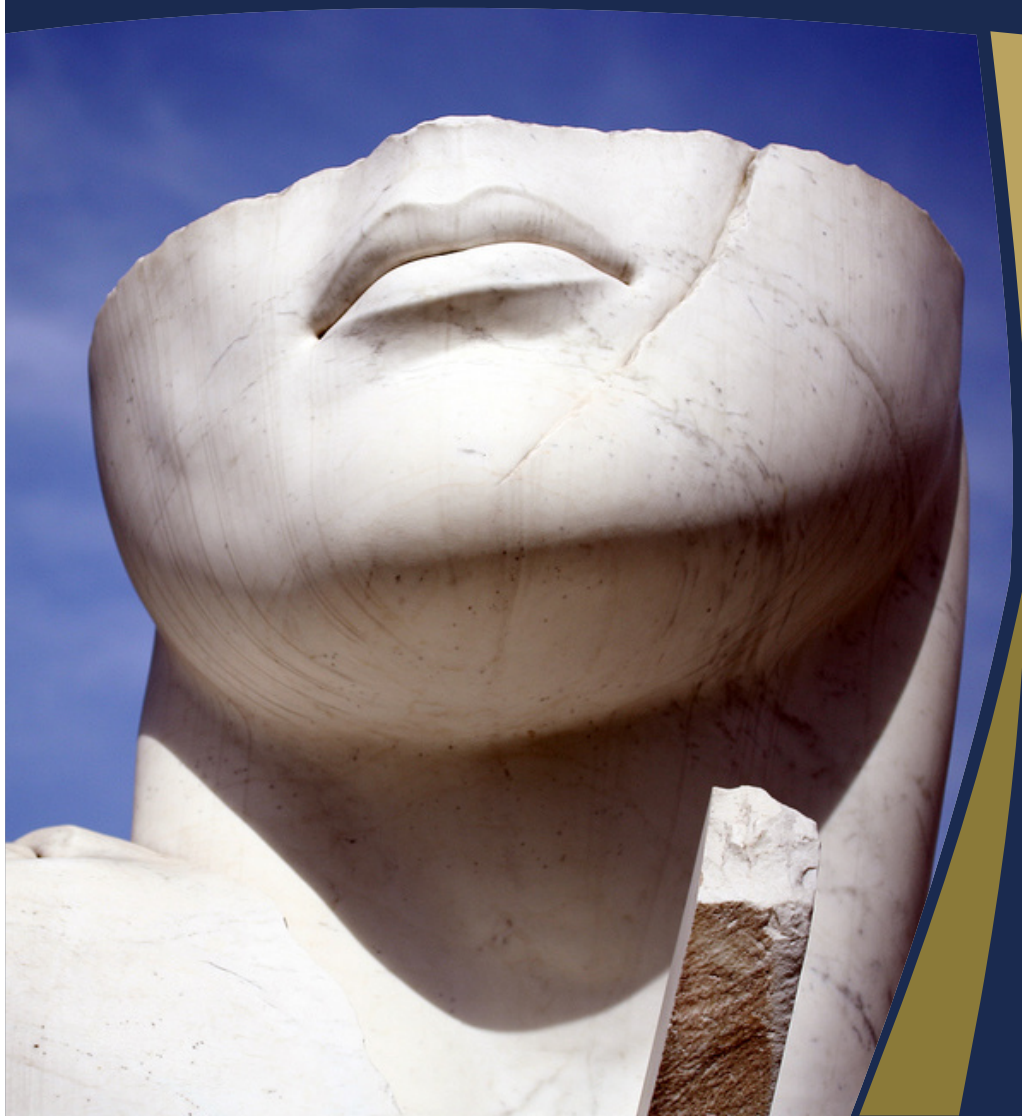

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# Digital phenotyping and machine learning in the next generation of digital health technologies: Utilising event logging, ecological momentary assessment & machine learning

Prof Maurice D. Mulvenna
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orcid.org/0000-0002-1554-0785

ulster.ac.uk

# @mauricemulvenna

## bio

- Researching in: artificial intelligence, digital interventions for mental health and wellbeing, assistive technologies
- UK Ofcom Advisory Committee on Older and Disabled People
- Winner European €100,000 IST Grand Prize
- 32nd British Human-Computer Interaction conference in 2018
- 31st European Cognitive Ergonomics conference in September 2019

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# Outline

- Assistive technology
- Growing importance of data
- Event logs
- Data analytics workflows
- Case study
  - Introduction
  - Results
  - Ecological momentary assessment
  - Machine learning
- Going mainstream with event logs
- Discussion and conclusions

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# Utilising event logging, ecological momentary assessment & machine learning

## Assistive technology

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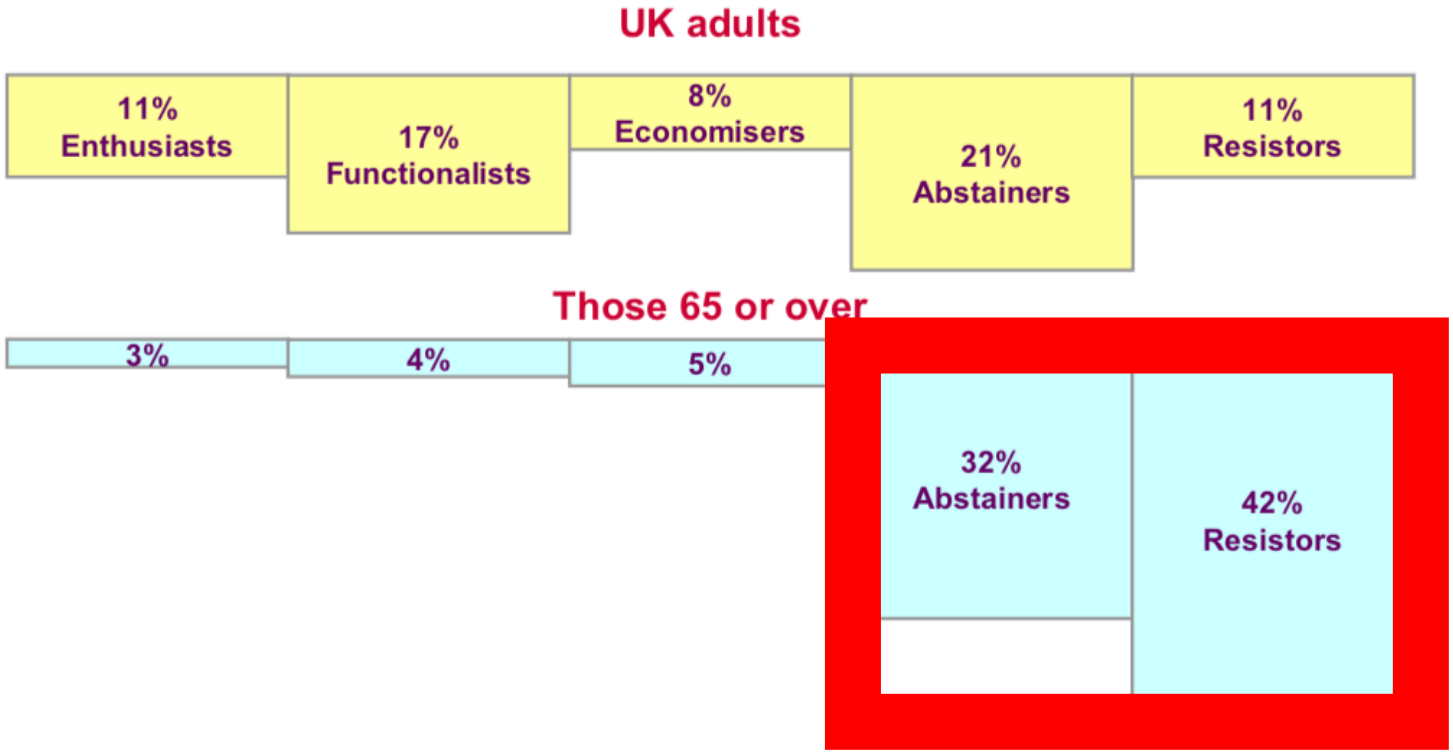
# Engagement with digital services

## Older people

- The majority of those 65 or over (73%) were classified as **Resistors** or **Abstainers**

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Source: Thickett, J., (2006) Connecting Older People: Consumer Engagement with Digital Services, Ofcom Report

COGKNOW


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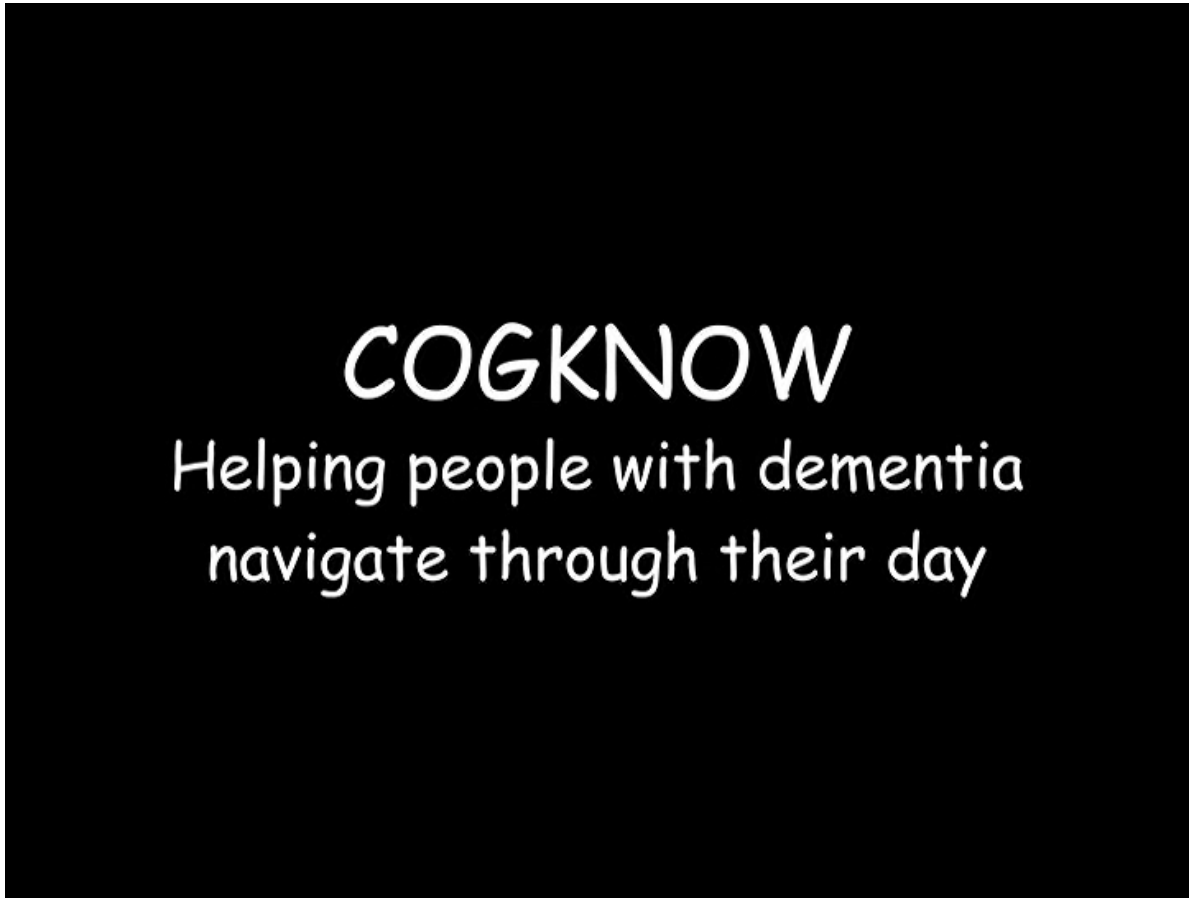
Lauriks, S., Reinersmann, A., Roest, H. van der, Meiland, F.J.M., Davies, R.J., Moelaert, F., Mulvenna, M.D., Nugent C.D., Dröes, R.M., (2007) Review of ICT-based Services for Identified Unmet Needs in People with Dementia, *Aging Research Reviews*, 6(3): 223–246. https://doi.org/10.1016/j.arr.2007.07.002

COGKNOW

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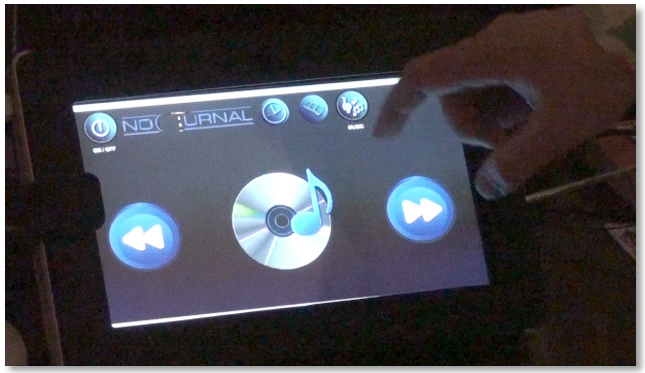
Davies, R.J., Nugent, C.D., Donnelly, M., Hettinga, M., Meiland, F., Moelaert, F., Mulvenna, M.D., Bengtsson, J.E., Craig, D., Droes, R.-M. (2009) A User-Driven Approach to Develop a Cognitive Prosthetic to Address Unmet Needs of People with Mild Dementia, *Journal of Pervasive and Mobile Computing*, 5(3): 253-267. https://doi.org/10.1016/j.pmcj.2008.07.002




