Emergent Patterns of Mate Choice in Human Populations

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Abstract

We present a model of human mate choice that shows how realistic population-level patterns of assortative mating can self-organize and emerge from the behavior of individuals using simple mate search rules. In particular, we model plausible psychological mechanisms for mate search and choice in a realistic social ecology. Through individual interactions, patterns emerge that match those observed in typical human societies, particularly in terms of correlated quality levels within couples, distributions of the ages at which couples mate, and effects of skewed sex ratios on these mating age distributions.

Keywords: Human mate choice, emergence, courtship, assortative mating, age at marriage

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1 Introduction — How to find a mate

The emergence of more or less stable social relationship structures in monogamous mating systems may at first appear paradoxical. On the one hand, individuals are expected to be under strong selective pressure to be highly discriminating about which partner to choose, preferring higher quality partners to lower quality ones. On the other hand, not all individuals can find very high quality mates, because these valued mates constitute only a small fraction of the available pool of alternatives. Despite these two antagonistic facts of life, the vast majority of humans beings are able to mate during their fertile years, and many of them are able to maintain stable romantic relationships for long periods of time. Somehow the psychological mechanisms used by individuals in the ruthless games of reproduction, essential for passing on their genes to the next generation, must solve this problem of choosing a reasonable mate. What can these mechanisms be, and what population-level outcomes do they lead to through self-organizing processes?

1.1 Previous simulations of human mate choice strategies

To find out, we can approach the questions from at least three angles: empirical observation of the emergent population-level patterns (as done by demographers for instance), experimentation to find the individual level mechanisms (as done by psychologists), and simulation modeling to connect the two levels. Our work draws on the first two approaches to build models using the third approach. In doing so, we follow an earlier tradition of models that were based for the most part on psychological or biological findings. Seminal work on the mechanisms underlying emergent patterns of human mating using computational models was done Kalick and Hamilton in the 1980's [15]. They started with the fact that observations of many human populations show that individuals in couples are highly correlated in attractiveness (correlations between 0.4 and 0.6 in different studies). This finding had led social scientists in the 1960's to propose the "matching hypothesis" that people actively seek a mate matched to them in attractiveness. But this seems to contradict experimental data indicating that people in general tend to prefer more physically attractive individuals over less attractive ones as prospective partners (i.e., not taking their own attractiveness into account). To explain this apparent contradiction, Kalick and Hamilton set up individual-based simulations to study the relationship between individual-level preferences and population-level patterns. In their simulations, randomly selected individuals with particular attractiveness values were paired up sequentially in "dates." Both individuals in a date then used a probabilistic acceptance criterion to decide whether or not to accept the other, and, if both agreed, they mated and left the population. A discounting factor was introduced to make individuals less choosy with time.

Kalick and Hamilton's results demonstrated that universal preferences for high attractiveness, as opposed to preferences for similarity in attractiveness (matching), can enable a population to self-organize via selective mating into pairs with a realistic degree of intra-couple correlation of attractiveness (.55). This is because higher attractiveness individuals tend to pair (and leave the mating pool) earlier than lower quality individuals, leaving the lower quality individuals with no option other than mating amongst themselves, which leads to assortative (non-random) mating. One critique of Kalick and Hamilton's support for preferences for high attractiveness was that an unrealistically high number of dates (evaluations of members of the opposite sex) was required in the model for a realistic intra-couple attractiveness correlation to be obtained and a significant percentage of the population to mate (e.g., it took 40 "dates" for the correlation to reach .43 and 86% of the individuals to mate) [1].

More recently, Todd and Miller used a similar type of simulation to explore the efficacy of different individual rules for searching through a sequence of encountered potential mates [30]. The authors were particularly interested in whether individuals could make reasonably good (satisficing) mate choices without having to check many potential partners, such that the population of mating individuals could self-organize relatively quickly into mated pairs with similar levels of mate quality. In their model, an "adolescence" (learning) period is used by individuals to adjust an *aspiration level* based on the feedback provided by the mating offers and rejections of potential mates they encounter. For example, in one of the learning rules, individuals raise their own aspiration level (by a fixed amount) for every proposal received from a higher-quality member of the opposite sex, and lower their aspiration level for every lower-quality individual encountered who does not propose (i.e., who rejects them). After the adolescence period, individuals make mating offers to everyone they meet who exceeds their aspiration level, and whenever both individuals in a pair make mutual offers to each other, they mate and are removed from the population. Todd and Miller's results showed that simple learning rules can adjust individual aspiration levels quickly (e.g., after an adolescence comprising 12 dates or partner-assessments) to yield mated pairs of highly matched mate value. However, these learning rules typically left an unrealistically large proportion of the population unmated (e.g., over 50%). This approach was later applied to explore how cross-cultural marriage demographic patterns could emerge from individual choice [29], but because the same individual mating rules were used, some of the same problems of empirical fit remain. (We will return to this topic in the results section.)

1.2 Important factors for developing new models

To overcome the difficulties of these simulations (and of some others proposed in the literature that make biologically implausible assumptions, e.g., that individuals have full information regarding the mating pool [14, 2, 19]), we have been developing a series of models of human mate choice based on an evolutionary functional analysis. By this, we mean making appropriate proposals for the top-level goals that individuals should care about, particularly ones that contribute to biological fitness (e.g., be choosy about the quality of mating partners, and take one's own limited reproductive lifetime into consideration), and then postulating psychologically plausible behavior rules that satisfy these goals [10, 9]. We do not assume, however, that behavior rules are fully specified by genetic instructions [21]. Culturally transmitted behavior rules can also arise that enhance or retard genetically shaped drives and values [8, 4]. By including more realistic constraints on individual strategic behavior and on the social ecology, our new models produce more realistic population-level patterns.

