Maintenance Required: Updating and Extending Bootstrapped Human Activity Recognition Systems for Smart Homes

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ABC Conference 2024   **School of Interactive Computing, Georgia Tech**

Georgia Tech

KDDI Research

Research in Smart Homes

- Smart Home Devices and Applications - to provide seamless interaction

- Technological advancements - reduced cost of sensors, advance in IoT technologies

- Ambient Assisted Living

https://www.samma3a.com/tech/en/best-buy/best-smart-home-devices-2021/

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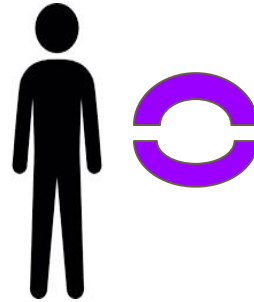
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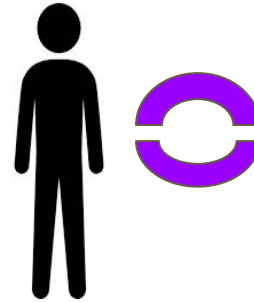
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Use-Case

- "Life is ever-changing"

- Active Learning - minimal supervision from resident

Smart Home

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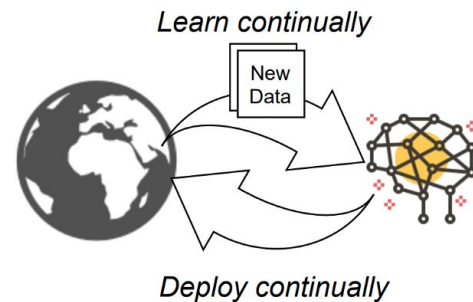# Maintaining Human Activity Recognition Systems(HAR) for Smart Homes

Systematic Approach-

- Develop an procedure to **maintain and update** activity recognition systems, for smart homes

- Evaluate on real smart home data

Application-

- "Life is ever changing" - Continuous activity logging

Adaptive ML

Learn continually

New Data

Deploy continually

Maintaining Human Activity Recognition Systems(HAR) for Smart Homes
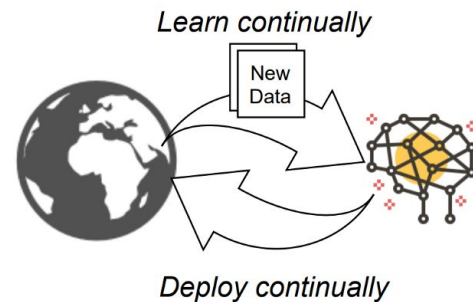
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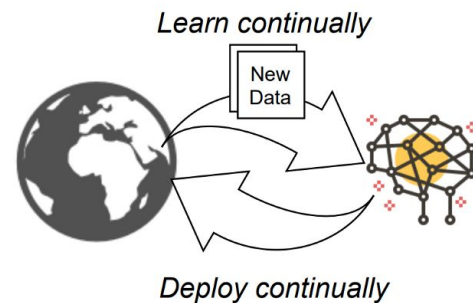# Maintaining Human Activity Recognition Systems(HAR) for Smart Homes

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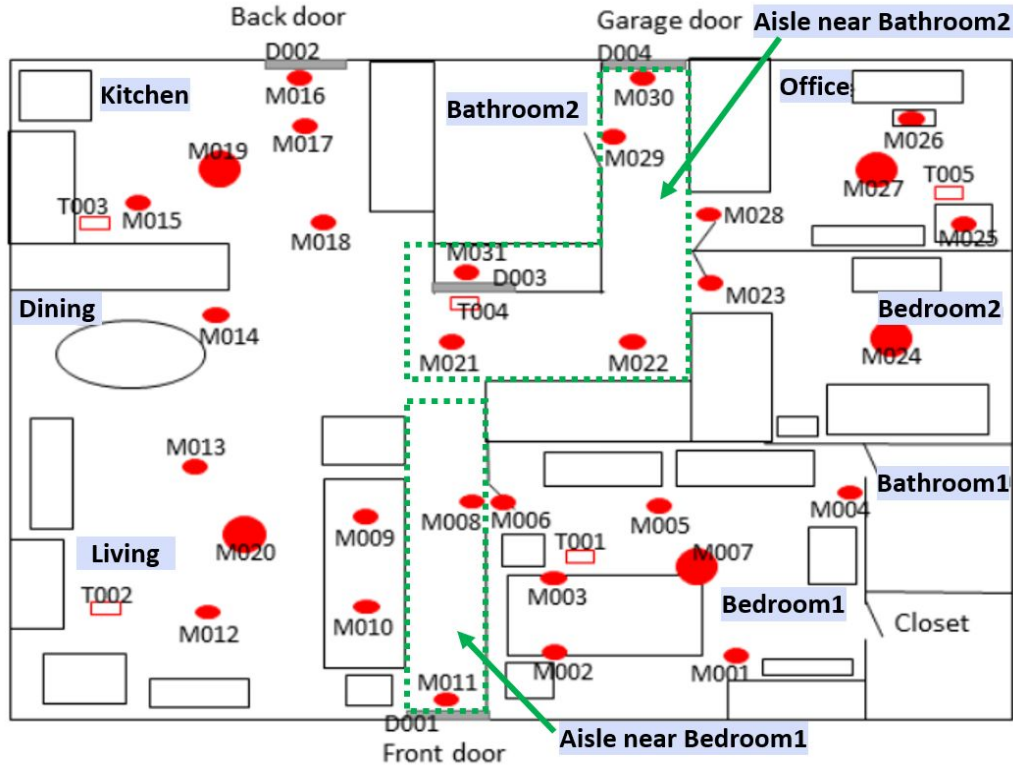
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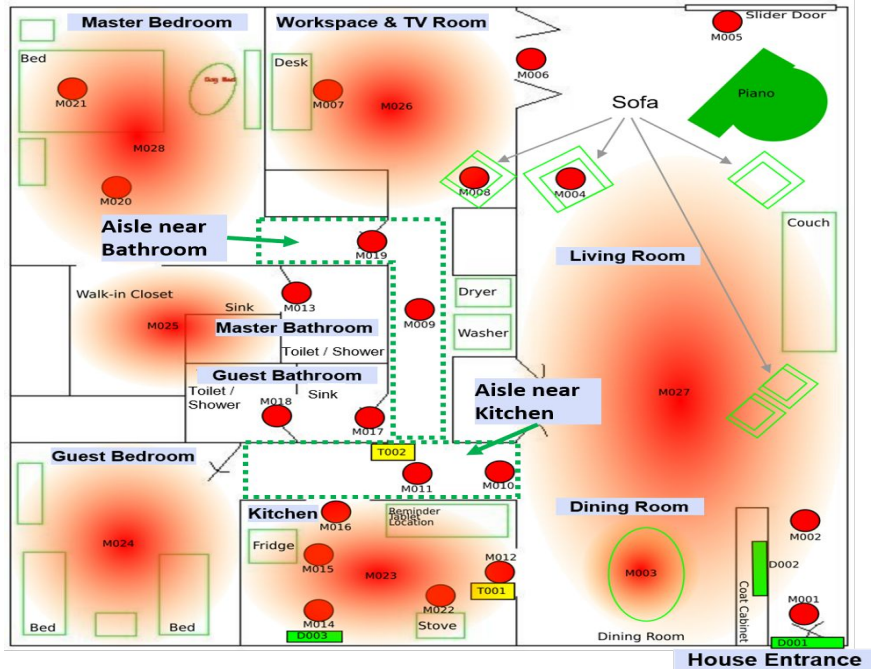*Learn continually*

