Introduction and Summary

To understand the role of ritual in religious complexes, this paper supports the claim that key explanatory threads are to be found in human memory devices and their associated mental systems (Whitehouse, 1995, 2000; McCauley and Lawson, 2002; Whitehouse and McCauley, 2005). For a ritual to do its work on participants and observers, it must make an impact on their long-term memory. Stated differently, ritual must at some level find egress into human memory banks in order to be recalled over long periods of time, to influence later cognition, and to drive human behavior to replicate the ritual. As in all things cognitive, the explanatory work is to display the mental mechanisms that constrain and inform human behavior.

A second set of issues has to do with the associated costs of rituals. Ritual is classically a costly behavior for which there is little tangible evidence that it has achieved its desired results. Does the ritual result in rain, placation of the ancestors, greater control over targeted enemies’, or the conferring of divine blessing upon offspring or matrimonial states? These are the questions that must of necessity be entertained in the face of the
costs, often exorbitant, associated with the staging of rituals. Why do people continue to pay the price if the ritual’s outcomes are inevitably in doubt?

In the following model of ritual behavior, these considerations are linked in a network of relations that continuously generate stable distributions of rituals. The model simulates human behavior using multi-agent modeling. Four factors inform and constrain human behavior in the model: 1.) cost, 2.) tedium and habituation effects, 3.) attentional uptake factors associated with sensory pageantry and emotional arousal, and 4.) cognitive biases toward certain intuitions about ritual form.

Multi-agent models are formal constructs that simulate behavior in simplified, information-rich environments. This model simulates an ideal and mature ritual system left to its own devices. As a formal or ideal system, it assumes no external permutations, nor any sudden modifications to the basic conditions governing the resource network that sustains it. It represents, if you will, a complete and isolated cultural economy. One might think of the world of the model in terms of the biogeographic descriptions of an island ecosystem, or more fittingly still, the discovery of an isolated, highly developed cultural system. Both of these analogies would accurately describe the qualities of a formal model and what it can and cannot tell the user.

The paper consists of five sections: first, I introduce the reader to some of the basic vocabulary and design features of multi-agent modeling; second, I outline the McCauley-Lawson theory of ritual form; third, I present the model; fourth, I describe the four
variables in modeling the theory; and fifth, I explain the outcomes of the modeling exercise.

Because the essay requires some understanding of the mechanics of multi-agent modeling as well as the McCauley-Lawson theory of ritual form, the first two sections serve as primers for those unfamiliar with either subject. As a result, readers who are already familiar with multi-agent modeling may wish to skip section I. Likewise, readers who are familiar with the McCauley-Lawson theory may wish to skip section II.

I. Multi-agent Modeling

Multi-agent modeling is one of several forms of modeling procedures employed in the social sciences. Following the excellent overview work of Gilbert and Troitzsch (2002), computer models of social dynamics may be classed in six categories: system dynamics, microanalytical simulations, queuing models, multilevel simulations, cellular automata, and multi-agent models. Multi-agent models simulate agent-autonomy such that agent-specific features like motives, beliefs, desires, and emotions can be successfully transferred to the modeling realm. As Gilbert and Troitzsch note, while “it would be unrealistic to expect multi-agent models to be able to simulate the great majority of human psychological and social phenomena in any level of detail…the requirement is to extract the features of the target which are of most theoretical significance and concentrate on those, disregarding the many features which are fundamental aspects of humans but which are not thought to be central to the matter under investigation” (p. 163). For the model under consideration here, the salient features have been identified as
cost, emotional arousal/sensory pageantry, impact on memory, and ritual form bias. These features are described in detail in section IV of the current essay.

Netlogo 4.0 is the software package employed for this model (Wilensky, 1999). Netlogo is a multi-agent modeling environment developed initially at MIT and now under continuous development at the Center for Connected Learning under the leadership of Uri Wilensky. It has been employed for almost 10 years to model complex network systems in the natural and social sciences. In the social sciences some of its applications have been the study of altruism, birth rates, ethnocentrism, language change, voting patterns, and wealth distribution. Deployment in cultural selection models, and particularly with regard to the evolution and distribution of religious systems, is a relatively novel application.

The world of Netlogo consists of agents and behavioral procedures. Agents are of two types. The first type of agent – a “patch” – is employed to create the geography of world. Collectively, patches make up the world in a coordinate system represented in the visual interface as a checkerboard. For most purposes, the checkerboard is wrapped so that it forms a torus. The second type of agent – a “turtle” – is identical to the patch with the exception that it possesses motility. Generally, then, patches make up the world and turtles rove the world visiting and interacting with patches and other turtles. Behavioral procedures are instructions that govern patch and turtle actions. Such instructions can govern all agents, only some agents, or just one agent. Finally, each agent possesses various attributes unique to it. For example, in this model “resources” and an array of
memory registers are attributes possessed by the patches only and the status of this attribute at any given time governs how patches may or may not implement their behavioral instructions. Netlogo constructs its complex dynamical worlds by creating an information-rich environment through which agents (turtles) rove, modifying both the environment and themselves.

