Adaptive Behavior

KAMA: A Temperature-Driven Model of Mate Choice Using Dynamic Partner Representations

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KAMA is a model of mate-choice based on a gradual, stochastic process of building up representations of potential partners through encounters and dating, ultimately leading to marriage. Individuals must attempt to find a suitable mate in a limited amount of time with only partial knowledge of the individuals in the pool of potential candidates. Individuals have multiple-valued character profiles, which describe a number of their characteristics (physical beauty, potential earning power, etc.), as well as preference profiles, that specify their degree of preference for those characteristics in members of the opposite sex. A process of encounters and dating allows individuals to gradually build up accurate representations of potential mates. Individuals each have a "temperature," which is the extent to which they are willing to continue exploring mate-space and which drives individual decision making. The individual-level mechanisms implemented in KAMA produce population-level data that qualitatively matches empirical data. Perhaps most significantly, our results suggest that differences in first-marriage ages and hazard-rate curves for men and women in the West may to a large extent be due to the Western dating practice whereby males ask women out and women then accept or refuse their offer.

Keywords mate choice · mate selection · sexual selection · computational temperature · mating strategies · emergence · mate-choice modeling · first-marriage age · first-marriage hazard rates · males-ask/females-decide · dating · marriage

1 Introduction

Marriage, at least in the West, is generally the culmination of a long process of searching for an appropriate mate. The process leading up to marriage is a complex one, requiring numerous encounters with members of the opposite sex, an initial selection of potentially compatible individuals, further contacts, possibly leading to dating, breaking off of relationships and beginning new ones—in short, exploring in breadth and in depth various avenues of the vast space of potential mates—until gradually two individuals settle into a stable relationship that leads to marriage.

We are interested in the mechanisms underlying mate selection. From an evolutionary point of view, the adaptive value of good mate-selection mechanisms is clear. The genes that code for mate-choice mechanisms that allow individuals to select high-quality mates are more likely to end up in offspring and, ultimately, propagate through a population than genes for bad mate-choice mechanisms, which, in the words

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of Miller and Todd (1998) "usually end up in fewer or lower-quality offspring, who take them to evolutionary oblivion."

In this article we develop a model of mate choice that is based on a gradual, stochastic process of building up representations of potential partners over time through encounters and dating, ultimately leading to marriage. Our model, KAMA, attempts to reproduce empirically verifiable population-level demographic trends based on mate-choice mechanisms implemented at the level of individuals in the population and involving the interplay of a number of simple, competing pressures and constraints. Specifically, individuals must attempt:

1. to find a suitable mate
2. to do so in a limited amount of time
3. to do so with only partial knowledge of the individuals in the pool of potential candidates.

Individuals, when they first enter the mating pool, do not have an accurate idea of the kinds of people already present in the pool and, crucially, do not know the kinds of individuals likely to agree to go out with—and, ultimately, marry—them. The process of encounters and dating allows them to gradually build up more accurate representations of individuals in that population.

In spite of these constraints on search time and information gathering, most individuals are generally able to find a mate. Although decisions involved in mate choice are highly personal, there are nonetheless constraints that all members of the population are subjected to, such as limited reproductive lifetime, social norms, and so forth. Demographic studies have shown that there are regularities across populations in the pattern of ages at which people first get married (e.g., Coale, 1971; Kreider & Fields, 2001; Eurostat, n.d.). We will attempt to show that a limited number of relatively simple mechanisms at the individual level are sufficient to enable individuals to find mates and, in so doing, generate realistic (i.e., similar to those found in the empirical literature) population-level behavior. This has been shown before in other models (e.g., Simão & Todd, 2003; Todd, Billari, & Simão, 2005), but in what follows, we develop a model of mate choice that differs with respect to current mate-choice models in the four major aspects listed here.

1. It incorporates "computational temperature" as a measure of the amount of energy willing to be devoted to finding a mate.
2. It uses, for each individual, a multi-dimensional vector of values for a variety of characteristics to describe an individual's mate value, rather than a single, overall mate value. Some of these values, in particular, those associated with wealth and beauty, evolve with the age of the individual.
3. It employs a fluid representational structure for a potential mate that evolves over time as new information about that person becomes available.
4. It uses subjective mate values, since mate value is largely, although certainly not completely, subjective ("beauty is in the eye of the beholder") incorporating empirical findings on male–female preference profiles for various characteristics found in their mates (Buss & Barnes, 1986).

Our motivation for these choices was two fold. First, and most importantly, we wanted to increase the power of the model by incorporating the above features. Using preference-weighted multi-dimensional mate values allows KAMA to make predictions about the potential effects of changes, not only in the values of individual features such as, attractiveness, wealth or being a good housekeeper, but also in the preferences people associate with these values (e.g., as women earn more, a decrease in the importance of wealth in a male partner). The use of temperature gives us a context-dependent means of modeling individuals' willingness to devote time, energy and resources to finding a mate. An individual's temperature, therefore, fluctuates depending on his/her age or involvement in a relationship. As a woman's biological clock is ticking longer and longer in the 21st century—a 66-year-old Romanian woman recently gave birth to a healthy baby girl!—it is reasonable to suppose that the shape that we have given to the temperature curve could well change. Our second motivation for developing the present model was that we wanted to develop a more behaviorally plausible model in which mate value is *subjective* ("beauty is in the eyes of the beholder") and in which the *manner* of dating in the Western world (i.e., males ask females out, females accept or refuse the males' offer) is taken into account. As we will show later in this article, simulating this men-ask/women-decide manner of Western dating allowed us to show that male–female marriage-age differences are, at least in part, simply a product of this Western dating practice.

2 Recent Human Mate-Choice Models

The recognition that sexual selection emerges as the combined effect of many low-level (i.e., individual) decision-making processes has led to the development of mate-choice models that incorporate individual strategies (Bergstrom & Real, 2000). Many of these mate-choice models involve non-human mate choice, undoubtedly due to the traditional focus on non-human animals in many early studies in evolutionary biology. In what follows, however, we will focus only on a small subset of human mate-choice models, with a particular emphasis on the family of models by Todd and colleagues (Simão & Todd, 2002, 2003; Todd et al., 2005; Todd & Miller, 1999).

One of the earliest mate-choice procedures was presented by Gale and Shapely (1962) in a paper provocatively entitled, "College admissions and the stability of marriage." They developed a simple, stable "match-making" algorithm for a population with an equal number of males and females. In their match-making procedure each individual begins by making an ordered preference list of all members of the opposite sex. Each male then asks the female at the top of his list to become "engaged." Each female who receives one or several proposals says yes to the male highest on her own preference list (who thereby becomes "engaged" to her) and rejects the others (who thus remain "unengaged"). Each unengaged male then removes from the top of his preference list the female who rejected him and the process is repeated. Each unengaged male asks the female now at the top of his list to become engaged. If a female who is already engaged gets a proposal from a male higher up on her preference list than her current partner, she rejects the latter (who then becomes "unengaged" and will then participate in the next round of proposals) and accepts the new male's engagement proposal. It is easy to prove that this procedure allows all males and females to pair up in a "stable" manner, which means that there will never be A–X and B–Y pairings for which Y is higher on A's preference list than X, while at the same time X is higher on B's preference list than Y. In a number of ways this algorithm resembles the KAMA model presented in the present article and, in particular, it implements the "beauty is in the eyes of the beholder" philosophy of KAMA in that each individual has his or her own preference list of the members of the opposite sex. The notion of temporary pairing and rejection of one's current partner if something more attractive comes along also resembles what happens in KAMA. The Gale–Shapely algorithm, however, requires perfect information by all members of the population of all members of the opposite sex, a highly unrealistic assumption. It is possible that the Gale–Shapely algorithm, appropriately modified to incorporate temperature and restricted preference lists that evolve based on encounters, would be a close cousin to KAMA.

An early human mate-choice simulation was done by Kalick and Hamilton (1986). The aim of their model was to resolve two conflicting findings in human mating behavior. According to studies in mate preferences, individuals tend to prefer individuals of the opposite sex that are highly physically attractive regardless of the individual's own physical attractiveness. On the other hand, it was found that there is a correlation in physical attractiveness among married couples (Kalick & Hamilton, 1986). Based on this, others theorized that people tend to prefer mates to whom they are physically similar. Kalick and Hamilton set up a social simulation where they used these two findings and managed to demonstrate that it was possible to achieve a high intra-couple physical-attractiveness correlation, even when individuals preferred the most attractive individual. The simulation revealed that, since high-value mates seek high-value mates as well, they accept only high-value mates and tend to leave the population early. Mid-quality individuals follow, with low-quality individuals taking the longest to find mates. Although their model has subsequently been criticized for the overly high number of dates for each individual and the low percentage of the population who got married (Aron, 1988; Simão & Todd, 2002, 2003; Todd et al., 2005), it was originally designed to resolve what was perceived to be a contradiction, and it was, indeed, able to show how this could be possible.

Todd and Miller (1999) proposed and tested a number of simple search heuristics in both one-sided search (i.e., search by either males or females in the population) and mutual search. In their model there is a learning period that corresponds to the adolescent period where the individual learns about its own mate value and the values of potential mates. They learn this through feedback from individuals (i.e., offers and rejections) whom they encounter in the population. They showed that the heuristics they tested could achieve satisfactory results while making use of very little information.

Recently a number of human mate-choice models have been developed by Simão, Todd, and colleagues (Simão & Todd, 2001, 2002, 2003; Todd et al., 2005). These models are based on realistic assumptions drawn from findings in psychology and have realistic outputs that have been validated against sociological and demographical findings. Some of them include a courtship period, thereby changing the mating decision from a single yes/no decision to a process in which the decision forms gradually over time. Each individual's aspiration level for various characteristics in potential mates is determined by a series of encounters. Simulation results were tested against empirical findings on intra-couple correlations, first-marriage age patterns and a sociological theory based on the effect of sex ratios to the rate of marrying.

