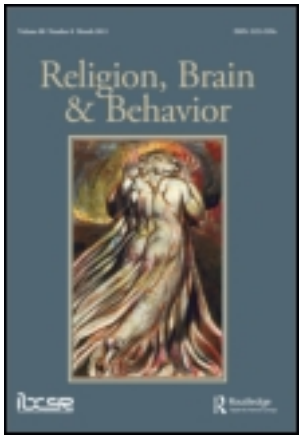

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The role for simulations in theory construction for the social sciences: case studies concerning Divergent Modes of Religiosity

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TARGET ARTICLE

The role for simulations in theory construction for the social sciences: case studies concerning Divergent Modes of Religiosity

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Religion is, at the very least, a highly complex social phenomenon. The theories we use to understand religion – and sociocultural systems more generally – are often so complex that even experts in the field may not be able to see all their consequences. Social simulations can help us understand and communicate the consequences of a theory, provided we can describe the theory with sufficient precision and comprehensiveness in order to run it on a computer. In this article we demonstrate the benefits of simulating the predictions of a well-known theory in the Cognitive Science of Religion, the theory of Divergent Modes of Religiosity. Many of these predictions have already been tested against contemporary and longitudinal evidence, using the methods of both qualitative case study and large-scale survey, and some of the mechanisms responsible for the patterns observed have been investigated by means of controlled experiments. Nevertheless, in simulating the patterns of religious transmission and transformation predicted by the modes theory we discovered numerous aspects that were underspecified, generating new hypotheses for investigation in future empirical research. This back-and-forth between simulation and theory testing has the potential to accelerate progress in the scientific study of religion.

Keywords: ABM; cargo cult; computational modeling; modes of religiosity; religion; ritual; simulations; socio-cultural evolution

Introduction: simulation as a scientific tool for the study of religion

Since its introduction to the social sciences by Axelrod and Hamilton (1981), social simulation has been widely viewed as a powerful tool with obvious applicability to the full range of social sciences, including the study of religion. There have been outstanding recent examples of social science informed by simulations such as the Powell, Shennan, & Thomas (2009) anthropological account of the Paleolithic transition, or the work done by Laver (2005) to test the fit between theories of political party policymaking and real party behavior. Yet the vast majority of social simulation papers languish in specialist conferences and journals. While such venues may help advance the technological state of the art for simulation, the substance-area contributions of these works are often overlooked. Indeed, given review processes that take place outside of the mainstream for their substance areas, in the worst case the substantial social science contributions of these papers may not even be fully tested. This process may account for the suspicion with which some academics view work done in social simulation.

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All new research methodologies, whether quantitative or qualitative, deservedly meet scrutiny before they are considered to have proved their utility. In this article we both argue and demonstrate that social simulation has by now proved its utility at least in some contexts. We hope also to help make those contexts more apparent – not only to those who do not yet include social simulation as part of their research tool set, but also to those modelers who have had difficulty publishing in or otherwise engaging with the mainstream literature of their chosen application field.

Although there has been some debate and discussion about the exact role of simulation in not only the study of religion but science more generally, there is increasing consensus that a simulation simply *is* a theory (Bryson, Ando, & Lehmann, 2007; Kokko, 2007). Like any other theory, a simulation must be tested against data derived from observations of the world that pertain to the target system that the theory seeks to explain. What makes simulation a special methodology is that in order to be simulated a theory must be specified so completely that its consequences can be demonstrated by executing it on a computer. This allows the discovery of unanticipated emergent outcomes, which may serve as additional evidence for or against the theory.

A critical aspect of the scientific process is that theories can change. They may be extended, generalized, or specified to create more or better explanations. Science itself can be viewed as an evolutionary process, in which peer review and other forms of expert opinion (e.g., choices made for teaching curricula or studies to replicate) continually narrow the field of available theories by selecting between them, but then subsequently broaden the field by varying the surviving theories – applying a variety of enhancements to these theories in order to increase their validity or predictive value. Simulation can perform several key roles in this process. Simulations not only allow better understanding of theories, they allow theories to be communicated with unprecedented precision as the actual code of the simulation can be transmitted from researcher to researcher over the Internet.

The simulation process therefore has the potential to improve and accelerate the process of the scientific understanding of religion, but it also has some risks. Theories represented as computer simulations might become so complex that they could not be truly understood by any one mind. This could result in a situation where our ability to predict religious behavior could continue to improve, but without an associated increase in individual human understanding. Besides potentially decreasing the pleasure or accessibility of scientific reasoning, such circumstances might also result in a reduction of scientific innovation where that innovation is based on human insight. On the other hand, many doubt that phenomena as complex as religion could ever be represented in the crude digital, quantitative ways that computational approaches typify.

In his article we attempt to address both of these concerns by demonstrating the value of simulation to theory construction. We detail progress we have made in extending the development of a well-known and well-established theory in the Cognitive Science of Religion, the Divergent Modes of Religiosity theory, via the use of two different social simulations. We begin with a recapitulation of the Modes theory itself, and of a case study of a religious system that inspired it, the birth and death of religious splinter groups in the Kivung. We then present qualitative descriptions of two models, the full details of which (including code) can be found in an electronic supplement to this article. The first simulation replicates the doctrinal-imagistic oscillations seen in the Kivung, while the second, more abstract simulation looks at processes underlying cycles in religious conservatism and ritualism more

generally. Following from these we enumerate changes we have made to the Modes theory as a result of these simulations, before concluding with a brief discussion of the general value of simulation in the religious context.

Modes of religiosity

The theory of 'Divergent Modes of Religiosity' (hereafter DMR) makes a series of testable predictions about the effects of ritual frequency and arousal on group size, structure, and patterns of transformation in a religion over time (Whitehouse, 1995, 2000, 2004). The theory seeks to explain the striking differences we see between two broadly contrasting patterns of religious organization and transmission: the doctrinal mode exemplified by the many varieties of world religions embracing vast followings and promulgating a body of standardized teachings; and the imagistic mode uniting much smaller communities cultivating somewhat personal and esoteric revelations. The doctrinal mode is relatively recent, with origins around 8000 years ago associated with agriculture and urbanization. The imagistic mode is older. It currently often takes the form of localized traditions within a larger doctrinal system but it may still occur independently, as it does in many of the world's remaining small-scale stateless societies.

The doctrinal mode entails frequently repeated teachings and rituals. Much of the religious knowledge is codified in language and transmitted primarily via recognized leaders and authoritative texts. High-frequency ritual performances allow complex networks of ideas to be transmitted and stored in semantic memory. At the same time, routinization tends to suppress certain kinds of creative thinking about the meanings of the rituals. For both reasons, routinization is probably a necessary condition for the establishment of religious orthodoxies. The emphasis on verbal transmission facilitates the highly efficient and rapid spread of doctrinal religions, through processes of evangelism and missionization. The emphasis on oratory and learning also facilitates the emergence of venerable leaders and teachers: gurus, prophets, and priests. Together these features favor the emergence of centralized ecclesiastic hierarchies which exert influence over the content and organization of authoritative religious knowledge.

By contrast, the imagistic mode of religiosity is based on infrequent, dysphoric rituals – for instance, the traumatic ordeals of initiation cults, millenarian sects, vision quests, and so on – typically involving extreme forms of deprivation, bodily mutilation and flagellation, or participation in shocking acts. Such practices trigger enduring and vivid episodic memories for ritual ordeals, encouraging long-term rumination on the mystical significance of the acts and artifacts involved. Imagistic practices are much harder to spread than doctrinal traditions. A major reason for this is that the religious knowledge is created through collective participation in costly rituals rather than being summed up in speech or text. Traumatic rituals create strong bonds among those who experience them together, establishing in people's episodic memories exactly who was present when a particular cycle of rituals took place. This tends to generate localized cults based on direct transmission through following by example, and so we never find the same kind of scale, uniformity, centralization, or hierarchical structure that typifies the doctrinal mode.

The DMR theory has been used to explain a number of long-standing puzzles in the study of religion. For instance, historians and biologists have used this theory to explain why routinized religions sometimes break up into splinter groups or sects and why reformations occur (Gragg, 2004; Hinde, 2005; Pyysiainen, 2004). Archaeologists

have used the theory to account for the great transition from small-scale Neolithic societies to the vast and complex civilizations of the Near East, Mediterranean, and North Africa (Johnson, 2004; Mithen, 2004; Whitehouse & Hodder, 2010). The modes theory has now been tested against over 100 case studies based on ethnography (papers in Whitehouse & Laidlaw, 2004, 2007), history, classics, and archaeology (papers in Martin & Pachis, 2009; Martin & Whitehouse, 2004, 2005; Whitehouse & Martin, 2004), and the cognitive sciences (papers in McCauley & Whitehouse, 2005 and Whitehouse & McCauley, 2005; see also McCauley, 2001 and McCauley & Lawson, 2002). Some of the evidence needed to test the modes theory was not available from established scholarship and so a number of new field research projects have been undertaken, targeting data collection towards areas where evidential needs of the theory were especially great (Barrett, 2005; Ketola, 2002; Xygalatas, 2007). To obviate potential problems of researcher and selection bias, additional strategies have been adopted, including experimental research (Richert, Whitehouse, & Stewart, 2005), and the construction of large-scale comparative datasets coding selected features of ethnographic descriptions of hundreds of rituals from a large sample of religious traditions (Atkinson & Whitehouse, 2011).

Case study: mainstream Kivung movement and splinter groups

The DMR theory was first applied to a religious tradition in East New Britain Province, Papua New Guinea, known as the Kivung (Whitehouse, 1995). In Tok Pisin (the lingua franca of PNG), the word *Kivung* means "a meeting" or "to meet" but for several ethnic groups in New Britain it also designates a large religious movement exemplifying all the main features of the Doctrinal Mode of Religiosity. Established in the early 1960s and spreading to encompass scores of villages in some of the more remote regions of the island, the movement has a centralized leadership, based at the coastal settlement of Malmal, from which regular patrols to outlying villages are sent: bringing news, collecting taxes, and policing the orthodoxy. Each Kivung village has its designated orators, trained at Malmal, charged with the responsibility of preaching a standard body of doctrines and overseeing a wide range of authorized rituals. At the heart of Kivung teachings is the idea that the ancestors of followers will one day return from the dead, bringing with them all the wonders of western technology. It is said that the returning ancestors will take the physical appearance of white men and women, describing themselves as British or American financial investors and scientists. They will establish factories and shops where all the goods on display will be freely available to members of the Kivung. After this era of plenty, known as "Taim Bilong Kampani" (the period of the companies), there will be a great Day of Judgment, presided over by God and the ancestors. Those who use their riches wisely will be saved but those who are greedy and debauched will be cast into Hell. The saved will then enjoy eternal Paradise on earth, known as "Taim Bilong Gavman" (period of the government) during which there will be no aging, no illness, no hunger, no childbirth, and no pain.

In order to persuade the ancestors to return from the dead and fulfill this eschatology, Kivung followers are required to perform a great variety of rituals and to obey various religious laws. Kivung rituals fall into four main categories: temple offerings, spiritual cleansing, sermonizing, and garden/cemetery rites. There are three categories of temple in each Kivung village: a cemetery temple, a temple dedicated to one of the movement's spiritual leaders (now deceased), and family temples. All have

basically the same function – providing a suitable setting in which to lay out offerings to the ancestors of food, water and (if available) money. Each village has only one cemetery temple where offerings are presented twice a week. After the tables are laden, one man described as a "witness" remains behind in the temple sitting on a rough bench in the corner listening for signs that the ancestors are present (such as a creaking door, or sounds of chewing or drinking). Sometimes the food is found to have been disturbed (for instance, a morsel mysteriously removed), which is also taken as evidence of ancestral presence. At an appointed time, the witness emerges into the daylight to find the whole village assembled, eager to learn what has been seen or heard within the temple. The witness whispers into the ear of an orator who solemnly conveys the news. If evidence of ancestral presence is lacking this is a cause for concern, suggesting that somebody in the community has offended the dead.

Kivung ancestors are quite easily offended. The most common affront is to break one of the 10 sacred laws, based loosely on the Decalogue of the Old Testament (as taught originally by Catholic missionaries in the region). Although invisible, the ancestors are thought to be present at any given time and take a keen interest in people's comings and goings. They are pleased when people obey the 10 laws and are offended by sinful behavior. Only when the living have eliminated sin will the ancestors return from the dead. The observations of the witness in the cemetery temple provide a way of gauging levels of sinfulness, and the offerings, when received, are thought to strengthen the resolve of the ancestors to return. The sins of individuals, families, and whole communities are regularly absolved through special rituals designed to restore harmonious relations with the ancestors.

Other regular communal activities that take place in the Kivung are special tasks and rituals associated with the village cemetery (where the dead are said to be "planted" rather than "buried") and communal gardens. An important site in any Kivung village is the "Paradise Garden", representing the environment of Adam and Eve prior to the original sin. In Kivung accounts of the fall, offense was caused not by the eating of forbidden fruit but by Eve climbing a betel palm in which Adam had implanted a sharpened stone. As Eve slithered down she cut herself between her legs producing a strong flow of blood, the origin of her childbearing capacities (and those of her female descendants). For this reason, Kivung followers distinguish themselves from most other New Guinea peoples by abstaining from the chewing of betel nut. They say that the red substance spat out by chewers is like menstrual blood, which is regarded as a dangerous pollutant in many indigenous cultures of PNG. One of the laws of the Kivung is that menstruating women cannot help to prepare offerings for the ancestors.