In particular, we have previously shown [25] that by making individuals go through a premating courtship period that can be used to switch to better partners — instead of forcing them to make decisions about whether or not to mate with somebody in a single and irreversible event (as done in all models referenced above) — population-level patterns that match observed human populations emerged. Namely, this particular model produced reasonably high correlation of qualities between the two individuals in mated pairs, enabled most of the population to mate, and required a reasonably low number of dates (courtships) before mating. These patterns arose because individuals did not have to make irrevocably final decisions about which individuals to mate: Instead, they could hold onto the best partner they could find (and get) at the moment, and leave open (for a while) the option of moving to a better partner if one were found later.

In this initial model, individuals always entered the first possible relationship when they were single, and courtship time was held constant. That is, individuals would engage in a potentially fully committing relationship — one that could ultimately lead to mating and leaving the population — with the very first individual they met. As a consequence, the model produced unrealistically low correlations of qualities in mated pairs when meeting rates were low and/or imposed courtship time was small. To fix this, in [26] we made a thorough comparative analysis of several individual strategies that added aspiration levels to decide when to enter into a relationship to the courtship period that enabled the switching of partners. In this expanded model, the aspiration levels were set during an initial adolescence or flirting period, thus following an approach similar to that of Todd and Miller [30]. Still, because the abrupt transition made from a flirting period to a "true" mate search period is unnatural (given what is known about the social ecology of human mating [18, 31]), that model too called for further refinments.

In this paper, therefore, we present a model of individual human mate choice that overcomes the oversimplification of absolute mating and non-mating states or periods. Because human reproductive potential starts low in the period immediately after the onset of puberty and then starts rising [12, 6, 27], it is reasonable to assume that females (or both sexes) impose longer courtship periods before conceding sexual access in the earlier phases of their lives [18, 31]. Additionally, because they do not need to fully commit to relationships from the start, they can switch to better partners if they become available, for instance by raising their aspiration level over time contingent on their perceived self-quality. As a consequence of many interactions of these individual-level mechanisms, self-organized patterns of mating emerge at the population level; here we consider specifically assortative correlations of mating quality as well as ages of mating.

An important point for what follows is that (as in the models referenced earlier) we conceptualize preferences and attractiveness as being based on some combination of different relevant features[1] into an overall *mate value* or *mate quality*, as suggested by Donald Symons [27]. This design decision is a sensitive one as it touches on one of the central questions to be asked when studying human mating — the nature of interpersonal attraction. From an evolutionary perspective, it is expected that humans (like other animals) have traits that influence their ability to survive, reproduce, and successfully raise their offspring. Because they also present some degree of variation in those features, it is reasonable to assume that evolution would endow individuals with the capability to discriminate among potential partners, preferring the ones with better traits. Moreover, many of these traits seem to be significantly intercorrelated [28]. On the other hand, some of the preference dimensions identified in the traditional social psychology literature may not be easily accommodated by an evolutionary framework (e.g. shared political or religious values) [3]. Thus the notion of *mate quality* as a one-dimensional feature should be seen only as a first approximation to allow models to be kept simple.

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[1] In Kalick and Hamilton's work *attractiveness* is equated with *physical attractiveness* alone when the model is interpreted and tested against empirical data [15].

Additionally, we make the further simplifying assumption that preferences are universal ("type preferences" [5]). This is useful for our purposes, as it entails the most extreme degree of mate competition, with everyone prefering the same types of mates. Thus this model provides a test-case for the self-organization of macro-level patterns in the limit-case of maximal inter-sexual competition, which makes it difficult for every individual to find a mate. While inter-rater agreement on attractiveness is high [15], in the real world we should expect to find *some* individual variation in the preferences for many mating-relevant traits. For example, in [13] the authors used computer manipulated images of human faces to show that "women born to old parents were less impressed by youth and more positive to age cues in male faces than women with young parents", and "[male] preferences for female faces were influenced by mother's but not father's age". Nonetheless, our strong universal-preference assumption here should not much hinder the generalizability of our results. (See also [26] for further discussion on the issue of multi-dimensional quality features, "type preferences" vs."homotypic" or "like-prefers-like" preferences [5], and how the results presented in this paper can be compared with traditional social science theories of satisfaction and investment in inter-personal relationships [24, 23].)

The rest of the paper is organized as follows. In the next section, we present the model of the social ecology we set up for mate choice, followed by a description of the strategic behavior rules used by individuals. After this, we present some of the population-level patterns generated by the self-organizing dynamics of the model and finally draw conclusions regarding the role of such modeling.

2 Modeling the social ecology of mate choice

To model what happens when a set of individuals interacts to find mates, we begin by establishing a population of constant size with P males and $P \cdot R$ females (so R is the sex ratio of females to males). Individuals of both sexes have a one dimensional quality parameter q_i, randomly generated from a normal distribution with mean μ and standard deviation σ, truncated such that $0 < Q_{min} \leq q_i \leq Q_{max}$. Time is modeled as a sequence of discrete steps. Pairs of males and females meet at a certain stochastic rate: in each time step each individual has a probability $Y \cdot p_i$ of meeting a new individual of the opposite sex, where Y is a constant model parameter specifying the maximum meeting rate, and p_i is an individual-specific discount factor that is dependent on the individual's *interaction capability* (described below). The specific individual j to be met is chosen randomly with a probability proportional to p_j. The meeting rate is assumed not to be dependent on the sex ratio R, because we do not want to conflate possible effects of partner availability and meeting rates. Thus, the only effect of R is to change the relative size of the male and female pools.

Each individual maintains a list of the potential mates already met — the *alternatives list*. The alternatives list has a maximum size of N, the number of opposite-sex individuals an agent can maintain in his or her social network and possibly make courting proposals to. If the social network becomes saturated, that is, if the alternatives list is filled, new meetings happen at the expense of forgetting one randomly selected individual already in the list (other than the current partner). Moreover, if the individual met is already present in an individual's alternatives list, no new individual is added to its social network. Because each meeting has the effect of putting a male and a female into each other's social network, the average number of new individuals met in each time step by each agent is therefore $2 \times Y - \epsilon$, where ϵ is a discounting factor due to repeated encounters. Overall, this models a scenario where individuals go out to meet new people of the opposite sex, sometimes successfully, sometimes not, and occasionally encountering people whom they already know.

