1 Introduction

The world faces the highest number of violent conflicts since the end of World War II. As a result, the United Nations estimates that 2 billion people live in conflict environments [1]. Currently, after decades of low prevalence of interstate violent conflict, intrastate violent conflicts and civil war are expanding into global dimensions. The impact of violent conflict is enormous. Intrastate warfare has been the predominant form of violent conflict over the past half decade, and has accounted for approximately 4 times more deaths and injuries than violent conflicts between nations. On the financial level, 349 billion dollar has been spent on peacekeeping, humanitarian relief and refugee support globally over the last decade, and the annual military expenditures rose to 2 trillion in 2020 [1].

In intrastate violent conflicts, it is often the case that organised insurgents aim to harass the ability of governments to control and secure territory and consequently hurt the legitimacy of the incumbent. Therefore, insurgency is defined as *a protracted political-military struggle directed toward subverting or displacing the legitimacy of a constituted government or occupying power and completely or partially controlling the resources of a territory through the use of irregular military forces and illegal political organisations* [2]. Consequently, insurgents are often relatively small, lightly armed groups, that use guerrilla tactics against stronger government organisations [2]. While many fledgling rebellious movements do not survive, some flourish and evolve into sophisticated insurgent organisations, that further destabilise societies and increase the fragility of living conditions. Well-known insurgent organisations exist across the globe, such as the Fuerzas Armadas Revolucionarias de

Colombia (FARC), the Irish Republican Army (IRA), the Euskadi Ta Askatasuna (ETA), the Taliban or more recently the Islamic State of Iraq and the Levant (ISIL) and Boko Haram [3].

In insurgency conflicts, the government and insurgent organisations are involved in a violent conflict, in which they compete for the willingness of noncombatant civilians to supply resources, recruits, shelter, and local information [4, 5]. Information plays a crucial role, especially for the emergence and endurance of an insurgency [6]. On one side, insurgent organisations are able to spread rumours through their favourably disposed kinship networks about their cause and their potential to obtain political power [7]. These rumours aim to convince noncombatant civilians of the insurgents' chances of winning, and facilitate the emergence and survival of insurgent organisations, as civilians provide the necessary recruits and resources to compete. However, insurgent organisations are forced to balance between growth and secrecy, in order to hide their operations due to the asymmetry in coercive military power between insurgents and the government forces [8]. This stresses the important role information in insurgency conflicts. Government institutions rely on the supply of information by the noncombatant civilians to the identify and locate insurgents, and exploit the military advantage of governmental security forces [4]. The violent actions by insurgents and governments may have inadvertent effects on the support by civilians [9] and their provision of services, even education may yield unexpected effects [10]. Consequently, insurgent organisations emerge in an environment where insurgents, governments, and noncombatant civilians are intertwined through complex interactions and relationships. As such insurgency conflicts are examples of complex adaptive systems (CAS, see Figure 1.1), with distinct properties that arise from these interacting actors [11]. Predominantly, insurgencies yield collective behaviour, feedback mechanisms, self-organisation, and adaptation. Understanding the emergence of insurgency requires analysing how different dynamics occur at the same time. Therefore, many scholars argue for a multilevel approach that bridges the micro-level approach, which focuses on dynamics at the level of individuals, and the macro-level approach, which focuses on societal conditions and dynamics [12, 13]. This multilevel approach should help policy makers, analysts and other practitioners to understand the multilayered identity and complex evolution of insurgency, and provide better analysis methods to evaluate the long-term impact of countermeasures [5, 14]. This thesis targets at understanding the emergence of insurgent organisation through a multilevel approach by analysing interactions, relationships, and dependencies between the described actors and the conditions of the environment that allows the onset of insurgency.

