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OpenSHS: Open Smart Home Simulator

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Outline

- Background
- Architecture
- Implementation
- Analysis
- Limitations
- Summary

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Related work (1)

- Datasets generated by:
  - Real Smart Home Test Beds
    - Need a lot of equipment
    - Takes a lot of time
  - Smart Home Simulation Tools
    - Model-Based approach
    - Interactive approach
    - Most of these models are not available in the public domain

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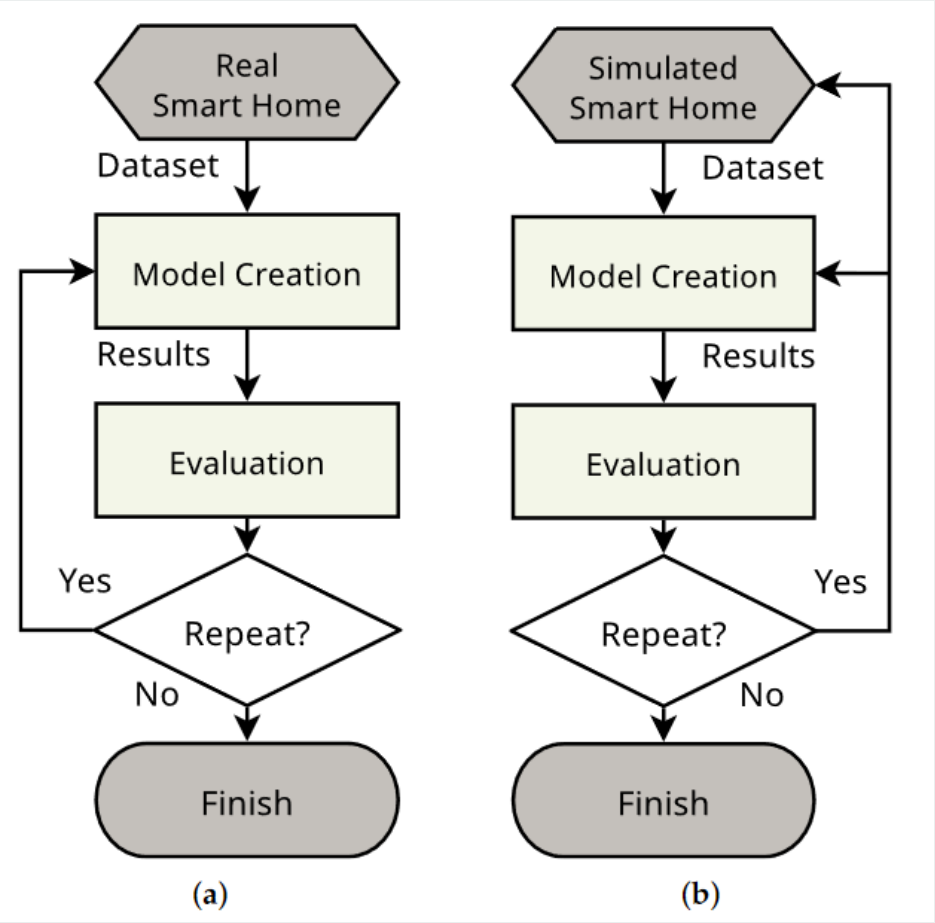
Related work (2)

- If the results **revealed the need to change** something, this is usually a **costly** and **infeasible** choice to make
  - The researcher can only be able to tweak the model parameters
- With a simulated smart home, this can be easily done, and the researcher can go back and modify the smart home design



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Related work (3)

- Model-Based Approach
  - Uses pre-defined models of activities to generate synthetic data.
    - These models specify the order of events, the probability of their occurrence and the duration of each activity.
  - Facilitates the generation of large datasets in a short period
  - BUT!
    - Sacrifices the granularity of capturing realistic interactions
    - It cannot capture unexpected accidents that are common in real homes

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Related work (4)

- Interactive Approach
  - Can capture more interesting interactions and fine details
  - This approach relies on having an avatar that can be controlled by a researcher, human participant or simulated participant.
  - The avatar moves and interacts with the virtual environment, which has virtual sensors and/or actuators.
  - The interactions could be done passively or actively.
  - BUT!
    - It is a time-consuming approach since all interactions must be captured in real time.