Within the alternatives list, one member can have the "special status" of being the individual's current partner (or "date"). This happens when both individuals previously agreed to court and have not changed partners in the mean time (see below). It is also possible for an individual not to be courting anybody (e.g., in the beginning of its "life", or when it gets "dumped"). The length of time that two individuals are courting is regarded as the courtship time c_t. Each individual as a specific *minimum courtship time* (K_i), which specifies how long it takes for the individual to fully commit him/herself to a relationship and become willing to mate (metaphorically, to fall in love with its partner). If both courting individuals "fall in love" in this way, then they mate, and do not consider further dating opportunities. Every individual has a maximum *reproductive* lifetime of L time steps, so some individuals may be never be able to find a mate.

Because individual fertility is lower at very young ages and reproductive lifetime is finite, the costs of delaying mating is higher later in life. Therefore, we assume that K_i has a maximum value at the beginning of the individual's reproductive life and decreases monotonically with time. Specifically, we define $K_i = K \cdot (1 - \frac{t_i}{L})$, where t_i is the age of individual i, and K is a constant model parameter defining K_i at age 0.

The interaction capability p_i of an individual is negatively correlated with the degree of involvement in the current courtship process (and therefore with c_t). This is intended to model increasing levels of intimacy and exclusivity as courtship progresses (see [26] and [19] for a detailed discussion of this issue). Specifically, $p_i \in [0,1] = max\{0, 1 - \left(\frac{c_t}{K_i}\right)^I\}$, where $I > 0$ is a model constant that defines the shape of the "intimacy curve".

In each time step, every individual i has a certain probability of interacting with every member j of its alternatives list. This probability is set as $p_i \cdot p_j$. We call the set of all alternatives for which an interaction is selected to occur, according to these probabilities, the *interaction list* of i. After the interaction lists are computed for all individuals, each one decides what action to perform based on his or her state: If an individual is single, he/she has to decide whether to try to start a relationship (with some member of the interaction list), or postpone that decision to see if a better alternative becomes available. If an individual is courting, he/she has to decide whether to continue to court the same partner or try to court another individual. Below we specify the exact decision functions used by the agents in our model. Note that, although an individual can make requests to court several others in each time step, he/she can only court one individual at a particular point in time. (See [26] for a more formal description of the matching algorithm used.)

3 Individual mate choice strategies

We make individual behavior consistent with evolutionarily plausible constraints by defining a fitness function F that individuals behave so as to maximize. Specifically, we define $F(q_m, t) = q_m \times \frac{L-t}{L}$, were q_m is the quality of the individual's chosen mate, and t is the age at which the individual mates. Thus, we reward a preference for high quality, and introduce time pressure to motivate individuals to mate early (in addition to the motivation stemming from their limited life-time).

If an individual is already courting somebody else, he/she will switch partners whenever it provides a fitness gain. Specifically, partner switching attempts are made by an individual i if the following inequality holds:

$$F(q_a, t + K_i) > F(q_d, t + max\{0, K_i - c_t\}) \tag{1}$$

where q_a is quality of the alternative partner being considered, q_d is the quality of the current partner (date), c_t the current courtship time, and t is the age of agent i. The equation specifies that if the expected fitness of mating with the alternative (calculated using an optimistic estimation of the required courtship time K_i) is greater than the expected fitness of mating with the current partner (calculated using an optimistic estimation of the remaining courtship time $K_i - c_t$), then switching should be attempted. For example, if the agent i has just started a date or courtship period ($c_t = 1$), then virtually all individuals with higher quality than the current partner would be sought as alternative partners. On the other hand, if agent i was courting for a long time ($c_t \approx K_i$), then prospective alternative partners would need a quality somewhat higher than the current partner to be considered as a date, because any switch needs to compensate for the lost investment already made in the current relationship.

Because there are costs to entering a relationship, a reasonable strategy is for individuals to set acceptance or aspiration levels to decide whether or not to begin courting some partner. Potential partners falling below the aspiration level in quality are not sought (or proposed to) as dates. This aspiration level should reflect to some extent the individual's own quality, with high quality individuals avoiding lower quality ones, and lower quality individuals having realistic aspiration levels tuned to their unfortunate lower rank. Because rationally bounded agents cannot be assumed to have information about their own relative quality automatically — their rank is relative to all other individuals in the population, which they cannot know ahead of time — agents must estimate their quality dynamically and use it to perform mating decisions as they go along.

Specifically, an individual i starts out being totally non-discriminating by setting his/her self-quality estimate q_i^* (here equivalent to the individual's aspiration level) to 0. If an agent was previously dating and the partner j took the initiative of breaking the relationship, q_i^* is updated according to the following rule:

$$q^*_{i_{new}} = q^*_{i_{old}} \cdot (1 - \alpha) + \omega \cdot q_j \cdot \alpha \tag{2}$$

where q_j is the quality of the agent's departing partner, $\omega \in [0, 1]$ is a correction factor to decrease the agent's expectations to slightly below the quality of that partner (we will use the value .8), and α corresponds to the learning rate which is used to avoid individuals moving aspiration levels too fast (we use the value .2 in our simulations). The overall procedure is likely (although not certain) to assign q^* an appropriate value, because the agent's partner will break the relationship only to start courting a higher quality individual — and this gives a rough indication that the agent is aiming too high and is unable to retain partners of quality q_j, so that a new aspiration level less than q_j is called for.

