Using digital sensors to understand activity in the home

Nigel Gilbert,

Klaus Moessner,

Kristrún Gunnarsdóttir

and Jie Jiang

HomeSense
digital sensors in social research

UNIVERSITY OF SURREY

cress

5G INNOVATION CENTRE

Microsoft

NCRM
National Centre for Research Methods

E·S·R·C
ECONOMIC & SOCIAL RESEARCH COUNCIL

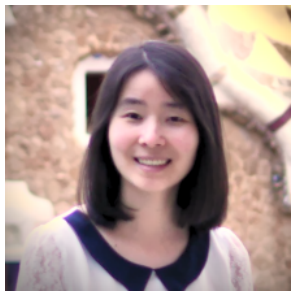
HomeSense: digital sensors for social research

- The project will make it easier and more productive for **social researchers** to use the **digital sensors** that are becoming available as a result of the rise of the 'internet of things' and ubiquitous computing.

- The project will yield *guidelines* for and *examples* of the use of digital sensors, including consideration of **technical**, **methodological** and **ethical** issues.

The project

- Started formally on 1 January 2016 (actually, February 2016)
- Three years
- Staff
  - Dr Kristrún Gunnarsdóttir
  - Dr Jie Jiang
  - PI
    - Nigel Gilbert
  - Co-I
    - Klaus Moessner, Surrey 5G Centre
  - Advisor
    - Ewa Luger, Microsoft Cambridge



HomeSense
digital sensors in social research

Three strands

1. *Demonstrate* the use of sensors via household trials
2. *Catalogue* technical, methodological and ethical issues
3. *Create guidelines* for using sensors and analysing sensor data

HomeSense
digital sensors in social research

Life at home

- What do we know about activities and interactions in households?
- Time use diaries can find out – but are tedious to complete and often inaccurate

- 20-30 volunteer households
- Fitted with sensors for 3 months
- Triangulation with
  - Time use diaries
  - Questionnaires
  - Walking interviews

HomeSense
digital sensors in social research

Strand 1: Adapt, develop and test sensors

- In home fixed sensors
  - Temperature, humidity, dust, noise, movement, brightness
  - Electricity consumption
- Wearable sensors
  - Movement, location in the home
- Smart phones
  - Geo-location, answers to questions

