11-21-2016 12:00 AM

Cultural Diversity in Artificial Societies: Case Studies of the Maya Peoples

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Graduate Program in Hispanic Studies
A thesis submitted in partial fulfillment of the requirements for the degree in Doctor of Philosophy

Abstract

The existence of cultural diversity in a connected world is paradoxical given that all individuals constantly interact and share information, and that individuals are all part of one giant network of connections. In the long term, it seems logical to assume that everybody should hold the same cultural information and, therefore, the same culture. Yet cultural diversity is still manifest around the globe. Cultural diversity as a phenomenon becomes even more puzzling when we take into account how it survives catastrophic events which regularly befall societies, such as invasions, natural disasters, and civil wars. In this thesis, agent-based computer simulations are employed to study this phenomenon of emergence and resilience of cultural diversity.

The paradox of cultural diversity has been explored with different formal and computational models before. This is the first time institutions are introduced into these models. Moreover, previous models as well as my institutional model are extended in this thesis by the addition of events such as decimation, foreign settlement and institutional conversion, all of which can be used to test the resilience of cultural diversity. Combination of these events enables the approximation of real-life catastrophes; examples of possible applications is given in the form of case studies with a variety of sources of information. The three case studies presented correspond to different moments in the history of the Maya population: the so-called Classic Maya Collapse (~800AC), the Spanish invasion of the Maya highlands area (15th century), and the Guatemalan Civil War (1960s-1980s).

This thesis contributes to the literature by (a) demonstrating that institutions and mechanisms associated to them (democracy, propaganda), play a role in the emergence of cultural diversity in computer simulations; (b) offering a novel framework to study cultural diversity in computational models, including tools to introduce and combine events that target cultural information in the system; and (c) showcasing that cultural diversity, as portrayed in the simulations, is resilient to catastrophic events. The value of agent-based models to the field of cultural studies is illustrated by the parallels that are drawn between results from simulations and real-life scenarios.

Keywords

Cultural diversity, cultural resilience, Maya peoples, agent-based models, computer simulations, digital humanities

Co-Authorship Statement

Chapter 2: "Institutions and Cultural Diversity: Effects of Democratic and Propaganda Processes on Local Convergence and Global Diversity"

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Status: Published in PLoS ONE Journal (by the Public Library of Open Science)

Credits: Contributed reagents/materials/analysis tools: RU. Conceived and designed the experiments: RU CK FS. Performed the experiments: RU. Analyzed the data: RU CK. Wrote the paper: RU CK FS.

Chapter 3: "CulSum: CulSim: A simulator of emergence and resilience of cultural diversity"

Author: Roberto Ulloa

Status: Accepted for publication in SoftwareX Journal (by Elsevier)

Acknowledgments

I thank Prof. Rafael Montano for his thoughtful questions, for our conversations these past years, for his trust in my work, for his support of my applications and research travels, for teaching me not to take myself so seriously, and for his humor and his ever-welcoming smile in our meetings. I deeply appreciate his support to reintegrate me to the program just in the right time, and to allow me to pursuit my own ambitious ideas.

I thank Celina Kacperski for her support along this process; for using all of her strategic thinking to figure out how to enjoy our lives while doing our PhDs, for joining me in spontaneous bike rides and walks to escape the tedious periods that this process comprises, for the time she spent helping me with my eternal bureaucratic nightmares, for being the best computer or board game opponent and/or companion, for always being happy to play the guitar for me, for being an awesome travelling and life partner,…, for all the discussions and conversions regarding the arguments of my thesis, and for all the revisions of my English writing, which has improved by now and for that I am also grateful.

I thank Prof. Fernando Sancho for his ideas, which were a support that helped me tune up the models of my thesis, for his generosity with both his time and knowledge in answering my questions regarding technical issues and for his genuine curiosity in my models, for his invitation to work with him in Sevilla, and for the wonderful times that we shared there.

I thank Prof. Juan Luis Suárez for offering me the opportunity to undertake this challenge, for the learning experience in the CulturePlex, for his early contributions to the general ideas behind my thesis, for pointing out relevant theories and literature at the early stages of my research, and for his helpful feedback on the models.

I thank the faculty members and colleagues of the Department of Modern Languages and Literature for their contributions to my research, their constructive commentary, their interest in my work, and their enthusiasm towards new approaches to the study of humanities. In particular, I thank Sylvia Kontra for being excellent at her job, for her continuous support and patience in university matters, for her dedication to the department and students, and for her understanding during difficult moments.

I thank my colleagues at the Department for their time, their friendship and their recommendations on how best to survive in London. I thank particularly those who dedicate a big part of their time to the improvement of the Department and the University.

I thank Prof. Gabriela Barrantes for being a source of inspiration in my life, for encouraging me to continue my academic career, and for supporting my ability to think critically.

Finally, I thank my parents for cultivating my curiosity, for teaching me the value of knowledge, for not imposing limits upon my dreams, for supporting me although the same dreams are keeping s us countries apart, and for teaching me to take pleasure in the small joys of life.

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Preface

Ten years ago, when I worked as a United Nations volunteer in Guatemala, I was amazed by the vibrancy of the different cultural groups of the Maya peoples; more than twenty different languages are spoken by different groups in Guatemala and many of the groups are well represented. I felt fortunate of having the opportunity of experiencing this cultural diversity in an era where globalization and cultural homogenization are taking over.

The more I learned about the Guatemalan civil war, the more I wondered how it was possible that the diversity inherent in the Maya peoples' social organization survived after all the atrocities committed against the Maya by the government. These atrocities have even been labeled acts of genocide against the Maya population.

The civil war can be linked to an unresolved racial issue that started long ago, when the Spanish arrived in Guatemala. This arrival in itself constitutes another devastating page in Maya history that involved violent conflicts, imported plagues, and the destruction and aberration of Maya institutions.

Even before the Europeans arrived, another chapter of Maya history also tells of catastrophic events that befell both the population and its institutions. During my stay in Guatemala, I had the opportunity to explore numerous Maya archeological sites, from which I learned that almost all major Maya cities declined or were abandoned around ~AC800. Many scholars have attempted to explain this sudden collapse of an entire civilization, with scenarios that include a combination of drought, natural disasters, warfare, revolutions, or epidemic diseases. Whichever theory may be true, in terms of the Maya peoples' cultural resilience, it is once again astonishing that this collapse, which represents an extreme transformation in, and devastation of political systems, and which must have had major repercussions for the Maya culture, did not manage to eradicate the cultural diversity manifested in the different artistic traits of the cities.

These events, and the questions that they pose, have motivated my work and culminated in the creation of this thesis, which attempts to shed light on the mechanisms of human interactions that allow for the formation and continuance of diverse cultural groups.

Chapter 1

1 Introduction

This chapter will provide definitions and theories that are relevant for the contextualization of the following chapters. The first section provides a definition of culture, explains how cultural diversity is understood within the thesis, and introduces the idea that emergence of groups is possible under social influence. The second section introduces agent-based models in the context of complex systems, and how different models from the literature and the present thesis fit into this category. The third section summarizes the literature on cultural diversity and cultural drift, and some mechanisms that have been used in the past in simulations to preserve cultural diversity against perturbations. The fourth section explores the role of institutions in the preservation of culture on a theoretical level. The fifth section contextualizes all previous sections and following chapters by introducing the concept of cultural resilience.

1.1 Emergence of cultural diversity under social influence

The ubiquity of different cultural groups around the globe has previously raised questions among researchers about the emergence of cultural diversity under social influence. Here, *social influence* refers to the process in which one individual transmit information to another individual; *culture* is the information that can be transmitted between individuals (i.e. what social influence influences); and a *cultural group* refers to individuals that share the same cultural traits (e.g. Spanish language, salsa music) in their respective *cultural features* (i.e. language, music). Depending on the context, *culture* may be also used instead of *cultural group*, in which case it specifically refers to the common set of traits (information) that a cultural group shares (and can transmit); thus, *culture* does not lose its original meaning, but it is applied to only a particular group. Finally, *cultural diversity* refers to the number of *cultural groups* or *cultures* that exist in the system.

It is intuitively appealing to believe that if people constantly influence each other, then sooner or later, everyone will end up with the same information. Indeed, the globalization process has been attributed to an increase in communication (Wolf, 2014). This intuition also finds ground in formal (mathematical) models, which have demonstrated that everyone should, in the long term, converge to the same opinions when all individuals are connected to the same social network (Harary, 1959; J. R. French, 1956; Robert P.

Abelson, 1964). But although global converge is intuitive, diversity does exist, and, to give an illustrative example, bipolarization of opinions such as political left wing versus right wing, is very common. This suggests that a mechanism of group formation is at work. Abelson (1964) proposed three ideas that amend the outcome of universal agreement in mathematical models (pp. 153).

First, he considered that the network might indeed be disconnected. For our purposes, this idea can be disregarded, as in the modern world most barriers have arguably disappeared; indeed, studies on the phenomenon of six degrees of separation suggest we live in a small-world network (Gurevitch, 1961). Also, diversity does obviously emerge even in interconnected groups, as the case of the Maya illustrates.

Second, Abelson suggested that an initially moderate negative persuasive effect could develop into disconnect due to a boomerang effect, i.e. constant feedback in each opposite direction until extreme states are reached (Hovland, Harvey, & Sherif, 1957; Sherif & Hovland, 1961). Later on, this idea was proven effective by Schelling (1969, 1971), who used a model in which a small "dislike" of an agent for a dissimilar neighbor led to bipolarization. These models helped explain the at the time predominant segregation of black and white people in the United States, but lacked enough dimensionality to explain cultural diversity.

Finally, Abelson pointed out previous literature that suggested that social influence occurs generally among individuals who hold similar opinions anyhow (Coleman, 1957; Festinger, Schachter, & Back, 1950). A long list of theoretical models used the latter idea with partial success, for example Carley (1991) or Epstein & Axtell (1996), but it was not until Axelrod (1997) that a model able to generate various stable cultural groups was published. Axelrod's model introduced the idea that social influence depends on the similarity of multiple distinctive cultural features at the same time, and that the alternatives of the features (i.e. cultural traits) are categorical (not continuous) and bigger than two (multidimensional). This mechanism is henceforth known as homophily, the principle that "like attracts like" (McPherson, Smith-Lovin, & Cook, 2001).

1.2 Agent-based models and complexity

Many of the models used to explain the emergence of cultural diversity can be classified as agent-based models; i.e. computational models that simulate interactions between individuals (autonomous entities called *agents*), with the objective of gaining insights into the emergent collective behavior associated with complex systems (Gilbert & Troitzsch, 2005). The emergence of cultural diversity in Axelrod's model is only one of many examples. Any model can be implemented as a software program in order to run simulations; in other words, a *simulation* is an instance of a *model*. A model usually comprises multiple parameters; a specific configuration of those parameters is called *scenario*. A set of *simulations* that belongs to exactly the same configuration of parameters are called *repetitions,* which are used to calculated averaged results when the model includes random variables.

Agent-based models and simulations have proven to be a successful paradigm for modeling complex systems (Niazi & Hussain, 2013). A commonly accepted definition of what constitutes a complex system (or, even more fundamentally, complexity) has not so far been proposed. Johnson (2007), however, has offered a useful definition for *complexity science*, stating that it is "the study of the phenomena which emerge from a collection of interacting objects" (pp 3-4). Based on this definition, I propose to define a complex system as *a collection of components that in interaction produce the emergence of macro-scale phenomena*. And based on this, furthermore, complexity can be then defined as *the collection of interactions between components and the underlying logic that is needed to explain how these interactions originate the emergence of macro-scale phenomena*.

One of the most interesting observations in complex systems has been that the interactions between the components tend to be very simple, and that the emergent phenomena relies on the large amount of interactions. It is therefore common to build networks of components to analyze and understand these interactions. All agent-based models indirectly depend on one of these kind of networks as communication plays a big role in these models.

Although the agent-based model term appeared around the late 90s, it is possible to trace models back to the origin of computers with the self-replication machine, the idea of a machine that is able to replicate itself (Von Neumann & Burks, 1966), who used the term *(cellular) automaton* to describe this type of system (Von Neumann, 1951). One of the early examples that illustrate the potential of the approach is John Conway's *Game of Life*, a cellular automaton that generates macro-behaviors out of very simple rules of birth, reproduction and death of organisms (Gardner, 1970). While Conway used a computer to run his biological simulation, Schelling (1969, 1971) employed a checkerboard for his segregation model with its simple sociological rules (Aydinonat, 2006). In both these models, each cell of a two dimensional grid represent an individual, called *agent*, which makes them examples of agent-based models. Although, a two dimensional grid is not strictly necessary, (for an example, see Ulloa & Froese, 2016), it can be useful to define underlying social networks that are based on geographical proximity. This particular type of agent-based models has been named *artificial societies* (Epstein & Axtell, 1996), and it is the type of model used in the presented thesis. In particular, the models are extensions of Axelrods model (1997), as Axelrod's work has been judged as the seminal model in generating cultural diversity.

1.3 Cultural drift and the limits of culture diversity

Certain parallelisms between biology and culture have been pointed out in the literature. For example, the way information travels across generations has been called *cultural evolution*, although the mechanisms used to explain cultural evolution are more akin to Lamarck's ideas than Darwin's (Boyd & Richerson, 1985; Cavalli-Sforza & Feldman, 1981; Richerson & Boyd, 2004).

While the models presented in this thesis do not transcend generations, and transmission happens on an individual basis, among the same generation, similarities to biological models are still relevant, as the information flows between neighboring individuals. A concept such as cultural drift, which in cultural sciences is used analogously to genetic drift, is therefore applicable. Genetic drift is defined as the change in the frequency of a gene variant in a population due to random sampling of organisms (Wright, 1929), whereas cultural drift is the fluctuation in the frequency of cultural traits in a population due to random variations in the transmission of traits (Hahn & Bentley, 2003). Genetic drift can, for example, explain the spread of mutations across populations or, conversely, the disappearance of gene variants from the population (Kimura, 1968), in similar way that cultural drift can explain spread of innovations or the disappearance of cultural traits from the population. Cultural traits have been called *memes* in the past, as they share the property of self-replication with genes (Dawkins, 1976). Extending the concept of genetic drift analogously to culture, i.e. cultural drift is therefore not more far-fetched than aligning concepts such as biodiversity and cultural diversity.

Axelrod's artificial societies model of social influence and homophily provided a successful and well-grounded explanation for the emergence of cultural diversity.

However, it was later found to be sensitive to cultural drift, which was modeled in the way of mutations (also termed *noise*, or *perturbations*). Mutations are represented in the simulation as random changes in an agent's cultural features (Klemm, Eguíluz, Toral, & Miguel, 2003; Klemm, Eguíluz, Toral, & San Miguel, 2003). Klemm et al. (2003) found that even tiny mutation rates produced a convergence towards a monoculture without any diversity (globalization), while large rates produced a state of anomie. Anomie was first introduced by Durkheim (1951, 1982) to describe a state in which each individual is culturally different from all its neighbors, which he hypothesized would lead to a break of communication (and eventually, degradation of society).

Ever since Axelrod's model was shown to be unstable under drift conditions, many studies have addressed the robustness of the emergence of cultural diversity against perturbation, using a variety of approaches. Researchers have proposed a dynamic social network where individuals are able to adjust their ties to others (Centola, González-Avella, Eguíluz, & Miguel, 2007), they have attempted to integrate Boyd & Richerson's idea of a frequency bias (Boyd & Richerson, 1985), by making social influence multilateral, i.e. interactions happen between several individuals at once (Parisi, Cecconi, & Natale, 2003), instead of being dyadic, i.e. just between two individuals (Axelrod), and they have combined frequency bias and homophily in one model (Flache & Macy, 2011).

1.4 The role of institutions

In chapter 2, I will present a novel approach to stabilize Axelrod's seminal model in the presence of noise, theoretically extending the current theory on emergence of cultural diversity to include another cornerstone of human interactions: the institutions that emerge from these interactions (Ulloa, Kacperski, & Sancho, 2016).

The role institutions play in the social domain has been increasingly acknowledged, possibly due to the fact that human interaction is now understood to mostly dependent on explicit and implicit rules, such as the ones that are assumed to be affected by the cultural traits in Axelrod's model. Based on this understanding, a novel definition of institutions as "systems of established and prevalent social rules that structure social interactions" has been proposed by Hodgson (2006, p1), building on previous ideas put forth by Jack Knight (1992) and Alan Wells (1971, p3), who claimed that "social institutions form an element in a more general concept known as social structure."

Already at the beginning of the 19th century, institutions had been theoretically scrutinized and defined as a subtype of social structure that can influence individuals' preferences and purpose, and potentially change them (Thorstein & Stuart, 1912; Commons, 1990). Ultimately, the earliest hypothesis of institutional influence that these ideas are based on seems to stem from the 18th century philosopher Emile Durkheim, who hypothesized that institutions play a large role in group formation, and who predicted anomie on a sociological level upon the annihilation of institutions (Durkheim, 1951, 1982).

Thus, while a good foundation exists to analyze institutions in terms of social interactions and social structures, surprisingly few theoretical foundations can be found in terms of impact of institutions on cultural diversity, though attempts have been made to discuss diversity in terms of political, religious and educational institutions (Banks, 2015; Parekh, 2002; Reilly, 2008). Empirical research on the impact of institutions on culture and its underlying processes of social influence is also rare. To the best of our knowledge, just a few agent-based models exist, studying authoritarian regimes (institutions), integration of information repositories, institutional effectiveness (Bhavnani, 2003; Makowsky & Rubin, 2013; Suárez & Sancho, 2011) and mass media influence (Shibanai, Yasuno, & Ishiguro, 2001), the latter the only one to focus on cultural diversity, and some methodologically similarities with my institutional model introduced in Chapter 2.

The role of institutions raises questions about another process, one which is largely driven by institutions: globalization (Held, 1999; Robertson, 1992). Globalization and cultural diversity run, in many ways, counter each other – though globalization has been claimed to reduce minority discrimination due to a variety of factors such as reduction of poverty, social unrest and economic insecurity (Vadlamannati, 2008), some have argued that globalization does not actually reduce discrimination; when it seems like it does, it instead reduces the existence of minorities by homogenizing their opinions and cultural expressions into those of the majority, harming the cultural diversity as in many cases of indigenous peoples (Azarya, 2004; Daes, 2004; Dunklin, 2005; Rothkopf, 1997; Smith & Ward, 2000). One particular case that will be the focus of this thesis is the fate of the Maya. Institutions have explicitly attempted to implement a unification through the Pan-Maya movement. This movement has achieved its goals with only limited success, as local identities persist (Chase-Dunn, Jonas, & Amaro, 2001; Montejo, 2005).

1.5 Resilience of cultural diversity

As previously discussed, cultural diversity has been extensively investigated with regards to its tolerance against different perturbations, such as mutations and selection error (Flache & Macy, 2011; Klemm, Eguíluz, Toral, & Miguel, 2003), as Axelrod's original model (1997) was shown to be particularly sensitive to them. These perturbations have always been integrated in constant values, and in relatively small doses.

Cultural diversity can also be tested against another force: events which occur in catastrophic proportions, and in a sudden manner. In this thesis, *cultural resilience* will refer to the capability of a world (in the simulation, the geographical grid) to retain its cultural composition after the application of a sudden, catastrophic event. Here, *cultural composition* refers to the distribution of the cultural traits among the individuals. Therefore, composition includes geographical location, size and content of each cultural group. Ultimately, cultural resilience is the main focus of this thesis; in particular, I will study and analyze the resilience of cultural diversity, i.e. how multiple cultural groups are able to endure disturbances caused by large-scale events which are capable of altering the information within the system in a sudden and all-encompassing manner.

Chapters 2, 3 and 4 will all, in their own way, address this question. In Chapter 1, I will introduce an agent-based model that extends the existing frameworks of cultural diversity through the introduction of institutions. In Chapter 2, I will present CulSim, the cultural simulator, a computational framework that includes tools which allow the introduction of events to existing models such as Axelrod's (1997) and Flache's (2011) models, and the institutional model from Chapter 1. Events proposed can be used to target both agents or institutions. Finally, Chapter 3 will propose an application of the CulSim software to three case studies. Cultural diversity and cultural resilience will be tested in the context of three catastrophic events that befell the Maya: the so-called Classic Maya collapse (Webster, 2002), the Spanish Invasion of the Guatemalan Highlands (Lovell, 2005; Restall & Asselbergs, 2008) and the Guatemalan Civil War/Genocide (Historical Clarification Commission (CEH), 1999a, 1999b).

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Chapter 2

2 Institutions and Cultural Diversity: Effects of Democratic and Propaganda Processes on Local Convergence and Global Diversity

In a connected world where people influence each other, what can cause a globalized monoculture, and which measures help to preserve the coexistence of cultures? Previous research has shown that factors such as homophily, population size, geography, mass media, and type of social influence play important roles. In the present paper, we investigate for the first time the impact that institutions have on cultural diversity. In our first three studies, we extend existing agent-based models and explore the effects of institutional influence and agent loyalty. We find that higher institutional influence increases cultural diversity, while individuals' loyalty to their institutions has a small, preserving effect. In three further studies, we test how bottom-up and top-down processes of institutional influence impact our model. We find that bottom-up democratic practices, such as referenda, tend to produce convergence towards homogeneity, while top-down information dissemination practices, such as propaganda, further increase diversity. In our last model – an integration of bottom-up and top-down processes into a feedback loop of information – we find that when democratic processes are rare, the effects of propaganda are amplified, i.e. more diversity emerges; however, when democratic processes are common, they are able to neutralize or reverse this propaganda effect. Importantly, our models allow for control over the full spectrum of diversity, so that a manipulation of our parameters can result in preferred levels of diversity, which will be useful for the study of other factors in the future. We discuss possible mechanisms behind our results, applications, and implications for political and social sciences. A brief introduction suggested here.

2.1 Introduction

2.1.1 Models of culture and social influence

In light of inherent tensions in international integration (James, 2006) and a contemporary trend towards cultural policy (D’Angelo, Vesperini, & Europe, 2000; McGuigan, 2004), factors that impact cultural globalization and the preservation of diversity have been a recent focus in computational modeling. The question how diversity, i.e. the co-existence of many varied cultures, can be sustained in the face of a growing tendency towards globalization has been explored with various approaches (Abelson, 1964; Axelrod, 1997; Hegselmann & Krause, 2002; Macy, Kitts, Flache, & Benard, 2003; Mäs, Flache, & Helbing, 2010). Culture is here construed as the information which is transmitted between individuals in a social manner (such as music, customs, and language). The process of transmission is also known as social influence (Festinger, Back, & Schachter, 1950).

Formal mathematical models of social influence illustrated that, when everyone in a network is connected, a global monoculture is inevitable – all cultures converge to a global consensus and become homogenous (Abelson, 1964; French, 1956; Harary, 1959). Cultural simulations, among them artificial societies (Axelrod, 1997; Epstein & Axtell, 1996), have since then been adopted to facilitate the study of patterns of cultural transmission. They have enhanced our understanding of how diversity and global consensus emerge in societies, and how societies can fluctuate between one and the other, exploring these dynamics by introducing various factors to social influence to find ways by which diversity can be preserved.

One example of a social process that has yielded valuable insights is homophily, the principle of "like attracts like": the higher the similarity between two individuals, the more likely they are to influence each other (Lazarsfeld & Merton, 1954; McPherson, Smith-Lovin, & Cook, 2001). Schelling used this idea to show that a small "dislike" for a dissimilar neighbor could lead to complete segregation in an agent-based model (Schelling, 1969, 1971). Following this, Axelrod's seminal paper (Axelrod, 1997) introduced an agent-based model that integrated both, the proposed network structure of previous models (Abelson, 1964) and homophily (Lazarsfeld & Merton, 1954), but instead of looking at segregation by movement like Schelling (Schelling, 1971), he studied segregation by attitude change, in particular the question: when individuals change their values and opinions based on similarities with each other, do cultures become more alike or more diverse?

He found that cultural diversity emerges and persists under homophily, because groups of agents with similar characteristics grow more similar inside each group, until the groups do not share any common characteristics. Once complete dissimilarity between two groups is reached, they no longer interact. Initial parameters, such as population size, neighborhood interaction size, and number of cultural features and traits, impacted the emergence of cultural diversity, for example, a smaller population size was conducive to diversity, while an increase in neighborhood size increased cultural homogeneity (Axelrod, 1997; Greig, 2002).

In recent research, mass media has been shown to increase cultural diversity when the mass media messages are strong enough, whereas weaker messages were more likely to lead to global homogeneity (González-Avella, Cosenza, Eguíluz, & Klemm, 2007; Shibanai, Yasuno, & Ishiguro, 2001). A change in geography, such as modelling mountains that minimize contact between groups of agents, increased levels of diversity as well (Parisi, Cecconi, & Natale, 2003). The types of interaction between agents have been also explored: while in Axelrod's original model, interactions were of dyadic nature, i.e. individuals interacted with and influenced each other on one-on-one basis, Parisi et al (Parisi et al., 2003) and Flache et al (Flache & Macy, 2011) implemented multilateral social influence models based on Richardson et al (Boyd & Richerson, 1985), in which agents consider opinions of multiple neighbors around them (instead of just one), before changing their traits.

Finally, Axelrod's original idea of testing the model against random noise was implemented, in the form of "mutation rates" (Klemm, Eguíluz, Toral, & Miguel, 2005; Parisi et al., 2003), and later, "selection error" (Flache & Macy, 2011). Klemm et al (Klemm, Eguíluz, Toral, & Miguel, 2003; Klemm et al., 2005) introduced various rates of noise into Axelrod's model finding that the model quickly destabilized and converged into a monoculture (without any diversity) even at very small rate of noise, while, at a larger rate of perturbation, it devolved into anomie, the complete cultural isolation of each individual from their neighbors (E. Durkheim, 1982; É. Durkheim, 1951). The "selection error", which is based on the assumption of an occasional perception error of a neighbor's similarity (or dissimilarity), was added to cultural drift as another level of noise, and produced a similar instability (Flache & Macy, 2011).

By integrating multilateral social influence with Axelrod's original postulation of homophily, Flache et al (Flache & Macy, 2011) proposed, to the best of our knowledge, the thus far most successful model, facilitating the emergence of cultural diversity and stabilizing Axelrod's original model (Axelrod, 1997) against the two sources of noise. It will therefore serve, along with Axelrod's model, as a comparison point in our results.

2.1.2 Models of institutions

Following cultural drift, limited communication, terrain effects, technology and broadcasting, with the present paper, we would like to introduce a novel question to extend Axelrod's original model: what role do institutions play in the emergence and resilience of diversity?

First analyses of institutional influence supposed that a diminishing impact of social institutions on values and behavior would increase individualistic tendencies and could, in extreme cases, lead to anomie (É. Durkheim, 1951). Since then, much research into social institutions has investigated their effects in terms of social networks (L. C. Freeman, White, & Romney, 1991; L. Freeman & White, 1993) and theory of games approaches, such as prisoner's dilemma and coordination games (Axelrod & Keohane, 1985; Snidal, 1985; Wagner, 1983). Very little research has looked at the impact of institutions on culture and its underlying processes of social influence. To our knowledge, only three major projects have used agent-based models in this context: (1) one study showcases how individuals hide their true beliefs in authoritarian regimes (institutions), and how the regimes are affected by this (Makowsky & Rubin, 2013); (2) one platform exists that allows an integration of information repositories, and lets researchers analyze patterns of cultural dynamics (Suarez & Sancho, 2010), and (3) a line of research exists that investigates mass media influence (González-Avella et al., 2007; Shibanai et al., 2001; Quattrociocchi, Caldarelli, & Scala, 2014), which can be interpreted as institutional influence and shows several methodological similarities to ours.

The addition of institutions to an agent-based model of cultural patterns, as we propose, can add insight into processes of cultural diversity emergence and resilience by for example analyzing the impact of varying levels of institutional influence and institutional loyalty on culture. Furthermore, we can analyze the way in which individuals and institutions interact with each other inside different political systems, for example through means of democratic processes (like referenda), or organized dissemination of information (like propaganda), and then explore how this impacts the system's composition.

In agent based models, the idea of "central authorities" has been mostly excluded from the methodology so far. This might be due to the assumption that they can only play the part of central coordinating agents (Axelrod, 1997; Epstein & Axtell, 1996). To the contrary, we would like to establish that central authorities and institutions do not denote the same concept. At the center of institutional research lies the exchange between human autonomy, i.e. the agency in human behavior; and social structure, i.e. influences derived by institutions in society (Bourdieu, 1977). Axelrod (1997) explicitly excludes powerful authorities from his model because of their absolute coordinating impact on culture (where an authority influences individuals' beliefs and values, but is not in turn influenced in any way). An example of a previous implementation of central authority is the inclusion of geography, such as a mountain range (Parisi et al., 2003). It impacts agents' behavior (by preventing interaction between neighborhoods of agents), but cannot be impacted by agents itself.

However, authorities are not necessarily absolute. With our present work, we aim at a use of institutions which exert influence on individuals and govern people's behavior and are in turn influenced by individuals, especially in their creation (Berger & Luckmann, 2011). We speak of institutions in terms of information centers, i.e. mechanisms of political, economic or social interactions (North, 1991). They can be more formal, such as governments, marriage, organized religion, or informal agreements, such as vegetarianism or spiritual beliefs.

In general, the space in which shared information is stored does not need to be tangible, but in artificial representations, there is a need to conceptualize a second level of information that lies beyond first level individual interaction patterns. This idea has been previously applied in cultural algorithms (a branch of evolutionary algorithms) in the way of "belief spaces" (Reynolds, 1994). Belief spaces inherit cultural knowledge; they are the storage of agents' shared beliefs, and are updated as those beliefs change. At the same time, belief spaces have an impact on how the agents evolve alongside each other; they impact who interacts with who and who is influenced in what way. In agent-based models, this particular kind of belief space has been termed a "cultural repository" (Suarez & Sancho, 2010).

In order to illustrate the relationship of these two levels of information storage, let us assume, for example, that Romeo interacts with Juliet, discussing the value of certain types of music. In Axelrod's model (Axelrod, 1997), there is only one level: through homophily and social influence, Romeo can be convinced by Juliet that salsa music is better than hard rock, and Romeo and Juliet would then share a common "trait". In our model, both Romeo and Juliet still interact on an individual level, but they also have a belief space that represents the two different institutions that they belong to, for example their respective familial units, House Montague and House Capulet (Figure 1). When Romeo interacts with Juliet, he is not only aware of their interpersonal similarity and their own traits, he is also pressured by how representative his institution (i.e. his family) is of him, and how much influence this has on him. The level of institutional influence that Romeo perceives can prevent him from liking salsa music. He needs to check whether his family approves of salsa music, and if it does not, whether his homophily with Juliet is strong enough to ignore his family.

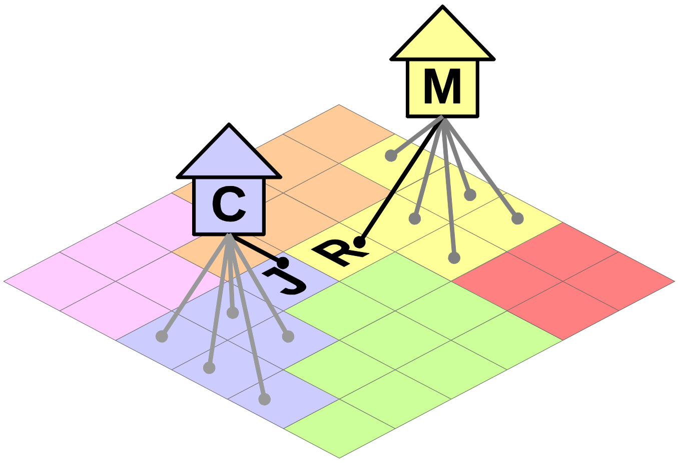

Figure 1. Model of institutions, Romeo and Juliet example. "R" represents agent Romeo, "J" represents agent Juliet, "M" and "C" their respective houses, Montague and Capulet. Agents from one cultural region (e.g. yellow, blue) are connected to the institution that they belong to (also colored yellow and blue).

If Romeo does change his trait, because he likes Juliet better than his family, he can then also choose to change his institution, i.e. see if becoming a Capulet will suit him better than being a Montague, as Juliet’s family, the Capulets, might be more representative of who he is than his own family. This choice will depend on Romeo's loyalty towards his family, i.e. how willing he is to give up his family name and connections.

The different levels of institutional influence and agent loyalty can be exemplified by different types of institutions. For example, there are institutions that promote strong identification and exert a lot of influence, such as families or nationalities, or those that do less so, such the school one went to, or the TV channels one watches. Individuals can feel varying levels of loyalty to their institutions as well, for example when someone is part of a political party because it has always been this way in their family (conservatism), or when social punishment is normative (e.g. some familial structures or religious organizations).

With all these considerations in mind, we would like to propose our initial research questions: How is the diversity of a system impacted by varying amounts of influence that institutions exert on individuals? How is the system impacted by varying amounts of loyalty that institutions demand from their followers? And how does the inclusion of institutional influence and agent loyalty to an agent-based cultural dissemination model compare with results obtained by Axelrod (Axelrod, 1997) and Flache et al (Flache & Macy, 2011)?

2.1.3 Referendum and propaganda

Our previous research questions look at the impact of various levels of influence and loyalty on cultural diversity in a way in which institutions only prevent possible cultural changes (the influence is indirect). An additional focus of our work are the two directions in which social influence can function between low level interactions (individuals) and high level interactions (institutions) (Berger & Luckmann, 2011; Bourdieu, 1977), and how this impacts cultural dissemination; on one hand, influence can be exerted in a bottom-up trend, on the other hand, it can be exercised in a top-down manner. Thus, conceptually, the processes of institutional influence we propose can be understood as a feedback loop of information.

These two forms of direct influence have found translation into forms of governance employed in political systems. Common bottom-up influences upon institutions are voting, and mechanisms of direct democracy such as referenda or plebiscites (Kollman, Miller, & Page, 1998), while a common form of top-down influence by institutions is the use of information dissemination, such as campaign advertising or propaganda (Jowett & O'Donnell, 2014). Some previous agent-based models have looked at the impact of a feedback loop of influence on cultural diversity and have related this procedure to mass media coverage on a global population level (Shibanai et al., 2001) or differentiated by predetermined local neighborhoods (González-Avella et al., 2007). However, those models do not differentiate between top-down and bottom-up processes, and they lack a validation against noise levels, which have been shown to greatly impact system stability (Klemm et al., 2005).

By reason of this, we would like to propose another line of investigation, subdivided into three specific research questions. We will first individually explore a bottom-up process, in which the institutions adapt their traits towards population majority beliefs, similar to the execution of referenda, and see how this process impacts the composition of institutions, their influence, and therefore, the emergence and persistence of diversity within the system. Then we will explore a top-down process in the same manner, in which individuals adapt their traits due to institutional pressures, similar to the employment of propaganda. Lastly, we will combine the two in one system to show the effects of the feedback loop of social influence. We will also see how a variety of frequencies of occurrence of these processes affect system stability under noise.

2.2 Methods

2.2.1 Agent-based models

Agent based models are a popular tool for empirical testing of realistic concepts in complex systems. Initial models were common in economy and biology (Föllmer, 1974; Gardner, 1970; Wolfram, 1983) and have since then permeated many knowledge fields ranging from psychology to physics. In the social sciences, Epstein & Axtell popularized their use with their sugarspace model (Epstein & Axtell, 1996).

Models commonly include a two-dimensional grid, which serves as the “world”. It is inhabited by agents, which can be interpreted as individuals, tribes or villages/towns. How agents interact with each other and their world environment is based on the rules of any given model. This type of abstraction allows a representation of a variety of patterns and ideas, such as cultural patterns, while not applying it to any specific, named culture.

In our model, we follow and expand the arrangement of Axelrod’s original converging diversity model (Axelrod, 1997) with the following units:

1. Individual agents: Each individual agent is an autonomous entity that holds a certain amount of information, its culture. In the simulation, this culture is represented by a string of features, such as for example music, cuisine, language, etc. Each agent exhibits a preference on each feature, which is called a trait; an agent might like salsa music, Mexican food and Spanish language. In simulations, these traits are represented by integer values. Based on Flache et al (Flache & Macy, 2011), we used 5 features and 15 possible traits per feature. An agent a can be represented as follows: [2, 4, 12, 9, 14], in which a_f refers to the trait on feature f for agent a.

2. Institutional repositories: Each institution is a second layer "agent" that represents a belief space. It is denoted by a string of features and their trait exhibits are based on integer values, exactly as individual agents. However, unlike individual agents, institutions are not attached to a grid and they also can have empty features (features without an assigned trait), internally represented with -1. An agent a can only belong to one institution at a time, denoted i_a, and it follows that i_{af} will represent the trait for feature *f* of *a*'s institution. Every individual agent is initially associated with an institution with all empty features. The agent can then, in interaction and agreement with another agent, overwrite one feature. An agent can also switch their institutional association to be associated with a different institution instead.
3. Grid environment: Agents are arranged on a two-dimensional lattice. We follow Flache et al (Flache & Macy, 2011) in selecting three varying sizes for the lattice, 10x10, 32x32, and 100x100, making up world populations of 100, 1024 and 10000 agents. Although human populations are generally much bigger, 10000 agents can be a representation of a town, or, according to Axelrod (1997), each agent can be representative of one village. By studying different sizes, we can observe whether our patterns will stay consistent across various population sizes (bigger populations than 10000 agents were difficult to study due to high computational demands). Neighborhoods are defined as the areas within which agents can interact. We define a Von Neumann neighborhood within a distance of 6, meaning each agent can interact with a maximum of 84 agents (Figure 2).

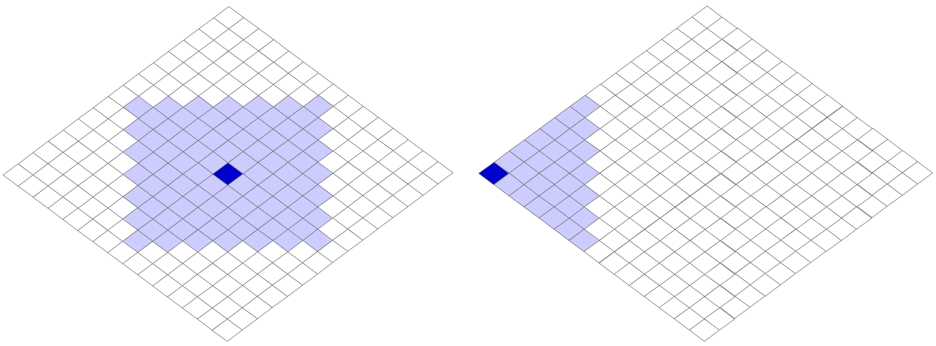

Figure 2. Two possible von Neumann neighborhoods with distance 6. Two example neighborhoods on a 15x15 grid. Left: central agent (dark blue) with 84 neighboring agents (light blue) that it can interact with. Right: border agent (dark blue) with 27 neighboring agents (light blue).

The environment is represented as a non-toroidal world, so agents have fewer neighbors when they are closer to the borders. Agents that share the exact same trait combination on all their features and are located next to each other in the grid are considered to be of the same culture. All agents that belong to the same culture determine a "cultural region". Diversity is defined as at least two existing trait variations, e.g. cultural regions, existing at the same time. Anomie indicates that there are as many cultural regions as there are agents; conversely, complete globalization denotes that there is only one cultural region.

4. Rules: The model integrates dynamical rules which allow agents to interact based on probabilities associated to cultural similarity. Cultural similarity is the number of cultural traits that are equivalent on two vectors of agents or institutions.

There are three types of probabilities working in the model: (1) agent similarity, which is the similarity between two agents (i.e. homophily); (2) internal institutional similarity, which exists between an agent and its own institution, and (3) external institution similarity, which exists between an agent and the institution of a neighbor.

Institutions impact agent interactions based on these cultural similarities, and based on two factors: institutional influence and agent loyalty. Agents impact institutions when they create institutions, or when they join an existing institution and the institution's "active feature" is empty. An "active feature" denotes the one particular feature that is being discussed when two agents interact.

Table 1 presents an overview over the most important rules that we are including in our simulations, and the combinations in which they were implemented in previous research.

Table 1 Overview over previous models and their included parameters, and our model. The first column identifies models by author. The second to sixth column indicate different rules that have been tested in the different models.

Model	**Homophily**	**Perturbation Mutation**	**Perturbation Selection Error**	**Multilateral Social Influence**	**Institutions**
Axelrod 1997	Yes	No	No	No	No
Klemm 2003	Yes	Yes	No	No	No
Flache 2011	Yes	Yes	Yes	Yes	No
Ours	Yes	Yes	Yes	No	Yes

Firstly, Axelrod's original model (Axelrod, 1997) generated cultural diversity by using homophily to regulate dyadic social influence. Secondly, Klemm et al (Klemm et al., 2003) showed that various rates of mutations destabilize Axelrod's cultural diversity, with low rates converging the model into monoculture while higher rates led to anomie.

Finally, based on work by Parisi et al (2003), Flache et al (2011) introduced multilateral social influence to Axelrod's homophily.

We are adopting the same conceptualization of social influence (directed by homophily) as Axelrod (Axelrod, 1997). Homophily of agents ***a*** and ***n*** determines whether an interaction occurs or not, based on the number of equivalent traits in both agents, so we can use the following function of similarity (***Sim(a, n)***) to calculate the homophily between agents:

$$Sim(a,n) = \frac{1}{F}\sum_{f=1}^{F} \delta\left(a_f, n_f\right) \tag{1}$$

Here, ***F*** is the total amount of features and the ***δ(i,j)*** function refers to the Krockener delta:

$$\delta(i,j) = \begin{cases} 1, & i = j \\ 0, & i \neq j \end{cases} \tag{2}$$

We will conceptualize noise in the same way Flache et al (Flache & Macy, 2011) did: an instance of mutation (Klemm et al., 2005) occurs when the trait of an agent, after a possible interaction, is randomly selected and set to a new feature. A mutation occurs with probability ***m***. An instance of selection error (Flache & Macy, 2011) occurs after the initial interaction outcome has been decided based on homophily, and it reverses the initial decision to interact (or not). A selection error occurs with probability ***s***. In order to simplify the study we will keep ***m* = *s*** across all the experiments, as Flache et al (Flache & Macy, 2011) did.

We also decided to integrate the selection error into the homophily rule, resulting in one formula, which we call Perceived Homophily (***PH(a,n)***):

$$PH(a,n) = (1 - s)Sim(a,n) + s(1 - Sim(a,n) \tag{3}$$

Our Perceived Homophily rule is equivalent to Flache et al's approach of applying homophily first, and selection error second (Flache & Macy, 2011).

Finally, our response variable will be the number of cultural regions remaining after the final agent interaction iteration. We decided on a different response variable than Flache et al. (2011) due to the different outcomes that we are analyzing. Flache et al. used the "normalized size of the largest region" in order to observe how noise affects the tendency towards a monoculture or globalization in a system, with the assumption that this measure does reflect diversity, without the need to explicitly state the number of cultures. We have chosen to examine the number of cultures, since we are interested in cultural diversity per se as it emerges and is preserved by manipulation of different institutional factors, so our measure is more fitting and expressive of our purposes. It will be normalized through division by the total number of agents (denoted ***N***) in the given simulation, to best showcase similarities across different population sizes.

$$response\ variable = \frac{total\ number\ of\ cultural\ regions}{N} \tag{4}$$

For a comparison of the two response variables in question and how they affect our results, please refer to Appendix 1.

2.2.2 Baseline: Models of institutional influence and loyalty

The main purpose of our investigation of institutions is their impact on cultural patterns reflected in Axelrod's model of dyadic social influence. For our baseline model we integrate institutional influence into our combination of dyadic social influence with homophily (Axelrod, 1997), mutation (Klemm et al., 2003, 2005), and selection error (Flache & Macy, 2011). For this intent, we use the institutional influence function (***Inf(a,n)***):

$$Inf(a,n) = \frac{\alpha \cdot Sim(a,i_a)}{(1-\alpha) \cdot Sim(a,n) + \alpha \cdot Sim(a,i_a)}\text{ , where } \alpha \in [0,1] \tag{5}$$

Institutional influence is exerted as a combination of agent similarity, (***Sim(a,n)***) and institutional similarity ***Sim(a,i_a)***. We define institutional similarity in the same way as the original homophily formula of similarity. As the formula expresses, the probability of trait change decreases as the agent's similarity to its own institution increases. Moreover, the alpha parameter (α) controls the amount of institutional influence. This same value is applied to all the agents in the simulation. The bigger the α, the more importance agents give to their institutions, and therefore the less likely it is that a trait change will occur.

Institutional influence, ***Inf(a,n)***, is applied only when there is an institutional conflict, i.e. a situation in which the agent ***a*** currently holds the same trait as its own institution, i_a, but the "active trait" (i.e. the agent's to-be-adopted trait by social influence) is different from the trait that the institution i_a holds. The agent is "being tempted" into dissimilarity from its own institution, and the institution is exerting its influence to stop this from happening.

In the case where there is no institutional conflict, the formula for Perceived Homophily ***PH(a,n)*** is used instead, and no institutional influence is exerted.

Because of constant interactions with neighbors, an agent's cultural vector can turn out to be more similar to its neighbor's institution than its own. In this case, after the interaction with its neighbor, the agent checks if a change of institutions is favourable. We determine whether an agent $\boldsymbol{a}$ will remain loyal to its own institution $\boldsymbol{i_a}$ when confronted with the institution $\boldsymbol{i_a}$ of the neighbor $\boldsymbol{n}$ by applying the agent loyalty function ***Loy(a,n)***:

$$Loy(a,n) = \frac{\alpha' \cdot Sim(a, i_a)}{(1-\alpha') \cdot Sim(a, i_n) + \alpha' \cdot Sim(a, i_a)} \text{, where } \alpha' \epsilon [0,1] \tag{6}$$

The $\boldsymbol{\alpha'}$ parameter controls the agent's loyalty to its current institution and applies identically to all agents: the higher the $\boldsymbol{\alpha'}$ parameter, the higher the agent's loyalty towards its original institution, and the less likely an institutional change. We introduce the agent's similarity to the neighbor's institution, $\boldsymbol{Sim(a, i_n)}$, into the denominator's function, so that the probability of institutional change increases as the agent's similarity to its neighbor's institution increases.

2.2.3 Extensions: Models of referenda and propaganda

After investigating the stability and diversity values of our baseline model, we will investigate the influence processes between agents and institutions in two ways.

The first extension is a bottom-up process that resembles a democratic process, e.g. a referendum. Agents can influence their institutions with the intention of aligning the institution towards the agents' traits. When many individuals in a population manifest disagreement with their institution's current stance on a particular issue, they can force the institution to change towards the popular opinion. In our model, we adopt this extension by selecting one institutional trait that is the least popular among the given population at the time; then we allow agents to "vote" to change it to that trait which the majority approves. We can control the prevalence of democracy by specifying the number (***X***) of interaction opportunities that each agent has with another agent before they are allowed to act together in a voting process. This is called the frequency of democracy, ***fd***, and it is the reciprocal of ***X***, i.e. ***1/X***.

The second extension is a top-down process that resembles a propaganda campaign of an institution, by way of dissemination of its cultural traits with the intention of aligning more of the agents' traits towards itself. In our model, we adopt this extension by allowing the institution to try and push its traits onto each of its affiliated agents. Whether an agent allows the propaganda to change its trait depends on how similar this agent ***a*** already is to its own institution, i.e. $Sim(a, i_a)$. We control the prevalence of propaganda the same way we did for democracy, i.e. by a certain number (***Y***) of interaction opportunities between agents, and define the frequency of propaganda, ***fp,*** as the reciprocal of ***Y***, i.e. ***1/Y***.

We will also combine the two extensions in our last model to analyze the results of a combination of both bottom-up and top-down processes together, in the form of a feedback loop of institutional influence.

We summarize all formal rules which we are adopting for our six model variations inTable 2. Rules are constructed based on Axelrod's model (A), to which we add our baseline (B, institutional influence and agent loyalty), and which we then extend by adding a democratic process (D, e.g. a referendum), or a propaganda process (P, e.g. advertisement campaigns), or both combined.

Table 2. Formal rules of presented models. The first column indicates the rules inherent in each step of a given model. The second to fifth column indicate the model to which they apply (A: Axelrod, B: Our Baseline, D: Democracy extension, P: Propaganda extension). The star symbol (*) indicates a specific value of a variable.

Step	**A**	**B**	**D**	**P**
1. At random, pick one agent ***a*** and one of its neighbors ***n*** from ***a***'s possible neighbors, as defined by a radius ***r***	X	X	X	X
2. Randomly select a feature ***f**** (of those features that have differing traits of **a** and **n**). Then, select $t^* = n_{f^*}$	X	X	X	X
3. **(Institutional conflict)** If the current trait of the agent's institution i_{af^*} (1) is not undefined ($i_{af^*} \neq -1$), and (2) it is equal to the agent's existing trait a_{f^*} (i.e. $i_{af^*} = a_{f^*}$), and (3) if the institution's trait i_{af^*} is different to the to-be-adopted trait ***t**** ($i_{af^*} = t^*$), then		X	X	X
3.1. **(Perceived Homophily + Institutional Influence)** Agent **a** accepts the trait ***t**** for ***f**** with a probability of trait change P_{tc} equal to ***Inf(a, n)***		X	X	X
3.2. **(Agent loyalty)** If agent **a** accepts the trait ***t****, then ***a*** changes its institution to i_n with a probability of institutional change P_{ic} equal to ***Loy(a, n)***		X	X	X
3.3. If the agent ***a*** changes its institution to i_n, and if i_n does not yet have a trait on the selected feature ***f****, then assign ***t**** to i_{nf}.		X	X	X
4. **(Perceived Homophily)** If the conditions in the previous step were not met or for a model without institutions; then the agent ***a*** accepts the trait ***t**** with a probability of trait change P_{tc} equal to ***PH(a, n)***	X	X	X	X
5. **(Mutation)** With probability ***m***, randomly change one of the features of agent **a** to randomly selected trait	X	X	X	X
6 **(Democracy)** After $fd \times N$ (***N*** is the population size) repetitions of steps 1 to 5, initiate a Democratic process. For each institution ***i***:			X	
6.1 A subset ***D*** containing all agents belonging to ***i*** is created.			X	

6.2 All agents in ***D*** cast a vote containing their current trait for each of their features. A voting matrix ***V***, is generated, where V_{ft} corresponds to the number of votes that trait ***t*** received for feature ***f***, i.e. $V_{ft} = \Sigma_{d \in D}\ \delta(d_f, t)$			X	
6.3 A matrix **W** is defined by $W_{ft} = V_{ft} - V_{fc}$, where ***c*** is the current trait for the feature ***f*** of the institution ***i***. This matrix holds the differences on popularity (votes) between the current traits of the institution and their alternatives.			X	
6.4 Create a subset ***FT*** of pairs ***(f, t)*** in which W_{ft} is maximal in ***D*** and bigger than zero. This subset contains the traits that comprise the biggest differences between each institution and its agents.			X	
6.5 Randomly select a pair ***(f*,t*)*** from ***FT*** and replace i_f with ***t****			X	
7. **(Propaganda)** After $fp \times N$ (***N*** is the population size) repetitions of steps 1 to 5, initiate a Propaganda process. For each institution ***i***:				X
7.1. A subset ***P*** containing all the agents belonging to ***i*** is created. For each agent ***a*** in ***P***:				X
7.1.1 Calculate the similarity between agent ***a*** and ***i***, and set this as the probability of trait change, i.e. $Ptc = Sim(a, i)$				X
7.1.2. For each feature ***f,*** change $a_f = i_f$ with probability of trait change ***Ptc***				X

2.2.4 Experimental Design

We are exploring the effects of institutional influence and agent loyalty, and comparing some results with Axelrod and Flache et al by replicating their models with our code. We are also integrating democratic processes, propaganda processes, or both together into simulations. We are therefore presenting the results of six different experiments, called experiments A to F. For all six experiments, we hold certain factors constant. Results are presented across the three chosen population sizes (10x10, 32x32, 100x100), and for six chosen levels of noise (10^{-n}, where e $n \in \{6,5,4,3,2,1\}$). Agents hold 5 features (F), 15 traits (T), and between 27 and 84 neighbors (depending on their position on the grid and a Von Neumann neighborhood of 6). All these values were chosen based on Flache et al (Flache & Macy, 2011). The number of agent interaction iterations is set at 100000 possible interactions on average per agent, which has previously been shown to be the number at which a population can be expected to have converged to a stochastically stable state (Axelrod, 1997). Please find results that validate an equilibrium state after 100000 interactions for our model in Appendix 5. Since each simulation is non deterministic (e.g. agent traits, social and institutional influences depend on probabilities), every run can, and often does, produce different results even when undergoing the exact same treatment (i.e. when we run the simulation with the same combination of factors levels). Therefore, we repeat each treatment 50 times, and our response variable is the average of the 50 results, with each result being one normalized number of cultural regions after the last iteration.

For an overview over the contrasting factors for experiments A to F, please refer to Table 3. For the sake of readability, unless explicitly specified by the formula (***Inf(a,n)***), institutional influence will from now on be referred to as the alpha parameter (***α***) and agent loyalty, (***Loy(a,n)***), as the alpha prime parameter (***α'***). Notation to identify specific models will be population/α/α', for example 10x10/0.8/0.95 for the smallest population with institutional influence of 0.8 and agent loyalty set at 0.95.

Table 3. Contrasting factors for experiments A to F. The first row identifies the letters assigned to each of our experiments (A to F), the second row is a brief description of the models. The first column identifies all the factors involved in each experiment. Remaining columns display the values that were chosen in the respective models.

	A	**B**	**C**	**D**	**E**	**F**
Model (M)	Ours	Axelrod's, Flache's, Ours	Ours	Ours + Democracy	Ours + Propaganda	Ours + Democracy + Propaganda
Institutional influence (α)	[0.5, 1[	Axelrod's: N/A, Flache's: N/A, Ours:0.8, 0.9	10x10: 0.85, 32x32: 0.8, 100x100: 0.75	10x10: 0.85, 32x32: 0.8, 100x100: 0.75	10x10: 0.85, 32x32: 0.8, 100x100: 0.75	10x10: 0.85, 32x32: 0.8, 100x100: 0.75
Agent loyalty (α′)	0.5	0.5	0.05, 0.5, 0.95	0.5	0.5	0.5
Frequency of democracy (fd)	N/A	N/A	N/A	1/10,1/100, 1/1000	N/A	1/10,1/100, 1/1000
Frequency of propaganda (fp)	N/A	N/A	N/A	N/A	1/1, 1/3, 1/5	1/1, 1/3, 1/5

For the first three experiments, A, B and C, we are exploring the effects of varying values of institutional influence and agent loyalty on cultural diversity: for experiment A, we manipulate institutional influence ***α***, from 0.5 to 1.0 to test its impact on cultural diversity, while holding agent loyalty, ***α'***, constant at 0.5. Experiment B replicates Axelrod's model (Axelrod, 1997) and Flache's model (Flache & Macy, 2011) to directly compare their results with the values that achieved the most similar results to Flache et al in experiment A, i.e. ***α*** = 0.8 and ***α*** = 0.9.

For experiment C, we are manipulating agent loyalty by applying extreme values of 0.05 and 0.95, and comparing this to the 0.5 baseline value from experiments A and B. We also select three different ***α*** values for the three given populations: 0.85 for 10x10, 0.8 for 32x32, and 0.75 for 100x100. We do this in order to showcase that the subsequent results are not dependent on one particular value of influence, and because they provide some variance in initial cultural diversity (higher for smaller populations, and lower for bigger populations) while not being extreme, i.e. too near of either globalization or anomie. This moderate rate is valuable in our study of others factors; if the institutional influence chosen induces too much diversity to start with, we might not be able to see whether loyalty values increase diversity as well.

Experiments D and E manipulate the frequency of democratic and of propaganda processes by changing the number of interaction opportunities that each agent has with another agent; for democracy, these values are set at 1/10,1/100,and 1/1000, for propaganda at 1/1,1/3 and 1/5.

Experiment F combines democracy (at frequency 1/10,1/100 and 1/1000) and propaganda (at frequency 1/1,1/3,and 1/5) with their above described frequencies, and investigates the interaction of both.

2.3 Results

The following section is subdivided into two parts: we will first explore and discuss the effects of our two main model parameters, institutional influence and agent loyalty, on diversity, and compare them against results obtained in two previous models, i.e. Axelrod's and Flache's, in experiments A to C. We will then in the second section provide the results of our democratic model, of our propaganda model, and the integration of both democracy and propaganda in one model, i.e. experiments D to F, and discuss the implications inherent in those extensions.

2.3.1 Results: Experiment A to C

2.3.1.1 Experiment A: Institutional influence

In our first experiment, we manipulated institutional influence while holding agent loyalty constant ($\boldsymbol{\alpha}'$ = 0.5). We explored all institutional influences from 0 to 1.0, but we found no relevant results for values for $\boldsymbol{\alpha}$ < 0.7. For those values, the model was highly sensitive to low levels of noise, and, for populations of 10x10 and 32x32, we found very small differences in cultural diversity, even in a configuration with almost no noise.

In Figure 3 we present values for which we found relevant results of institutional influence, i.e. $\boldsymbol{\alpha}$ = 0.5, 0.7, 0.8, 0.9 and 0.95, and we show how they affect our three chosen population sizes.

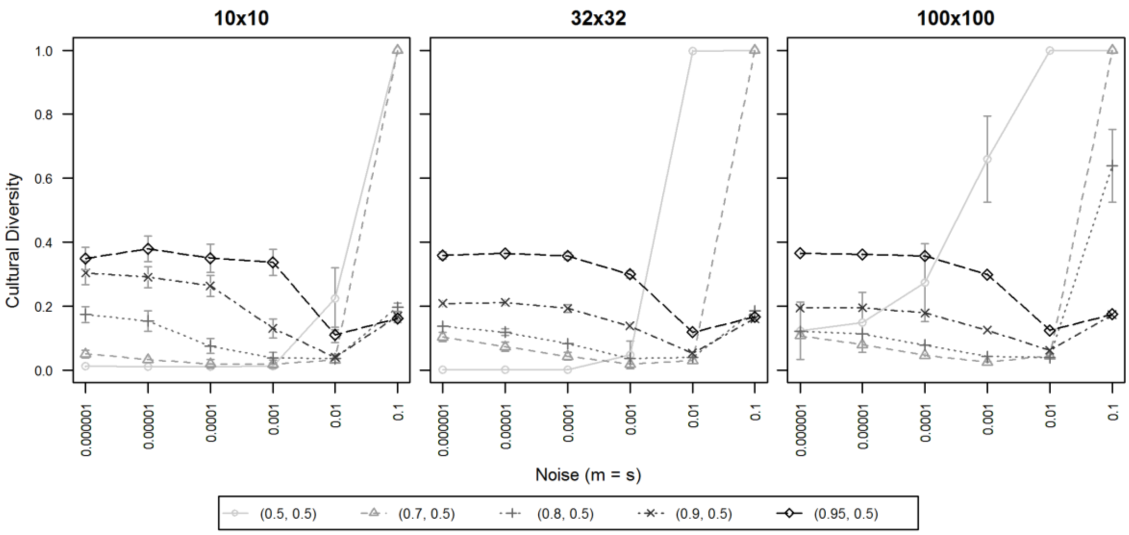

Figure 3. Cultural diversity for varying levels of institutional influence. X-axis displays levels of noise; Y-axis displays normalized cultural diversity. Each line symbol denotes one α of institutional influence. 95% confidence intervals are displayed only when exceeding the size of the line symbol. Data points are averages of 50 repetitions per territory with 100,000 iterations per agent.

Based on the graphic representation of our results, we can identify that cultural diversity varies greatly depending on institutional influence, in particular when levels of noise are very low (<= 0.001). In this range of noise, we found that the more institutional influence was exerted, the more diversity was found across the entire population. While for low noise (<= 0.01), high values of alpha (***α*** >= 0.7) did still sustain diversity, we observed that under the highest level of noise (0.1), only higher values of alpha (***α*** >= 0.8) were able to sustain diversity. Lower values of noise (<= 0.7) induced a state of anomie.

These results are similar for all three population sizes, and similarity increase with an increasing α value. We found no significant effect that would suggest differences based on population size, with $F(2, 882) = 0.17$, $p = 0.85$, when we input all population sizes and noises as factors in an ANOVA and calculated differences for ***α*** = 0.95.When we compared 32x32/>=0.7/0.5 and 100x100/>=0.7/0.5 in an ANOVA (with noise <= 0.01), we also found no significance effect between them, with $F(1, 1960) = 1.41$, $p = 0.23$. For further details on the performed ANOVA calculations, please refer to Appendix 1.

Since we normalized the number of cultural regions by population, a proportional diversity by population means that calculated by absolute values, on average, the bigger the given population, the more cultural regions remain after the last interaction. Consequently, on average, reported normalized cultural regions tend to be of the same size. Table 4 gives an overview over the absolute number of cultures obtained for our models at the lowest level of noise (0.000001). Especially for the higher alphas (***α*** >= 0.8), a linear relationship is visible, as we perceived an increase of cultural regions by a factor of 10, in linear relation with the increase of the population size by a factor of 10.

Table 4. Number of cultures and institutions (cultures / institutions) per population size over alpha values 0.5 to 0.95. Averages of 50 repetitions, after 100000 iterations per agent, with noise level at 0.000001.

	100 (10x10)	1024 (32x32)	10000 (100x100)
0.5	1.14 / 10.9	1.02 / 48.00	1219.46 / 102.98
0.7	4.98 / 7.94	106.12 / 76.98	1073.12 / 691.68
0.8	17.32 / 8.28	139.88 / 55.50	1210.38 / 462.92
0.9	30.38 / 6.92	212.98 / 31.58	1944.98 / 243.5
0.95	34.82 / 6.32	367.28 / 41.98	3647.70 / 370.98

Table 4 also displays the total number of institutions and its similar linear relationship with population size. For all data, there was a strong positive correlation between the population and the number of institutions, r = 0.53, p < 0.0001. This correlation increased for higher alphas, e.g. for ***α*** >= 0.9, r = 0.84, p < 0.0001. At this point (α >= 0.9), there was a very strong positive correlation between the number of cultures and the number of institutions, r = 0.93, p < 0.0001. We can observe in Table 3 that for most data points, more cultures than institutions exist, with the only exceptions at lower alphas (i.e. at 32x32/0.5/0.5, and at 10x10/0.7/0.5).

2.3.1.2 Experiment B: Replication of Axelrod's and Flache's models

In order to compare the results of our first experiment with other models, we replicated Axelrod's (Axelrod, 1997) and Flache's models - experiments 1 and 3, p.978 & p.984 in Flache & Macy (2011); using an implementation with our own code. For a detailed comparison of the implementations, please see Appendix 6, in which we also include graphs for all our results with the response variable S_{max}/N, i.e. normalized size of largest region, as used by Flache et al (2011).

Qualitatively, the replications exhibited an equivalent behavior to the originals, especially regarding stability against noise. Statistically, we do not find a significant difference between the model implementations of Axelrod's model, with $F(1, 1176) = 0.007$, $p = 0.935$. However, we find a significant difference between the model implementations of Flache's model, with $F(1, 1176) = 80.491$, $p < 0.0001$, as our code resulted in slightly higher levels of diversity in our implementation of Flache's model, compared to their original results. However the effect size was found to be small ($\eta p^2 = 0.064$).

From experiment A, we chose institutional influence α = 0.8 and 0.9 f or the graphs presented in Figure 4, and compared them with our implementation of Axelrod's and Flache's models at various levels of noise, with our values otherwise equivalent to Figure 3.

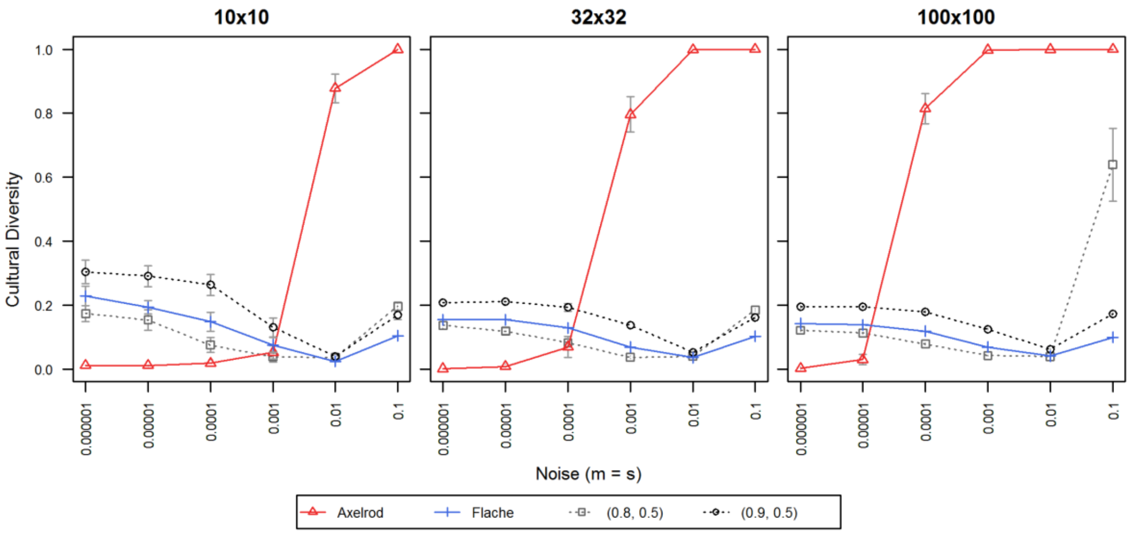

Figure 4. Cultural diversity for different models (Axelrod's, Flache's, and ours). X-axis displays levels of noise; Y-axis displays normalized cultural diversity. Each colored line symbol denotes one of three models, i.e. Axelrod's (continuous red), Flache's (continuous blue), ours with α = 0.9 and α' = 0.5 (dotted black) and ours with α = 0.8 and α' = 0.5 (dotted gray). 95% confidence intervals are displayed only when exceeding the size of the line symbol. Data points are averages of 50 repetitions per territory with 100,000 iterations per agent.

Consistent with previous research (Flache & Macy, 2011; Klemm et al., 2003, 2005), in our replication, Axelrod's model was highly sensitive to noise (and the threshold where monoculture turns to anomie decreased for bigger populations), while Flache's did not display this high sensitivity to noise, just as in the original research (Flache & Macy, 2011). Our model exhibited a similar robustness at higher studied levels of institutional influence, α >= 0.8 (except in model 100x100/0.8/0.5 and noise level at 0.1).

In terms of the number of cultural regions, while for α <= 0.8, our diversity generally fell below the levels researched by Flache's model, at a high institutional influence α >= 0.9, our model was able to sustain more diversity than Flache's across all levels of noise and population sizes, as is evident from Figure 4.

2.3.1.3 Experiment C: Agent loyalty

For experiment C, we chose three different values of institutional influence: α = 0.85 for the population of 10x10, α = 0.8 for 32x32, and α = 0.75 for 100x100. Figure 5 illustrates results obtained by manipulation of agent loyalty (***α'***) in addition to the just mentioned ***α*** values that we chose as institutional influence.

Unlike in the previous figures, a visual analysis of the graphs does not provide a clear overview over the effects, however, a statistical analysis yields some information: across all populations, low values of loyalty (***α'*** = 0.05) (compared to the baseline (***α'*** = 0.5)) did significantly reduce the level of diversity, $F(1, 1764) = 32.57$, $p < 0.0001$. This is particularly visible in Figure 5 for the medium and large populations and noise <= 0.0001. An analysis of high values of loyalty (α' = 0.95) produced an effect in the other direction, i.e. an increase of diversity, however, we only found significate differences for 32x32/0.8 and noise <= 0.01, $F(1, 490) = 12.31$, $p = 0.00049$; and for 100x100/0.75, $F(1, 588) = 109.87$, $p < 0.0001$. In general, effects were stronger for bigger populations and lower institutional influences. Detailed explanations of the calculated F-values and significance levels can be found in Appendix 2.