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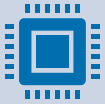
Motivation

The cost to build real smart homes and the collection of datasets for such scenarios is **expensive**/infeasible

Finding the optimal placement of the sensors, the appropriate participants and privacy and ethical issues

The majority of the existing tools are **not available** in the public domain as an **open-source project**



Most of the publicly-available simulation tools **lack** the flexibility to **add** and **customise** new sensors or devices

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Challenges

- Having a continuous capturing mechanism for the sensors' data.
- An appropriate annotation method for the inhabitants' activities.
- Can they offer:
  - Flexibility and scalability to add new/customised types of smart devices
    - Change their generated output(s), change their positions within the smart home
  - Fast dataset generation
  - The ability to pause and fast-forward the simulation to enable more accurate activity annotation.

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Contribution

- OpenSHS is a new hybrid, open-source, cross-platform 3D smart home simulator for dataset generation
  - Based on Blender and Python
- OpenSHS combines advantages from both interactive and model-based approaches.
  - This approach reduces the time and efforts required to generate simulated smart home datasets
- OpenSHS includes a library of smart devices that facilitates the simulation

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Architecture

Follows a hybrid approach

- Model based approach
- Interactive approach

Three main phases:

- Design
- Simulation
- Aggregation

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Experiment

- A virtual smart home environment consisting of:
  - a bedroom
  - a living room
  - a bathroom
  - a kitchen
  - an office
- Each room is equipped with several sensors
  - Totalling 29 sensors of different types.
    - Sample rate: 1 second by default
- The sensors are binary, and they are either on or off at any given time

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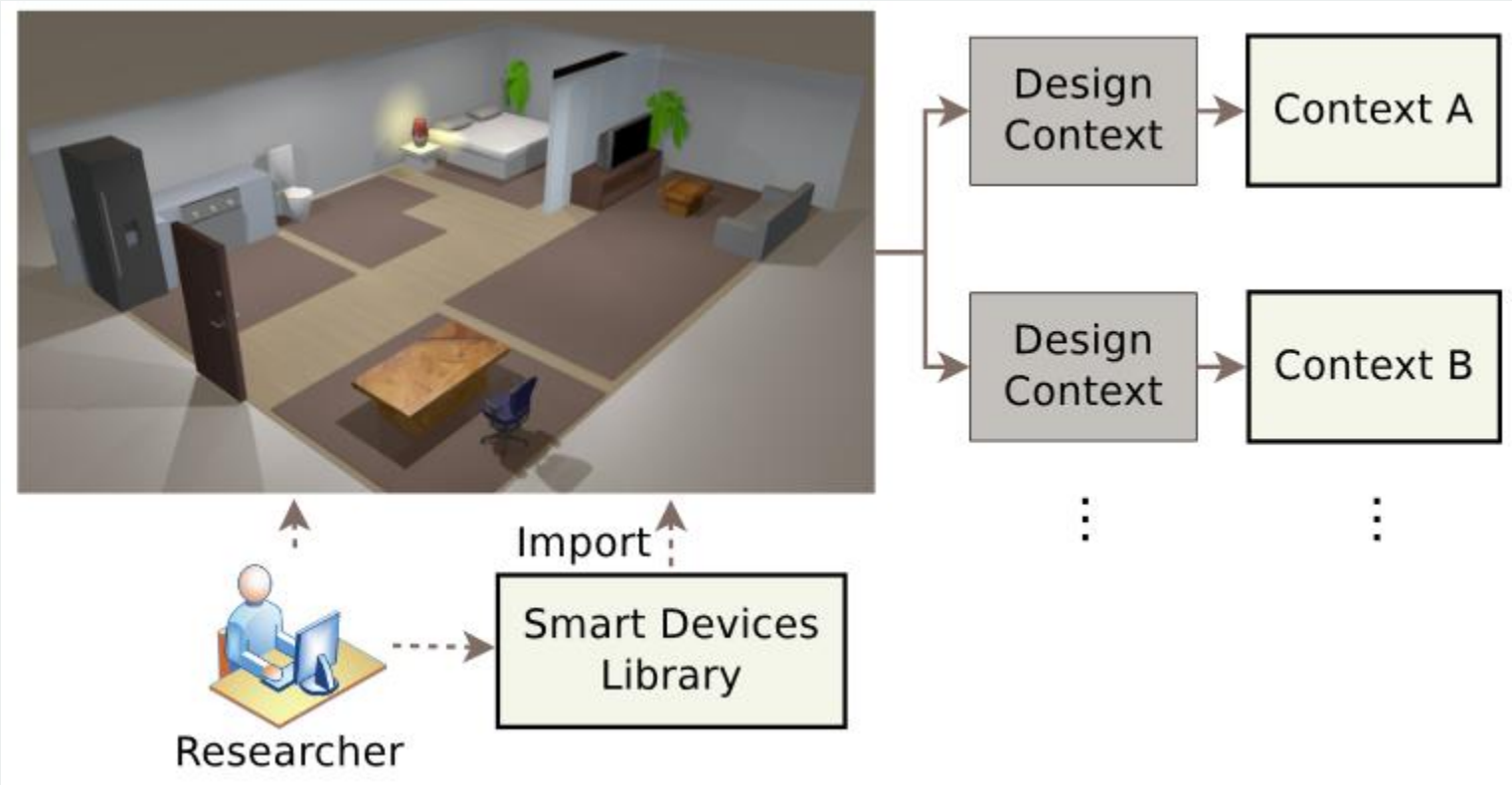
Design phase



