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Title: The spontaneous formation of stereotypes via cumulative cultural evolution

Authors: Douglas Martin[1]*, Jacqui Hutchison[1], Gillian Slessor[1], James Urquhart[1], Sheila J. Cunningham[2], Kenny Smith[3]

Affiliations:

[1]University of Aberdeen

[2]University of Abertay

[3]University of Edinburgh

*Correspondence to:

Dr Doug Martin
School of Psychology
University of Aberdeen
Kings College
Aberdeen, Scotland
Tel: +441224 273647
doug.martin@abdn.ac.uk

Abstract

We all share knowledge of the cultural stereotypes of social groups – but what are the origins of these stereotypes? We examined whether stereotypes form spontaneously as information is repeatedly passed from person to person. As information about novel social targets was passed down a chain of individuals, what initially began as a set of random associations evolved into a system that was simplified and categorically structured. Over time, novel stereotypes emerged that were not only increasingly learnable but that also allowed generalizations to be made about previously unseen social targets. By understanding how cognitive and social factors influence how stereotypes form and change, these findings show how stereotypes might naturally evolve or be manipulated.

Keywords: stereotypes; stereotype formation; cultural evolution; social cognition; person perception

Introduction

Stereotypes are template-like cognitive representations whereby membership of social groups is associated with the possession of certain attributes (e.g., scientists are geeky, Scottish people are miserly, men like the color blue; Allport, 1954). There are high levels of consensus about the content of cultural stereotypes, even though individuals' personal beliefs about their accuracy differ greatly (Devine, 1989; Madon et al., 2001). Irrespective of whether we endorse stereotypes, our knowledge of them has profound implications for our thoughts and behaviors (Bargh, Chen, & Burrows, 1996; Dijksterhuis & van Knippenberg, 1998; Fiske, 1998). Psychology has done much to inform our understanding of the nature of stereotypes and the influence they exert, yet one fundamental question remains unresolved: how do cultural stereotypes form? Here we present evidence that cognitive limitations and biases we all share result in stereotypes forming spontaneously as social information is repeatedly passed from person to person.

Stereotypes simplify the way we process information about people (Brewer, 1988; Fiske & Neuberg, 1990). While we are very adept at processing social information, our capacity to do so is constrained by our ability to attend to, perceive, and recall information (Fiske & Taylor, 1991). Stereotypes help to ease this cognitive burden by providing a system of easily learnable, simplified, highly structured relationships, whereby group membership indicates possession of a relatively small number of associated attributes. Notwithstanding the potential cost in accuracy, the functional value of stereotypes lies in their capacity to act as mental shortcuts, providing us with rapid and efficient access to knowledge stored in memory whenever a social category is detected (Macrae & Bodenhausen, 2000).

The functional value of stereotypes may also offer an explanation as to their origin. When remembering, we do not precisely recall our experiences; rather, our memories are subjective reconstructions susceptible to distortion (Schacter, 1999). Consequently any memory we have is prone to both the omission of details that were originally present and the addition of details that were not (Roediger & McDermott, 1995). Importantly, it seems our memories are not shaped entirely at random; instead, we show a bias towards internal consistency (Schacter, 1999; Spiro, 1980), sense-making (Bartlett, 1932), and categorical structure (Medin & Smith, 1981), with inconsistent information often lost from memories and consistent information more likely to persist or be erroneously added (Bartlett, 1932; Sherman & Bessenoff, 1999). Thus, when we encounter different people who belong to the same social group, we are more likely to remember similarities between them – both correctly and incorrectly – and to forget the ways in which they differ (Stangor & McMillan, 1992). It seems as individuals we possess numerous cognitive limitations and biases that are likely to lead us to store social information in a simplified, categorically structured, stereotype-like manner.

While cognitive limitations and biases might help explain how nascent stereotype-like knowledge can accrue within individuals, to understand how cultural stereotypes form we must examine how information changes as it is transmitted between individuals. The effects of social transmission have been examined using linear diffusion chains, a method where information is repeatedly passed from one person to another down a chain (Bartlett, 1932; Griffiths, Kalish, & Lewandowsky, 2008; Kirby, Cornish, & Smith, 2008; Mesoudi, 2009; Mesoudi, 2011). As information passes down a chain of individuals it begins to change in predictable ways; it becomes simpler, more structured, and more easily learnable and, as a consequence, more easily

transmittable (Kirby et al., 2008). Through a process of cumulative cultural evolution information that is initially complex, incongruous or random becomes simplified, consistent and systematic as it is repeatedly filtered through the cognitive limitations and biases of individuals; eventually it develops a form that can be easily remembered and accurately transmitted. Given that social transmission has demonstrable effects on the evolution of information across a diverse range of tasks, methods and species (Mesoudi, 2009), it must surely be a candidate mechanism for the formation of stereotypes.

Utilizing a linear diffusion chain methodology similar to that previously used to investigate how artificial languages evolve (Kirby et al., 2008), we examined whether passing social information down a chain comprising multiple ‘generations’ of individuals would result in the spontaneous formation of stereotypes. To provide novel social targets that were individually unique but that also shared category membership we created 27 ‘alien beings’ by combining three category dimensions that each had three possible features (Figure 1). We initialized each chain by randomly assigning six personality attributes to each alien (Generation 0; Figure 2). During an initial training phase the first participant in a chain (Generation 1) attempted to learn the association between a subset of aliens and their attributes. During a subsequent recall phase participants were shown all 27 aliens and were asked to identify the attributes associated with each. A subset of the aliens and the associated attributes that had been selected at test were used as the training materials for the next participant in the chain (i.e., Generation 2). The process of using the test responses from one generation as the training materials for the next was repeated seven times per chain to create social transmission chains of eight generations (i.e., Generation 0 through to Generation 7).

We predicted that our initially random associations of categories and attributes would develop into an easily learnable, simple, categorically structured system of stereotypes. Specifically, we expected to find that: participants at Generation 7 would be more accurate in their responses than those at Generation 1; participants at Generation 7 would use fewer attributes than those at Generation 1; the responses of participants at Generation 7 would be more categorically structured than those at Generation 1; aliens who shared more category features would share more attributes.

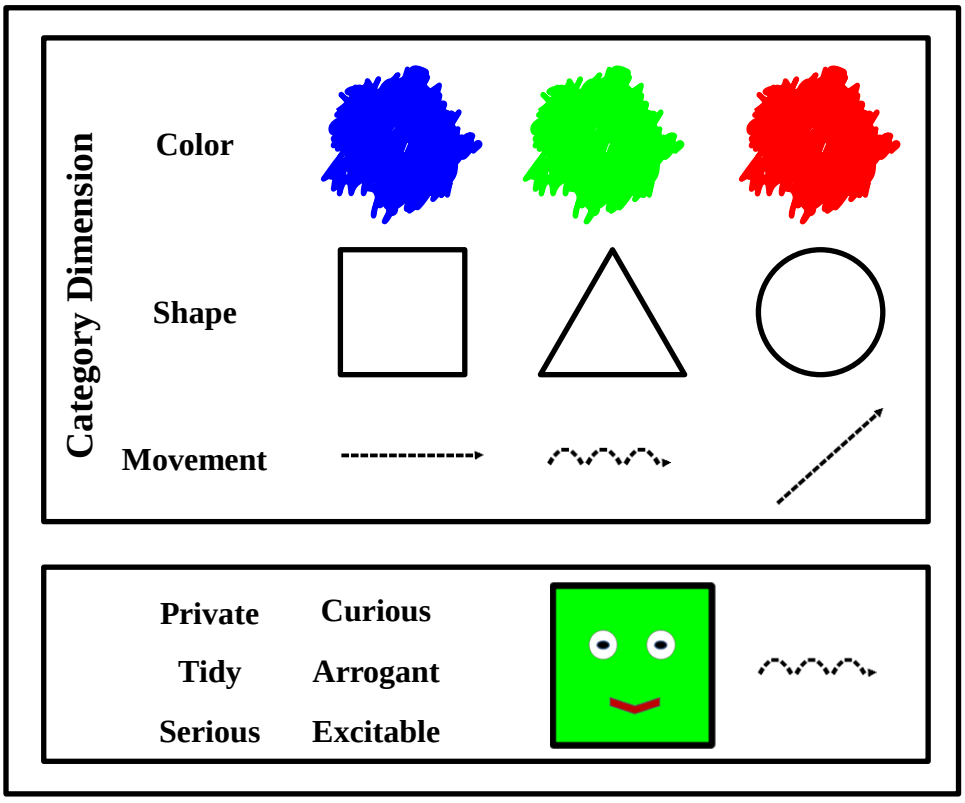

Figure 1. Alien category dimensions and features (top panel); example of an alien stimulus with associated attributes (bottom panel).

