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A GA-based household scheduler

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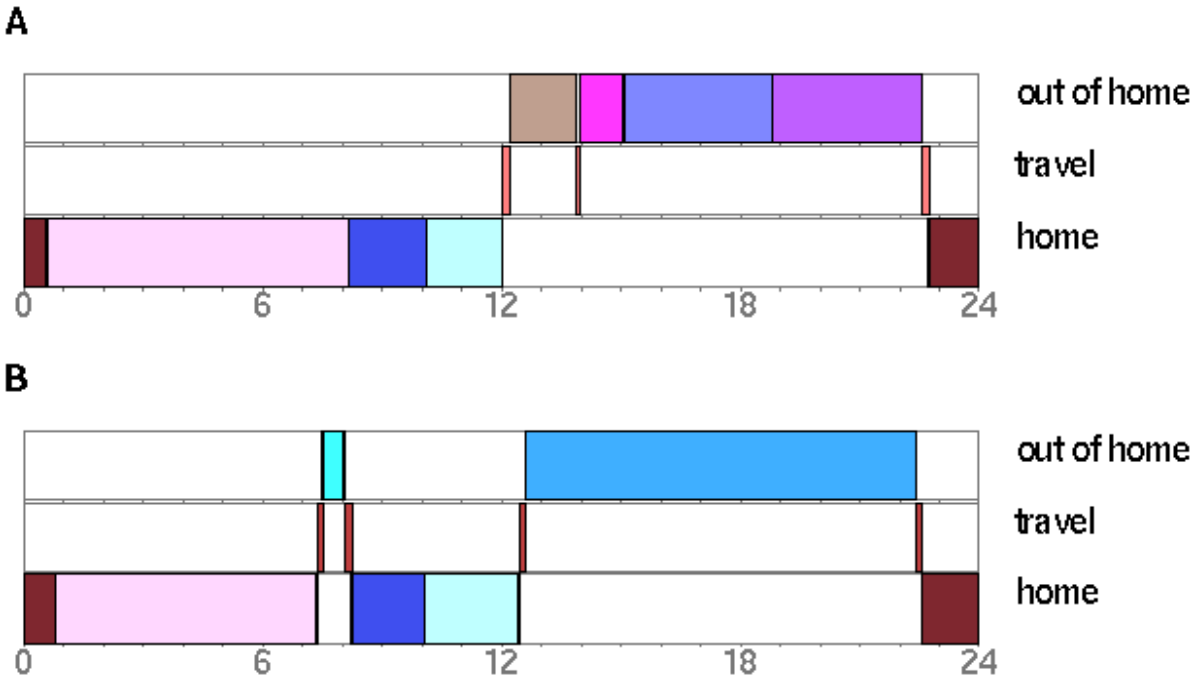

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A GA-based household scheduler

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Arbeitsbericht Verkehrs- und Raumplanung

Ein Zeitplaner für Haushalte auf Grundlage einer GA-Optimierung

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Kurzfassung

Dieser Aufsatz stellt einen Ansatz vor, der unter Verwendung eines Genetischen Algorithmus (GA) optimale Zeitpläne für Haushalte berechnet. Dazu wird ein bestehender Ansatz für Einzelpersonen erweitert, um a) die gemeinsame Zeit im Haushalt zu synchronisieren und b) um die rhythmischen Muster der nachfrage abzubilden. Testanwendungen mit zwei- und drei Personen zeigen, dass der Ansatz erwartungsgemässe oder durchaus neue Lösungen liefern kann. Zielwahl und Verkehrsmittelwahl sind berücksichtigt.

Schlagworte

Zeitplanung, GA, Mehrpersonen-Haushalt, Zielwahl, Verkehrsmittel

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Working paper

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Abstract

The paper presents a genetic algorithm based scheduler for households of arbitrary size, which is based on the earlier single person scheduler of Charypar and Nagel, 2004. It achieves the synchronisation of activities through the inclusion of an additional utility element for the shared time. It also expands the description of the utility function by considering the interval between rhythmic activities, such as sleep or hunger.

The paper presents initial tests with two and three person households visualising the resulting schedules and discussing the run time experiences. A sensitivity analysis of the impact of the joint activity utility parameter is also included.

This first implementation of such GA-based and efficient household scheduler opens up new avenues for travel behaviour research.

Keywords

Scheduler, Household, GA, Rhythm, Travel Behaviour, Activity Analysis

Preferred citation style

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1 Scheduling households

The generation of activities and their associated trips has been a neglected area of travel behaviour research as long as comparative static approaches to policy analysis were the rule. The two most relevant recent advances were the idea of homogeneous groups of travellers and their associated activity chain distributions (e.g. Poeck and Zumkeller, 1976; or Fellendorf, Haupt, Heidl and Scherr, 1997; Axhausen, 1990) and the successful integration of the choice of the activity pattern into random utility models (e.g. Bowman, 1998; or Bowman, Bradley, Shiftan, Lawton and Ben-Akiva, 1998). The first approach allows the representation of the whole variability of the activity patterns in a simulation, but it does not provide for a mechanism to change the activity patterns themselves, or their distributions for the particular homogeneous group. The patterns and the generalised costs are linked in the model structures of the second approach, but their effects tend to be small, while the socio-demographic variables dominate the model, which reduces them often to sophisticated cross-classifications. In addition, as utility maximising approaches, they have to impose the assumption that the daily pattern is planned in one step at one point in time. It is well known from introspection and empirical work since the late 1970s (e.g. Jones, Dix, Clarke and Heggie, 1983), that this assumption is unrealistic, if computationally and econometrically necessary. In particular, the work of Doherty (Doherty and Miller, 2000 or Rindsfüser, 2003 and references there) with his activity scheduling surveys has shown, that a large share of the activities undertaken is planned during the day or even started at short notice, spontaneously.

Two developments have now increased the interest in trip generation again: first, the interest in the household interaction and therefore the allocation of tasks to the different household members; second the interest in responses to real time traveller information and traffic management systems, including tolling. Both are therefore interested in activity scheduling, i.e. the determination of the timing and duration of an activity and its associated characteristics (location, mode, group size, expenditure), either as a bargaining process within the household or as a response to information pr pricing signals. This process of activity scheduling involves the identification of activity needs, instances of activity suppression, as well as their planning and re-planning over arbitrary time horizons and is therefore inherently dynamic.

