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Sacred text as cultural genome: an inheritance mechanism and method for studying cultural evolution

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ABSTRACT
Any process of evolution requires a mechanism of inheritance for the transmission of information across generations and the expression of phenotypes during each generation. Genetic inheritance mechanisms have been studied for over a century but mechanisms of inheritance for human cultural evolution are far less well understood. Sacred religious texts have the properties required for an inheritance system. They are replicated across generations with high fidelity and are transcribed into action every generation by the invocation and interpretation of selected passages. In this article we borrow concepts and methods from genetics and epigenetics to study the "expressed phenotypes" of six Christian churches that differ along a conservative–progressive axis. Their phenotypic differences, despite drawing upon the same sacred text, can be explained in part by differential expression of the sacred text. Since the invocation and interpretation of sacred texts are often well preserved, our methods allow the expressed phenotypes of religious groups to be studied at any time and place in history.

Introduction

Inheritance – the transmission of information across generations – is a requirement for any evolutionary process. Darwin conceptualized inheritance as a resemblance between parents and offspring without knowing anything about the underlying mechanisms. Recognizing the importance of Mendel's work in the early twentieth century was a breakthrough in the study of inheritance mechanisms, leading to the modern science of genetics. Genetics features so prominently in evolutionary theory that evolution is often defined as a change in gene frequencies in a population. However, this definition misses an important point: genes are not necessarily the *only* mechanism of inheritance. Defining evolution in terms of genetic evolution is too restrictive.

Evolutionary theory can be broadened by including at least four mechanisms of inheritance: (1) genetics (conventionally defined as a change in gene frequencies); (2) epigenetics (defined as transgenerational changes in gene expression rather than gene frequencies); (3) forms of social learning found in many species; and (4) forms of symbolic thought (including but not restricted to language) that are distinctively human. Studying all four mechanisms of inheritance and their interactions with each other greatly enlarges the explanatory scope of evolutionary theory (Jablonka & Lamb, 2005).

The social transmission of information important for survival and reproduction is especially prominent in our species, enabling human populations to inhabit all climatic zones and to occupy dozens of ecological niches (Pagel & Mace, 2004). The advent of agriculture led to an autocatalytic cycle between the production of resources and the scale of human societies, leading to the mega-societies

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of today. These facts are self-evident and many branches of scholarship are devoted to the study of human cultures and cultural change. Some theories of cultural evolution proposed after Darwin led to a bad reputation for promoting social inequality, a connotation that colors the term "Social Darwinism" to this day (Leonard, 2009). Other, less ideologically laden efforts focused on the emergence of large-scale societies as the central question rather than how any society adapts to its environment (Carneiro, 2003). Efforts to interpret cultures as well-adapted to their environments were often criticized for ignoring the diversity of cultures that exist in any given environment (e.g., Kelly, 1985). For these and other reasons, studying human cultural change as an evolutionary process with its own mechanisms of inheritance is still at a formative stage (Henrich, Boyd, & Richerson, 2008; Paul, 2015; Richerson & Boyd, 2005; Richerson & Christiansen, 2013).

Any mechanism of inheritance must transmit information across generations with high fidelity and translate this information into phenotypic expression during each generation. In this article we argue that sacred texts have these properties and therefore qualify as important inheritance mechanisms in cultural evolution. Sacred texts are cultural productions that serve as repositories of information. Their designation as "sacred" gives them increased salience and affords them protected status such that they are more faithfully and persistently reproduced than other forms of cultural production. Additionally, they are often divided into discrete sections for ease of reference, giving them an almost particulate organization so that different parts can be readily accessed as circumstances demand. Finally, the special status afforded to sacred texts means that their invocation is likely to have a potent effect on action. In short, the role of sacred texts in building, structuring, and maintaining religious communities is analogous to how different genes within an organism's genome operate in response to environmental stimuli to influence expressed phenotypes.

Cultural epigenetics

It is a familiar but remarkable fact that religious communities can differ greatly from each other despite drawing upon the same sacred text. Even the most cursory survey of, say, Protestant denominations in the United States reveals tremendous variation in the religious communities that profess to hold the same Christian Bible sacred and central to their beliefs and practices. These differences can be found in community structure, in political organization, in ritual practice, and even in different religious beliefs, many of which can be diametrically opposed to one another. Moreover, this phenomenon is hardly limited to North American Protestantism and applies to all major religious traditions. How can a single sacred text support such diversity?

Considering sacred texts as cultural inheritance systems analogous to genomes suggests an approach to answering this question. However, it requires that we look beyond genetics and instead focus on epigenetics. Broadly speaking, epigenetics refers to heritable differences in gene expression that are not caused by changes in DNA sequence. It is a fast growing and complex field and one that seems rife with potential cultural analogs. Two processes that seem particularly applicable to our question about sacred texts are gene silencing and differential gene expression. Only some genes within a cell are expressed at any given time. As a normal part of cell differentiation, some genes are turned off or silenced permanently. This silencing is heritable in that all subsequent daughter cells comprising the same tissue will also have these same genes turned off. Other genes, however, need to be expressed to different levels in different tissues such that their products will be found in higher or lower concentrations than in other tissues expressing the same genes. Through these and other epigenetic processes, liver, skin, brain, and muscle cells within an organism come to perform widely disparate functions and to bear little resemblance to one another despite all sharing identical genomes.