Method

Participants

The participants were 168 undergraduate students from the University of Aberdeen, who took part in return for course credit or were reimbursed for their time[1]. On arriving in the lab, participants were informed that they would be taking part in an experiment examining how we form impressions of other people and that their task would be to try and remember the personality attributes associated with novel 'alien' social targets. Participants were then assigned to the next sequential generation in an active chain before being given full instructions about the nature of the tasks they would be completing. The sample size was based on previous work in evolutionary linguistics which uses a similar methodology (Kirby et al., 2008). Importantly, participants were not informed about the social transmission aspect of the experiment until they were debriefed at the end of the testing session.

Stimulus Materials

Alien images: Each alien was represented by a simple line drawing combining *features* from the category dimensions of shape (*circle*, *square*, *triangle*), color (*blue*, *green*, *red*), and movement (*bouncing*, *diagonally*, *horizontally*; see Figure 1). Factorial combination of the three features from each category dimension resulted in 27 unique aliens, each of which shared some category features with some other aliens. Each alien image was 240 x 120 pixels.

[1] The 24 diffusion chains we report here comprise data from two experimental conditions (12 chains per condition). We chose to collate the data because the same pattern of effects is replicated across both conditions and because there was no interaction between the conditions. The only difference between the conditions was that in one condition the chains began from entirely unique random alien/attribute pool start points (i.e., the attributes associated with each alien were different for each chain), whereas the chains in the other condition all shared the same random alien/attribute pool (i.e., the attributes randomly associated with each alien were the same). However, because every chain began with aliens in the seen set being chosen from the pool at random, all 24 chains began with effectively unique seen sets.

Attributes: The attributes used to describe each alien were drawn from a total pool of 48 attributes that could be used to describe a human (e.g., *arrogant*, *caring*, *confident*). The attributes had been screened previously using a separate sample of equivalent undergraduates to ensure they would be likely to be unambiguously familiar to the participants in the diffusion chains. Six attributes were used to describe each alien.

Procedure

Overview (see Figure 2): Before the first participant in a chain was tested, six personality attributes were randomly assigned to each alien to create the Generation 0 alien/attribute pool. During an initial training phase the first participant in a chain (Generation 1) was shown 13 of the 27 aliens from this pool and attempted to learn their associated attributes. During the subsequent test phase participants were shown all 27 aliens – both the 13 aliens they had encountered during training and the 14 aliens that had remained unseen during training – and were asked to identify the attributes associated with each alien. The attributes the participant selected for each alien were used as the training materials for the next participant in the chain (i.e., Generation 2), with 13 randomly-selected aliens plus their attributes being seen during the training phase and the remaining 14 aliens being withheld. The process of using the test responses from one generation as the training materials for the next was repeated seven times per chain (see *Supplementary Materials S1* for an example of data documenting the entire generational lineage from one of the 24 chains included in the experiment).

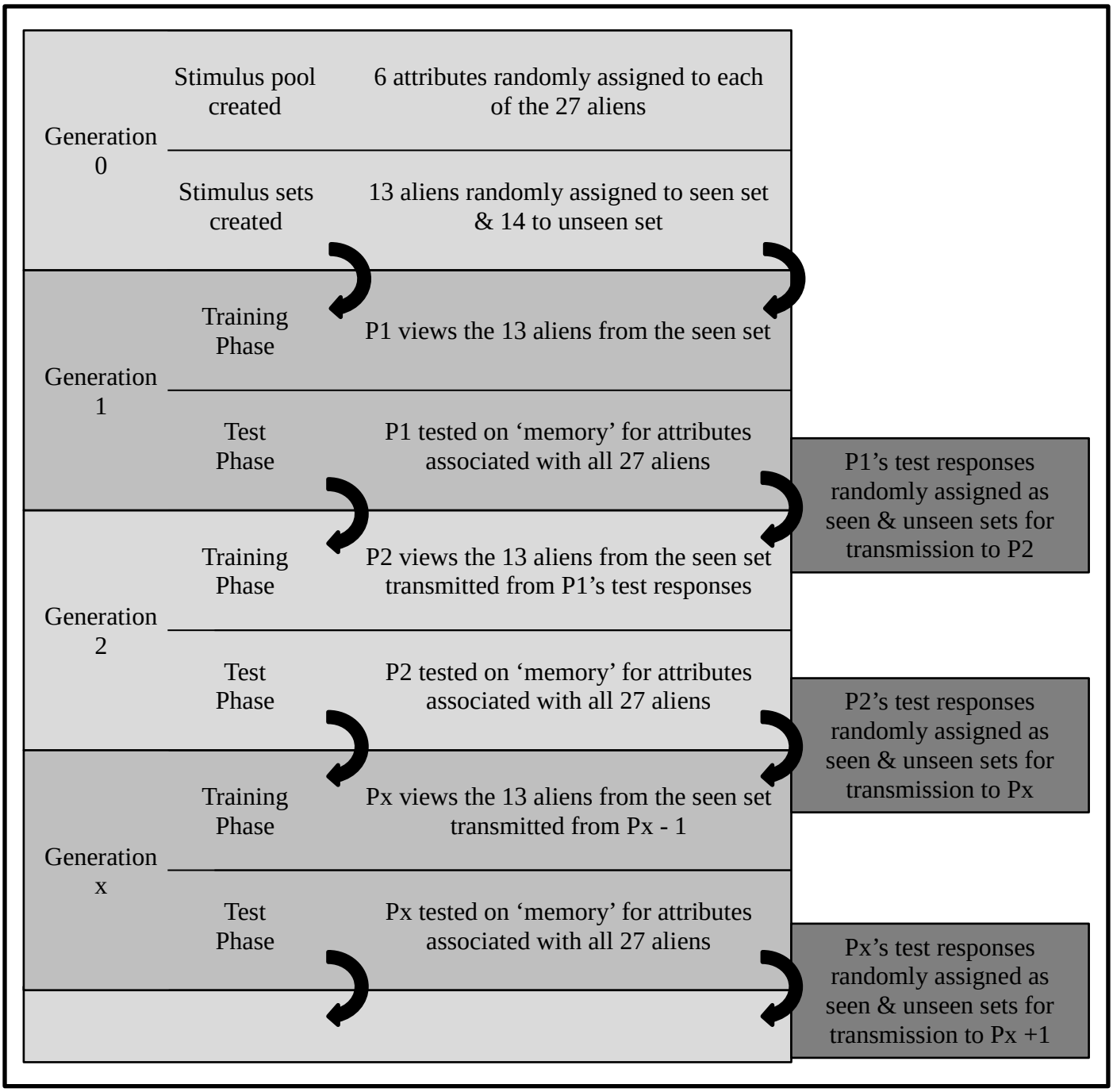

Figure 2. Outline of the processes of social transmission of information across multiple generations.

Generating the initial randomized system (Generation 0): Before the first participant in a chain was trained (i.e., Generation 1), it was necessary to randomly generate a pool of associations between aliens and attributes that would act as the materials from which the first participant would learn and be tested against; we called this initial pool of attribute to alien associations Generation 0.

The creation of seen and unseen sets: The only information participants received about the aliens came during the training phase when they were exposed to a randomly selected subset of 13 aliens and their attributes (i.e., the seen set). Images of the other 14 aliens remained hidden until they appeared at test (i.e., the unseen set); the aliens in the unseen set were never seen in conjunction with their associated attributes.