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Deploy continually

CASAS-Aruba

- Mxxx - Motion Sensor (ON/OFF)
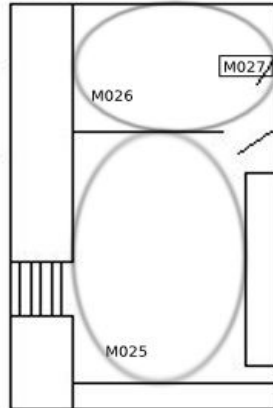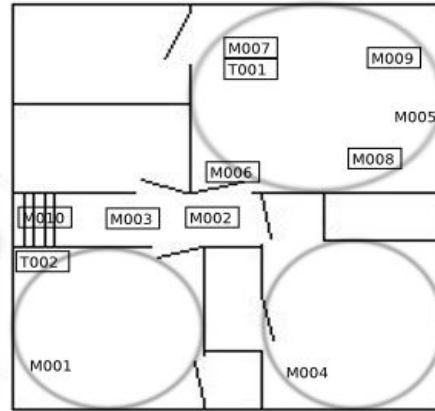
- Dxxx - Door Sensor (OPEN/CLOSE)

- Txxx - Temperature sensor

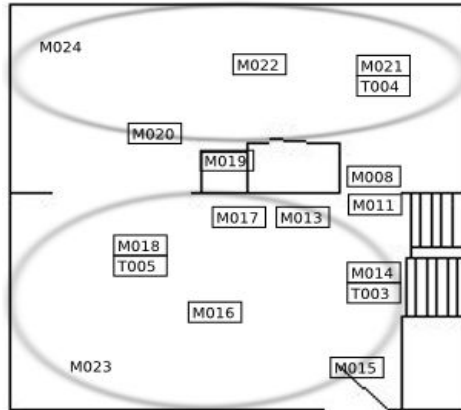# CASAS-Milan

- Mxxx - Motion Sensor (ON/OFF)

- Dxxx - Door Sensor (OPEN/CLOSE)

- Txxx - Temperature sensor

CASAS-Cairo

- Mxxx - Motion Sensor (ON/OFF)