The concept of scheduling has therefore become central to the current work in acticity-based analysis (Damm, 1983; Jones, Koppelman and Orfeuil, 1990; Kitamura, 1996 or Pas and Harvey, 1997). Four lines of work can be distinguished:

- empirical work observing the scheduling process through tracking plans and realised behaviour (see above)
- stated-response work trying to understand the scheduling process as it happens (Ettema, Borgers and Timmermans, 1997)
- econometric estimates of the utility functions of activity participation and other attempts to reproduce and predict activity patterns (Arentze and Timmermans, 2000; Joh, 2004; Zhang, Fujiwara, Borgers and Timmermans, 2004; Recker, 1995 or Gliebe and Koppelman, 2002)
- conceptual and simulation models of the activity scheduling process (e.g. Gärling, Brännäs, Garvill, Golledge, Gopal, Holm and Lindberg, 1989; Gärling, Kalen, Romanus and Selart, 1998; Gärling, Kwan and Golledge, 1994; Doherty and Axhausen, 1998; Roorda and Miller, 2004; Axhausen and Goodwin, 1991; Charypar and Nagel, 2004)

In addition, the work on departure time choice is related to this work through the implied trade-offs between the two activities at the start and the end of the trip (see Noland and Small, 1995 and the literature there).

This paper wants to contribute to the fourth stream of work by presenting a genetic algorithm based scheduler, which is able to accommodate arbitrary number of household members. Next to the normal task of a scheduler, i.e. the finding of the optimal schedule in terms of timing and duration of activities including location and mode used for each individual, it has to provide a mechanism to synchronise the activities of the household members.

The paper has the following structure. Before describing the scheduler and the proposed solution for the synchronisation of the activities, the next section will place the model into a dynamic framework to sketch the limitations of the approach at this point in time. After the description of the model and its capabilities, the paper will discuss the results for two households. Separate sections will be devoted to a sensitivity analysis of the parameter describing the utility of joint activities and of the run time experiences. The final section discusses future research needs.

2 A dynamic framework

The individual's position in time-space at any one time is the product of his or her biography. In a first step it is useful to concentrate on activity scheduling for the tasks of daily life. We assume that the longer term choices, such a partnership, children, home and work locations, but also the available set of mobility tools (motorised vehicles, bicycles, public transport season and discount tickets) are fixed in the short term.

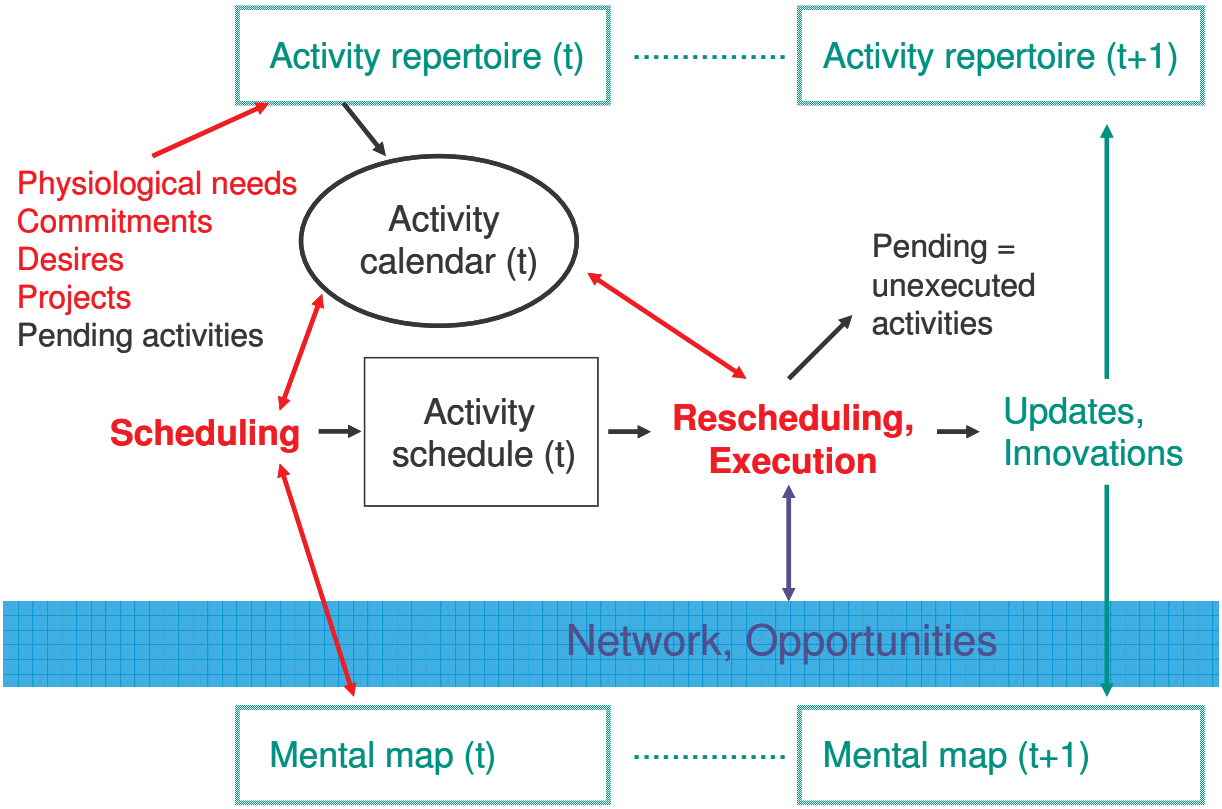
A person's personal world can be described in two ways, each stressing a different facet of that knowledge: the mental map describes the locations, their relative positions, the networks and routes linking them (Lynch, 1960; Bovy and Stern, 1990) with associated generalised costs reflecting the experiences and expectations of the person; the activity repertoire consists of the locations and the types of activity, which can be performed there for a given generalised costs and returning a particular level of satisfaction. It is worth pointing out, that the number of locations included in the mental map/repertoire is substantially larger then observed set of locations for a given time period, which constitute the activity space (see Schönfelder and Axhausen, 2003). The third element of the personal world is set of the expectations, which the traveller has formed about the world based on his/her experiences, which determines his/her assessment of parts of the network, which he/she has not visited so far. Parts of these expectations are the search rules and methods, which are available to answer questions about daily activities, their locations, costs and expected satisfaction levels.

The performance of everyday life is limited by the personal world, which in turn continues to evolve (See Figure 1). The physiological needs, the higher level needs, the commitments accepted, but also the seasons activate elements in the activity repertoire, which could satisfy these needs or allow the traveller to fulfil his/her obligations. These activated elements constitute the activity calendar, which is continuously evolving in response to the needs, desires and activity execution, but also in response to unforeseen opportunities. The entries of the calendar have priorities, which respond to the level of need or commitment to the activity (type). There is, as a rule, no one to one match between an activity type and need, or even commitment. The substitutability should be lower for commitments, such as work or the care of a person, as they are more specific in their description of the necessary activities, then the need for relaxation, which can be achieved in many ways. The entries in the calendar of things to do will always have more entries then can be accommodated during the next day or generally, short term planning period. It is important to note, that the commitments and the projects of the traveller structure the activity calendar some time into the future (Axhausen, 1996). Survey work is only now starting to provide empirical evidence on the frequency, duration and

effort involved in the various projects, which person and household undertake at any one time. The concept of the project is important, as it links various disparate activities into a coherent whole and as it provides the time frames for the subsidiary activities.