HomeSense
digital sensors in social research

Sensors

Wearable sensor: MiBand

Energy monitor: IAM

Fixed sensor: the Egg

Microphone

Ranging sensor

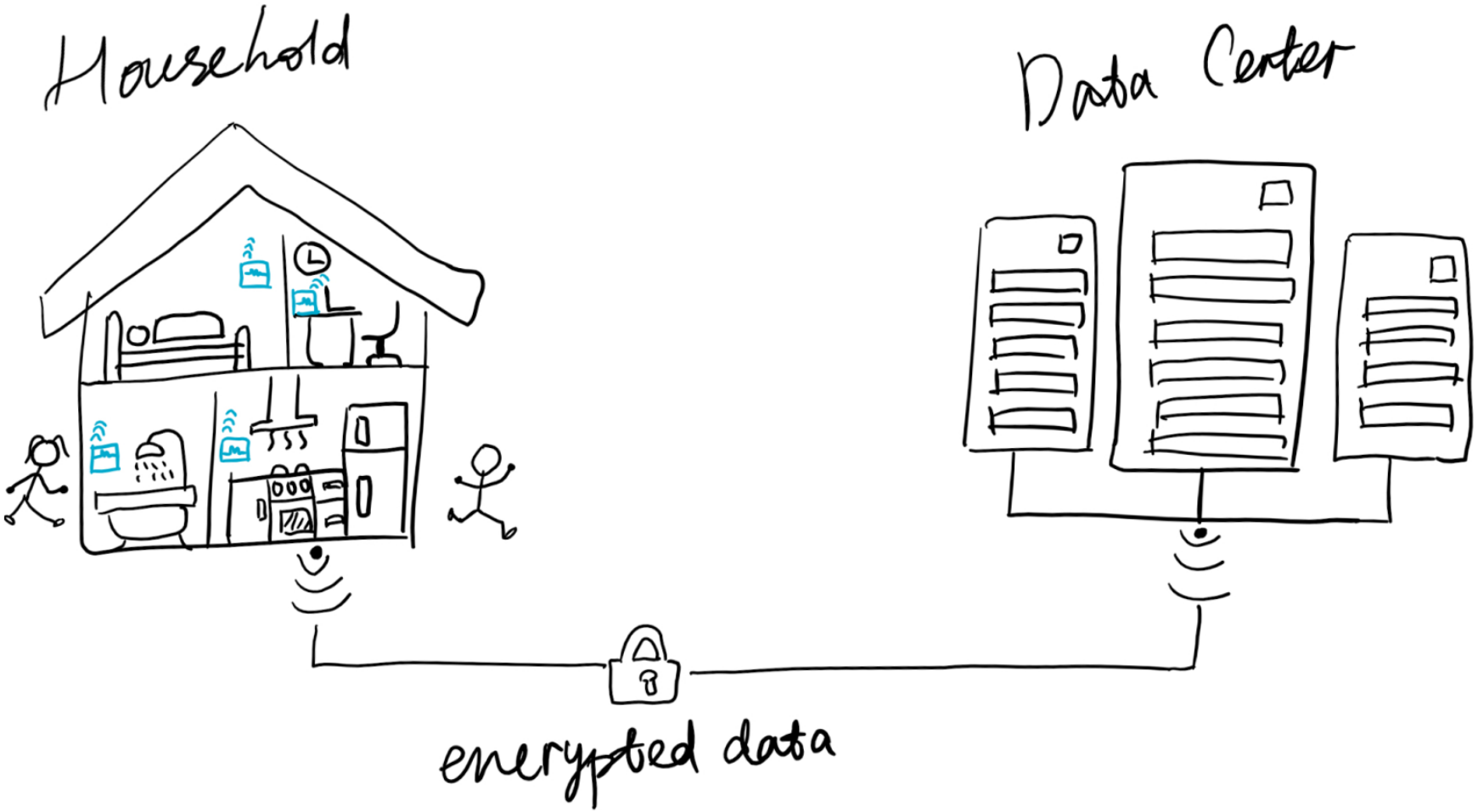
Particulate sensor

Temperature & humidity

RGBC Light & gesture sensor

WiFi™

Data flow

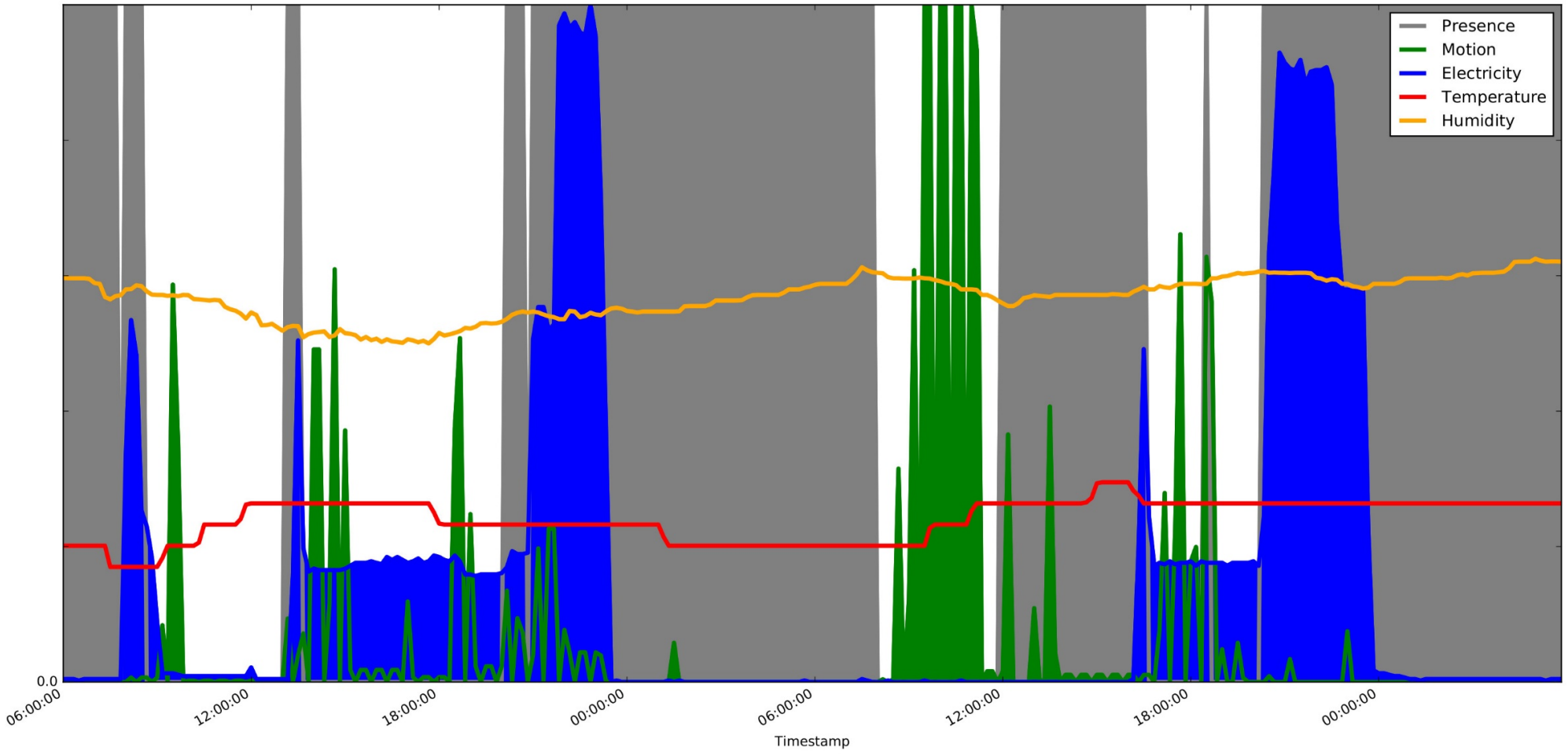


Visualization of the data stream in real time

HomeSense
digital sensors in social research

Testing: in a study bedroom

From 23 Sept 6:00am until 25 Sept 6:00am

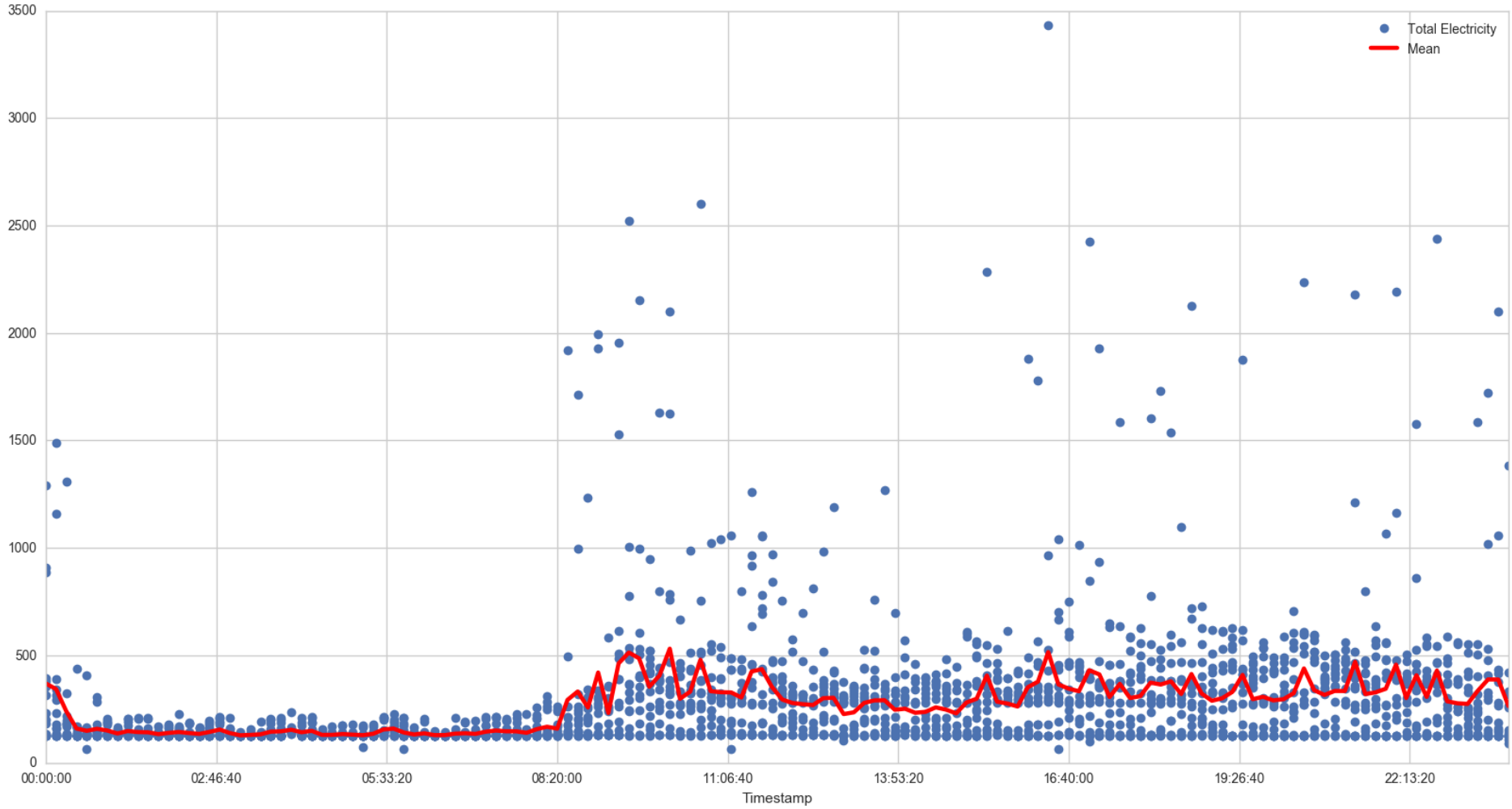