Mulvenna, M.D., Carswell, W., McCullagh, P., Augusto, J.C., Zheng, H., Jeffers, W.P., Wang, H.Y., Martin, S., (2011) Visualization of Data for Ambient Assisted Living Services, IEEE Communications Magazine feature topic on New Converged Telecommunications Applications for the End User, *IEEE Communications Magazine*, January 2011, 49(1): 110-117. https://doi.org/10.1109/MCOM.2011.5681023

NOCTURNAL
Night Optimised Care Technology for UseRs Needing Assisted Lifestyles

# SERVICE SOLUTION WALKTHROUGH

University of ULSTER FOLD TeleCare Technology Strategy Board Driving Innovation EPSRC Engineering and Physical Sciences Research Council

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Augusto, J.C., Mulvenna, M.D., Zheng, H., Wang, H., Martin, S., McCullagh, P., Wallace, J., (2014) Night Optimised Care Technology for Users Needing Assisted Lifestyles, *Behaviour & Information Technology*, 33(12): 1261-1277. https://doi.org/10.1080/0144929X.2013.816773

# Utilising event logging, ecological momentary assessment & machine learning

## Growing importance of data

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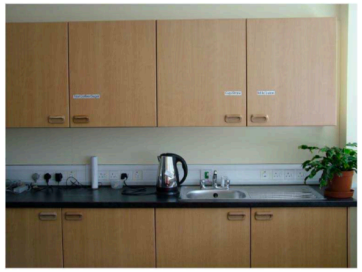
# Knowledge-based approaches

## Handling uncertainty in activities of daily living

Fig. 1: Sensors within smart kitchen environment to assess the ADL of preparing a drink (a) picture of the semi-functioning kitchen, (b) cupboard with door sensor, (c) kettle with tilt switch and contact switch on tap, (d) contact sensors on sugar, tea and coffee jar and (e) contact sensor on coffee in 'on' state



(a)

(b)

(c)

(d)

(e)

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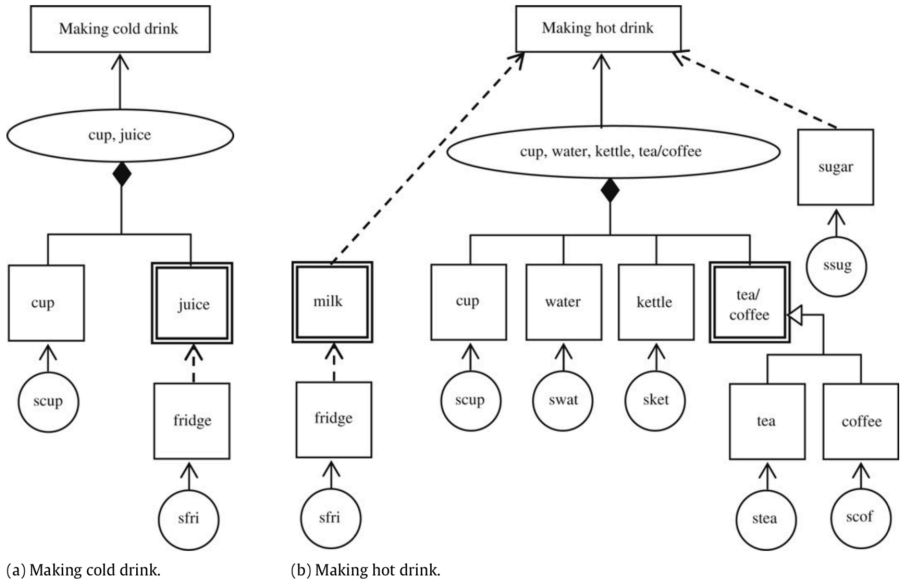
Hong, X., Nugent, C., Mulvenna, M.D., Martin, S., Devlin, S., Wallace, J.G., (2012) Dynamic Similarity-based Activity Detection and Recognition within Smart Homes, *International Journal of Pervasive Computing and Communications*, 8(3): 264-278. https://doi.org/10.1108/17427371211262653

# Knowledge-based approaches

## Handling uncertainty in activities of daily living




(a) Making cold drink. (b) Making hot drink.

Hong, X., Nugent, C., Liu, W., Ma, J., McClean, S.I., Scotney, B.W., Mulvenna, M.D., Uncertain Information Management for ADL Monitoring in Smart Homes, In: McClean, S.; Millard, P.; El-Darzi, E.; Nugent, C.D. (Eds.), Intelligent Patient Management, in series: *Studies in Computational Intelligence*, Vol. 189, 2009, pp. 315-332. https://doi.org/10.1007/978-3-642-00179-6_19

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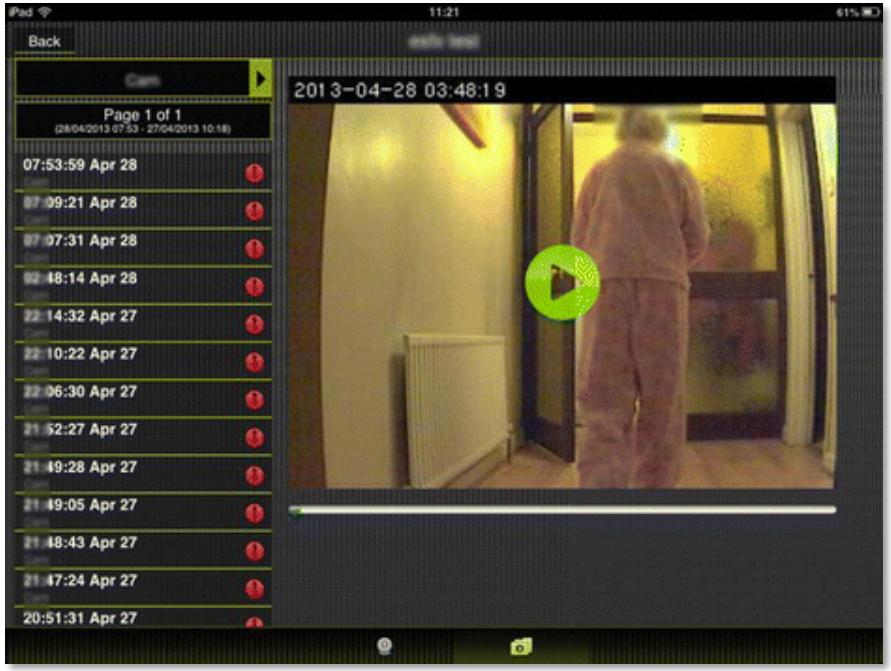
# Ethics of assistive technology

## Home surveillance of people living with dementia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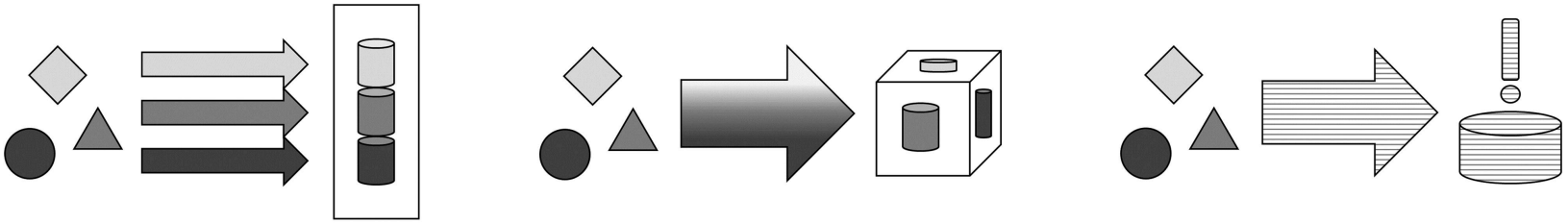
Mulvenna M.D., Hutton A., Coates V., Martin S., Todd S., Bond, R.B., Moorhead, A., (2017) Views of Caregivers on the Ethics of Assistive Technology used for Home Surveillance of People Living with Dementia, *Neuroethics*, 10(2):255-266. https://doi.org/10.1007/s12152-017-9305-z

# Working together

## What does this mean?



Multidisciplinary | Interdisciplinary | Transdisciplinary

Ulster University

Boger, J., Jackson, P., Mulvenna, M.D., Sixsmith, J., Sixsmith, A., Mihailidis, A., Kontos, P., Polgar, J., Grigorovich, A., and Martin, S. (2017) Principles for Fostering the Transdisciplinary Development of Assistive Technologies. *Disability and Rehabilitation: Assistive Technology* 12(5):480–90. https://doi.org/10.3109/17483107.2016.1151953

# Utilising event logging, ecological momentary assessment & machine learning

## Event logs

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# Everyday technologies

## Event logging

| User ID | Date | Time Stamp | Event ID | Event |
|---|---|---|---|---|
| 6 | 16/02/2018 | 16:41:31 | 82993 | Log-in |
| 6 | 16/02/2018 | 16:47:02 | 82994 | Home page |
| 6 | 16/02/2018 | 16:48:05 | 82995 | Search Query |
| 6 | 16/02/2018 | 16:48:59 | 82996 | Search Results |
| 6 | 16/02/2018 | 16:49:31 | 82997 | User Profile |

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# Utilising event logging, ecological momentary assessment & machine learning

## Data analytics workflows

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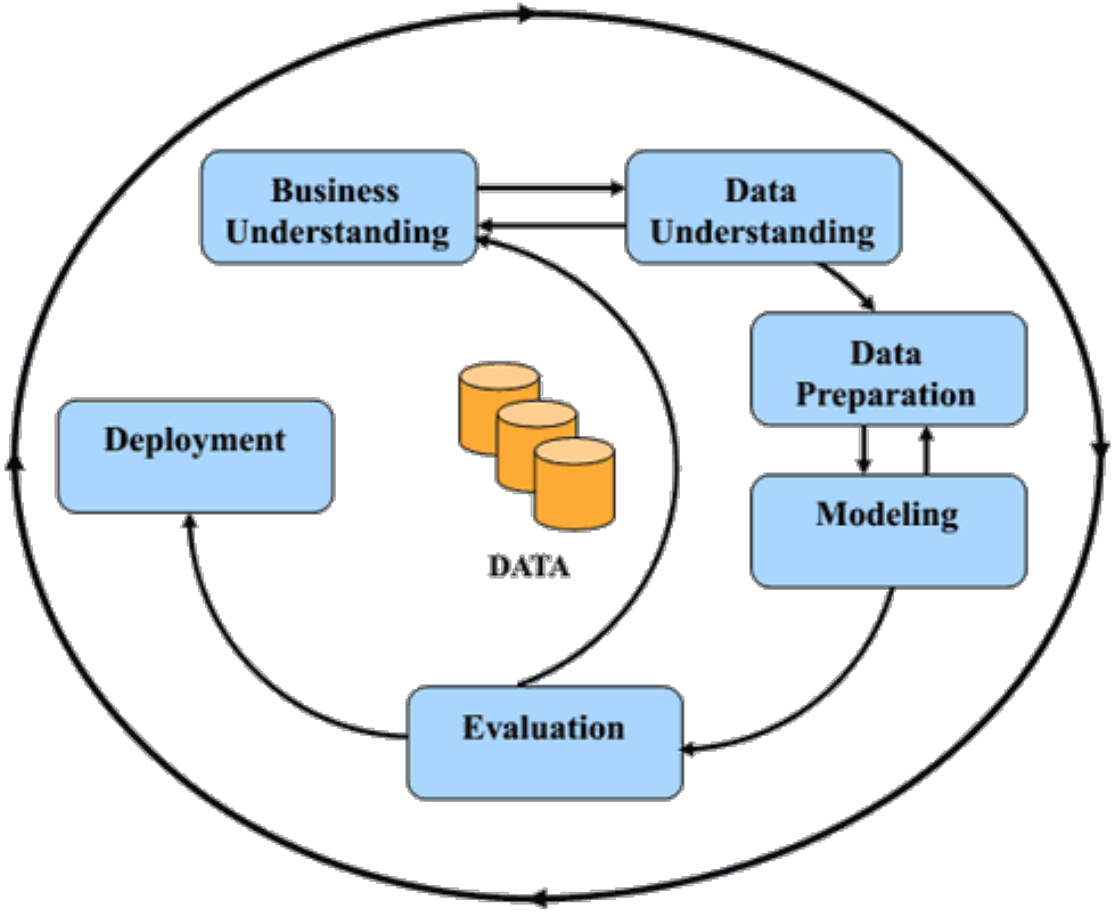
# Workflows

