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CARP Mobile Sensing

v. 0.33.x

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University of Copenhagen

Technical University of Denmark | DTU | REGION H | The Capital Region of Denmark | CITY OF COPENHAGEN | UNIVERSITY OF COPENHAGEN

carp.cachet.dk/cams/

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CARP Mobile Sensing

The CARP Mobile Sensing (CAMS) **Flutter package** is a **programming framework** for adding **digital phenotyping** capabilities to your mobile (health) **app**.

CAMS is designed to collect research-quality **sensor data** from the smartphone **on-board** sensors and attached **off-board** wearable devices.

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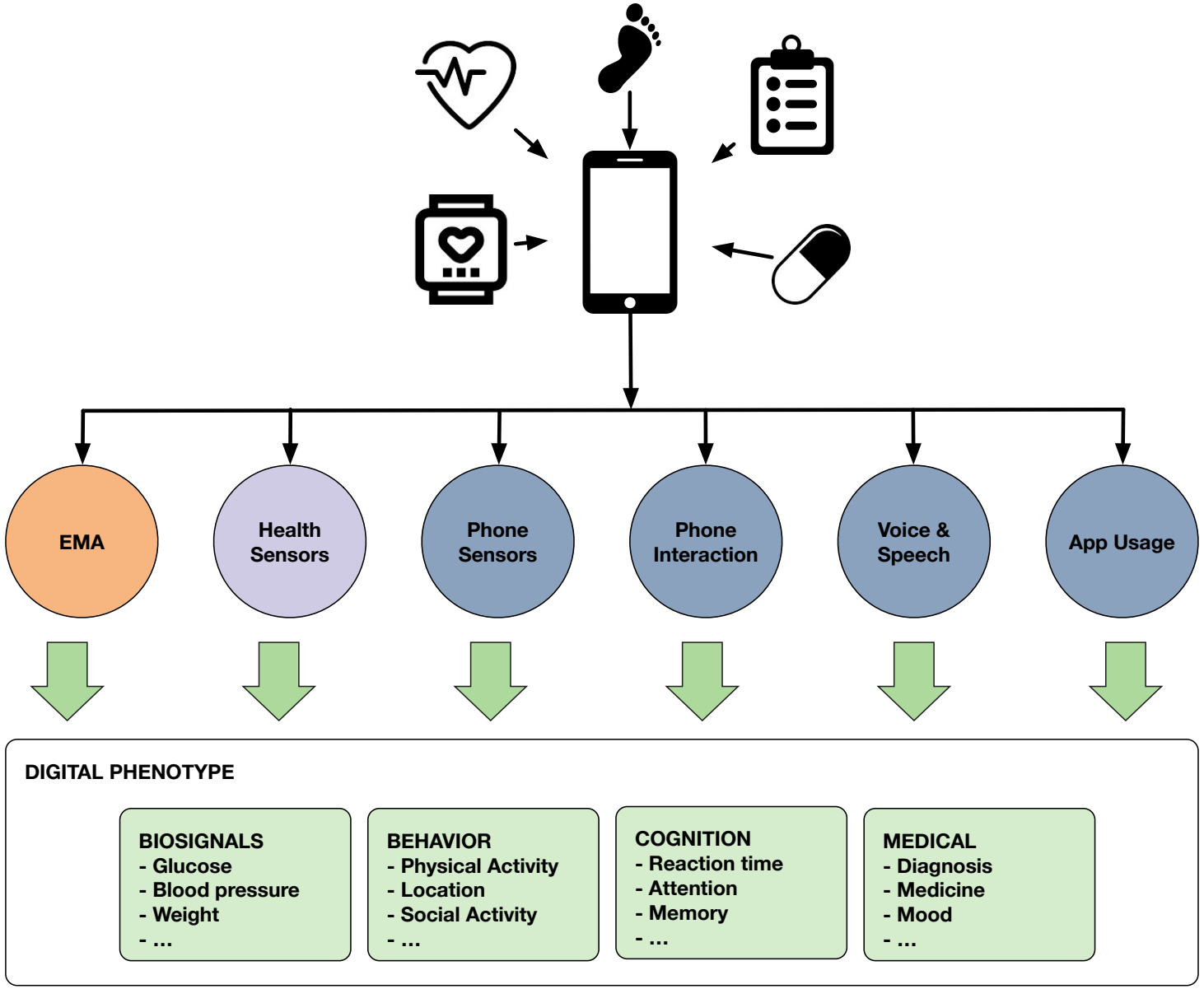
Digital Phenotyping

Continuous and unobtrusive measurement and inference of health, behavior, and other parameters from wearable and mobile technology



- Jain, S. H., Powers, B. W., Hawkins, J. B., & Brownstein, J. S. (2015). The digital phenotype. *Nat Biotech*, 33(5), 462–463.
- Insel, T. R. (2017). Digital phenotyping: Technology for a new science of behavior. *JAMA*, *318*(13), 1215–1216.

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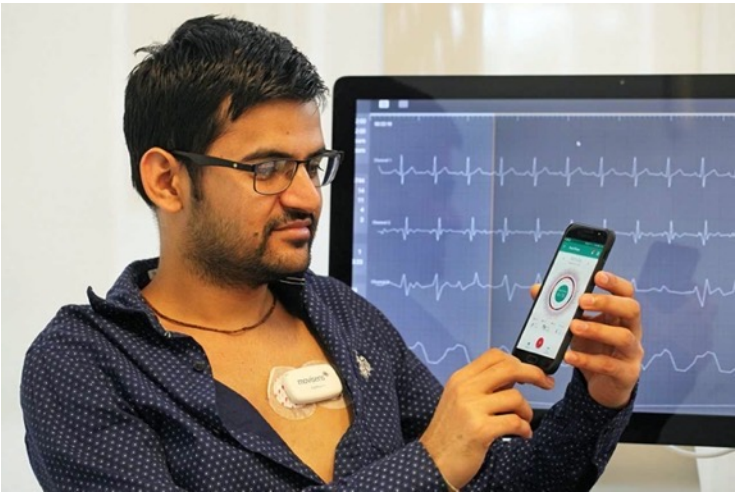
mCardia

- A Context-Aware System for Arrhythmia Screening
  - **physiological** (ECG, HR, HRV, …)
  - **contextual** (location, accelerometer, …)
  - **behavioral** (steps, position, sleep, …)
  - **patient-reported** (symptoms, sleep quality, food, …)
- Novel digital phenotyping technology for arrhythmia screening
  - **ambulatory** – data collection under free-living conditions
  - **longitudinal** – 2-5 weeks of data collection
  - **contextual** – behavior, environment, activity, self-reports
- 2 studies :: Denmark & India
  - N=24
  - high usability and user engagement scores
  - huge ambulatory dataset collected
  - patient annotation of experienced “events”



Kumar, D., Maharjan, R., Maxhuni, A., Dominguez, H., Frølich, A., & Bardram, J. E. (2022). mCardia: A Context-Aware ECG Collection System for Ambulatory Arrhythmia Screening. *ACM Transactions on Computing for Healthcare (HEALTH)*, *3*(2), 1-28.

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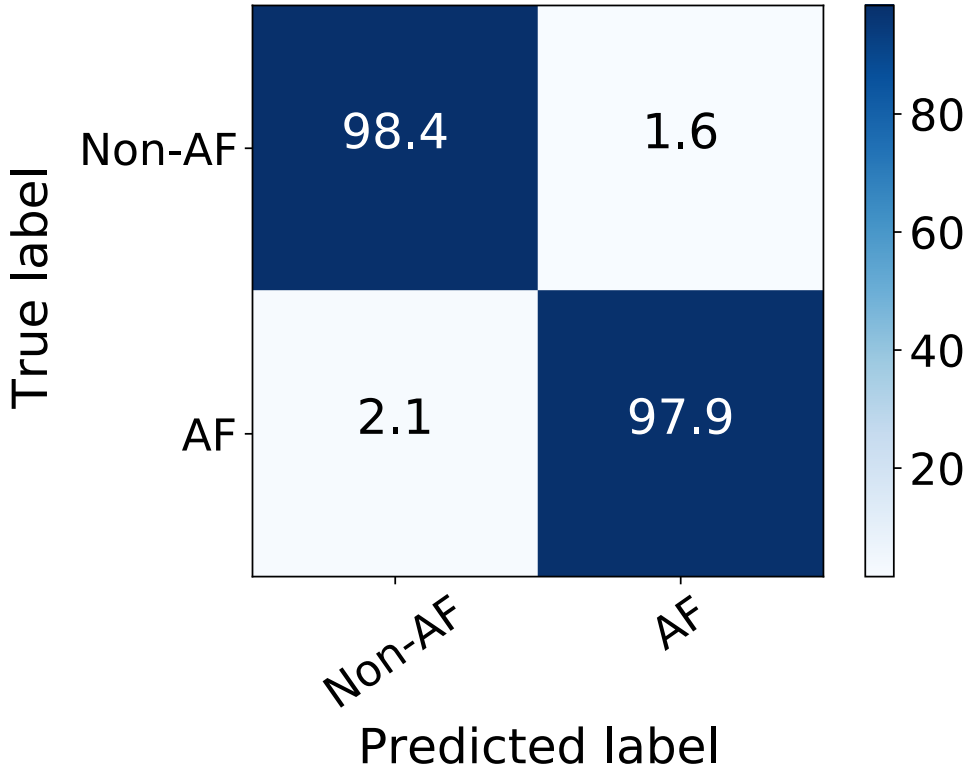
Deep-learning Method for Ambulatory AF Detection