UNIVERSITY OF SURREY

HomeSense
digital sensors in social research

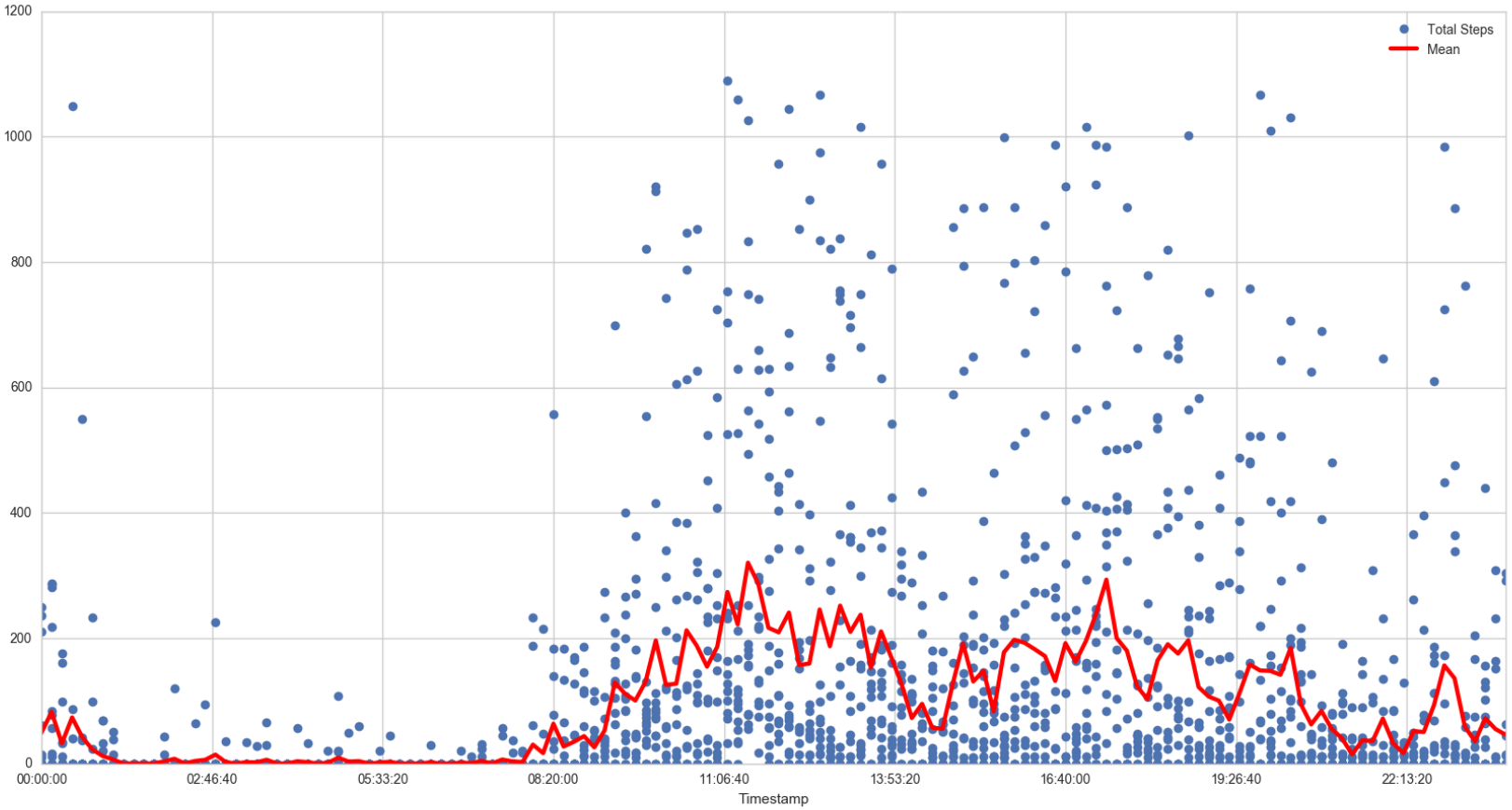
Testing: electricity daily distribution

From 05-12-2016 to 05-01-2017



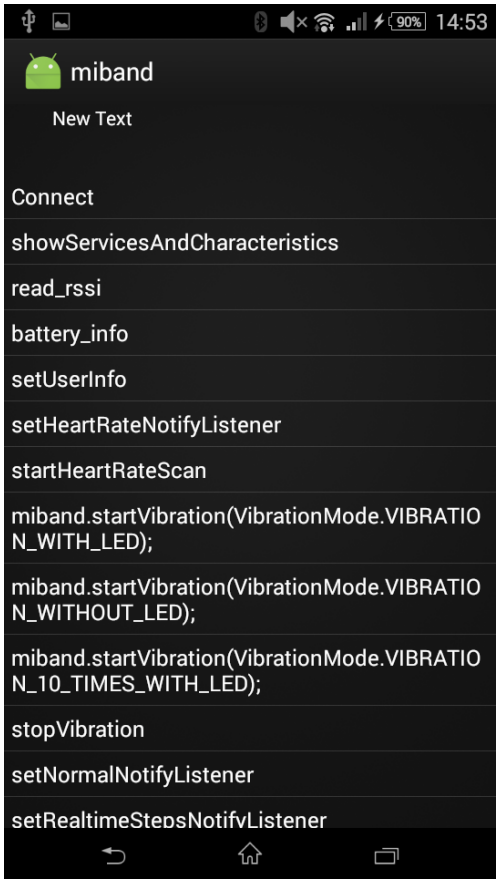
Testing: motion daily distribution

From 05-12-2016 to 05-01-2017

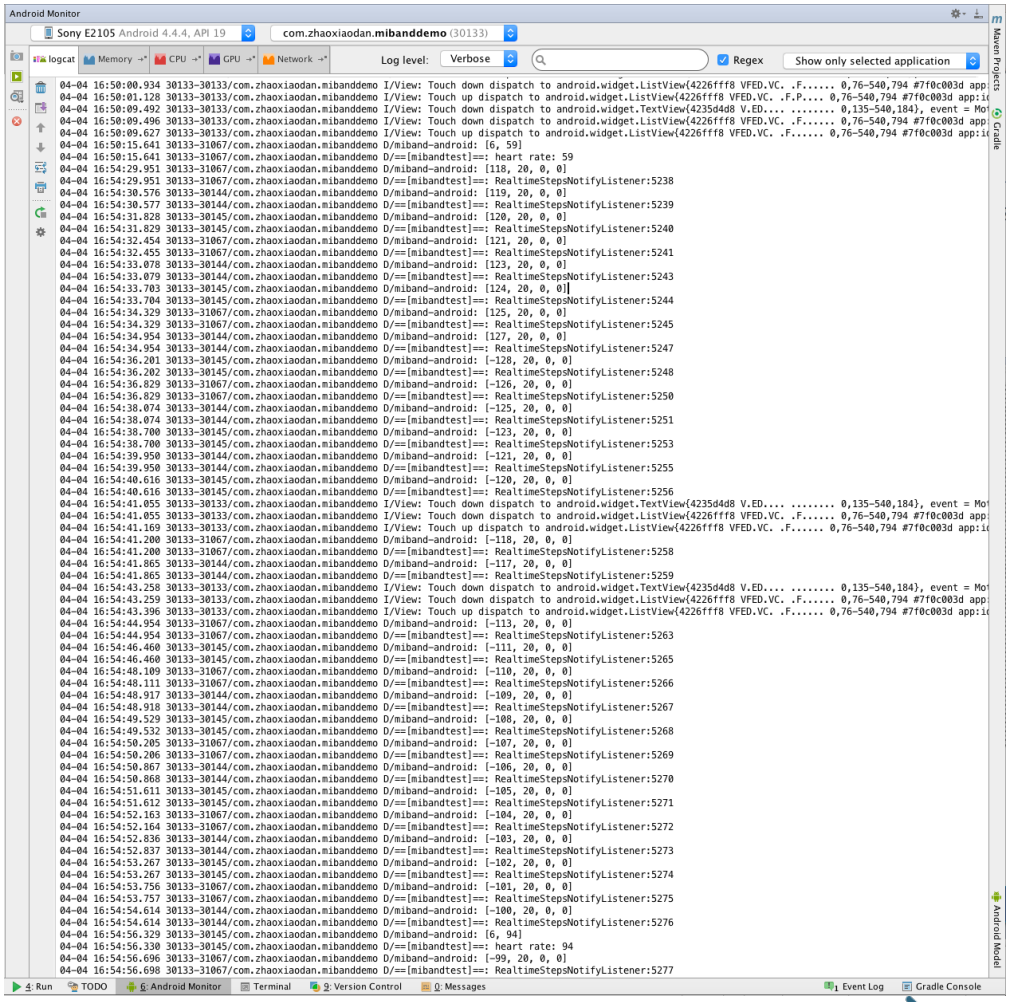


Data from wearable device

App to extract data



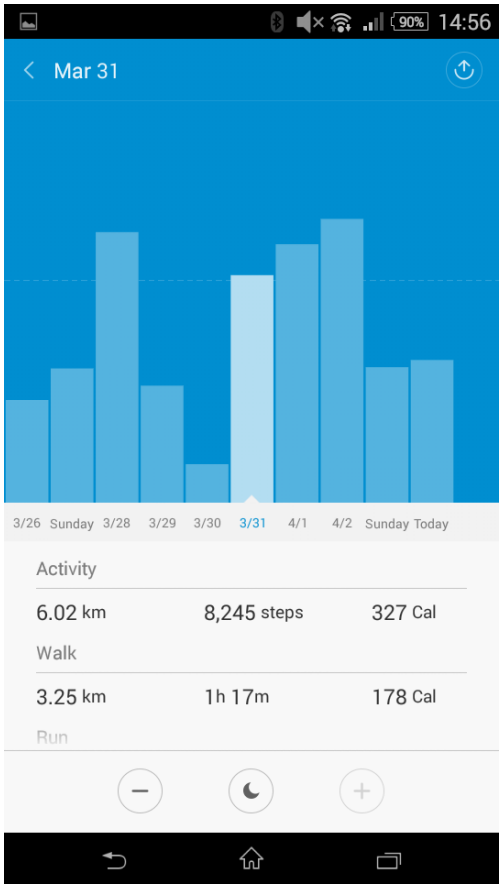
Real-time data stream of a Mi Band



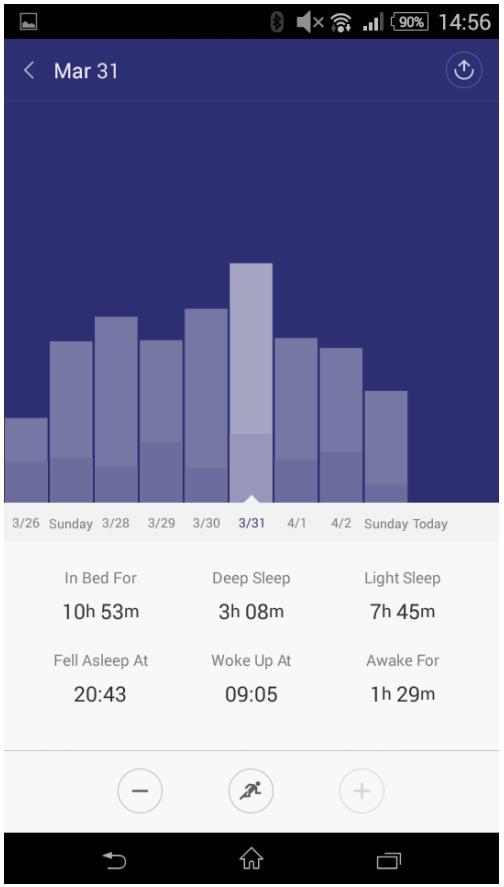
HomeSense
digital sensors in social research

