Duet
Making Localization Work for Smart Homes

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Presenting on behalf of

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The Smart Home Dream

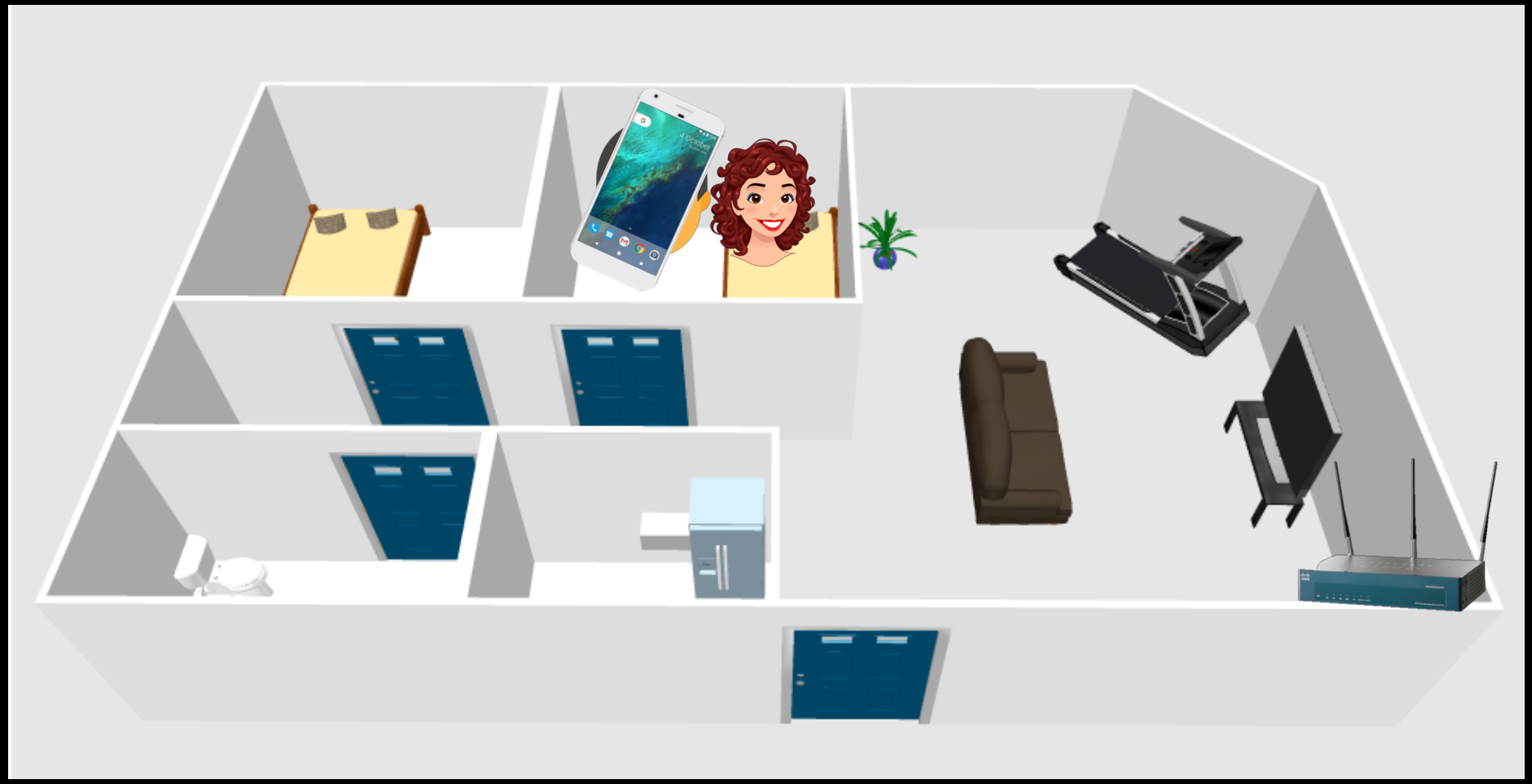
Problem Statement

Smart homes need continuous tracking of location and identity of occupants

Cannot use camera, privacy-invasive

How about RF?

RF-Based Localization



Problem 1: People **Do Not Always** Carry Phones

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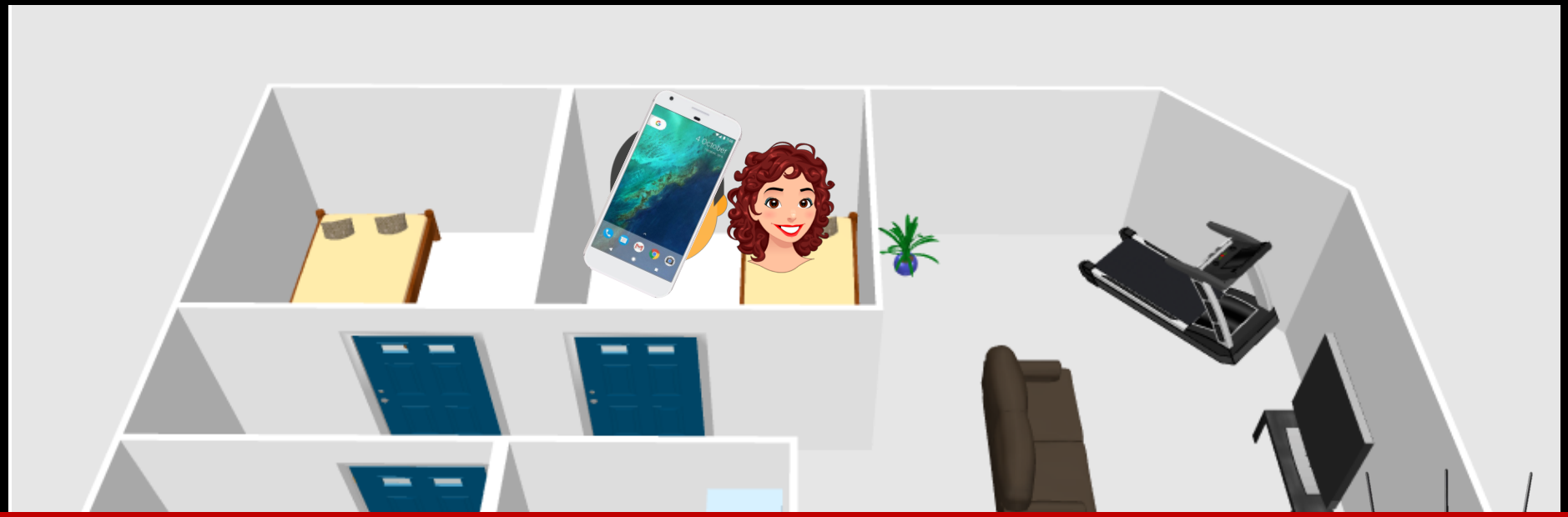