- **"In-the-Wild"** real-time detection of atrial fibrillation
  - ambulatory, contextual data
  - patient-reported data
  - based on CACHET-CADB ("in-the-wild" data)
  - **98% accuracy**

- Implications
  - reduction of **manual** Holter analysis
  - **pro-active** detection of AF
  - semi-automatic **triage**
  - early **intervention**



D Kumar, A Peimankar, K Sharma, H Dominguez, S Puthusserypady, and JE Bardram. "*DeepAware*: A Hybrid Deep Learning and Context-Aware Heuristics Based Model for Atrial Fibrillation Detection" Under review.

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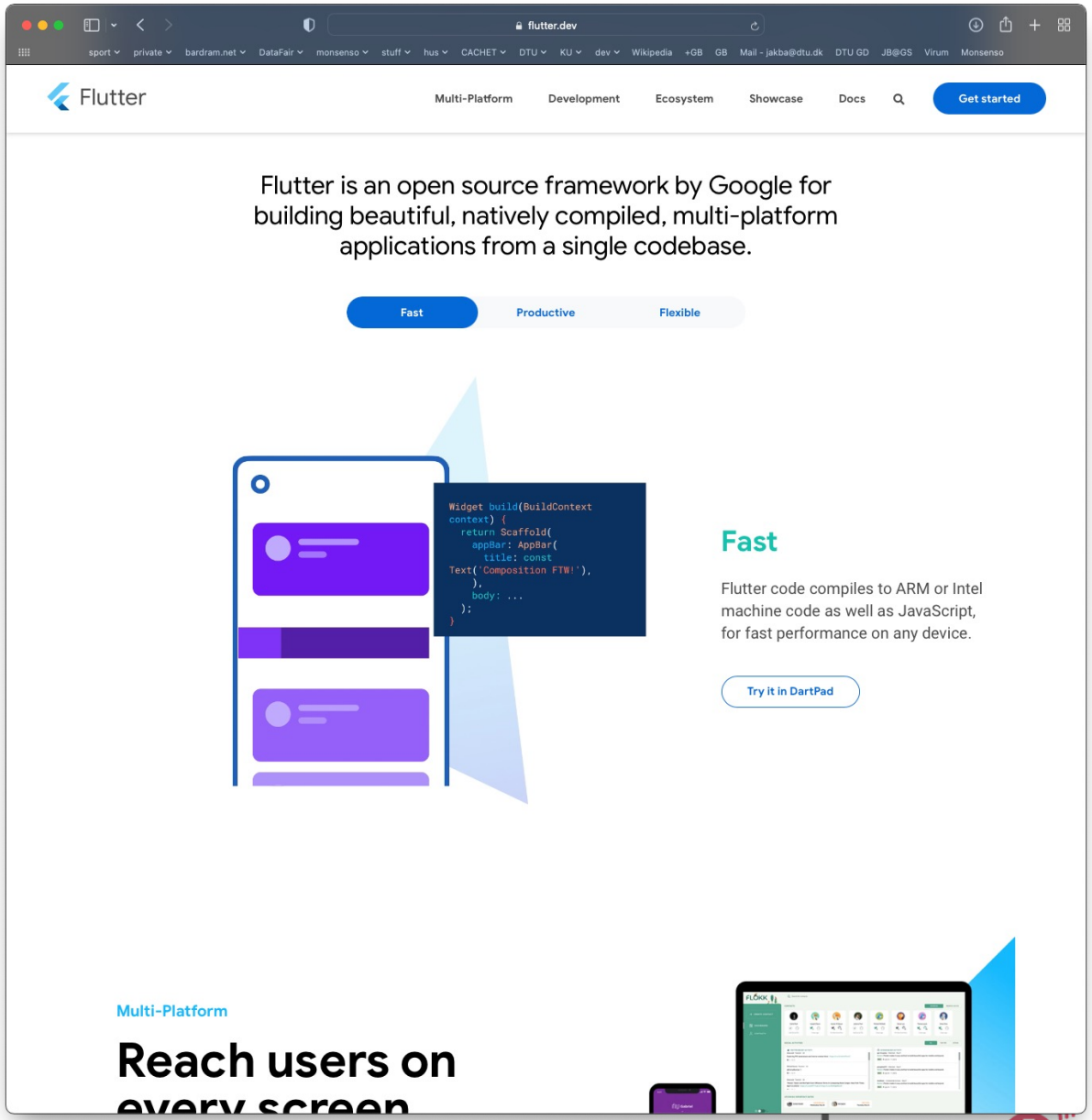
Flutter

- **Cross-platform** framework
  - Android & iOS (web, Windows, ...)
  - UI framework (write once!)
  - compiles natively (fast!)
  - OS-level plugins (hackable!)
- **Dart** programming language
  - modern, reactive, ... (like Swift)
- Significant traction
- Large number of 3rd party packages and plugins
  - pub.dev



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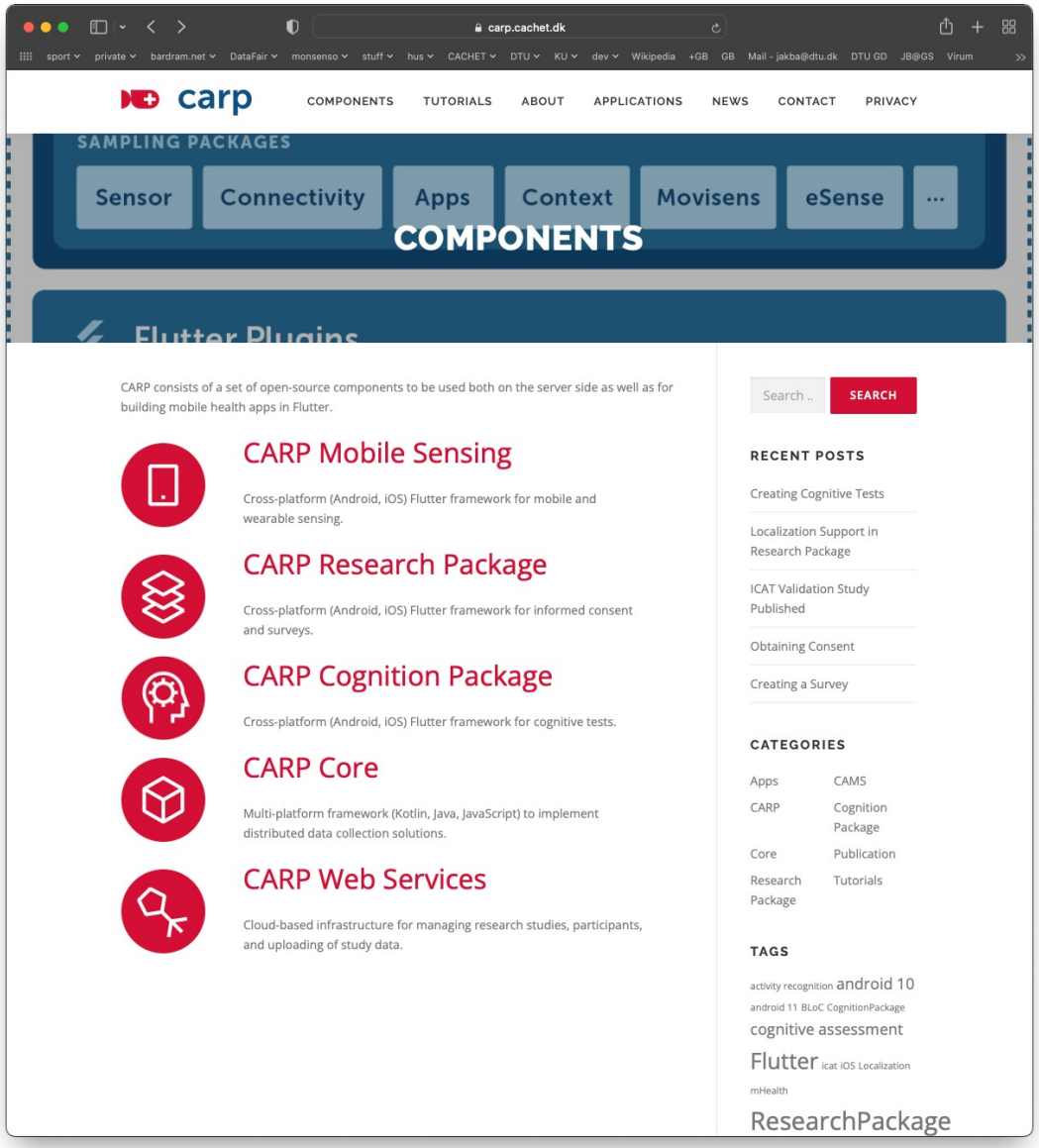
Flutter