The class of agents called turtles can be programmed into subdivisions called breeds. Breeds are classes of turtles that collectively possess distinctive features and may follow unique sets of behavioral instructions. In this model presented below, six breeds of turtles are represented called, in order, eggs, books, birds, cats, wolves, and monsters. Further details about the breeds and their significance are presented in section III.

Finally, models run simulations. When employed as a noun, a run signifies a complete performance where the model was initiated and it has cycled through a specified number of iterations. In Netlogo, an iteration consists of one complete performance of all the behavioral instructions given to the agents. These instructions are performed serially. Models can be designed to run the behavioral procedures once, multiple times, or infinitely. Generally, models are allowed to run for specified numbers of iterations and then told to stop if one of two events occur. The first stopping mechanism tells the model to scan itself upon completion of a cycle (iteration), checking for a designated termination state. If the state is found, the model stops. A second stopping mechanism is to specify a desired number of iterations. This feature functions as a kind of clock, effectively representing the lifespan of the model’s run. A complete iteration constitutes
a “tick” of the model, hence the clock metaphor. In the model under consideration, the latter option is employed.

In summary, multi-agent modeling creates complex, dynamic worlds with information-rich landscapes and independently acting agencies. Patches constitute the world. Agents called turtles (or breeds) populate the world, roving and reacting to the conditions encountered on the patches they visit and the other turtles they meet. The movements of turtles and the behavior of both patches and turtles are governed by procedures. The model runs these procedures serially until either a prespecified state is achieved or a desired run-time has elapsed. When I discuss the model below in sections III and IV below this terminology will be employed.

II. The McCauley and Lawson Theory of Ritual Form

Robert McCauley and Thomas Lawson published their ritual form theory in 2002 in *Bringing Ritual to Mind*. Their basic claim is that the form rituals assume and the distributions of these forms manifested across cultures “depends upon perfectly ordinary machinery that humans possess which is dedicated to the representation of agents and actions generally” (p. x.). The psychological machinery all humans possess imposes constraints on the generation of ritual systems, determining how impactful ritual performances are on human memory dynamics. One important variable in this set of constraints is the display of sensory pageantry in ritual and the resultant production of relative degrees of emotional arousal in participants and observers. Another important
variable is a suggested cognitive bias for certain ritual forms on the basis of how humans represent supernatural agents and the actions associated with such agents. Taken together, these two variables account for what rituals enjoy recurrent cultural success. They argue that these variables interact to generate a bimodal distribution of ritual forms. On the one hand, rituals that are high-frequency but low arousal have a cognitive advantage in the face of cultural selection pressures. On the other hand, low-frequency rituals with very high degrees of sensory pageantry and emotional arousal form a second privileged form. These two forms constitute attractor basins toward which most rituals gravitate, thus producing the bimodal distribution found in ritual systems throughout the world.

The McCauley and Lawson ritual form theory suggests other consequences. These consequences have to do with ritual competence, ritual well-formedness, a subtle hierarchy of ritual depth dependent upon the relative immediacy of superhuman agency, and the structure of what might be called a mature and balanced ritual system. Only the idea of a mature and balanced ritual system is of relevance in the context of this essay. As I stated in the introduction and I will return to in the description of the model, the assumption of this modeling exercise is that it simulates a culturally isolated system of rituals ranging from very cheap and low-demand rituals (called eggs in the model) to very rare and high-demand rituals (called monsters in the model). Essentially, the model floods the world with six ritual forms in equal distribution and allows the rituals to compete for the attention of a human population. A run is completed when the model achieves a stable distribution pattern, what according to the McCauley and Lawson
theory would be its mature and balanced form. The six ritual types are designed to cover
the logical range of all potential rituals given human cognitive constraints. The reader is
encouraged to be aware of the fact that in real world settings ritual systems are in
constant flux and they are always in competition with other cultural influences. Thus, the
idea of a mature and balanced system of rituals is an idealized state not intended to
replicate any real-world system. The model is designed to replicate the abstract
machinery and dynamics of ritual systems.