- Txxx - Temperature sensor

Maintenance and Update of HAR Systems in Homes

- **Step 1 - Initial HAR System→identifies activity segments**

- Step 2 - Update and Extension Procedure → improves segmentation accuracy

- Continuous Evaluation Procedure

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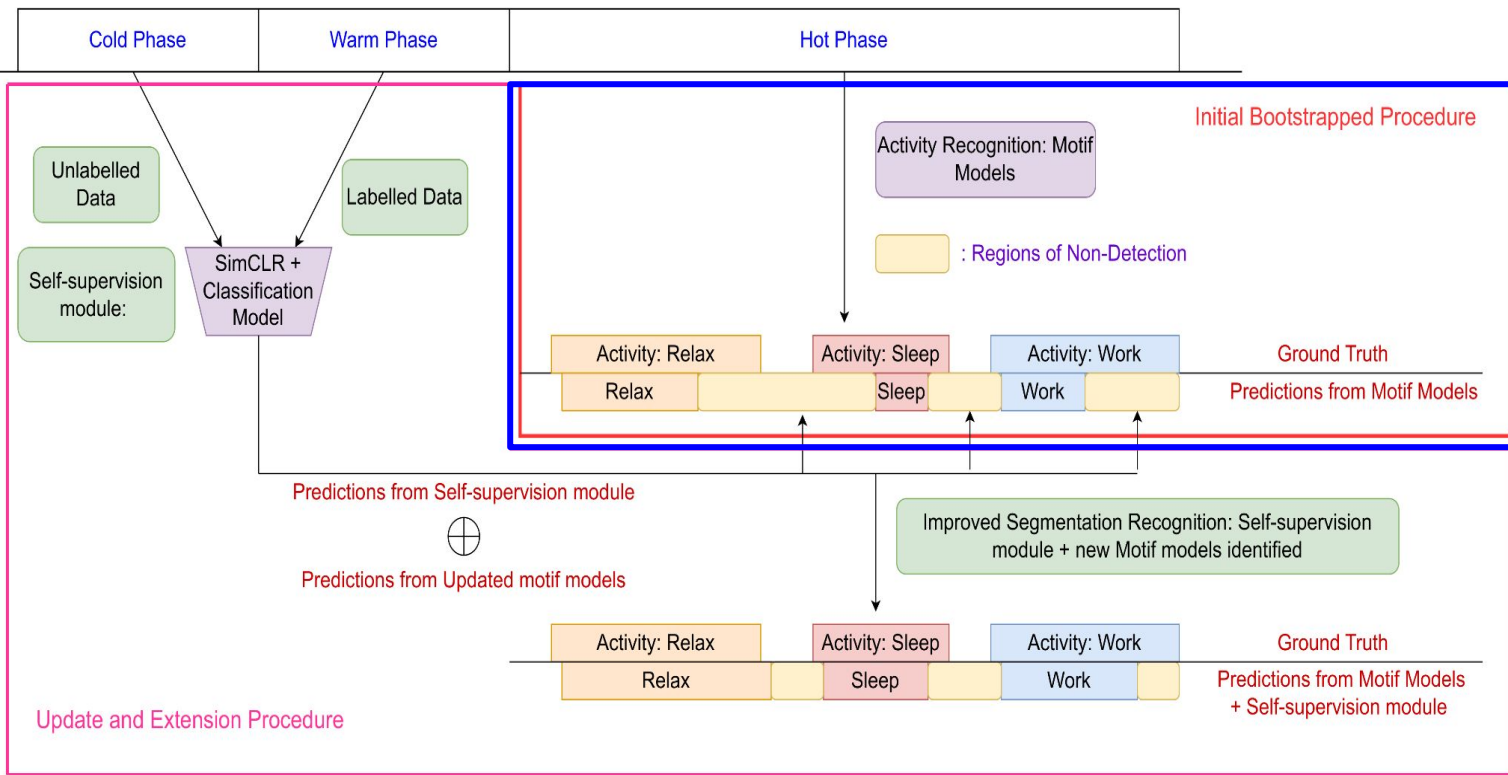
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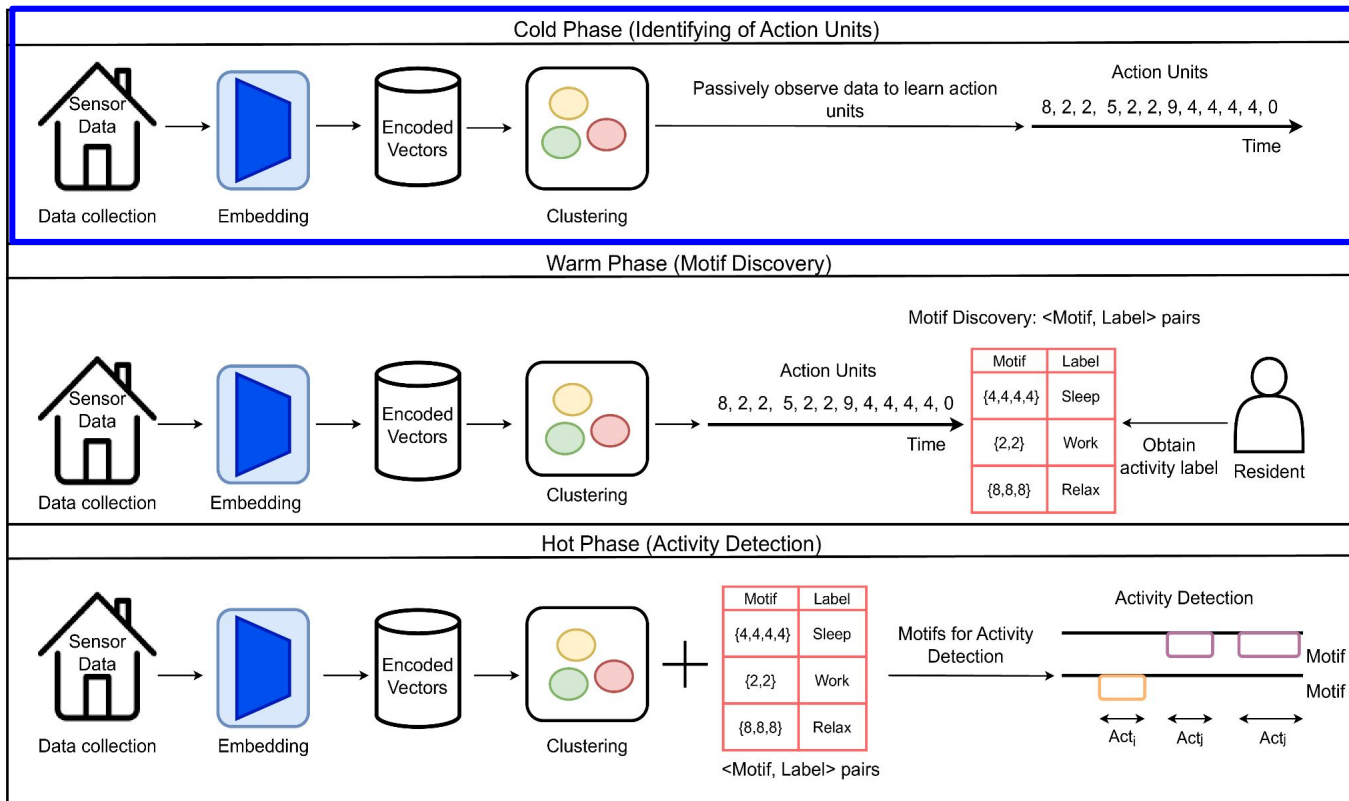
Maintenance and Update of HAR Systems in Homes

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- **Continuous Evaluation Procedure**

UPDATING ACTIVITY MODELS FOR HAR - Step 1

1. Initial HAR system

Hiremath, Shruthi K., Yasutaka Nishimura, Sonia Chernova, and Thomas Plötz. "Bootstrapping human activity recognition systems for smart homes from scratch." *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies* 6, no. 3 (2022): 1-27.

Initial HAR System

Cold Phase (Identifying of Action Units)

Sensor Data — Data collection → Embedding → Encoded Vectors → Clustering → Passively observe data to learn action units → Action Units: 8, 2, 2, 5, 2, 2, 9, 4, 4, 4, 4, 0 — Time

Action Units (AU)

Warm Phase (Motif Discovery)

Sensor Data — Data collection → Embedding → Encoded Vectors → Clustering → Action Units: 8, 2, 2, 5, 2, 2, 9, 4, 4, 4, 4, 0 — Time → Motif Discovery: <Motif, Label> pairs

Motif	Label
{4,4,4,4}	Sleep
{2,2}	Work
{8,8,8}	Relax

Obtain activity label — Resident

Recognition models

Hot Phase (Activity Detection)

Sensor Data — Data collection → Embedding → Encoded Vectors → Clustering +

Motif	Label
{4,4,4,4}	Sleep
{2,2}	Work
{8,8,8}	Relax

<Motif, Label> pairs → Motifs for Activity Detection → Activity Detection — Motif 1, Motif 2 — Act$_i$, Act$_j$, Act$_j$

Deployment of HAR

Initial HAR System

Cold Phase (Identifying of Action Units)

Warm Phase (Motif Discovery)

Hot Phase (Activity Detection)