CARP Flutter Components

- **CARP Mobile Sensing** (for sensing)
  - sensing framework
  - onboard sensors (e.g. light, location, ...)
  - sensing packages (e.g. ECG, ...)
  - user tasks
  - demo apps
- **CARP Backends** (for data upload)
  - Google Firebase
  - CARP cloud
- **Research Package** (Apple ResearchKit in Flutter)
  - informed consent flow
  - questionnaires / surveys
- **Cognition Package** (for cognitive assessment)
  - 14 cognitive tests on the phone
  - integrated to Research Package
- **Open mHealth** schemas (for standardization)
  - IEEE P1705 standard for mobile health data



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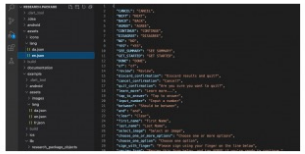
COGNITION PACKAGE / TUTORIALS

Creating Cognitive Tests

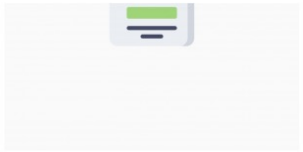
Creating cognitive assessment tests is the core features of Cognition Package. This tutorial will guide you through how to create the needed domain model objects for a cognitive assessment task, ...



RESEARCH PACKAGE / TUTORIALS

Localization Support in Research Package

Research Package (RP) supports localization, i.e., the ability to support different languages in an app. This is done in different ways and this tutorial seeks to provide an overview of ...



RESEARCH PACKAGE / TUTORIALS

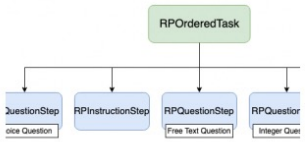
Obtaining Consent

A core feature of Research Package is to create and collect informed consent from users participating in a research study. This entails providing a set of information pages (called "consent ...

RESEARCH PACKAGE / TUTORIALS

Creating a Survey

Creating surveys is one of the core features of ResearchPackage. This tutorial will guide you through how to create the needed domain model objects for a survey task, how to ...



RESEARCH PACKAGE / TUTORIALS

Research Package API

This tutorial describes the overall software architecture of ResearchPackage and its API, and how to get started. Architecture and API API Naming We are following the API naming pattern from ...

CAMS / TUTORIALS

Creating your first CAMS app

This tutorial will help you create your first app that incorporates mobile sensing using the CARP Mobile Sensing (CAMS) framework in Flutter. Note that CAMS is designed to be a ...

Search ... SEARCH

RECENT POSTS

- Creating Cognitive Tests
- Localization Support in Research Package
- ICAT Validation Study Published
- Obtaining Consent
- Creating a Survey

CATEGORIES

Apps CAMS
CARP Cognition Packa
Core Publication
Research Package Tutorials

TAGS

activity recognition android 10 andro
11 BLoC CognitionPackage cognitive
assessment Flutter icat iOS
Localization mHealth
ResearchPackage
RP sampling
coverage sensor
Survey

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Creating your first CAMS app

POSTED ON NOVEMBER 13, 2020 BY JAKOB BARDRAM

This tutorial will help you create your first app that incorporates mobile sensing using the CARP Mobile Sensing (CAMS) framework in Flutter. Note that CAMS is designed to be a framework implemented as a Flutter plugin which allow you to add mobile sensing to your own app. Hence, CAMS is not an app on its own, and you need to design and implement you own app.

So – having said that – let's get started.

Step #1 – Learn, install, and understand Flutter & Dart

The first obvious step is to get yourself familiarised with Flutter, including understanding its programming language Dart. I will not provide a long tutorial on how to do this – there are plenty of resources available online – both in text, video, and tutorial formats.

But – one obvious starting point is the Flutter "Get Started" site, including the tutorial on "Write your first Flutter app".

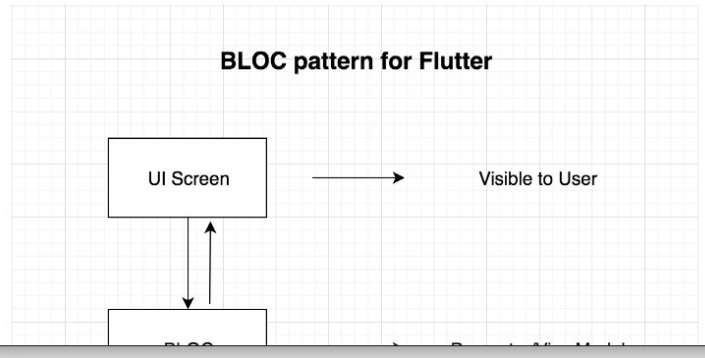
Step #2 – Get familiar with the BLoC architecture

A Flutter app can be implemented using many different software architectures. The Flutter Samples website provides a very nice overview and have many examples available on Github. So the problem in Flutter is not the lack of useful software architectures – the problem is rather to *pick a architecture that fits your app design, your skills, and not least; your preference*.

CAMS is designed as a Flutter plugin, which can be added to a Flutter app and agnostic to whatever architecture the app is using. So far, CAMS have been used in apps using an "Vanilla Lifting State Up", "InheritedWidget", and "Business Logic Component (BLoC") architecture.

However, having said this, **we recommend using the BLoC software architecture** for CAMS apps. The BLoC software architecture is very mature in terms of many supporting frameworks and examples in Flutter, and it fits very nicely with the reactive, stream-based programming model of Dart.

So – go and check out the "Getting Started" BLoC tutorial. And check out the `flutter_bloc` package. And this Medium post provide a very good starting point too, from where the image below is taken from.



Search ... SEARCH

RECENT POSTS

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- Localization Support in Research Package
- ICAT Validation Study Published
- Obtaining Consent
- Creating a Survey

CATEGORIES

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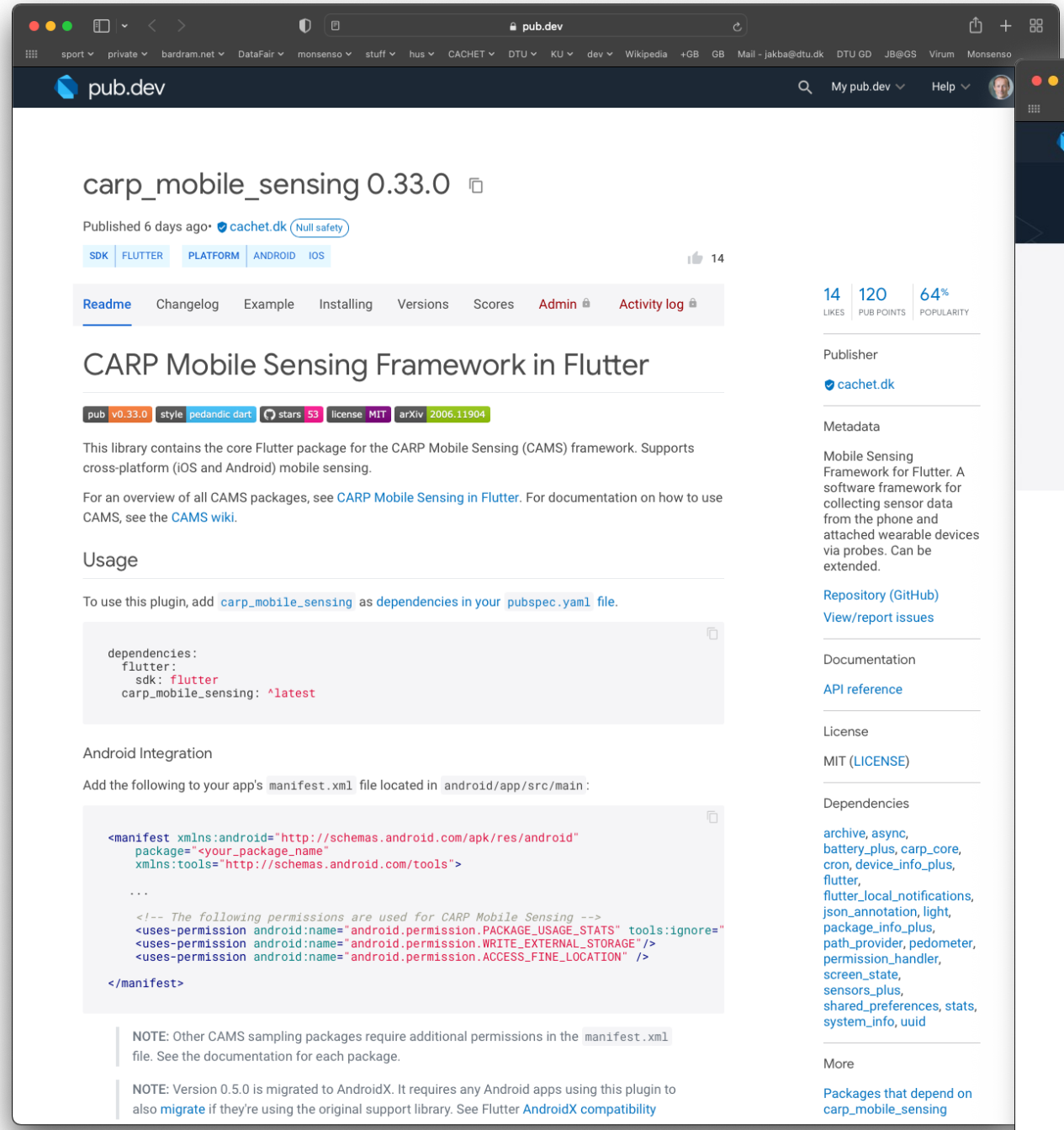
RP sampling
coverage sensor
Survey

