# Intra-household interactions in ABMs: Household-level choice set generation and parameter estimation

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# Overview

# Introduction

- **Activity-based models (ABMs)**: Activity-based models portray how people plan their activities and travels over a period of time.
- Traditional ABMs treat individuals as **isolated entities**.
- Individuals do **not** plan their day in **isolation** from other members of the household.
- Various **interactions**, **time arrangements**, **constraints**, and **group decision-making** affect the activity schedules of individuals.

Hence, models dealing with individual choices need to be revisited to take into account the intra-household interactions.

# Example intra-household interactions

- **What are some examples of intra-household interactions?**
  - Individuals in a household synchronise their schedules to create time window overlaps for **joint activities**.


*Joint participation in a recreational activity*

*A family dinner at home*

# Example intra-household interactions

- **What are some examples of intra-household interactions?**
  - Household members **coordinate their travels** as well.

*Escorting children*

*Sharing a ride*

# Example intra-household interactions

- **What are some examples of intra-household interactions?**
  - The members of a household also **share responsibilities and resources** with each other to satisfy household needs.

*Sharing household maintenance responsibilities*

*Sharing resources*

# Research question 1

- How to incorporate **in-home** and **out-of-home activity scheduling** in a **single** scheduling model with **intra-household interactions**? (Rezvany et al. 2023)
  - An econometric ABM framework for joint simulation of in- and out-of-home activities, capturing intra-household interactions.

Rezvany, N., Bierlaire, M. Hillel, T. (2023), 'Simulating intra-household interactions for in- and out-of-home activity scheduling', Transp. Res. Part C Emerg. Technol. 157.'

# Household-level OASIS with interactions: Choices in household scheduling

- Econometric ABM, assuming agents choose their schedules such that the utility that the household gains is maximised.
- Activity scheduling is explained as a result of discrete and continuous choices treated jointly (e.g. activity participation, start time, duration, location, transport mode, accompaniment).

# Background: Household-level OASIS with interactions

- A mixed-integer utility optimisation approach.
- Objective: Maximise the household utility.

$$\max \sum_{n=1}^{n=N_m} \sum_{a_n \in A^n} w_n \; U_{a_n}$$

- Subject to set of schedule continuity constraints and household-level constraints, such as:
  - Allocation of the resources to household members,
  - Sharing household maintenance responsibilities,
  - Joint participation of household members in activities, and
  - Escorting.

# Background: Household-level OASIS with interactions

- Household-level daily schedule **simulation** framework, **explicitly** accommodating **multiple interactions**:
    - Adopts the **Optimisation-based Activity Scheduling Integrating Simultaneous choice dimensions (OASIS)** framework (Pougala et al. 2021).
    - **Simultaneous simulation** of different choice dimensions.
    - **Group decision-making** paradigm.
    - **Explicit** interactions.
        - Ensures consistency of choices.
    - **Multiple interaction** dimensions.
    - High level of **flexibility**.

# Motivation: Operationalisation considerations

- Econometric ABMs assume agents schedule activities to **maximise utility**, explained through **discrete choices**.
- Using discrete choice models implies the need for **calibration of maximum likelihood estimators of the parameters** of the utility functions.

$$\hat{\theta} = \arg\max L_n(\theta)$$

$$L_n = \prod_{n=1}^{N} \prod_{i \in C_n} P_n(i)^{y_{in}}$$

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- Full choice set in activity-based context is **combinatorial**.

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- Full choice set in activity-based context is **combinatorial**.
- Possible to estimate using only a **sample of alternatives**.

# Research question 2

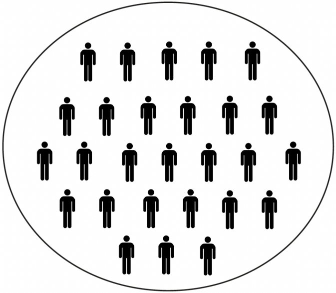
Gap: Defining a representative choice set for household activity pattern problem, necessary for operationalising household RUMs.