CRISP-DM Cross-industry standard process for data mining




Anand S.S., Mulvenna M., Chevalier K. (2004) On the Deployment of Web Usage Mining. In: Berendt B., Hotho A., Mladenič D., van Someren M., Spiliopoulou M., Stumme G. (eds) Web Mining: From Web to Semantic Web. EWMF 2003. Lecture Notes in Computer Science, vol 3209. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-540-30123-3_2

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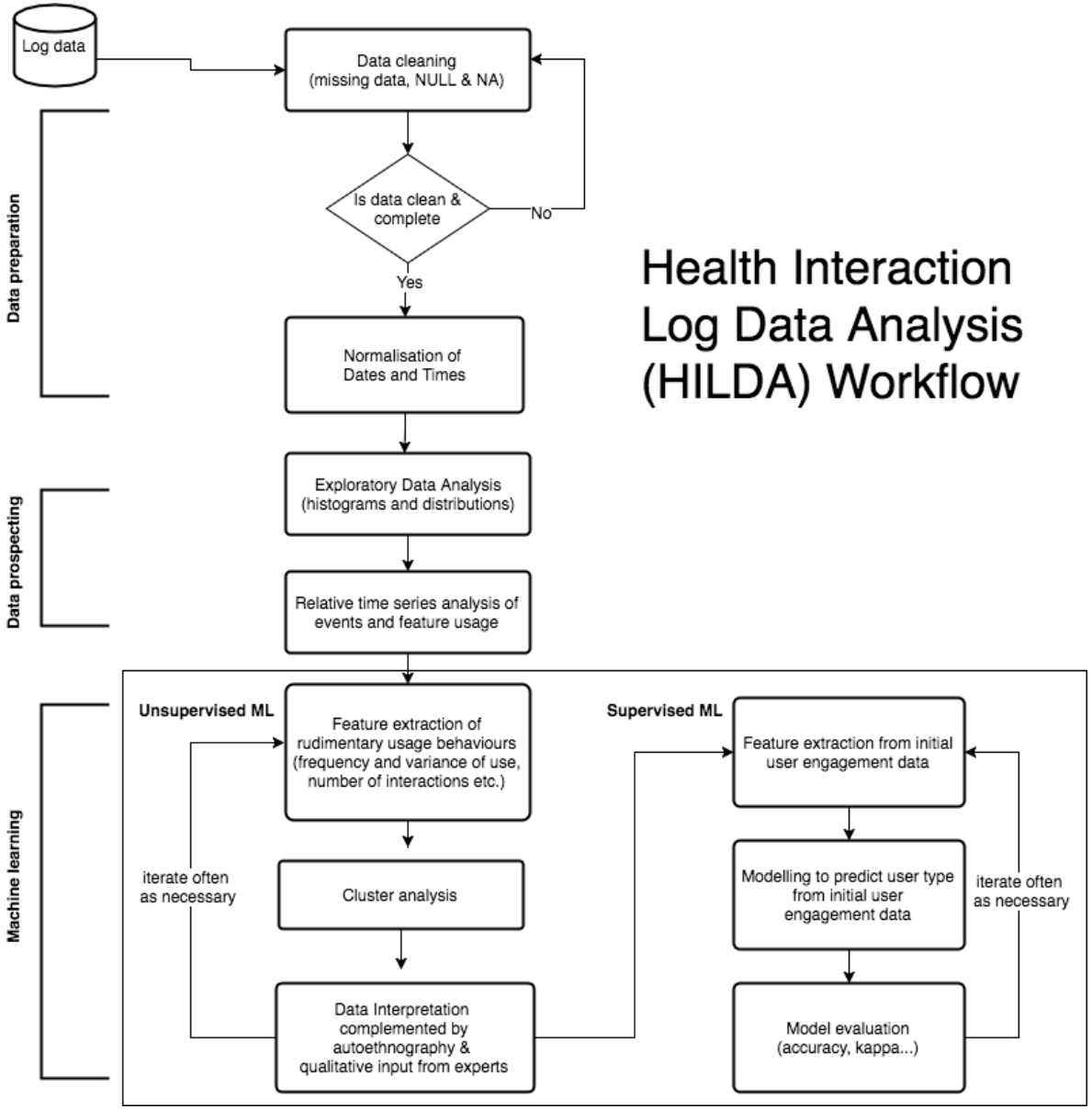


# Health Interaction Log Data Analysis (HILDA) Workflow

# Workflow

- Log data
- Descriptive statistics and visualisation
- Select machine learning method
- For K-means clustering
  - Elbow method
  - Cluster labelling
- Predictive modelling

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Mulvenna, M.D., Bond, R.B., Grigorash, A., O'Neill, S., Ryan, A.A. (2018) HILDA - A Health Interaction Log Data Analysis Workflow to Aid Understanding of Usage Patterns and Behaviours, Symposium on Social Interactions in Complex Intelligent Systems (SICIS-2018) at Artificial Intelligence and the Simulation of Behaviour (AISB-2018), 4-6 April 2018, Liverpool, UK.

# Utilising event logging, ecological momentary assessment & machine learning

## Case study - Introduction

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# Case study in Ageing Well and e-Health

## Reminiscence health app


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Laird, E.A., Ryan, A.A., McCauley, C.O., Gibson, A, Bunting, B.P., Mulvenna, M.D., Bond, R.B., Curran, K., Ferry, Finola (2018) “There is still so much inside”: The impact of personalised reminiscence, facilitated by a tablet device, on people living with mild to moderate dementia and their family carers. Dementia, https://doi.org/10.1177/1471301218795242

# InspireD

## A Reminiscence App

Reminiscence
Network Northern Ireland

- Reminiscence is the sharing of memories of our personal life experiences
- Reminiscence as an intervention can enrich the lives of people with dementia
- InspireD is an app developed with input from the Reminiscence Network Northern Ireland and people with dementia and their caregivers

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Laird, E.A., Ryan, A.A., McCauley, C.O., Bond, R.B., Mulvenna, M.D., Curran, K., Bunting, B.P., Ferry, Finola, Gibson, A, (2018) Using mobile technology to provide personalised reminiscence for people living with dementia and their carers: An appraisal of outcomes from a quasi-experimental study, *JMIR Mental Health*, 5(3):e57, https://doi.org/10.2196/mental.9684

# Overall Study

## Outline

- Aim was to investigate the effects of individual specific reminiscence activity facilitated through the use of the InspireD app on people living with dementia and their caregivers, using a range of outcome measures
- Quasi-experimental study incorporating a paired sample of 28 dyads (person living with dementia and their caregiver), using repeated measures design was conducted with each participant serving as his or her own control
- Applied several scales at start, mid- and end-point of a 12-week use of the InspireD app in the homes of people living with dementia and their caregivers, with one-to-one interviews with participants carried out at the end of the 12 weeks
- Scales included mutuality*, quality of care-giving relationships and emotional wellbeing

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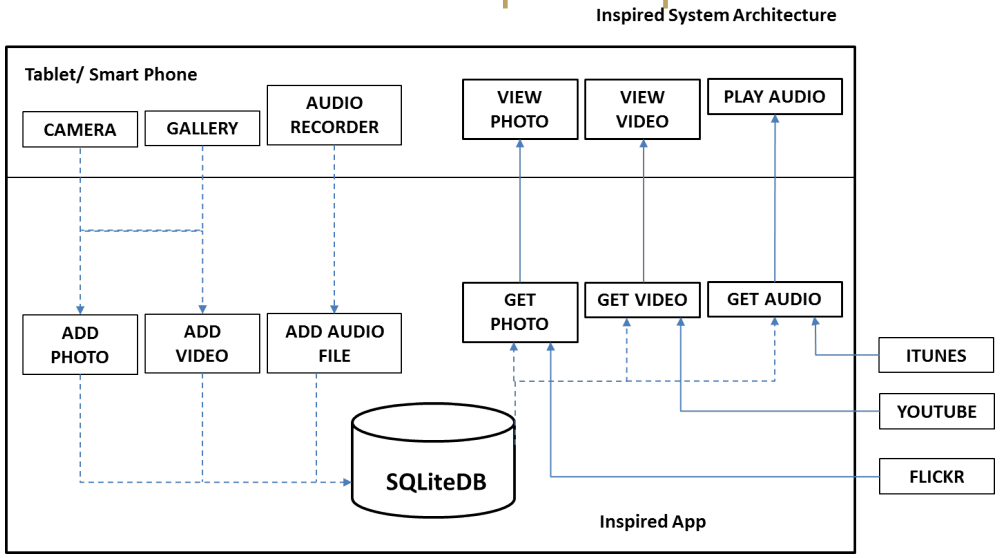
* P.G. Archbold B.J. Stewart M.R. Greenlick T. Harvath (1990) Mutuality and preparedness as predictors of caregiver role strain. *Research in Nursing & Health*. 13: 375-384.

# InspireD App

## System architecture & development process





Gibson, A, McCauley, C-O, Mulvenna, M, Ryan, A, Laird, L, Curran, K, Bunting, B, Ferry, FR & Bond, RR 2019, How Usable Are Usability Tests? Examining the Suitability of Standard Usability Testing Methods for the Assessment of Apps for People Living with Dementia. in HM Fardoun, AAM Hassan & ME de la Guía (eds), New Technologies to Improve Patient Rehabilitation: 4th Workshop, REHAB 2016, Revised Selected Papers. Communications in Computer and Information Science, vol. 1002, pp. 126-143, REHAB 2016, Lisbon, Portugal, 13/10/16. https://doi.org/10.1007/978-3-030-16785-1_10

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# Event logging study

## Summary

- Digital technology is being increasingly used by older people yet there is a paucity of relevant usage interaction research* (aside from usual proprietary platforms)
- InspireD app designed to incorporate logging facility for key events by users across 45 specific activities, covering five different types of events:
  - Entry (Logging in),
  - Admin (Adding a photo, deleting an audio, etc.),
  - Reminiscing (Viewing a video, viewing a photo, etc.),
  - In the Moment (ITM) questions (Experience Sampling Method (ESM) (aka Ecological Momentary Assessment)) and
  - Exit (Logging out).

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# Utilising event logging, ecological momentary assessment & machine learning

## Case study - Results

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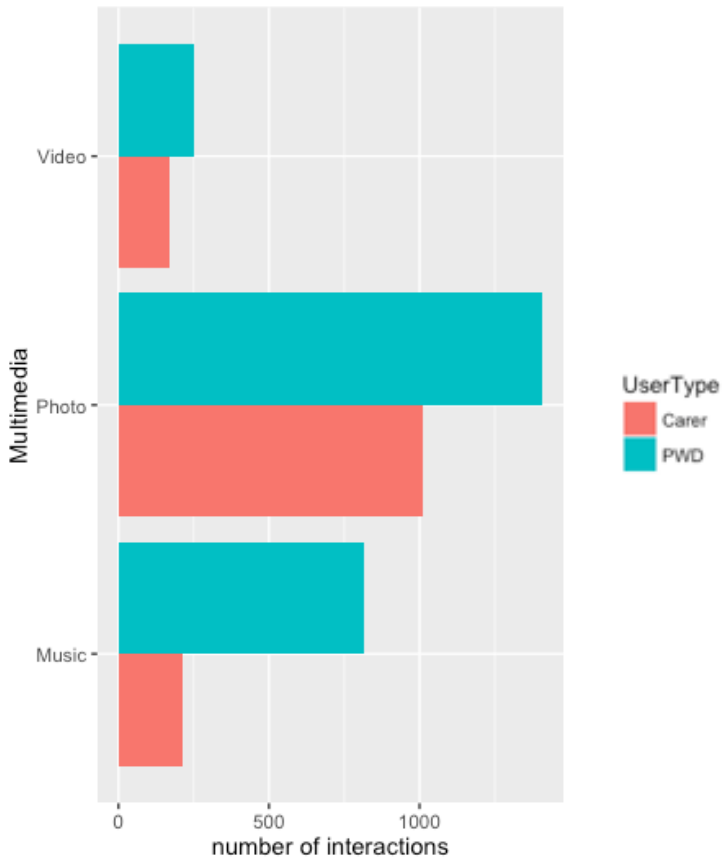
# Results

## Media

- Number of interactions by caregivers and people living with dementia in each of the multimedia features used to facilitate reminiscing