ology


pub.dev
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Help
carp_mobile_sensing 0.33.0
Published 6 days ago • cachet.dk Null safety
SDK FLUTTER PLATFORM ANDROID IOS
14
Readme Changelog Example Installing Versions Scores Admin Activity log
CARP Mobile Sensing Framework in Flutter
pub v0.33.0 style pedandic dart stars 53 license MIT arXiv 2006.11904
This library contains the core Flutter package for the CARP Mobile Sensing (CAMS) framework. Supports cross-platform (iOS and Android) mobile sensing.
For an overview of all CAMS packages, see CARP Mobile Sensing in Flutter. For documentation on how to use CAMS, see the CAMS wiki.
Usage
To use this plugin, add carp_mobile_sensing as dependencies in your pubspec.yaml file.
dependencies:
flutter:
sdk: flutter
carp_mobile_sensing: ^latest
Android Integration
Add the following to your app's manifest.xml file located in android/app/src/main:
<manifest xmlns:android="http://schemas.android.com/apk/res/android"
package="<your_package_name"
xmlns:tools="http://schemas.android.com/tools">
...
<!-- The following permissions are used for CARP Mobile Sensing -->
<uses-permission android:name="android.permission.PACKAGE_USAGE_STATS" tools:ignore="
<uses-permission android:name="android.permission.WRITE_EXTERNAL_STORAGE"/>
<uses-permission android:name="android.permission.ACCESS_FINE_LOCATION" />
</manifest>
NOTE: Other CAMS sampling packages require additional permissions in the manifest.xml file. See the documentation for each package.
NOTE: Version 0.5.0 is migrated to AndroidX. It requires any Android apps using this plugin to also migrate if they're using the original support library. See Flutter AndroidX compatibility
14 LIKES 120 PUB POINTS 64% POPULARITY
Publisher
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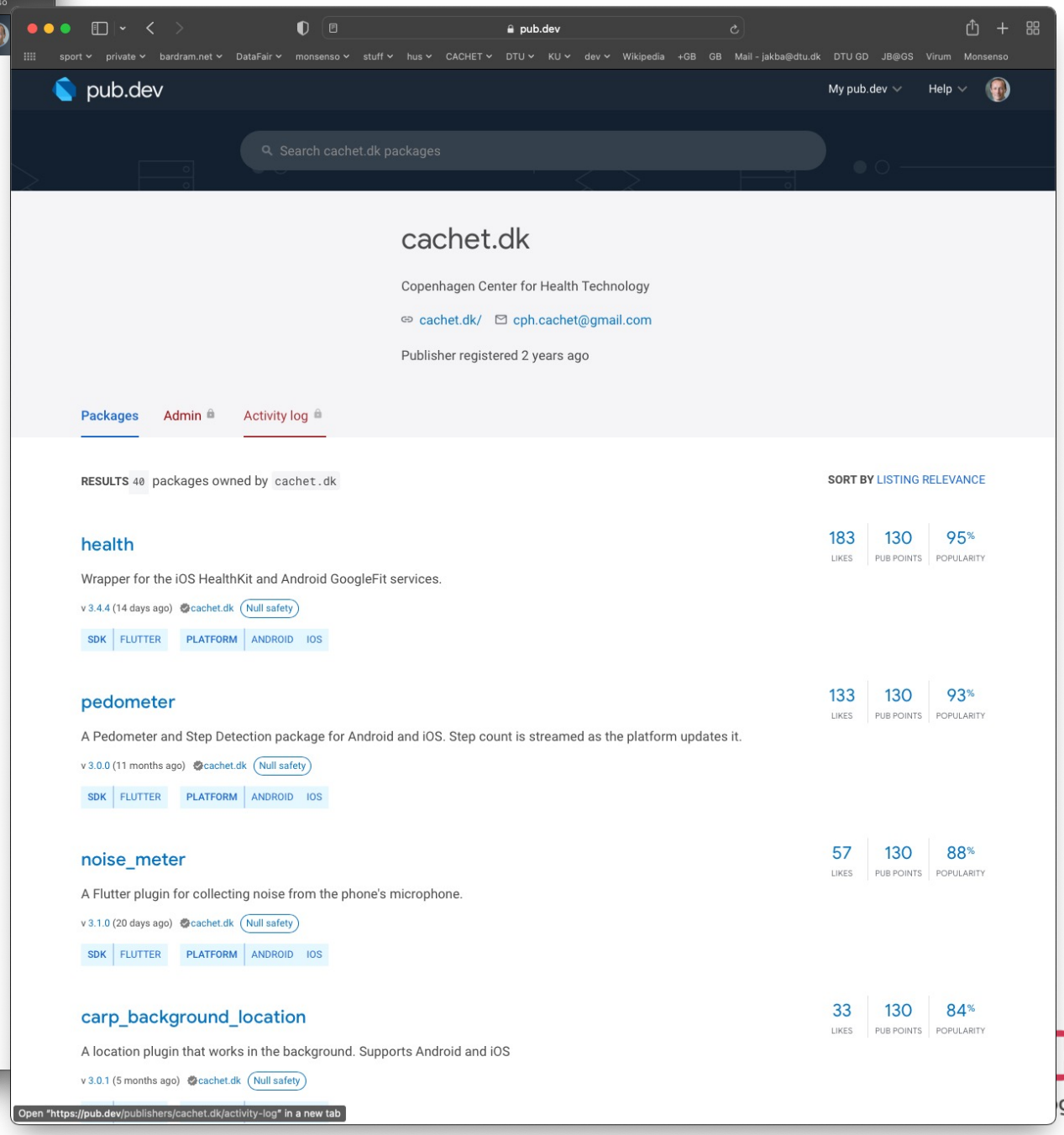
Metadata
Mobile Sensing Framework for Flutter. A software framework for collecting sensor data from the phone and attached wearable devices via probes. Can be extended.
Repository (GitHub)
View/report issues
Documentation
API reference
License
MIT (LICENSE)
Dependencies
archive, async, battery_plus, carp_core, cron, device_info_plus, flutter, flutter_local_notifications, json_annotation, light, package_info_plus, path_provider, pedometer, permission_handler, screen_state, sensors_plus, shared_preferences, stats, system_info, uuid
More
Packages that depend on carp_mobile_sensing


pub.dev
My pub.dev
Help
Search cachet.dk packages
cachet.dk
Copenhagen Center for Health Technology
cachet.dk/ cph.cachet@gmail.com
Publisher registered 2 years ago
Packages Admin Activity log
RESULTS 40 packages owned by cachet.dk
SORT BY LISTING RELEVANCE
health
Wrapper for the iOS HealthKit and Android GoogleFit services.
v 3.4.4 (14 days ago) cachet.dk Null safety
SDK FLUTTER PLATFORM ANDROID IOS
183 LIKES 130 PUB POINTS 95% POPULARITY
pedometer
A Pedometer and Step Detection package for Android and iOS. Step count is streamed as the platform updates it.
v 3.0.0 (11 months ago) cachet.dk Null safety
SDK FLUTTER PLATFORM ANDROID IOS
133 LIKES 130 PUB POINTS 93% POPULARITY
noise_meter
A Flutter plugin for collecting noise from the phone's microphone.
v 3.1.0 (20 days ago) cachet.dk Null safety
SDK FLUTTER PLATFORM ANDROID IOS
57 LIKES 130 PUB POINTS 88% POPULARITY
carp_background_location
A location plugin that works in the background. Supports Android and iOS
v 3.0.1 (5 months ago) cachet.dk Null safety
33 LIKES 130 PUB POINTS 84% POPULARITY
Open "https://pub.dev/publishers/cachet.dk/activity-log" in a new tab