III. From Eggs to Monsters: Formal Characteristics of the Model

The model, nick-named Eggs2Monsters, is an example of a multi-agent strategy
employing the program Netlogo where various classes of agents are ascribed specific and
varying attributes (Wilensky, 1999; Gilbert and Troitzsch, 1999). These attributes govern
the behavior of the classes of agents as they navigate the information-rich two-
dimensional checkerboard that is their world. The individual squares of the checkerboard
(called patches and representing in this model minds in a cognitive landscape) have their
own attributes but they do not move. Rather, they keep records of the history of the
agents that visit them (called “turtles” in the language of Netlogo and representing
various rituals in this model). A complete list of turtle and patch attributes is given in
Table 1.
The model possesses six classes of turtles (called breeds). They represent the six forms of ritual candidates that rove a cognitive landscape seeking performance. The breeds are organized on a scale of lowest to highest degrees of sensory pageantry (SP) in the ritual system. Since cost follows sensory display, cost is positively correlated with SP. The impact of the performing of a ritual display by each of the breeds is registered in memory for each patch, and this too follows the same scale from lower to higher impact. Finally, tedium effects are the same for all breeds since repeated exposure to the same ritual results in identical degrees of tedium regardless of SP. The six breeds and their actual values are provided in Table 2.

<table>
<thead>
<tr>
<th>Breed</th>
<th>Cost</th>
<th>Memory Impact</th>
<th>Tedium Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eggs</td>
<td>1</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Books</td>
<td>2</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>Birds</td>
<td>4</td>
<td>30</td>
<td>1</td>
</tr>
<tr>
<td>Cats</td>
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<td>40</td>
<td>1</td>
</tr>
<tr>
<td>Wolves</td>
<td>8</td>
<td>60</td>
<td>1</td>
</tr>
<tr>
<td>Monsters</td>
<td>10</td>
<td>60</td>
<td>1</td>
</tr>
</tbody>
</table>

**Table 2: Breeds and Attributes**
The least expensive ritual form is the “egg ritual”, followed by various intermediate forms until one arrives at the “monster ritual”. The names of the rituals are meant to be suggestive of the degrees of arousal associated with the particular form, but in fact are quite meaningless designations. No assumptions are made about the rituals themselves other than their formal characteristics. In other words, the rituals are complete abstractions.

All breeds keep a running tally of their history in terms of performances allowed. If they are allowed to perform the ritual they add one unit to the performance tally. If they fail to find acceptance, they lose one from their tally.

The patches of this world represent the potential host minds for ritual performances. Each patch has a running tally of its resource availability and its current tedium state relative to each ritual. Resources are newly acquired at the end of an iteration of the model. During a model run, patches check their resource count to see if they can afford a ritual performance when visited by a particular ritual. If they can afford it, patches are always willing (perhaps unrealistically) to entertain a ritual performance. If they cannot afford the performance, they decline the request by the visiting turtle, and hold their resources in the ready until the next request. Such a request may come within the same iteration if more than one turtle is visiting the patch, or it may come in the next iteration, or it may not come at all. All decisions are handled on a first come, first served basis. If it comes in the next iteration, then the patch will have additional resources because new resources are allocated at the end of each cycle. Tedium effects subject all visiting turtles
to an additional constraint on their performances, since a high degree of tedium translates into a condition where even if the resources are available to stage the ritual display, the patch decides it is not worth the effort and tells the visiting turtle no. Of course, the obverse is also possible since a patch may be interested, as measured by low tedium effects, but not possess the resources. We might call this state “a reluctant pass.”

The algorithms are the procedures each turtle and patch runs during an iteration of the model run. All turtles run through a sequenced script of calculations governed by their breed type. First, all turtles move five squares in a random direction to a new location. Second, the new patch asks what kind of turtle is visiting and registers its presence in its tedium registry. Third, the turtle now calls the patch and asks if it has the requisite attributes for a ritual display. This information takes two forms, consistent with patch attributes – current resources and current tedium effects for the visiting breed. If the visiting turtle finds that all conditions are met, then it prepares to stage its ritual display. If it finds that one or more conditions are not met, it will not perform. Fourth, the visiting turtle records in its performance history the results of the exchange, adding one unit if it has been successful, or subtracting one unit from the tally if it has failed perform. Fifth, after these transactions have been completed for all turtles, all patches check to see what breeds are completely absent during the current iteration. If a particular breed is not represented, the patch subtracts a small amount from its memory for that breed-type to represent slow memory erosion. The sixth step is to simulate cognitive biasing associated with intuitions of well-formedness. In the case of this model, books and wolves receive special privileging in the form of value-add memory effects in proportion to their
inherent memory impact values. The seventh step asks the turtles to evaluate their condition after all these procedures, and to make a judgment about their future states. Four outcomes are possible: turtles can decide to downgrade to a lower level of sensory pageantry because of their lack of success at this level; turtles can reproduce themselves at intermediate stages of success; turtles can decide to upgrade themselves to a higher degree of sensory pageantry if they have been especially successful; and turtles can die if they are in abysmal shape. This decision is governed by the state of their performance tally after the aforementioned transactions. This step is called the transformation procedure. Any transformation event resets the turtle to the default values of the new breed the turtle adopts. The eighth and final step is to replenish resources for all patches for the next iteration. These eight steps constitute one complete iteration or cycle in a model run. The model tracks the number of iterations through its time measurement system called “ticks”, as in ticks of a clock. This model is set to a default run-time of 70 ticks.