- Generate choice set of **considered** schedules to **estimate** significant and meaningful parameters.
- Efficient exploration of solution space:
  - High probability alternatives to ensure **robust parameters estimates**.
  - Low probability alternatives to **reduce parameter bias**.
- Aims to generate behaviourally sensible parameter estimates, estimated on ensemble of schedules with **consistent alternatives** for all household members. $\rightarrow$ enhance model realism in capturing household dynamics.

# Methodology

- **Parallel generation** for all agents.
- Ensures **inter-agent validity** of alternatives in the choice-set.
- Generates ensemble of **clusters** of schedules with **consistent alternatives** for all agents.
- Adopts a **Metropolis-Hastings** based sampling algorithm to explore the **solution space** (Pougala et al. 2021).

# Household choice set generation: General scheme



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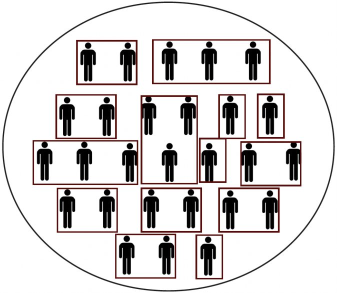

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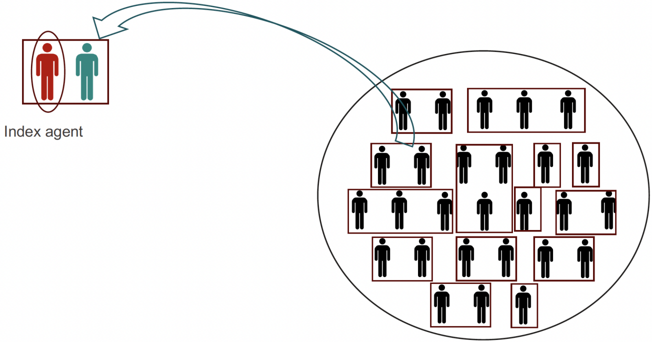

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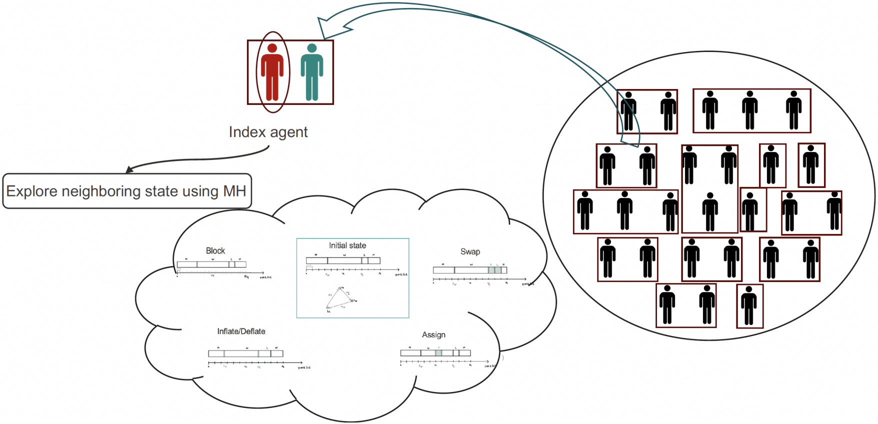

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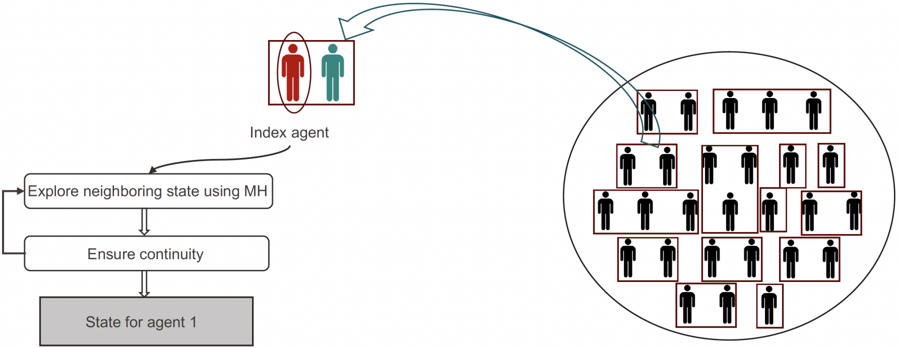