Such beliefs and practices are common to all Kivung villages, expressed regularly in public acts and pronouncements. Routinized transmission of Kivung beliefs and practices produces a high level of standardization of the mainstream orthodoxy, with even minor innovations and infractions being easy to identify and collectively policed. As noted above, in terms of DMR theory the mainstream Kivung has all the features of the 'doctrinal mode' (Whitehouse, 1992, 1995, 2000). The resulting shared tradition comprises a shared meaning system roughly depicted in Figure 1 as a "semantic network" (Carley & Kaufer, 1993) of related ideas. Semantic networks are an analytic tool useful for evaluating theories like the DMR. The nodes in Figure 1 represent publicly transmitted concepts, framed in everyday discourse, in ritual and in the speeches of Kivung leaders and orators. The links between nodes represent especially close thematic or implicational associations, such that discourse pertaining

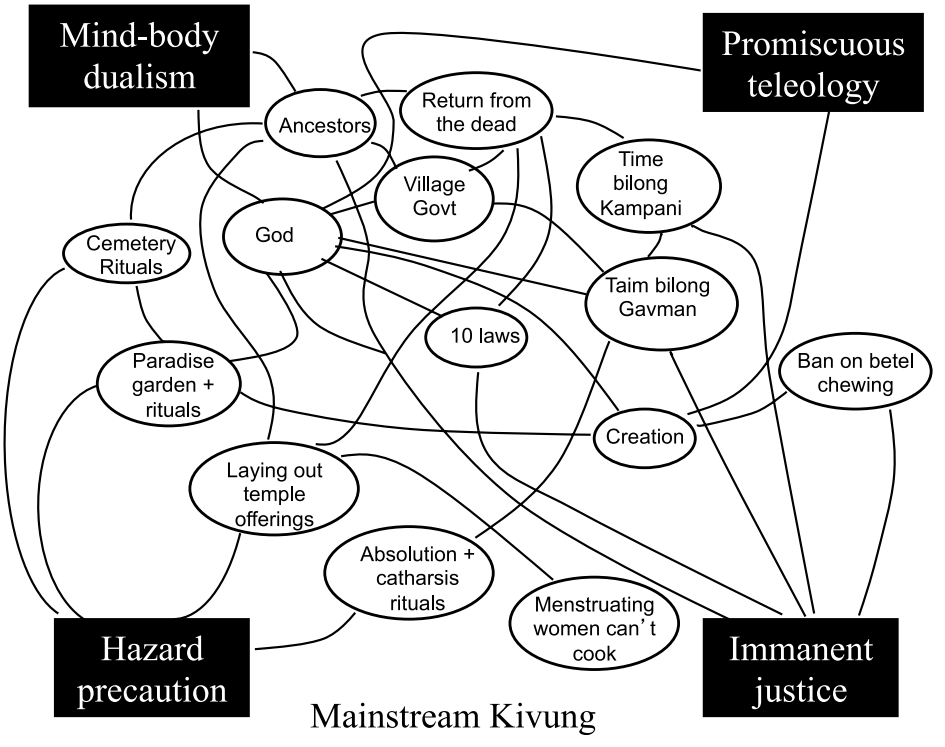

Figure 1. Mapping the mainstream meaning system.

to any given node has a high probability of referring also to those nodes to which it is directly linked. The strength of links between nodes, as represented here, is a function of how directly they are linked. In this simple network some nodes (e.g., God) are directly linked to most of the others but a few are more distantly connected and so more weakly linked to most other nodes (e.g., the ban on betel chewing is directly linked to only two other nodes). This also means that God is a more central node in the network than certain others, such as the ban on betel chewing.

However exotic the Kivung may seem to western observers, the mainstream semantic network is grounded in at least four implicit beliefs that are shared by all human populations (Barrett, 2004; Boyer, 2001). These implicit beliefs or "intuitive anchor points" are depicted as black rectangles in the four corners of Figure 1. The intuitive anchors in our model are common to all religious traditions: (1) mind–body dualism delivers the ubiquitous intuition that higher level cognitive capacities such as beliefs, memories, and desires can occur outside bodies, e.g., in incorporeal beings such as ghosts, ancestors, and gods (Bloom, 2004); (2) promiscuous teleology supports the recurrent belief that features of the natural world were designed with a purpose, e.g., as proposed by creation myths (Kelemen & DiYanni, 2005); (3) hazard precaution helps to explain the obligatory character of ritual, accounting also for the exaggerated concern in many rituals with symmetry and exactness, threshold and entrance, redundant repetition, etc. (Boyer & Lienard, 2006); (4) immanent justice is the ubiquitous intuition that bad deeds lead to punishment and prosocial behavior leads to rewards (Callen, Ellard, & Nicol, 2006). As is typical of religions generally, most Kivung teachings and practices are directly rooted in one or more of these

anchoring implicit beliefs. The more distantly a belief is connected to an anchor point the more mnemonic support and cultural scaffolding it requires to be preserved intact, for instance in the form of regular repetition in sermons or sacred texts. In the absence of such pedagogic aids, religious beliefs tend to be converted over time into more intuitive expressions, a process that has been described as the Cognitive Optimum Effect (Whitehouse, 2004). Our model incorporates four anchor points; a more complete model would require several more (Whitehouse, 2008).

The mainstream orthodoxy of the Kivung depicted in Figure 1 is occasionally eclipsed by small splinter groups comprising no more than a few villages at most, which break away temporarily from the larger religious movement, claiming that they have a new plan for bringing the ancestors back from the dead. Outbursts of this kind occur in most Kivung villages roughly every five years. Each time a splinter group occurs, its prophesies fail and followers typically return to the fold, resuming their daily rounds of mainstream Kivung rituals more or less as if nothing had happened. Splinter groups are usually inspired by some extraordinary event, interpreted as a sign that the ancestors are ready to return. It is quite common for individuals to claim to have witnessed such a sign but generally the consensus is skeptical. When motivation levels are high among mainstream followers, skepticism is strong. But after years of unremitting commitment to routinized practices, people grow weary and impatient,[1] becoming more credulous of claims that now, at last, the longed-for miracle is due. Splinter group activities invariably whip up high levels of excitement, in stark contrast to the dullness of everyday ritual life. Once hopes are ignited, some followers defect. But a more common pattern is for followers to return to the mainstream movement with renewed vigor and conviction, listing any number of rationalizations for the failure of prophesies. In effect, splinter groups typically rejuvenate commitment to Kivung orthodoxy. Similar patterns have been observed in millenarian movements and "activist" religions more generally (Whitehouse, 2000). Splinter groups predicting impossible events such as the return of a messiah or of the ancestors tend not to endure, whereas those with less falsifiable prophesies may turn into more lasting mainstream traditions in their own right (Stark & Bainbridge, 1979). But either way, group morale following a splintering event tends to be raised considerably.

Figure 2 shows the semantic network generated by one instance of a splinter group documented during a two-year period of fieldwork in the late 1980s (Whitehouse, 1995). The trigger for this particular splintering event was the alleged possession of a young man, Tanotka, by a local ancestor. During his spirit possession, Tanotka uttered various cryptic statements such as "I am a post." This was interpreted as a reference to the construction of traditional round houses, where the rafters of the roof converge upon a central post. For many, this meant that the possessing ancestor (post) would support the community (multiple rafters) in its efforts to be reunited with the village government. As this idea gained currency a series of new rituals were invented, involving the symbolism of circles and posts (for instance, dancing in a circle or creating rings of human bodies with Tanotka in the center). Other novel ideas rapidly caught on. For instance, it was suggested that people should discard all western-style clothes such as shorts and T-shirts and go virtually naked as their ancestors had once done. Since the sudden appearance of naked bodies prompted widespread erotic excitement, the leaders of the splinter group decided to organize a mass marriage to pair off those at greatest risk of temptation to fornicate (especially young bachelors). Witnesses in the temples, who had previously only heard noises attributable to the visiting spirits, now claimed to be

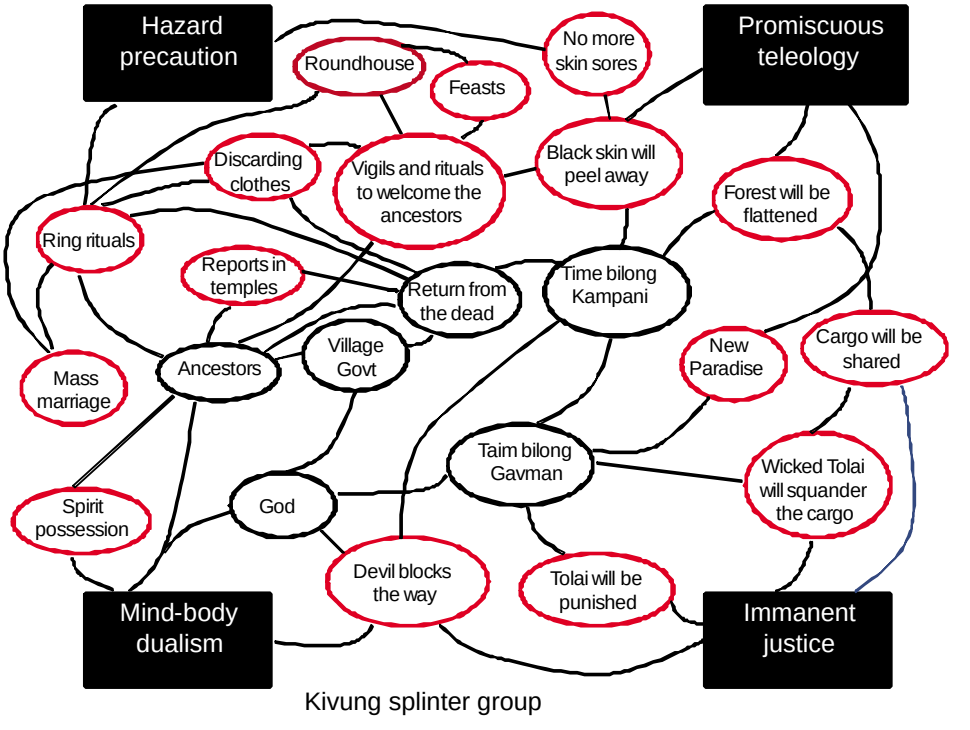

Figure 2. The meaning system of a Kivung splinter group.

hearing fully articulated statements from the ancestors which became known as "reports" (reminiscent of the authority of government reports). Great feasts were held to celebrate the imminent return of the ancestors. New teachings became widely accepted: for instance, that when the ancestors returned the living would peel away their black skins to reveal a fresh white skin underneath, free of blemishes and sores. The forest would be flattened and a concrete "paradise" of high-rise buildings would replace it. The dominant ethnic group in the region, the Tolai (who had long ridiculed the Kivung), would receive a share of the riches brought by the ancestors. But this would be their undoing, because they would squander their wealth and be cast into Hell. In preparation for these much-desired events, splinter group members constructed a traditional round house where they held nightly vigils to await the returning ancestors. Feasting continued until all local food stocks had been depleted (but there was no sign of the returning ancestors). A government patrol ordered everyone back to their homes and gardens. Most people claimed that the Devil had blocked them but that next time they would succeed.

The splinter group lasted only a matter of months. During this period it produced a novel belief system consisting primarily of new nodes, which we depict in Figure 2 with red circles. This system overlaps with the core elements of the mainstream movement, which are depicted with black circles in Figure 2. At its height, this short-lived semantic network gained general acceptance in two villages but never spread more widely than that. In terms of DMR theory, the splinter group exemplifies the "imagistic mode" (Whitehouse, 1995, 2000). A diagnostic feature of this shift from the doctrinal to the imagistic is the appearance of low-frequency, highly arousing rituals.

Model 1: simulating doctrinal-imagistic oscillations in the Kivung

For the purpose of modeling the oscillation between a doctrinal mainstream movement and an imagistic splinter group in the Kivung, we broke the process into two parts: (1) a tool kit consisting of a set of high-level domain-specific behaviors; and (2) specific Kivung models built from the tool kit by composing and parameterizing behaviors (Kahn & Noble, 2010). Dividing the simulation task in this way facilitates the construction of multiple related models. It also facilitates understanding, because it clarifies which aspects of a model are unique to the specific target system, and which are general to the theory under which the model is constructed. Finally, the tool kit permits researchers lacking the technical expertise to build computer models from scratch to still modify and refine models by recombining or reparametrizing established theoretical components by using the abstractions provided by the tool kit.

Here we implemented about 100 simulation action components which can be used to give behaviors to people including leaders and followers, anchor points, belief nodes, links, homes, temples, and any other entities relevant to a religious practice. We co-developed this tool kit along with the model of the Kivung and their splinter group as described above. The tool kit includes action components we developed to support the visualization of the state of the model and the semantic network of the simulated agents. Other components are used to make observations of the simulation such as plotting the mean motivational level of religious participants. The models we implemented within this tool kit are a small semantic network for the Kivung religion consisting of 18 nodes and a splinter group consisting of 26 nodes.