Training phase: Before the training phase, participants were told that they would passively view a series of alien images and six associated attributes and that their task was to try and remember which attributes went with which aliens. To aid learning, aliens and associated attributes from the seen set were presented three times. To this end, the training phase was separated into three blocks, with each of the 13 aliens from the seen set presented once per block. The order of the seen set alien presentation was randomized within blocks. Each exposure to an alien began with a fixation cross (500ms) which was replaced with the target alien image and associated six attributes (15s). Each training block was followed by a 20s break.

Test phase: Before the test phase, participants were told that they would see a series of alien images, and that their task was to indicate which six attributes they thought were associated with each alien. Each alien appeared individually below a list of the entire pool of 48 attribute traits

that could have been associated with an alien. Participants were instructed that they had to choose whichever six attributes they thought was associated with each alien and were encouraged to make their "best guess" if they were unsure. The alien remained onscreen until six attributes had been selected. Participants did not receive any feedback as to the accuracy of their responses.

There were 27 trials during the test phase, with participants responding to the 13 aliens from the seen set and the 14 aliens from the unseen set. The order of alien presentation was randomized. Participants were not told that they would see aliens they had not previously encountered during the training phase and funneled debriefing at the end of the experiment revealed that the vast majority of participants were unaware that the test phase contained previously unseen aliens.

Social transmission of information (Generations 1-7; see Figure 2): The 'social transmission' component of the experiment involved taking a subset of the test responses from one participant and using these as the training materials for the next generation. Specifically, the test responses to all 27 aliens from Generation 1 – whether correct or incorrect – acted as the pool of materials from which the next participant's training materials were created. This involved randomly dividing the aliens and their associated attributes (i.e., the attributes that had been assigned at test by the participant at the previous generation) into new seen and unseen sets; the 13 aliens in the newly created seen set were then used as the training materials for Generation 2. This process of passing a random sample of the test responses from one participant as the seen set training materials for the next was repeated to create a continuous diffusion chain of seven generations. Participants were initially unaware of the social transmission component of the experiment as

they were merely asked to form impressions of the aliens they saw and to attempt to remember which attributes went with which aliens; they were fully debriefed following their participation.

Dependent Measures

Accuracy: Accuracy was the percentage of attribute/alien association responses made during the test phase that correctly matched the attribute/alien associations *of the previous generation*. In other words, in order for a participant's test response to an individual alien to be considered accurate it must match the test response to that alien from the previous generation. For example, accuracy at Generation 1 was the percentage of attribute/alien test responses that matched the random attribute/alien pool allocated at Generation 0; similarly, accuracy at Generation 2 was the percentage of attribute/alien test responses that matched the test responses at Generation 1 and so on. Importantly, accuracy refers both to items that had been seen during training (i.e., does the participant's responses match those of the seen aliens they were trained on?) and the items that were unseen (i.e., does the participant's responses match the responses of the previous generation for unseen aliens not seen during training?).

Total attributes: The total attributes dependent measure was merely the total number of unique attributes used across the entire pool of aliens at a given generation (i.e., the number of unique attributes assigned randomly at Generation 0 or assigned by participants at test). The total attributes score can vary between a minimum of 6 and a maximum of 48. For example, if a participant used the same 6 attributes to describe all 27 aliens then the total attributes score would be six; however, if across all of the aliens a participant made use of all 48 attributes then the total attributes score would be 48.

Structure: To quantify the amount of structure at each generation of a chain we first calculated the overlap in attributes between each individual alien and the other 26 aliens in the same generational pool; this gave us 351 within-generation alien overlap scores. Any two aliens that had no overlap in attributes were given score of 0, any two aliens that shared one attribute were given a score of 1 and so on up to a maximum score of 6 for aliens that had 6 identical attributes. Based on the overlap scores between all aliens, we then calculated three *raw structure scores* by taking the mean across all pairs of aliens who either shared two category dimension features (e.g., same shape and color but different movement), one category dimension feature (e.g., same shape but different color and movement) or zero category dimension features (e.g., different shape, color and movement).

Rather than using the raw structure scores as a dependent measure in its own right, it was necessary to represent structure as standard scores because raw structure scores typically increase by chance as the total number of unique attributes used decreases (e.g., if only 8 unique attributes were randomly assigned across the 27 aliens one would expect very high structure scores because there would be considerable chance overlap between aliens; whereas, if 48 attributes were randomly assigned across the 27 aliens one would expect much lower structure scores because there would be considerably less chance overlap between aliens). To examine whether the raw structure scores in a generation was greater than would be expected by chance we generated random simulated structure data by running Monte Carlo simulations (12000 runs) based on a random allocation of attributes to aliens (limited to the total attributes used at each generation). The simulated structure data was then used as a comparison dataset in order to

calculate z-scores for the raw structure data – these z-scores are our dependent measure of 'Structure'.

Results

Accuracy data by Generation (Generations 1-7) and Studied Status (Unseen vs. Seen) can be seen in Figure 3. Participants were more accurate at Generation 7 (*M* = 46%, 95% CI [38%, 53%]) than at Generation 1 (*M* = 15%, 95% CI [13%, 16%]); mean difference = 31% (95% CI [24%, 39%]). Similarly, participants were more accurate for aliens they had Seen during training (*M* = 36%, 95% CI [33%, 39%]) than those aliens that were Unseen until test (*M* = 30%, 95% CI [27%, 33%]); mean difference = 6%, 95% CI [5%, 7%]. As can be seen from Figure 3, accuracy for Seen aliens was above chance for all generations; importantly, accuracy for unseen aliens was no different from chance at Generation 1 but then rose to significantly above chance for all subsequent generations.

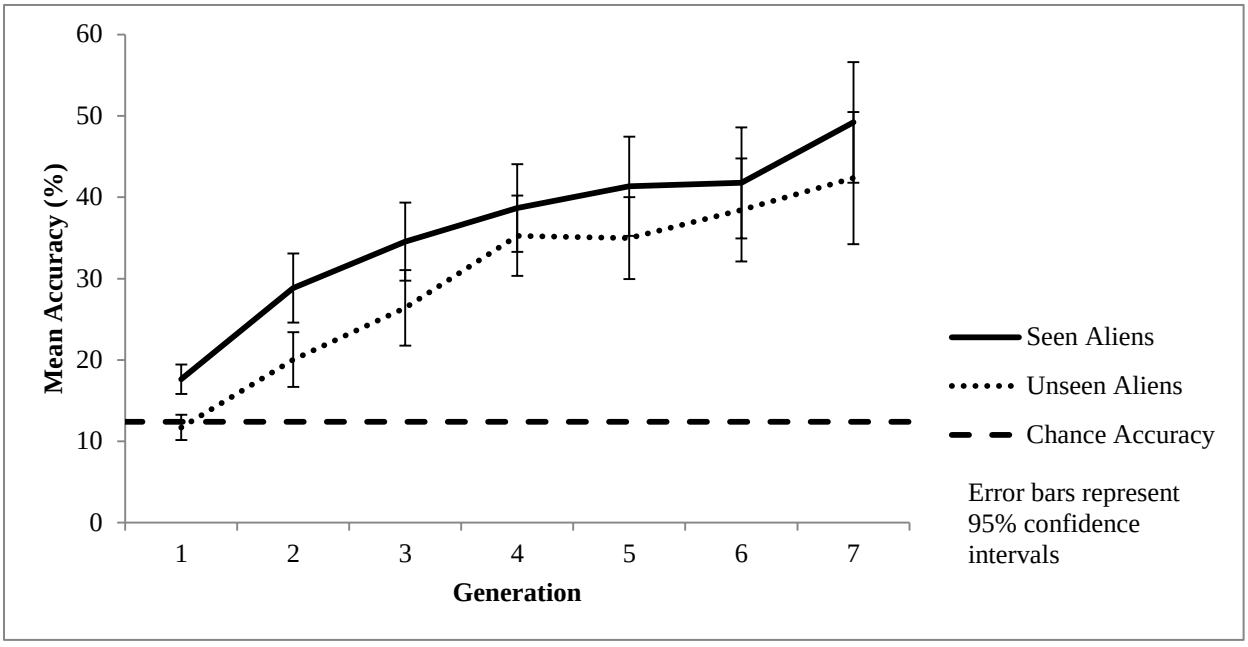

Figure 3. Mean level of accuracy at each generation**.** For Seen Aliens, accuracy is the percentage of attributes correctly assigned to aliens that appeared during the training phase; for Unseen Aliens, accuracy is the percentage of responses that matched the responses of the previous generation for those aliens that did not appear during the training phase.

