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[Personal] Health Technology – Research & Trends

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Cetrea | Monsenso | DataFair

Research interests

- Ubiquitous Computing
- Pervasive Health
- Human-Computer Interaction
- Software Architecture (incl. standards)

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DTU Technical University of Denmark

DET SUNDHEDSVIDENSKABELIGE FAKULTET
KØBENHAVNS UNIVERSITET

Cetrea GETINGE GROUP

MONSENSO

DataFair

@jbardram

DTU HEALTH TECH

40
Nationalities

Non-Danish
46%

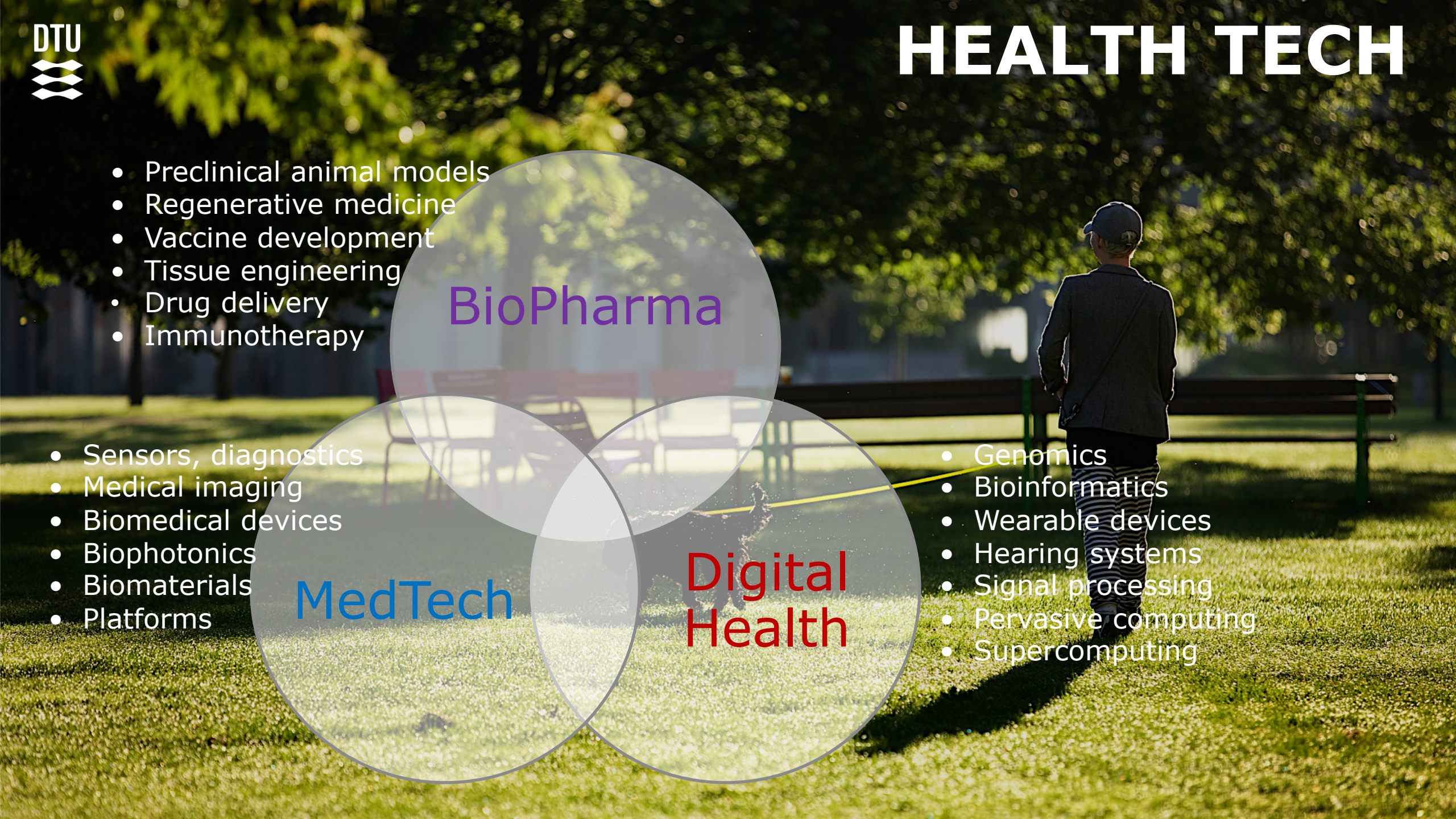
50
Technical and
administrative

Professors
Associated Professors
Assistent Professors
Senior researcher
Researchers
Postdocs
PhD Students

40% of the
staff are women

38% of
scientific
staff are
women

HEALTH TECH



- Preclinical animal models
- Regenerative medicine
- Vaccine development
- Tissue engineering
- Drug delivery
- Immunotherapy

- Sensors, diagnostics
- Medical imaging
- Biomedical devices
- Biophotonics
- Biomaterials
- Platforms

- Genomics
- Bioinformatics
- Wearable devices
- Hearing systems
- Signal processing
- Pervasive computing
- Supercomputing

BACKGROUND

Key figures

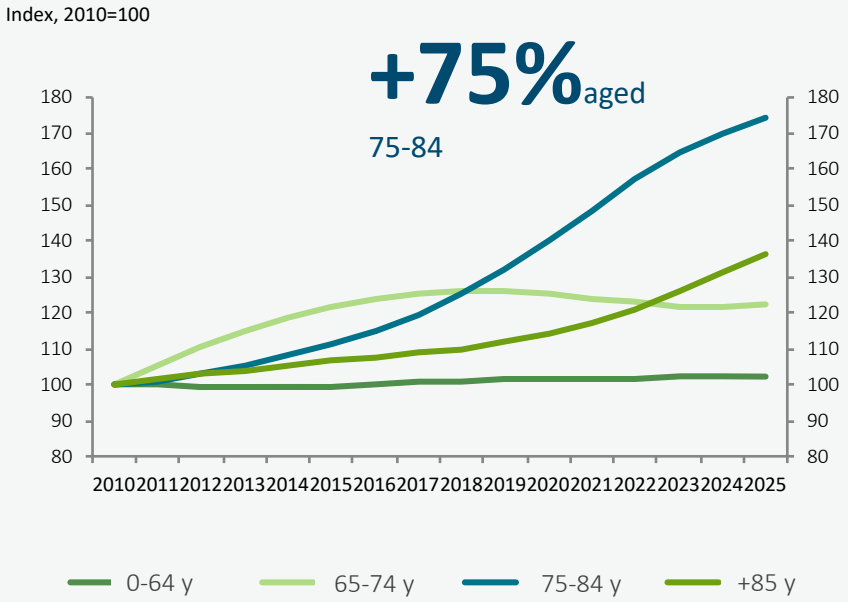
A change in our demography

The population is getting older

In 2025 the number of citizens aged 0-64 will be the same as in 2010.