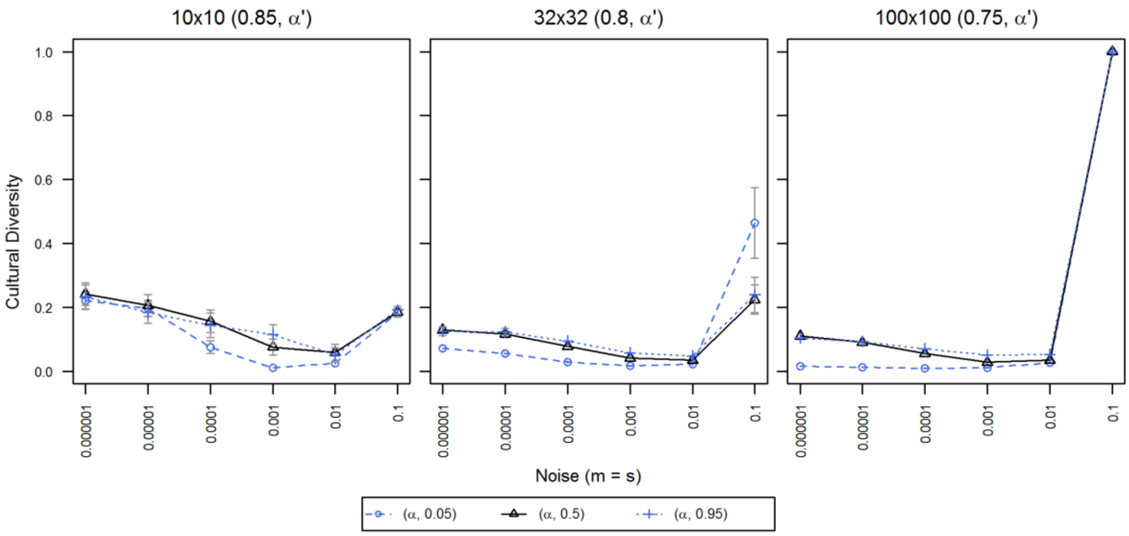

Figure 5. Cultural diversity for different levels of agent loyalty. X-axis displays levels of noise; Y-axis displays normalized cultural diversity. Each line symbol denotes one alpha prime of agent loyalty. 95% confidence intervals are displayed only when exceeding the size of the line symbol. Data points are averages of 50 repetitions per territory with 100,000 iterations per agent.

2.3.1.4 Discussion: Experiments A to C

The first three experiments extend on previous institutional research [26-36] by directly modelling the effects of institutions on social influence processes and diversity. Our primary findings establish that institutional influence is successful in preserving cultural diversity by allowing multiple cultural regions to exist simultaneously in a stable system. Agents' loyalty to their institutions did play a small role in the preservation of diversity; however, it did not facilitate any increases. In multiple cases, our experiments compare favorably with previous results obtained by Axelrod (1997) and Flache et al. (2011) in terms of stability and diversity.

Extending on the main result obtained in experiment A, we found that various amounts of institutional influence ($\boldsymbol{\alpha}$ >= 0.7) impact the extent of diversity that can be obtained and can be used to control the number of cultural regions that will emerge. It is important to consider the implications of the values that are presented in our model: an institutional influence $\boldsymbol{\alpha}$ < 0.5 reflects that agents are giving more importance to their neighbor's opinion than to that of their institution. Probabilistically speaking, if an institutional influence value of α < 0.5 privileges the neighbor's influence, it is unsurprising that our results converge towards results obtained in Axelrod's original model, in which the neighbor's influence (regulated by homophily) is the only factor that matters. Notice that our model with $\boldsymbol{\alpha}$ = 0 implies removing homophily from Axelrod's model, a scenario where the neighbor's influence is extreme. Thus, values around $\boldsymbol{\alpha}$ = 0.7 are not in reality as high as they might first appear.

We found adequate and stable results for values of $\boldsymbol{\alpha}$ between 0.7 and 0.95, and experiment B clarifies that our model with high levels of institutional influence ($\boldsymbol{\alpha}$ >= 0.9) was able to sustain even more diversity than Flache's model of multilateral social influence (Flache, 2011), which, to our knowledge, had yielded the best results so far in terms of diversity and stability. Additionally, for high levels of institutional influence, our model proved to be resilient when tested against the same levels of noise as Flache's model.

We did not find any strong effects in experiment C, when analysing the impact on agent loyalty, although a small impact on preserving diversity was established. The main obstacle in this case seems to be that $\boldsymbol{\alpha'}$ is applied as a factor only in a very limited number of occasions, as it heavily depends on the initial institutional influence, i.e. the institution has to allow a trait change in the first place before an agent gets to decide whether they will switch to another institution (see Rule 3.1 and Rule 3.2 in Table 2), thus reducing the probability of institutional change. We found that the model in which we used the lowest alpha (100x100/0.75/0.5 in experiment C) showed the strongest effect of agent loyalty, which provides some empirical support for this post-hoc hypothesis. The alternative hypothesis, i.e. that the size of the population is the explanatory factor, is not supported by Experiment A, as our data shows that population size had no strong effects in any of the simulations. However, experiments that specifically address this hypothesis will be necessary to expand on our findings.

We found that, in our models, the normalized number of cultural regions was proportional to the population (when α/α' is held constant) which suggests that our results are scalable, i.e. the results hold regardless the population size. Consequently, there is a linear trend for the absolute number of cultural regions , where the bigger the population, the more cultures emerge. This implies that the size of the cultural regions (i.e. number of agents per cultural region on average) is similar across populations, but changes for each model through the given α and α' values. Thus, an alternative interpretation of our results is that the addition of strong institutions to the simulation impacted the size, not the number, of the cultural regions that emerged in the system. Our model here replicates the reversal behaviour of Axelrod's previous finding (that number of cultures decreases with increasing population size (p219, Axelrod, 1997), which had previously also been addressed and discussed by Flache et al (p9842011).

Lastly, our results in Table 4 show that, generally speaking, more cultures than institutions emerged in our models. This means that even under the influence of one institution, multiple agents can all belong to different cultures and those cultures can survive. In other words, an institution can allow the simultaneous existence of several cultures. This result is consistent with Shibanai et al (Shibanai et al., 2001), in which mass media, as a globally acting entity, was also found to promote the emergence of cultural diversity.

So far, our models support the idea that institutional influence can be used to control cultural diversity. In the following experiments D to F, we will now extend our study of institutions to include two mechanisms of influence used by and on institutions: democracy and propaganda.

2.3.2 Section 2: Experiments D to F

In this second set of experiments, we show how two directions of institutional influence affect the system: bottom-up (democracy) and top-down (propaganda). We explore how they impact cultural regions and institution numbers when we apply the influence-loyalty model from experiment C, i.e. model values of 10x10/0.85/0.5, 32x32/0.8/0.5 and 100x100/0.75/0.5.

2.3.2.1 Experiment D: Rare and frequent democratic processes

In our democratic model, we manipulated the frequency at which democratic processes (referenda) occur in a system. We defined a unit of time as equivalent to the number of iterations necessary to have one iteration on average per agent, i.e. a unit of time is equivalent to 100 iterations in 10x10; 1024 in 32x32; and 10000 in 100x100. Then, a period is the duration of time between events. For example, a period of 10, i.e. a frequency of 1/10, means that the referenda occur after an average of 10 iterations per agent. We have set the frequency in exponential decrements of 1/10 (high democracy), 1/100 (moderate democracy) and 1/1000 (low democracy), in order to study a broad spectrum of possible values.

As can be seen in Figure 6, in a model where democratic processes are allowed, cultural diversity was sustained, but it was strongly reduced compared to the previous baseline of diversity that we achieved in experiment A. This was the case at all three frequencies of democracy and all population sizes. Additionally, for the 10x10 population, the lower the democracy, the higher the diversity, when noise <= 0.01, with $F(2, 735) = 48.806$, $p < 0.0001$. For populations >= 32x32 this effect was non-monotonous. The lowest amount of diversity was reached by allowing moderate democracy (1/100). The difference was significant when compared to low democracy (1/1000) when noise <= 0.01, with $F(1, 980) = 259.595$, $p < 0.0001$, as well as compared to high democracy (1/10), with $F(1,980) = 181.324$, $p < 0.0001$ when noise <= 0.01. We present the results with noise <= 0.01 to avoid the extreme effect with noise = 0.1 observed in the figure, although that effect is consistent with our results. For further details on the performed ANOVA calculations, please refer to Appendix 3.

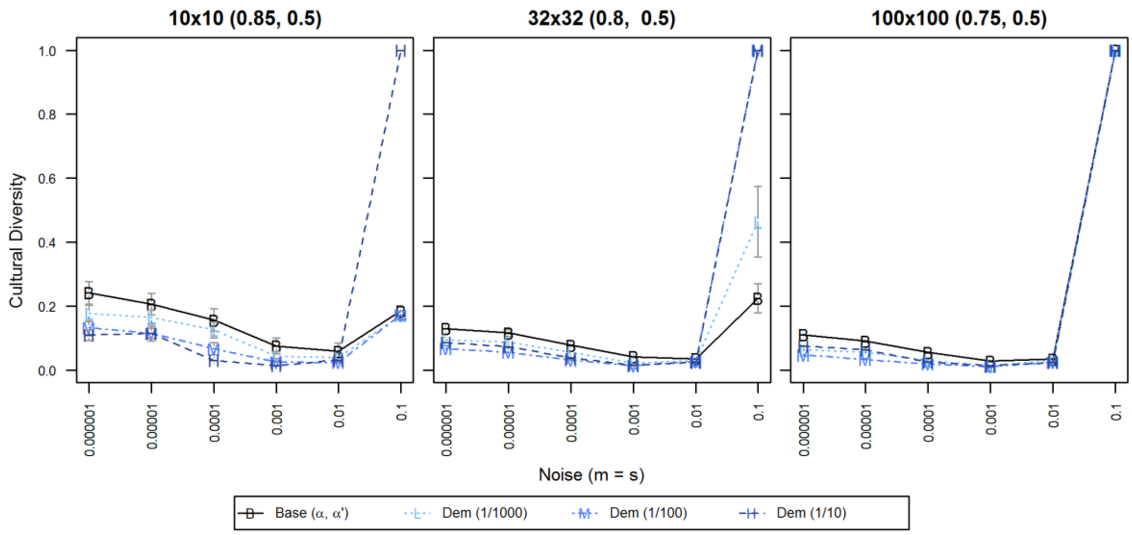

Figure 6. Cultural diversity for different frequencies of democracy. X-axis displays levels of noise; Y-axis displays normalized cultural diversity. Each colored line symbol denotes one frequency of democracy, from low (light blue) to high (dark blue). 95% confidence intervals are displayed only when exceeding the size of the line symbol. Data points are averages of 50 repetitions per territory with 100,000 iterations per agent.

With regards to robustness, the system with added democracy turned somewhat unstable from a noise level of 0.01 onwards; at noise equals to 0.1, a state of anomie was reached for low democracy in 100x100, for medium democracy in 32x32 and 100x100, and for high democracy in all population sizes. Thus, an exploration of even more frequent democratic processes was deemed unnecessary; the results indicated that higher levels of democracy would only further destabilize our model against noise.

2.3.2.2 Experiment E: Rare and frequent propaganda processes

Just as with democracy in experiment D, in our model with propaganda, we manipulated the frequency at which propaganda processes occur in a system. When one looks at the occurrence of these two political tools, one finds that referenda are, in reality, rare (Serdült & Welp, 2012, p.76), whereas instances of propaganda are quite common and frequently encountered (*The Propaganda Society*, 2011), so this time, we used higher frequencies of 1/1, 1/3 and 1/5. When we attempted rarer frequencies of propaganda in an earlier exploratory analysis, aligned with our predictions, once propaganda becomes too rare, effects become indiscernible.

As can be seen in Figure 7, our model with propaganda generated many co-existing cultural regions, i.e. in general, more propaganda led to more diversity. The only exception of this effect was found at the highest value of noise (0.1). At this level of noise, it was the rarer level of propaganda (1/5) which yielded more diversity than the moderate level (1/3).

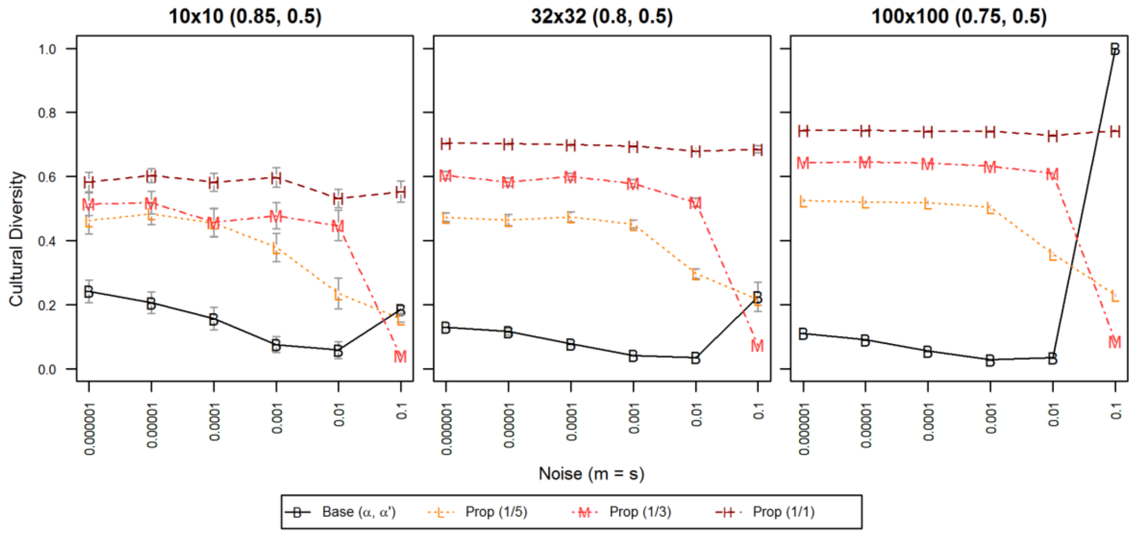

Figure 7. Cultural diversity for different frequencies of propaganda. X-axis displays levels of noise; Y-axis displays normalized cultural diversity. Each line symbol denotes one frequency of propaganda, from low (light red) to high (dark red). 95% confidence intervals are displayed only when exceeding the size of the line symbol. Data points are averages of 50 repetitions per territory with 100,000 iterations per agent.

In terms of resilience against noise, propaganda was able to stabilize the system even at the highest levels of noise (0.1). However, we found noticeable variations of diversity for the chosen frequencies of propaganda under higher levels of noise. For example, there was a tendency to monoculture, i.e. diversity was reduced significantly at noise levels = 0.01 and 0.1 and when propaganda was rare to medium frequent. This is a clear departure from the behavior of our previous models, where we so far tended to observe a convergence to anomie, which is better substantiated theoretically (as the highest possible noise value (1.0) can be equated with anomie).

2.3.2.3 Experiment F: Referendum + Propaganda

Our final experiment explored what effects the combination of the two studied process in experiments D and E, democracy and propaganda, would have on the diversity in our system. We combined the two processes, generating a feedback loop of information that flows from individual to institutions (democracy) and vice versa (propaganda), so that institutional influence could run in both directions. This idea has been implicitly proposed in previous institutional research [35]. We manipulated the frequency at which both these processes occur in a system with the same values as we explored before, so for propaganda, we applied it on average every 1/1, 1/3 and 1/5 of interactions, while for democracy, we chose to apply it at frequency levels of 1/10, 1/100 and 1/1000; in the following graph (Figure 8), we omitted medium democracy (1/100) for brevity and readability, as it did not add additional information, i.e. it followed the prevailing trend described below. For the graph including medium democracy, please refer to Appendix 8.

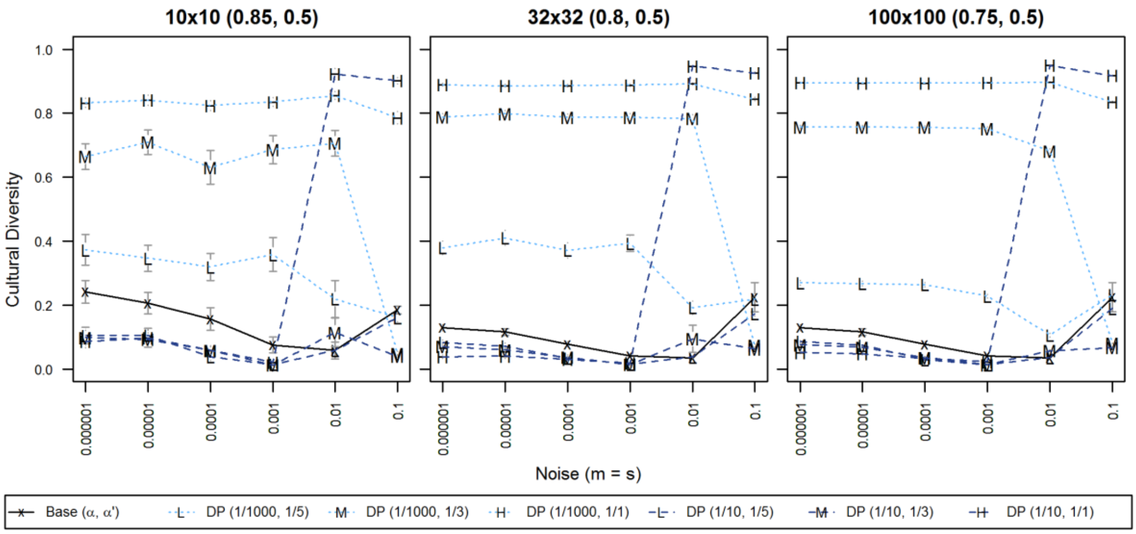

Figure 8. Cultural diversity for combinations of democracy and propaganda frequencies. X-axis displays levels of noise; Y-axis displays normalized cultural diversity. Each line symbol denotes one combination of democracy and propaganda. 95% confidence intervals are displayed only when exceeding the size of the line symbol. Data points are averages of 50 repetitions per territory with 100,000 iterations per agent.

In our feedback loop of institutional influence, the main effects of propaganda and democracy were partly confirmed from previous experiments: high levels of democracy still produced less diversity than baseline values that we obtained in experiment C (black lines in Figure 8), and also significantly less than low democracy, similar to experiment D. Furthermore, when we analyzed effects of propaganda interacting only with low democracy, propaganda held a positive relationship with diversity, i.e. the more propaganda, the more cultural regions, just as was the case in experiment E.

The effects are more difficult to discern for common democratic processes (1/10). For noise levels <= 0.001, differences in diversity are small, and for noise levels >= 0.01, the model turns very sensitive to propaganda. The interaction of democracy and propaganda for noise levels <= 0.00001, however, significantly impacts diversity. In this situation, the way propaganda impacts diversity was reversed, i.e. a system with high propaganda and high democracy produced less diversity, while less propaganda in a state of high democracy produced more cultural regions. This effect is only marginally visible in Figure 8, but statistically, we found a significant difference for populations >= 32x32, with F(2, 588) = 142.552, $p < 0.0001$. Further details regarding our calculations can be found under Appendix 4.

Finally, we would also like to present some data with regards to the numbers of institutions for this last experiment. Data and figures illustrating institutional numbers from experiments A, C, D and E can be found under Appendix 7.

We previously indicated in Table 4 that the number of institutions is generally smaller than the number of cultures across all our models. As illustrated in Figure 9, in this combined model, both democracy and propaganda increased the number of institutions when compared to the baseline. Democracy had the stronger effect. These effects were qualitatively similar for a separate analysis of democracy (Figure C in Appendix 7), and propaganda (Figure D in Appendix 7), but somewhat less extreme in their individual applications, i.e. numbers of institutions tended to be smaller than shown here. In particular for high levels of democracy, the number of institutions increased such, that it was higher than the resulting number of cultural regions, i.e. one cultural region could be governed by multiple different institutions.

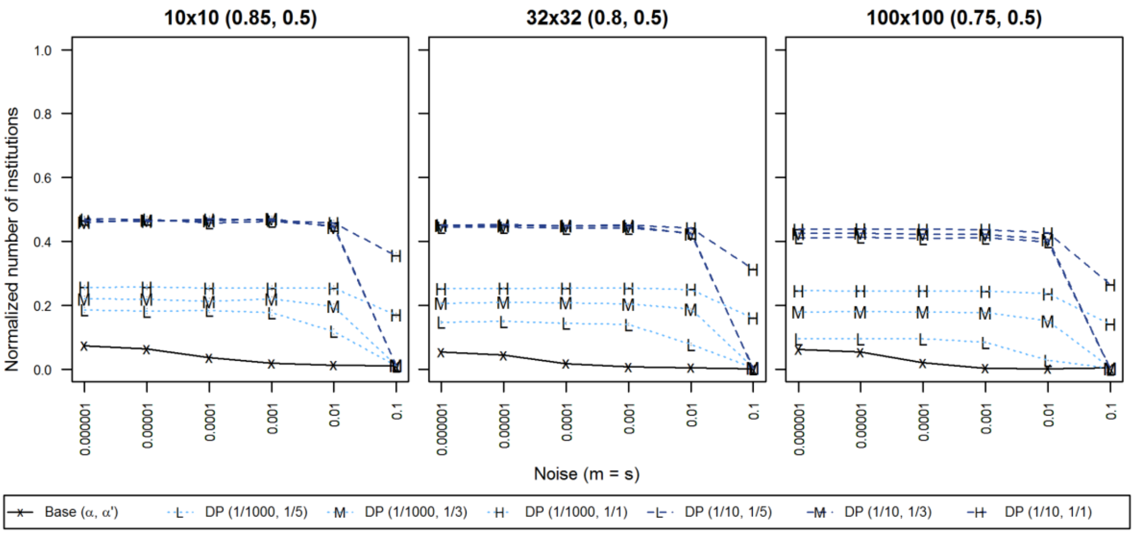

Figure 9. Number of institutions for combinations of democracy and propaganda frequencies. X-axis displays levels of noise; Y-axis displays normalized numbers of institutions. Each line symbol denotes one combination of democracy and propaganda. 95% confidence intervals are displayed only when exceeding the size of the line symbol. Data points are averages of 50 repetitions per territory with 100,000 iterations per agent.

2.3.2.4 Discussion: Experiments D to F

Although the goal of democracy and propaganda is the same; i.e. to increase similarity between agents and institutions in order for each to exert more influence on the other, the impact of the two processes on cultural diversity was found to be opposite. Generally speaking, frequent democratic processes led to fewer, larger cultural regions (as shown in experiment D), while frequent propaganda led to more, smaller cultural regions (as shown in experiment E). Our results also reflect intuitive assumptions about these processes: propaganda needs to be common to succeed, so rarer frequencies did not produce any relevant results; referenda are rarer, and we found that the system destabilized more quickly when they were permitted too frequently.

When both institutional influence processes are combined, we found that the results observed in experiments D and E were reinforced, except in a state of high democracy, where higher frequencies of propaganda induced a more homogenous state in the population.

With regards to institutional numbers, we found that that they increased in the presence of democracy and propaganda. One possible explanation for this increase is that the feedback loop of institutional influence that exists in our model allows for a more consistent exchange of information between agents and institutions, so that the numbers of cultures and institutions converge more. Additionally, we found that frequent democratic processes increased the number of institutions even more; in fact, for models with high democracy we found that there were more institutions than cultures. This is the case when one culture is split into regions that each have its own institution, but are culturally identical. In this situation, a number of agents who belong to the same culture each subscribe to a different institution.

It is important to highlight that by using different combinations of propaganda and democracy, we are able to control most of the cultural diversity spectrum. Several combinations prove very successful at preserving diversity without destabilizing the system (i.e. not resulting in extremes such as anomie or global convergence), even when the noise is set at its highest level.

2.4 General Discussion

Over the course of six experiments, we explored the effects of institutions on cultural diversity. We found that our model of institutional influence and agent loyalty compare well against previous models proposed by Axelrod (Axelrod, 1997) and Flache et al (Flache & Macy, 2011): high levels of institutional influence successfully promoted diversity and sustained it against perturbations in our system, and the agents' loyalty helped preserve this diversity, though it did not further increase or impact it in any significant way.

The promotion of diversity can be understood if we look at the mechanism of institutional influence. The more an institution affects individuals' lives, the more it controls interactions between people, their traits and values, and how they socially influence each other. Strong institutions can keep people of one cultural belief system from associating with people from other cultures, which leads to isolation and reduces assimilation. This becomes particularly evident when we consider societies in which familial units play a very strong influencing institutional role: in cases where this is true, people are much less likely to interact about cultural beliefs with other "rival" families, or take on the cultural beliefs of strangers; instead, distrust towards the general public, political and social isolation and selfishness towards outgroups are found to be predominant (A. Alesina & Giuliano, 2013; Ermisch & Gambetta, 2010).

Aside from simple institutional influence, the second goal of our research was to investigate how individuals' power to change their institutions affects the world in which they live, and what happens when institutions attempt to directly convince their members to re-adopt more traditional traits, even when those members might have been tempted away towards new beliefs. To study this, we implemented bottom-up and top-down institutional influence processes. Here, we found that democracy (bottom-up influence) promoted global convergence, whereas propaganda (top-down influence) by itself boosted diversity.

A possible explanation for this divergent result can be found in the source of institutional traits. In both cases, agents are the initiators of institutions. However, in the propaganda model, institutions are created, and then they preserve their configuration, they are fixed. "Old" traits are kept in the system, even when agents change towards more popular cultural opinion (due to interactions with neighbors). The traits that are stored in the institutions can be reused to influence agents once again through propaganda. This way, many small pockets of cultural regions can emerge and re-emerge.

Institutions' traits in the democracy model do not stay fixed. They are modified when agents are influenced by interactions with their neighbors, i.e. institutions are updated with the more recent, popular traits as old traits are abandoned by their agents. These new traits have successfully spread through the population and are converging agents' cultures.

A bottom-up process generates the possibility that these new traits permeate the institutions as well, and institutions in turn can help to preserve these traits in the future. This way, less diverse, larger cultural regions emerge.

In our final model, in which we integrated both bottom-up and top-down influence in a feedback loop of information, we replicated the main effect of democracy, and the main effect of propaganda under low democracy. Additionally, we found an interaction in which the inclusion of high levels of democracy led to a reversal of propaganda effects: now, lower levels of propaganda increased diversity, while higher levels of propaganda reduced the amount of diversity in the system. Considering the previous explanations of the origins of institutional traits, we found a similar logic operating behind this interaction: if institutions can be modified towards the traits that are popularized across cultures (which then tend to convergence), the institutions' propaganda then does not reverse agents' traits back to 'older' values; they instead now help spread the new ideas that are growing popular in the population through propaganda, and if these propaganda processes are very frequent, they homogenize the population even more than before.

Measuring amounts of cultural diversity and frequencies of the mentioned institutional processes (such as how much democratic power people exert and how much propaganda exists) is very difficult in real societies. One attempt to apply our ideas can be to look at how cultural diversity is commonly perceived across the world. For example, we find a highly fragmented landscape with many small, diverse cultural pockets across the African continent (i.e. Chad alone holds around 100 distinct ethnic groups), which tends to also be low in democracy and high in propaganda, compared to for example a Western European political landscape which is more democratic, and arguably less diverse - i.e. we commonly use the term "Western culture" to describe many features that are identical across it (A. F. Alesina, Easterly, Devleeschauwer, Kurlat, & Wacziarg, 2002; Gören, 2013).

One concrete "trait" that can be mentioned, which is spreading across already fairly similar cultural regions through democracy and propaganda, and which is turning those regions more similar, is marriage equality; the idea of tolerance towards sexual orientations has been expanding across the Western world in recent years, with multiple referenda being held on the (Jacobs, 2012; Sio1Net, 2015; The Irish Times, 2015). This movement, in turn, has been taken up by the media, is popularized further through positive institutional portrayals of tolerance (such as in school curriculums), and has successfully led to new, more inclusive laws in some countries. This stands in stark contrast to many smaller, autocratically governed areas across the world where homosexuality is treated very differently, ranging from ostracism over criminalization to punishment by death penalty (Rupar, 2014). This finding is reminiscent of Flache's hypothesis that maybe, ironically, conformist cultures are able to sustain more diversity than individualistic ones (Flache & Macy, 2011, p.990), and that not all cases of persistent diversity are necessarily positive, as sometimes they can be a disguise for xenophobic and ostracizing, discriminative tendencies (Fisher, 2013a, 2013b).

2.4.1 Limitations and further research

We have substantially extended the current line of research on cultural diversity on a theoretical level by incorporating central authorities, i.e. institutions, for the first time, and by providing a system which, for future research, will facilitate controlling the full spectrum of possible diversity levels. However, three of our findings in particular will need to be clarified by further research.

Firstly, we only found a small effect of agent loyalty; it was able to preserve diversity but not increase it. We assume the main reason for the small size of the effect is that an agent's change of institutions is dependent on the probability of it changing its trait first. We added this assumption to the model because we perceived that realistically, it is unlikely that a person will change their institutional affiliation to that of their neighbor if the neighbor did not convince them of their cultural trait in the first place. Further research into the agent loyalty parameter when it is conceptualized as independent of institutional influence should clarify if it will indeed stay a small effect or have a bigger impact in its own right.

Secondly, we did not find a clear relationship between the number of institutions and the number of cultural regions (Experiment F, Figure 9); in some cases they were more cultural regions than institutions, but in other cases, the reverse was true. In real life settings, both options are possible: one cultural region can be governed by multiple institutions, and one institution govern multiple cultures; however, we cannot be sure how this impacts diversity. From our results, we hypothesize that artificially manipulating the number of institutions would not consistently change the resulting diversity (in either direction), but this should be clarified in further studies.

Thirdly, the question remains how cultural diversity can be sustained even when institutions are permeated by novel ideas that are gaining approval in the population (i.e. under democracy). We hypothesize that democratic institutions still exert enough influence to slow down cultural drift patterns that would otherwise lead to complete monoculture. Possibly, allowing influences from other cultural regions to permeate institutions is what promotes the here established levels of cultural diversity. Further research should consider not only investigating the amount of cultural diversity that exists in a system, but also use a measure of frequency at which cultural change has occurred inside those cultural regions.

We also consider important the integration of multilateral social influence into our model of institutions, which has been used previously to induce and maintain cultural diversity (Flache & Macy, 2011; Parisi et al., 2003). In this sense, further research can also consider the inclusion of new parameters that expands the conditions in which the interactions occur, for example the distinction between normative and informational social influence (Deutsch & Gerard, 1955), agents' differing personalities - openness, desire for control (Brandstätter & Farthofer, 1997; Caldwell & Burger, 1997); situational factors - such as cultural resilience in the presence of peace and war, wealth and poverty (Manzo & Baldassarri, 2015; Montiel, 1997); or the possibility of agent mobility within the system (Schelling, 1969, 1971).

Finally, we found that little research has investigated the patterns presented here in real life settings as of yet. Field studies and experimental research on the impacts of institutions on diversity need to be carried out in order to test the practical and empirical relevance of our model's predictions.

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Chapter 3

3 CulSim: A simulator of emergence and resilience of cultural diversity

CulSim is an agent-based computer simulation software that allows further exploration of influential and recent models of emergence of cultural groups grounded in sociological theories. CulSim provides a collection of tools to analyze resilience of cultural diversity when events affect agents, institutions or global parameters of the simulations; upon combination, events can be used to approximate historical circumstances. The software provides a graphical and text-based user interface, and so makes this agent-based modelling methodology accessible to a variety of users from different research fields.

3.1 Motivation and Significance

The existence of diverse cultural groups is considered paradoxical given that we live in an interconnected world where individuals constantly share information with each other. Moreover, this diversity persists, despite confrontations with drastic changes over the course of population lifetimes. As an example, the Maya have often been recognized for their cultural diversity, although they have been victims of catastrophic events: pre-Hispanic collapses around 800 AD (Diamond, 2011); Spanish invasion after 1521 (Means, 1917); and genocide, 1981-1983 (1999).

CulSim, the computer simulation software presented here, is a tool to explore proposed models of the emergence of cultural groups (Axelrod, 1997; Flache & Macy, 2011; Ulloa, Kacperski, & Sancho, 2016). It introduces events that, upon combination, can simulate catastrophic situations such as wars, pests, invasions, or natural disasters. The results allow researchers to study the resilience of cultural diversity in the provided models. CulSim includes my own recently proposed model, which introduced institutions to explore their effects on cultural diversity (Ulloa et al., 2016). Here, it offers the possibility to analyze events on an institutional level (e.g. institutional collapses). Although the institutional model shows some methodological similarities with other studies focused on mass media (Gonzalez-Avella, Cosenza, Klemm, Eguiluz, & Maxi, 2007; Quattrociocchi, Caldarelli, & Scala, 2014; Shibanai, Yasuno, & Ishiguro, 2001), it distinguishes itself for letting the agents build their institutions and for dividing the feedback loop of information into two processes: bottom-up (democracy) and top-down (propaganda).

The ubiquity of different human groups raises questions regarding the emergence and resilience of cultural diversity. Researchers have proposed models to study the emergence of cultural diversity under social influence (Festinger, Schachter, & Back, 1950). Formal models demonstrated that everyone should, in the long term, converge to the same opinion when all individuals are connected to the same social network (Harary, 1959; J. R. French, 1956; Robert P. Abelson, 1964). More recently, agent-based models have facilitated the study of multiple factors that have been shown to affect the emergence and preservation of cultural diversity. Initially, Schelling (Schelling, 1969, 1971) used the idea that a small “dislike” for a dissimilar neighbor could lead to complete segregation between multiple groups. Conversely, Axelrod (Axelrod, 1997) proposed a model that successfully allows the emergence of cultural diversity by using categorical opinions (as opposed to continuous (Harary, 1959; J. R. French, 1956; Robert P. Abelson, 1964) and homophily, i.e. the principle of "like attracts like" (Byrne, 1969; Lazarsfeld & Merton, 1954; McPherson, Smith-Lovin, & Cook, 2001a), to regulate social influence. In this model, initial parameters heavily impacted the emergence (or non-emergence) of cultural diversity. For example, a smaller population size was conducive to diversity (Axelrod, 1997), while an increase in neighborhood size increased cultural homogeneity (Greig, 2002).

Later on, Axelrod's model was found to be sensitive to perturbations, noise that was introduced in two forms: mutations (Klemm, Eguíluz, Toral, & Miguel, 2003; Klemm, Eguíluz, Toral, & San Miguel, 2003), i.e., random changes in a feature of an agent's cultural vector, and selection error (Flache & Macy, 2011), i.e., occasional perception mistakes of a neighbor’s similarity (error estimating homophily). Klemm et al. (Klemm, Eguíluz, Toral, & Miguel, 2003; Klemm, Eguíluz, Toral, & San Miguel, 2003) found that even tiny mutation rates produced a convergence towards a monoculture without any diversity, while large rates produced anomie, a term introduced by Durkheim (Durkheim, 1951, 1982) to describe a state in which each individual is culturally different from its neighbors. Since then, several researchers have addressed the robustness of the emergence of cultural diversity against perturbation, for example by proposing a dynamic social network (Centola, González-Avella, Eguíluz, & Miguel, 2007); by using frequency bias (Parisi, Cecconi, & Natale, 2003), where social influence is multilateral, meaning one is influenced by several individuals at once, instead of dyadic, where influence occurs between just two individuals - based on Boyd and Richerson (1985); by combining frequency bias and homophily (Flache & Macy, 2011), or, most recently, by introducing institutions (Ulloa et al., 2016), following up on Durkheim's idea that institutions play a large role in group formation (Durkheim, 1951, 1982).

To my knowledge, no research has investigated how events that can affect many individuals at the same time might impact cultural diversity in these kind of models.

CulSim includes four models, all based on Axelrod's. The main social mechanisms that distinguish the models are indicated in Table 5. The description of the algorithms of models M1-M3 can be found in Flache and Macy (Flache & Macy, 2011, p. 975); the algorithm of model M4 can be found in Ulloa, Kacperski and Sancho (Ulloa et al., 2016).

Table 5. Social mechanisms used by the models. The first column provides the identifier used in CulSim. The other columns indicate main social mechanisms that distinguish the models.

Identifier	**Homophily**	**Frequency bias**	**Institutions**
M1	Yes	No	No
M2	No	Yes	No
M3	Yes	Yes	No
M4	Yes	No	Yes

CulSim supports eleven parameters. Seven (rows, columns, radius, features, traits, mutation, and selection error) can be applied to all models, and four (institutional influence, agent's loyalty, democracy and propaganda) are exclusive to the institutional model (M4). The Initial Parameters section of CulSim's user manual describes the parameters in depth, and summarizes some known effects according to previous studies. The user manual also presents a table with recommended values to start explorations (Ulloa, 2016). Finally, the user manual describes in detail the ten configurable types of combinable events of CulSim (including population-related events, institutional-related events and parameter change events). The software provides a graphical user interface to visually explore singular scenarios or multiple repetitions, and a command-line interface to configure comprehensive experimental designs in computer servers. A video that gives a brief overview over the functionality of CulSim is available in the supplementary material.

3.2 Software Description

CulSim allows users to test different hypotheses about cultural diversity, in particular which conditions can sustain it, or which factors promote globalization instead. It is based on previous research on agent-based models (Axelrod, 1997; Centola et al., 2007; Flache & Macy, 2011; Klemm, Eguíluz, Toral, & Miguel, 2003; Klemm, Eguíluz, Toral, & San

Miguel, 2003; Parisi et al., 2003; Ulloa et al., 2016). In this line of research of agent-based models, also known as artificial societies (Epstein & Axtell, 1996), a world is represented by a number of agents interacting with each other on a grid layout (a NxM matrix). In CulSim, each cell of the grid represents an agent (which can be imagined to represent an individual). This agent has a list of F cultural features. Each feature can contain one of T cultural traits, for example a music feature could contain rock, salsa, or jazz (T=3). Two agents are said to belong to the same cultural group if the agent's cells are adjacent to each other, and if they share the same trait for each of the possible features. An interaction occurs when an agent accepts (copies) another agent's trait (or group of agents' trait - when influence is multilateral) which could occur depending on the conditions imposed by the model, e.g. the homophily between the agents. The two agents that participate in an interaction have to be in a "Von Neumann" neighborhood of radius r; e.g. agent b is in the Von Neumann neighborhood (r = 2) of agent a in Figure 10.

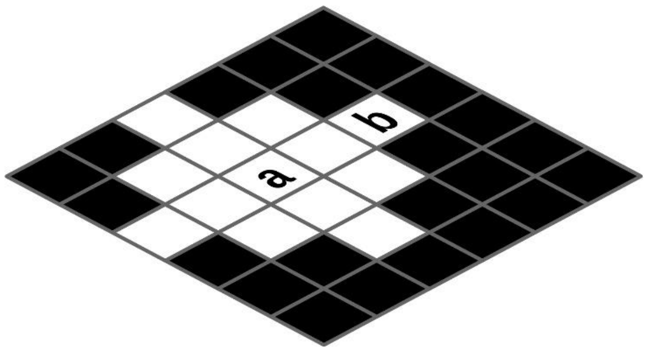

Figure 10. Von Neumann neighborhood of radius 2. In the grid, white cells represent the "Von Neumann" neighborhood of agent a. All agents (e.g. agent b) in this neighborhood can potentially influence agent a, or vice versa.

When the institutional model (M4) is used (Ulloa et al., 2016), an agent can belong to an institution that also contains a list of F cultural features. Institutions do not occupy any position on the grid. Figure 11 represents all elements within an institutional model. It illustrates a situation in which the institution's cultural vector (termed I) shares the first two features (out of three) with the blue cultural group (vector A) - both cultural vectors carry traits 3 and 4 in the first two positions). Vector I also shares two features (the first and the third one) with the pink cultural group (vector B) – both cultural vectors carry 3 and 2 in the same positions. This similarity can explain why one of the agents (located between agent a and agent b), who is part of the pink group, belongs to institution i. At some point, this agent can change its institution to j, or it can become part of the blue group if it lets institution i influence it down the line.

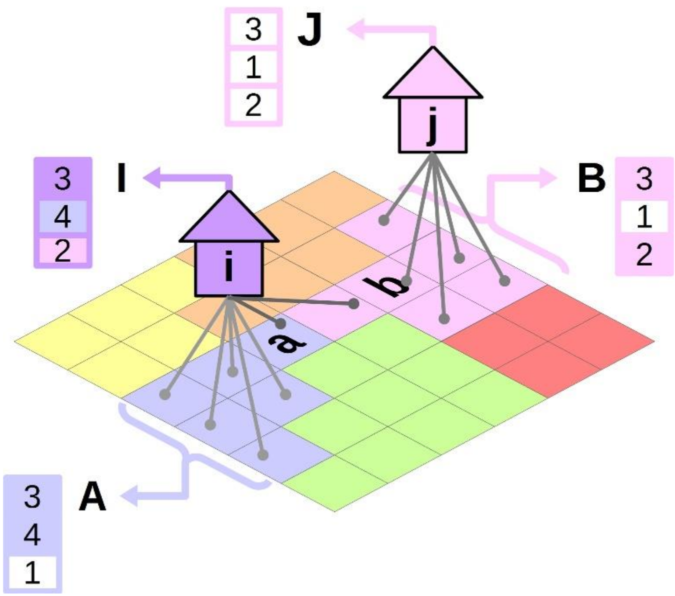

Figure 11. Overview over a world state in CulSim using the institutional model. The grid shows 6 cultural groups (yellow, orange, blue, pink, green and red) in a world of size 6x6. Since all agents (cells) of each cultural group carry exactly the same cultural traits, vector A is representative of each agent of the blue cultural group, and vector B representative of each agent of the pink group; in reality, each agent has its own cultural vector. Each cultural vector in this case contains 3 features (F=3), and each feature could contain 1 of 4 possible traits (T=4). The houses i and j on top of the grid represent two institutions. Grey lines connect institutions to the agents that belong to them. The vector I represents the cultural vector of the institution i (purple), and J represents the cultural vector of institution j (pink).

In the example, an interaction of agent a with agent b (in which one of vector B's traits would be copied to a's cultural vector) depends on the similarity of vectors A and B - this similarity requisite is called homophily (Centola et al., 2007; McPherson, Smith-Lovin, & Cook, 2001b) - and also the similarity with its institution j. The institutional influence, denoted by α, controls the importance that the agent-institution similarity has over the agent-agent homophily, and the agent loyalty controls the likelihood of agent a changing its institution towards b’s - depending on the similarity between a and j, and a and i - given that agent a accepted b’s trait. The institutions are also at the center of two social mechanisms regulated by their corresponding parameters. First, propaganda is a top-down process in which an institution sends a message to convince its subscriber agents of a particular trait, and second, democracy is a bottom-up process in which the agents vote for a particular trait to become part of the institution’s vector. For a full description of the institutional model and parameters, see Ulloa et al. (2016).

In this context is where CulSim can be used to execute events in order to affect the current state of the simulation. The events were conceived by exhaustively considering possible ways of targeting the information stored in the simulation. First, it is possible to target the cultural vectors of the institutions, or the agents. In terms of institutions, the cultural vector of one institutions could be targeted *fully* (i.e. remove all traits of the institution according to certain probability), or *partially* (i.e. for each trait, remove it according to certain probability). Also, the traits can be targeted by removing them (*content removal*) or by replacing them by foreign (external) ones (*conversion*), i.e. traits that does not exist in the simulation. In terms of individuals, it only makes sense to fully target the cultural vector to either simulate death (full traits removal, called *decimation*), or the arrival of a foreign agent[1] (full traits conversion, called either *settlement* or *immigration* depending if the foreign agents are associated to in institution or not respectively). Second, it is possible to attack the connections between the institutions and the agents. On one hand, an institution could be destroyed and all the agents that belonged to it become stateless (*institutional destruction*); on the other hand, some agents can leave the institution (*apostasy*). CulSim allows for the configuration of the events according to different (probabilistic and non-probabilistic) distributions (e.g. uniform or normal distributions) across the grid, and there is the option of combining events to represent compounded social catastrophes (e.g. an invasion involves at least *settlement* and *decimation*). For full details on events, please refer to the Events section of the user manual.

All of the above is accessible through the graphical user interface. Additionally, the interface includes a batch mode to run experimental designs in personal computers. For servers, a command-line interface is available with access to the same functionality. When multiple simulations are being run, CulSim takes advantage of all the cores available in the machine by running one simulation on each core. For the sake of efficiency, the implementation of the models was done using static data structures (instead of dynamic ones).

3.3 Illustrative Example

In the proposed example, I compare the effects of two events, decimation and settlement. Decimation is represented by removing all cultural traits from a group of agents leaving them empty (new-born). Settlement is represented by replacing all traits from a group of

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[1] Partial conversion is possible through other agents or institutions inside the system, but not a collective change of mind towards an unknown trait. Alternatively, mutation provides a mechanism for random conversion.

agents with foreigner traits; i.e. the settlers take previously occupied positions. The group of agents are selected by configurable events distributions; in this example, both events are assigned to cells (agents) in the grid, using a normal probability distribution function (standard deviation = 0.2) with its maximum value (1.0) at the center of the grid. The scenario uses the institutional model (Ulloa et al., 2016) with the following fixed parameters: institutional influence of 0.65, grid size of 50x50, 6 cultural features, 14 cultural traits, Von Neumann neighborhood of radius 3, mutation and selection error with probability 0.001, agent loyalty to 0.5, and no propaganda or democracy. Figure 12 illustrates the cultural spaces at different times for the two events: (A) before the event, (B.1) just after decimation, (B.2) 100000 iterations after decimation, (C.1) just after settlement, (C.2) 100000 iterations after settlement. Each agent is colored according to its cultural traits.

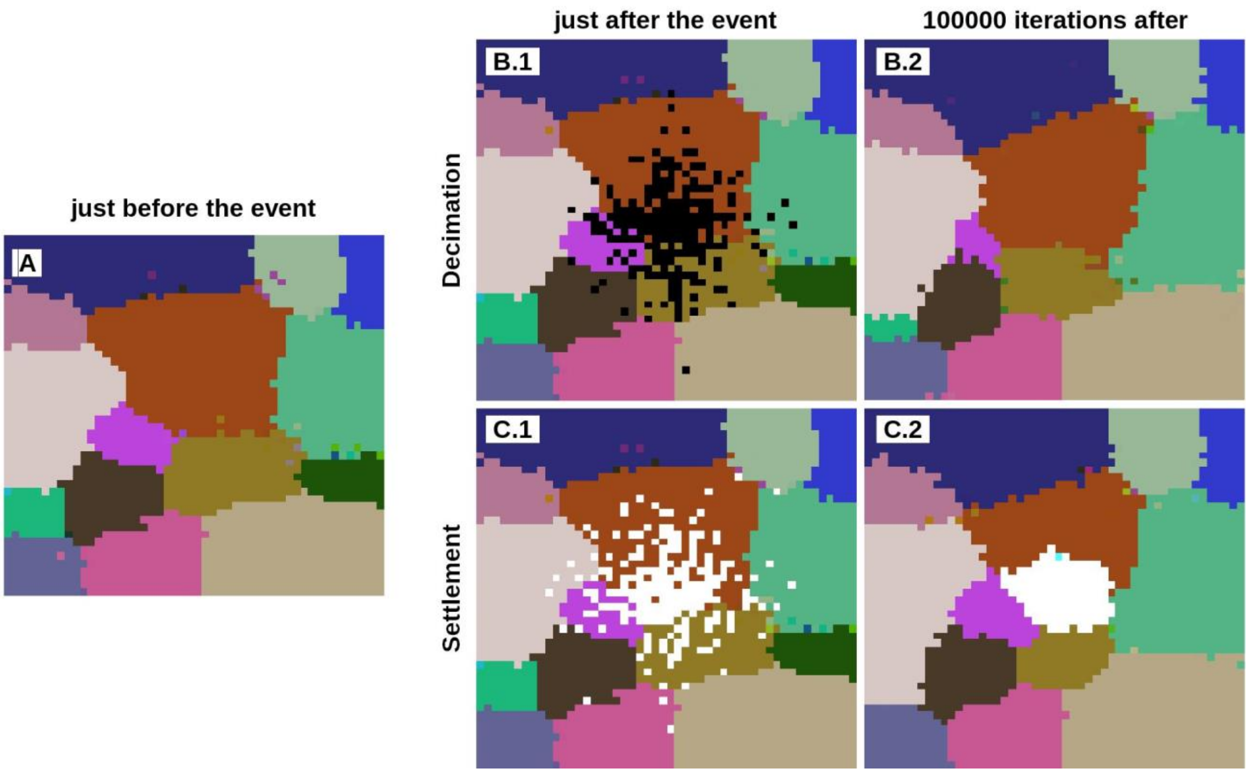

Figure 12. Cultural spaces before and after decimation and settlement. Left column shows the cultural spaces just before the event. The middle and right columns show the state just after the event and 100000 iterations after; the top row correspond to decimation, and the bottom one to settlement. The black cells in (B.1) represent the dead agents, and the white cells (C.1) represent the settlers.

High similarity exists between the states before and 100000 iterations after the events, although some changes are noticeable. For example, in B.2, the pink cultural group located near the center is smaller compared to A, and the green group on the right hand side has vanished completely; in C.2, the settlers (white cells) stabilized themselves in the center.

CulSim also displays the progression of 20 different response variables as the simulation runs its course. For example, Figure 13 shows how to track the evolution of cultural similarity (i.e. a comparison of the cultural vectors of all the cells, agents, between two states) between the cultural space just before the events (decimation or settlement) and 50 iterations after they occurred (green lines).

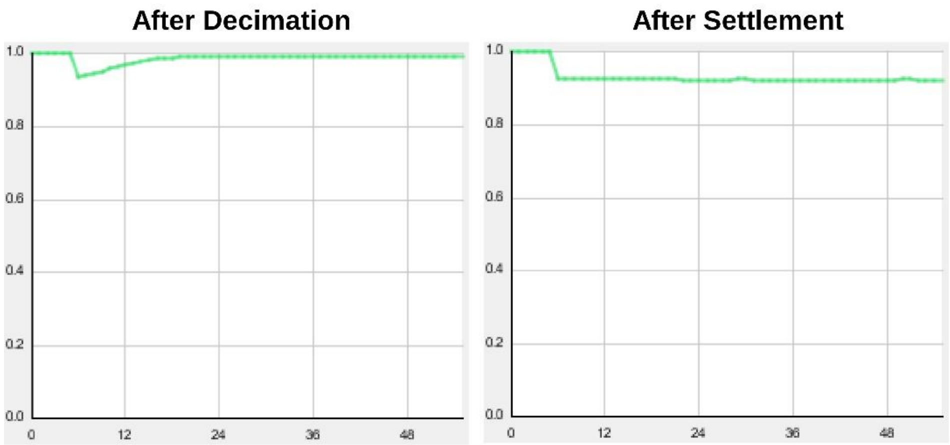

Figure 13. Progression of cultural similarity and energy after decimation and settlement. Green lines show the similarity between the state just before the event (left, decimation, and right, settlement) and the state of the 50 consecutive iterations (x-axis) after it. The similarity is calculated by comparing the cultural vectors of each cell in two states of the simulation. The blue lines show the energy of each state of the iterations.

In Figure 13, the similarities between the 50th iteration after decimation and settlement are .99 and .92 for decimation and settlement respectively. From this exploration, a hypothesis emerges: it is possible that cultural groups are resilient against decimation as they can recover successfully after the event, but might not be able to recover as well when settlers arrive, bringing their own culture.

As with all stochastic processes (such as the simulation example I present here), a single iteration that is obtained by tracking the simulation via main interface cannot be taken as representative of a general trend and needs to be repeated for reliability and validity purposes. Using the batch mode dialog of CulSim, we can run many repetitions in order to statistically test whether the observed effects reflect replicable trends. In our example, the experiment was repeated 10 times, and based on the analysis of the generated data files, Figure 14 exhibits the average similarities found between the state of the simulation just before the events occurred, and the one reached 50 iterations after the events were applied. We can confirm the observation to establish that the chosen scenario is resilient against decimation, but unable to recover the area taken by settlers.

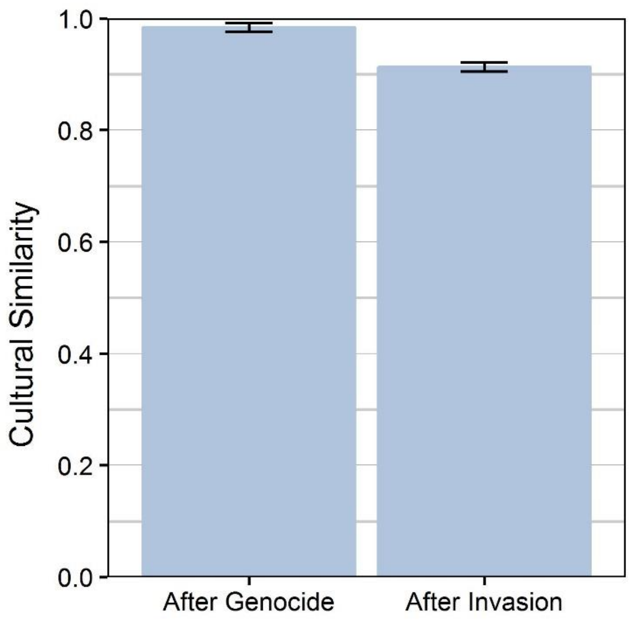

Figure 14 Similarity after applying the events. The graphs show the average similarities (over 10 repetitions) between the state of the simulation just before the events occurred, and the state reached after 50 iterations. The y-axis shows the cultural similarity, and the x-axis the type of event applied. On top of each bar we see the confidence intervals at 99%.

3.4 Impact

CulSim extends the use of computer simulations to the emerging area of digital humanities, in particular to cultural studies, by providing a tool that addresses a non-technical audience. The software has a default configuration that allows its immediate use to quickly grasp the concepts behind this type of research, and it allows storage of interesting configurations, events and simulation states that can be shared among users. In this sense, CulSim makes available a methodology that has proven fruitful in other fields of study such as physics, biology, and sociology. Within the proposed methodology, complexity of culture is taken literally, i.e. it is understood as a complex system (Miller & Page, 2007) in which macro behaviors can be explained from micro behaviors, as is the case with the models implemented in the project: agent-based simulations that model essential mechanisms and concepts that have been described in theoretical works.

In the field of social sciences, CulSim can expand our understanding of how cultural diversity persists throughout catastrophic events that target human populations, and is, to the best of my knowledge, the first tool available to study these types of scenarios on models based on Axelrod's (Axelrod, 1997), focusing on the effects on cultural diversity. CulSim enables the study of combinations of various events, approximating scenarios that have occurred to societies in the past, as is the case of for example the Maya peoples, whose cultural diversity has persisted despite the historical events that have befallen their population. For example, to simulate the Spanish invasion into Mexico and Guatemala that devastated the Maya, historians can review the available documentation and find appropriate values and distributions to configure events such as decimation, institutional conversion (to Spanish beliefs) and destruction, on top of the introduction of (Spanish) settlers into the population.

CulSim also becomes relevant in the context of contemporary controversial discussions about globalization. It has been claimed that a global (mono-)culture is necessary in order to promote world peace (Vadlamannati, 2008), while at the same time, we celebrate the importance of cultural diversity as a source for ideas to overcome a variety of problems facing our world today (Ashraf & Galor, 2011). In particular, the inclusion of an institutional model (Ulloa et al., 2016) gives opportunity to explore the role of these two concurrent discourses, which can provide insights into how to shape institutions that favor a peaceful global community while at the same time promoting cultural diversity.

3.5 Conclusions

CulSim will help researchers answer novel questions related to the emergence of cultural diversity based on existent models from the sociological literature. It allows the exploration of ranges of parameters and interactions that have not been yet studied in the literature. CulSim makes agent-based models accessible to researchers of different fields, and brings new questions related to resilience of cultural diversity, by introducing different types of events that target populations, institutions and global parameters. The possibility of combining events offers the opportunity to approximate circumstances of historical scenarios within the simulation.

3.6 Code and software metadata

Table 6 and Table 7 present metadata associated with the code and the software of CulSim

Table 6. Code Metadata.

Code metadata description	***Please fill in this column***
Current code version	*2.2*

Permanent link to code/repository used of this code version	https://github.com/robertour/CulSim/archive/2.2.zip
Legal Code License	*GNU General Public License (GPL) Version 3*
Code versioning system used	*Git*
Software code languages, tools, and services used	*Java*
Compilation requirements, operating environments & dependencies	*JDK 1.7 (or 1.8)*
If available Link to developer documentation/manual	https://github.com/robertour/CulSim/releases/download/2.2/javadoc2.2.zip
Support email for questions	*roberto.ur@protonmail.com*

Table 7. Software Metadata.

(Executable) software metadata description	***Please fill in this column***
Current software version	*2.2*
Permanent link to executables of this version	https://github.com/robertour/CulSim/releases/download/2.2/culsim2.2.jar
Legal Software License	*GNU General Public License (GPL) Version 3*
Computing platforms/Operating Systems	*Linux, OS X, Microsoft Windows, Unix-like*
Installation requirements & dependencies	*Java 7 (or 8)*
If available, link to user manual - if formally published include a reference to the publication in the reference list	*https://github.com/robertour/CulSim/wiki*
Support email for questions	*roberto.ur@protonmail.com*

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Chapter 4

4 Case Studies based on the Maya peoples

The third chapter presents three studies borrowed from the Maya history that serve to exemplify the usefulness of cultural diversity simulations in real world applications and historical contexts. In particular, the focus will lie on the institutional model of diversity first introduced in Ulloa, Kacperski, & Sancho (2016). Furthermore, a prominent aim of the following chapter will be to give an in-depth illustration of the utility of the CulSim tool presented in Ulloa (2016), and this will be the first instance in which the events will be methodologically explored in order to study their impact in the stability and diversity of different scenarios.

The history of the Maya peoples will be introduced to serve as the backdrop against which the research will be presented. The Maya peoples' history is a good choice for multiple reasons. First, they are an exemplary case of how diversity can be resilient against a multitude of events (*decimation*, *apostasy*, *settlement*, institutional damages and *institutional conversion*). Second, the three selected events illustrate different cases that demonstrate the flexibility of the simulation tool. Third, because the existing data, coming from archaeological studies, qualitative and quantitative historical studies, and dating from different ages and different historical settings, can be used to choose parameters for the simulation in different and multidisciplinary ways. Therefore, this chapter shows the great potential as a research tool of the proposed simulator CulSim.

4.1 A brief introduction to Maya history

Even though the term "Maya" in today's popular understanding is often used to refer to the Mesoamerican civilization that, before the European invasion, lived in what is now Mexico and Central America, it also denotes an estimated seven million individuals who live in this area today, and belong to a number of indigenous communities that share some cultural and linguistic heritage, and are considered descendants of ancient Maya civilizations (Nations, 2010). There are many distinct Maya groups, which have their own traditions, cultures, historical identities, and even 30 unique languages, which can be clustered into 5-6 major language groups and which are spoken in different regions of Mesoamerica (Figure 1).

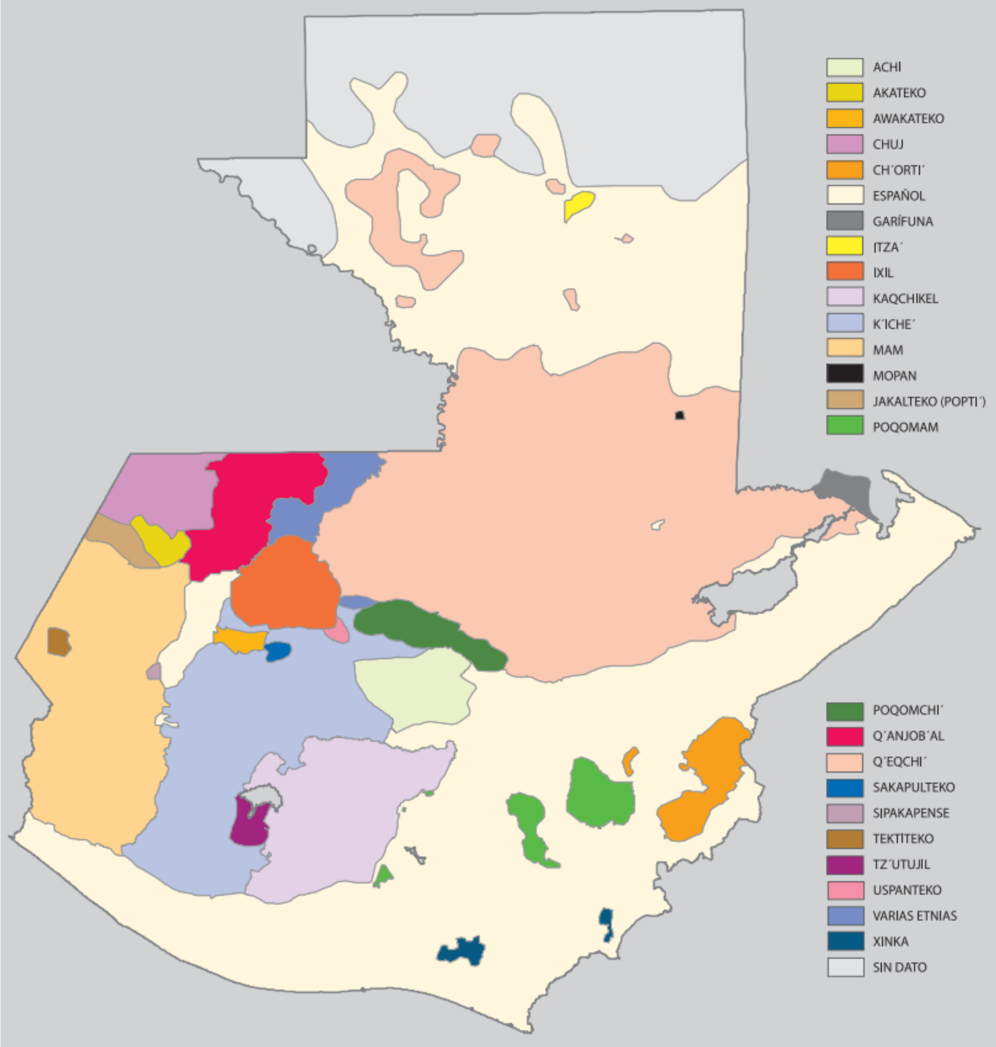

Figure 15. A map showing the present-day locations of the different linguistic groups in Guatemala. Source: (Informe Nacional de Desarrollo Humano, 2005, p. 65). Licence: Creative Commons Attribution 3.0 IGO licenseThe Maya region is an excellent example of an ecosphere with a population that, while sharing certain traits, has remained diverse over a large period of time, as, despite what is often believed, the composition of the Maya system today is, in terms of diversity, not so different from that of the Maya civilization prior to the 15th century, or of the 9th century (Sharer & Traxler, 2006, pp. 6, 9–11; Suárez, 1983; Thompson, 1932, 1970; Zorich, 2012).

The earliest Maya villages are thought to have been build prior to 2000 BC (the Archaic Period; Estrada Belli, 2011; Sharer & Traxler, 2006), while the Pre-classic and Classic Periods were defined by a development of complex societal structures, cities and the establishment of writing and trade systems (Estrada Belli, 2011). A large number of city states existed during this time period, ruled by dynastic political systems and in a state of constant warfare with each other (Demarest, 2004; Sharer & Traxler, 2006). The Maya political system never unified the area to form a large state; power fluctuated greatly between city states and alliances, whose areas were very culturally diverse, with distinctive regional architectural styles (Foster, 2005), over 30 languages (Sharer & Traxler, 2006), a variety of deities (Demarest, 2004) and unique regional art styles (Miller, 1999).

This diversity has remained resilient into modern times even though the Maya ecosphere had been greatly impacted by several major devastating events that occurred within a period of over a thousand years. In terms of language, "linguistic contacts were primarily among the upper classes and ... their potential effects reached lower groups only sparingly" (Suárez, 1983, p. 92), and while cultural intrusions by the Toltec or Spanish colonizers did affect urban populations, in particular the ceremonial aspects of Maya culture, the rural peasantry was not affected significantly (Lutz, 1976, p. 50, 1997).

In modern times, the true Maya culture and identity is said to consist of features surviving from the pre-European contact period. Identification with dress and language, which are markers of authentic and intact cultural identity, is key (Fischer & Brown, 1997). In particular, “for the modern Maya, the most conspicuous link to that past that is indisputably non-Spanish is found in Maya language” (Fischer & Brown, 1997, p. 14). Government forces of the extreme right and political organization from the extreme left promoted goals of assimilation and ideological indoctrination with attacks on Maya culture and language, but this goal was not achieved (Fischer, 1996). “Today, Maya identity and culture remain strong… But we cannot ignore the enormous weight of five centuries of continuous assimilationist and integrationist policies that we have suffered” (Raxche’, 1996).

The following three catastrophic events that impacted the Maya will be the major focus of this chapter: the so-called Classic Maya collapse (D. Webster, 2002), the Spanish Invasion (Lovell, 2005; Restall & Asselbergs, 2008) and the Guatemalan Civil War/Genocide (Historical Clarification Commission (CEH), 1999a, 1999b) . Only a brief introduction into the events will be given, but references will be provided for readers interested in a more complete historical knowledge. The three events will be analyzed from the perspective of diversity, and models of diversity introduced in previous chapters.

4.2 Brief summary and relevant aspects of the model

The base model used in this chapter is described in Ulloa et al. (2016), and the modelling of the events used is described in Ulloa (2016a). In this section, the simulation of this chapter is briefly summarized, highlighting only those elements that are relevant.

In the simulation, each individual is placed in a cell of a grid which contains a trait (e.g. Spanish, Jazz) for a list of cultural features (e.g. language, music). A cultural group is defined as individuals that are adjacent to each other and that also have the same cultural traits on each of the possible cultural features. The two images of Figure 16 contain 25 individuals (in a 5x5 grid) and 4 cultures represented by different colors. The color depends on the cultural traits that each individual has. For example, the two green agents (cells with arrows pointing out their cultural vectors) belong to the same culture (green), because their features music and sport both hold the same trait each, jazz and tennis.

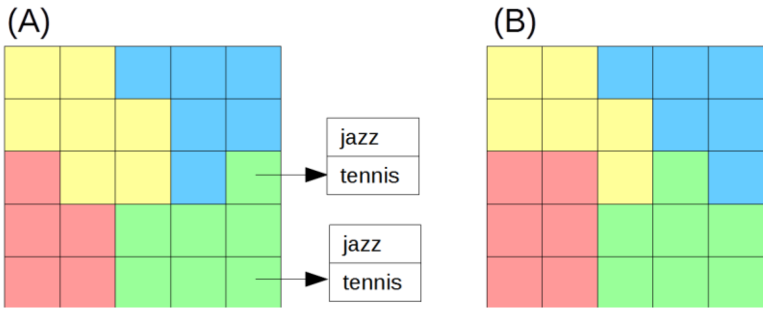

Figure 16. Hypothetical example of two cultural spaces of states of a simulation at different times. Each of the 25 cells (5x5 grid) represent an individual. The colors of each cell are based on the cultural traits that the individual contains. The arrows point to two cultural vectors of the two individuals with identical traits, therefore they belong to the same institutions (green). The left image (A) presents the state of the simulation at time t, and the right image at time t + 100.

The cultural groups in Figure 16 can be characterized by three criteria: the number of individuals that belong to it (*size*), the *place* they occupy on the grid (*position*), and the cultural traits that they contain (*content*). These criteria are used to calculate the similarity between two *states* of the simulation. A *state* of the simulation is a snapshot of the cultural composition at any given time.

For example, the left side image (A) of Figure 16 represents the cultural composition of the simulation at time *t*, whereas the right side image (B) represents the state at time *t+100.* In the simulation, time is controlled via iterations; in each iteration, agents have the opportunity to interact with each other and share traits, depending on several conditions explained in Ulloa et al (2016) . Therefore, it is possible to compare the simulation between two given times by comparing their respective states.

Given two states, A and B of Figure 16, each cultural group in A can be compared to the most similar one in B in terms of the three criteria (*size, position* and *content*), and at the same time, these criteria are used to find the most similar cultural group. The similarity between two groups a and b, which belong to two different states, A and B respectively, is calculated as follows for each individual criteria:

- $Sim_{size}(a,b) = 1 - |a_{size} - b_{size}|$, where g_{size} is the size of group g
- $Sim_{position}(a,b) = 1 - \sqrt{\left(\frac{a_x - b_x}{N}\right)^2 + \left(\frac{a_y - b_y}{N}\right)^2}$, where g_x and g_y represents the coordinate x and y of group g, and N the totals of columns (or rows) of the grid.
- $Sim_{content}(a,b) = \frac{1}{F}\sum_{f=1}^{F} \delta\left(a_f, b_f\right)$, where $\delta(i,j) = \begin{cases} 1, & i = j \\ 0, & i \neq j \end{cases}$, g_f represent the trait for the cultural f_{th} feature of cultural group g, and F represent the total number of features

Then, the similarity between groups a and b is calculated by multiplying the three previous similarities:

$$Sim_{group}(a,b) = Sim_{size}(a,b) * Sim_{content}(a,b) * Sim_{position}(a,b)$$

Now it is possible to calculate the similarity between the two states, A and B:

$$Sim_{st}(A,B) = \frac{\sum_{a \in A}^{A} min(\{Sim_{group}(a,b): b \; in \; B\}) + \sum_{b \in B}^{B} min(\{Sim_{group}(b,a): a \; in \; A\})}{\|A\| + \|B\|}$$

Notice that in the numerator of the formula, the comparison is done from A to B and from B to A. This is necessary because it is common to have an unmatched number of cultural groups from one state to another (i.e. one state has more or less cultural groups than another, which could happen when, for example, one of the states of Figure 16 disappeared in a future iteration, or conversely a new state emerged). By considering a comparison in both directions, all cultural groups get an opportunity to compare themselves to one another.

