An Evolutionary Model for Household Interactions in Daily Activity Scheduling

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ABSTRACT

Household members interact in many ways during their daily activity and travel related decision-making. Individuals undertake both independent and joint activities and travel as part of their overall daily activity-travel patterns. The joint activity pursuits are often motivated by social factors such as desire for companionship and altruism (i.e., enabling activity participation of the mobility-constrained), or by resource constraints (i.e., limited vehicle availability). Undertaking joint activities with household and/or non-household members introduces strong linkages among the activity-travel patterns of the individuals involved. Consequently, the activity-travel patterns of all household members become inter-dependent. As a result during the past few years, there have been a significant number of studies aimed accommodate household interactions in daily activity and travel models. In this paper, we develop a more comprehensive theory and model of household interactions. We propose a strategic negotiation model that takes into account the passage of time during the negotiation process itself in order to solve the problem of task allocation and coordination for joint participation between members of the household. The model considers situations characterized by complete information. Using this negotiation mechanism the individuals have simple and stable negotiation strategies that result in efficient agreements without delays. We propose that the individuals decide on a mechanism that will find an agreement that must, at the very least, give each individual his/her conflict utility and under, these constraints maximize some social-welfare criterion. Further, we demonstrate the proposed negotiation mechanism by a system for bilateral negotiations in which artificial agents are generated by an evolutionary algorithm (EA). In this adaptive system, each negotiating agent maintains a collection of strategies which is optimized by an evolutionary algorithm (EA). The proposed evolutionary system relaxed the perfect rationality assumption that has been under criticism by researchers. The agents in these simulations are not assumed to be completely rational, but rather they learn by doing, and adjust their negotiation strategies. Such evolutionary agents learn in different ways: by selection and reproduction of successful strategies, and by random experimentation (by “mutating” existing strategies) or by recombining or “crossing over” previously-tested strategies.

Keywords: Household Interactions, Negotiation model, evolutionary algorithms

INTRODUCTION

In this paper, we develop a more comprehensive theory and model of household interactions. We model the household decision making as a sequential negotiation process [1]. The result of this negotiation process is coordination between household members for joint activity participation and task allocation between household members. We consider situations when household members need to reach an agreement on a given start time for to be allocated for a certain activity. We propose a negotiation mechanism that the household members may use solving the allocation problem.

Negotiation is a means for individuals to compromise to reach mutually beneficial agreements [2, 3, 4, and 5] in such situations, individuals have a common interest to cooperate, but have conflicting interests over exactly how to cooperate. Put differently, individuals can mutually benefit from reaching agreement on an outcome from a set of possible outcomes, but have conflicting interests over the set of outcomes. In this context, the main problem that confronts individuals is to decide how to cooperate before they actually enact the cooperation and obtain the associated benefits. On the one hand, each individual would like to reach some agreement rather than disagree and not reach any agreement. But, on the other hand, each individual would like to reach an agreement that is as favourable to it as possible.

In this contribution, we are presenting a strategic-negotiation model that the household heads may use in their daily activity planning. The proposed model extends the Rubinstein [6] basic model in the following three main components as follows: 1) The negotiation protocol; 2) The negotiation strategies; 3); and The negotiation equilibrium.

As for The protocol, we specify the rules of encounter between the negotiation participants. That is, we define the circumstances under which the interaction between individuals takes place, what deals can be made and what sequences of offers are allowed. In general, individuals must reach agreement on the negotiation protocol to use before negotiation proper begins.

The individual's negotiation strategy is a specification of the sequence of actions (usually offers or responses) the individual plans to make during negotiation. There will usually be many strategies that are compatible with a particular protocol, each of which may produce a different outcome. For example, an individual could concede in the first round or bargain very hard throughout negotiation until its timeout is reached. It follows that the negotiation strategy that an individual employs is crucial with respect to the outcome of negotiation. It should also be clear that the strategies which perform well with certain protocols will not necessarily do so with others. The choice of a strategy to use is thus a function not just of the specifics of the negotiation scenario, but also the protocol in use. In this contribution we present a range of Negotiation strategies that is behaviourally sound that individuals may use to reach an agreement.

A negotiation mechanism consists of a negotiation protocol together with the negotiation strategies for the individuals involved. A negotiation mechanism has to be stable (i.e., strategy profile must constitute an equilibrium), the earliest concept of which was the Nash equilibrium for games of simultaneous offers [7]. Two strategies are in Nash equilibrium if each individual's strategy is a best response to opponent's strategy. For sequential offer protocols, the Nash equilibrium concept was strengthened in several ways by requiring that the strategies stay in equilibrium at every step of the game [8]. In summary, rationality, as understood in game theory, requires that each individual will select an equilibrium strategy when choosing independently. In contrast, research in experimental economics [9] suggests that the perfect rationality assumption does not apply in human settings. Such individuals are said to be boundedly rational. In this paper we consider the setting where individuals are adaptive, and learn effective bargaining policies by trial and error. We apply learning techniques from the field of artificial intelligence, specifically evolutionary algorithms [10, 11] to model the adaptive nature of bargaining agents in practical settings.

It should be noted that, however, we limit our analysis to the negotiation between two heads of the household over a possible start time for an activity; the proposed solution could be extended to accommodate other facets of household interactions in daily activity scheduling models (e.g., location of the activity, transportation mode to travel between activity locations). In particular, we assume that household members in their negotiation they first negotiate on a possible start time allocation (Hence, the tasks allocation and joint activity coordination are determined), then they negotiate over other facets of activity participation e.g., location of the activity, transportation mode to travel between activity locations). It should be mentioned that the proposed negotiation mechanism assumes that, because individuals are boundedly rational, they don't negotiate on all the relevant attributes (i.e., timing, location, transport mode) of the activity simultaneously. Rather, it assumes that the negotiation process is a hierarchical process in which individual first negotiate on timing of the activity, and then they negotiate on activity location, travel mode to use and so on. The current study is focused on the household negotiation on activity timing (that result in joint participation and or tasks allocation).

The paper is organized as follows. Next section conceptualizes the problem of household bargaining. Further, it develops a theory of strategic negotiation process consists of a protocol for the individuals interactions, the utility functions of the individuals, and the individual's strategies. We first assess the efficiency of the agreements reached by the individuals. We then analyze to what extent the agreement outcomes are fair. The following Section presents the household negotiation kernel agent with the evolutionary model. Final section concludes this paper.