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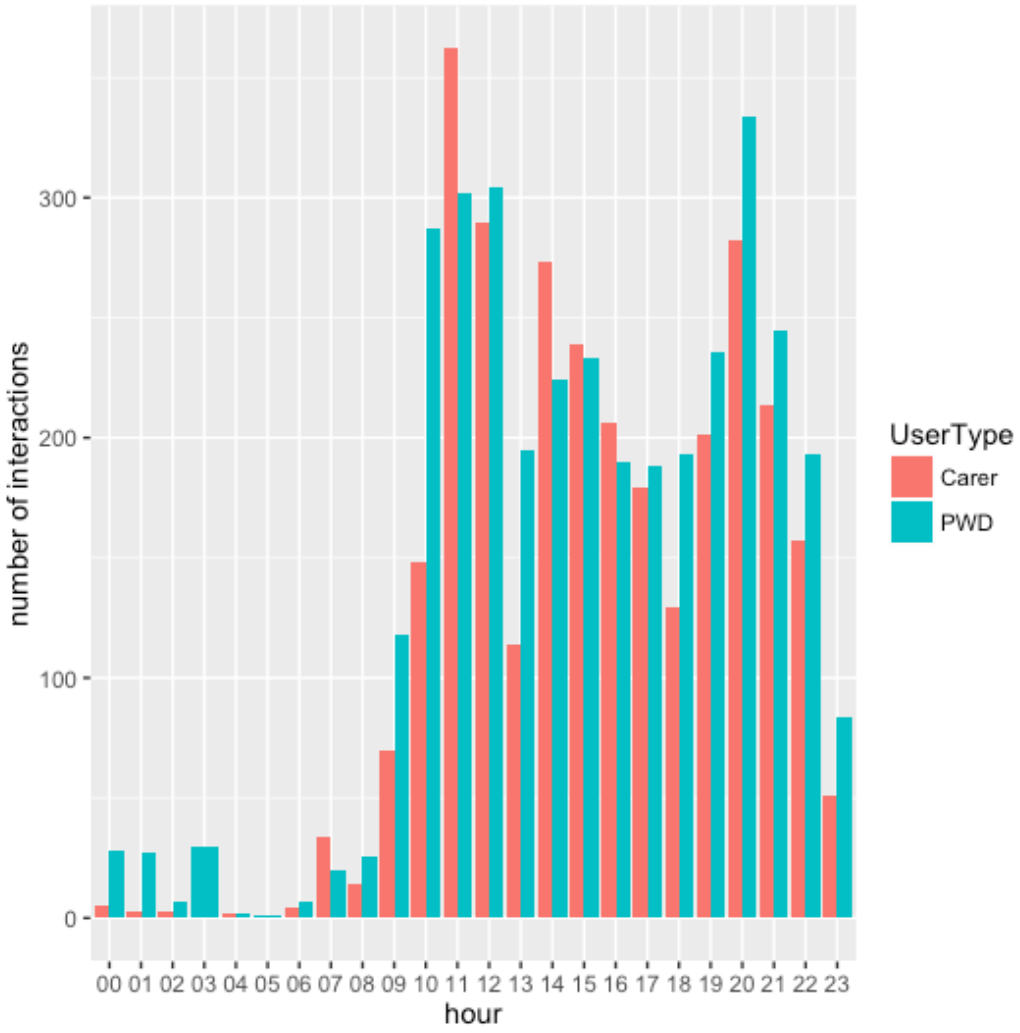
Mulvenna, M, Gibson, A, McCauley, C, Ryan, A, Bond, R, Laird, L, Curran, K, Bunting, B & Ferry, F (2017). Behavioural Usage Analysis of a Reminiscing App for People Living with Dementia and their Carers. In: Proceedings of the European Conference on Cognitive Ergonomics 2017 (pp. 35-38) https://doi.org/10.1145/3121283.3121289

# Results

## Daily

- Number of event interactions by caregivers and people living with dementia per hour

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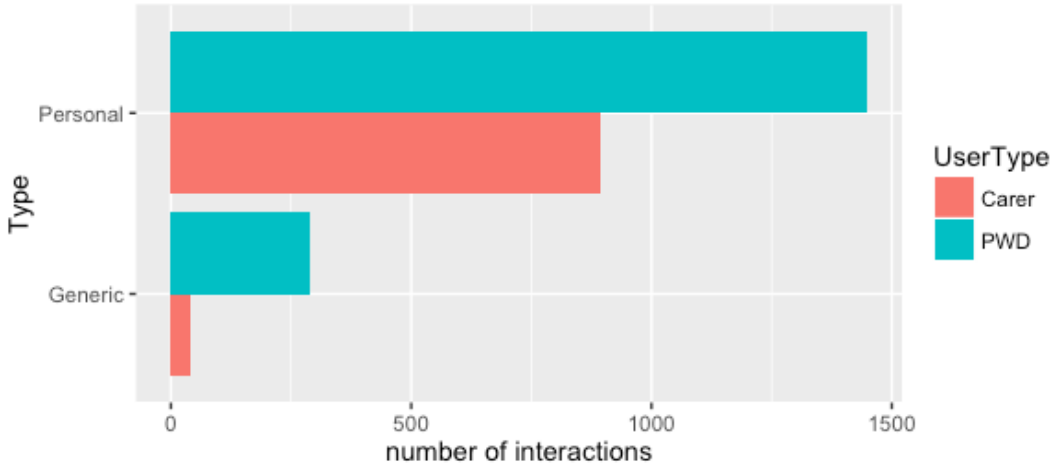
# Results

## Type

- Number of personal and generic interactions by caregivers and people living with dementia

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# Results

## Events

- Number of interactions by caregivers and people living with dementia (PWD) users in each of the classified events


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# Utilising event logging, ecological momentary assessment & machine learning

## Case study - Ecological momentary assessment

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# Ecological momentary assessment

## Concept

- Also called Experience Sampling Method
- Capture real-time data in an individual's natural environment through repeated sampling, using:
  - Psychometric scales,
  - Open-ended questions, or
  - anything else used to assess an individual's condition in that place and time.
- Provide a high degree of ecological validity as they study people as they go about day-to day life.
- EMA requires participants to respond to questions 'in the moment', so it avoids recall bias which makes it a useful tool for people living with dementia where their memory is impaired.

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# Ecological momentary assessment

## Concept

- Traditionally, EMA made use of paper diary techniques but nowadays can utilise devices such smartphones or tablets to record digital data.
- Recently, EMA was used to identify major areas of concern for caregivers of persons with Alzheimer's disease, with the overall goal to provide support and information for caregivers in their home.
  - C. Lazzari, Ecological Momentary Assessments and Interventions in Alzheimer's Caregiving, Curr. Alzheimer Res. 15 (2018) 1027–1031.
- Another study used ESM to examine the day-to-day burden of caregiving for dementia carers which could be used to tailor interventions to their individual need
  - S. Pihet, C.M. Passini, M. Eicher, Good and Bad Days: Fluctuations in the Burden of Informal Dementia Caregivers, an Experience Sampling Study, Nurs. Res. 66 (2017) 421–431. doi:10.1097/NNR.0000000000000243.

# Ecological momentary assessment

## Items from the mutuality scale used to capture EMA data

- A total of 5 different EMA questions from the mutuality scale were presented to people living with dementia and their carers

| Number | Question |
|---|---|
| Q1 | How attached are you {partners name}? |
| Q2 | How much do the two of you laugh together? |
| Q3 | How much do you confide in {partners name}? |
| Q4 | How much do you enjoy sharing past experiences with {partners name}? |
| Q5 | How much do you like to sit and talk with {partners name}? |

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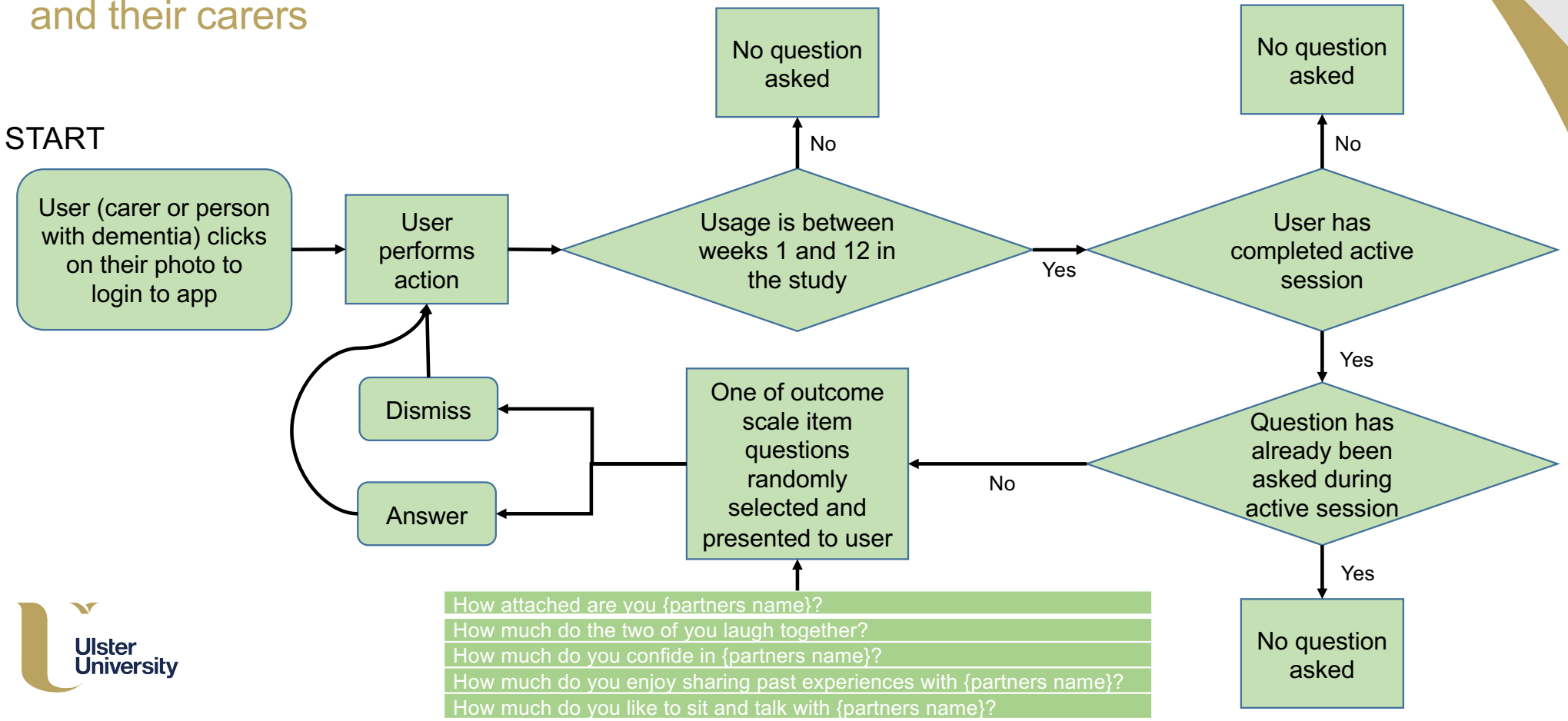
# Ecological momentary assessment

## Logic for EMA questions presented to people living with dementia and their carers

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# Ecological momentary assessment

## Questions presented and dismissed

- Overall dismissal rate for questions asked during the trial period was 30.9%. Hence, almost 70% of questions were answered
- People living with dementia used the app more in the trial period than carers but despite this had a lower dismissal rate for questions (26.8%) compared to their carers (36.8%)
- Dismissal rates were significantly different from the answer rates for each question

| Question | Presented n(%) | Dismissed n(%) | p-value |
|---|---|---|---|
| Q1 | 197 (26.09) | 48 (20.60) | <0.001 |
| Q2 | 131 (17.35) | 39 (16.74) | <0.001 |
| Q3 | 116 (15.36) | 38 (16.74) | <0.001 |
| Q4 | 165 (21.85) | 54 (23.18) | <0.001 |
| Q5 | 146 (19.34) | 53 (22.75) | <0.001 |

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# Ecological momentary assessment

## Total number of questions presented across hours of day (left) and trial week (right) for each user


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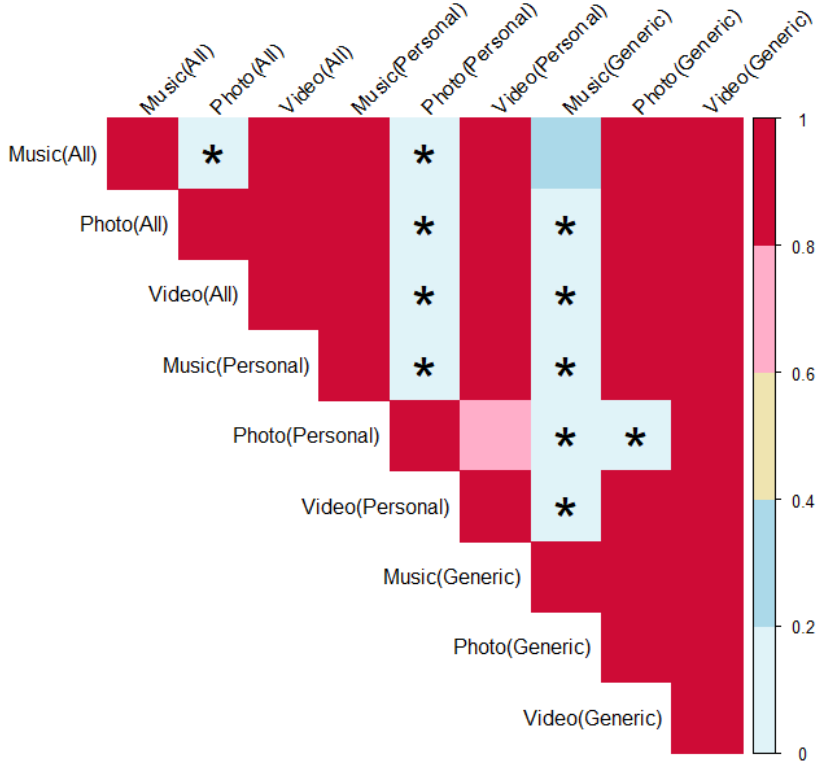
Potts, C., Bond, R., Ryan, A., Mulvenna, M.D., McCauley, C., Laird, L., Goode, D., (TBD) Evaluating the use of ecological momentary assessment within a digital health intervention for reminiscence: how do people living with dementia and their carers engage?, JMIR mHealth and uHealth, Accepted.