Gene silencing and differential gene expression would seem to have natural counterparts when considering sacred texts. Most sacred texts, or at least those of the major world religions, share the common property of being large volumes comprised of hundreds of thousands of words arranged in some sort of categorical order such as books, chapters, and verses. Even in oral cultures, however, the body of stories considered sacred can be extensive. As such, it is impossible for any

individual or group to engage with the entirety of their sacred lore at any given time. Just as epigenetics dictates which parts of an organism's total genome are active and to what degree in different tissues, those parts of a sacred text that a particular group chooses to engage with or to ignore can have important consequences for their beliefs, behaviors, and practices.

When developing analogies, there is always a risk that common misunderstandings about the source concept might be transferred to the target as well (Baker & Lawson, 2001). Therefore, an important point needs to be emphasized before exploring the analogy between sacred texts and genomes further. In genetics the mapping between genotype and phenotype is often complex and it is not uncommon for a given genotype to manifest as multiple phenotypes. This is because a single gene or gene variant can have very different effects depending on the context in which it is expressed (Lewontin, 2011). This is why finding one-to-one correspondences between mutations and genetic diseases is so often elusive. There are myriad factors contributing to this difficulty, including complex gene by environment interactions, developmental processes, epigenetics, pleiotropy, canalization, epistasis, and so on. Reviewing these is far beyond the scope of this work. The salient point is that even at the level of genes in molecular inheritance systems, context affects phenotype. We should expect the same to hold true for cultural inheritance systems as well and perhaps even to be more prominent given the role of language in conveying meaning. In addition to the importance of differential citation, then, differential interpretation of passages should play an important role in how a group's engagement with its sacred text contributes to its beliefs, behaviors, and practices. While an exact one-to-one correspondence between molecular and cultural inheritance systems is neither required nor expected, the phenomenon of differential interpretation is entirely in keeping with the analogy of sacred texts as genomes.

These considerations suggest that some of the empirical methods for studying differential gene expression in cells can be used to study the differential expression of a common sacred text in religious congregations. We explore this possibility by using attitudes toward same-sex marriage as a marker of phenotypic differences among American Christian congregations. Churches differ greatly on this and other issues associated with conservatism (C) and progressivism (P), despite drawing upon the same sacred text. We chose three churches with clearly expressed opinions against same-sex marriage to compare with three churches with clearly expressed opinions that are supportive of same-sex marriage. Using sermons available on church websites or church bulletins, we created heat maps of Biblical expression at three levels: the 66 books of the Protestant Bible; chapters within a frequently cited book; and verses within that chapter. We also examined the differential interpretation of a single verse cited by two of the churches.

Our results show that even though conservative and progressive churches draw upon the same sacred text, as far as their invocation and interpretation of different parts of the sacred text are concerned they are as different from each other as liver and skin cells. More generally, our results contribute to the study of the inheritance mechanisms underlying human cultural evolution.

Methods

The first conservative church in our sample (C1) is a radically insular Baptist church in Kansas. The second (C2) is a conservative evangelical megachurch located in Washington State, while the third (C3) is a United Methodist Church located in New York State. All three churches have clearly defined positions against same-sex marriage, although they differ in their extremism (C1, for instance, actively stages protests). The first progressive church in our sample (P1) is a Congregationalist church in Maine. The second (P2) is a Baptist church in Alabama that was dismissed from the Southern Baptist Convention for its pastor's support of same-sex marriage. The third (P3) is a United Methodist Church (UMC) located in the same small city as C3 but whose pastor and congregation are highly supportive of same-sex marriage.

We chose to include these churches in our sample for several reasons. First, a large number of sermons or Bible citations were accessible from online repositories or church bulletins. Second, they represent Protestant denominations that vary in their average degree of conservatism (Baptist

> UMC > Congregationalist) (Iannaccone, 1994). Third, two pairs of churches (C1 vs. P2 and C3 vs. P3) represent variation within a denomination, with C3 and P3 geographically located within 10 miles of each other.

For all churches, Biblical citations were either taken from sermon transcripts downloaded from each church's online sermon repository or from church bulletins (see Table 1 for sample sizes). Transcripts were imported into NVivo 9, a qualitative data analysis program, which was used to perform 66 text search queries, one for each book of the Protestant Bible. For most queries, both the full name of the book being searched for and common abbreviations were used. However, this was not always possible. For example, a standard, two-letter abbreviation for the Book of Amos is "Am." Including this as part of the text search was impractical since it returned every instance of the first person singular conjugation of the verb "to be." Each query was set to return not only the search terms, but also the surrounding context. This allowed the results to be checked manually to be sure they actually referred to Bible citations and not to other uses of the search terms. For example, searching for "Job" returned not just passages from the Book of Job, but more frequently to ministers' references to employment. Similarly, "John" might refer to any of four different books of the Bible (John, 1 John, 2 John, or 3 John) or to someone's name. Results that were unambiguously Bible citations were coded as such while others were discarded. Similar search queries and manual checks were conducted for chapters within books and verses within chapters.