In order to model the Kivung, we began with a series of assumptions about the memorability and motivational force of various nodes in the mainstream network. A starting assumption is that the more distant a given belief or practice is from an intuitive anchor point, the more rapidly it will be forgotten or garbled if not encountered regularly. We also assume that different nodes in the network have variable motivational force or emotional salience, ranging from low (e.g., the Kivung dogma of original sin) to high (the expectation of returning ancestors or the fear of eternal damnation). We assume further that the frequency of exposure to a given node in the network will impact both memory and motivation: as frequency increases the risk of forgetting is reduced but so too is emotional salience; as frequency decreases, garbling and forgetting become more likely but emotional intensity is enhanced. Motivation is maximal when a belief is first acquired or refreshed. Motivation drops with time and with repetition. When mean motivational levels drop below a threshold, agents will be open to novel ideas.

Our models of Kivung followers currently include two kinds of agents with artificial minds: expert orators and lay adherents. Orators are ascribed the semantic network portrayed in Figure 1. They transmit the contents of this network to the laity in accordance with standard Kivung schedules, which follow a five-week cycle of twice-weekly speeches about the 10 laws. Followers update their semantic networks based on what the orators tell them. Agents forget nodes in the network that are not repeated frequently and the rate of forgetting is partly determined by the distance of a given node from an intuitive anchor point – the further away from an anchor point, the more easily the node decays. Each node has a maximum level of motivation, represented in the visualization tools and the figures below by a color. Colors towards the red end of the spectrum represent high motivation; those towards

the blue end indicate low motivation. Levels of motivation diminish over time and with repetition.[2] When motivation levels drop below a threshold, tedium sets in, the orthodoxy loses its authority, and more appealing innovations begin to enjoy a selective advantage. Figure 3 is a snapshot taken from one of our simulations of the semantic network of a typical member of the Kivung splinter group around the mid-point of its existence.

Our model executes by simulating the individuals in the population. Some are religious leaders who regularly transmit parts of the doctrine. Others, when receiving those transmissions, add nodes (practices and beliefs), add links between nodes, and strengthen existing links. Nodes and links in each individual's semantic network have some probability of being forgotten. The motivational levels of the population are derived from the properties of the nodes representing practices and beliefs. These levels decay with repetition.

Followers in the model are periodically exposed to novel religious ideas. As long as most agents are regularly exposed to mainstream orthodoxy they notice unauthorized innovations, and as long as motivation levels are sufficiently high they will reject these ideas as erroneous or heretical. Once motivational levels have dropped to the threshold of the tedium effect (noted above) followers become open to adopting mutant beliefs and practices. Thus, in the case of the splinter group described earlier, we can simulate the process by which agents came to accept the possession of Tanotka, the veracity of reports from the temples, the need for ring rituals, the mass marriage, and so on. This general pattern is captured in Figure 4, which depicts changes in motivation levels over time. We observe a steady decline of motivational level as the mainstream doctrine is repeated frequently until motivation becomes low enough for followers to begin to accept the novel beliefs necessary for splinter-group formation. Under the influence of the new nodes the motivation level increases, although older nodes contribute less to motivational levels due to repetition.

While we believe there is much to learn from this coarse modeling of the Kivung, the tool kit we used to implement these models can accommodate much larger and more detailed networks. The tool kit supporting the model will be extended so that we can model the transmissions and motivational changes caused by followers interacting with kin, in-laws, neighbors, and others. We have begun extending the tool kit to model multiple villages and a hierarchy of leadership. Several behaviors could be added to enable the modeling of long-term dynamics including birth, death, migration, and interactions between generations. As we extend and enhance the construction kit, models can be constructed to explore new issues. These might include group cohesion, the creation and role of social networks, nested groups within wider organization and different levels of jurisdictional hierarchy, competition between groups, and multigenerational dynamics. The Kivung is our first case study: a means of establishing 'proof of concept.' Nevertheless, the tool kit presented here would only need a few additional components to be capable of modelling a wide range of substantially different religious traditions from around the world.

Model 2: expanding the explanatory reach of the DMR theory through simulations

Model 1 was designed to explore the mechanisms by which intuitive, mnemonic, and motivational constraints impact the reproduction and transformation of religious systems. Viewed in an evolutionary framework, these are problems of *proximate*

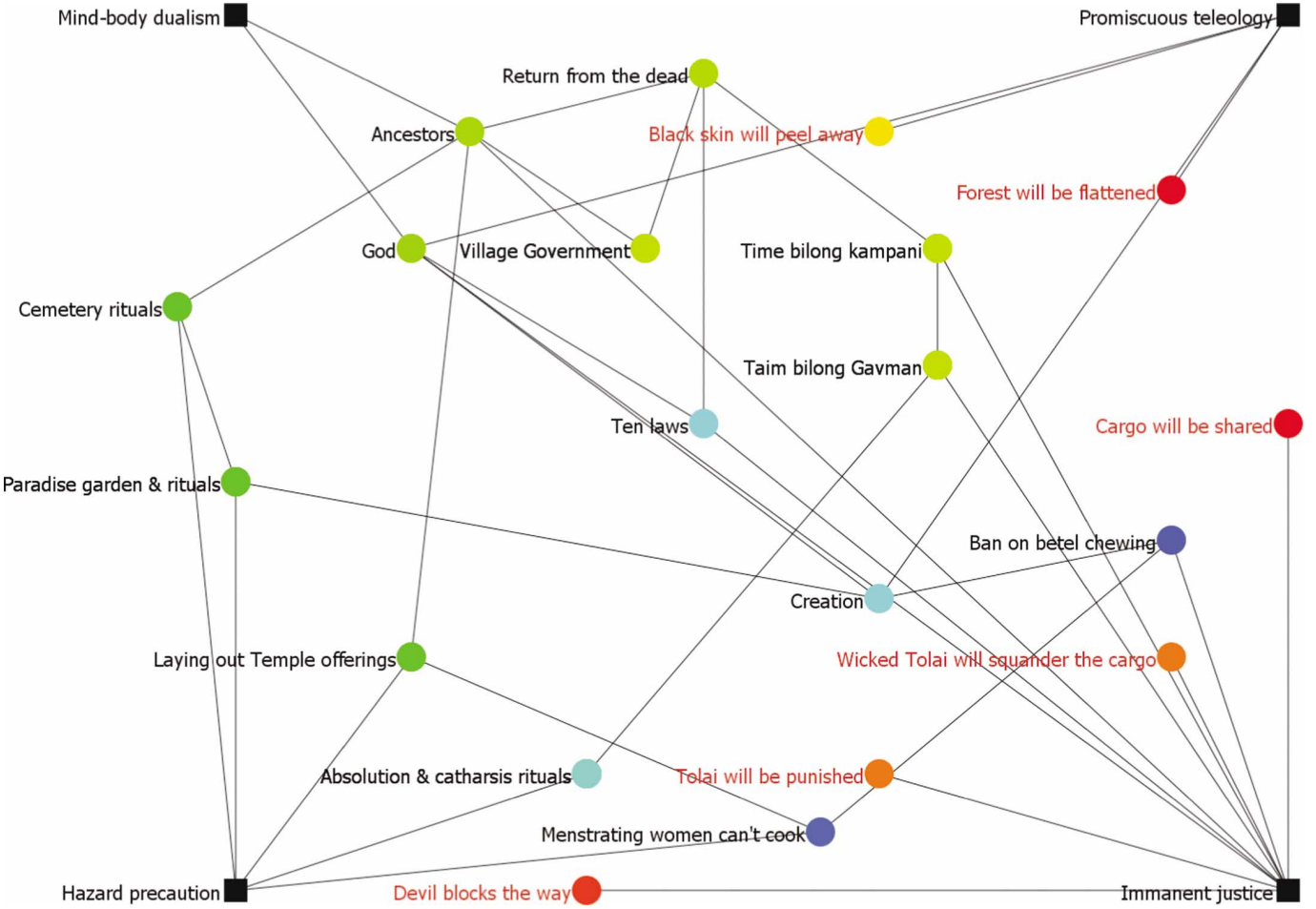

Figure 3. Snapshot of semantic network for typical Kivung splinter group member.

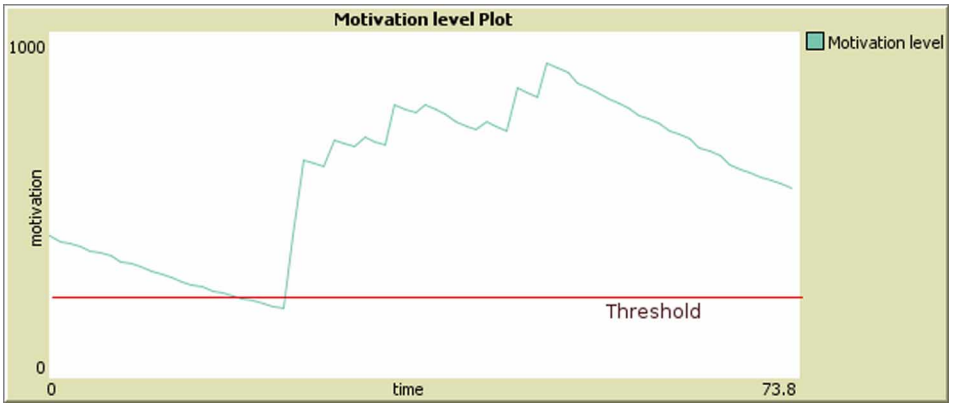

Figure 4. Dynamics of mean motivational level for the population plotted against time.

causation. But modes of religiosity are also adaptations to varying ecological conditions, often including competition with other cultural groups for scarce resources. To explain how and why modes of religiosity emerge and spread is thus also a question of *ultimate causation*.

Population and evolutionary processes can be modeled in a variety of ways. The level of detail for a model and the values estimated for its parameters depend on both our level of knowledge about the target system we are trying to understand and also our objectives in describing the system. In the models reported here we take a joint population dynamic/cultural evolution approach by modeling religious groups as units that can change in membership and in behaviors. Depending on our objectives, we could investigate short- or long-term dynamics, the birth, evolution and extinction of groups, or we could model behavioral trait evolution.

Model 2 is based on hypothesized patterns of recruitment and defection in a pluralistic religious environment comprising traditions operating in the doctrinal mode, where opportunities to move between traditions are motivated by incentives or "carrots," or impeded by sanctions or "sticks." If we imagine, for instance, a bustling American city with numerous Christian churches vying for members, then it seems reasonable to assume that euphoric practices such as gospel singing, speaking in tongues, miraculous healings, and so on will be highly visible to potential recruits. Such practices in our model function as "carrots," enticing potential converts as well as maintaining high motivation levels among existing members. But traditions also commonly impose sanctions on defection, ranging from the withdrawal of social support networks to the threat of terrible forms of supernatural punishment such as eternal damnation. These sanctions or "sticks" serve to reduce the rate at which members of a tradition defect, even when incentives to do so are present.

The survival of a religious tradition depends not only on its capacity to attract and maintain a following, but also on its capacity to achieve cultural stability over time. Beliefs and practices that are frequently and publicly repeated (for instance, on a daily or weekly basis) come to be somewhat fixed in procedural and semantic memory and widely shared in the participating population (Whitehouse, 1992). When the frequency of participation is reduced, however, innovations are less readily noted (Whitehouse, 2004) and there is a tendency to favor innovations that are pleasing (thereby functioning as "carrots"). In this way a doctrinal orthodoxy can be

reconfigured as (or augmented by) more popular expressions of religiosity, such as local festivals, cults, and related customs, typically occurring less frequently than the mainstream tradition (e.g., according to seasonal or annual cycles). Where a doctrinal orthodoxy is substantially displaced by more colorful 'little traditions' (Redfield, 1955), the stage is set for reformations (Whitehouse, 2000; cf. Weber, 1947). Typically, reforming ambitions seek to restore the basics or 'fundamentals' of the original doctrinal orthodoxy and the more routinized forms of worship needed to reproduce these elements (Pyysiainen, 2004). By contrast, when the frequency of worship increases, even the most euphoric practices gradually lose their charm. Excessive routinization of a tradition can produce the "tedium effect" (see above), a state of affairs in which openness to major innovations, and thus splintering from the mainstream tradition, becomes increasingly likely. In some cases, splinter groups return to the fold, their motivation levels rejuvenated (as in the Kivung case study described above). Such a scenario is especially common where the goals of the splinter group are unachievable, as in most "activist" religions such as millenarian movements and cargo cults (Worsley, 1957). Other splinter groups, however, may present teachings and prophesies capable of sustaining their credibility indefinitely and so can form more or less stable buds, offshoots from the mainstream religion that in some cases spread widely, even displacing the more ancient tradition. Our present question is whether the same patterns would emerge from a computational simulation based on quite parsimonious assumptions.

Model 2, although conceptually simple, requires a surprising number of rules to achieve even this essential level of realism. The model is simulated numerically through an iterative process (cf. details in this article's electronic appendix). The model can follow any specified number of religious groups from year to year, and deploys a set of rules governing practices, ritual frequencies, splintering, and reformation, and between-group migration. In *practices*, depending on ritual frequency, groups change in their ability to attract new followers or maintain existing followers. For low frequencies, groups tend to become more attractive to outsiders, whereas for high ritual frequencies, they tend to maintain their population through fear. In *frequencies*, a group may increase or decrease its ritual frequency, based on recent tendencies to become more repressive towards existing members (in which case ritual frequencies increase), no net change in practices (ritual frequency is lowered), or more attractive to outsiders (no change occurs in frequency). *Splintering events and reformations* may occur when groups become polarized in their practices. For groups that can no longer attract outsiders there is a chance that the group splinters, in which case its ritual frequency decreases and it becomes more directed at attracting new members from the outside. In contrast, a group that is no longer able to maintain its following may experience a reformation, in which case it increases its ritual frequency and adopts techniques to increase group cohesion. Finally, individuals may *migrate* from group to group, and tend to do so when other groups are more attractive than their own, and their own group has weak cohesion mechanisms.