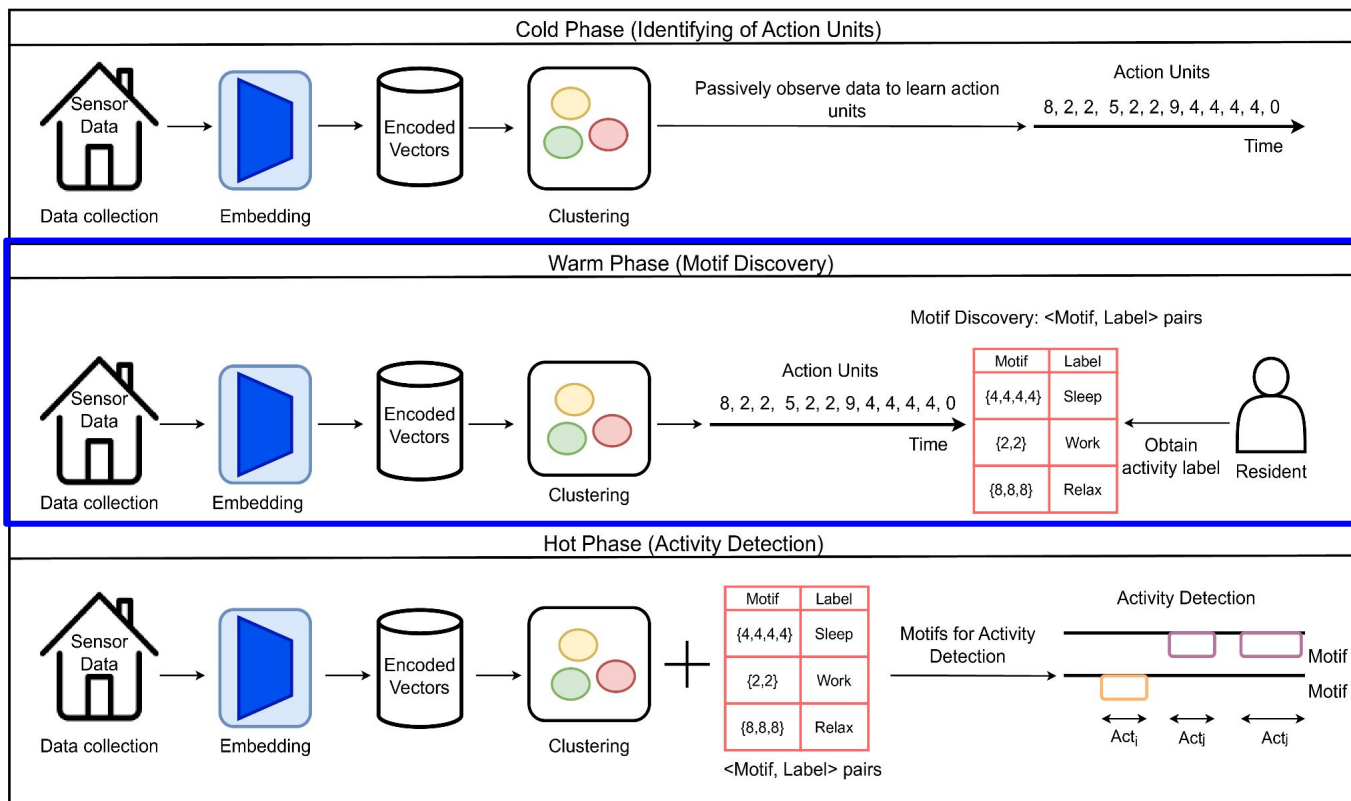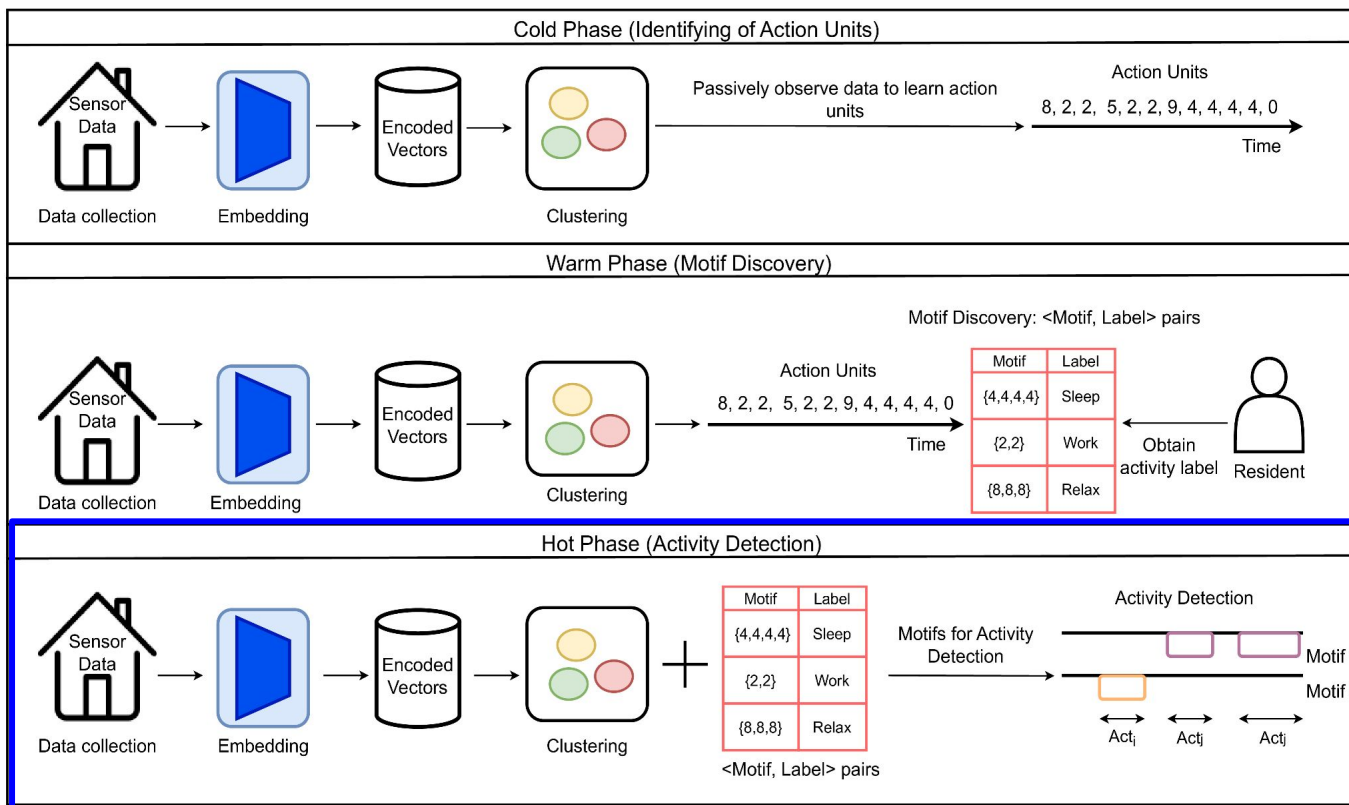Action Units (AU)

Recognition models
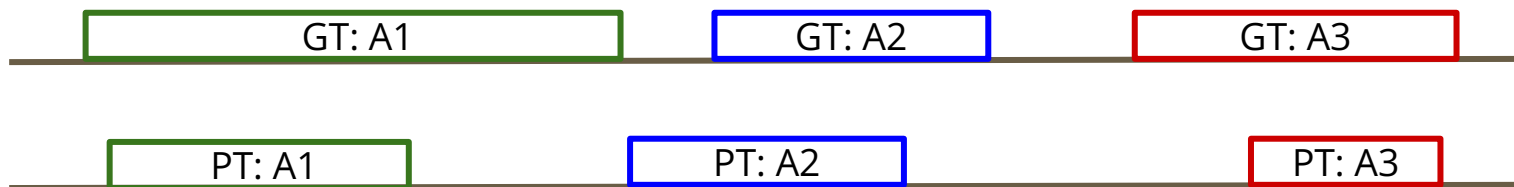
Deployment of HAR

Initial HAR System

Action Units (AU)

Recognition models

Deployment of HAR

Results of Initial HAR System

- Identified frequently occurring activities - Sleeping, Meal preparation, Work etc.