# Ecological momentary assessment

Heatmap comparing dismissal rates for each media overall (all) and specific type (generic and personal). Plot coloured by p-value, significant values (P >0.001) are denoted with *

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# Ecological momentary assessment

## Future design recommendations for digital health apps incorporating EMA

| Aspect | Proposed strategy |
|---|---|
| **Questions asked** | The actual EMA questions which are presented should be informed by user group co-design (e.g. user group made up of people living with dementia and their carers). |
| **First question** | EMA questions should only be presented after a period of 2-3 weeks to give users time to get comfortable using the app. |
| **Frequency** | No more than one question presented to users per day. |
| **Hour of day** | Questions presented at times when users were more likely to answer rather than dismiss questions i.e. after 8pm in the evening. |
| **Current task** | If user is trying to complete a task within the app such as uploading content to the app, then a question should not be presented. |

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# Utilising event logging, ecological momentary assessment & machine learning

## Case study – Machine learning

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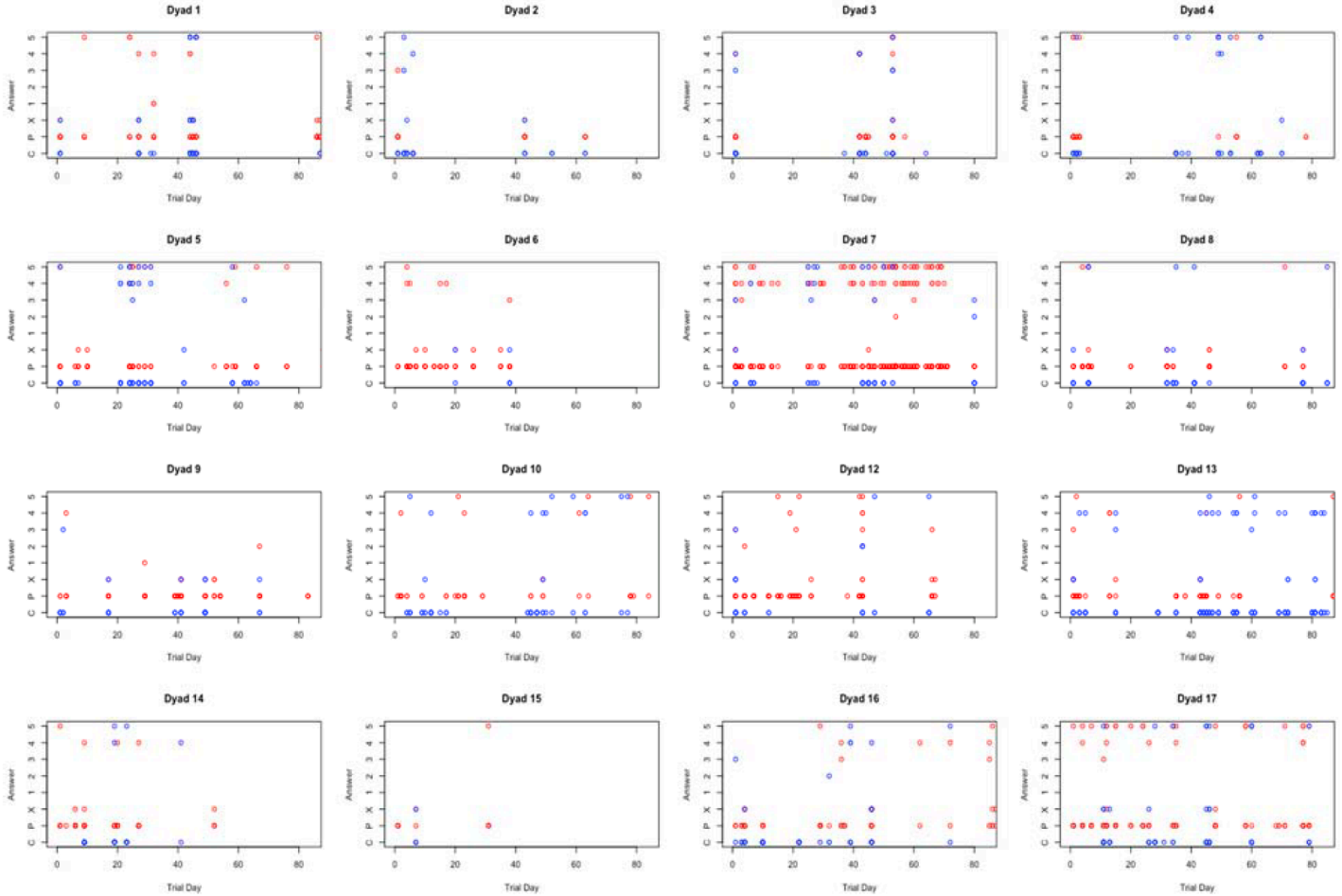


Potts, C., Bond, R., Ryan, A., Mulvenna, M.D., McCauley, C., Laird, L., Goode, D., (TBD) Evaluating the use of ecological momentary assessment within a digital health intervention for reminiscence: how do people living with dementia and their carers engage?, JMIR mHealth and uHealth, Accepted.

## Feature selection

- numOfPWDInteractions,
- numOfCarerInteractions,
- numOfPWDUniqueDaysInteractions,
- meanUsageInterval,
- SDUsageInterval

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McCauley, C-O, Bond, RR, Ryan, A, Mulvenna, M, Laird, LEA, Gibson, A, Bunting, B, Ferry, FR & Curran, K 2019, 'Evaluating User Engagement with a Reminiscence App Using Cross Comparative Analysis of User Event Logs and Qualitative Data', Cyberpsychology, Behavior, and Social Networking, vol. 22, no. 8, pp. 543-551. https://doi.org/10.1089/cyber.2019.0076

## Cluster 1: The hooked adopter

A very small number of users (3.6% or 1 user per 28 users) who fully adopted the system. They had 7.2 times more interactions than their carer. Whilst the PWD obsessively used the app, the carer showed a normal amount of usage, hence the PWD was independently dedicated.

## Cluster 2: Typical user

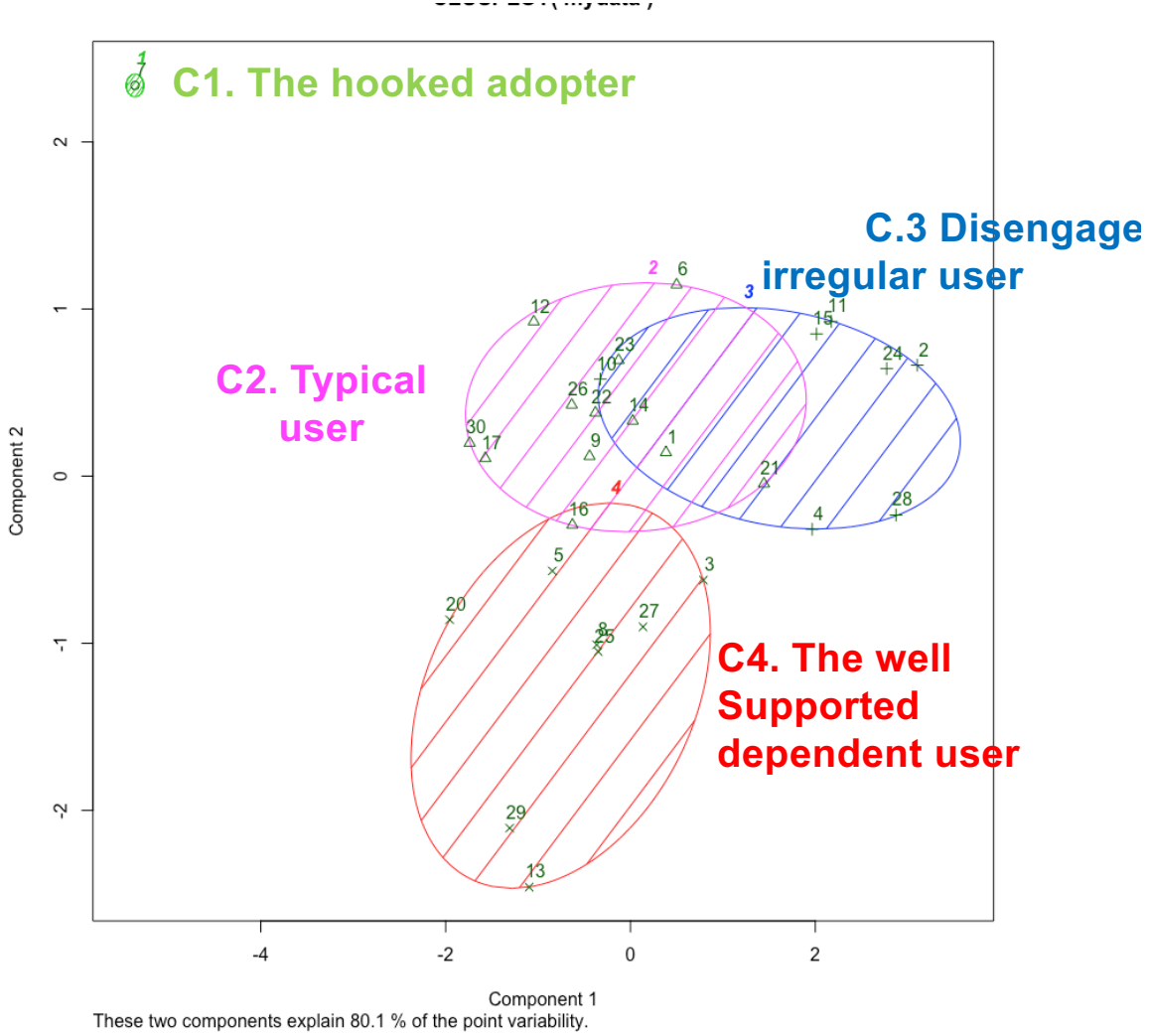
The plurality of users (43%) fall into this cluster, hence making them the most typical user. This user has 1.7 times more interactions with the app than their carer. This indicates that this user has some dependence on the carer for app usage. This dyad uses the app 15% of days in a month.

## Cluster 3: Disengaged irregular user

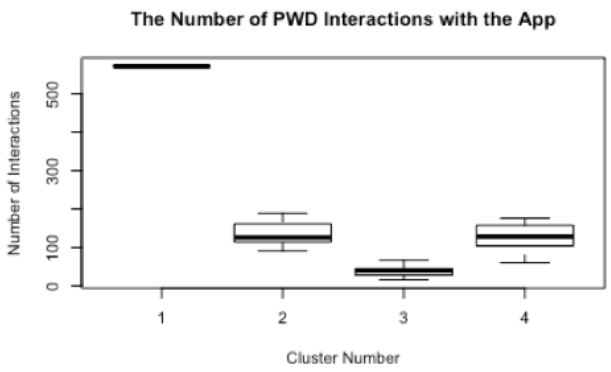
25% of users. These users had 25% less interactions with the app than the carer. Whilst the PWD had fewer interactions than there carer, the carer has fewer interactions than other carers in all other clusters.

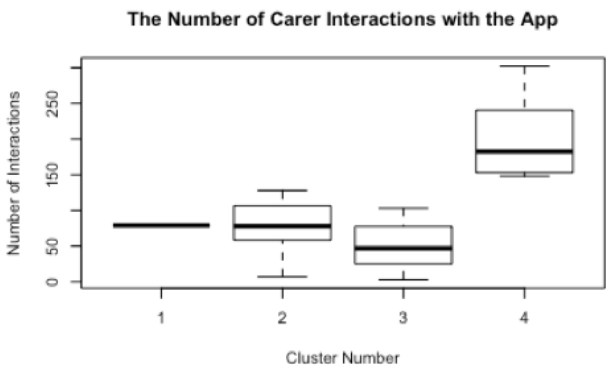
## Cluster 4: The well supported dependent user

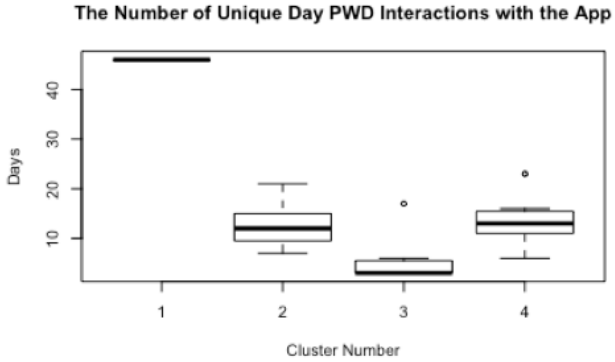
29% of users - the second largest group of users. These users have 36% less interactions with the app than their carers. The carers are very enthusiastic and have more interactions than other carers in all other clusters but they seem to struggle to get PWD users to the same engagement level.