The number of unique attributes used during test at each Generation (Generation 0-7) can be seen in Figure 4. There was a decrease in the number of attributes used by participants at test between Generation 1 (*M* = 39, 95% CI [36, 42]) and Generation 7 (*M* = 22, 95% CI [18, 26]); mean difference = 17 (95% CI [12, 21]). To determine whether alien/attribute associations were being passed intact from the beginning of the chain to the end, we examined whether attributes assigned to aliens at Generation 7 matched those assigned in the initial, random assignment (Generation 0). While there was some correspondence between attributes assigned at Generation 0 and those assigned at Generation 7 (*M* = 13% of attributes preserved to Generation 7, 95% CI [11.9%, 14.1%]), this was not greater than would be expected by chance (chance = 12.4%), even for aliens whose traits were seen during the training phase by the Generation 1 participant (*M* = 13.3%, 95% CI [11.2%, 13.6%]); unsurprisingly, aliens assigned at Generation 0 but unseen by the participant at Generation 1 were no more likely to appear at the end of the chain (*M* = 12.7%, 95% CI [11.3%, 14.1%]).

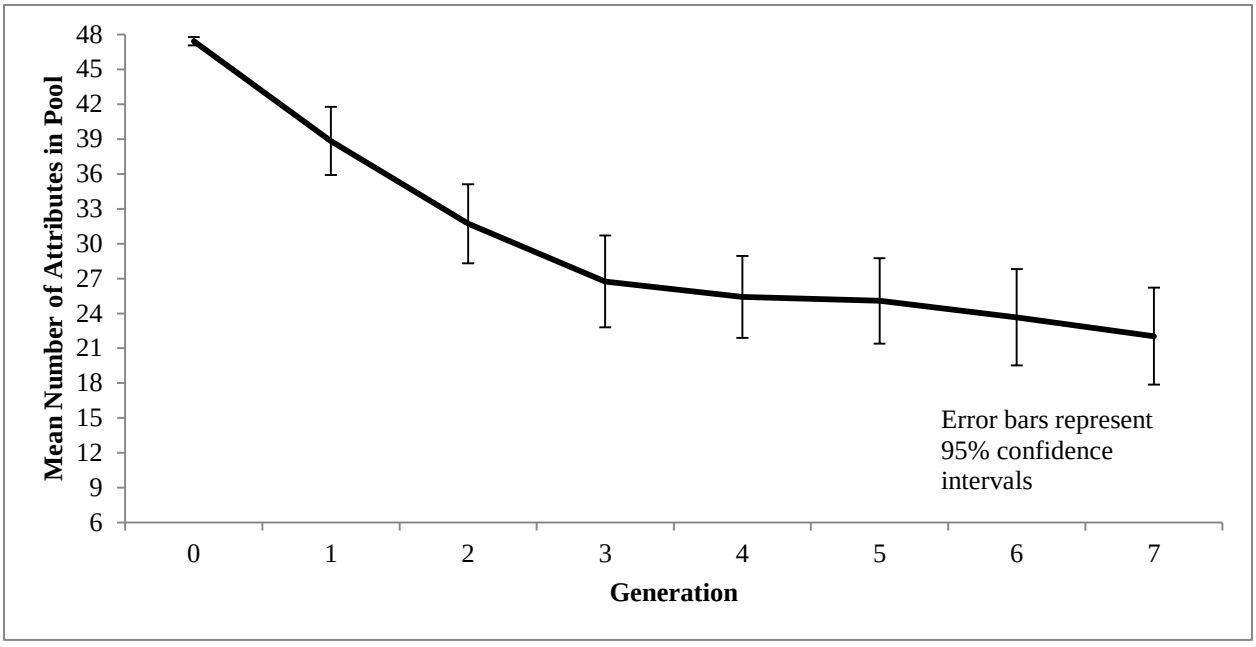

Figure 4. Mean number of attributes used at each generation. For Generation 0, the mean attributes in the pool are those that were randomly assigned to aliens; for Generations 1-7, the mean attributes are those that participants assigned to aliens at test.

While a huge amount of information was lost as the chains progressed, both in terms of the number of attributes and in terms of the original content, clearly something was being added that allowed succeeding generations to predict the knowledge of the previous generation with increasing levels of accuracy. Figure 5 illustrates the amount of structure by Generation (Generations 0-7) and Number of Shared Category Features (two shared features, one shared feature and zero shared features). There was higher levels of structure at Generation 7 (*M* z = 5.5, 95% CI [4.1, 6.8]) than at Generation 1 (*M* z = 2.0, 95% CI [1.2, 2.9]); mean difference = 3.4 (95% CI [1.9, 4.9]).

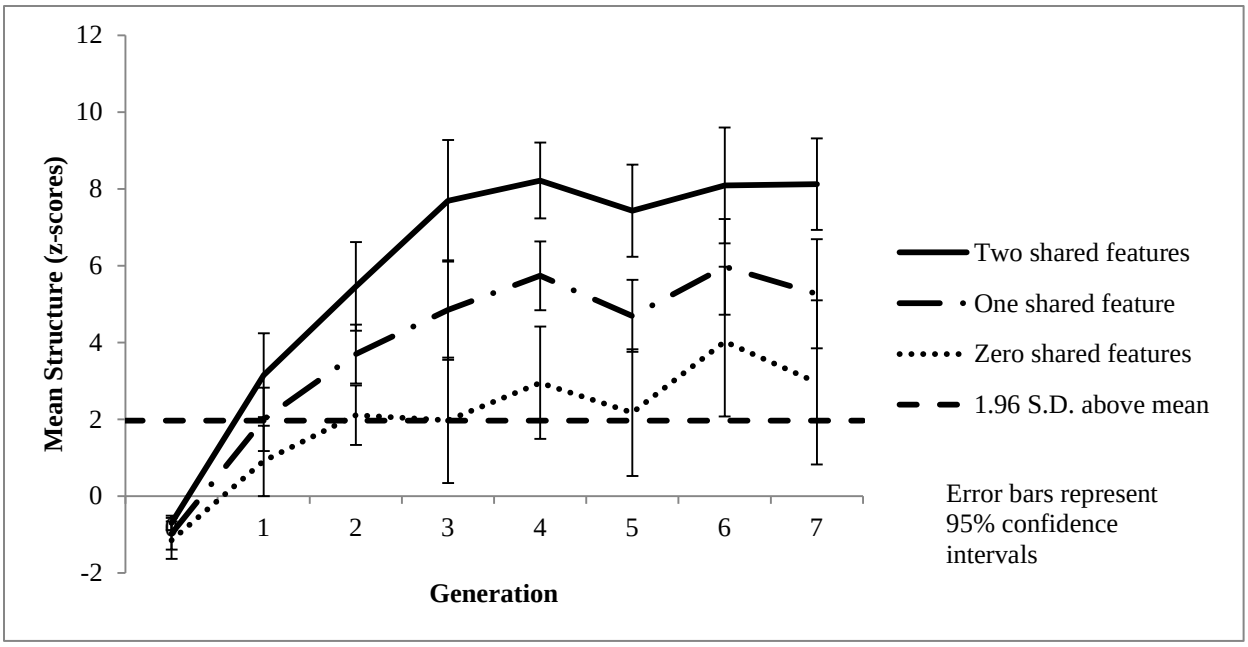

Figure 5. Mean level of structure at each generation by number of shared features. Increasing positive z-scores indicate increasing structure, with z-scores greater than +1.96 indicating higher structure than would be expected by chance ($\alpha = .05$).