Through scheduling the travellers creates the schedule, which guides the day in question. The scheduling has to provide time for the high priority activities in the calendar, fill the gaps, deliver the commitments on the basis what the persons knows of his environment or can find out about it in reasonable time. It is the central management process of everyday life and therefore of its dynamics.

Figure 1 Daily scheduling within a dynamic framework



Source: Axhausen, 2002

The conceptual framework of Figure 1 sees scheduling taking place at the start of the day, but continuing during the execution of the day through rescheduling, when parts of the schedule have been addressed. Changes might become necessary because the transport system has been unreliable, an event was cancelled, a store did not have the good sought, etc.

At the end of the day/planning period the traveller is left with unexecuted activities, which he/she needs to carry over into the next day, cancel (suppress) or reshape. In addition, the

traveller has updated the mental map against current experiences, in particular innovations, which he/she might have developed during the day or participated in on suggestion of a third party: a restaurant, a new public transport connection, a new parking garage etc.

This conceptualisation does not specify, what form the scheduling takes. It rather assumes that the scheduling is not strictly speaking optimal, but that it is heuristic and preliminary, accounting for the expected unexpected. In line with the results of Doherty and others, one would assume that the scheduling traveller leaves empty spaces in his plans and cannot achieve the equilibrium conditions of the economics of time-use (Becker, 1965; de Serpa, 1971; Jara-Diaz and Farah, 1988; Bates, Williams, Coombe and Leather, 1996)

3 Model structure

Most schedulers implemented in software so far have, in-spite of the apparent lack of realism of this assumption, enforced the equilibrium condition on the marginal utilities of activity participation (See Charypar and Nagel, 2004 or Joh, 2004). The computational advantages and the link to the random utility choice models, which impose the same assumption in the estimation of the parameters of the utility functions of the activities, argue for this. The model presented here follows this tradition. In the conceptual scheme above, it has to select activities from the calendar and schedule them completely (timing, duration, mode, location and joint participation of other household members). It is consistent with the conceptualisation, if not all elements present in the calendar are scheduled for the day in question.

The aim of the model is to overcome the limitation of previous model to single individuals. The goal is to allow the schedules of the household members to interact and to achieve an optimal synchronisation of them. The basic instrument is the extension of the individual utility function by an element, which reflects the additional utility of a joint activity, i.e. we assume that household members like to do things together. Given the complexity of the resulting joint utility function, the model employs the genetic algorithm (GA) approach (Goldberg, 1989) to search for the joint household schedule. The basic idea of the GA is to iteratively improve an initially random set of *individuals*, in our case household schedules. The instruments for this search are the cross-breeding of selected good schedules (cross-over) and their further, slow, random mutation. Experience has shown that GAs are able to find near optimal solutions after a sufficient number of iterative applications of these two instruments, even for very badly behaved utility surfaces.

Following the approach of Charypar and Nagel (2004) for individual travellers, the model has to specify the coding of the schedules, to describe the elements (activities) of the calendar and to define a suitable utility function.

The activities (elements) of the calendar are described with the following variables:

- Priority p_i reflecting the urgency of the activity i given the recent history of the person
- Optimal duration $t_{opt,i}$ (working point)
- Latest arrival (start) time for the activity $t_{latest.ar}$
- Earliest departure time (end) time of the activity $t_{earliest.dp}$
- Minimum duration $t_{shortest}$
- Parameter $\beta_{joint,i}$ of the utility of joint activity performance.
- Association of the activity with a basic need, here implemented for hunger
- Possible participants in the activity specified as a list of the relevant household members
- Facility type suitable for the activity. It is possible to specify, if an activity type can only be undertaken at a particular location, such as home or a pre-allocated work place or kindergarten.

The reference to a basic need is a new element of the model. Certain activities have clear rhythms over time, such as sleeping or eating. The GA cannot assure this spacing in its naïve form. The model therefore discounts the utility of such an activity with a logit curve, if it occurs too quickly after the previous activity of the same type. Over longer time horizons these rhythms are observable also for other activity types. See for example Bhat, Frusti, Zhao, Schönfelder and Axhausen, 2004 (case of shopping), or Schönfelder and Axhausen, 2001 for all activity types.

The parameter *Possible Participants* allows the modeller to describe allocations of the activity to persons, or their participation in shared activities. For allocated activities, only one of the possible participants may execute a scheduled activity. For a possibly shared activity, it says which household members may participate in it.

There is little empirical guidance for the formulation of the utility function of an activity (See Axhausen, 1990 or Joh, 2004 for reviews). Reflecting current assumptions the model adds the following elements: Waiting time (early arrival), late arrival, departing before the earliest departure time and violations of the minimum time constraint as linear functions of their respective durations. The contribution of the performance of activity i is logarithmic to the ratio of

actual and optimal duration, which is scaled to reflect the priority p of the activity and multiplied with a weighted share of the joint activity times and the current value of the hunger function, if relevant:

$$U_{dur,i} = \beta_{dur,i}\, t_{opt}\, \ln\left(\frac{t_{dur,i}}{t'_{opt,i}}\right)\left(1 + \beta_{joint,i} \sum_{\forall j \neq i} \frac{t_{joint,i,j}}{t_{dur,i}}\right) h_i(t)$$

with:

$$t'_{opt,i} = t_{opt,i}\, e^{\left(\frac{-c_i}{p_i\, t_{opt,i}}\right)}$$

$t_{dur,i}$	Duration of the activity i
$t_{joint,i,j}$	Duration of the overlapping participation of person j in activity i
$t_{opt,i}$	Working point of activity i
p_i	Priority of activity i
c_i	Scaling constant for activity i
$h_i(t)$	Value of the hunger function at time t, if the activity is eating, otherwise 1
$\beta_{dur,i}$	Weighting parameter of duration of activity i
$\beta_{joint,i}$	Weighting parameter of joint activity participation

The travel time utility is a non-linear function of travel time, which is calculated with a reasonable mean speed for the mode. A null mode exists for movements within the same location, home for example. The contribution of travel with mode m is:

$$U_{travel,m} = \beta_m\, t_{travel,m}^{\lambda_m}$$

With

$t_{travel,m}$	Travel time with mode m
λ_m	Exponent for mode m
β_m	Weighting parameter for travel with mode m

The modes can be specified as generally available, such as walking and public transport, or as tied to a vehicle, such as cycling or car driving. The algorithm enforces that only available modes can be chosen. In particular, a car can only be used, if it has been driven to the current

location of the traveller. The availability of vehicles to household members was described with a similar method as the allocation of activities to persons.