People don’t carry their phone
over 50% of the time

Problem 2: Wireless Signals get Blocked

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RF based location data is:

- Error-prone: Users don’t always have their phone
- Intermittent: Homes have several blockages for RF signals (TV, bathroom tiles, etc)

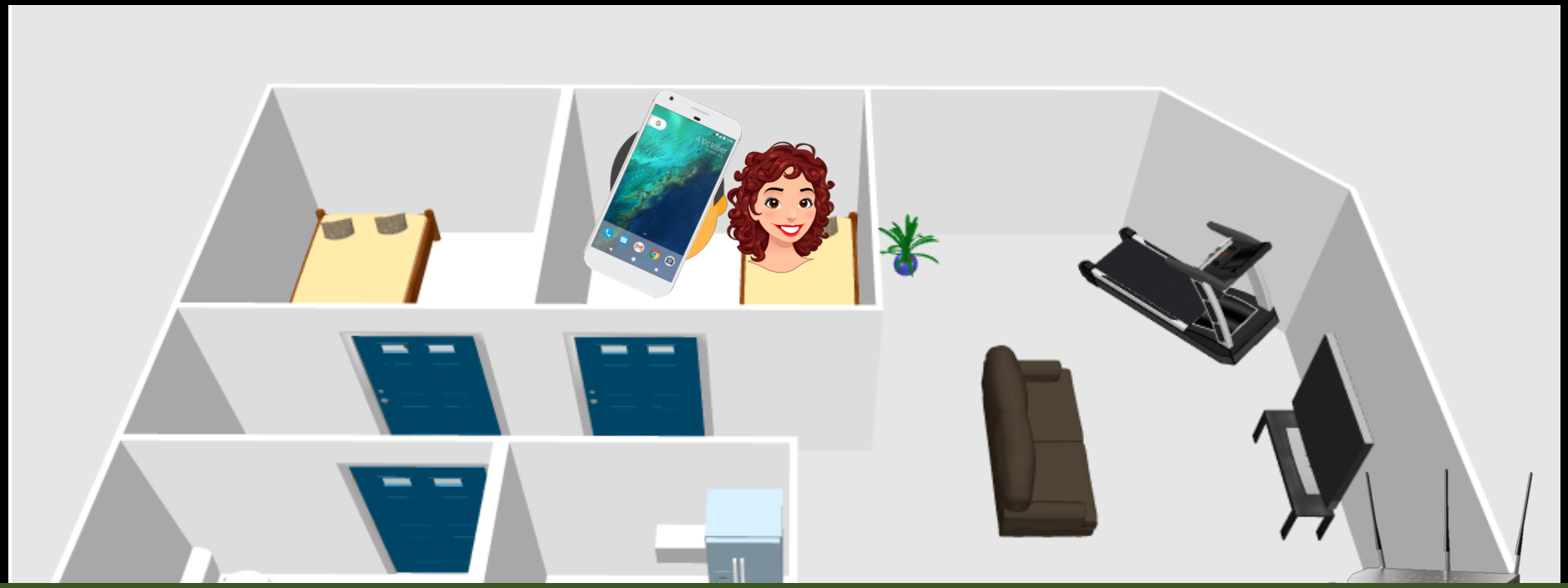
Problem Statement

Smart homes need continuous tracking of location and identity of occupants
in spite of error-prone and intermittent RF data

Duet

- Delivers continuous tracking of occupant location and identity with error-prone, intermittent RF data
  - Error-prone data: Combine information from device-free and device-based systems
  - Intermittent data: Use probabilistic logic to encode spatio-temporal constraints
- Evaluated over two weeks in two environments with user devices

Problem 1: People **Do Not Always** Carry Phones



Idea: Use device-free localization

Device-free Localization

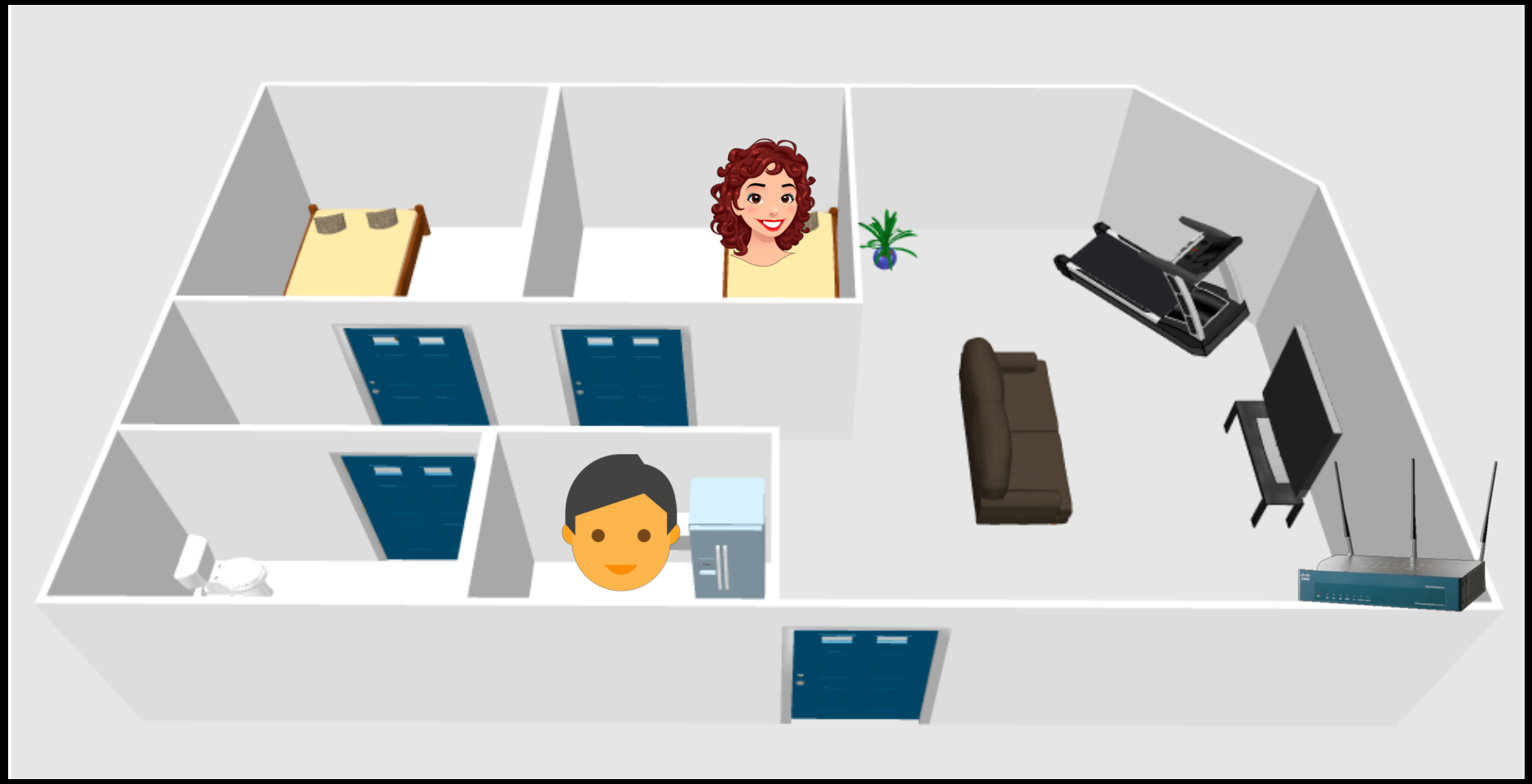
Uses reflections to track people
Doesn’t need a device