We created heat maps to visualize differences in Biblical expression between churches. While heat mapping is a generic visualization tool used in a wide variety of disciplines, the analogy to the heat maps in molecular biology seems particularly apt. These are often constructed so that cells are marked in some way, for instance by using bioluminescent markers that cause cells expressing genes of interest to glow. In this way, it is possible not only to see where genes are active and inactive in response to specific stimuli, but also to quantify gene expression by measuring the amount of light produced in different tissues. As applied in the following analyses, each church can be likened to different cells while the books, chapters, and verses of the Protestant Bible become the functional equivalent of expressed genes. The more brightly colored a book appears in the heat map, the more frequently it is cited by a given church during its Sunday services.

To create heat maps, tallies were taken of the Bible books referenced in Sunday services by each church. Due to idiosyncrasies of different pastors in the way they referenced books of the Bible and to artifacts created by the coding process within NVivo, no attempt was made to keep track of the number of times a particular book was referenced within a given service. Rather, a simple binary tally was used; either a book was referenced in a sermon or it was not. Totals for each unit (book, chapter, or verse) of the Bible across the entire corpus for each church were then taken and normalized using the formula:

$$\frac{100(x - A)}{B - A}$$

where x is the sum for a particular unit and A and B are the minimum and maximum sums, respectively. Put differently, this formula assigns the least frequently cited unit a value of zero, the most frequently cited unit a value of 100, and all other units a proportional value between these two limits. The normalized values were then graphed using ggplot2 in R.

Table 1. Church information.

Church	Denomination	State	Citation Source	Source Size
C1	Baptist	Kansas	Sermons	393
C2	Non-denominational	Washington	Sermons	397
C3	United Methodist	New York	Bulletins	172
P1	United Church of Christ	Maine	Sermons	137
P2	Baptist	Alabama	Sermons	122
P3	United Methodist	New York	Bulletins	206

Differences in Biblical expression between any two churches (x vs. y) were measured by creating a distance measure according to the formula:

$$D = \frac{\sum (b_x - b_y)^2}{n}$$

where b_x and b_y are the normalized sums of a particular unit from the first and second churches' citations, respectively, and n is the number of units under comparison in a particular analysis. To test for the statistical significance of the difference between any two churches, a randomization test (Edgington & Onghena, 2007) was created in R that combined and randomly resampled the Biblical citations 10,000 times. The distribution of difference scores for the randomized data was then compared with the actual difference score.

To test the hypothesis that the three conservative churches are more similar to each other in their Biblical expression patterns than to the three progressive churches (and vice versa), we calculated the average difference of a given church to the three churches of the other type, minus the average difference between the church and the two churches of the same type. For C1, for example, this works out to:

$$(D_{c1p1} + D_{c1p2} + D_{c1p3})/3 - (D_{c1c2} + D_{c1c3})/2$$

This index will be positive if a church is more similar to its own type than the other type. The index was summed for all six churches to create the test statistic. Then the distance measures were randomized and the test statistic recalculated 10,000 times to create a null distribution to compare with the actual test statistic.

To compare the differential interpretation of a single passage, we chose one of the few passages (John 3:16) that was discussed frequently by the pastors of both C1 and P1 in their sermons. We combined all of the discussions into a single block of text for each pastor ($n = 1851$ words for C1 and $n = 853$ words for P1) and processed the blocks through a text analysis program called Linguistic Inquiry and Word Count (LIWC), which generates scores for psychologically relevant variables based on word counts (Tausczik & Pennebaker, 2010). Differences between churches were then compared statistically with a Wilcoxon rank sum test (Wilcoxon, 1945).

Results

For illustrative purposes, we begin with a pairwise comparison between C1 and P1 before presenting results for all six churches. The heat maps for these two churches at the level of books within the Protestant Bible are shown in Figure 1. There are clearly large differences in the books that the two churches cite, with P1 drawing upon a much narrower range. For the New Testament, both churches frequently cite the four canonical Gospels (Matthew, Mark, Luke, and John). However, P1 cites John more frequently while C1 prefers Matthew. Moreover, C1 also draws heavily from Acts, the Epistles, and the Book of Revelation. P1 seldom cites Old Testament books, but when it does it focuses its attention on Job, the Book of Psalms, and Isaiah. C1 also frequently cites these same books, but clearly includes a much broader range of Old Testament books in its sermons as well, most notably drawing frequently from Genesis, Deuteronomy, and a wider range of the prophetic books, especially Jeremiah, Ezekiel, and Daniel.