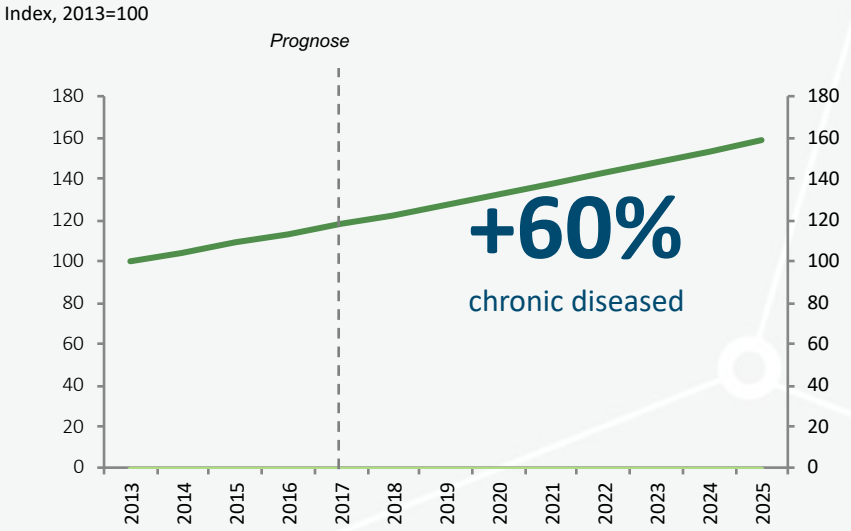
- but the number of citizens aged 75-84 will have increased by 75 percent.

→ Less tax payers and fewer health care workers



- and more people will suffer from chronic diseases

From 2013 to 2025 the number of citizens living with the most common chronic diseases is expected to increase by 60 pct.



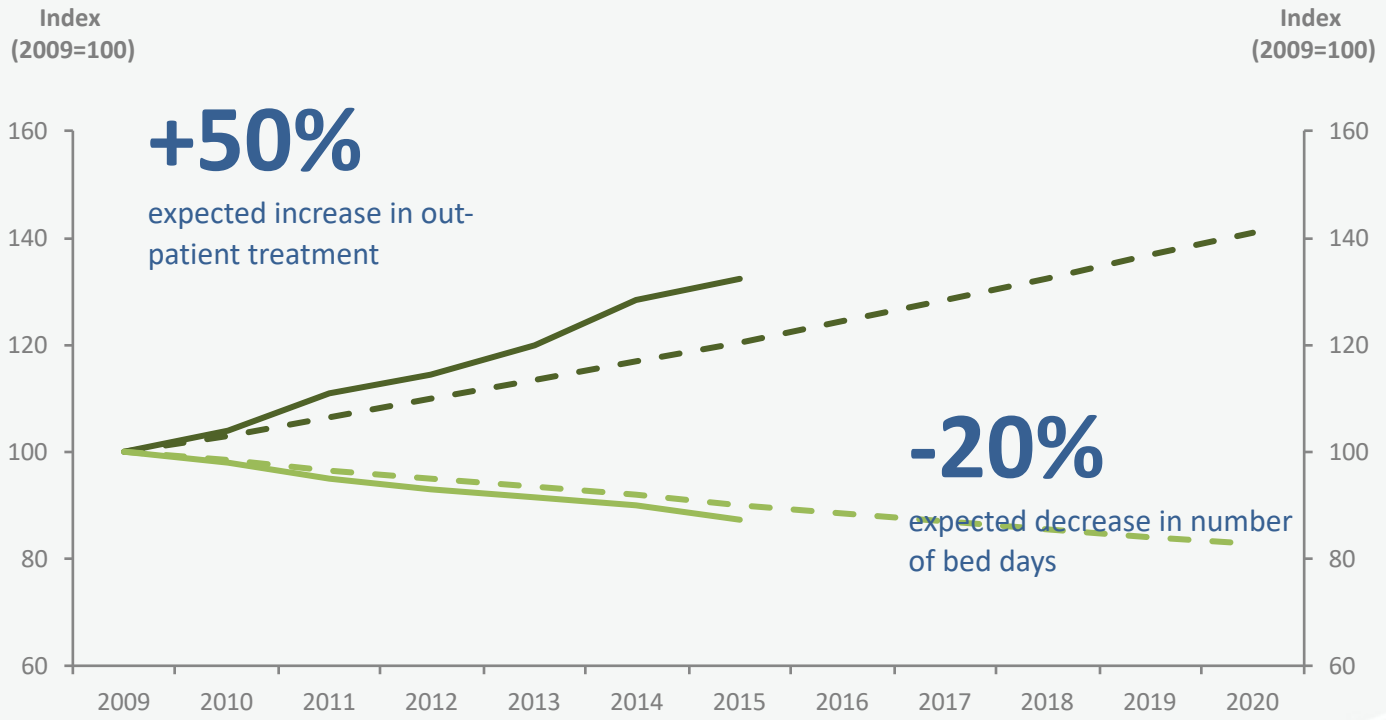
Source: Digital Health Strategy 2018-2022, Danish Ministry of Health, 2018.

A change in our structuring of hospitals

Source: Digital Health Strategy 2018-2022, Danish Ministry of Health, 2018.

Key numbers

A change in hospitalisation and technology



Source: Digital Health Strategy 2018-2022, Danish Ministry of Health, 2018.

There is no real alternative to increased digital cooperation

- The percentage of elderly people will increase
- More people will live with a chronic disease
- Fewer, larger and more specialised hospitals
- Patient pathways will be faster
- More treatment will take place in the patient's home

Source: Digital Health Strategy 2018-2022, Danish Ministry of Health, 2018.

MARTS 2018

Vækstplan for life scienc

Danmark som førende life science nation

Erhvervsministeriet

Figur 1
Udvikling i life science industriens andel af den samlede vareeksport i sammenlignelige lande, 2008-2016.

GLOBAL V
— SUNDH
EKSPORT
— *DI analyse*

D I

Eksport af sundhedsprodukter outperformer øvrig eksport
Indekseret eksport målt i løbende priser

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Global venture capital (VC) fu
private equity and corporate
2018. This sets a new record
signs of waning.

GOOGLE | TECH | WEARABLE

Google buys Fitbit for $2.1 billion

The fitness tracking company will join Google

By Chaim Gartenberg | @cgartenberg | Nov 1, 2019, 9:02am EDT

SHARE

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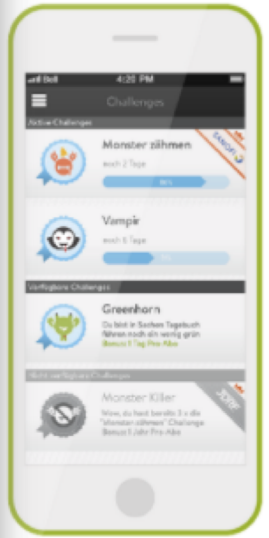
0M

Comment



form which emerged
ealth giant Roche. It
now becomes the heart of Roche Diabetes Care's new patient-centered