But… No Identity

Device-based Localization	Device-free Localization
✗ Needs people to carry cellphones	✓ Doesn't need cellphones
✓ Can identify people	✗ Cannot identify people

Idea: Track both people and devices
Use interactions to match

Idea: Capture interaction between people & devices



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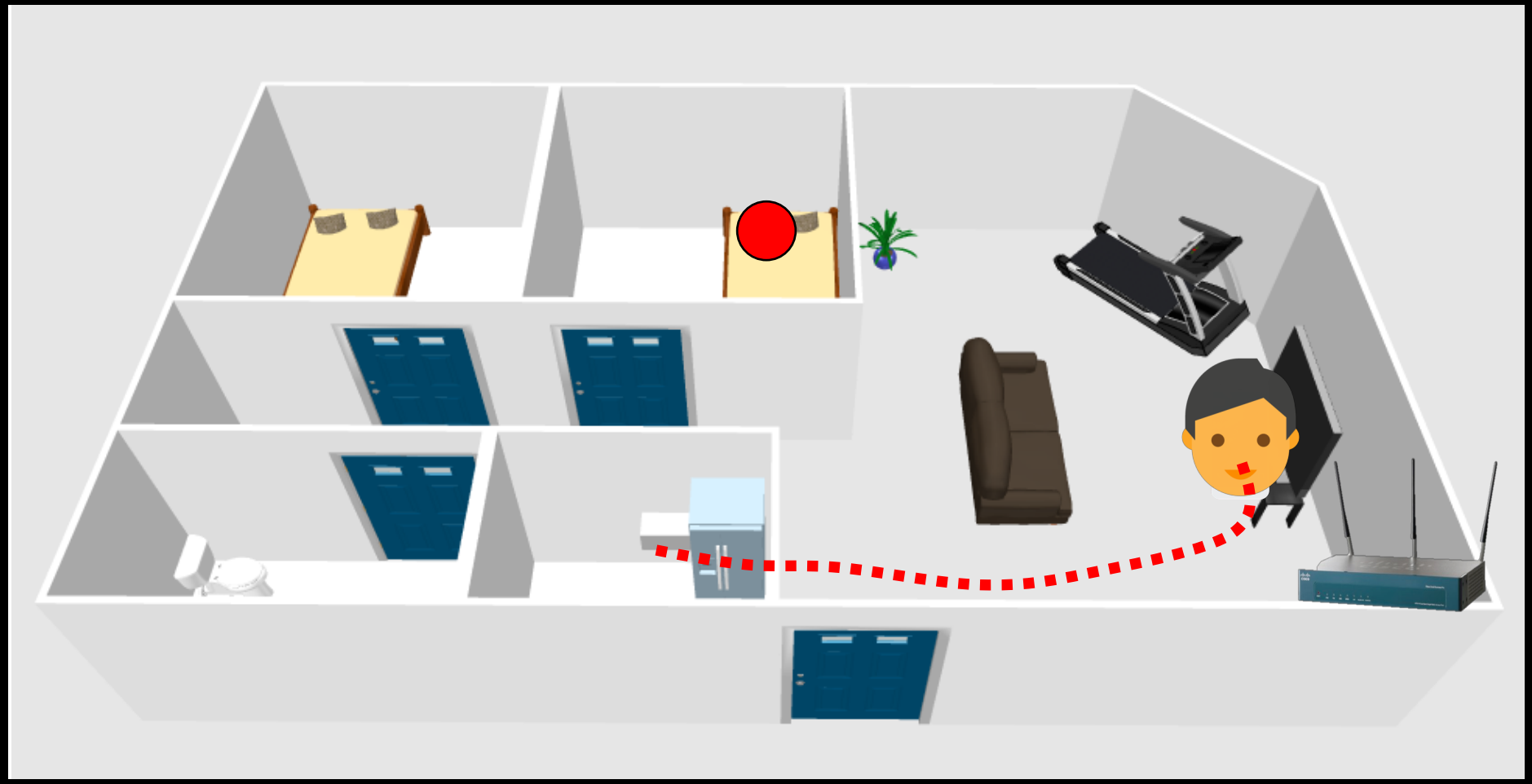
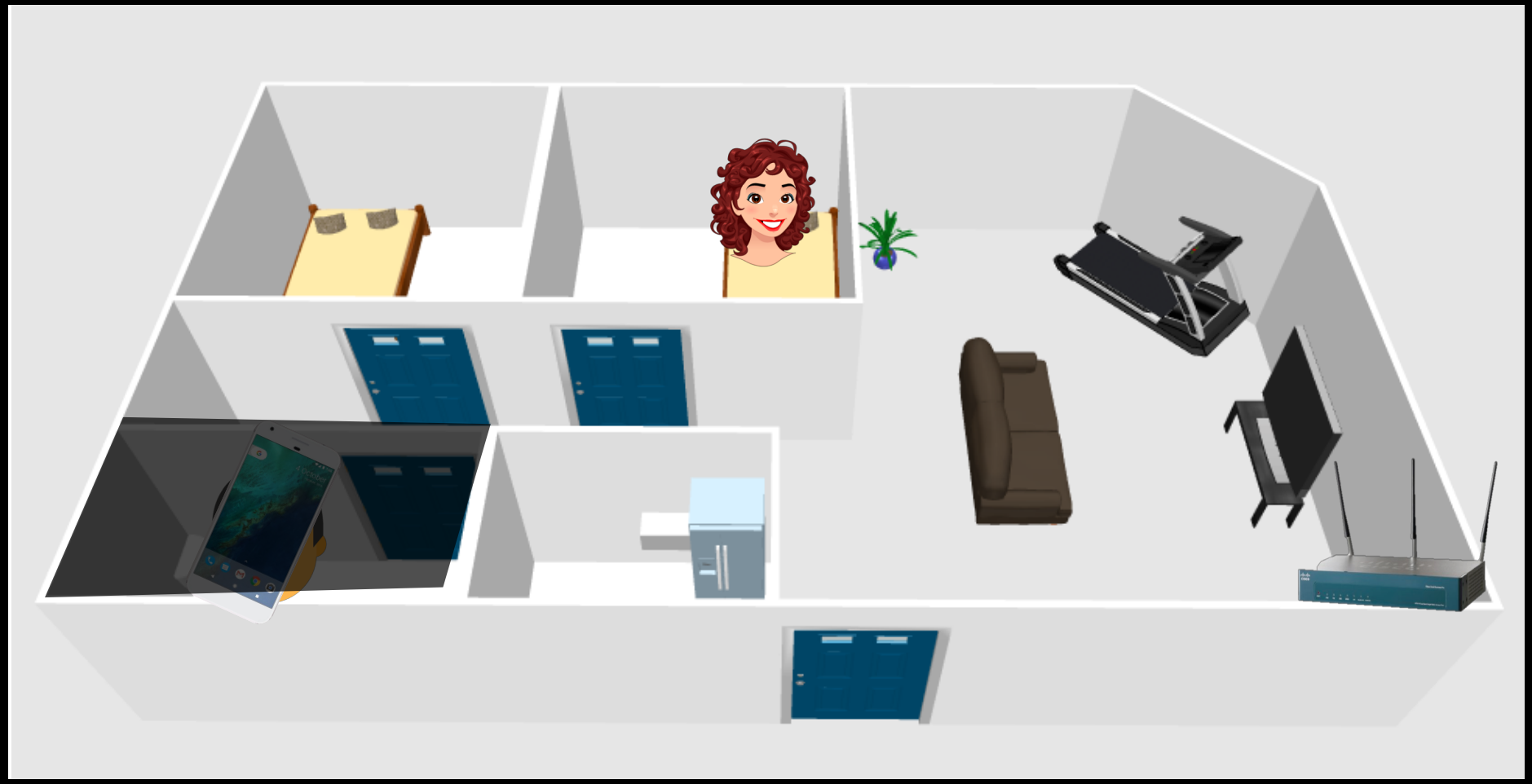
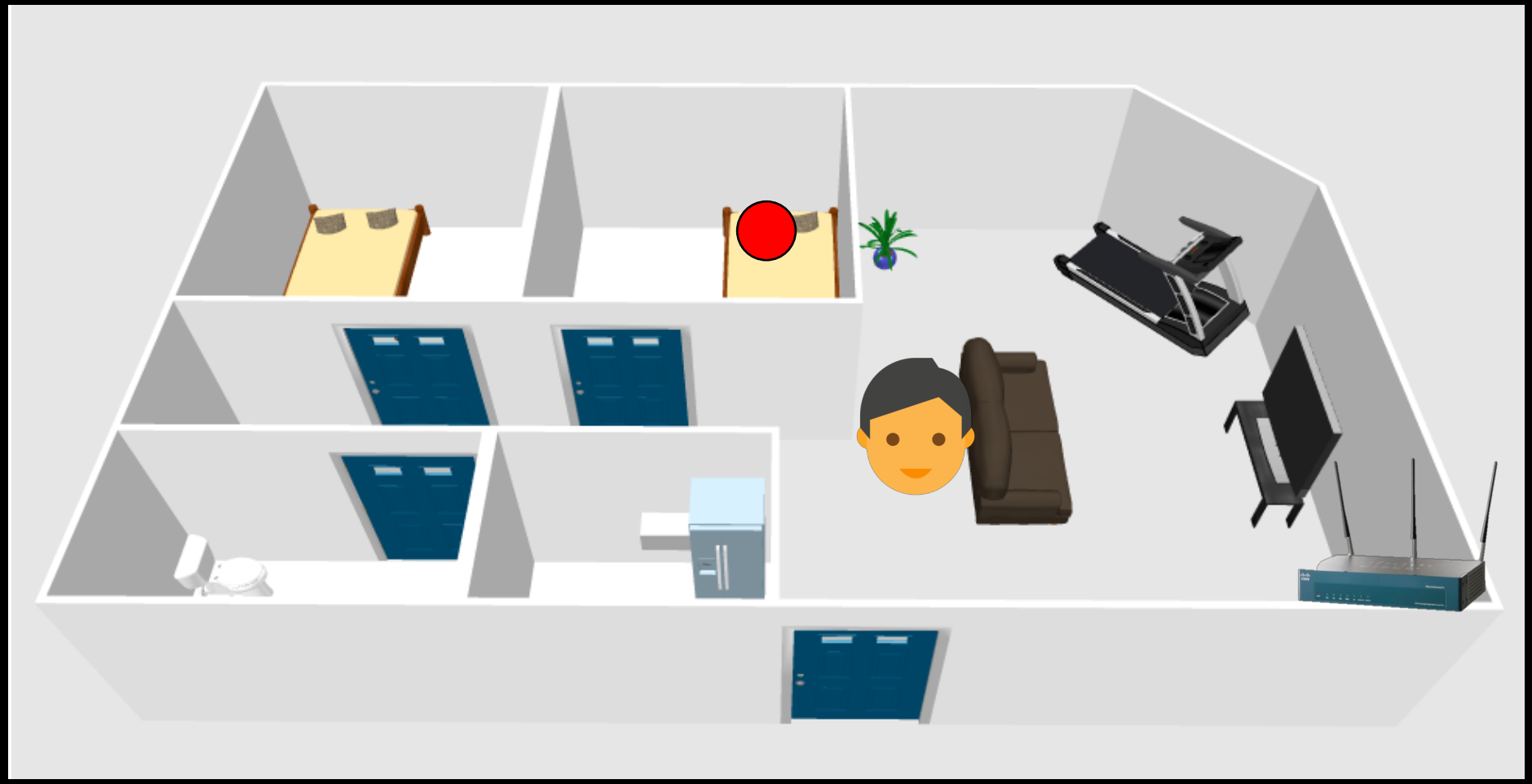