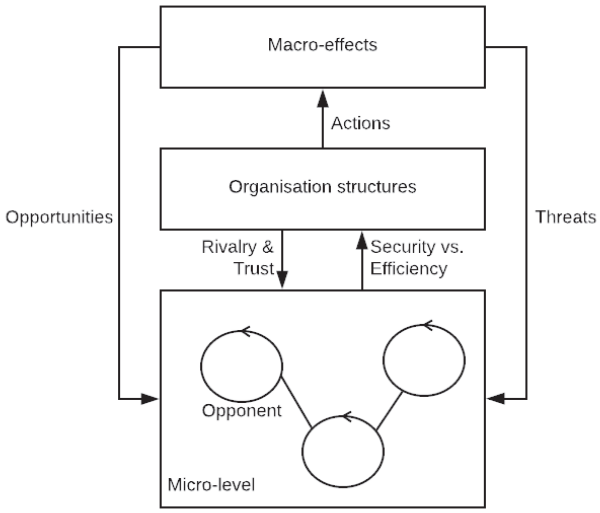

Figure 1.1: Insurgency as a complex adaptive system

1.1 Research framework

In spite of its global impact, research is still challenged to analyse and predict the emergence of insurgency conflicts. Consequently, counterinsurgency (COIN) efforts have yielded mixed results [15]. Continued efforts to develop new datasets provide opportunities to empirically study and potentially predict the emergence of insurgency conflicts. According to [16] the last ten years of research have shown that the prediction of violent conflicts has provided new insights, however it did not manage to predict low level incidence of conflict, and to understand the underlying processes of the emergence of insurgency. Ultimately, the expectation that theory-free data analysis models are able to forecast conflicts with brute force algorithms seems to be misplaced [17]. Implicit models express hidden assumptions of certain behaviour, and therefore it is more difficult or impossible to test their logical consequences and consistency. In contrast to implicit models, modellers that create explicit models are required to describe the model assumptions in detail, which enables analysis of how the behaviour of the modelled system reacts when changes of the model assumptions occur, which allows calibration and sensitivity analysis [18]. In contrast to prediction, by formalising explicit models it is aimed to obtain a better understanding of the behaviour of complex systems in several ways. In particular, developing explicit models using com-

putational modelling methods focuses on explaining, guide data collection, illuminating core dynamics, suggesting dynamical analogies, discovering new questions, demonstrating trade-offs, challenging the robustness of prevailing theory, and training practitioners [19].

Computational modelling methods that combine theory-driven and data driven concepts through formalisation of explicit models facilitate analysis of complex system dynamics. The multilevel approach to model and analyse insurgency conflicts creates a bridge between bottom-up and top-down modelling methods to analyse how various dynamics that differ on spatial and temporal scale influence the behaviour of these conflicts. The governmental, political and economic dynamics of a society often have a top-down effect upon the social dynamics [11]. However, the emergence of an insurgent organisation is a typical bottom-up phenomenon [20]. As such, its modelling requires a paradigm shift from top-down modelling to micro analysis and bottom-up modelling [12]. This thesis analyses the implications of these different modelling paradigms for modelling insurgency and emphasises both practical and theoretical perspectives.

1.1.1 Practical perspective

The development of computational models for analysing insurgency conflicts primarily aims to improve counterinsurgency policies, strategies and tactics. These COIN efforts aim to prevent or contain the emergence of insurgency conflicts through kinetic and non-kinetic actions [21]. Over the years, COIN has experienced a paradigm shift from a enemy-centric to first a population-centric and second an information-centric approach [6]. A challenge in the development and deployment of COIN strategies is the need to get insight in the possible effects and counter-effects of such strategies. The complex essence of insurgency has made military practitioners and planners receptive to developments in complexity science [22]. Application of complex adaptive systems tools have been able to provide quantitative substantiated insights in the self-organising dynamics of insurgency in Iraq [23]. Further development of computational models should enable the ability to understand and evaluate the effect of policies 'ex-ante' i.e. before application in the real world, both on a tactical, operational and strategical level.

Practitioners have several reasons to develop and implement computational models. First, the development of computational models helps to structure the data collection process. As most modelling efforts aim to provide an accurate representation of the real world, using relevant datasets is important. These datasets enable to test the operational validity of the model that is determined by the accuracy of the model to generate useful predic-

tions and usability for the intended purpose. Furthermore, well designed models should match the scope and scale of the system. Through iterative model development, modellers identify new opportunities which may require new type of data, like specific data at the micro-level, that describes the influence of individuals on organisational behaviour of an insurgent organisation, or the influence of a leader figure on an organisation at the meso-level.

The iterative procedure of modelling enables a second benefit, as it provides the ability to illuminate the core dynamics and uncertainties of the system. Therefore, it may lead to new questions that were not identified during the initial problem analysis. For instance, the interconnected society yields the need to analyse how different social relationships and individual attributes impact the probability of individuals to be attracted by an insurgency and exert typical violent behaviour. As such, the development of social network analysis methods for analysing insurgent or terrorist organisations has urged practitioners to collect more network data that describes the relationships and roles of individuals in insurgent organisations. Additionally, these developments have highlighted the necessity to explore and model the dynamics of insurgent organisations in order to identify potential disruption tactics and determine which tactics will be more effective and sustainable, for example by analysing the dynamics that steer the flow of information, money and weapons through these organisations.