An approach by Kenrick, Li, and Butner (2000) uses dynamic social influence networks as a means of propagating "influence" throughout a population. The population model that Kenrick et al. used represented individuals by their location and orientation with respect to their neighbors, a concept that we hope to implement in later versions of the present model. The perceived mate values of individuals by members of the opposite sex were able to change over time. Their model implemented the idea that males are inclined to take advantage of unrestricted relationships whereas females prefer restricted relationships and examined how males and females were affected by each other's mating options.

Finally, an animal mate-choice model by Luttbeg (1996) should be mentioned because of its structural similarity to our model. This model relaxes the assumptions of random encounter and perfect information during mate assessment. Females repeat visits to males and concentrate subsequent efforts on those males that earlier had appeared the most promising. This is reminiscent of some of the key mate-exploration mechanisms implemented in the present model.

This review is not meant to be exhaustive, but rather focuses on models that include some of the mechanisms that we have incorporated in our model. We wish to relax assumptions about unique mate value descriptors of individuals. Further, it is unimportant for individuals to assign a mate value to themselves and thus there is no learning period during which this occurs. There is no topology on the space of individuals and therefore any given individual is equally likely to encounter any other available person of the opposite sex. The notion of aspiration levels is largely incorporated in our temperature mechanism, and we have, like Luttbeg, relaxed the notion of perfect information transfer when two individuals meet.

3 The Need for a New Model of Mate Choice

The present model is an attempt to develop a more "fine-grained" model of mate choice than those that currently exist. KAMA does not use a single number to characterize an individual's mate value, but rather a number of real-valued characteristics (the "characteristic profile") that, together, constitute the individual's "inherent" mate value. Because mate value varies significantly depending on the beholder, however, each individual in the population has a "preference profile" that defines his or her degree of appreciation of each of the attributes in the characteristic profile of a potential mate.

Replacing a single mate value by a vector of values allows KAMA to simulate the population-level effects of the modification over time of particular characteristics of individuals. So, for example, the model can simulate the effect of both men and women becoming richer or becoming less attractive with age. It can also simulate the effect of changing preference values over time.

Computational temperature, the mechanism that drives the model, corresponds to the amount of energy that people put into encountering and dating potential mates (i.e., the higher the temperature, the greater the energy expended in mate-finding). For example, unmarried women approaching their mid thirties (i.e., the end of the period during which they can bear children) have more aggressive mate finding strategies (i.e., higher temperature) than younger women (Pawlowski & Dunbar, 1999) and men of the same age. We have modeled this by having somewhat different temperature curves for males and females.

By giving all males and females identical temperature curves as well as identical preference profiles, we were able to show, somewhat surprisingly, that the Western dating strategy of "males-ask/females-decide," by itself, produces a male–female first-marriage age shift in which older males marry younger females.

In addition, empirical data for various Western countries shows a significant change in first-marriage ages in the final quarter of the last century. Part of this change could be due to the documented decrease in societal pressure to marry early (Qu, 2003). In KAMA this decrease in pressure to marry early can be simulated by a lowering of the marriage temperature threshold, and when we do this, the model shows an overall lowering and rightward shift of first-marriage hazard rates, an effect that can be seen in data from Norway between 1978 and 1998.

4 KAMA: An Overview

In the following sections we will begin with a brief description and justification of the fundamental mechanisms of our model of mate choice. We will then proceed to a more detailed description of these processes.

4.1 Dating in the West, a Fundamental Asymmetry: Males-Ask/Females-Decide

Darwin (1859, 1871) observed that, in general, in nature males display themselves ostentatiously before a female in order to be chosen as her mate and the female makes the final mating decision. In our model, we implement a similar mate-choice asymmetry because this reflects a fundamental dating practice in Western society—namely, the male selects someone to ask out among a number of available alternatives (we call this a "parallel" decision process since he is considering a number of alternatives simultaneously); the female then accepts or declines his invitation immediately upon receiving it (we refer to this as a "serial" decision process since she must make a yes/no decision immediately for each individual who asks her out; she cannot accumulate offers and then choose one of them, which would constitute a parallel decision process). This necessarily implies that the female's "serial" strategy for accepting or refusing a date proposition is fundamentally different from the male's "parallel" strategy for deciding whom to ask out among a number of alternatives. We will show that this has a significant effect on the differences in male and female first-marriage hazard rates.

This distinction between "parallel" versus "serial" decision-making procedures is crucial to the present model. This difference engenders a fundamental asymmetry in the courtship process, one that has received little or no attention in the human mate-choice literature. One way that courtship symmetry could be established would be by allowing women to "accumulate" dating propositions and when she had a given number of offers, to choose among them. Or, alternatively, symmetry could be achieved by women asking men out. Later in this article we compare the standard asymmetric courtship procedure with the latter means of establishing courtship symmetry. This latter procedure is, in fact, what occurs in "speed dating" (Kurzban & Weeden, 2005).

4.2 Computational Temperature

The willingness to invest resources in the search for a mate is implemented in KAMA by a feedback-driven internal parameter called *temperature*. In the area of analogy making, Hofstadter (1984) proposed context-dependent computational temperature as a means of driving parallel search. Further development of this notion can be found in Mitchell (1993) and French (1995). One important difference in temperature as implemented in KAMA compared to its implementation in previous work on analogy making is that in the latter models it is a global parameter reflecting the quality of the structures (i.e., groups of similar objects, correspondences between objects, etc.) being built or discovered by the program when solving a particular analogy problem. In contrast, in KAMA each agent has its own temperature that regulates its behavior.

Temperature is a function of both an individual's recent dating history and his/her age (see Figure 3 below). The higher the temperature, the more willing an individual is to explore mate-space for a mate; the lower the temperature, the less willing he/she is to do so; this generally means that he/she is concentrating on one particular relationship, largely to the exclusion of others. When both individuals in a dating relationship have low enough temperatures, "marriage" occurs and they drop out of the mate pool.

Temperature is a measure of the energy (i.e., time, resources, physical effort, etc.) that one is willing to expend to find a partner. First, this affects the number of people that an individual encounters: an individual with high temperature will meet more people than one with a low temperature. It does more than that, however, as it also determines how choosy someone is in their selection of partners. This requires some explanation. We start by assuming that a person in a stable or semi-stable relationship will be less willing to expend considerable energy seeking a new partner as an unattached person. So, for an attached person to go out with someone new—thereby putting their current relationship at risk—will require the new potential mate to have a relatively higher mate value than for someone who was unattached. This means that a mate value in a woman that would be high enough for an unattached male to ask her out would be less likely to be high enough for a male in a relatively stable relationship. Similarly, a mate value in a male that would be high enough for an unattached woman to respond positively to a date offer would be less likely to be high enough for a woman in a relatively stable relationship. This corresponds, in effect, to shifting the perceived mate value of new potential mates downward if one is already in a stable relationship, upward if one is not. This is precisely the role that temperature plays in KAMA, which is why we say that it determines how "choosy" (Jennions & Petrie, 1997) a person is in their mate selection. The details of exactly how this works for males and females will be explained later in this article.

Thus, there are two separate, but related, functions to temperature, the first being related to the number of potential mates encountered and the other being related to how selective one is. It would seem, however, that the overarching principle that "temperature falls when you are in a stable relationship, goes up when you are not" means that, in general, as temperature falls, the number of encounters with intent to date will fall and, *at the same time*, it will take someone with a higher than normal mate value to entice the person away from his/her current, stable mate.

Finally, KAMA is a fundamentally *stochastic* model, meaning that essentially all choices are made probabilistically, on the basis of the individual's temperature. So, for example, if one potential mate has an overall mate value of 8, and another a mate value of 5, the first will not automatically be chosen. The latter will also have a chance—when temperature is high, essentially the same as that of the former individual—of being chosen.

4.3 A Run of the Program

Each run of the simulation starts with 600 individuals (300 males, 300 females) whose ages vary randomly between 18 and 48. Unmarried individuals who turn 49 are removed from the population and replaced with an 18-year-old of the same sex with default characteristic values. In addition, a number of individuals amounting to a small percentage of the total population are added to the population each "year." Each year has 52 "weeks" and the program stops after running for 60 years.

At the beginning of each week, half of the males encounter between one and three randomly chosen females. The higher the "temperature" of the male (see below), the greater will be the number of encounters. This is reminiscent of the "interaction capability" parameter in Simão and Todd (2003), whose value, like that of temperature, is related inversely to the level of involvement in the current relationship. During each encounter, both individuals exchange a limited amount of information with each other.

Both males and females maintain a list of all previously encountered individuals (similar to the "alternatives list" in Simão and Todd, 2003) and the values of their characteristics, updated with each new encounter. If a recently encountered female has a sufficiently high mate value, she will be put on his "short list" of potentially datable females. (The length of this list was set to five in the model.) He then considers which of the potentially datable females to ask out for a date. This probabilistic decision (see below) is based on his temperature-biased, preference-weighted perception of the mate value of each of the females on his list of potentially datable females. The female, who must either accept or refuse his offer essentially on the spot, makes her decision based on her own temperature-biased, preference-weighted evaluation of the proposing male's mate value, relative to that of other males she has recently dated (see below).

After acceptance or refusal of a date, the temperature of the individuals involved is updated. If the temperature of both the man and woman on a date falls below a (pre-set) threshold value, they marry and leave the population.

5 KAMA in Detail

Below are found the details of the mechanisms of the present mate-choice model.