There was higher structure among aliens who shared two category features (*M* z = 6.9, 95% CI [6.3, 7.5]) than aliens who shared only one feature (*M* z = 4.6, 95% CI [4.0, 5.2]); mean difference = 2.3 (95% CI [1.8, 2.8]). There was also higher structure among aliens who shared two category features (*M* z = 6.9, 95% CI [6.3, 7.5]) than aliens who shared zero features (*M* z = 2.4, 95% CI [1.5, 3.4]); mean difference = 4.4 (95% CI [3.4, 5.4]). Similarly, there was higher

structure among aliens who shared one feature (*M* z = 4.6, 95% CI [4.0, 5.2]) relative to those who shared none (*M* z = 2.4, 95% CI [1.5, 3.4]); mean difference = 2.2 (95% CI [1.6, 2.7]). The observed increase in structure by Generation 7 was highly reliable, with aliens who shared two features exhibiting levels of structure higher than would be expected by chance in all 24 chains (i.e., z > 1.96) and aliens who shared one feature exhibiting levels of structure higher than would be expected by chance in 22 out of 24 chains.

Discussion

People routinely discuss the attributes and actions of other people – our findings suggest the process of repeatedly passing social information from person to person can result in the unintentional and spontaneous formation of cultural stereotypes. When social information passed down a chain, people became better at remembering the attributes associated with social targets as a consequence of the task became increasingly simplified through the loss of attributes and the development of a systematic categorical structure. The emergence of this stereotype-like structure suggests participants' memory failures and successes were not arbitrary and that any tendency towards categorical structure evidenced in the attribute assignments of one person was detected and amplified in the recollections of the next. Over multiple generations a systematic relationship developed, until category features were so strongly associated with the possession of specific attributes they could be used to accurately infer information about previously unseen aliens (e.g., by the end of one chain Blue aliens were predominantly *sensible* and *successful* while Green aliens were *vulgar*[2]*; see Supplementary Materials S1*). We propose the formation of novel stereotypes via cumulative cultural evolution seen here, albeit in highly artificial

[2] It is notable that by Generation 7, the category dimension of color had more structure associated with it than either shape or movement in 17 of the 24 chains; future research should examine this apparent color dominance.

laboratory conditions, can provide a framework for understanding how real-world stereotypes form and change.

The loss of attributes from the chains is explained by our limited memory capacity and our bias towards both categorical structure (Schacter, 1999; Spiro, 1980) and within-category consistency (Medin & Smith, 1981). From the beginning of the chains people overestimated the within-category similarity of aliens and were more likely to think that aliens who shared features also shared attributes (Shepard, Hovland, & Jenkins, 1961). Cumulatively these overestimations led to the development of a categorical structure with some attributes becoming associated with some alien features (Kirby et al., 2008). We suggest that without any need for volition or intent, social information will become organized categorically as it is repeatedly transmitted between people.

While participants in later generations undoubtedly detected and reproduced the within-category similarities between aliens, it seems they were also sensitive to within-category variation. The willingness of participants to ascribe aliens with attributes in both an individuated and category-based manner seems to have led to a structural plateau, typically around Generation 4, at a level well below that which is theoretically possible if attributes were solely determined by category membership. This suggests that once simple category stereotypes had evolved they could be passed with greater fidelity from one generation to the next, with the resulting lack of change preventing any further substantial increase in structure (Bartlett, 1932).

The increase in accuracy on the recall task is directly linked to the emergence of these category stereotypes – it is easier to remember information when it is organized categorically than when it

is not (Shepard et al., 1961). Importantly, the emergent stereotypes not only increased the accuracy with which people *learned* information about aliens seen during training but also the accuracy with which they *inferred* information about previously unseen aliens: just as stereotypes allow us to make inferences about strangers, so participants at later generations were able to identify the attributes of previously unseen aliens (Medin & Smith, 1981). This increasing learnability does not reflect an improvement in the precision with which people could report the attributes that aliens originally possessed at generation 0 – by Generation 7 people were no better than chance at this – rather it was an indication of how proficient people were at identifying the emergent stereotypes. In everyday life, stereotypes do not necessarily provide us with a reliable indication of the attributes an unfamiliar person possesses but they do provide us with a reliable indication of the attributes society associates with the social categories to which that person belongs (Devine, 1989; Madon et al., 2001). Irrespective of whether attributes are representative of category members or not, cumulative cultural evolution can account for the formation of category stereotypes that, once in existence, can be easily learned and transmitted.

Many cultural stereotypes contain a 'kernel of truth', based as they are on a genuine relationship that exists between attributes and categories (e.g., the Scottish stereotype includes attributes over-represented among Scots, such as wearing kilts and having red hair; Judd & Park, 1993; Madon et al., 1998). Where such category-based over-representations exist – such as those we see after the initial generations of our chains – these relationships are detected and repeatedly amplified as a consequence of the shared cognitive biases and limitations of those who transmit the information (Lyons & Kashima, 2003). Where there is no existing category-based over-representation – such as at the very beginning of our chains – it seems our shared cognitive

biases and limitations result in the spontaneous creation of relationships between attributes and features as information passes from one mind to the next (for an analogous finding see Griffiths, Lewandowsky, & Kalish, 2013). In this way cumulative cultural evolution can provide a mechanism to explain not only those aspects of stereotypes based on an underlying reality but also those that are seemingly arbitrary or of no obvious origin (e.g., the stereotype of Scottish people as miserly or the gender stereotypes of the colors of pink and blue; (Allport, 1954; Cunningham & Macrae, 2011; LaPiere, 1936).

The current research provides a novel theoretical mechanism that can explain how stereotypes form – via cumulative cultural evolution – and a methodology for studying this process in the lab – using linear diffusion chains. Our results show that as information about novel social targets is repeatedly passed from person to person it begins to develop stereotype-like properties; what begins as an random distribution of attributes among members of different social categories evolves into a progressively simplified, highly structured, and easily learnable system that can be used to generalize to previously unseen social targets – a stereotype has formed. By examining how social, cognitive, and perceptual biases affect the cumulative cultural evolution of stereotypes in the lab, future research can further inform our understanding of the origins and evolution of stereotypes in the wild (Judd & Park, 1993; Madon et al., 1998, 2001; Mesoudi, 2011).

Author contributions

D. Martin had the original idea and was awarded funding from the *Economic and Social Research Council*. D. Martin designed the experiment. G. Slessor prepared the stimulus materials. J. Urquhart programmed the experiment. G. Slessor and J. Hutchison collected the data. D. Martin and J. Hutchison processed the data. D. Martin analyzed the data and wrote the manuscript. J. Hutchison, G. Slessor, S.J. Cunningham, and K. Smith contributed to the preparation of the manuscript. K. Smith provided feedback at all stages of the project.

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Supplementary Materials S1

Example of the attributes assigned to aliens across seven generations from a chain in the current dataset.