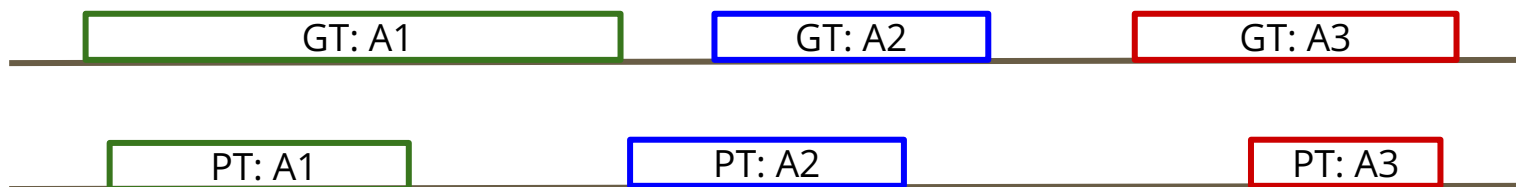- Sub-optimal lengths of segments of activities identified

GT: Ground Truth; PT: Predictions

A1: Activity 1; A2: Activity 2; A3: Activity 3

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- Sub-optimal lengths of segments of activities identified

GT: A1	GT: A2	GT: A3
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UPDATING ACTIVITY MODELS FOR HAR - Step 2
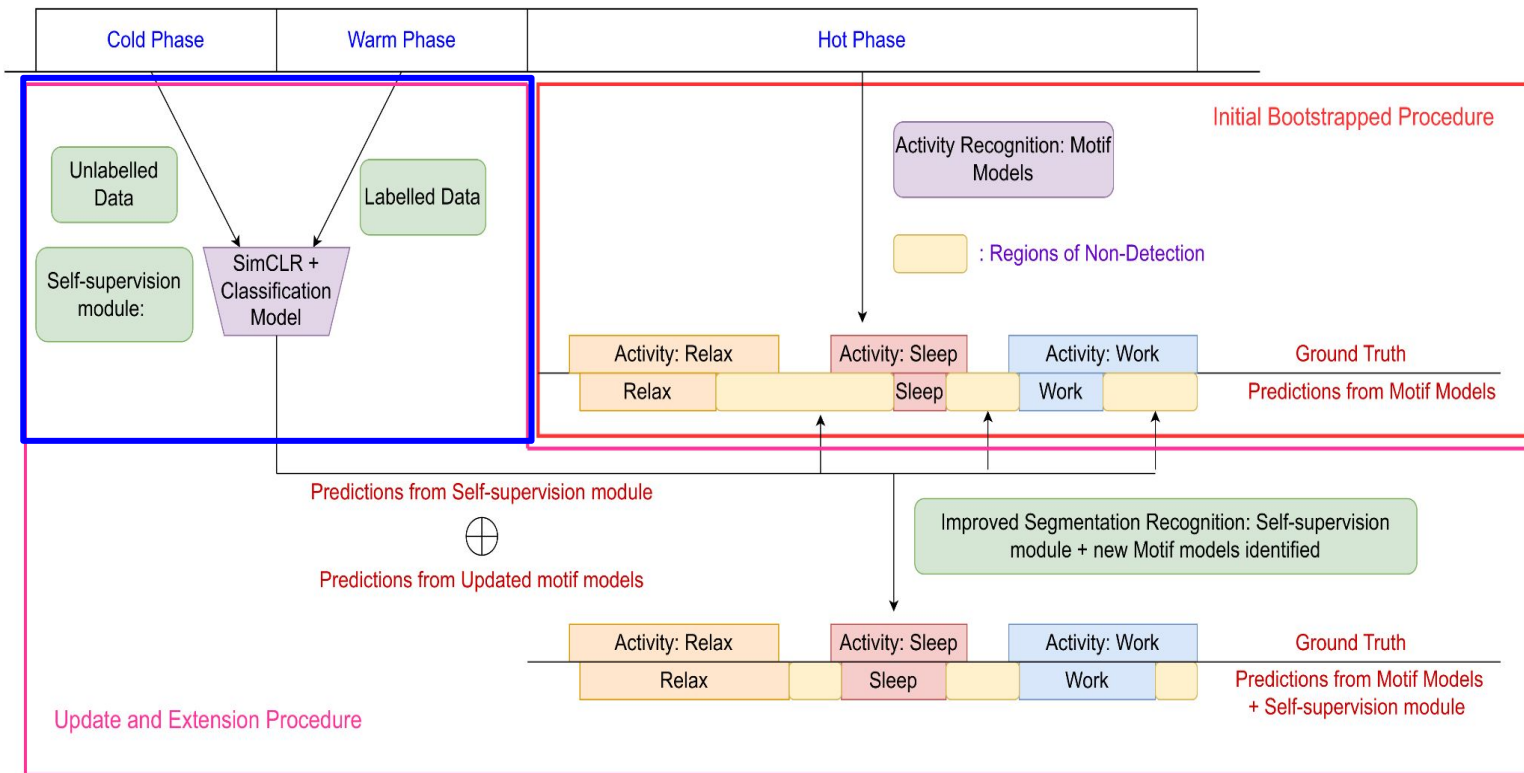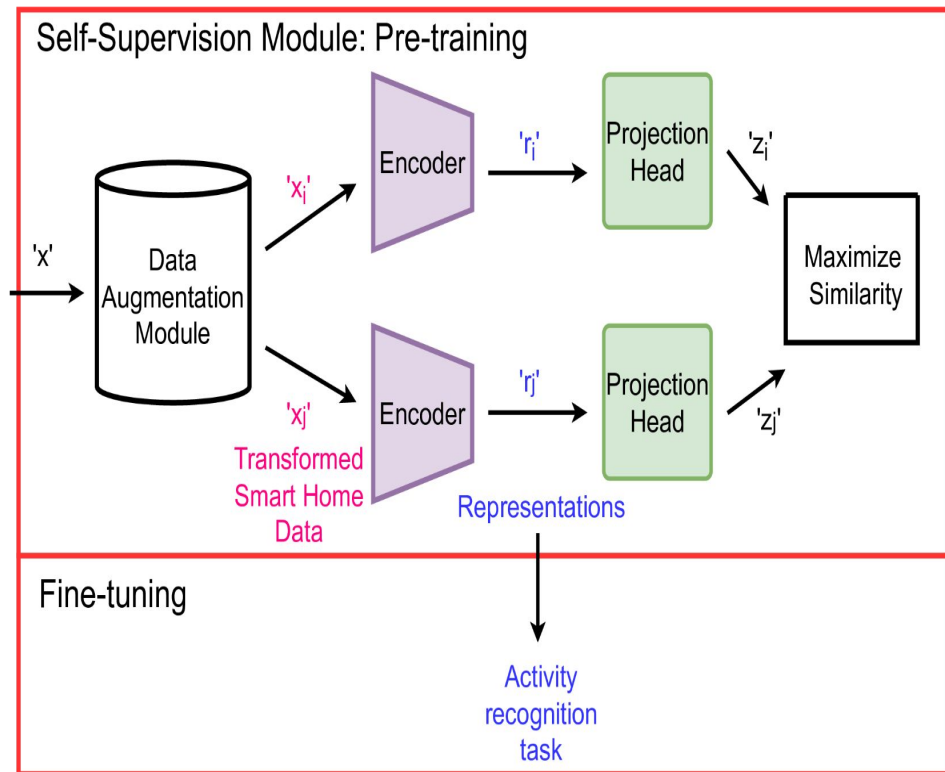