The model used in this chapter also includes institutions. The institutions have an impact on cultural traits that an individual may adopt when an interaction between agents occurs. Basically, each individual can belong to an institution, and an institution is generally associated with several individuals. The influence that the institutions exert over their associates is controlled by a parameter that is called institutional influence (see Ulloa et al., 2016 for details). There are also two processes associated with two institutions, a bottom up process called *democracy*, in which individuals vote for the traits they would like to be represented in the institution, and a top-down process, called *propaganda*, in which the institution promotes an unpopular trait among its associates.

The underlying idea of institutions is to provide a repository, in the way of a secondary form of cultural traits (Suarez & Sancho, 2010). The interpretations can be manifold. The concept can represent many real-life institutions, from libraries to governments. Therefore, it is necessary to clarify its use across the Maya case studies. Generally speaking, institutions refer, in an abstract form, to a political and cultural center. These could be cities or influential individuals (kings, local leaders). In Study 3 institutions are explicitly stated to refer to sacred places which were destroyed, and to economical centers such as cooperatives, which were commonplace in the 80s in Guatemala. It is possible, in Study 3, to name institutions directly, because the available sources contain many details on how these constructs worked. It can be assumed that Maya cities in the past contained many sacred places and local leaders as well, but sources rarely offer exact details.

One final detail that needs mentioning is that a cultural group qualifies as such only if it contains a minimum of three members, as suggested by Flache & Macy (2011), and based on the idea that triad social interactions are fundamental for social consensus (Simmel, 1950). This is relevant because inside the simulation, purely on a computational level, cultural groups that have less than 3 members are not uncommon mainly due to mutation rates (i.e. random changes in the agent's traits). Such changes generally do not persist over time. It is reasonable to take them out of the $Sim_{st}(A, B)$ formula because they could, just by chance, be over-represented if included.

4.3 Study 1: Classic Maya Collapse

4.3.1 Literature Review

Between the 8th and the 9th century, archeological records, such as decrease of monument construction and recorded lists of reigning royalty in the southern Maya lowlands of Mesoamerica, for example Palenque, Copán and Tikal (Acemoglu & Robinson, 2013; D. L. Webster, Freter, & Gonlin, 2000) point to a drop in the Maya population, which coincided with a mass abandonment of Maya cities and a decline of the Maya civilization in general (D. Webster, 2002). This historical development has been termed a "collapse" in anthropological research literature, even though the term might wrongly suggest that the Maya civilization vanished completely, which is, as evidenced by the existing Maya population today, not the case (D. Webster, 2002). Still, the collapse is a widely discussed mystery in Mesoamerican history, as no definite cause or even explanation has proven true so far. While over 80 different theories have been proposed, none are universally accepted (Gill, 2000).

Foreign invasion, revolution, economic and trade route collapse, mega-droughts and diseases have all been suggested as major driving forces of the collapse, though these theories are, up to a certain degree, still speculative. Only recently, evidence in support of some of these theories has emerged from interdisciplinary research. For example, the decipherment of Maya glyphs now allows for a better understanding of the warfare and political instabilities of the period, although Ulloa & Froese (2016) argue that warfare might not by itself explain a collapse unless documents are found that prove that warfare increased to very high levels in some particular instances. Archeological evidence supports an explosion of warfare so far only for the Petexbatún area (D. Webster, 2000).

Evidence for a competing hypothesis, the drought hypothesis, has been found in the Yucatán Peninsula: periods of drought have been ascertained here (Curtis, Hodell, & Brenner, 1996), and one of the most extreme spikes of drought recorded coincides with the Maya collapse (Hodell, Brenner, Curtis, & Guilderson, 2001; Hodell, Curtis, & Brenner, 1995; Medina-Elizalde et al., 2010).

As is often the case with historical events, it is more likely that there is no single cause of the collapse, but that a combination or sequence of factors provides a more satisfactory explanation. Webster (2002) illustrates one possibility for a combination of factors and theories in his framework, summarizing many of the more popular theories (pp. 327–329). He proposes that the collapse originated from environmental caused by population growth, rulers' over-ambitious decision-making, and agricultural choices. Environmental degradation then triggered increased vulnerability to natural disasters (storms, droughts, diseases), abusive economic practices, famine due to extreme soil exhaustion, external warfare, and internal problems (ideological rebellions, intercity competition, ineffective ritual regulation). Finally, Webster hypothesizes that any of these events would result in a political decline that might then lead to the abandonment of political centers and regions.

Webster's framework (2002, pp. 327-329) can be adapted to emphasize specific theories. For example, Webster uses the framework to argue how soil exhaustion could increase internal competition, lead to warfare, and then ultimately to the failure of the political structure of kingship (D. Webster, 2002).

4.3.2 Methodology

The purpose of this study is to showcase the usefulness of CulSim by applying its simulated events to segments of Webster's framework; therefore, demonstrating that CulSim can be configured to approximately represent popular theories of the collapse. Since this is the first time CulSim is being applied in a study of a real life case, the events will be studied separately. This is a good starting point to provide a panoramic overview of the effects of each possible event provided by the simulator. Therefore, the combination of events to represent an specific historical situation will be illustrated in the following studies.

Table 8 summarizes the nine events that will be analyzed in this study. A full description of each of these events can be found in the user manual of CulSim (Ulloa, 2016b).

Table 8. Events of CulSim. The first Column describes the name of the event. The Second column presents the type of event depending on the way it targets the information in the simulation. The third column describes the effects of the event in the simulation.

Event	Type	Description
Decimation	Decimation	A percentage of the population is killed. Dead individuals are represented as agents with empty traits.
Settlement	Foreigners	A percentage of existing individuals are replaced by settlers. Settlers are represented as agents with foreign traits, and are associated to a foreign institution, an institution with foreign traits.
Immigration	Foreigners	A percentage of existing individuals are replaced by immigrants. Immigrants are represented as agents with foreign traits; they are not associated to any institution.
Apostasy	Structural damage	A percentage of the population become apostates. Apostates are represented as agents without an institution.
Institutional destruction	Structural damage	A percentage of the institutions are destroyed. Destroyed institutions are removed from the system, and all agents formerly attached to them become stateless and are represented as agents without an institution (apostates).
Partial content removal	Institutional content removal	A percentage of institutional traits are removed from the existent institutions.
Full content removal	Institutional content removal	All institutional traits from a percentage of institutions are removed.
Partial conversion	Institutional conversion	A percentage of institutional traits are converted to foreign traits.
Full conversion	Institutional conversion	All institutional traits from a percentage of institutions are converted to foreign traits.

All the events in Table 8 can be configured by assigning a certain size to the event; this is done by assigning a percentage of the total number of individuals, institutions or traits (*event targets*). This percentage is *expected* (i.e. not exact all the time). The reason is that probabilities are associated to targets according to certain probabilistic distributions. For example, if the percentage of a uniformly distributed *decimation* is 20%, each agent has a 0.2 probability of being removed; therefore, it is expected that 20% of the agents will be removed. The same logic is applied for normally distributed *decimations*; however, in this case, probabilities are distributed to agents based on their proximity to the center of the event. For both types of distributions, thus, an expected percentage is the parameter. This expected percentage will, from now on, be referred to as *the size of the event*. Also, for normally distributed probabilities, two other parameters are relevant: the *center* of the event, i.e. a cell of the grid that will receive the highest probability of the normal distribution (and the further a cell is from the center, the less probability it will receive), and the *ceiling* of the distribution, i.e. the value of the highest probability assigned to the cell in the *center* of event.

As discussed previously, the events that were presented in Table 8 can be associated to prominent theories about the Maya collapse. Table 9 gives an overview over possible associations of CulSim events with a small selection of common theories explaining the Maya collapse. The terminology used in the first column of Table 2 is taken from Webster's framework (Webster, 2002). It is important to note that in Webster's framework, the consequence of all collapse theories is the abandonment of cities. This abandonment of the cities is interpreted as a complete *institutional destruction* (5th event in Table 8); I argue that practically all the links between individuals and their instutions (cities) were lost as a consequence of this abandonment.

The content of Table 9 is not exhaustive; however, it should suffice in order to illustrate how popular theories (which we provide along with the literature where they are discussed most prominently) can be represented by different events in CulSim.

Table 9. Relations between Webster's framework, Classic Maya collapse theories and CulSim events. This table illustrates how CulSim can be used to establish parallels between the theories and the simulation events. The first column shows, in terms of Webster's framework, the terminology to generally describe the theory. The second column presents common Maya collapse theories with some references that describes or criticizes them. The last column relates these theories to possible events that can be used to simulate them.

Terminology	Theory (References)	Related Events
Increased vulnerability	**Disease** (Anderson & May, 1982; Dunn, 1968; Santley, Killion, & Lycett, 1986; Shimkin, 1973)	**Decimation:** representative of victims of disease or starvation **Apostasy:** representative of loss of an institution's

	Droughts (Gill, 2000, p. 311; McKillop, 2006; Medina-Elizalde & Rohling, 2012; D. Webster, 2002, p. 239; Weiss, 1997, 2001)	credibility (e.g. individuals might consider it unable to control weather)
Famine, physiological stress	**Soil Exhaustion** (Cook, 1919; Culbert, 1977; Demarest, 2004)	**Decimation:** representative of starvation **Apostasy:** representative of loss of an institution's credibility (e.g. individuals might consider it unable to govern cities well)
Inappropriate elite economic meddling	Institutional collapse due to increasing **socioeconomical complexity** (Tainter, 2011)	**Institutional destruction:** representative of an internal collapse of inflexible institutions (e.g. institutions that were unable to adapt) **Apostasy:** representative of loss of an institution's credibility (e.g. individuals might consider it incapable of governing well)
Increased competition	**Collapse of Teotihuacan's trade** partner (D. Webster, 2002)	**Immigration:** representative of immigrants of the collapsed state **Apostasy:** representative of loss of an institution's credibility (e.g. individuals might consider it unable to balance economies)
Ideological resistance	**Revolution** (Thompson, 1954)	**Apostasy:** representative of rebels **Decimation:** representative of casualties of a possible civil war **Institutional content destruction:** representative of damages caused by rebels
Increased external warfare	**Foreign invasion** (Chase, 1983; Sabloff & Willey, 1967)	**Settlement:** representative of hostile invaders **Decimation:** representative of war casualties **Institutional content destruction:** representative of damages caused by invaders **Institutional conversion:** representative of a take-over of institutions by rebels

While CulSim provides multiple response variables that can be used to analyze the effects of events, the response variable used in the present study is the similarity between the state before the event (s_bef), and the state 100000 iterations after the event (s_aft), i.e. Sim_states (*s_bef*,*s_aft*). From now on, this variable will be called *similarity*. Similarity is used indirectly to test the feasibility of events listed Table 8 as realistic candidates for the Maya collapse.

Given that the Maya peoples' cultural diversity persisted even after the so-called Maya collapse (i.e., there are high levels of similarities between the diversity of the population of the classic Maya and the Maya today, with the main marker being the preservation of languages, (Raxche' (Demetrio Rodríguez Guaján), 1996; Sharer & Traxler, 2006; Suárez, 1983; Thompson, 1932), whatever happened during this period and caused the collapse did not result in complete cultural disintegration. In this first case study, this argument will be applied as a criterion to discard events, i.e., based on the axiom that this simulation in some way represents real events, its results will indicate that all those events, that in the simulation result in major cultural disintegration, are unlikely to have occurred, or, if they did, they should be assumed to have occurred at a very low order of magnitude.

As the focus of the following experiments will be to separately analyze the events of Table 8, the next important decision is to choose sizes for the events representing the theories proposed. However, literature on the Classic Maya collapse rarely offers concrete values that can be used to approximate or estimate the size of the events. Therefore, the strategy for this case study will be to explore events of all sizes, i.e. ranges of values from 0% to 100%, with increasing steps of 20% each. This will enable a panoramic exploration of the behavior of each event. Additionally, to compare for competing possible distributions, each event will be applied once with a uniform distribution, in which the probability of the event is equal across the grid, and once with a normal distribution, in which the probability is distributed with the ceiling (set as 0.95) at the center of the grid, and decreases with distance from the center.

Events will be tested on two versions of the scenarios shown in Table 10. In the first version (which will be called the red version, and is colored red in figures), individuals are initialized with random traits and, over time, many cultural groups emerge together, along with the corresponding institutions. Because here, agents are initialized with random cultural traits, after many iterations, a variety of cultural groups will exist, all with different institutional arrangements (Ulloa et al., 2016). For example, one red scenario can stabilize with a number of 5 cultural groups, while another stabilizes at 55 groups. This depends not only on parameters but also on the initial traits. In the second version, all individuals are initialized with the same cultural traits and assigned to the same institution. This is done, so that even after many iterations only one cultural group exists, thus representing the monoculture (which will be called the blue version, and colored blue in figures). The red and the blue versions are in a state of equilibrium, i.e. they remain constant over 1000000 iterations of the simulation before the event is applied. The idea is to compare effects of events on societies that are comprised of cultural diversity (many cultures) against effects that these events would have on a monoculture (a completely homogenous society).

Table 10. Scenarios for Study 1. This table present the factors and values for the scenarios of Study 1. The first column, show the identifier of the scenario. The second column, the population size expressed in number of rows and columns. The third column, the radius that define the size of the interacting neighborhood, e.g. an agent can have up to 84 neighbors with radius 6, and 24 with radius 3 (it could be less if the individual is in the borders). The last column indicates how much the institutions influence the individual, e.g. preventing trait changes to happen. The top row shows in parenthesis the notation used to describe each parameter.

Scenario (S)	Population (NXN)	Radius (R)	Institutional influence (I)
A	32x32	6	0.85
B	32x32	3	0.85
C	100x100	6	0.80
D	100x100	6	0.85

Both the diverse and the monoculture version use the same four scenarios, presented in Table 10 with their associated parameters. In terms of notation, the scenarios of Table 10 are going to be identified by the following pattern: S(G): NxN/R/I. The meaning of initials S, N, I and R, are given in parentheses in the header column of the table. The letter G represents the average of cultural groups generated by the scenario.

Values of the parameters listed in Table 10 were chosen based on prior literature. Scenarios A and C were previously explored in Ulloa et al. (2016). B and D are variants of A and C respectively, and were chosen to study possible interactions, and to enable generalizations from the obtained results of scenarios A and C. For example, according to results from the previous literature, larger neighborhood interactions decrease cultural diversity in simple versions of the here presented model (Greig, 2002), and smaller institutional influence decreases the number of diverse cultures (Ulloa et al., 2016). For the methodology, thus, the hypothesis is that scenario B will produce more diversity than its corresponding scenario A, and scenario D will produce less diversity; this, in turn, will ease the interpretation of the results after events are introduced into the simulation.

All other parameters that are used in the current simulation are held constant, i.e. they are fixed across all simulation runs. Agents always hold 5 features (F) and 15 possible traits

(T); both noise sources, mutation and selection error, are set at 0.001; the number of iterations before the event are set at 1000000, the event always occurs at iteration 1000000, and the similarity is calculated at 100000 iterations after the event. Finally, since each simulation is non-deterministic, 24 repetitions with each scenario are run. Each repetition involves 1100000 iterations. In order to avoid variance disturbances due to different initial conditions, the 4 scenarios (without events) and 24 repetitions are run until 1000000 iterations are reached (i.e. before the event). At this point, the states of the 96 repetitions are stored and loaded to execute each of the events. Therefore, all events will be executed in exactly the same 24 conditions per scenario.

4.3.3 Results

All results sections below will be accompanied by images, which will serve as the main source of information to the reader. Images will be described first in abstract terms, with only the most important features of the results pointed out, on the basis of the simulation only. Following this, the results delivered by the images will then be discussed in the context of theories that have attempted to explain the Maya collapse.

The images will contain two graphs in two columns, the left graphs present a uniformly distributed event and the right graph a normally distributed event. Both graphs display, as explained in the Methodology section, two version of the scenarios (colored red and blue) in which the Red scenarios start with a population in which individuals are initialized with random traits and where many cultures emerge over time (1000000 iterations), and the Blue scenarios start out with a population that is homogenous, i.e. comprise only one culture. The dependent variable is always the similarity of the resulting state 100000 iterations after the event occurred and the state just before the event, e.g. when the similarity is 1.0, the states are identical, whereas if the similarity is 0.2, the simulation state has changed almost entirely.

4.3.3.1 Decimation

Figure 17 presents the effects of uniform and normally distributed *decimation* on the two version of the scenarios (Red, many cultures, and Blue, one culture). Following the x axis with increasing event size, we can observe that the similarity stays high for both versions until the 80% mark is reached. At an event size of 100%, the population is eradicated.

In general, the graph indicates that cultures, whether diverse or homogenous, are generally highly resilient to *decimation*. There is a difference for Blue versus Red, such that monoculture scenarios show higher resilience against *decimation*, however, diversity also displays a very good resilience, especially for scenarios with bigger populations (100x100). Finally, the number of cultures in Red can be used to see a more differentiated picture (in the legend, the scenarios are sorted by number of cultures and distinguished by different symbols). Once it is assumed that at least a few different cultures existed a priori, the simulation shows a trend where the more cultures exist, the more resilient they prove against *decimation*.

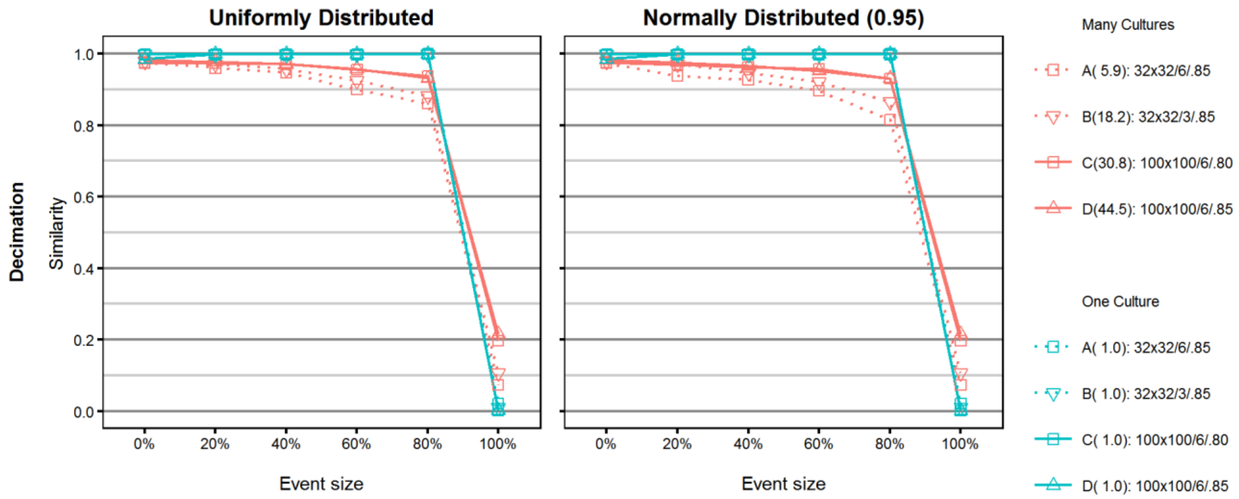

Figure 17. Effects of *decimation* on diverse and monoculture scenarios with either uniform or normal distribution. The Blue lines represent the monoculture version of four scenarios, and the Red lines the diverse version of four scenarios. The left graph shows the results for an uniformly distributed event, and the right graph results for a normally distributed event. The symbols in the legend denote parameters that characterize scenarios in the format S(G): NxN/R/I where S is the identifier; G is the average number of cultural groups; NxN is the number of rows and column; R is the distance for neighborhood interaction; I is the level of institutional influence. The Y-axis holds the dependent variable, in this case the similarity between the state just before the event (1000000th iteration), and 100000 iterations after the event. The X-axis shows the size of the event as a percentage of the affected agents.

In terms of the Maya case study, the simulation suggests that those hypotheses which postulate that the Maya collapse occurred due to high levels of *decimation* are plausible. Even in scenarios where we assume that 80% of the population died, we see that diversity is preserved. To reiterate the criterion, this is what we expect considering the real life consequences of the collapse, in which the Maya diversity persisted and was preserved.

4.3.3.2 Foreigners

Figure 18 presents the introduction of uniform and normally distributed foreigners to the two versions of four scenarios: Red lines again represent scenarios with many cultures, and Blue lines scenarios with one culture. In this graph, we distinguish between two different types of foreigner events: *settlement* (top row) and *immigration* (bottom row). We can see that both have a higher impact on the cultural similarity than *decimation* did: the introduction of a *settlement* of even a small size decreases the similarity, for both Red and Blue versions.

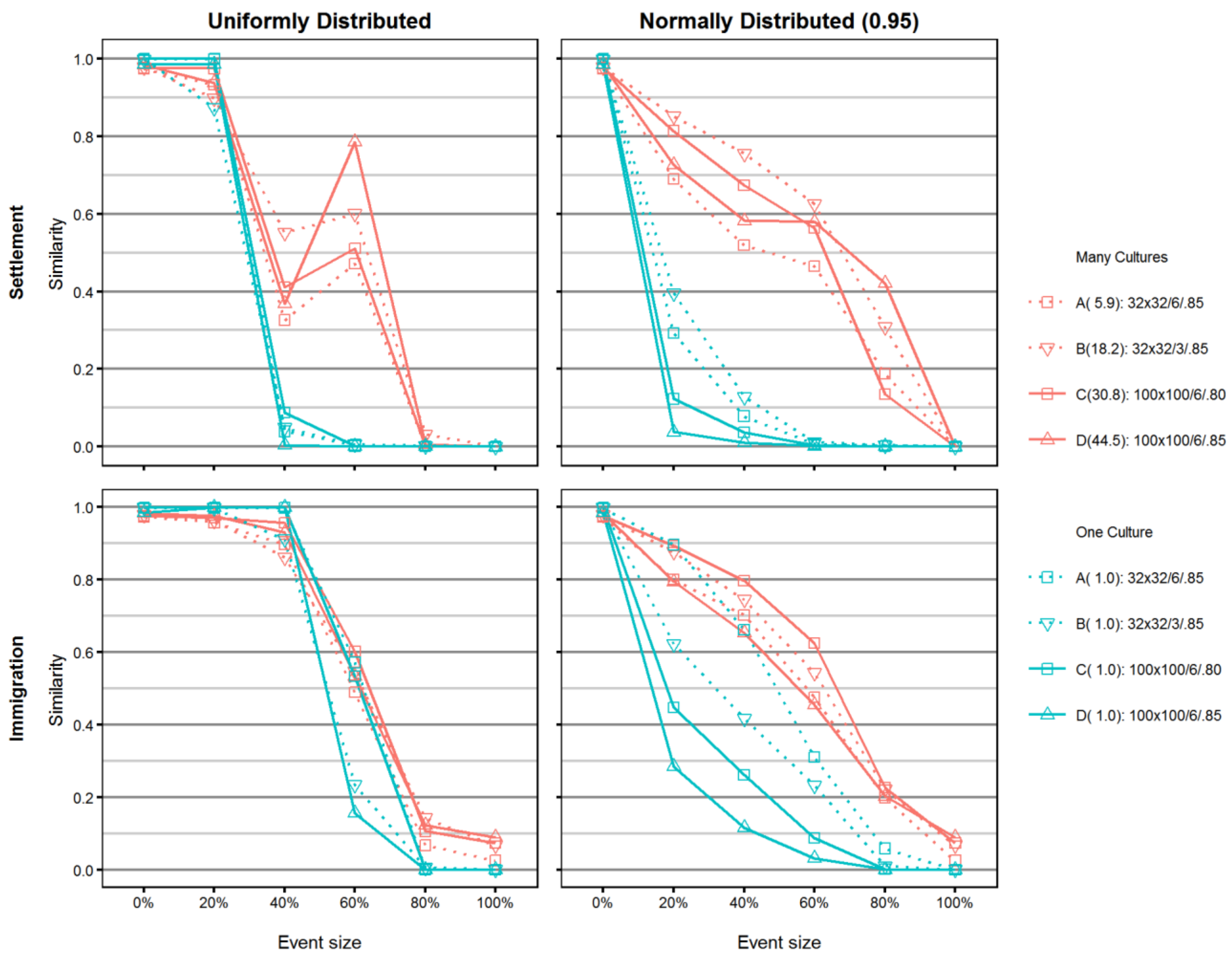

Figure 18. Effects of *immigration* and *settlement* on diverse and monoculture scenarios with either uniform or normal distribution. The Blue lines represent the monoculture version of four scenarios, and the Red lines the diverse version of four scenarios. The left graphs show the results for an uniformly distributed event, and the right graphs results for a normally distributed event. The top graphs present the *settlement* event, and the bottom graphs the *immigration* event. The symbols in the legend denote parameters that characterize scenarios in the format S(G): NxN/R/I where S is the identifier; G is the average number of cultural groups; NxN is the number of rows and column; R is the distance for neighborhood interaction; I is the level of institutional influence. The Y-axis holds the dependent variable, in this case the similarity between the state just before the event (1000000th iteration), and 100000 iterations after the event. The X-axis shows the size of the event as a percentage of the affected agents.

Settlement has a stronger impact than *immigration* (the downward gradient is higher), which is an expected result: settlers bring along their institutional allegiance, which affects the native population much more strongly. Immigrants come without institutions and thus, when their numbers are low, adopt existing institutions. This differentiation disappears when the event size increases, probably because high numbers of immigrants create their own institutions (i.e. they end up acting in a similar fashion as in the *settlement* scenario).

A diverse cultural world (Red) is significantly more resilient to foreigner introduction overall than a monoculture (Blue): the gradient of the descent is generally slower and starts at a larger event size. No clear relation was found between the number of cultures (in the cases of Red scenarios) and the resilience.

In regards to the Maya case, there is some evidence that minor migratory movements might have occurred during the time of the Classic Maya. According to the simulation, however, any larger number of foreigners would have severely destabilized the Maya cultural make-up. We can conclude that, for example, a small number of Teotihuacan immigrants could have been easily tolerated and they might have assimilated well, especially if they distributed fairly uniformly across Maya territory. However, a strong invasion, such as the one suggested for Seibal (Chase, 1983; Sabloff & Willey, 1967), would have left a very noticeable fingerprint on the cultural composition of the Maya, so it is less likely that the hypothesis of Maya collapse due to foreigner introduction holds true. Webster (2002) agrees with this, pointing out that foreign representation, for example in the form of an attack, would have had far-reaching consequences. Instead, the foreign influences first detected in Seibal's iconography are now considered less exotic due to the accumulation of recent research and excavations (D. L. Webster, 2002).

4.3.3.3 Institutional structural damage

Figure 19 shows how uniform and normally distributed institutional structural damage could have affected scenarios Red and Blue. Two different types of structural damage, *apostasy* (top row; abandonment of institutions by agents through for example a revolt) and *institutional destruction* (bottom row; destruction of institutions in terms of political decline or collapse) are presented. Both have a higher impact on the cultural similarity than *decimation* did, although the effect of *apostasy* by itself is fairly similar to that of *decimation*.

The introduction of institutional damage even of a small size significantly decreases the similarity of the starting scenarios. Overall, *institutional destruction* tends to affect the composition of the simulation at a faster rate than *apostasy*. For example, for a 40% event size, the similarity when destruction is applied has already been reduced to 80%, whereas for *apostasy,* the similarity is still near 100%, as good as when no event is applied (0%), i.e. the only changes are a product of cultural drift.

The diverse scenarios (Red) prove to be somewhat more resilient to complete (100%) *institutional destruction*, regardless of the type of destruction (*apostasy* or *institutional destruction*); all of them are above at least 50%, and the scenarios with bigger populations (100x100) are above 75%. Moreover, at the 100% rate, the number of cultures (for Red scenarios) is positively correlated with similarity, i.e. the more cultures, the higher the similarity. The simulation reflects the ability of a diverse culture (as compared to a homogenous one) to preserve individual group cultures and, presumably, to rebuild institutions.

Homogenous cultures tolerate high rates of *apostasy* as well, but they then collapse; particularly against *institutional destruction*, they perform badly. For the normal distribution, at event sizes of 20%, the similarity for Blue drops to around 15%. This could be considered unbalanced, as the Blue scenarios' institution is centrally attacked, and receives the highest probability of the distribution (0.95). But a pre-post similarity of 15% is still much lower than the 50% similarity that is held by the Red scenarios even at event sizes of 100%.

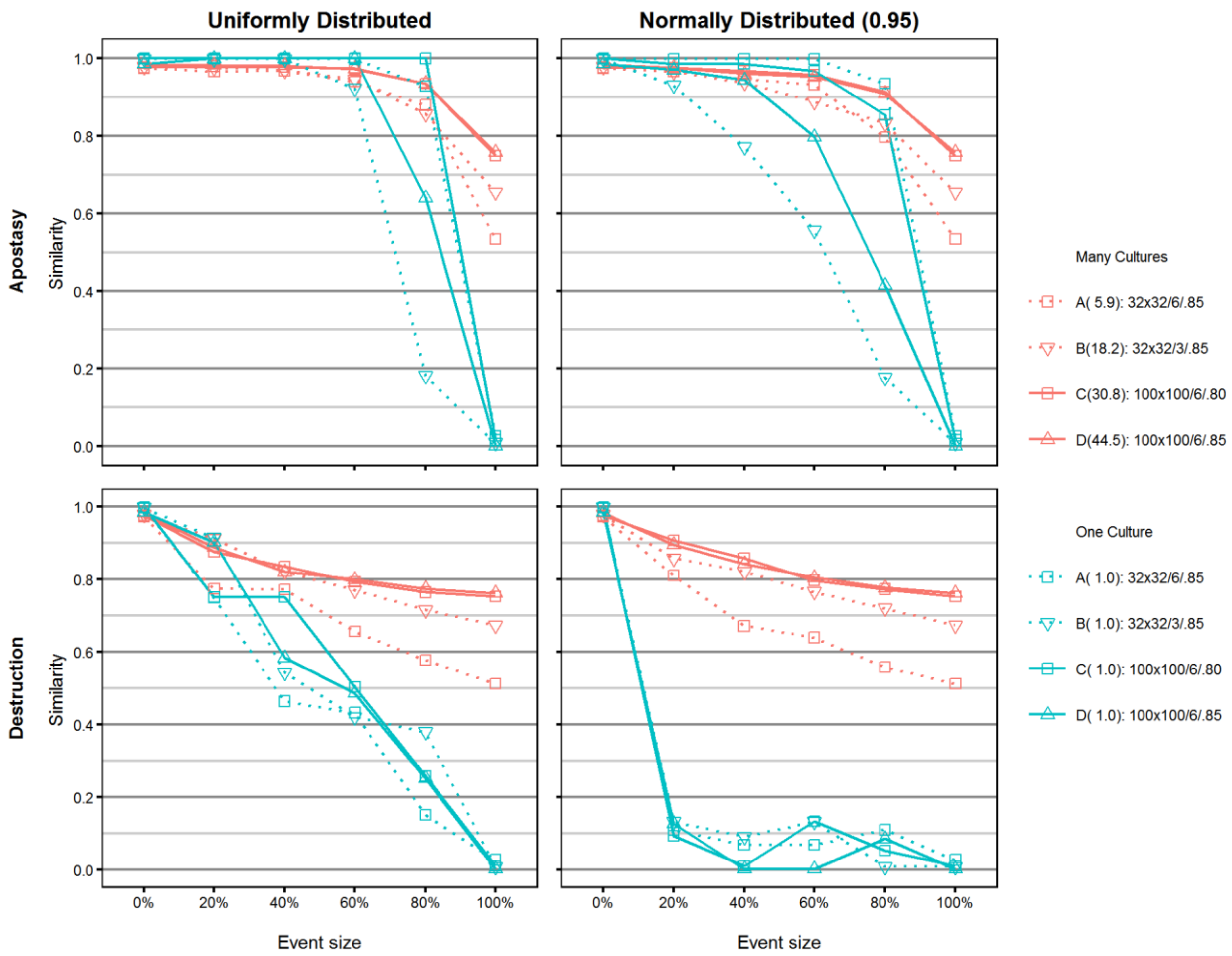

Figure 19. Effects of *apostasy* and *institutional destruction* on diverse and monoculture scenarios with either uniform or normal distribution. The Blue lines represent the monoculture version of four scenarios, and the Red lines the diverse version of four scenarios. The left graphs show the results for an uniformly distributed event, and the right graphs results for a normally distributed event. The top graphs present the *apostasy* event, and the bottom graphs the *institutional destruction* event. The symbols in the legend denote parameters that characterize scenarios in the format S(G): NxN/R/I where S is the identifier; G is the average number of cultural groups; NxN is the number of rows and columns; R is the distance for neighborhood interaction; I is the level of institutional influence. The Y-axis holds the dependent variable, in this case the similarity between the state just before the event (1000000th iteration), and 100000 iterations after the event. The X-axis shows the size of the event as a percentage of the affected agents.

In general, the results obtained for institutional structural destruction are very important because, according to Webster's framework, any theory cannot simply ignore that sooner or later the events caused an institutional collapse, so that cities and regions were abandoned. Moreover, the results also suggest the ability of individuals to rebuild their institutions in spite of complete destruction.

Finally, the resilience shown in the Red version of the scenarios illustrates the validity of the simulation process in general; a different result, such as a total cultural disintegration when testing the effects of 100% *institutional destruction*, would have been difficult to explain considering the survival of diverse Maya cultural groups after the Classic Maya institutional collapse.

4.3.3.4 Institutional content removal

Figure 20 shows how uniform and normally distributed *institutional content removal* could have affected Scenarios Red and Blue. *Partial removal* (top row) and *full content removal* (bottom row) will be explored. Results for partial and *full content removal* are comparable to those we obtained for structural destruction in Figure 19.

Noting the gradient of the lines, *partial content removal* seems to have had a larger impact than *full content removal*. This estimate is based on the shape of the curve; the line following partial removal descends sooner (i.e. at smaller value size) than full *institutional content removal*. One possible explanation is that partially removing content is more likely to affect institutions of adjacent cultural groups, degrading the cultural border akin to a two-way street. Conversely, *full content removal* enables individuals to consistently rebuild their institutions from within a homogeneous population, and maybe even improve the way institutions were created at the beginning (from random assigned traits to individuals). The improved resilience of the simulation against *full content removal* illustrates the capacity of the individuals to reconstruct their institution's content even when they had completely lost all traits.

Once again, diverse scenarios (Red) proved to be more resilient to the proposed events. The statement holds true even when the number of cultures of Red scenarios is taken into account, i.e. the more cultures the Red scenarios has, the more similarity they are able to hold. As with *institutional destruction*, the degradation in the Blue scenarios is due to monocultures starting out with one institution, which then receives full impact and splinters into multiple different institutions, that do not manage to recover to the original state. It is noteworthy that the only scenario that shows an (inversely) proportional decrement is a *full content removal* with a uniform distribution (in the Blue scenarios). This is expected as the destruction of the only existent institution depends on its associated event probability; this probability is equal to the event size and therefore the proportional trend.

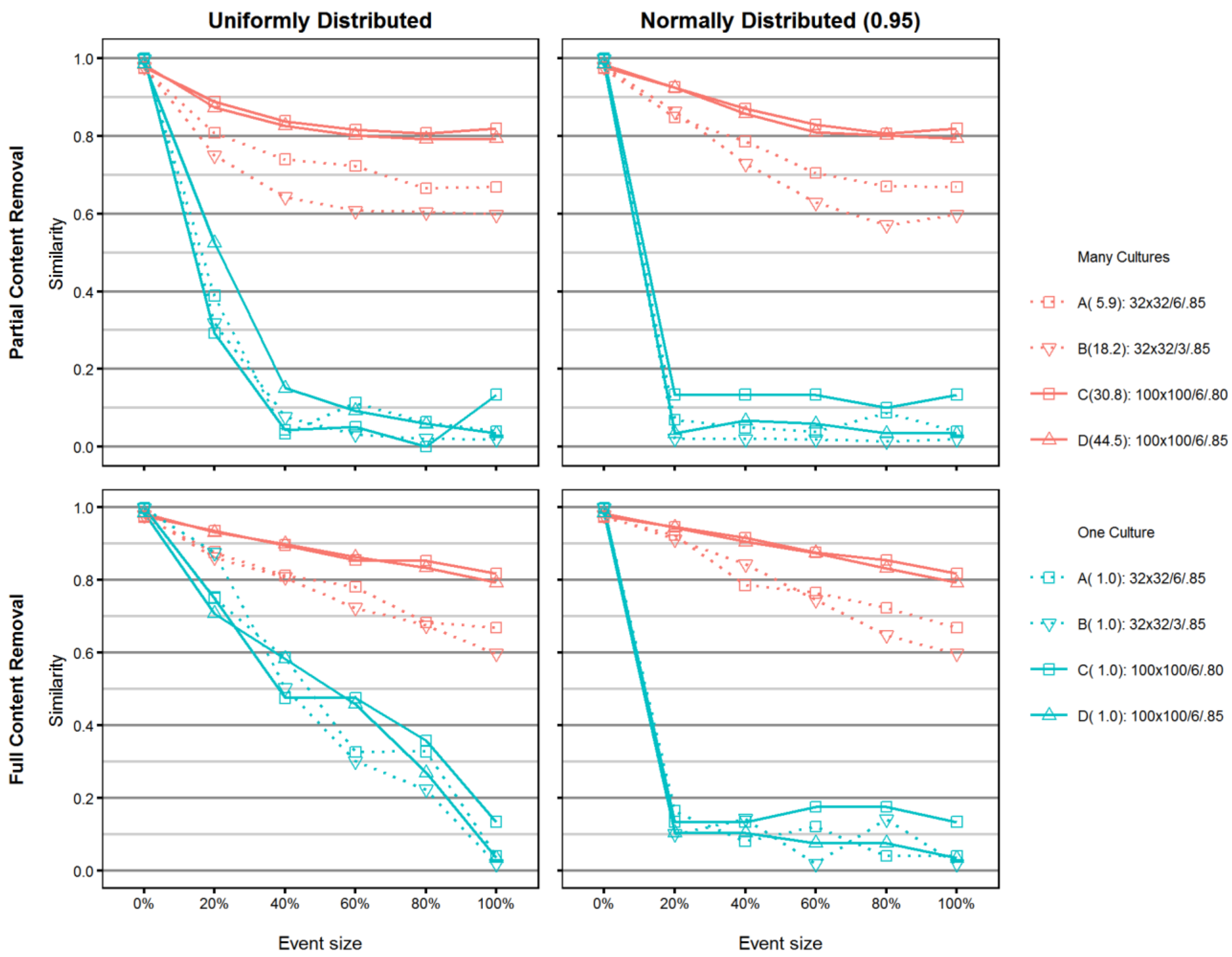

Figure 20. Effects of partial and full *institutional content removal* on diverse and monoculture scenarios with either uniform or normal distribution. The Blue lines represent the monoculture version of four scenarios, and the Red lines the diverse version of four scenarios. The left graphs show the results for an uniformly distributed event, and the right graphs results for a normally distributed event. The top graphs present the *partial content removal* event, and the bottom graphs the *full content removal* event. The symbols in the legend denote parameters that characterize scenarios in the format S(G): NxN/R/I where S is the identifier; G is the average number of cultural groups; NxN is the number of rows and columns; R is the distance for neighborhood interaction; I is the level of institutional influence. The Y-axis holds the dependent variable, in this case the similarity between the state just before the event (1000000th iteration), and 100000 iterations after the event. The X-axis shows the size of the event as a percentage of the affected agents.

In terms of the Maya case study, the simulation gives some support for hypotheses, such as the proposition of revolutions, which suggests destruction of content (or structure) as a cause of the Maya collapse. It is plausible that the Maya cultural diversity would have persisted after even large events of this type, especially since the values for *institutional destruction* were accepted. It is important that the removal of content, as a separated event from destruction, does not cause more damage than *institutional destruction*, i.e. *institutional destruction* eliminates the content and the structure at the same time. That is to say, keeping the institutional structure but losing all the content does not affect the cultural composition more than losing the structure and the content.

4.3.3.5 Institutional conversion

Figure 21 shows how uniform and normally distributed *institutional conversion* could have affected Red and Blue scenarios. Partial conversion (top row) and full content conversion (bottom row) will be explored. Both have a high impact on cultural similarity. Compared to all the previous events, the conversion is the one that presents the highest impact: changing content in institutions even just at 20% in the partial conversion event leads to big changes in the cultural make-up of all scenarios. Although, with the full conversion event the results similarity holds slightly higher, the deterioration slope is still pronounced.

The Red (diverse) scenarios are still more resilient to institutional content conversation than homogenous populations (Blue). The positive correlation of number of cultures (of Red scenarios) and similarity holds up. Similar to *institutional content removal*, for conversion at a uniform distribution, a partial conversion is even more drastic than a full content conversion.

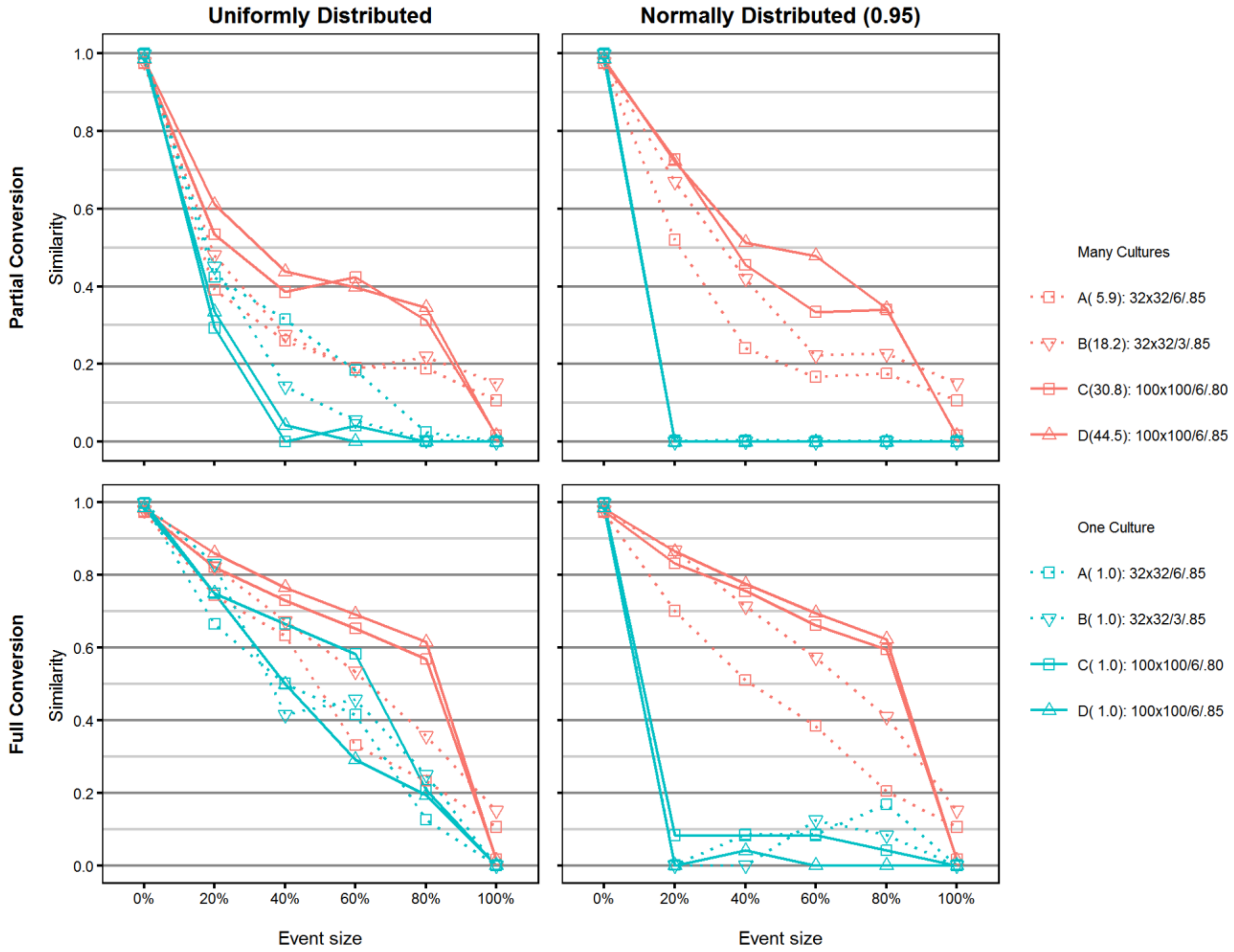

Figure 21. Effects of partial and full conversion on diverse and monoculture scenarios with either uniform or normal distribution. The Blue lines represent the monoculture version of four scenarios, and the Red lines the diverse version of four scenarios. The left graphs show the results for an uniformly distributed event, and the right graphs results for a normally distributed event. The top graphs present the partial conversion event, and the bottom graphs the full conversion event. The symbols in the legend denote parameters that characterize scenarios in the format S(G): NxN/R/I where S is the identifier; G is the average number of cultural groups; NxN is the number of rows and column; R is the distance for neighborhood interaction; I is the level of institutional influence. The Y-axis holds the dependent variable, in this case the similarity between the state just before the event (1000000th iteration), and 100000 iterations after the event. The X-axis shows the size of the event as a percentage of the affected agents.

In terms of the Maya case study, according to the result of this simulation, theories that directly or indirectly suggest a conversion, in the sense of for example an institutional shift of values, are unlikely to have occurred without leaving a major impact on the cultural composition of the Maya people. This is consistent with the results obtained by *settlement* and *immigration*. In general, it seems that the introduction of foreign traits quickly affects the cultural composition of the simulation.

4.3.4 Discussion

The proposed events can be clustered into three groups, according to the impact they have on the cultural composition of a stable state (such as the one reached after 1000000 iterations).

The first group consists of events called *decimation* and *apostasy*. These events had the least impact on the cultural composition. The second group consists of the events called *institutional destruction* and (*full* or *partial*) *content removal*. These events had a moderate impact. Incidentally, these two groups can also be distinguished by the target of their attack: events of the first group attack agents, whereas events of the second group attack institutions. Thus, we can conclude that events that attack institutions have a bigger impact on the simulation state than those that just attack agents.

Settlement, *immigration*, and *conversion* belong to the third group, events with the highest impact. The events of the third group also share a special characteristic: they are all events that introduce foreign traits into the simulation. *Settlement* and *immigration* do this by introducing foreigner individuals, and *conversion* does by changing specific traits of the simulation itself.

In terms of the Maya collapse, the results of the simulation mainly challenge those theories that base the cause of the Maya collapse on foreign invasions and use attacks or *immigration* events as justifications for the institutional decline or abandonment of the cities. In order to be considered valid after the results of the simulation presented here, these theories would need to find solid evidence that a drastic cultural shift occurred in the Maya populations after the collapse, or propose how a small impact of foreign invasions could be possible.

Theories that propose *decimation* events (such as drought, diseases or natural disasters) or *apostasy* (revolts) as causes for the Maya collapse are well-supported by the simulation. Similarly, theories based on attacks to the institutional content, such as internal warfare (battles between cities) or revolutions, are plausible. In general, the present simulation shows that none of these events by themselves would affect the cultural composition more than institutional structural destruction would. This is important because, according to Webster's framework (2002), theories that attempt to explain the Maya collapse should at some point explain the institutional collapse (abandonment of the cities), which for the current simulation was interpreted as a complete rupture of the structure between the individuals and the institutions. Results of this simulation support the idea that populations are able to rebuild their institutions even after such a rupture occurs, sometimes in a very similar fashion to the intuitions they had before the collapse. Although the simulation does not model the geographical motion of individuals, there are no restrictions to the idea that new institutions might emerge, for example in different geographical locations.

On a more general note, the results indicate that cultural diversity is more resilient to events than cultural uniformity (monoculture). Although monoculture scenarios were more resilient than diverse ones in the particular cases of *decimation* and *apostasy*, they performed much worse across all other events, in particular those in which institutions were involved. This holds true even (especially) when event sizes of 100% were used. In those cases, cultural diversity scenarios are capable of sustaining their cultural composition, whereas monocultures completely disintegrate. And, importantly, even though cultural diversity allows for the existence of multiple institutions, these institutions do not seem to be the main factor behind the resilience, as it is for monoculture cases.

Finally, in most cases, there was a positive correlation between the number of cultures of the starting scenario (only applicable in the Red version) and the resilience of this scenario, i.e. the more diverse scenarios were largely more resilient than the less diverse (with some exceptions). It is possible that an optimal degree of diversity exists, depending on the circumstances, and while formulating an in-depth hypothesis about this would go beyond the scope of the present chapter, it is possible to conclude that monoculture scenarios are not the optimal ones for the majority of cases.

Methodologically speaking, the presented experimental design was not meant to provide an exhaustive analysis of any particular theory, but to offer a panoramic view of the effects of multiple events and the whole spectrum of their event sizes. This panoramic view was essential to showcase the possibilities and uses of CulSim in a first applied study for the simulator, and also managed to help advance modelling of the Maya collapse by adapting and testing components of an existing framework (Webster, 2002).

An exhaustive combination of events (at the proposed levels) is theoretically possible. However, it is computationally prohibitive, as there are over $10x10^6$ combinations only exploring uniformly distributed events in one scenario at the levels here proposed. In this sense, it was also a more appropriate use of CulSim to focus on each particular theory of the collapse individually. In the case that testing of event combinations is desired for a smaller number of chosen combined scenarios, several events and their respective sizes can be combined in order to represent more complicated frameworks. This is especially interesting if there is more information about the values of events regarding their sizes. The presented theories here do not often provide any data to support specific sizes, but other historical events certainly do. Two of these will be the focus of the next two studies. Importantly for this study, by matching simulated events to a framework, CulSim tool was shown adaptive, and flexible enough to be useful in a wide variety of theories.

4.4 Study 2: Spanish Invasion of the Guatemalan Highlands

4.4.1 Literature Review

The common assumption of the Maya as a homogenous group stems from colonial assumptions of Native peoples as one unified "Other" to be pitted against the European invader. As previously noted, in reality, Maya people form distinct, diverse communities. Up until the Spanish conquest in the early 15^{th} century, termed the post-class period, diverse Maya city states were locked in a constant struggle of cooperation and war (Lovell, 2005). Figure 22 illustrates the expansion of the two main states, Quiché and Caqchikel, in order to control other territories.

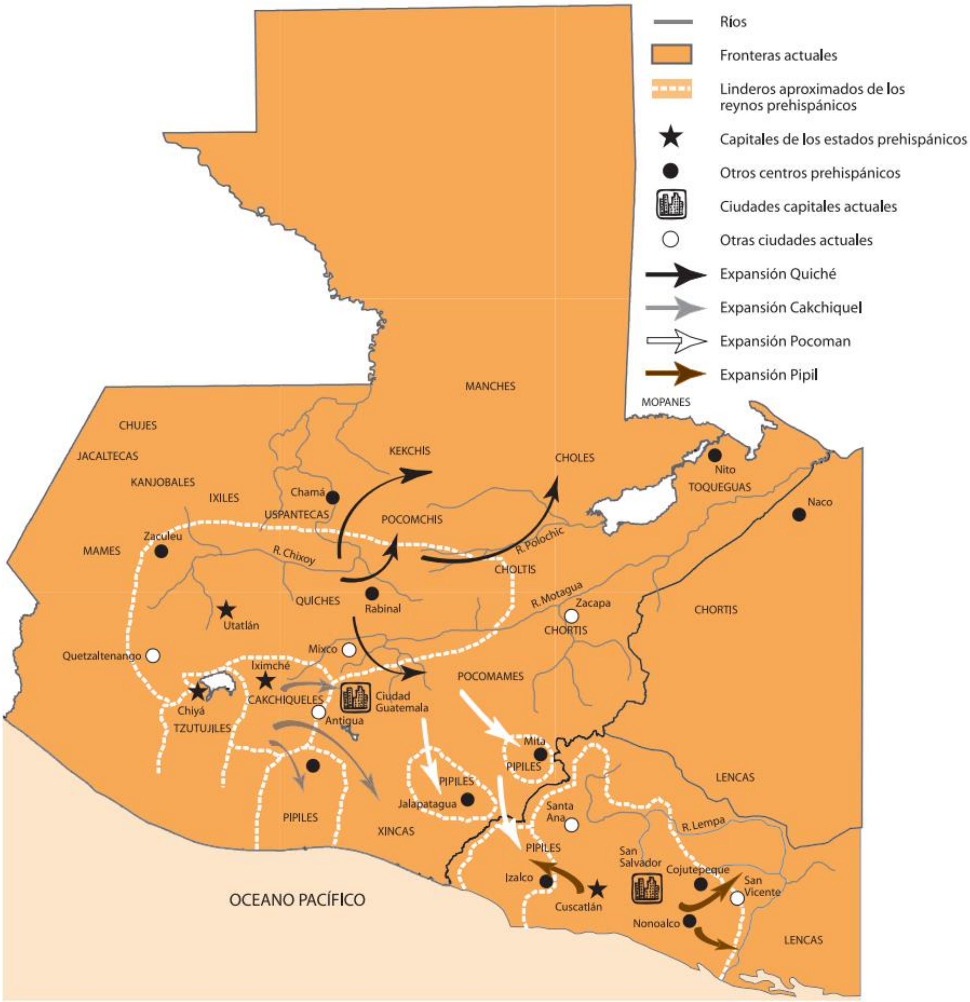

Figure 22. Political centers of the regions at Spanish arrival. Sources: (Informe Nacional de Desarrollo Humano, 2005, p. 28). Licence: Creative Commons Attribution 3.0 IGO license

The Spanish made use of these pre-existing tensions by setting up rivals against each other. For example, they made alliances both with the Mexica, who had previously fought over territories with Maya groups, but also with Maya city states who had struggled against or been subject to another Maya group. As such, the Spanish conquest was not a clear-cut fight between Spanish invaders and a homogenous Maya people, but instead a complex network of cooperation and betrayal between multiple fronts that each had their own individual ulterior motives. The Spanish colonizers could not have taken over most of Mesoamerica without the assistance of the Mexican and Maya warriors (Sharer & Traxler, 2006, p. 762).

Lovell (2005) writes that following the first confrontation between a Spanish expedition force led by Pedro de Alvarado and representatives of the Quiché nation, "the Quiché … tried to force an alliance with the Cakchiquel and the Tzutuhil peoples" (2005, p. 59). Both Cakchiquel and Tzutuhil were enemies of the Quiché and refused an alliance.

Instead, in an example of the prior described political machinations, Caqchikel peoples and the Spanish collaborated to subjugate the people of Quiché (Restall & Asselbergs, 2007). Caqchikel people, after this, were taken by the Spanish as vassals, and, treated poorly, incited a rebellion, which led to their own subjugation (Restall & Asselbergs, 2007). Still, while on one hand, the diversity of the Maya peoples (and the wars for control accompanying it) made them more susceptible to politically instigated defeat, according to Lovell, "Spanish subjugation of the Guatemalan highlands was made an arduous, protracted affair by the political fragmentation of the region [...] [as there was] no single, dominant native group to be overcome" (2005, pp. 59–60).

Thus, the Spanish employed a set of various strategies such as burning of high ranking Maya officials (Recinos, Adrián, 1952; Sharer & Traxler, 2006), burning of entire Maya cities and their artefacts such as their art and literature (Jones, 2000; Lehmann, 1968; Recinos, Adrián, 1952; Sharer & Traxler, 2006) as well as the forceful relocation of Maya populations into colonial towns (*reducciones*, *congregaciones*) (Sharer & Traxler, 2006), which made them responsible for the mass destruction of Maya institutions. Some Maya populations chose to retreat into inaccessible regions (mountains and forest areas), abandoning their institutions and restructuring their organization (Pugh, 2009, p. 191; Schele & Mathews, 1999; von Houwald, 1984, p. 256).

Finally, Spanish colonists could also not have taken over Central America without the help of "Old World diseases" (Jones, 2000), in particular smallpox, measles and influenza, malaria, parasites and tuberculosis, as the native indigenous population had no resistance to these diseases and many communities were strongly devastated (between 33-90% of various populations in Yucatán, Petén Itzá, Belize, Nojpetén) especially within the first century after the Spanish arrived (Coe, 1999; Lovell, 2005; Thompson, 1954).

4.4.2 Methodology

From the historical overview of events, it is clear that the Spanish invasion involved multiple types of aggressions against the Maya population. In this study, data and textual descriptions of the events related to the Spanish conquest were compiled, analyzed and associated to different events of the simulation. This work is presented in the Appendix 12. Based on the literature, appropriate distributions and values for occurring event sizes were selected. Table 11 presents the results of this selection, and for each selection, I provide an exemplary citation which supports my choice of values.

Table 11. Distributions and values for Invasion. The table presents the selected events, distribution and values for the events in the simulation. The first column presents the name of each event. The second column the distribution and selected values together with a short explanation of what they represent. The third column present a reference that illustrates the presence of the event.

Event	Distribution	Reference Example
Decimation	**Uniform (50%):** represents the casualties of plagues brought by the Spanish	"… one-third to one-half of the Indian population of highland Guatemala must have perished as a consequence of this pestilence" (Lovell, 2005, p. 71)
Apostasy	**Uniform (50%):** represents survivors that escaped and found refuge in the mountains, leaving behind institutions	A Kaqchikel priest foretold that the Kaqchikel gods would destroy the Spanish and the Kaqchikel people abandoned their city and fled to the forests and hills on 28 August 1524 (7 Ahmak in the Kaqchikel calendar). Ten days later the Spanish declared war on the Kaqchikel. (Schele & Mathews, 1999, p. 298)
Institutional content removal	**Uniform (10%):** represents scattered damages (incomplete destruction) to the communities	Pedro de Alvarado "… advanced killing, ravaging, burning, robbing, and destroying all the country wherever he came… " (Sharer & Traxler, 2006, p. 764).
Institutional destruction	**5 x Centralized (10%):** represents destructive events to various cities across the country, one in the center and one in each corner	Alvarado decided to have the captured K'iche' lords burnt to death, and then proceeded to burn the entire city (Recinos, 1950; Recinos, Adrián, 1952, pp. 74–75; Sharer & Traxler, 2006, pp. 764–765). Similar destructions occurred in Kacqchikel, Utatlán, Mazatenango, Nebaj (Lovell, 2005, pp. 59–65; Recinos, Adrián, 1952, p. 19; Schele & Mathews, 1999, p. 298, 310, 386n19).
Settlement (invaders)	**Centralized (2.5%) and Uniform (2.5%):** represents one event (of size 5%) divided in two; one, the colonizers settling in the center, and two, the foreigners controlling territories	Cortés dispatched Pedro de Alvarado with 120 cavalry (with 50 spare horses), 300 infantry, crossbows, musketeers, 4 field pieces (cannons), large amounts of ammunition and gunpowder, and an unspecified (hundreds or thousands) number of allied Mexican warriors from Tlaxcala, Cholula and other cities in central Mexico (Lovell, 2005, p. 58; Matthew, 2012, pp. 78–79; Sharer & Traxler, 2006, p. 763)
Institutional conversion	**Centralized (10%) and Uniform (10%):** represents one event (of size 20%) divided in two; one, conversion of institution near the Spanish base, and two, the colonization of other cities	"Se impuso un nuevo tipo de asentamiento territorial, cuya base la constituyó el sistema de "pueblos de indios" establecido hacia mediados del siglo XVI; formados muchas veces con indígenas pertenecientes a distintas etnias. Así se rompería el sentido de la antigua pertenencia étnica y territorial. Los nuevos referentes del poder y la identidad serían la Corona de Castilla, Santiago de los Caballeros, España, la ciudad de Guatemala, las parroquias y gobernaciones, con sus distintas instituciones y funcionarios, y la Iglesia." (Informe Nacional de Desarrollo Humano, 2005, pp. 28–29)

The selection of values for the following analyses is not trivial, and worthy of examination. In terms of *decimation*, Coe provides some figures as high as 90% of the population (Coe, 1999, p. 297); however, this number estimates *decimation* over the entire first century. A 50% *decimation* is an estimate made considering the sizes of the Maya group armies, and taking into account the size of the area; it seems more appropriated for the first decade. Regarding *apostasy*, the value of 50% was chosen to represent how indigenous people were relocated onto *reducciones*, or those that, after the destruction of main cities, abandoned the remaining cities in order to look for protection in the mountain areas (Schele & Mathews, 1999).

The content removal of 10% represents only the scattered damage caused by the Spanish armies while transiting the lands, i.e. the destruction of small communities; this is why the value is kept low. The destruction of important Maya centers is represented by the institutional structure damage event. The literature points to several big battles in which cities were completely devastated: these major destructions are represented by 5 centralized events with different centers in a five-face dice configuration (one in the middle and 4 in the corners). In total, this represents a destruction of ~50% of the existent institutions. These institutions completely lost their content (adding to the institutional content event), and in the simulation, all the agents that belong to them become stateless (adding to the *apostasy* event).

The 5% figure for *settlement* is inflated, as sources indicate that no more than 10000 invaders including native warriors (Sharer and Traxler 2006; Lovell 2005; Matthew 2012) participated in the conquest; assuming more than one million habitants - just the Quiche was controlling around a million (Informe Nacional de Desarrollo Humano, 2005), 10000 invaders would be equivalent to less than 1% of the population. The figure is inflated to 5% as these estimates refer to the population before the Spanish arrival, and a higher percentage should be assumed as the population did not recover to comparable values until modern days (Veblen, 1977). This 5% is split into two distributions in the simulation in order to reflect a pattern of conquest: although many Spanish people remained clustered in the center, as the conquest advanced some of them were sent on conversion missions and stayed in different communities. This principle was also applied when executing the *institutional conversion* event, which was split across two distributions of 10%, one centralized and another uniformly distributed over the territory. Here, the figure is less reliable as it is difficult to estimate how radically institutions were converted; 20%

was chosen to reflect the main conversion agenda of the Spanish conquest: religion and language.

Based on results from Study 1, we can infer that conversion and *settlement* (colonization) are the two most damaging events. Incidentally, for the case study of the Spanish invasion into Maya territory, they are the events that are the most interesting to study in terms of their effect on Maya civilization. For this reason, in this study, we will study how the events related to *Colonization* (i.e. insertion of foreign traits: *settlement* and conversion) affected the Maya population in comparison with the other events, i.e. the four events that are not related to the insertion of foreign traits (*decimation*, *apostasy*, *institutional content removal* and institutional damage). The first group of events (termed *event-set*) will from here on forward be called *Colonization*, while the second event-set will be called *Damages*.

We will mainly discuss how the presence or absence of damages during colonization affected the make-up of the Maya cultural composition. However, for the sake of completeness, a full 2x2 experimental design was run, with the two factors *Colonization* and *Damages* set as either absent or present. To exemplify, *Damages* without *Colonization* would be equivalent to a scenario where destruction is caused by external forces but foreigners never settle in the local territory or convert institutions. Conversely, *Colonization* without *Damages*, presents the case of a colonization that did not involve violence.

For our first experiment in this study, we applied two parameter settings from Study 1 across the two previously presented two different population sizes (32x32 and 100x100), as this allowed the results between the two studies to be compared. However, due to length considerations and because larger populations are generally more representative of real life scenarios, just population sizes of 100x100 will be presented in the results section. The results for population size 32x32 can be found in the Appendix 11. The presented scenarios correspond to scenarios C and D of Table 10.

For our second experiment in this study, we will introduce four new scenarios in order to test the generalizability of the results obtained in experiment 1. Table 12 presents these four new scenarios as variations of Scenario C of Table 10, created by changing one factor at a time (cells that are changed are highlighted in the table). Factors that are not specifically noted in the table are identical to Experiment 1. The notation of Study 1 has been extended to the following patter S(G): NxN/R/I/F/T. The meaning of initials S, N, I, R, F and T, are given in the parenthesis in the header of the table. The letter G represents the average of cultural groups generated by the scenario.

Table 12. Variations of scenario D. This table present the factors and values for the variations of scenario D for the second experiment.. The first column, show the identifier of the scenario. The second column, the population size expresed in number of rows and columns. The third column, the radius that define the size of the interacting neighborhood, e.g. an agent can have up to 84 neighbors with radius 6, and 24 with radius 3 (it could be less if the individual is in the borders). The fourth column indicates how much the institutions influence the individual, e.g. preventing trait changes to happen. The fifth column, the number of cultural feature that each individual has. The sixth column, possible cultural traits that each feature could have. The top row shows in parenthesis the notation used to describe each paramenter. The second row presents the original scenario D as a reference.

Scenario (S)	Population (NXN)	Radius (R)	Institutional influence (I)	Features (F)	Traits (T)
C	100x100	6	0.80	5	15
C1	100x100	4	0.80	5	15
C2	100x100	6	0.70	5	15
C3	100x100	6	0.80	10	15
C4	100x100	6	0.80	5	30

In the third experiment, first, *Colonization* events are split into two by separating uniform and normal distributions to study the effects of different distributions (See Table 8). Second, *settlement* and conversion events also split up to study the effects of the two different event types that comprise the event-set. Additionally, for this analysis, the size of the *settlement* event is increased to 20% in order to make it comparable with the conversion event, because the underlying goal of this experiment is to explore which of these two events and which of these two distributions is driving the main effects found in experiment 2.

Experiment 4 explores how two institutional mechanisms (democracy and propaganda), which were first proposed in Ulloa, Kacperski, & Sancho (2016), affect the simulation. It is important to remember that although the concepts of democracy and propaganda could be considered modern or even associated to Western culture, both terms are used to describe two abstract mechanisms that reflect the direction in which information flows between the institutions and the population, bottom-up and top-down. Thus, there is no anachronism in using these concept, as this flow can be argued to happen as part of the institutional role in societies.

To reiterate the two parameters, democracy is a bottom-up process that allows those agents that belong to the same institution to choose (by majority vote) a new trait that is then written into their institution. Propaganda is a top-down process that allows an institution to propagate a trait that exists in the institutional vector, but is the least popular trait in the population that belongs to this institution, which can be accepted or rejected by affected agents based on their affinity to their institution. Four combinations of propaganda and democracy are explored as extensions of scenarios C and D. The Table 13 presents the combinations. The values are presented as fractions in the form 1/X, meaning that a democratic or propaganda process occurred each X iterations.

Table 13. Extension of scenario C and D with institutional mechanisms. The table present extensions of scenarios C and D that include two institutional mechanisms: democracy and propaganda. The first column shows the value of democracy for each scenario and the second column the value of propaganda. The notation 1/X represents a frequency that reads 1 occurrence (of propaganda or democracy) each X iterations.

Democracy	**Propaganda**
0	0
1/5	0
1/5	1/10
0	1/5
1/10	1/5

Simulations are run in the same fashion as the diverse version of Study 1: (a) agents are assigned random traits at the beginning of the simulation (iteration 0), (b) the simulation runs for 1000000 iterations to reach an equilibrium, (c) the events are executed and (d) another 100000 iterations pass before results are collected (i.e. similarity is assessed); for all cases, 24 repetitions are performed of each configuration.

4.4.3 Results

For the sake of clarity, the results presented here are limited to scenarios of 100x100. The Appendix 11 holds full results, including the ones for population sizes of 32x32, and complete graphs with complementary results visualizations. In general, the results with populations of 32x32 were more difficult to interpret as the events had more drastic effects the cultural compositions. Further analyses are necessary to explore the reasons of such differences.

For experiment 1, we will contrast two event sets: *Colonization* and D*amages*. To reiterate, the first event set, *Colonization*, contains events that introduce foreign traits into the system (i.e. *settlement* and *institutional conversion*); the second event set, *Damages*, contains events that are related to the consequences of an invasion (i.e. *decimation*, *apostasy*, *institutional destruction* and *institutional content removal*). Figure 23 shows the results obtained for this experiment.