THE NEGOTIATION MODEL

The Household Negotiation Problem

We assume that the household is the fundamental level on which activity agenda generation and scheduling decisions are made. Further, we limit our conceptualization to couple households with or without children. Let $i = \{\mathrm{m}, \mathrm{f}\}$ be an index for male and female heads of a given household h . We assume that households are faced with a set of flexible out-of-home activities (a_n) that they wish to accomplish during a given day. Flexible means that the start and duration of the activity is not completely fixed on the day of performance of the activity. Let $A_h = \{a_1, a_2, a_3, ..., a_n\}$ denotes a given household activity agenda. Each activity (a_n) in the household agenda is characterized by activity priority (e.g. high, medium, low), earliest and latest possible start time, $t^{s-}(a)$, $t^{s+}(a)$, the earliest and latest possible end time $t^{f-}(a)$, $t^{f+}(a)$ and minimum and maximum duration $d^-(a)$, $d^+(a)$. Further, let $T_I = (T_m, T_f)$ denotes the total time budget individual i has on a given day after subtracting the time for fixed activities. Hence, for each activity $a \in A_h$ to be scheduled by the household *h,* let $W^i_{a,n} = \{W^i_{a,1}, W^i_{a,2}, W^i_{a,3}, ..., W^i_{a,n}\}$ be the set of available time windows that could be allocated to the activity a . The two household members (m) and (f), negotiate over a possible window $w_{n,i} \in W_i$ which is characterized by start times t^s to be allocated to a given activity $a \in A^h$. let $S = \{s_1, s_2, s_3, \ldots s_n\},$ be the set of possible agreements (i.e., possible start times for the activity). Further, let $U^i(S): S \rightarrow \mathrm{R}$ is individual i's utility defined over the set of all possible agreements S . We also assume that there is a special agreement δ^- which is the agreement of disagreement (Note that: from here on we denote δ^- as the conflict agreement). Without loss of generality we will assume that for all individuals $i = \{\mathrm{m}, \mathrm{f}\}$ $u^i(\delta^-) = 0$ so that individuals will prefer to reach an agreement rather than reach a conflict agreement. The problem then is to find a negotiation protocol which will lead the individuals to the best agreement. The next section describes the proposed negotiation protocol, followed by sections describing the mathematical formulations of the components of the proposed model.

The negotiation protocol

Here we extend what is basically an alternating offers protocol [*1, 12, and 13*] to model household decision making process in allocating a feasible time window for an activity. In our strategic model there are two individuals, $i = \{\mathrm{m}, \mathrm{f}\}$.The individuals need to reach an agreement to choose time window $w_{n,i} \in W_i$. The set of possible agreements (allocations) is called *S*. an outcome of the negotiation may be that an agreement $s \in S$ will be reached at time $t \in T$. The bargaining procedure is as follows (Figure 1). The individuals can take actions in the negotiation only at certain times in the set $T = \{0,1,2,\ldots\}$. In each period $t \in T$ one of the individuals, say m , will suggest a possible agreement $s^t_{m \rightarrow f}$, and the other individual f rates the offer using her utility function U^{f} . If the value of U^{f} for $s^t_{m \rightarrow f}$ at time t is greater than the value of the counter-offer individual f is ready to send in the next time period $t+1$, i.e., $U^{\mathrm{f}}(s^t_{m \rightarrow \mathrm{f}}, t) \geq U^{\mathrm{f}}(s^{t+1}_{\mathrm{f} \rightarrow m}, t+1)$, then individual f accepts the offer at time t and the negotiation ends successfully in an agreement. Otherwise a counter-offer is made in the next time period, $t+1$. Thus the action, A^{f} that individual f takes in time t in response to the offer $s^t_{m \rightarrow f}$, is defined as:

$$A^{\mathrm{f}}(t, s^t_{m \rightarrow f}) = \begin{cases} \text{Opt-out} & \text{if } U^f(s^t_{m \rightarrow f}, t) \leq U^f(\delta^-), \\ \text{Accept} & \text{if } U^f(s^t_{m \rightarrow f}, t) \geq U^f(s^{t+1}_{f \rightarrow m}, t+1), \\ \text{Offer } s^{t+1}_{f \rightarrow m} \text{ at } t+1 & \text{otherwise.} \end{cases}$$

The negotiation can end in one of two ways. We have a conflict at step t if $\forall i \in \{\mathrm{m}, \mathrm{f}\}, U^i(s^t_{j \rightarrow i}, t) \leq U^i(\delta^-), i \neq j and j \in \{\mathrm{m}, \mathrm{f}\}$, where δ^- is the conflict agreement. In which case the negotiation ends (opt-out) and the conflict agreement is implemented. The outcome of the negotiation in this case is (δ^-, t). We have an agreement at t if

$\forall i \in \{m, f\}, U^i(s^t_{j\to i}, t) \geq U^i(s^{t+1}_{j\to i}, t+1), i \neq j and j \in \{m, f\}$. This outcome is denoted by a pair (s, t).

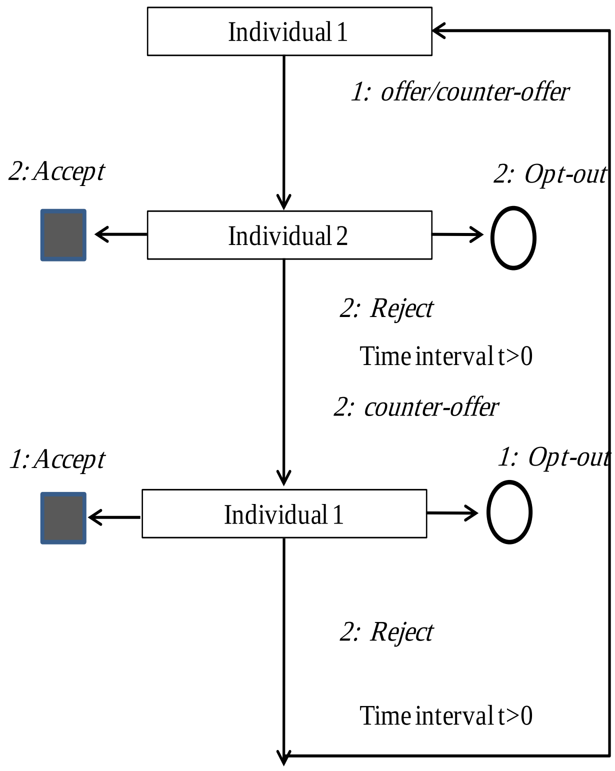

Figure 1-Negotiation procedures

Individuals' utilities are defined with the following two utility functions that accounts the effect of time discounting, $U^i : (S \times T) \cup \{\delta^-\} \to R$

$$U^i(s,t) = U^i_S(s) U^i_t(t)$$

The nature of the utility function depends on the specific domain of the negotiation and the time spent on the negotiation. Specification of $U^i_t(t)$ is given in the following section.

