Intra-household interactions in ABMs: Household-level choice set generation

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Outline

- Introduction and motivation
- Background
- Methodological approach and framework
- Case study
- Results and discussion
- To conclude

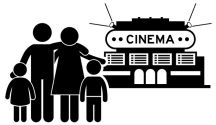
Introduction

- **Activity-based models (ABMs): Activity-based models** portray how people plan their activities and travels over a period of time such as a day.
- 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**, and **constraints** affect the activity schedules of individuals.

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

Example intra-household interactions

- **What are some examples of intra-household interactions?**
  - **Joint activities**:



Joint participation in a recreational activity

A family dinner at home

  - **Coordinate travels:**

Escorting children

Sharing a ride

  - **Share responsibilities and resources:**

Sharing household maintenance responsibilities

Sharing resources

Research question 1

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)
   - A 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.

Background: Household-level OASIS with interactions

- A framework to **simulate** the **daily activity schedules of individuals in a household**, **explicitly** accommodating **multiple interactions**:
  - A mixed-integer utility optimisation approach.
  - Adopts the **Optimisation-based Activity Scheduling Integrating Simultaneous choice dimensions** (**OASIS**) framework *(Pougala et al. 2022).*
  - **Simultaneous simulation** of different **choice** dimensions.
  - **Group decision-making** paradigm.
  - **Explicit** interactions.
    - Ensures consistency of choices.
  - **Multiple interaction** dimensions.
  - High level of **flexibility.**
  - Both **in-** and **out-of-home** scheduling are simulated within the same framework.

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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Enumeration over choice set C_n

- In principle, **maximum likelihood estimation** requires **complete enumeration of the alternatives** in the **choice set**.
- The **full choice set** of alternatives in activity-based context is **combinatorial.**

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Enumeration over sample choice set C_n^*

- In principle, **maximum likelihood estimation** requires **complete enumeration of the alternatives** in the **choice set**.
- The **full choice set** of alternatives in activity-based context is **combinatorial.**
- Possible to estimate the parameters using only a **sample of alternatives**.

Research question 2: Household-level choice set generation

Gap: Defining a **choice set** representative of activity-travel in **household activity pattern problem** is thus, **necessary** for **operationalising household random utility models**.

- 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 → enhance model realism in capturing household dynamics.

Methodology

- **Choice set generation** technique for **household scheduling**, generating an ensemble of schedules with **consistent alternatives** for all household members.
- To **explore** the combinatorial **solution space** of full set of feasible schedules, adopts a **Metropolis-Hastings** based sampling algorithm *(Pougala et al. 2021).*
- **Intra-household interactions** cause **additional choice dimensions**, **time arrangements**, **constraints**, and **group decision-making mechanism**, the interactions should be considered in the choice set formation to ensure **consistency of generated alternatives**.
- Extend this approach to encompass **parallel generation** for all household agents, **household-level choices**, and **time arrangements**.

Metropolis-Hastings based sampling strategy: A brief synopsis

- A strategy to **generate a choice set** containing **only feasible alternatives**.
- Alternatives = full daily schedules.
- Choice set generation modelled as a Markov process.
- Algorithm is **initialised** with a **random state** (e.g. reported schedule in the dataset)
  - **States** are defined as **daily schedules** with **choice dimensions** such as activity participation, timings, location, and transportation mode.
- Explore **neighbouring states**; candidate states generated with **operators.**
  - Operators are heuristics that modify specific aspects of the schedule.
- Check **feasibility** of generated state.
- At each iteration of the random walk, candidate state is accepted or rejected with a given acceptance probability defined by the modeller.

- **Output:** An **ensemble of schedules**, to estimate significant and meaningful parameters.

Household choice set generation

1. The **choice set** of **all individuals 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.

"How would the algorithm work now?"

- Initialisation = schedule of all household members.
- An **individual** is **selected** as **index**.
- The **combinatorial solution space of index person** is **explored** using the **Metropolis-Hastings algorithm**.
- **Their state** is then used as the **benchmark** for **ensuring schedule synchronisations** with **other agents** in the household → ensures schedules compatibility
- Solution space of other household individuals is explored using the MH technique, ensuring being compliant with **household-level,** as well as individual-level **validity constraints**.