Finally, in the Graphical User Interface or GUI (the window for the model in which the user observes the model’s behavior), a running set of plots track the model’s various states. A color-coded line graph tracks first a simple raw count of the number of exemplars of each breed and displays its comparative success or failure to achieve distribution in the world. The line graph is also equipped with a numerical monitor for each breed. A second color-coded line graph tracks the memory effects of each breed-type, again both in a comparative graph and a set of appended monitors that kicks out raw numbers. These displays help the model user to track world-level outcomes.
An image of the GUI is included below. It shows the model with the various features described above. In the image, the model is resting at the starting point before a run has been initiated. All settings in the sliders are at their default marks. The monitors to the right of the central world screen only register the initial count of ritual types to seed the population of this particular world.

![Image 1: Egg2Monster Model at the Start Setting](image.png)

**IV. The Four Variables of the Model and Why They Matter**

The model is designed to simulate the cognitive factors associated with ritual staging, observation, memory, and transmission. It follows closely key elements of the
McCauley-Lawson hypothesis of ritual form (McCauley and Lawson, 2002). Thus, the factors employed to simulate ritual form distributions are chiefly cognitive factors, with the notable exception of the most basic real-world constraint, cost. In real-world settings, additional factors would need to be included in the procedures that govern the model’s behavior. Among these factors would be the deployment of cultural scaffolding devices in a real-world geography, the impact of spatial relations (proximity and distance to concentrations of ritual practices), communication systems between the host-minds of the ritual forms, and political institutional constraints on the free pursuit of ritual forms, to name the most important. While these additional factors are important for generating descriptive detail of real-world data, model simplicity has the benefit of clarity regarding the specific effects of the targeted mechanisms. I elaborate the four factors below.

**Variable 1: The Cost of Religious Behavior**

Everywhere we look, human beings display a willingness to invest scarce resources in religious behaviors that often entail reduction in indices of fitness (Atran, 2002; Harris, 1974). Animal sacrifices, tithing, investment in the construction of architectural edifices that serve no other purpose than to point to counterfactual realities, the dedication of large blocks of productive time to non-productive activities, these are the hallmark of religion. How are we to account for the seeming willingness to invest in non-utilitarian activities when any return is non-tangible and ambiguous at best?

However one answers that question, and there are many good evolutionary explanations available for cultural selectionist models – inclusive fitness and costly signaling (Atran,
2002; Ruffle and Sosis, 2007; Bulbulia, 2008), sexual display strategies (Miller, 2000), group selection theories (Wilson, 2003), psychological comfort (Pargament, 1997), to name but a few – all must explain how religion pays its way. Religious displays are costly and practitioners must always decide whether the price is worth the pay-off.

Cognitive psychologists point to the role of emotional arousal in the formation of lasting memories (Uttls, Ohta, and Siegenthaler, 2006). Various sensory stimuli are better at alerting human attention to the events from which it develops lasting memory traces. Rituals exhibit widespread variability in terms of the amount of sensory pageantry they display to their viewership and there is very good evidence that increases in sensory pageantry translate into alarming human information processing into states of increased alertness (McCauley and Lawson, 2002). But while sensory pageantry is useful in achieving increased memory effects, it is also very costly. Cost is a real-world limiting factor in terms of how much sensory pageantry a religious grouping can or is willing to deploy to make an impression on its participants and viewership.

One final note on this factor and its use in the model: the attentive reader will note that the ultimate reasons governing the decisions of agents to subsidize ritual displays is left unspecified. In other words, the model is agnostic with regard to why humans decide to pay the price, only affirmative of the fact that they often do. Thus, the model can be combined with any theory of cost, of which there are many.

**Variable 2: Tedium and Habituation Effects**
The psychological consequences of ritual forms produces the second factor in modeling ritual. Rituals are scripted behaviors the performance of which follows predictable patterns. While many analysts of religion have underscored the importance of familiarity and emotional comfort associated with the control of the action space of ritual, fewer have investigated the fundamental dynamics of human attention and the role of tedium and habituation as a limiting factor to the staging of ritual. Tedium and habituation decrease attentiveness as a result of the monotony of ritual behavior. Given ritual’s repetitive nature, ritual frequency must negotiate a complex set of limiting factors. On the one hand, frequent performance is highly desirable for the consolidation of memory. On the other hand, boredom is an inevitable by-product of high frequencies of performance, a phenomenon addressed in psychological literature under the heading of habituation effects (Utts, Ohta, and Siegenthaler, 2006). As a result, rituals display a tendency to lose interest or cognitive salience and decline in their impact on participants and observers unless degrees of novelty are introduced. One particular manner in which rituals can “up their game” in order to maintain attention-arresting status is to migrate to domains with higher degrees of sensory pageantry. This dynamic is driven by competition in the cultural landscape among forms for the attention of potential participants and viewers. Rituals compete for a scarce resource – in this case, human attention – and the winners of the competition tend to be the rituals with greater impact on human cognitive systems. Of course, there is an upper limit in terms of how much sensory pageantry can be feasibly incorporated into any staging of ritual display. This upper limit is set by factors such as inherent limits in human sensory apparatus and the cost of ostentatious displays.
Variable 3: Sensory Pageantry and Emotional Arousal