For the GA each household member's activities are encoded with the following five elements:

- *scheduled*: This binary information defines whether an activity will be part of the schedule or not. In the latter case, it is ignored by the algorithm during the utility calculations.
- *sequence*: Here, the place of the activity in the schedule is encoded. This is an integer variable. Purpose is known for the description in the calendar.
- *location*: There are potentially multiple locations for each facility. For activities whose location choice is performed on a daily basis, a new location is chosen for every new plan. Activities associated with long-term commitments have a fixed location. This is an integer variable.
- *time allocation*: What share of a 24-hour-day is reserved for this activity? The algorithm divides the share for the activity between the travel time, possible waiting times and the performance of the activity. For this it considers distance, chosen mode of transportation and environmental constraints, e.g. opening times. Times are floating-point variables.
- *mode*: For each activity that takes place at a facility other than its predecessor, a mode of transportation is chosen. This is again integer information.

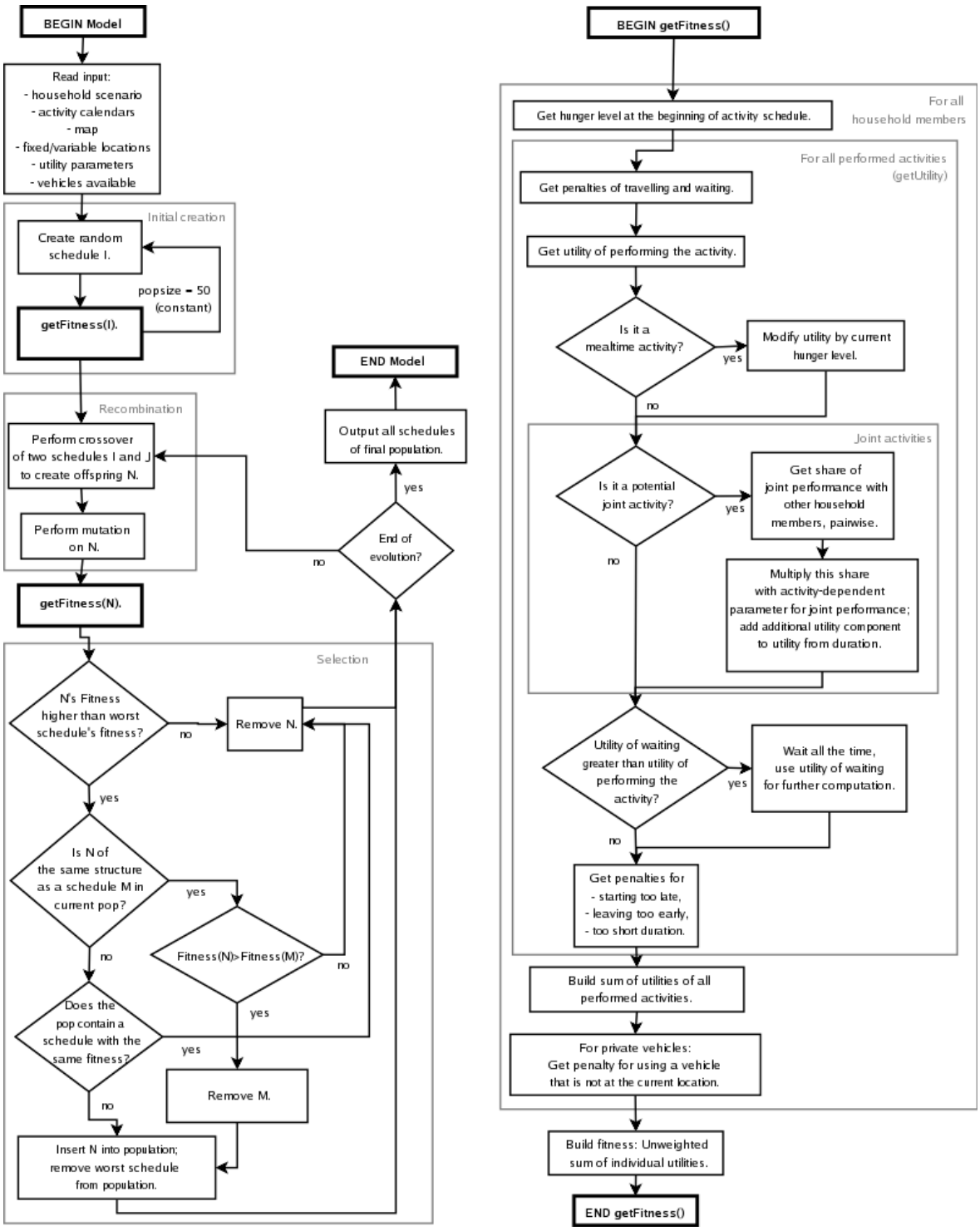
For a two-person-household, a complete schedule with eight activities on the calendar is thus a vector of up to 2*8*5 (80) variables. When creating the initial population, all of them are set randomly. During the evolution, their values depend on the existing schedules (for comparison, see also Charypar and Nagel, 2004), but for the mutations taking place during the iterations.

The population of schedules was classified by three of the five variables (purpose, location and mode for all household members and scheduled activities). If a second schedule of the same class was generated, the plan with higher fitness is kept in the population while the other one is deleted. If a second schedule with the same fitness is generated, it is also deleted. By ignoring time information, the variance in the population is decreased. This reduces the ability of the GA to optimise departure times and activity durations, but also the danger to get stuck in a local optimum. In this implementation, this trade-off was accepted, as it was felt, that it was more important to cover the solution space with a small number (50) of schedules.

Figure 2 summarizes the calculation of the utility and the generation of the next population. The equalisation of the marginal utilities is not explicit in the optimisation, but is achieved implicitly in the search for improvement.

The programme was developed in C++ under Linux using gcc-3.3. The activity plan visualisations were created from scratch using libEMF, a free C/C++ library for the Enhanced Metafile vector graphics format.

Figure 2 Structure of programme



4 Example results

In this development phase, the model was applied to a number of household types and related activity calendars. The specification of the household also involves the definition of the available modes and of pre-defined activity locations, such as home, work, or schools. The full scenarios can be found in Meister, 2004. The spatial environment is loosely modelled on Karlsruhe, as found in the Mobidrive survey (Axhausen, Zimmermann, Schönfelder, Rindsfüser and Haupt, 2002), which is intended as the validation data source in later stages of this work. It is unusually large for such applications with 160 home locations, 123 work places and 30 locations for each of the other activity types (shops, leisure, schools, kindergarten) (See also Figure 4 for a map). These are grouped in eleven clusters representing a city centre and its suburbs. There is one school and kindergarten per cluster.