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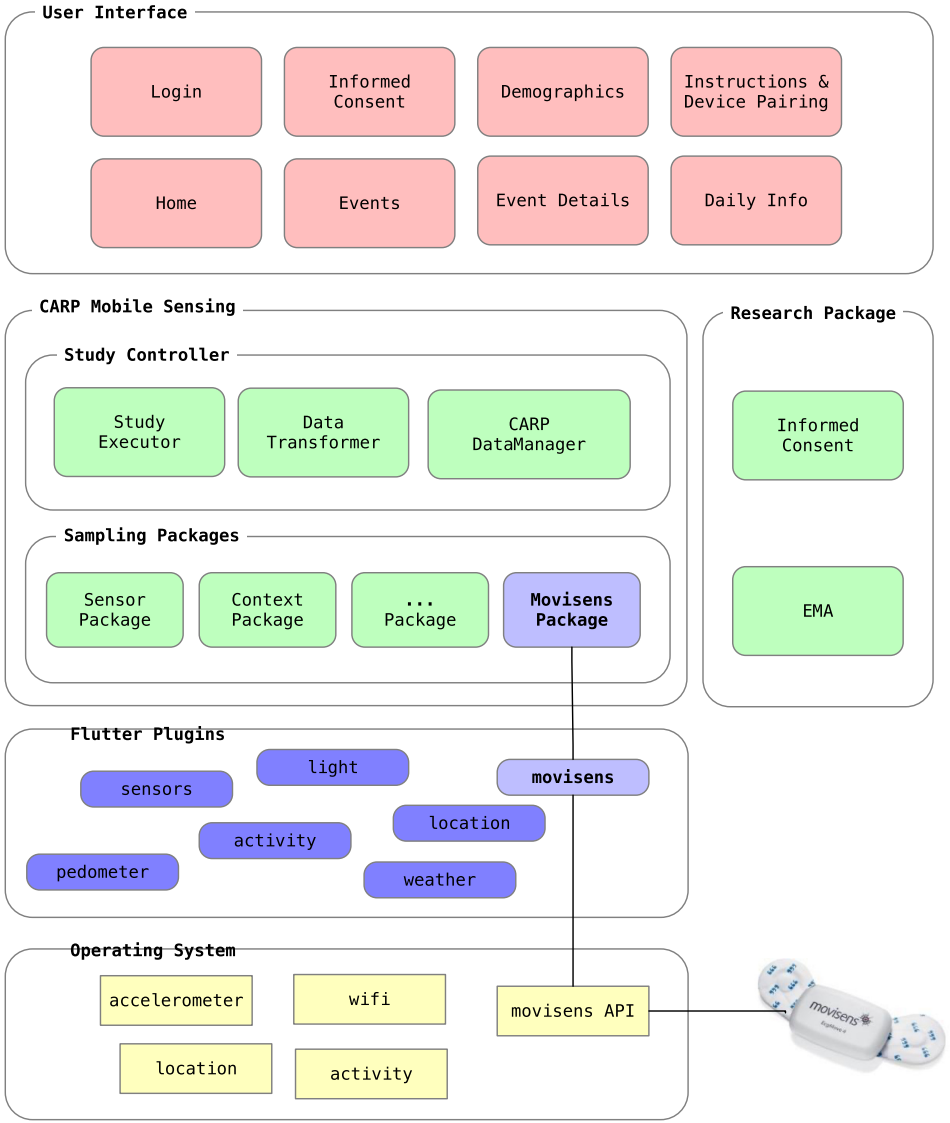

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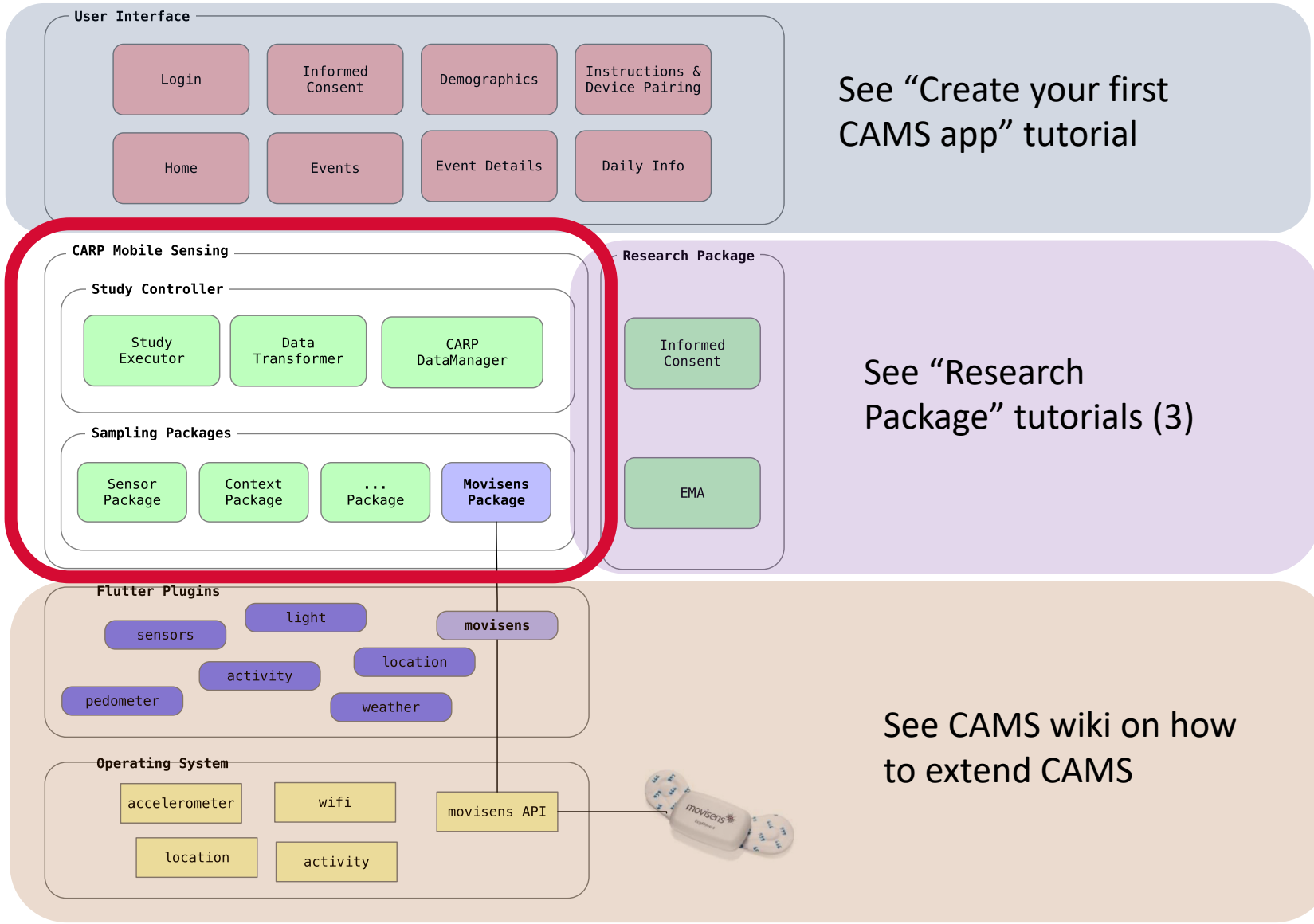

See “Create your first CAMS app” tutorial

See “Research Package” tutorials (3)