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Assigning Activity Labels

- Researchers can define unlimited number of activity labels

- This list represents a sample of activities

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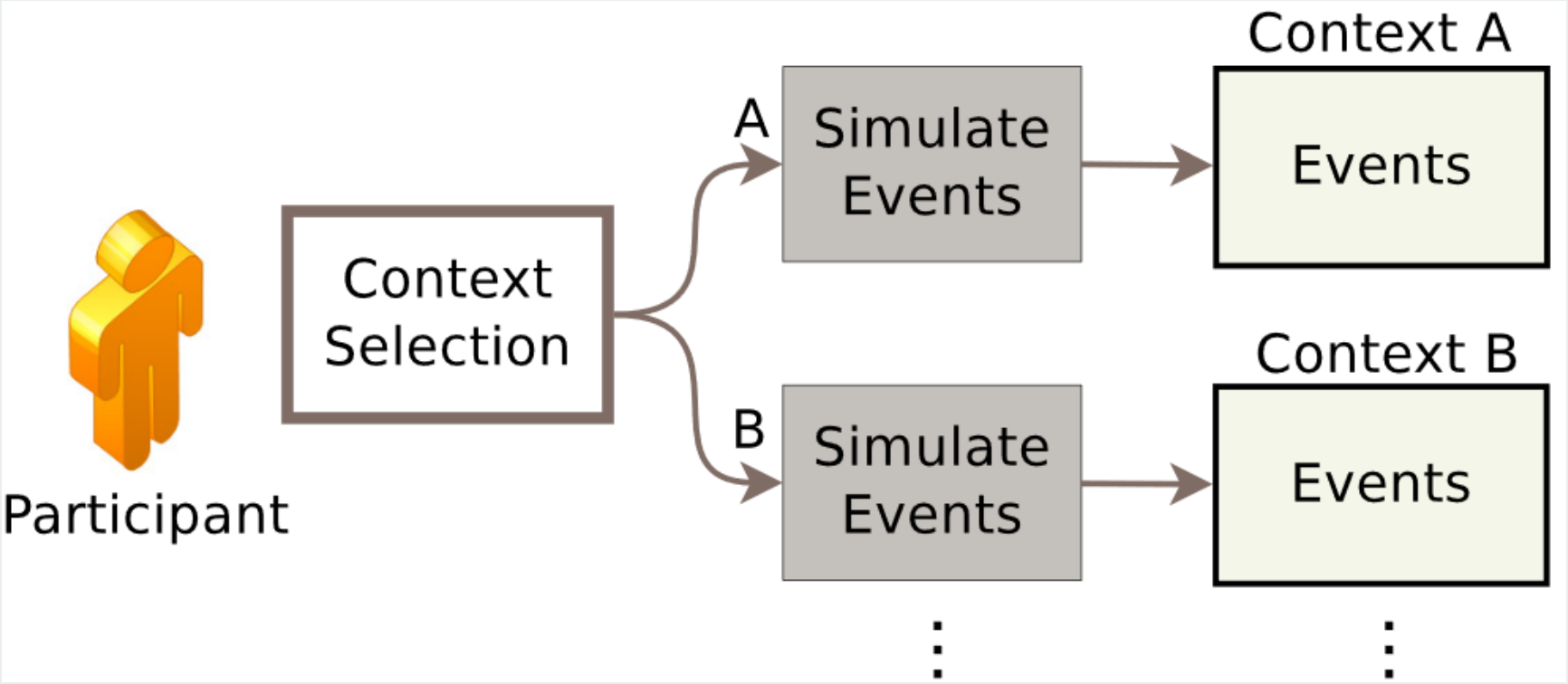
Simulation phase