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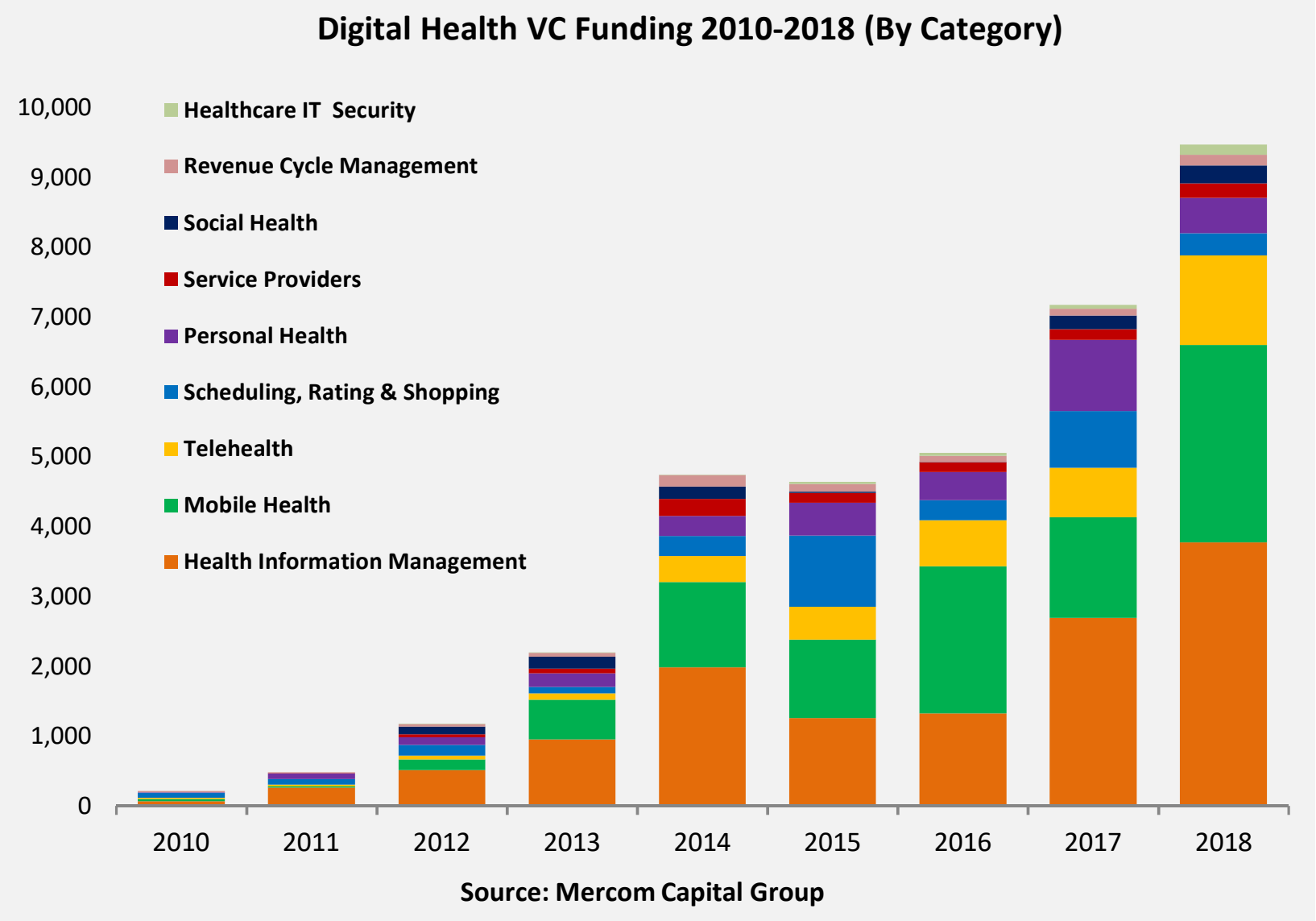

Source: 2018 Fourth Quarter and Annual Digital Health Funding and M&A Mercom Capital Group .

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PERSONAL HEALTH TECHNOLOGY

Personal Health Technology

Personal Medical Devices
- Hearing aids
- Diabetes, drug delivery, glucose mon.
- Respiratory
- EKG, EEG, .. monitoring
- Pacemaker

Telemedicine
- Telemedicine platforms
- Ambient Assisted Living
- CGM / Pumps

Mobile Health Technology (mHealth)
- Intel Mobile Sensing Platform
- UbifitGarden
- BeWell
- Mobilize!
- MONARCA

Fitness / Wellness Tech
- GPS & pulse
- Activity Trackers
- Smartphone apps
- Smart Watches
- Smart Devices (scales, ...)

1990 2000 2010

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Definition of Personal Health Technology

- Two broad categories
  - Professional Medical Devices
    - targeted a specific disease / health
    - 'prescribed' by doctors => customer == clinicians
    - strongly regulated – CE marked | FDA approved
  - Wellness and Consumer Health Technologies
    - targeted general wellness and wellbeing
    - 'consumed' by end-users => customer == consumers
    - not regulated (CE | FDA)
- … but the lines are *blurring*

Withings

One Drop

- glucose monitor (strip based)
- 24/7 expert support
- mobile/watch apps

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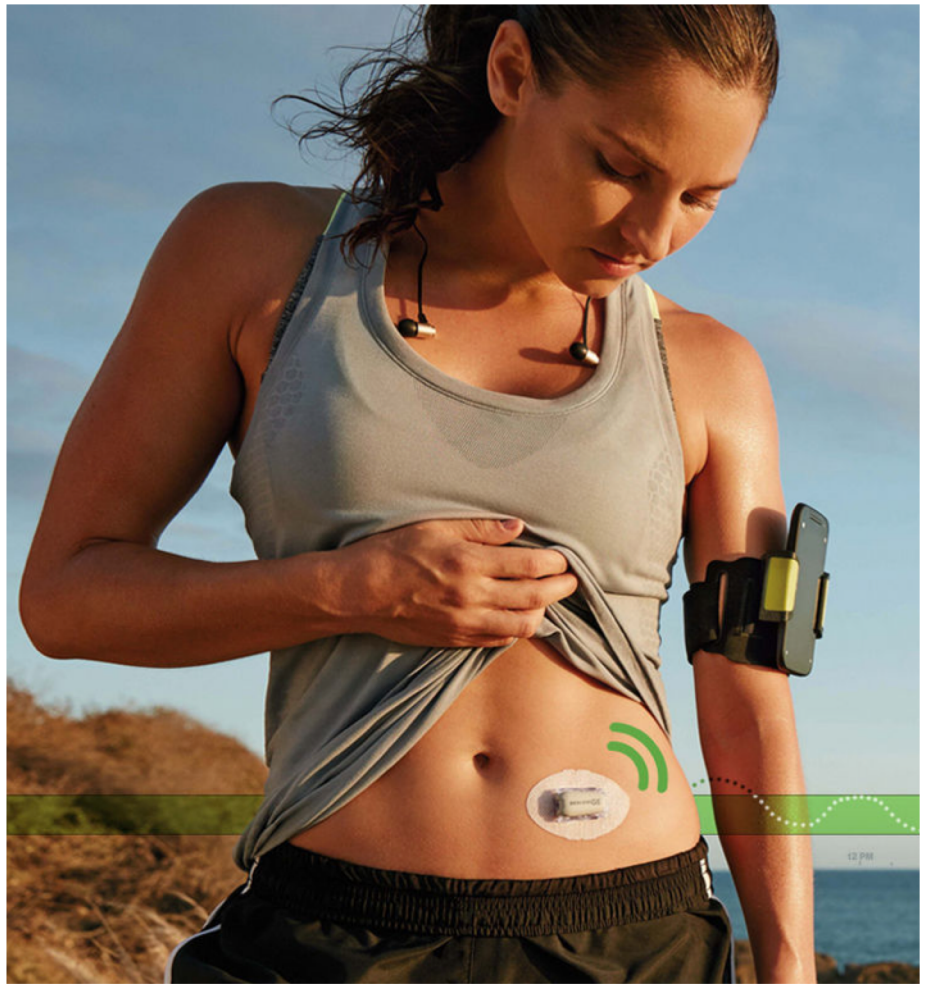
Dexcom G6 CGM

- Continuous Glucose Monitoring (CGM)
- SmartPhone / SmartWatch
- Alerts
- Sharing



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Apple Watch s5

- Workout
  - move | exercise | stand
  - running | swimming | gym | …
  - competing (social)
- Health
  - HR | HRV | ECG
  - cycle | stress | noise
  - glucose | food | …
  - fall detection | emergency