	Alien Category Features				Assigned Attributes					
Generation	**Color**	**Shape**	**Movement**	**Transmitted**	**Attribute 1**	**Attribute 2**	**Attribute 3**	**Attribute 4**	**Attribute 5**	**Attribute 6**
0	Blue	Circle	Bouncing	No	nervous	sensitive	confident	serious	easy-going	imaginative
0	Blue	Circle	Diagonally	Yes	flirty	boring	private	nervous	shy	friendly
0	Blue	Circle	Horizontal	Yes	easy-going	adventurous	troublesome	playful	nasty	friendly
0	Blue	Square	Bouncing	Yes	confident	anxious	troublesome	easy-going	passive	private
0	Blue	Square	Diagonally	No	adaptable	nervous	thoughtless	bullying	hostile	tidy
0	Blue	Square	Horizontal	No	nervous	private	offensive	serious	talented	excitable
0	Blue	Triangle	Bouncing	Yes	adaptable	thoughtless	nervous	hostile	arrogant	rude
0	Blue	Triangle	Diagonally	Yes	sensitive	tactful	vulgar	tidy	private	cheerful
0	Blue	Triangle	Horizontal	Yes	reserved	anxious	bullying	ambitious	adventurous	private
0	Green	Circle	Bouncing	No	flirty	sensitive	nasty	passive	offensive	shy
0	Green	Circle	Diagonally	Yes	excitable	imaginative	warm	patient	arrogant	sensible
0	Green	Circle	Horizontal	Yes	arrogant	shy	bullying	successful	aggressive	easy-going
0	Green	Square	Bouncing	Yes	adventurous	ambitious	anxious	friendly	rude	serious
0	Green	Square	Diagonally	No	flirty	imaginative	adaptable	organised	shy	talented
0	Green	Square	Horizontal	No	flirty	nasty	tidy	troublesome	easy-going	playful
0	Green	Triangle	Bouncing	No	imaginative	sensitive	lonely	tactful	sensible	aggressive
0	Green	Triangle	Diagonally	No	sensitive	private	shy	warm	playful	vulgar
0	Green	Triangle	Horizontal	Yes	friendly	nervous	vulgar	proud	tidy	flirty
0	Red	Circle	Bouncing	Yes	curious	adaptable	sensitive	adventurous	shy	thoughtless
0	Red	Circle	Diagonally	No	playful	excitable	rude	reserved	brave	lonely
0	Red	Circle	Horizontal	Yes	passive	brave	private	vulgar	tactful	affectionate
0	Red	Square	Bouncing	No	passionate	confident	cheerful	brave	playful	reserved
0	Red	Square	Diagonally	No	boring	rude	jealous	reliable	flirty	playful
0	Red	Square	Horizontal	No	patient	tactful	hostile	passionate	passive	serious
0	Red	Triangle	Bouncing	No	nervous	nasty	reliable	shy	anxious	easy-going
0	Red	Triangle	Diagonally	Yes	offensive	passionate	nasty	bitter	jealous	troublesome
0	Red	Triangle	Horizontal	No	easy-going	serious	passive	flirty	brave	arrogant

	Alien Category Features				Assigned Attributes					
Generation	**Color**	**Shape**	**Movement**	**Transmitted**	**Attribute 1**	**Attribute 2**	**Attribute 3**	**Attribute 4**	**Attribute 5**	**Attribute 6**
1	Blue	Circle	Bouncing	Yes	adaptable	playful	private	thoughtless	tidy	vulgar
1	Blue	Circle	Diagonally	Yes	adaptable	brave	bullying	successful	talented	tidy
1	Blue	Circle	Horizontal	Yes	aggressive	anxious	friendly	nasty	playful	thoughtless
1	Blue	Square	Bouncing	Yes	anxious	private	successful	tactful	thoughtless	warm
1	Blue	Square	Diagonally	No	adventurous	excitable	lonely	nasty	playful	troublesome
1	Blue	Square	Horizontal	Yes	adventurous	aggressive	arrogant	friendly	nasty	vulgar
1	Blue	Triangle	Bouncing	Yes	adventurous	brave	bullying	private	reserved	tidy
1	Blue	Triangle	Diagonally	No	adventurous	bullying	playful	private	rude	tidy
1	Blue	Triangle	Horizontal	No	adventurous	curious	friendly	passionate	playful	rude
1	Green	Circle	Bouncing	Yes	adaptable	adventurous	easy-going	nasty	private	vulgar
1	Green	Circle	Diagonally	Yes	adaptable	aggressive	ambitious	curious	easy-going	troublesome
1	Green	Circle	Horizontal	No	brave	confident	jealous	nervous	organised	thoughtless
1	Green	Square	Bouncing	Yes	ambitious	nervous	passive	proud	reserved	thoughtless
1	Green	Square	Diagonally	No	friendly	nasty	patient	reserved	sensitive	shy
1	Green	Square	Horizontal	No	anxious	flirty	private	reserved	sensible	troublesome
1	Green	Triangle	Bouncing	No	affectionate	cheerful	curious	easy-going	passionate	playful
1	Green	Triangle	Diagonally	Yes	affectionate	cheerful	curious	easy-going	friendly	playful
1	Green	Triangle	Horizontal	No	affectionate	anxious	brave	friendly	nervous	shy
1	Red	Circle	Bouncing	No	adaptable	affectionate	flirty	thoughtless	vulgar	warm
1	Red	Circle	Diagonally	No	affectionate	arrogant	flirty	jealous	passionate	shy
1	Red	Circle	Horizontal	No	affectionate	flirty	jealous	rude	shy	warm
1	Red	Square	Bouncing	Yes	anxious	arrogant	excitable	friendly	playful	troublesome
1	Red	Square	Diagonally	No	anxious	easy-going	friendly	reserved	sensitive	tactful
1	Red	Square	Horizontal	Yes	adaptable	arrogant	cheerful	nervous	passive	warm
1	Red	Triangle	Bouncing	No	adaptable	affectionate	curious	passionate	shy	warm
1	Red	Triangle	Diagonally	Yes	adaptable	cheerful	excitable	jealous	nasty	rude
1	Red	Triangle	Horizontal	No	excitable	friendly	successful	thoughtless	vulgar	warm

	Alien Category Features				Assigned Attributes					
Generation	**Color**	**Shape**	**Movement**	**Transmitted**	**Attribute 1**	**Attribute 2**	**Attribute 3**	**Attribute 4**	**Attribute 5**	**Attribute 6**
2	Blue	Circle	Bouncing	Yes	adaptable	adventurous	arrogant	friendly	thoughtless	vulgar
2	Blue	Circle	Diagonally	No	adaptable	ambitious	excitable	friendly	nervous	tactful
2	Blue	Circle	Horizontal	Yes	adaptable	aggressive	arrogant	friendly	playful	tactful
2	Blue	Square	Bouncing	No	adaptable	adventurous	arrogant	friendly	playful	troublesome
2	Blue	Square	Diagonally	Yes	adventurous	friendly	nasty	playful	reserved	vulgar
2	Blue	Square	Horizontal	Yes	arrogant	brave	friendly	playful	successful	thoughtless
2	Blue	Triangle	Bouncing	Yes	anxious	bullying	friendly	nasty	playful	warm
2	Blue	Triangle	Diagonally	No	adventurous	bullying	friendly	proud	tactful	vulgar
2	Blue	Triangle	Horizontal	Yes	adventurous	anxious	brave	nasty	playful	thoughtless
2	Green	Circle	Bouncing	Yes	adaptable	anxious	friendly	nasty	playful	vulgar
2	Green	Circle	Diagonally	Yes	aggressive	arrogant	excitable	proud	tactful	thoughtless
2	Green	Circle	Horizontal	No	adaptable	nasty	playful	reserved	tactful	vulgar
2	Green	Square	Bouncing	Yes	adaptable	adventurous	friendly	nasty	proud	thoughtless
2	Green	Square	Diagonally	No	aggressive	ambitious	nervous	playful	proud	successful
2	Green	Square	Horizontal	No	affectionate	excitable	friendly	playful	reserved	thoughtless
2	Green	Triangle	Bouncing	No	adaptable	adventurous	brave	nervous	reserved	vulgar
2	Green	Triangle	Diagonally	No	adventurous	friendly	nervous	playful	thoughtless	vulgar
2	Green	Triangle	Horizontal	No	adaptable	adventurous	bullying	playful	thoughtless	vulgar
2	Red	Circle	Bouncing	Yes	arrogant	bullying	friendly	reserved	tactful	vulgar
2	Red	Circle	Diagonally	Yes	adaptable	aggressive	bullying	playful	reserved	thoughtless
2	Red	Circle	Horizontal	No	ambitious	arrogant	friendly	playful	tactful	troublesome
2	Red	Square	Bouncing	No	arrogant	brave	bullying	tactful	troublesome	warm
2	Red	Square	Diagonally	No	adventurous	nasty	reserved	thoughtless	troublesome	warm
2	Red	Square	Horizontal	No	arrogant	excitable	friendly	successful	thoughtless	warm
2	Red	Triangle	Bouncing	Yes	adventurous	arrogant	friendly	playful	reserved	thoughtless
2	Red	Triangle	Diagonally	No	adaptable	arrogant	friendly	playful	thoughtless	vulgar
2	Red	Triangle	Horizontal	Yes	arrogant	bullying	friendly	nasty	proud	tactful