The data from C1 were drawn from 393 sermons while the data from P1 were taken from 137 sermons. A careful reader might wonder, then, if these differences are an artifact of sample sizes. We do not believe this to be the case. The data are normalized so that relative frequencies, rather than raw numbers, are being compared. If the citation patterns were following some kind of simple power law such that the wider variety of books cited by C1 was a function of the number of sources rather than real differences in citation practices, then we would not expect books such as Hebrews and Revelation to show up as brightly on the heat map as the canonical Gospels, which are cited with
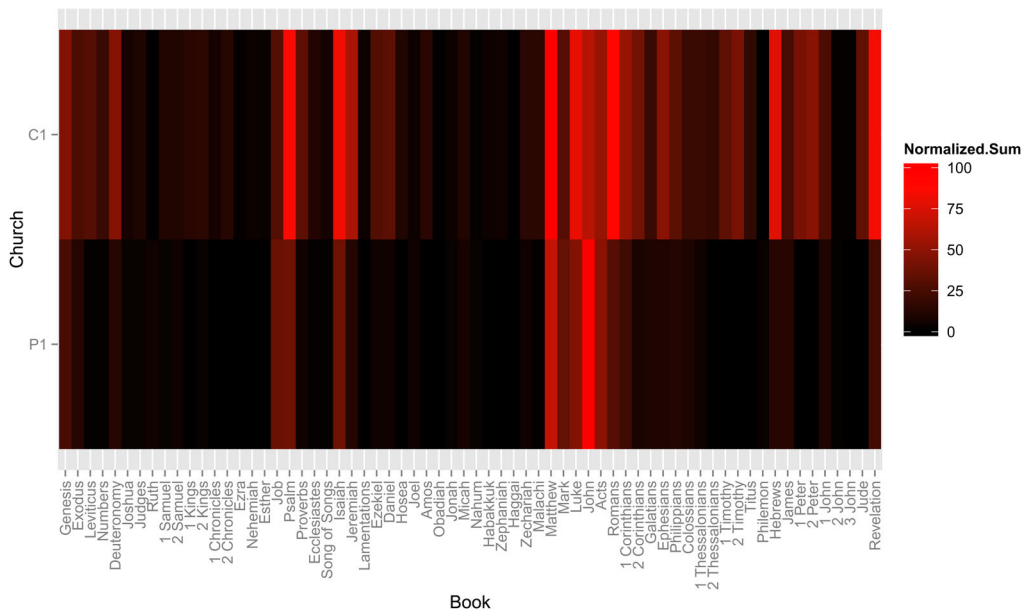
Figure 1 . Heat map showing the frequency with which two churches, one highly conservative (C1) and one highly progressive (P1), cite specific books of the Protestant Bible in their Sunday sermons.

similar frequency by both churches. Moreover, as we show below, the citation practices of C1 and P1 are similar to patterns shown by other conservative and progressive churches, respectively, regardless of sample size. C3, for instance, shows citation patterns similar to C1 and C2 despite being derived from less than half the number of sources. By the same token, P3 shows citation patterns similar to P1 and P2 even though its data were taken from nearly twice as many sources as either of the other progressive churches.

Continuing with our pairwise comparison, to see if differences in Biblical expression exist at a finer scale, we created heat maps for chapters of a single book (the Gospel According to John) and verses of a chapter within that same book (chapter 3) that were cited by both C1 and P1. Figures 2 and 3 show that differences in Biblical expression also occur at these two finer scales. Hence, there is remarkably little overlap in the passages of the Bible that the two churches draw upon.

The difference score for the two churches at the level of books is 778.82. In 10,000 randomization runs, the largest difference score was 150.05. Hence, the difference between C1 and P1 in Biblical expression at the book level is statistically significant at a level far below 10^{-4}.