Rituals vary along two interrelated axes. One axis has to do with the degrees of sensory pageantry displayed by ritual forms (McCauley and Lawson, 2002). Some rituals are rather low-key events performed either privately or in small groups. For example, one might consider a prayer meeting, a weekly mass, a small ceremony to make crops thrive, a grave visitation, or a changing of the food offerings at a household shrine. Many of these kinds of rituals are carried out with a minimum of attention, often almost on “automatic pilot” to put it colloquially. Other rituals are full of pomp and circumstance with many unfamiliar but exacting formulae. A wedding ceremony, the consecration of a new cathedral, a coming-of-age ritual among Native Americans, or the funeral rites for a king are all likely candidates for high degrees of sensory pageantry. These rituals leave deep impact on their participants and viewership because such ostentatious displays, arduous performances, and high-stakes behavior excite cognitive processing.

The second axis is frequency (Whitehouse, 1995, 2002). Low-demand rituals with little fanfare are cheap and quick behaviors that can be repeated often because their associated investments are so low. Daily devotions at a household shrine, for example, can be performed in the morning with the simple burning of incense and a few momentary prayers. By contrast, high sensory pageantry is very expensive, requiring months of preparations, perhaps years of careful stockpiling of resources, and often marking a key transition in life that will not come again. In many societies, marriages are of such a nature where preparations have been underway since the bride was a child. Dowries are
set aside, negotiations with other families have been carried out, and the training of the young man and woman has been continuous for many years.

The result is an inverse relationship between sensory display and frequency of performance. The higher the costs, the less frequent the performance, often diminishing to one performance in a lifetime. Similarly, the lower the cost, the more frequent the performance, ranging from monthly, weekly, or daily engagements.

We know from studies of human memory that emotional arousal has a direct impact on how humans attend to various phenomena in their environment (Uttls, Ohta, and Siegenthaler, 2006). Low-arousal states tend to reduce the amount of information that is off-loaded from working memory into the all-important long-term memory system. Likewise, as emotional arousal increases, intensifying alarm signals tell people that something of significance is in the offing and is worth paying especially close attention to. Depending on the level of stimulation, increasing amounts of information are recorded by offloading data from working to long-term storage systems for later full-scale elaboration, investigation, and cognitive integration. This process knows an upper-limit, however, in terms of how much the senses and memory can absorb, with potential evidence for extremely rare instances of so-called flash-bulb memories that seem to violate normal operating procedures. It is clear that rituals take advantage of these mechanisms and constraints by exploring the full range of options from low cost, high frequency rituals to the once-in-a-lifetime pomp of, say, a divinely sanctioned coronation. Ritual forms exploit evolved cognitive mechanisms.
Variable 4: Cognitive Bias for Types of Ritual Forms

The final factor required for modeling of cultural selection pressures in ritual types derives from the formal nature of ritual behavior itself. Ritual is first and foremost action (Lawson and McCauley, 1993). All action carries with it certain formal demands. Specifically, action requires first a principal agent who initiates the behavior. Second, action requires an end state such that it is possible to say the action is complete. This formal logic of all action suggests that rituals contain two key variables: the subject of the action vector and the patient of the action vector. The third category of ritual action has to do with the instrumentality of action, e.g., the instruments through which the action is mediated between agent and patient. (McCauley and Lawson, 2002)