Finally, because the expectations of an individual should reflect not only its own quality but also the availability of partners, aspiration levels should be reduced whenever waiting for a higher quality partner does not pay off in terms of lost reproductive lifetime. Moreover, since the initial aspiration level might not have been properly calibrated, individuals should not be too confident about it. This means it might be advisable to attribute failure to mate to an inflated value of one's aspiration level — which, in turn, should prompt a drop in the value of q^*. One simple way to model this is to keep track of the time t_w an individual has been waiting for a partner, and to lower his/her aspiration when a waiting time threshold t_{max} is reached. Specifically, we will define this threshold as follows:

$$t_{max} = \tau \cdot \frac{L - t}{L} \cdot (1 - \frac{q_b}{q^*}) \tag{3}$$

where τ is a proportionality constant (we use the value 60), t is the age of the current individual, and q_b is the quality of the best alternative in the alternatives list whose quality is lower than q^*. Intuitively, this threshold specifies that the time an individual is willing to wait to court someone with the current minimal sought quality is inversely proportional to the individual's age and the quality of the best (attainable) alternative likely to be already available. If t_w reaches t_{max} the aspiration level q^* is set to q_b (and t_w is reset to 0).

Overall, this behavior strategy can be interpreted, metaphorically, as individuals trying to climb up (and sometimes falling down) a ladder of qualities. When accepted by higher quality individuals, individuals tend to move their aspiration level higher (although no actual update of q^* is done or required until a relationship breaks). On the other hand, when rejected, or in any case with the passage of time, individuals will tend to move their aspiration level down.

4 Simulation Results

4.1 Patterns of correlation in quality

In this section, we investigate the kind of global patterns that emerge from the individual decision rules and social interaction model described above and see how well they account for the self-organization of real human mating populations. We set the male population size parameter $P = 100$, and the female to male sex ratio $R = 1$ (initially), giving 100 males and 100 females in the population. Additionally, we set the individual reproductive lifetime to $L = 200$ (corresponding to 20 years, with each time step as a tenth of a year). The parameters for the (quasi) normal quality distribution were set by equating agent quality with the total number of offspring produced during a complete (female) lifetime using a data set from a particular human population, the *Ache* [12] — although similar values apply to other societies that do not have significant contraceptive use. The intimacy constant I was set to 2.0 to model a quadratic reduction of interaction capabilities, which corresponds to a super-linear increase in couples' intimacy as courtship develops. Each simulation run consists of the pairing and mating of individuals until L time steps are reached. The results shown correspond to averages across 100 such runs.

Figure 1 depicts the linear correlation between the qualities of individuals in mated pairs as a function of rate-of-meeting Y and the initial courtship time K. The results show that the more alternatives individuals meet (as $Y \times K$ gets bigger), the more likely they will mate with an individual close to them in quality. Only a small value of K is required to make the correlation value almost independent of the meeting rate. This suggests that individuals are making good use of their mating potential even if encounters are rare and despite the fact that they have no initial, direct knowledge of their own mate value. Most importantly, the results are in accordance with the reasonably high correlation coefficients (mostly between .6 and .7) empirically observed in sampled human populations [15].

Additionally, we found that for the same parameter values only a small number of dates is required for individuals to mate (mean between 1.4 and 3.2), and the average age at mating time is always lower than $K + 20$. This means that (on average) individuals do not delay mating by searching for partners for long periods of time, beyond the required courtship. Moreover, in virtually all simulation runs all individuals in the population were able to mate before the end of their lifetime. This occurs because the sex ratio here is $1 : 1$ and all individuals become less and less choosy over time. If the model is modified so that agents are replaced in the population by new ones as soon as they mate (as we did in our previous models [25, 26]), the percentage of mated individuals drops slightly, but its always above 90%. Again, these findings are consistent with demographic data, which indicates that in most human populations between 85% and 95% of individuals are able to mate at least once in their lives (typically under the official seal of the marriage institution) [16].

Overall, the current model replicated the empirically realistic results we found in [26], without requiring the previous artificial split between a flirting period to set aspiration levels and a separate period to search for mates. This move to a more plausible psychological design makes it more likely that the model assumptions better approximate the actual causal mechanisms producing the macro-level patterns found in the real world — although further empirical work is needed to establish this. It should be noted that the combination of these three empirically validated statistics — correlated mate values, high rate of matings, and little search — was never obtained in previous models of (human) mating using realistic psychological constraints. Kalick and Hamilton's attractiveness-preference model requires a high number of courtships (or at least individuals met) to achieve a realistic intra-couple quality correlation and a realistic proportion of mated individuals [15]. Todd and Miller's model produces unrealistically low proportions of individuals mated [30]. Finally, a game-theoretical model presented by Johnstone produces statistics similar to ours, but only by giving individuals initial knowledge of the distribution of qualities in the population and their own exact quality, and by assuming that the cost of waiting or searching for a potential partner is constant [14]. Our model avoids the full-information requirements typical of normative, optimizing approaches used in behavioral research, by assuming bounded rational agents that are able to gather and exploit the rich information structures presented in their task-environments to make robust decisions [22, 10].

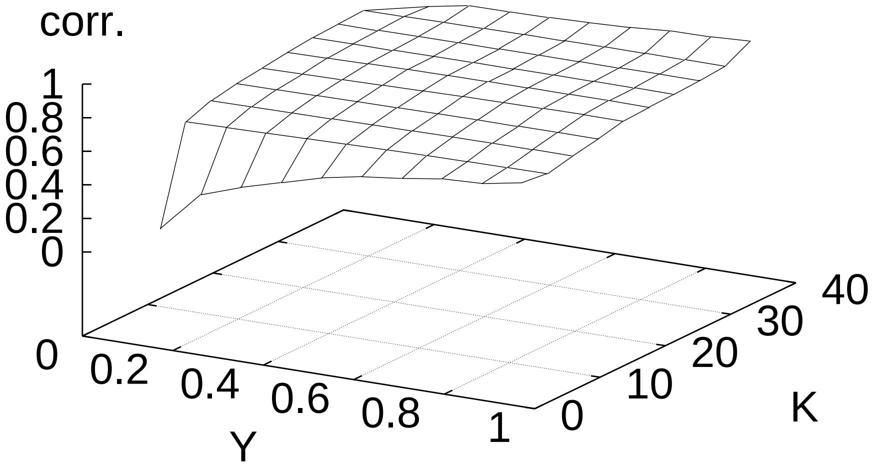

Figure 1: Correlation of qualities of the two individuals in each mated pair, across a range of settings for parameters Y (meeting rate) and K (courtship time).