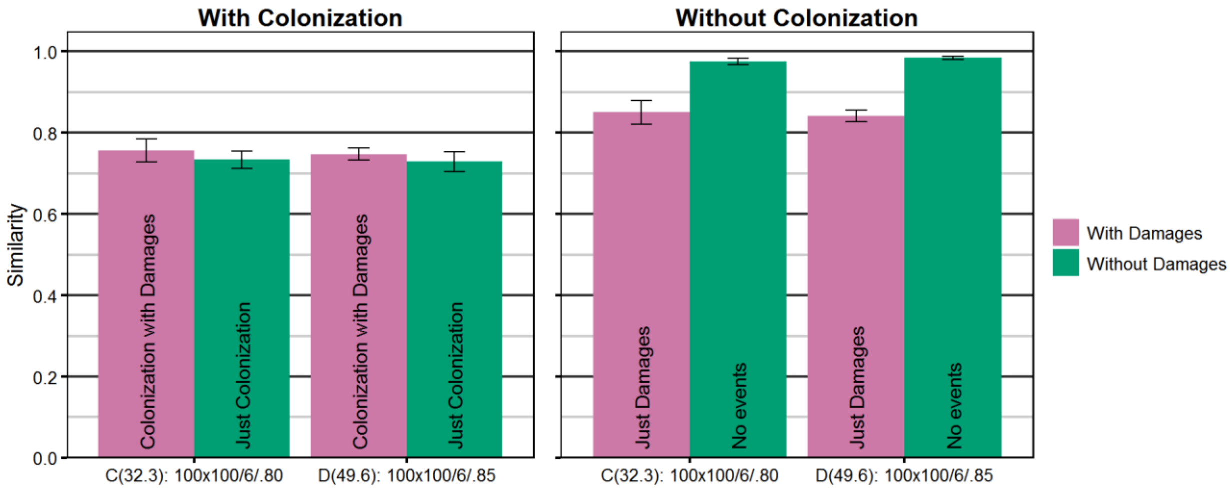

Figure 23. Effects of *Damages* and *Colonization* on the similarity of diverse scenarios. The purple bars present the results for cases in which the event set contained the *Damages* event, whereas the green, the results for cases that did not. The left graph presents the results with *Colonization* event-set, whereas the right graph the ones without *Colonization*. The Y-axis shows the similarity between the state just before the event (1000000th iteration), and 100000 iterations after the event. The X-axis shows the results for two scenarios in the format S(G): NxN/R/I: S is the identifier; G, average number of cultural groups; NxN, number of rows and column; R, distance of neighborhood interaction; I, institutional influence.

We can see from Figure 23 that for all the instances where at least one event-set is introduced (six in total), the similarity between pre-event and post-event states remains above 70%. As expected, this is lower than the *baseline* similarity (scenarios called *No events* in Figure 23), which are above 95%. For the scenarios *Colonization and Damages*, i.e. scenarios where all events are integrated, similarity is at about 75%. In general, similarity across all scenarios is acceptably high to represent the resilience of diversity among the Maya population. We can also observe that in instances where a culture experiences *Just Damages* (without foreigner traits introduction), similarity is higher; this is in line with findings from the previous study, which showed that any introduction of foreigners into the simulation impacts the state of the simulation more strongly. It is interesting that, on average, the combination of *Colonization and Damages* resulted in slightly higher similarity than when *Just Colonization* was introduced; although the difference only qualifies as a trend, with an ANOVA $F = 3.356$, $n = 94$, $p = 0.07$, it is important to underline that the expected result would have been in an opposite direction of the trend.

Figure 24 presents some further scenarios to corroborate the reliability of the findings from Figure 23 (i.e. the scenarios uphold similarity around 75% when the *Colonization and Damages* event sets are used). Although significant differences were found regarding similarity between the scenarios C1 to C4, these differences cannot be associated with the diversity (i.e. number of cultures) because this diversity is confounded with the simulation parameters, which in turn lead to the diversity. Nonetheless, given the lack of a clear relation between diversity and similarity, it is most likely that the different parameters of the scenarios are the ones driving the main resilient effect that explains the difference among scenarios.

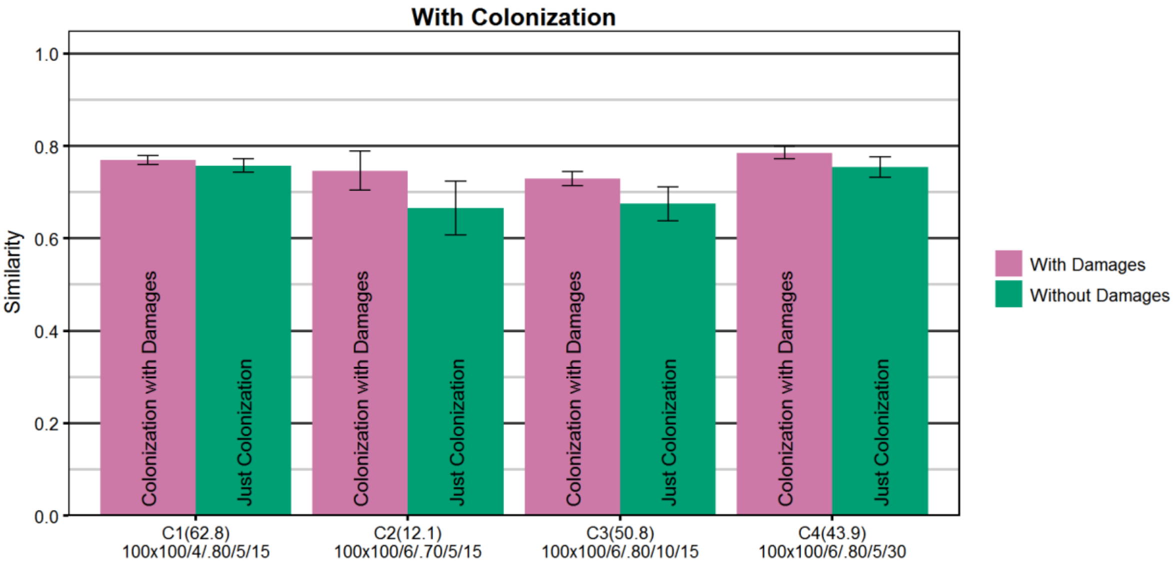

Figure 24. Effects of *Damages* with *Colonization* on the similarity of variations of scenario D. The purple bars present the results for cases in which the event set contained the *Damages* event-set, whereas the green the results for cases that did not. All cases contain the *Colonization* event-set. The Y-axis indicates the similarity between the state just before the event (1000000th iteration), and 100000 iterations after the event. The X-axis indicates the results for four extensions of scenario D format S(G): NxN/R/I/F/T, where S is the identifier; G, average number of cultural groups; NxN, number of rows and column; R, distance of neighborhood interaction; I, institutional influence; F, number of cultural features fo each agent; T, number of posible cultural traits for each feature.

Figure 24 confirms that previously noted non-significant trend that *Just Colonization* (i.e. scenarios with colonization but without damages) on average affected the composition of the cultural state more strongly than the scenario where both events sets were included (i.e. *Colonization with Damages* scenarios). This time, the observation proved to be significant with an ANOVA, $F = 17.17$, $n = 188$, $p < 0.001$. As *Colonization* is in itself a compound event, i.e. it involves two types of distributions (uniform or centralized) and two types of event (*settlement* or *conversion*), it is possible that this effect might be an interaction between those individual two events and their distributions. In order to clarify this, distributions and events were explored separately.

Figure 25 confirms that *institutional conversion* is the main driving force for the significant difference found in the previous scenarios. Institutional conversion events seem to be more destructive when no damages are inflicted, or, conversely, conversion events are less destructive when damages occur. We can note the opposite pattern for the *settlement* events, where damages increase the effects on the cultural composition.

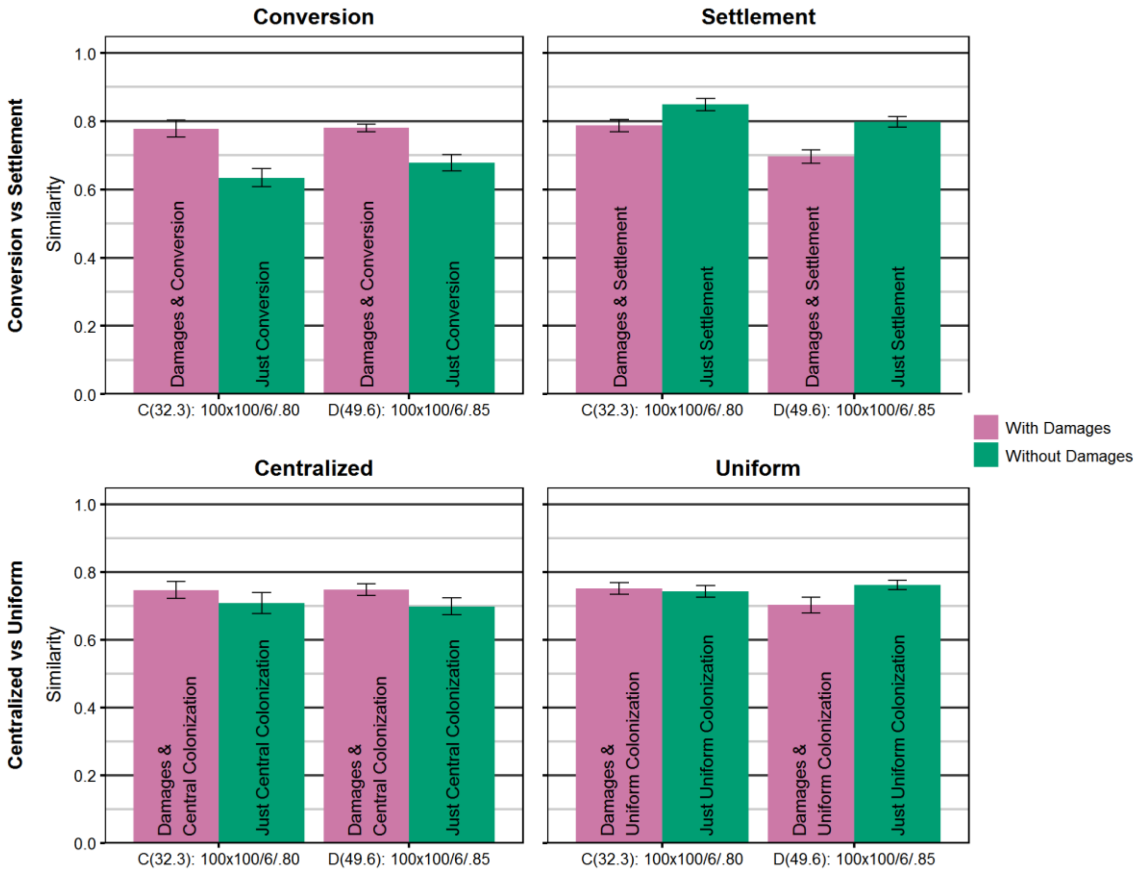

Figure 25. Effects of *Damages* with Conversion, Settlement, Centralized and Uniform *Colonization* on the similarity of variations of scenario D. The purple bars present the results for cases in which the event set contained the *Damages* event-set, whereas the green the results for cases that did not. All cases contain a version of the *Colonization* event-set: the top-left graph, Conversion Colonization; the top-right, Settlement *Colonization*; the bottom-left, Centralized *Colonization*, and the bottom-right, Uniform *Colonization*. The Y-axis indicates the similarity between the state just before the event (1000000th iteration), and 100000 iterations after the event. The X-axis presents the results for four extensions of scenario D in the format S(G): NxN/R, where S is the identifier; G, average number of cultural groups; NxN, number of rows and column; R, distance of neighborhood interaction; I, institutional influence.

From the presented simulation experiments, it was not possible to ascertain how *Damages* are preventing *institutional conversion* events from affecting the similarity pre- versus post-event, however, there is a strong likelihood that *institutional destruction* could be the factor at play, as a destruction of institutions reduces the number of available institutions that can be converted. Future experiments could attempt to provide support for this hypothesis.

Finally, for the last experiment, the role of democracy and propaganda processes was explored. Figure 26 illustrates how these processes affect cultural composition and resilience. Results are similar for scenarios C and D, and will thus be discussed together.

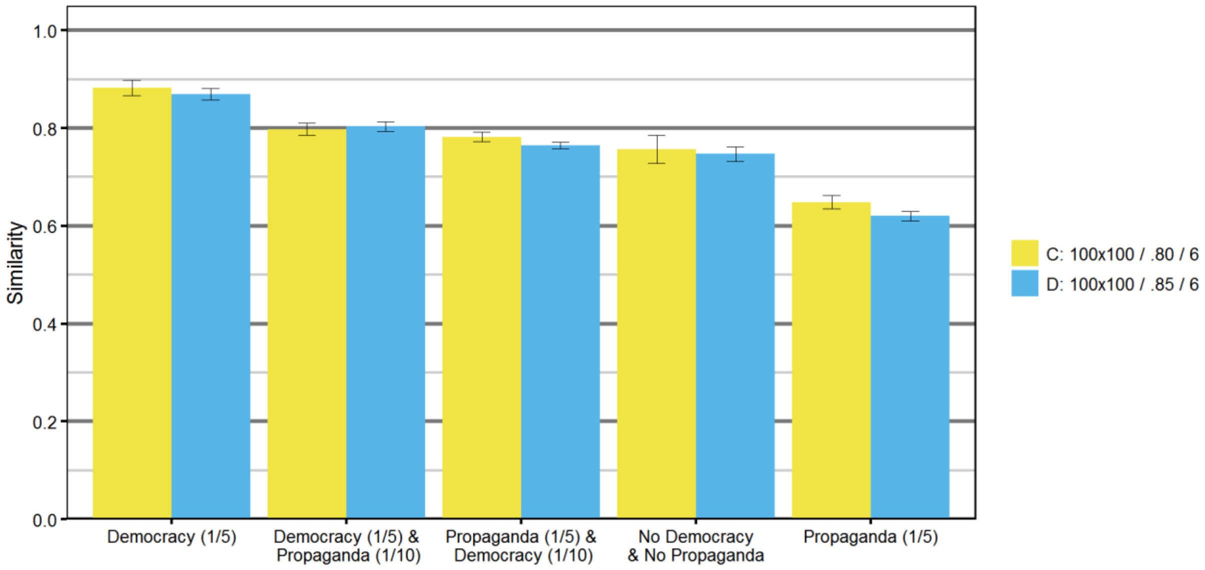

Figure 26 Effects of invasion (*Damages* and *Colonization*) in scenarios with Democracy and/or Propaganda. The yellow and blue bars present results for the scenarios C and D with the extensions presented in the X-axis. Each extension is a combination of Democracy and Propaganda showed in the parenthesis of X-axis labels. The Y-axis indicates the similarity between the state just before the event (1000000th iteration), and 100000 iterations after the event.

Firstly, Figure 26 demonstrates that democracy by itself increases cultural resilience, whereas propaganda on its own has the opposed effect. The make-up of the world is affected fairly strongly, with similarity only slightly over 60%. This result can be explained due to the fact that democracy processes in the simulation provide a mechanism for agents to reconstruct their institutions according to traits they themselves possess. Therefore, effects of events that target institutions are less severe and their long-term effects on the composition of the simulation state are diminished. Conversely, propaganda as an institutional mechanism increases promotion of foreign traits among the population; this ultimately affects similarity strongly.

Scenarios that combine democracy and propaganda perform better at protecting the diversity of the simulation state than the baseline scenarios with only propaganda. And finally, even the scenario in which propaganda is more frequent than democracy performs better than the scenario without any institutional mechanism; though the effect is very small, the difference is significant (ANOVA, F=6.934, df=93, p=0.01).

4.4.4 Discussion

In this study, the concept of an invasion was introduced in the form of two event-sets, which were divided to distinguish the effects of *Damages* caused by invaders (*decimation*, *apostasy*, *institutional destruction* and *institutional content removal*) from the effect of the *Colonization* of invaders in the form of foreign traits (*settlement* and *institutional conversion*). This decision was undertaken based on previous results from Study 1, where a strong effect was found for *Colonization*-type events.

One of the most intriguing findings from the results section of this case study shows that scenarios that included *Just Colonization* were affected in terms of the similarity of pre and post-event states more than scenarios that included both *Damages and Colonization*. Intuitively, expectations might be that the combination of all events would be more disruptive than just a subset of them. However, it can be theorized that *institutional destruction* and *apostasy* are responsible for this unexpected result. It is possible for example that *institutional conversion* becomes less effective when institutions have been destroyed, or when agents have stopped identifying with their institutions (*apostasy*).

The findings of this study are highly applicable to the Mesoamerican case study proposed here. Given the Maya diversity and lack of centralized control, there was no clear institutional target in the Maya area. Instead, the conquerors had to attack a wide range of centers of control, spreading damages and destructions across the region without being able to take over any existent structural organization (such as was possible in two other conquests in America). When the Spanish invaded and colonized regions in which the Mexica and the Inca lived, in both cases, a centralized empire existed at the Spanish arrival, and this mega-structure was overtaken with the replacement of the figure head of the empire by someone who claimed to be representative of the Spanish crown (Cortés & Pagden, 1986; Prescott, 1843). Contrarily, after Pedro de Alvarado killed the Quiche lords, the Spanish conquerors still had to defeat all the other city states' rulers, one by one. As the Spanish mostly achieved this by completely obliterating cities and their associated institutions, conversion attempts made in the region where the Maya lived were less effective: there were no converted promoters of the new cultural traits.

An important component that is not featured in the presented simulation is the costs associated with a uniform conversion, as opposed to a centralized one (which has been demonstrated to be the least effective conversion strategy against diversity). Uniform deployment of military (that pursues the goal to cover a big territory) is self-evidently more expensive to upkeep due to the necessary infrastructure and transport of goods and services for the troops; keeping a centralized force concentrated on a smaller, singular territory is in turn cheaper and more practical in terms of infrastructure. This logic can be followed across all events that include any form of damages. It follows that the successful invasion of a culturally diverse territory costs more or will necessary be less efficient, or, if a compromise is taken, both. In part, this kind of military decision-making in the face of Maya diversity could be responsible for the fact that Maya cultural groups have survived the Spanish conquest.

Finally, it is important also to highlight that institutional mechanisms within the simulation play a significant role in the resilience of cultural diversity. In particular, democratic institutions have been shown in the simulation to promote resilience, whereas propaganda has been shown to decrease it. Future analyses of the types of institutions that were used by the Mayas should be considered following these primary exploratory experiments. For now, in this study, the general ranges were deemed satisfactory to argue intrinsic resilience of cultural diversity and apply the case study as presented here.

4.5 Study 3: Guatemalan Civil War

4.5.1 Literature Review

From 1960 until 1996, a civil war between government and leftist rebel groups (who were demanding social reforms and improved conditions because of high levels of inequality and poverty among the Maya peoples. According to McClintock (1985), the war between the government forces and the leftist rebel groups is considered a small fragment of the violence that took place in Guatemala during this period. In reality, the war was fought between the Guatemalan government and the ethnic Maya indigenous populations from the rural areas of Guatemala. The much larger occurrence of violence was one-sided, perpetrated by the government forces against the Maya population, and is considered a large-scale violation of human rights (Amnesty International, 1976) and a genocide (Amnesty International & International Secretariat, 1982; Ball, Kobrak, & Spirer, 1999; Historical Clarification Commission (CEH), 1999b; Rothenberg, 2012). Politically, the

Guatemalan government of that time is considered to have been a military fascist dictatorship, with different military factions assuming control across the described 36-year time span (Ball, Spirer, Spirer, & American Association for the Advancement of Science, 2000; Schirmer, 1999).

Multiple military organizations have been called responsible for the killings, disappearances and destruction of rebel alliances, including massacres of villages and executions of those individuals suspected of collaborating with the Maya indigenous people, such as Ladino peasants, leftist academics and politicians, trade unionists and journalists (Ball et al., 1999; Historical Clarification Commission (CEH), 1999a, 1999b). Disappearances have been estimated at around 40,000 individuals during the entire war, while more than 160,000 killings are considered, most of them indigenous people (Historical Clarification Commission (CEH), 1999a, p. 73 Vol I). The findings of an investigation into the war crimes have been recorded in the "Memoria del Silencio", a UN report - written by the Commission for Historical Clarification (Historical Clarification Commission (CEH), 1999a, 1999b), which includes detailed accounts of the events occurring during this time period, and geographical and economic data to support claims of violence and genocide against the Maya population. An overview over all sources used in the following analyses is given in Appendix 13, with the "Memoria del Silencio" as the main literary source for figures and parameter sizes chosen for this study.

4.5.2 Methodology

Similar to the Spanish invasion of Study 2, the civil war involved multiple types of events at different degrees of magnitude. However, while there is not much surviving reliable evidence about the events and in particular numbers regarding the Spanish invasion, the level of documentation, information about specific cases, there is a great amount of evidence regarding the Guatemalan civil war. As mentioned, Appendix 13 holds much of this information, presented in the form of tables. Each table holds supporting figures for each event in one simulation, highlighting important accounts on the civil war, and according to them, events sizes have been selected for this study's simulations. A detailed justification for individual values is provided. The tables also refer to complete sections of the Memoria del Silencio United Nations report for sections which can be directly related to the simulations events. Finally, a collection of important figures from the Memoria del Silencio are provided along with the figures to illustrate important data. Table 14 presents a summary of Appendix 13, showcasing the final values that have been selected to be included in the simulation, along with one illustrative reference to support the selection of the value.

Table 14. Distributions and values for Invasion. The table presents the selected events, distribution and values for the events in the simulation. The first column presents the name of each event. The second column the distribution and selected values together with a short explanation of what they represent. The third column present a reference that illustrates the presence of the event.

Event	Distribution	Illustrative references
Decimation	**Centralized (0.75, 10%):** representative of 200.000 executions and disappearances divided by population according to the 1981 census (2.500.000)	"… la CEH estima que en términos muy aproximados tuvieron lugar más de 160,000 ejecuciones y 40,000 desapariciones." (Historical Clarification Commission (CEH), 1999a, p. 73 Vol I) "In El Quiché, 344 massacres took place, representing more than half of the total deaths and over 45 percent of the human rights violations in the country." (Manz, 2002, p. 294) See Figure 2. of Appendix 13.
Apostasy	**Uniform (50%):** representative of the part of the population who renounced their heritage and indigenous institutions out of fear	"Mayans were obliged to conceal their ethnic identity, manifested externally in their language and dress." (Historical Clarification Commission (CEH), 1999b, pp. 29–30) "Por lo tanto, aparte de la eliminación física de gran cantidad de sus miembros, también se vulneró en la población la confianza hacia las organizaciones sociales y sus miembros." (Historical Clarification Commission (CEH), 1999a, p. 119 Vol IV)
Settlement (Settlement)	**Uniform (3%):** representative of the size of the army divided by the population according to the 1981 census (2.500.000)	"Guatemala's military almost doubled in just one year, from 1983-84 (21,560) to 1984-85 (40,000)" (Coerver & Hall, 1999, p. 155) "… el Ejército alcanzó el objetivo estratégico territorial a través de la creación de nuevas zonas y bases militares. Esta organización territorial en el interior del país se realizó desplegando una o más unidades militares por departamento, que coincidieron con los límites políticos administrativos." (Historical Clarification Commission (CEH), 1999a, p. 47 Vol II) See Figure 6 of Appendix 13.
Institutional destruction	**Centralized (0.75, 25%):** representative of attacks and destructions on Maya institutions (such as cooperatives, unions) in the central region	"… a government agency created with US funds, declared 250 cooperatives illegal because of their supposed 'Marxist inspiration'" (Davis, 1992, p. 22) "… after the 1976 earthquake (…) Guatemala boasted 510 cooperatives, 57% of them in the Highlands with more than 132,000 members (Brockett, 1998, p. 112)" (Lyon, 2007, p. 245)

Institutional content removal	**Full Centralized (.75,.25%):** representative of destruction of entire buildings or indigenous sacred places **Partial Centralized (.75,.25%):** representative of damage done to institutions with some survived content **Uniform (~16%):** representative of the general damage across all territories	The following sections of the United Nations Report broadly illustrate this type of losses (Historical Clarification Commission (CEH), 1999a, pp. 172–189 Vol IV) : - Persecución y muerte de autoridades indígenas - Pérdida de valores, normas, costumbres - La identidad maya y expresiones religiosas - Ocupación y destrucción de lugares sagrados - Uso de los idiomas y trajes mayas "En Quiché el Ejército realizó acciones represivas, asesinando a 68 líderes de cooperativas en Ixcán, 40 en Chajul, 28 en Cotzal y 32 en Nebaj entre febrero de 1976 y noviembre de 1977, según el IGE." (Historical Clarification Commission (CEH), 1999a, p. 162 Vol I)
Institutional conversion	**Full Centralized (.75,.25%):** representative of the entire conversion of certain Maya institutions **Partial Centralized (.75,.25%):** representative of partial changes introduced to Maya institutions	"Beginning in 1982, traditional Maya authorities were generally substituted by delegates from the armed forces, such as military commissioners and PAC commanders. In other cases, the Army tried to control, co-opt and infiltrate the traditional Maya authority structures" (Historical Clarification Commission (CEH), 1999a, pp. 118–119 Vol IV)

A copious amount of information is available describing the circumstances of the civil war, thus the selection of the values is not a trivial process. Values for events such as *decimation*, *settlement* and *institutional destruction* were highly evident from the sources and are highly reliable in approximating the events. Others, like *apostasy*, *institutional content removal*, and *institutional conversion*, require some justification. The *apostasy* size of 50% for example are representative of one out of two individuals who decided to give up their Maya heritage in some way. This is an estimate, and the resulting figure is bigger when the number of individuals that completely lost their institutions because of *institutional destruction* events are taken into consideration. In the case of the destruction event, the numbers we have on how many cooperatives were destroyed serves as the main point of reference to estimate the event size (Lyon, 2007; Manz, 2002). As cooperatives and trade unions were, strategically speaking, a special target of the military, this number might have been lower in actuality, and 25% might be a high figure even for the accumulated destruction.

The quantification of *institutional conversions* and *content removals* is somewhat subjective. It seems to make sense, as a point of reference, to assume that these events were similar or equivalent in magnitude to those of *institutional destruction*. Therefore, centralized distributions for conversion and content removal are introduced at the same size as *institutional destruction*, i.e. at 25%. Additionally, this distribution is used twice; once for partial events (partial conversion or removal of traits) and once for full events (complete conversion or removal of traits). There is after all evidence that some content was damaged all across the Guatemalan territory (Historical Clarification Commission (CEH), 1999a). Thus, a uniform 20% content removal event has been added to the previous two in order to affect the whole space.

In studies 1 and 2, a ceiling (i.e. probability of the event occurring in the center of a centralized distribution) of 0.95 was used for all centralized events. In the present study, this value was reduced to 0.75. The reason for this change is that we have information about how the military was distributed across the Guatemalan territory, i.e. we know that it was spread more evenly and wider, and that there were different troops, different military zones and multiple attacks across the territory (Ball et al., 1999; Davis, 1992; Historical Clarification Commission (CEH), 1999a, 1999b; Schirmer, 1999). Thus, the damaged caused by attacks was also more evenly spread (as compared, for example, to what we know about the Spanish invasion, where attacks were executed in a very concise manner, and with clear objectives). Military attacks in Guatemala were directed at multiple targets simultaneously.

The current approach and configuration settings were used not only to adequately simulate the scenario in question, but also in order to further illustrate capabilities of CulSim, and to gain insights into the internal happenings while the simulation runs. Thus, the experiment uses four scenarios, which were chosen based on a different criterion than the scenarios in the previous two studies: Maya cultural groups were selected as the criterion for this study. Figure 15 showed a map of the various linguistic groups of Guatemala, and will serve as one possible way of organizing the Maya cultural composition, i.e. for the following simulation, the existing number of linguistic groups (more than 20) are used as a point of reference to search for appropriate scenarios that approximate well the Maya cultural diversity. In reality, some of these linguistics groups contain subgroups, and some of groups might be separated by other barriers than the language that they share; however, language presents a strong cultural barrier between the groups and, therefore, a good criterion for the selection of the scenarios.

Results gained from studies 1 and 2 were used, as well as some initial exploration using CulSim, to find 4 scenarios (shown in Table 15) that would provide the best starting points to generate worlds with between 20 and 30 separate cultural groups. On these four scenarios, the above selected events were applied, in the order *apostasy*, *institutional destruction*, content removal, *decimation*, invasion and conversion.

Instead of 5 features and 15 traits, as was the case for previous studies, the presented scenarios will all employ agents and institutions carrying 6 features, with 14 traits on each feature. This configuration was chosen because it makes use of the maximum range of colors available on computer screens, and enables the clearest visualizations of results. Number of iterations and number of repetitions before and after the event are constant across all three studies. We did not introduce democracy or propaganda into these scenarios as we did in Study 2 to simplify presentation of the results and to focus on main findings.

Table 15. Scenarios for Study 3. The scenarios presented in this table present the factors and values used for Study 3 that, upon previous exploration, were found to produce between 20 and 30 cultural groups. The first column shows the identifier of the scenario. The second column, the population size expresed in number of rows and columns. The third column, the radius that define the size of the interacting neighborhood, e.g. an agent can have up to 84 neighbors with radius 6, and 24 with radius 3 (it could be less if the individual is in the borders). The last column indicates how much the institutions influence the individual, e.g. preventing trait changes to happen. The top row shows in parenthesis the notation used to describe each paramenter.

Scenario (S)	Population (NXN)	Radius (R)	Institutional influence (I)
E	32x32	3	0.80
F	32x32	6	0.80
G	100x100	3	0.35
H	100x100	6	0.55

Three analyses were performed on the selected scenarios. Firstly, similarity was used, in the previous two studies, to explore the effect of events in the similarity. Secondly, the number of cultures existing before and after the events were analyzed in order to explore how the diversity of the population was affected further. Thirdly, an image of the repetition of each scenario with the lowest and highest similarity will be supplied. This will allow the visualization and analysis of the processes of change inside the simulation.

Finally, correlations were employed to test significances and strengths of important observation made through visualization to have statistical support for conclusions.

4.5.3 Results and Discussion

The first image, Figure 27 provides an overview over similarity of pre and post events states across the four scenarios described in Table 15. In all chosen scenarios, the post-events state stabilizes near 70%. This suggests that, despite the existence of major destructive forces, cultural diversity has retained major similarities to the composition before the destruction, while carrying some unavoidable changes. This result is highly promising regarding the validity of the simulation, as it reflects historical events well; the Maya population suffered major destructions, but was able to sustain a large part of its cultural heritage while some changes were undeniable, e.g. the appropriation of violence from the youth that make it impossible for them to reintegrate themselves with the community (Historical Clarification Commission (CEH), 1999a, Vol IV p. 196).

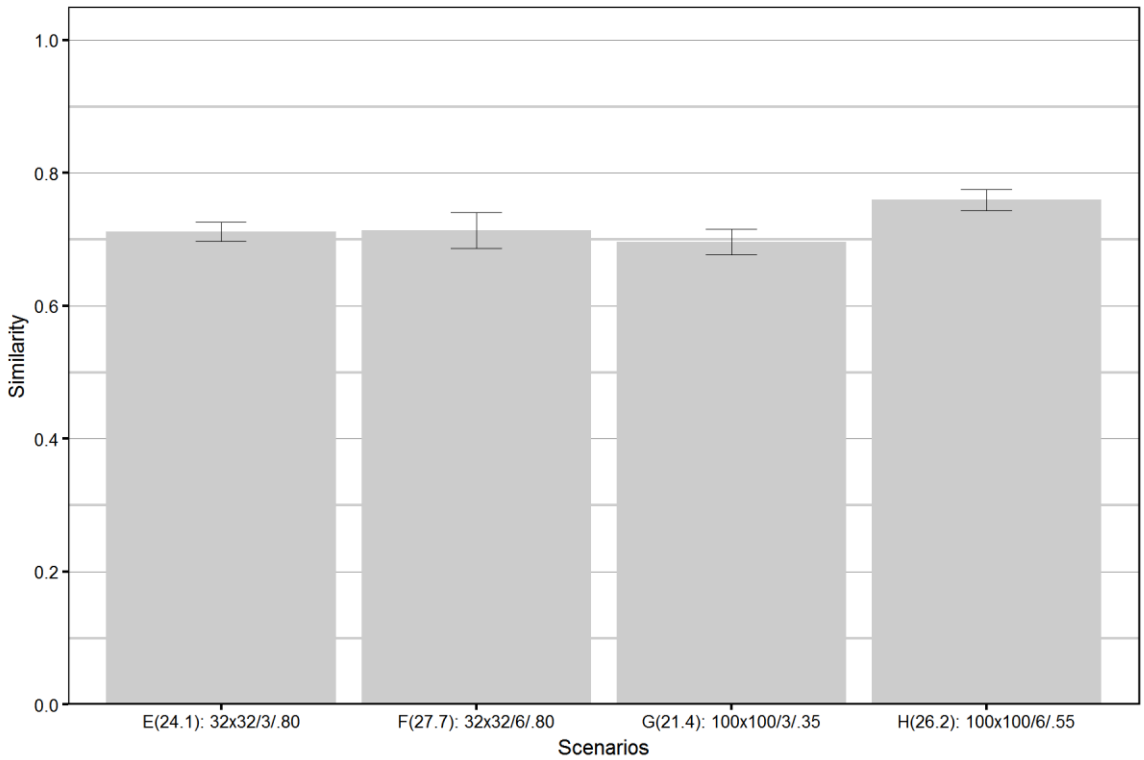

Figure 27. Effects of the civil war on different scenarios. The Y-axis expresses the similarity between the state just before the event (1000000th iteration), and 100000 iterations after the event. The X-axis present the results for four scenarios in the format S(C): NxN/R/I: S is the identifier; C, average number of cultures; NxN, number of rows and column; R, distance of neighborhood interaction; I, institutional influence.

The previous two studies were heavily focused on interpreting results in terms of the similarity pre and post events. In order to extend in the direction of possible dependent variables to showcase CulSim's further capabilities, another response variable will be presented, the effect of the events being applied on the number of cultures existing before and after the event. Figure 28 illustrates the change that has occurred.

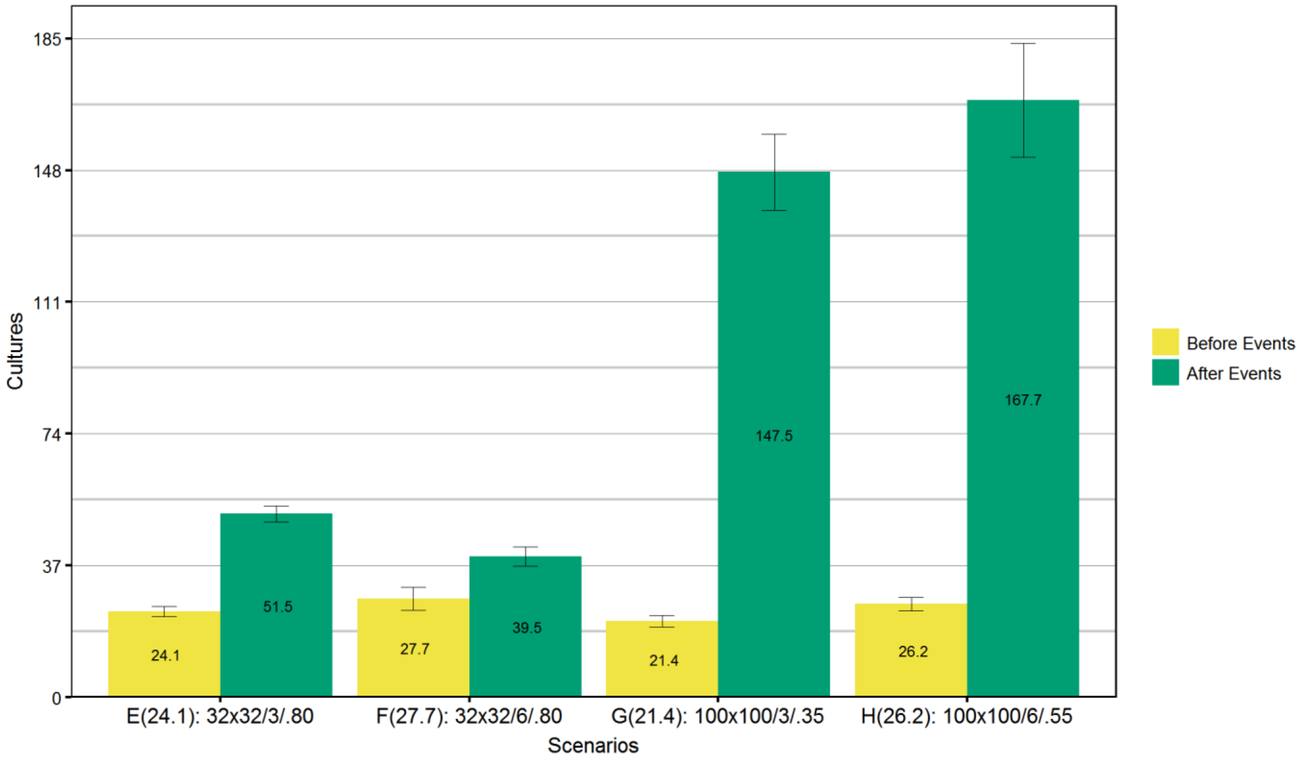

Figure 28. Effects of the civil war on cultural diversity. The Y-axis indicates the number of cultural groups before the events (yellow, 1000000th iteration) and 100000 iterations after the event (green). The X-axis indicates the results for four scenarios in the format S(C): NxN/R/I: S is the identifier; C, average number of cultures; NxN, number of rows and column; R, distance of neighborhood interaction; I, institutional influence.

We can observe that in all cases there is an increase in the number of cultures for the post-event state as compared to the pre-event state. Scenarios that started with more agents (i.e. 100x100 scenarios, see Table 15) ended up splitting into far more cultures. There are two main hypotheses to explain this explosion of diversity: (a) institutional damage events (both in terms of content and structure) decreased how much control institutions had over the population, causing instabilities which were then exploited by random mutations occurring in the system (random changes in the population traits); (b) foreign traits (also introduced as an event) permeated the population, allowing emergence of hybrid cultures.

In order to illustrate better which of the scenarios more likely occurred, Figure 29 presents images for each scenario. Each pair of horizontal images represents 2 repetitions per scenario; one of them is the repetition (out of 24) that resulted in the least similarity and the other is the repetition that showed the most similarity. The figure shows, in each pair of images the state right before the event occurred (1000000th), and the state 100000 iterations after the event.

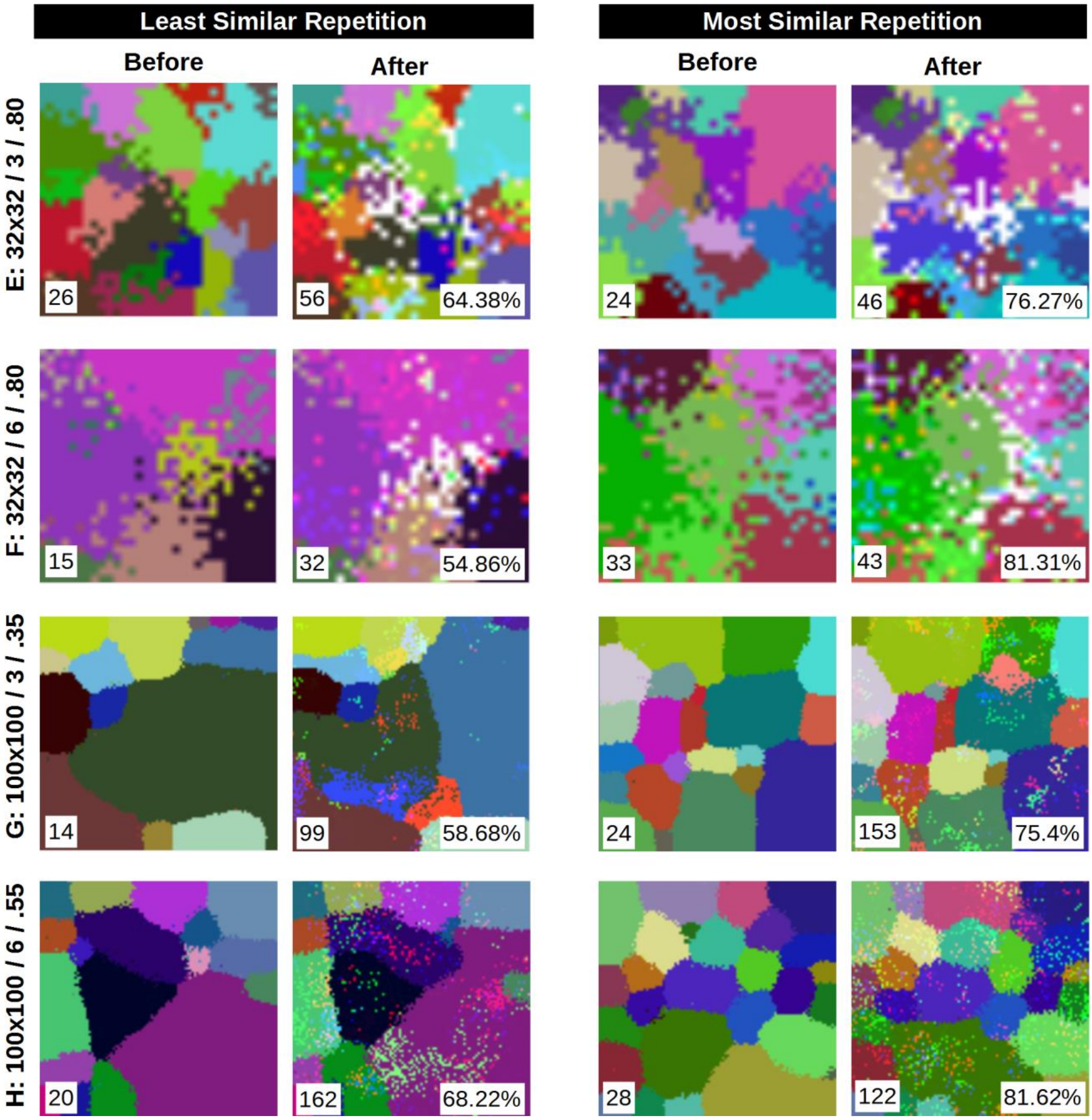

Figure 29. Repetition with the lowest and highest similarity per scenario. Each row in the figure presents a pair of images per repetition of one scenario. In each pair, the left image represents the state before the event (1000000th iteration) and the right image the state 100000 iterations after the event. For each scenario: the first repetition, corresponding to the first pair of images on the left, is the one with the least similarity for each scenario (out of 24 repetitions); the second repetition, corresponding to the last pair of images on the right, is the one with the most similarity for each scenario (out of 24 repetition). Each image presents the number of cultural group in the bottom-left corner. The bottom-right corner of the second and fourth columns (the ones that represent the state after the event) indicate the similarity between the two images.

Within the simulation, an entirely foreign culture (i.e. a culture of agents that were introduced from outside and share no traits with the native agents) would be represented as white (some agents of white color prevail in the after-event images above). A hybrid agent of a foreigner and a native agent in the simulation is represented with a color of a light shade. For all the scenarios in Figure 29, we can observe that scattered cultural groups have emerged after the event. Most of these scattered groups are colored in lighter shades. The foreigner hybrid hypothesis (hypothesis b) is therefore the more likely hypothesis responsible for the increase in cultural groups variations.

The hybrid cultures, as mentioned, appear scattered across the grid, i.e. they do not have clearly defined borders. This is the explanation for why we perceive that there is an explosion of cultures when analyzing Figure 2. As separate cultures are counted only when they have at least 3 agents of the same culture adjacent to themselves, the scattered agents are counted as single cultures despite that fact that one could argue that they possess the same roots. Therefore, the Figure 2 over-represents the diversity of cultures actually in existence.

Secondly, all these new scattered smaller cultural groups have a strong effect on the similarity response variables. This illustrates that sometimes, the similarity variable might not be the optimal choice to represent changes between the before and after scenarios, although generally speaking they provide a general perspective of what is happening. Graphs such as the ones in Figure 3 should be used to help analyze similarity across different time spans in a more detailed view of the simulation.

Notoriously, in 3 out of the 4 scenarios (F, G, H), the repetitions that were affected the most by the event (i.e. the one least similar after it) were the ones with the least number of cultural groups. Correlations between number of cultures and the similarity were computed for the 4 scenarios. A significant positive correlation was found for the 100x100 scenarios (C and D): for 100x100/.35/3, $r = 0.618$, $n = 24$, $p = 0.001$; and for 100x100/.55/6, $r = 0.637$, $n = 24$, $p < 0.001$. In the 32x32 scenarios, number of cultures and similarity were not significantly correlated: for 32x32/.8/3, $r = -0.078$, $n = 24$, $p = 0.716$, and for 32x32/.8/6, $r = 0.23$, $n = 24$, $p = 0.27$.

4.5.4 Discussion

Study 3 presents the results of experiments that attempt to simulate events of a recent event in Guatemala, the Guatemalan civil war, and the effect this war had on Maya cultural diversity. This study differs from the other two mainly because of the voluminous amount of information available about it. A considerable effort and part of the methodological challenge of this experiment was the condensation of this information into parameters and values. The goal was to present a depiction of the violent conflict of the civil war that would be as accurate as possible and to transform this information into the scope allowed by a simulation.

Based in the results, the civil war had a considerable impact on the cultural composition of the Maya communities, yet despite this, it is evident that the cultural groups manage to thrive. What can be considered the more worrisome outcome of the simulation is the endurance of foreign traits in the population. Inside the simulation, these foreign traits were introduced to represent marks that the military left on the country. The presence of these traits in the population even long after the event is evident in Figure 29, in particular also the mingling of the traits within the communities. This outcome is paralleled in Guatemalan modern reality. In one prominent instance, the existence and power position of current Guatemalan gangs has been ascribed to be a consequence of the civil war, in particular of the participation of civilians in the confrontations, for example in the form of civil patrols (PACs) or military commissioners (Historical Clarification Commission (CEH), 1999a, pp. 258–301. Vol 2.).

The introduction of military traits was used to explain the explosion of diversity evident in the simulation results. Although it seems that the number of cultures is magnified by the way cultures are counted in the simulation, when we look in-depth at the state of the simulation after the events by using visualizations, we can observe that a large number of novel and hybrid cultures indeed emerged as a consequence of the events introduced to represent the Guatemalan war. This should be seen not only as representative of violent groups but Guatemala has also had a large increase in the number of NGOs that were founded as by-product of governmental distrust with the goal to have positive impact on the community (Rohloff, Díaz, & Dasgupta, 2011). Additionally, the formation of NGOs (which are often supported by international funds) can be taken to represent the formation of new institutions as well as the presence and propagation of institutional traits that are reflective of indigenous groups, forming hybrid institutions of old and new. In other words, it is possible that the post-war international presence has found the space to generate organizations in conjunction with indigenous communities.

Methodologically speaking, Study 3 expands on the ways in which analyses have so far been proposed in CulSim. This exploration exemplifies how the simulator can be used to find patterns in the data, and more importantly, how to interpret them. At the same time, this study also presents different ways in which data can be explored and hints at a few more avenues which can be explored with CulSim which are not presented here. As one example, institutional analyses can be performed. These would occur in a similar fashion to the analyses done with the number of cultural groups and the accompanying visualizations that are proposed in this chapter, but instead of looking at the group cultural level, these analyses would help understand patters of institutional re-emergence. They would allow an investigation of the number of institutions, of the similarity of pre and post-event institutions, and of the visualizations of individuals' allegiances to institutions.

Furthermore, one possible future study could investigate the individual components of the simulation result variable; currently, the response variable termed *similarity* joins three criteria (*size*, *position* and *content*) into one. It would be interesting to study these response variables separately, as each of them could offer information about the internal changes at different stages of the simulation. In particular, the combination of *position* and *size* (regardless of the *content*) would make it possible to study the patterns of displacement of information. In terms of visualizations, such as those in Figure 29, the question for example could be whether there are parameters that help assimilation of foreign traits and promotion of local uniformity. Adding or manipulating institutional parameters, i.e. democracy or propaganda, before and after the events could increase the probability that less disintegrated cultural groups could rebuild. An exploration of such mechanisms is important, as the current simulation results suggest that a solution of the violence problem is unlikely to occur without intervention, as violence traits have created stable cultural groups that can survived over long periods of time.

Finally, although extensive work was done to realistically simulate the events of the Guatemalan civil war with the values provided by sources such as the UN report and literature that exists about the occurrences of this time, some values that were chosen, such as *apostasy*, were not as well-supported as others, for which exact figures were available. Additionally, sources of data on events such as the civil war should always be evaluated critically. Thus, conclusions drawn from studies such as this one should be judged with care and further ranges of parameters based on corroborated data as well as further evidence and available documentation should be taken into account to justify and validate the presented results.

4.6 Summary and General Discussion

In this chapter, results from three studies were presented. Study 1 was a simulation study based on the case of the historical event of the Maya collapse and used popular theories presented in Webster's framework of the Maya collapse to demonstrate a possible way to adapt a simulation to integrate a variety of theories and explore their implication on cultural diversity. Several ranges of values were explored for events that were found to be representative of the theories discussed. Results indicated that events that introduced foreign traits (i.e. *settlement*, immigrants and *institutional conversion*) affected cultural composition of an environment most strongly, followed by events that targeted institutions (*institutional conversion* and *institutional content removal*), which affected the composition moderately. Finally, events that targeted the population had minor effects on cultural composition. Monoculture scenarios were found to be more sensitive to institutional and foreign traits introduction, while they were found to be quite robust against population attacks, differences as compared to diverse scenarios were small. On multiple occasions, scenarios that displayed a higher starting diversity acted in a more resilient fashion, whereas the reverse was rare.

Study 2 demonstrated that the cultural diversity of the Maya contributed to their cultural survival after Spanish invaders attacked their territories. For one, the complete annihilation of the Maya peoples or conversion of their institutions was impossible as there was no centralized target to defeat. Furthermore, in order to achieve such a conquest, the Spanish invaders would have had to spread their forces uniformly across the entire Maya territory, this was expensive, inefficient and probably impossible to successfully execute due to lack of infrastructure. Results of the simulation indicate that the colonization process can be much less effective when it is accompanied by high levels of damages. Attempts at *institutional conversion*s are unsuccessful when associations between existing institutions and the population are destroyed by *institutional destruction* or *apostasy*, and thus, fast and complete conversion is made impossible.

Finally, exploratory simulations of Study 2 showcased the important role of institutional processes such as democracy and propaganda. Democracy was shown to increase cultural resilience of the population, whereas propaganda deteriorated it. This suggests that a bottom-up process (democracy) can help in the reconstruction of institutional entities, whereas a top-down process (propaganda) disseminates foreign traits across the population.

Results from Study 3 illustrate that the introduction of foreign traits was the main cause responsible for cultural changes suffered by the Maya populations after the Guatemalan civil war. Results from the previous studies support findings that even the extreme violence and population *decimation* of this war would not have affected the cultural composition of the Maya communities too strongly; however, in this case, the foreign traits led to a large increase in cultural diversity. The real life equivalent of foreign traits represented in the simulation were military factions. As within the simulation, certain cultural groups were partially disintegrated, as was done in real life to obtain higher conformity, newly formed groups partially adopted violent traits, forming hybrid cultures. This is discussed in the context of modern Guatemalan state forms and politics.

As part of the third study, ideas regarding the reintegration of cultural groups in the simulation through institutional mechanisms and simulation parameters were proposed. Future experiments in this direction are important as they can provide first ideas as to of how to help with the regeneration of cultural diversity in Guatemala.

Aside from an application of the results to the Maya case, an aspect of the simulation worth mentioning is the frequent positive correlation between diversity and resilience that was found across the three studies. This adds to the evidence of the benefits of diversity that are discussed throughout the chapter. To analyze the results in more detail, Studies 1 and 3 offer this evidence suggesting that resilience increases together with diversity, while Study 2 presents evidence in both directions, i.e. in some cases resilience increases with diversity and in others it seems to decrease. However, in Study 2, it is important to note that in most presented scenarios, the diversity depended on initial parameters fed into the simulation. For example, the higher the institutional influence, the more diversity is generated. In this sense, the relation between diversity and resilience is confounded, as it is not possible to discern which percentages of the effect stem from initial parameter settings, and which actually occur due to the existing internal diversity. Study 1 and Study 3 partially resolve the issue with different strategies. Study 1 introduces pre-set scenarios (i.e. artificially introduced and not organically generated within the simulation) that assigs all agents the same cultural group and institution, therefore eluding the problem of generating a monoculture scenario with specific parameters that would normally produce diversity. Conversely, Study 3 tackle the problem by providing correlations between the initial number of cultural groups and the similarity (pre and post-event) within the repetitions of the same scenario types. This strategy allows to keep all parameters even. However, some control over the resulting diversity in each repetition is lost.

An extended analysis is necessary to verify all of the conclusions drawn in these three studies about the relationship between resilience of cultural diversity with increasing starting diversity. However, it is possible to conclude that there exist scenarios in which diversity does increase resilience. It might not be possible to generalize this to all scenarios; and most likely there is a non-linear relation where an optimal degree of diversity exists is the better alternative hypothesis.

Although cultural diversity is proposed as a mechanism of resilience, it is certainly not the only possible mechanism, and other factors can be hypothesized to contribute to resilience. Geographical accessibility has previously been shown to serve as a cultural barrier (Parisi, Cecconi, & Natale, 2003) and it can be applied to Maya communities in for example the Cuchumatanes highlands (Lovell, 2005). Related to this, the distance between the group centers (e.g. cities or tribes) could serve to increase resilience, as would be the case for the Tarahumaras (Sheridan & Naylor, 1979), who have proven resilient and been able to sustain their culture despite their homogenous culture. Another factor that needs to be studied in depth is how the number of institutions affects cultural resilience. The possibility that there is a connection between institutions and resilience is supported from a combination of results, from Chapter 4, Study 2 and from other studies, especially from Ulloa et al. (2016). The results from Study 2 showed that democracy increased cultural resilience, whereas Ulloa et al. (2016) had shown that democracy also increased the number of institutions in the system. It is from this study possible to hypothesize that the presence of replicated information across institutions might help a culture to stay resilient against events. One final possibility is that the content of some cultural traits might affect the receptiveness of an individual to new traits, or the degree of institutional influence and loyalty.

Methodologically speaking, the three studies presented in this chapter cover a wide spectrum of experimental analysis that can be done with CulSim. Study 1 adapted a theoretical framework of the Maya collapse to the events provided in the simulator; it offered a comprehensive exploration of individual events that can be used to model future studies. Study 2 used historical sources and phenomenological accounts to recreate the

Spanish invasion of the Maya highlands. Using previous results of Study 1, the experimental design explored the interaction between events related to foreign intervention and the damages caused by it. Study 3 used quantitative data collected by international organizations, and interpreted it in terms of the simulation in order to approximate the Guatemalan civil war. It analysis the results in-depth using different response variables and visualizations to compare the simulation with a real-life event.

In summary, simulations were successfully applied to historical events in the form of case studies related to the Maya peoples; many similarities were found between the cases and the simulations. The demonstrated applications of the model are also manifold. CulSim can help archeologist find plausible ranges of values to describe at what size events might have occurred historically, when they do not have access to conclusive information or quantitative data. A second application is the possibility to provide explanations and possible causes for different outcomes of comparable historical events, as for the case of Spanish conquest in different territories of America. Finally, it is possible for researchers to make use of large amounts of detailed information collected about certain events, in order to replicate them in a controlled environment, where it is possible (a) to explore the complex interactions among the components, (b) to compare different outcomes if circumstances would have been different and (c) to analyze parameter changes that could help to reverse or improve after-effects of the events.

On a theoretical level, CulSim can be used to explore scenarios with the goal to analyze effects of events on cultural diversity and interactions of various simulation parameters. Cultural similarity and resilience as well as institutional variables can be studied in-depth, and it is possible to determine how changes in parameters, regardless of existence of events, can affect cultural compositions across simulations.

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Chapter 5

5 Summary and Discussion

5.1 Summary

The main purpose of this thesis was to model cultural diversity in a computer simulation and explore factors that could affect the stability and resilience of cultural diversity, such as institutions, democracy and propaganda, and drastic events. A second major purpose was to show the applicability of the simulation on a study case of the Maya peoples. For this purpose, multiple experiments were conducted, and a cultural simulator (CulSim) was created based on previous models suggested by Axelrod (1997) and, more recently, Flache and Macy (2011). Results from conducted experiments were presented across two major experimental manuscripts (Chapters 2 and 4), with one further manuscript serving to introduce CulSim, a simulator of cultural diversity, addressed to a broader, non-technical audience of researchers (Chapter 3). Contributions were made to the field of agent-based models, in particular artificial societies, by extending mechanisms to the study of cultural diversity, and to the field of digital humanities and cultural studies, as a particular focus of this thesis was on applying results to historical scenarios about the diversity of Maya culture.

Chapter 2, titled "Institutions and Cultural Diversity: Effects of Democratic and Propaganda Processes on Local Convergence and Global Diversity", introduced an approach to analyze emergence of cultural diversity across several computational models. One purpose of this chapter was to review sociological ideas of group formation across the scientific literature dedicated to artificial societies (e.g. Axelrod, 1997; Flache & Macy, 2011); the primary goal of Chapter 2 was to test whether the introduction of institutions could stabilize group formation in the face of different types of perturbations (such as cultural drift and selection error). Perturbations have across the literature posed a problem difficult to overcome when simulating cultural diversity (Flache & Macy, 2011; Klemm, Eguíluz, Toral, & Miguel, 2003; Klemm, Eguíluz, Toral, & Miguel, 2005; Parisi, Cecconi, & Natale, 2003).

Chapter 2 was successful in its goal to illustrate the important role that institutions play in regulating, stabilizing and directing cultural diversity. It was shown for example that higher values of institutional influence increased diversity in the simulation. More importantly, we could show that institutions lowered the sensitivity of the simulation to both types of perturbations, making it more stable.

As a second major contribution, Chapter 2 contrasts the role of two important mechanisms of information flow, which were termed *democracy* and *propaganda*. While both democracy and propaganda are programmed in such a way that their main impact inside the simulation is the increase of similarity between agents and institutions (in order for each to exert more influence on the other), we found that the end result was opposed for the two processes: propaganda was shown to increase cultural diversity, while democracy was shown to decrease it. Also, democracy increased the number of institutions much more than propaganda did.

These findings are then applied to general political scenarios. Following the discourse on the situation of Maya communities in Guatemala from Chapter 4, Chapter 2 provides insights as to how it might be possible to intervene in Guatemala to improve the situation. Our simulation suggests that the attempts to homogenize and integrate the Maya population through top-down processes to address issues of governability of the country are doomed to only further splinter and divide the country into smaller subgroups that are completely separate and are unwilling to communicate (Fischer, 1996; Morgan Jesse, 2005). Based on the results of Chapter 2, a more efficient approach to achieve dialogue would be an increased democratization of institutions, for example by giving individuals across Maya communities more input into all aspects of society and ensuring their voices are heard in all matters of decision-making (through for example referenda and voting). However, this can also only be done while taking into account a wide variety of trust issues and loss of institutional connections stemming from the Guatemalan civil war, and as a byproduct of current corruption in Guatemalan institutions, as well as the cultural tensions still existing across the different populations living in Guatemala.

Chapter 3 presents a software platform, the cultural simulator *CulSim*, which serves to bring together decades of research in cultural diversity (such as Axelrod, 1997; Flache & Macy, 2011; Klemm et al., 2003; Ulloa, Kacperski, & Sancho, 2016), with the purpose of making simulation research of cultural diversity accessible to a broad academic audience. CulSim is therefore a contribution of this thesis to the fields of digital humanities and cultural studies.

Through CulSim, researchers can extend previous work that has employed agent-based simulations by exploring a wide range of parameters, which are introduced in Chapter 3 and the user manual provided in the Appendix 9. CulSim also includes the institutional model presented in Chapter 2, enabling researchers to explore further interactions between individuals, their cultures, and their institutions. Future research with this models might provide us with answers to questions on how to shape institutions that favor a global community while at the same time promoting cultural diversity, a discussion that has received much attention in the recent decades of globalization, cultural minorities, and immigration (Ashraf & Galor, 2011; Azarya, 2004; Daes, 2004; Dunklin, 2005; Rothkopf, 1997; Smith & Ward, 2000; Vadlamannati, 2008).

CulSim also introduces a set of tools to simulate drastic events that have struck societies in the past in order to explore their effects on cultural diversity. This set of tools has been inspired by the history of the Maya peoples, but it can be applied on this concrete level to explore other case studies across most other cultures in the same manner as is proposed in Chapter 4. Additionally, it can also be applied on an abstract level without relating it specifically to any particular culture. In that case, it can help testing or generating hypotheses of the resilience or resistance of cultural diversity under particular parameter configurations.

In Chapter 4, three historical scenarios are simulated, all of which concern the diversity of the Maya peoples' community: The Classic Maya collapse (Webster, 2002), the Spanish invasion of the Guatemalan Highlands (Restall & Asselbergs, 2008) and the Guatemalan civil war (Historical Clarification Commission (CEH), 1999). On one hand, an overview over historical, literary and archeological records is provided to give readers an adequate understanding of the historical events that unfolded in Central America over the time span of the chosen 1500 years. This overview is provided to illustrate that simulations such as the one proposed in this thesis can be usefully applied to a wide variety of cases and, in particular, to showcase that a wide variety of literary sources, be they speculative (theories on the Maya collapse), qualitative (literary records of Spanish invaders such as letters), or quantitative (such as numerical data collected in the Memoria de Silencio) can be adopted and translated into useful study designs or parameter/factor levels.

On the other hand, CulSim is used to simulate these three historical study cases in order to illustrate its capability and applicability. It is shown that CulSim is can be used to simulate events such as decimation through disease, war, starvation, or foreign invaders such as immigrants or settlers; it is also shown that CulSim can be used to analyze institutional theories, which focus on events such as apostasy or institutional structural destructions.

In general, the major contribution of Chapter 4 is the introduction of reproducible methodological approaches which enable researchers to simulate the above mentioned types of events with the goal to support or undermine versions of theories proposed by preceding literature, in accordance with obtained results.

Many results from the simulations presented in Chapter 4 support the idea that cultural diversity proves resilient against many of the events that the Maya community has suffered. This means that Maya cultural diversity persisted in a state similar to the way it was 1500 years ago. Results also support the idea that diverse cultures are resistant in general to a majority of threats, when we are referring to the preservation of the same or very similar cultural traits across centuries. This is particularly evident for cultures that start out as diverse from our results, whereas globalized monocultures do not show the same level of resilience and resistance, in particular towards those events which target the culture's institution.

5.2 Discussion

The following general discussion will focus on three major topics of the presented thesis: (a) the role of institutions in the emergence of cultural diversity, (b) the resilience of cultural diversity against drastic events, and (c) the applicability of the simulations to real life scenarios. The discussion on each of this topics will include contributions, limitations and future directions.

5.2.1 Role of Institutions

The general contribution of the presented thesis is the introduction of a new computational model of emergence of cultural diversity. The model is based on Axelrod's ideas of homophily and categorical cultural traits (1997), and introduces institutions to the system. The institutions regulate the interaction between agents, and help stabilizing diversity in the presence of perturbations. Similar to Flache & Macy's model (Flache, 2011), the institutional model is able to extend the configurations in which cultural diversity emerges. Improving on Flache's model, global parameters, associated with the introduced institutions in our model, are able to control the whole spectrum of cultural diversity. Thus, they can serve to explain the emergence of different degrees of diversity where other parameters fail to give a plausible explanation. In a previous model, an increase in neighborhood size was interpreted as the expansion of telecommunications, which in turn was shown to reduce cultural diversity (Greig, 2002). And yet, in the real world, cultural diversity does exist even in highly interconnected places. Institutional parameters can, for such cases, be useful as a possible explanation which keeps cultural boundaries intact.

At the same time, institutions do differ in the amount of institutional influence that they exert. To name just one example, ideologies (religion) exert a different level of influence over their followers, as opposed to libraries do over visitors. Parameters that control the democracy and propaganda inside the simulation also extend possibilities provided by institutional influence.

The results of Chapter 2 indicate that societies where institutions strongly influence their member individuals are more likely to produce a wider variety of cultural groups. Conversely, individuals that are not strongly connected or do not strongly identify with their institutions might end up belonging to more homogeneous societies where values and ideologies have mingled. In terms of real life scenarios, this might represent the effects of institutions like religions, which tend to demand high levels of identification from their members, and which, each by way of excluding individuals who follow other religions, form a culturally diverse social landscape. This would be opposed to institutions like libraries, who exist in the lives of individuals as areas of providing a wide variety of knowledge and meeting spaces, but do not take any approaches to influence their members and do not require strong identification but which, just by default of existence, homogenize their members by providing for example a certain level of education to everyone equally. While those two are examples of institutions that differ extremely, the model can also be used to compare differences between similar types of institutions such as provinces in Canada as opposed to states in the US.

While institutions are necessary for cultural groups to emerge, they are not indispensable for them to persist over time. The simulation shows that after institutional damages or even complete institutional destruction, cultural groups preserve enough distributed information to thrive until institutional reconstruction can occur. This is a hopeful outlook, especially in view of many disasters that we observe continuously in our modern world, such as catastrophic earthquakes like the one in Port-au-Prince, Haiti, or

Indonesian tsunamis, which are always devastating for the affected diverse communities. It is an interesting point to make when addressing difficulties in planning for disaster recovery. During devastating events like those mentioned, it might be more important to work with local populations and use the option of helping to rebuild previously existent institutions (with improvements that all parties agree on) instead of attempts of completely replacing local institutions with ones that come from countries that provide disaster relief, sometimes with the “conscious exercise of power in pursuit of gain or advantage by the politically strong” (Duffield, 1993, p. 1)

Limitations and Future Directions

Although the introduction of institutions to Axelrod’s model is a contribution, it has the limitation of lacking enough institutional granularity to describe different levels of institutions. In other words, parameters are not intrinsic to cultural groups (or institutions), and they do not adjust over time. And although CulSim comes with an event which enables a change of institutional parameters at any point of time during the run of the simulation, for some scenarios, it would be preferable for parameters to emerge from the population. One possible way to approach this feature would be to make the institutional parameter dependent on the cultural traits. So far, they affect the behavior of agents, but this effect has not gone beyond a simple decision whether they will accept or reject a trait. In a way, this proposal would imply that cultural features have an institutional association (for example, political or civic engagement). For example, certain traits could guide how much institutional influence an institution can exert over each agent, or change the institution to act in a more or less democratic manner.

In the presented simulations, institutions were conceived to act independently from each other, only interacting indirectly by way of negotiations among agents. On one hand, the assumption that institutions are not autonomous entities is reasonable, as people need to take actions for them to exist. On the other hand, it is clear that institutional associations do exist (for example, the tax exempt status of churches in many countries combines a governmental and religious agreement that comes from different institution). As an extension of the present model, institutional hierarchies could be artificially introduced by allowing the formation of direct connections between institutions. However, a better approach would be to allow individuals to subscribe to multiple institutions, and then it would be possible to reconstruct the institutional associations organically, by using the people that connect them. This would, at the same time, address the current restriction of agents only being associated to just one institution at a time and also suggest the possibility to describe different types of institutions (e.g. by restricting the features they could store).

It is also important to consider the mechanisms of emergence of new institutions. At the current state of the simulation, the model only allows new institutions to be formed at the beginning of the simulation, or after an institutional destruction event. It would be beneficial for future models to implement the possibility of institutional formation at all times whenever the population demands.

All these different and exciting directions of research show the future potential of the presented novel institutional model. As with most simulation models, this one is a simplification and does not and cannot represent reality with all its complexity and factors. Thus, all conclusions made in this thesis should be judged by the restrictions that simplifications produce. At the same time, the reduction of complexity is what allows the generation of more objective results. In this sense, it is very encouraging that, in spite of all the simplifications, the model has been able to provide interesting data on the role that institutions play in the formation of cultural groups.

5.2.2 Resilience of Cultural Diversity

The formalization of a measurement for resilience in a simulation environment is an important contribution of the present thesis. Methodologically speaking, resilience is calculated by measuring the state of the simulation at two given times and comparing the two states in terms of their similarity with each other. A number of events can be introduced between the two states, and the change afterwards will reflect the loss of similarity, so resilience is therefore the counterpart, i.e. the extent of similarity between the two states.