Religious rituals differ from secular ritual behavior though the supposition that a supernatural agency is involved in the action schema, either as the principal actor, or as the patient of the actions of others. When the supernatural entity is the agent of the action sequence, humans, or dimensions of the non-human world of vital interest to humans (e.g., crops, animal populations) are the patients. When humans are the agents then supernatural entities are the patients. Thus, religious rituals per force must have either special agents or special patients included in their design. Instruments, to the extent that instruments are included in the ritual behavior, are also special in the sense that they carry the supernatural powers thought to emanate either directly or indirectly from supernatural agencies.
The upshot of these considerations is that human beings will display various cognitive biases toward interpreting, and hence experiencing, rituals that map better or worse onto this logical schema. Humans carry a cognitive bias, on McCauley and Lawson’s view, to expect that when a supernatural being is represented as the actor the act will be a one-off intervention (non-repeatable) and will display extraordinary sensory traits. Likewise, humans carry a cognitive bias in favor of the belief that when humans are the agents of ritual behavior, the action will be repeatable, may vary in efficaciousness, and will carry lower levels of pomp and circumstance. An example clarifies the distinction between these representations. In the Christian tradition, baptism is a one-off ritual where the supernatural agent transforms the initiate. It is represented as always efficacious, non-repeatable, and associated with extraordinary sensory traits such as immersion, special clothing or even ritual nudity, and often the ritual manipulation of infants. By contrast, weekly devotionals are performed frequently, are represented to vary in efficaciousness dependent on right performance, and require little, if any special sensory traits. Thus, according to the McCauley and Lawson theory, rituals that fail to conform to these default expectations suffer negative selective pressures. They do not map as well onto human cognition. All other considerations being equal, rituals that conform to these traits will tend to seem well-formed, more likely to be efficacious, and thereby receive a transmissive boost among competing ritual forms. In fact, to the extent that these cognitive biases have already shaped the likely forms ambient in any given cultural setting, they create a “cultural scaffolding” of expectations that will privilege some ritual forms over others, namely those forms that human minds are evolved to register, attend
to, and transmit. (See below in this section for more on the concept of cultural scaffolding.)

In summary, cognitive explanations for the success or failure of rituals are focused on the ways in which evolved cognitive biases constrain and inform the design space in which any potential ritual might emerge, gain in popularity, endure, or go extinct (Sperber, 1995; Richerson and Boyd, 2005). Among the most important cognitive constraints of ritual form are human action schemas, the settings of human attentional systems, and the mechanisms of human memory. Further important constraints are the pragmatic consideration of cost and frequency of performance given resource constraints. There may, of course, be additional factors contributing to the selection pressures of ritual types. The argument here is not intended to claim exhaustiveness of the potential factors. Rather, the argument is that the four identified factors are the necessary, if not sufficient, conditions for successfully modeling the distributions of ritual forms we find in the ethnographic record. In the absence of any of these factors, even rudimentary modeling of ritual becomes impossible.

**Often-cited Variables Not Employed in the Model: Frequency and Cultural Scaffolding**

An important metric in the study of ritual systems is the frequency with which particular rituals are performed. (Whitehouse, 1995; 2002) Some rituals are engaged daily, weekly, monthly, and on up the scale while others are once-off affairs. Scholars have long noticed this basic difference in frequency of ritual performances and employed the distinction for classificatory purposes: starting with van Gennep in 1908 and fairly
universally followed since that time, one-off ritual affairs often cluster, for example, around so-called rites of passage. Said rituals seem to cluster around key transitional times in normal human development – particularly sexual maturation and reproductive opportunities, but also birth and death, installation in novel official vocations, and the like. By contrast more frequently practiced rituals cluster around the pedestrian concerns of maintaining right relationship with unseen forces of great pragmatic concerns – fertility of land, people, livestock, and crops, manipulation of circumstances of vital interest to the well-being of individuals and communities – disease and illness, weather, various forms of trade and other social relations.

In the model I present, frequency is handled as a natural by-product of other factors rather than as a causal mechanism itself in explaining differential success. In the model, the frequency of performance is left unspecified and emerges only as the result of other constraints. These constraints are the already specified variables of cost, tedium effects, sensory pageantry, and cognitive bias. These constraints determine how frequently the ritual form is performed in the world made up of potential hosts. In runs of the model, a quite stable equilibrium of frequencies emerges that displays a.) how much overall ritual the world can sustain and b.) what the ratio of low- and high-level frequency rituals will be. Thus, frequency is a by-product of other factors rather than a fundamental determinant of the distribution of the rituals.

While simply correlating cost and frequency can go some way toward explaining distribution within any particular cultural network, it fails to identify the mechanisms
whereby rituals achieve their cumulative effects in culture and why they might be maintained in such relatively stable proportions over time. In other words, how has the culture being modeled been changed on a macro-level by the kinds of distributions produced from the interaction of these four variables? And more importantly how might these cultural environment features feed back on the information exchanges transacted by the world’s agents.