The evaluation of policies and tactics through computational modelling provides a third advantage as it forces practitioners to rethink how a system works, which often exposes biases once prevailing wisdom is incompatible with the developed models. For example, in Chapter 2.5.2 we discuss how computational models can be used to grasp how COIN efforts generate inadvertent effects that actually stimulate the growth of an insurgency over time. These above perspectives suggests that a sound computational modelling approach, will provide new insights to the design and evaluation of COIN strategies. With these insights, computational modelling methods provide a potential future in which theory-driven and data-analysis models offer real-time analysis methods for complex insurgency conflicts.

1.1.2 Theoretical perspective

Insurgency conflicts are examples of a complex adaptive system in which insurgents organisations seem to emerge 'spontaneously' as a decentralised 'self-organising swarm' [24]. The decentralised emergence of insurgency suggests a typical bottom-up form of warfare.

The social contexts wherein the insurgency conflict arises influences the strategy, operations, and tactics of the insurgency organisations [3]. Understanding and explaining the emergence of bottom-up dynamics in insurgency requires to consider the dynamics of non-equilibrium systems in societies that are continuously changing and adapting. The field of complexity science aims to find the common denominator of these systems through analysis of generators of complexity, that drive the mechanisms and in particular the properties of complex systems [25]. The distinct properties that characterise complex systems are, not limited to, collective action, emergence, adaptation, feedback mechanisms, and self-organisation. The interplay between the social dynamics of cooperation and competition causes that autonomous individuals form interdependent relationships that facilitate 'spontaneous' contagion of emotions, norms and group behaviour from which collective behaviour emerges [11]. Insurgent organisations are flexible and adaptive, and are therefore able to cope with disruption efforts and other challenges that they are confronted with. For example, insurgent organisations can fragment into smaller decentralised parts that are better equipped to hide their operations. Additionally, insurgent organisations are often able to adopt criminal business processes and facilitate illicit supply chains to obtain sufficient financial support. The decentralised operations and adaptive capacity of an insurgency entail processes that might induce self-organisation from which order arises, and seemingly spontaneous collective behaviour.

Advancements in models of complex systems, such as ecological models, suggest dynamical analogies for analysing insurgency. For example, the dynamics of predator-prey models can be linked to the competition between government and insurgency for the 'resource' population, and therefore provide an interesting analogy [26]. The analysis of the underlying processes and the so-called tipping-points related to the regime shifts of ecological systems demonstrate the importance of analysing the spatial and temporal scope and scale of complex systems [27]. This is an important argument for analysing the aspects and behaviour of insurgent organisations at a micro-level, meso-level, and macro-level in order to include all important facets. The bottom-up and top-down perspectives provide different approaches to analyse these aspects. Therefore, it is necessary to obtain a better understanding of the implications of the paradigm shift towards modelling insurgency as a bottom-up phenomena. This requires understanding the attributes, interactions, and behaviour changes at the micro-level of individuals. Secondly, complex interactions and feedback in the system causes that the larger context of insurgency should be analysed to understand the influence of societal dynamics at a macro-level.

1.2 Research aims and contributions

This dissertation contributes to the development of computational modelling methods to help understand the emergence of insurgent organisation in conflict environments through multilevel modelling and analysis. Our thesis is that computational modelling methods offer an appropriate tool to design an experimental environment using a multilevel approach. This thesis proposes:

1. A multilevel approach provides the necessary framework to both analyse the complexity of emergent insurgent organisation and develop modular computational models to better understand the underlying process and context that facilitate this behaviour.

2. A computational modelling approach using the introduced multilevel framework is able to provide insight into the dynamics of insurgent organisations at different spatio-temporal scales, and highlights the type of data required to model insurgent behaviour in more detail.

The main contributions of this dissertation are:

- Identifying key factors and concepts to model insurgency conflicts, using a multilevel approach. Providing a framework to scope the analysis of the complexity of insurgency. Identifying and discussing the concepts and dynamics essential for grasping the complexity of insurgency. These insights are the starting point for the development of computational models in this thesis and for future efforts.

- Identifying the pitfalls and scientific challenges for computational modelling insurgent organisations. Proposing a literature-based analysis framework to assess the current state of the art of modelling insurgency conflicts and in particular insurgent organisations. Providing an overview of computational models for insurgency modelling in literature. Applying the proposed framework to a selection of insurgency computational models to assess the contribution, the promises, and the pitfalls of different computational modelling methodologies.