Idea: Capture interaction between people & devices

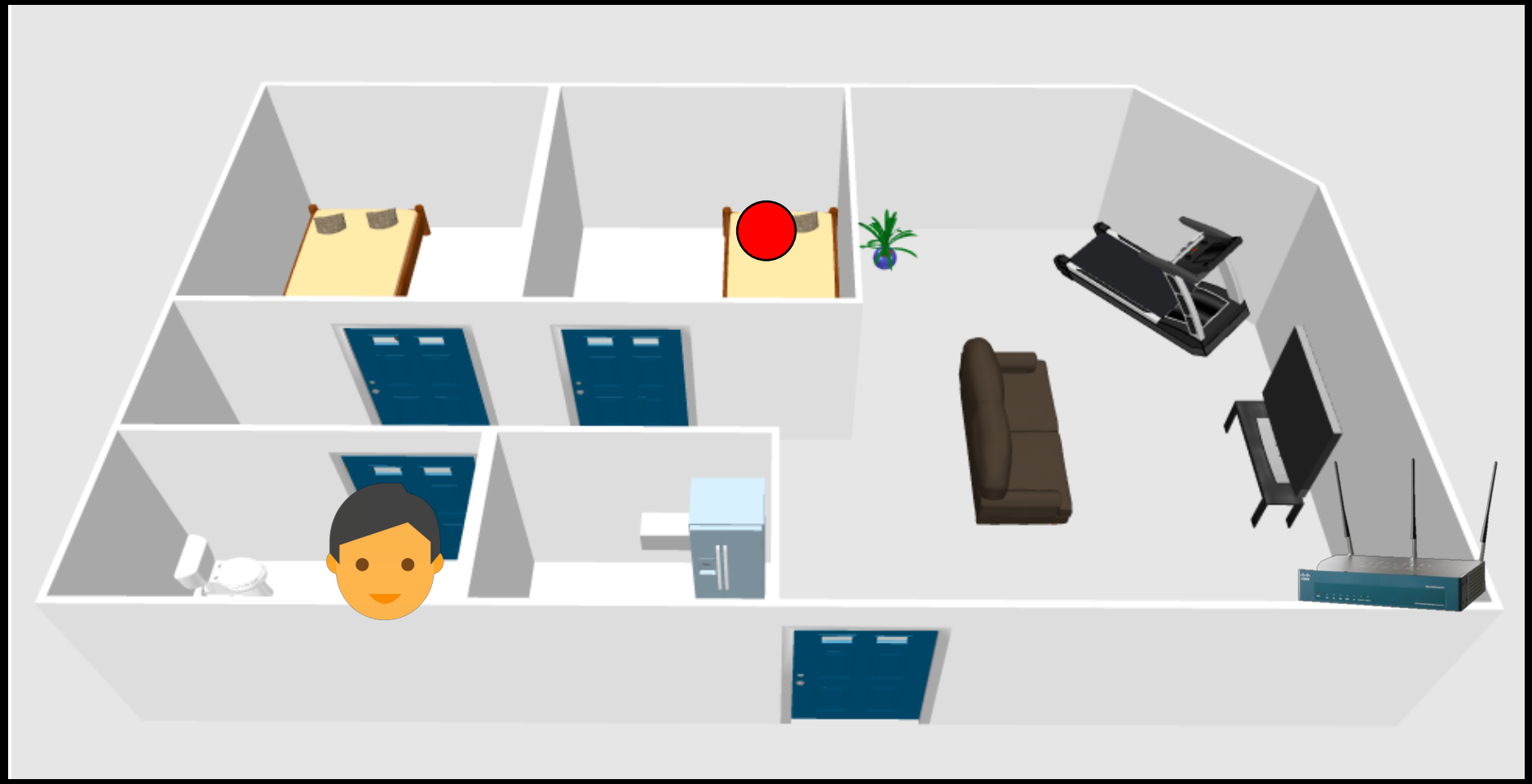
Problem 2: Wireless Signals get Blocked



Observation 1: Logical Spaces have Transition Points



Observation 2: Logical Dependencies in Space-Time



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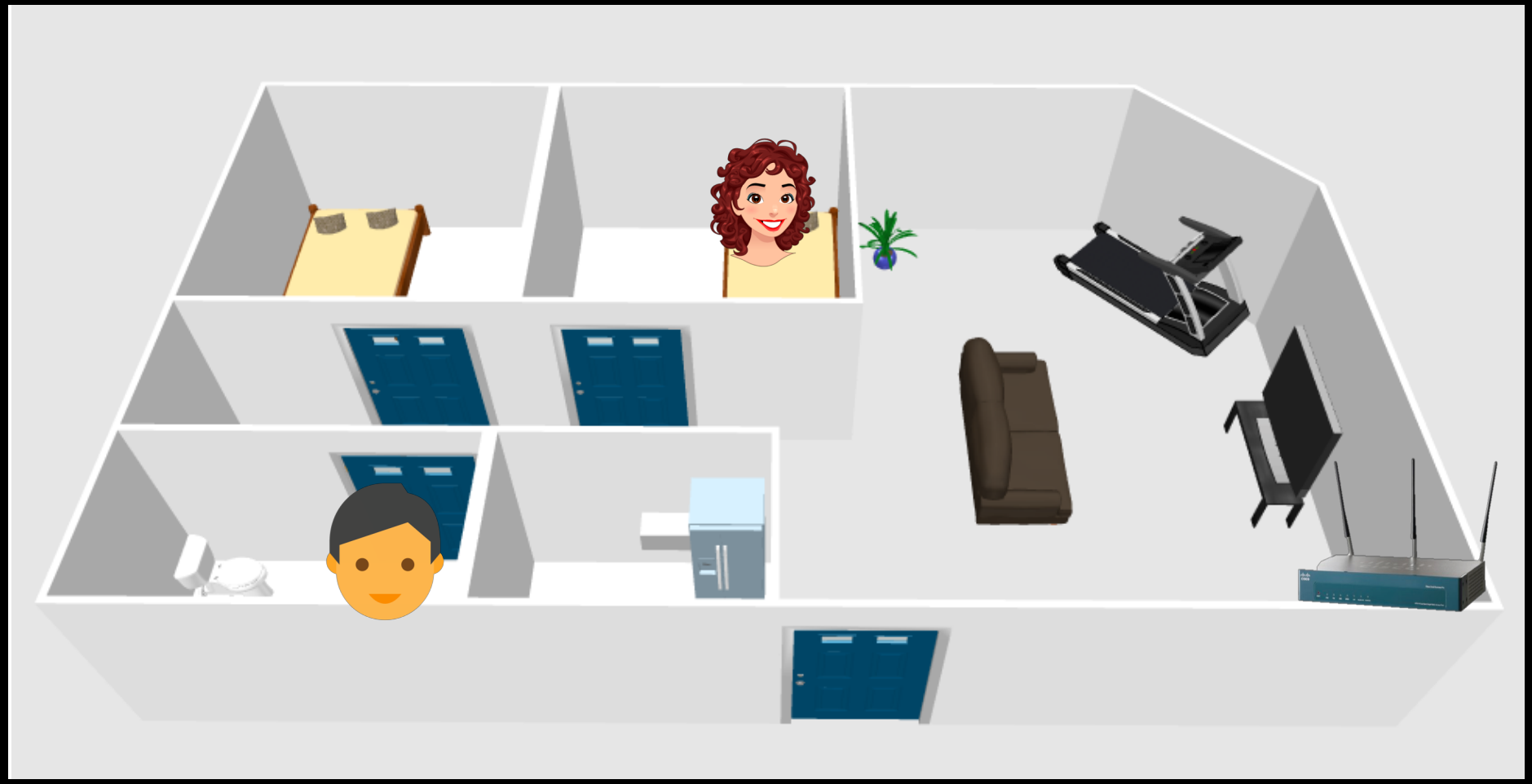