I answer this question employing Richerson and Boyd’s concept of cultural scaffolding (Richerson and Boyd, 2005). Cultural scaffolding refers to the institutional structures that emerge around recurrent patterns of cultural variants generated, in this case, by the rituals themselves. What happens in the real world, for example, when a ritual achieves a kind of long-term success? Take the example of morning Tai Chi callisthenics. Do these morning rituals occur every morning without impact upon their environment? Of course not. They unleash a variety of consequences that offload information about the ritual behavior onto the environment itself and reinforce the ritual. It may start as simple erosion in the field where morning Tai Chi is practiced. From such humble beginnings, it may lead to physical improvements in the field such as tending to the grass, the tying of ribbons in the trees, or even decorative additions like topiaries, statues, or paving. These transformations have impact in terms of storing information about the ritual in the landscape and then making that information available for others to upload. Children are told what the garden is for. They may hear narratives of grandparents who performed the ritual every morning or were widely admired for their mastery of a particular form. Children may even be moved to observe the ritual of their own accord and imitate the
behavior in play rituals during times when the adults are not performing. These are important forms of cultural reinforcement that accumulate around recurrent patterns of ritual behavior. They have significant impact on the memories of witnesses and potential participants. This is emergent cultural scaffolding and it self-assembles stochastically around any successful ritual form, reinforcing the impact of the inherent mechanisms of the ritual performance itself.

Since this model is concerned with cognitive mechanisms as they facilitate selection procedures in the minds of potential hosts, and not in processes such as cultural scaffolding that are often treated under the heading of distributed learning (Payette, 2008), they are simply assumed but not factored. In later elaborations of this basic model, it will be possible to store such accreted information in the landscape and allow it to feedback on the calculations governing rituals

V. Outcomes

Here is a summary of the model’s settings.

<table>
<thead>
<tr>
<th>Category</th>
<th>Patches</th>
<th>Eggs</th>
<th>Books</th>
<th>Birds</th>
<th>Cats</th>
<th>Wolves</th>
<th>Monsters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>N/A</td>
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<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Memory</td>
<td></td>
<td>5</td>
<td>10</td>
<td>30</td>
<td>40</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Cognitive Bias</td>
<td>N/A</td>
<td>N/A</td>
<td>40</td>
<td>N/A</td>
<td>N/A</td>
<td>80</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Table Three: Model Settings
What happens when we run the model? We plug these values into the algorithms, we set the number of exemplars of each ritual at 10, and we set the run time for 70 ticks. In 10 runs of this model, I produced the following results:

<table>
<thead>
<tr>
<th></th>
<th>Eggs</th>
<th>Books</th>
<th>Birds</th>
<th>Cats</th>
<th>Wolves</th>
<th>Monsters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Count Ave.</td>
<td>4567</td>
<td>2814</td>
<td>820</td>
<td>474</td>
<td>230</td>
<td>44</td>
</tr>
<tr>
<td>High/Low</td>
<td>5388/4004</td>
<td>3106/2663</td>
<td>1000/706</td>
<td>543/431</td>
<td>277/198</td>
<td>54/39</td>
</tr>
<tr>
<td>Memory Ave.</td>
<td>0</td>
<td>361</td>
<td>359</td>
<td>226</td>
<td>356</td>
<td>1</td>
</tr>
<tr>
<td>High/Low</td>
<td>0/0</td>
<td>361/361</td>
<td>361/358</td>
<td>237/207</td>
<td>359/350</td>
<td>2/0</td>
</tr>
</tbody>
</table>

**Table Four: Outcomes of Default Settings at 70 Ticks**

So what should we note in this set of runs and how does this influence our interpretation of the data? I believe four points should be underscored.

First, we need to think about what we are measuring. There is a sense in which the measures employed by the model are abstract units, and therefore do not translate readily into any metric in the real world. For example, 2814 book rituals do not translate directly into, say, the same number of daily prayer sessions. Nor would, to give another example, a 226 average for memory effects translate into a percentage of neuronal entanglements, or even a concrete enumeration of people inhabiting the world with full-blown commitment to the practice of, say, the cat ritual. Rather, the units’ true significance is in the proportional relationships within their own system. Thus, 2814 book rituals are only significant in relation to the wolf rituals with an average of 230. We can express this relationship as the ratio of exemplars within the model, in this case an average 12.25 book rituals for every wolf ritual in the run, or roughly 12:1. This relationship is what can be applied to real world dynamics. Specifically, if the model is accurate, it suggests that we ought to look for distributions of rituals with concentrations centered on a 12 to 1
ratio of high and low displays of sensory pageantry. Or in other words, for every high arousal ritual, 12 complementary low arousal rituals ought to be the norm. Here is where empirical investigation should be directed.