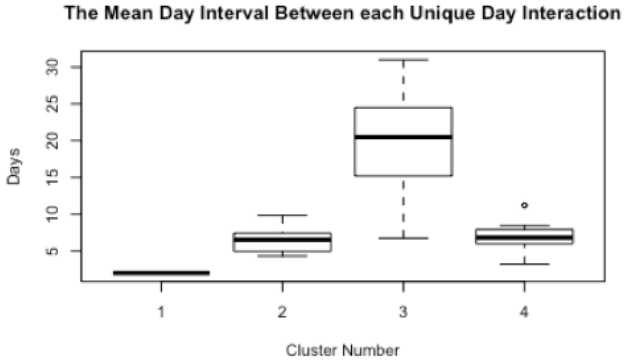


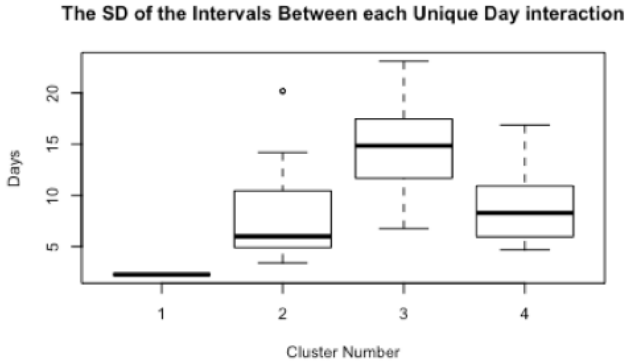

| Group.1 | numOfPWDInteractions | numOfCarerInteractions | numOfPWDUniqueDaysInteractions | meanUsageInterval | SDUsageInterval |
|---|---|---|---|---|---|
| 1 | 572.00000 | 79.00000 | 46.000000 | 2.000000 | 2.276361 |
| 2 | 134.83333 | 78.41667 | 12.583333 | 6.614044 | 8.054116 |
| 3 | 38.28571 | 51.14286 | 5.714286 | 19.664286 | 14.707964 |
| 4 | 127.00000 | 200.25000 | 13.500000 | 6.978716 | 8.986534 |

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# Utilising event logging, ecological momentary assessment & machine learning

## Going mainstream with event logs

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# Northern Ireland Department of Health

- “HSCNI, have partnered up with ORCHA (the Organisation for the Review of Care and Health Applications) to provide this site for you all to solve just those problems.”

- “ORCHA carry out independent and impartial reviews of health and care related apps, and you’ll see that the resultant information is clearly presented for us throughout this website. We can be reassured that any apps shown on this site have undergone a rigorous review process, and can feel confident as we choose the best app for us.”

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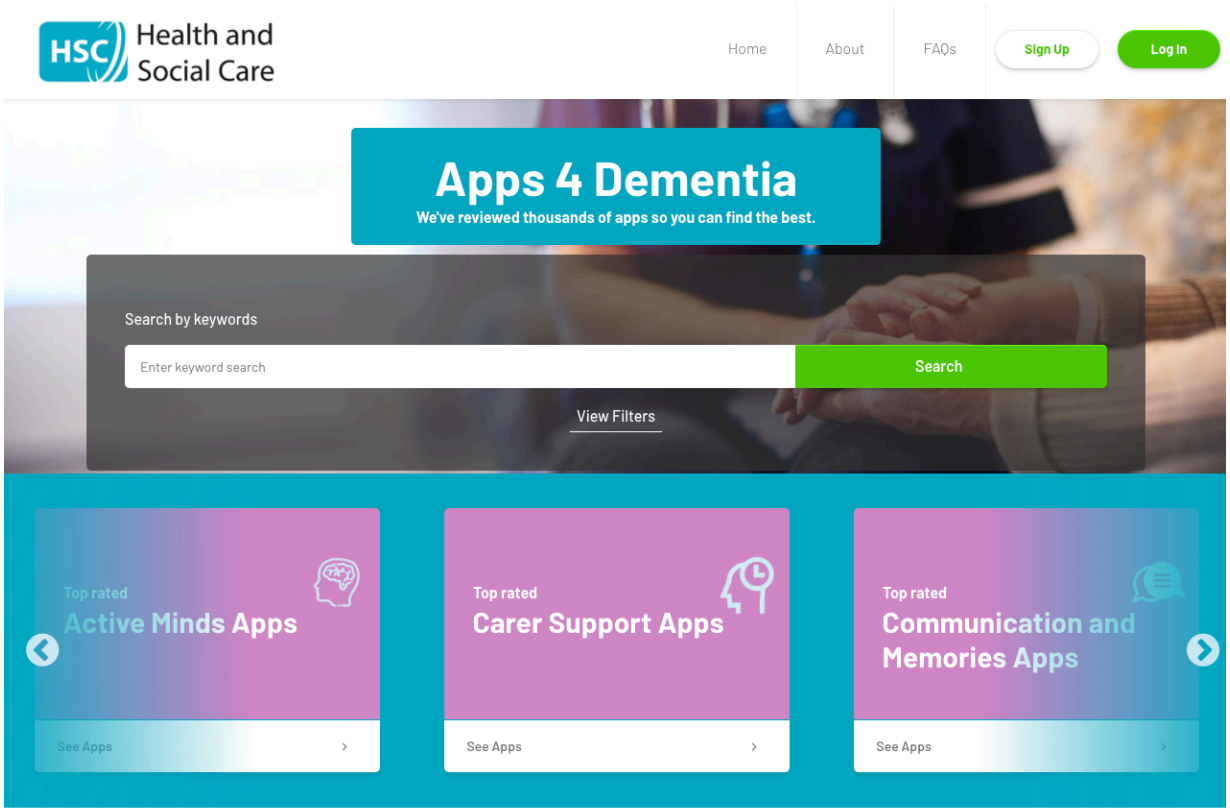
Department of Health
An Roinn Sláinte
Männystrie O Poustie
www.health-ni.gov.uk

HSC Health and Social Care

https://apps4healthcareni.orcha.co.uk/

https://apps4dementia.orcha.co.uk/about/




## Unlock the power of digital health

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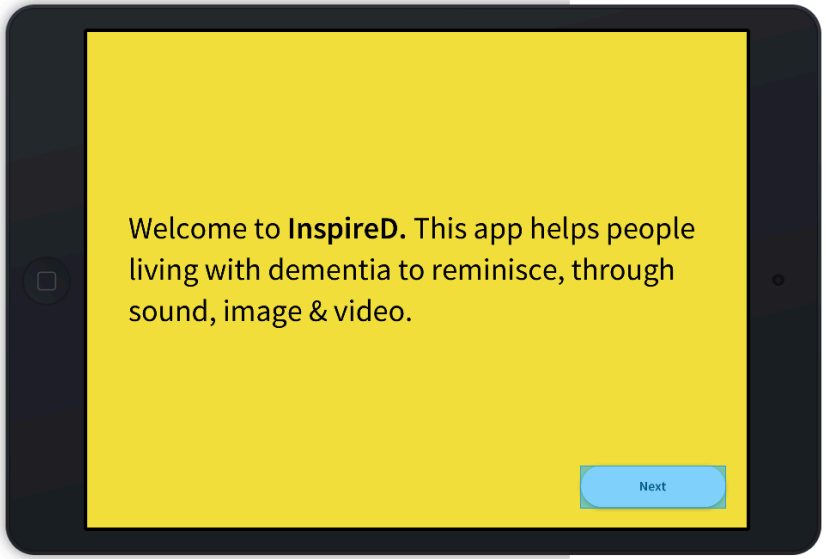


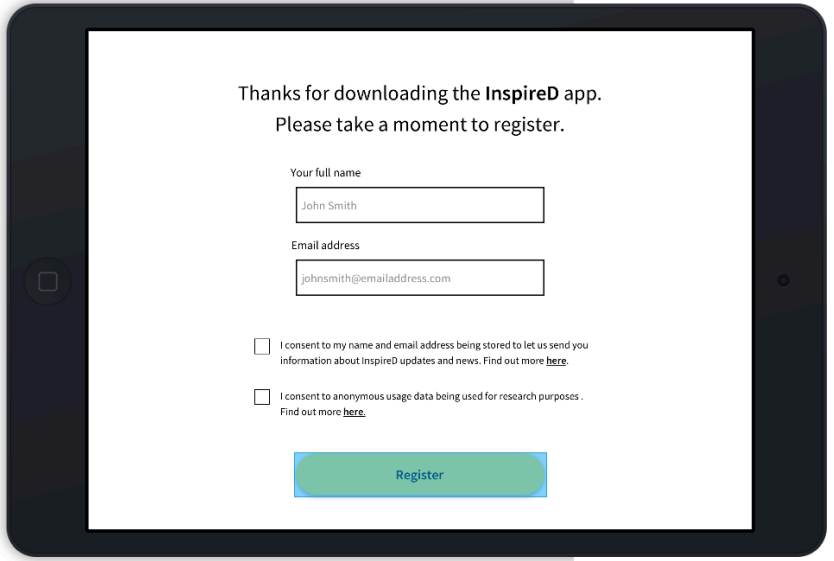


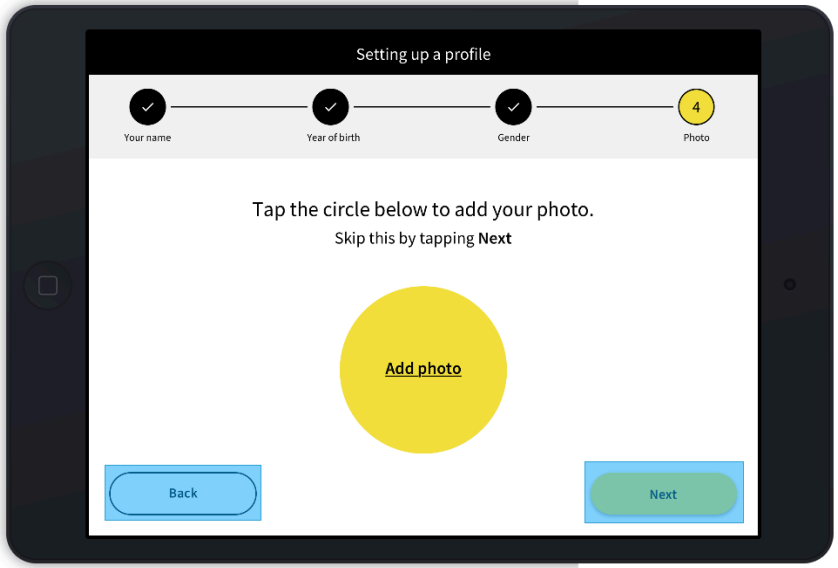


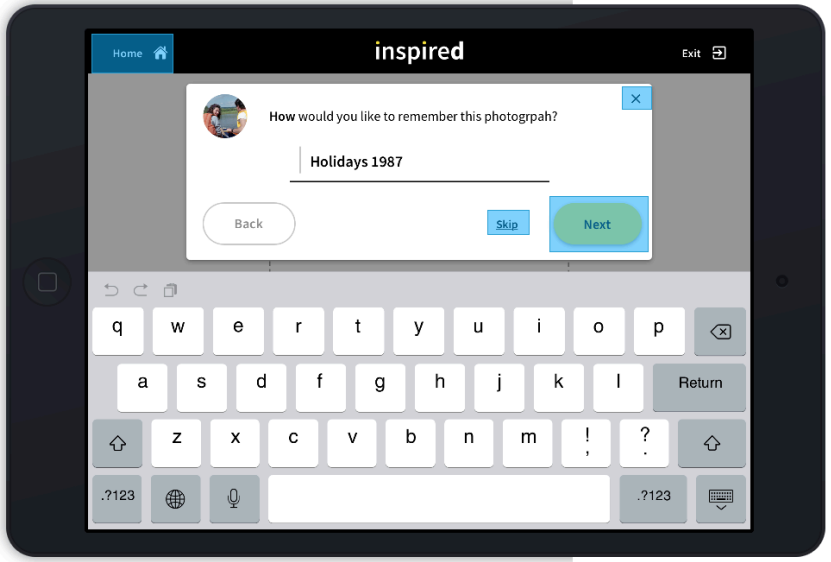


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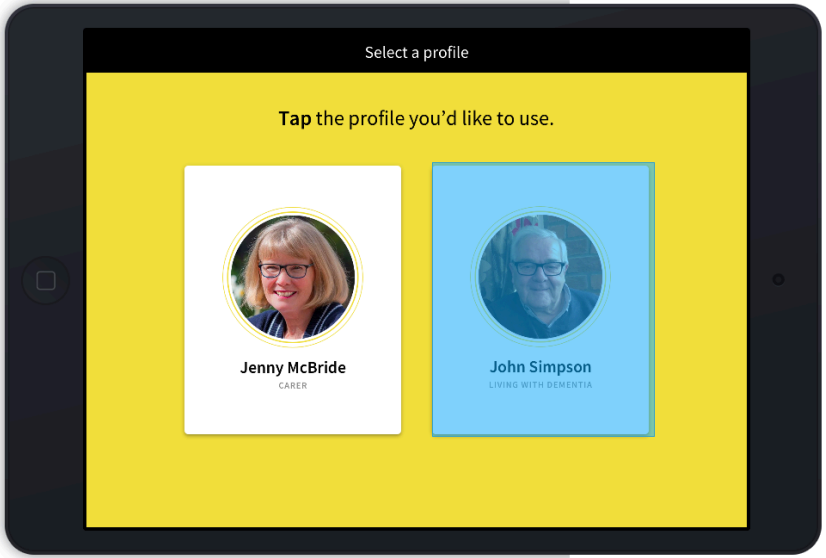