Logical Dependencies in Space-Time

- Cannot be present in two places at the same time
- Cannot enter places that they already occupy
- Cannot exit from places that they don’t occupy

Step 1: Track Entries and Exits to Spaces

- Duet uses a Hidden Markov Models to identify entry and exits trajectories

- Does not need training per region

Step 2: First Order Logic Formulation

State

$$S_t = \{v_j | j = \{1,2, \dots K\}\}$$

$$v_j = (P, I, R)$$

P: Possible identities for the individual

I: Impossible identities for the individual

R: The location of the individual

Step 2: First Order Logic Formulation

$$S_i = \{v_j | j = \{1,2, \dots K\}\}$$

$$v_j = (P, I, R)$$

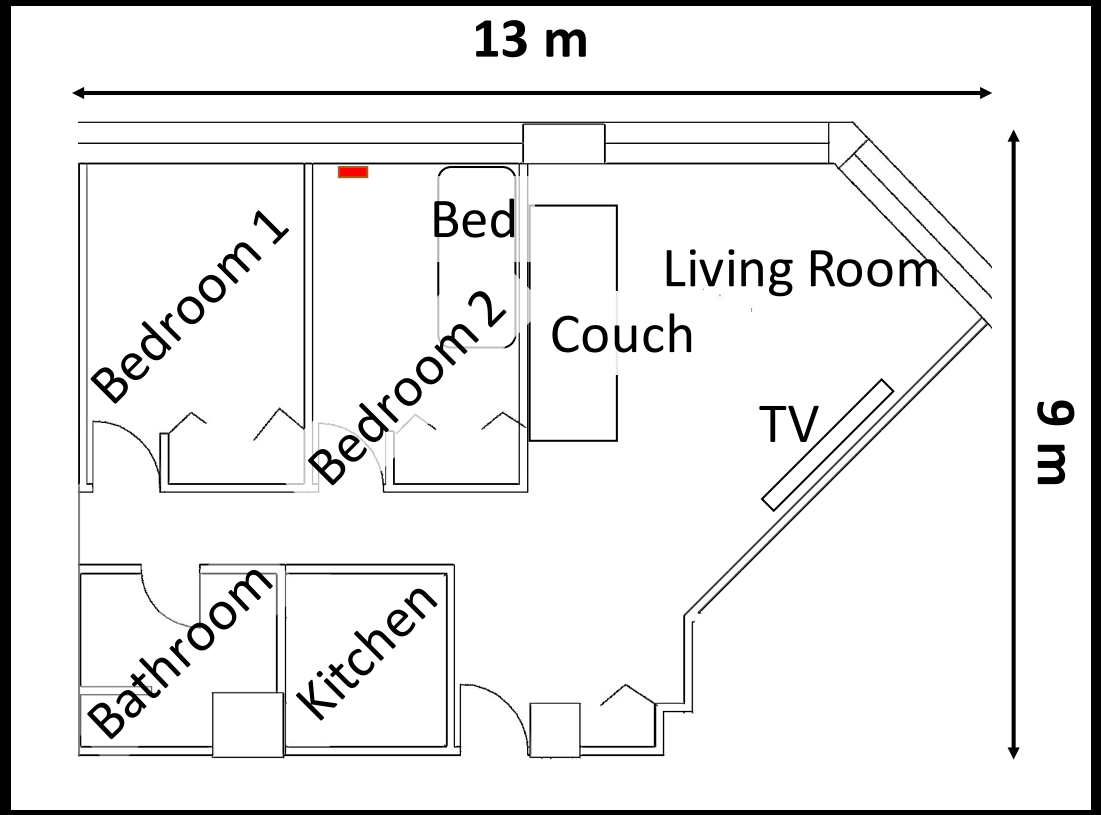
- Can reason about a rich set of constraints
- Provable satisfiability algorithm to prune out invalid states

Experimental Evaluation

Implementation

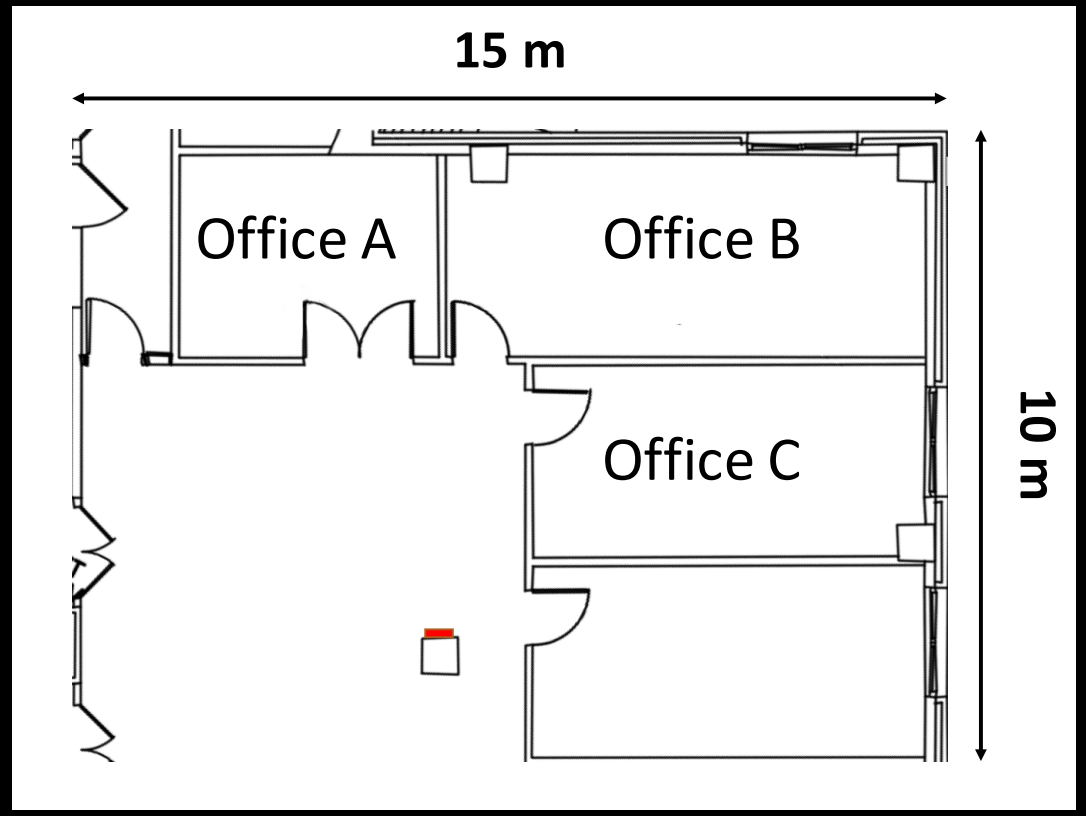
- 2-week studies in two setups: home and office space
- Occupants used their own cellphones, did not install an app
  - One time registration with the system
- Required no changes to user behavior