Data from wearable device

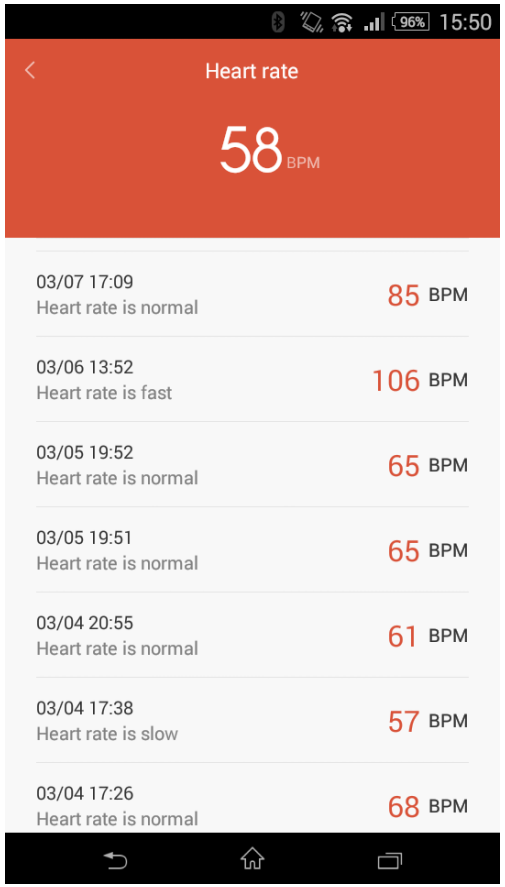
Movement



Sleeping



Heart rate



HomeSense
digital sensors in social research

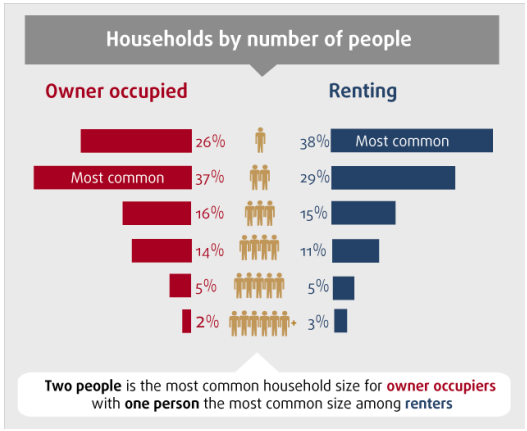
Strand 2 research questions

- What are the practical problems of installing sensors in homes?
- How should one handle privacy and security?
- What are the ethical issues to be considered?
- What are the risks that need to be managed?
- How does one obtained informed consent, and from whom?
- What is the best way to recruit and motivate participants?

Pilot sample

- Pilot sample of 20-30 households in South-East England, each participating for 3 months
- Recruited by neighbourhood advertising and snowballing
  - Six households of one adult;
  - Eight households of two or more adults;
  - Six households of parent(s) with dependant(s) 0-16yrs.

  (roughly corresponding to the proportions in the UK population)



Fieldwork

- One *key respondent* in each household
  - **Interviewed** twice, before and after the trial
  - Fills in two 10-15 minute **questionnaires**, one before and one after the trial
    - first to record information about the household
    - second to record the experience of living with sensors
  - Asked to fill in a diary of **Time Use** for 4 consecutive days, at 10 minute intervals
  - Given a **MiBand** to wear for the whole trial period
  - Rewarded with £100, in staged payments
- Other household members (if any)
  - Optional MiBand
  - Rewarded with £25

HomeSense
digital sensors in social research

First visit

- Preliminary consent obtained from key respondent and other household members aged 16+
- Operation of sensors explained and demonstrated: *principle of demystification*
- Walking interview around the home, to:
  - Observe the narratives of what goes on, who does what (where with whom), what routines are common, what devices are typically used, what is shared, what is private, and so on.
  - identify ideal / acceptable spots for Eggs and energy monitors.
- Information sheet given to key respondent to hand to visitors and houseguests.

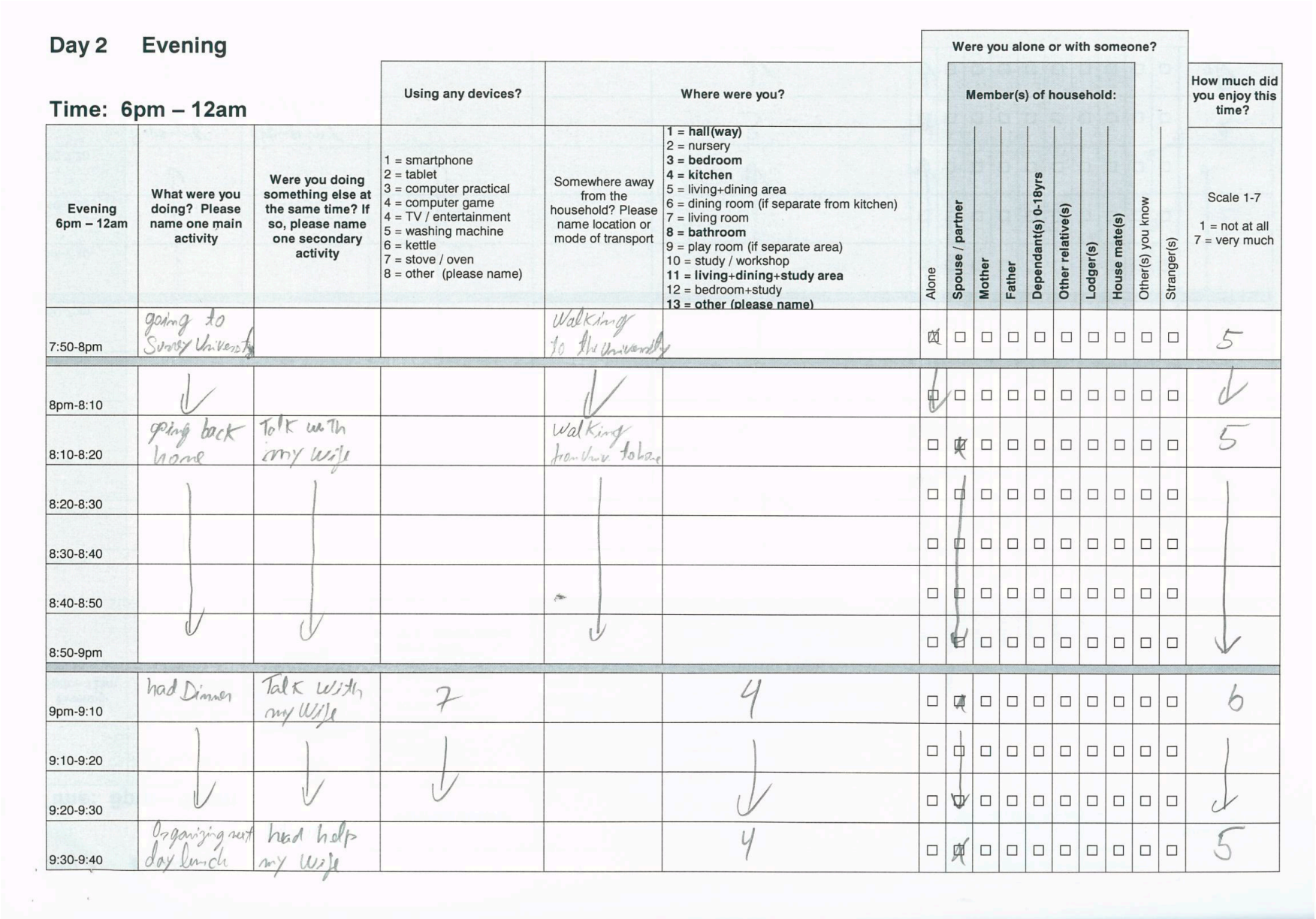
Second visit

- Install:
  - Up to 10 sensor boxes (Eggs)
  - Up to 8 energy monitors
- 1 or 2 MiBand(s) distributed
  - MiBand data accessible to the wearer on their own smart phone, but also transmitted to data centre
  - MiBands retained by respondents after the data collection finishes as an additional reward
- Data capture demonstrated during installation
  - Consent confirmed or revoked (*incremental consent*)
  - Children allowed the opportunity to assent