4.2 Distribution of ages at marriage

One of the most robust empirical findings concerning population-level patterns of mating is that the distribution of age at first marriage follows a right-skewed bell curve in many cultures, rising more or less sharply from an early age to a broad peak between 20 and 30 years of age and then trailing off slowly into older ages [7, 29][2]. How can this consistent pattern be produced through the self-organization of individuals following simple mate choice rules? A parsimonious hypothesis is that this could arise if age at marriage is negatively correlated with an individual's quality, that is, higher quality individuals marry earlier than lower quality individuals. Then, given that quality is normally distributed, this should be enough to create the common right-skewed bell curve. However, we found that our model did not produce such a linear relationship between age at mating and quality. Instead, low-quality individuals ($q < \mu$) show great variation in mating age while high-quality individuals ($q \geq \mu$) show little variation (see Figure 2). This occurs because high-quality individuals mate assortatively with similarly high-quality individuals, who are few in number and therefore harder to find than average-quality individuals. Thus, although high-quality individuals are sought-after, they are unable to mate much earlier than the average individual (nor do they mate much later than average). As a consequence, the expected overall age-at-marriage pattern does not emerge[3]. Instead, a spike pattern appears with the majority of individuals mating as soon as it is possible, but low-quality individuals spreading the age of mating across the lifespan (see Figure 3). Thus, if the nonlinear relationship between quality and age at marriage holds in the real world as well, then normal variation in individual quality is not sufficient to generate the empirically-observed age-at-marriage curve.

To match the demographic data through their individual-level mate search model, Todd and Billari [29] found it necessary to introduce variation in the number of dates (or potential marriage partners) that individuals encounter during adolescence. But because we do not use a distinct (and artificial) period for setting up aspiration levels in our model, we must look for another explanation of the age-at-marriage pattern. Indeed, the explanation is quite similar: When we include normally-distributed individual variation in the courtship time K, the distribution of marriage times comes much closer

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[2] In the analyses that follow, we consider demographically-observable marriage as a stand-in for long-term mating behavior.

[3] When we made the quality distribution uniform ($q \in [Q_{min}, Q_{max}]$), the relationship between age at mating time and quality become linear, but because the quality distribution is no longer bell-shaped the typical age-at-marriage pattern does not emerge then either.

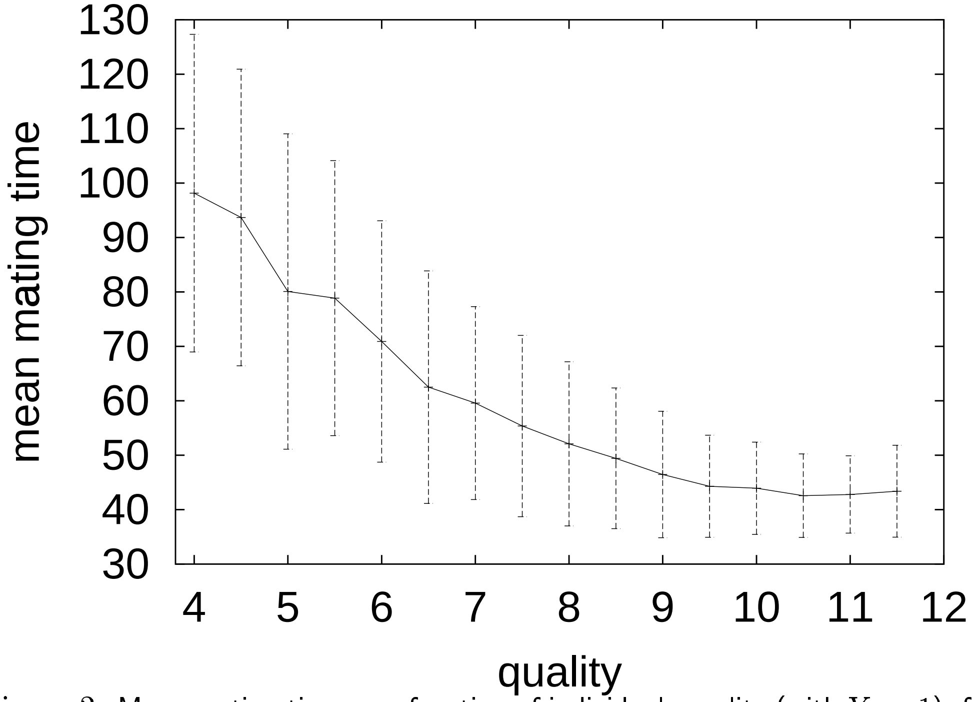

Figure 2: Mean mating time as a function of individuals quality (with $Y = .1$), for a fixed value of courtship time $K = 40$.