Implementation: Home



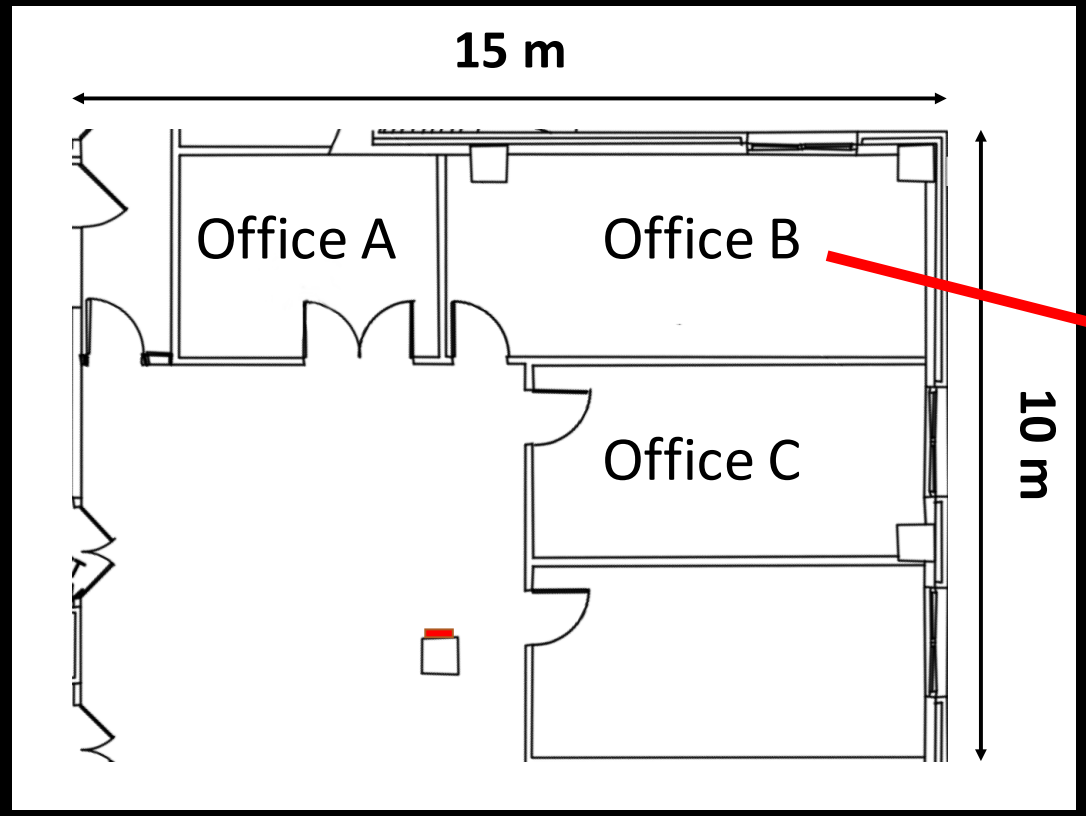
- 2 occupants, 2 frequent visitors
- Smallest area: couch (1.3 m^2)