- **Output:** An ensemble containing **clusters of schedules** for all individuals in a household.

Household choice set generation

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

agent priority parameter

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

Household choice set generation

3. Ensure that the possible interaction aspects are captured in the **utility function**.

- Utility of a schedule: $\mathrm{U_n} = \sum_{a_n} \omega_{a_n} U_{a_n}$
  - For individual n, considering activity a_n:

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

Duration deviations

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

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

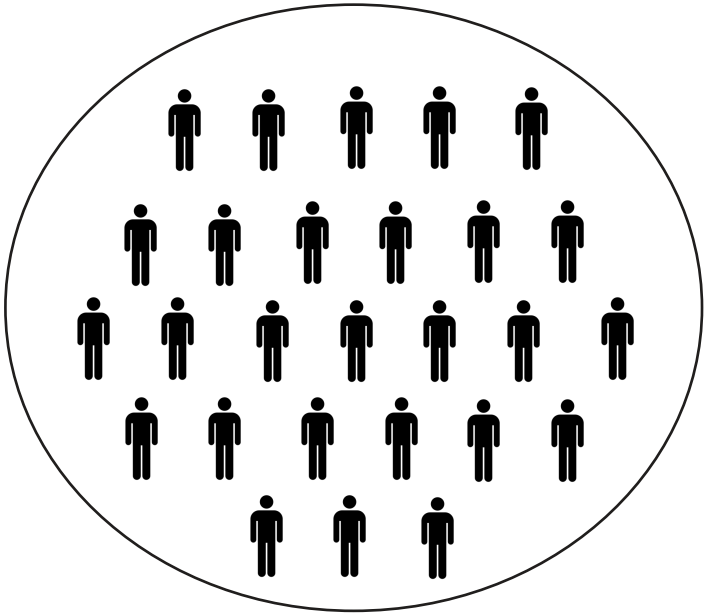
Escort

Household choice set generation

4. Operators to **modify choice dimension aspects** related to **household scheduling**, such as **activity participation mode** (ω_{partic_mode}).

- Changes the participation mode p_{a_n} of a randomly selected activity a_n for individual n, with a given probability P_{partic_mode}.
- In case of change in participation mode, the **schedule synchronisation** among agents in the household should be **checked** and the corresponding activity is planned in the schedule of accompanying member(s) with the same timings and participation mode.

Household choice set generation: General scheme



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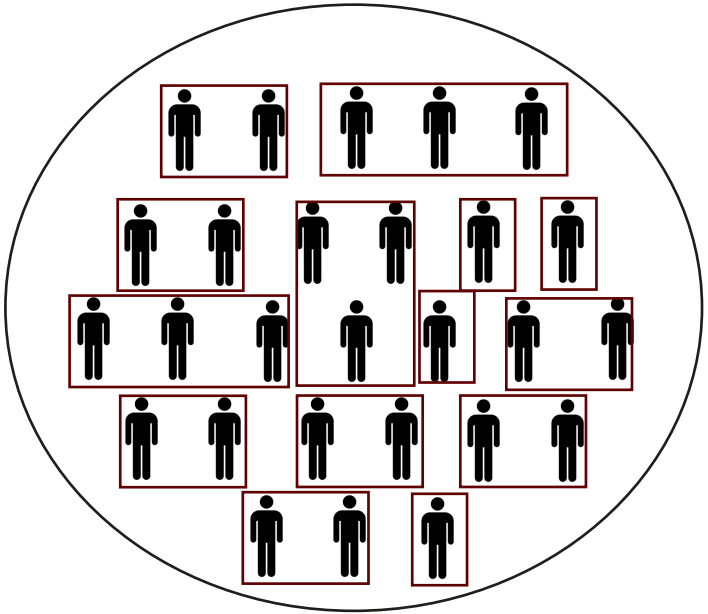