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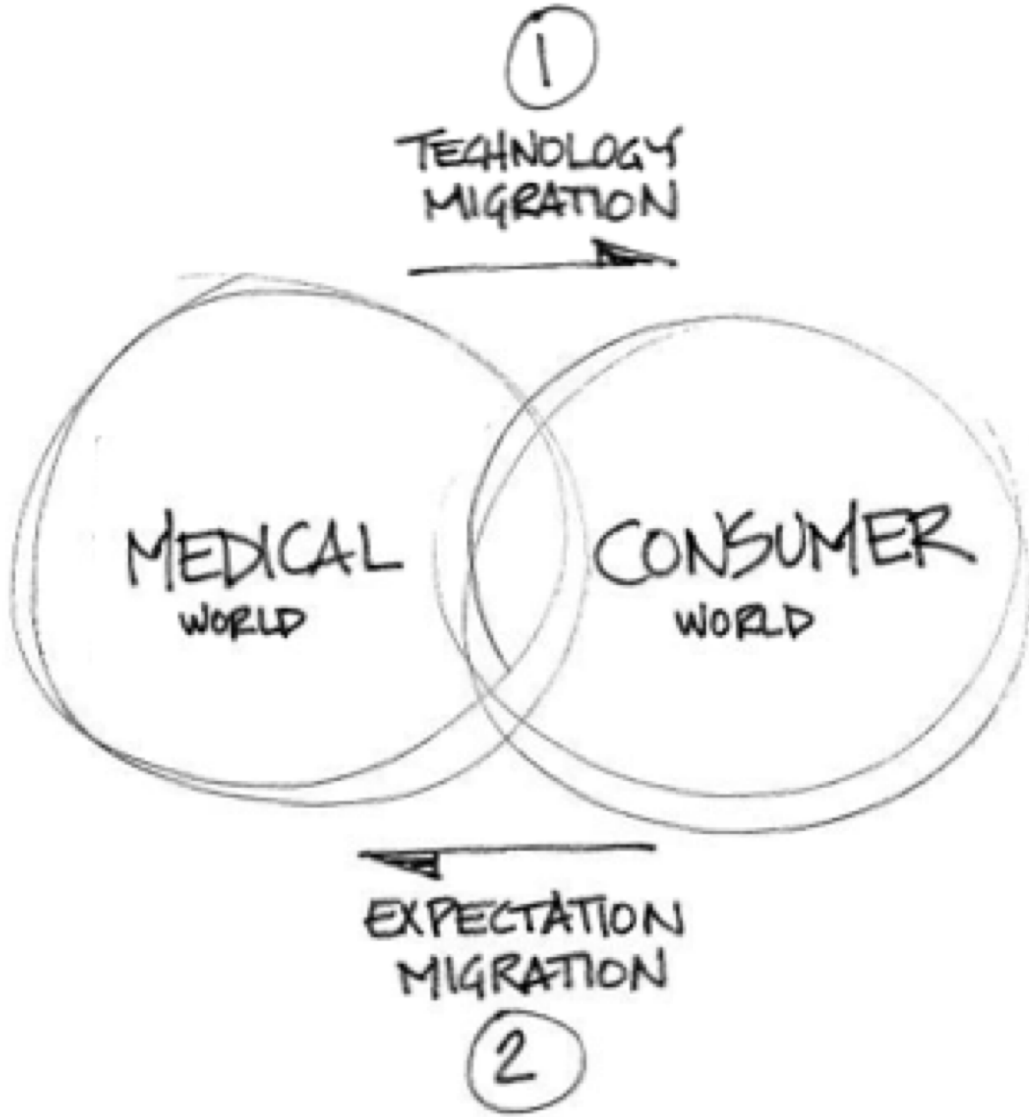
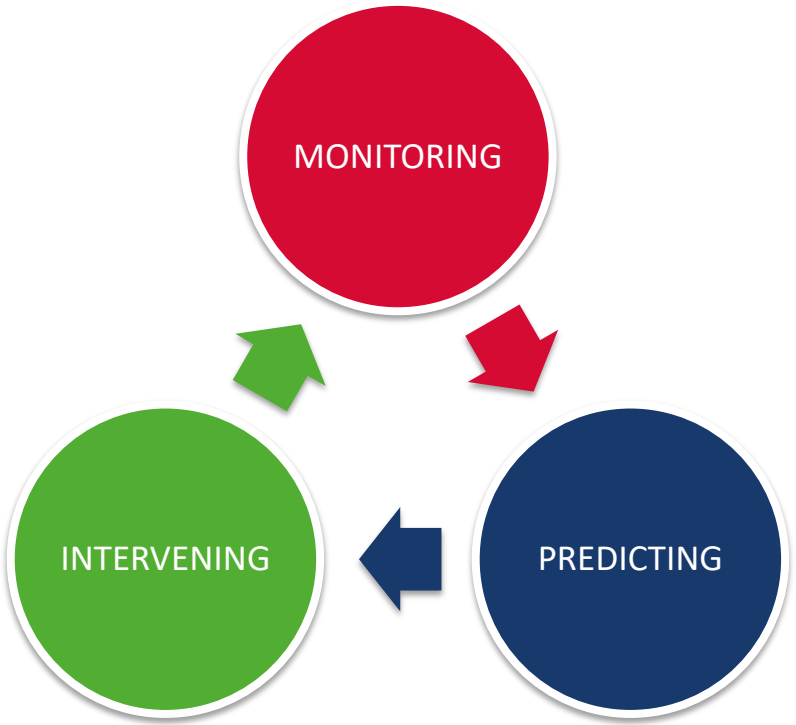

1
TECHNOLOGY
MIGRATION
MEDICAL
WORLD
CONSUMER
WORLD
EXPECTATION
MIGRATION
2

Personal Health Technology

- **MONITORING**
  - health progression & regression
  - behavior
  - context
  - longitudinal & continuously
- **PREDICTIVE**
  - pattern recognition
  - correlation analysis
  - disease forecasting
  - clinical alerts & decision-support
- **INTERVENTION**
  - early detection
  - context-aware feedback & treatment
  - clinical intervention & prescription



JE Bardram & M Frost. The Personal Health Technology Design Space.
IEEE Pervasive Computing 15(2), 70-78, IEEE, 2016

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Single Loop

Lane, N.D., Choudhury, T., Campbell, A., Mohammod, M., Lin, M., Yang, X., Doryab, A., Lu, H., Ali, S., Berke, E., 2011. BeWell: a smartphone application to monitor, model and promote wellbeing. In: *Proceedings of the 5th International ICST Conference on Pervasive Computing Technologies for Healthcare (Pervasive Health 2011).* IEEE Press.

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DOUBLE LOOP

Bardram JE, Frost MM. Double-Loop health technology: Enabling socio-technical design of personal health technology in clinical practice. In: *Designing Healthcare That Works: A Sociotechnical Approach*. ; 2017.