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Fast forward mode

- OpenSHS allows the participant to control the time span of a certain activity
- The participant wants to watch the TV for a period of time and does not want to perform the whole activity in real time
- The participant can initiate that activity and specify how long this activity lasts.
- The tool will simply copy and repeat the existing state of all sensors and devices during the specified time period.

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Example

- A set of five samples with their activity labels for a certain context.
  - The first sample has five activities and so on
- When the researcher aggregates the final dataset, the samples of every context are grouped by the number of activities in each sample.
  - Sample 1 will be in one group and so on

Samples	Activities				
1	sleep	personal	work	eat	other
2	sleep	personal	other		
3	sleep	personal	other		
4	sleep	eat	personal	other	
5	sleep	eat	personal	other	

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Activities Labelling

- During a simulation and before transitioning from one activity to another, the participant will choose the new activity from the available list.
- The sample consists of three activity labels
  - ‘sleep’, ‘personal’ and ‘other ’.
- Each activity label corresponds to a set of sensors’ readings.
  - The small circles correspond to an ‘ON-state’ of that sensor.

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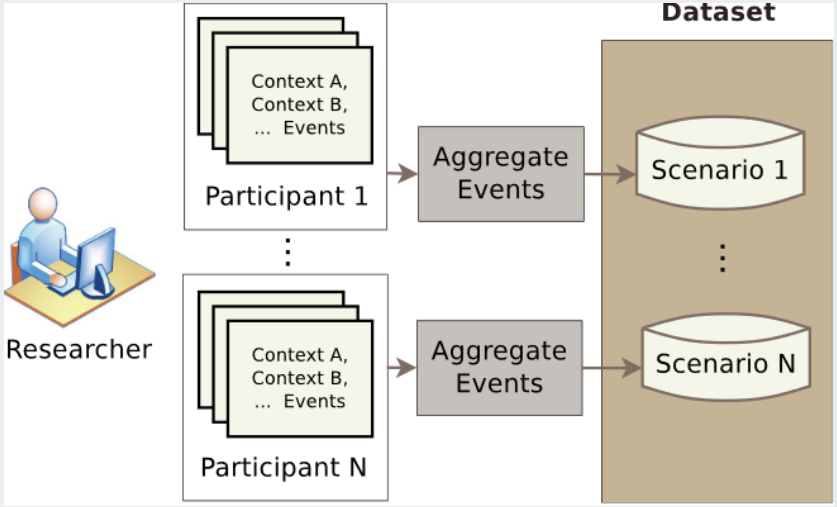
Aggregation Phase



- Provides a solution for the generation of large datasets in short simulation time.
- Aggregates the participants' generated sample activities to produce the final dataset.
- The results form a pool of sample activities for each context.
- An algorithm is developed to replicate the output of the simulation phase by drawing appropriate samples for each designated context.
- This feature encapsulates the model-based approach's advantage with the interactive approach adapted by the simulation phase,
  - OpenSHS combines the benefits of both approaches