Events in CulSim were conceptualized in Chapter 3 using an exhaustive approach in terms of the possible ways information in the system can be targeted. This was done with regards to both population and institutions, and the structures that connect them. By definition, thus, two forms of classification were introduced, (a) the type of information: the content and the structure, and (b) the type of target: the population and the institutions. This classification proved to be useful to understand the results obtained in terms of cultural resilience. One particular finding that was obtained suggested that events that targeted institutions were more detrimental to cultural similarity pre- and post-event, than events targeting the population. However, results also suggested that another form of classification was possible: events that introduced foreign traits or institutions were found to be the most detrimental to similarity, regardless whether these traits were introduced at the level of institutions or the population.

Regarding cultural diversity specifically, it was shown that it (in particular as compared to monoculture) was very resilient against all implemented events. In Chapter 4, the first case study, in which levels of event sizes were explored across all events, indicated a strong vulnerability of monocultures to certain events, especially those which targeted institutions in a centralized fashion. This result finds support in biological systems: it has been suggested that biodiversity increases the resilience in ecosystems on the whole (Elmqvist et al., 2003; Peterson, Allen, & Holling, 1998). At the same time, diversity in a species' genetic pool is praised as an advantage to the species overall (Frankham, 2005).

The resilience of cultural diversity in the presented experiments could also be partially attributed to the presence of multiple institutions when there are more cultural groups. This hypothesis is supported by the fact that institutional attacks were overall more damaging to the cultural composition. This argument has also been made previously: for example, the Internet was created as a distributed system of computers, to strengthen the system to random failures and avoid attacks to the central nodes (Cohen, Erez, ben-Avraham, & Havlin, 2000).

Limitations and Future Directions

Further studies are required to establish a clearer connection between the amount of diversity and the resilience of a cultural system, as many other parameters of the simulation, which were not controlled, could be confounding the results. Nonetheless, the high values of similarity that were obtained in the three presented case studies serve as evidence in the proposed direction. Should it be true that the model resilience found is caused by other parameters in the system (e.g. institutional influence, interaction neighborhood), the results still show that cultural diversity can emerge under those conditions imposed by the parameters. In this sense, it is important to remember that the amount of information also increases with diversity (e.g., more cultural traits are conserved, but also, more information is associated with the spatial distribution of the cultures); in other words, under exactly the same conditions a diverse system would preserve more information.

While, as mentioned, the formalization of resilience adds to the literature, as it provides a measurable output variable for the study of cultural diversity and its stability over time, studying diversity in terms of resilience might be argued to be problematic: critics might say that it provides a very rigid measurement of a concept that in itself implies elasticity. In response, it is also true that the concept of resilience by definition implies a comparison over time. In order for a resilient system to be considered as such, it has to in some way return to its original form after an event, or more generally speaking, a perturbation – and this implies a comparison.

In a simulation, the problem of comparing two states of the simulation is in some way equivalent to the comparison of two copies of the same picture. Judging the extent of their similarity is a non-trivial problem, in particular as subjectivity might be an issue (see Figure 29 in Chapter 4). In order to balance the subjectivity of the analysis and raised criticism of measurement rigidity at least partially, three criteria were used, aiming at several components of cultural composition: the size, position and content (traits) of each culture. Multiplication was used to combine these criteria (as opposed to, for example, an average) in order to provide a very conservative measure – a low value in any of the three criteria will result in a low similarity score for the entire comparison.

Other measures of similarities should not be completely disregarded. For example, researchers might be interested in studying only individual criteria of the three used here, such as using cultural content as the sole criterion. This could be useful to improve our understanding of the internal dynamics of the model.

5.2.3 Applicability of the institutional model and CulSim

Axelrod’s model has inspired a large number of follow-up studies as well as many extensions that integrate novel and interesting ideas within the original simulation. The vast majority of research reports applicability on a very general level, not unusual within the simulation literature (Sokolowski & Banks, 2009), as the purpose of simulations is usually to show the key characteristics of a certain type of behavior or process. To my knowledge, Axelrod’s model has been applied only once to a real-life scenario by Bhavnani (2003) to describe civic traditions across Italy. While it also presents a model of institutions and historical events, its methodology, goals and interpretations are completely different from the here described simulation, and therefore, any possible comparison would be, for one, beyond the scope, and secondly, meaningless due to differences in conceptualization. It is, however, important because it supports the idea that it is possible to broaden the scope of applicability of simulations, which has merit in itself.

The present thesis provides another possibility with this objective. Three case studies inspired by Maya history are introduced, to show how CulSim can be used by researchers from cultural studies, and humanities in general, to explore possible historical scenarios in terms of their cultural diversity. In all three case studies, it was possible to draw similarities between the simulation and the real life scenarios, and to connect the results with implications of the related literature. Moreover, the chosen scenarios differed on multiple dimensions, extending the applicability further. They differed regarding (a) the area of application: archeology, history, and sociology; (b) the sources of information: theories, phenomenological sources, and human rights records; and (c) the methodology: exploration of event sizes, analysis for categorization of events, and an in-depth approach showcasing different possible dependent variables.

Finally, with regards to applicability, it is important to point out, as has been mentioned by researchers before (Flache & Macy, 2011) that diversity and homogeneity are not meant to represent any value judgment in the current thesis. They are not, by value of their existence, good or bad. While our case studies in Chapter 4 argue that Maya diversity has been important for the preservation of Maya culture and that in this example, this is important and valuable, there are instances in which diversity brings with it a variety of issues, as can be exemplified by accounts of in-fighting and wars between the Maya communities and city states (Webster, 2000). Diverse populations tend to ostracism and xenophobia (Fisher, 2013a, 2013b; Flache & Macy, 2011). On the other hand, while globalization has been described as less resilient to institutional attacks, the benefits of improved communication can be mentioned as an advantage in terms of a discourse of integration that has to begin between the Maya communities and the rest of the Guatemalan population and the government, in order to improve the Maya peoples' life quality and education.

Limitations and Future Directions

As mentioned before, in the context of institutions, any model is by definition a simplification of reality, and thus always subject to improvement. Here, I point to some ideas that emerged after the application of the model to the Maya case studies.

First, an important event, displacement, was omitted from CulSim. It is well documented that one of the biggest consequences of the Guatemalan civil war was the internal and external displacement of its people (Historical Clarification Commission (CEH), 1999; Stepputat, 1999). External displacement could be approximated with the event of decimation, but simulating internal displacement is not possible in the current version of CulSim. One possible way to simulate this kind of event would be to relocate the agents in the grid by swapping agents' coordinates. This would alter the internal cultural composition, and, based on the results obtained for foreign traits, it could have severe consequences for the number of cultural groups. Future researchers could attempt this proposal, or suggest better methods to attempt the simulation of this type of event.

As a second flaw of the proposed model with particular regard to its applicability is the timing of the events. When combinations of events are executed in the simulation, they are usually executed in a specific order at the same time (iteration) within the simulation. A more realistic approach might be to distribute events through a period of time, timing them to be more historically accurate. This would be implemented in the simulation by introducing a way to schedule events after a certain number of iterations. In terms of consequence to the simulations, effects of simultaneous events are more drastic; it is very likely that effects of timed events would be lower than the current impact, as a spaced timing would allow the system to partially recover between events instead of forcing a recovery from one major synchronic combination of events.

Finally, although the three case studies that were investigated were represented with values that were chosen to best approximate real life scenarios, the results presented cannot claim to be exhaustive. They were chosen and presented in a way that best showcases the possibilities and range of applicability of CulSim, including methodological considerations. A comprehensive research project on the Maya case studies should extend the scope of the performed literature review and more in-depth evaluate values in order to allow a more accurate exploration of different theories related with the topic. Many parallels were found between simulation results and real-life scenarios, but it is still important to point out that presented studies mainly illustrate the way the proposed models and the simulation can be used. Conclusions made from the results should be corroborated with further studies; this thesis provides the methodological framework and computational tool to continue the analysis.

5.3 Conclusions

The presented thesis here contributes to the existent literature and research on cultural diversity in three important ways. It provides (1) a new model of emergence of cultural diversity, (2) a computational framework with the necessary tools to study catastrophic events that befall societies, and (3) a number of possible application cases that enable future researchers to use the provided tools to test further hypotheses related to cultural diversity.

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Postface

Recently, I visited Guatemala again. I spent a few days in Nebaj, in the Ixil region, the community where, 10 years ago, I spent the most time working. Some things have for sure changed. The eyes of the observer, to start with, but objective things as well: Internet and cellphone coverage reaches everywhere, tourism has grown, and the connecting road is completely paved now. Other things seem to be frozen in time: the apprehensive gaze of inhabitants toward foreign tourists, the lack of visitors from the capital, the market, and the traditional clothing. The weakness of Guatemalan institutions is reflected in the unceasing violence, a byproduct of both, the armed conflict of the 80s, and the staggering corruption of the government. The last president is in jail, the previous one on trial for acts of genocide during the armed conflict. The current president ran his campaign with the slogan: "Neither corrupt, nor a thief". And while cultural diversity thrives in Guatemala, the lack of governmental, centralized leadership has obstructed the development of an otherwise resourceful country. At the same time, the inefficiencies of the government have allowed the reemergence of local institutions that, with the help of international collaboration, might find the ways to find appropriate representation in Guatemala.

Appendices

Appendix 1. Chapter 1. Diversity differences by populations.

Legend:

Yellow: reported values
Green: main effects and interactions that corroborate reported results
Blue: means and standard deviations that drive the significant differences
Purple: alternate possible result that could have been reported
Noise = level of mutation (ranges from 0.000001 to 0.1)
Size = population sizes (10x10, 32x32, 100x100)
Alpha = level of institutional influence (usually between 0.5 and 0.95)
Alpha_prime = level of agent loyalty (values of 0.05, 0.5 or 0.95)

Diversity differences by populations

Although some differences are obvious in the Fig 3. of the main document, we found that the results seem fairly proportional, especially for the two biggest population (>=32x32) and higher alphas. Here is some of the evidence:

1. We found no statistically difference for alpha 0.95 as it is shown in Test 1, in which case not even the interaction with noise was significant.
2. For populations >= 32x32, if we just control for alpha >= 0.7, we find a significant difference for the population size with a considerable high F value in the main effect and interactions (see ANOVA 2 in Test 2). However, when we check the averages and standard deviations, it seems that two treatments are driving this main effect: 32x32/0.7/0.5 vs 100x100/0.7/0.5 and 32x32/0.8/0.5, 100x100/0.8/0.5 both with noise of 0.1 (see the averages highlighted in cyan in the averages of the Test 2). In order to statistically corroborate this, we tested the following:
   2.1. For populations >= 32x32, when we control for alpha >= 0.7 and noise <= 0.01, we did not find any significant difference for the main effect of the population size (see ANOVA 2 in Test 2). The interactions did present a significant difference (highlighted green in ANOVA 2 in Test 2) although the low F values suggest a very small effect.
   2.2. For populations >= 32x32, when we control for alpha >= 0.9, we did not find any significant difference for the main effect of the population size (see ANOVA 3 in Test 2). The interactions did present a significant difference (highlighted green in ANOVA 3 in Test 2) although the low F values suggest a very small effect.

For alpha = 0.95

Test 1 – Two-way ANOVA comparing main effect of populations on cultural diversity for alpha = 0.95.

```
Anova Table (Type I tests)
Response variable: Cultural Diversity

Factors: Noise*Size for alpha = 0.95
             Df  Sum Sq Mean Sq F value              Pr(>F)
Noise         5  8.930  1.7859 332.844 <0.0000000000000002 ***
Size          2  0.002  0.0009   0.167               0.846
Noise:Size   10  0.073  0.0073   1.358               0.195
Residuals   882  4.732  0.0054
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Averages of the compared groups
     0.000001   0.00001    0.0001     0.001     0.01       0.1
10   0.3482000 0.3786000 0.3502000 0.3368000 0.109400 0.1608000
32   0.3586719 0.3646094 0.3567773 0.2993945 0.118125 0.1665625
100  0.3647700 0.3610040 0.3567580 0.2985580 0.123676 0.1744460

Standard deviations of the compared groups
       0.000001     0.00001      0.0001       0.001         0.01          0.1
10   0.12310092 0.14159456 0.15516272 0.14299194 0.085509517 0.041641816
32   0.03890176 0.03069054 0.04192173 0.03812455 0.021656675 0.028318704
100  0.01397752 0.01396468 0.01198097 0.01415235 0.007738047 0.008887763
```

For alpha > 0.7

Test 2 – Three-way ANOVA comparing main effect of populations on cultural diversity, ANOVA 1 including all noise and size models with alpha >= 0.7. ANOVA 2 subsets data by noise <= 0.01 for alpha >= 0.7, and ANOVA 3 displays results for all noises and sized, but for alpha >=0.9.

```
Anova Table (Type I tests)
Response variable: Cultural Diversity


ANOVA 1
Factors: Alpha(>=0.7)*Noise*Size
                    Df Sum Sq Mean Sq F value               Pr(>F)
Alpha                3   7.35   2.451  622.40 < 0.0000000000000002 ***
Noise                5  32.83   6.567 1667.44 < 0.0000000000000002 ***
Size                 1   0.21   0.209   52.99    0.000000000000454 ***
Alpha:Noise         15  58.87   3.925  996.57 < 0.0000000000000002 ***
Alpha:Size           3   0.59   0.195   49.57 < 0.0000000000000002 ***
Noise:Size           5   1.21   0.242   61.51 < 0.0000000000000002 ***
Alpha:Noise:Size    15   3.20   0.213   54.20 < 0.0000000000000002 ***
Residuals         2352   9.26   0.004
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

ANOVA 2
Factors: Alpha(>=0.7)*Noise(<=0.01)*Size
                    Df Sum Sq Mean Sq  F value               Pr(>F)
Alpha                3 18.054   6.018 9207.907 < 0.0000000000000002 ***
Noise                4  4.989   1.247 1908.434 < 0.0000000000000002 ***
Size                 1  0.001   0.001    1.406               0.2359
Alpha:Noise         12  2.016   0.168  257.089 < 0.0000000000000002 ***
Alpha:Size           3  0.020   0.007   10.023           0.00000149 ***
Noise:Size           4  0.011   0.003    4.036               0.0029 **
Alpha:Noise:Size    12  0.011   0.001    1.350               0.1836
Residuals         1960  1.281   0.001
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
ANOVA 3
Factors: Alpha(>=0.9)*Noise*Size
                   Df Sum Sq Mean Sq  F value                 Pr(>F)
Alpha               1  4.399   4.399 7735.524 < 0.0000000000000002 ***
Noise               5  6.023   1.205 2118.309 < 0.0000000000000002 ***
Size                1  0.001   0.001    1.638                0.20085
Alpha:Noise         5  1.243   0.249  437.001 < 0.0000000000000002 ***
Alpha:Size          1  0.005   0.005    9.636                0.00195 **
Noise:Size          5  0.018   0.004    6.256             0.00000975 ***
Alpha:Noise:Size    5  0.006   0.001    2.236                0.04861 *
Residuals        1176  0.669   0.001
---s
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1)


Averages of the compared groups
32x32:

      0.000001    0.00001     0.0001      0.001       0.01         0.1
0.7  0.1036328 0.07275391 0.04289063 0.01794922 0.02898437 0.9999609
0.8  0.1366016 0.11832031 0.08208984 0.03654297 0.03953125 0.1848047
0.9  0.2079883 0.21148437 0.19265625 0.13765625 0.05285156 0.1605859
0.95 0.3586719 0.36460937 0.35677734 0.29939453 0.11812500 0.1665625


100x100:
     0.000001  0.00001   0.0001    0.001     0.01      0.1
0.7  0.107312 0.079202 0.046138 0.024656 0.044248 0.999938
0.8  0.121038 0.112404 0.078220 0.041880 0.038652 0.639134
0.9  0.194498 0.194736 0.178012 0.124836 0.061804 0.173120
0.95 0.364770 0.361004 0.356758 0.298558 0.123676 0.174446


Standard deviations of the compared groups
32x32:
       0.000001    0.00001     0.0001      0.001       0.01          0.1
0.7  0.05196727 0.05134128 0.04172406 0.01776962 0.02527264 0.0001933087
0.8  0.03242833 0.03695716 0.03067827 0.01333619 0.01679011 0.0126984702
0.9  0.03494106 0.03223964 0.04148088 0.03021904 0.01137599 0.0134539850
0.95 0.03890176 0.03069054 0.04192173 0.03812455 0.02165668 0.0283187043

100x100:
       0.000001     0.00001      0.0001       0.001        0.01            0.1
0.7  0.01858153 0.012621095 0.014854215 0.010980877 0.024396071 0.00006667007
0.8  0.01066135 0.010140582 0.009223661 0.004281617 0.004210300 0.40198894726
0.9  0.01389960 0.009546316 0.012931636 0.009466024 0.004440397 0.00853676324
0.95 0.01397752 0.013964678 0.011980973 0.014152350 0.007738047 0.00888776297
```

Appendix 2. Chapter 1. Diversity differences by agent loyalty.

Legend:

Yellow: reported values
Green: main effects and interactions that corroborate reported results
Blue: means and standard deviations that drive the significant differences
Purple: alternate possible result that could have been reported
Noise = level of mutation (ranges from 0.000001 to 0.1)
Size = population sizes (10x10, 32x32, 100x100)
Alpha = level of institutional influence (usually between 0.5 and 0.95)
Alpha_prime = level of agent loyalty (values of 0.05, 0.5 or 0.95)

Diversity differences by agent loyalty

For alpha_prime = 0.05 vs 0.5

We find a statistically difference for alpha_prime when we compare 0.05 vs 0.5 in the main effects and in the interactions. The low values of F suggest that the effects are small, which can be appreciated in Fig 5.

Test 3 – Three-way ANOVA comparing main effect of alpha_prime on cultural diversity when alpha_prime 0.05 and 0.5.

```
Anova Table (Type I tests)
Response variable: Cultural Diversity

Factors: Noise*Size*Alpha_Prime
                       Df Sum Sq Mean Sq  F value              Pr(>F)
Noise                   5  49.66   9.931 1318.90 < 0.0000000000000002 ***
Size                    2   2.69   1.347  178.92 < 0.0000000000000002 ***
Alpha_Prime             1   0.25   0.245   32.57         0.0000000135 ***
Noise:Size             10  37.94   3.794  503.89 < 0.0000000000000002 ***
Noise:Alpha_Prime       5   1.03   0.207   27.47 < 0.0000000000000002 ***
Size:Alpha_Prime        2   0.19   0.095   12.65         0.0000034979 ***
Noise:Size:Alpha_Prime 10   0.97   0.097   12.84 < 0.0000000000000002 ***
Residuals            1764  13.28   0.008
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1


Averages of the compared groups
10x10:
     0.000001 0.00001 0.0001  0.001   0.01    0.1
0.05   0.2204  0.1966 0.0754 0.0112 0.0244 0.1824
0.5    0.2416  0.2058 0.1558 0.0752 0.0582 0.1844

32x32:
       0.000001     0.00001      0.0001       0.001        0.01        0.1
0.05 0.07212891 0.05546875 0.02761719 0.01611328 0.02095703 0.4638867
0.5  0.12921875 0.11574219 0.07742187 0.04136719 0.03480469 0.2240820

100x100:
     0.000001  0.00001   0.0001    0.001     0.01      0.1
0.05 0.015178 0.012350 0.009108 0.011186 0.026418 0.999938
0.5  0.110166 0.090392 0.054666 0.027842 0.034284 0.999958


Standard deviations of the compared groups
10x10:
       0.000001     0.00001     0.0001         0.001        0.01          0.1
```

```
0.05 0.09774937 0.08913668 0.0723994 0.003282607 0.01342553 0.04569464
0.5  0.12253046 0.11770059 0.1249504 0.087975878 0.09272936 0.04248217

32x32:
       0.000001    0.00001     0.0001      0.001        0.01       0.1
0.05 0.02715806 0.02796937 0.01348416 0.00752120 0.009566712 0.3889801
0.5  0.03407586 0.03706017 0.02921841 0.01934477 0.012353845 0.1607923

100x100:
        0.000001     0.00001      0.0001       0.001        0.01           0.1
0.05 0.007169587 0.004478714 0.002681824 0.004027407 0.003808567 0.00008302938
0.5  0.010767517 0.012383314 0.008317589 0.005293126 0.006277636 0.00007024738
```

For alpha_prime = 0.5 vs 0.95

In the case of the comparison between alpha_prime of 0.05 and 0.5, the differences become even smaller.

First, we found and almost not significant effect for alpha_prime in ANOVA 1 (Test 4). However, when we control by population size = 32x32 and noise <=0.01 (ANOVA 2 in Test 4), we find a significant difference. The low F value also suggest a very small effect. When we control by population size = 100x100 (ANOVA 2 inTest 4), we find a significant difference. In this case the F value is considerable, and the interaction with noise is also significant.

We see a higher significant for higher population sizes. However, we are using different values of alpha for different population sizes: 0.85 for 10x10, 0.8 for 32x32 and 0.75 for 100x100. It is more likely that the difference has to be attributed to the alpha values than the population size because:

1. We show in Experiment A that the results were fairly proportional across populations.
2. Alpha_prime is a dependant variable of alpha. We can appreciate this in Table 2 (Chapter 1), Step 3.

Test 4. Three-way ANOVA comparing main effect of alpha_prime on cultural diversity, with ANOVA 1 displaying results when alpha_prime 0.5 and 0.95. ANOVA 2 subsets data for noise levels <0.1 and population size 32x32 only. ANOVA 3 displays results for all noise levels and population size 100x100.

```
Anova Table (Type I tests)
Response variable: Cultural Diversity


ANOVA 1
Factors: Noise*Size*Alpha_Prime
                         Df Sum Sq Mean Sq  F value               Pr(>F)
Alpha_Prime               1   0.02   0.017    3.051               0.0809 .
Noise                     5  37.52   7.504 1311.228 <0.0000000000000002 ***
Size                      2   4.02   2.010  351.288 <0.0000000000000002 ***
Alpha_Prime:Noise         5   0.05   0.010    1.743               0.1215
Alpha_Prime:Size          2   0.01   0.006    0.981               0.3750
Noise:Size               10  39.84   3.984  696.190 <0.0000000000000002 ***
Alpha_Prime:Noise:Size   10   0.04   0.004    0.629               0.7901
Residuals              1764  10.10   0.006
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
ANOVA 2
Factors: Noise(<0.1)*Alpha_Prime for Size=32x32
                   Df Sum Sq Mean Sq F value                Pr(>F)    
Noise               4 0.6162 0.15405 157.902 < 0.0000000000000002 ***
Alpha_Prime         1 0.0120 0.01201  12.307             0.000493 ***
Noise:Alpha_Prime   4 0.0074 0.00186   1.908             0.107849    
Residuals         490 0.4781 0.00098                                 
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1


ANOVA 3
Factors: Noise*Alpha_Prime for Size=100x100
                   Df Sum Sq Mean Sq F value                Pr(>F)    
Noise               5  72.63  14.527 141740.94 <0.0000000000000002 ***
Alpha_Prime         1   0.01   0.011    109.87 <0.0000000000000002 ***
Noise:Alpha_Prime   5   0.02   0.003     31.84 <0.0000000000000002 ***
Residuals         588   0.06   0.000                                  
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1


Averages of the compared groups
10x10:
     0.000001 0.00001 0.0001  0.001   0.01    0.1
0.5    0.2416  0.2058 0.1558 0.0752 0.0582 0.1844
0.95   0.2326  0.1832 0.1436 0.1154 0.0506 0.1912

32x32:
      0.000001   0.00001     0.0001      0.001       0.01       0.1
0.5  0.1292188 0.1157422 0.07742187 0.04136719 0.03480469 0.2240820
0.95 0.1250000 0.1233789 0.09439453 0.05718750 0.04759766 0.2396094

100X100:
     0.000001  0.00001   0.0001    0.001     0.01      0.1
0.5  0.110166 0.090392 0.054666 0.027842 0.034284 0.999958
0.95 0.103798 0.093024 0.070262 0.049850 0.052394 0.999966

Standard deviations of the compared groups
10x10:
      0.000001   0.00001    0.0001       0.001        0.01        0.1
0.5  0.1225305 0.1177006 0.1249504 0.08797588 0.09272936 0.04248217
0.95 0.1312702 0.1166442 0.1340539 0.10725156 0.08092350 0.04288761

32x32:
       0.000001     0.00001      0.0001       0.001        0.01       0.1
0.5  0.03407586 0.03706017 0.02921841 0.01934477 0.01235384 0.1607923
0.95 0.04607260 0.03860573 0.03067649 0.03018372 0.01938804 0.1945799

100X100:
       0.000001     0.00001       0.0001        0.001         0.01            0.1
0.5  0.01076752 0.01238331 0.008317589 0.005293126 0.006277636 0.00007024738
0.95 0.01169407 0.01637560 0.015129912 0.009628047 0.009869566 0.00006262946
```

Appendix 3. Chapter 1. Diversity differences by democracy.

Legend:

Yellow: reported values
Green: main effects and interactions that corroborate reported results
Blue: means and standard deviations that drive the significant differences
Purple: alternate possible result that could have been reported
Noise = level of mutation (ranges from 0.000001 to 0.1)
Size = population sizes (10x10, 32x32, 100x100)
Alpha = level of institutional influence (usually between 0.5 and 0.95)
Alpha_prime = level of agent loyalty (values of 0.05, 0.5 or 0.95)

Diversity differences by democracy

For democracy = 1/10 vs 1/100 vs 1/1000, population 10x10

For a population size of 10x10, we observe a monotonous result for democracy when noise <=0.01 in Figure 6 (chapter 1), i.e. the higher the democracy, the lower the diversity.

1. The ANOVA 1 in Test 5 shows a significant effect for democracy, although observing the Fig 6. it is clear that the noise = 0.1 is driving a big portion of the effect,
2. For noise < 0.1, ANOVA 2 in Test 5, democracy still shows a significant difference, and there is a significant effect for the interaction.

Test 5 – Two-way ANOVA comparing main effect of democracy on cultural diversity. First reported ANOVA displays results for population 10x10 only. ANOVA 2 displays subset results for noise <= 0.01.

```
Anova Tables (Type I tests)
Response variable: Cultural Diversity

ANOVA 1
Factors: Noise*Democracy for population size of 10x10:
                  Df Sum Sq Mean Sq F value              Pr(>F)
Noise              5 18.547   3.709  1189.5 <0.0000000000000002 ***
Democracy          2  2.662   1.331   426.8 <0.0000000000000002 ***
Noise:Democracy   10 20.685   2.069   663.3 <0.0000000000000002 ***
Residuals        882  2.751   0.003
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1


ANOVA 2
Factors: Noise(<=0.01)*Democracy for population size of 10x10:
                  Df Sum Sq Mean Sq F value               Pr(>F)
Noise              4 1.7095  0.4274 122.464 < 0.0000000000000002 ***
Democracy          2 0.3406  0.1703  48.806 < 0.0000000000000002 ***
Noise:Democracy    8 0.1209  0.0151   4.331            0.0000407 ***
Residuals        735 2.5649  0.0035
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Averages of the compared groups
       0.000001 0.00001 0.0001  0.001   0.01    0.1
1/10     0.1094  0.1148 0.0302 0.0140 0.0306 1.0000
1/100    0.1318  0.1142 0.0664 0.0246 0.0234 0.1716
1/1000   0.1772  0.1650 0.1252 0.0426 0.0394 0.1712
```

```
Standard deviations of the compared groups
         0.000001    0.00001     0.0001      0.001       0.01        0.1
1/10    0.05950167 0.05406874 0.03100296 0.01511858 0.01391079 0.00000000
1/100   0.07678993 0.08119239 0.06598577 0.03796938 0.01334166 0.04210579
1/1000  0.08845707 0.07568059 0.08813811 0.05041906 0.04661654 0.04488716
```

For democracy = 1/10 vs 1/100 vs 1/1000, populations 32x32 and 100x100

For bigger populations sizes (or smaller alphas), the effect of democracy is non-monotonous. We observe the lowest values of diversity with moderate democracy (1/100). To corroborate this observation we decided to test the two contrast, Low (1/1000) vs Moderate (1/100) and Moderate (1/100) vs High (1/10):

1. For noises <= 0.01, the contrast 1/1000 vs 1/100 (ANOVA 3 in Test 5) shows a significant difference for democracy with a strong effect. The ANOVA 2 in Test 5 removes the control for noise which in the Figure 6 (chapter 1) is evident that is driving a strong effect; the significance persist, but as expected the effect is moved to the interactions.
2. For noises <= 0.01, the contrast 1/100 vs 1/10 (ANOVA 5 in Test 5) also shows a significant difference with a strong effect. The ANOVA 4 in Test 5 removes the control for noise which in the Figure 6 (chapter 1) is evident that is driving a strong effect; the significance persist, but as expected the effect is moved to the interactions.

A complete ANOVA removing the controls for noise and democracy is also shown for reference (ANOVA 1 in Test 5)

Test 6 – Three-way ANOVA comparing main effect of democracy on cultural diversity. ANOVA 1 displays results for population 32x32 and 100x100. ANOVAs 2 and 3 display subset results for democracy at 1/1000 and 1/100, and ANOVA 3 displays results for noise <= 0.01. ANOVAs 4 and 5 dusplay subset results for democracy at 1/10 and 1/100 and ANOVA 5 displays results for noise <= 0.01.

```
Anova Tables (Type I tests)
Response variable: Cultural Diversity

ANOVA 1
Factors: Noise*Size(>=32x32)*Democracy (1/1000,1/100, 1/10):
                        Df Sum Sq Mean Sq F value                Pr(>F)
Noise                    5 189.53   37.91 8675.34 < 0.0000000000000002 ***
Size                     1   0.17    0.17   38.17        0.000000000804 ***
Democracy                2   0.56    0.28   64.11 < 0.0000000000000002 ***
Noise:Size               5   2.32    0.46  106.01 < 0.0000000000000002 ***
Noise:Democracy         10   4.33    0.43   99.00 < 0.0000000000000002 ***
Size:Democracy           2   0.66    0.33   75.92 < 0.0000000000000002 ***
Noise:Size:Democracy    10   4.14    0.41   94.75 < 0.0000000000000002 ***
Residuals             1764   7.71    0.00
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

ANOVA 2
Factors: Noise*Size(>=32x32)*Democracy(1/1000,1/100):
                        Df Sum Sq Mean Sq F value                Pr(>F)
Noise                    5 113.98  22.797 3513.33 < 0.0000000000000002 ***
Size                     1   0.30   0.304   46.84       0.0000000000123 ***
Democracy                1   0.31   0.305   47.01       0.0000000000114 ***
Noise:Size               5   3.38   0.676  104.11 < 0.0000000000000002 ***
Noise:Democracy          5   3.36   0.673  103.69 < 0.0000000000000002 ***
```

```
Size:Democracy            1    0.52    0.521    80.31 < 0.0000000000000002 ***
Noise:Size:Democracy      5    3.08    0.615    94.79 < 0.0000000000000002 ***
Residuals              1176    7.63    0.006
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

ANOVA 3
Factors: Noise(<=0.01)*Size(>=32x32)*Democracy(1/1000,1/100):
Df Sum Sq Mean Sq F value               Pr(>F)
Noise                    4 0.3808 0.09521 420.305 < 0.0000000000000002 ***
Size                     1 0.0594 0.05941 262.274 < 0.0000000000000002 ***
Democracy                1 0.0588 0.05880 259.595 < 0.0000000000000002 ***
Noise:Size               4 0.0292 0.00731  32.271 < 0.0000000000000002 ***
Noise:Democracy          4 0.0188 0.00470  20.750 < 0.0000000000000002 ***
Size:Democracy           1 0.0032 0.00321  14.187           0.000175 ***
Noise:Size:Democracy     4 0.0022 0.00056   2.452           0.044485 *
Residuals              980 0.2220 0.00023
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

ANOVA 4
Factors: Noise*Size(>=32x32)*Democracy(1/100,1/10):
                        Df Sum Sq Mean Sq    F value               Pr(>F)
Noise                    5 154.57  30.915 215284.136 < 0.0000000000000002 ***
Size                     1   0.02   0.019    129.615 < 0.0000000000000002 ***
Democracy                1   0.03   0.026    181.358 < 0.0000000000000002 ***
Noise:Size               5   0.01   0.003     18.730 < 0.0000000000000002 ***
Noise:Democracy          5   0.03   0.007     46.648 < 0.0000000000000002 ***
Size:Democracy           1   0.00   0.001      8.109              0.00448 **
Noise:Size:Democracy     5   0.00   0.000      2.684              0.02024 *
Residuals             1176   0.17   0.000
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

ANOVA 5
Factors: Noise(<=0.01)*Size(>=32x32)*Democracy(1/100,1/10):
                       Df Sum Sq Mean Sq F value              Pr(>F)
Noise                   4 0.4327 0.10816 627.728 < 0.0000000000000002 ***
Size                    1 0.0224 0.02237 129.824 < 0.0000000000000002 ***
Democracy               1 0.0312 0.03124 181.324 < 0.0000000000000002 ***
Noise:Size              4 0.0097 0.00242  14.059     0.0000000000369 ***
Noise:Democracy         4 0.0283 0.00707  41.047 < 0.0000000000000002 ***
Size:Democracy          1 0.0014 0.00141   8.154             0.00439 **
Noise:Size:Democracy    4 0.0017 0.00042   2.446             0.04491 *
Residuals             980 0.1689 0.00017
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1


Averages of the compared groups
32x32:
         0.000001    0.00001     0.0001      0.001       0.01        0.1
1/10   0.08638672 0.07287109 0.03712891 0.01599609 0.02455078 0.9999414
1/100  0.06660156 0.05585938 0.03074219 0.01355469 0.02613281 0.9999023
1/1000 0.09386719 0.08761719 0.05460937 0.02238281 0.02902344 0.4639063

100x100:
       0.000001  0.00001   0.0001    0.001     0.01      0.1
1/10   0.074994 0.063752 0.025664 0.013628 0.023452 0.999946
1/100  0.046554 0.033660 0.018570 0.010562 0.024394 0.999972
1/1000 0.062926 0.055344 0.029582 0.013508 0.031136 0.999958

Standard deviations of the compared groups
32x32:

         0.000001    0.00001     0.0001        0.001         0.01          0.1
1/10   0.02478725 0.01947626 0.01302671 0.007270249 0.008854169 0.0002342747
1/100  0.01947936 0.02021195 0.01485654 0.012223785 0.017675908 0.0002959424
1/1000 0.02968469 0.02265209 0.02050149 0.011604996 0.017506053 0.3888418404
```

```
100x100:
         0.000001     0.00001      0.0001       0.001        0.01
0.1
1/10   0.00998407 0.010479294 0.005551163 0.004795620 0.003979039
0.00008621284
1/100  0.01294161 0.007113769 0.006142500 0.008590286 0.008499806
0.00005360475
1/1000 0.01259677 0.008950776 0.006065953 0.004614522 0.010260062
0.00006417451
```

Appendix 4. Chapter 1. Diversity differences by democracy / propaganda combined.

Legend:

Yellow: reported values
Green: main effects and interactions that corroborate reported results
Blue: means and standard deviations that drive the significant differences
Purple: alternate possible result that could have been reported
Noise = level of mutation (ranges from 0.000001 to 0.1)
Size = population sizes (10x10, 32x32, 100x100)
Alpha = level of institutional influence (usually between 0.5 and 0.95)
Alpha_prime = level of agent loyalty (values of 0.05, 0.5 or 0.95)

Diversity differences by democracy/propaganda combined

For democracy = 1/1000 and all propaganda levels = 1/5, 1/3, 1/1

Apart from the sensitivity for propaganda after noise >= 0.01, other effects are difficult to perceive in Fig.8. This sensitivity is driving the main effect. For noise >= 0.001, we observe very little effects. However, we did find a significant difference (ANOVA 3 of Test 7), especially when we control for bigger population sizes (>=32x32), and high noises (>=0.0001). Although the effects are small, they are very interesting because they move in the opposite direction of Propaganda in Experiment E, when Democracy was not present; i.e. there is an interaction between propaganda and democracy.

Test 7 – Three-way ANOVA comparing main effect of propaganda on cultural diversity when democracy is rare (1/1000). ANOVA 1 displays results for all noises, propaganda frequencies, and populations. ANOVAs 2 and 3 displays results for subsetted data for noise levels below 0.0001. ANOVA 3 displays results only for populations 32x32 and 100x100.

```
Anova Tables (Type I tests)
Response variable: Cultural Diversity

ANOVA 1
Factors: Noise*Size*Propaganda(1/5,1/3,1/1):
                       Df  Sum Sq Mean Sq   F value                  Pr(>F)
Noise                   5   62.08  12.416  5951.435 < 0.0000000000000002 ***
Size                    2    0.09   0.046    22.182        0.000000000279 ***
Propaganda              2   44.89  22.446 10759.077 < 0.0000000000000002 ***
Noise:Size             10    0.25   0.025    11.881 < 0.0000000000000002 ***
Noise:Propaganda       10   96.86   9.686  4642.764 < 0.0000000000000002 ***
Size:Propaganda         4    0.01   0.002     0.783                 0.536
Noise:Size:Propaganda  20    0.13   0.006     3.068        0.000005245431 ***
Residuals            2646    5.52   0.002
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

ANOVA 2
Factors: Noise(<=0.0001)*Size*Propaganda(1/5,1/3,1/1):
Df Sum Sq Mean Sq F value                 Pr(>F)
Noise                  1 0.0038 0.00378   1.489              0.2228
Size                   2 0.2294 0.11472  45.199 < 0.0000000000000002 ***
Propaganda             2 0.1112 0.05561  21.911         0.000000000516 ***
```

```
Noise:Size                2 0.0045 0.00227   0.896                0.4088
Noise:Propaganda          2 0.0062 0.00312   1.227                0.2936
Size:Propaganda           4 0.0203 0.00508   2.002                0.0923 .
Noise:Size:Propaganda     4 0.0015 0.00038   0.152                0.9623
Residuals               882 2.2387 0.00254
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

ANOVA 3
Factors: Noise(<=0.0001)*Size(>=32x32)*Propaganda(1/5,1/3,1/1):
                         Df  Sum Sq Mean Sq F value               Pr(>F)
Noise                     1 0.00788 0.00788  18.563             0.0000193 ***
Size                      1 0.00682 0.00682  16.070             0.0000689 ***
Propaganda                2 0.12098 0.06049 142.552 < 0.0000000000000002 ***
Noise:Size                1 0.00008 0.00008   0.198                0.6561
Noise:Propaganda          2 0.00318 0.00159   3.744                0.0242 *
Size:Propaganda           2 0.00149 0.00074   1.750                0.1747
Noise:Size:Propaganda     2 0.00062 0.00031   0.735                0.4802
Residuals               588 0.24951 0.00042
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1


Averages of the compared groups
10x10:
    0.000001 0.00001 0.0001  0.001   0.01    0.1
1/1   0.0860   0.0978 0.0578 0.0216 0.9230 0.9022
1/3   0.0982   0.0924 0.0584 0.0126 0.1146 0.0394
1/5   0.1046   0.1052 0.0382 0.0144 0.0578 0.1606

32x32:
      0.000001    0.00001     0.0001      0.001       0.01        0.1
1/1 0.03835938 0.04074219 0.03046875 0.01876953 0.94769531 0.92603516
1/3 0.07048828 0.05957031 0.03685547 0.01375000 0.09410156 0.06259766
1/5 0.08279297 0.07183594 0.03351562 0.01503906 0.03740234 0.17296875

100x100:
    0.000001  0.00001   0.0001    0.001     0.01      0.1
1/1 0.052162 0.047994 0.033640 0.022672 0.949994 0.918334
1/3 0.075648 0.068164 0.035686 0.013492 0.057712 0.066692
1/5 0.086306 0.073970 0.029030 0.013694 0.035884 0.189448


Standard deviations of the compared groups
10x10:
      0.000001    0.00001     0.0001       0.001        0.01         0.1
1/1 0.06809357 0.10400726 0.04482574 0.023678114 0.06078567 0.03430297
1/3 0.08100617 0.07075569 0.04896313 0.007507819 0.15868349 0.02024442
1/5 0.08981182 0.07420985 0.04173238 0.011807988 0.03052533 0.04455723

32x32:
      0.000001    0.00001     0.0001      0.001        0.01         0.1
1/1 0.02060112 0.02536458 0.02052157 0.01645530 0.008467996 0.008671598
1/3 0.03042746 0.02191401 0.02558900 0.01464889 0.149118766 0.013177872
1/5 0.02856650 0.03017663 0.02040214 0.01200263 0.012138479 0.025101250

100x100:
      0.000001     0.00001      0.0001       0.001        0.01          0.1
1/1 0.01041206 0.014719769 0.006935740 0.018619510 0.005588706 0.003508858
1/3 0.01435031 0.010723097 0.012583533 0.008457260 0.011089279 0.004795229
1/5 0.01217529 0.009868301 0.009435436 0.007042739 0.007500676 0.014852035
```

Appendix 5. Chapter 1. Stable states of equilibrium.

Fig. A to Fig. F display convergence in our experiment A models for all 6 different levels of noise (Fig. A starting with 0.000001 to Fig. F at 0.1). Each line displays (as an average over 50 repetitions) the behavior of the systems as the agents attempt on average 100,000 interactions with their neighbors. The end point of each line (at 100,000 interactions) corresponds to one single point in Figure 3 in chapter 1.

To summarize, we can see that some configurations of alpha = 0.5 do not reach an equilibrium, so they may further converge towards a monoculture. Less extreme, but similarly the lines at alpha = 0.95 do not seem to have reached complete stability yet, and some decrease is to be expected. For all other values and noise levels, the level of stability is satisfactory.

Fig. G shows single runs from the same configurations as above. Each run was randomly selected out of the 50 repetitions that we performed. Comparing Fig. G to L to Fig. A to F, we can say that our averaged lines are good representations of individual lines' behaviors.

Cultural regions over time at n=0.000001

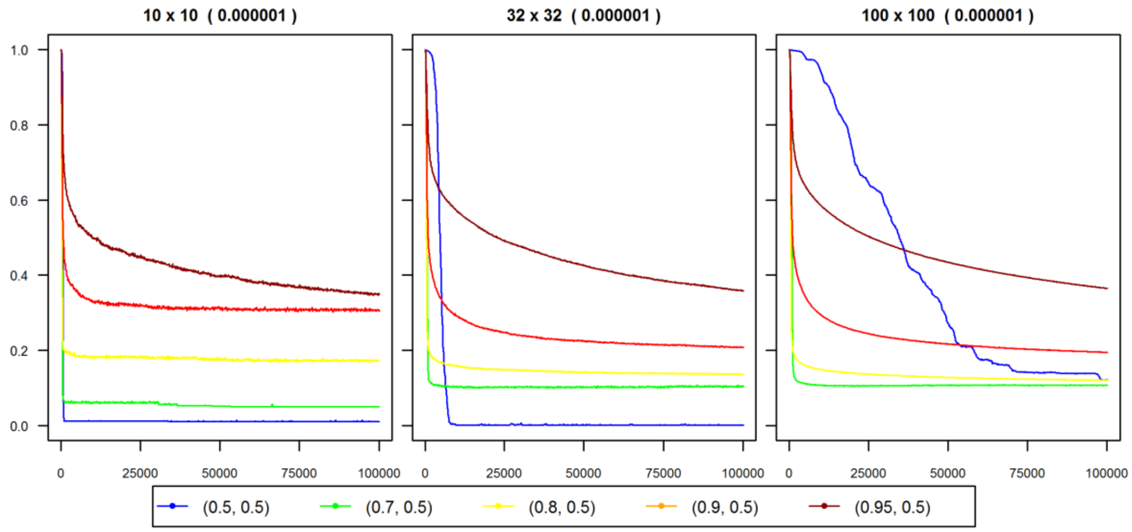


Fig. A. Average number of cultural regions over time with n=0.000001. The averages are calculated out of 50 repetitions. Axis-x represent the iteration number, and Axis-Y the cultural diversity (number of cultures divided by population size). From left to right, the graph represents 10x10, 32x32 and 100x100 populations. The legend shows the color use for the different values of alpha (institutional influence).

Cultural regions over time at n=0.00001

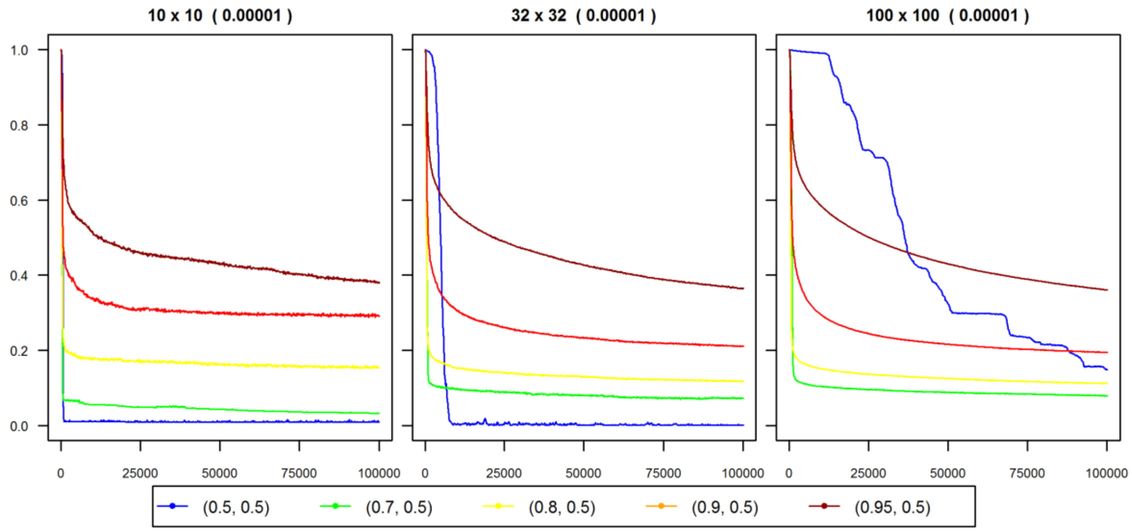


Fig. B. Average number of cultural regions over time with n=0.00001. The averages are calculated out of 50 repetitions. Axis-x represent the iteration number, and Axis-Y the cultural diversity (number of cultures divided by population size). From left to right, the graph represents 10x10, 32x32 and 100x100 populations. The legend shows the color use for the different values of alpha (institutional influence).

Cultural regions over time at n=0.0001

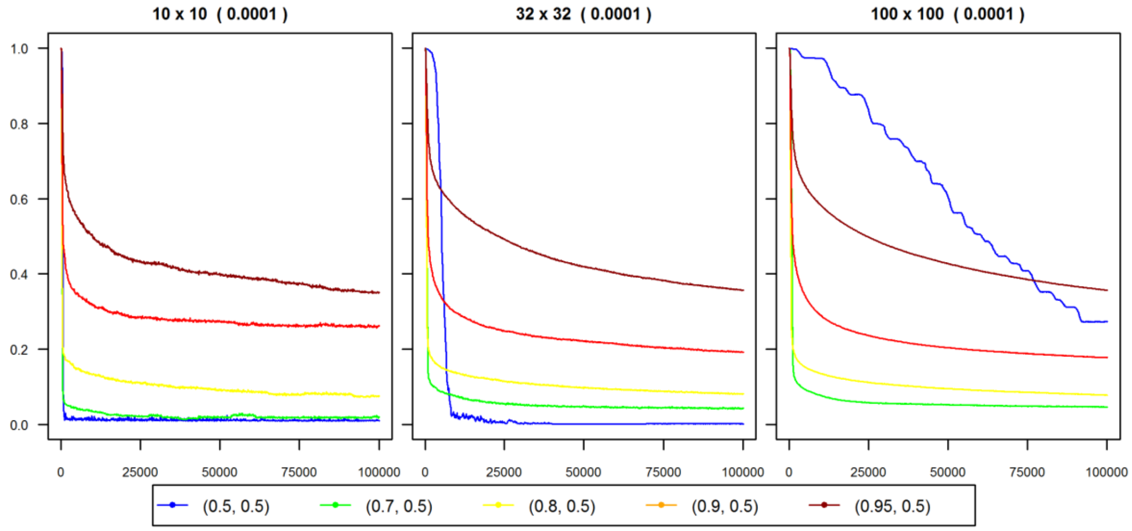


Fig. C. Average number of cultural regions over time with n=0.0001. The averages are calculated out of 50 repetitions. Axis-x represent the iteration number, and Axis-Y the cultural diversity (number of cultures divided by population size). From left to right, the graph represents 10x10, 32x32 and 100x100 populations. The legend shows the color use for the different values of alpha (institutional influence).

Cultural regions over time at n=0.001

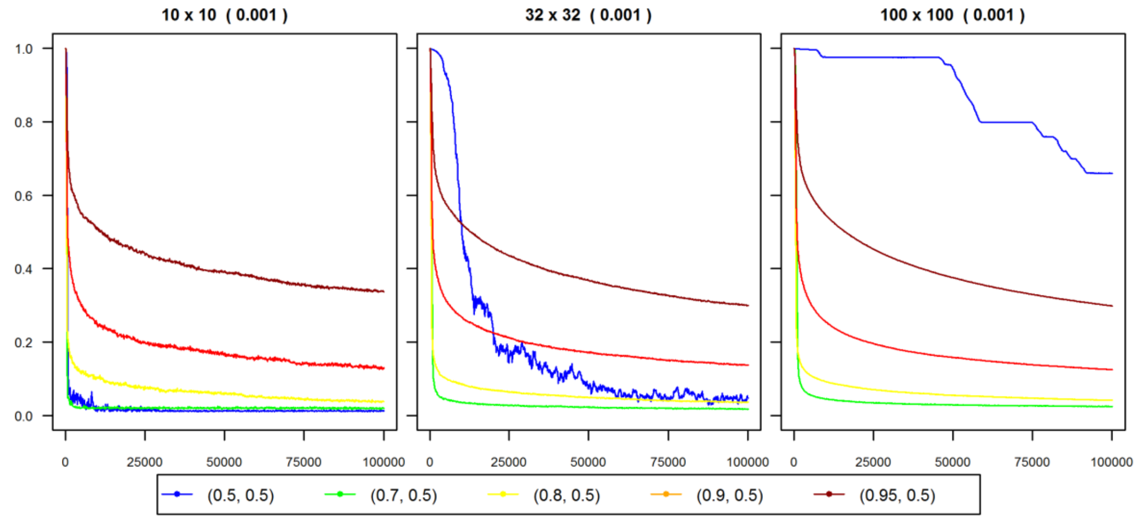


Fig. D. Average number of cultural regions over time with n=0.001. The averages are calculated out of 50 repetitions. Axis-x represent the iteration number, and Axis-Y the cultural diversity (number of cultures divided by population size). From left to right, the graph represents 10x10, 32x32 and 100x100 populations. The legend shows the color use for the different values of alpha (institutional influence).

Cultural regions over time at n=0.01

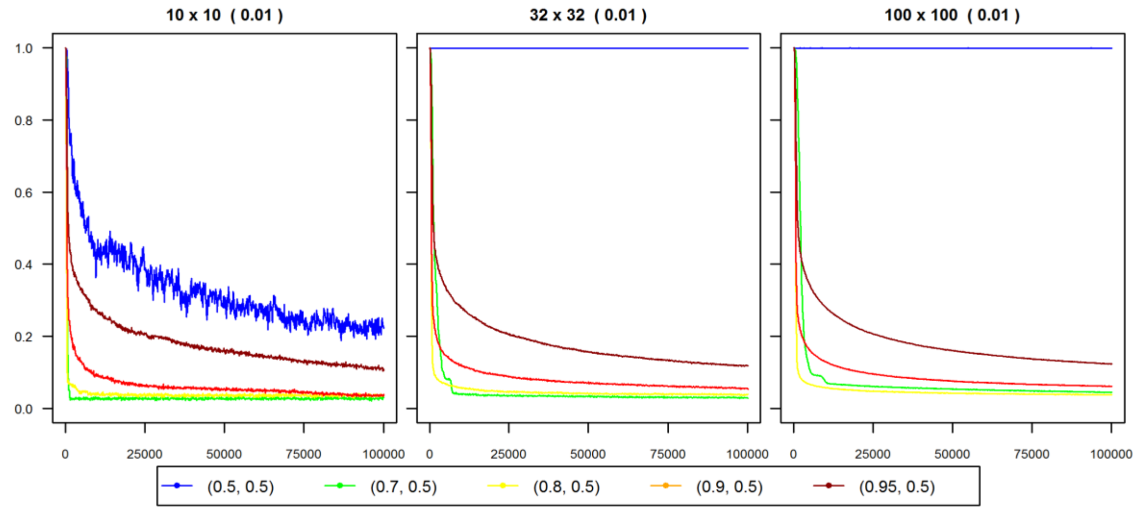


Fig. E. Average number of cultural regions over time with n=0.01. The averages are calculated out of 50 repetitions. Axis-x represent the iteration number, and Axis-Y the cultural diversity (number of cultures divided by population size). From left to right, the graph represents 10x10, 32x32 and 100x100 populations. The legend shows the color use for the different values of alpha (institutional influence).

Cultural regions over time at n=0.1

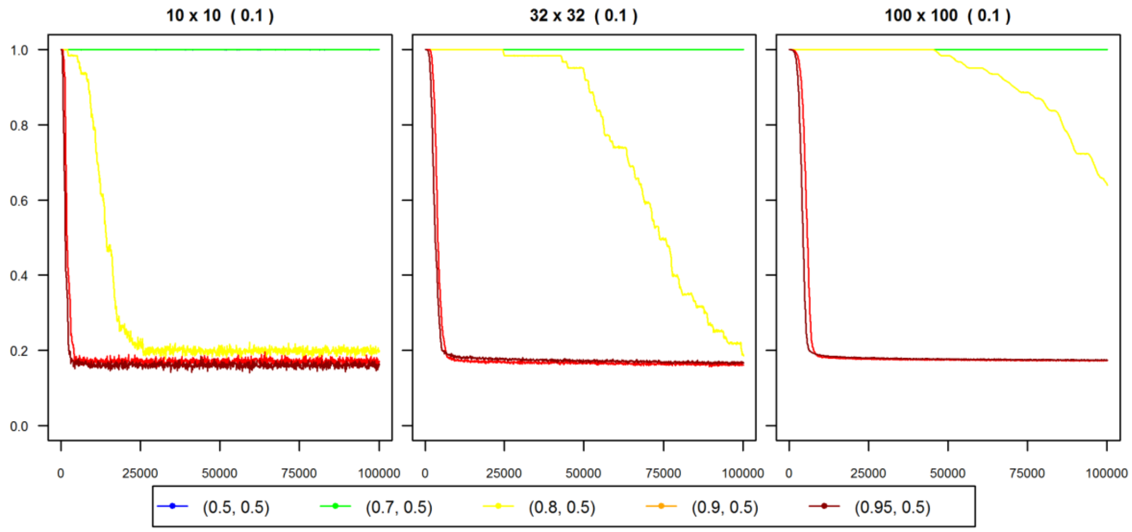


Fig. F. Average number of cultural regions over time with n=0.1. The averages are calculated out of 50 repetitions. Axis-x represent the iteration number, and Axis-Y the cultural diversity (number of cultures divided by population size). From left to right, the graph represents 10x10, 32x32 and 100x100 populations. The legend shows the color use for the different values of alpha (institutional influence).

Cultural regions over time for one run at n=0.000001

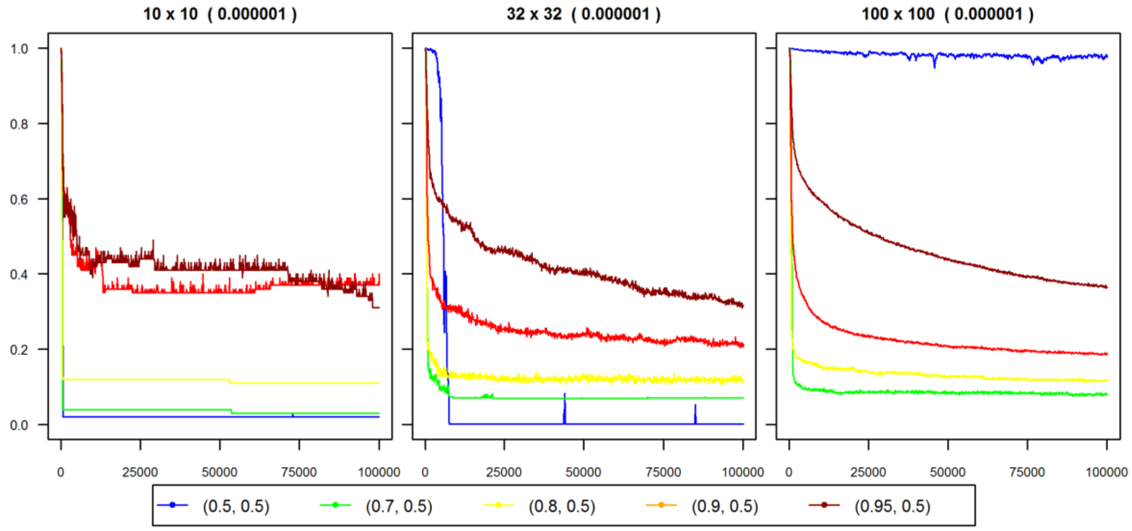


Fig. G. Number of cultural regions over time for single runs with n=0.000001. Each line represent a single run of the simulation. Axis-x represent the iteration number, and Axis-Y the cultural diversity (number of cultures divided by population size). From left to right, the graph represents 10x10, 32x32 and 100x100 populations. The legend shows the color use for the different values of alpha (institutional influence).

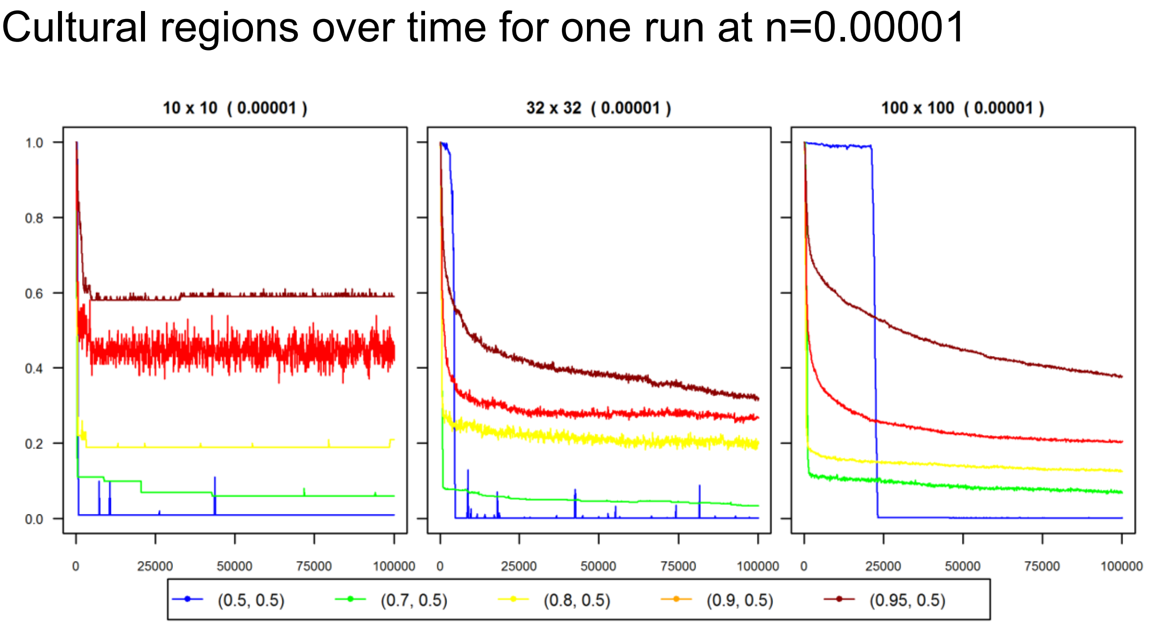


Fig. H. Number of cultural regions over time for single runs with n=0.00001. Each line represent a single run of the simulation. Axis-x represent the iteration number, and Axis-Y the cultural diversity (number of cultures divided by population size). From left to right, the graph represents 10x10, 32x32 and 100x100 populations. The legend shows the color use for the different values of alpha (institutional influence).

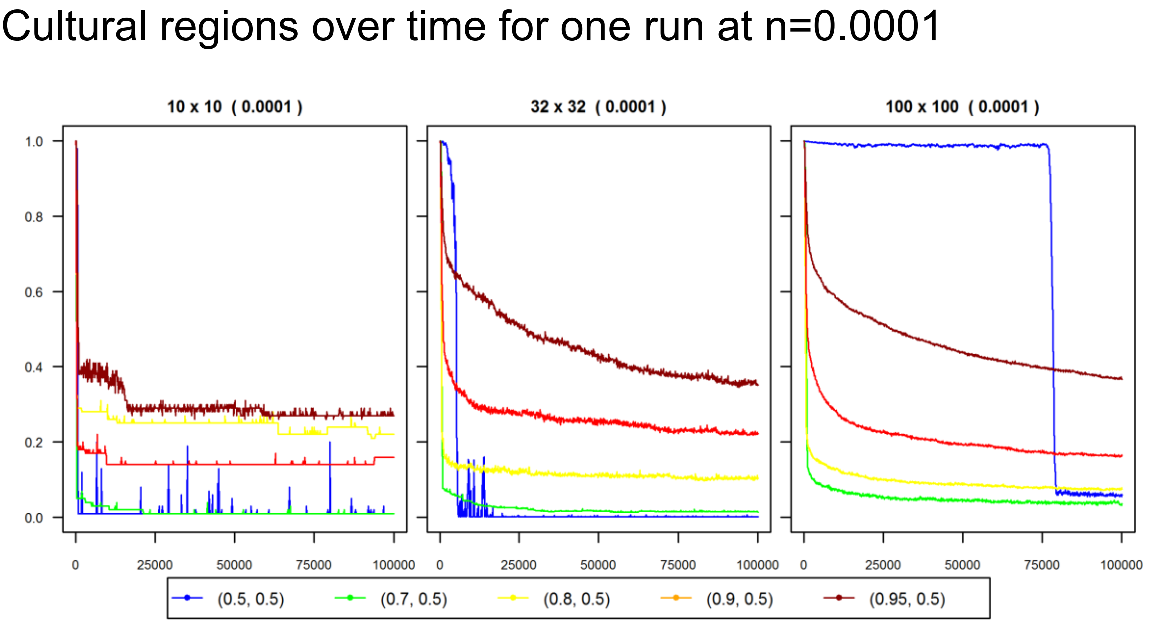


Fig. I. Number of cultural regions over time for single runs with n=0.0001. Each line represent a single run of the simulation. Axis-x represent the iteration number, and Axis-Y the cultural diversity (number of cultures divided by population size). From left to right, the graph represents 10x10, 32x32 and 100x100 populations. The legend shows the color use for the different values of alpha (institutional influence).

Cultural regions over time for one run at n=0.001

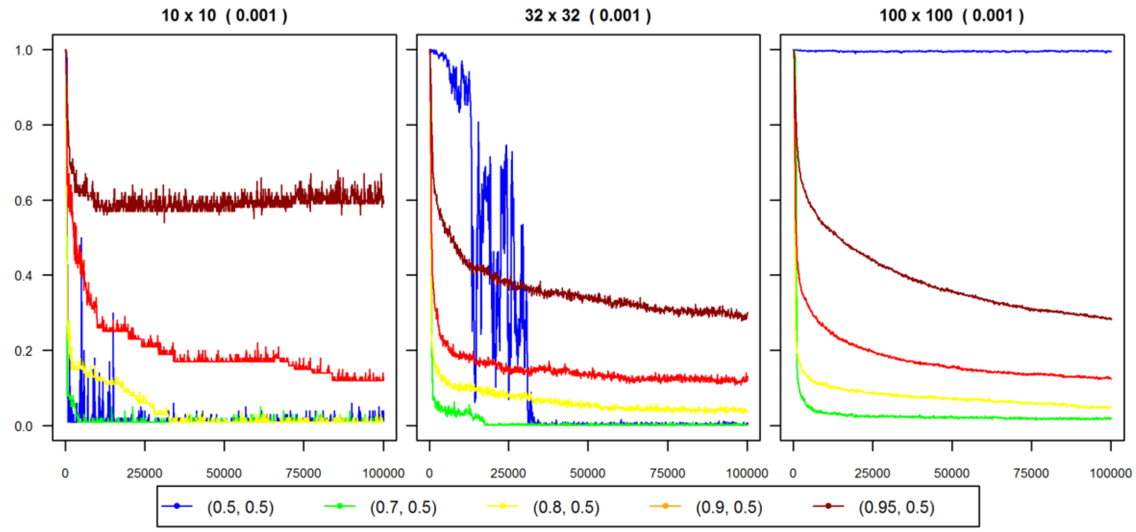


Fig. J. Number of cultural regions over time for single runs with n=0.001. Each line represent a single run of the simulation. Axis-x represent the iteration number, and Axis-Y the cultural diversity (number of cultures divided by population size). From left to right, the graph represents 10x10, 32x32 and 100x100 populations. The legend shows the color use for the different values of alpha (institutional influence).

Cultural regions over time for one run at n=0.01

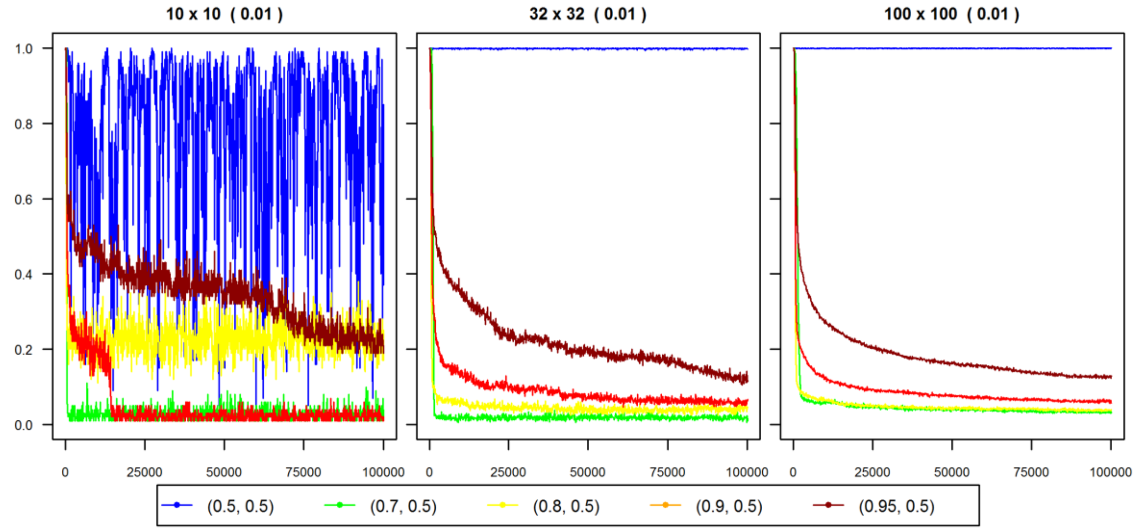


Fig. K. Number of cultural regions over time for single runs with n=0.01. Each line represents a single run of the simulation. Axis-x represent the iteration number, and Axis-Y the cultural diversity (number of cultures divided by population size). From left to right, the graph represents 10x10, 32x32 and 100x100 populations. The legend shows the color use for the different values of alpha (institutional influence).