The parameters of the utility function were chosen as shown in Table 1:

Table 1 Parameter values for the example application

Utility element	Symbol	Value	Comment
Activity performance	β_{dur}	20 €/h	This is roughly the average Swiss wage after taxes and health insurance
Joint performance	β_{joint}	0.2	See the sensitivity analysis below
Waiting	β_{wait}	⅓ β_{dur}	Is equal to early arrival
Late arrival	$\beta_{late.ar}$	0.9 β_{dur}	
Early departure	$\beta_{early.dp}$	0.3 β_{dur}	Leaving before earliest departure time
Violation of minimum duration	$\beta_{early.dp}$	0.3 β_{dur}	Same valuation as early departure
Travel by car	β_{car}	⅔ β_{dur}	
	λ_{car}	0.5	
Travel by slow modes	β_{slow}	8 β_{car}	The parameters are chosen to reflect the aversion to long walks
	λ_{slow}	2.0	

Expanded from Charypar and Nagel, 2004

The example results shown here will be discussed with respect to the performance of the GA. They are visualised in three styles:

- Time use by location type, as pioneered by the Household Activity Travel Simulator (HATS), the survey tool of Jones (1979), showing in a compact image, where each

person is over the course of the day, but only for three types of location (home, out-of-home and travel)

- Time use by activity type for all household members as a group, which allows to detect joint activity easily.
- Sequence of the locations visited over the course of the day on a map of the environment for each person.

The performance of the algorithm is measured with four variables:

- Average utility across all household members
- Variance of the marginal utilities of the schedules
- Similarity of the activity patterns measured with the unidimensional sequence alignment method (Joh, Arentze and Timmermans, 2001), but summing the similarities for purpose, mode and location of all household members.

Figure 3 traces these three measures over the 400'000 generations of the GA run. As the average utility of two persons in this household of two adult workers and a small, partially modelled child stabilises, the marginal utilities converge, as well as the internal consistency of the population of schedules. The two persons have synchronised their activities at home nearly completely. Person B drops off a child at the kindergarten, which is later returned by a friend. The child is assumed to be below six years. Given the general lack of information about the time use of such small children, it was not modelled here, but could be in the future. Note the unusal joint leisure during the morning, which is a response to the required late shift of person B. Person A also responds by shifting its work into the same time window. See Singhi, 2001 for empirical results on the number of shared trips and activities.

Figure 3 Development of the results (two-person household example)

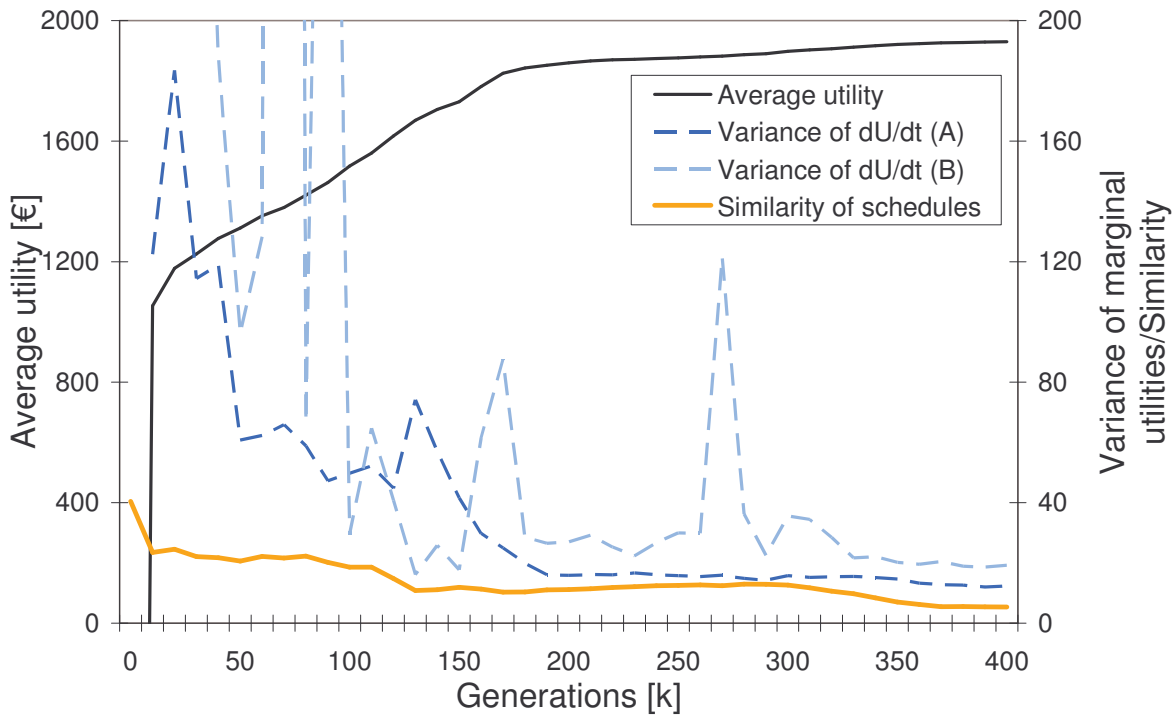
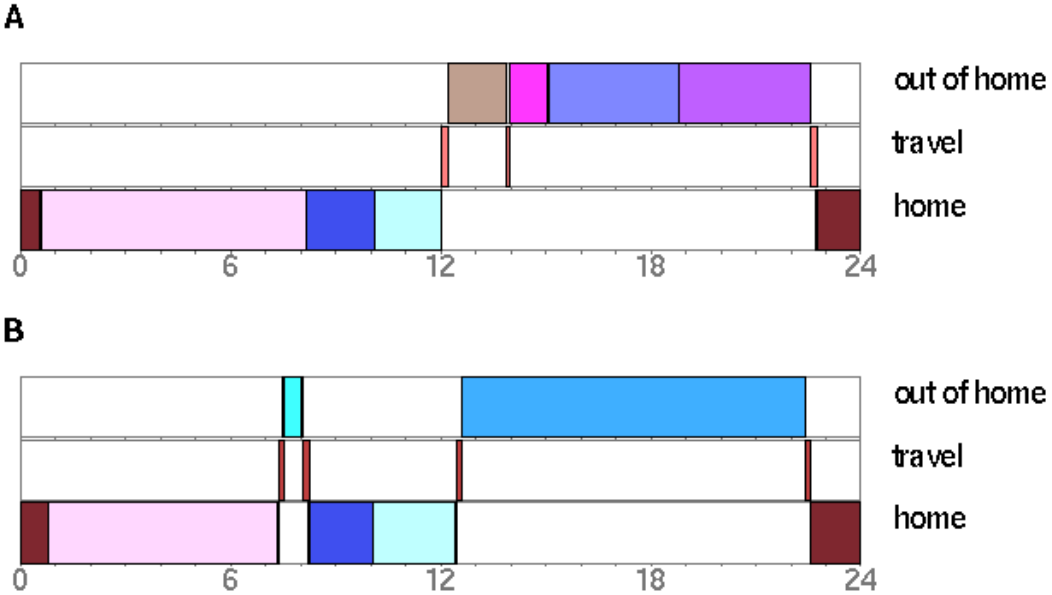