5.1 Attractiveness

There is a saying in French that goes, “It is better to be young, rich, and in good health than old, poor, and sick.” The point is, of course, that in real life such clear-cut choices almost never exist and what makes adult life hard is having to weigh the relative importance of the various characteristics comprising a situation and then having to make decisions based on those weightings. Moreover, although there are central tendencies for the preference weightings of various characteristics across individuals (Buss & Barnes, 1986), there are also significant subjective differences among individuals (Widemo & Sæther, 1999). In other words, whereas no 20-year-old woman would prefer an old, poor, and sick man over a young, rich, and healthy one, individual women would not all give the same weightings to wealth, age and good health in men (Li & Kenrick, 2006). We believe that models of mate choice should reflect the subjective nature of attractiveness at the level of the individual. It is for this reason that we have given each individual in the population a “preference profile” that specifies his/her preference weighting for each of the characteristics of members of the opposite sex.

5.2 Mate Value: Characteristic Profiles and Preference Profiles

The usual means of quantifying attractiveness in the context of mate-choice is by mate value. The standard notion of mate value is that for each individual in the population there is some value, an aggregate value derived from the values of myriad individual characteristics, which designates how attractive as a potential mate he or she is to members of the opposite sex. The higher an individual’s mate value, the more likely he or she is to have reproductive success (Ellis, 1992). As normally modeled, an individual’s mate value at any given time is an absolute value. In other words, any individual in the population observing an individual with a mate value of V will perceive, objectively, a value of V for that person.

In the present model we have chosen to model mate value somewhat differently. First, in contrast to previous models we assume a multi-dimensional characterization of each individual in the population. There are 13 distinct attributes (plus age) that characterize each individual in the population and each of these attributes has a value. We call this set of 13 values, the individual’s *characteristic profile*. For each individual in the population the initial values of these attributes were drawn from a uniform distribution over the interval [–1, 1]. Two attributes vary with age. “Good earning capacity” increases linearly with age, with male’s increasing 30% faster than female’s. “Physical attractiveness” also decreases linearly with age at the same rate for males and females.

There is nothing unique about this number of characteristics. We chose it because it was the number of characteristics tested by Buss and Barnes (1986). Other authors have chosen somewhat different numbers and types of characteristics (e.g. Buston & Emlen, 2003 who used 10 characteristics from four evolutionarily relevant categories).

In addition to his or her characteristic profile, crucially, each individual also has a *preference profile* that specifies how much weight he or she attaches to each attribute in the character profile of a mate of the opposite sex. The fact that individuals have different preference profiles means that the perceived mate value of a given individual is not the same across all individuals in the population. An individual’s mate value varies according to the preference profile of the beholder. Simply put, while that tanned, square-jawed fisherman may be fabulously attractive to the women of his coastal village, the fact that he cannot read will make him far less appealing as a permanent mate to urban women in the glitterati-literati set. There are, of course, universal tendencies in what individuals prefer and in defining the individuals in our population, we have respected these central tendencies but have included the spread of values reported by Buss and Barnes (1986).

5.3 Determining Individual Preference Profiles

Buss and Barnes (1986) studied mate preferences in males and females. Their findings showed that, in spite of significant individual differences, there are certain overall trends in the characteristics that males and females valued. In a further study, Buss also claimed that preferences for at least 60% of these characteristics were universal (Buss, 1989). A recent review (Jennions & Petrie, 1997) concluded that these individual variations in mate preferences are common and could have major consequences for models of mate choice. It is largely for this reason that we decided that it was important for individuals to have, not only a set of values for these characteristics that defined each individual (their character profile), but also to have a corresponding set of weights (the preference profile) allowing them to determine, *according to their own set of preferences,* the mate value of potential mates.

We assume that the overall mate value of a potential mate is the preference-weighted sum of the values in the character profile of that potential mate. In other words, the mate value of a potential mate, Y, for an individual, X, is calculated by multiplying the weights making up X's preference profile with the associated values for the 13 values of Y's character profile and dividing by 13. Other weighting schemes are, of course, possible, among them, so-called non-compensatory heuristics, which involve choosing potential mates based on only a few attributes—a reasonable strategy, especially in cases where there are a large number of potential mates (Miller & Todd, 1998).

We translated Buss and Barnes's preference rankings into preference weights by normalizing all rankings (R_i) with respect to the highest ranking (R_{max}) and then scaling these values between 10 and 1, thus: $W_i = 10(1 - (R_i/R_{max}))$. (Note that this means that the lowest ranks have the highest weightings.) In creating the population of individuals for our simulations, each person's preference profile is drawn from the preference distributions shown in Table 1. (We made the assumption of a normal distribution about each mean, from which we draw values when creating individuals.) Further, each individual's character profile and preference profile were independent, which is almost certainly an over-simplification of what really occurs.

These preferences also seem to vary depending on the dating situation. Kurzban and Weeden (2005), for example, found that in "speed dating" situations where

Table 1 Preferences weightings for the characteristics in the characteristic profile (SD in parentheses). Men and women differ most on their ratings of "Physical attractiveness" and "Good earning capacity". These two characteristics evolve with an individuals age in KAMA.

Characteristic preferences	Male: mean value of weights	Female: mean value of weights	Differences in means $\mu_{men} - \mu_{women}$
Kindness and understanding	8.1 (2.0)	8.4 (1.2)	–0.3
Exciting personality	7.2 (2.0)	7.5 (1.8)	–0.3
Intelligent	7.1 (1.5)	7.4 (1.2)	–0.3
Physical attractiveness	6.9 (1.8)	5.2 (1.9)	+1.7
Good health	5.8 (1.8)	5.5 (2.0)	+0.3
Adaptability	5.6 (2.0)	5.6 (2.3)	0
Creativity	3.6 (2.2)	4.2 (2.6)	–0.6
Desire for children	3.8 (1.9)	3.2 (2.2)	+0.6
College graduate	2.8 (1.7)	3.9 (2.1)	–1.1
Good earning capacity	2.4 (1.7)	3.8 (2.0)	–1.4
Good heredity	2.5 (2.0)	2.1 (1.6)	+0.4
Good housekeeper	2.1 (1.76)	1.9 (1.6)	+0.2
Religious orientation	2.1 (2.72)	1.5 (2.4)	+0.6

individuals are given 3 minutes to make a mate selection judgment, physical attractiveness, as measured by body-mass index, is, for both men and women, the most important selection characteristic. In particular, education and evidence of good earning capacity are of considerably less importance to women in this situation. This recent procedure, however, is far removed from the age-old Western "males-ask/females-decide" courtship procedure. Significantly, in the speed-dating procedure, we will argue that the appearance of a decisional symmetry will have marked long-term results on first-marriage age hazard rates.

5.4 Representing Individuals in KAMA

In addition to their preference profiles and characteristic profiles, all individuals maintain a memory of all individuals they have previously encountered, along with the values of the characteristics of these individuals that they have discovered through encounters and dates with them. Males also maintain a short list of "potentially datable females," that is, females he has encountered with the highest mate values. Each time females are encountered, they have the possibility, if they have a high enough mate value, of being put on this "potentially datable females" list. He will choose one of these females to ask out. However, if the female refuses his offer, she is then removed from his "potentially datable females" list. This is the only chance he will get to go out that week. The precise length of this list is not of great importance, but the existence of this kind of short-list is required to ensure that (1) the male will choose someone to ask out "in parallel" among a number of females and (2) he will not have to choose over all females he has ever encountered.

Unlike males, females do not maintain a list of "potentially datable males." (Note: we discuss later in this article a symmetric courtship version of KAMA in which both males and females are free to ask members of the opposite sex out. In this case, women also maintain a list of "potentially datable males.") Rather, women keep track of their past dating experience with other males in the population that allows them to calculate the expected distribution of males likely to ask them out.

The thirteen defining characteristics of individuals are gradually revealed to others through meeting and dating. Thus, mate information (i.e., an individual's representations of other potential mates in the population) improves gradually over time as a function of the number of contacts between two individuals. In other words, at the outset a given individual, A, has only a default representation—a "stereotypical" representation—of any other individual, B. As A and B encounter each repeatedly, they gradually learn each other's characteristics and build up their respective representations of each other. In the current implementation of KAMA, only 20% of the values in a given characteristic profile are communicated on each encounter and on each date with an individual of the opposite sex. Until the value of a particular attribute is known through encounters with the potential mate, a default value is used. This gradual representation building is reminiscent of the idea of multiple sequential hurdles in mate assessment (Miller & Todd, 1998).

On any given week, half of the males, randomly chosen, will participate in the courtship ritual. Depending on each male's temperature, he will meet between one and three females and, depending on their mate values, he will include them (or not) on his list of potentially datable females. He will then ask out someone from that list. Encounters occur at random with replacement. Although it would be more plausible ultimately to have agents moving on a grid, so that the possibility of meeting someone close would be higher than meeting someone further away, this has currently not been implemented. On both encounters and dates an equal amount of partial information is exchanged. (Thus, an encounter that leads to a date means that twice as much information will be exchanged as in the case of an encounter without a follow-up date.) This is not necessarily new information, but simply 20% of the information of each individual's characteristic profile is exchanged. If the receiving individual already has this information from a previous encounter with that person, the old information is simply updated with the new. This is especially important for characteristics whose values change with time (e.g., wealth and attractiveness).

The characteristics whose values are chosen to be communicated are selected randomly from the characteristic profile. It would no doubt have been better, rather than to select these characteristics randomly, to have selected them based on an individual's preference weightings. In other words, if a female puts a great deal of weight in finding out about good earning capacity in her potential mate, one would expect her to seek out the value of that characteristic in her mate before seeking out, say, information concerning his religious orientation, to which she attaches much less importance. Further, one could take into account how long it takes to assess the various cues (i.e., observing that someone is highly attractive is instantaneous; learning how kind and understanding he/she is will take considerably longer). Subsequent instantiations of this model should add these two factors to the dynamic representation-building process.