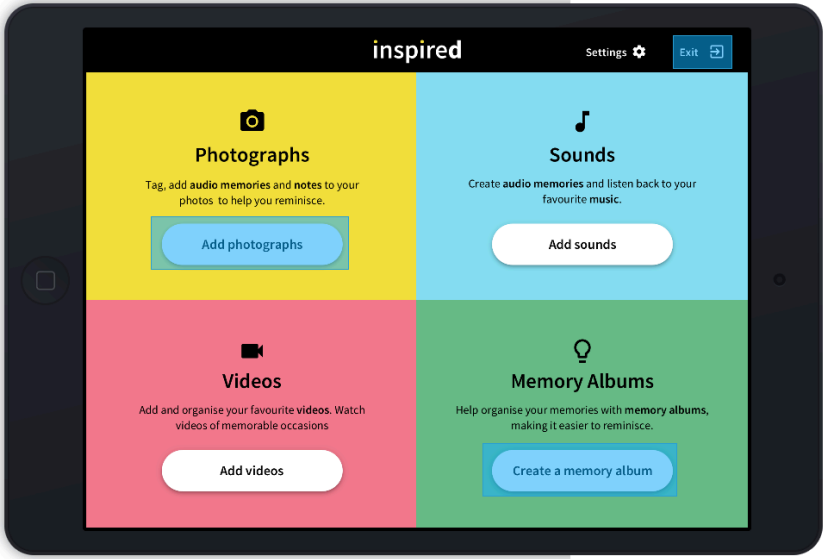


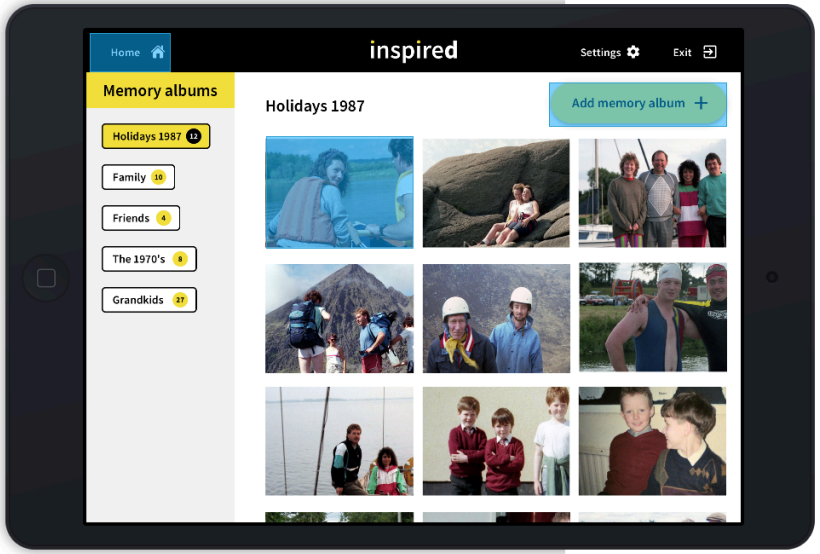


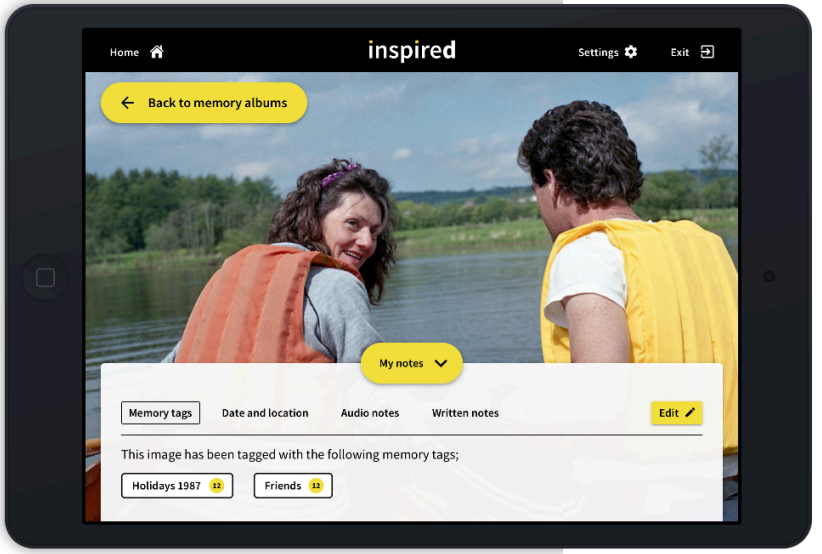


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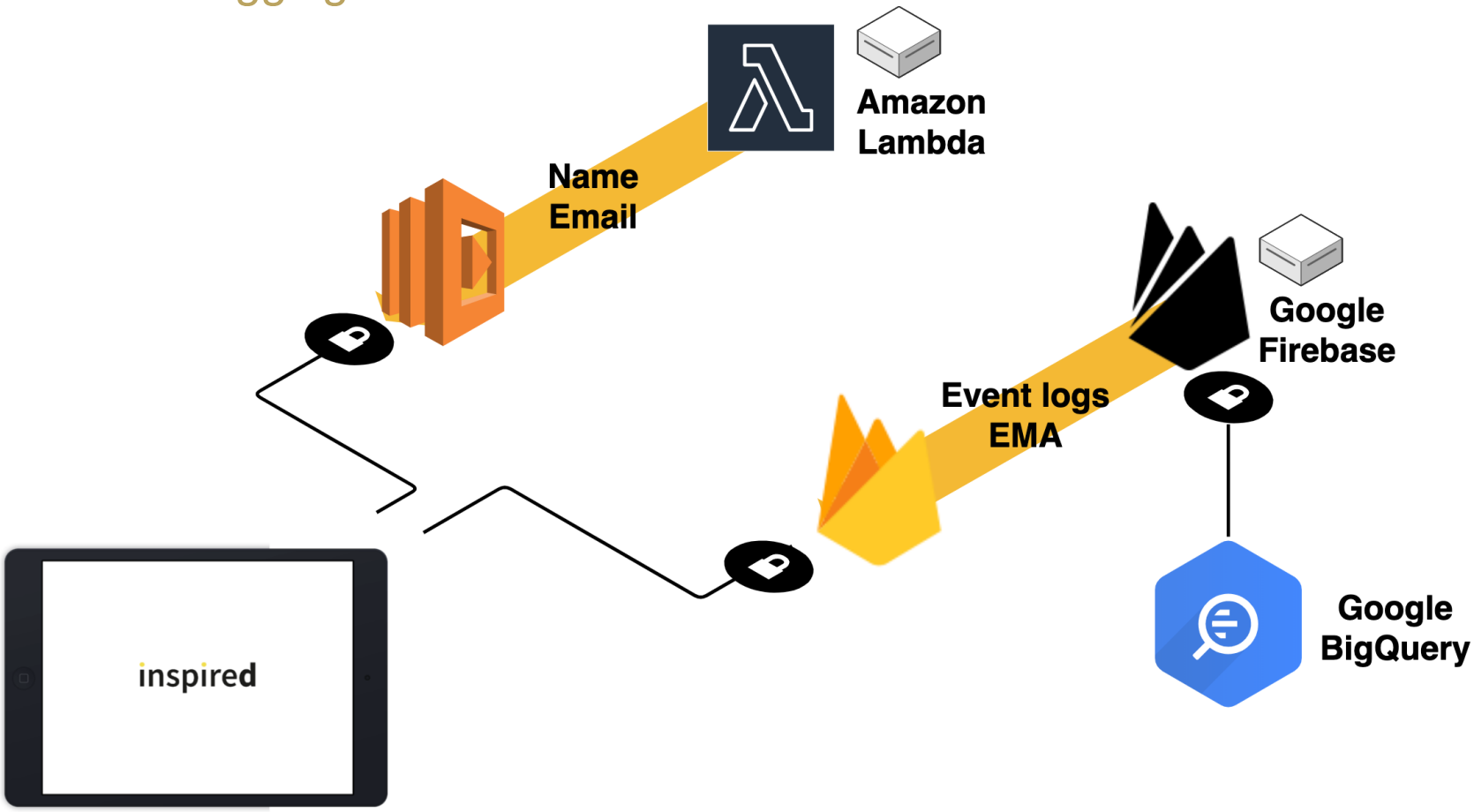
# Inspired reminiscence app

## Anonymous event logging architecture

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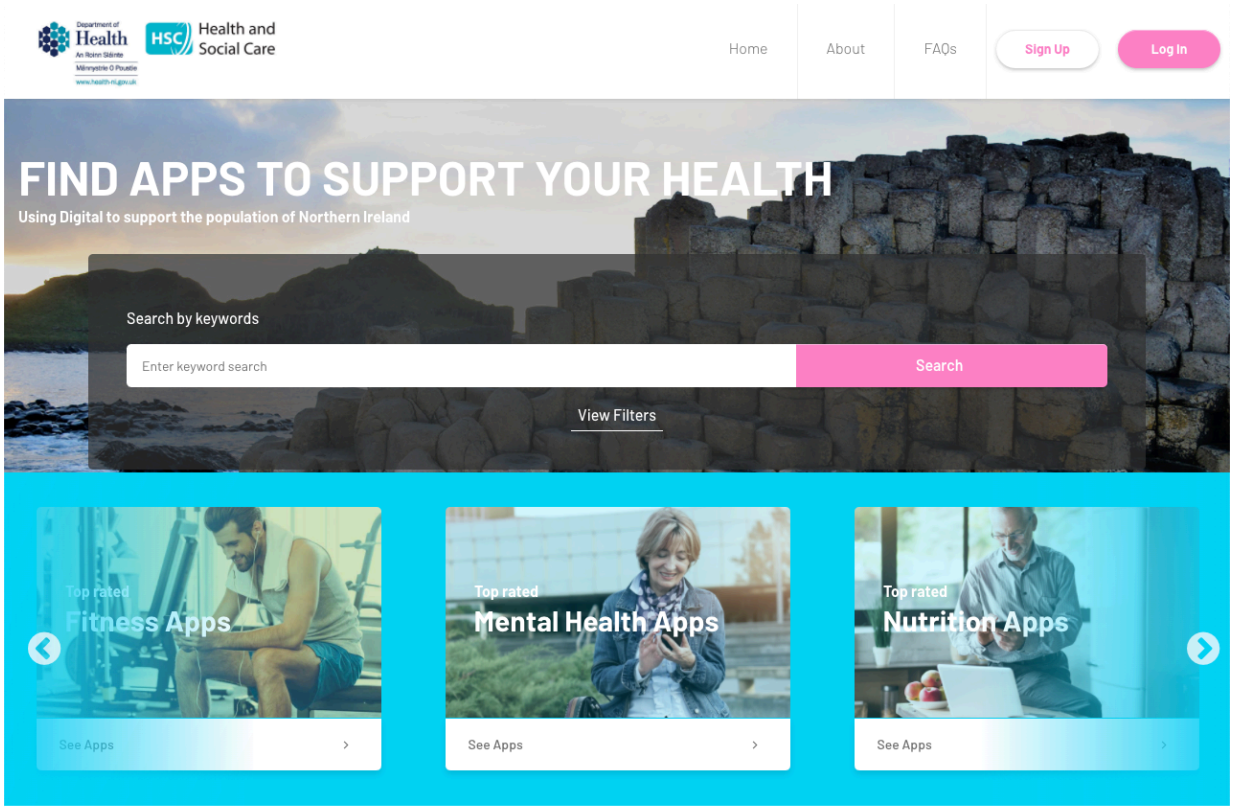