Figure 4 Example: Two-person household (two working adults)

Time use by location



Time use by activity

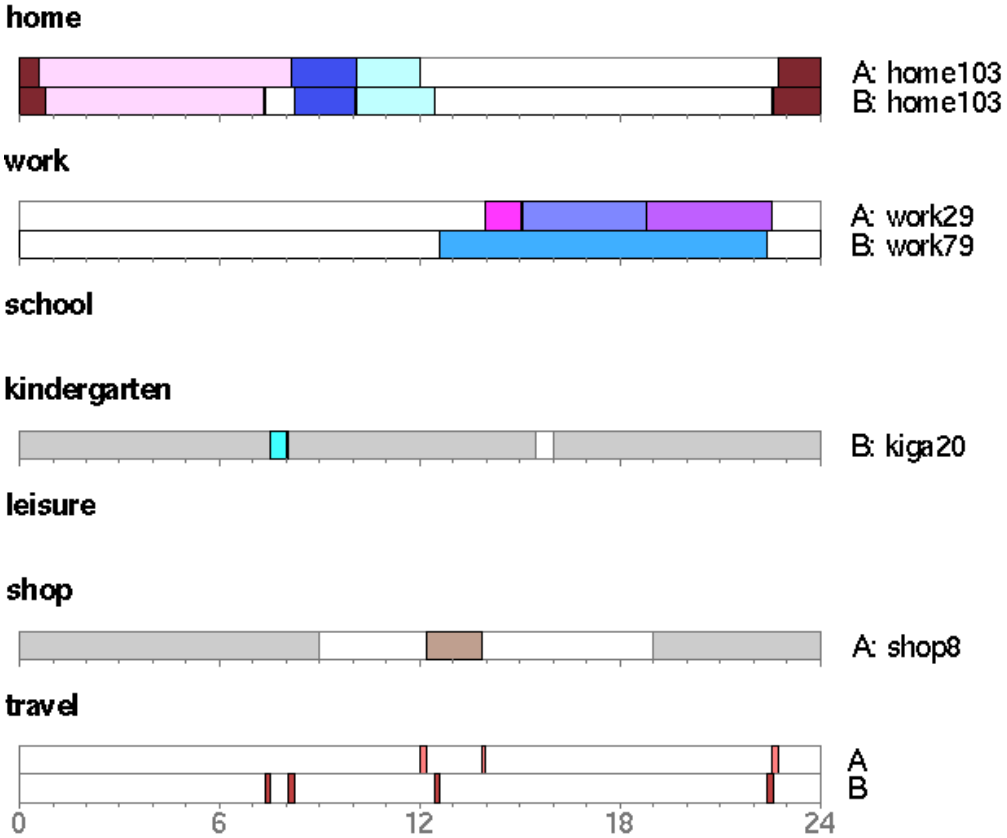


Figure 4 Example: Two-person household (Continued)

Spatial trace

Legend

activities

A	B
lunch_home	bring child
chill out	lunch_home
shop	chill_out
lunch_work	late shift
work1	dinner
work2	sleep
dinner	
sleep	

all persons: wait

opening times

open, closed

means of transportation

none, walk, car1

facilities

home, work, school, kindergarten, leisure, shop

household members on the map

Person A, Person B

The second scenario with three persons (two adults and one older child, which is simulated) shows again, that the algorithm performs as intended. Average utility increases steadily over all 600'000 iterations. The similarity of the plans stabilised early, indicating that few structurally new schedules are generated. The variances of the marginal utilities do converge, but not to near zero, which is also difficult in real life situations, which sometimes fixed durations for certain activities.

Figure 5 Development of the results (three person household example)

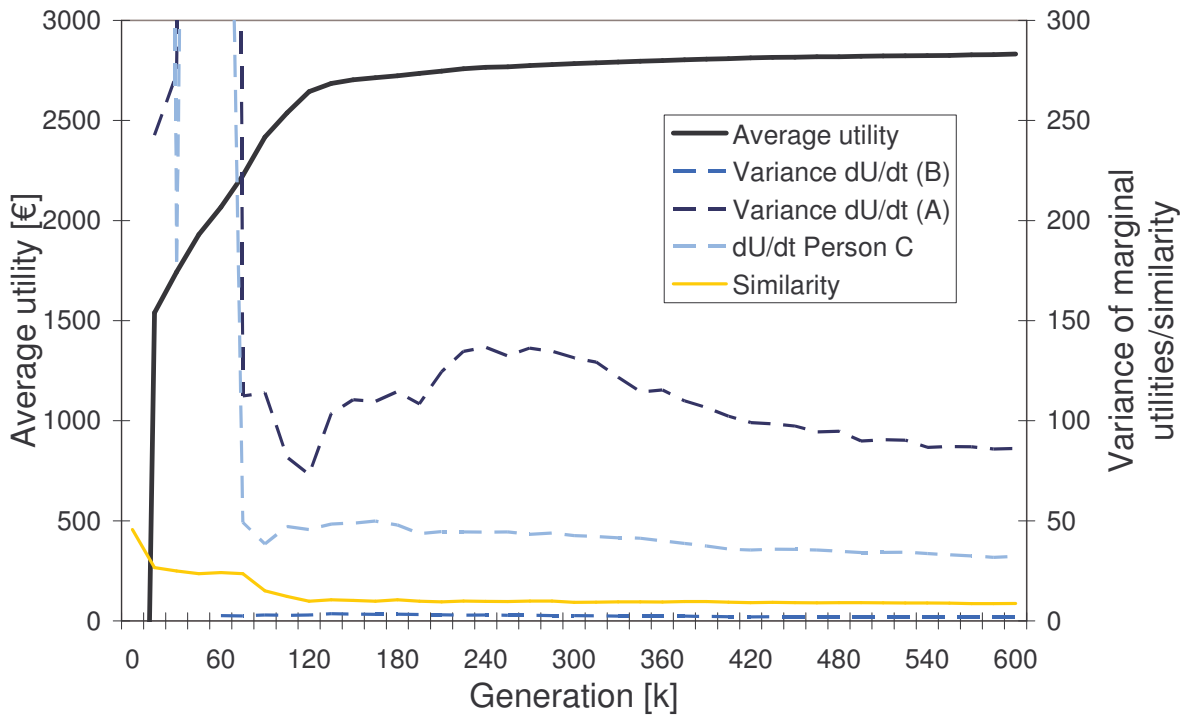
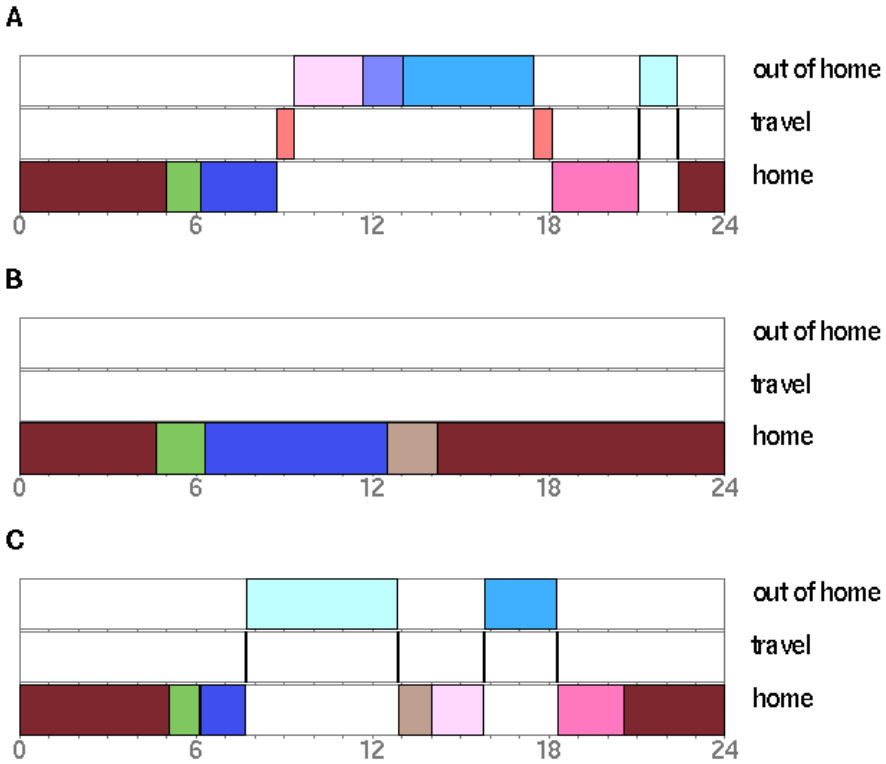