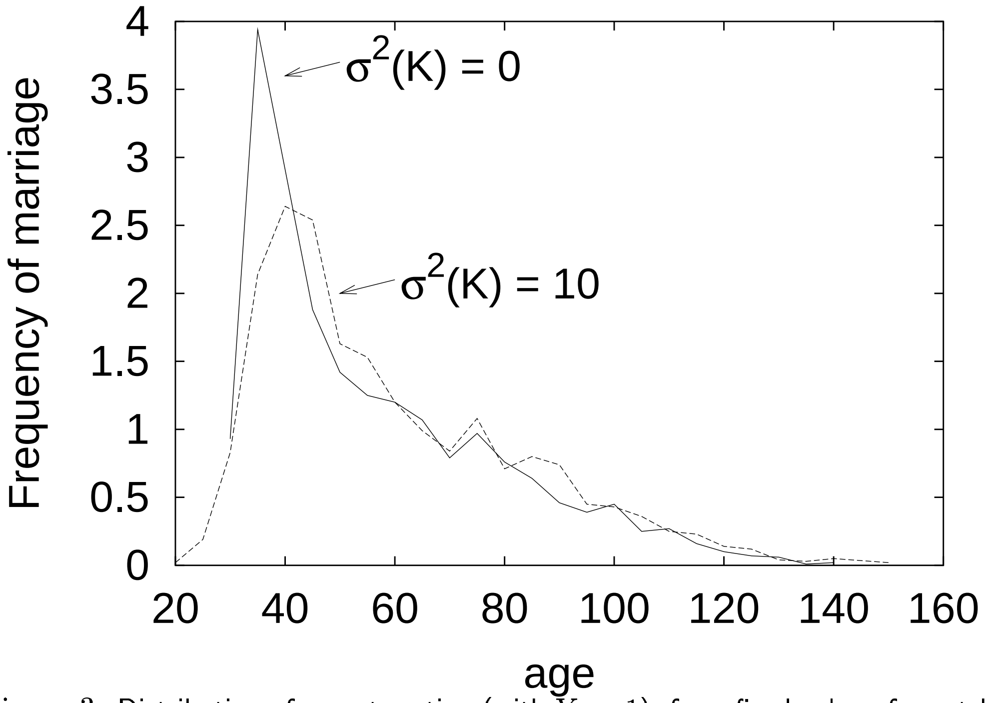

Figure 3: Distribution of age at mating (with $Y = .1$), for a fixed value of courtship time K ($\mu(K) = 40$) and for normally-distributed courtship time with same mean but variance 10.

to the observed right-skewed bell curve (see Figure 3). This form of individual differences is reasonable to build into the model, because variations in socio-economic and employment status are known to affect the propensity and ability of individuals to establish long-term relationships [17, 20]. Further comparison against empirical data could help to clarify how much variation in the age of mating (or marriage) can be accounted for by variation in courtship time (as well as individual quality), and in what ways these two factors relate to other individual differences in explaining this striking demographic pattern of human mating.

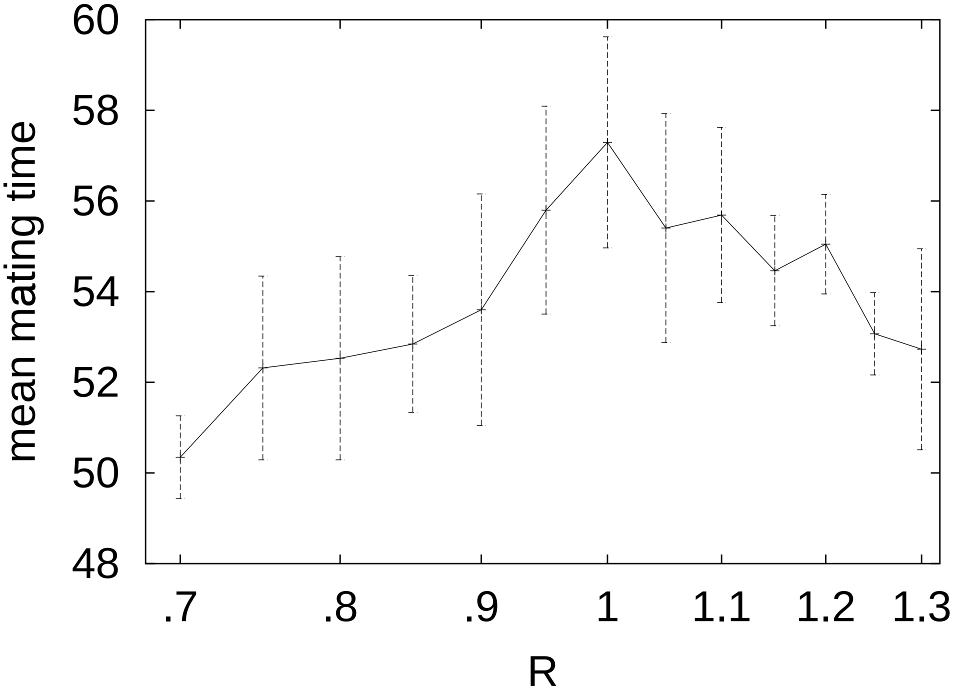

Figure 4: Mean mating time as a function of the (females to males) sex ratio R on logarithmic scale (with $Y = .1$ and $K = 40$).

4.3 Effects of skewed sex ratios

An additional factor that can affect the timing of marriage (or mating) is the female-to-male sex ratio in a particular population. Socal scientists have proposed two opposing hypotheses concerning the effect of sex ratio on marriage, motivated on both empirical and theoretical grounds, and so we wanted to test whether our model would lend further theoretical support to one or the other. *Marital search theory* [17, 20] proposes that an excess of members of one sex should accelerate the transition to first marriage by members of the opposite sex (e.g. an excess of females should make males marry earlier), because of the increased opportunities to find a suitable mate. Conversely, among the more common sex, the mean age at marriage may go up, because some will marry the rarer sex early but others will marry late or never. *Imbalanced sex ratio theory* [11], in contrast, argues that an excess in the relative number of women should reduce men's motivation to commit to marriage, and so lead to later marriage (for both men and women). (When men are more common than women, this theory makes roughly the same prediction as marital search theory, that those men who marry at all will marry earlier.) While our model cannot address the motivational mechanism proposed in imbalanced sex ratio theory (because we assume constant motivation to mate monogamously), we can assess whether individual search in the presence of an imbalanced sex ratio would lead to earlier or later marriage for those who marry.

To implement an imbalanced sex ratio in our model, we vary the relative number of males and females in the population by manipulating the model parameter R, as specified in the beginning of section 2. An alternative or additional arrangement could be to change the size of the social networks of each sex (e.g., make men meet and remember more women, or vice versa). However, in earlier work [26] we found that once the social network reached a reasonable size (around 8 acquaintances), there was little change in search performance, so this means of introducing imbalanced sex ratios into the model would have little impact.