UNIVERSITY OF SURREY

HomeSense
digital sensors in social research

Adapted HETUS format time use diary



Day 2 Evening

Time: 6pm – 12am

Evening 6pm – 12am	What were you doing? Please name one main activity	Were you doing something else at the same time? If so, please name one secondary activity	Using any devices? 1 = smartphone 2 = tablet 3 = computer practical 4 = computer game 4 = TV / entertainment 5 = washing machine 6 = kettle 7 = stove / oven 8 = other (please name)	Where were you? Somewhere away from the household? Please name location or mode of transport	Where were you? **1 = hall(way)** 2 = nursery **3 = bedroom** **4 = kitchen** 5 = living+dining area 6 = dining room (if separate from kitchen) 7 = living room **8 = bathroom** 9 = play room (if separate area) 10 = study / workshop **11 = living+dining+study area** 12 = bedroom+study **13 = other (please name)**	Were you alone or with someone? Alone	Member(s) of household: Spouse / partner	Mother	Father	Dependant(s) 0-18yrs	Other relative(s)	Lodger(s)	House mate(s)	Other(s) you know	Stranger(s)	How much did you enjoy this time? Scale 1-7 1 = not at all 7 = very much
7:50-8pm	going to Surrey University			Walking to the University		☒	☐	☐	☐	☐	☐	☐	☐	☐	☐	5
8pm-8:10	↓			↓		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	↓
8:10-8:20	going back home	Talk with my wife		Walking from Uni to home		☐	☒	☐	☐	☐	☐	☐	☐	☐	☐	5
8:20-8:30	↓	↓		↓		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	↓
8:30-8:40	↓	↓		↓		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	↓
8:40-8:50	↓	↓		↓		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	↓
8:50-9pm	↓	↓		↓		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	↓
9pm-9:10	had Dinner	Talk with my Wife	7		4	☐	☒	☐	☐	☐	☐	☐	☐	☐	☐	6
9:10-9:20	↓	↓	↓		↓	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	↓
9:20-9:30	↓	↓	↓		↓	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	↓
9:30-9:40	Organizing next day lunch	Had help my wife			4	☐	☒	☐	☐	☐	☐	☐	☐	☐	☐	5

Consent

- Respondents can withdraw from the study at any time
- Eggs can be temporally turned off or on by household members by waving a hand over them (they turn on again automatically an hour later)
- MiBands can disconnected at any time

CONSENT

Freely Given
Reversible
Informed
Enthusiastic
Specific

HomeSense
digital sensors in social research

Data management issues

- All data streams are encrypted at point of generation and decrypted at the data centre
- Data are identified only with an ID, with the link to the household address kept separately
- Only aggregate data (not individual data streams) will be available outside the project
- Time use diaries, questionnaire responses, interview transcripts will be available after anonymization
- Specific issues for household studies:
  - One household member recognising another member of the same household in data
  - Unlawful or compromising activities in the household

Strand 3: Data analysis

- Time use diaries
  - Self-assigned descriptors of activity
    - Every 10 minutes for a few days
- Data streams from the 'Egg'
  - A limited number of environmental measurements in a limited number of locations
    - Every 3 - 5 seconds
    - 3 Megabytes (MB) from each Egg every 24 hours
- Data streams from the energy monitors
  - Electricity usage of to 8 appliances monitored
  - Also total household electricity consumption
    - Every 6 seconds
    - 2.4 MB from each energy monitor every 24 hours
- Data streams from the MiBand
  - Motion
    - Every 15 minutes
    - 17 kB per day
- Up to 42 MB every day per household
- 76 Gigabytes for 20 households over 3 months

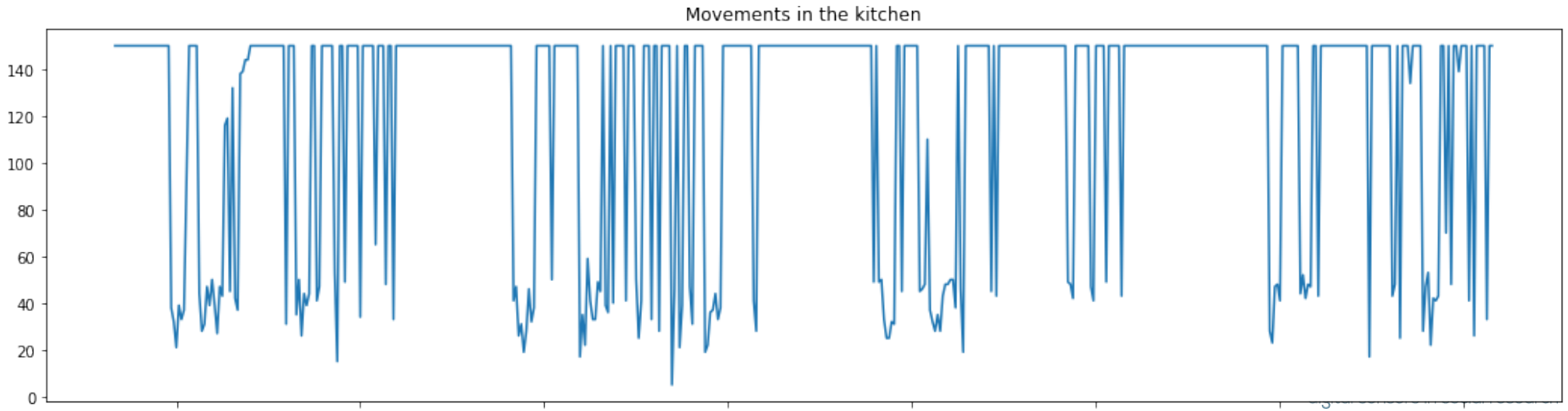
HomeSense
digital sensors in social research

Triangulating the data

- Time use data
  - Start and end times of activities may not be accurate
  - Activities may be recorded out of sequence
  - Some activities may not be recorded
  - Descriptors may be idiosyncratic
- Sensor data
  - Activities may take place out of range of the sensors
  - Sensors do not observe activities, but only their physical effects (e.g. 'cooking' could be recorded as an increase in temperature and noise in the kitchen)
- Hence there is a problem of inference: from sensor data to activity

Sensor data processing

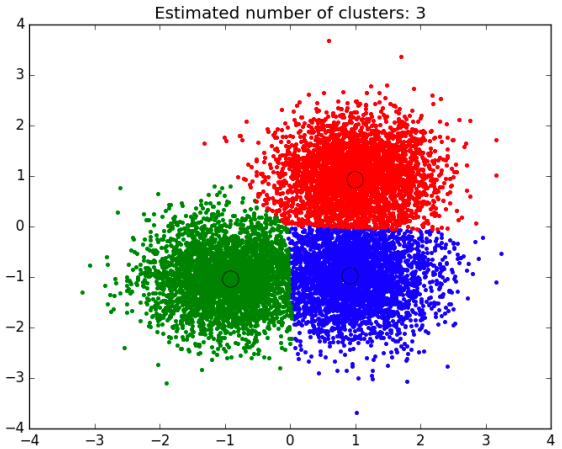
1. Preprocess sensor data
2. Smooth the data
   - Mean shift clustering
   - Change point detection
3. Recognise activities
   - Hidden Markov Modelling
4. Output a stream of activities