Figure 6 Example: Three person household

Time use by location type



Time use by activity

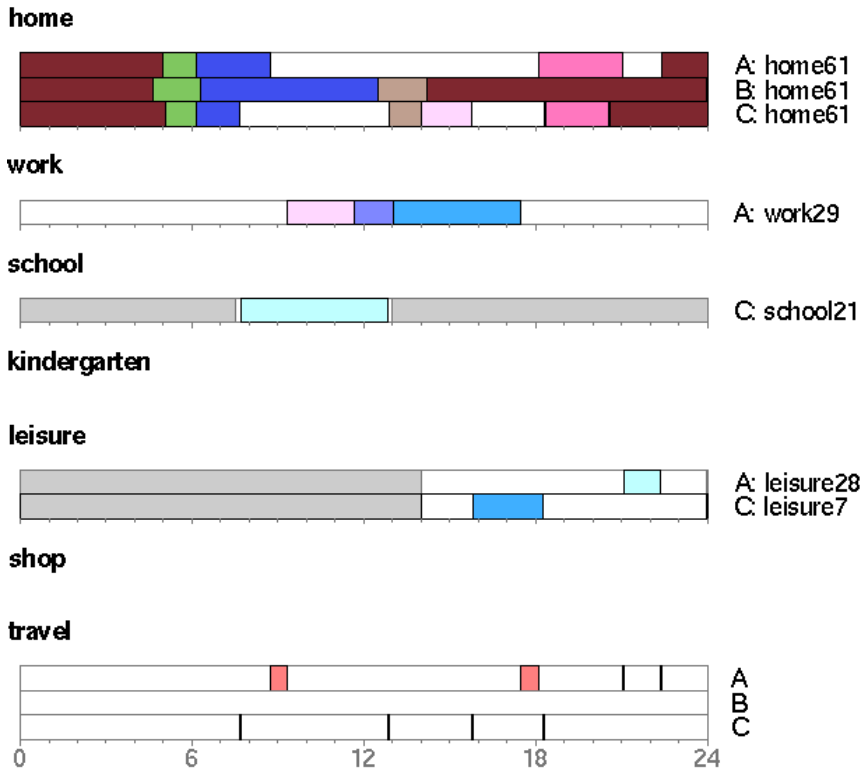


Figure 6 Example: Three person household (Continued)

Spatial trace

Legend

activities

A	B	C
breakfast	breakfast	breakfast
chill out	chill out	chill out
work1	lunch_home	school
lunch_work	sleep	lunch_home
presentations		homework
dinner		soccer
leisure		dinner
sleep		sleep