In addition, it turns out that if full information is made available immediately (i.e., a single encounter reveals all of the information in a potential mate's characteristic profile), the overall correlation between mate values in married couples increases considerably (in some simulations, this can double, going from approximately 0.21 to 0.39). This is due to the fact that making information available only gradually means that a significant number of people agree to marry even though they still have only default values for some of the characteristics in the representation of their mate.

5.5 Strategies for Searching the Space of Potential Mates

Numerous types of search strategies have been proposed by both empirical and theoretical studies in general mate choice models (Jennions & Petrie, 1997). Below is their brief classification of these strategies.

1. Random mating: Accept the first mate encountered.
2. Fixed threshold: Sample sequentially and accept the first mate that exceeds a pre-set criterion.
3. A satisficing approach in which aspiration levels are set adaptively based on experience (Simon, 1957; Todd & Miller, 1999).
4. Sequential comparison: Sequentially compare mates until the most recently encountered is of lower quality than the previously encountered individual, then accept the previously encountered male.
5. Adaptive search: Sample until the value of the mate encountered is greater than the a priori value expected from continued searching. The adaptive search rule also factors in the cost associated with continued searching.
6. Pooled comparison ("Best-of-*N*"): Sample *N* males and then accept the male with the highest value for the preferred trait(s).
7. Optimal stopping rule: This rule is similar to tactic (5), but is more realistic in that the individuals do not know beforehand the distribution of quality of the potential mates, although individuals do know how many potential mates they will encounter.

In the present model, we combine temperature-biased "parallel" decision making by males and temperature-biased "serial" decision making by females. The former parallel mechanism has been previously used in the computer modeling of analogy making (French, 1995; Hofstadter & Fluid Analogies Research Group, 1995; Mitchell, 1993; Mitchell & Hofstadter, 1990).

5.6 Males' Parallel Decision-Making Process

The idea behind the parallel decision-making process used in this model is that of initially exploring a number of possibilities in parallel and gradually devoting more time and effort to those avenues that seem more promising. Thus in KAMA, many potential partners are initially encountered (high temperature) and, as more information about each of them becomes available through subsequent encounters and dates, the number of potential partners is gradually reduced to a small set of individuals (low temperature), and finally to one. This process of winnowing the search space, similar to the search strategy employed in the nonlinear sequential cue assessment model (Miller & Todd, 1998), continues until the most eligible candidate is found. This is also similar to Tversky's Elimination by Aspects (EBA) heuristic (Tversky, 1972) and Categorization by Elimination (CBE) heuristic (Berretty, Todd, & Blythe, 1997).

5.7 Females' Serial Decision-Making Process

Once a male has asked a particular female out, she must decide immediately whether or not to accept his offer. This requires a different decision strategy than the one employed by males. For a given request, she will adjust the mate value of the suitor upward or downward based on her temperature. For a given mate value, she will be more likely to accept if her temperature is high, less likely if her temperature is low.

5.8 The Western Dating Practice of "Males-Ask/Females-Decide"

The established Western custom whereby "males-ask/females-decide" can be implemented by the kind of male parallel search and female sequential real-time acceptance or refusal described earlier. There are other, non-Western mating rituals where the woman (or the woman's family) gathers up offers from numerous males and then chooses the most promising among them. This, after all, is what many animals do. For example, the female sage grouse will spend several days examining many males' courting displays before she chooses the male with whom she copulates (Gibson & Bradbury, 1987). Traditional Western dating, however, requires an immediate (or quasi-immediate) response by the female to a male's offer to go out, and this is the reason we have implemented two different decision strategies for males and females in KAMA.

The recent development in the West of speed dating (e.g., HurryDate as described in Kurzban & Weeden, 2005) breaks with this tradition. At a single large meeting, both men and women very rapidly encounter a number of members of the opposite sex. Individuals must decide after each encounter if they would (or would not) like to go out with the person they have just met. Alternately, they meet a number of individuals and then decide a few minutes later—after "looking at their notes"—whom they would like to go out with. Either way, this is a radical break with the traditional Western "males-ask/women-decide" dating ritual. The implications of this change are discussed in the Results section of this article.

5.9 Context-Dependent Computational Temperature

Selection strategies, whether parallel, in the case of males, or serial, in the case of females, are associated with a desire to continue searching for a potential mate. This desire to continue searching for a mate is implemented in our mate choice model by *context-dependent computational temperature*. Both Mitchell (1993) and French (1995) illustrate this mechanism with a dating metaphor, one which is particularly relevant to the present mate choice model. French (1995) explains context-dependent computational temperature as follows:

> One metaphor for temperature involves the amount of effort one is willing to expend looking for a mate. Consider the case of Joe, a typical college freshman, who arrives on campus without a girlfriend. Initially his "mate-finding" temperature is high: he expends an inordinate amount of energy looking for a girlfriend, going to parties and other social events designed explicitly to bring single people together. Then, once a small number of potential candidates have been found, the temperature drops a bit, and Joe concentrates on the smaller group of women. By the end of his sophomore year, the temperature has dropped significantly: his relationship with one of the women has become solid and he is no longer actively looking, although certainly if a woman comes along whom he finds very attractive, he may well attempt to initiate something with her, in spite of his relationship with his girlfriend. About that time, a graduating senior with broad shoulders and blue eyes sweeps Joe's girlfriend off her feet and, within the space of a month, Joe is without a girlfriend. The temperature then soars. Joe starts going to parties he wouldn't have dreamed of going to before. He makes conversation with women in his classes and even on the sidewalk, on the flimsiest of pretexts. He may even put an ad in the Personals column in the student newspaper. His attempts to meet women take on a much more random "look anywhere" character. The strategy eventually works and, as before, he meets someone and gradually settles into a relationship and, once again, the temperature drops. Finally, when the temperature is low enough, he and his girlfriend decide to get married and the dating game is over. (However, extramarital flirtation can still take place, potentially leading to...)

To avoid any confusion related to terminology, temperature in the context of our model is a characteristic associated with *individuals*, rather than an entire population. (By contrast, we generally do not speak of individual water molecules as having a temperature. It is a value associated with collections of water molecules, for example, in a cup of coffee or in a swimming pool.) Here, temperature corresponds to an individual's willingness to continue to explore the environment of potential mates. Temperature falls as two individuals see each other more often and get to know one another (i.e., the desire to continue to explore the space of other potential partners decreases) and increases with age and if one does not fall into a dating relationship.

Simão and Todd (2003) have developed a mechanism that is quite similar to our context-dependent computational temperature. In their model, as people become more involved in a relationship, the rate of meeting new people drops. If a relationship lasts for a long time, it is evaluated as one in which there has been considerable investment and, thus, before switching to a new partner, this investment is taken into consideration. There is also a time pressure to marry, as people get older they are less choosy, and so forth. In other words, their mechanism, like ours, depends on age and level of involvement in their current relationship and, unlike ours, also depends on their self-quality estimate, which is determined by previous acceptances/rejections.

Finally, our notion of computational temperature is related to the one used in simulated annealing (Kirkpatrick, Gelatt, & Vecchi, 1983), but it differs in at least one crucial aspect. In classic simulated annealing, temperature gradually falls according to a predetermined "annealing" schedule where the value of temperature falls monotonically with respect to the number of iterations of the program. By contrast, temperature in the present model depends on the individual's age and on feedback on the state of his/her present relationship with a potential mate and, as such, may rise and fall over time.

5.10 Decision Criteria for Date Proposal and Date Acceptance/Refusal

As we have said on numerous occasions, in KAMA, men ask women out and women accept or decline each offer immediately. This requires two very distinct strategies. Males choose from among a number of females and ask one of them out, whereas females reply "in real time" to a given proposition. The details of these two strategies are discussed below.

5.11 Asking for a Date (Males)

The male's decision to ask a particular female out is based on his subjective perception of her mate value (i.e., based on his own preference profile) and his current temperature. Individual females with higher subjective mate values have, in general, a higher probability of being chosen (unless the male's temperature is very high, in which case the choice is essentially a uniform random one). Temperature makes the process of choosing a female either more random or more discriminating. The stochastic decision process is as described here.

First the male considers the mate values of the females on his "potentially datable females" list. The probability that he will ask out $Female_i$ is calculated as follows:

$$P_i = \frac{(MV_i)^{1/T}}{\sum_{j=1}^{R} (MV_j)^{1/T}}$$

where P_i is the probability of his asking $Female_i$ out; MV_i is the mate value of $Female_i$; R is the number of females on his "potentially datable females" list; and T is the male's temperature. (Note all mate values are translated so that the lowest among them is 0.01 above 0. This ensures that all MV values in the calculation are positive.)

Once the selection probabilities are calculated for each female on the male's "potentially datable females" list, roulette-wheel selection is then used to select the one who will be asked out.

If the value of T is high (e.g., 3.0 to 4.0, which means "I don't care very much who I ask out"), then the probability of selection of any given female on his "potentially datable female" list is largely independent of her mate value. On the other hand, when the value of T is low (less than about 1.5, which means "In general, I want to have a high probability of asking out the woman with the highest mate value"), then the highest mate value, even if it is only slightly higher than the other values, will tend to dominate the other mate values and, if temperature is low enough, the female with this value will have a high, almost deterministic, probability of being chosen. Figure 1 gives an example of the operation of this temperature-driven stochastic selection mechanism.