2. Self-supervision module

UPDATING ACTIVITY MODELS FOR HAR - Step 2
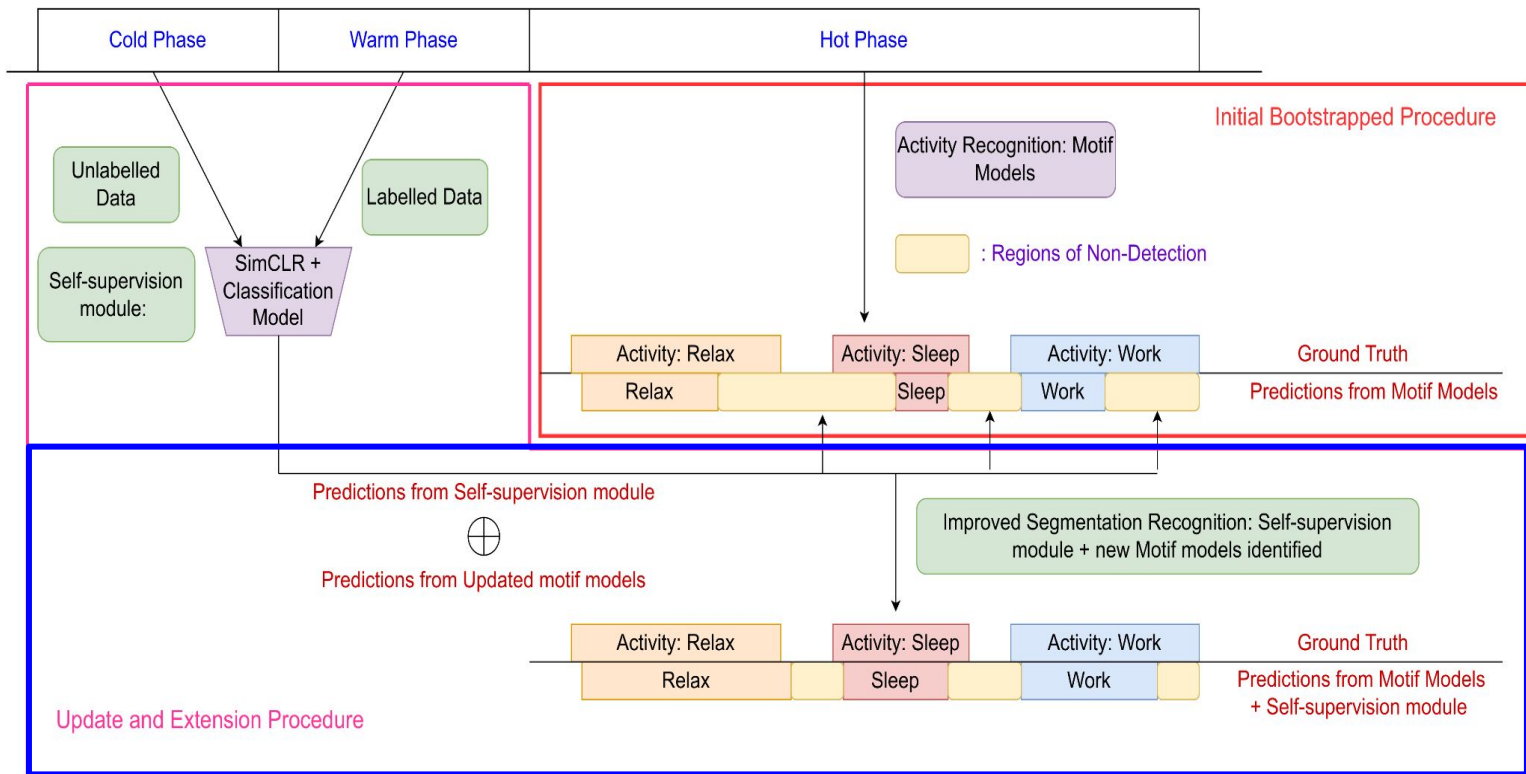
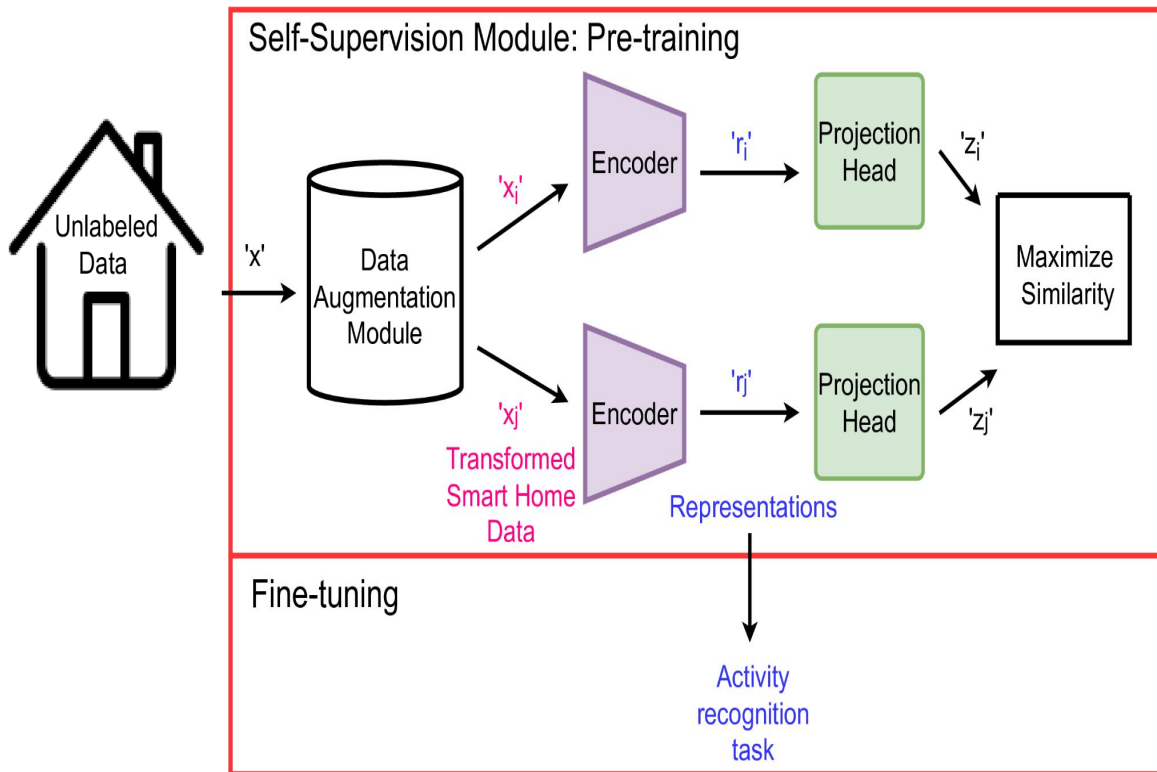**3. Improved segmentation accuracy**