Cultural regions over time for one run at n=0.1

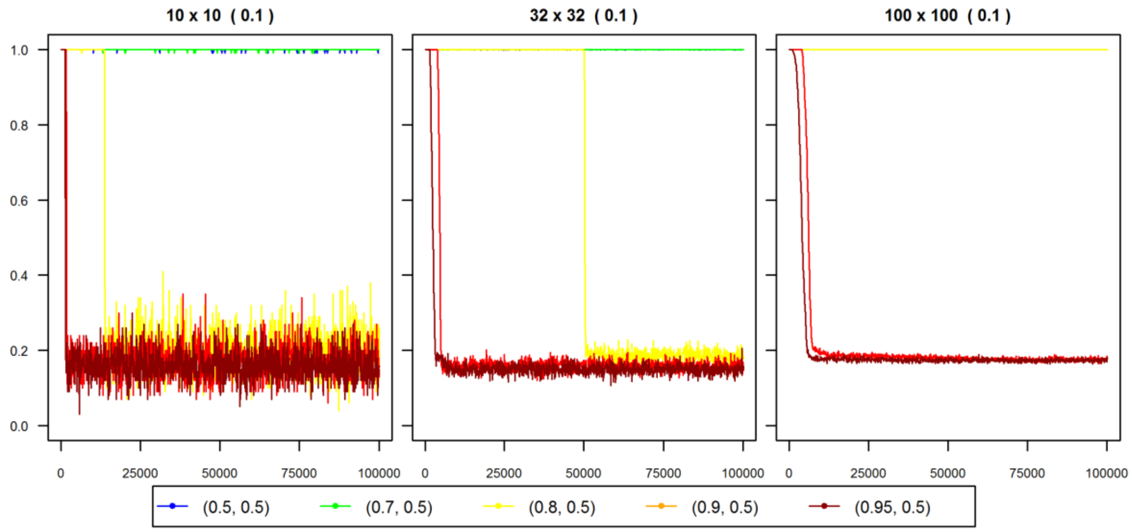


Fig. K. Number of cultural regions over time for single runs with n=0. 1. Each line represent a single run of the simulation. Axis-x represent the iteration number, and Axis-Y the cultural diversity (number of cultures divided by population size). From left to right, the graph represents 10x10, 32x32 and 100x100 populations. The legend shows the color use for the different values of alpha (institutional influence)

.

Appendix 6. Chapter 1. Replication of Axelrod/Flache's results.

Legend:

Yellow: reported values
Green: main effects and interactions that corroborate reported results
Blue: means and standard deviations that drive the significant differences
Purple: alternate possible result that could have been reported
Noise = level of mutation (ranges from 0.000001 to 0.1)
Size = population sizes (10x10, 32x32, 100x100)
Alpha = level of institutional influence (usually between 0.5 and 0.95)
Alpha_prime = level of agent loyalty (values of 0.05, 0.5 or 0.95)

We will now present results from a replication of both Axelrod's and Flache's models with Flache's implementation comparing them to our own code implementation.

We decided to re-implement Flache's model because:

1. we have the intention to integrate our model of institutional influence with Flache's model of multilateral social influence in the future
2. because when we attempted a replication of their model with their code, we had computational failures, especially for the biggest population size, which requires a lot of computational power

We optimized the code in several ways:

1. we do not implement a graphical user interface
2. we introduce thread management
3. we use native matrices
4. we avoid the use of classes, methods and unnecessary initializations (recycling structures)
5. we use buffers to manage the input and output of results

The replication of their model with our code was qualitatively successful (see continuous line in Fig. , where the lines in the plot are almost parallel and converge with higher values of noise). However, statistically, we did find a significant difference between the two implementations. Test 8 displays the ANOVA with three factors: implementation (i.e. two code variations), population size, and noise. The test is limited to only the two population sizes 10x10 and 32x32, because as mentioned before, due to computational difficulties we could not finish a run with their code for the population 100x100. Finally, our replications yields better results for our implementation of Flache et al's model, i.e. we manage to produce more diversity for their hypothesis (on their response variable, size of the biggest culture) with our code than when implementing theirs. This means that testing our data against theirs for comparison, we err on the side of conservatism.

Test 8. Anova comparing the two implementations (Implem), Flache's code vs our code, population size (N) and noise. The implementations are two replications of the multilateral social influence model proposed by Flache et al, one is Flache's code implementation, and the other is ours.

```
Anova Table (Type I tests)
Response: Size of the biggest culture
Factors: Size*Noise*Implem
                    Df  Sum Sq Mean Sq  F value                Pr(>F)
Size                 1 2451919 2451919 8856.959 < 0.0000000000000002 ***
Noise                5  626111  125222  452.335 < 0.0000000000000002 ***
Implem               1   22283   22283   80.491 < 0.0000000000000002 ***
Size:Noise           5  346196   69239  250.109 < 0.0000000000000002 ***
Size:Implem          1   12526   12526   45.247       0.0000000000271 ***
Noise:Implem         5   14355    2871   10.371       0.0000000009474 ***
Size:Noise:Implem    5    7693    1539    5.558       0.0000455284940 ***
Residuals         1176  325558     277
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1


Averages of the compared groups
Flache's implementation:
     0.000001 0.00001 0.0001 0.001  0.01    0.1
100     16.58   16.24  12.18  6.18  2.74  10.36
1024   130.26  131.36 105.12 65.16 34.14 101.90

Our implementation:
     0.000001 0.00001 0.0001 0.001  0.01   0.1
100     22.82    19.3  14.76  7.54  2.40  10.4
1024   157.84   158.2 131.62 69.88 36.38 104.5


Standard deviations of the compared groups
Flache's implementation:
     0.000001  0.00001    0.0001     0.001     0.01       0.1
100  10.45123 10.09457  8.416917  7.702875 2.655837  2.553589
1024 28.34252 27.02437 26.042070 18.505774 8.111493 10.842565

Our implementation:
     0.000001   0.00001    0.0001     0.001     0.01       0.1
100  10.73938  7.442981 10.62642  8.048856 1.428571  3.103652
1024 27.28486 29.686113 30.83524 20.800942 8.243464 10.689018
```

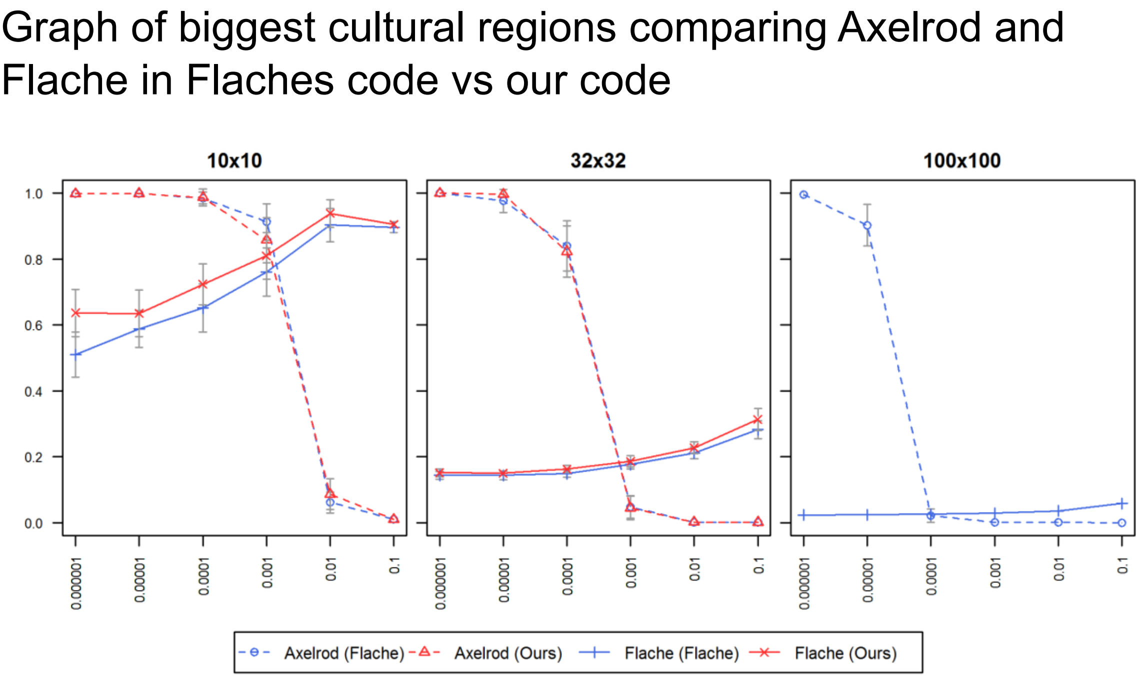


Fig. A Biggest cultural region on different implementation of the same model. The X axis shows the different levels of noise, and the Y axis the normalized size of the biggest cultural region (size of the biggest cultural region/population size). The results of the two different models (Axelrod and Flache), as implement by Flache (blue) vs ours (red) are represented in the graph for populations 10x10 and 32x32, while only Flache's code (for Axelrod and Flache) is displayed in 100x100. Each point on the line is an average of the final cultural diversity of 50 repetitions with 100000 iterations on average per agent. Confidence intervals at 0.95 are displayed only when bigger than the identifier symbols.

For this comparison, we are displaying size of the biggest culture, just as Flache did in his original paper. Flache opted for an indirect measurement that allows best for observation of the stability of the system against noise, i.e. whether there is a tendency towards globalization or anomie. Globalization is reached when the biggest culture absorbs all the agents in the population; similarly, anomie is reached when the biggest culture consists of one agent. Since we were more interested in the effects of institutions on actual cultural diversity rather than the stability of the system, we decided to keep the number of cultural regions to denominate cultural diversity as the main response variable across chapter 1. However, we are presenting the graphs using their response variable in this Appendix section.

Before that, we also show our implementation of Axelrod's model, and include the two noise sources as described by Flache. Fig. A displays our results here in dotted lines. We found no significant differences between Axelrod's model with Flache's code and our replication, as seen in Test 9.

Test 9. Anova comparing the two implementations (Implem), Axelrode with Flache's code vs our code, population size (N) and noise. The implementations are two replications of the dyadic social influence model proposed by Axelrod, one is Flache's code implementation, and the other is ours.

```
Anova Table (Type I tests)
Response: Size of the biggest culture
                    Df    Sum Sq  Mean Sq   F value               Pr(>F)
Size                 1  63001127 63001127 13974.324 <0.0000000000000002 ***
Noise                5  76508238 15301648  3394.069 <0.0000000000000002 ***
Implem               1        30       30     0.007                0.935
Size:Noise           5  56680215 11336043  2514.456 <0.0000000000000002 ***
Size:Implem          1       177      177     0.039                0.843
Noise:Implem         5      2113      423     0.094                0.993
Size:Noise:Implem    5      1898      380     0.084                0.995
Residuals         1176   5301818     4508
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Averages of the compared groups
Flache's implementation:
     0.000001 0.00001 0.0001  0.001    0.01     0.1
100      1.14    1.06   1.36   7.68   83.18   99.98
1024     1.00    2.88  80.98 817.08 1022.64 1024.00

Our implementation
     0.000001 0.00001 0.0001  0.001    0.01     0.1
100      1.12    1.10   1.84   5.24   87.82   99.98
1024     1.00    8.18  70.50 815.38 1023.08 1023.92


Standard deviations of the compared groups
Flache's implementation:
      0.000001   0.00001     0.0001     0.001      0.01       0.1
100  0.4952839 0.2398979   2.405436  10.02332 20.430759 0.1414214
1024 0.0000000 9.5096943 117.053187 197.68619  1.224911 0.0000000

Our implementation:
      0.000001     0.00001      0.0001      0.001       0.01       0.1
100  0.3282607  0.5802885   3.253632   7.487568 15.8393594 0.1414214
1024 0.0000000 26.3234899 116.409946 200.599498  0.8533248 0.2740475
```

Results graphs with response variable "size of biggest culture"

We will now show all our results graphs as presented in chapter 1, adopting Flache's chosen variable of "size of the biggest cultural region", to clarify that there were no meaningful differences even if we had used that variable instead of the one we chose. Fig. B to Fig. G display the results of Experiment A to F.

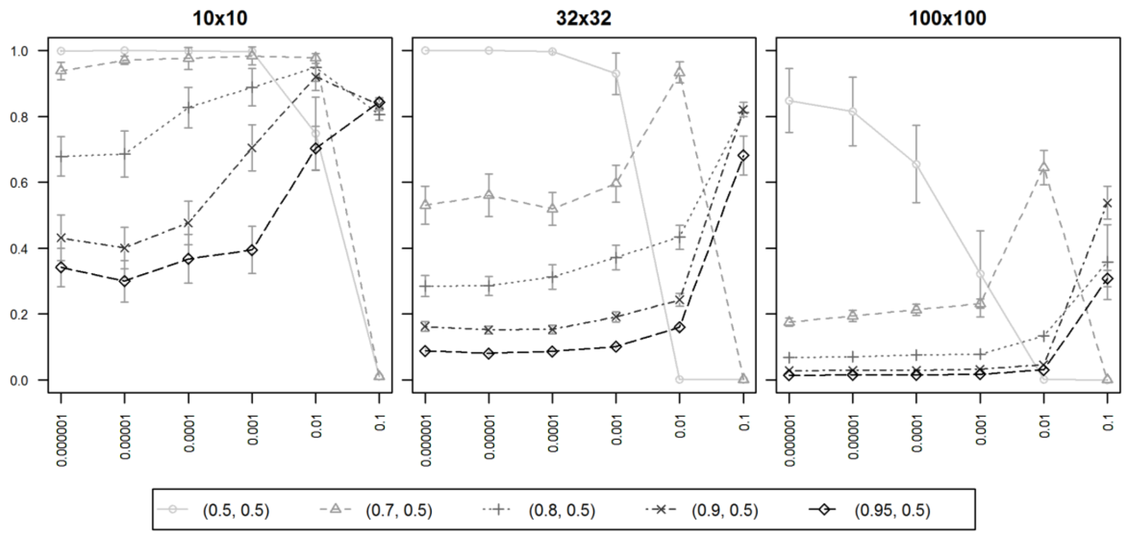


Fig. B. Size of the biggest culture for varying levels of institutional influence. X-axis displays levels of noise; Y axis displays biggest culture. Each line symbol denotes one alpha of institutional influence. 95% confidence intervals are displayed only when exceeding the size of the line symbol. Data points are averages of 50 replications per territory with 100,000 iterations per agent.

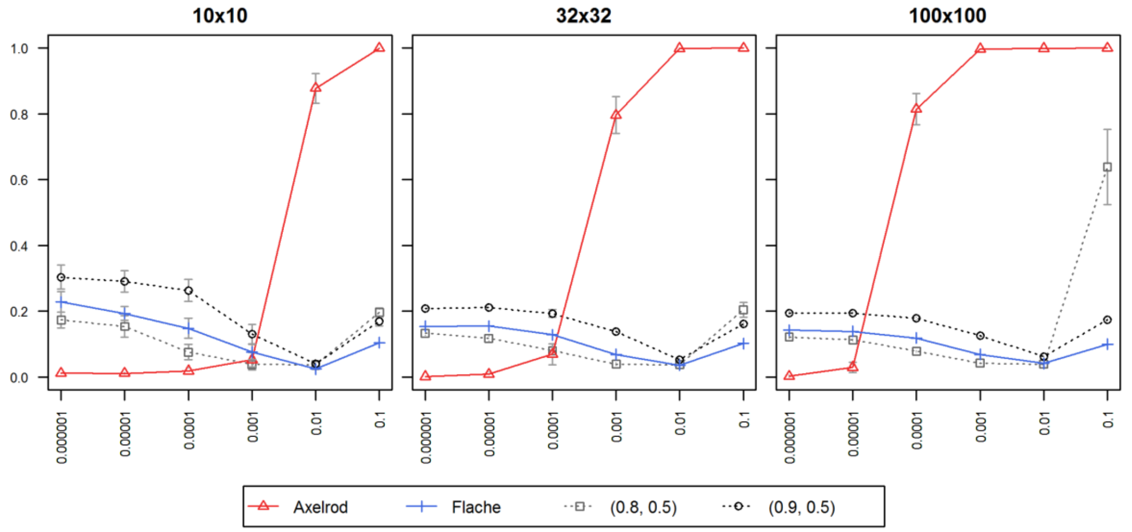


Fig. C. Size of the biggest culture for comparison with Axelrod and Flache. X-axis displays levels of noise; Y axis displays biggest culture. Each line symbol denotes the models we chose as comparisons. 95% confidence intervals are displayed only when exceeding the size of the line symbol. Data points are averages of 50 replications per territory with 100,000 iterations per agent.

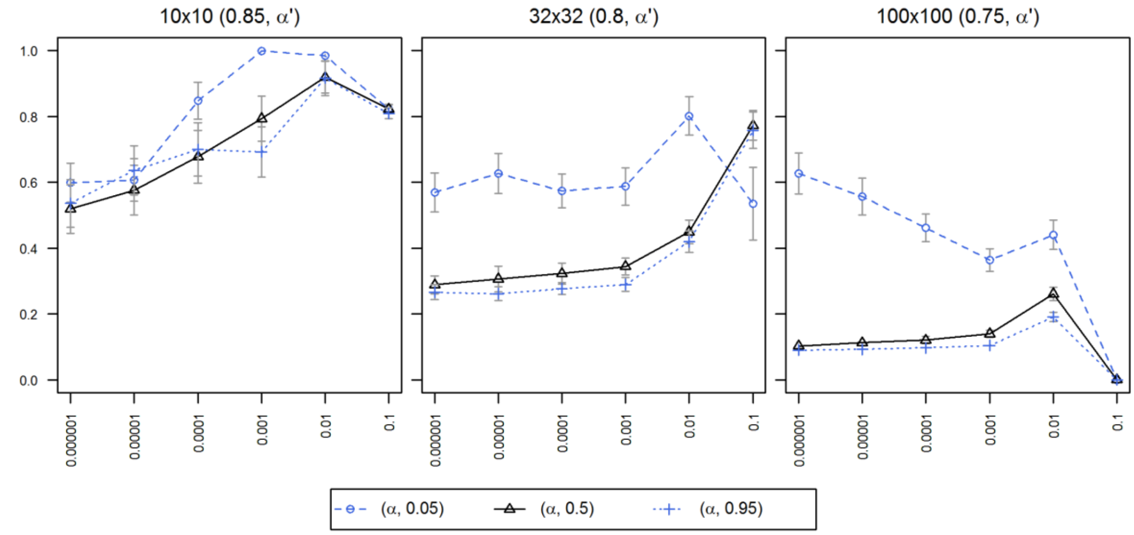


Fig. D. Size of the biggest culture for varying levels of agent loyalty. X-axis displays levels of noise; Y axis displays biggest culture. Each line symbol denotes one alpha prime of agent loyalty. 95% confidence intervals are displayed only when exceeding the size of the line symbol. Data points are averages of 50 replications per territory with 100,000 iterations per agent.

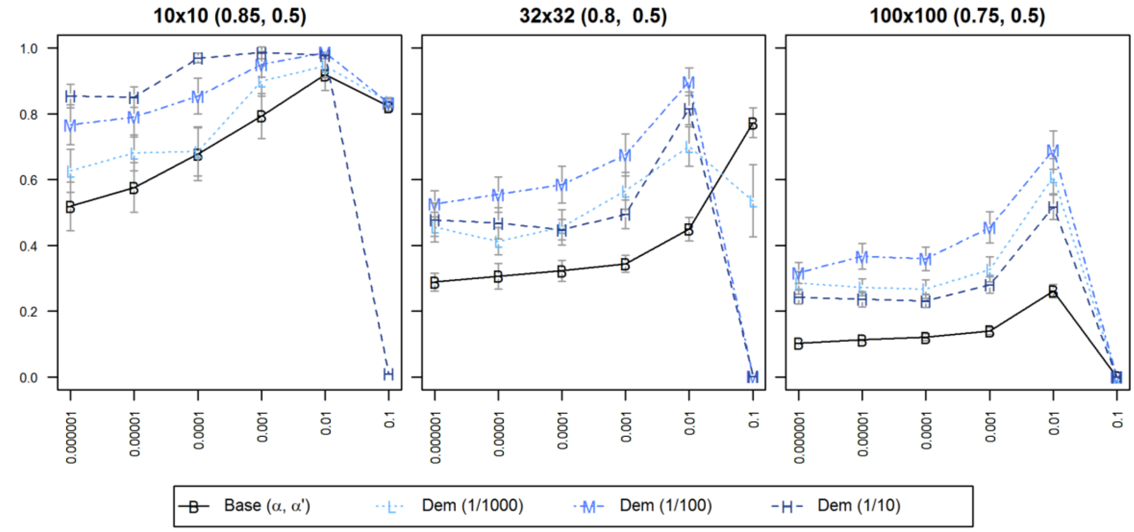


Fig. E. Size of the biggest culture for varying frequencies of democracy. X-axis displays levels of noise; Y axis displays biggest culture. Each line symbol denotes frequency of democracy. 95% confidence intervals are displayed only when exceeding the size of the line symbol. Data points are averages of 50 replications per territory with 100,000 iterations per agent.

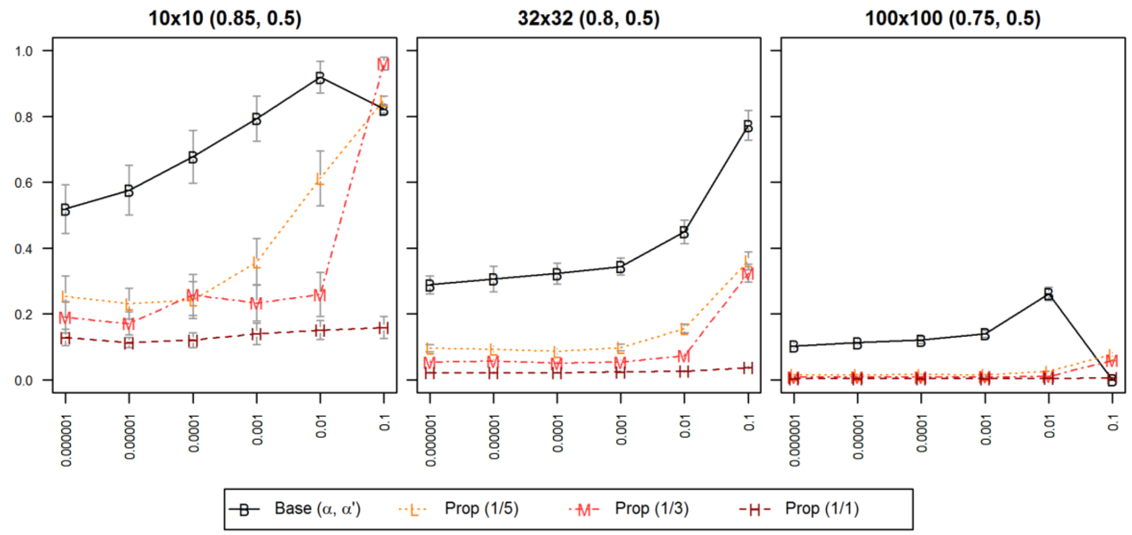


Fig. F. Size of the biggest culture for varying frequency of propaganda. X-axis displays levels of noise; Y axis displays biggest culture. Each line symbol denotes one frequency of propaganda. 95% confidence intervals are displayed only when exceeding the size of the line symbol. Data points are averages of 50 replications per territory with 100,000 iterations per agent.

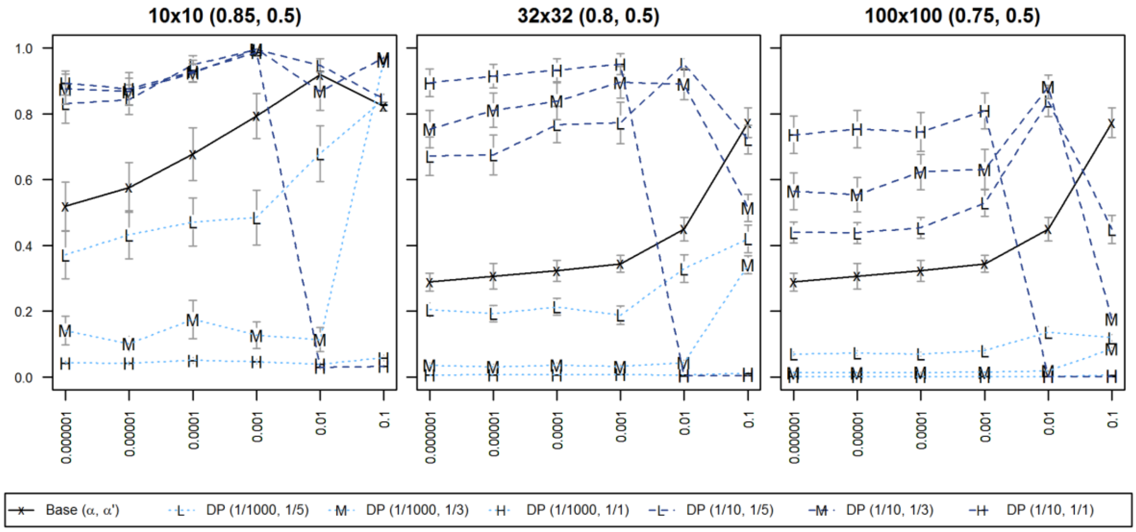


Fig. G. Size of the biggest culture for combined democracy and propaganda frequencies. X-axis displays levels of noise; Y axis displays biggest culture. Each line symbol denotes one combination of democracy and propaganda frequencies. 95% confidence intervals are displayed only when exceeding the size of the line symbol. Data points are averages of 50 replications per territory with 100,000 iterations per agent.

Appendix 7. Chapter 1. Number of institutions.

Fig. A to Fig. D give an overview over the number of institutions that resulted in our systems in experiments A (institutional influence), C (agents loyalty), D (democracy) and E (propaganda). The results of experiment F (democracy + propaganda) are discussed in chapter 1.

Fig. A (from experiment A) confirms the observations from Table 4 of chapter 1, i.e. the number of institution is proportional to the population size (the values in the graph are normalized by population), and they are not strongly affected by institutional influence. Similarly, Fig. B (from experiment C) shows that the number of institutions does not seem to be affected by agent loyalty, except for models 100x100/0.75/0.05, only when noise is low (<=0.001).

Conversely, Fig. C and Fig. D show that increasing democracy and propaganda leads to an increase in the number of institutions in either case. These graphs are consistent with Figure 9 and its associated discussion in chapter 1, although the effects of propaganda seems to be amplified by democracy when the two institutional processes are combined.

Results graphs with response variable "number of institutions"

Fig. A to **Fig. B** displays the normalized number of institutions for Experiments A, B, D and F. This is to complement the Figure 9 (chapter 1). **Fig. A** mainly confirm observations made in Experiment A regarding to Table 4, however the scale is too small to appreciate the effects. **Fig. B** shows no relevant information for institution loyalty. **Fig. C** shows how democracy promotes the preservation of institutions. **Fig. D** shows a similar, but weaker effect, for propaganda. This results are the same as observed in Figure 9, when both democracy and propaganda are present.

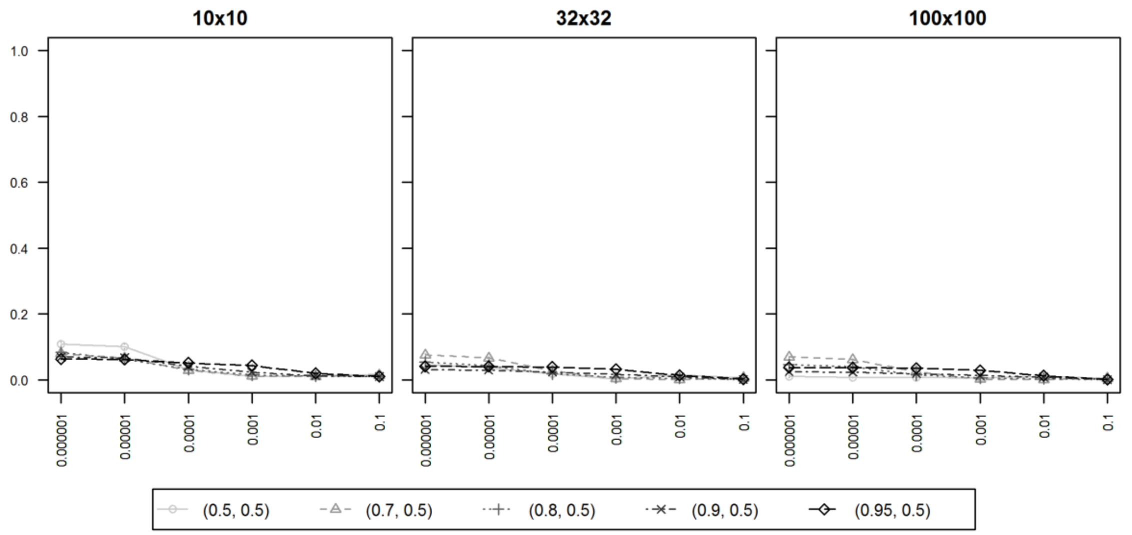


Fig. A. Number institutions for varying levels of institutional influence. X-axis displays levels of noise; Y axis displays normalized number of institutions. Each line symbol denotes one alpha of institutional influence. 95% confidence intervals are displayed only when exceeding the size of the line symbol. Data points are averages of 50 replications per territory with 100,000 iterations per agent.

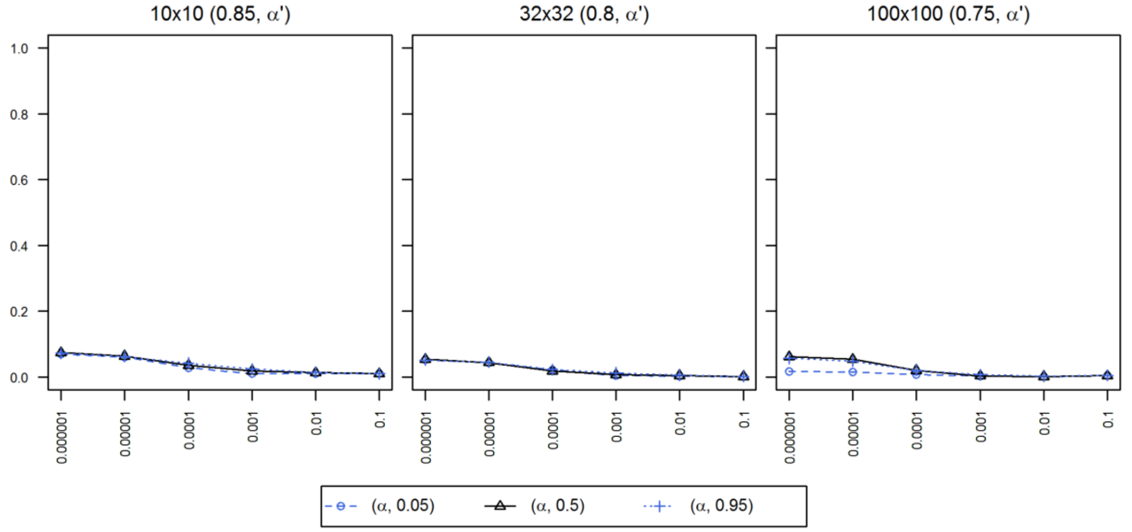


Fig. B. Number institutions for varying levels of agent loyalty. X-axis displays levels of noise; Y axis displays normalized number of institutions. Each line symbol denotes one alpha prime of agent loyalty. 95% confidence intervals are displayed only when exceeding the size of the line symbol. Data points are averages of 50 replications per territory with 100,000 iterations per agent.

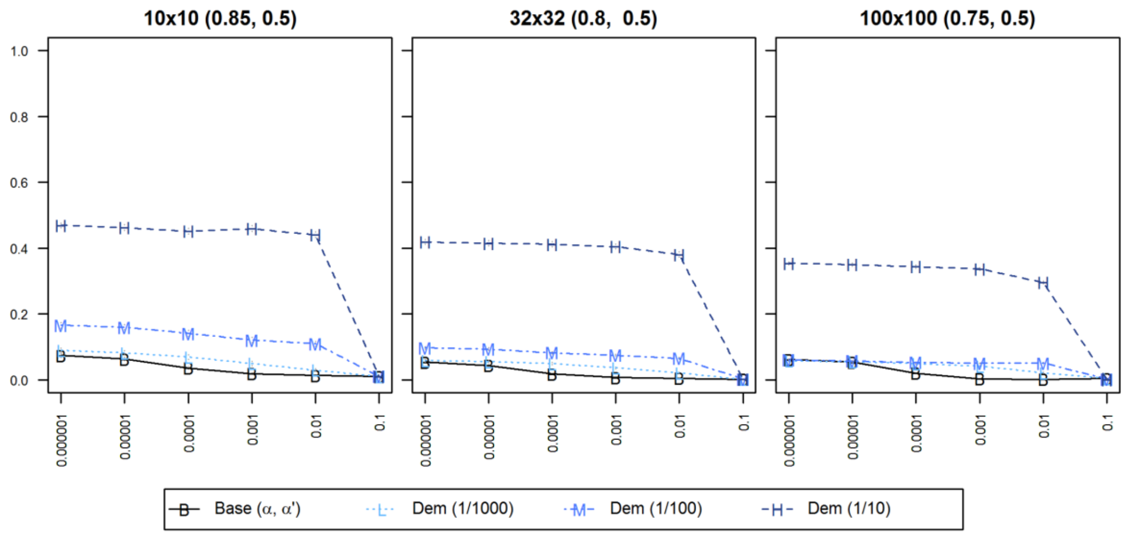


Fig. C. Number institutions for varying frequency of democracy. X-axis displays levels of noise; Y axis displays normalized number of institutions. Each line symbol denotes one frequency of democracy. 95% confidence intervals are displayed only when exceeding the size of the line symbol. Data points are averages of 50 replications per territory with 100,000 iterations per agent.

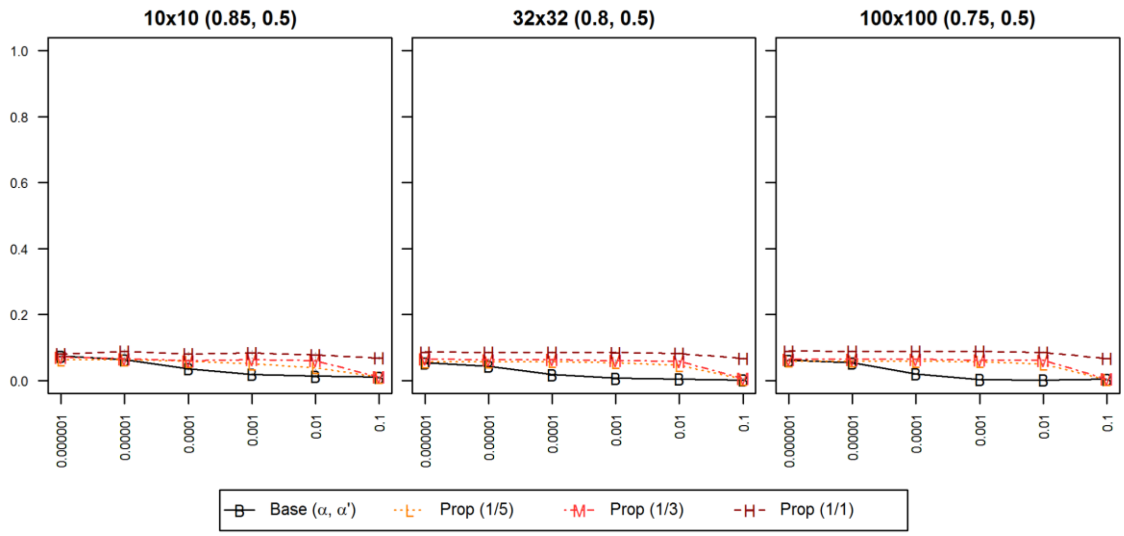


Fig. D. Number institutions for frequencies of propaganda. X-axis displays levels of noise; Y axis displays normalized number of institutions. Each line symbol denotes one frequency of institutions. 95% confidence intervals are displayed only when exceeding the size of the line symbol. Data points are averages of 50 replications per territory with 100,000 iterations per agent.

Appendix 8. Chapter 1. Complete results Experiment F (inclusion of democracy 1/100).

Fig. A displays the complete results for Experiment F, i.e. it includes the medium values of democracy (1/100). The results are represented with the dashed-dotted lines. We can observe that the lines are located between the high (1/10) and low (1/1000) values of democracy, with a few exceptions for high values of noise (>= 0.01). The only big effect we found for medium democracy (1/100) was at the highest frequency of propaganda (1/1).

In general, the results confirmed the observations in Figure 8 of chapter 1.

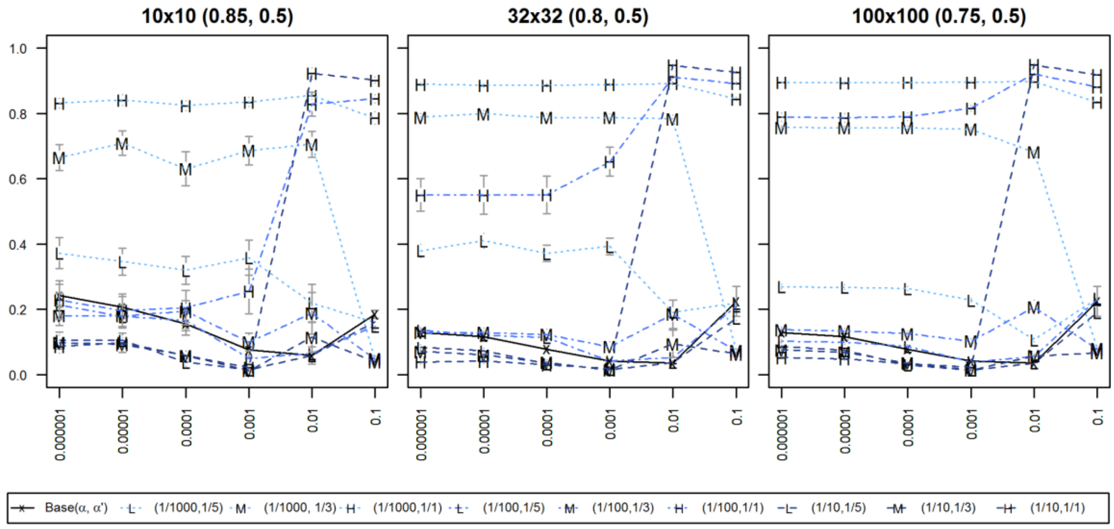


Fig. A. Cultural diversity for combinations of democracy and propaganda frequencies. X-axis displays levels of noise; Y axis displays normalized cultural diversity. Each line symbol denotes one combination of democracy and propaganda. 95% confidence intervals are displayed only when exceeding the size of the line symbol. Data points are averages of 50 replications per territory with 100,000 iterations per agent

Appendix 9. Chapter 2. User Manual.

The Cultural Simulator is an agent-based system that simulates how cultures emerge. Individuals are represented by agents that live on a grid. The interface shows the agents in colors according to their **cultural vector**, a list of **cultural features** with assigned **cultural traits**, e.g. the cultural feature *music* could have the cultural trait *jazz* assigned to it.

When two agents (1) have exactly the same cultural features on the cultural vector and (2) are adjacent neighbors on the grid, then they belong to the same culture. Over time, agents influence each other, transmitting their cultural traits to other neighboring agents in a Neumann radius.

As agents constantly transmit information to each other, do they all end up sharing the same culture? This really depends on the rules that are set up regarding how information is being shared, and the initial starting conditions. For example, ***homophily***, the principle that *like attracks like* has proven to promote cultural diversity. The size of the grid, the size of the cultural vector, the number of traits, and the size of the Neumann neigborhood have proven to be important paramaters that affect the final levels of diversity.

The Cultural Simulator gives the option to modify many of these parameters, plus it provides the possibility to use different rule sets - which represent the models as proposed by different authors: Axelrod (1997), Flache & Macy (2011), Ulloa, Kacperski & Sancho (2016).

The Cultural Simulator allows for elements such as random changes in the cultural vectors (**mutation**), errors in the selection of similar agents (**selection error**), simultaneous influence by several agents (**multilateral social influence**), and a second layer of information that serves as central repositories for group of agents (**institutions**). **Institutions** are able to influence agents indirectly - by preventing social influence (**institutional influence**) - or directly through top-down and bottom-up processes (**propaganda** and **democracy**).

Finally, the Cultural Simulator includes mechanisms to explore the resilience of convergence states. These are called **Events**. **Events** introduce (1) changes to the initial parameters of the simulation, or (2) changes to the content and structure of agents and institutions throughout the simulation run. For example, a **decimation event** allows destruction of a chosen percentage of the agent population. A **conversion event** allows the introduction of foreigners' traits to the institutions.

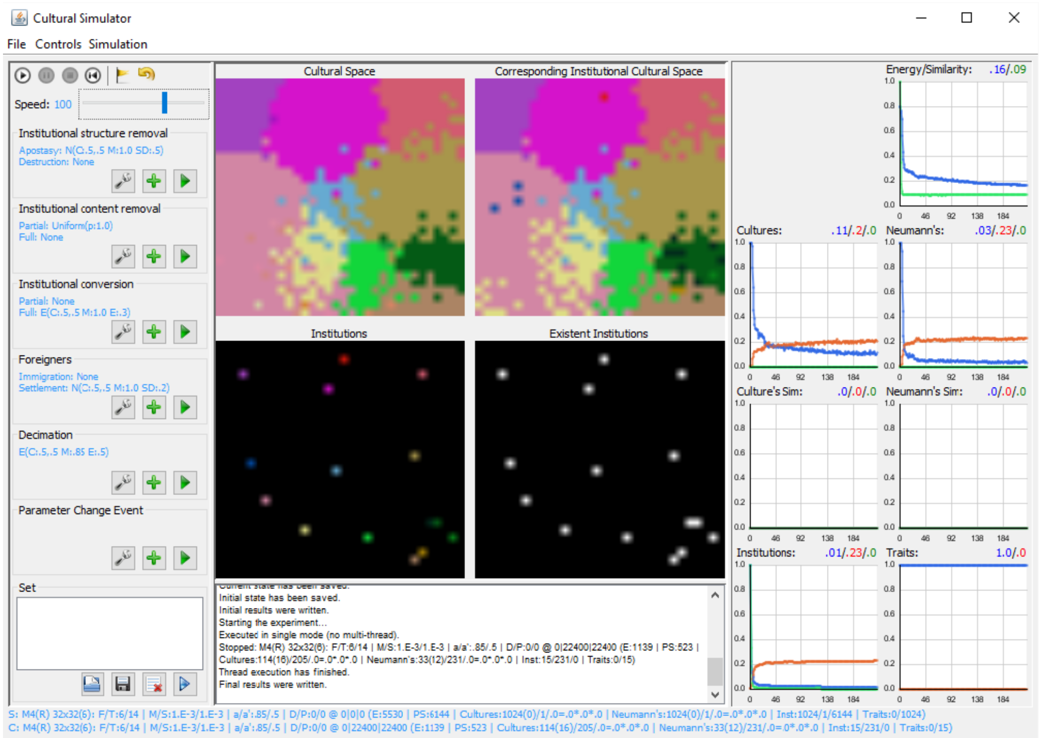
Continue with the Quick Start and start trying your parameters!

1. Quick Start

1.1. Execute a simulation and save its state:

1. Start the Cultural Simulator.

2. Click the **Play Button** and let it run until the simulation stops (or press the **Stop Button** to stop it manually if it is taking too long). The resulting cultures are displayed in one of the four center square **Panels** of the interface, specifically in the top-left colorful panel (titled **Cultural Space**). For other panels and more details on the panels, please see the section on Cultural Panels. The response variables are displayed on the right hand side of the screen in the way of **Graphs** (titled Energy, Cultures etc) and the **Status Bar** at the bottom of the interface. For information on this section of the interface, see the section on Graphs and Status Bar:



3. Save the current state of the simulation by clicking the **Save State Button** . From now on, you can resume the simulation from this state. You can also **save**

this state as a file by clicking on `File -> Save Simulation State` and, of course, recover it (`File -> Load Simulation State`).

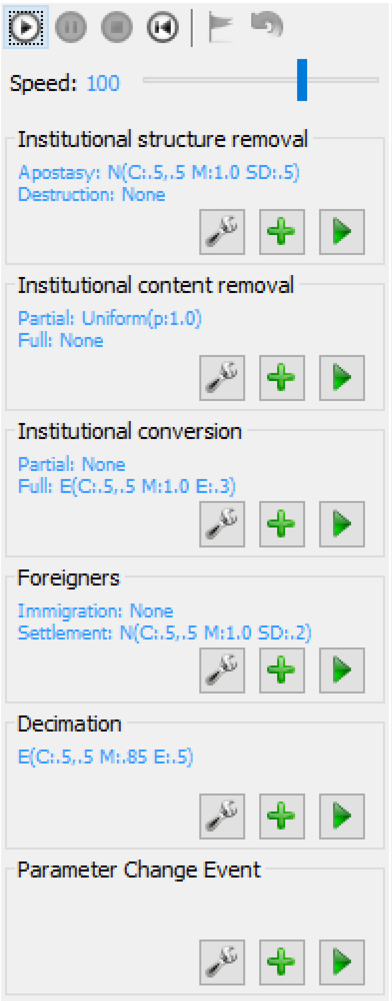
4. The **initial configuration** of the simulation can be modified in `Simulation -> Parameters` (See Initial Parameters for more details).

1.2. Execute Events in the simulation:

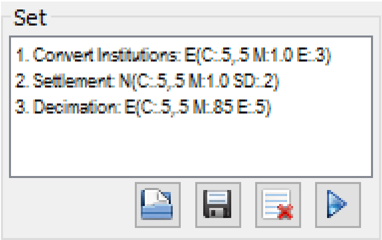
1. Let's continue the simulation by clicking the **Play Button** again.

2. **Events** can be chosen and set on the left hand side of the interface. You can introduce any of the events by itself as a **Single Event** (see the list below) by clicking on the **Execute Event Button** .

3. **Single Events** can be configured by clicking the **Configure Event Button** . For more details, see the section on Events.



4. You can also execute multiple events at the same time by using the **Add Event Button** to add the selected events to the **Event Set Panel** in the bottom left corner of the interface.



5. The **Event Set Panel** also allows you to **Save Composed Events**, an important feature if you are running big experiments in Batch Mode (See Batch Mode).

1.3. Restore the simulation state, compare single event with initial saved state and compare two events:

1.3.1. **Restore** simulation **state:**

1. Play the simulation by clicking the **Play Button**.

2. Save the current state of the simulation by clicking on the **Save State Button**. You can also **save this state as a file** by clicking on `File -> Save Simulation State`.

3. After the simulation runs for some iterations, you can go back to a previously saved state, by pressing the **Reload Simulation Button** (or reload a previously saved file with `File -> Load Simulation State`).

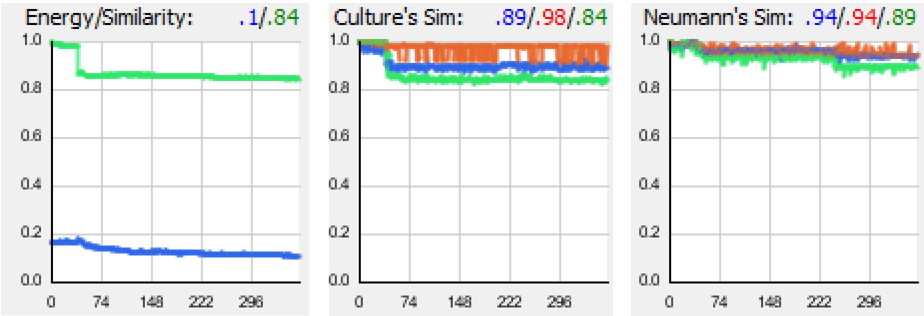
1.3.2. Compare Single Event with Initial Saved State:

4. Execute the Single Event called **Decimation** by clicking the **Execute Event Button** of the Decimation panel (second-last panel on the left hand side of the interface).

5. Click the **Play Button**, and wait for some iterations. You can now see the difference between the **Original Run** (started from the Saved State, without Event) and the **Decimation Run** (started from the Saved State with Decimation Event) in the center **Panels** and the **Graphs** and the **Status Bar**.

6. To compare the difference between the Saved State and the new state at any point following the Event, check the **Status Bar** (the bar at the very bottom of the interface, blue font) for detailed information. You can also for example follow the trend of the green line in the top-right graph titled **Energy** (and the example graphic below). It shows the **Pixel Similarity** of the current to the saved state. For more information on how to read this graph, see Pixel Similarity.

7. You can execute more events to see the effects of those particular events on the similarity between initial state and new state.



1.3.3. Compare two events:

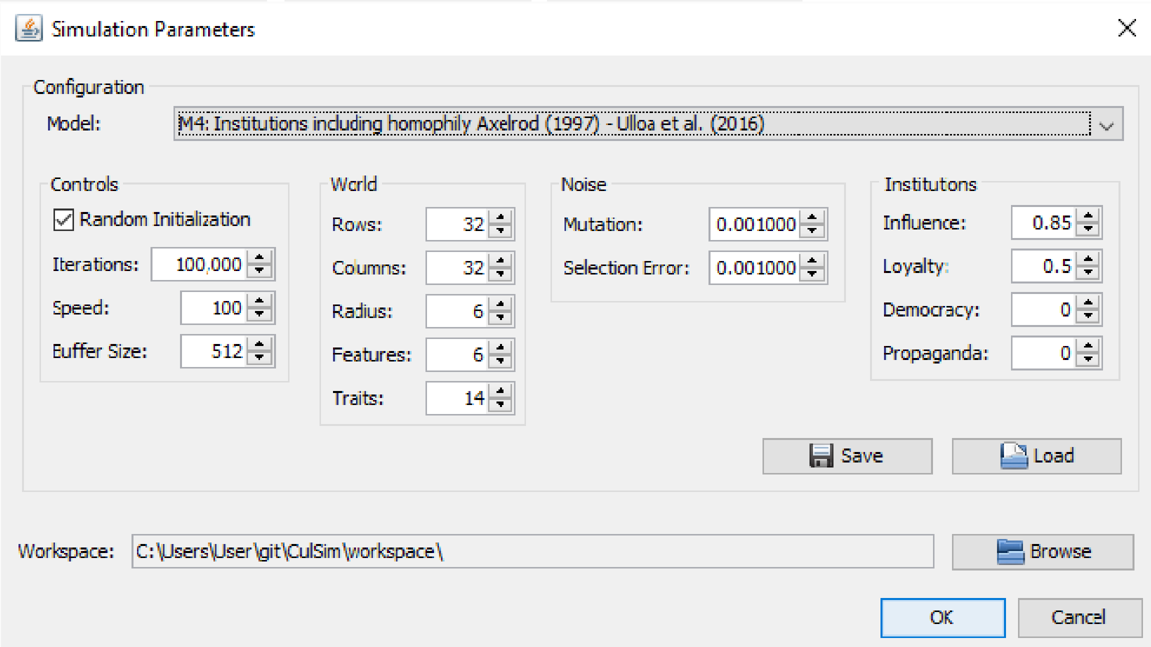
8. Go back to your previously saved state, by pressing the **Reload Simulation Button** (or reload a previously saved file with `File -> Load Simulation State`).

9. Click a different **Execute Event Button** for example the one called **Foreigners (Settlement)**.

10. Visually compare the effects that executing **Decimation** and executing **Foreigners (Settlement)** had on the panels and graph outputs. If you notice differences (or want to test statistical differences), you can use the **Batch Mode** (see Batch Mode.) You can also run bigger experiments in **remote machines** (See **Command Line Interface**).

2. Initial Parameters

In order to change the initial configuration of the simulation, go to `Simulation -> Parameters`. The following dialog will appear:



First, you need to decide which model you would like to use, and then adjust the parameters. At the end of the section, a table will give you a starting point of parameters that you can use with each model. Below you can find the explanation of models and parameters and references that point you to related literature (Flache & Macy (2011) and Ulloa (2016) are key readings to understand in detail the implementation details of the models):

- **Model:** This drop-down menu gives you multiple options for basic model implementation for the simulation. Four models are available in this version. Identifiers of the models (internally, the name of the class), are the initial letters of the descriptions:
    - **M1** - *Homophily (Axelrod, 1997) including mutation and selection error - Experiment 1, Flache & Macy (2011)*: This implementation is based on Axelrod (1997). Homophily, the principle that "like attracts like", is used to decide whether an agent can influence another agent. This model also includes two noise sources: mutation, where individual traits can change randomly (Klemm et al., 2003a, 2003b), and selection error, where individuals make a judgment error regarding the homophily of their neighbors (Flache & Macy, 2011). This model is equivalent to the model used in Experiment 1 of Flache & Macy (2011).
    - **M2** - *Multilateral social influence without homophily - Experiment 2, Flache & Macy (2011)*: This implementation includes multilateral social

influence, such that interactions can occur between multiple agents at the same time instead of in dyadic formation where only two agents can interact with each other at one time (Flache & Macy, 2011). The mechanism is also known as frequency bias (Parisi et. al, 2003; Boyd & Richerson, 1985). This implementation does not consider homophily. **Mutation** and **selection error** are included as in M1.

- **M3** - *Multilateral social influence with homophily - Experiment 3, Flache & Macy (2011)*: This implementation is an extension of M2, by including homophily as presented in M1.
- **M4** - *Institutions including homophily Axelrod (1997) - Ulloa et al. (2016)*: This implementation is based on M1, and thus includes **homophily**, **mutation** and **selection error**. It additionally introduces **institutions** as described by Ulloa (2016). An institution can influence agents that belong to it by making them adopt or keep traits that are equivalent to the institution's traits. The table below (taken from the original publication) presents all rules inherent in the (institutional) model.

Step	A	B	D	P
1. At random, pick one agent ***a*** and one of its neighbors ***n*** from ***a***'s possible neighbors, as defined by a radius ***r***	X	X	X	X
2. Randomly select a feature ***f**** (of those features that have differing traits of **a** and **n**). Then, select $t^* = n_{f^*}$	X	X	X	X
3. **(Institutional conflict)** If the current trait of the agent's institution i_{af^*} (1) is not undefined ($i_{af^*} \neq -1$), and (2) it is equal to the agent's existing trait a_{f^*} (i.e. $i_{af^*} = a_{f^*}$), and (3) if the institution's trait i_{af^*} is different to the to-be-adopted trait t^* ($i_{af^*} = t^*$), then		X	X	X
3.1. **(Perceived Homophily + Institutional Influence)** Agent **a** accepts the trait ***t**** for ***f**** with a probability of trait change P_{tc} equal to ***Inf(a, n)***		X	X	X
3.2. **(Agent loyalty)** If agent **a** accepts the trait ***t****, then ***a*** changes its institution to i_n with a probability of institutional change P_{ic} equal to ***Loy(a, n)***		X	X	X
3.3. If the agent ***a*** changes its institution to i_n, and if i_n does not yet have a trait on the selected feature ***f****, then assign ***t**** to i_{nf}.		X	X	X
4. **(Perceived Homophily)** If the conditions in the previous step were not met or for a model without institutions; then the agent ***a*** accepts the trait ***t**** with a probability of trait change P_{tc} equal to ***PH(a, n)***	X	X	X	X
5. **(Mutation)** With probability ***m***, randomly change one of the features of agent **a** to randomly selected trait	X	X	X	X
6 **(Democracy)** After $fd \times N$ (***N*** is the population size) repetitions of steps 1 to 5, initiate a Democratic process. For each institution ***i***:			X	
6.1 A subset ***D*** containing all agents belonging to ***i*** is created.			X	
6.2 All agents in ***D*** cast a vote containing their current trait for each of their features. A voting matrix ***V***, is generated, where V_{ft} corresponds to the number of votes that trait ***t*** received for feature ***f***, i.e. $V_{ft} = \Sigma_{d \in D}\, \delta(d_f, t)$			X	
6.3 A matrix **W** is defined by $W_{ft} = V_{ft} - V_{fc}$, where ***c*** is the current trait for the feature ***f*** of the institution ***i***. This matrix holds the differences on popularity (votes) between the current traits of the institution and their alternatives.			X	
6.4 Create a subset ***FT*** of pairs ***(f, t)*** in which W_{ft} is maximal in ***D*** and bigger than zero. This subset contains the traits that comprise the biggest differences between each institution and its agents.			X	
6.5 Randomly select a pair ***(f*,t*)*** from ***FT*** and replace i_f with ***t****			X	
7. **(Propaganda)** After $fp \times N$ (***N*** is the population size) repetitions of steps 1 to 5, initiate a Propaganda process. For each institution ***i***:				X
7.1. A subset ***P*** containing all the agents belonging to ***i*** is created. For each agent ***a*** in ***P***:				X
7.1.1 Calculate the similarity between agent ***a*** and ***i***, and set this as the probability of trait change, i.e. ***Ptc = Sim(a, i)***				X
7.1.2. For each feature ***f*****,** change $a_f = i_f$ with probability of trait change ***Ptc***				X

The first column indicates the rules inherent in each step of a given model. The second to fifth column indicate the model to which they apply (A: Axelrod, B: Our Baseline, D: Democracy extension, P: Propaganda extension). The star symbol (*) indicates a specific value of a variable.

doi:10.1371/journal.pone.0153334.t002

The parameters of the simulation are organized in four sections in the interface:

- **Controls:**

- **Random initialization**: When selected, the initial traits of the agents' cultural vectors (i.e. the list of cultural traits of each agent) are initialized randomly with a uniform distribution. When not selected, the initial state of the simulation has all agents belonging to one (the same) institution, and all cultural vectors contain exactly the same traits (i.e. agents all belong to the same culture). This provides an interesting baseline to compare effects of events between diverse and not-diverse scenarios.
- **Iterations**: Sets number of iterations after which the simulation stops. One iteration is defined as the time span after which all agents have had on average one *opportunity of interaction*. Notice that it is on average, so not necessarily all agents will participate each turn as the initiator agents of interactions are picked randomly. Also notice that the interaction might not actually occur (that it is why is called *opportunity of interaction*), for example when the homophily rule prevents an interaction, or due to selection errors). A recommended value of number of iterations is 100000, however certain parameters might cause the convergence to be slower; you can check if the simulation is converging to a value in the interface (See Response Variables) or in the progressions folder (See Output Values)
- **Speed**: Sets the number of iterations that occur between **checkpoints**. Several important things happen during **checkpoints**: (1) Results are calculated from the current state of the simulation, (2) Current response variables are sent to the result output files, (3) Interface is updated with current results, and (4) Simulation checks for current queued events and executes them, if any. (It is called **speed** because it affects how fast the simulation will run, as calculations of responses variables and output of results is costly. Events are always implemented at checkpoints to make sure they are visualized properly on the interface). Speed should be a multiple of iterations, and, in batch mode, you should be careful with very small values as it could produce big files and slow down the simulation.
- **Buffer Size**: Controls the size of the file buffer sizes. A larger buffer size makes the simulation more efficient, but waiting times to check intermediate results in output files are produced at a slower rate. (Buffer size can be important when Batch Mode is executed.)

- **World**: Sets informational space (vector sizes) of the model. These traits cannot be modified after initialization (See Events)
    - **Rows**: Number of rows of the world grid.
    - **Cols**: Number of columns of the world grid. So far, studies seems to have limited the grid sizes to less than 100 rows and column (100x100) because of computational costs. In terms of results, M1 produces fewer cultures the bigger the grid (Axelrod, 1997), M2 and M3 produce more cultures with bigger grids (Flache & Macy, 2011), and M4 produces a number of cultures that is more or less proportional to the size of the grid (Ulloa et al., 2016), meaning that the culture sizes are more or less equivalent regardless of the grid size.
    - **Radius**: The radius of the Von Neumann neighborhood is also known as the Manhattan distance. A Von Neumann nrighborhood of radius 6 can be seen here:

In terms of results, M1 produces fewer cultures as the interaction radius increases (Greig, 2012) and a value of 1 is recommended. Flache & Macy (2011) used a radius of 6 for M2 and M3. Ulloa et al. also used also a radius of 6. Preliminary results on M4 also indicate that, when democracy and propaganda (see below) are not activated, a smaller radius produces fewer cultures, but when (democracy and propaganda) are activated this effect is reduced substantially (do not hesitate to drop me a line if you are interested in a collaboration to publish this result).

- **Features**: Size of the cultural vector. Each feature represents a possible dimension of the culture, e.g. music. In M1, the more features the less cultures are obtained (Axelrod, 1997). No studies exist for the other models.
- **Traits**: Number of possible values that a feature can adopt. Each trait represent a possible cultural item for the feature, for example if the feature is music, one possible trait can be rock music, another jazz. In M1, the more features the more cultures are obtained (Axelrod, 1997). No studies exist for the other models, though preliminary results suggest the same effects in M4.
- **Noise**: Sources of perturbation inside the simulation.
    - **Mutation**: Probability of a random trait change in the agent's cultural vector after an interaction. M1 is very sensitive to mutation (Klemm,

2003a, 2003b). M2-M4 present different degrees of resistance to mutation (Flache & Macy, 2011; Ulloa, 2016). Values below 0.1 have been studied in the literature.

    - **Selection Error**: Probability of making a judgement mistake in the selection of the agent with which the interaction will happen. M3 and M4 are the more stable models against selection error (Flache & Macy, 2011; Ulloa, 2016). Values below 0.1 have been studied in the literature.

- **Institutions**: Set the levels at which institutions can affect agents. **These parameters only apply to M4**.
    - **Influence**: A value between 0 and 1 that determines the level of importance that is given to institutional influence (alpha value in the rule table above). Alpha is multiplied by the similarity with the institution, and a beta value (1 - alpha) is multiplied by the similarity with the agent (homophily). The resulting probability determines whether the interaction (an agent accepting the other agent's trait) will be successful. High values (>0.6) are necessary to generate diversity, and it is fairly stable across grid sizes (Ulloa et al., 2016). Preliminary results suggest that small values of influence can be used if democracy and propaganda are activated; e.g. grid size=100x100, radius=3, influence=0.35, democracy=10, propaganda=5 produces ~20-30 cultures (also, replacing radius=6, and influence=0.55). Please do not hesitate to contact me if you are interested and willing to collaborate to explore this result.
    - **Loyalty**: A value between 0 and 1 that determines the likehood of an agent staying or changing their institution after a successful interaction between agents (alpha prime value in the rule table above). Alpha prime is multiplied by a value that depends on the similarity with the institution, and a beta (1 - alpha) to the similarity with the neighbor's institution. The resulting probability determines whether an agent changes its institution to adopt the institution of its neighbor. The effect of loyalty is rather small compared to the influence (Ulloa et al., 2016); this is likely because there is a confounding effect (loyalty depends on the influence).
    - **Democracy:** Inverse frequency (called period) of a democratic process, **use 0 to turn it off**. A democratic process is a bottom-up process which consists of an institution changing its trait as a result of a referendum in

which multiple agents vote to change a trait, increasing similarity with their institution. The most voted trait is changed in the institution. Democracy by itself has a small effect in cultural diversity but creates more institutions; but it prevents (or has a moderator effect) the explosion of diversity when propaganda is present (Ulloa et al., 2016).

- **Propaganda:** Inverse frequency (called period) of a propagandist process, **use 0 to turn it off**. A propagandist process is a top-down process which consists of an institution propagating one of its traits on the agents that belong to it. The trait (and corresponding feature) is chosen based on the most *conflicting* trait, i.e. the one that produces most dissimilarity between the institution and its agents. Propaganda increases the number of cultures, though it can be partially reduced by the presence of democracy (Ulloa et al., 2016) .

The following table provides a guideline for parameter setting. It is possible that many other values will provide interesting results (that is the idea of the software), this is just a set of values that, according to the literature, will very likely produce diversity.

Parameter	**M1**	**M2**	**M3**	**M4**
Rows	10	32	32	32
Columns	10	32	32	32
Radius	1	< 6	<= 6	<= 6
Features	5	6	6	6
Traits	15	14	14	14
Mutation	0	< 0.001	< 0.01	< 0.01
Selection Error	0	< 0.001	< 0.01	< 0.01
Influence	n/a	n/a	n/a	0.8-0.82
Loyalty	n/a	n/a	n/a	0.05-0.95
Democracy	n/a	n/a	n/a	1-100
Propaganda	n/a	n/a	n/a	1-100

Finally, there are controls to load and save configuration. Indeed, you will find a preset configuration that fits inside the values of the table for each of the models M1-M4 in the package.

- **Load and save configurations**: This section at the bottom of the dialog helps to load pre-set configurations, for example those which are similar to experiments previously executed in literature, and others that the users can set up and save themselves.
    - **Save**: The user can save their own configurations. Saving configuration is important in order to run simulations in batch mode (see Batch Mode).

- **Load**: A user can load a previously saved configuration.

3. Control the simulation

The simulation advances in **iterations**. An iteration has passed when all agents have had on average one opportunity of interaction (i.e. an agent transmitting a trait to another agent). The number of opportunities to interact is the same as the number of agents in the system, however, not necessarily all agents receive an opportunity in each iteration, because agents are selected randomly for interaction. Additionally, agents might reject the interaction for several possible reasons outlined in the rules of each model (See B. Initial Parameters), which is why we call it a number of opportunities, and not a number of interactions, per iteration.

Progress of the simulation is not registered by iteration, instead, there are **checkpoints**. A checkpoint occurs per every `s` iterations. The parameter for `s` is Speed. We have also covered how to set the value for Speed in the section on B. Initial Parameters).

3.1. Checkpoints

During a **Checkpoint**, all the following steps occur:

1. **Response Variables** are calculated according to the current state of the simulation.
2. Response variables are sent to the **progression output file(s)**.
3. **Cultural Panels**, **Graphs and Status Bar** are updated with the current results.
4. The simulation checks for **current queued Events** and executes them, if any.
5. The simulation checks if the simulation has been paused via the **Pause Button**

3.2. Main Controls

The **Main Controls** of the simulation are in the top-left corner of the interface. Controls can also be found in the in the `Controls` menu.

From this bar, you can start the simulation via the **Play Button** and stop it via the **Stop Button** or the **Pause Button**. However, there are a few important things to consider when using the latter two:

- Their actions will take effect only at a checkpoint. Depending on the speed parameter, you might have to wait until their effects are processed.
- The main difference between pausing and stopping the simulation is that stop will store final file results. When the Play Button is pressed after you have stopped the simulation, a new result folder will be generated in the workspace (see Output Files for details). Pause is non-intrusive. It freezes the simulation without further implications. Pausing also does not allow saving or reloading simulation states. Visually, there is no difference between Pause and Stop.

The two last buttons (both yellow) in the main control area are straightforward. You can save the current state of the simulation by clicking the **Save State Button** . You can also save this state as a file by clicking on `File -> Save Simulation State`. After the simulation runs for some iterations, you can go back to a previously saved state, by pressing the **Reload Simulation Button** (or reload a previously saved file with `File -> Load Simulation State`).

One use of these two buttons is that the Saved State can become the state against which the progressing state of the simulation is compared, for example to compare how similar the results of Saved State and Current State are at any given moment. You can read further on this topic in the section on Response Variables. The response variables of both states, saved and current, can also be observed in the Status Bar at the bottom of the interface (blue font), while the Graphs are useful to note visual changes in the progression. A quick guide for this process is provided at the end of the Quick Start section.

3.3. Simulation states files

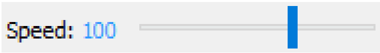
Apart from saving and reloading a state on memory with the **Save State Button** , it is possible to save a state in a file with `File -> Save Simulation State` and then recover it via `File -> Load Simulation State`. This can be useful for several things:

- Multiple saved files can be stored and accessed successively to compare many different Events.
- It is possible to run multiple instances of the program, loading different files in each one.

- Saved State files can be opened in the parameters dialog (See Setting Up Initial Parameters).
- Saved State files can be used to run simulations in Batch Mode.

3.4. Controlling Speed

Right below the Main Controls, you can find the **Speed Bar**:



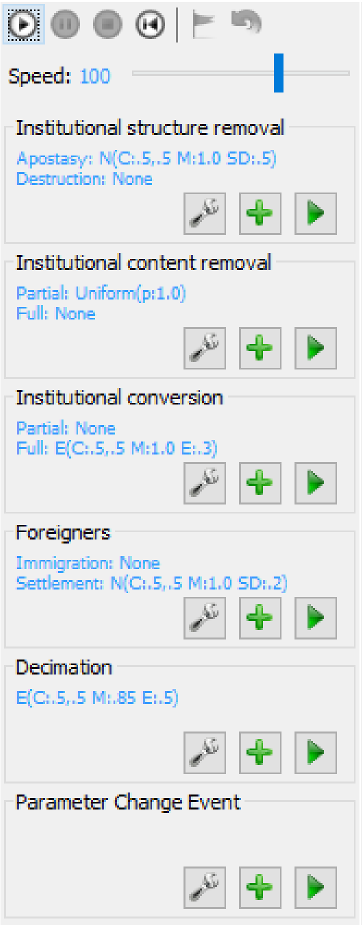
The Speed Bar controls the simulation speed via reduction or increase of the frequency of updates on the screen. Lower values cause the simulation to run for a longer time span, as updates are provided more often. The value next to the Speed label (set at 100 in the above figure) shows how many iterations have to pass in order for a checkpoint to occur. Review Checkpoints here.

Events are always added to the simulation at a checkpoint and visualized in the interface. When we change the speed via speed bar, updating the variable might take some time. The results file for the current simulation will also be affected because results are sent during checkpoints. Due to changes in speed, results will not be stored in regular intervals.