	Alien Category Features				Assigned Attributes					
Generation	**Color**	**Shape**	**Movement**	**Transmitted**	**Attribute 1**	**Attribute 2**	**Attribute 3**	**Attribute 4**	**Attribute 5**	**Attribute 6**
3	Blue	Circle	Bouncing	Yes	adventurous	arrogant	cheerful	nasty	thoughtless	vulgar
3	Blue	Circle	Diagonally	No	aggressive	cheerful	nasty	playful	thoughtless	vulgar
3	Blue	Circle	Horizontal	Yes	adventurous	bullying	nasty	patient	playful	thoughtless
3	Blue	Square	Bouncing	No	aggressive	friendly	nasty	playful	thoughtless	vulgar
3	Blue	Square	Diagonally	Yes	adventurous	aggressive	cheerful	nasty	offensive	thoughtless
3	Blue	Square	Horizontal	Yes	arrogant	bullying	friendly	jealous	reliable	vulgar
3	Blue	Triangle	Bouncing	Yes	adventurous	aggressive	arrogant	nasty	thoughtless	vulgar
3	Blue	Triangle	Diagonally	Yes	adventurous	aggressive	arrogant	cheerful	sensitive	thoughtless
3	Blue	Triangle	Horizontal	No	adaptable	adventurous	aggressive	brave	nasty	thoughtless
3	Green	Circle	Bouncing	No	aggressive	arrogant	brave	bullying	cheerful	vulgar
3	Green	Circle	Diagonally	No	arrogant	brave	cheerful	nasty	thoughtless	vulgar
3	Green	Circle	Horizontal	Yes	affectionate	aggressive	brave	excitable	nasty	offensive
3	Green	Square	Bouncing	Yes	adventurous	bullying	friendly	nasty	thoughtless	vulgar
3	Green	Square	Diagonally	No	aggressive	cheerful	friendly	nasty	offensive	thoughtless
3	Green	Square	Horizontal	No	aggressive	arrogant	brave	offensive	playful	vulgar
3	Green	Triangle	Bouncing	Yes	adventurous	aggressive	friendly	nasty	playful	vulgar
3	Green	Triangle	Diagonally	No	adventurous	arrogant	brave	cheerful	friendly	nasty
3	Green	Triangle	Horizontal	Yes	arrogant	brave	nasty	offensive	tactful	thoughtless
3	Red	Circle	Bouncing	Yes	brave	bullying	excitable	nasty	playful	vulgar
3	Red	Circle	Diagonally	No	aggressive	arrogant	cheerful	friendly	nasty	thoughtless
3	Red	Circle	Horizontal	Yes	aggressive	arrogant	bullying	cheerful	nasty	thoughtless
3	Red	Square	Bouncing	No	adventurous	brave	bullying	friendly	nasty	vulgar
3	Red	Square	Diagonally	No	aggressive	brave	friendly	nasty	playful	thoughtless
3	Red	Square	Horizontal	No	arrogant	cheerful	nasty	playful	selfish	thoughtless
3	Red	Triangle	Bouncing	No	adventurous	aggressive	friendly	nasty	thoughtless	vulgar
3	Red	Triangle	Diagonally	No	aggressive	brave	cheerful	jealous	nasty	thoughtless
3	Red	Triangle	Horizontal	Yes	aggressive	arrogant	brave	bullying	nasty	thoughtless

	Alien Category Features				Assigned Attributes					
Generation	**Color**	**Shape**	**Movement**	**Transmitted**	**Attribute 1**	**Attribute 2**	**Attribute 3**	**Attribute 4**	**Attribute 5**	**Attribute 6**
4	Blue	Circle	Bouncing	Yes	adventurous	arrogant	excitable	nasty	patient	vulgar
4	Blue	Circle	Diagonally	No	aggressive	brave	bullying	offensive	tactful	thoughtless
4	Blue	Circle	Horizontal	No	arrogant	bullying	hostile	jealous	reserved	thoughtless
4	Blue	Square	Bouncing	No	adventurous	bullying	friendly	nasty	tactful	vulgar
4	Blue	Square	Diagonally	No	bullying	imaginative	nasty	playful	talented	vulgar
4	Blue	Square	Horizontal	No	brave	bullying	excitable	proud	sensible	thoughtless
4	Blue	Triangle	Bouncing	No	adventurous	arrogant	bullying	nasty	thoughtless	vulgar
4	Blue	Triangle	Diagonally	Yes	adaptable	bullying	flirty	playful	talented	troublesome
4	Blue	Triangle	Horizontal	No	cheerful	excitable	friendly	playful	rude	vulgar
4	Green	Circle	Bouncing	Yes	adventurous	bullying	nasty	offensive	tactful	vulgar
4	Green	Circle	Diagonally	Yes	boring	hostile	nasty	private	successful	warm
4	Green	Circle	Horizontal	No	brave	bullying	excitable	reliable	thoughtless	vulgar
4	Green	Square	Bouncing	Yes	adventurous	imaginative	nasty	playful	tactful	vulgar
4	Green	Square	Diagonally	No	arrogant	brave	bullying	excitable	tactful	warm
4	Green	Square	Horizontal	Yes	bullying	cheerful	nasty	tactful	thoughtless	vulgar
4	Green	Triangle	Bouncing	Yes	adventurous	arrogant	excitable	nasty	tactful	vulgar
4	Green	Triangle	Diagonally	Yes	aggressive	brave	bullying	excitable	nasty	tactful
4	Green	Triangle	Horizontal	Yes	arrogant	boring	hostile	nervous	proud	vulgar
4	Red	Circle	Bouncing	Yes	adventurous	brave	bullying	nasty	thoughtless	vulgar
4	Red	Circle	Diagonally	No	adaptable	brave	bullying	excitable	nasty	thoughtless
4	Red	Circle	Horizontal	No	arrogant	cheerful	friendly	passive	selfish	tactful
4	Red	Square	Bouncing	Yes	adventurous	brave	bullying	nasty	tactful	vulgar
4	Red	Square	Diagonally	Yes	aggressive	brave	excitable	rude	shy	thoughtless
4	Red	Square	Horizontal	No	arrogant	brave	friendly	tactful	talented	warm
4	Red	Triangle	Bouncing	Yes	adventurous	excitable	nasty	playful	shy	vulgar
4	Red	Triangle	Diagonally	No	bullying	cheerful	nasty	reliable	tactful	vulgar
4	Red	Triangle	Horizontal	No	bitter	jealous	nasty	reliable	selfish	vulgar

	Alien Category Features				Assigned Attributes					
Generation	**Color**	**Shape**	**Movement**	**Transmitted**	**Attribute 1**	**Attribute 2**	**Attribute 3**	**Attribute 4**	**Attribute 5**	**Attribute 6**
5	Blue	Circle	Bouncing	No	affectionate	curious	lonely	patient	successful	warm
5	Blue	Circle	Diagonally	Yes	cheerful	curious	friendly	organised	patient	vulgar
5	Blue	Circle	Horizontal	Yes	ambitious	curious	friendly	organised	serious	vulgar
5	Blue	Square	Bouncing	Yes	ambitious	curious	jealous	reliable	rude	sensible
5	Blue	Square	Diagonally	No	ambitious	easy-going	lonely	passionate	successful	warm
5	Blue	Square	Horizontal	No	affectionate	curious	lonely	passive	serious	warm
5	Blue	Triangle	Bouncing	Yes	curious	lonely	passionate	passive	rude	sensitive
5	Blue	Triangle	Diagonally	Yes	affectionate	curious	friendly	organised	reliable	successful
5	Blue	Triangle	Horizontal	No	ambitious	curious	lonely	organised	successful	warm
5	Green	Circle	Bouncing	No	ambitious	friendly	jealous	lonely	selfish	vulgar
5	Green	Circle	Diagonally	No	ambitious	curious	lonely	organised	sensitive	vulgar
5	Green	Circle	Horizontal	Yes	curious	friendly	lonely	rude	sensible	vulgar
5	Green	Square	Bouncing	No	cheerful	friendly	lonely	reliable	successful	vulgar
5	Green	Square	Diagonally	No	affectionate	curious	friendly	reliable	sensitive	vulgar
5	Green	Square	Horizontal	No	aggressive	curious	lonely	passionate	selfish	vulgar
5	Green	Triangle	Bouncing	Yes	curious	friendly	passionate	selfish	sensitive	vulgar
5	Green	Triangle	Diagonally	Yes	affectionate	ambitious	curious	friendly	jealous	vulgar
5	Green	Triangle	Horizontal	Yes	friendly	lonely	passionate	proud	reliable	vulgar
5	Red	Circle	Bouncing	No	affectionate	easy-going	friendly	reliable	successful	warm
5	Red	Circle	Diagonally	No	ambitious	easy-going	friendly	passive	serious	warm
5	Red	Circle	Horizontal	Yes	ambitious	easy-going	jealous	patient	sensible	warm
5	Red	Square	Bouncing	Yes	ambitious	easy-going	friendly	reliable	successful	warm
5	Red	Square	Diagonally	No	ambitious	easy-going	patient	selfish	successful	warm
5	Red	Square	Horizontal	Yes	cheerful	nasty	organised	reliable	sensible	warm
5	Red	Triangle	Bouncing	Yes	curious	easy-going	lonely	reliable	sensitive	vulgar
5	Red	Triangle	Diagonally	No	ambitious	curious	easy-going	friendly	serious	warm
5	Red	Triangle	Horizontal	No	curious	easy-going	nervous	reliable	rude	warm