See CAMS wiki on how to extend CAMS

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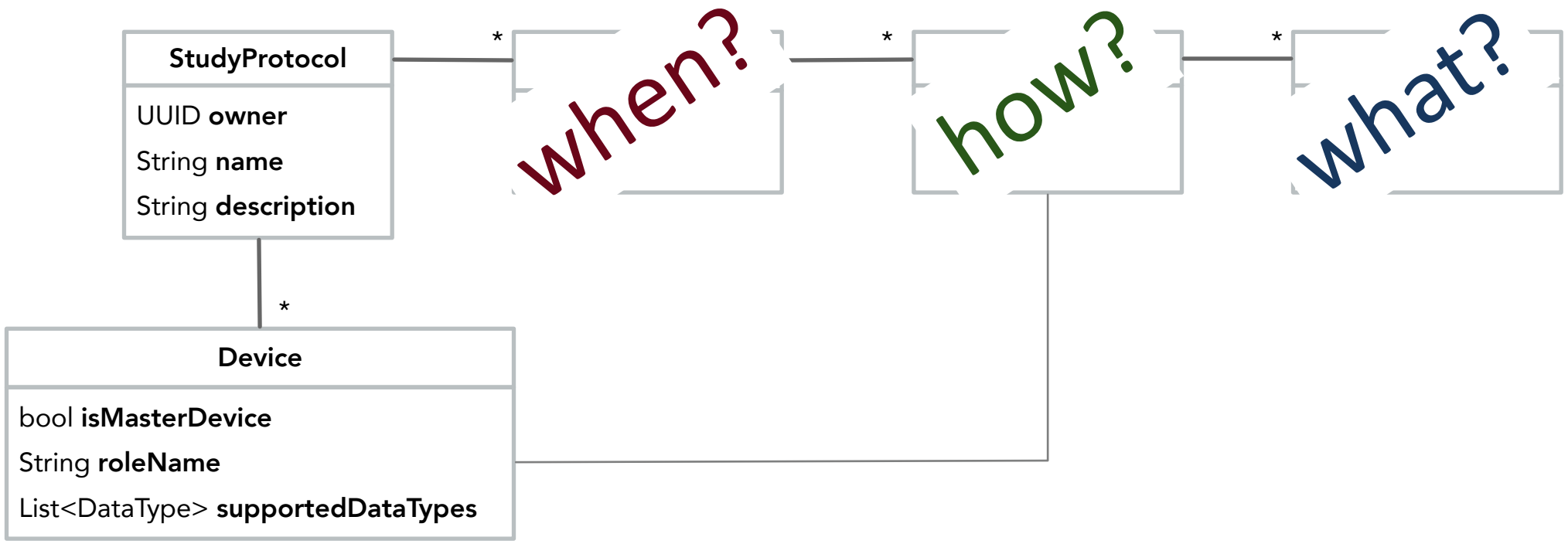
CAMS in a nutshell

1. a study protocol is **defined**;
2. the protocol is **deployed**,
3. the runtime environment is created, initialized and **started**, and
4. the stream of sampled data is **saved** and/or **used** in the app

Study Protocol



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```dart
import 'package:carp_core/carp_core.dart';
import 'package:carp_mobile_sensing/carp_mobile_sensing.dart';

/// This is an example of how to set up a the most minimal study
Future<void> sensing() async {
  // create a study protocol
  SmartphoneStudyProtocol protocol = SmartphoneStudyProtocol(
    ownerId: 'AB',
    name: 'Track patient movement',
  );

  // define which devices are used for data collection
  // in this case, its only this smartphone
  Smartphone phone = Smartphone();
  protocol.addMasterDevice(phone);

  // automatically collect step count, ambient light, screen activity, and
  // battery level, while delaying the sampling by 10 seconds
  protocol.addTriggeredTask(
      DelayedTrigger(delay: Duration(seconds: 10)),
      AutomaticTask(name: 'Sensor Task')
        ..addMeasure(Measure(type: SensorSamplingPackage.PEDOMETER))
        ..addMeasure(Measure(type: SensorSamplingPackage.LIGHT))
        ..addMeasure(Measure(type: DeviceSamplingPackage.SCREEN))
        ..addMeasure(Measure(type: DeviceSamplingPackage.BATTERY)),
      phone);
```

```dart
  // deploy this protocol using the on-phone deployment service
  StudyDeploymentStatus status =
      await SmartphoneDeploymentService().createStudyDeployment(protocol);

  String studyDeploymentId = status.studyDeploymentId;
  String deviceRolename = status.masterDeviceStatus!.device.roleName;

  // create and configure a client manager for this phone
  SmartPhoneClientManager client = SmartPhoneClientManager();
  await client.configure();

  // create a study runtime to control this deployment
  SmartphoneDeploymentController controller =
      await client.addStudy(studyDeploymentId, deviceRolename);

  // deploy the study on this phone
  await controller.tryDeployment();

  // configure the controller and resume sampling
  await controller.configure();
  controller.resume();

  // listening and print all data events from the study
  controller.data.forEach(print);
}
```

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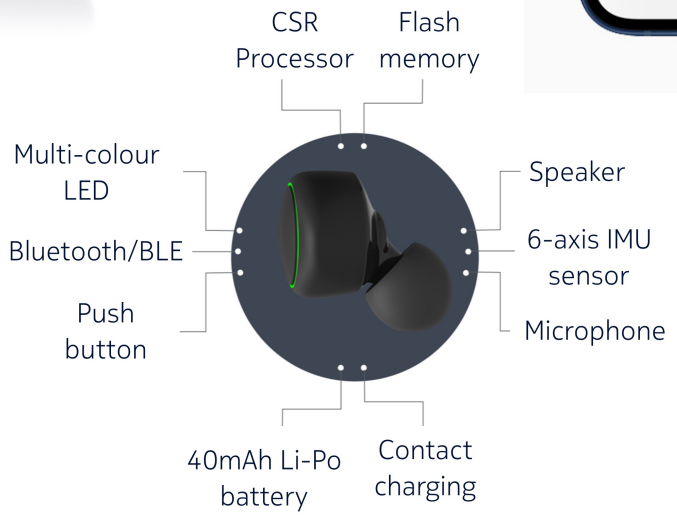
Type	Android	iOS	Package	Description
`accelerometer`	+	+	`sensors`	Accelerometer data from the built-in phone sensor
`gyroscope`	+	+	`sensors`	Gyroscope data from the built-in phone sensor
`pedometer`	+	+	`sensors`	Step counts from the device on-board sensor
`light`	+	-	`sensors`	Ambient light from the phone's front light sensor
`device`	+	+	`device`	Basic device information
`battery`	+	+	`device`	Battery charging status and battery level
`screen`	+	-	`device`	Screen event (on/off/unlock)
`memory`	+	-	`device`	Free memory
`connectivity`	+	+	`connectivity`	Connectivity status
`bluetooth`	+	+	`connectivity`	Scanning nearby bluetooth devices
`wifi`	+	+	`connectivity`	SSID and BSSID from connected wifi networks
`location`	+	+	`context`	Request the location of the phone.
`geolocation`	+	+	`context`	Listens to location changes.
`activity`	+	+	`context`	Activity as recognized by OS
`weather`	+	+	`context`	Current weather and weather forecasting
`air_quality`	+	+	`context`	Local air quality from land-based air pollution stations
`geofence`	+	+	`context`	Entry/dwell/exit events in circular geofences
`audio`	+	+	`audio`	Records audio from the device microphone
`noise`	+	+	`audio`	Detects ambient noise from the device microphone.
`phone_log`	+	-	`communication`	Log of phone calls in/out
`text_message_log`	+	-	`communication`	Log of text messages (sms) in/out
`text_message`	+	-	`communication`	Text message (sms) events when received
`calendar`	+	+	`communication`	All calendar events from all calendars on the phone
`apps`	+	-	`apps`	List of installed apps
`app_usage`	+	-	`apps`	App usage over time
`survey`	+	+	`survey`	User surveys via the Flutter `research_package`
`movisens`	+	-	`movisens`	ECG-related data from the Movisens EcgMove4 device.
`esense`	+	+	`esense`	Sensor and button events from eSense devices.
`health`	+	+	`health`	Wearable device data from Apple Health / Google Fit.

Devices

- Movisens Move4
- Movisens EcgMove4
- Nokia Bell Labs eSense

- Apple Health

- Empatica E4



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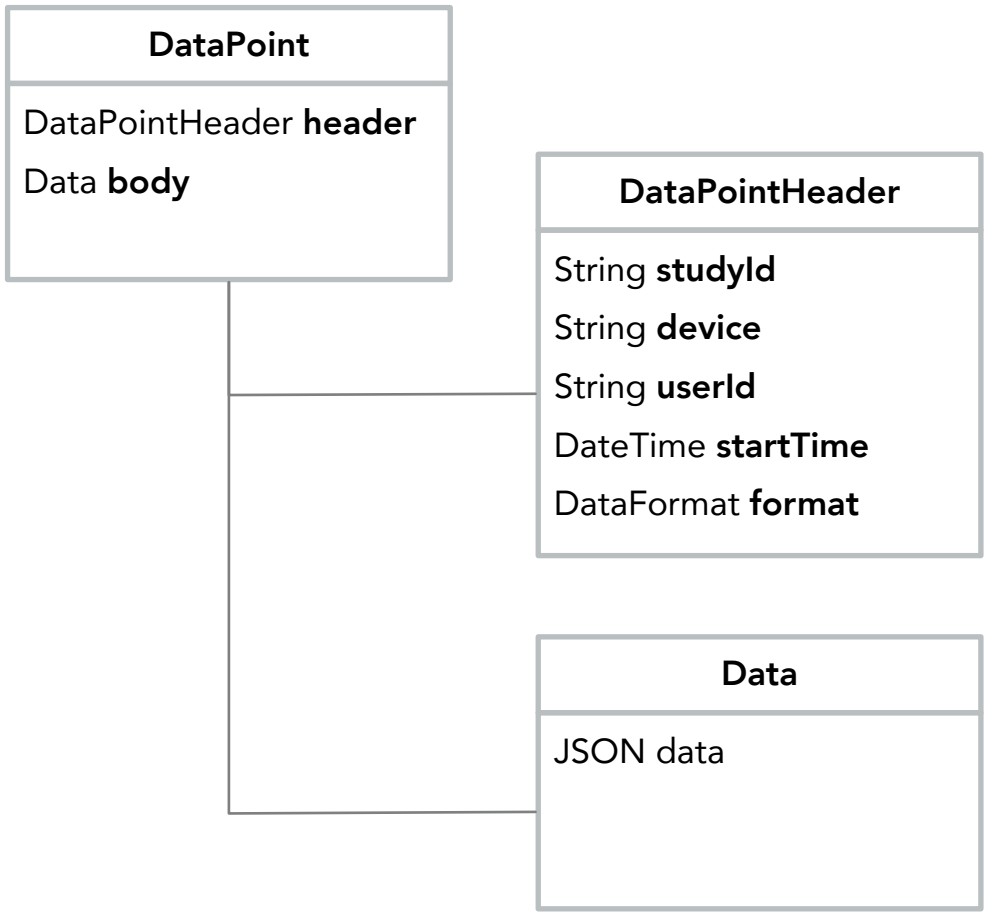
Data & Data Backends