While revealing, relying solely on Biblical citation patterns tells only part of the story. As discussed in the introduction, the context in which any part of an inheritance system is expressed will affect the ultimate phenotype. This should hold just as true for cultural inheritance systems as it does for genetic inheritance systems and our framework predicts that differential interpretation plays an important role in how a group's engagement with its sacred text affects beliefs, behaviors, and practices. We examined this possibility for C1 and P1 by focusing on a single verse (John 3:16) discussed by both churches: "For God so loved the world that he gave his one and only Son, that whoever believes in him shall not perish but have eternal life" (New International Version). The pastor of P1 argues that this passage should be understood as representing God's unconditional love. He sees it as a call for Christians to love their neighbors unconditionally and to perform "random acts of kindness." The pastor of C1 argues forcefully against this interpretation. He admonishes his congregants that John 3:16 can only be properly understood within the context of other Biblical passages which, taken together, plainly show that God does not love everyone equally or even at all. Thus, on
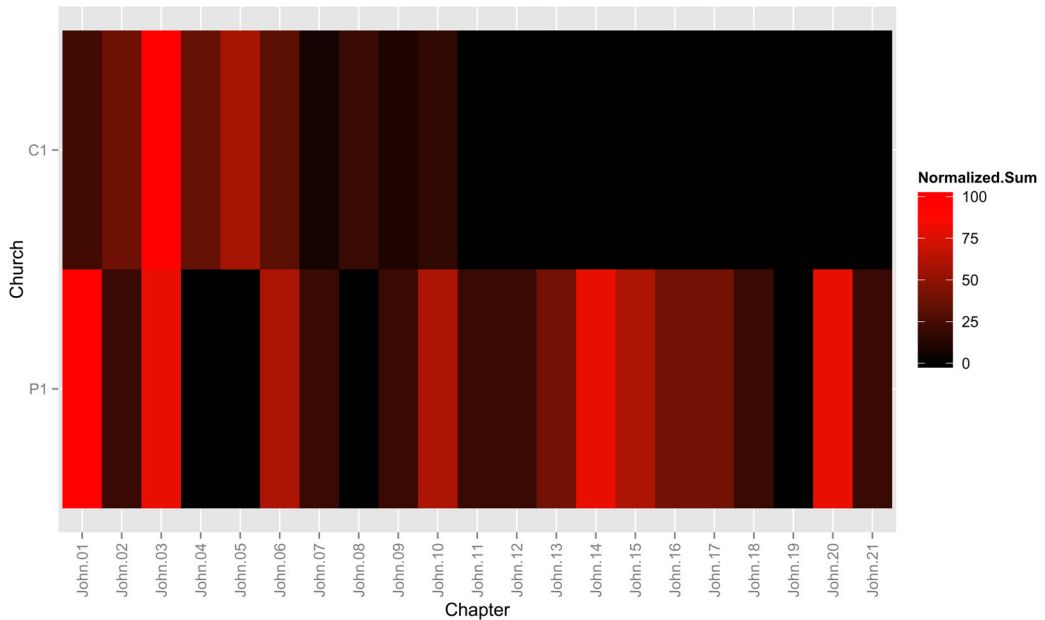
Figure 2. Heat map showing the frequency with which two churches, one highly conservative (C1) and one highly progressive (P1), cite specific chapters within the Gospel According to John in their Sunday sermons.

those rare occasions when both churches draw from the same Biblical text, there seems to be considerable room for exegetical flexibility. To quantify differences of interpretation, we employed the text analysis software LIWC. Even for these small samples of text, C1 (Mdn = 1.805) scored
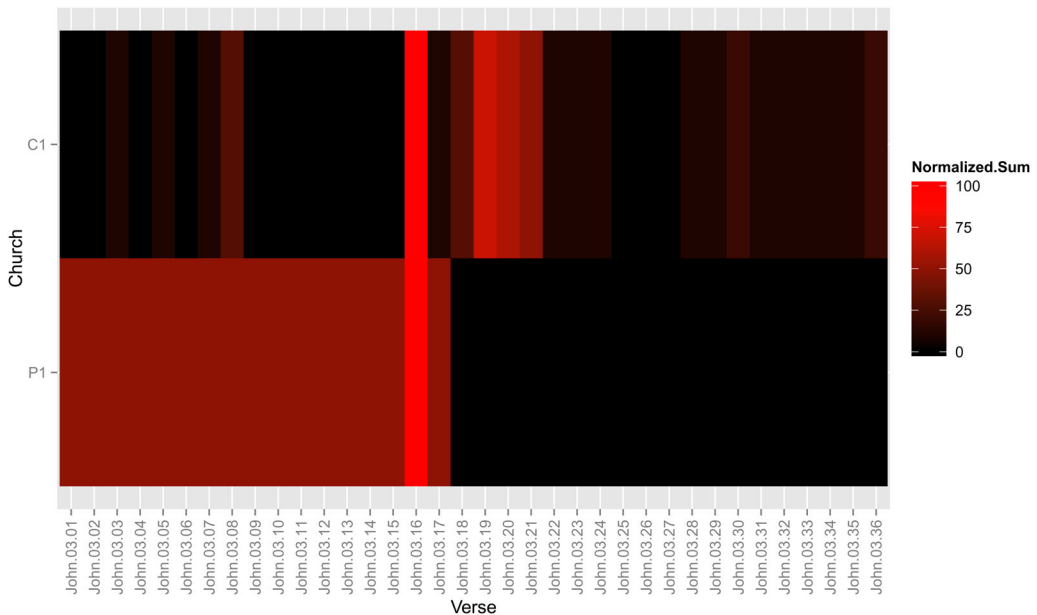
Figure 3. Heat map showing the frequency with which two churches, one highly conservative (C1) and one highly progressive (P1), cite specific verses within chapter 3 of the Gospel According to John in their Sunday sermons.

significantly higher than P1 (Mdn = 0) for the frequency of words connoting anger ($W = 2$, $p = 0.031$, $r = -0.68$).

Now that we have compared two churches in detail, we will proceed to our analysis of all six churches. Heat maps at the book level are shown in Figure 4 and the matrix of distance values is shown in Table 2. Visually, the three conservative churches appear to resemble each other more than they resemble the progressive churches and vice versa. However, all of the distance values in Table 2 are statistically significant so there are also differences in Biblical expression between conservative churches and between progressive churches. Nevertheless, the average conservative church is more similar to other conservative churches than to progressive churches and vice versa (randomization test, $p = .003$)

Discussion

Religions are often criticized for selectively using their sacred texts to justify any action, from love and peace to hate and war (e.g., Dawkins, 2006a; Harris, 2004). This critique is leveled not only by atheists but also by religious believers concerning each other's interpretations of the sacred text. The underlying assumption of the critique is that religions are supposed to counsel only one course of action (such as brotherly love) and that departures (such as practicing war) are hypocritical.