To examine the typical behavior of our model and to illustrate possibilities for future development and research, we conducted a number of numerical experiments. We present two of these briefly here (for details of the experiments and additional results please see the electronic appendix). In the first, we let a single religious group evolve to see how it may or may not change in isolation. In the second, we introduced

10 identical religious groups into the system, and explored how their characteristics changed through time.

Figure 5 shows the case in which a single religious group evolves in isolation. We see that rituals alternate between periods of high and low frequency, that the transients at low frequency tend to last longer than those at high, and that intermediate frequencies are also very transient (Figure 5 (i)). A characteristic feature of this group is that repressive practices tend to exceed those capable of attracting new recruits (Figure 5 (ii)), and peaks in repressiveness tend to correlate with high ritual frequency. Given the condition that repression/attraction capacities must go to very low frequencies in order for a splintering/reformation to occur, Figure 5 shows that splintering is fairly frequent (about every 200 simulated years), whereas reformation is never observed. Figure 6 starts with the same conditions as the experiment in Figure 5, except that 10 identical groups are initially present. We see that many groups rapidly become extinct, due to competition for group members. Only two groups remain after 800 simulated years. Note that the prevailing groups possessed high ratios of attractiveness to repressiveness at the beginning of the simulation (Figure 6 (iii)), and were thus able to recruit members of competing groups. After year 800, the two persisting groups cycle in apposition to one another (Figure 6 (i)) and show cycles in ritual frequency (Figure 6 (ii)) and repression to attraction ratios (Figure 6 (iii)) that are similar to those for the single group in Figure 5.

The goal of the competition model is to increase our understanding of long-term changes in religious group behaviors. We need to identify the main processes that influence behaviors and how these impact the relative success or failure of groups. As

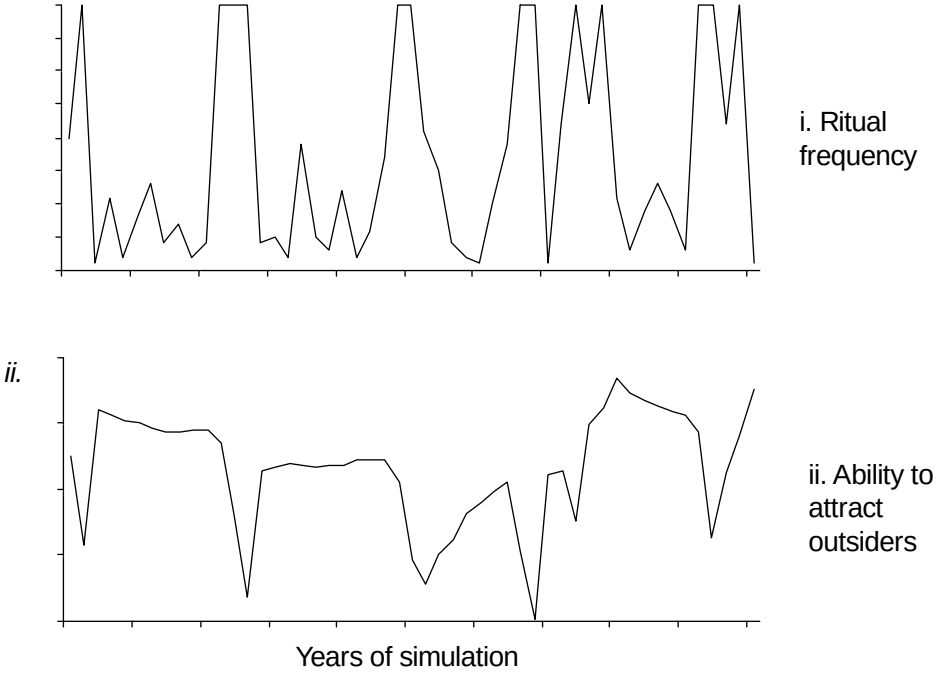

Figure 5. Dynamics of (i) ritual frequency and (ii) relative ability to attract outsiders compared to repress insiders in a single group over 1000 years of simulation.

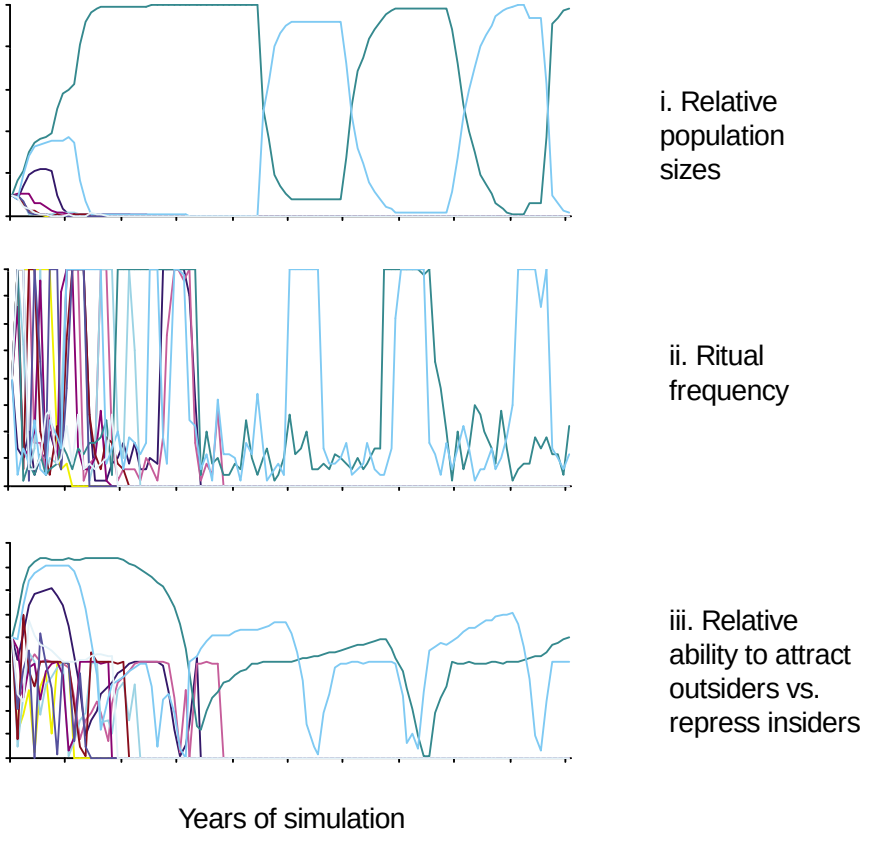

Figure 6. Competition between 10 religious groups over 2000 simulated years.

shown in the simulations, these changes may be rapid, and seemingly doomed groups may rebound and come to dominate what once were successful groups.

It is important to note that this is a highly abstract, descriptive, exploratory model. The parameters described as constants in the outline of the algorithm and held constant in the simulations could all be altered. Doing this systematically and observing the results is called *sensitivity analysis*, which is an important part of model development. A comprehensive sensitivity analysis will both highlight the model parameters that require accurate estimation and also identify those that are pivotal to explaining variance in religious group behavior.

The flexibility of the algorithm allows for many possible lines of investigation, including the origin of successful religious groups, their characteristics, and how changing social landscapes may affect the persistence of endangered groups. To achieve greater rigor, however, several notable modifications to the current model will be necessary. First, changes in ritual procedures and frequencies will need to be integrated into a framework that allows for emulation of surrounding, more successful groups. Second, the model will need to be spatial, such that groups in proximity to one another interact more often than those that are more distant. A spatially explicit model must also address the question of religious spread: is it via local transmission or long distance colonization? Third, the theory will need to be modified to include more demographic variables, including different birth rates

resulting from varied religious doctrines and practices. And fourth, future models should include defining cultural markers, allowing us to assess how the cultural landscape changes under variable competitive scenarios.

Discussion: recalibrating the DMR theory

The process of building a simulation leads to theory refinement, which is an absolutely critical aspect of science. Establishing a plausible, coherent explanation for the phenomena we see around us is after all the primary goal of scientific research. Where there has been no previous theory or the previous theory was unnecessarily complex, then the simple demonstration that a model could possibly serve as an explanation is already a major contribution. Detailed validation against data is a way to improve existing theories, or to determine which of two variant theories is better at predicting and explaining the world. But establishing in the first place that an explanation could account for the data on a qualitative level is not only a contribution, it is a necessary first step before the iterative improvement of a theory can take place.

For the DMR theory in particular, many of its predictions are motivated by postulated causal links between ritual frequency, emotional arousal, memory, intuitive ontology, codification, transmission, group cohesion, group structure and scale, and social identity. In attempting to model this theory, the precise nature of these causal links has had to be specified more closely than ever before. As a result, we have produced a raft of new hypotheses warranting further empirical investigation. Thus we demonstrate a significant benefit of modeling – that it enables us to expand and refine our repertoire of research questions. Here we detail just five examples.

First, building models has led to more fine-grained predictions concerning the effects of ritual frequency and systemic rigidity. In earlier formulations, the DMR theory proposed that high-frequency (''routinized'') rituals and associated doctrinal transmission would serve to rigidify both orthodoxy and orthopraxy by making unintended innovation more discernible (and therefore more readily sanctioned) than in lower-frequency traditions. As frequency drops, so the potential for alterations to the system of beliefs and practices to occur undetected would increase. Our simulation of Kivung dynamics in Model 1 entailed the construction of an explicit network of concepts and practices for a particular high-frequency religious tradition, represented as nodes in changing semantic networks. This demonstrated the need for more precise specification of nodes, revealing also that some of the nodes are publicly transmitted more frequently than others. Rather than aggregating the effects of frequency on religious systems as a whole, we were forced to recognize that some sectors of the system will be subject to decay (due to forgetting or garbling) more rapidly than other sectors, thereby helping to explain patterns of change in religious systems at a more detailed level.[3] For the purposes of modeling changes we needed to specify those rates of change and their consequences explicitly.

Second, modeling the DMR theory revealed hidden complexities in the relationship between frequency and intuitiveness. It has long been appreciated that processes of decay (garbling and forgetting) in doctrinal systems are non-random, being skewed towards more intuitive versions of the orthodoxy. Crudely describable as ''dumbing down,'' the more technical term for this process is the ''cognitive optimum effect'' (Whitehouse, 2004). Until building our Kivung simulation, however, nobody had considered how the relative proximity of nodes in a network to intuitive beliefs might

affect rates of decay as frequency drops. Building Model 1 made us realize that nodes which are more distantly connected to intuitive anchor points would inevitably decay faster than those with a more immediate intuitive grounding. This further refined our predictions with regard to the transformation of religious systems.

Third, our models have produced new insights into the relationship between frequency, arousal, and motivation. It has long been observed that the more frequently a node is encountered the lower its emotional impact and motivating force are likely to be, all else being equal. Consequently religious traditions requiring the most frequent levels of participation will be vulnerable to the "tedium effect" (Whitehouse, 2004). Specifying the effects of frequency on the emotionality of beliefs and practices in the Kivung lead to a realization that the rate of decay in the affective and motivational qualities of nodes in the meaning system will be moderated by the intrinsic content of the nodes themselves, leading to a more nuanced and explicit set of predictions regarding the processes by which demoralization and the tedium effect come about. Similar insights resulted from the development of Model 2, particularly with regard to the emotional and motivational characteristics of beliefs and practices.

Fourth, our efforts to model imagistic splintering revealed that not all religious innovations are created equal. Earlier formulations of the DMR theory proposed that low-frequency, high-arousal rituals would be most likely to arise in a doctrinal tradition as a consequence of the tedium effect. Although the process of splintering typically involves the stepwise introduction of novel nodes to a semantic network, little thought had previously been given to the effects of sequencing in the appearance of novel beliefs and practices on emotional and motivational states, both during the lifetime of a splinter group and following its collapse. Simulating the process of splintering in the Kivung required explicit consideration of the effects of sequencing, as nodes in the network would lose emotional salience and motivational force through repetition, whereas late-appearing nodes would do so to a lesser extent. Exploring these previously neglected aspects of doctrinal-imagistic oscillations also forced us to consider more explicitly how the collapse of splinter groups impacts emotion and motivation in the mainstream tradition in which they occur. These insights also played an important role in building Model 2.

Fifth, our models generated novel insights into the nature of between-group competition among doctrinal traditions. While efforts to test the DMR theory have provided valuable insights into patterns of transformation within individual doctrinal traditions over time, less effort has been directed to the question of competition for members among rival traditions. In an environment in which opportunities to convert to rival traditions are very limited, emotional appeal and sanctions for defection can be quite limited. But when multiple groups compete for members, their survival (measured by numerical strength of membership) will be affected by the capacity of individual groups to attract non-members and to retain those already committed. The construction of Model 2 generated a raft of specific predictions concerning the relative pulling power and retention capacities of doctrinal traditions, prompting unforeseen questions about the evolution of religious systems.