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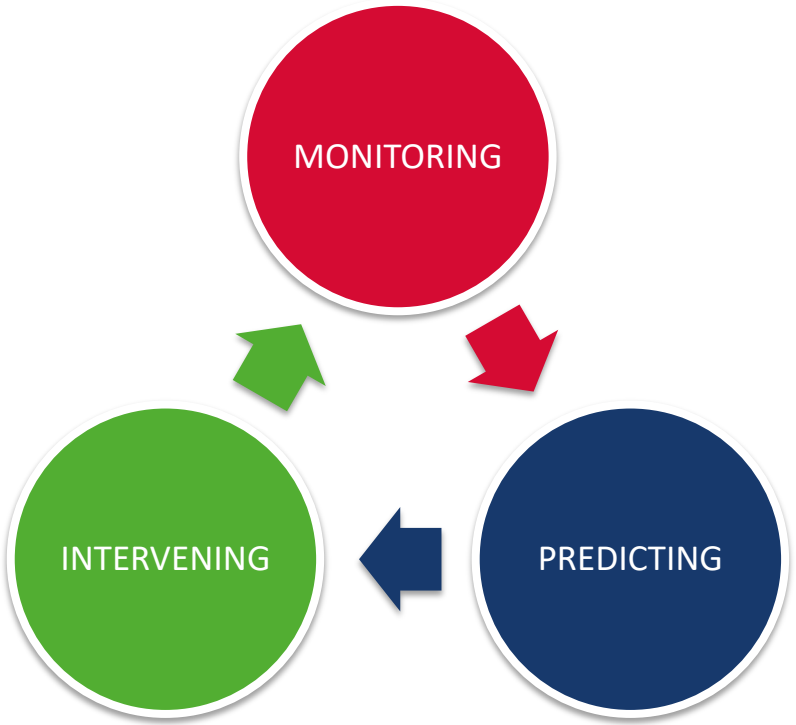
RESEARCH EXAMPLES

Health Topics

- Psychiatry
  - depression
  - bipolar disorder
- Cardiovascular diseases
  - atrial fibrillation
- Diabetes
  - type 2
- Neurology
  - sleep disorders



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Psychiatry

- Data Collection & Monitoring
  - self-assessment – mood | sleep | stress | medicine | …
  - sensor data – physical activity | mobility | social activity | phone usage | voice features
- Predicting
  - mood forecast, relapse of depression
- Intervention
  - visualizations | medication | actions-to-take | triggers | early-warning-signs | impact factors
- Context-aware CBT
  - psycho-education
  - behavioral activation
  - thought parking

MONSENSO

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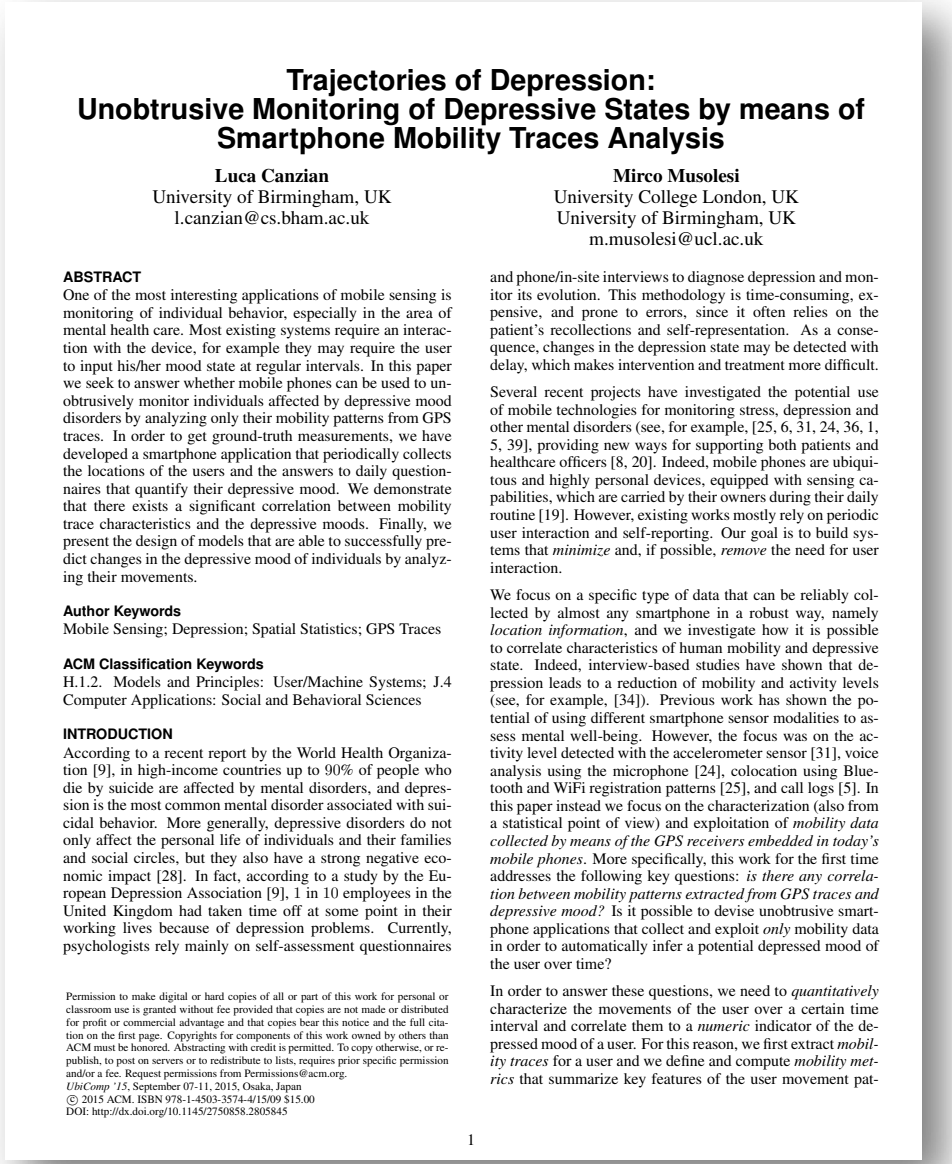
Mobility & Depression

- "significant **correlation** between mobility trace characteristics and depressive moods"

- "possible to develop **inference** algorithms for unobtrusive monitoring and prediction of depressive mood disorders"



Trajectories of Depression: Unobtrusive Monitoring of Depressive States by means of Smartphone Mobility Traces Analysis

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ABSTRACT
One of the most interesting applications of mobile sensing is monitoring of individual behavior, especially in the area of mental health care. Most existing systems require an interaction with the device, for example they may require the user to input his/her mood state at regular intervals. In this paper we seek to answer whether mobile phones can be used to unobtrusively monitor individuals affected by depressive mood disorders by analyzing only their mobility patterns from GPS traces. In order to get ground-truth measurements, we have developed a smartphone application that periodically collects the locations of the users and the answers to daily questionnaires that quantify their depressive mood. We demonstrate that there exists a significant correlation between mobility trace characteristics and the depressive moods. Finally, we present the design of models that are able to successfully predict changes in the depressive mood of individuals by analyzing their movements.

Author Keywords
Mobile Sensing; Depression; Spatial Statistics; GPS Traces

ACM Classification Keywords
H.1.2. Models and Principles: User/Machine Systems; J.4 Computer Applications: Social and Behavioral Sciences

INTRODUCTION
According to a recent report by the World Health Organization [9], in high-income countries up to 90% of people who die by suicide are affected by mental disorders, and depression is the most common mental disorder associated with suicidal behavior. More generally, depressive disorders do not only affect the personal life of individuals and their families and social circles, but they also have a strong negative economic impact [28]. In fact, according to a study by the European Depression Association [9], 1 in 10 employees in the United Kingdom had taken time off at some point in their working lives because of depression problems. Currently, psychologists rely mainly on self-assessment questionnaires and phone/in-site interviews to diagnose depression and monitor its evolution. This methodology is time-consuming, expensive, and prone to errors, since it often relies on the patient's recollections and self-representation. As a consequence, changes in the depression state may be detected with delay, which makes intervention and treatment more difficult.

Several recent projects have investigated the potential use of mobile technologies for monitoring stress, depression and other mental disorders (see, for example, [25, 6, 31, 24, 36, 1, 5, 39], providing new ways for supporting both patients and healthcare officers [8, 20]. Indeed, mobile phones are ubiquitous and highly personal devices, equipped with sensing capabilities, which are carried by their owners during their daily routine [19]. However, existing works mostly rely on periodic user interaction and self-reporting. Our goal is to build systems that *minimize* and, if possible, *remove* the need for user interaction.