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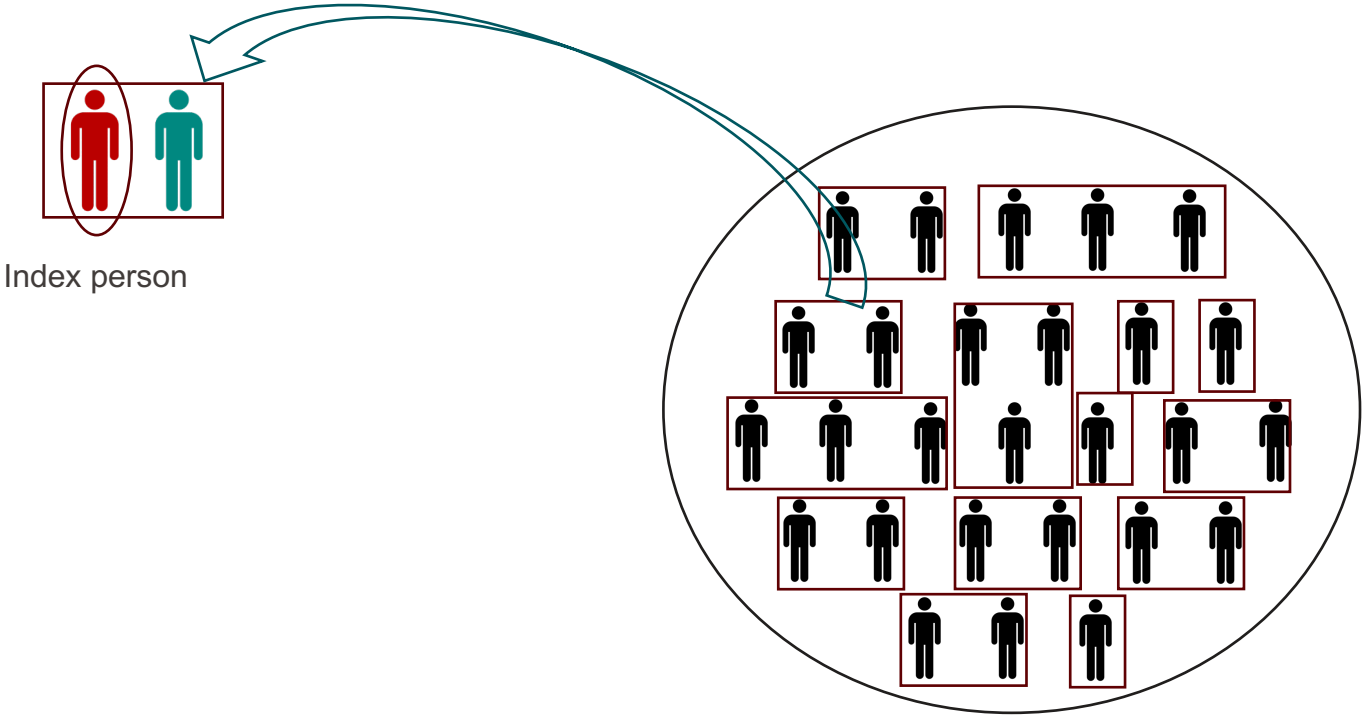