Conclusions

We have shown that the interdisciplinary exercise of social simulation in general and of modeling religious change in particular can provide many benefits. We have

demonstrated here how simulation illuminates and extends a theory while at the same time testing its plausibility and providing new predictions to be tested against empirical data. We have described two very different sorts of models. First, we modeled a particular documented case of religious change: the formation of a splinter group from the Kivung movement. This enabled us to explore the proximate causes of various features of splinter group formation and collapse. Note that this model did not miraculously replicate the exact course of historic events. Rather, we programmed in the sorts of changes in belief and ritual observed, and then used this model to determine which parameter sets could account for agents shifting between networks of beliefs and practices, and which could not. Second, we described a model of competing doctrinal religions. This was a far more abstract model developed from a population perspective. Here, rather than directing the results toward a particular outcome, we explored the consequences of the theorized dynamics underlying the DMR. Again we find the outcomes surprising and indicative of additional research that needs to be carried out. Perhaps systems similar to those we observe in our model do exist in human societies but were previously unobserved or not recognized for what they are, or perhaps our model and the theories it embodies need further development. Only data derived from observing real religions can tell us this.

Our overarching goal has been to demonstrate the utility of simulations for exploring and refining the coherence and plausibility of existing theories in the social sciences even prior to quantitative validation against empirical data. The work described here may be seen as work in progress, in that we still hope (and indeed plan) to take the new predictions forward by gathering more complete field data to test the validity of these models. But contributions have already been made here in terms of better specifying the theory itself, and in showing the theory's consequences, as we outlined in the Discussion. The process of theory construction and communication is in itself an academic contribution.

Acknowledgements

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Notes

1. This impatience has been described as the "tedium effect" (Whitehouse, 2004).
2. We assume that a religious practice (such as gospel singing), just like any cultural practice (such as going to a rock concert), is always higher-impact when first experienced than after many years of having similar experiences.
3. Kirby (1999) shows similarly how selection on a culture for expressivity can result in artificial languages that show characteristics previously thought to be a consequence of innate, uniquely human cognitive capacities (Chomsky, 1965).

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COMMENTARIES

How do we convince agent-based modeling agnostics?

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I'm very pleased to see this paper offered commentary in a "subject" journal rather than, as the authors worry, somewhere only seen by agent-based modeling (hereafter ABM) specialists. In my contribution I will highlight three likely challenges to ABM acceptance by "subject specialists."

The first is the importance of literature reviewing. While there are no papers I would have *obliged* the authors to cite had I been a reviewer, failure to cite (and discuss their contribution in the context of) papers like Bainbridge (1995), Chattoe-Brown (2006), Doran (1998), Dow (2008), and Iannaccone and Makowsky (2007) inaccurately portrays how much has already been published in this area. (Further, the advantage of progressive modeling which the authors raise is lost if all models are developed from scratch in practice.) While publishing ABM anywhere for the first time makes it reasonable to give background anew for a distinct audience, there is a

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tendency for some arguments (for example, about the relative rigor of theory specification through ABM discussed in the introduction) to be mentioned repeatedly in a non-attributed way. In fact, research into the history of simulation suggests that many of these ideas are *much* older than the ABM community believes and this arises directly from citation failure. We should not risk boring potential converts to ABM by reinventing the wheel or lower our credibility by over-stressing (even accidentally by omission) the novelty of the approach. One solution to this problem may be for ABM experts to make themselves more available for peer reviewing.

The second issue is being honest (but not defensive) about the extent to which ABM are supported by data. There are several good (i.e., scientifically reasonable) claims about why ABM cannot yet be expected to calibrate and validate models completely (though examples exist – see Hägerstrand, 1965). For example: (1) such a requirement does not compare like with like (other methods like statistics took considerable time to reach their current rigor); (2) the scientific method does not require it (scientific models only need to be specified in a *falsifiable form*, not actually falsified); (3) it is only reasonable that looking at the world anew should draw attention to data that we have not yet collected; and so on. This paper, despite its interesting content and good organization, suffers from what might be called "defensive empirical rhetoric." Early in the paper the empirical support for the *theory* is stressed, and in the middle section (Model 1) ABM assumptions are presented but not linked back to the empirical work that was already mentioned. In the closing section, the impression is given that what was earlier an assumption (or possibly data) is actually a "result" (namely, that the further beliefs are from intuitive anchor points, the less likely they are to be preserved). It may be that the authors are very clear what are data, what are assumptions (needed to make the model "work" absent data) and what are results, but unless the skeptical "subject specialist" is kept excruciatingly clear about these distinctions, they may draw unfavorable conclusions. It may be that the solution to this problem is a technical one – for example, standardizing model specification and "tagging" each assumption with a standard status: "assumption absent data," "data from specified academic source," and so on. This procedure would also facilitate progressive research and correctly targeted critiques of model assumptions.

The third issue is not limited to ABM. The hazard is letting models dominate the system they are supposed to represent so one fails to ask "non-model" questions of equal significance. At several points I found myself asking questions about the relationship between the model and reality that badly seemed to require answers. For example, if it is an assumption of the ABM that agents get bored with repeated ritual then it is inevitable that *something* new must happen. However, it isn't clear from the results whether it is contingent or necessary that this is a new imagistic religion (rather than a different doctrinal religion). If, as suggested, falsifiable religions (e.g., those with definite dates for the apocalypse) tend to die out at the expense of non-falsifiable ones, then does this disallow (or enhance) the possibility of ongoing competition between different non-falsifiable religions "suppressing" new possibilities for imagistic religion? Although details of the ABM may be important, there are many equally important questions that can be expressed clearly using more "qualitative" specifications of the system, and I suspect some of these may be the ones that "subject specialists" are most keen to engage with. For example, what is the overall ecology of doctrinal and imagistic religions? Other examples of these "forgotten but important" questions exist in the paper. One is whether the details of the semantic networks really matter to the system or

whether the same dynamics could occur with only direct communication of motivation through repeated ritual. Another is whether it is necessary or contingent to the theory that the two semantic nets presented have very little overlap – the claim that religions *are* diverse seems very different from the claim that they *must* be. At the boundary between model and reality, the paper also leaves empirical puzzles. Is Kivung the dominant/sole religion in the area of Papua New Guinea studied? If so, presumably we would need to attend to the "single religion" version of the simulation rather than the "multiple religion" version when making an evaluation.

I raise these issues not in a critical spirit – the paper is well worth the attention of those interested in religion and novel methodology – but to show why ABM needs to develop and refine effective practices for presenting itself to non-specialist audiences. However, the field is new and ABM cannot be expected to get everything right at once. The most useful thing that can happen at this stage (for which I thank the authors and the editors) is that debate should take place between ABM and subject specialists at academically "visible" sites.

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Can simulation be more than a heuristic tool for studying belief systems?

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Computer simulation of human social systems has a long history, and has properly been concerned from the start with belief systems. While the earliest simulation efforts harnessed the power of computers to test population hypotheses in micro-demographic contexts (see Gilbert & Hammel, 1966, for some discussion), they were at least partially motivated by questions about mores and beliefs. When Kunstadter, Buhler, Stephan, & Westoff (1963) used computer simulation to find out "what frequency of the preferred type of marriage can be expected" under various demographic conditions, they in fact were asking how strong is the impact of beliefs about ideal marriage in moving observed cases away from what could be expected if belief were unimportant or absent. In other words, they were fundamentally interested in what makes human systems human.

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It wasn't until the 1990s that agent-based simulation explicitly tackled the question of agent belief systems (for example, de Vos & Zeggelink, 1994; Doran, 1997). But again, the early emphasis seems to have been on how observed behavior deviated from what could be expected in the absence of agent beliefs, and focused mainly on the behavior of other agents, as exemplified in experimental economics and related disciplines (Axelrod, 1980, for an early non-computer-based simulation effort).

However, work on simulating the behavior of beliefs *themselves* has been much rarer outside the realm of memetics. Interestingly, while the early work on "indirect" simulation of belief systems was concerned primarily with the content of the beliefs and its impact on agent behavior (by comparing null expectations with observations in which belief plays a role), this second class of work, exemplified in Gabora (1995), for example, has typically jettisoned the content of beliefs and has treated them as interchangeable objects with different levels of fitness that interact with each other, rather than with their hosts.

In this paper, Whitehouse, Kahn, Hochberg, and Bryson attempt to bridge the gap between these two approaches to the evolution and behavior of belief systems. They model the beliefs themselves and their interaction with each other, but also their content value and its impact on the behavior of the host. They also try to model the impact of host characteristics on the behavior of the belief system, which is a rare thing in this sort of literature. This is a bold approach. How well does it succeed, and what do we learn from it?

The most obvious success here is that the work demonstrates that DMR theory as presented is internally consistent. This is a good example of the heuristic value of computer simulation (see Zubrow, 1982). By forcing us to specify our models and to identify a limited set of elements and rules for their interaction, simulation allows us to see the holes in our intuitions for systems that are too complex to iterate in our minds or on paper (which probably describes most systems relevant to the study of humans and beliefs).

Interestingly, the authors don't claim much success beyond this check of internal consistency, and some ability to "recalibrate" theory (i.e., increase internal consistency) in light of simulation results. But there is material here to suggest that it isn't entirely unreasonable to hope that beyond this, simulation can be used to test hypotheses about the actual dynamics of belief systems. The authors certainly show that the study of beliefs as objects (or even as organisms) is not incompatible with the study of the relationship between belief content and host behavior (and vice versa). The current paper makes too many untested (even if apparently reasonable) assumptions. For example, do low-frequency, high-impact rituals really increase fervor and attract converts? While frequency is a straightforward trait, impact might be more resistant to quantification. A clearly defined model that focuses on quantifiable attributes of beliefs and their hosts without completely ignoring content value could allow us to move farther in the direction of belief system modeling and simulation for understanding the phenomena, rather than for the mere heuristic value of the process itself.

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We need focused, transparent, and validated models of religion

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The theory of Divergent Modes of Religiosity (DMR) is one of the early theories in the cognitive science of religion (CSR) that attempted to explain religion with reference to the cognitive structure of the human mind. What distinguished this theory from other early contributions to the CSR was its serious engagement with the sociopolitical aspects of religion and the connection of these factors with the psychological concepts of semantic and episodic memory systems. Ideas are transmitted either by frequent repetition (in the doctrinal mode) or with the help of strong emotional stimuli (in the imagistic mode). Recent developments in memory studies have made the cognitive foundations of the theory questionable (Czachesz, 2010) and empirical work has not confirmed its predictions about the imagistic mode (Konvalinka et al., 2011). DMR theory as presented in the target article thus minimizes the role of the two memory systems and focuses instead on the role of repetition in maintaining less intuitive beliefs. However, the simple and appealing systemic structure of the initial theory is thereby lost and the emergent dynamics of the original system are replaced by a centralized regulating agency represented by "expert orators." The problem with these experts is that they act in the fashion of deus ex machina: their behavior not being determined by the behavior of the rest of the system. In fact, they are technically speaking not parts of the religious system (Czachesz, in press-a), but rather they form an external system providing input data. Another problematic element of the present form of the theory is "motivation," an important psychological concept (Hood, Hill, & Spilka, 2009; Keijzer, 2011; Nolen-Hoeksema, Fredrickson, & Loftus, 2009) which is used here in an ad hoc fashion.

The authors take a maximalist stance when it comes to the philosophy of modeling, suggesting that the purpose of a simulation is to "understand and communicate the consequences of a theory" with "unprecedented precision." They expect that theories will be spelled out in full detail so that their consequences can be tested in computer simulations. The problem is that modeling does not usually function in this way in the social sciences (Gilbert, 2008). Whereas the practical utilization of computer simulations requires that they be very detailed, complete, and

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elaborate, this is not a fruitful approach for models that serve experimentation and the discovery of systemic features and mechanisms. In such contexts, computer modeling is a heuristic tool that enables scholars to experiment with simple hypotheses using a carefully selected subset of variables. As the complexity of simulations increases, they hide, rather than reveal, important systemic features. It is doubtful that the complexity of real-life historical phenomena can be ever simulated by computer modeling; further, it is doubtful whether such a simulation would lead to any substantial theoretical insight. The actual models presented in the article have a much more limited ambition (fortunately), yet lack a clearly formulated hypothesis. Network theory, indeed, is a very promising tool for modeling systems (Backlund, 2000; Gazdík, 2006). The "semantic network" presented by the authors, however, is a heterogeneous collection of abstract concepts (Creation), actions (Cemetery rituals), and social institutions (Village Government), partly connected to cognitive processes (Promiscuous teleology), and complex behavioral patterns (Hazard precaution). The model resembles a system flow model or constraint network rather than a semantic network. Moreover, there is no validation of the elements of the model or its overall behavior, which relegates the conclusions drawn from the simulation to the realm of speculations. The very ambitious claims of DMR (explaining local and short-term dynamics in religious groups as well as long-term historical developments) make validation in a narrow sense challenging, while offering ample opportunity for validating the model against almost any segment of the history of religions. A quick look at the development of religious traditions on historical scales, however, reveals that the kind of competitive oscillation predicted by the model is not the typical way religions develop. Recruitment of membership is characteristic of religious free markets, which existed in very restricted locations and periods, such as the late Roman Empire or industrialized Europe. We do not even know if the short-term dynamics of the Pomio Kivung documented in Whitehouse's fieldwork are typical of pre-state societies. Factors such as population density, ecological constraints, colonial influence, mode of production, inefficient but present central power and its clientele might each be crucial variables to consider in order to draw more general conclusions.