We focus on a specific type of data that can be reliably collected by almost any smartphone in a robust way, namely *location information*, and we investigate how it is possible to correlate characteristics of human mobility and depressive state. Indeed, interview-based studies have shown that depression leads to a reduction of mobility and activity levels (see, for example, [34]). Previous work has shown the potential of using different smartphone sensor modalities to assess mental well-being. However, the focus was on the activity level detected with the accelerometer sensor [31], voice analysis using the microphone [24], colocation using Bluetooth and WiFi registration patterns [25], and call logs [5]. In this paper instead we focus on the characterization (also from a statistical point of view) and exploitation of *mobility data collected by means of the GPS receivers embedded in today's mobile phones*. More specifically, this work for the first time addresses the following key questions: *is there any correlation between mobility patterns extracted from GPS traces and depressive mood?* Is it possible to devise unobtrusive smartphone applications that collect and exploit *only* mobility data in order to automatically infer a potential depressed mood of the user over time?

In order to answer these questions, we need to *quantitatively* characterize the movements of the user over a certain time interval and correlate them to a *numeric* indicator of the depressed mood of a user. For this reason, we first extract *mobility traces* for a user and we define and compute *mobility metrics* that summarize key features of the user movement pat-

UbiComp '15, September 07-11, 2015, Osaka, Japan
© 2015 ACM. ISBN 978-1-4503-3574-4/15/09 $15.00
DOI: http://dx.doi.org/10.1145/2750858.2805845

Canzian L, Musolesi M. Trajectories of Depression: Unobtrusive Monitoring of Depressive States by means of Smartphone Mobility Traces Analysis. In: *Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing (ACM UbiComp'15)*. ACM; 2015.

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Voice & Mood

Collection of voice features in naturalistic setting

- N=28 | 12 weeks
- HDRS-17 (depression) and YMRS (manic)
- 179 clinical ratings (fortnightly)
- openSMILE (emolarge)

Classification results (user-spe

- depressive state : 70% (0.13
- manic state : 61% (0.04)

OPEN

Citation: Transl Psychiatry (2016) **6**, e856; doi:10.1038/tp.2016.123
www.nature.com/tp

ORIGINAL ARTICLE

Voice analysis as an objective state marker in bipolar disorder

M Faurholt-Jepsen[1], J Busk[2], M Frost[3], M Vinberg[1], EM Christensen[1], O Winther[2], JE Bardram[2] and LV Kessing[1]

Changes in speech have been suggested as sensitive and valid measures of depression and mania in bipolar disorder. The present study aimed at investigating (1) voice features collected during phone calls as objective markers of affective states in bipolar disorder and (2) if combining voice features with automatically generated objective smartphone data on behavioral activities (for example, number of text messages and phone calls per day) and electronic self-monitored data (mood) on illness activity would increase the accuracy as a marker of affective states. Using smartphones, voice features, automatically generated objective smartphone data on behavioral activities and electronic self-monitored data were collected from 28 outpatients with bipolar disorder in naturalistic settings on a daily basis during a period of 12 weeks. Depressive and manic symptoms were assessed using the Hamilton Depression Rating Scale 17-item and the Young Mania Rating Scale, respectively, by a researcher blinded to smartphone data. Data were analyzed using random forest algorithms. Affective states were classified using voice features extracted during everyday life phone calls. Voice features were found to be more accurate, sensitive and specific in the classification of manic or mixed states with an area under the curve (AUC) = 0.89 compared with an AUC = 0.78 for the classification of depressive states. Combining voice features with automatically generated objective smartphone data on behavioral activities and electronic self-monitored data increased the accuracy, sensitivity and specificity of classification of affective states slightly. Voice features collected in naturalistic settings using smartphones may be used as objective state markers in patients with bipolar disorder.

Translational Psychiatry (2016) **6,** e856; doi:10.1038/tp.2016.123; published online 19 July 2016

INTRODUCTION

Observer-based clinical rating scales such as the Hamilton Depression Rating Scale 17-item (HAMD)[1] and the Young Mania Rating Scale (YMRS)[2] are used as golden standards to assess the severity of depressive and manic symptoms when treating patients with bipolar disorder. However, using these clinical rating

important aspects to evaluate in the assessment of symptoms' severity in bipolar disorder. Based on these clinical observations there is an increasing interest in electronic systems for speech emotion recognition that can be used to extract useful semantics from speech and thereby provide information on the emotional state of the speaker (for example, information on pitch of the

"Voice features collected in naturalistic settings using smartphones may be used as objective state markers in patients with bipolar disorder. "

M Faurholt-Jepsen, J Busk, M Frost, M Vinberg, EM Christensen, O Winther, JE Bardram, LV Kessing (2016,). Voice analysis as an objective state marker in bipolar disorder. *Transl Psychiatry.* Macmillan Publishers Limited.

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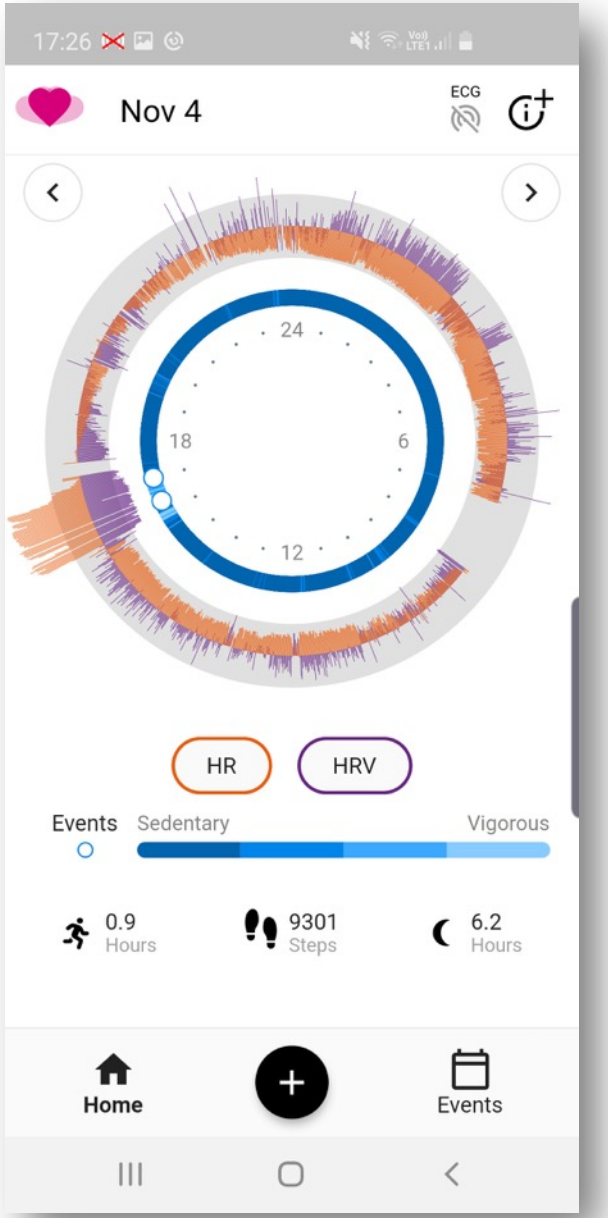
Cardio Vascular Diseases

- ECG monitoring is core to most cardio-vascular diseases
  - a constrained Holter Monitoring setup w. manual data upload
  - a manual labeling and detection process

- Automatic 24/7 monitoring
  - HR, HRV, ECG, physical activity, sleep, …
  - patient-reported events & outcome
- Novel deep learning model for real-time detection of atrial fibrillation (AFIB)
  - 98% accuracy
  - both seen and unseen (benchmark) data
  - analyze 24 hours of data in less than one second
- Intervention
  - continuous feedback to patient
  - triggers & alarms to clinicians



Andersen, Rasmus S., Abdolrahman Peimankar, and Sadasivan Puthusserypady. "A deep learning approach for real-time detection of atrial fibrillation." *Expert Systems with Applications*115 (2019): 465-473.