5.12 Accepting/Rejecting a Date (Females)

A male has asked a particular female out. She must now decide whether or not to accept his offer. As we explained earlier, in keeping with traditional Western dating practices, we assume that she cannot postpone her reply and choose among many offers. She must say yes or no to the current offer. This requires a different decision-making procedure than the "parallel" (i.e., choice among many) procedure used by the male to decide whom to ask out. Her stochastic decision procedure is as described here.

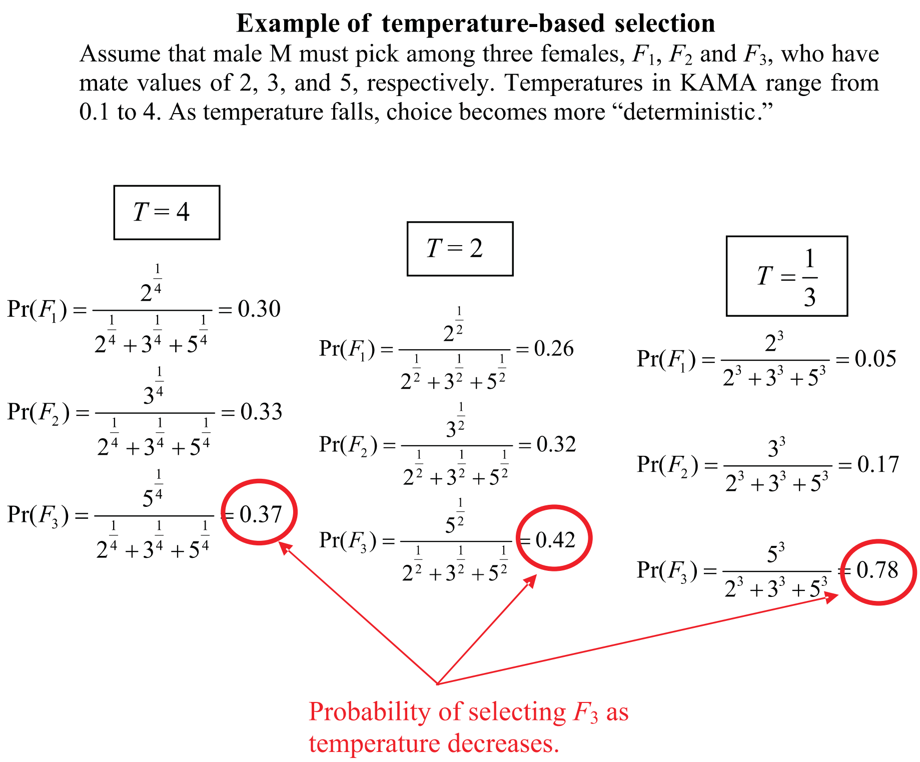

Figure 1 An example of temperature-based stochastic selection. When temperature is high, there is uniform random selection that is essentially independent of mate value. When temperature is low, the individual with the highest mate value, even if it is only somewhat higher than the other mate values, has a high probability of being selected.

She has a record of all of her past dates. The mean and variance of the (subjective) mate values of these dated males are used to calculate a normal distribution, which provides her with a rough estimate of the distribution of mate values of the kind of males likely to ask her out. (Note: she would not have to actually maintain a record of all past dates to get this mean and variance. She could simply maintain values for the overall mean and variance, updating them each time she goes out with someone.) This allows her to situate her new potential suitor with respect to males she has gone out with in the past. Thus, *where her new suitor's mate value falls on this normal curve will determine her probability of accepting a date with him*. The probability that she accepts is the area under the probability curve below where she places the mate value of her present suitor as shown in Figure 2.

For the female who has just been asked out, she calculates the mate value of the proposing male by first computing the inner product of her own preference-weight vector and his characteristic vector (filled in either with information that she has acquired in previous encounters/dates with him or default values). This value must now be adjusted on the basis of her current temperature. If her temperature is low (i.e., she is in a pretty stable relationship and the new suitor will have to be really special to get her to accept), she will adjust his *MV* to fall to the left of where it would normally fall, thus decreasing her probability of accepting his offer (Figure 2). If, on the other hand, her temperature is high, she will adjust her suitor's mate value upwards, thereby increasing the probability of accepting his offer.

There are myriad ways in which this temperature-driven increase/decrease in the suitor's mate value could be implemented. We adopted a very simple algorithm in which we simply added to the raw mate value of the male a constant times the log of the female's temperature:

$$MV_i^{\text{adjusted}} = MV_i^{\text{raw}} + k\log(T)$$

where: MV_i^{raw} is the unadjusted mate value of her suitor, $Male_i$; MV_i^{adjusted} is the adjusted mate value of

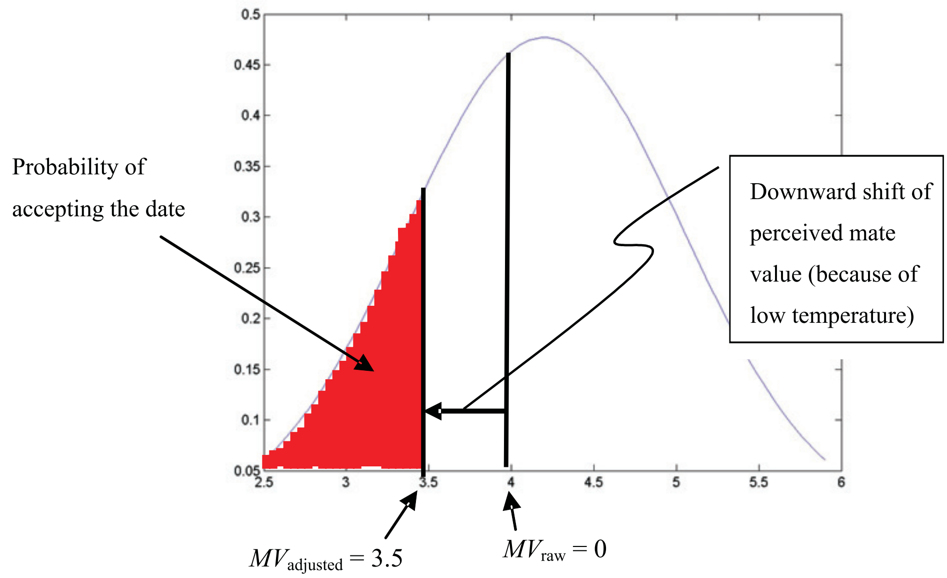

Figure 2 When the female's temperature is low (i.e., already in a relatively stable relationship), the perceived mate value of a potential suitor must be higher than normal for her to accept a date with him. This is implemented by shifting his raw mate value downward. (The probability of the female accepting the male is shown in red.)

her suitor, $Male_i$; T is the value of the temperature of female who has been asked out; and k is a constant (0.5 in the simulations reported below).

5.13 How Computational Temperature is Calculated

Each individual has a context-dependent computational temperature, corresponding to the amount of energy he or she is willing to put into finding a mate. Temperature (Figure 3) is determined by two factors, namely:

- age of the individual;
- length of current relationship (i.e., number of dates with the same individual).

For the first factor, age, in one's late teens and early twenties, there is a considerable expenditure in time and energy to meet members of the opposite sex (a fact that hardly needs documentation!). This then falls as one becomes involved in other pursuits, principally career pursuits, and then gradually rises again as one gets older and is still without a permanent mate. We further assume that there is a difference in this regard between men and women, because of the problem for women of their "ticking biological clock" that prevents them from conceiving children after a certain age. A woman's fertility begins to drop in her late twenties, and by the age of 40, the chance of ever becoming pregnant thereafter is less than 10% (Dunson, Colombo, & Baird, 2002). As a consequence, it is reasonable to assume that a less selective mate-choice strategy would be appropriate for (and adopted by) females from approximately 30 years of age until child conception is no longer possible. It is known (Pawlowski & Dunbar, 1999), for example, that women make increased efforts (that include, in particular, age deception) to meet men after age 35 years. Consequently, we have made the female temperature curve rise considerably more steeply between ages 30 and 42 years than in the equivalent curve for males.

For the second factor, the length of one's current relationship, we assume that one's willingness to expend energy exploring the space of potential mates also depends on the "stability" of the current relationship. The stability of a relationship between two individuals in KAMA is measured by the number of times they have gone out together. The more dates, the greater the stability of the relationship. Temperature,

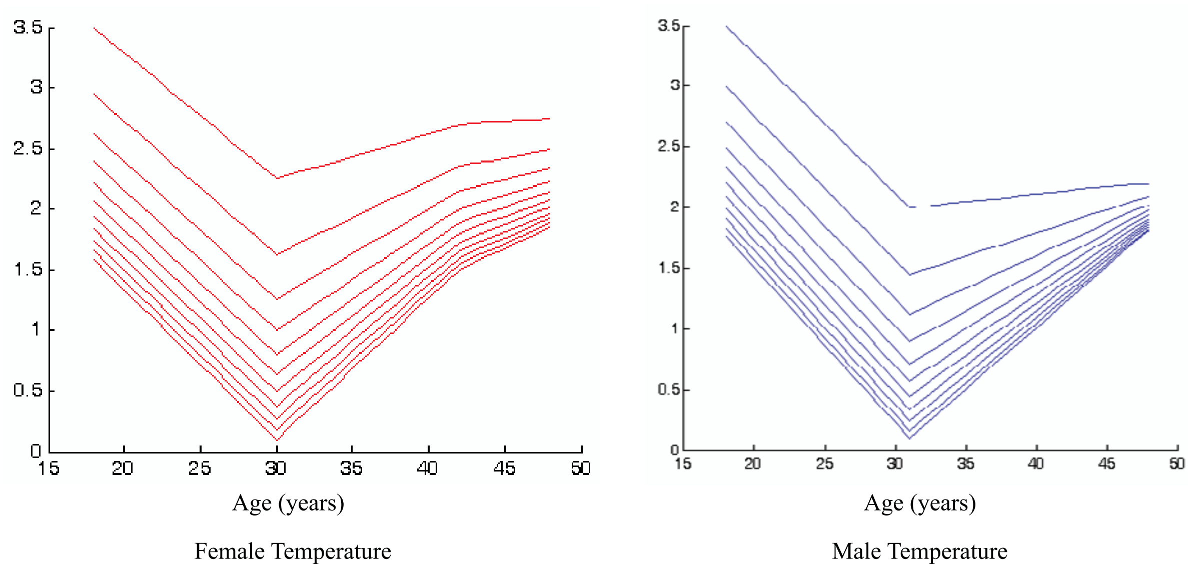

Figure 3 Temperature as a function of age and number of dates with the person involved in the encounter/date. Each successive curve represents a number of dates, starting with 0 dates for the highest curve, 1 date for the next curve, and so forth. Females' temperature (left) increases significantly between 30 and 42 years of age and falls more rapidly with number of dates at this age than for males.

therefore, decreases with each successive date with the same person. We made the amount of temperature decrease a logarithmic function of the number of dates. Our reasoning was that your temperature falls less on your 10th date with someone than it did when you fell madly in love with that person after your first and second dates.