We show the effect of sex ratio on mean mating time of those who find a mate in Figure 4, where we the sex ratio (R) on the x-axis on logarithmic scale to highlight the symmetry of the results for imbalanced sex ratios above and below 1. The results are averaged across 10 runs, each with P males and $R \times P$ females. Error bars represent standard deviation of the mean mating times from each run. (This is different from Figure 2 where the error bars represent the standard deviation of mating time for all individuals in all runs). Individuals who are unable to mate are left out of the calculation. We vary the sex ratio parameter R over a very wide range (beyond what is typically observed in natural populations, though historically there has been such variation — see [11]) to more clearly observe the general trend. The male population size parameter P is kept fixed at 100, as before, so that when $R = .8$ for example there are $.8 \times P = 80$ females. The clear result in Figure 4 is that the mean mating time decreases when the sex ratio is imbalanced (away from $R = 1.0$. When $R < 1$, the deficit of females means that some males remain without mates. This has the effect of actually reducing the mean mating time of those who mate, because those males who mate are of higher quality on average (as shown in Figure 5), and they typically find mates earlier (as shown in Figure 2). Thus, by removing the very low quality males who are now unable to win a mate from the marriage pool, the average marriage time is shifted downwards. In addition, because the mean quality of mated males increases, females are less likely to break relationships, which also leads to less delay before mating. These same factors (but from the female perspective) lead to decreased age at mating when $R > 1.0$.

Thus, while the overall strength of the effect of changing sex ratios on mean mating time is relatively small (compare the mean mating time differences of up to 8 in Figure 4 with the mating time range from 40 to 120 in Figure 2), the consistent decrease in mating time is in line with the predictions of marital search theory and not with those of imbalanced sex ratio theory. It is understandable that results stemming from a model based on individual search like ours would match the predictions of a search-based theory; but it is also important to point out that the simplicity of our model prevents us from being too conclusive about this suggestive consistency. With more realistic assumptions (and complexity) regarding differences between male and female search behavior and goals, our model could perhaps support aspects of imbalanced sex ratio theory instead. (For example, if we were to introduce into the model the possibility for individuals to divorce and remarry, and a substantial number of low quality individuals later married higher-quality divorcees, then this could weaken the timing effects suggested by marital search theory.)

The current picture is nonetheless filled out by considering the mean quality of males and females in mated couples as the sex ratio changes, shown in Figure 5. When there is a deficit of females ($R < 1$), the average quality of the males who are able to mate grows increasingly higher than μ as R gets smaller, while the average quality for mated females stays fixed at μ because they are all able to mate. When there is an excess of females ($R > 1$) the reverse occurs: All males are able to mate, and the average quality of mated females increases as R gets larger. Finally, whenever R deviates from the fully balanced sex ratio ($R = 1$), the correlation between the qualities of individuals in mated pairs gets smaller (not plotted). This occurs because the effective quality variation among mated individuals of the more common sex gets smaller, which implies reduced linear correlation between the sexes [1][4]. For example, with $R = 1$ the correlation between the qualities of individuals in mated pairs is 0.64, while with $R = .6$ the correlation coefficient drops to

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[4] All of these sex-ratio-related effects emerge even in a simplified model where courtship time is constant for each individual (i.e., it does not change with age), and does not vary across individuals, as was introduced to explore the distribution of age at marriage.

.49.

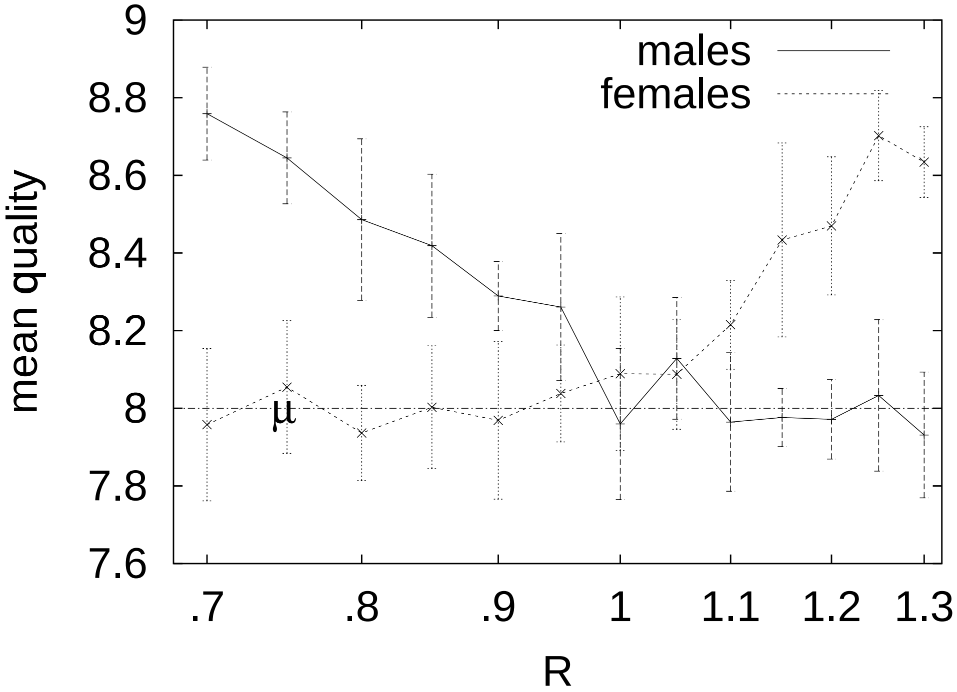

Figure 5: Mean quality of mated individuals as a function of the (females to males) sex ratio R on logarithmic scale (with $Y = .1$, and $K = 40$).