Effect on negotiation time in the utility function

Following [*1*], we assume that individuals are impatient with the unproductive passage of time. That is, the individuals' utility for all possible agreements is reduced as time passes. Thus the utility function of an agreement depends on the details of the agreement and on its time. In particular, the utility functions of the individuals belong to the following category.

$$U^i(s,t) = \lambda^t_i U^i_S(s,0)\text{, where } 0 < \lambda_i < 1$$

In the case of time constant discount rate each individual has a fixed discount rate $0 < \lambda_i < 1$. Figure 2 illustrates the utility discount rate at various stages of the negotiation rounds.

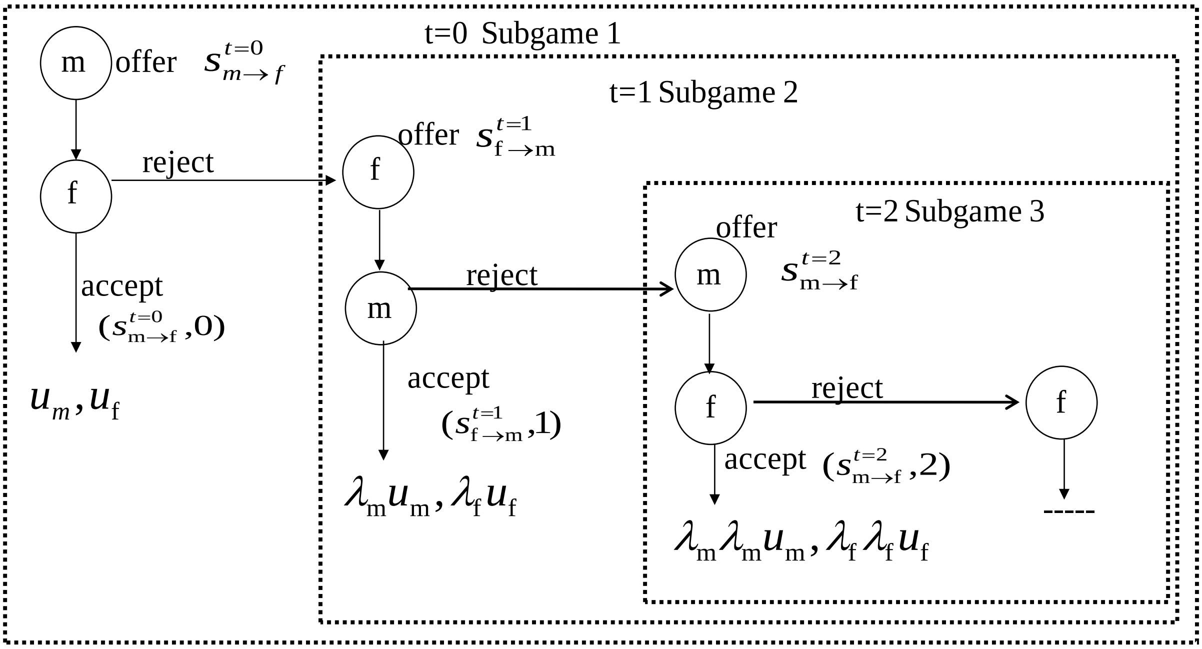

Figure 2- The Utility Discount Factor at Different Stages of the Negotiation

Properties of the utility function

The individuals' *negotiation time preferences* and the preferences between agreements and opting out are the driving force of the model. They will influence the outcome of the negotiation. In particular, individuals will not reach an agreement that is not as good as the conflicting agreement (opting out) for all of them, the individual that prefers opting out over the agreement will opt out.

In the following we assume that both individuals prefer to reach a given agreement sooner rather than later, whenever the utility derived by the individual from this agreement in the first time period of the negotiation is non-negative. We also assume that the utility derived from the conflict agreement δ^- decreases over time. Finally we assume that the relation between the utilities of two offers that yield positive utility at time 0 is independent of time. This trait is important for the negotiation process.

For every $t_1, t_2 \in T$, $i \in \{\mathrm{m}, \mathrm{f}\}$ and $s_1, s_2 \in S$ the following hold:

1) Agreements over time: if $U^i(s_1, 0) \ge 0$, then if $t_1 < t_2$, then

$$U^i(s_1, t_2) \le U^i(s_1, t_1)$$

2) Conflict agreement cost over time: if $t_1 < t_2$, then

$$U^i(\delta^-, t_2) \le U^i(\delta^-, t_1)$$

3) Relations between offers: if $t_1 < t_2$, if $U^i(s_1, t_1) > 0$ and $U^i(s_2, t_1) > 0$, then

$$U^i(s_1, t_1) > U^i(s_2, t_1) \text{ ,if } U^i(s_1, t_2) > U^i(s_2, t_2)$$

4) Conflict agreement and other offers: $\forall s \in S, t_1, t_2 \in T, i \in (\mathrm{m}, \mathrm{f})$, if $U^i(s\ , t_1) > U^i(\delta^-, t_1)$, then

$$U^i(s\ , t_2) > U^i(\delta^-, t_2).$$

As we discussed in the above section, only agreements that are not worse for the two individuals than the conflict agreement can be reached. Since the relation between the utilities of offers and the utility of the conflict agreement that is impalements if one of the individuals opts out does not change over time in the proposed negotiation model. The set of offers that are not worse for individual $i \in \{\mathrm{m}, \mathrm{f}\}$ than the conflict agreement is independent over time.