	Alien Category Features				Assigned Attributes					
Generation	**Color**	**Shape**	**Movement**	**Transmitted**	**Attribute 1**	**Attribute 2**	**Attribute 3**	**Attribute 4**	**Attribute 5**	**Attribute 6**
6	Blue	Circle	Bouncing	No	friendly	jealous	organised	rude	successful	vulgar
6	Blue	Circle	Diagonally	Yes	ambitious	friendly	lonely	reliable	rude	sensible
6	Blue	Circle	Horizontal	No	friendly	jealous	lonely	organised	proud	rude
6	Blue	Square	Bouncing	Yes	ambitious	friendly	lonely	reliable	rude	successful
6	Blue	Square	Diagonally	Yes	ambitious	friendly	lonely	rude	sensible	successful
6	Blue	Square	Horizontal	Yes	lonely	proud	reliable	sensible	serious	successful
6	Blue	Triangle	Bouncing	No	cheerful	curious	friendly	jealous	sensitive	successful
6	Blue	Triangle	Diagonally	No	ambitious	friendly	lonely	organised	selfish	successful
6	Blue	Triangle	Horizontal	No	curious	friendly	jealous	organised	reliable	rude
6	Green	Circle	Bouncing	Yes	jealous	lonely	organised	passionate	successful	vulgar
6	Green	Circle	Diagonally	Yes	ambitious	curious	organised	patient	proud	vulgar
6	Green	Circle	Horizontal	No	ambitious	curious	friendly	lonely	selfish	vulgar
6	Green	Square	Bouncing	Yes	ambitious	friendly	lonely	reliable	successful	vulgar
6	Green	Square	Diagonally	Yes	ambitious	friendly	jealous	lonely	organised	vulgar
6	Green	Square	Horizontal	No	curious	jealous	organised	proud	successful	vulgar
6	Green	Triangle	Bouncing	No	friendly	jealous	lonely	patient	sensitive	vulgar
6	Green	Triangle	Diagonally	No	ambitious	friendly	lonely	rude	sensible	vulgar
6	Green	Triangle	Horizontal	Yes	friendly	organised	proud	reliable	successful	vulgar
6	Red	Circle	Bouncing	Yes	friendly	organised	reliable	successful	vulgar	warm
6	Red	Circle	Diagonally	No	ambitious	curious	friendly	sensible	successful	warm
6	Red	Circle	Horizontal	Yes	friendly	jealous	passive	rude	successful	warm
6	Red	Square	Bouncing	No	ambitious	friendly	organised	proud	successful	warm
6	Red	Square	Diagonally	Yes	ambitious	cheerful	friendly	lonely	organised	warm
6	Red	Square	Horizontal	Yes	ambitious	organised	patient	proud	reliable	warm
6	Red	Triangle	Bouncing	No	friendly	lonely	passionate	rude	sensible	successful
6	Red	Triangle	Diagonally	No	ambitious	curious	friendly	lonely	rude	successful
6	Red	Triangle	Horizontal	No	curious	jealous	organised	proud	reliable	successful

	Alien Category Features				Assigned Attributes					
Generation	**Color**	**Shape**	**Movement**	**Transmitted**	**Attribute 1**	**Attribute 2**	**Attribute 3**	**Attribute 4**	**Attribute 5**	**Attribute 6**
7	Blue	Circle	Bouncing	N/A	ambitious	cheerful	passionate	reliable	sensible	successful
7	Blue	Circle	Diagonally	N/A	cheerful	friendly	organised	reliable	sensible	successful
7	Blue	Circle	Horizontal	N/A	cheerful	friendly	jealous	reliable	sensible	successful
7	Blue	Square	Bouncing	N/A	ambitious	cheerful	friendly	reliable	sensible	successful
7	Blue	Square	Diagonally	N/A	cheerful	friendly	reliable	rude	sensible	successful
7	Blue	Square	Horizontal	N/A	ambitious	cheerful	friendly	reliable	sensible	successful
7	Blue	Triangle	Bouncing	N/A	ambitious	cheerful	curious	reliable	sensible	successful
7	Blue	Triangle	Diagonally	N/A	ambitious	lonely	reliable	rude	sensitive	successful
7	Blue	Triangle	Horizontal	N/A	friendly	lonely	organised	reliable	sensible	successful
7	Green	Circle	Bouncing	N/A	lonely	organised	passionate	reliable	sensible	vulgar
7	Green	Circle	Diagonally	N/A	lonely	passionate	reliable	sensible	successful	vulgar
7	Green	Circle	Horizontal	N/A	friendly	lonely	passionate	rude	sensible	vulgar
7	Green	Square	Bouncing	N/A	ambitious	cheerful	friendly	rude	successful	vulgar
7	Green	Square	Diagonally	N/A	friendly	lonely	reliable	sensible	successful	vulgar
7	Green	Square	Horizontal	N/A	cheerful	curious	friendly	rude	successful	vulgar
7	Green	Triangle	Bouncing	N/A	ambitious	cheerful	lonely	sensible	successful	vulgar
7	Green	Triangle	Diagonally	N/A	cheerful	flirty	lonely	organised	sensible	vulgar
7	Green	Triangle	Horizontal	N/A	friendly	lonely	reliable	sensible	successful	vulgar
7	Red	Circle	Bouncing	N/A	ambitious	cheerful	jealous	reliable	rude	warm
7	Red	Circle	Diagonally	N/A	ambitious	cheerful	jealous	reliable	rude	warm
7	Red	Circle	Horizontal	N/A	jealous	organised	rude	sensible	successful	warm
7	Red	Square	Bouncing	N/A	ambitious	cheerful	organised	rude	successful	warm
7	Red	Square	Diagonally	N/A	ambitious	cheerful	jealous	rude	vulgar	warm
7	Red	Square	Horizontal	N/A	cheerful	friendly	jealous	rude	successful	warm
7	Red	Triangle	Bouncing	N/A	ambitious	lonely	rude	sensible	successful	warm
7	Red	Triangle	Diagonally	N/A	ambitious	jealous	lonely	organised	rude	warm
7	Red	Triangle	Horizontal	N/A	cheerful	jealous	reliable	successful	vulgar	warm

Table summarizing dependent measures associated with each generation of example chain.

	Accuracy			Structure		
Generation	**Seen Set**	**Unseen set**	**Total Unique Attributes**	**Two Shared Features**	**One Shared Feature**	**Zero Shared Features**
0	N/A	N/A	47	-0.56	-0.09	0.95
1	21%	13%	40	2.97	0.18	-0.62
2	29%	13%	22	4.69	3.27	4.11
3	40%	23%	21	10.39	9.06	7.89
4	37%	32%	36	8.45	9.06	5.69
5	29%	15%	25	6.58	3.97	2.89
6	45%	45%	20	8.35	5.60	5.04
7	51%	46%	16	8.57	4.74	0.36