The other metric we track in this model is memory effects. By memory effects, we mean the ability of rituals to leave traces in the minds of their hosts. These traces are proportionate to the sensory pageantry of each ritual. Successful performance positively enhances memory effects for a ritual form. Denial of the chance to perform, or the absence of any ritual form, takes away from the memory register for that particular ritual form. Remember, also, that the totals are abstract representations and don’t really signify anything themselves. The real benefit is to see the proportional distribution in the relationships between ritual forms, particularly the book and wolf rituals. Thus, for memory effects, when we look at book rituals to wolf rituals we get roughly a 1 to 1 patch ratio with memory effects in excess of 30 units (the threshold metric for memory counts). These relationships can be better appreciated in the performance plot below:
Image 2: Performance Plot for Typical Run

Note first that the raw count of exemplars of the six ritual forms is roughly evenly spread as a result of their cost. Eggs are very cheap to perform and monsters are extremely expensive. The other ritual forms align themselves in the spectrum respectively. The numerical read outs at the right of the plot confirm this. By contrast, the plot of memory effects shows a different picture where books, birds, and wolves top out the scale, eggs and monsters inhabit the bottom regions, and cats vacillate in the middle. When working with a model not employing empirical data as its starting point, we need to keep the
formal nature of the model at the center of our attention at all times, otherwise we may be misguided to read real world descriptions into the model’s performance. What we do have, however, is a working model of McCauley and Lawson’s attractor basins, a kind of formal evidence for the fact that the mechanisms they identify do generate the distributions they predict.

Second, the distributions can be derived symmetrically at other levels of analysis. Because rituals are constantly transforming, many adjacent rituals are recent converts from other forms. If we divide the scale in half, that is, if we divide the scale down the middle into two groups of three, we get roughly the same distribution: 11:1 for performance frequency and 1:1 for memory effects. If we employ a gravity well image for the two attractor basins in the model, then we have two domains where rituals tend to concentrate even if some circle closer to the center than others. This indicates we have the dynamic equilibrium of a mature system of rituals so long as it is not perturbed by outside influences.

Third, the two extreme ritual forms were consistently the worst performers in terms of memory, although egg rituals were by far the most prolific in sheer count. This is to be expected since both of these rituals violate some of our basic assumptions about memory. Eggs are extremely cheap at one unit per performance, but then their memory effects run at a paltry 5 units. Similarly, monsters are very expensive at 10 units and their memory effects are no better than wolves that only cost 8 units. Both eggs and monsters are clearly not well-formed rituals and, in reality, they are included primarily to eliminate a
pernicious quality of bounded model systems, usually called “boundary effects.” In fact, the target of interest in the model is to watch the behavior of book and wolf rituals. Here’s why eggs and monsters are included at all.

As we saw in the outline of the procedures in this model, all rituals face “choices” at the end of a cycle in the model’s run. They can transform upward or downward based on their success rates, they can reproduce themselves, or they can die. The two breeds at the end poles of the scale of ritual pageantry are thus deprived of a choice because of their location on the scale. Eggs cannot downgrade. Monsters cannot upgrade. This feature is important since the local conditions governing the ritual at a specific point in a run may lead a ritual to move up or down, even if only temporarily, before they return to their previous state. Thus, books can become eggs temporarily and then go back to being books. Wolves can become monsters temporarily and then return to being wolves. In fact this behavior is rather common. Under the right conditions, this behavior can optimize books and wolves under short-term conditions. Eggs and monsters cannot make this one choice, (eggs downgrading and monsters upgrading) and this places them at a competitive disadvantage. So why let them compete at all? The answer is that they both serve important buffer conditions for books and wolves, the two targets of interest in the model. In effect, they preserve the space whereby the range of possible behaviors of books and wolves are maintained.

Fourth, this model concentrates on the ritual form hypothesis of McCauley and Lawson, namely that rituals will tend to cluster around the book and wolf conditions in this world.
because they are better situated to take advantage of human cognition. For example, in the model the ratio of memory effects for books and wolves is 1:6. This ratio is not a random number but rather derives from studies of human working memory (Uttls, Ohta, and Siegenthaler, 2006). Eggs underperform because their memory effects are paltry or, if one prefers, simply very forgettable. Monsters underperform because they achieve no greater memory effects than wolves even though they are more expensive. In other words, monsters try to take the game of SP/emotional arousal/memory effects even higher in disregard to how much information humans can process. They literally bombard participants (patches) but achieve no better results than the less dramatic wolf rituals. They have crossed the line of diminishing returns and simply produce sensory overload. By contrast books and wolves are perched just on this side of a productivity threshold and therefore consistently dominate the run.

Summary
In summary, the initial set of runs supports a clustering of rituals around the forms of high frequency, low arousal rituals and low frequency, high arousal forms, just as predicted by the ritual form hypothesis. In other words, the model replicates the McCauley-Lawson theory. Additionally, it generates a proposed distribution frequency of 12 low arousal rituals to 1 high arousal rituals that is an empirically corrigible claim. It also predicts that ritual systems not conforming to this distribution will underperform its rivals, forcing, all other factors being equal, either adaptation or diminishment into extinction. Of the two variables not included in the explanatory framework of the model,
frequency has now been explained. Incorporating cultural scaffolding effects is the next logical step in the model’s development.

Works Cited