5 Conclusions

The patterns of human mating and marriage that we observe around us can be explained as the outcome of a self-organizing system of individuals following simple mate search rules. In this paper, we have used simulation models of populations of agents searching for mates to show how a variety of realistic mating patterns can emerge. In particular, we have shown how most individuals can find mates of similar levels of quality after meeting a reasonably small number of potential partners. By including individual-level variation in the minimally imposed courtship time in our model, we could generate a realistic distribution of ages for entering into (first) marriage. Finally, when we shifted the sex ratio of the population away from parity, we found that age at marriage was reduced among those who marry, supporting the predictions of marital search theory. We believe our approach, based on a combination of agent-based modeling and an evolutionary functional analysis, can be used to gain insights into both the psychological mechanisms that humans use in the process of choosing mates, and the population-level outcomes that these mechanisms generate.

References

[1] Arthur Aron. The matching hypothesis reconsidered again — comment on Kalick and Hamilton. *Journal of Personality and Social Psychology*, 54(3):441–446, 1988.

[2] C. Bergstrom and L. Real. Towards a theory of mutual mate choice: Lessons from two-sided matching. *Evolutionary Ecology Research*, 2(4):493–508, 2000.

[3] Ellen Berscheid and Harry T. Reis. Attraction and close relationships. In Daniel T. Gilbert, Susan T. Fiske, and Gardner Lindzey, editors, *Handbook of Social Psychology*, pages 193–281. New York: McGraw-Hill, 1998.

[4] Robert Boyd and Peter J. Richerson. *Culture and the Evolutionary Process*. Chicago: University of Chicago Press, 1985.

[5] Nancy Burley. The meaning of assortative mating. *Ethology and Sociobiology*, 4(4):191–203, 1983.

[6] David Buss. *The Evolution of Desire*. New York: Basic Books, 1994.

[7] Ansley J. Coale. Age patterns of marriage. *Population Studies*, 25:87–94, 1971.

[8] William H. Durham. *Coevolution: Genes, Culture, and Human Diversity*. Standford, CA: Standford University Press, 1990.

[9] Gerd Gigerenzer and Reinhard Selten, editors. *Bounded Rationality: The Adaptive Toolbox*. Cambridge, MA: MIT Press, 2001.

[10] Gerd Gigerenzer, Peter M. Todd, and the ABC Research Group. *Simple Heuristics that Make Us Smart*. New York: Oxford University Press, 1999.

[11] Marcia Guttentag and Paul F. Secord. *Too Many Women? The Sex Ratio Question*. Beverly Hills: Sage Publications, 1983.

[12] Kim Hill and A. Magdalena Hurtado. *Ache Life History — The Ecology and Demography of a Foraging People.* Chicago: Aldine de Gruyter, 1996.

[13] Perrett D. I., Penton-Voak I. S., Little A. C., Tiddeman B. P., Burt D. M., Schmidt N., Oxley R., and Barrett L. Facial attractiveness judgements reflect learning of parental age characteristics. *Proceedings of the Royal Society of London, series B.*, 269:873–880, 2002.

[14] Rufus Johnstone. The tactics of mutual mate choice and competitive search. *Behavioral Ecology and Sociobiology*, 40(1):51–59, 1997.

[15] S. Michael Kalick and Thomas E. Hamilton. The matching hypothesis reexamined. *Journal of Personality and Social Psychology*, 51(4):673–682, 1986.

[16] S. Michael Kalick and Thomas E. Hamilton. Closer look at a matching simulation: Reply to Aron. *Journal of Personality and Social Psychology*, 54(3):447–451, 1988.

[17] Kim M. Lloyd and Scott J. South. Contextual influences on young men's transition to first marriage. *Social Forces*, 74(3):1097–1119, 1996.

[18] Raymond Montemayor, Gerald R. Adams, and Thomas P. Gullotta, editors. *Personal Relationships During Adolescence.* London: Sage Publications, 1994.

[19] Andrzej Nowak and Robin R. Vallacher. *Dynamical Social Psychology.* New York: Guilford Press, 1998.

[20] Valerie Kincade Oppenheimer. A theory of marriage timing. *American Journal of Sociology*, 94(3):563–591, 1988.

[21] Susan Oyama. *The Ontogony of Information (second edition).* Durham, NC: Duke University Press, 2000.

[22] Edward S. Reed. *Encountering the World: Toward an Ecological Psychology.* New York: Oxford University Press, 1996.

[23] Caryl E. Rusbult and Bram P. Buunk. Commitment processes in close relationships: An interdependence analysis. *Journal of Social and Personal Relationships*, 10:175–204, 1993.

[24] Caryl E. Rusbult, John M. Martz, and Christopher R. Agnew. The investment model scale: Measuring commitment level, satisfaction level, quality of alternatives, and investment size. *Personal Relationships*, 5:375–391, 1998.

[25] Jorge P. Simão and Peter M. Todd. A model of human mate choice with courtship that predicts population patterns. In *Sixth European Conference on Artificial Life*. Heidelberg: Springer-Verlag, 2001.

[26] Jorge P. Simão and Peter M. Todd. Modeling mate choice in monogamous mating systems with courtship. *Journal of Adaptive Behavior*, 10(2), 2002.

[27] Donald Symons. *The Evolution of Human Sexuality*. New York: Oxford University Press, 1979.

[28] Randy Thornhill and Karl Grammer. The body and face of women: One ornament that signals quality? *Evolution and Human Behavior*, 108(3):105–120, 1999.

[29] Peter M. Todd and Francesco C. Billari. Population-wide marriage patterns produced by individual mate-search heuristics. In Francesco C. Billari and A. Prskawetz, editors, *Agent-Based computational demography*, pages 117–137. Berlin: Springer Verlag, 2003.

[30] Peter M. Todd and Geoffrey F. Miller. From pride and prejudice to persuasion: Satisficing in mate search. In Gerd Gigerenzer, Peter M. Todd, and the ABC Research Group, editors, *Simple Heuristics that Make Us Smart*, pages 287–308. New York: Oxford University Press, 1999.

[31] Glenn Weisfeld. *Evolutionary Principles of Human Adolescence*. New York: Basic Books/Wayne State University, 1999.