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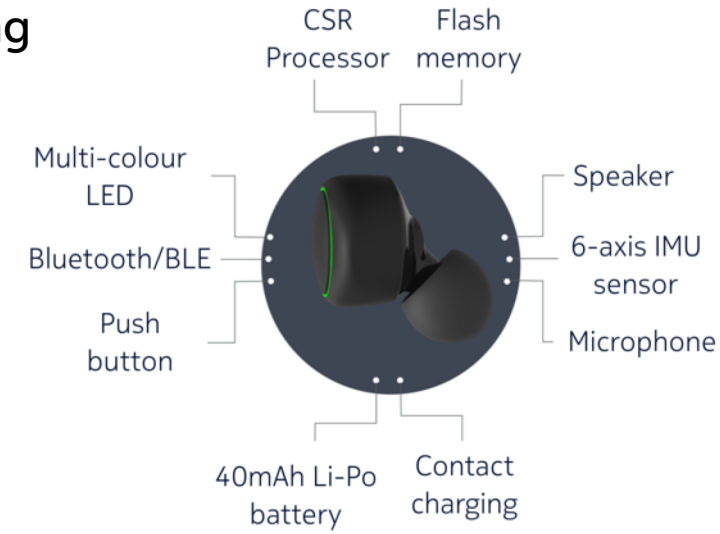
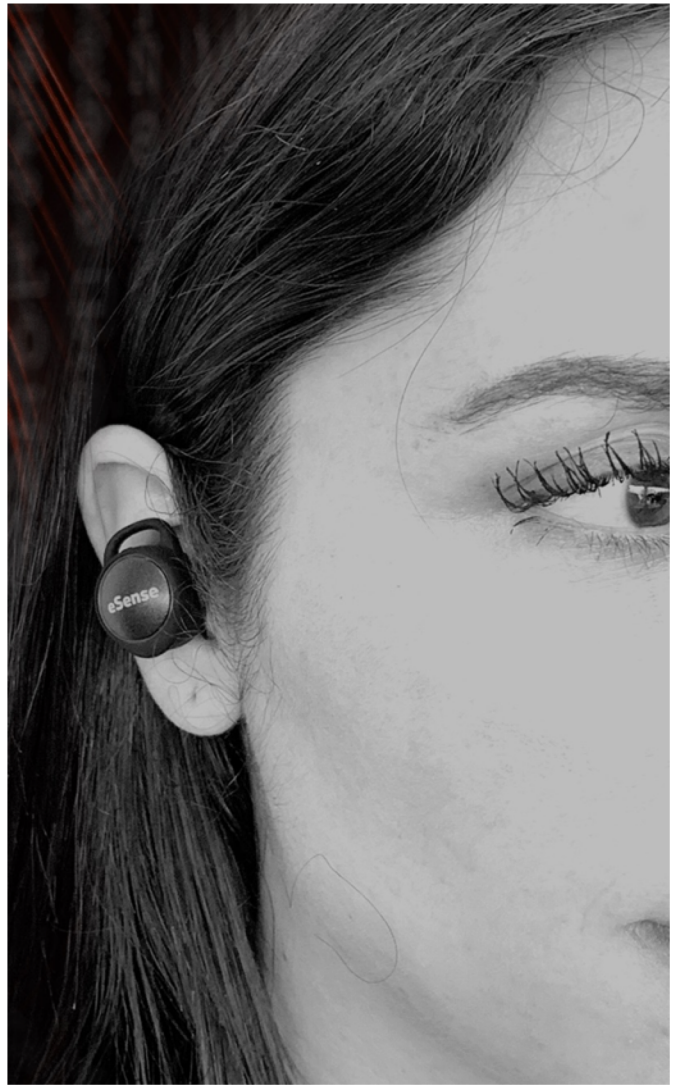
Earable [Intimate] Computing

- laptop > mobile > wearable > earable [> implanted]
- **earable computing**
  - intimate & subtle interaction
  - unique for robust & private sensing
  - established purpose
  - aesthetic & ergonomic
- **health sensing**
  - physical activity
  - eating & drinking
  - heart rate / HRV
  - conversation & noise
  - facial expressions (mood)
- **health intervention**
  - context-aware
  - just-in-time-adaptive-intervention (JITAI)





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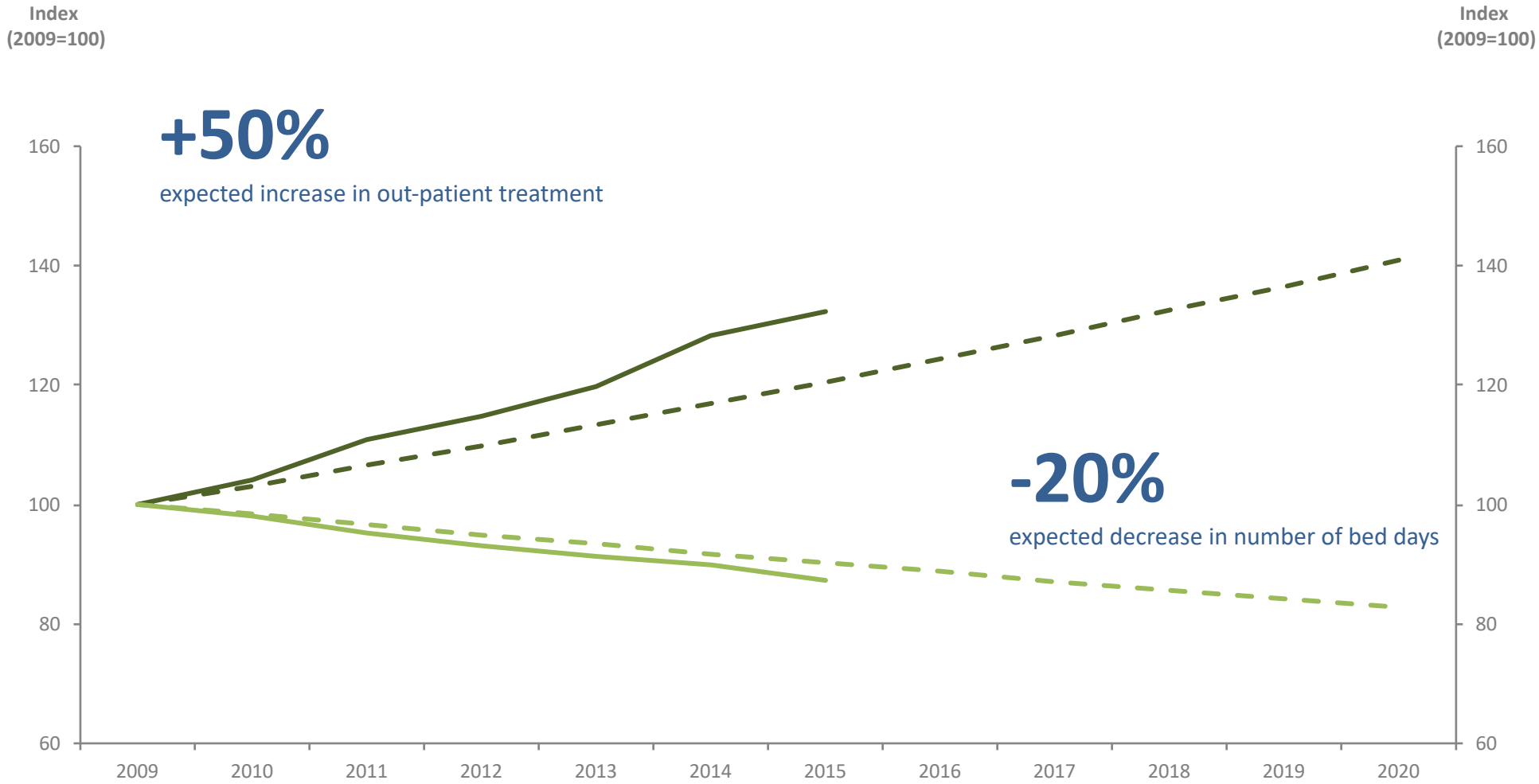
LOOKING AHEAD