Explaining what actually drives religious innovation, which is one of the important aims of DMR theory, remains an open question. A key concept of the theory is "tedium," which in the model appears as the lack of "motivation." If we set aside the conceptual problems with "motivation" (see above), there remains a serious concern with regard to its measurement in the model. The mean level of motivation to follow some teaching or perform some ritual is not a good measure of the stability of a group. What if 50% of the group has very high motivation, whereas the other 50% has very low motivation? This presents a perfect scenario for schism, or at least for serious inner conflict, which is completely concealed by the mean value. An alternative to DMR theory could be the model of different styles of religious experience (Czachesz, in press-b), which connects neurological variables with social and theological constructs. Subjective experience is a central part of every religious system, lending beliefs and activities subjective validity and a sense of personal significance. Whereas early attempts to localize religion in the brain hypothesized that there was a single form of subjective experience underlying religiosity, recent neuroimaging studies reveal a variety of neural correlates of such experience. Perhaps different types of group organization, modes of transmission, and ritual practices are needed to evoke different types of experience. This system is governed by feedback loops that connect experience, theology, and practice, rather than postulated external agencies.

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"There shall be life!" Some critical remarks on modeling modes of religiosity

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Commenting on extensive modeling and simulation work is seductive and a curse: it is an opportunity to discuss a model and its results in context, and thus provides an appropriate platform for modeling and simulation. On the other hand, it is also very easy to simply criticize the work because modeling and simulation in social sciences adhere to few commonly accepted *scientific* practices. The latter rings particularly true for the multi-agent models that stand at the center of the article I will be discussing in this commentary. Therefore, I focus on modeling and simulation aspects that Whitehouse et al. touch upon: theory building, agent design, and empirical evidence. I am less concerned with simulation technicalities, the details of which remain underexposed in Whitehouse et al. But I am ranting already . . .

One important reason for using multi-agent models is to study group organization and the dynamics that result from the interactions of purposive actors (Axtell, 2000; Bonabeau, 1998). The authors intend to build a model that is theoretically and empirically justified, and explore its outputs within a given parameter space. Assuming a population of individuals endowed with some notion of religion, under what circumstances will religious groups, intergroup competition, and doctrinal or imagistic modes of religious organization emerge? Based on the simulation's results the authors conclude that their theory of "Divergent Modes of Religiosity" (DMR) makes valid predictions about when a religion turns doctrinal or imagistic.

The simplicity of making this prediction makes me think. If we assume that religion is a social system that has something to do with a shared belief system as well

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as repeated, ritualized behaviors, can we then explain that system's behavior, stability, and trajectory based on probabilities? For the DMR theory, the authors explain that "many of its predictions are motivated by postulated causal links between ritual frequency, emotional arousal, memory, intuitive ontology, codification, transmission, group cohesion, group structure and scale, and social identity." It appears to me and others I have worked with (Alam, Geller, Meyer, & Werth, 2011; Latek & Mussavi Rizi, 2011; Moss & Edmunds, 2005) that more expressive agent behavior and environment design are required to represent "codification," "group cohesion," "group structure," and "social identity." Let me briefly explain my assertion against a "multi-agent ontology" of individual–group–intergroup.

The authors implicitly present semantic networks as agent minds and a network of semantic networks as a group mind, but leave unclear – apart from crude probabilities – how agents reason over this semantic network and, more importantly, why they reason over this network. Since there is no pulse of life in the simulation, there is no purpose for these agents to reason in religious terms. For example, what motivates agents to come up with a new plan for bringing their ancestors back, to take an example from the target article. From a multi-agency perspective the semantic network in Figure 2 therefore remains incomplete.

The model can improve most in its specification of agent–agent and agent–environment interaction rules. Agents should have an intrinsic purpose to act. They should also be able to react to actions of other agents and changes in their environment, and be endowed with anticipatory and strategic reasoning capabilities. Newell and Simon's (1961) classic work and recent trends in rich cognitive design (Sun, 2008) demonstrate the usefulness of moving away from probabilities as explanations for socio-scientific discovery. Given one of the author's works on action selection I have reason to believe that work along this line is conducted, but this is just an assumption, since the models presented incorporate (for example) no political economy and identity entrepreneur.

This raises more general epistemological and "theory of science" considerations. The authors' models come with a great number of assumptions. Why do these assumptions need to be made, given that the DRM theory has been empirically tested successfully? Also, why does the predictive cross-validation of the model – no real attempt to relate the data to simulation results is undertaken – remain only on a crude level 0 on Axtell and Epstein's (1994) scale, given the available data?[1] One answer may be that the authors are wedded to an antiquated model of scientific discovery in which prediction at some arbitrary scale[2] remains the hallmark of modeling and simulation in social sciences.[3] However, creating plausible explanatory and future alternatives (e.g., Popper, Lempert, & Bankes, 2005), producing a body of models that serve as containers for knowledge rather than chasing grand theories (e.g., Merton, 1949), building models from first principles rather than theories (e.g., Corbin & Strauss, 1990; Moss, 2002), and using models as data generation engines and data collection tools (Geller et al., 2012) are all plausible alternative motivations and uses of scientific enterprise too. These approaches to modeling are not new, just unorthodox.

I made public these critical comments about the work presented by the authors, not because I disagree with what they have done, but because I believe that modeling and simulation in the social sciences stand a true chance to return to some of the ideals of science, one of which is making research intelligible and thus open to criticism and progress. The authors also deserve credit for taking this risk in the name of science.

Notes

1. Technically speaking, a protocol should enable the reader, for example ODD (Overview, Design concepts, and Details; Polhill, Parker, Brown, & Grimm, 2008), to compare empirical evidence with the model.
2. Note that often temporal scales are not properly dealt with in the article, e.g., Figures 4, 5, and 6.
3. See, in this regard, the critical report by Danzig (2011).

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Modeling the evolution of religious institutions

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The stimulating target article by Whitehouse, Kahn, Hochberg, and Bryson provides an argument for the general utility of computational simulation as a tool for advancing theories of social human behavior. I fully agree, and believe that disciplines such as anthropology, sociology, and history will particularly benefit

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from a greater emphasis on the development of explicit, mathematically specified models – whether using formal analytical methods or simulations. On balance, the strengths of closed-form analytical models and computational simulations complement each other. Simulations are often more technically tractable to construct than fully formal models, and can produce startling levels of complexity with relatively small investments in programing. The two models presented by the authors also illustrate the natural ability of simulations to produce explicit (usually stochastic) dynamics of system change through time (van der Leeuw & Kohler, 2007). The pitfalls of simulations (including agent-based models), on the other hand, are well known. First, because they require the specification of functional forms and parameter values, simulations usually lose generality relative to analytical models. Second, simulations can be constructed with such complexity that all clarity about cause and effect is lost, leading to results that are as undecipherable as reality itself (McElreath & Boyd, 2007). Finally, it can be quite computationally costly to sufficiently explore the full parameter space of a simulated model (to be able to know, for example, how the effect of change in one parameter value may depend on the value of other parameters in the model; Kokko, 2007). The authors are also to be applauded for emphasizing the need for tight linkage between empirics and theory development; without grounding our models in empirical reality, we may as well be counting angels on pinheads.

The two models developed by the authors contribute concrete computational theories of cultural and institutional evolution. This is valuable work. Despite our knowledge that human behavior is governed to a non-negligible extent by culturally acquired social norms and institutions, there is still a relative lack of models that describe their evolution. Evolutionary models of cultural change (e.g., Boyd & Richerson, 1985) have tended to consider changes in the frequency of culturally transmitted individual-level traits, but only more recently have such models addressed the evolution of enduring higher-order institutional complexes (see, for example, Gavrilets Anderson, & Turchin, 2010; Ostrom, 2005; Shennan, 2009; van der Leeuw & Kohler, 2007). The conditions favoring the enforcement of social norms within communities are captured to some extent by the literature on the evolution of punishment in the evolutionary theory of cooperation (e.g., Axelrod, 1986; Boyd, Gintis, & Bowles, 2010), but it is clear that these models only begin to scratch the surface of the potential complexity of human cultural rule systems (Hill, Barton, & Hurtado, 2009). The authors' implementation of DMR theory provides a fresh take on the mechanics and dynamics of institutional change, and lays a nice foundation for future theoretical development.

It is interesting to consider the factors that motivate human behavioral choices in social simulations. For models steeped in economics and evolutionary biology, these motives are assumed to be linked to the economic and/or reproductive benefits and costs of alternative behavioral choices (discussed in the case of religion by Sosis & Bulbulia, 2011). The implementation of carrots and sticks in the second Whitehouse et al. model introduces this dimension of the value of a religion (and its constituent parts) to its adherents and propagators. In the simulation, the carrots offered by a religious group allow it to attract and retain members, while sticks prevent members from leaving. We are prompted to ask: what *are* the benefits that religions provide; what costs do they impose; and how do these benefits and costs vary with their content and the context in which they are practiced?

One recurring carrot of religion is its apparent ability to promote social cohesion and a sense of common community. This cohesion can be achieved through both bottom-up and top-down means. Sosis and colleagues have hypothesized that religious practices such as self-flagellation and scarification may serve to signal commitment between group members, and thus promote within-group trust and cooperation (Bulbulia & Sosis, 2011). Religious practice can also carry out or catalyze the enforcement of pro-social norms, either by commandment, threat of supernatural punishment/reward, direct institutional sanctioning, or by stimulating bottom-up norm enforcement. For example, from the Qur'an 3:104: "Let there be one community of you, calling to good, and commanding right and forbidding wrong," and Leviticus 19:17: "You shall reprove your neighbor, or you will incur guilt yourself" (Cook, 2000, pp. 570, 597).

My own theoretical work shows that evolutionarily self-interested individuals can be motivated to buy into institutions (at a cost) in order to gain the benefits of collective action that are possible with institutionally fostered norm enforcement (Hooper, Kaplan, & Boone, 2010). This work focuses on the relationship between the scale of social integration and the character of norm enforcement mechanisms. The willingness to buy into top-down and catalytic institutional mechanisms of norm enforcement – such as norm-enforcing religions or governments – is expected to increase under the conditions that there are large returns to scale in aggregation, but little chance of success through non-institutional means (due to a failure of cooperation). By adopting the unifying institution, failures of cooperation can be alleviated, and returns to scale can be achieved. Such institutions are expected to entail costs to adherents, not only to subsidize the cost of the services the institution provides, but also in terms of loss of autonomy and other sacrifices made to the institution.

The effectiveness of different religious means of fostering community and pro-sociality may similarly depend on the attempted scale of integration. In terms of the authors' theory, we might speculate that doctrinal practices facilitating norm enforcement (e.g., top-down pedagogy, religious courts) may be better suited to achieving cohesion at the scale of, say, world religions, while imagistic practices promoting social bonding (e.g., mutilating rituals) may be better suited to bringing together smaller, more intimate communities. Fortunately, the authors' modeling framework appears to be nicely equipped to consider the specific factors motivating individuals toward one form of religious practice or another, and how these factors may vary as a function of social, ecological, and historical context.

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The spread of conventions and the search for the optimal strategy

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In their insightful paper, Whitehouse, Kahn, Hochberg, and Bryson discuss the applicability of mathematical and computational tools in the social sciences, and argue that at the present state of the field, mathematical modeling can be an important methodology in developing and testing theories. As an example, the authors offer two sets of models: one developed for a particular case study, and another for a more general description of the dynamics of religious beliefs. In spirit, these models have a lot in common with evolutionary models used in theoretical and population biology. In this short communication, I would like to continue this analogy and offer a different set of tools and ideas that could be of use in the social sciences. First, I will present the framework of quasi-species equations (Eigen & Schuster, 1989; Hadeler, 1981), which is widely used in evolutionary biology and game theory (Hofbauer & Sigmund, 1998), and show that this framework can reproduce quantitatively some of the verbal reasoning presented in the target article. Second, I will draw an analogy between aspects of group behavior modeling and cancer modeling. Instead of talking specifically about religious beliefs, I will use the term "complex conventions," to emphasize the broad applicability of the theory.

To formulate a quasi-species model, let us suppose that each complex convention can be described by a set of values, $(k_1, \ldots, k_n)$. For simplicity we assume a binary description such that each of these can assume values of zero or one. We will assume that the vector $(0, \ldots, 0)$ corresponds to the original convention. A change from zero to one in any of the positions of the vector corresponds to an innovation, modification, or simplification/elimination of the corresponding component of the convention (see Figure 1(a)).

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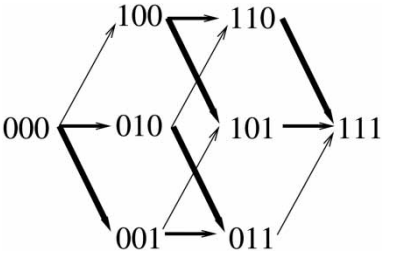

Figure 1(a). A schematic of transitions among different conventions ($n = 3$). Thicker arrows correspond to a larger rate of change.

We will use the index s to refer to each of the binary numbers. We further denote by x_s the fraction of individuals adhering to convention s.[1] We have the following equations describing the dynamics of change of convention:

$$\dot{x}_s = r_s x_s (1 - \sum_j u_{s \to j}) + \sum_j r_j x_j u_{j \to s} - \phi x_s, \tag{1}$$

where r_s are "fitnesses" of individual complex conventions, $u_{s \to j}$ is the rate at which convention s changes into convention j (the "mutation rate"), and $\phi = \sum_s r_s x_s$.