Negotiation Strategies

An individual's negotiation strategy specifies what the individual should do next, for each sequence of offers $s^{t_1}, s^{t_2}, s^{t_1}, s^{t_3}, ...s^t$. In other words, for the individual whose turn it is to make an offer, the strategy specifies which offer to make next. That is, it indicates to the individual which offer to make at $t+1$, if in periods 0 until t the offers $s^{t_1}, s^{t_2}, s^{t_1}, s^{t_3}, ...s^t$ had been made and were rejected by the other individual, but has not opted out. Similarly, in time periods when it is the individual's turn to respond to an offer, the strategy specifies whether to accept the offer, reject it, or opt out of the negotiation.

More precisely, a strategy can be expressed as a sequence of functions $f = \{f^t\}_{t=0}^{\infty}$, the domain of the t' th element of the strategy is a sequence of offers of length t and its range is the set $\{accept, reject, opt\} \cup S$. Thus for $i = offers$ $f_i^t : S^t \mapsto S$, and if $i \neq offers$ $f_i^t : S^t \times S \mapsto \{accept, reject, opt\}$. We would like to find simple strategies that both individuals would use such that no individual will benefit by using another strategy. We will define this notation formally in the next sections.

Subgame Perfect Equilibrium

Now consider the problem of how a rational individual will choose its negotiation strategy. Particularly, the following questions will be sought. In equilibrium, do the individual reach an agreement or do they perpetually disagree? In the former case, what is the agreed allocation? A useful notation is the Nash Equilibrium [*7*], which is stated as follows: A strategy profile $f = \{f^t\}_{t=0}^{\infty}$ is in Nash equilibrium of a model of alternating offers, if each individual i does not have a different strategy yielding an outcome that individual prefers to that generated when it chooses f_i , given that individual j chooses f_j . Briefly: no individual can profitably deviate, given the actions of the other individual. This means that if both individuals use the strategies specified for then in the strategy profile of the Nash equilibrium, then no individual has a motivation to deviate and use another strategy. However, the use of Nash equilibrium in a model of alternating-offers leads to an absurd Nash equilibrium [*13*]. Therefore, we will use the concept of subgame perfect equilibrium (SPE) to analyze the negotiation. A strategy profile is a *subgame perfect equilibrium* of a model of alternating offers if the strategy profile induced in every subgame is a Nash equilibrium of that subgame. This means that: 1) whenever an individual has to make an offer, his/her equilibrium offer is accepted by the other individual; 2) in equilibrium, an individual makes the same offer whenever he/she has to make an offer.

The above definition shows that the number of equilibrium can be very large. If the individuals follow the negotiation protocol described above, any offer s_i , which gives each individual at lease its conflict utility, has a SPE, which leads to the acceptance of s_i . The selection of one equilibrium in such situations is very difficult. Since the individuals are self motivated, there is no one equilibrium that is the "best" for all individuals. Game theory has developed equilibrium selection theories that can distinguish between Nash equilibrium [*14, 15]*. A significant amount of work has been performed on the evolution of conventions in games that are played repeatedly within a population [*16, 17*]. These conventions lead to a selection of one equilibrium by the individuals. Another approach is using "cheap-talk", which may be defined as non-binding, non-payoff relevant pre-play communication for selecting equilibrium.

In the next section we will define an equilibrium selection strategy that results in a Pareto efficient allocation, and in same time is a fair agreement. Additionally, we define a range of Negotiation strategies that individuals may use to reach an agreement. In particular the following Negotiation strategies is proposed and discussed; 1) time-dependent strategies; and 2) behaviour-dependent strategies.

Pareto efficient strategy

In the basic Rubinstein model, individuals are interested only in maximizing their own utilities; considerations of moral nature are not made by the players. This section introduces Pareto efficient strategies as a measure of how fairly an agreement divides total utility across the two individuals [18, 19, and 20]. We propose that the individual agree in advance on a joint strategy for choosing s that on average will give each individual a beneficial outcome. Analogously, the individuals decide on a mechanism that will find an allocation that must, at the very least, give each individual his/her conflict utility and under, these constraints maximize some social-welfare criterion. The objective for the proposed strategy, accordingly, is to find the agreement point that satisfies the Nash bargaining solution.

In particular, we model the agreement that will be offered by individual i to individual j at time t as the following expression shows: Propose $s^t_{i\to j}$ that solve the following maximization problem:

$$\operatorname{argmax}(U_i(s^t,t)-U_i(\delta^-)(U_j(s^t,t)-U_j(\delta^-)$$

Hence, the agreement point that satisfies the previous function fulfils Pareto optimality.

Time-dependent strategies

Since the two individuals have a deadline, we assume that they use a time dependent tactic (i.e., linear,Boulware, or Conceder [21,22). Thus these strategies consist of varying the acceptance offer depending on the remaining negotiation time. Let $t_i^{\max}$ be the deadline of individual i to end the negotiation. Thus, the allocation offer that to be uttered by individual i to individual j $s^t_{i\to j}$ at time t, with $0 \le t \le t_i^{\max}$,is determined by a function α^i depending on time as the following expression shows: Propose $s^t_{i\to j}$ such that:

$$U_i(s^t,t) = U_i(\delta^-) + (1-\alpha^i(t))(\max U_i(s^t,t) - U_i(\delta^-))$$

A wide range of time-dependent strategies can be defined simply by varying the way in which $\alpha^i(t)$ is computed. However, functions must ensure that $0 \le \alpha^i(t) \le 1$ and $\alpha^i(t_i^{\max}) = 1$. That is, when the time deadline is reached the strategy will suggest offering the reservation value "the conflict offer". The function $\alpha^i(t)$ could be defined by two families of functions: polynomial and exponential.

Two families of functions with this intended behaviour could be distinguished: polynomial and exponential.

- Polynomial

$$\alpha^i(t) = k^i + (1-\mathrm{k}^i)\left(\frac{\min(t,t^{\max})}{t^{\max}}\right)^{\frac{1}{\beta}}$$

- Exponential

$$\alpha^i(t) = e^{(1-\frac{\min(t,t^{\max})}{t^{\max}})^{\beta}\ln(k^i)}$$

An infinite number of functions can be defined for different values of β. However, two extreme sets showing clearly different patterns of behaviour can be defined. Other sets in between these two could also be defined:

1. Boulware Strategies [23]. Either exponential or polynomial functions with $\beta < 1$. This strategy maintains the offered value until the time is almost exhausted, whereupon it concedes up the reservation value.
2. Conceder Strategies [24]. Either exponential or polynomial functions with $\beta > 1$. The individual goes to its reservation value very quickly.