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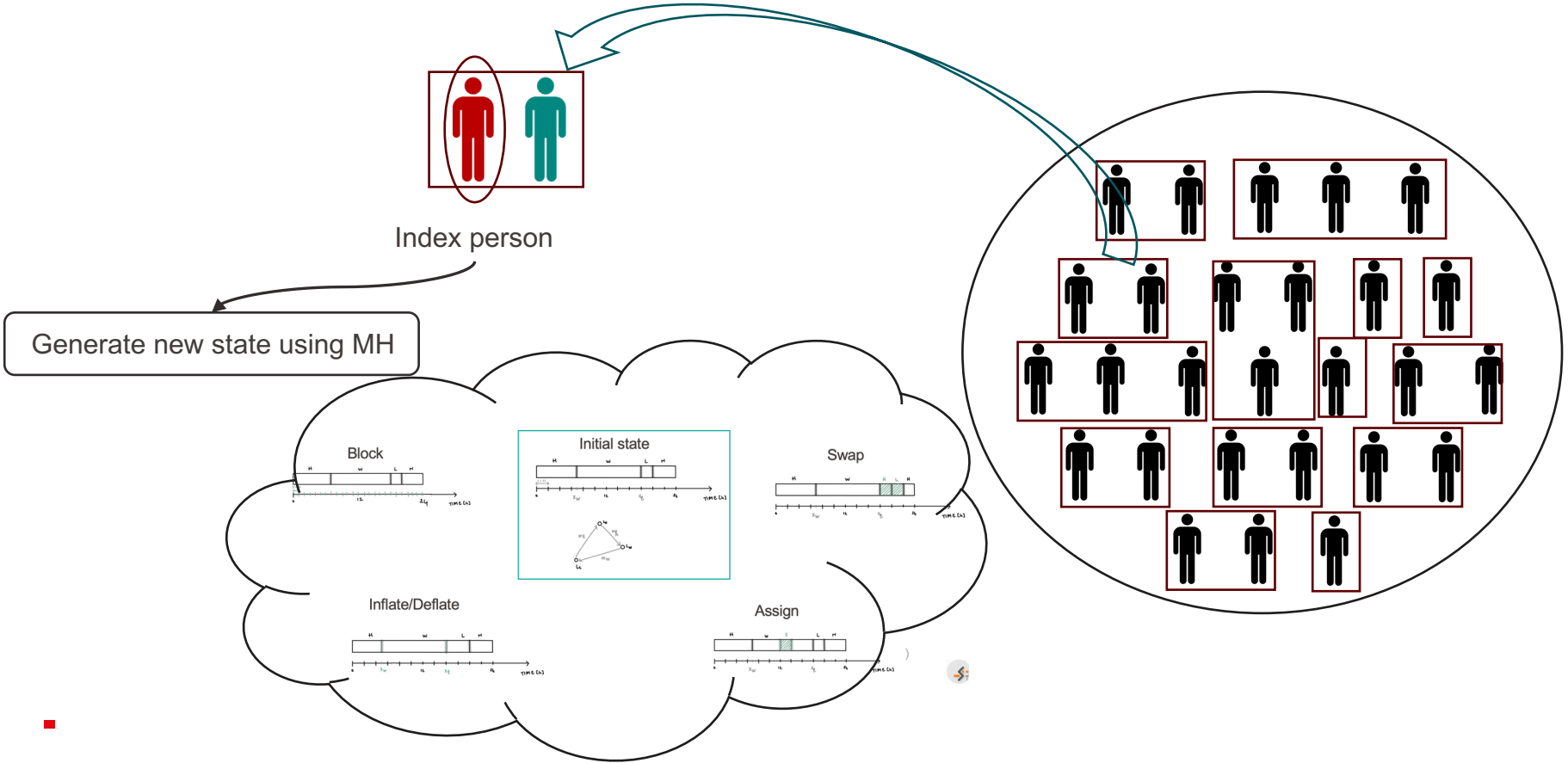

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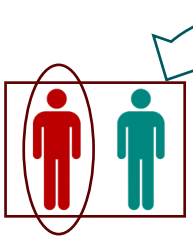
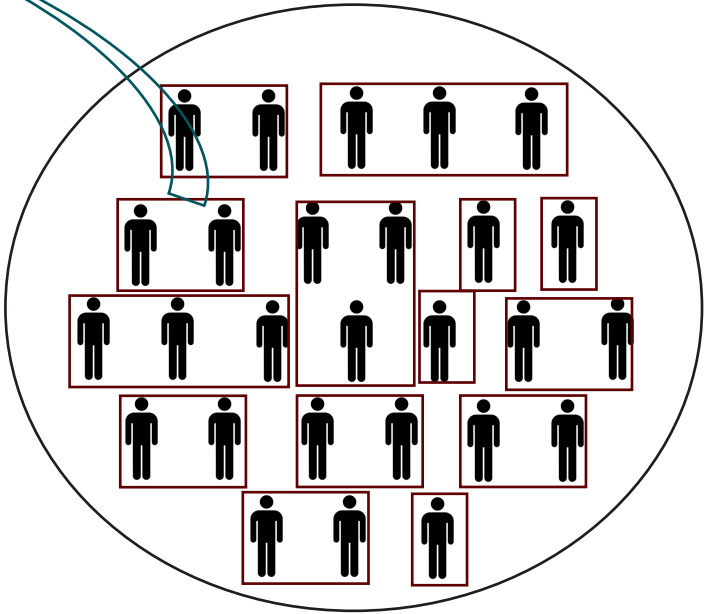