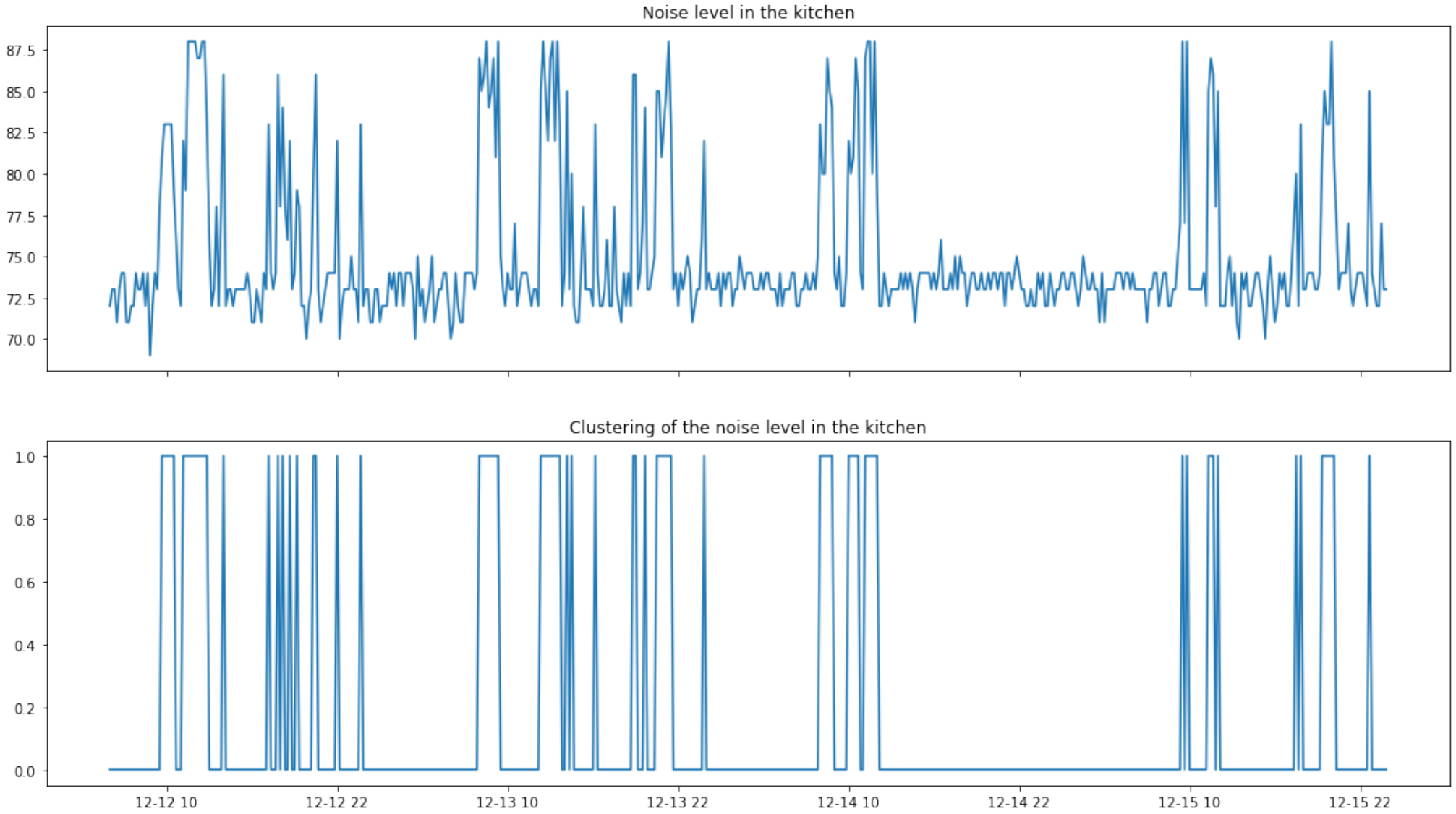
Normalising the sensor data

- Preprocessing
  - Find maximum value within each 10 minute to yield a data stream with values every 10 minutes for each sensor

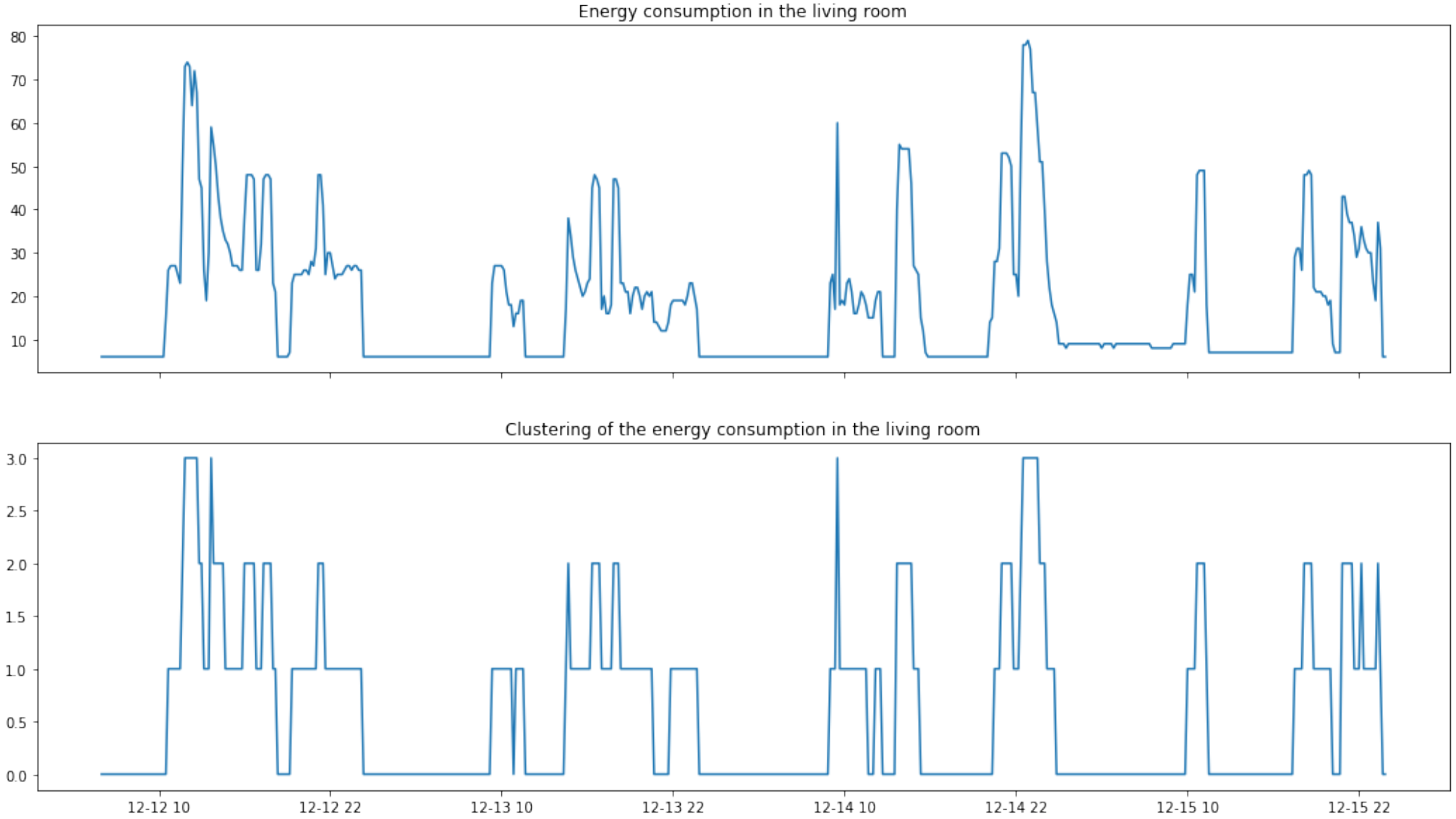
    (10 minutes to match Time Use Diary time intervals)
- Discretisation
  - Transform data stream from a continuous value to an set of integer values (representing e.g. on/off; near/middle/far; hot/warm/cold)
  - But where to change from one value to another?
    - Mean shift clustering



Mean shift clustering of noise-level readings from the sensor box placed in the kitchen