Viewing sacred texts as cultural genomes leads to a very different interpretation of religious belief and practice. All human communities are faced with the challenge of surviving and reproducing in their environments. In this respect they are no different from other biological species, but humans are unique in the amount of fitness-enhancing information that is learned and culturally transmitted across generations and the speed of adaptation to new environments. This statement does not deny the importance of cultural transmission in other species, but the human capacity for cumulative cultural evolution is undeniably in a class by itself. Against this background, a sacred text that counsels only one course of action would be highly maladaptive. Far from hypocritical, the ability of a sacred
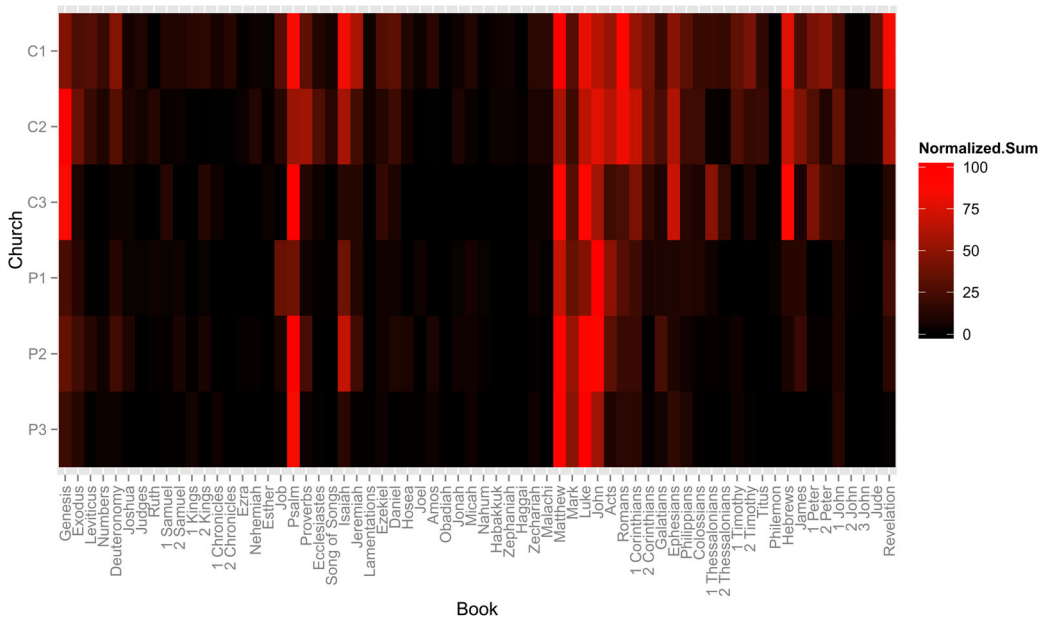
Figure 4. Heat map comparing the frequency with which six churches, three highly conservative (C1–C3) and three highly progressive (P1–P3), cite specific books within the Protestant Bible in their Sunday sermons.

Table 2. Difference scores for Bible citation patterns from six churches.

	P3	P2	P1	C3	C2	C1
P3	–					
P2	120.4598*	–				
P1	195.6572	169.0924	–			
C3	347.9863	375.7162	452.4797	–		
C2	703.6483	505.4802	461.7997	409.2415	–	
C1	778.8209	543.6078	616.3263	503.6523	253.8373	–

All $p << 10^{-4}$ except $*p = 5 \times 10^{-4}$.

text to prescribe different behaviors for different circumstances can be a highly adaptive form of phenotypic plasticity.

The fact that religious communities are often well adapted to their environments is already firmly established, especially based on the study of religion from an explicitly evolutionary perspective during the last 15 years (Atran & Henrich, 2010; Bellah, 2011; Norenzayan & Shariff, 2008; Richerson & Christiansen, 2013; Wilson, 2002, 2005). Elements of religion that appear maladaptive, such as belief in supernatural agents and costly rituals, upon closer examination often turn out to play an important role in the functional organization of religious groups (Bulbulia & Sosis, 2011; Sosis, 2004) or in the maintenance of the society as a whole (Cox, Villamayor-Tomas, & Hartberg, 2014; Hartberg, Cox, & Villamayor-Tomas, 2014). The main contribution of this study is to examine cultural inheritance and expression in more mechanistic detail than previous studies. Elements of a culture that are regarded as sacred almost by definition will be transmitted across generations with high fidelity and will be translated into action. Insofar as many elements of a culture are regarded as sacred and elements are differentially invoked in response to environmental circumstances, then collections of sacred elements have the makings of a cultural epigenetic inheritance system, with the addition and subtraction of sacred elements the cultural analog of genetic change.