Index person

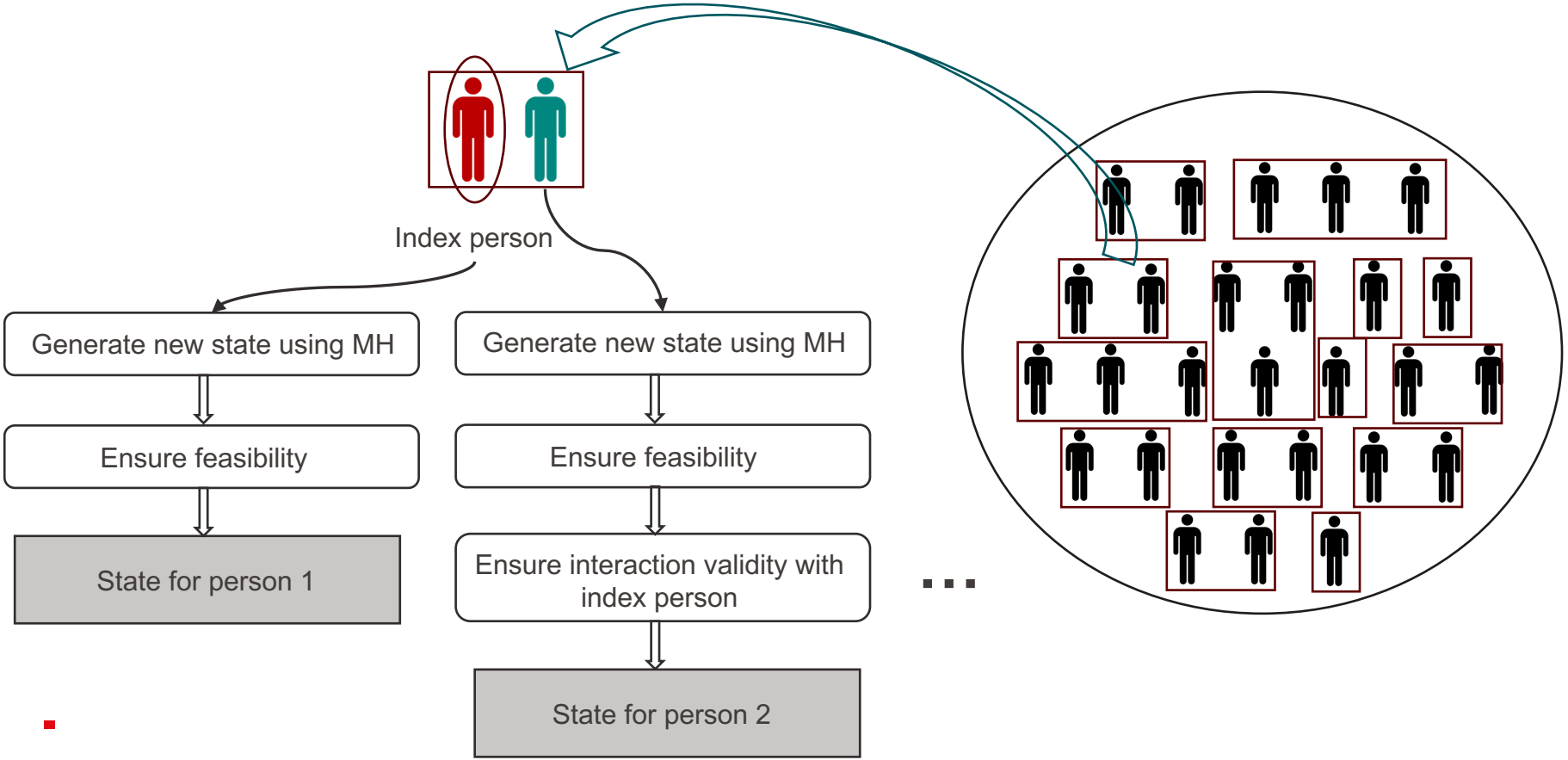


Generate new state using MH

Ensure feasibility

State for person 1

Household choice set generation: General scheme

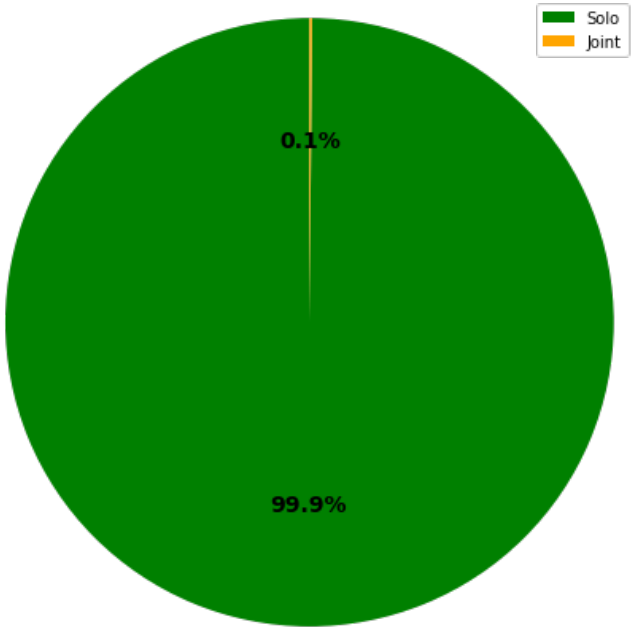


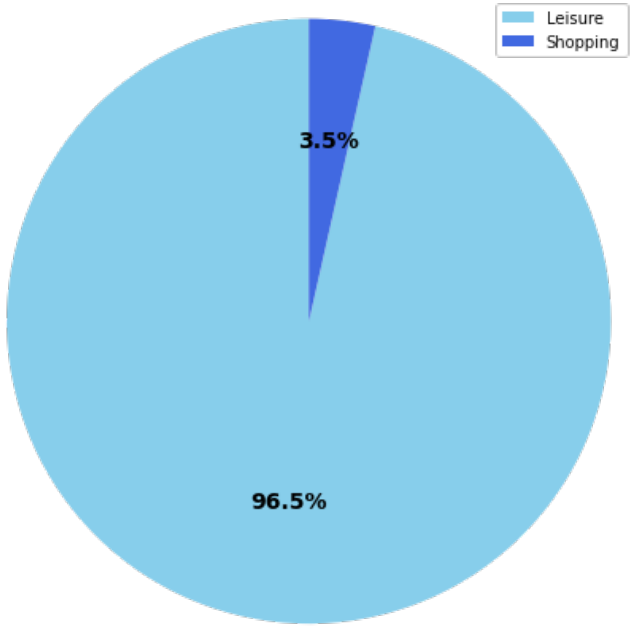
Case study

- Utilising MH algorithm to generate the choice sets, we estimate the parameters of Household-level OASIS.
- **Sample data:**
  - 2018-2019 UK National Travel Survey (NTS).
  - A sample of schedules for **2-membered households** of 2 adults.
  - A sample of schedules for 500 households is selected.
  - Activity participation modes (solo/joint) are extracted from the data, using a set of rules inspired by Ho & Mulley (2013).
- **MH setup:**
  - 1’000 iterations
  - Choice set size = 100 alternatives
  - Initial state: observed schedule from dataset
  - Operators: block, assign, swap, partic_mode, metaoperator

Analysis of activity participation modes in NTS data

- **Only 0.1%** of activities in diaries are performed **jointly**.
- Among which **Leisure** activities make a **substantial** portion (97%) of joint activities.