```
{
   "carp_header":{
      "study_id":"2f893630-82ac-11ec-82dc-b9f4301f58ec",
      "device_role_name":"masterphone",
      "trigger_id":"0",
      "user_id":"902186de-2759-4ffb-a1d4-08a4a0d52e77",
      "start_time":"2022-01-31T17:45:28.994345Z",
      "data_format":{
         "namespace":"dk.cachet.carp",
         "name":"light"
      }
   },
   "carp_body":{
      "id":"9449d820-82bd-11ec-8b73-17fa5b741200",
      "timestamp":"2022-01-31T17:45:28.993800Z",
      "mean_lux":0.0,
      "std_lux":0.0,
      "min_lux":0,
      "max_lux":0
   }
}
```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Data & Data Backends

Local **Files**

- zipped json files (buffered)

Firebase

- Database – raw json data points
- Storage – json files

CARP Web Services (**CAWS**)

- data points (directly + buffered)
- files (e.g. images, sound, ...)

Data & Data Backends

Local **Files**

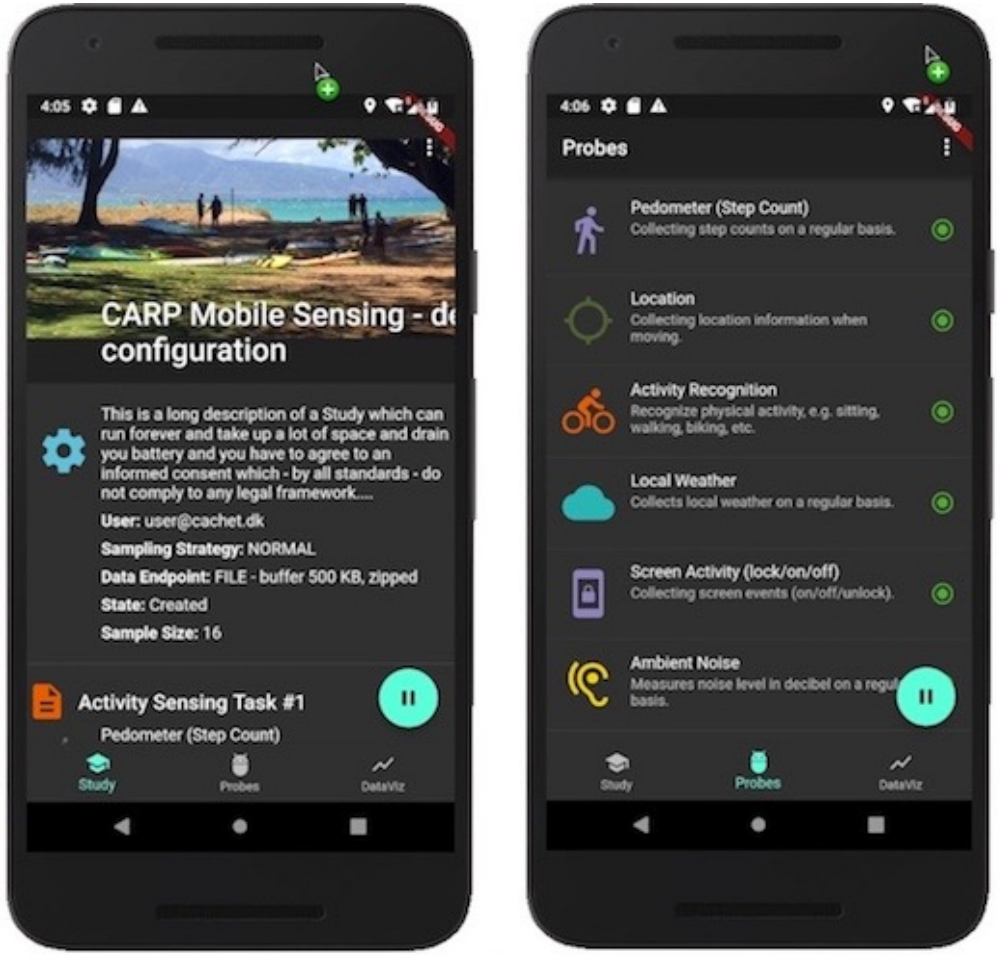
- zipped json files (buffered)

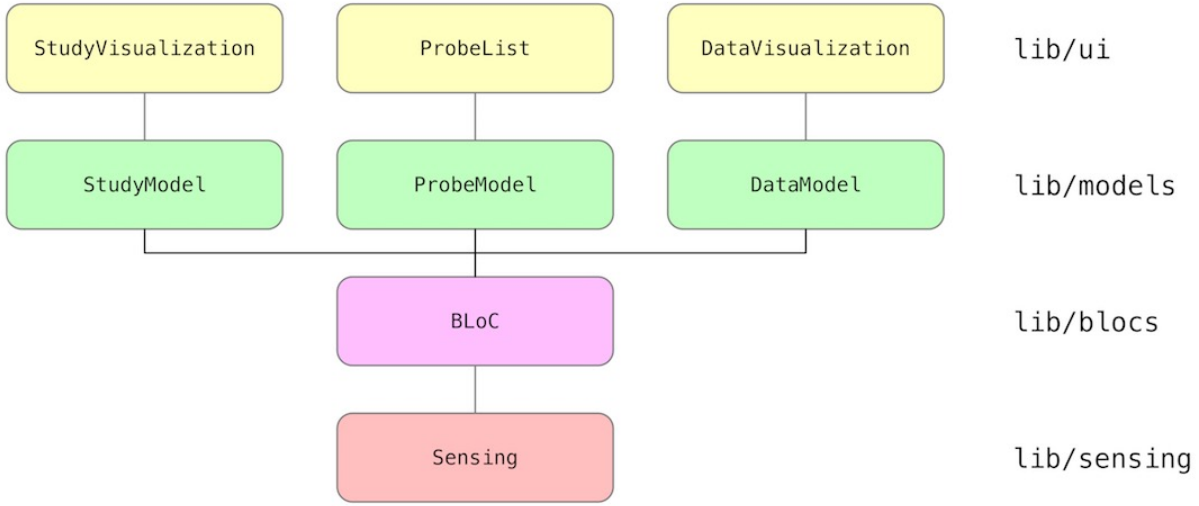
```dart
void example() async {
  // create a study protocol
  SmartphoneStudyProtocol protocol = SmartphoneStudyProtocol(
    ownerId: 'AB',
    name: 'Track patient movement',
    dataEndPoint: FileDataEndPoint(
      bufferSize: 500 * 1000,
      zip: true,
      encrypt: false,
    ),
  );
```

DEMO TIME

RESOURCES

CARP Mobile Sensing App





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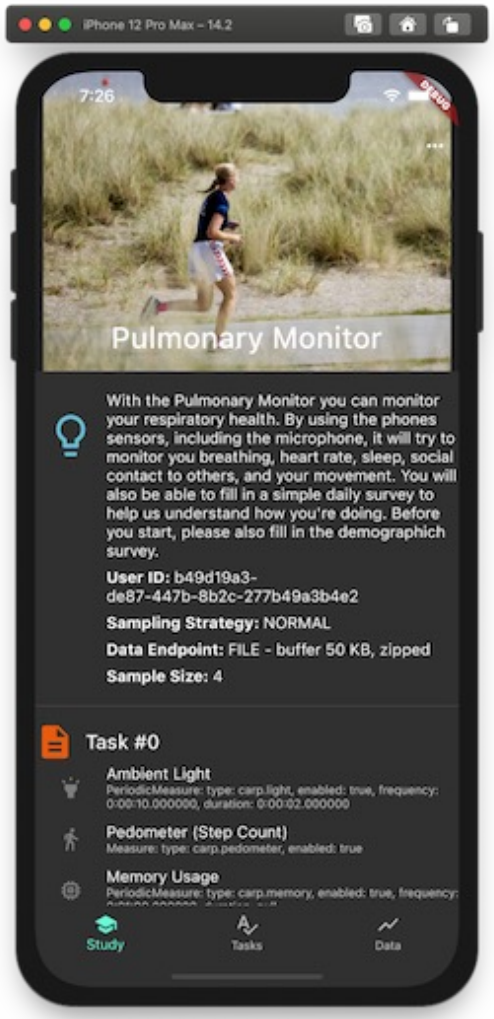
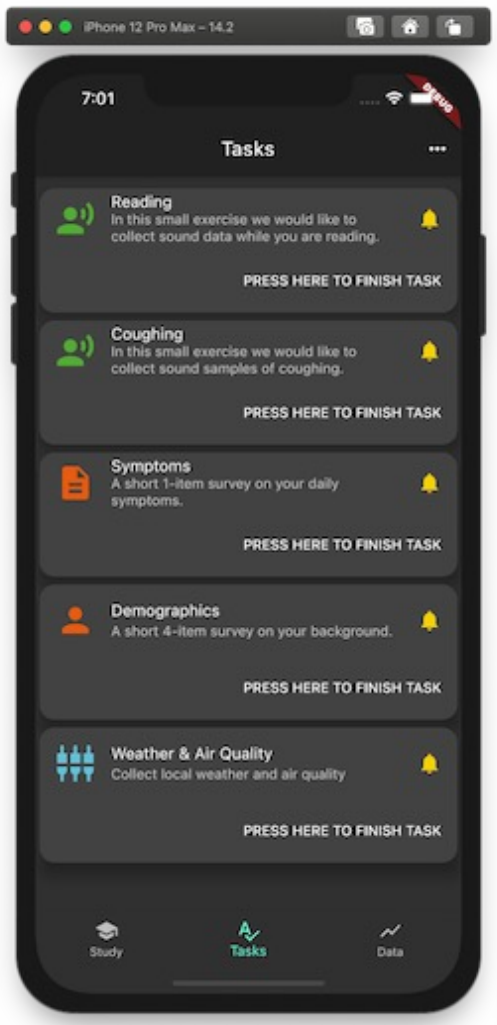
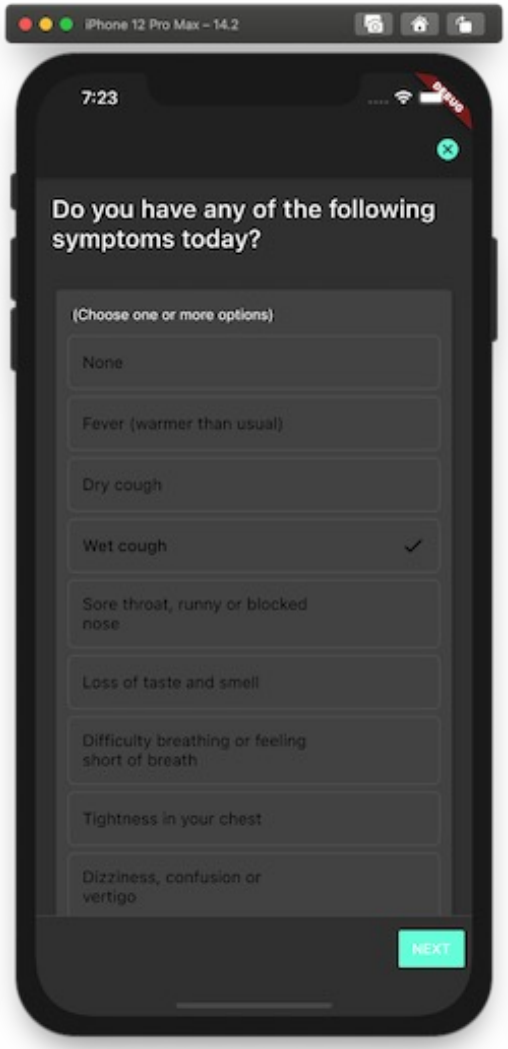
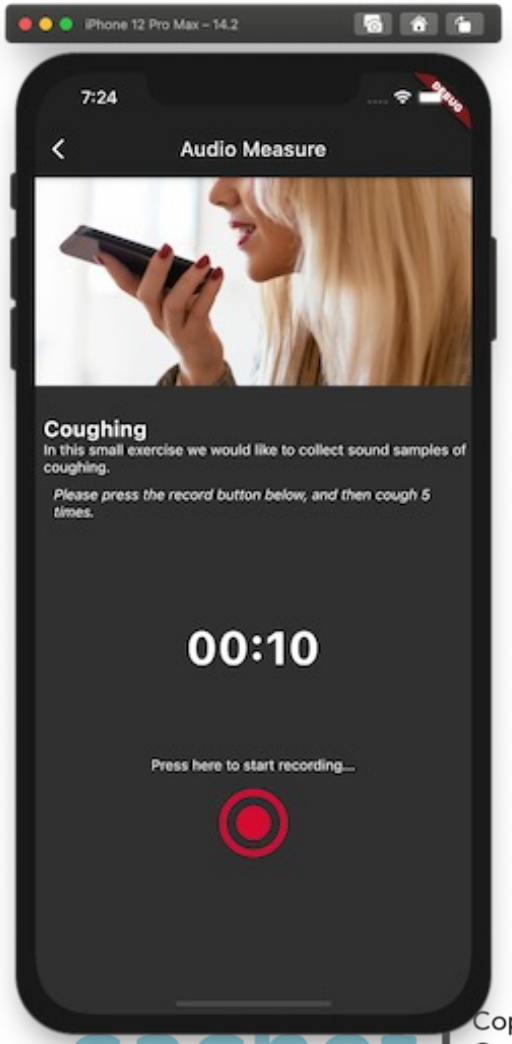
Pulmonary Monitor









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Resources

- CARP Mobile Sensing **home page** & Github **repro**
  - https://carp.cachet.dk/cams/
  - https://github.com/cph-cachet/carp.sensing-flutter