Self-Supervision Module

- SIMCLR training
  - BERT-based features
  - Augmentations - Noise and scale
  - NT-Xent loss

- Predictions from Initial HAR used for fine-tuning
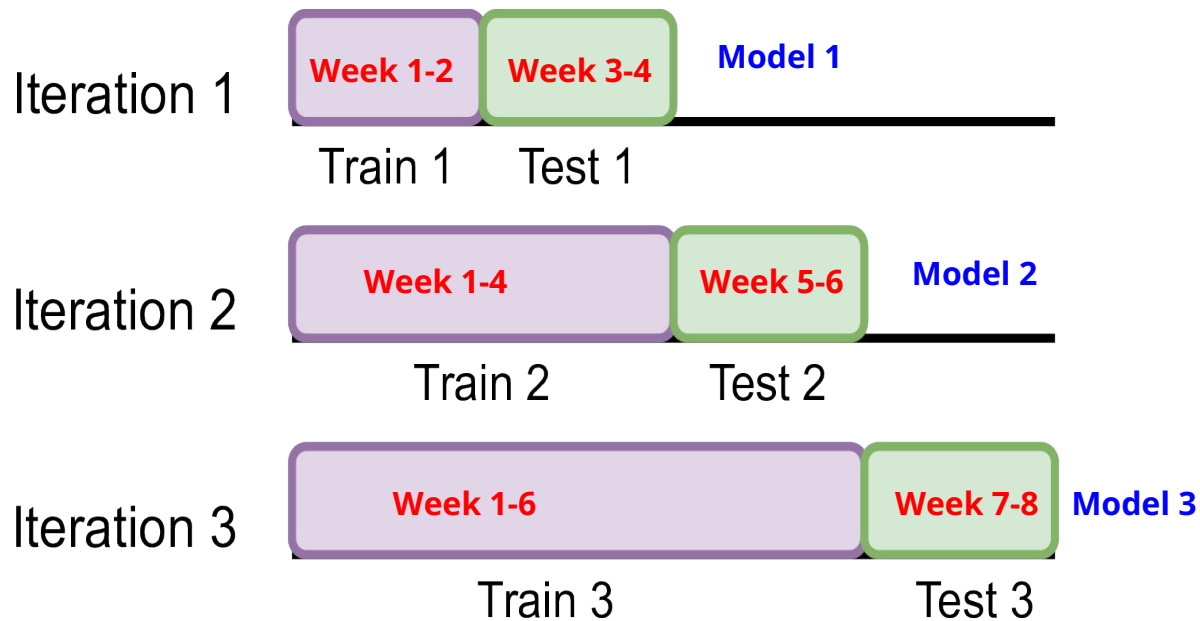
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Continuous Evaluation Procedure

- Updates (2 weeks) using predictions from Self-supervision module

- Updates (2 weeks) using predictions from updated motif models

Results: CASAS-Aruba

$$Seg.\ Accuracy = \frac{\sum_{n=1}^{N}(AU_{identified} \in AU_{activity})}{\sum_{n=1}^{N} AU_{activity}}$$

Activity	Week 4-6 (Test 1)	Week 6-8 (Test 2)	Week 8-10 (Test 3)
Meal Prep	GT: 9.37±8.09 M1: 5.11±6.65	M1: 5.61±10.01 M2: 7.37±11.99	M2: 4.66±7.11 M3:6.89±6.07
Relax	GT: 3.86±3.56 M1: 2.86±3.55	M1: 2.92±3.66 M2: 3.12±3.64	M2: 3.96±6.08 M3: 4.45±7.03
Sleep	GT: 6.94±6.92 M1: 5.10±3.75	M1: 2.59±2.87 M2: 2.90±2.95	M2: 5.58±5.31 M3: 5.58±5.31