all persons: wait

opening times

open, closed

Verkehrsmittel

none, walk, car1

facilities

home, work, school, kindergarten, leisure, shop

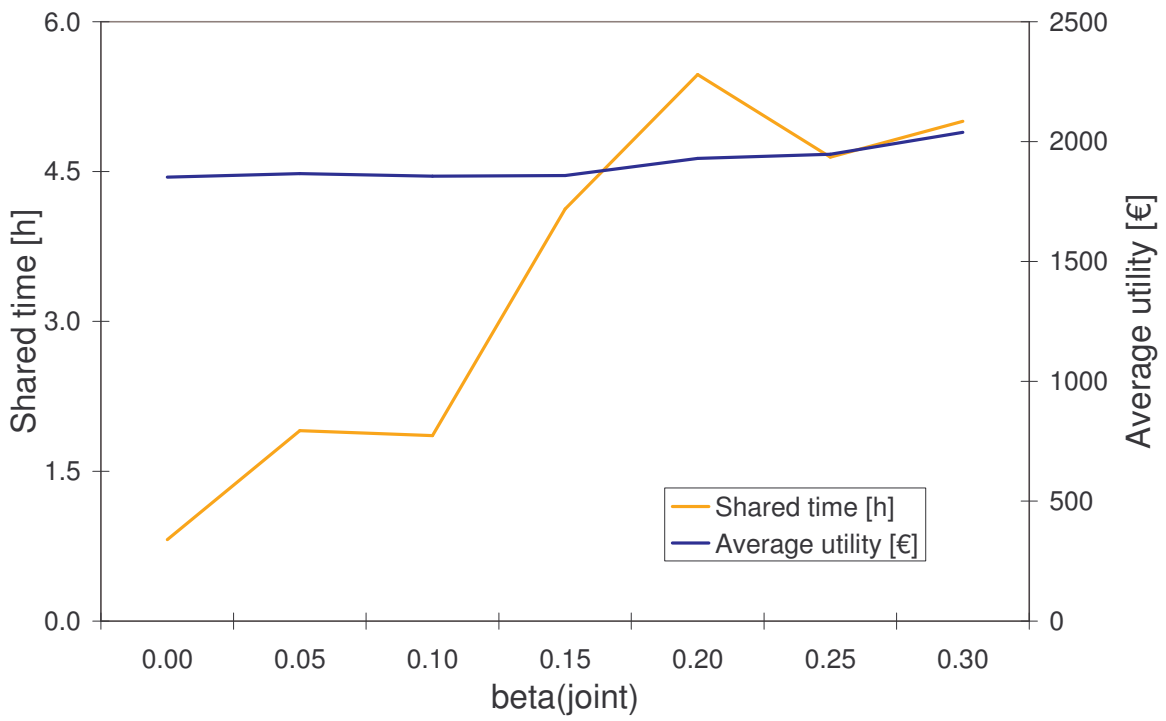
household members on the map

Person A, Person B, Person C

5 Sensitivity to the valuation of joint activities

The introduction of β_{joint} and therefore of the explicit valuation of joint activity raises the question, if the schedules respond to change in β_{joint} in the expected way. The expected increase in the joint time and in synchronisation (not shown, as it is closely parallel) is observable (Figure 7) up to a value of β_{joint} of 0.20, as used in the scenarios above. This value quadruples the joint time in comparison to a valuation of zero for joint time. Interesting is that the increase in shared time stops at this point, even seems to reverse. The average utility does not increase as quickly, but continues to increase. The household members reconfigure their activity patterns in response to the incentive offered by the joint utility. It is difficult to generalise from this one experience, as the content of the calendar is likely to influence the results, especially if the schedule has exhausted the joint activities at some point. Nevertheless, this first experiment is reassuring, as it demonstrates that the algorithm responds in the expected way.

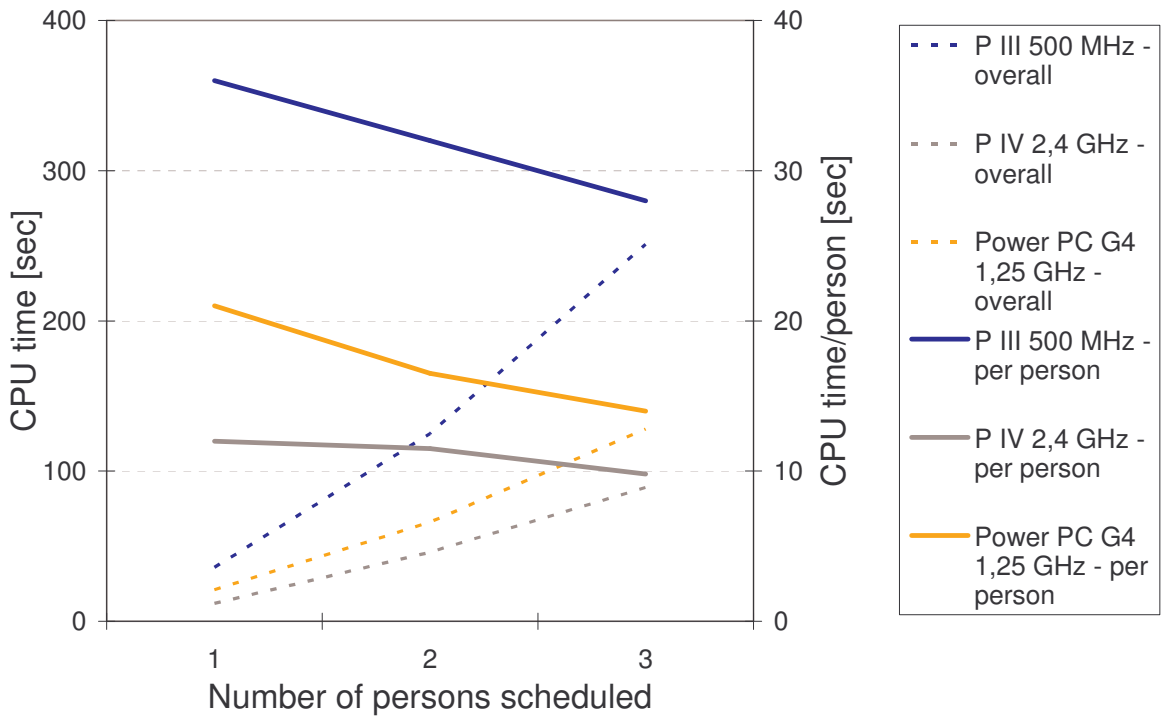
Figure 7 Shared time and synchronisation as a function of β_{joint} in the two person household scenario



6 Runtime experiences

The software was tested on three different machines with differing clock speeds (Figure 8). The run times decrease per person modelled, while increasing with the number of iterations and persons They also decrease with the clock speed, but the household size-independent simulation components limit the rate of decrease. The size of the environment and of the number of choice options has no impact, as expected.

Figure 8 Runtime experiences



The 10 seconds taken in the best case to generate one household schedule is acceptable for many applications. For iterative large scale simulations, such as the one reported in Raney et al. (2003) involving 10^6 persons, it is not. Strategies will have to be found to improve calculation speeds by at least a factor 10^4 to make its integration possible without producing excessive run times for the combined model.

7 Future directions

The work reported here has outlined a method to find near-optimal schedules for households. It open up new avenues to realize the promise of the activity-based approach to understand and forecasts not individuals, but households. There are obviously a large number of questions, which need to be addressed before the potential can be realised.

The computational performance needs to be improved before the model can be used in large scale applications. While brute power (faster or more CPUs) help, the solution has to be in smarter search strategies: parameterised rules to limit the number of generations, optimised parameters of the GA itself, using more than just one schedule from the generated populations, recycling solutions as starting points for households which face slightly different conditions (work place and home locations for example).

This effort needs to come first to be able to permit the estimation of the utility functions. Speed is required, as a comprehensive measurement of the goodness of fit between observed and simulated schedules itself requires substantial computing efforts (Joh, 2004) in itself. Even for models without random parameters, the schedules will have to be generated often before the parameter estimate converges. High speeds will be required to allow extensive tests of different formulations of the utility functions.

At this point, the algorithm does not directly include the monetary expenditures involved for different activity types, or specific activities. It is clear, that this is desirable in the long term, especially if the model were to address the scheduling over multiple days. Still, before this can be achieved there is a need to improve our empirical understanding of the link between activity costs and hedonic benefit gained (See also Axhausen et al., 2002 for an examplke of the relevant survey work).

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