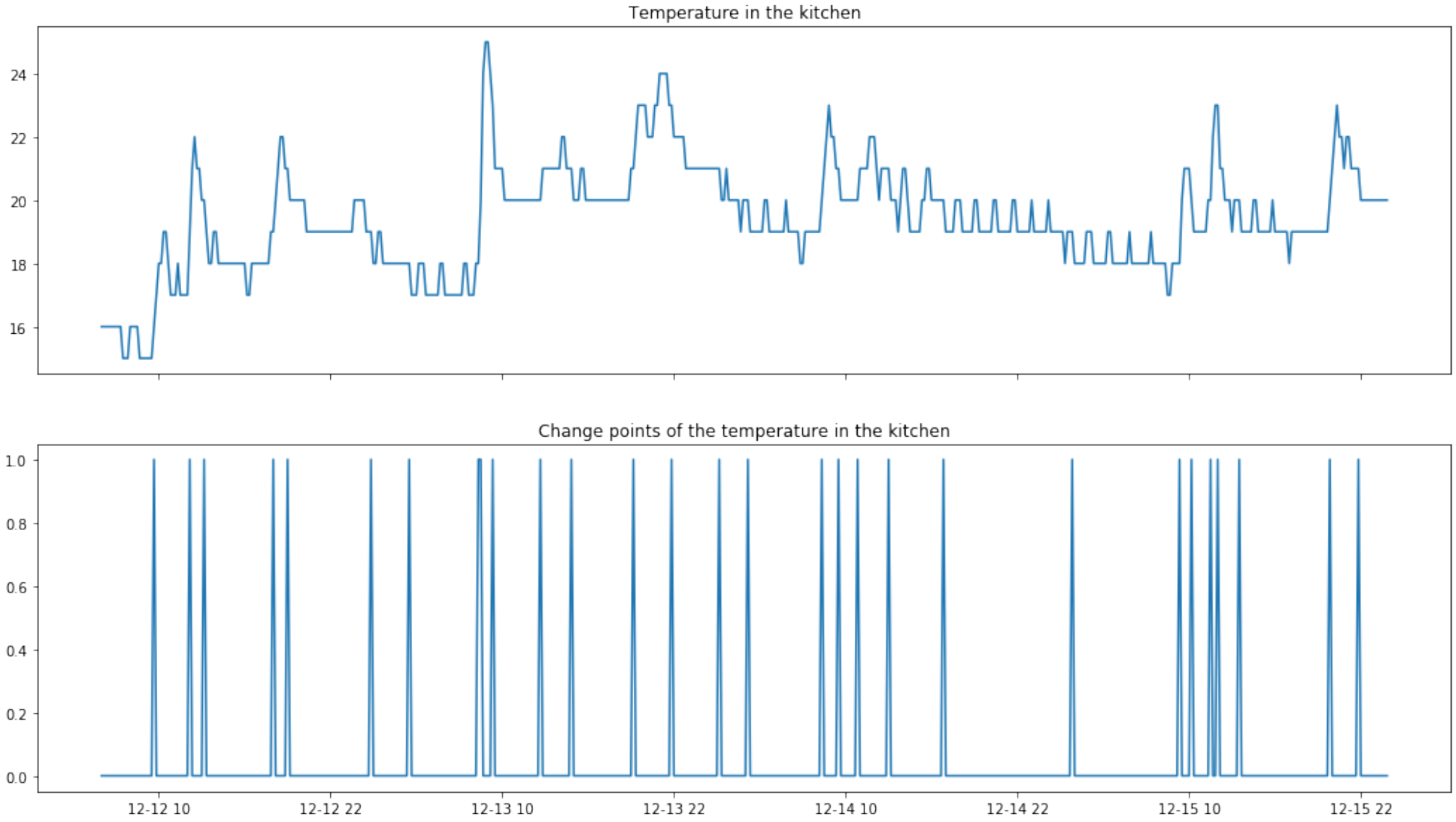


Mean shift clustering of electricity readings from the electricity monitors in the living room



Change point detection

Assumes that the data points are drawn from some PDF with parameters that change at the changepoint.



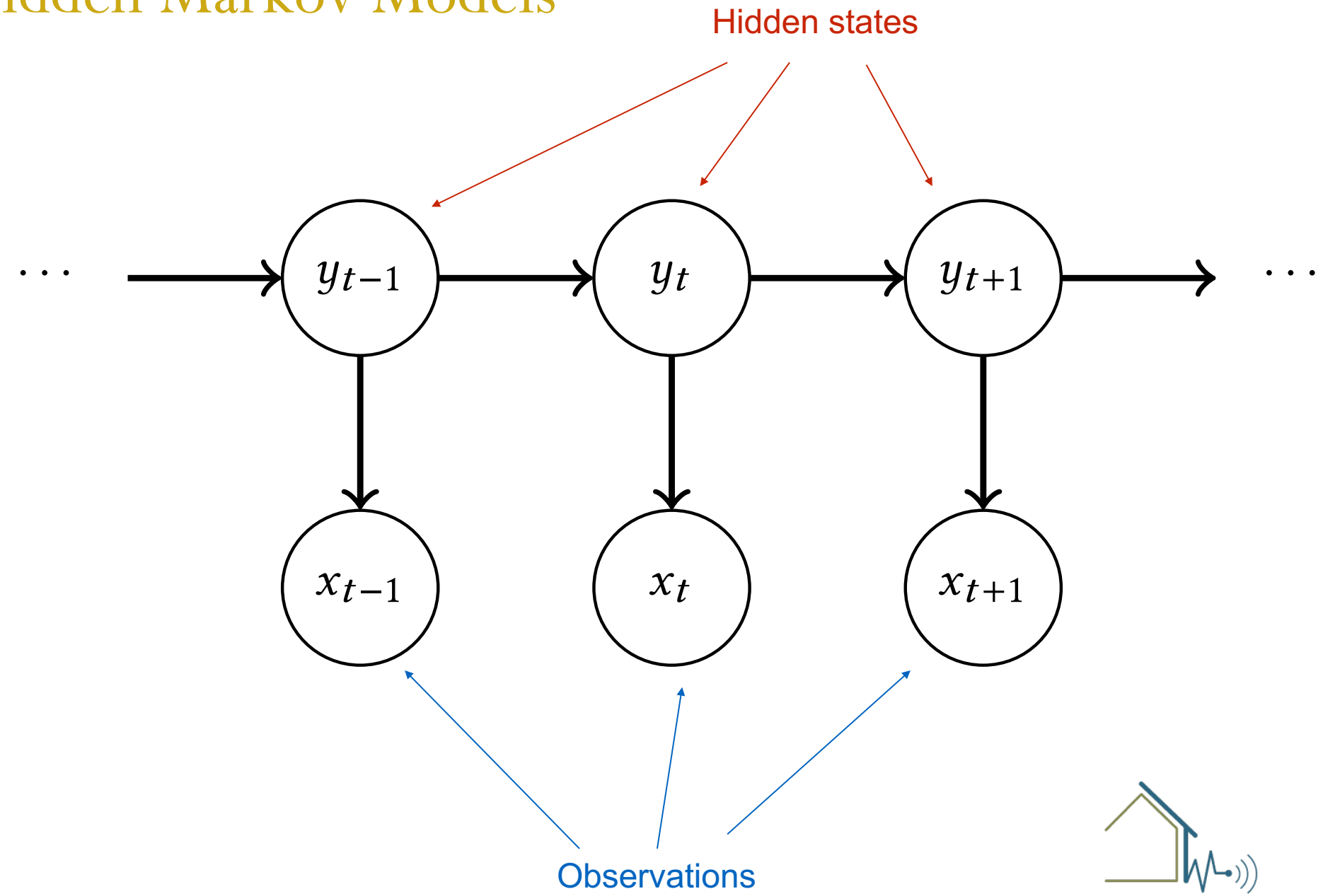
Labelling the data

- The household members are carrying out some activities.
  - These activities result in data that the sensors can detect.
  - One of the members fills in a Time Use Diary that records the activities and gives them names.
- The activities correspond to states that are 'hidden' or 'latent' but which generate *observable sensor data* and *observable marks* in the Time Use Diaries. We want to reveal the hidden activities and label them.
- Use a Hidden Markov Model (HMM)

UNIVERSITY OF SURREY

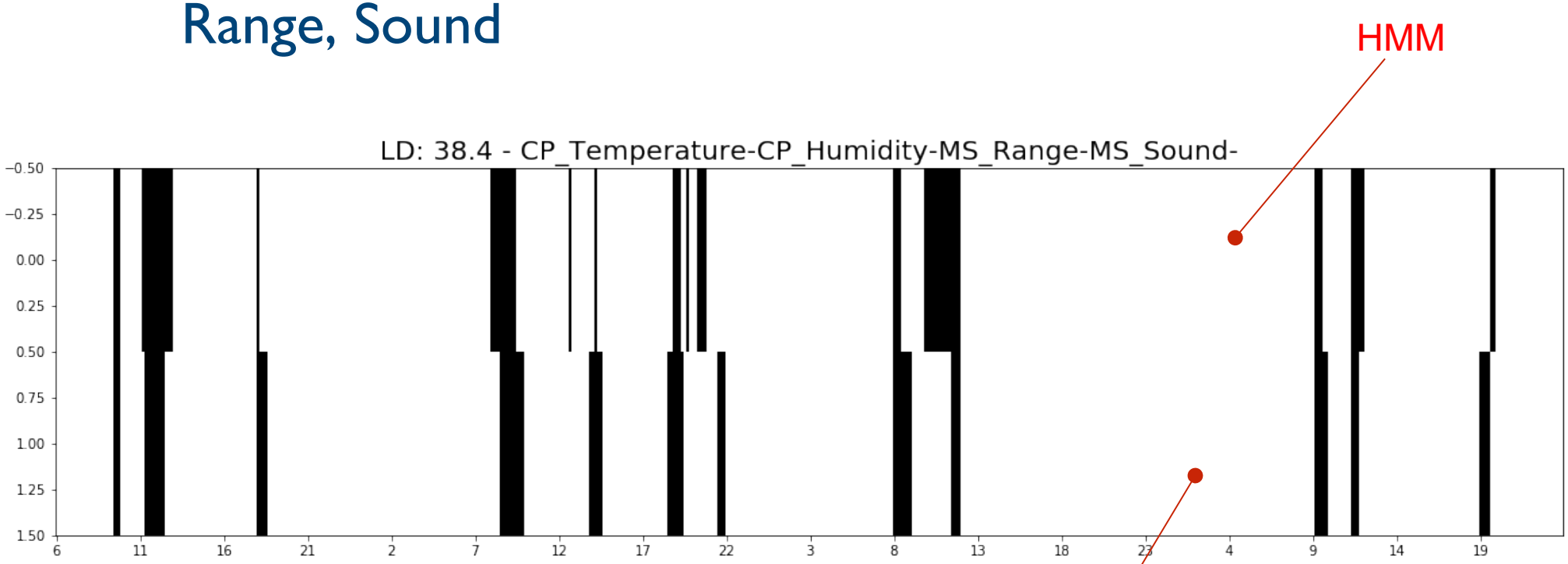
HomeSense
digital sensors in social research