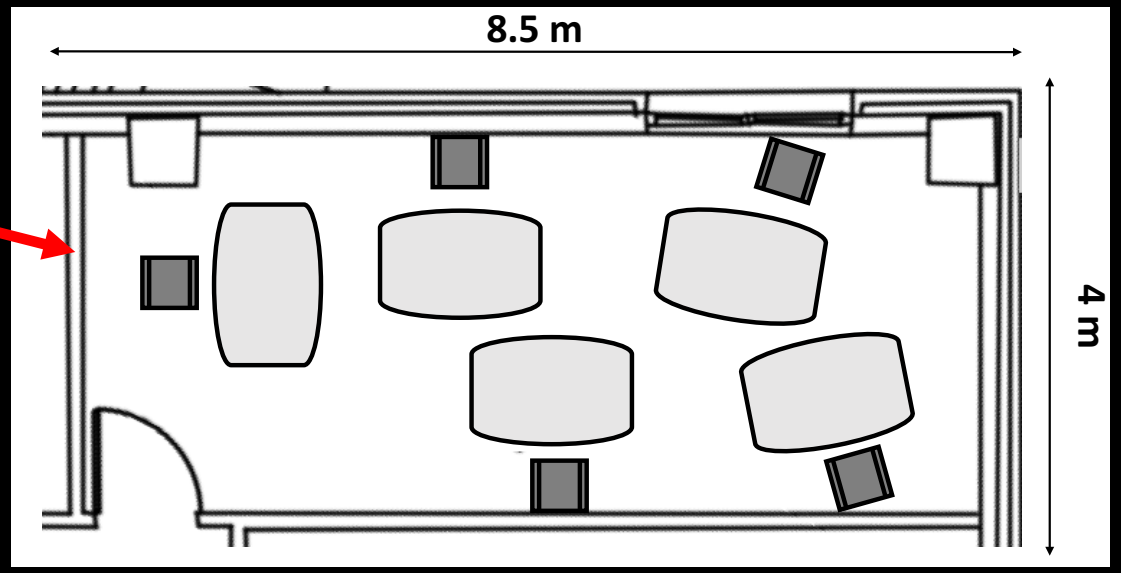
Implementation: Office



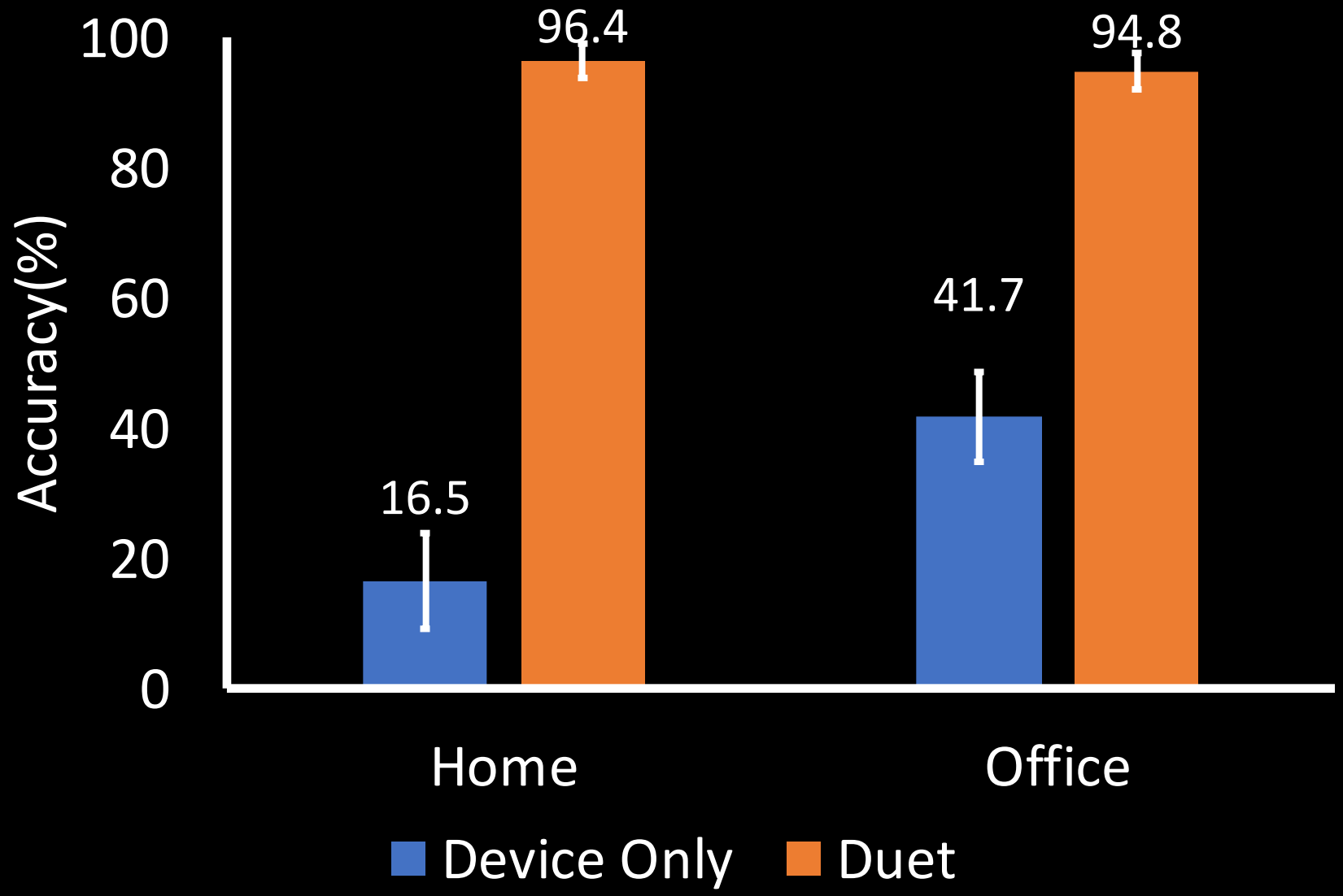
- Office A: 3, Office B: 5, Office C: 1 occupants

Implementation: Office

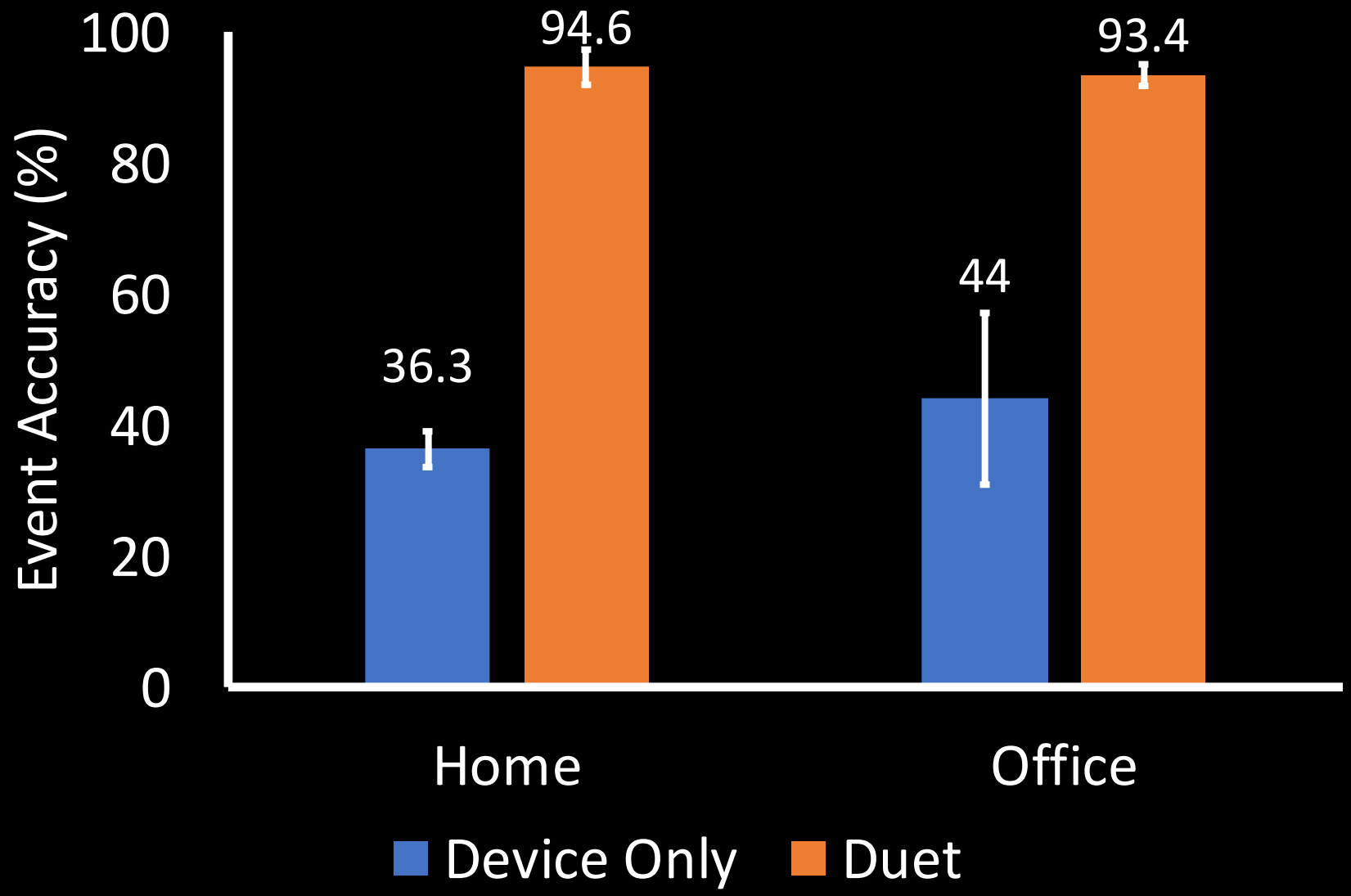




Evaluation: Accuracy



Evaluation: Event Accuracy



Conclusion

- Duet: Combine information from multiple modes of RF tracking
- Uses First Order Logic based reasoning to overcome intermittent, partially correct information
- User study over two weeks and two different environments