We have summarized these observations and empirical data in the simple straight-line-segment temperature curves indicated in Figure 3.

6 Simulation Results

One of the goals of the present set of simulations is to show that the present model, based on stochastic choice mechanisms and changing representations can qualitatively reproduce population-level empirical data. To test KAMA, we drew on empirical data from Stat-Bank Norway (2005) and from Todd et al. (2005), which they derived from data from the Eurostat (n.d.) We have chosen these data because they were readily available and came from a country (Norway) that has traditional Western dating customs—in particular, the custom of men asking women out and women deciding whether or not to accept.

We have used a standard demographics statistic called the *hazard rate* to measure marriage rates for each age for during a given year. Marriage hazard rate is calculated such that for a particular year, the marriage hazard rate for a given age is the proportion of people of that age who married during that year.

6.1 Overall Marriage Rate

We created a combined male–female hazard-rate function for Norwegians in 1978 by averaging the hazard-rate curves for Norwegian men and women from 1978.[1] At that time, the average first-marriage age for Norwegians was 26.1. These data qualitatively match similar data for the USA for the same period (Kreider & Fields, 2001).

In the simulation results shown in Figure 4, the results were averaged over 20 runs of the program. The marriage temperature threshold was set at 1.15.

6.2 Male–Female Marriage Hazard-Rate Shift

When we look at the empirical data for Norway for males and females separately, we see a male–female shift in these curves (Figure 5). In the USA, for a population presumably similar to that of Norway (at least

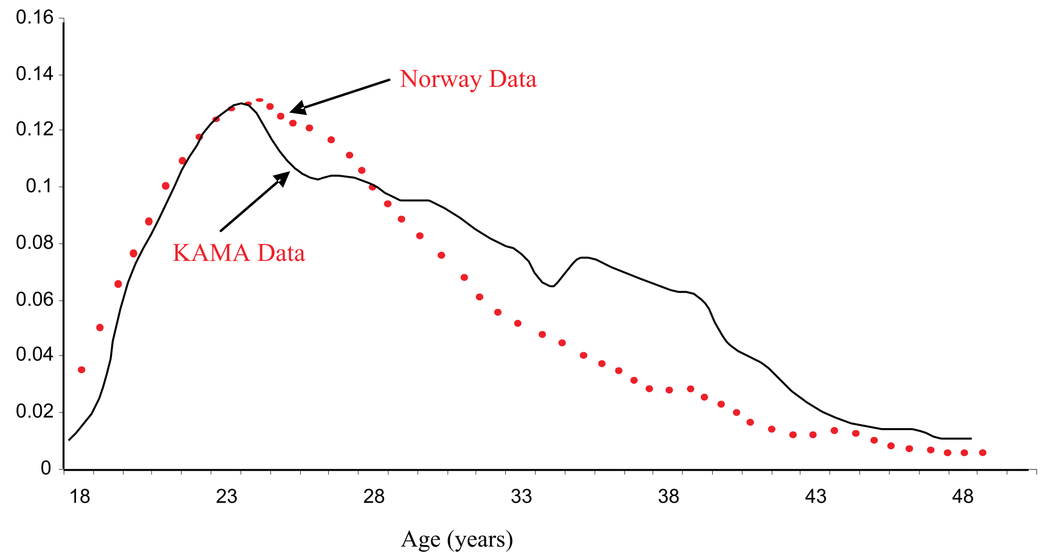

Figure 4 First-marriage hazard-rate marriage rates for Norway in 1978 and KAMA.

Figure 5 Initial rightward and downward shift of the hazard-rate curve for men (redrawn from Todd et al., 2005).

in terms of general socio-economic status and dating traditions), women when they first married were on average slightly more than 2 years younger than their husbands (Kreider & Fields, 2001).

Figure 6 shows that KAMA produced a similar rightward and downward displacement of the hazard-rate curve for men that is observed in the empirical data in Figure 5. This shift is due to at least two factors; namely, the Western courtship ritual in which men-ask/women-decide, which we will discuss at greater length below, and preference-profile asymmetries between males and females. In our model, physical attractiveness decreases with age and wealth increases for all individuals. The greatest preference-weight asymmetries between males and females are for physical attractiveness and wealth. On average, males' preference weighting for physical attractiveness is higher than the corresponding preference weight for females' and females' preference weighting for good earning capacity (i.e., wealth) is higher than men's (Table 1). This means that, on average, older men will marry younger women.

Figure 6 Marriage hazard-rate curves for men and women produced by KAMA. Note the downward and rightward shift of the hazard-rate curve for males.

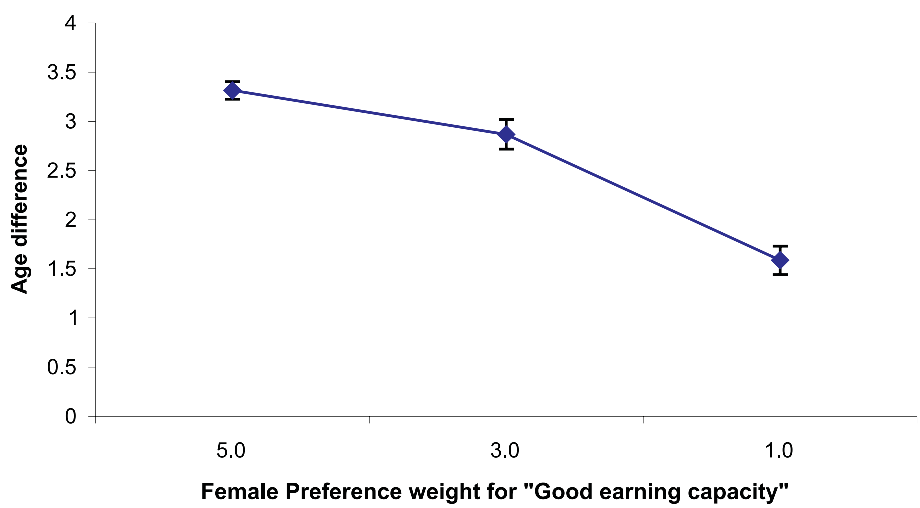

Figure 7 Lowering women's preference weight for "good earning capacity" results in a decrease in the male–female marriage-age difference. (Results averaged over 10 runs for each preference weight; standard error bars are shown.)

6.3 Male–Female Difference in First-Marriage Age

It is an empirical fact that men, in general, marry somewhat later than women. There are, no doubt, many factors involved in this marriage-age gap in Western society, but, as we said above, one is almost certainly related to the fact that women have a high preference for "good earning capacity" and that on average, older men are wealthier than younger men. When we manipulated women's average preference weighting for "good earning capacity" in a mate and kept all other preferences weights the same for both males and females, we found that decreasing the value of this preference weight resulted in a closing of the marriage-age gap. We fixed all preference weights for both males and females at 1.0 and varied the female preference weight for "good earning capacity" from 1.0 to 5.0. The results shown in Figure 7 show a decrease in the first-marriage age gap from 3.31 years when the female preference-weight for "good earning capacity" is high (5.0) to 1.59 years when that preference-weight drops to 1.0.

This result suggests that, all other things being equal, as women place less weight on wealth in a potential spouse, presumably because they have achieved a

Figure 8 The increased social acceptability of unmarried cohabitation produces a flattening of the marriage hazard-rate curve.

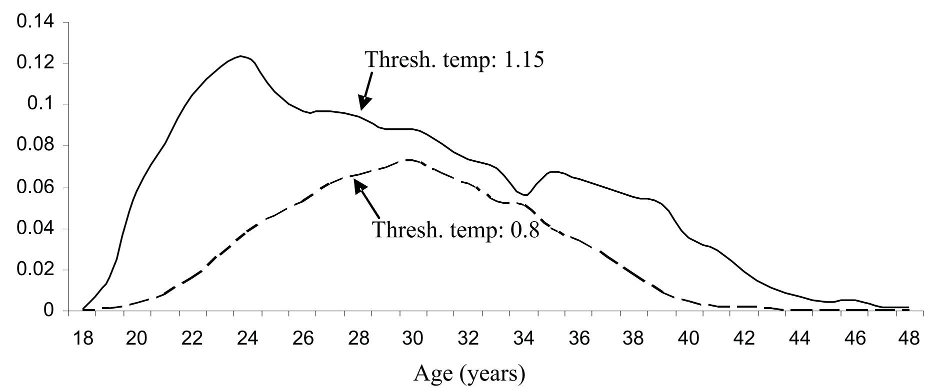

Figure 9 Flattening and rightward shift of the male marriage hazard-rate curve is achieved in KAMA by decreasing the marriage-threshold temperature.

certain measure of financial independence, the difference in first-marriage age will decrease. Empirically, this decrease in male–female first-marriage age gap has been observed both in the European Union, falling from 2.6 years at the beginning of the 1960s to 2.3 years in 1998 (ONC, 2003), and in the USA where, for the period from 1960 to 1989, the first-marriage age gap fell from 2.5 to 2.1 years (Kreider & Fields, 2001).