Hidden Markov Models



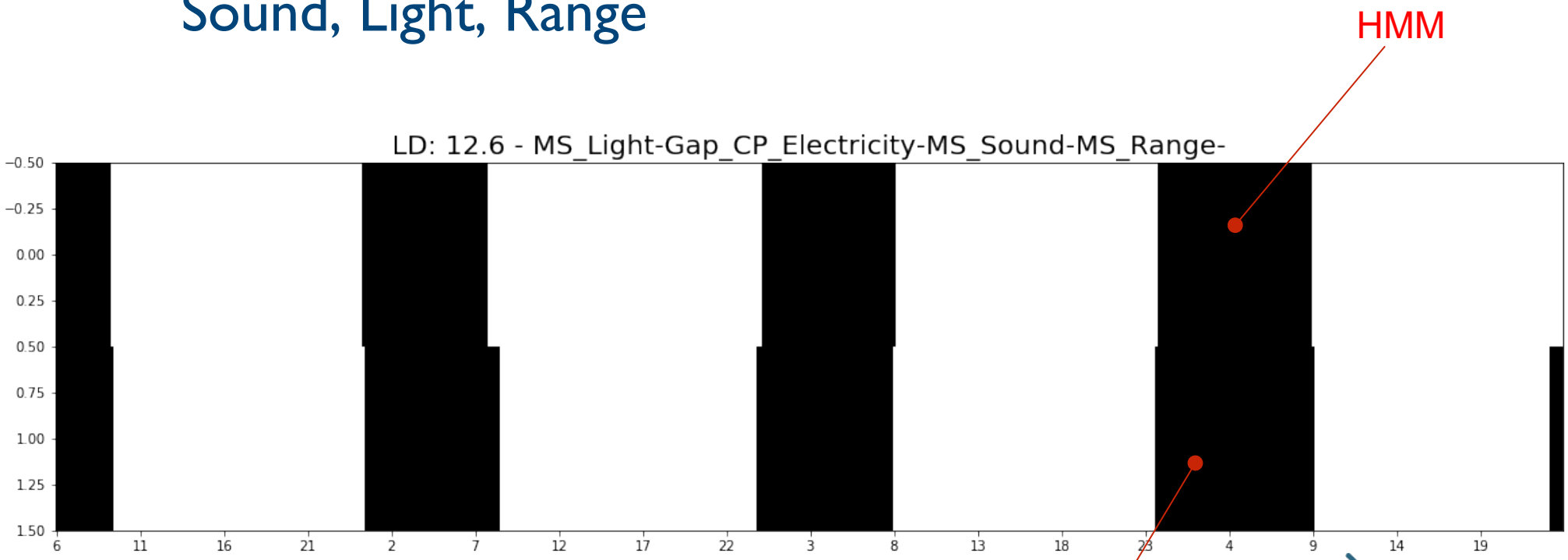
Hidden Markov Model: example output

- **Cooking**, using data from the Egg sensors in the kitchen
- Significant data streams: Temperature, Humidity, Range, Sound



Hidden Markov Model: example output

- **Sleeping**, using data from the Egg sensors and energy monitors in the bedroom
- Significant data streams: Whole house electricity, Sound, Light, Range



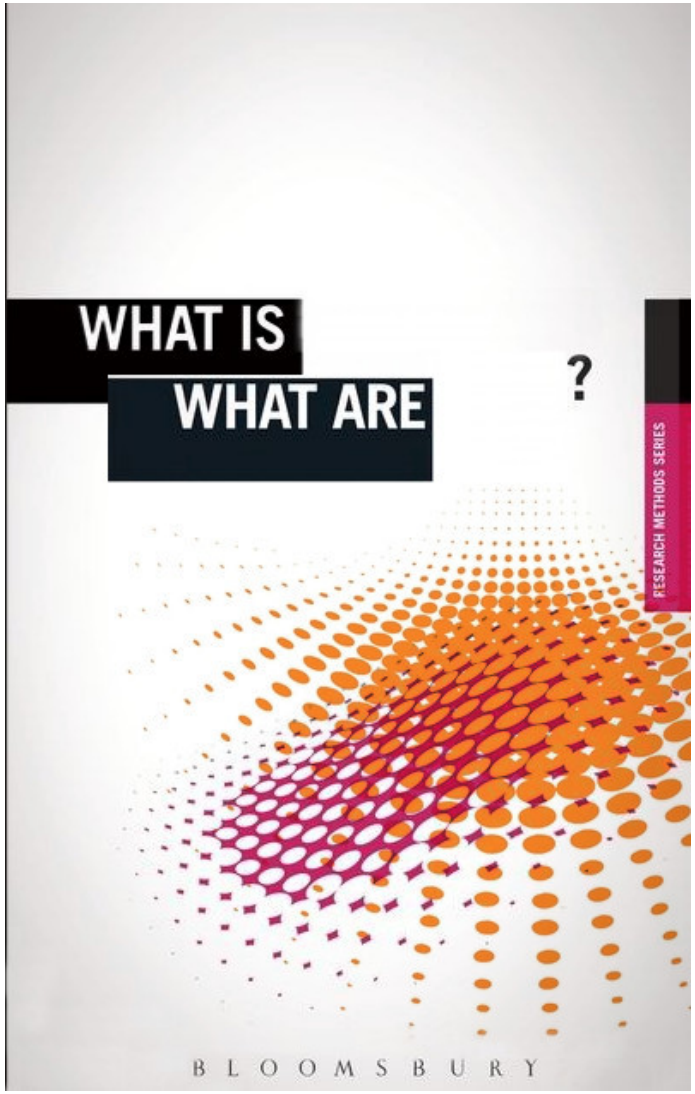
HomeSense
digital sensors in social research

Outputs

INSIGHTS: bringing together sensor technology and social research

- Workshops
- NCRM Short courses, starting in late 2017
- Book: *What are sensors in social research?*

HomeSense
digital sensors in social research



'What is?' Research Methods series

Graham Crow (ed.) University of Southampton

What are sensors in social research?

UNIVERSITY OF SURREY

HomeSense
digital sensors in social research

HomeSense timeline until now

UNIVERSITY OF SURREY

2016

February / March:
- Started testing wristbands
- First prototype test of the IoT Egg
- Reviewed the state-of-the-art in tracking, time use, profile analysis, etc.

April / May:
- Set up database
- Developed data processing and visualization techniques

June:
- Bloomsbury workshop
- Developed quantitative and qualitative research instruments

July / August:
- Drafted data collection guidelines
- Prepared and submitted ethics approval application

September / October:
- Tested sensors and other methods in 'friendly' household
- Liaised with meet-ups and other relevant groups to publicise HomeSense

November / December:
- Second pilot test (comprehensive)

January / February:
- Ethics approval
- Start recruitment

2017

March / April:
- Fieldwork
- Data collection and visualizations
- Submit book proposal

May / June:
- Fieldwork
- Data collection and visualizations
- Start developing data-analytic techniques

HomeSense
digital sensors in social research

facebook.com/sensoresearch/

@CRESS_HomeSense

HomeSense

digital sensors in social research

UNIVERSITY OF SURREY

What would you like to use digital sensors for?

HomeSense
digital sensors in social research