4. Events

4.1. Single Events

The Event Panels control the events that can be executed inside the simulation. Some events are applied to agents, and others to institutions. Events, when initiated, are added to an internal queue and will be executed during the next Checkpoint.



Any event can be configured, i.e. various parameters can be set for it in order to affect only certain parts of the world or only certain agents. This is done with the Configure Button of each individual Event panel and will be covered in-depth in the Configure Events subsection of this section. For now, we will proceed working with a uniform distribution of the event's effects across all parameters.

There are six event panels in total. Of these six, the first four contain two similar types of events. We will now cover all six in-depth:

- **Institutional structure removal** affects the associations between agents and institutions. There are two types:
  - **Apostasy**: A number of agents abandon their institutions. Internally, these agents will now be assigned institutions with empty traits. A change in the distribution parameter of the event affects the agents.
  - **Destruction**: A number of institutions are destroyed. The agents that belonged to them are each assigned a new institution with empty traits. The change in the distribution parameter of the event affects the institutions.

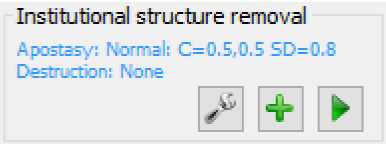
- **Institutional content removal** removes traits inside the institutions. Again, there are two types:
    - **Partial**: Some traits are removed from a number of institutions. A change in the distribution parameter of this event affects the institution's traits. When a **Non Probablistic Distribution** (see Configure Events Section) is used for this event, then there is no difference between this event (**Partial**) and the next (**Full**).
    - **Full**: All traits are removed from a number of institutions. A change in the distribution parameter of this event affects all the traits of the institutions.
- **Institutional conversion** instroduces foreigner (invader) traits into institutions. This invader trait is new to the population and different from any of the previously existent traits. This event groups two types:
    - **Partial**: Some traits from some institutions are converted into foreigner (invader) traits. A change in the distribution parameter of the event affects some traits of the institutions. When a **Non Probablistic Distribution** (see Configure Events Section) is used for this event, then there is no difference between this event (**Partial**) and the next (**Full**).
    - **Full**: All traits from some institutions are converted into foreigner (invader) traits. A change in the distribution parameter of the event affects all the traits of the institutions.
- **Settlement** (called invasion in previous versions): A number of agents such as settlers (foreigners with their own institutions) are introduced into the simulation. They enter into positions that were occupied by other agents. Settlers have only foreigner traits in their cultural vectors, and all of them belong to the same settler institution. A change in the distribution parameter of this event affects the distribution of agents that will be replaced by settlers.
- **Immigration**: A number of agents such as immigrants (foreigners without their own institutions) are introduced into the simulation. They enter into positions that were occupied by other agents. Immigrants have only foreigner traits in their cultural vectors and, in principle, do not belong to any institution until other agents persuade them to do so. A change in the distribution parameter of this event affects the distribution of agents that will be replaced by settlers.
- **Decimation** (called genocide in previous versions): A number of agents are killed within the current population. Internally, all traits of the simulation are replaced

by a dead trait. A change in the distribution parameter of this event affects the distribution of agents to be killed.

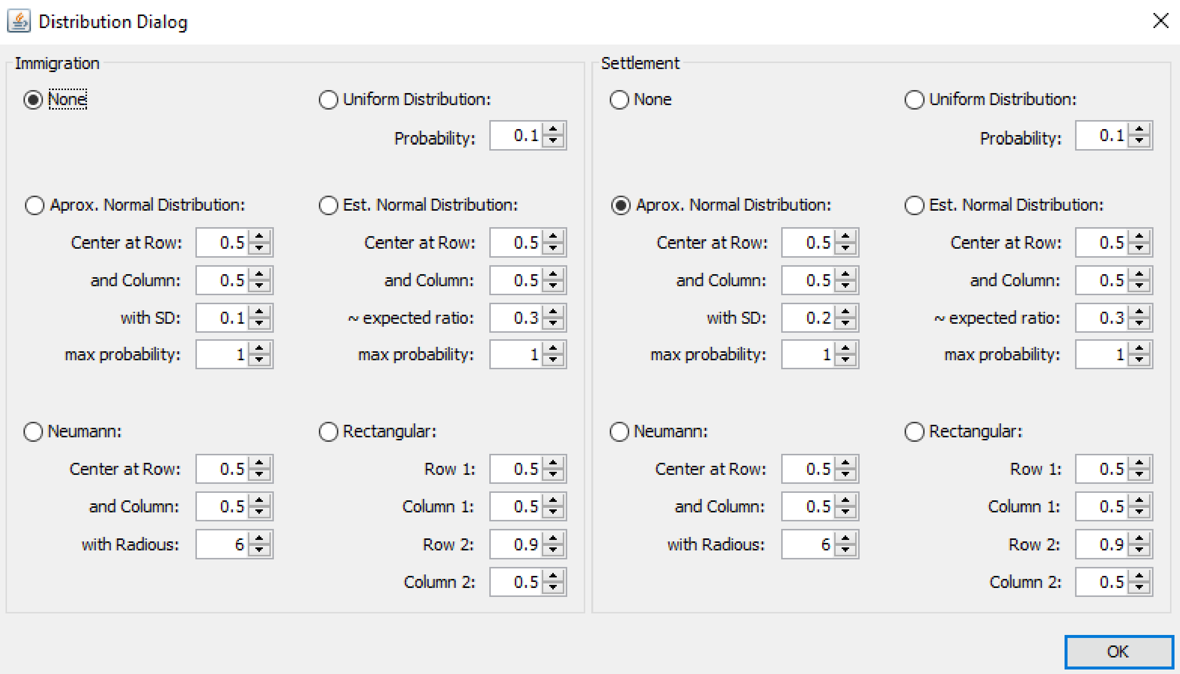
- **Parameter Change Event**: This event does not affect agents or institutions directly. Instead, with it, it is possible to change many of the parameters of the simulation that were initially set in `Simulation -> Parameters`. (see Initial Parameters).

4.2. Configure Events

The configuration of each event appears in blue font in each Event Panel.



Clicking the Configure Event Button opens the Configuration Distribution Panel, which enables you to change the parameters.



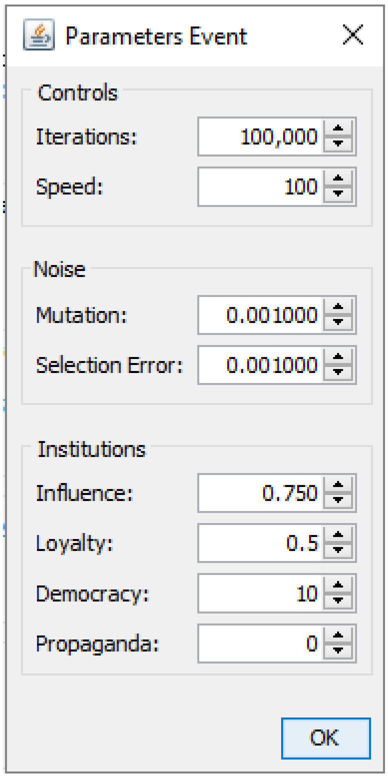
Changing the configuration for an event consists (except for **Parameter Change Event**) of adjusting the distribution allocated on the grid. In general, the distribution will indicate which agents or institutions are affected by the event. Four types of distributions are implemented. The first two are probabilistic and the latter two are deterministic.

- **Probabilistic Distributions**: These distributions use a probabilistic function to assign a probability to each agent or institution. This probability is used to decide whether the event affects that particular agent or institution.
  - **Uniform Distributions**: They assign the same probability to all agents or institutions. The only parameter in this distribution is the probability of an event occurring to an agent or institution.
  - **Aprox. Normal Distributions**: They assign probabilities to each agent or institution according to the normal distribution. The agent in the center of the distribution receives a probability of a maximum `value`, and the other agents receive a probability depending on the distance from this center. The first two parameters indicate in which row and column the distribution will be centered. You can use -1 to select the row and column randomly. The third parameter specifies the `maximum value`. The fourth parameter is the standard deviation, to indicated how much the event spreads from its center.
  - **Est. Normal Distributions**: Equivalent to **Aprox. Normal Distributions** except that instead of the standard deviation (as fourth parameter), it receives a proportion of cells that will be affected. Internally, CulSim uses this proportion to estimate a corresponding standard deviation. The rest remains the same.
- **Non Probabilistic Distributions**: These distributions select the specific agents or institutions that will be affected by the event. The event will occur with a probability of 1.0 to the agents or institutions selected. When a Non Probabilistic Distribution is used for the **Institution Content Remove** and **Institution Conversion** there is then no difference between the **Partial** and **Full** version of their events.
  - **Neumann**: This distribution uses Von Neuman neighborhoods with a distance r to distribute the events, to select the agents or institutions that will be affected by the event. The first two parameters indicate in which row and column the neighborhood will be centered. Use -1 to select the row and column randomly. The third parameter indicates the radius of the neighborhood, i.e. how far the event spreads from its center.
  - **Rectangular**: These distributions use two coordinates (by providing rows and colums) to define a rectangle on the grid. The institutions or agents

that fall into this rectangle are the ones that will be affected by the event. The first two parameters indicate the first coordinate of the rectangle, and the last two parameters the second coordinate of the rectangle.

4.3. Parameter Change Event

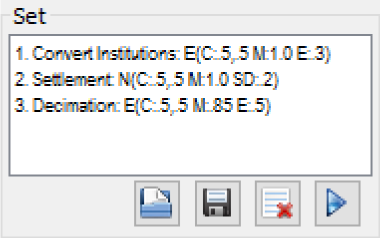
A special case for the configuration of events is the **Parameter Change Event**. Select new parameters that you want to apply to the simulation here. When the Configure Event button [Configure Event Button]() for this event is pressed, the following dialog box is shown:



It is possible to change most of the parameters that were set in the Initial Parameter Setup, except those that involve changes in static data structures (arrays) such as the size of the grid, the cultural vector, or the neighbors.

4.4. Composed Events

You can create combinations of events with the Add Event Button ✚. The events are added to the Event Set:

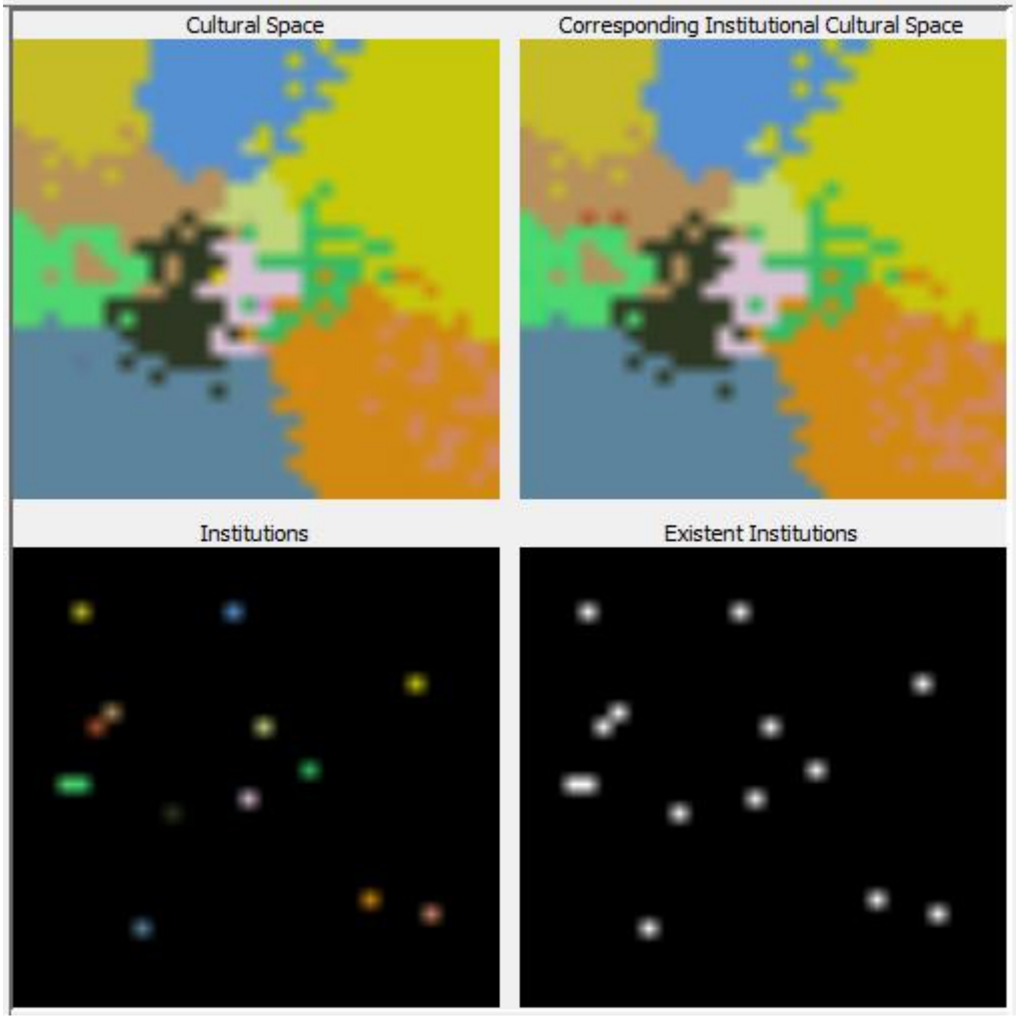


The order in which the events are added matters. For example, a decimation after a settlement will kill some of the settlers, but this would not happen if the settlement came after the decimation. It is also possible to add two events of the same type. This is useful, for example to simulate a settlement occurring at two different locations of the grid. You can start a new event set by cleaning the list with the ***Clean Event Set Button*** .

The composed events can be saved or loaded to files with the ***Save Event Button*** . You can apply the same event to different simulation states or configurations. Moreover, saved events are essential when using Batch Mode.

5. Cultural panels

The cultural panels show the progression and distribution of cultures as the simulation advances. There are four panels in total, one representing the agents' belief space. The other three represent institutional spaces. The *Institutions including homophily Axelrod (1997) - Ulloa(2016)* model (See B. Initial Parameters) is the only model that includes institutions, and therefore the only model available that uses all four panels. The other three models only reflect in the upper left Cultural Space panel.

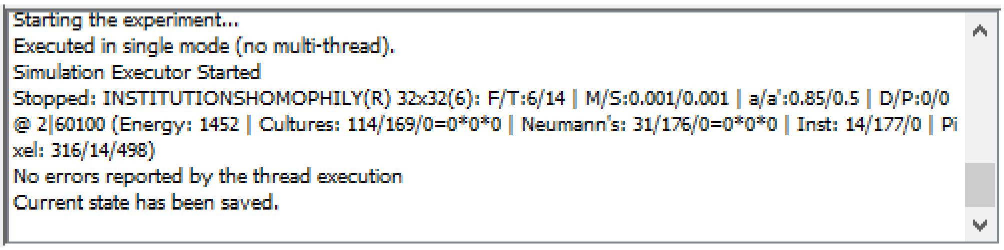


- **Cultural Space (top-left)**: Each agent is represented in its corresponding location in the World (grid). The color of the agent reflects its cultural vector, picked according to the trait values. The default number of features is 6, and the number of traits is 15, plus 1 foreigner trait (See B. Initial Parameters). They have been selected in order to use the maximum spectrum of computer screen colors (i.e. 6 hexadecimal values), higher values might make interpretation of the panels difficult due to repeated colors. In general, the cultural space provides an idea of the simulation state. A more reliable way to supervise the progress of the simulation are the graph panels (See Response Variables).
- **Corresponding Institutional Cultural Space (top-right)**: Each agent belongs to an institution, and this institution also has a cultural vector. Therefore, an interesting way to represent the relationship between an agent and its institution is by showing the corresponding color of the institutional cultural vector, along with the agent's. Each agent is represented in its corresponding location in the World

(grid), but the institutional cultural space shows the color of the institution's cultural vector to which the agent belongs to.

- **Institutions**: This panel shows every institution's "location" as an average position of all the agents that belong to it, i.e. the "center". Internally, institutions do not have a pre-defined "location". Additionally, each location dot is also denoted by the color associated with the institutional cultural vector.
- **Existent Institutions**: This panel shows only the location of the existent institutions, and changes the color to white. This panel is a visualization help to spot institutions that have been assigned a darker color that might be hard to see on the black background of the panel. The Existent Institutions panel makes it easier to detect those institutions.

There is also a **Output text panel** below the cultural panels. This panel (shown below) reports important occurrences in the simulation, e.g. initializations, errors, final states, etc.



6. Responsive Variables

The simulation keeps a record of an extensive amount of response variables, which will be explained in depth in this section. These variables can be accessed in several ways: through the graph panels, the status bar, and the output files. These are briefly introduced here, but have their own sections.

- **Graph Panels** show the progression of the response variables (See Graphs and Status Bar)
- **Status Bar** displays the exact values of the response variables of the current and saved state (See Graphs and Status Bar)
- **Output Files** contain the values saved over the progression of the simulation (set according to the Checkpoints), and the final results of the simulation (See Output Files).

Here is a comprehensive list of the simulation response variables and counters.

6.1. Simulation counters:

- **Epoch**: passes every time the current state of the simulation is saved to memory (with the Save State button or into a file (`File -> Save Simulation State`)
- **Generation**: is the total number of iterations of all epochs.
- **Iteration**: is the current iteration in the current epoch.

6.2. Simulation measurements:

- **Energy**: is an abstract response variable that measures how culturally different agents are from their immediate neighbors. Each agent's cultural vector is compared to its' adjacent neighbors' vector. The energy counts each differing trait, every time it exists. For normalization purposes, the maximum value that a simulation could have is set by the adjacent features (`((Rows*(Rows-1)+(Columns*(Columns-1))*Features`).
- **Pixel Similarity**: directly compares the cultural vector of each agent in the current state against the agent in the same position from the world grid before, in the saved state. As explained in the Main Controls, a saved simulation state can be generated by pressing the Save State Button, saving the current state in a file (`File -> Save Simulation State`) or loading a state from a file (`File -> Load Simulation State`).

6.3. Cultural measurements:

These measurements involve calculations that are made with cultures. Two agents belong to the same **culture** when they are adjacent neighbors (immediate top, left, right, bottom neighbors) and when they share the same traits in their cultural vector.

- **Cultures**: Number of cultures in the system.
- **Cultures with at least 3 agents**: Number of cultures of with three agents or more (N > 2)
- **Biggest culture**: The culture that contains the most agents.
- **Cultural similarities**: The current cultures of the simulation can always be compared with the cultures of last saved state of the simulation, either via the Save State Button, or by saving them in a file (`File -> Save Simulation State`). There are several ways of comparing two cultural states.

- **Position similarity**: First, the average centers of all the cultures in the current and saved simulation states are calculated (and normalized according to the total rows and columns in the world grid). Second, each center of the cultures of the *current simulation state* is matched with the center of the culture that proved to be the most similar in terms of Full Similarity (see below) among the cultures of the *saved simulation state*. Third, the inverse difference (i.e. `1 - difference`) between these two centers is added to the similarity. Fourth, the second and third steps are repeated in the other direction, from the saved state to the current state. Fifth, the similarity is normalized by dividing the amount of cultures on both the current and the saved state.
- **Size similarity**: First, the size (amount of agents that belong to a culture) of all the cultures in the current and saved simulation states are calculated (and normalized according to the total agents in the world). Second, each size of the cultures of the *current simulation* state is matched with the size of the culture that proved to be the most similar in terms of Full Similarity (see below) among the cultures of the *saved simulation state*. Third, the inverse difference (`1 - difference`) between these two sizes is added to the similarity. Fourth, the second and third steps are repeated in the other direction, from the saved state to the current state. Fifth, the similarity is normalized by dividing the number of cultures in both the current and the saved state.
- **Traits similarity**: First, the cultural vectors (number of agents that belong to a culture) of all the cultures in the current and saved simulation states are stored in lists. Second, each cultural vector of the cultures of the *current simulation state* is matched with the cultural vector of the culture that proved to be the most similar in terms of Full Similarity (as defined below) among the cultures of the *saved simulation state*. Third, the similarity between these two cultural vectors is calculated and normalized by dividing the number of features that the vectors have, and then added to the similarity. Fourth, the second and third steps are repeated in the other direction, from the saved state to the current state. Fifth, the similarity is normalized dividing by the number of cultures on both the current and the saved state.

- **Full similarity**: This similarity measurement combines the previous three into one. First, the position, size and cultural vectors of all the cultures in the current and saved simulation states are calculated. Second, each culture in the current simulation is matched with the most similar culture in all these three criteria; the similarity between the three values (position, size and cultural traits) is calculated by multiplying each individual similarity. Third, the similarity of the matched cultures is added to the full similarity. Fourth, the second and third steps are repeated in the other direction, from the saved state to the current state. Fifth, the similarity is normalized, divided by the amount of cultures on both the current and the saved state.

6.4. Von Neumann cultural measurements:

This set of response variables is equivalent to the cultural measurements, with the difference that the definition of "culture" changes: two agents belong to the same **Neumann culture** if they are **von Neumann neighbors** (of the same radius that the simulation uses, See B. Initial Parameters), and they share the same traits in their cultural vector. When the radius is bigger, then the cultures can contain members that are visually apart, but near each other. All the following responses use the same definition as their analogous responses in the previous section:

- **Neumann cultures**: Number of Neumann cultures in the system.
- **Neumann cultures with at least 3 agents**: Number of Neumann cultures of with three agents or more (N > 2)
- **Neumann biggest culture**: The Neumann culture that contains the most agents.
- **Neumann cultural similarities**: See the **cultural similarities** above and replace cultures by Neumann cultures. The explanation are analogous.

6.5. Institutional measurements:

- **Institutions**: Number of institutions existing in the simulation.
- **Biggest institution**: Number of agents belonging to the biggest institution.
- **Institution similarity**: The institution similarity is calculated by comparing the traits of the institutions in the current state with the corresponding institutions in the saved states. A saved simulation state can be generated by pressing the Save State Button , saving the current state in a file (`File -> Save Simulation State`) or loading a state from a file (`File -> Load Simulation State`).

6.6. Event-related measurements:

These response variables are related to events that were executed in the simulation (See D. Events for details of event types)

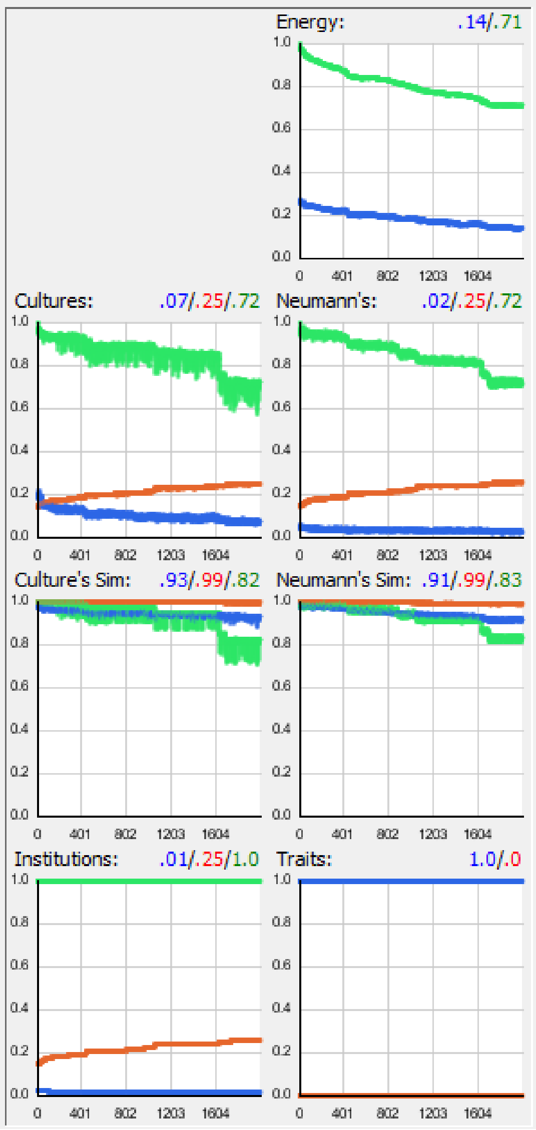
- **Alive**: Number of alive traits. This is related to Decimation events, in which a dead agent is represented by changing all the traits in its cultural vector to a special dead trait
- **Foreign**: Number of foreign traits. Foreign traits in the population are introduced directly during the settlement or immigration events, and indirectly during institutional conversion events. This measurement shows the dispersion of foreign traits in the population
- **Destroyed institutions**: Number of destroyed institutions caused by Destroy Institution Events
- **Stateless**: Number of agents that go into stateless state because their institutions were destroyed in Institutional Destruction Events
- **Apostates**: Number of agents that abandon their institutions in Apostasy Events
- **Removed institutions**: Number of institutions whose traits were removed entirely in Full Remove Content Events
- **Removed traits**: Number of traits that were removed in Partial Remove Content Events
- **Converted institutions**: Number of institutions whose traits were Converted entirely in Full Conversion Events
- **Converted traits**: Number of traits that were converted in Partial Conversion Events
- **Settlers**: Number of settlers that were introduced in Settlement Events
- **Immigrants**: Number of immigrants that were introduced in Immigration Events
- **Casualties**: Number of agents that were killed in Decimation Events

7. Graphs and status bar

The Graphs Panel and Status Bar display the values of the response variables. The Graph Panels show how the normalized response variable progresses over time whereas the Status Bar displays the absolute values of the current and the saved state.

7.1. Graph Panels

There are seven Graph Panels, each of them displays up to 3 response variables, which are represented by 3 different colors: (1) blue, (2) red and (3) green.



The response variables are always normalized in order to be comparable within the same graph. The following list gives an overview of the graphs with the corresponding response variables that they display; the graph panel is identified by its title above each graph. See F. Response variables for details about each of the response variable

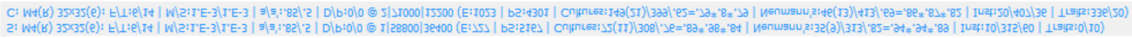
Graph Title	Blue	Red	Green
Energy	Energy		Pixel similarity
Cultures	Cultures	Biggest Culture	Full similarity
Neumann	Neumann Cultures	Neumann Biggest Culture	Neumann Full similarity
Culture's Sim	Position Similarity	Size Similarity	Traits Similarity

Neumann's Sim	Neumann Position Similarity	Neumann Size Similarity	Neumann Traits Similarity
Institutions	Institutions	Biggest Institution	Institution Similarity
Traits	Alive	Foreign	

Each graph panel also displays the corresponding normalized values on the top-right (in the same color as the display lines that are associated with them). If you hover over these values, a tooltip text will display the response variable name according to its color.

7.2. Status Bar

The Status Bar on the bottom displays most of the initialization parameters and response variables of the saved (first line indicated with `S:`) and current states (second line indicated with `C:`) of the simulation.



Starting from the left, initials are provided that refer to response variables. The following table gives an overview:

Initials	**Response Variable**
S|C	(S)aved or (C)urrent state
M1|M2|M3|M4	Identifier of the model, see B. Initial Parameters
R|S	(R)andom or (S)tatic (non-random) initialization, see B. Initial Parameters
#x#(#)	Rows x Columns (Radius), e.g. 32x32(6)
F/T	Features / Traits
M/S	Mutation / Selection error
a/a'	Institutional Influence / Agent Loyalty
D/P	Democracy / Propaganda
`@ #/#/#	Epoch / Generation / Iteration
E	Energy
PS	Pixel Similarity
Cultures:#/#/#=#*#*#	Cultures (Cultures with at least 3 agents) / Biggest culture / Full similarity = Position similarity * Size similarity * Traits similarity
Neumann's:#/#/#=#*#*#	Neumann cultures (Neumann Cultures with at least 3 agents) / Neumann biggest culture / Neumann full similarity = Neumann position similarity * Neumann size similarity * Neumann traits similarity
Inst.:#/#/#	Institutions / Biggest institution / Institution similarity
Traits: #/#	Foreigners / Alife

A tooltip text is also provided and serves as a reminder of the parameter names and response variable names.

8. Output Files

The Cultural Simulator graphical interfaces uses a workspace directory, which is the directory that will contain the results directories and files. When using the Command Line Interface, the results will be stored in the folder where the command is executed.

An execution could be composed of one simulation, which is the case when the main controls of the simulation are used (See C. Control the simulation), or by several simulations (either repetitions of the same, or different configurations) which is common when using the Batch Mode or the Command Line Interface. In all these cases, however, the output structure inside a result folder is the same.

When using the main interface or the Batch Mode, the results folder name is **`results`**, however if there is already a folder with that name then a number is added after the name, e.g. **`results0`**. This happens quite often, so you will always find the results of your last execution in the folder with the highest number.

The following is the structure inside a result folder for all cases:

- **`progressions`**: a directory containing csv files. Each file contains the response variables (and parameters) for each Checkpoint of each executed simulation. The information contained here can be used to recreate and analyze the Graph Panels in any statistical software that accepts csv files. The csv file name consist of an internal unique identifier (a numeric sequence), an identifier of the used model, and the rows and columns of the simulation.
- **`simulations`**: a directory containing the final state of the each executed simulation. These files can be opened with `File->Load Simulation State` to visualize the state at the end of the execution. More importantly, these files can be used to build experimental designs, in which the effects of different events are compared against the same set of simulation states (see Batch Mode or Command Line Interface)
- Results file (**`results.csv`**): a csv file that collects all the response variables and parameters at the end of the simulation. The `results.csv` file name will vary if an ID is used in the Command Line Interface
- **`events.txt`**: a folder that contains a description of the executed events inside the simulation when the Batch Mode or the Command Line Interface are used.

Apart from the results directory (and its internal structure), another directory, called **`resultSet`**, is generated in the work space. This directory will contain a copy of the **`results.csv`** file, adding the folder name to the file name (e.g. `results0-results.csv`). When several experiments are executed, the resultSet directory will contain all the results files, which is practical when you want to open all results with a statistical program or you simply want to take (zip, send, or backup) the main results all together. Going to each result folder to collect the results is not necessary.

When the Batch Mode or the Command Line Interface are used to execute simulations from a results directory (e.g. to execute two different types of Events in the same simulation state sets), the input folder that contains the **`simulations`** folder becomes the workspace folder. From this moment on, all the previous rules of the internal structure remain valid.

The following tables show the names of the columns of the csv files (the result files, and the files in the `progression` folder).

8.1. Identifiers and timestamps:

Column	Description
`id`	Unique identifier for a simulation inside an experiment
`timestamp`	The timestamp where this line was printed
`duration`	The diferrence between the current timestamp and when the experiment was started

8.2. Parameters of the simulation

Column	Parameter
`model`	Model
`random_initialization`	Random initialization
`iterations`	Interations
`speed`	Speed
`rows`	Rows
`cols`	Columns
`radius`	Radius
`features`	Features
`traits`	Traits
`mutation`	Mutation
`selection_error`	Selection Error
`institutional_influence`	Influence
`agent_loyalty`	Loyalty
`democracy`	Democracy
`propaganda`	Propaganda

8.3. Simulation counters

Column	Simulation counter
epoch	Epoch
generation	Generation
iteration	Iteration

8.4. Simulation measurements

Column	Simulation measurement
energy	Energy
pixel_similarity	Pixel Similarity

8.5. Cultural measurements

Column	Cultural measurement
cultures	Cultures
cultures_at_least_3	Cultures with at least 3 agents
biggest_culture	Biggest Culture
full_sim	Full similarity
pos_sim	Position similarity
size_sim	Size similarity
traits_sim	Traits similarity

8.6. Von Neumann cultural measurements

Column	Von Neumann cultural measurement
neumann_cultures	Neumann cultures
neumann_cultures_at_least_3	Neumann cultures with at least 3 agents
biggest_neumann_culture	Neumann biggest culture
neumann_full_sim	Full similarity
neumann_pos_sim	Position similarity
neumann_size_sim	Size similarity
neumann_traits_sim	Traits similarity

8.7. Institutional measurements

Column	Institutional measurement
institutions	Institutions
biggest_institution	Biggest institution
institution_similarity	Institution similarity

8.8. Event-related measurements

Column	Event-related measurement
alive	Alive
foreign	Foreign
destroyed_institutions	Destroyed Institutions
stateless	Stateless
apostates	Apostates
removed_institutions	Removed institutions

removed_traits	Removed traits
converted_institutions	Converted institutions
converted_traits	Converted traits
settlers	Settlement
immigrants	Immigration
casualties	Decimation

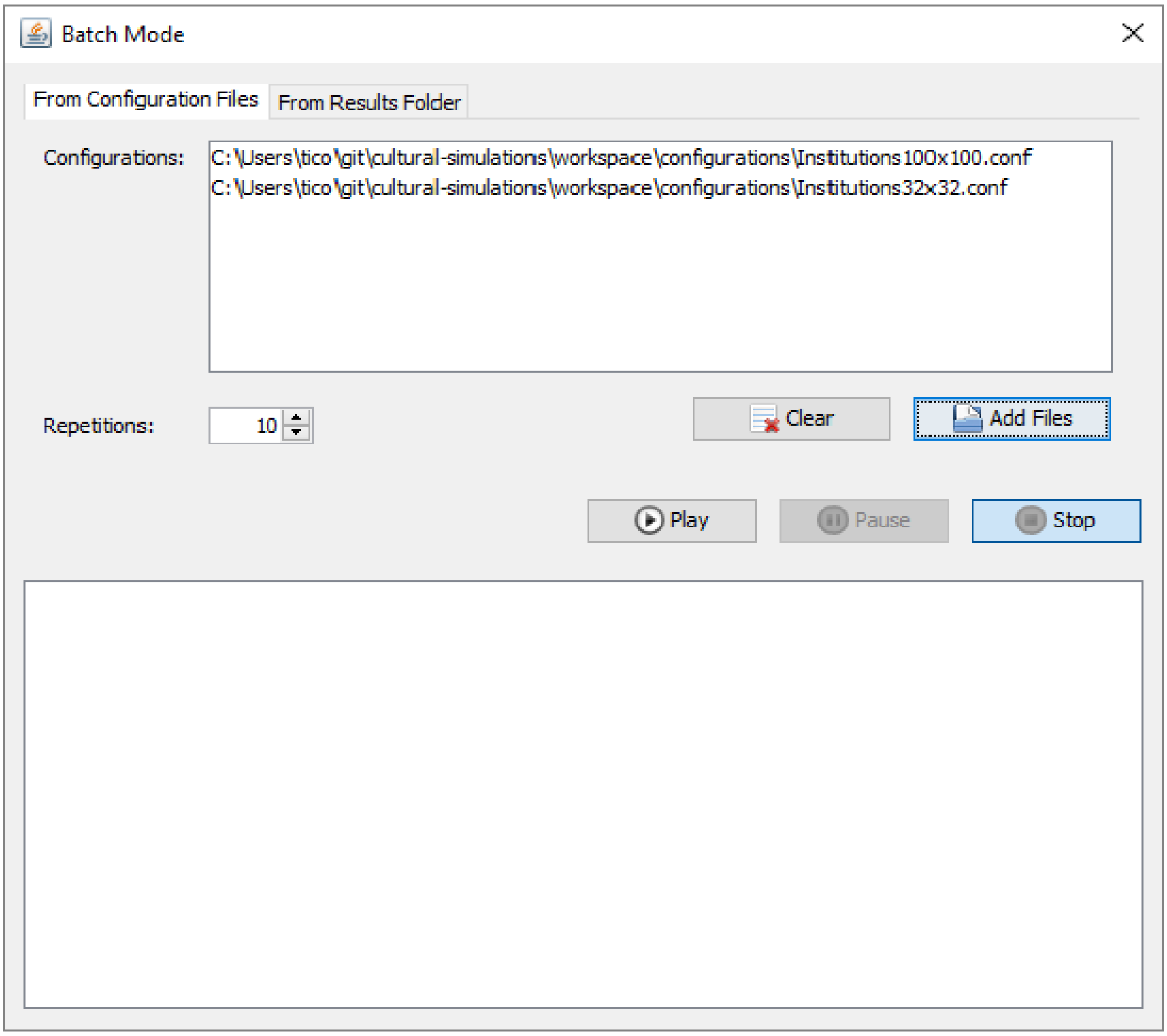
9. Batch Mode

The Batch Mode and the Command Line Interface are useful to run repetitions of interesting observations of particular simulation configurations that need to be further explored. The output files of the repetitions from this method can be analyzed with any statistical tool that reads csv.

As opposed to the Command Line Interface, the Batch Mode offers a graphical user interface to easily run the experiments. In order to access the Batch Mode, you click on `Simulation -> Batch Mode`. There are two general tests that can be performed in Batch Mode:

9.1. Testing convergence states of simulations (From Configuration Files):

Which is the ("average") final state (measured in any response variable , e.g. **cultures**, i.e. cultural diversity) that is produced given one or several initial configurations of the simulation? The first tab (From Configuration Files) of the Batch Mode provides this functionality.

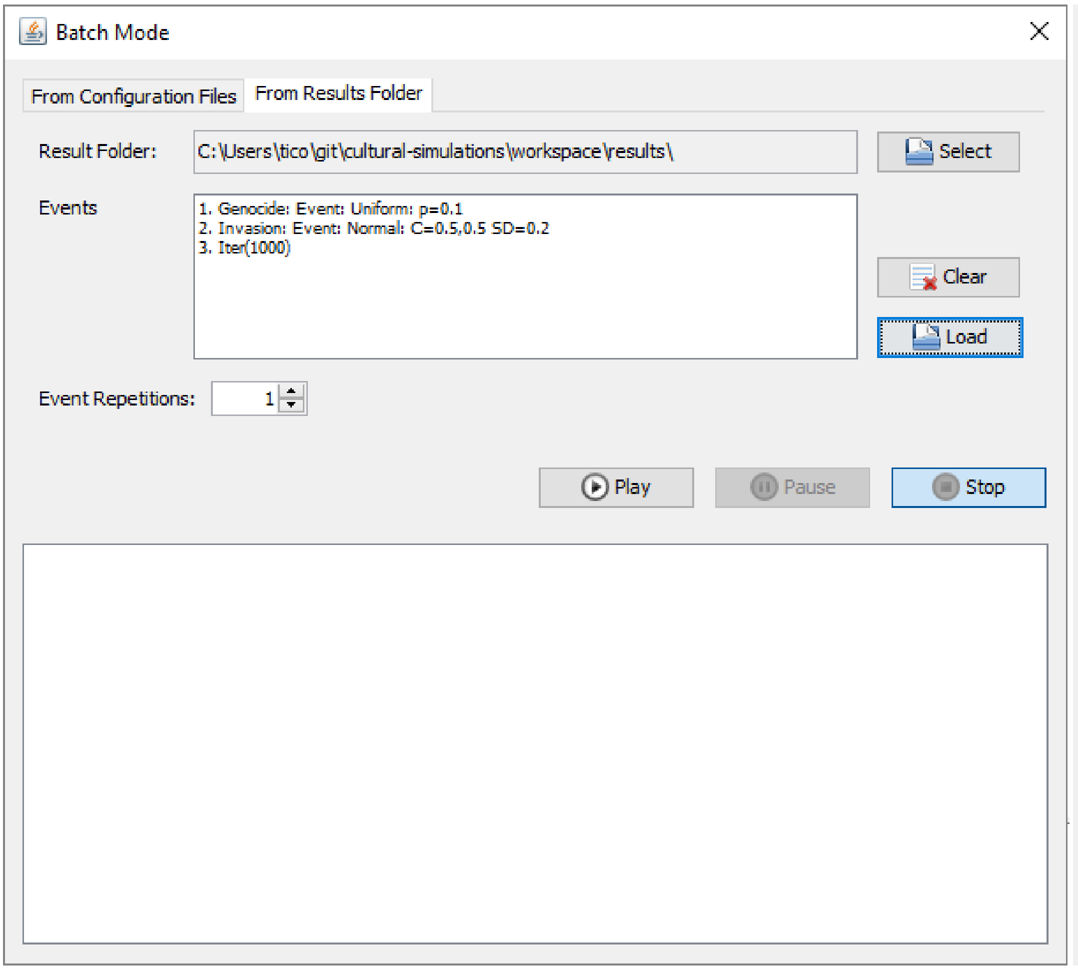


All you need to do is add the configuration files that you want to test with the Add Files button .

You should then decide on the number of times you want to repeat the simulation with the Repetitions selector. To be sure, each repetition will initialize the simulation from scratch (e.g. it will randomly choose new initial cultural traits). Once this is ready, you can start the simulation . This does not resume from the stored state, however, the states of the simulations are stored in the simulations folder. If you wish, you can resume these states by indicating the corresponding Results Folder in the From Results Folder tab.

9.2. Testing the effect of an event in simulation sets (From Results Folder):

Let's assume that you would like to test the effect (measured in any response variable, e.g. **traits similarity**) of a simple or composed event in the set of simulation states generated in the previous state. The second tab (From Results Folder) of the Batch Mode provides this functionality.



The input will be a result folder. Usually the selected folder will be the one generated with the first tab (From Configuration Files). This results folder contains the final states of the simulations that will be tested against a particular singular or composed [event] that was previously stored in the main interface (See 4. Events).

In order to select the events, you load the saved file with the Load Button .

You then decide on the number of times you want to **repeat the event** in each simulation state. You do this with the Event Repetitions selector. *Note that the event will be executed in each simulation state, so if you previously ran 10 repetitions from the Configuration Files tab, and now you are repeating an event 10 times, you will be executing 100 simulations.*

Repeating events is useful when the event is not deterministic, for example for Uniform and Normal Distributions. In the case of Normal or Neumann distributions, it makes more sense to select the center of the event randomly (i.e. set the row and col parameters at -1). If you do not select an event, you are basically resuming the simulation set from the saved simulation state.

10. Command Line Interface

The command line offers the same functionality as the Batch Mode, but is meant to be used with servers and without a graphical user interface. It might also be preferred by individuals who prefer the keyboard over the mouse. After the introductory learning phase with the GUI, the command line is the fastest way to interact with the Cultural Simulator. It is also more flexible than Batch Mode, as creating configuration files is not necessary. Instead, the main input is a csv file, a results folder), or event files (and the language is parsed from the parameters in the command line).

In order to use the command line, you open a terminal and go to the directory on your computer that contains the `culsim.jar`, a Java executable. You can execute this file directly with `java -jar culsim.jar $ARGS`, but you will also find two executables, `culsim.bat` for Windows and `culsim.sh` for Unix/Linux (and iOS - note that this is not tested). If no arguments (`$ARGS`) are provided, then the Graphical User Interface will appear. As with Batch Mode, the are two general tests that can be performed with the Command Line:

10.1. Testing convergence states of simulations (from a csv file):

Here is an example of how to test the convergence state of different simulation configurations in Unix/Linux (for Windows, use `culsim.bat`):

```
./culsim.sh -id sample_experiment -ef sample.csv
```

The `-id` parameter is optional; it sets a name for the results folder and final results file (See H. Output Files) that are stored in the current directory; the directory where the command is executed. If no `-id` is provided, `results` will be used by default.

The `-ef` parameter indicates the csv file that contains the configurations of the simulations that are going to be executed. The file `sample.csv` is provided in the same folder as an example (the two rows are equivalent except for the institutional influence). Here is a description of all columns (parameters) of the simulation, corresponding to the

Initial Parameters (with the exception of `REPETITIONS`, which indicate the number of times the configuration will be repeated):

CSV Column	Parameter
REPETIONS	Repetitions
MODEL	Model
RANDOM_INITIALIZATION	Random initialization
ITERATIONS	Iterations
SPEED	Speed
BUFFER_SIZE	Buffer size
ROWS	Rows
COLS	Columns
RADIUS	Radius
FEATURES	Features
TRAITS	Traits
MUTATION	Mutation
SELECTION_ERROR	Selection error
INST_INFLUENCE	Institutional influence
AGENT_LOYALTY	Agent loyalty
DEMOCRACY	Democracy
PROPAGANDA	Propaganda

10.2. Testing the effect of an event in simulation sets (from Results Folder):

There are two ways of inputting events in the batch mode. One is configuring the event(s) directly in the command line. The other requires the use of the interface, first, to define and save the event(s) into a file and, then, to use the file to execute the event.

10.2.1. Configuring events directly in the command line

Here is an example of a (composed) event in the simulation, set in Unix/Linux (for Windows, use `culsim.bat`):

```
./culsim.bat -r -id sample_event_experiment -rd ./sample_experiment/ -r
1  -evs G@U,0.1 I@N,0.5,0.5,0.2 P@iterations,1000
```

The `-id` parameter is optional; it sets a name for the results folder and final results file (See H. Output Files), so that, instead of the current directory, they are stored inside the results folder (see `-rd` parameter). If no `-id` is provided, `results` will be used by default.

The `-rd` parameter indicates the results directory that will be used to test the (simple or composed) event. In this case we are assuming that you executed the previous step with the example, and that you keep the same ID, i.e. `sample_experiment`.

The -r is optional; it indicates the number of times the (simple or composed) event will be executed, for each simulation state (repetitions). Repetitions make more sense when the events depend on a probabilistic distribution, e.g. a uniform distribution of the event, or there is an element of probability, e.g. when the (non-probabilistic) Neumann distribution has a center that is selected randomly, by using -1 in the rows and/or columns.

The -evs parameter indicates the events which will be executed in the provided simulation sets. A special syntax (instead of events files) has been provided to define events. It basically follows the format `Event_type@Distribution` for events that affect institutions or agents, and `P@parameter,value` for parameter change event. The first letter(s) before the @ indicates the event type according to the following table:

Id	Event
A	Apostasy
D	Institutional destruction
RP	Content removal (Partial)
RF	Content removal (Full)
CP	Conversion (Partial)
CF	Conversion (Full)
S	Settlement
I	Immigration
G	Decimation
P	Parameter Change Event

The part after the @ defines a distribution for events that affect agents or institutions. The table below explains the meaning of each parameter for each distribution (the first parameter identifies the distribution, and the rest its parameters):

Parameters	Distribution
U,p	(U)niform distribution with probability p
N,row,col,max,sd	(N)ormal distribution centered at (row,col) with maximum value of max and standard deviation sd. The center can be chosen randomly by using -1 in the rows and/or columns.
E,row,col,max,p	Normal (E)stimated distribution centered at (row,col) with maximum value of max and proportion p. The center can be chosen randomly by using -1 in the rows and/or columns.
W,row,col,r	Neumann (not ne(W) man) distribution center at (row,col) with radius r. The center can be chosen randomly by using -1 in the rows and/or columns.
R,row1,col1,row2,col2	(R)ectangular distribution with the initial position at (row1,col1), and final position at (row2,col2)

For the **Parameter Change Event**, instead of a distribution, the part after the @ defines the parameter that will be affected, and its value. For example `P@iterations,1000` will change the number of iterations to 1000. The following table shows the list of arguments that can be used instead of `iterations`.

Argument	Parameter
`iterations`	Iterations
`speed`	Speed
`mutation`	Mutation
`selection`	Selection error
`influence`	Institutional influence
`loyalty`	Agent loyalty
`democracy`	Democracy
`propaganda`	Propaganda

10.2.2. Using pre-configured file event

Alternatively, you can create event files with the interface (see D. Events), and use -evs_file to specify the path of the file. An equivalent to the previous command would be:

```
./culsim.bat -r -id sample_event_experiment -rd ./sample_experiment/ -r
1  -evs_file path/to/even
```

Appendix 10. Chapter 3. Study 1: Theories of the Maya Collapse

Some 88 different theories or variations of theories attempting to explain the Classic Maya Collapse have been identified. From climate change to deforestation to lack of action by Maya kings, there is no universally accepted collapse theory, although drought is gaining momentum as the leading explanation. (Gill, 2000)

"Like most things, collapse explanations are subject to fashion, and the one most in the limelight today is climatic change, or more specifically, megadrought." Quote is from (Webster, 2002, p. 239) see also article by (Diamond, 2003)

The dynasty is believed to have collapsed entirely shortly thereafter. In Quirigua, twenty miles north of Copán, the last king Jade Sky began his rule between 895 and 900, and throughout the Maya area all kingdoms similarly fell around that time (Acemoglu & Robinson, 2013, pp. 143–149)

Between 400 and 450, the population was estimated at a peak of twenty-eight thousand between 750 and 800 - larger than London at the time. Population then began to steadily decline. By 900 the population had fallen to fifteen thousand, and by 1200 the population was again less than 1000 (Webster, 2002; Webster, Freter, & Gonlin, 2000)

References Table 1. Simulation events and references for different theories of the Maya collapse.

References	Event
The archaeological evidence of the Toltec intrusion into Seibal, Peten, suggests to some the theory of foreign invasion. (Chase, 1983; Sabloff & Willey, 1967)	Foreign Invasion / Content Removal
As life became more burdensome, work began to undermine the religious development and collective enterprise of ordinary people. For it was the strength of Mayan religions that historians believe allowed the Mayans to build such great monuments and temples. The increased burden of work is what many believe caused Mayan people to abandon their values and revolt against the elite of society. This would explain the abrupt collapse of elite functions as well as unfinished buildings, and ceremonial centers. Peasant revolt also explains the evidence of the burning of temples and smashing of thrones. It is believed that once the elite lost ceremonial centers they no longer had the power to sway people with religion through demonstrations and sacrifices. (Thompson, 1954) the population should have increased because of the lack of elite power. Further, it is not understood why the governmental institutions were not remade following the revolts (Webster, 2002; Webster et al., 2000)	Revolution / Apostasy / Content removal
Teotihuacan was believed to have fallen during 700–750, forcing the "restructuring of economic relations throughout highland Mesoamerica and the	Political destabilization /

Gulf Coast" (Webster, 2002, p. 231) This remaking of relationships between civilizations would have then given the collapse of the Classic Maya a slightly later date.	Institutional destruction
Widespread disease could explain some rapid depopulation, both directly through the spread of infection itself and indirectly as an inhibition to recovery over the long run. According to Dunn (1968) and Shimkin (1973), infectious diseases spread by parasites are common in tropical rainforest regions, such as the Maya lowlands. (Dunn, 1968; Shimkin, 1973) The Maya may have encountered endemic infections related to American trypanosomiasis, Ascaris, and some enteropathogens that cause acute diarrheal illness. Through development of their civilization (that is, development of agriculture and settlements), the Maya could have created a "disturbed environment," in which parasitic and pathogen-carrying insects often thrive. those that cause the acute diarrheal illnesses would have been the most devastating to the Maya population. (Anderson & May, 1982; Santley, Killion, & Lycett, 1986)	Diseases / Decimation
Mega-droughts hit the Yucatán Peninsula and Petén Basin areas with particular ferocity (Gill, 2000, p. 311; Webster, 2002, p. 239) Gill analyzes an array of research from different sources (climatic, historical, hydrologic, tree ring, volcanic, geologic, lake bed, and archeological research) and demonstrates that a prolonged series of droughts probably caused the Classic Maya Collapse (Gill, 2000) "Many lines of evidence now point to climate forcing as the primary agent in repeated social collapse. (Weiss, 1997, 2001) “Within the past five years new tools and new data for archaeologists, climatologists, and historians have brought us to the edge of a new era in the study of global and hemispheric climate change and its cultural impacts. The climate of the Holocene, previously assumed static, now displays a surprising dynamism, which has affected the agricultural bases of pre-industrial societies. The list of Holocene climate alterations and their socio-economic effects has rapidly become too complex for brief summary” [Studies of] Yucatecan lake sediment cores ... provide unambiguous evidence for a severe 200-year drought from AD 800 to 1000 ... the most severe in the last 7,000 years ... precisely at the time of the Maya Collapse. (Gill, 2000, p. 276) “Given this precarious balance of wet and dry conditions, even a slight shift in the distribution of annual precipitation can have serious consequences.” (Webster, 2002, p. 239) LSU archaeologist Heather McKillop found a significant rise in sea level along the coast nearest the southern Maya lowlands, coinciding with the end of the Classic period, and indicating climate change. (McKillop, 2006, p. 312) A study published in Science in 2012 found that modest rainfall reductions, amounting to only 25 to 40 percent of annual rainfall, may have been the tipping point to the Mayan collapse. Based on samples of lake and cave sediments in the areas surrounding major Mayan cities, the researchers were able to determine the amount of annual rainfall in the region. The mild droughts that took place between 800-950 would therefore be enough to rapidly deplete seasonal water supplies in the Yucatán lowlands, where there are no rivers.(Medina-Elizalde & Rohling, 2012; “Mild drought caused Maya collapse in Mexico, Guatemala,” n.d.)	Drought / Decimation / Apostasy

Hypothesis of soil exhaustion (Culbert, 1977, pp. 23–24) based on (Cook, 1919) Similar soil exhaustion assumptions are associated with erosion, intensive agricultural, and savanna grass competition. Systemic ecological collapse is said to be evidenced by deforestation, siltation, and the decline of biological diversity.(Demarest, 2004)	Soil exhaustion / Agricultural disaster / Apostasy
development of and the declining marginal returns from the increasing social complexity of the competing Mayan city-states (Tainter, 2011, pp. 152–177) Failure in the social control systems of religion and political authority, due to increasing socioeconomic complexity that overwhelmed the power of traditional rituals and the king's authority to compel obedience. (Jaynes, 2000, p. 197)	Institutional collapse

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Appendix 11. Chapter 3. Study 2: Complementary graphs

Fig. A and **Fig. B** show an analogous graph to Figure 23 and Figure 25 (Chapter 4), but for populations of 32x32. **Fig. C** present a separated analysis for *Colonization* and *Damages* (similar to Figure 23) for each of the combinations of democracy and propaganda on Figure 26. **Fig. D** is analogous to Figure 26, but for populations of 32x23. **Fig. E** is analogous to **Fig. C**, but for populations of 32x32. **Fig. D** and **Fig. E** just show results of scenarios with both, propaganda and democracy.

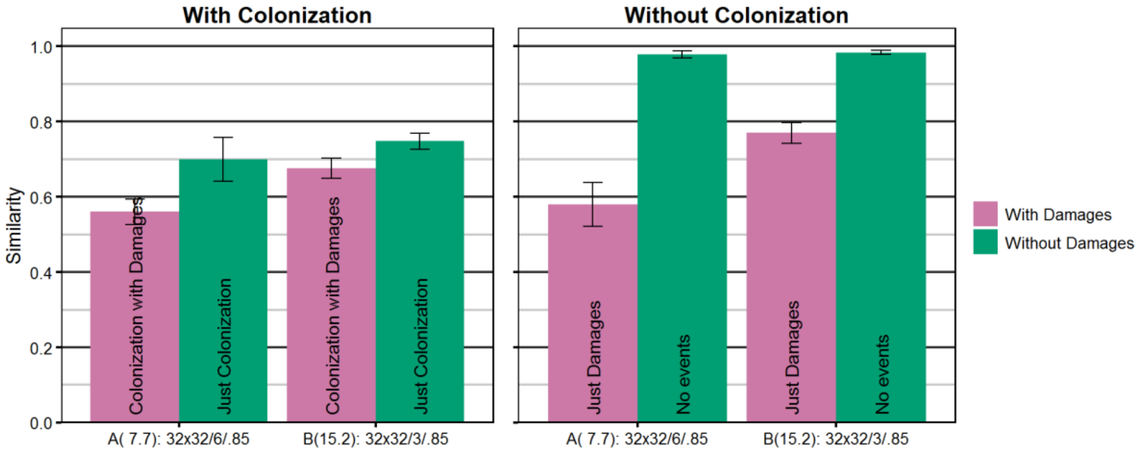

Fig. A. Effects of Damages and Colonization on the similarity of diverse scenarios (populations of 32x32). The purple bars present the results for cases in which the event set contained the Damages event, whereas the green, the results for cases that did not. The left graph presents the results with Colonization event-set, whereas the right graph the ones without Colonization. The Y-axis shows the similarity between the state just before the event (1000000th iteration), and 100000 iterations after the event. The X-axis shows the results for two scenarios in the format S(G): NxN/R/I: S is the identifier; G, average number of cultural groups; NxN, number of rows and column; R, distance of neighborhood interaction; I, institutional influence.

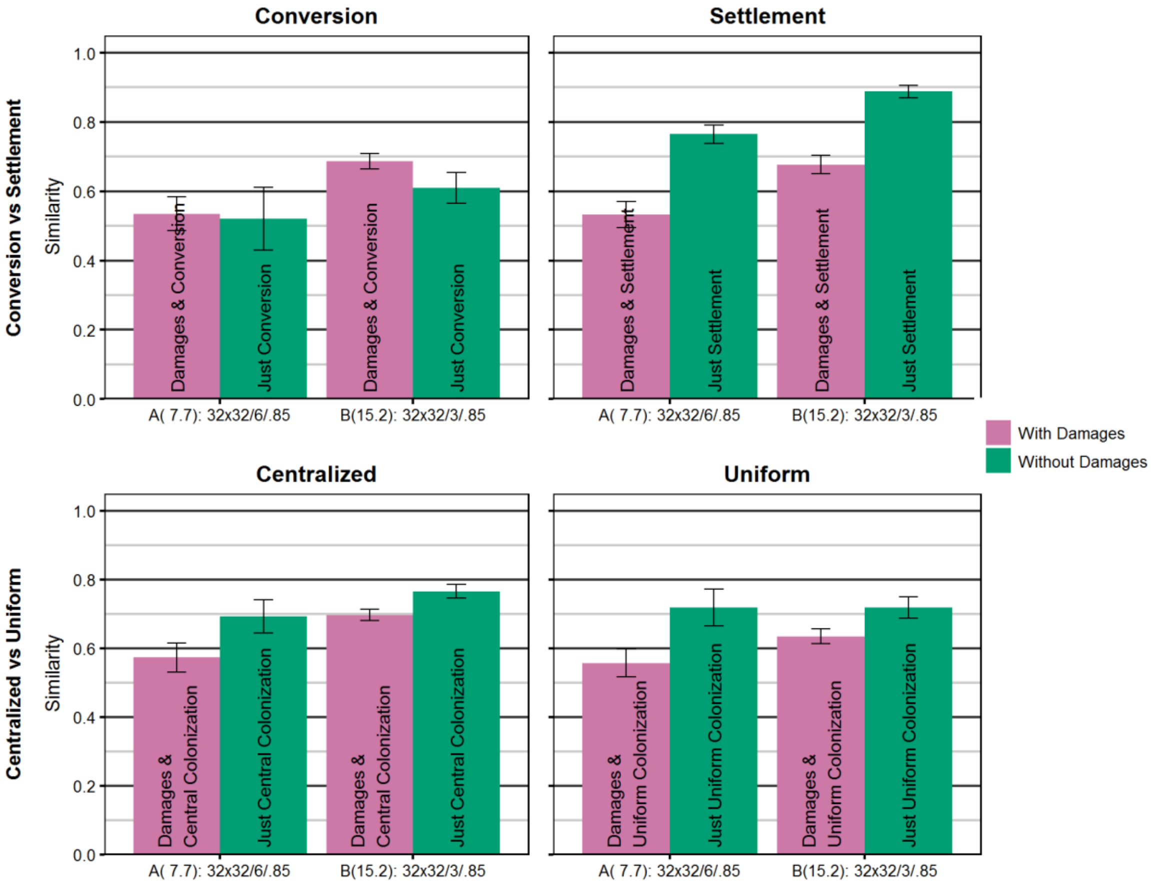

Fig. B. Effects of Damages with Conversion, Settlement, Centralized and Uniform Colonization on the similarity of variations of scenario D. The purple bars present the results for cases in which the event set contained the Damages event-set, whereas the green the results for cases that did not. All cases contain a version of the Colonization event-set: the top-left graph, Conversion Colonization; the top-right, Settlement Colonization; the bottom-left, Centralized Colonization, and the bottom-right, Uniform Colonization. The Y-axis indicates the similarity between the state just before the event (1000000th iteration), and 100000 iterations after the event. The X-axis presents the results for four extensions of scenario D in the format S(G): NxN/R, where S is the identifier; G, average number of cultural groups; NxN, number of rows and column; R, distance of neighborhood interaction; I, institutional influence.

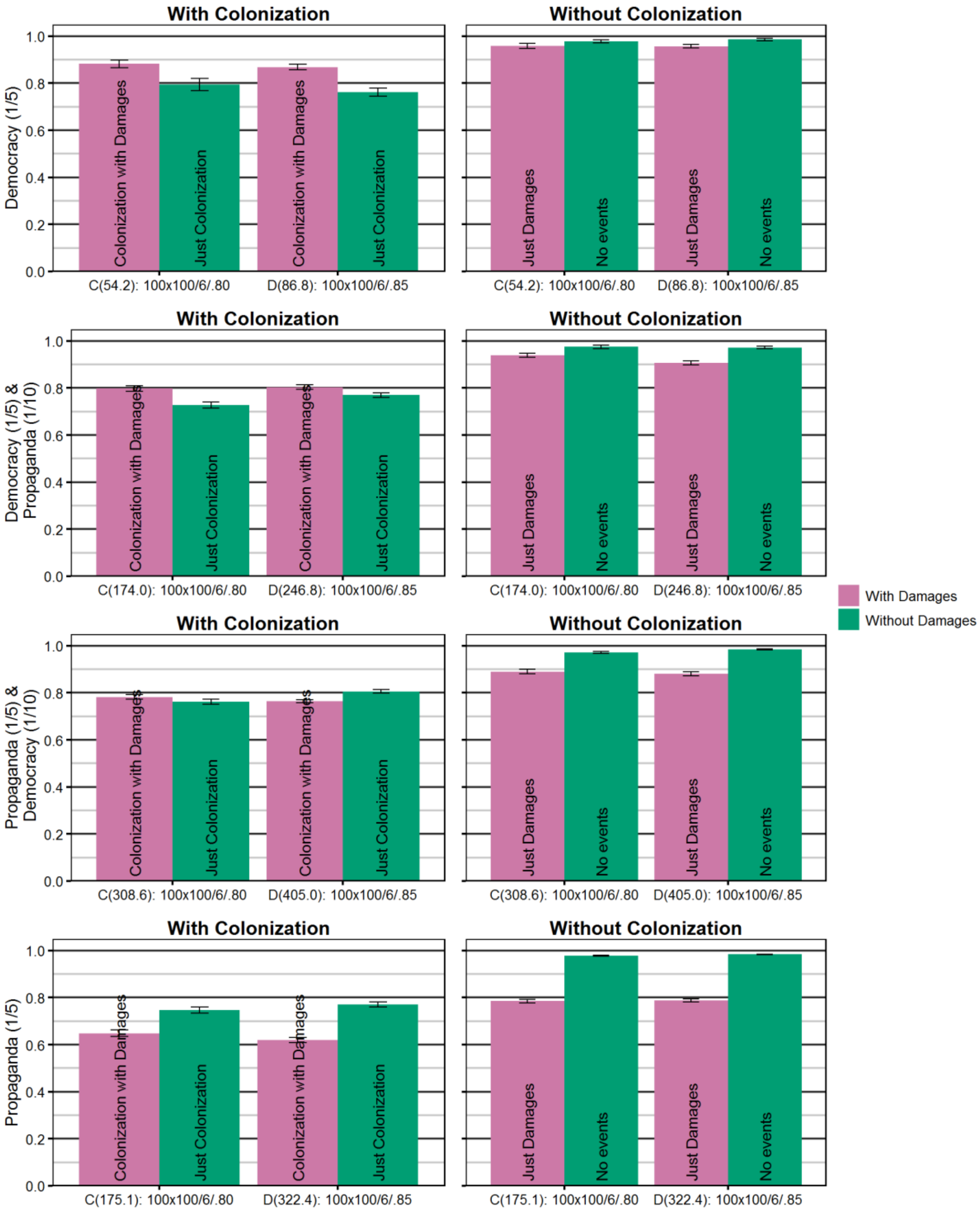

Fig. C. Effects of Damages and Colonization on the similarity of diverse scenarios (populations of 100x100) for different values of Propaganda and Democracy. The purple bars present the results for cases in which the event set contained the Damages event, whereas the green, the results for cases that did not. The left graphs present the results with Colonization event-set, whereas the right graphs the ones without Colonization. Each row of graps present different values of propaganda and democracy. The Y-axis shows the similarity between the state just before the event (1000000th iteration), and 100000 iterations after the event. The X-axis shows the results for two scenarios in the format S(G): NxN/R/I: S is the identifier; G, average number of cultural groups; NxN, number of rows and column; R, distance of neighborhood interaction; I, institutional influence.

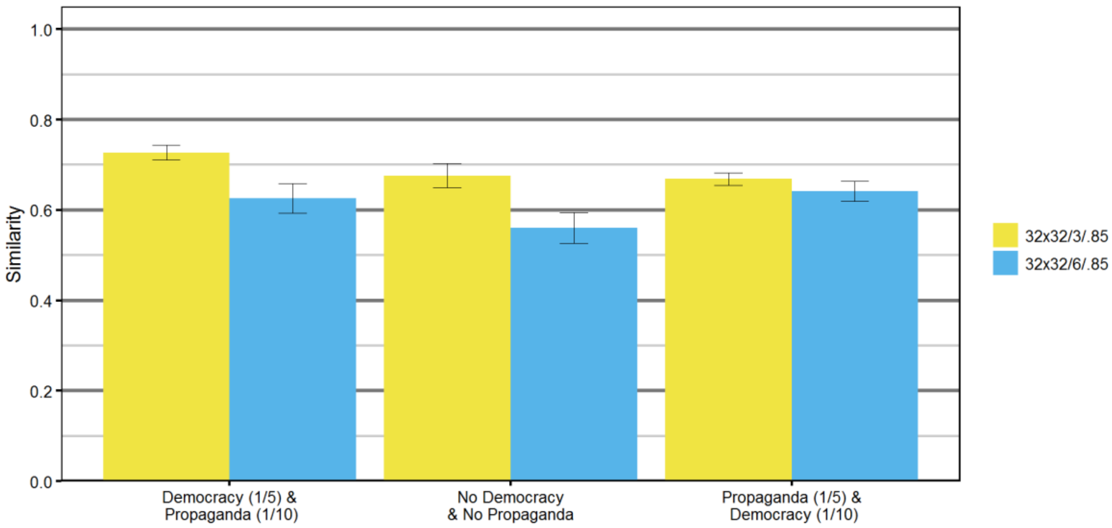

Fig. D Effects of invasion (Damages and Colonization) in scenarios with Democracy and/or Propaganda (32x32). The yellow and blue bars present results for the scenarios C and D with the extensions presented in the X-axis. Each extension is a combination of Democracy and Propaganda showed in the parenthesis of X-axis labels. The Y-axis indicates the similarity between the state just before the event (1000000th iteration), and 100000 iterations after the event.

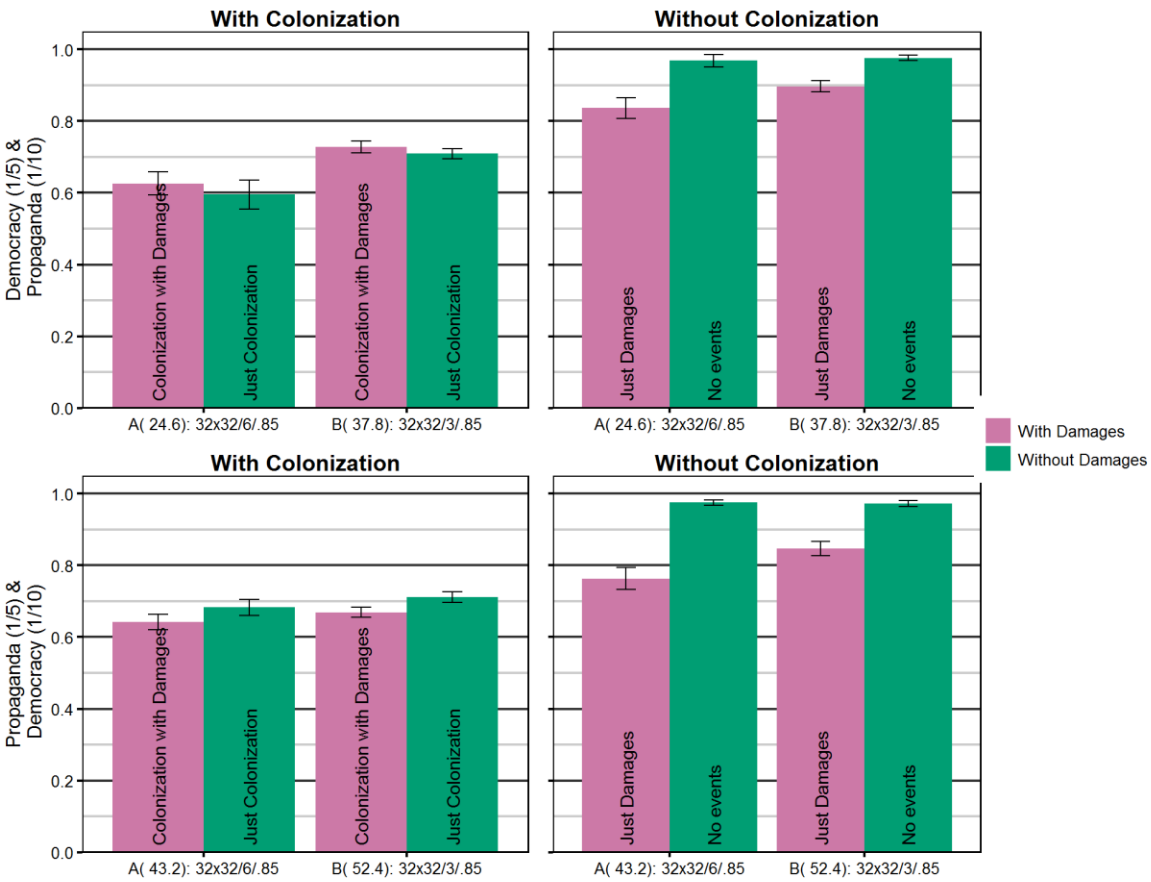

Fig. E Effects of Damages and Colonization on the similarity of diverse scenarios (populations of 32x32) for different values of Propaganda and Democracy. The purple bars present the results for cases in which the event set contained the Damages event, whereas the green, the results for cases that did not. The left graphs present the results with Colonization event-set, whereas the right graphs the ones without

Colonization. Each row of graps present different values of propaganda and democracy. The Y-axis shows the similarity between the state just before the event (1000000th iteration), and 100000 iterations after the event. The X-axis shows the results for two scenarios in the format S(G): NxN/R/I: S is the identifier; G, average number of cultural groups; NxN, number of rows and column; R, distance of neighborhood interaction; I, institutional influence.