Behaviour-dependent strategies

These strategies compute the next offer based on the previous attitudes of the negotiation opponent [25]. When an individual use this strategy to compute his/her next offers, the individual reproduce in percentage term, the behaviour that his/her opponent performed $r \ge 1$ steps ago. The condition of applicability of this strategy is $n > 2r$. Where n is the number of negotiation rounds done so far. This strategy works as follows: Propose $s^t_{i \to j}$ such that:

$$U_i(s^t,t) = \min(\max(\frac{U_i(s^{t_{n-2r}}_{j\to i})}{U_i(s^{t_{n-2r+2}}_{j\to i})} U_i(s^{t_{n-1}}_{i\to j}), U_i(\delta^-)), \max U_i(s^t_i\ )$$

DEVELOPING A PROTOTYPE ACTIVITY BASED SCHEDULING MODEL WITH A HOUSEHOLD KERNEL AGENT

Model architecture

The Prototype model presented in this section is designed as a multi-agent system with a household negotiation kernel agent (Figure 3). The household kernel agent explicitly presents negotiation mechanism between the interactive household agents. Multi-agent systems (MAS) are under the umbrella of Distributed Artificial Intelligence (DAI) and have triggered increasing interest among scientists from different knowledge fields [*26, 27*]. The main premise of Multi-Agent systems is to interpret the real world in terms of agents that exhibit intelligence, autonomy, and some degree of interaction with other agents and with their environment [*26*]. Other characteristics of agents include for example, Reactivity, Adaptability, Pro-activity and the ability to communicate and to behave socially.

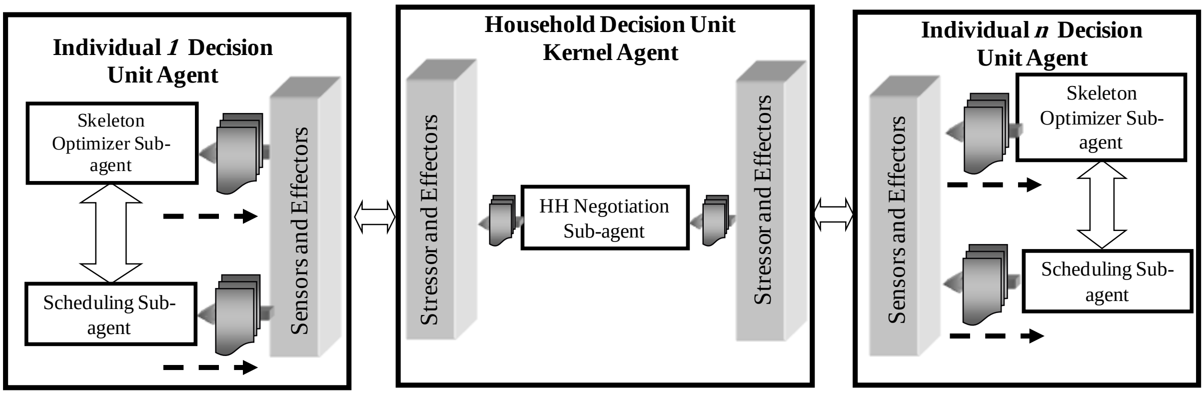

Figure 3-The Prototype Model

The household negotiation kernel decision agent

At the core of the system is the household negotiation decision kernel agent as shown in Figure 3. It is the agent that controls the negotiation mechanisms. Figure 4 sketches the household negotiation kernel agent. As indicated in this figure, the household negotiation module is responsible for controlling the negation process of household-level activities (i.e., those activities episodes that are generated by household agenda). The household negotiation kernel agent is designed as evolutionary system based on genetic algorithm GA. Evolutionary system refers to a class of algorithms which are inspired by natural evolution. Related methods to this work are Genetic Programming (GP) [*28*] and Genetic Algorithms (GA) [*29*]. The EAs transfer the principles of natural evolution, first discovered by Darwin, to a computational setting. These algorithms have been used in the past, with considerable success, to solve difficult optimization problems. Examples include problems with huge search spaces, multiple local optima, discontinuities, and noise [*30*, *31*]. Using EA, the household negotiation agent considers the negotiation process between the two household heads as an adaptive negotiation mechanism between two bounded rationality individuals.

The negotiation between two adaptive individuals as represented by the household kernel agent is boundedly rational for several reasons. Firstly, the performance of an individual's strategy depends on the strategies employed by his/her counterpart. Secondly, individuals learn each other's behaviours through trial and error negotiation experience. Thirdly, individuals are trying to find out the best response to the other's strategies so as to maximize their own utility. Fourthly, the adaptive individuals only maintain a limited collection of strategies. In the next sections, detailed description of the evolutionary system is given. Furthermore, a numerical simulation is presented.

As shown in Figure 4 the process. The incorporated process can be written as follows:
Step (1): *Skeleton optimization*. At this step, each of the individual decision agents constructs his Skeleton schedule, and initializing the individual's schedule with the given set of routine activities,

Step (2): *Generation of available time budget*. After building individual skeleton schedule, individual scheduling sub-agent generates available Time budget $T_i = (T_m, T_f)$ based on the available open periods in his initialized schedule. Just after this, each individual decision agent's reports his generated time budget T_i to the household negotiation kernel;

Step (3): *Activity selection*. Based on the activity priorities, the household negotiation kernel agent selects the activity with high priority from the household activity agenda. The selected activity (a_n) is characterized by earliest and latest possible start time, $t^{s-}(a)$, $t^{s+}(a)$, the earliest and latest possible end time $t^{f-}(a)$, $t^{f+}(a)$ and minimum and maximum duration $d^{-}(a)$, $d^{+}(a)$;

Step (4): *Negotiation offers generation*. Using the available time budget of two household heads $T_i = (T_m, T_f)$, the household kernel agent generates the set of negotiation offers (agreements) $S = \{s_1, s_2, s_3, \ldots . s_n\},$ on which the household negotiate;

Step (5): *The evolutionary system*. Details of the evolutionary system are given in next section.