Without any further assumptions, this model predicts a scenario whereby the "fittest" convention will win in the long run. A more complicated and rich behavior is possible if we further introduce some of the modeling features used by the authors:

- The tedium factor: the appeal of the dominant convention may fade with time. This means that the function r_0 is some decaying function of time.
- Innovations (or simplifications) can be appealing and popular. For example, in the simplest case, the more "ones," the fitter the convention.
- There could be a highly appealing convention (e.g., $s = (1, \ldots, 1)$), which has only a finite life span, similar to the splinter group described in the context of the Kivung religion, or any other convention with unrealistic expectations.
- After a certain time-lapse during which the original convention is abandoned, its fitness can return to its original value.
- The authors hypothesize that the components of the convention (the nodes) that are more distantly connected to certain intuitive anchor points will decay/become modified faster than those with a more immediate intuitive grounding. This can be modeled in a straightforward way by assuming that the probability rate at which changes occur may be a function of the position (see Figure 1(a)).

This model produces dynamics similar to those described by the authors (see Figure 1(b)). Initially, convention x_0 dominates. As time passes, it begins to lose its appeal, and modifications appear and gain popularity. Eventually, a highly appealing convention with unrealistic expectations pops up, gaining almost universal acceptance and displacing other conventions. Due to its finite life span, however, it is eventually abandoned and replaced by the original tradition, which returns because of its renewed appeal to the public. Note that if the highly appealing convention was not based on unrealistic expectations, it could have remained attractive and

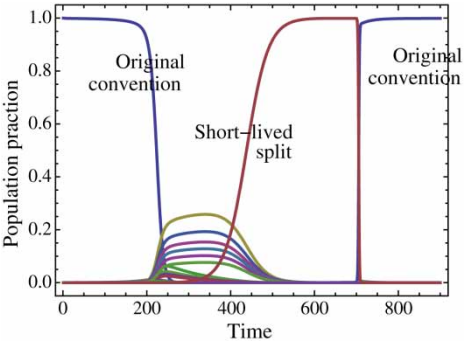

Figure 1(b). The result of model (1) with $n = 5$. The tedium effect is modeled by taking $r_0 = 1 + n\text{Ú}e^{-t/t_0}$, where t_0 is the characteristic time of the tedium effect to set in. After a certain time-lapse during which the original convention is abandoned, its fitness returns to its original value, $r_0 = 1 + n\text{Ú}$. The attractiveness of modifications is reflected in $r_s = 1 + \text{Ú}\ rank(s)$, $n \neq 0$, $n \neq 31$, where $rank(s)$ is the number of ones in the vector s. The short-lived attractive convention $(1,1,1,1,1)$ has fitness $r_{31} = 1 + (n+1)\text{Ú}$ until $t = 700$, and then it drops to low numbers relatively quickly, modeling the loss of appeal of this convention. The mutations are modeled to be the same for all the changes, with $u_{ij} = 10^{-5}$. Other parameters are $t_0 = 100$, $\text{Ú} = 0.05$.

completely replaced the original convention. Similarly, if several conventions had an equally high appeal (or, more realistically, catered to different subgroups of the population), then the original convention would be displaced by a number of competing spin-offs.

The frequency of practicing a religious convention is one of the focal points of the religious "modes" theory put forth by the authors. This aspect of the model can also be introduced very naturally in the current framework. In the simplest case we can assume that the first entry in each vector encodes the frequency. If the frequency is high, the rate of change away from the given convention is very low, but the tedium factor may be stronger for this convention. If the frequency is low, the convention could be more appealing, but the rate of modification/forgetting/innovation is relatively high. This brings me to the second idea that I would like to propose.

An interesting question that arises from the target article is the effectiveness, from the point of view of a convention, of various methods of self-maintenance. The authors suggest that high-frequency practices tend to have a high fidelity of self-replication. People do not tend to forget concepts, and innovations cannot go unnoticed. On the other hand, the tedium factor could be strong in this case, which results in lower fitness of the convention. Finally, various measures are routinely implemented to keep the followers from switching. This again has an impact similar to lowering the "mutation" rate. On the other end of the spectrum, conventions characterized by low-frequency practices and a relatively high degree of arousal, in the framework of this model, have a high "mutation" rate and relatively high fitness. The set of questions that arises here in the context of various conventions' strategies is not dissimilar to the questions raised in another field of evolutionary biology – the biology of cancer. Cancers can be described as cellular colonies with high levels of fitness, which tend to grow and replace healthy tissue (Wodarz & Komarova, 2005). In a natural setting, various colonies that differ by the phenotypic properties of the cells compete with each other. It has been observed on multiple occasions that cancers are characterized by heightened

mutation levels (Lengauer, Kinzler, & Vogelstein, 1998). The following issue has attracted the attention of oncologists and evolutionary biologists for several decades: is the heightened mutation level some sort of a side-effect of cancer, or is it a means for the cancerous colony to get ahead and spread, displacing other colonies that replicate with higher degrees of fidelity? The cells characterized by elevated mutation rates have been termed "the mutator phenotype" (Loeb, 1997). A comparison can be made between the mutator phenotype colonies and low-frequency, high-arousal conventions. These have a higher risk of "losing" (genetic or non-genetic) information, but, in their search of the "space of possibilities," they have a chance to stumble across a highly-successful, very "fit" phenotype (convention), which can be successful in the long term. From the point of view of a convention, is it better to keep the frequency of practicing high (and the mutation rate low), and risk losing its followers to the more exciting conventions, or is it more advantageous to lower the frequency of practicing and raise the level of excitement, and risk losing some essential information?

These questions can and should be studied using the tools of evolutionary biology, and should be informed as much as possible by field studies and specific historical cases. The resulting theory specific to human religious conventions could be very powerful, and could explain aspects of peculiar or poorly understood phenomena in the history of religion.

Note

1. $s = \sum_{j=1}^{n} 2^{k_j}$, with $0 \leq s \leq 2^n - 1$. Further, $\sum_s x_s = 1$.

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Ancestors in the simulation machine: measuring the transmission and oscillation of religiosity in computer modeling

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In this target article, Whitehouse, Kahn, Hochberg, and Bryson run two computer simulations based upon one mature theory in the Cognitive Science of Religion

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(CSR) – the Divergent Modes of Religiosity (DMR) (see Whitehouse, 2004). First, the authors replicate the "oscillation" between the "doctrinal" and "imagistic" binary oppositions, found in the ethnography of Whitehouse's Kivung data set (1995). Second, they simulate the underlying processes of the DMR, perhaps also simulating ritual transmission in general. In doing so, the authors attempt to generate a more precise, testable theory for the DMR, and put forth an argument for the value of social simulation in the study of religion.

According to the authors, most simulation studies in the social sciences are relegated to specialized journals (and audiences) that focus on the technological, or operational, method of inquiry. Because of this focus, many of the substantive-based aspects of these simulations may not have been noticed or tested. The authors further argue that "social simulation" is a proven vehicle for experimentally based paradigms, and provide a context in which some (if not many) social scientific research paradigms may benefit from such plausible applications. The method of simulation (with its meta-theoretical basis) is like any other approach, in that it may be tested against real world data. The complexity of social simulation is apparent in the fact that for experimental value in the social sciences, the specificity of the data determines the validity of the outcome (i.e., the more precise the input, the better the output). As theories can change, simulations may allow researchers the benefit of narrowing and altering existing theories as a scientific evolutionary process (via peer review and hypothesis testing) by critically narrowing or widening the validity, reliability, and predictive value of the target theory.

If the process of simulation has the aforementioned capacity, then – according to the authors – it should have the power to test certain hypotheses in the study of religion, and many of its features. What a simulation reveals, however, may be so complex that it is indecipherable to individual human minds, and the "creative" processing/theorizing of such data. In addition, "religiosity" may be too complex a phenomenon to be tested by such methodologies. Nevertheless, Whitehouse et al. argue that social simulation should be encouraged because its "predictive" value may refine theories of religion over time.

In the simulation of Model 1 in the target article, we find an explicit overview of one of the DMR's most crucial aspects – the correlation between ritual frequency, emotional intensity, and the mode of memory in religious transmission. If one accepts the motivational argument of "Modes" theory, this simulation gives a very powerful model of the process of religious revitalization. However, this model needs important changes to the simulation in order to allow for the repeated process of splintering and re-assimilation that has been specified by Whitehouse (2004). As it stands, the model shows one period of motivational increase, but it dies out as the model is "run" to its limit and the "mean-motivation-level" eventually falls well below the "minimum-motivation-level" after splintering. A basic reintegration function could be added to this model to better show the limit cycles seen in the ethno-historical record that Whitehouse has proposed previously (1995).

Figures 1 and 2 represent two runs of the target article's simulation. The grey lines represent the "minimum-motivation-level" set by the user.

Our revised model (see electronic addendum/auxiliary file) uses almost all of the original code from the target article but adds a "re-assimilate" function to allow for the splinter group to form (this revision, like the code from the target article,

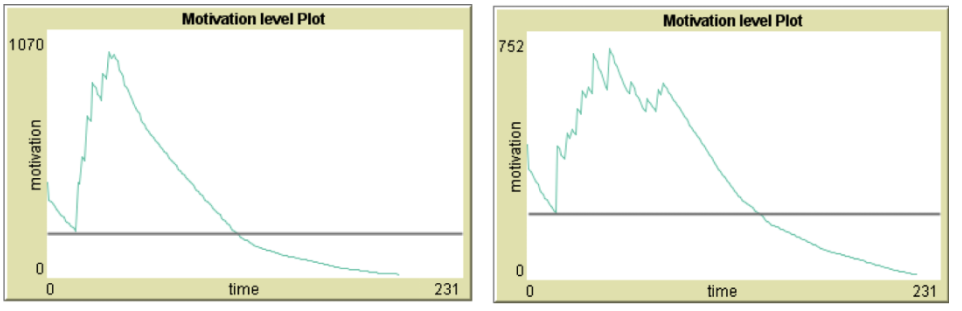

Figure 1.

also requires the auxiliary file). As the motivation for the "beliefs" of the splinter group dissipate, the agents re-assimilate into the original group identity (or as the authors specify – the mainstream Kivung). For the purpose of the simulation the threshold level for re-assimilation was set to 1.5 times the "minimum-motivation-level" (a variable set by the user in the target article's simulation). Whenever the "mean-motivation-level" (the average motivation level of the group's members) falls below the "minimum-motivation-level" a splinter group will form, introducing a "splinter group leader" and asking the followers to start accepting the splinter group beliefs and replenishing their motivation. This allows for the simulation to cycle over time, as the DMR theory predicts, rather than showing only one splintering event.

Figures 1 and 2 show the results of running the revised model. The grey lines of Figure 1 represent the "minimum-motivation-level." In Figure 2 the red lines depict points of "splintering" and the yellow lines depict points of "re-assimilation."

After a number of these cycles, this model shows similar patterns of repetition; this is to be expected because similar belief networks are being reinvigorated. Future simulations (and we advocate further refinement to both the model in the target article and to our additions) can expand on what we refer to as a

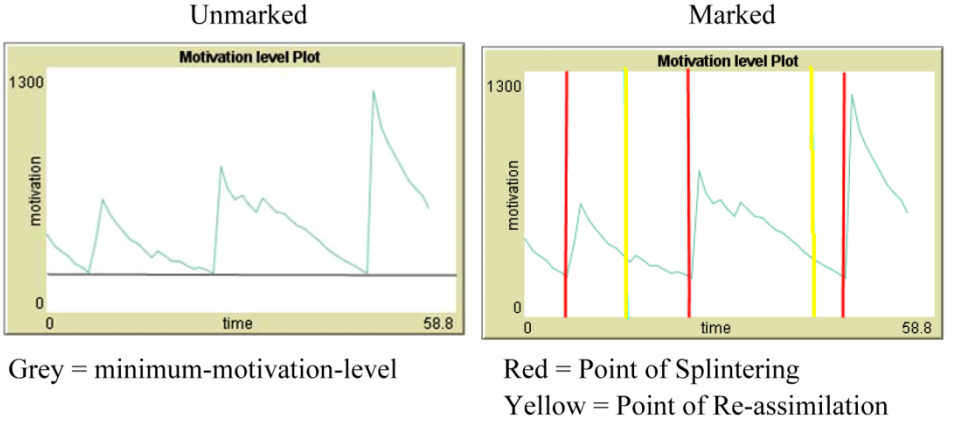

Figure 2.

"splintering/re-assimilation oscillation hypothesis," by allowing for novel belief schemas, as it is unlikely that splinter groups are identical even within the history of the Kivung. Tracing the "theological/ritual" innovations each splinter group represents may further improve the model, thus serving to inform investigators of more precise "semantic networks" for simulating the DMR and theorizing in the field of CSR more generally. It is also extremely unclear why the "cognitive anchors" are not given any motivational properties in the model, as there is ample empirical evidence for cognitive anchors to motivate behaviors (Hafer & Bègue, 2005; Woody & Szechtman, 2011) even in ritual contexts (Boyer & Liénard, 2006; Liénard, 2011).