Appendix 12. Chapter 3. Study 2: Events related to the Spanish Invasion

References Table 2. References that support the distributions of the events

Event	References	Distribution	Comments
Decimation	In the course of the fifth year the pestilence began, O my children. First there was a cough, then the blood was corrupted, and the urine became yellow. The number of deaths at this time was truly terrible. The Chief Vakaki Ahmak died, and we ourselves were plunged in great darkness and great grief, our fathers and ancestors having contracted the plague, O my children. (Annals of the Kaqchikel, p.171) "There was a locust plague in 1513, a bad fire that swept through Iximche' in 1514, and in 1519 a devastating plague that did not end until 1521. It was likely the first appearance of small pox, which had ravaged Yukatan a few years early" (Schele & Mathews, 1999, p. 297) "First, and foremost were epidemic diseases previously unknown in the New World, such as smallpox, influenza, and measles. It is generally agreed among scholars that these produced a holocaust unparalleled in the new world's history: within a century, 90% of the native population had been killed off, including that of the Maya area." (Coe & Houston, 2015, p. 289) "… one-third to one-half of the Indian population of highland Guatemala must have perished as a consequence of this pestilence" (Lovell, 2005, p. 71) Los dominios de los K'iche' probablemente alcanzaron su máxima extensión a mediados del siglo XV, cuando se extendían desde lo que sería el Soconusco, en las tierras bajas del Pacífico, hasta las tierras altas de lo que después fueron las Verapaces. Durante esa época, los K'iche' habrían ejercido dominio sobre una región de unos 25,000 kilómetros cuadrados y una población aproximada de un millón de habitantes. (Informe Nacional de Desarrollo Humano, 2005, p. 27) Pedro de Alvarado described their actions: "We surrounded a bare mountain where they had take refuge, and pursued them to the top, and took al that hado gone up there. That day we killed and imprisoned many people, many of whom were captains and chiefs and people of importance" (Sharer & Traxler, 2006, p. 764)	**Uniform (50%)**: represents the casualties of plagues brought by the Spanish	There is a problem with this and it is that it occurred a few years before the invasion. Well, to be fair there is a super problem with my simulation and it is that all individuals are born almost immediately The 90% is across all the century, so 33 to 50% seems a more plausible figure in this case… to be sure, the simulation is able to resist values as high as 83% (I have not tried higher), however the massacre combined with 90% would probably wipe out the whole thing

	"At dawn the following morning, the Spaniards were about to march on Huehuetenango, only three kilometres away, when they were confronted by a Mam army, reported as five thousand strong,10 from the neighbouring town of Malacatin (now Malacatancito). Already in battle formation, the Malacatecos approached the Spaniards over an open plain. Alvarado immediately ordered his cavalry into action. Those Indians not killed by Spanish lances or trampled to death beneath the horses' hooves were soon dispatched by the infantry who followed in the cavalry's wake." (Lovell, 2005, p. 61) "Inside the stronghold, Caibil Balam had gathered an estimated six thousand warriors, drawn not only from Huehuetenango and Zaculeu, but also from the Mam communities of Cuilco and Ixtahuacan (...) A batallion of two thousand warriors was dispatched from Zaculeu to rejuvenate the Mam defence, but still the Spaniards lost no ground. Soon the battlefield was strewn with green crests covered in Mam blood (...) Alvarado declared victory, and consolidated his position by laying siege to the stronghold. (...)Shortly after initiating the siege, the Spaniards were forced to return to the field of battle by a massive Mam army descending on the beleaguered Zaculeu from the mountains to the north. This army, reported as eight thousand strong,16 came from the heart of the Cuchumatanes and was composed of warriors drawn from towns politically aligned with the Mam of Zaculeu. Communities such as San Martin, Todos Santos, Santiago Chimaltenango, and San Juan Atitan probably all contributed a supply of warriors. Leaving a command of men under Antonio de Salazar to maintain the siege of the fortress (…) Once again the Indians were more than a match for the Spanish infantry, but collapsed under the assault of the cavalry. (…) The siege of Zaculeu, begun in early September, lasted until the middle of October before the Mam showed signs of capitulation(...) A lack of provisions and a falling morale left the Mam weak, sick, and hungry. (…) When the weeping Caibil Balam finally surrendered, itwas not until the Mam of Zaculeu had reached the point of starvation." (Lovell, 2005, pp. 63–64) "On reaching the upper slopes, Castellanos's troops came upon an army of between four and five thousand "rebellious and ferocious" warriors from Nebaj and other neighbouring towns (…) Ixil warriors who were not killed during the fighting were rounded up." (Lovell, 2005, p. 65) "Following the capture of Nebaj and the capitulation of Chajul, Spanish forces, rested and buoyed by victory, marched eastward once again towards Uspantan. Castellanos's		

	troops arrived at the town to find an estimated ten thousand Indian warriors, drawn from Uspantan, Cunen, Cotzal, Sacapulas, and Verapaz, waiting in hostile confrontation. castellanos's strategic deployment of cavalry, plus the firearm superiority of his foot soldiers, finally won the day for the Spaniards. Uspantan was seized; and, as at Nebaj, those warriors not slaughtered on the field of battle were taken prisoner and branded as slaves." (Lovell, 2005, p. 66) "The ability of Indian communities to raise strong armies to oppose the entradas of 1525 to 1530 is an important indication that the Cuchumatan region at the time of Spanish contact supported a population of considerable magnitude." (Lovell, 2005, p. 66)		
Settlement (Invaders)	Cortés decided to despatch Pedro de Alvarado with 120 cavalry (with 50 spare horses), 300 infantry, crossbows, musketeers, 4 field pieces (cannons), large amounts of ammunition and gunpowder, and an unespicified (hundreds or thousands) number of allied Mexican warriors from Tlaxcala, Cholula and other cities in central Mexico (Lovell, 2005, pp. 59–65; Recinos, Adrián, 1952, p. 19; Schele & Mathews, 1999, p. 298, 310, 386n19).	**Centralized (2.5%) and Uniform (2.5%)**: represents one event (of size 5%) divided in two; one, the colonizers settling in the center, and two, the foreigners controlling territories	The figure is inflated as the Maya population never recover until very late in history.
Apostasy	"At the instigation of a priest, the outraged Kaqchikels abandoned their capitalon 7 Ahmak (August 28, 1524) and retreated to the hills and forests, expecting their gods to destroy the Spaniards. The destruction never came, and the Spaniards began their war against the Kaqchikels ten days later." (Schele & Mathews, 1999, p. 298) "Bernal Díaz reported returning to Iximche' and spending the night "in the site of the old city of Guatemala where once lived the caciques called Sinakan and Saqachul." He said that the rooms and houses were still in good shape, but this is the last known description of Iximche as a habitable city." (Recinos, 1998, p. 19; Schele & Mathews, 1999, p. 298) "The Indians of Malacatan fought bravely; but when their leader, Canil Acab, fell to a blow from the lance of Gonzalo de Alvarado, the courage of the Malacatecos quickly waned. Native resistance collapsed and the remaining Indians fled from the field of	**Uniform (50%):** represents survivors that escaped and found refuge in the mountains, leaving behind institutions	The Maya run away in the mountains

	battle into the surrounding hills. Alvarado then marched unopposed into Malacatan, where only the aged and the sick remained. Delegates of the community later arrived from the mountains with offerings of peace. Alvarado accepted their unconditional surrender and declared them subjects of the King of Spain. The campaign against the Mam had successfully begun. After a few days' rest, the Spaniards marched into Huehuetenango, only to find it completely deserted. Having already received reports of the Spaniards' approach, Caibil Balam had ordered the evacuation of Huehuetenango and had retreated with his forces to the nearby stronghold of Zaculeu." (Lovell, 2005, p. 61)		
Institutional destruction	On 9 February 1526, a group of sixteen (or sixty) Spanish deserters burnt the palace of the Ahpo Xahil, sacked the temples and kidnapped a priest, acts that the Kaqchikel blamed on Pedro de Alvarado. (Recinos, Adrián, 1952, pp. 21–22; Schele & Mathews, 1999, p. 298,310,386n19) Alvarado decided to have the captured K'iche' lords burnt to death, and then proceeded to burn the entire city. (Schele & Mathews, 1999, p. 297; Sharer & Traxler, 2006, p. 765) "Alvarado then ordered his soldiers to fall on the Quiché without mercy. Utatlán was laid to waste, and the rulers responsible for conspiring against the Spaniards burned to death. In complete disarray, the Quiché nation collapsed" (Lovell, 2005, p. 61) "The march continued until the invaders reached the plain where the Mam town of Mazatenango stood, near the present settlement of San Lorenzo. The Spaniards attacked, and in less than four hours Mazatenango was taken." (Lovell, 2005, p. 59) "The failure of the Ixil to defend adequately all sides of the Nebaj fortress enabled several Indian auxiliaries to scramble over the ravine, scale the stronghold's walls, and gain entry. Once inside, they set the town on fire." (Lovell, 2005, p. 65)	**5 x Centralized (10%):** represents destructive events to various cities across the country, one in the center and one in each corner	The destruction of the cities is seen as institutional destruction.
Institutional content removal	"On March 9 [1524], he [Pedro de Alvarado] burned the defian K'iche' kings at the stake…" (Schele & Mathews, 1999, p. 297) Pedro de Alvarado "advanced killing, ravaging, burning, robbing, and destroying all the country wherever he came... ". (Sharer & Traxler, 2006, p. 764)	**Uniform (10%):** represents scattered damages (incomplete	Kings as seen as institutional content, as people uses them as reference points

	Pedro de Alvarado described their actions: “We surrounded a bare mountain where they had take refuge, and pursued them to the top, and took al that hado gone up there. That day we killed and imprisoned many people, many of whom were captains and chiefs and people of importance” (Sharer & Traxler, 2006, p. 764)	destruction) to the communities	
Institutional conversion	“After accepting Caibil Balam's surrender, Alvarado ordered a reconnaissance to be made of all the towns subject to Zaculeu, and established a Spanish garrison in nearby Huehuetenango under the command of Gonzalo de Solis.” (Lovell, 2005, pp. 63–64) “Se impuso un nuevo tipo de asentamiento territorial, cuya base la constituyó el sistema de “pueblos de indios” establecido hacia mediados del siglo XVI; formados muchas veces con indígenas pertenecientes a distintas etnias. Así se rompería el sentido de la antigua pertenencia étnica y territorial. Los nuevos referentes del poder y la identidad serían la Corona de Castilla, Santiago de los Caballerros, España, la ciudad de Guatemala, las parroquias y gobernaciones, con sus distintas instituciones y funcionarios, y la Iglesia. (…) En cuanto a su asentamiento territorial, el indígena, en su mayoría, fue confinado en los pueblos creados en el área rural hacia mediados del siglo XVI, en cuya jurisdicción tenían prohibido el asentamiento españoles, criollos y mestizos, lo que trató de mantenerse en mayor o menor medida hasta finales del periodo colonial. Desde este núcleo poblacional se organizó todo el sistema económico de exacción, con base en tributos y trabajo forzado de la población que vivía en ellos; y de él se desprende el sistema de pueblos y localidades indígenas prevaleciente hasta la actualidad en Guatemala. En menores proporciones existió también una población indígena urbana, sobre todo en los barrios de la capital del Reino, en la ciudad de Santiago de los Caballeros de Guatemala, la hoy ciudad de Antigua. En el área rural se conformaron con el tiempo centros de población indígena que lograron sustraerse al control colonial, en lugares apartados y remotos, conocidos como “pajuides”. Sus dimensiones nunca fueron mayores, pues existió el interés y la preocupación general de los demás sectores, incluyendo a la Iglesia, de su control, dominación, explotación y lucro. Con el tiempo, se dio también el indígena adscrito como mano de obra laboral a las fincas, un fenómeno menor, pues el terrateniente lograba la mano de obra a través de los repartimientos indígenas de los mencionados pueblos. En la medida de lo posible, la población indígena debía vivir rigurosamente controlada en sus pueblos por los encomenderos, la corona española y el clero seglar y	**Centralized (10%) and Uniform (10%):** represents one event (of size 20%) divided in two; one, conversion of institution near the Spanish base, and two, the colonization of other cities	Future work: add some propaganda after the conversion. It would be interesting if the propaganda could be apply just to certain institutions

	regular, quien había tenido un papel determinante en su fundación y lo mantendrían así una buena parte del período colonial.” (Informe Nacional de Desarrollo Humano, 2005, pp. 28–29)		

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Appendix 13. Chapter 3. Study 3: References and citations related to the civil war

References Table 3. Supporting reference for a Decimation event

Quote Text	Summary	Simulated distribution	Comments
"In Guatemala, the (Historical Clarification Commission (CEH), 1999a) – as the Truth Commission is officially called – was created in June 1994 as part of the Oslo Accords between the Guatemalan government and the umbrella group of insurgent forces, the Guatemalan National Revolutionary Unity (URNG). […] In a stunning judgement, the CEH charged the Guatemalan military with genocide; '[T]he CEH concludes that agents of the State of Guatemala, within the framework of counterinsurgency operations carried out between 1981 and 1983, committed acts of genocide against groups of Mayan people' (Historical Clarification Commission (CEH), 1999b, p. 41)**.** According to its findings, 83 percent of the victims were Maya." (Historical Clarification Commission (CEH), 1999a; Manz, 2002, p. 293) "También se notó que la relación entre ejecutados y desaparecidos en las violaciones documentadas por la CEH es aproximadamente 4:1. La cifra de 40,000 desaparecidos resulta completamente coherente con esta proporción. Una vez expuesta, la CEH estima que en términos muy aproximados tuvieron lugar más de 160,000 ejecuciones y 40,000 desapariciones." (Historical Clarification Commission (CEH), 1999a, p. 73 Vol I) "751. Este Informe demuestra que el recurso a las armas no mejoró la vida de los guatemaltecos, sino que condujo a una espiral de violencia fratricida que, según las estimaciones de la CEH, dejó un saldo de aproximadamente 200,000 muertos" (Historical Clarification Commission (CEH), 1999a, p. 15 Vol II)	200000 people killed or disappeared over 3 decades.	A centralized massacre equivalent to 10% of the population. X = 200000/2500000 < 10%	We consider displaced people part of the casualties since geographically they are not part of the cultural tissue that the simulation tries to capture. Though massacres occurred in many different parts of Guatemala, they were concentrated in Quiche, in particular Ixil Region opposed some resistance. A new parameter, ceiling of the normal distribution, might be necessary, so the distribution does not always reach 1 in the center.
"The CIIDH database records nearly 18,000 state killings in 1982 alone." (Ball, Kobrak, & Spirer, 1999, p. 24; Ball, Spirer, Spirer, & American Association for the Advancement of Science, 2000) "After Ríos Montt took over, the level of violence increased (…) The number of state killings and disappearances rose even higher in April 1982, Ríos Montt's first full month in office. The 3,330 documented deaths and disappearances in the CIIDH database that month represent the highest one-	18000 killings are documented for 1982 alone, the most violent period, although non oficial		

month total number of documented violations of the right to life for the entire armed conflict (the actual total is higher).” (Ball et al., 1999, p. 40) “The database documents over 800 killings and disappearances per month during Ríos Montt’s 17-month occupation of the National Palace. The actual numbers must include tens of thousands of murders not documented by any database project, certainly higher than those reported here.” (Ball et al., 1999, p. 38) “and 1813 killings per month during the first four months of the Ríos Montt regime” (Ball et al., 1999, p. 60) See graph on Fig. 1 for a distribution disappearances and executions by dates. (Historical Clarification Commission (CEH), 1999a, p. 407 Vol II) “This concentration of energies and forces resulted in the most closely coordinated, intensive massacre campaign in Guatemalan history, killing 75,000 in 18 months (most in the first eight months, between April and November 1982, primarily in the departments of Chimaltenango, Quiché, Huehuetenango and the Vérapaces)” (Schirmer, 1999, p. 44)	sources presents much higher tolls		
“The army’s brutal and targeted repression, especially in the province of El Quiché (...) went far beyond the threat posed by the armed insurgency. In El Quiché, 344 massacres took place, representing more than half of the total deaths and over 45 percent of the human rights violations in the country.” (Manz, 2002, p. 294) “The murder of one hundred fifty Kekchí Indians took place in the northeastern village of Panzós only twenty-nine days after (the May 1st demonstration 1978), shaking ‘the highlands, indicating to what point the regime would go in response to the legal claims and demands of the campesinos’ (Arias, 1990, p. 250) See map on Fig. 2 for a distribution of the massacres by department. (Historical Clarification Commission (CEH), 1999a, p. 519 Vol II) and graph on Fig. 3. for a distribution of the massacres by department and dates (Historical Clarification Commission (CEH), 1999a, p. 258 Vol II).	344 massacres in el Quiche, half of the total deaths		

"as many as 1.5 million people were internally displaced or had to flee the country, including about 150,000 who sought refuge in Mexico" (Manz, 2002, p. 294) "Las tareas y plazos del movimiento revolucionario en su conjunto están determinados ahora por 35,000 muertos, 900,000 organizados en PAC, más de 18,000 concentrados en polos militarizados, más de 45,000 refugiados en el exterior, 1,200,000 desplazados internos, más de 200,000 huérfanos por la represión, más de 40,000 viudas. En pocas palabras, el costo humano más grande del país después de la conquista" (Historical Clarification Commission (CEH), 1999a, p. 285 Vol II) "The Inter-American Commission also described the serious situation of displaced persons inside Guatemala, who, according to church sources, were estimated to number between 250,000 and 1 million people. (…) in four areas of northern Guatemala alone – Huehuetenango, El Quiché, western Péten, and Playa Grande – there were at least 150,000 people who had fled and were in Mexico and another 250,000 people (representing 50,000 families) who were internally displaced…" (Davis, 1992, pp. 10–11)	1.25 or 1.5 million people internally displaced		

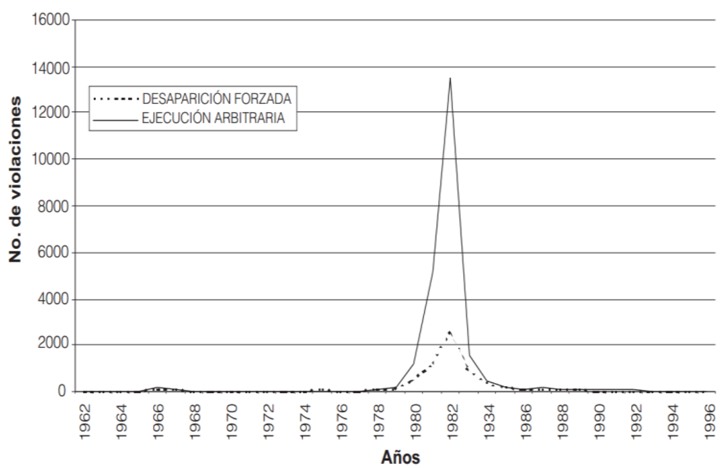

Fig. 1. Total of forced disappearances and arbitrary executions, Guatemala (1962-1966). Original image is from (Historical Clarification Commission (CEH), 1999a, p. 407 Vol II)

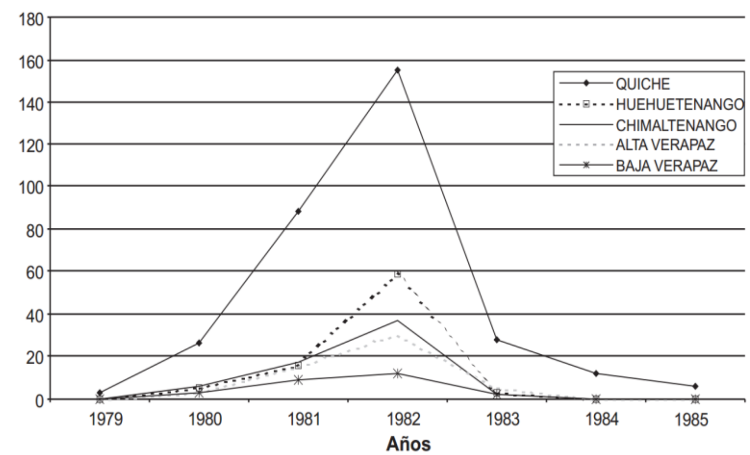

Fig. 3. Total of massacres per department (5 most frequent), Guatemala (1979-1985). Original image is from (Historical Clarification Commission (CEH), 1999a, p. 258 Vol II)

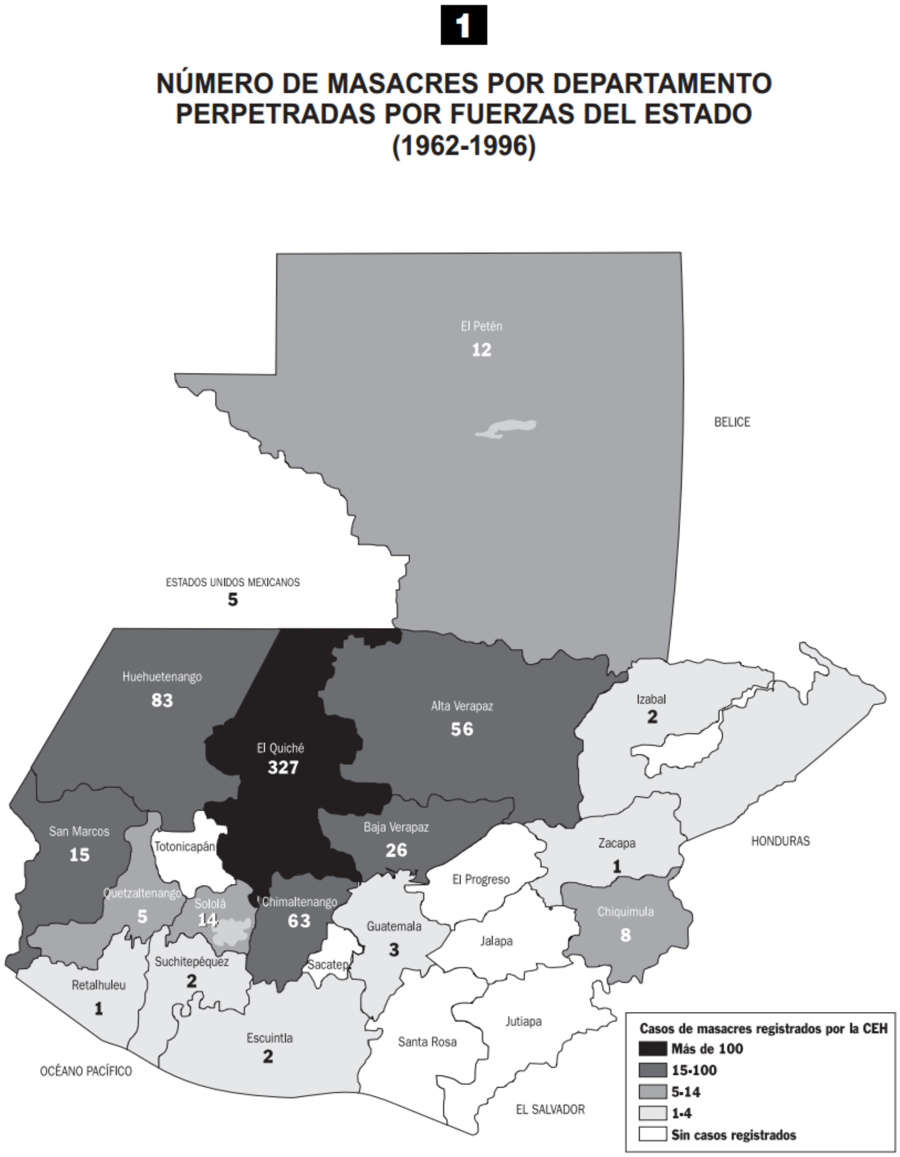

Fig. 2. Number of massacres per department committed by state forces. Source: CEH, database. It was not possible to identify the one masacre. Original image is from (Historical Clarification Commission (CEH), 1999a, p. 519 Vol II)

References Table 4. Supporting reference for an Invasion event

Quote Text	Summary	Simulated distribution	Comments
"From 1980 to 1984, the size of the Guatemalan armed forces expanded from fifteen to forty thousand" (Hall, 1994; Historical Clarification Commission (CEH), 1999a, p. 87 Vol III) "Guatemala's military almost doubled in just one year, from 1983-84 (21,560) to 1984-85 (40,000)" (Coerver & Hall, 1999, p. 155)	Around 50 000	A uniform distribution seems to be the best approximation in this case as the invaders were distributed across all the territory. X = 50000/2500000 < 3%	The uniform distribution is preferred because it is not clear where the army was concentrated. Although civilians were forced to participate as part of the government forces in the forms of civil patrols and military commissioners, most of the crimes were committed by the official army forces, or in their presence and orders. Therefore, the official army forces are the only ones counted as invaders, as the civilians involved were generally acting against their will.
"The army began *Operación Ceniza* in November 1981 and continued in 1982. The name "Operation Ashes" clearly stated the campaign's intent, suggesting how the army planned to deal with villages in the guerrilla zone of activity. The army first committed mass killings and burned villages to take control of the Pan-American Highway running through Chimaltenango and southern Quiché. Then some 15,000 troops participated in a slow sweep through the department of El Quiché, into Huehuetenango, and all the way to the border with Mexico" (Ball et al., 1999, pp. 26–27) "Operación Ceniza" ("Operation Ash"). In a strategy developed jointly by Benedicto Lucas Garcia and Lieutenant Col. George Maynes (U.S. Defense Attache and Chief of the U.S. MilGroup in Guatemala), [Report on Guatemala, Guatemala News and Information Bureau, 1986, p. 24] some 15,000 troops were deployed on a gradual sweep through the highlands. (Grupo de Apoyo Mutuo, 1996, p. 42)	15000 troops		
"1291. Las referencias que se tienen con relación al número de patrulleros civiles en todo el país, inician en 1981 con aproximadamente 25,000 hombres. Según cifras oficiales del Ejército, "en el año de 1982 se contaba con un millón de patrulleros civiles". Desde el reinicio de los gobiernos civiles en 1986 es que empiezan a disminuir: "en 1996 habían menos de 40,000 organizados"; según el Ejército, para ese año tenían registrados 270,906 en 15 departamentos del país." (Historical Clarification Commission (CEH), 1999a, p. 190 Vol II) See graph on Fig. 4 for a distribution disappearances and executions by dates. (Historical Clarification Commission (CEH), 1999a, p. 168 Vol II)	The army forced the population to help them in the form of civil patrollers (PAC) and military commissioners.		

"In the CIIDH database, for cases in which the perpetrator is known, testimonies and documentary sources attribute the greater share of killings and disappearances to army personnel. Other types of government perpetrators include civil patrollers (PACs), military commissioners, clandestine death squads, the National Police and even the Treasury Police" (Ball et al., 1999, p. 96) See graph on Fig. 5 for an overview of the involvement of the different parts in the disappearances and killings. (Historical Clarification Commission (CEH), 1999a, p. 337 Vol II)			
"858. La evolución de las operaciones contrainsurgentes y la regionalización del enfrentamiento armado fueron factores determinantes para el despliegue territorial de las unidades militares. La doctrina del Ejército en la década de los sesenta fue, básicamente, de protección de sus fronteras ante una agresión militar externa para enfrentar operaciones de índole convencional. Sin embargo, después de los inicios del enfrentamiento armado, la importancia estratégica de las diferentes regiones en que se dividió el país en esta década, obedeció a una distribución con carácter geopolítico militar y estuvo puntualizada principalmente en la región del Oriente del país, donde se focalizó la acción de la guerrilla." (Historical Clarification Commission (CEH), 1999a, p. 47 Vol II) See left map on Fig. 6 for a territorial distribution of the military zones before 1961 (Historical Clarification Commission (CEH), 1999a, p. 524 Vol II) "859. Hacia finales de la década de los setenta y principios de la década de los ochenta, con el resurgimiento de las acciones militares por parte de la guerrilla, el Ejército empleó dos conceptos y objetivos estratégicos: uno, el control físico del terreno ocupado por efectivos militares; y dos, la utilización de las Patrullas de Autodefensa Civil (PAC). Estas últimas consolidaron el control territorial, cubriendo el espacio físico que el Ejército no ocupaba y ejerciendo labores de control sobre la población civil." (Historical Clarification Commission (CEH), 1999a, p. 47 Vol II) "860. En 1983 el Ejército alcanzó el objetivo estratégico territorial a través de la creación de nuevas zonas y bases militares. Esta organización territorial en el interior del país se realizó desplegando una o más unidades militares por departamento, que coincidieron con los límites políticos administrativos. En la ciudad capital siguieron existiendo varias unidades militares, en proporción al	The army was scattered all over the Guatemalan territory, although the military zones were used as the main basis.		

número de población y al concepto de despliegue militar urbano." (Historical Clarification Commission (CEH), 1999a, p. 47 Vol II) See maps on Fig. 6 for a territorial distribution of the military zones after 1983 (Historical Clarification Commission (CEH), 1999a, p. 524 Vol II) "861. Las zonas militares, por su distribución geográfica y número de miembros, recibieron a las unidades más preparadas durante el enfrentamiento. Estas instalaciones militares conformaron la base estructural del Ejército y en ellas prestaron su servicio la mayoría de los oficiales. Al ser instalaciones militares fijas y permanentes, permitieron al Ejército tener una o más bases de operaciones centralizadas en cada región del enfrentamiento, las que podía crear, reunificar o replegar cada vez que fuese necesario. La permanencia de estas unidades dentro de las zonas, significó la continuidad operativa en el terreno, a diferencia de las Fuerzas de Tarea, que se articulaban para una operación determinada y se desactivaban una vez cumplida la misión. Las tropas especiales, como los paracaidistas y kaibiles, estaban constituidas para dar apoyo a las operaciones de estas unidades militares." (Historical Clarification Commission (CEH), 1999a, pp. 47–48 Vol II) "862. De la totalidad de violaciones de los derechos humanos atribuidas al Ejército durante el enfrentamiento, el 89.99% corresponde a las unidades regulares desplegadas en las zonas y bases militares." (Historical Clarification Commission (CEH), 1999a, p. 48 Vol II)			

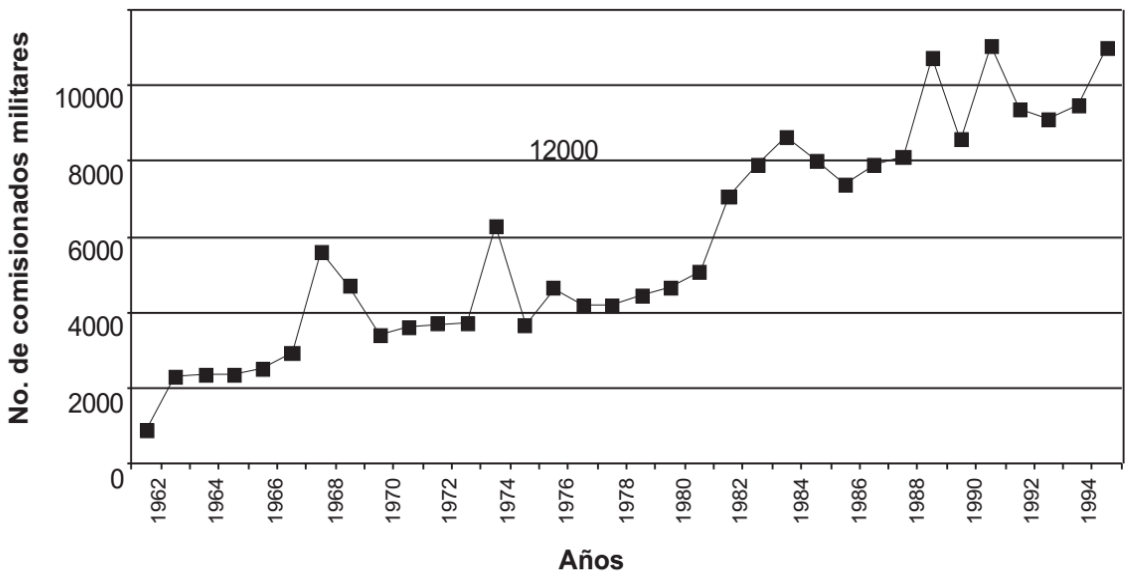

Fig. 4. Total of military commissioners by date, Guatemala (1962-1995). Original image taken from (Historical Clarification Commission (CEH), 1999a, p. 168 Vol II)

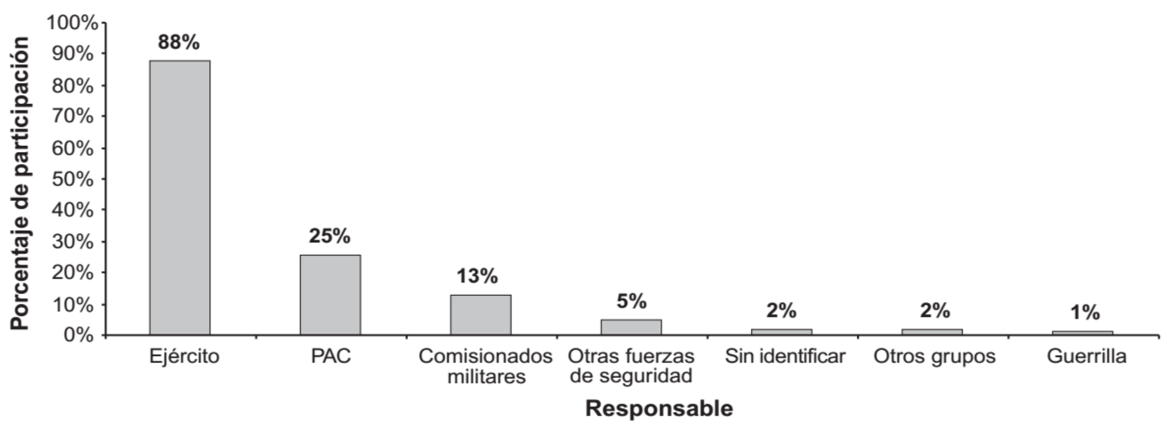

Fig. 5. Percentage of participation of responsible forces in arbitrary killings. Percentages are calculated without considering if the force performed on its own, or together with another force, so percentages do not add up 100%. Original image taken from (Historical Clarification Commission (CEH), 1999a, p. 337 Vol II)

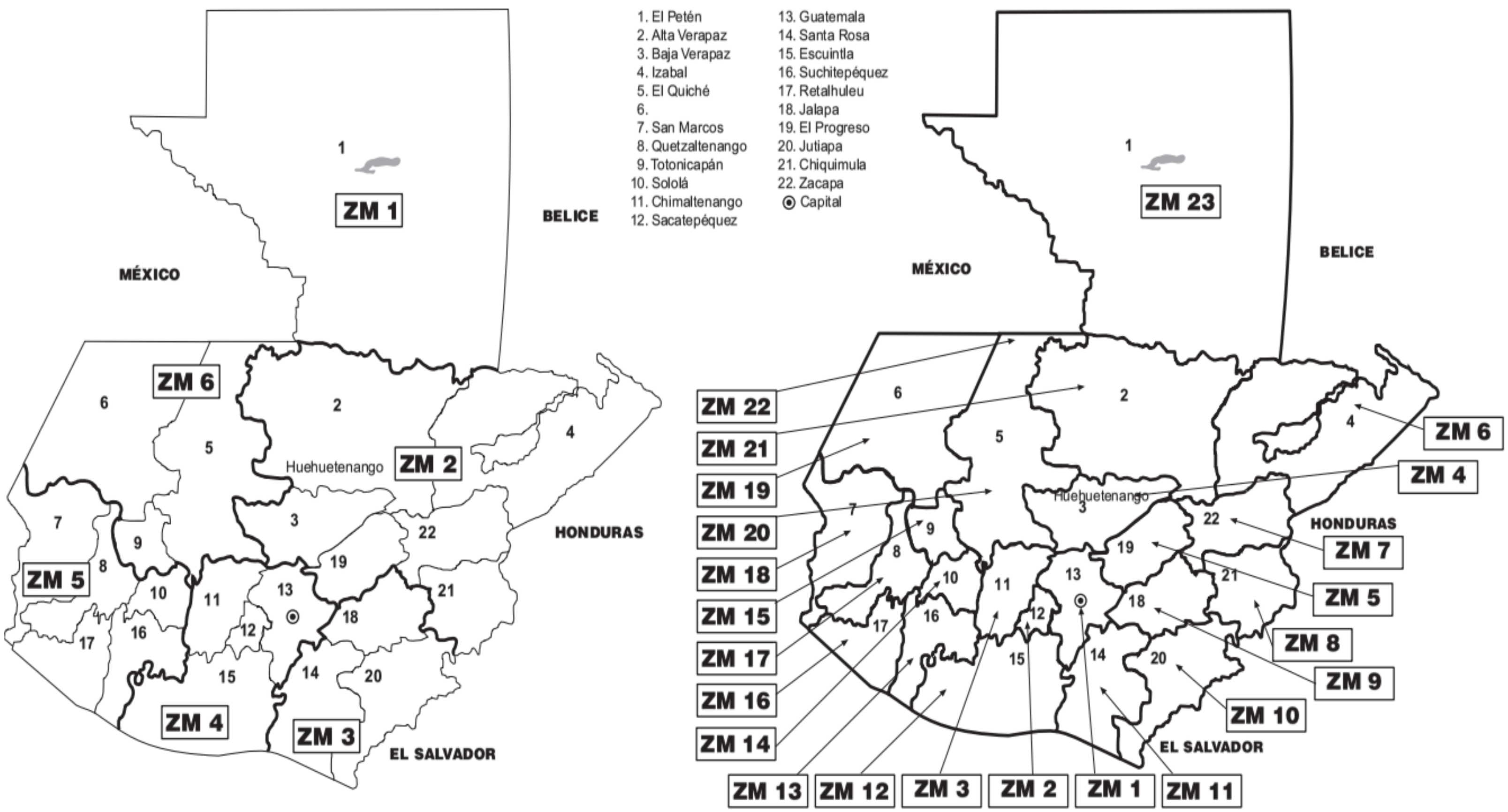

Fig. 6. Territorial distribution of the military zones in 1961 (left) and 1983. Original images taken from (Historical Clarification Commission (CEH), 1999a, pp. 524–525 Vol II)

References Table 5. Supporting reference for an Apostasy event

Quote Text	Summary	Simulated distribution	Comments
'Marxists,' a word used derogatorily by (orthodox indigenistas) to refer to Indian campesinos who resented both ethnic-cultural and class oppression" (Arias, 1990, p. 255) "in October 1981, when the president's brother, Benedicto Lucas García, took command of the counterinsurgency campaign in the highlands, the president of the National Institute of Cooperatives (INACOOP), a government agency created with US funds, declared 250 cooperatives illegal because of their supposed 'Marxist inspiration' (Davis, 1992, p. 22) "59. As well as repression and exile, the weakening and fragmentation of social organisations were largely due to the various mechanisms activated during the armed confrontation by the State to destroy them. These mechanisms continue to be present in the collective memory. **Stigmatisation, fear, mistrust and the perception in some sectors that the signing of the peace accords has not yet changed the repressive State, are still obstacles which prevent the full participation of society**, even though the process of peace and national reconciliation indicates an encouraging reversal of this tendency. 60. **The participation by members of insurgent** groups in social organisations also affected them, not only because it created one more reason for their repression, but also because in many cases it **led to division, polarisation and serious in-fighting in the organisations, inevitably weakening them**. The vertical structure that the insurgency brought to the social organisations in which it participated curtailed their freedom to make their own decisions, suffocating their autonomy and exacerbating the effects of the State's repressive policies of **dismantling the country's social and political opposition**. (…) 62. The CEH concludes that the Mayan communities also became a military objective during the bloodiest years of the confrontation. In some regions and years, because of the terror and persecution**,**	People had to hide their identities to avoid prosecution. The association between Marxism and indigenous people made it dangerous to show strong affiliation with the Maya identity. Many people were forced to join the armies in the PAC and military commissioners, at least temporarily	Uniformly distributed all across Guatemala. There is very little point to assume that the distribution was concentrated in Quiche because everybody would have been scared specially toward in the Rios Montt period. An arbitrary value of 50% is picked for the uniform distribution.	People where prosecuted as part of the communism movement, we can then assume that a lot of people stopped being officially part of institutions.

Mayans were obliged to conceal their ethnic identity, manifested externally in their language and dress. 63. Beginning in 1982, traditional Mayan authorities were generally substituted by delegates from the armed forces, such as military commissioners and PAC commanders. In other cases, the Army tried to control, co-opt and infiltrate the traditional Mayan authority structures. **This strategy caused the rupture of both community mechanisms and the oral transmission of knowledge of their own culture**, likewise damaging Mayan norms and values of respect and service to the com-munity. In their stead, authoritarian practices and the arbitrary use of power were introduced."" (Historical Clarification Commission (CEH), 1999b, pp. 29–30) "4188. **El discurso persuasivo usado en las constantes campañas para estigmatizar a las organizaciones del movimiento social las presentaba como el brazo político de la insurgencia, mensaje que fue interiorizado por importantes sectores de la sociedad**. Por lo tanto, aparte de la eliminación física de gran cantidad de sus miembros, **también se vulneró en la población la confianza hacia las organizaciones sociales y sus miembros**." (Historical Clarification Commission (CEH), 1999a, p. 119 Vol IV) "4295. Igualmente, la pérdida de cuadros del movimiento social que durante décadas habían intentado obtener espacios para actuar políticamente en el país, significó un importante rezago en la formación de futuros dirigentes de la sociedad guatemalteca. **En el caso de las comunidades mayas, la pérdida de los ancianos en las masacres, pero también, en los rigores del desplazamiento**, impuso la ausencia de las cabezas de la comunidad, de la sabiduría y del conocimiento acumulados." (Historical Clarification Commission (CEH), 1999a, pp. 153–154 Vol IV) "4412. **Por el terror y la persecución los pueblos mayas se vieron obligados, en ciertas regiones y durante años, a ocultar su identidad expresada en su idioma y en su traje. Con la militarización se perturbó el ciclo de fiestas y ceremonias y se afirmó en la clandestinidad el conjunto de las prácticas ceremoniales mayas.** La agresión estuvo dirigida a dañar elementos			

que poseen profundos contenidos simbólicos para la cultura maya, como fue la destrucción del maíz y el asesinato de ancianos. Estos hechos vulneraron elementos de la identidad de los mayas y alteraron la transmisión intergeneracional de la misma." (Historical Clarification Commission (CEH), 1999a, p. 191 Vol IV)			

References Table 6. Supporting reference for an Institutional Destruction event

Quote Text	Summary	Simulated distribution	Comments
"in October 1981, when the president's brother, Benedicto Lucas García, took command of the counterinsurgency campaign in the highlands, the president of the National Institute of Cooperatives (INACOOP), a government agency created with US funds, declared 250 cooperatives illegal because of their supposed 'Marxist inspiration'" (Davis, 1992, p. 22) "By the fall of 1975 nearly 20% of Highland Maya participated in some form of cooperatives (Handy, 1984, p. 240) and after the 1976 earthquake and the influx of additional international lenders, Guatemala boasted 510 cooperatives, 57% of them in the Highlands with more than 132,000 members (Brockett, 1998, p. 112)" (Lyon, 2007, p. 245)	250 cooperatives where declared illegal	A normal distribution better reflect the way in which the destruction happen given the centralization of events in Quiché. Based on the amount of cooperatives that were destroyed (250) and the amount existing in 1976 (510) we could estimate a destruction of ~50% of cooperatives. However, cooperatives seem to have been the primary targets, and since there are many others forms of organizations (institutions) that	There is an intrinsic relation between institutional destruction and institutional content. It is also difficult to distinguish between them. In order for an institution to be destroyed, its content has to be removed as well as its leaders. This means that the mere destruction of the physical space doesn´t mean the immediate destruction of the institution as an abstract entity. For example, people could still find more meaning in the leaders of the institutions, than in
The following appendices of the CEH report tabulates reported damages and destruction of cooperatives, farms, infrastructure and civil records. - Destrucción y daños a las cooperativas (Historical Clarification Commission (CEH), 1999a, pp. 266–268 Vol IV) - Destrucción y daños a fincas, 1978-1994 (Historical Clarification Commission (CEH), 1999a, pp. 269–271 Vol IV) - Infraestructura destruida, 1981-1995 (Historical Clarification Commission (CEH), 1999a, pp. 272–274 Vol IV) - Registros civiles destruidos por causa del enfrentamiento armado (Historical Clarification Commission (CEH), 1999a, p. 275 Vol IV) A summary of the economic costs in terms of cooperatives, farms and infrastructure can be found in (Historical Clarification Commission (CEH), 1999a, pp. 209–210 Vol IV)	Destruction and damage of cooperatives, farms, infrastructure, civil records		
The geographical distribution of the costs reflect that the attacks where centralized in Quiché (Historical Clarification Commission (CEH), 1999a, pp. 216–219 Vol IV)	Centralized		

The following sections of the CEH report qualitatively describes the effects in terms of institutional destructions: - La desestructuración de los sistemas de autoridad y organización comunitarias (Historical Clarification Commission (CEH), 1999a, pp. 167–172 Vol IV) - Persecución y muerte de autoridades indígenas (Historical Clarification Commission (CEH), 1999a, pp. 172–174 Vol IV) - Ruptura de estructuras de solidaridad (Historical Clarification Commission (CEH), 1999a, pp. 182–183 Vol IV)	Also shows the relation between institutional destruction and institutional content removal.	were not explicitly targeted as a military strategy, 50% is a very high value in general. Since destruction happen all over the Guatemalan territory but still concentrated in the quiche, a low ceiling of 50% will be used.	its physical assets. In this case, it is considering content removal (see next table). Some institutions would be almost impossible to destroy because even if all the content is lost, the connection towards the abstract institution is so strong that the institution gain content just by its name. For example, the connection to myths such as the relation with land and specifically with corn would not be easily destroyed, not even burning down all corn fields.
“58. **The CEH has confirmed that during the armed confrontation, social organisations were an important target of the State's repressive action. Considered as part of the "internal enemy", hundreds of leaders and grassroots members of a wide spectrum of groups were eliminated.** These actions left civil society weakened and still affect its full participation in Guatemala's political and economic debates. The loss of professionals, academics and researchers, the "creative powers" who died or went into exile, not only created a vacuum during a specific period of political and cultural history, but also resulted in the loss of an important part of the pedagogic and intellectual capacity to educate several future generations in Guatemala 59. **As well as repression and exile, the weakening and fragmentation of social organisations were largely due to the various mechanisms activated during the armed confrontation by the State to destroy them**. (…) 64. The presence of the guerrillas also led to the displacement of traditional authorities and to a reduction of their power, especially through **the establishment of their own authority structures, such as the Local Irregular Forces and the Local Clandestine Committees, which generated new leadership within the communities**” (Historical Clarification Commission (CEH), 1999b, pp. 29–30) 4187. A lo largo del enfrentamiento armado**, la organización social fue un objetivo primordial para el Estado, un objetivo que debía desestructurarse en tanto fuera considerada una amenaza para la seguridad nacional**. De ahí que **la represión eliminara a gran cantidad de líderes, así como a cuadros medios y a miembros de base, dejando como saldo la discontinuidad en el trabajo organizativo de las diferentes entidades de la sociedad civil**, la pérdida de su experiencia acumulada y el			

vacío de formadores de futuros dirigentes. (Historical Clarification Commission (CEH), 1999a, pp. 118–119 Vol IV) “4409. En los años de exacerbación del enfrentamiento y la violencia, entre 1979 y 1984, con la ampliación del campo de operaciones de la guerrilla, el Ejército identificó a los indígenas como guerrilleros, sin la individualización pertinente. La consecuencia de ello fue la agresión masiva e indiscriminada contra las comunidades mayas, con independencia de que estuvieran o no colaborando con la guerrilla. Con las masacres, la política de tierra arrasada, el secuestro y la ejecución de autoridades, líderes mayas y guías espirituales, no sólo se buscaba **quebrar las bases sociales de la insurgencia**, sino también desestructurar los mecanismos de identidad y de cohesión social que facilitaban las acciones colectivas de las comunidades (…) 4412. Por el terror y la persecución los pueblos mayas se vieron obligados, en ciertas regiones y durante años, a ocultar su identidad expresada en su idioma y en su traje. Con la militarización se perturbó el ciclo de fiestas y ceremonias y se afirmó en la clandestinidad el conjunto de las prácticas ceremoniales mayas**. La agresión estuvo dirigida a dañar elementos que poseen profundos contenidos simbólicos para la cultura maya, como fue la destrucción del maíz y el asesinato de ancianos. Estos hechos vulneraron elementos de la identidad de los mayas y alteraron la transmisión intergeneracional de la misma.**” (Historical Clarification Commission (CEH), 1999a, pp. 190–191 Vol IV)			

References Table 7. Supporting reference for an Institutional Content Removal event

Quote Text	Summary	Simulated distribution	Comments
On 7 July 1975, one month to the date after the assassination of Arenas, a contingent of army paratroopers arrived in the marketplace of Ixcán Grande. There they seized 30 men who were members of the Xalbal cooperative and took them away in helicopters; all were subsequently "disappeared". (Amnesty International, 1976, p. 9; McClintock, 1985, p. 133) A total of 60 cooperative leaders were murdered or "disappeared" in Ixcan between June and December 1975. An additional 163	Cooperative leaders were prosecuted, and murdered	**Full Centralized (.75,.25%):** reflects when complete buildings or sacred places were destroyed. **Partial Centralized (.75,.25%):** reflects when the institutions	Two types of content removals can be distinguished, the ones in which all the content of some institutions is wiped out, and others in which only partial information is removed. Both types are possible

cooperative and village leaders were assassinated by death squads between 1976 and 1978. Believing that the Catholic Church constituted a major part of the social base of the EGP, the regime also began singling out targets among the catechists. Between November 1976 and December 1977, death squads murdered 143 Catholic Action catechists of the 'Diocese of El Quiche.' (Hayes & Tombs, 2001) 511. En Quiché el Ejército realizó acciones represivas, asesinando a 68 líderes de cooperativas en Ixcán, 40 en Chajul, 28 en Cotzal y 32 en Nebaj entre febrero de 1976 y noviembre de 1977, según el IGE. (Historical Clarification Commission (CEH), 1999a, p. 162 Vol I)		were damaged but some content survived **Uniform (~16%):** most of the damage was in the central region but this percentage reflects a general damage on all the territory	to simulate with the tool. The examples of the first case (full content) are better illustrated in the previous table of institutional destruction. As argued there, the elimination of the whole physical space doesn´t immediately imply the loss of the link to an abstract (empty institutions). It is, though, impossible to clearly distinguish the proportion of the cases that belongs to institutional destruction or to full content removal. However, I would argue that losing the connection with an institution is much harder, so the institutional destruction will be much lower that the full-content removal. It also seems that a full-content removal is pre-requisite for the institutional destruction. This is to say that an institution will continue existing if there is content associated to it. A
The following sections of the CEH report qualitatively describes the effects in terms of institutional content removal: - Persecución y muerte de autoridades indígenas (Historical Clarification Commission (CEH), 1999a, pp. 172–174 Vol IV) - Pérdida de valores, normas, costumbres (Historical Clarification Commission (CEH), 1999a, pp. 179–182 Vol IV) - La identidad maya y expresiones religiosas (Historical Clarification Commission (CEH), 1999a, pp. 183–186 Vol IV) - Ocupación y destrucción de lugares sagrados (Historical Clarification Commission (CEH), 1999a, pp. 186–187 Vol IV) - Uso de los idiomas y trajes mayas (Historical Clarification Commission (CEH), 1999a, pp. 187–189 Vol IV)	Indigenous symbols were attacked and destroyed.		
"58. (…) **The loss of professionals, academics and researchers,** the "creative powers" who died or went into exile, not only created a vacuum during a specific period of political and cultural history, but also **resulted in the loss of an important part of the pedagogic and intellectual capacity to educate several future generations in Guatemala**" (Historical Clarification Commission (CEH), 1999b, p. 29) 62. (…) **Militarization of the communities disturbed the cycle of celebrations and ceremonies, and concealment of their rituals became progressively more widespread. Aggression was directed against elements of profound symbolic significance for the Mayan culture, as in the case of the destruction of corn and the killing of**	With the elimination of the leaders, many values and ideals were also lost.		

their elders. These events had a serious impact on certain elements of Mayan identity and disturbed the transmission of their culture from generation to generation. Similarly, the culture was degraded through the use of Mayan names and symbols for task forces and other military structures. structures. (Historical Clarification Commission (CEH), 1999b, p. 29) 63. Beginning in 1982, traditional Mayan authorities were generally substituted by delegates from the armed forces, such as military commissioners and PAC commanders. In other cases, the Army tried to control, co-opt and infiltrate the traditional Mayan authority structures. This strategy caused the rupture of both community mechanisms and the oral transmission of knowledge of their own culture, **likewise damaging Mayan norms and values of respect and service to the community**. In their stead, authoritarian practices and the arbitrary use of power were introduced. (Historical Clarification Commission (CEH), 1999b, p. 30) 64. **The presence of the guerrillas also led to the displacement of traditional authorities and to a reduction of their power** (Historical Clarification Commission (CEH), 1999b, p. 30) 4187. A lo largo del enfrentamiento armado, la organización social fue un objetivo primordial para el Estado, un objetivo que debía desestructurarse en tanto fuera considerada una amenaza para la seguridad nacional. De ahí que la represión eliminara a gran cantidad de líderes, así como a cuadros medios y a miembros de base, dejando como saldo la discontinuidad en el trabajo organizativo de las diferentes entidades de la sociedad civil, **la pérdida de su experiencia acumulada y el vacío de formadores de futuros dirigentes**. (Historical Clarification Commission (CEH), 1999a, pp. 118–119 Vol IV) “4409. En los años de exacerbación del enfrentamiento y la violencia, entre 1979 y 1984, con la ampliación del campo de operaciones de la guerrilla, el Ejército identificó a los indígenas como guerrilleros, sin la individualización pertinente. La consecuencia de ello fue la agresión masiva e indiscriminada contra las comunidades mayas, con			different consequence is that the members might quit the institution given its lack of content. In this case the agents in the simulation possess the mechanisms to move to another simulation, also some of this institutional abandonment is contained in the apostasy. A less controversial topic is the partial content removal. To better reflect this across the grid, two partial removal events are superposed, a uniform event with low probability to make sure all the grid gets affected. Then a centralized event is created to reflect the areas that were affected the most.

independencia de que estuvieran o no colaborando con la guerrilla. Con las masacres, la política de tierra arrasada, el secuestro y la ejecución de autoridades, líderes mayas y guías espirituales, no sólo se buscaba quebrar las bases sociales de la insurgencia, sino también **desestructurar los mecanismos de identidad y de cohesión social que facilitaban las acciones colectivas de las comunidades**.” (Historical Clarification Commission (CEH), 1999a, pp. 190–191 Vol IV)			

References Table 8. Supporting reference for an Institutional Conversion event

Quote Text	Summary	Simulated distribution	Comments
“63. **Beginning in 1982, traditional Mayan authorities were generally substituted by delegates from the armed forces, such as military commissioners and PAC commanders. In other cases, the Army tried to control, co-opt and infiltrate the traditional Mayan authority structures.** This strategy caused the rupture of both community mechanisms and the oral transmission of knowledge of their own culture, likewise damaging Mayan norms and values of respect and service to the com-munity. **In their stead, authoritarian practices and the arbitrary use of power were introduced**. (Historical Clarification Commission (CEH), 1999a, pp. 118–119 Vol IV)	Violent substitution of traditional Maya authorities for military ones.	**Full Centralized (.75,.25%):** reflects when complete institutions were taken **Partial Centralized (.75,.25%):** if an institutions was not completely taken, it was at least partially changed.	In this case, the militarization is happening across all the territory. It is important to highlight that some of this occupation was temporal, but some stick with the institutions. The most important are the permanent changes. Considering that the transformation was merely military, e.g. there was no religious evangelization, a low partial conversion as starting point is enough (20%) Some of the institutions were transformed
The following sections of the CEH report qualitatively describes the effects in terms of institutional conversion: - Sustitución de autoridades mayas y sus funciones por autoridades militares (Historical Clarification Commission (CEH), 1999a, pp. 174–177 Vol IV) - Control, cooptación e infiltración de las estructuras de autoridad indígena (Historical Clarification Commission (CEH), 1999a, pp. 177–179 Vol IV) - Pérdida de valores, normas, costumbres (Historical Clarification Commission (CEH), 1999a, pp. 179–182 Vol IV) - Ocupación y destrucción de lugares sagrados (Historical Clarification Commission (CEH), 1999a, pp. 186–187 Vol IV)	Norms were replaced at an institutional level. Sacred placed were taken by the police.		
“4380. La mayor parte de jóvenes indígenas difícilmente se escapaba de la experiencia castrense. Muchos jóvenes, después de estar en el Ejército, abandonaban sus comunidades. Otros, al regresar, se convertían en un elemento perturbador dentro de la misma. Haber servido en el Ejército era valorado positivamente por los militares al nombrar a los jefes de las	Most of the (male) young people become part of the army and followed		

<table>
<tr>
<td>patrullas o a los comisionados militares. Así, la experiencia violenta del Ejército se trasladaba e implantaba en el seno de las comunidades.” (Historical Clarification Commission (CEH), 1999a, pp. 181–187 Vol IV)</td>
<td>this tradition afterwards.</td>
<td rowspan="2"></td>
<td rowspan="2">completely into militarism. For example, a lot of young people were completely militarized and followed this tradition. A full-conversion of 20% is introduced to model this.

The 20% is not completely arbitrary. In the partial-conversion case, the value tries to only reflect the military values that infiltrated the institutions, as others sectors (e.g. religion, economy, justice values) might have not been converted, at least directly.

The other 20% tries to reflect a sector of the population that were militarized. The value might seem low but we need to consider that a lot of the militarized people actually migrated out of their communities.</td>
</tr>
<tr>
<td>“63. Beginning in 1982, traditional Mayan authorities were generally substituted by delegates from the armed forces, such as military commissioners and PAC commanders. In other cases, the Army tried to control, co-opt and infiltrate the traditional Mayan authority structures. This strategy caused the rupture of both community mechanisms and the oral transmission of knowledge of their own culture, likewise damaging Mayan norms and values of respect and service to the com-munity. In their stead, authoritarian practices and the arbitrary use of power were introduced. (Historical Clarification Commission (CEH), 1999b, p. 30)

“4022. No es posible analizar las consecuencias del debilitamiento del Estado y la falta de confianza en la administración de justicia enfocando el problema sólo en las instituciones formales. Para grandes sectores de la población guatemalteca, sus autoridades y su sistema normativo provienen de otras fuentes culturales vinculadas a su propia evaluación como pueblo, preexistente incluso a la conquista española. Al tradicional racismo y menosprecio por este antiguo orden de autoridades y formas de resolver conflictos, es decir el sistema de derecho maya, con la represión y militarización de sus comunidades, se sumó una nueva y más intensa política de agresión y sometimiento cultural.
4023. Históricamente, el poder central permitió las modalidades organizativas propias de las comunidades indígenas en sus espacios locales, siempre y cuando no afectaran los intereses de otros sectores. Esta relación de relativa tolerancia, cuando no abandono o ignorancia de parte del Estado hacia las comunidades, se modificó profundamente durante el enfrentamiento armado. Intervenir en la vida del pueblo maya, en particular a través de los comisionados militares y las PAC, se convirtió en un elemento central de la estrategia contrainsurgente y del terrorismo de Estado. Esta intromisión militar afectó las relaciones de poder legítimo dentro de las comunidades, con enormes consecuencias en los patrones legales que regían las mismas. El cambio de un modelo de resolución de conflictos y de convivencia comunitaria por otro centrado en la arbitrariedad, el autoritarismo y el castigo cruel, afectó toda la</td>
<td>This seems to have happened across all the territory. There is no indication that the conversion was stronger in the most affected areas. It was probably more violent.</td>
</tr>
</table>

estructura de normas de la comunidad y las relaciones sociales que éstas pretenden regular. 4024. **Esta sustitución violenta de las autoridades y formas judiciales propias de las comunidades mayas y el debilitamiento consiguiente de su sistema normativo y judicial, realizados por el Ejército y sus agentes, avalados por el sistema judicial y propiciados por el conjunto del Estado,** se convirtió, entonces, en otra de las consistentes razones que tiene el ciudadano guatemalteco para desconfiar en las leyes" (Historical Clarification Commission (CEH), 1999a, pp. 65–55 Vol IV) "4191. La intervención de miembros de la insurgencia en las organizaciones sociales también afectó a éstas, no sólo porque la participación insurgente fue un factor más para que fueran reprimidas, sino también porque en muchos casos provocó **divisiones, polarización y fuertes luchas en el seno de las propias organizaciones que al final resultaron muy debilitadas**." (Historical Clarification Commission (CEH), 1999a, p. 119 Vol IV) "4410. A las estrategias referidas se **sumaron la sustitución de autoridades mayas por mandos o delegados militares, la imposición de elementos militarizados como los comisionados militares y los patrulleros civiles, el control, la cooptación y la infiltración de las estructuras de autoridad indígenas**. El conjunto de estas medidas tuvo como consecuencia **la ruptura de los mecanismos comunitarios de reproducción de la vida social, de la transmisión del conocimiento oral de la propia cultura, así como la vulneración de las estructuras de autoridad, las normas y los valores mayas de respeto y de servicio a la comunidad. En su lugar se introdujeron prácticas de autoritarismo, desprecio por la vida humana y uso arbitrario del poder**." (Historical Clarification Commission (CEH), 1999a, p. 191 Vol IV)			

References Table 9. Other references excluded from the simulation

Quote Text	Comments
"61. Freedom of speech goes hand in hand with the free exercise of civil rights. When opportunities for social and political participation are closed, then, implicitly, so are opportunities for freedom of speech. During the long period of armed confrontation, even thinking critically was a dangerous act in Guatemala, and to write about political and social realities, events or ideas, meant running the risk of threats, torture, disappearance and death. In exercising freedom of speech, citizens, writers, artists,	Since democracy is not used in the simulation, certain circumstances cannot be simulated.

poets, politicians and journalists were subject to the risks that repression and ideological polarisation imposed upon them. Although there were people who spoke out despite the risks, the large news agencies, in general, supported the authoritarian regimes through self-censorship and distortion of the facts. The price was very high, not only in the number of Iives lost, but also because Guatemala became a country silenced, a country incommunicado."(Historical Clarification Commission (CEH), 1999b, p. 29)	
"the Inter-American Commission, in its discussion of the right to freedom of religion and conscience, expressed <u>concern about threats to the integrity of the Roman Catholic church in rural areas</u> of Guatemala, especially given the previous human rights violations against church personnel and the espoused Protestant fundamentalism of the then president of Guatemala. Although the commission noted that there were no new reports of priests being assassinated, kid-napped, or tortured, as had occurred with great regularity during the previous regime of Gen. Romero Lucas García, it did describe how an Indian catechist was murdered during the visit of Pope John Paul II to Guatemala in march 1983. It also described how Roman Catholic clergy feared reopening more than seventy social-action centers that had been closed during the previous regime, how religious polarization has increased since Gen. Ríos Montt had assumed power, and how Catholic lay leaders were being harassed by local military commanders." (Davis, 1992, pp. 7–8) The CEH report describes the role that the catholic church played in the community and the consequences of the attacks against its members (Historical Clarification Commission (CEH), 1999a, pp. 109–155 Vol IV)	The role of the catholic church is entangled. Christianity on the ladino is very different from the indigenous Christianity. Although the catholic church tries to project itself as a unique institution, it is clear that there exist divisions, Guatemalan syncretism is just another example. Therefore, the simulation captures attacks to members of the clergy.
"4324. La experiencia de resistencia, que manifestó una diversidad de modalidades a través de los esfuerzos de la gente por preservar su identidad, provocó igualmente importantes cambios precisamente en ésta. La interacción con otros grupos étnicos, con gente de las áreas urbanas, con ciudadanos de otros países, con otros sistemas educativos, con diferentes entornos naturales, y la misma experiencia de la persecución y muerte, transformaron ese elemento relacional que es la identidad para producir una sociedad guatemalteca marcada por el conflicto, pero también fortalecida potencialmente en la experiencia de la diversidad." (Historical Clarification Commission (CEH), 1999a, p. 163 Vol IV) The CEH report describes many implications of the internal and external displacement (Historical Clarification Commission (CEH), 1999a, pp. 119–163 Vol IV), among them the cultural re-composition of the society: "4324. La experiencia de resistencia, que manifestó una diversidad de modalidades a través de los esfuerzos de la gente por preservar su identidad, provocó igualmente importantes cambios precisamente en ésta. La interacción con otros grupos étnicos, con gente de las áreas urbanas, con ciudadanos de otros países, con otros sistemas educativos, con diferentes entornos naturales, y la misma experiencia de la persecución y muerte, transformaron ese elemento relacional	The internal displacement of people is not covered in the simulation. Future work should include this.

que es la identidad para producir una sociedad guatemalteca marcada por el conflicto, pero también fortalecida potencialmente en la experiencia de la diversidad.” (Historical Clarification Commission (CEH), 1999a, p. 163’ Vol IV)	
“4411. Con la introducción de las Patrullas de Autodefensa Civil, comisionados militares, confidentes del Ejército y la aculturación violenta de los jóvenes a través de reclutamiento militar forzado, se trastocaron las relaciones sociales, socavando la confianza y los lazos comunitarios de solidaridad. Lo grave del fenómeno radica en que estos mecanismos de violencia y delación tenían lugar en el interior de las comunidades y las familias, por lo cual sus efectos han sido más profundos y duraderos.” (Historical Clarification Commission (CEH), 1999a, p. 191 Vol IV)	According to this, some individuals where converted to follow a military tradition. This situation escapes the simulation possibilities. It would be equivalent to an individual partial conversion; a full conversion is still possible by introducing more invaders.
“In 1979 it changed its methods of struggle, and began implementing actions such as sabotage, propaganda bombs, blocking highways and barricades.” (Historical Clarification Commission (CEH), 1999a, p. 252 Vol IV)	This also suggests changes in the institutional mechanisms, in this case propaganda. Propaganda has not been analyzed in the current research

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	Western Graduate Research Scholarship (WGRS) 2011-2013/2014-2016
	Award of Excellence. USC Teaching Honor Roll 2012-2013
	Mitacs Globalink Research Award 2015
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Related Work Experience

Teaching Assistant
The University of Western Ontario
2012-2013

Research Assistant
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Lecturer, Course Coordinator
University of Costa Rica
2008-2010

Publications:

Ulloa, R. (In Press). CulSim: A simulator of emergence and resilience of cultural diversity, SoftwareX. http://dx.doi.org/10.1016/j.softx.2016.07.005

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