The point of this simulation is not only to show that by varying a particular preference weight, KAMA can qualitatively reproduce effects observed empirically, but, in a more general sense, to demonstrate the value of being able to manipulate changing preferences for individual characteristics, something which other current mate-choice models cannot do. In short, this is an argument for the use of multi-valued individual characteristic profiles and associated preference profiles to describe agents in mate-choice models.

6.4 Consequences of Decreased Pressure to Marry

Since the 1970s, in Western society, especially Northern Europe, North America, Australia, New Zealand, and so forth, the social stigma attached to unmarried couples living together has given way to a general acceptance of the practice. Numerous countries have even gone so far as to create a special category for

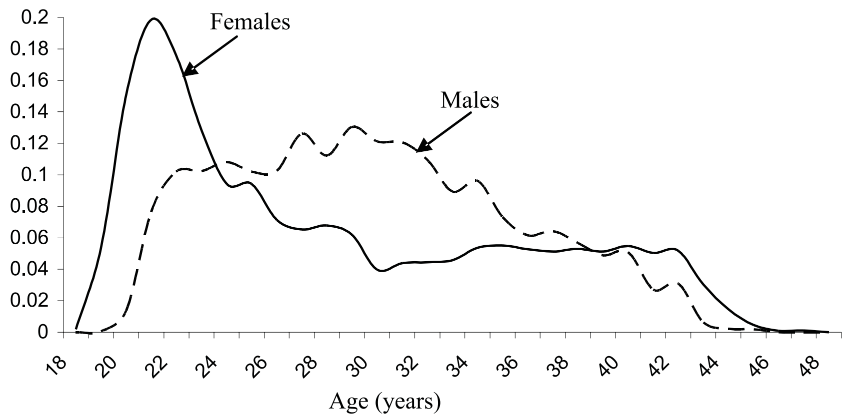

Figure 10 Marriage hazard-rate curves for males and females with no difference in preference profiles or temperature curves (averaged over 20 runs). The difference in average marrying age is approximately 1.00 year compared to 1.27 years in the standard case (Figure 5).

unmarried couples living together (e.g., "Paxé" in France, POSSLQ in the USA, etc.). Consequently, the age-old pressure, especially for women in Western society, to marry early has decreased. Empirical data (cf. Eurostat, n.d.) for Norway, for example, shows a flattening of the hazard-rate curve (Figure 8) and an overall increase in the age of first marriage.

In KAMA, decreased pressure to marry translates, in part, as an overall decrease in the marriage-threshold temperature. By lowering only the marriage-temperature threshold, we achieve (Figure 9) the empirically observed flattening and rightward shift of the curve. Average first-marriage age for males increases by 0.64 years and for females by 0.5 years.

6.5 Effect of the Males-Ask/Females-Decide Dating Custom on First-Marriage Hazard Rates and First-Marriage Ages

Perhaps the most surprising results to emerge from these simulations is that when males and females have identical preference profiles and identical temperature curves, we continue to see a marked male–female hazard-rate shift (Figure 10). In other words, the *only* difference between males and females is the asymmetry in the males-ask/females-decide custom. We must therefore conclude that this is at least partly responsible for the difference in the first-marriage hazard-rate curves for males and females. Without any of the other influences (e.g., differing preference weights for wealth, beauty, etc., different temperature curves, etc.), the average marriage-age gap is, as might be expected, somewhat smaller than in the standard condition, dropping from 1.27 years in the standard condition to 1.0 years when the only difference is the males-ask/females-decide custom. This general result was obtained for several different temperature curves, as long as the curves were identical for males and females.

To demonstrate that the shift observed in Figure 10 is due to the Western males-ask/females-decide dating, we ran the program in "symmetric courtship" mode, in which both males and females can ask each other out (parallel selection) and decide to accept or refuse a date offer (serial strategy). As above, all preferences weights were identical and male and female temperature curves were identical. As can be seen in Figure 11, in the symmetric courtship mode, the male and female hazard-rate curves become identical (Figure 11). We must conclude, therefore, that the difference in hazard-rate curves observed in Figure 10 is a result of the Western males-ask/females-decide dating custom.

Why does the fact that males ask women out and women accept or refuse lead to this difference in hazard rates? Let us begin by considering an 18-year-old woman entering the population. She will be asked out by men whose ages range from ages 18 to 48. Thus, if she agrees to go out with someone, the chances are very high that he will be older than her. In addition, and crucially, she will be unattached and wanting to kick off her social life, which means her temperature is high and she has few other mate value references (because she has not yet gone out with anyone, or has only gone out with a few males) with which to judge

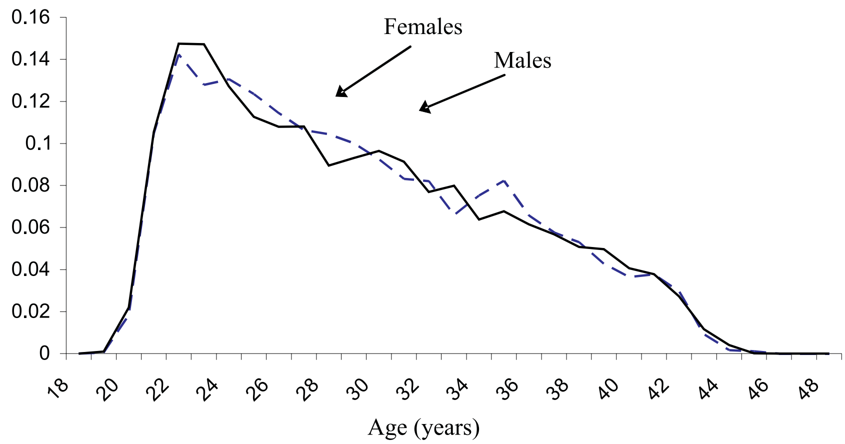

Figure 11 Male and female hazard-rate curves coincide when we have a symmetric courtship system in which both males and females can ask each other out. There is now no longer any significant difference in age of first marriage (averaged over 20 runs).

early male suitors. Consequently, she is very likely to accept early date offers and, most likely, the males she dates will be older than she is. Further, once she has started dating an older male, this gives him, on average, a head start on the competition, and there is a non-zero probability that she will end up marrying him.

But why doesn't the same reasoning apply to an 18-year-old *male* entering the population? To see this, consider an 18-year-old male entering the population. As encounters in KAMA are random, the chances are almost certain that his early encounters will be with females older than himself. These women will have, on average, lower temperatures than the 18-year-old females entering the population because a significant number of them *will already be dating someone*, in addition to the fact that generally their temperatures will, simply by dint of their age (Figure 3), be lower than those of 18-year-olds. It will therefore be somewhat less likely that an older female will accept a date offer from an 18-year-old male compared to an 18-year-old female accepting a date offer from an older male. This asymmetry is what produces the male–female first-marriage hazard-rate shift in Figure 10, and no doubt significantly contributes to it in real life. When women can ask men out, of course, this asymmetry disappears and, as shown in Figure 11, all other things being equal, the male–female hazard-rate shift disappears as well. Thus, in a society where women ask men out as often as men ask women out, one would expect the male–female first-marriage age gap to shrink and, our model would suggest, to shrink considerably.

6.6 Scaling Up

One issue with all agent-based simulations is whether, when the number of agents is increased to more realistic levels, the model will continue to function and that, in particular, problems of combinatorial explosion will not result. To this end, we tested the model on populations ranging in size from 500 to 2000 individuals. In all cases, the curves produced were essentially identical.

6.7 Sensitivity to Changes in the Temperature Curves

We ran numerous simulations to determine the sensitivity of the results to changes in the temperature curves for males and females. We tested temperature curves that started with temperature high, decreasing with age and number of dates with the same person. Figure 12 shows male and female temperature curves that differ markedly from those in Figure 3.

Figure 13 shows a male–female average hazard-rate curve comparable to the one in Figure 4 but derived from the temperature curves in Figure 12.

It can be seen that, while the curve does not match empirical data as well as the curve produced by KAMA in Figure 4, the overall form is still correct, with a fast rise in the early twenties and a gradual fall-off for older individuals.

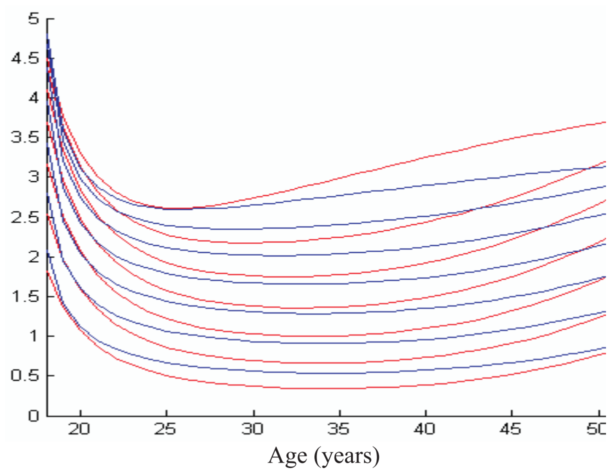

Figure 12 A different choice of temperature curves.