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# Utilising event logging, ecological momentary assessment & machine learning

## Discussion and conclusions

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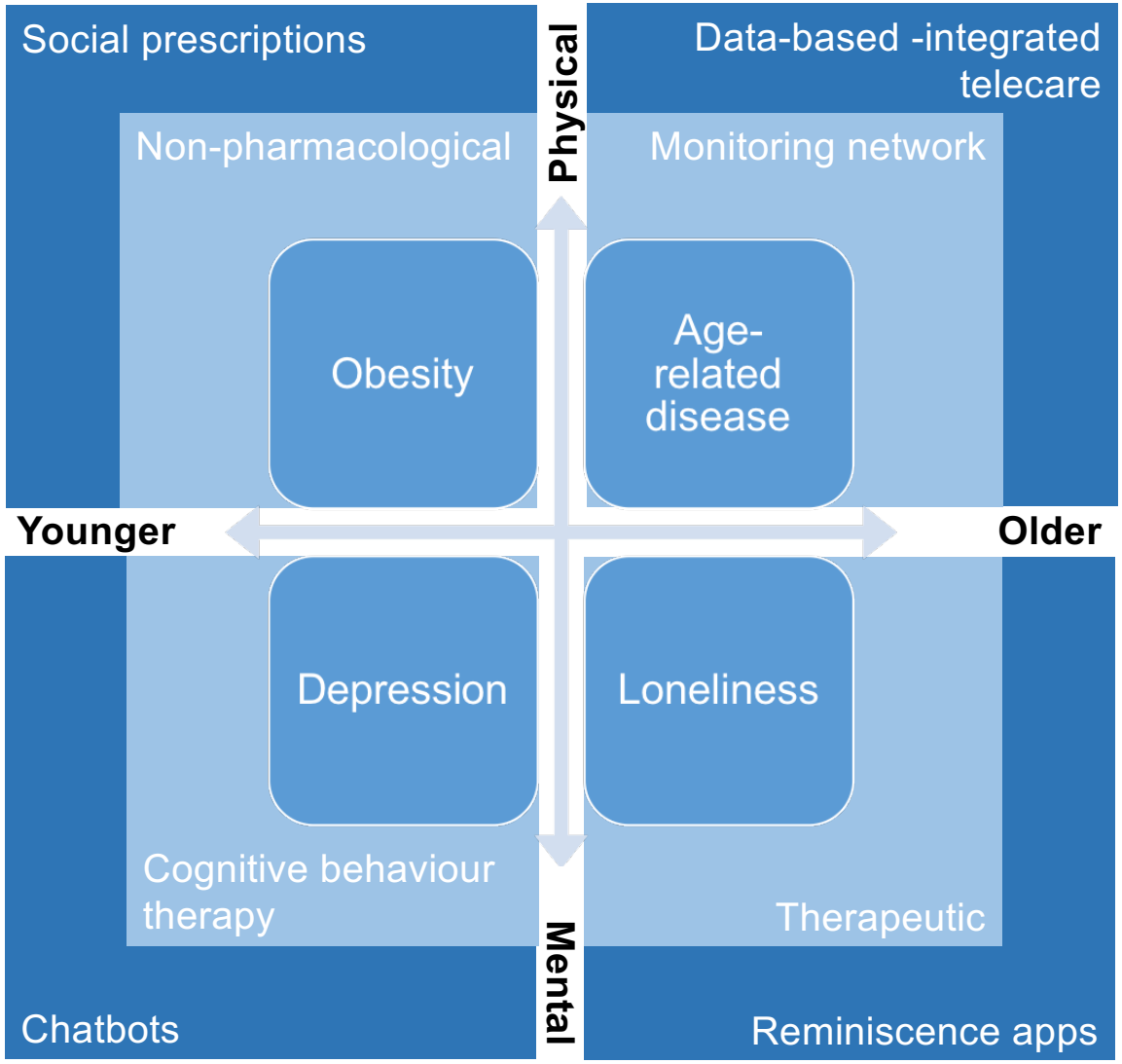
# Discussion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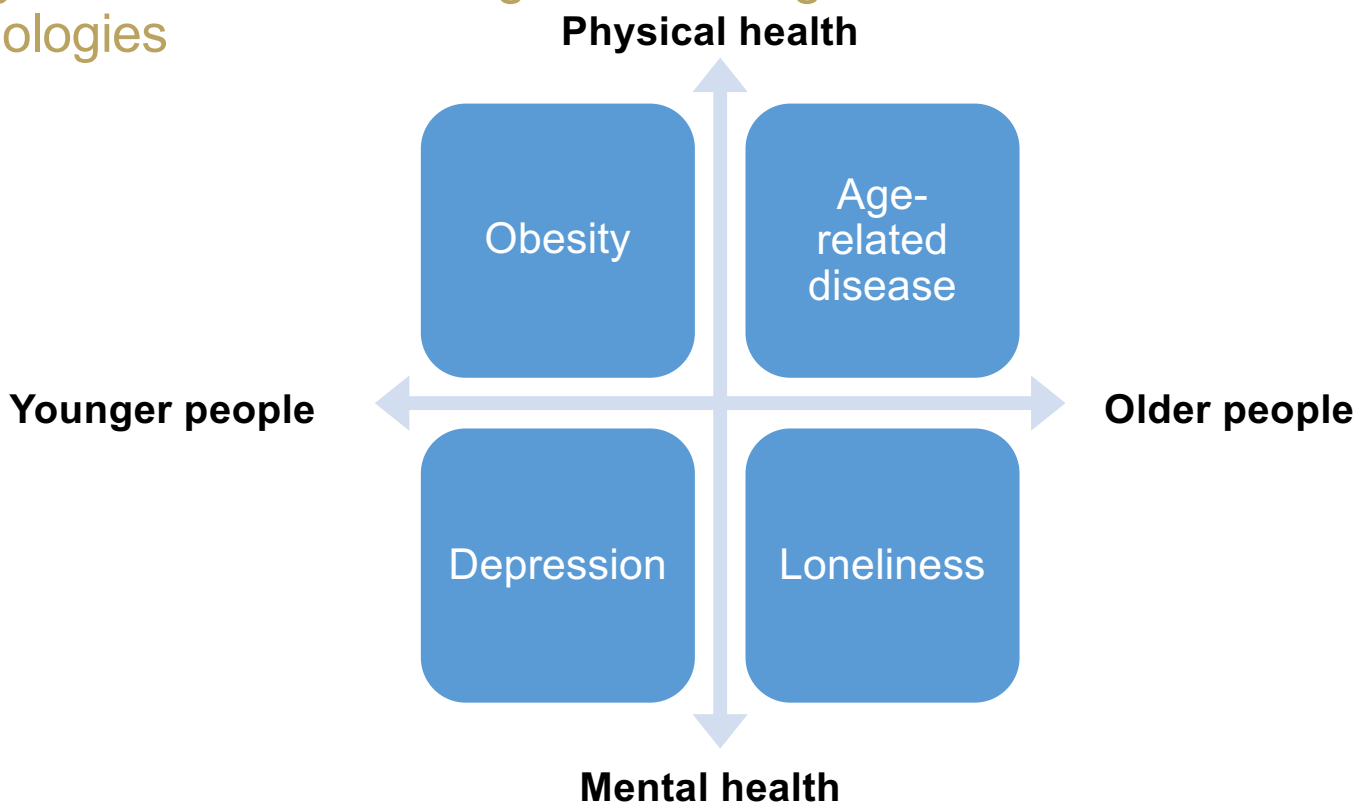
# Discussion

## Digital phenotyping and machine learning in the next generation of digital health technologies

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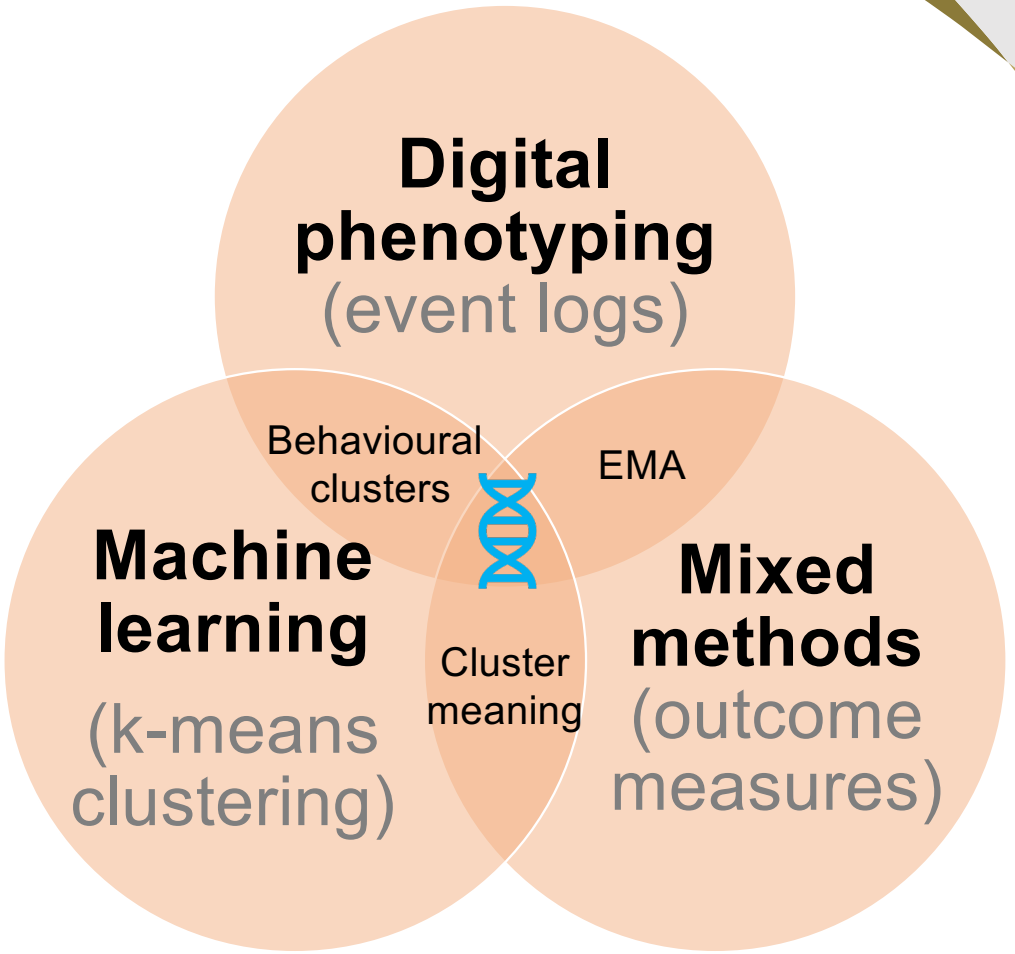
# Conclusions

## Summary

- Assistive technology
- Growing importance of data
- Event logs
- Data analytics workflows
- Case study
- Going mainstream with event logs

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# Conclusions

## Public health

- Use of digital phenotyping data and analysis using artificial intelligence and machine learning is growing
- Many national public health organizations are exploring how to use digital technologies such as health apps and cloud-based services for the self-management of diseases
- Logging users' interactions allows for greater insight into user needs and provides ideas for improving these digital interventions, for example through enhanced personalization
- However, the risks in using this data are manifold

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# Conclusions

## Issues

- Ethics
- Bias
- Surveillance

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# Conclusions

## Public health

- However, on balance it can be argued that public health (services) benefit since data can be automatically and hence cost-effectively collected
- Such data may facilitate new ways for digital epidemiological analyses and provide data to inform health policies
- Public health organisations can, should and do promote health apps
- Digital phenotyping analysis using machine learning and artificial intelligence will be taken up by these organisations
- Clear need for guidelines on the ethical application of these ‘democratized’ algorithms and techniques and on ownership of digital phenotype data

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# Thanks

Any questions?

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# Acknowledgements

The InspireD app for research study was co-created and designed with input from the Alzheimer's Society, Reminiscence Network Northern Ireland (RNNI) and people living with dementia and their caregivers. Special thanks to Alex Turnbull, Software Engineer from Kainos Software Limited for invaluable assistance in technology selection decisions. The team (Prof A Ryan, Dr L Laird, Prof K Curran, Prof B Bunting, Prof M Mulvenna, Dr Finola Ferry, Dr R Bond) gratefully acknowledge the research funding provided by **HSC R&D Grant COM/5016/14** in Northern Ireland

The freely available commercially-developed InspireD app was co-created and designed with input from the Dementia NI, Dementia Empowering and Engaging Derry-Strabane (DEEDS). Special thanks to Scaffold Digital for developing the app. The team (Prof A Ryan, Prof M Mulvenna, Dr C McCauley, Dr L Laird, Dr D Goode, Dr R Bond, Ms C Potts) gratefully acknowledge the support provided by **HSC R&D** for commercial app development

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