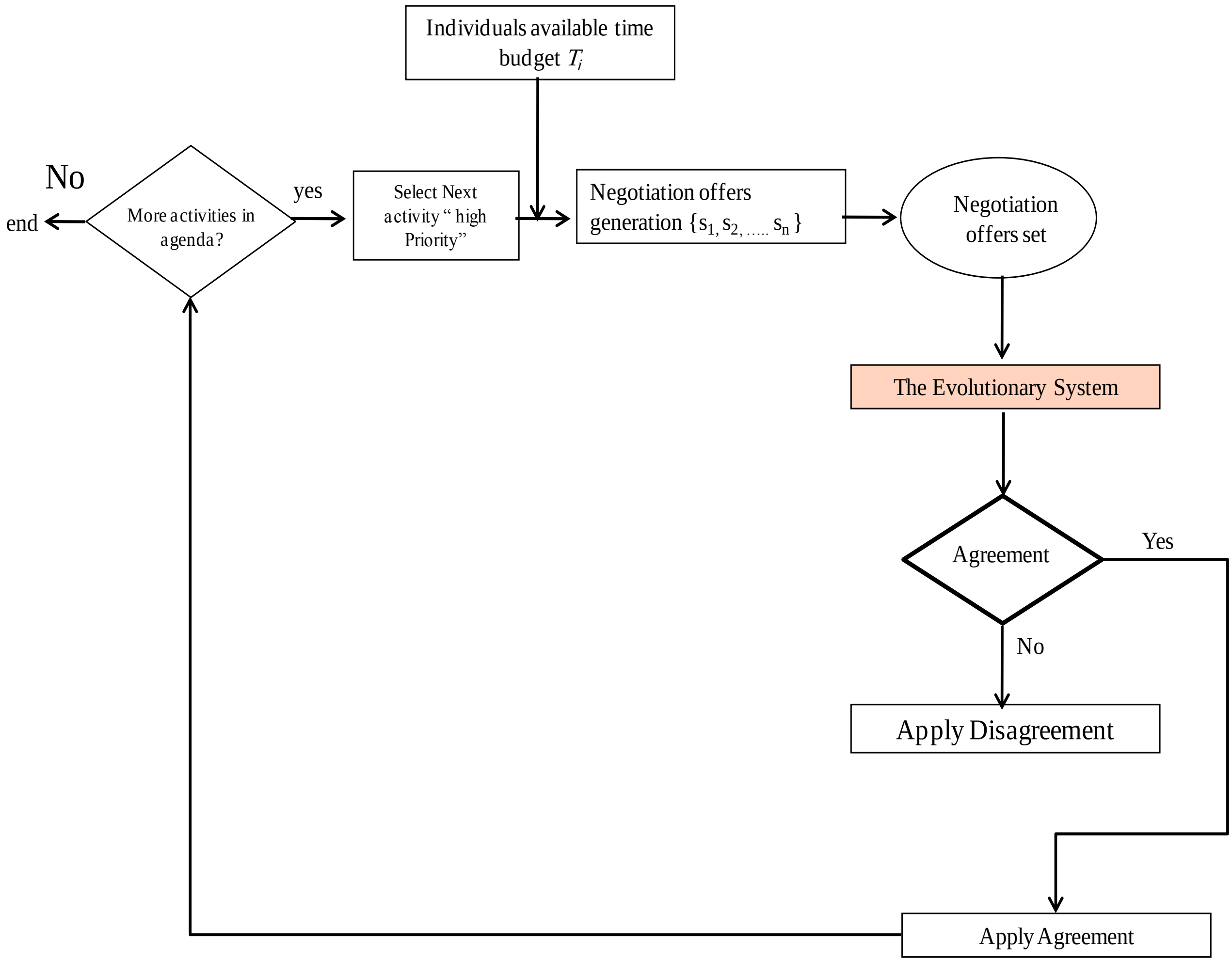

Figure 4- The household negotiation kernel agent

The Evolutionary System

The dissertation by Oliver [*32*] was the first work that succeeded to show that evolutionary algorithms could design strategies for agent's negotiation. Oliver's motivation has its origin in the observation that negotiation problems are rather inefficiently resolved by humans, who rarely settle in suboptimal agreements. The negotiation process is framed as a search problem for a mutual agreement, in a scenario where the parties' dispute shares of items that revert to utilities, according to their private valuations. In that framework, a strategy consists of a vector of numerical parameters that represent offers and counteroffers. Negotiation occurs with agents alternating offers to each other.

In this section, based on Oliver's work, we describe the abstract evolutionary system model that constitutes the core of the household negotiation kernel agent. We model an adaptive individual as a collection of strategies which is optimized by an evolutionary algorithm (EA). The evolutionary system imagines the negotiation as being done not by single set individuals, but by large populations of individuals. The system initially starts with two separate (and randomly initialized) "parental" populations of negotiation individuals; one representing the male head and the other representing the female head. In such asymmetric populations, the evolution of strategies in each subpopulation affects the evolution of strategies in the other subpopulation, (i.e., the strategies co-evolve). Thus we study the competitive co-evolution in which the fitness of an individual in one population is based on direct competition with individuals of the other population.

We assume that one of the individuals, denoted as "Male", has the privilege to open the negotiations. Each agent within a population contains a negotiation strategy, which encoded on his "chromosome" as a set of real values. These values specify an offer $s^{t}_{i\to j}$ and a counteroffer $s^{t+1}_{i\to j}$ for each time step t in the negotiation process for individuals $i,\ j \in \{\mathrm{m}, \mathrm{f}\}$. The agents evaluate the offers of their opponent using their utility functions. As the negotiation proceeds, each agent observes the utility of its strategy. It is also observes the utility and strategies of other agents in the opponent population. In the light of these observations, it adjusts its strategies. These adjustments involve experiments with strategies that it has not tried, but are overall designed to switch away from strategies that give low utilities to strategies that give high utilities.