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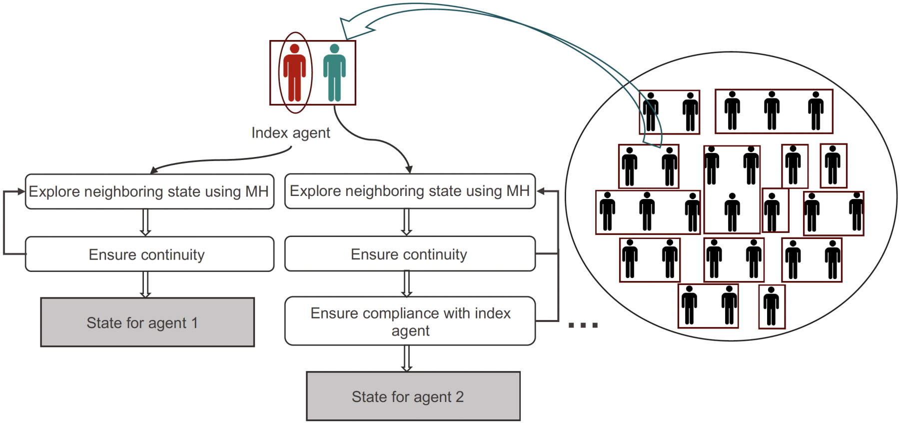

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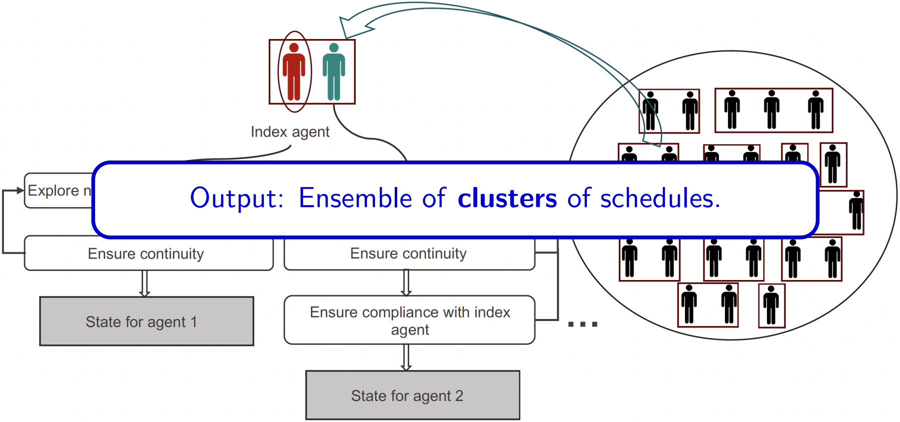



Output: Ensemble of **clusters** of schedules.

# Household choice set generation

1. The **choice set** of **all agents** in a **household** generated **in parallel**.
   - The **relation** between **individuals** and **their household** is **lost** in **individual-level** choice-set formations, leading to **separate choice set formation** procedures with **no feedback** between them.

# Household choice set generation

2. Move from individual utility function to **household utility function**.

$$\text{HUF} = \sum_{n=1}^{n=N_m} w_n \; U_n$$

# Household choice set generation

3. Ensure possible interaction aspects are captured in **utility function**.
   - Utility of a schedule:

$$U_n = \sum_{a_n \in A^n} \omega_{a_n} U_{a_n}$$

   - For agent $n$, considering activity $a_n$:

Utility purely associated with participation in activity, irrespective of timing and trips

Duration deviations

$$U_{a_n} = U_{a_n}^{partic} + U_{a_n}^{start} + U_{a_n}^{duration} + \sum_{b_n \in A^n} U_{a_n,b_n}^{travel} + \varepsilon_{a_n}$$