We also used more complex curves that were a smooth, highly parameterizable version of the simple multiple straight-line curves that were used. The temperature curves in Figure 14 also produce a hazard-rate curve that is qualitatively similar to empirical data (Figure 15).

We also tested the model using the simplest possible "reasonable" temperature curve which, for zero dates, is a straight line from a maximum of 3.5 at 18 years of age to a minimum of 2.0 at 48 years old. For each date with the same person (at any age), temperature fell by 0.2 degrees. Figure 16 shows that we still get a hazard-rate curve that, even though it peaks too early, rises about 50% too high and whose tail does not drop far enough, is, nonetheless, qualitatively accurate in its overall form.

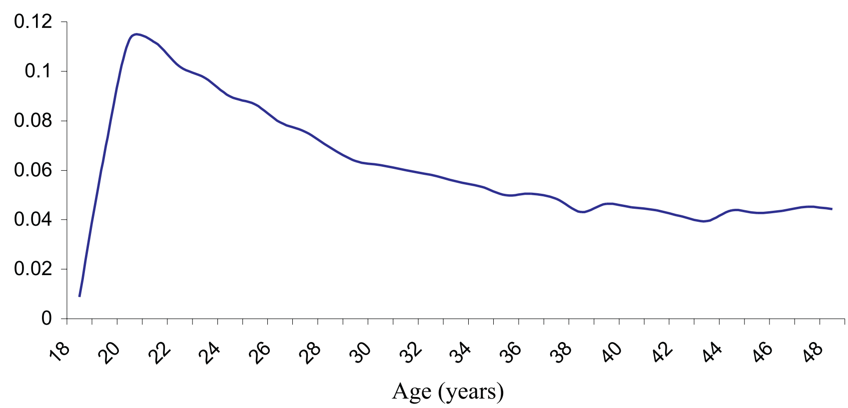

Figure 13 Average hazard-rate curve with the temperature functions used in Figure 12.

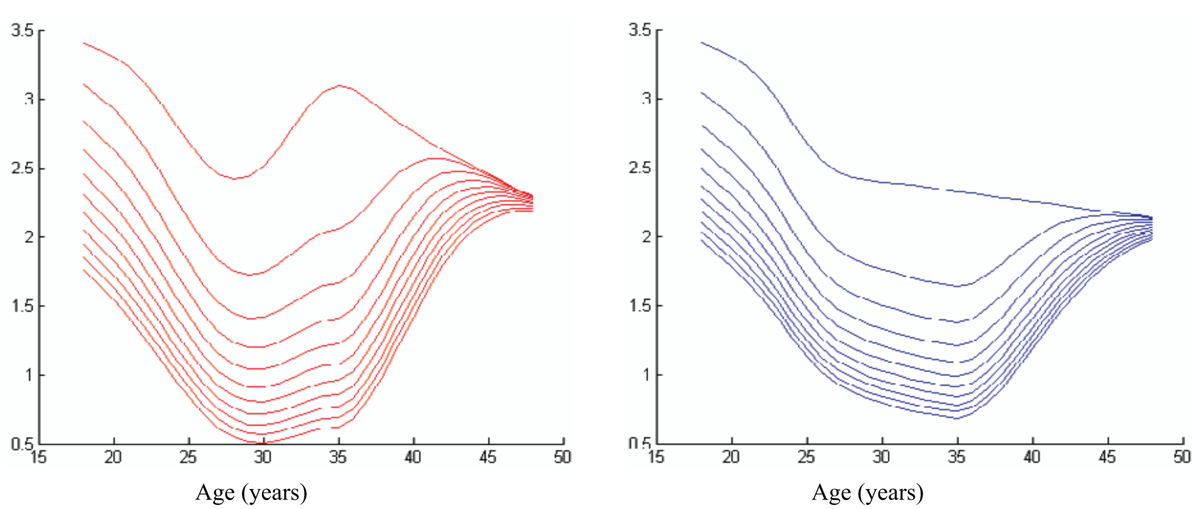

Figure 14 More complex male (left) and male (right) temperature curves.

Figure 15 Overall hazard-rate curve corresponding to the temperature curves in Figure 14.

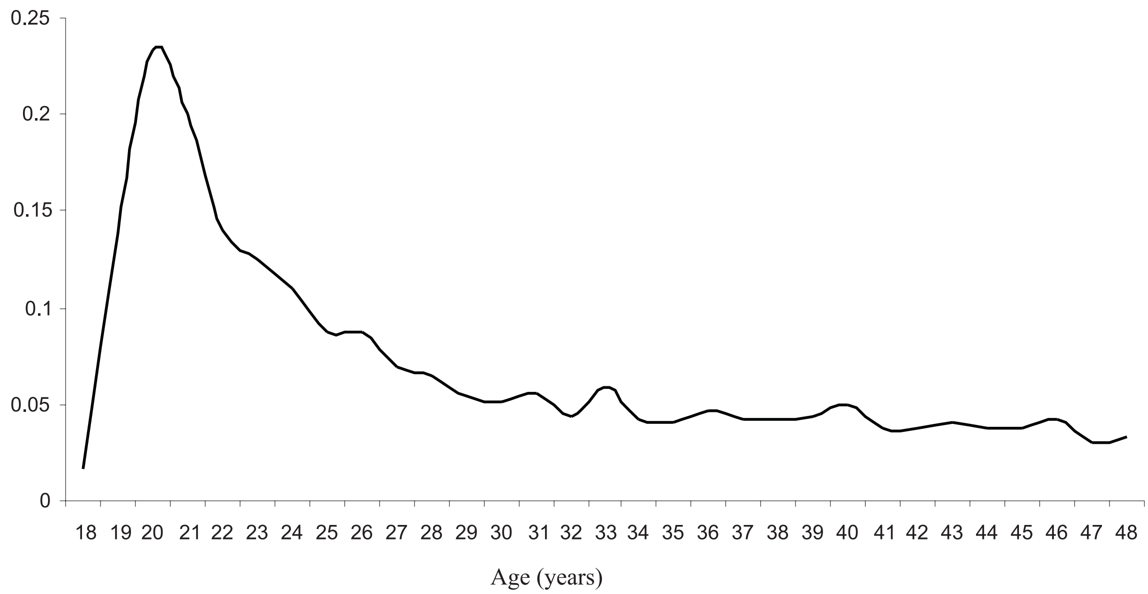

Figure 16 Overall first-marriage hazard-rate curve with a linear monotonically decreasing temperature function, identical for males and females.

7 Conclusions

In this article we have presented a mate-choice model, KAMA, that incorporates a number of novel features. The model uses multi-valued characteristic profiles to describe agents instead of a single mate value and introduces the idea that agents have individualized preferences for these characteristics when evaluating the mate value of agents of the opposite sex. In other words, the notion of an intrinsic, same-for-all-observers mate value has been replaced by a subjective, beauty-is-in-the-eye-of-the-beholder mate value. In this way, the same individual will have a somewhat different mate value depending on who is observing him or her. Further, individuals do not gain access to information about potential mates all at once, as in many other models, but, rather, gradually, over the course of numerous contacts and dates. Finally, the model is driven by computational temperature, which controls the focus of decision making. At high temperatures decision making has an almost random character; at low temperatures it is far more focused.

We believe that the added complexity of this model is justfied, not only by the increased psychological validity associated with multi-dimensional mate values, preference profiles, and computational temperature, but, most importantly, by the additional power that this gives the model to explore mate choice in the face of changing societal conditions, such as, changing female preferences for male wealth in a society where women have greater financial independence, changes in the male preferences for female beauty in a less sexist society, or simply changing Western dating practices (e.g., speed dating, women asking men out). In addition, the present model incorporates the key mechanism of temperature that is designed to simulate the energy people are willing to expend to seek out a partner, something that changes with age and relation satisfaction. This mechanism provides, inter alia, a simple way to model Western society's decreased pressure to marry.

Some possible directions in which this work could be taken include imposing a geographical topology on mate space and a "movement cost" on individuals. We believe that this would lead to the emergence of geographical clusters of like individuals. Further, in the current model, during the encounters and dates, the characteristics of individuals whose values are exchanged are randomly chosen. Instead, the values of characteristics should be gathered in the order of their importance to the gatherer. Further, some characteristics require different times to assess. Physical beauty, for example, can be perceived immediately, whereas assessing personality requires weeks (Miller & Todd, 1998). This, too, could and should be modeled in later versions of KAMA.

At the moment preference profiles and characteristic profiles are independently assigned in KAMA. However, in real life a person's defining characteristics and preferences are certainly not independent. For example, if you are hard working, tidy and educated, it is likely that you will prefer a mate who is also hard working, tidy and educated. In later versions of this program, this alignment of an individual's personal characteristics and preferences could be implemented.

It would also be interesting to explore the effect of adding domain general mechanisms, such as computational temperature, to existing algorithms for mate selection, notably to variants of the Gale–Shapely algorithm (Gale & Shapely, 1962).

In short, all of these extensions would be relatively easy to implement in KAMA and, most importantly, would not require recasting the entire architecture.

In summary, the modest and preliminary results presented in this article seem to show that a model constructed with individual-level mechanisms similar to those described here is capable of accurately reproducing empirical population-level marriage-rate data. We believe that the underlying structure of this model will allow relatively straightforward development of more sophisticated versions of the model that will allow it to explore a much wider range of questions, including those involving changing selection strategies, geographical and sociological constraints on the pool of potential mates, and so on.

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Notes

1 The exact weighted average of male and female hazard rates and the simple average values [i.e., $h_n = (m_n + f_n)/2$] have a correlation in excess of 0.99. We have therefore simply used the standard average for the Norway Data curve in Figure 4.

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