A sacred text such as the Christian Bible is especially amenable for developing this analogy. Its hierarchical organization into books, chapters, and verses bears an intriguing similarity to chromosomes, genes, and subunits of genes. The ways that different parts of the Bible are invoked in response to environmental circumstances can be studied in minute detail. Insofar as Biblical citations are preserved in the historical record, it is even possible to measure the "expressed phenotypes" of religious communities in the past and how they change over time in response to environmental change.

Our study of three conservative and three progressive American Protestant churches should be regarded as a proof of concept for studying sacred texts as cultural genomes, using the same theoretical concepts and empirical methods that are well established for the study of genetic inheritance systems. The profound differences between progressive and conservative worldviews have been extensively studied for both secular and religious cultures (e.g., Haidt, 2012; Lakoff, 2002; Norris & Inglehart, 2004; Storm & Wilson, 2009). Our goal was to show how churches can have such different worldviews while drawing upon the same sacred text. Part of the answer is that they draw upon different portions of the sacred text, in the same way that different cell types of a multicellular organism draw upon different portions of the genome. Another part of the answer is that even the same passages of the sacred text can be interpreted in different ways, in part by linking them differently to other passages, much as a given gene can result in different phenotypes depending on how it is linked with other genes.

All of the distance measures in Table 2 are statistically significant, but the existence of a conservative cluster and a progressive cluster is also statistically significant. This is not surprising. Two members of the same species displaying identical phenotypes often have different underlying genotypes. Nevertheless, *ceteris paribus* we would expect that individuals with the same phenotype should have on average greater genetic similarity to one another than to individuals expressing a different phenotype. Moreover, we have classified conservative and progressive churches based on their

stances on same-sex marriage, which likely serves as a proxy for other similarities. Even so, their beliefs, behaviors, and practices differ in other ways and they occupy different niches, responding to different pressures. Insofar as there are multiple ways to justify a given position from the shared sacred text, we expect to see idiosyncratic differences in Biblical expression among churches that are conservative or progressive to the same degree. However, these differences should be smaller than the differences among churches that differ in their degree of conservatism and progressivism.

The results for our six churches fit well with these expectations. Certain books, chapters, and verses are more amenable to a given worldview than others, so their expression is not entirely idiosyncratic. This accounts for the conservative and progressive patterns of Biblical citations shown in Figure 4. All churches in our sample cite from the canonical Gospels with similar frequencies, although progressive churches cite Mark slightly more often than conservative churches who for the most part seem to ignore this Gospel in their Sunday sermons. Similarly, all churches make relatively frequent references to the Book of Psalms from the Old Testament. Although we will need to collect far more data to confirm this, the Gospels and Psalms seem to form a kind of core set of passages, perhaps both necessary and sufficient to sustain a progressive Christian congregation. Considerably more text, however, seems to be required to sustain conservative churches.

As Figure 4 shows, conservative churches draw from far more parts of the Bible than progressive churches. Some of these come from the Old Testament, most notably from Genesis but also a wider range of the prophetic books. Most of the additional source material for conservative churches, however, comes from the Epistles in the New Testament. This is probably not an accident. The Epistles are collections of letters from early Christian leaders (most attributed to Paul) to burgeoning churches in the ancient world addressing, among many other things, topics such as church governance, traditional behavioral norms, resolving conflict within congregations, and sanctioning transgressions. As such, they provide specific interpretations of what people should believe and how they should behave. It is not surprising that these texts should be accessed more often by conservative churches whose conservatism is largely defined in modern discourse along these same themes. Similarly, it is not surprising that these texts and their associated topics would not be activated as often in progressive churches whose progressivism often hinges on personal autonomy. Both conservative and progressive churches draw heavily from the Gospels. However, for progressives, the Gospels are largely divorced from the Epistles, which likely provides considerably more exegetical flexibility, especially inasmuch as the Gospels rely heavily on parables that invite individual interpretation. On the other hand, churches with the same worldview are no more likely to draw upon exactly the same sections of the sacred text than isolated populations of a given species are likely to have exactly the same genetic mutations. Even though our sample size of churches is small, the separation of the conservative and progressive churches into two clusters is unlikely to occur by chance ($p = .003$).

It is notable that the clustering is in terms of conservatism and progressivism and not in terms of denominations. As far as Biblical expression patterns are concerned, the progressive UMC church in New York (P3) is more similar to a progressive congregational church in Maine and a progressive Baptist church in Alabama than to a conservative UMC church 10 miles away. Likewise, the progressive Baptist church (P2) is more similar to the other two progressive churches than to the conservative Baptist church. As shown in Table 2, the average differences between progressive churches in our sample are smaller than the average differences between conservative churches. We believe this to be an artifact of the progressive vs. conservative citation practices themselves. As shown in Figure 4, all the progressive churches we examined draw from nearly the same, highly restricted subset of Bible books, with a particular emphasis on the Gospels and Psalms. As such, they have fewer degrees of freedom than conservative churches upon which they are likely to vary. Obviously, more data will be needed before we can draw firmer conclusions about "signature" Bible citation patterns for either progressive or conservative churches, but the significant difference we found between progressive and conservative clusters suggests that we can expect the patterns we have found here to hold true more generally.