Conclusion
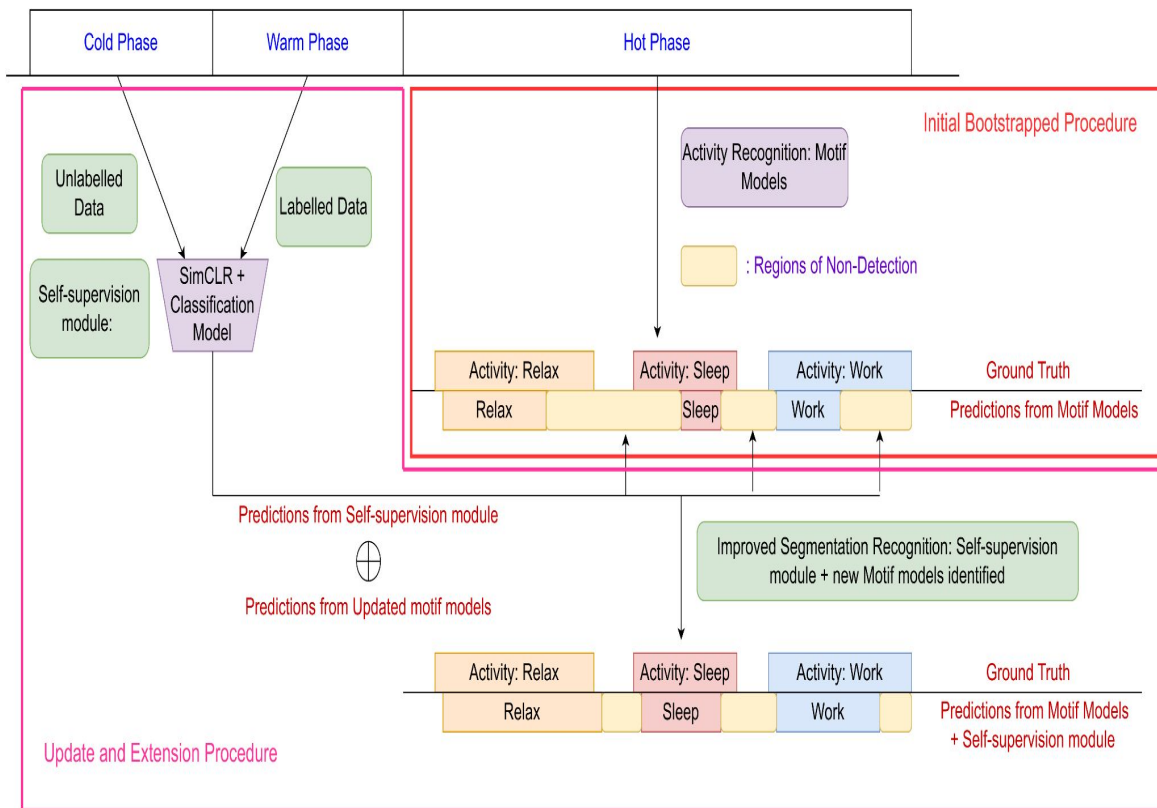
Initial HAR - identifies frequently occurring activities

Update HAR - self-supervision module; update motif models

Continuous Evaluation - every 2 weeks

Discussion: Refinement of Seed Points

- Reliance on *performance* of Initial HAR

- Use *Context* information
  - Location pertaining
  - Time of occurrence, duration
  - Sequence of activities (routines)

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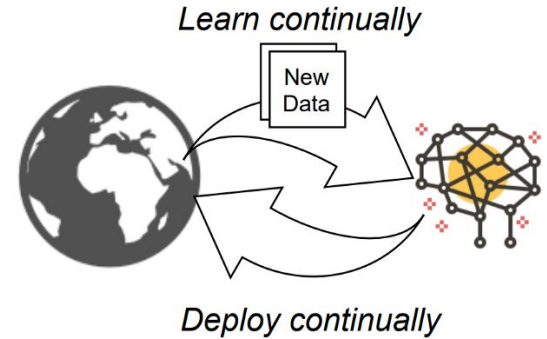
Future Work: Continual Learning

Continual Learning -

- Life is ever changing

- Adapt to changing data pattern in the smart home

Utilizing Human in the Loop-

- General proof of procedure

- Incorporate direct access to actual residents (Resident- in-the loop)

Adaptive ML

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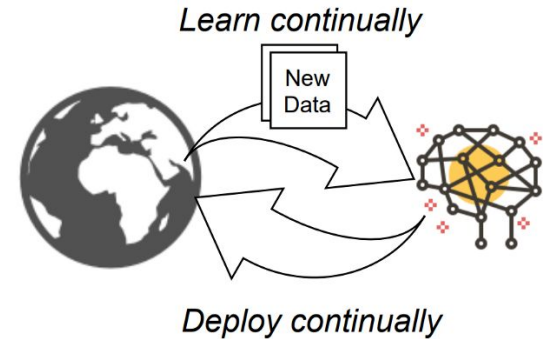
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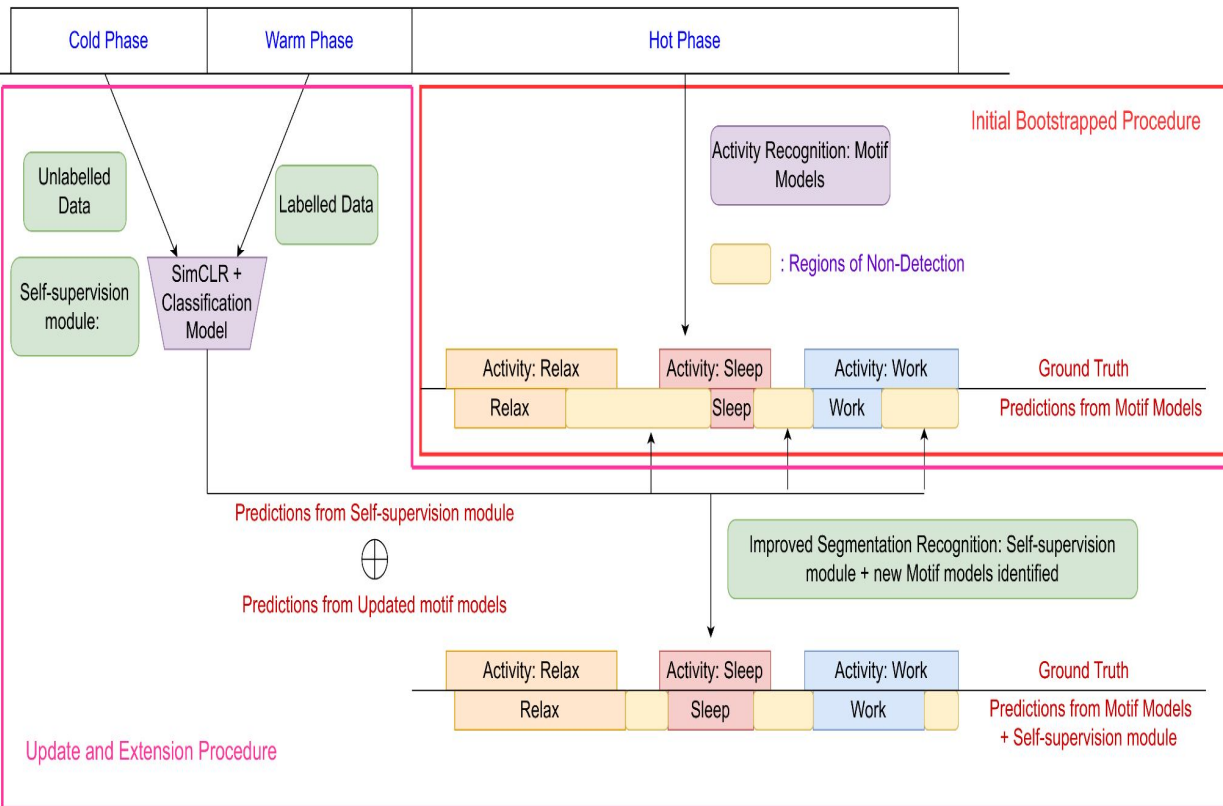
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Contact Information

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Thank You!