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Event replication

- Instead of having the user simulating the activities for extended periods of time, the user simulates only a particular context in real time.
- Assume we are interested in an ‘early morning’ context, and we want to capture the activities that the inhabitant is doing in this time frame,
  - What is usually done in the weekdays compared to the weekends in the same context (the ‘early morning’ context).
- The user will only perform sample simulations of different events in real time.
  - The greater the number of samples simulated, the richer the generated dataset will be.

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Replicated copies

- Then a random group will be chosen, and from that group, a sample will be made for each activity.

i	Activity 1	Activity 2	Activity 3	Activity 4	Activity 5
1	**sample 1** sleep	**sample 1** personal	**sample 1** work	**sample 1** eat	**sample 1** other
2	**sample 4** sleep	**sample 5** eat	**sample 5** personal	**sample 4** other	
3	**sample 3** sleep	**sample 3** personal	**sample 2** other		
4	**sample 3** sleep	**sample 3** personal	**sample 2** other		
5	**sample 5** sleep	**sample 4** eat	**sample 5** personal	**sample 5** other	
6	**sample 1** sleep	**sample 1** personal	**sample 1** work	**sample 1** eat	**sample 1** other
7	**sample 2** sleep	**sample 2** personal	**sample 2** other		
8	**sample 5** sleep	**sample 5** eat	**sample 5** personal	**sample 5** other	
9	**sample 4** sleep	**sample 4** eat	**sample 4** personal	**sample 5** other	
10	**sample 2** sleep	**sample 2** personal	**sample 2** other		

Ten replicated copies based on the samples

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Replication Algorithm

- It is not realistic to aggregate the final dataset by trivially duplicating the contexts samples
- There is a need for an algorithm that can replicate the recorded samples to generate a larger dataset
- The number of unique replicated copies for a single context is calculated by:
  - **G** denotes the number of the groups of unique length of activities
  - **Sg** denotes the number of samples for the group **g**;
  - **A** denotes the number of activities within a sample **Sg**. The total number of unique replicated copies **R** is:

$$\mathcal{R} = \sum_{g=1}^{\mathcal{G}} \mathcal{S}_g^{\mathcal{A}}$$

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Dataset generation

- After running the aggregation algorithm, the researcher can combine all of the scenarios, generated by different participants

Timestamp	Bed Table Lamp	Bed	Bathroom Light	Bathroom Door	...	Activity
2016-04-01 08:00:00	0	1	0	0	...	sleep
2016-04-01 08:00:01	0	1	0	0	...	sleep
2016-04-01 08:00:02	0	1	0	0	...	sleep
2016-04-01 08:00:03	0	1	0	0	...	sleep
2016-04-01 08:00:04	1	1	0	0	...	sleep
2016-04-01 08:00:05	1	0	0	0	...	sleep
2016-04-01 08:00:06	1	0	0	1	...	personal
2016-04-01 08:00:07	1	0	0	1	...	personal
2016-04-01 08:00:08	1	0	1	1	...	personal
2016-04-01 08:00:09	1	0	1	1	...	personal
2016-04-01 08:00:10	1	0	1	1	...	personal
⋮	⋮	⋮	⋮	⋮	⋮	

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Future work

- Include multiple inhabitants support in real time
- More sensors
- Add a floor plan editor
- The labelling of activities is performed by the participant during the simulation phase
  - OpenSHS does not perform automatic recognition of these activities
  - Plan to investigate the possibility of adding automatic recognition of the participants' activities

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Summary

- OpenSHS, a novel smart home simulation tool
- Uses the ability of model-based tools to generate large datasets in a reasonable time
- Keeps the fine-grained interactions that are exhibited by interactive tools
- It can generate seeds of events rapidly
  - A replication algorithm that can extend the simulated events to generate multiple unique large datasets.
- OpenSHS offers partial support for multiple inhabitants.

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Thank you!

Questions?