- Identifying the potential of statistical and computational methods for the analysis of the relationship between societal conditions and the emergence of social unrest. Evaluating this approach in the context of the emergence of protests and riots during the COVID-19 pandemic. Introducing a holistic approach, that accounts for the impact of dynamics' time-scales. This aspect is often neglected by data analysis efforts while it is essential for computational modelling as the analysis demonstrates. The introduced approach shows the potential of combining theory driven and data driven methods to analyse the impact of societal disruptions on the emergence and dynamics of insurgent behaviour.

- Modelling the emergence of illicit organisation from micro-level dynamics. Theoretical and empirical analysis of insurgent organisations extensively analyse the trade-off between secrecy and efficiency and found both confirmatory and contradicting examples. Proposing a novel agent-based model that comprises micro-level dynamics and interactions that yield cooperation. The introduced model includes feedback mechanisms between the micro-level, meso-level, and macro-level as agents interact with other agents and their environment. Showing how the model could be used to study the dynamics of emergence, coalescence and fragmentation that characterise insurgency conflicts and insurgent organisations.
- Developing a multilevel modelling framework to analyse the temporal and structural dependencies of insurgent organisation dynamics for illicit supply chains. Empirical studies of insurgent organisations or criminal networks are often based on static representations. Proposing a novel agent-based model that comprises a game-theoretic model for analysing opportunistic organisational behaviour. This approach enables to explore of the potential impact of group interactions, and the temporal dependencies of the adaptation capacity of the underlying networks. Moreover, it provides means to increase the understanding of the functioning of illicit supply networks, and it provides a framework to further analyse illicit supply chains.

1.3 Outline of the dissertation

In Chapter 2, we analyse the contributions of computational modelling methods for the analysis of insurgency conflicts. We formalised a specific literature-based analysis framework using the identified key factors and drivers, which enables evaluating specific models in this domain. Through a systematic literature search, we identified 64 computational models. We highlighted the development and contributions of various methodologies through an in-depth analysis of 13 high-quality models.

In Chapter 3, we propose a holistic approach to explore the relationship between societal conditions and the emergence of protests and riots in the context of the COVID-19 pandemic. First, a literature survey was performed to identify key factors that lead to the emergence of protests. These conditions and underlying relations have been captured in a causal loop diagram in order to conceptualise the emergence of civil resistance as a result of intertwined dynamics. A dataset was constructed for quantitative analysis. By means of statistical and computational modelling we conducted a quantitative analysis in which we compared the protest dynamics of 27 countries during the pandemic. We constructed a systems dynamics model to test the explanatory value of different theoretical models that

explain the causal relationships, as the results of our data analysis demonstrated a strong need for other modelling approaches that are better able to grasp the complexity and underlying dynamics of protests.

In Chapter 4, we introduce a multilevel agent-based modelling approach that integrates insights from complex systems, criminology, psychology, and organisational studies. We used a bottom-up approach to model the adaptation by individuals to social dynamics, the economic situation and law enforcement activity. This approach enables analysing the behavioural transitions of individuals and associated micro processes, and the emergent networks and organisations influenced by events at meso-level and macro-level. The potential of our approach for analysing the emergence of insurgent behaviour is illustrated with the computational results, that provide a insights in how explicit modelling enables better understanding into the mechanisms leading to social transitions at the macro-level.

In Chapter 5, we aim to understand how opportunistic behaviour yields collective organisation of illicit supply chains that provide insurgent organisations with financial support. For this purpose, we propose an agent-based model that incorporates the necessary dimensions to represent a generalisation of the dependencies in illicit supply chains, and model different organisation dynamics that enable individuals to share information and subsequently make strategic decisions. This enabled us to model relationships between agents, incorporate temporal and spatial dimensions that affect the behaviour of the system, and distinguish interactions between individuals and groups. This is specifically of interest when testing prevailing hypotheses on the dependencies in the system. These hypotheses might be focused on the importance of individual characteristics such as social capital (degree and betweenness centrality), or human capital (importance of roles). Additionally, it enabled us to formalise new hypotheses on the resilience of illicit markets such as the impact of agents with different behaviour types, or the impact of group interactions compared to individual interactions. Second, our model enabled us to analyse various scenarios in order to analyse the effect of different initial network characteristics such as the degree distribution or average group size. Also the model enables to study to what degree the adaptive capacity of the system is limited by specific actions and attributes of the agents. This enabled us to compare the emergent behaviour of the model with prevailing knowledge on the emerging structures of illicit supply chains, such as the importance of low visibility brokers or resource brokers to connect different parts of insurgent organisations.

In Chapter 6 we described in detail the contributions of the research and reflect on the practical and theoretical perspectives, the limitations, and provide directions for future research.