Start time deviations

Travel from activity $a_n$ to $b_n$

$$U_{a_n}^{partic} = U_{a_n}^{const} + U_{a_n}^{joint} + U_{a_n}^{escort}$$

Joint activity participation

Escort

# Household choice set generation

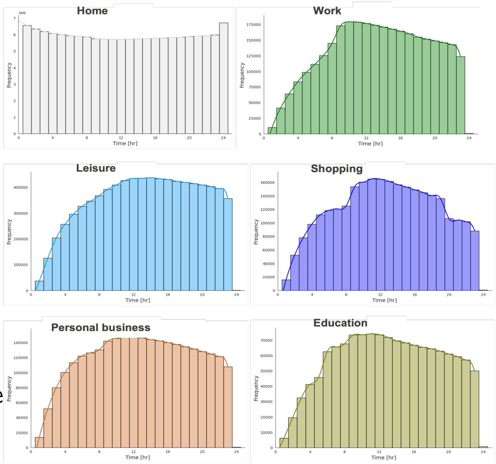
4. **Operators** to **modify choice dimension aspects** related to **household scheduling**, such as **activity participation mode (solo/joint)**.
5. Individual and household **socio-demographic** characteristics are preserved and reported in the generated choice-set.
   - Enables testing model specifications containing socio-demographic variables.

# Case study

- **Sample data**:
  - 2018 – 2019 UK National Travel Survey (NTS).
  - Sample of 2-membered households of 2 adults: 3126 households.
  - Activity participation modes (solo/joint) extracted from the data, using set of rules inspired by Ho & Mulley (2013).
- **MH Choice set generation**:
  - Generate a choice set of consistent schedules with MH algoritm.
  - MH setup: $1'000$ iterations, choice set size: 10 alternatives
- **Parameter estimation**:
  - Discrete choice model: specification with interaction of socio-economic attributes.
  - Activity-specific constants.
  - Activity-specific penalties.
- **Schedule simulation**

# Results: Distribution of activity participation across different hours of the day in generated sample

- **Distinct peak** activity times for **work**.
- **Leisure**: more spread-out pattern.
    - Reflect more scheduling flexibility.
- **Home**:
    - **Peak** at **midnight** (common resting period).
    - **Decline** (begin of day, participate in out-of-home activities).
    - **Gradual increase** towards the **evening** (return home after daily activities).



# Example generated alternative with joint participation

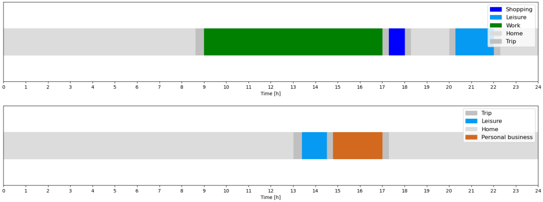



Figure: Initial schedules for agents in a household

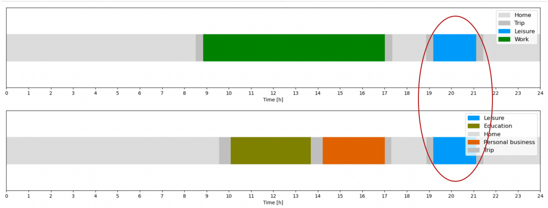
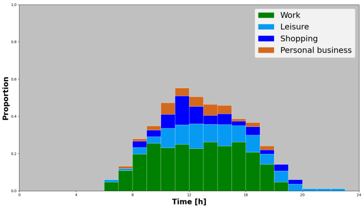