The kind of individual interactions in an evolutionary system are different from the individual interactions in negotiation theoretical model. In the negotiation theoretical model, a single set of individuals interact with each other. In contrast, in every generation, individuals in the evolutionary model are repeatedly, randomly matched to negotiate. In our evolutionary system, agents in population 1 start the negotiation process. The utility that result from these negotiations forms an individual's fitness value. Subsequently, "offspring" individuals are created. This is done by means of evolutionary operators. An evolutionary operator is realized by three basic operators' *selection, crossover, and mutation.*

Selection is a means of deriving a new population from an old one. Selection is done by selecting particular individuals out of the pool of the old population. The assignment of fitness to each of the individuals is a crucial part of the selection process. Selection is the process of passing on individuals that have a high fitness value, relative to other individuals, to the next generation.

The second operator (i.e., crossover) is a recombination operator. Crossover, randomly chooses two genetic individuals, called parents, from the population and creates offspring by combining parts of the bit strings of the two parents. A complete strategy that is produced by crossover may not be the same as any of the strategies in the initial population, but parts of the strategy are those that are already there in the initial population. Crossover can be interpreted as a form of learning by communication. Two individuals meet, talk to each other about their strategies, and adapt parts of each other's behaviour.

The third operator is mutation. Mutation randomly alters single bits of the bit string by which a genetic individual is coded. It can be viewed as learning by experimentation. While selection and crossover can reproduce strategies already in use (at least partially) by other individuals, mutation is able to find strategies that have never been used before. Mutation is the only operator that is able to introduce completely new strategies into the system. The initial populations evolves as a result of selection, crossover, and mutation, and reaches a stable state in which large majority of individuals in the population play the most effective strategy.

The fitness of the new offspring is evaluated by interaction with the parental strategies. An economic interpretation of this parent-offspring interaction is that new strategies need to be able to compete with existing or "proven" strategies before they gain access to the individual's strategy pool. In the final stage of the iteration, the fittest strategies are selected as the new "parents" for the next iteration.

The Evolutionary Experiment Example

The aim of this evolutionary experiment example is to show the general ability of the developed evolutionary system to model the negotiation process between two household heads in daily activity planning. Further, is to investigate and analyze the evolution of The Pareto efficient negotiation strategy for male and female heads. In particular, we want to determine how the negotiation behaviour between the two individuals is defined by this strategy.

Example scenario

As a development phase, the evolutionary negotiation model was tested to model the negotiation process between male and female heads of a typical dual workers household on a working day. The household agenda of activities is shown in Table 1.

The household activity agenda has only one activity (Maintenance- grocery shopping) that the household is planning to participate during a working day. The duration of the activity as indicated by the household is 60 minutes with higher priority of 1 to this activity. Both male and female heads has a total time budget T=10 hours, with working last until 2 pm (840 minutes from midnight). Figure 5 shows a schematic representation of the household time budget and negotiation set. The two household heads are negotiating on a possible allocation of feasible time window (defined by a possible start time of the activity).

The negotiation set is $S = \{840{,}1260{,}60\}$, where of that, 840 min. is the earliest possible start time for the activity, 1260 min. is the latest possible start time, and 60 min. is the interval value between two successive offers (the size of the time window).

Table 1-The Example Scenario

Activity Type	**Priority**	**d_n**	**$t_{n,start}$ (Male)**	**$t_{n,early\ start}$ (Female)**	**$t_{n,\ late\ start}$ (Male)**	**$t_{n,\ late\ start}$ (Female)**
Daily Grocery Shopping	1	60	840=2pm	840=2pm	1260=9pm	1260=9pm

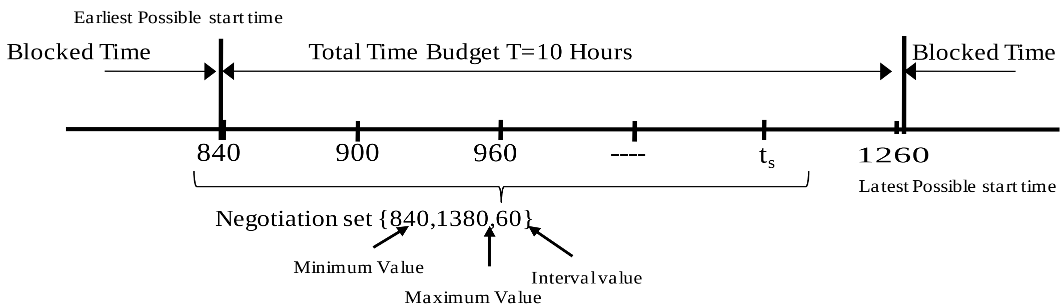

Figure 5- The household time budget and negotiation set

Encoding strategies as genes

In our model, each strategy specifies a list of offers and counteroffers for the different negotiation rounds. Each strategy is encoded as a sequence of real-coded genes (together called a "chromosome") in our evolutionary system. This representation is depicted in Figure 6. Notice that in each round, the strategy specifies either an offer or a counteroffer, depending on whether the individual who uses the strategy proposes or receives an offer in that round. The length *l* of each chromosome is thus equal to the number of rounds (*n*).

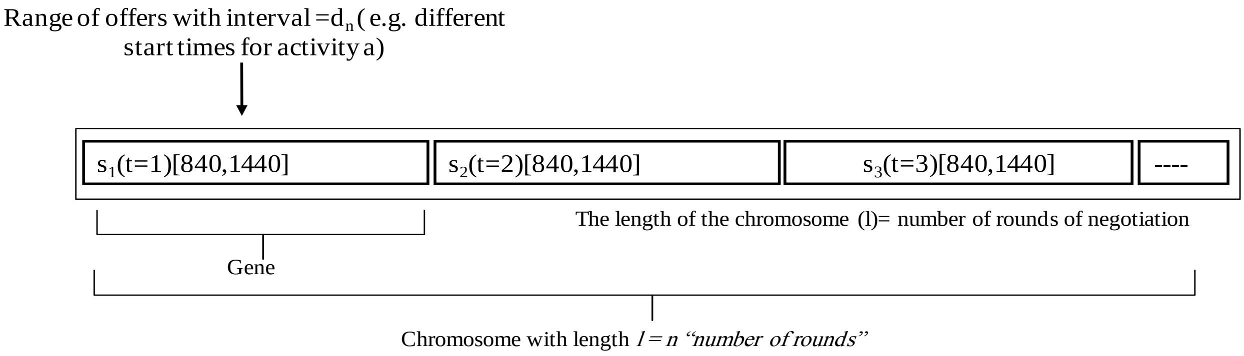

Figure 6- Encoding of the strategies

Measuring strategy's fitness

A strategy's performance highly depends on other strategies whom it meets. The design of using a group of fixed representative strategies as the fitness assessment has a risk that evolution may exploit the weaknesses of the pre-defined representatives, but perform poorly against others. So the fitness of a strategy should be based on its performance against the opponent's co-evolving strategies at the same evolutionary time. We define the goodness of fitness (G.O.F) of a strategy $s^t_{i\to j}$ is defined as the average Pareto efficient utility gained from agreements with strategies in the opponent's population J which has a set of n number of negotiation strategies.

$$G.O.F(s^t_{i\to j}) = \frac{\sum_j \prod \; (U_i(s^t_{i\to j}, t)(U_j(s^t_{j\to i}, t)}{n}$$

This G.O.F measure plays the role of a fairness measure and is used in selecting one agreement from the Pareto-optimal set.