So does a sacred text like the Bible shape beliefs or do groups, rather, fabricate a set of beliefs and then cherry pick the abundant and flexible material contained in their sacred texts to give their beliefs official sanction? There is likely no single answer to this question, nor should we necessarily expect one from our analogy of sacred texts as cultural genomes. If sacred texts constrain beliefs, then we are left with a cultural system very much in line with the central dogma of molecular biology, wherein DNA is transcribed into RNA which, in turn, is translated into proteins whose interactions with one another and the environment determine phenotypes. This is a tidy paradigm, and a powerful one too. Moreover, in at least some senses it must hold true. The human genome, for instance, is flexible enough to generate cells as different from one another as hepatocytes and neurons. Nevertheless, it does not contain the information necessary to create flower parts or bird feathers. In this sense, genomes constrain phenotypes by virtue of the limited information they contain. The same no doubt holds true for cultural inheritance systems as well. A group's acceptance of some particular set of texts as sacred and not others almost surely forecloses certain possibilities for acceptable beliefs, behaviors, and practices available to that group. It would be exceedingly odd, for instance, if a nascent Christian group taking up the Bible as its sole sacred text were to independently develop Telugu marriage rituals or Tibetan sky burials. There is simply no information within the Bible to support such ceremonial constructs or compatible beliefs to contextualize them.

However, considering inheritance systems from the standpoint of information storage alone is insufficient for understanding evolutionary processes. Even at the molecular level, parents pass on far more to their offspring that affects phenotypes than simply genetic information. They also pass along factors such as patterns of DNA methylation, proteins, hormones, and RNA, many of which are to one degree or another heritable (Ashe & Whitelaw, 2007; Jablonka & Raz, 2009; Lalancette, Miller, Li, & Krawetz, 2008; Nowacki et al., 2008). Day and Bonduriansky (2011) refer to these factors as the interpretive machinery of the cell and argue that a unified approach to understanding evolution must take these non-genetic factors, and especially non-genetic inheritance systems, into account. This is because the information stored in an inheritance system is only subject to natural selection when that information affects phenotypes and it is largely the interpretive machinery that makes that possible. Even in an extreme case, then, in which a hypothetical group entirely constructed its beliefs independently and only then sought sanction for those beliefs by cherry picking its sacred texts for supportive passages, there would still be utility in considering its sacred texts as a cultural inheritance system. In order to maintain its beliefs, the group must pass on to future generations its pattern of sacred text citations and its interpretations of those passages just as surely as tissues must ensure the preservation of epigenetic states passed on to daughter cells. Conversely, change to the group's beliefs will most likely be accompanied by changes in its citation patterns and interpretations, just as evolution acting at the molecular level can occur through epigenetic changes without undermining the importance or influence of the organism's genome. The methodology piloted here provides new and powerful ways to address interesting cultural evolutionary questions such as how groups negotiate change from within the confines of a shared body of authoritative texts and the degrees to which beliefs might be constrained.

The concept of sacred text as cultural genome avoids many of the shortcomings associated with the concept of memes (Blackmore, 1999; Dawkins, 2006b), an idea that has been roundly criticized for being too atomistic and for not accounting for the embeddedness of replicators within their environmental or social contexts (e.g., Deacon, 1999; Henrich et al., 2008). The emphasis is not on single cultural traits but rather on an entire inheritance system that is perpetuated by groups of people. In our formulation, it is the combination of expressed units and their interpretation by higher-order systems that is of paramount importance. Moreover, the inheritance system is highly accessible to empirical inquiry and can be studied independently of the expression of any particular phenotypic trait. A given phenotypic trait can even not be expressed for many generations and then be expressed when warranted by the circumstances, which is impossible for the atomistic concept of memes. In general, the analogy between a cultural inheritance system and a genetic and epigenetic

inheritance system is on much firmer ground than the analogy between memes and Dawkins' highly problematic concept of genes (Dawkins, 1982, 2006b).

While we have focused on written sacred texts, our work should be expandable to consider other kinds of cultural production that are transmitted across generations and influence how groups are constituted and function. Examples include myths, folk tales, poetry, songs, and proverbs, which might not be regarded as sacred but nevertheless can motivate action when cited as apropos to a given circumstance. All human cultures require an inheritance system, even when it does not consist of a written sacred text. It is even possible that the major religious traditions achieved their world-wide dominance, spreading in competition with other religions, in part by virtue of having a superior inheritance system.

Finally, our work has practical implications for understanding and perhaps even predicting religious radicalization. As we have shown, groups with similar positions on same-sex marriage share similar Bible citation patterns despite being of different denominations and despite likely holding differences on other political and theological issues. There is every reason to think that there could be "signature" citation patterns of sacred (and/or secular) texts that predict other group characteristics, including radicalization. We will only be able to address these questions, though, with a much larger sample size and richer database.

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