Figure: Example generated schedules for the agents in the household

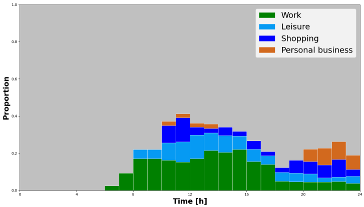
# Estimation

| Name | Value | Rob. Std Err | Rob. t-test | p-value |
|---|---|---|---|---|
| Leisure:joint_partic_noCar | -0.364 | 0.214 | -1.7 | 0.0885 |
| Leisure:joint_partic_twomoreCar | -0.262 | 0.123 | -2.13 | 0.0328 |
| Education:constant | 2.35 | 0.617 | 3.81 | 0.000139 |
| Education:early | -2.13 | 0.645 | -3.3 | 0.000979 |
| Education:late | -0.457 | 0.166 | -2.86 | 0.00422 |
| Education:long | -1.21 | 0.224 | -5.41 | 6.14e-08 |
| Education:short | -0.728 | 0.133 | -5.47 | 4.54e-08 |
| Leisure:constant | 3.22 | 0.146 | 22 | 0 |
| Leisure:early | -0.459 | 0.0324 | -14.2 | 0 |
| Leisure:joint_partic | 0.244 | 0.109 | 2.25 | 0.0246 |
| Leisure:late | -0.176 | 0.0169 | -10.4 | 0 |
| Leisure:long | -0.322 | 0.0188 | -17.2 | 0 |
| Leisure:short | -0.486 | 0.0607 | -8 | 1.33e-15 |
| Personal business:constant | 3.77 | 0.239 | 15.8 | 0 |
| Personal business:early | -0.75 | 0.107 | -7.03 | 2.06e-12 |
| Personal business:late | -0.326 | 0.0492 | -6.62 | 3.51e-11 |
| Personal business:long | -0.533 | 0.0497 | -10.7 | 0 |
| Personal business:short | -3.6 | 0.853 | -4.22 | 2.44e-05 |
| Shopping:constant | 5.61 | 0.207 | 27.1 | 0 |
| Shopping:early | -1.32 | 0.13 | -10.2 | 0 |
| Shopping:late | -0.237 | 0.0395 | -6 | 2.02e-09 |
| Shopping:long | -0.634 | 0.0438 | -14.5 | 0 |
| Shopping:short | -4.67 | 0.654 | -7.14 | 9.34e-13 |
| Work:constant | 5.67 | 0.231 | 24.5 | 0 |
| Work:early | -0.738 | 0.0839 | -8.8 | 0 |
| Work:late | -0.423 | 0.0559 | -7.56 | 4.04e-14 |
| Work:long | -0.747 | 0.0501 | -14.9 | 0 |
| Work:short | -0.576 | 0.0426 | -13.5 | 0 |

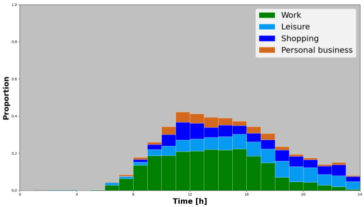
# Simulation outputs: First results




Data




Isolated agent model




Household model

# To conclude

Summary:

- Algorithm for household-level choice set formation.
- Estimate parameters of household-level OASIS using sampled choice set.
- Simulation of daily activities.

Future work:

- Further investigation on simulation.
- Non-homogenous scheduling preferences across individuals.
- Travel related interaction dimensions, travel parameter estimates.
- Validation techniques.

# Bibliography I

Ho, C. & Mulley, C. (2013), 'Tour-based mode choice of joint household travel patterns on weekend and weekday', *Transportation (Amst).* **40**(4), 789–811.

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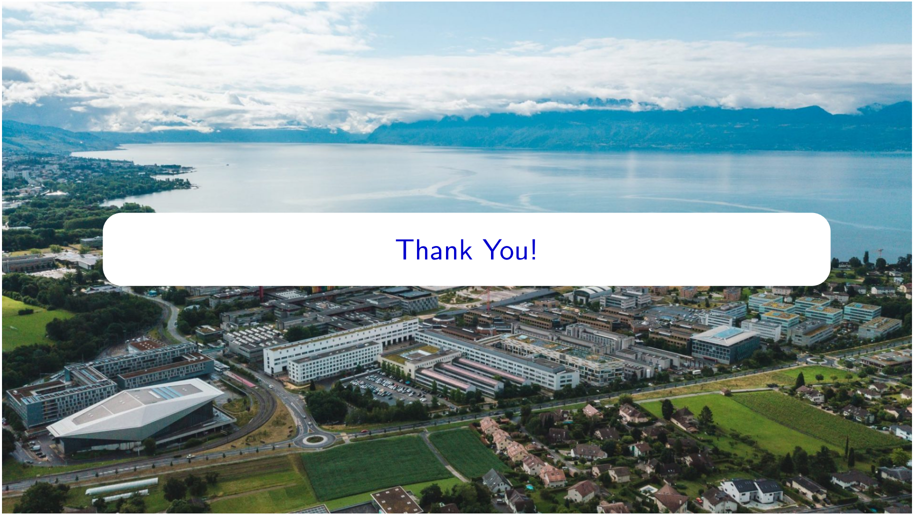

Thank You!