In conclusion, although we find "refinement" in the simulation of DMR in Model 1 is needed, we find the authors' methodological engagement with computer simulation refreshing and warranted in the CSR, and in the social sciences in general. Although first embraced by William Sims Bainbridge in the 1980s, it is best exemplified in his book *God from the machine: Artificial intelligence models of religious cognition* (2006). Here Bainbridge used computer simulations to explicitly test certain features of his theory (Stark & Bainbridge, 1987) concerning religious transmission, innovation, and social cooperation/competition. We find the target article engages more recent debates in the CSR field between McCauley and Lawson (2002) and Whitehouse on ritual "form" versus ritual "frequency," and the implications of such an approach. Additionally, we must assume the computer simulation research of Donald Braxton and others (in press; Braxton, Nielbo, & Upal, in press; Upal, 2005) must also play a role in the evolution of modeling the DMR, and in other hypotheses generated by scholars in the field. This target article may provide dialogue and collaboration in creating an intellectual space in which simulation adds to the "tool-box" of CSR, Religious Studies, Anthropology, and other social sciences. We agree with Whitehouse et al. and argue that simulation does have an important role to play in these fields.

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RESPONSE

From the imaginary to the real: the back and forth between reality and simulation

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We are grateful to all the respondents for their insightful commentaries. Many clearly welcome the dialogue we were hoping our article would facilitate between modelers and social scientists. The intention of our article was to present a case study that primarily advances a specific line of inquiry in relation to religion, and secondarily prompts discussion about the role and practice of social simulation in the humanities and social sciences. We thank our reviewers for their many observations and for improving and broadening the scope of our contribution with their arguments and many useful references to previous work.

We appreciate the efforts Chattoe-Brown and McCorkle & Lane have made to document previous work in their commentaries. We, of course, never claimed to be the first to use agent-based modeling (ABM) to study religious phenomena, nor to be offering a complete review of the technique. We also did not claim to be the first to say that a model is a well-specified theory, and in fact cited two texts that do provide more extensive reviews on this matter (Bryson, Ando, & Lehmann, 2007; Kokko, 2007). It is worth noting, though, that a "growing consensus" on this approach is by no means an indication of unanimity. There are still many who hold with Axelrod's (1997, p. 4) statement that ABM is

> a third way to do science . . . the purpose of induction is to find patterns in data and that of deduction is to find consequences of assumptions, the purpose of agent-based modeling is to aid intuition. Agent-based modeling is a way of doing thought experiments.

Czachesz also provides a critique of contemporary researchers applying this latter approach. Those of us promoting the model-as-theory approach to ABM believe that the thought-experiment perspective both underestimates the utility of simulations and overestimates the formality and certainty of the standard scientific methods for deducing predictions from theories. Viewing model building as *exactly* theory building demands more rigor from the models while simultaneously facilitating the scientific process in novel ways. The discussion section we provide ("Recalibrating the DMR Theory") is intended to contribute not only to the DMR theory but also methodologically to the scientific application of ABM, by demonstrating good practice in model outcome communication and by validating through demonstration the model-as-theory approach.

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We thank Costopoulos and Hooper both for drawing attention to a more unusual feature of our paper – that we seek to bring together salient features of cognition, behavior, and cultural systems in our models, rather than to treat these features in isolation. We agree in principle with Costopoulos that this approach has the potential to go further still by providing novel insights into the mechanisms and processes of selection governing sociocultural evolution. In practice, however, there is a computational cost to this complexity of modeling that affects not only the speed that a simulation can run but also the complexity of its results, particularly where those are combined with learning and evolution. This is why the primary goal of Model 1 has been to use ABMs as a way of examining the internal consistency of our theories. In contrast, Model 2 looks at long-term dynamics, and therefore is a far simpler model of religion and agents. Both models are hybrids, which look at the dynamic functioning of features of a system both in place and over time, but each has different emphases in order to allow detailed exploration of different parts of the problem.

By standard scientific practice a model/theory should only be exactly as complex as necessary to simulate/explain the phenomenon it intends to address. Some of our commentators seem uncomfortable with this basic aspect of scientific method. We can see this in the critique of the agents in our models raised in different ways by Geller and Costopoulos. Geller argues that the semantic networks in Model 1 lack a motivational component and "since there is no pulse of life in the simulation, there is no purpose for these agents to reason in religious terms." These comments, however, present something of a puzzle. Each node in the semantic network was explicitly accorded a motivational value that was a function of its combined psychological properties (emotional salience and intuitiveness) and its frequency of activation (motivational force declining as frequency increases). So we are at a loss to understand Geller's point about lack of "purpose" or "pulse of life." Costopoulos is perturbed by the level of detail in our models and the number of unjustified assumptions. But there are no new assumptions here that have not been previously published – in fact, if anything there are fewer and the models are more detailed. It is unfortunately common that when scientists and philosophers see their ideas spelled out in a detailed model they may not recognize them, seeing suddenly only the deficits, gaps, and lack of detail. All models, indeed all theories and all science, take place at a level of abstraction. This is the goal of science, to abstract what matters – what is predictive of the future – from causally irrelevant (or less relevant) details of everyday life and the physical world. Hooper makes this point well. That a simulation brings out the complexity of the system and its assumptions is useful and can hopefully accelerate progress improving the DMR theory. This is not to say that there are no gaps or unwarranted assumptions in our model, or scope for alternative hypotheses. Of course there is much more work to be done beyond the contributions demonstrated here. Indeed, McCorkle and Lane and Komarova propose several such extensions and improvements, which we discuss below.

According to Czachesz, there are conceptual problems with our attribution of motivation to agents. He suggests that these problems have been solved by the psychological research he cites, but does not specify what the problems are (still less how they have been overcome by psychologists). Later he returns to the issue of motivation: "If we set aside the conceptual problems with 'motivation' (see above), there remains a serious concern with regard to its measurement in the model." Thus, the nature of the alleged conceptual problems is never stated, only set aside in order to address issues of measurement instead. According to Czachesz, we have

proposed that motivation levels regulate the stability of the group (we presume he means here the stability of the group's beliefs). Nevertheless, Czachesz continues, "what if 50% of the group has very high motivation, whereas the other 50% has very low motivation? This presents a perfect scenario for schism, or at least for serious inner conflict." It is not clear that this is a concern about *measurement* of motivation levels per se, but rather about what levels of uniformity of motivational states in a population can be assumed by the model. We have assumed that the continual repetition of ritual and creed over time gradually erodes motivation levels and does so quite uniformly with a given community as a whole (the so-called "tedium effect," in support of which we cited empirical evidence). Owing to this uniformity, periodic efforts to advance unorthodox beliefs are crushed by consensus when motivation levels are high and, by the same token, embraced by consensus when motivation levels are low. Does this mean that our model could not account for schism? We think not, because communities differ in terms of motivational levels even if internally they tend towards motivational homogeneity. If we were to enlarge the Kivung model to include not only groups undergoing splintering but other groups within the mainstream movement that are not, it would be obvious that splinter groups are schisms in that wider context (as the notion of "splintering" of course implies). While we might debate the empirical evidence for these assumptions in our model, we think Czachesz's concerns about the way we measure motivation are unfounded.

The commentary by Czachesz raises a number of other issues that would seem to reflect misunderstandings. For instance, he argues that (unspecified) recent developments in the study of memory have cast doubt on the cognitive foundations of the modes theory and then goes on to argue that we "minimize" the role of memory in our model. In fact, the entire semantic network in Model 1 must be stored in memory, and the frequency with which information is presented and the rate with which it decays are key parameters. With regard to the doctrinal mode, as the article states,

> high-frequency ritual performances allow complex networks of ideas to be transmitted and stored in semantic memory . . . as frequency increases the risk of forgetting is reduced but so too is emotional salience; as frequency decreases, garbling and forgetting become more likely but emotional intensity is enhanced.

With regard to the imagistic mode, we observe:

> Such practices trigger enduring and vivid episodic memories for ritual ordeals, encouraging long-term rumination on the mystical significance of the acts and artefacts involved . . . Traumatic rituals create strong bonds among those who experience them together, establishing in people's episodic memories exactly who was present when a particular cycle of rituals took place.

These claims with regard to the effects of memory on the production and transmission of religious beliefs, norms, and practices have been a key feature of the modes theory since its inception (Whitehouse, 1992, 1995). Moreover, these claims were systematically integrated into our models. Czachesz's comments suggesting otherwise are hard to interpret. What might be more to the point is that Model 1 would need to be expanded to take account of the longevity of episodic recall for low-frequency, high-arousal rituals, enabling us to ensure that recurring

imagistic outbursts produce novel semantic networks rather than repeating earlier ones (a point to which we return in our concluding paragraph).

Czachesz maintains that "empirical work has not confirmed . . . predictions about the imagistic mode", a claim that rests on a single publication (Konvalinka et al., 2011). The study cited measured heart rates among a range of observers and participants in an emotionally arousing ritual (fire walking) and concluded that levels of emotional arousal (using heart rate as a proxy) were equally high among fire walkers and those members of the audience related to them (by kinship or close association) but not among audience members who were unrelated, or more distantly related. This is an interesting study but certainly does not disconfirm any predictions of the modes theory. If the claim is merely that it "has not confirmed" it either, this is a rather odd statement because the study in question was not intended to test predictions of the modes theory.

Although many of the points raised by Czachesz left us somewhat puzzled, we welcome his query about whether the doctrinal-imagistic oscillation in the Model 1 is generalizable to other religions (he asks whether it applies generally to "pre-state" societies, but that is not really a relevant question since it has never been proposed that doctrinal traditions and patterns of splintering within them are found particularly or only in "pre-state" societies). A central goal of our article was to show how models could be used to explore the implications of evidence-based theories. So it is entirely appropriate to ask where the evidence for our modeling assumptions comes from. We cited evidence for the generalizability of the oscillation simulated in Model 1, but a more general articulation of Czachesz's concern is provided by Chattoe-Brown when he writes:

> It may be that the authors are very clear what are data, what are assumptions (needed to make the model "work" absent data) and what are results, but unless the skeptical "subject specialist" is kept excruciatingly clear about these distinctions, they may draw unfavorable conclusions.

Chattoe-Brown's suggestion that we tag each assumption of a given model as either supported by data (sources cited) or currently unsupported is well taken. Perhaps this should be standard practice in all efforts to model complex social phenomena. From the viewpoint of presentation such a practice might seem inelegant (hence "excruciating") but clarity and precision should no doubt come before style and readability.

The simulations reported in our article are focused largely on proximate mechanisms rather than on questions of function, adaptation, and selection. Hooper encourages us to address the kinds of resource extraction problems that the two modes of religiosity might resolve. Chattoe-Brown similarly urges us to consider the ecologies of groups in our simulations. We agree that these are important issues and plan to tackle them directly in the next wave of models to be developed (though see our earlier comments on complexity). The work presented in the current paper is a foundation on which to build, as demonstrated by some of our commentators who have done so. Nevertheless, Hooper's comments on the kinds of issues at stake are remarkably penetrating, as, for instance, where he observes:

> we might speculate that doctrinal practices facilitating norm enforcement (e.g., top-down pedagogy, religious courts) may be better suited to achieving cohesion at the

scale of, say, world religions, while imagistic practices promoting social bonding (e.g., mutilating rituals) may be better suited for bringing together smaller, more intimate communities.

Indeed, we may soon do more than speculate since we are gathering increasingly systematic evidence in support of this prediction, not only from comparative ethnography but also from archaeology, historiography, and from a host of new experiments and surveys investigating the relationship between ritual and the scale and structure of social groups (http://www.cam.ox.ac.uk/ritual/).

A key strand of our argument, echoed by Costopoulos, was that one of the considerable benefits of modeling is to establish whether our theories are internally consistent. Sometimes lacunae and gaps in our theories dawn on us for the first time in the process of designing models, and sometimes only when analyzing the results. But it can also happen that such problems are identified and debated for the first time after the models are published. This could hardly be demonstrated more clearly than in the commentary by McCorkle and Lane. They point out that our model of the oscillation between mainstream and splinter group systems in Model 1 is incomplete. And they demonstrate one way of filling in that gap by modifying the code. This encourages us to attend not only to issues of internal consistency in the model but to questions about what is happening in the real world when cults collapse but cardinal beliefs persist. Moreover, by taking a longer-term view of these oscillations, as McCorkle and Lane do, it becomes clear that historically documented innovations in successive splinter groups must be informed by the memories of previous ones, and so future instantiations of Model 1 would need to reflect this. There is, and should be, a two-way street between research in the real world and modeling in a simulated environment. It is this potential for a productive back-and-forth between reality and simulation that we hope our article, and the commentaries it has provoked, will convey to modeling agnostics.

We were particularly impressed and excited by the improvements and extensions made directly to our models and theories by both McCorkle and Lane (who edited our code directly) and by Komarova, who expressed the models mathematically. A common pattern in the scientific use of ABM is the more formal description, where possible, of the simulation findings in mathematics. When multiple methods and tools for reasoning can be brought together in this way and their results correlate, we can have greater confidence that we are making progress theoretically. Drawing on the tools of theoretical and population biology, Komarova not only reveals alternative methods of modeling similar patterns of transformation in religious systems but perhaps even more profoundly the possibility that similar mechanisms can emerge in different evolutionary systems. The parallels that Komarova postulates between imagistic dynamics and colonies of cancer cells exhibiting the "mutator phenotype" are striking and potentially open up new questions about the nature of activist religions in general (and cargo cults in particular), for instance, concerning patterns and rates of spread as compared with missionary teachings exhibiting much lower rates of mutation. What might seem a fanciful analogy could turn out to be a novel insight into processes of religious evolution when a common mechanism is specified with the mathematical precision that modeling provides. These encouraging and constructive extensions to our models even in the brief period allowed for the preparation of commentaries demonstrate the utility of scientific communication through open-source model sharing.

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