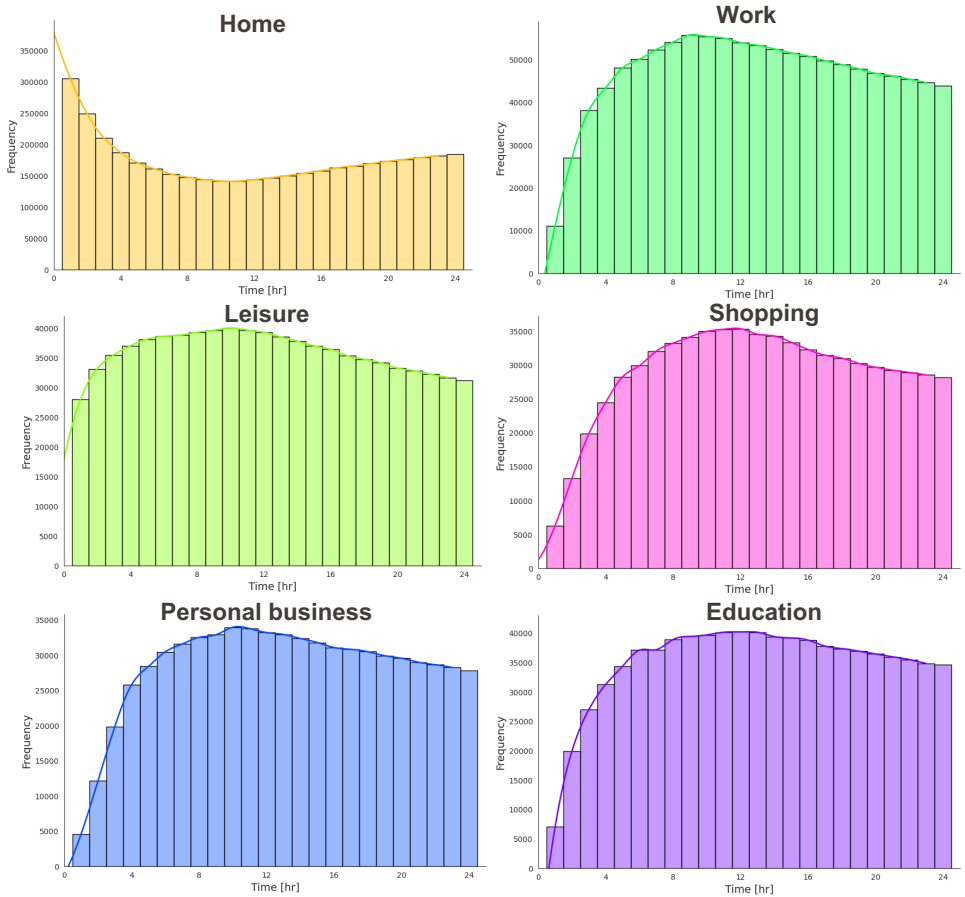




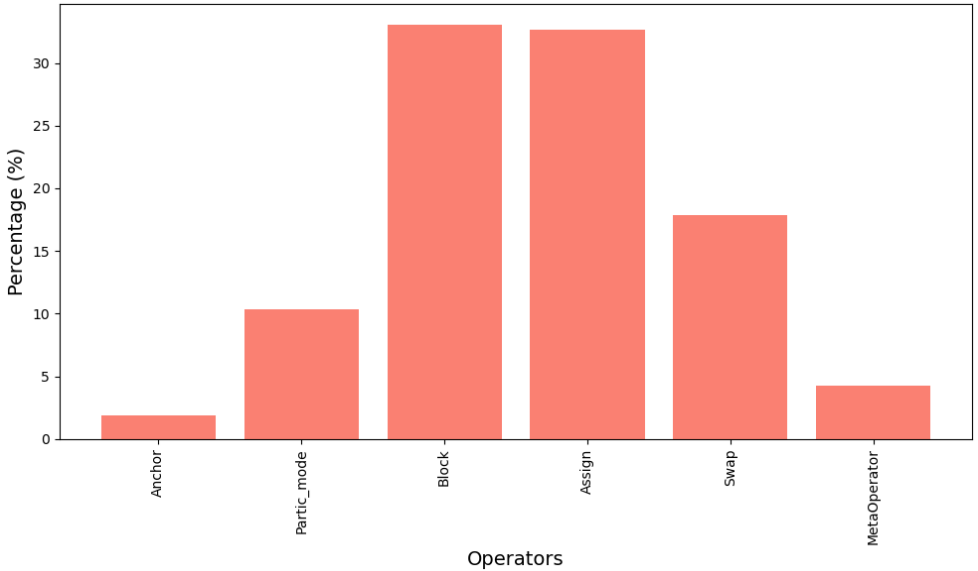
Results:

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

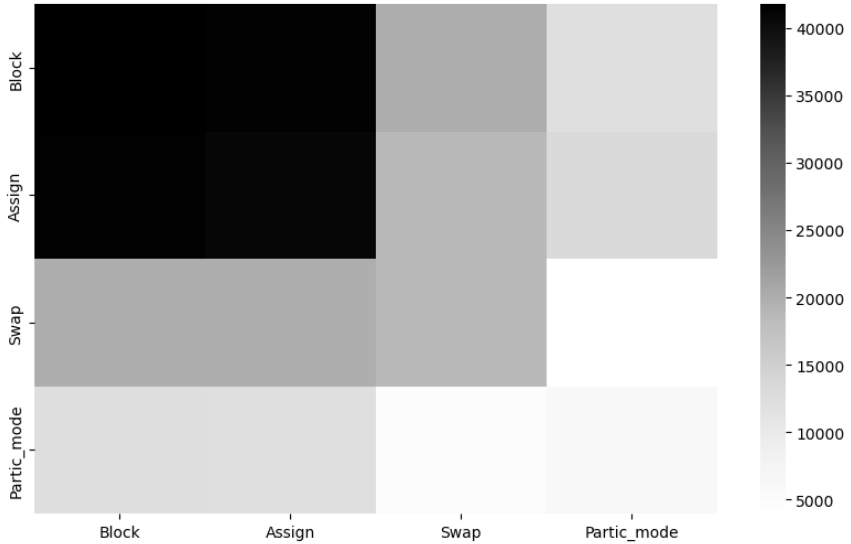
- **Distinct peak** activity times for **work**.
- **Leisure:** more spread-out pattern.
  - Reflecting more scheduling flexibility and less constrained feasible activity hours.
- **Home:**
  - **Peak** at **midnight** (common resting period).
  - Sharp **declines** (begin of day, participate in out-of-home activities).
  - **Gradual increase** towards the **evening** (return to home after the daily activities).



Results:
Operators



Frequency of accepted operator changes



Typology of accepted combinations of Meta-operator

Results:
Estimation

- Reference: ASC Home = 0
- Model specifications:
  - Activity-specific constants
  - Activity-specific penalties
- For the sake of simplification, travel parameters not estimated to focus solely on activity parameters.

Notes:

- ⊕ ASC: baseline preference for doing an out-of-home activity
- Shopping > Personal business > Work > Leisure
- ⊖ penalties
- Most parameter estimates statistically significant (p-value < 0.05).
- Zero p-value: parameter is highly statistically significant predictor
- Duration parameter for Leisure not significant; not particularly time constraining activity.
- Joint_partic positive and significant; highlight social aspect of leisure.

Parameter	Param. estimate	Rob. std err	Rob. t-stat	Rob. p-value
Leisure: ASC	2.26	0.0874	8.71	0
Leisure: joint_partic	0.259	8.71	-1.84	0
Leisure: early	-0.778	0.0874	-8.9	0
Leisure: late	-0.737	0.0857	-8.6	0
Leisure: long	0.0095	0.0227	-0.416	0.677*
Leisure: short	-0.14	0.216	0.648	0.517*
Personal business: ASC	4.8	0.682	7.03	2.01e-12
Personal business: early	-0.96	0.113	-8.51	0
Personal business: late	-0.775	0.0977	-7.93	2.22e-15
Personal business: long	-0.547	0.165	-3.31	0.000944
Personal business: short	-1.5	0.507	-2.95	0.00316
Shopping: ASC	7.45	0.944	7.89	2.89e-15
Shopping: early	-1.23	0.166	-7.43	1.09e-13
Shopping: late	-0.697	0.0927	-7.52	5.28e-14
Shopping: long	-0.803	0.165	-4.88	1.08e-06
Shopping: short	-3.43	0.789	-4.35	1.36e-05
Education: ASC	1.38	1.07	1.29	8.15e-04
Education: early	-2.36	0.58	-4.06	3.02e-02
Education: late	-0.399	0.174	-2.29	4.24e-02
Education: long	-2.44	0.989	-2.47	1.44e-03
Education: short	-1.52	0.257	-5.88	1.36e-05
Work: ASC	4.28	0.476	8.99	0
Work: early	-0.828	0.108	-7.68	1.58e-14
Work: late	-0.45	0.0975	-4.62	3.92e-06
Work: long	-0.272	0.0438	-6.22	5.03e-10
Work: short	-0.828	0.13	-6.39	1.7e-10

* Not statistically significant at 95%

To conclude

Summary:

- Household-level choice set formation
- Estimate household-level OASIS using sampled choice set

Future work:

- Investigate other household structures
- Estimate relative influence of individuals
- Socio-demographic variables (e.g. as presence of children, family structure, work characteristics of individuals) on schedule choices; interaction with activity participation
- Non-homogenous scheduling preferences across individuals
- Investigate model stability
- Validation techniques

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