Source: Digital Health Strategy 2018-2022, Danish Ministry of Health, 2018.

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4P Healthcare Technology

Preventive

avoid (chronic) health problems in the first place

Predictive

catch health problems early

Participatory

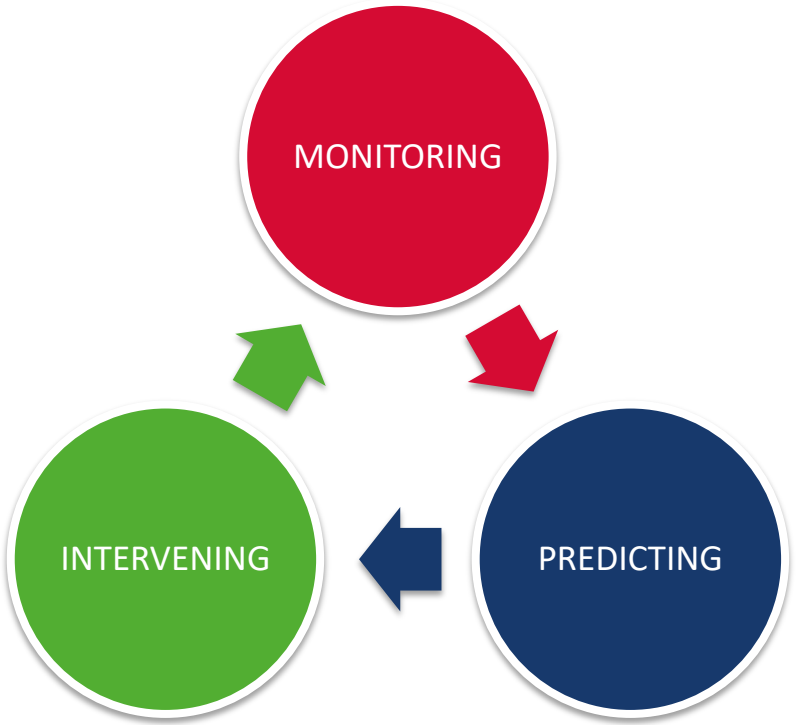
engage people in their own health

Personalized

tailor treatment to the individual ("personalized medicine")

4P Technology – Patient

- Continuous monitoring
- Micro-interventions
- Self-awareness
- Engagement
- Personalization
- Health service subscriptions



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4P Technology – Clinicians

- From reactive to proactive
- From patient- to population-based
- From diagnosis to monitoring
- From ad-hoc to data-driven
- From activity- to outcome-based
- From monopoly to partner
- From insourcing to outsourcing
- From hospital to home

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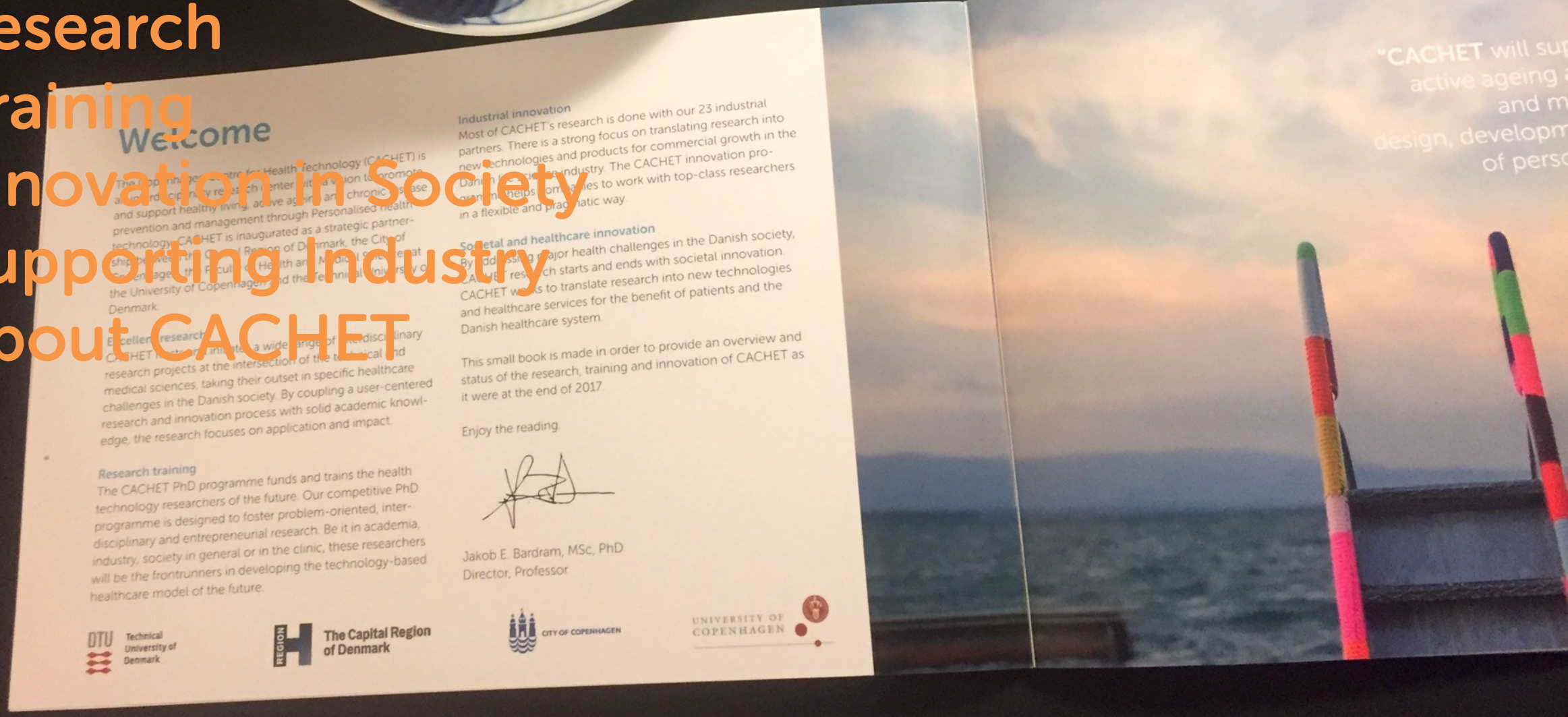

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Copenhagen Center for Health Technology

Technical University of Denmark

The Capital Region of Denmark

CITY OF COPENHAGEN

UNIVERSITY OF COPENHAGEN