Algorithm steps

The details of the GA used are as follows (recall there are two families of individuals: Male m and female f):

- Randomly create initial male (P^0_m) and female (P^0_f) populations;

While not (Stopping Criterion) **do**

  - Make a tournament and calculate the fitness of all the individuals in P^0_m and P^0_f ;
  - MP_m =Tournament Selection P^0_m ;
  - MP_f =Tournament Selection P^0_f ;

- Best MP_m =Best Individual MP_m ;
- Best MP_f =Best Individual MP_f ;
- Rm =Crossover-Mutation (MP_m -Best MP_m);
- Rf =Crossover-Mutation (MP_f -Best MP_f);
- P_m^1 = Best MP_m + Rm
- P_f^1 = Best MP_f + Rf

end while

1. *Generation of the First Population*. This represents the search's starting point and is created by randomly generating genes from the range of specified values. The male and female population size were each set to *N*,
2. *Selection Process*. All GAs use some form of mechanism to chose which strategies from the current population should go into the mating pool (MP) that forms the basis of the next population generation. To be effective, the selection mechanism should ensure that as diverse a range of fit strategies make it into the MP as possible (especially in the early stages). A selection mechanism known to work well in such circumstances is *Tournament Selection*. For this reason, it is the mechanism we employ to select from P_m^0 and P_f^0 , those individuals that will reproduce. Tournament selection works in the following way: *k* strategies are randomly chosen from the population. The strategy with the highest fitness among the selected *k* is placed in the MP. This process is repeated *N* times, where *N* is the size of the population. *k* is called the tournament size (which in our case is 2) and it determines the degree to which the best individuals are favoured. Once the male and female MPs have been created, the individual with the highest fitness in each pool is selected (respectively, Best MP_m s and Best MP_f s). These strategies will definitely form part of the new population. The remainder of the strategies in the next population, Rm and Rf, are created by applying crossover and mutation to the reset of strategies in the MP. Thus, the next generation of the male and female strategies P_m^1 and P_f^1 , are composed of the best of the individuals of the old population plus a newly created strategies,
3. *Crossover Process.* This mechanism exchanges genetic material between individuals. We randomly select two individuals from the population. c crossover points are then randomly chosen and sorted in ascending order. Then the genes between successive crossover points are alternately exchanged between the individuals, with a probability P_C ,
4. *Mutation Process.* Mutation is the other technique for creating strategies in new generations. It works by randomly selecting some of the genes present in the population in order to mutate. If a mutation occurs, a random value is chosen from the domain of the gene. This aims to avoid successive generations leading to local minima by introducing entirely new genetic structures. The genes are given a chance P_m of undergoing mutation.

We determined the stable outcome of different values on *N*, P_C, *C*, P_m in the range of 20 to 100 for *N*, 0.1 to .09 for P_C, 2 to 6 for *C* and 0.005 to 0.05 for P_m. Increasing the population size beyond 75 did not change the stable outcome (i.e., 95% of the individuals in each subpopulation have the same fitness for 10 successive generations) but only increase the time to stabilize. Further, the stable outcome was found for P_C =0.5, *C* =6, P_m=0.002. Furthermore, number of generation for each EA run was set to 1000.

DISCUSSION AND CONCLUSION

This paper proposed theoretical models of household interactions. We have developed several negation models that the household members may use solving the allocation problem. The study reported in this paper represents an important attempt to gain an understanding of the complex phenomena of the household interactions in activity planning/generation process by developing a negotiation mechanism of household interactions in daily activity planning. Defining the household negotiation problem in daily activity planning and scheduling, the protocol that the household could use in their negotiation, the strategies that they use while negotiating and the utility that individual use to evaluate offers and counter offers.

In this contribution, this paper extends the basic Rubinstein model to accommodate the household interactions in daily activity and travel planning. In particular, in this context, we define the problem of household group decision making as a negotiation process between a two heads of a couple household. we conceptualize the negotiation problem as follows: two household members (m) and (f) each with an available time budget T (defined as the available time after subtraction the time allocated for mandatory activities ,i.e., sleep and work, for the 24 hours) , negotiate over a possible set of time windows $W^i_{a,n} = \{W^i_{a,1}, W^i_{a,2}, W^i_{a,3}, ..., W^i_{a,n}\}$, to be allocated to a given activity a.

In this contribution, we present an equilibrium selection strategy that results in a *Pareto efficient agreement*, and in same time is a *fair agreement*. This paper introduces Pareto efficient strategies as a measure of how fairly an agreement divides total utility across the two individuals. We propose that the individuals decide on a mechanism that will find an allocation that must, at the very least, give each individual his/her conflict utility and under, these constraints maximize some social-welfare criterion. The simplest strategy that could be fairness enough is the Nash's product social welfare function that we have used.

Furthermore, this paper introduces behaviour agent architecture for household activity scheduling that is used to reproduce the daily activity scheduling behaviour of individuals as well as the household. The model designed as a multi-agent simulation system with a negotiation kernel agent. The kernel agent is developed as an evolutionary system that is thought to be able to model the negotiation between two household heads in their activity planning process. Furthermore, the proposed evolutionary system relaxed the perfect rationality assumption that has been under criticism by researchers. The agents in these simulations are not assumed to be completely rational, but rather they learn by doing, and adjust their negotiation strategies based on feedback from interactions with each other. Evolutionary algorithms (EAs) are used in this paper to govern the adaptive behaviour of the agents in the computational experiments

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