- Documentation of CARP Mobile Sensing Flutter packages on **pub.dev**
  - https://pub.dev/packages/carp_mobile_sensing
  - README | API docs
- CAMS **Wiki**
  - https://github.com/cph-cachet/carp.sensing-flutter/wiki
- CARP **Tutorials**
  - https://carp.cachet.dk/category/tutorials/

The CARP Mobile Sensing Framework– A Cross-platform, Reactive, Programming Framework and Runtime Environment for Digital Phenotyping

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Mobile sensing – i.e., the ability to unobtrusively collect sensor data from built-in phone sensors – has long been a core research topic in Ubicomp. A number of technological platforms for mobile sensing have been presented over the years and a lot of knowledge on how to facilitate mobile sensing has been accumulated. This paper presents the CARP Mobile Sensing (CAMS) framework, which is a modern cross-platform (Android / iOS) software architecture providing a reactive and unified programming model that emphasizes extensibility, maintainability, and adaptability. Moreover, the CAMS framework supports sensing from wearable devices such as an electrocardiography (ECG) monitor, and configuring data transformers. The latter allows to transform collected data to a standardized data format and to implement privacy-preserving data transformations. The paper presents the design, architecture, implementation, and evaluation of CAMS, and shows how the framework has been used in two real-world mobile sensing and mobile health (mHealth) applications. We conclude that CAMS provides a novel cross-platform application programming framework which has proved mature, stable, scalable, and flexible in the design of digital phenotyping and mHealth applications.

CCS Concepts: • **Human-centered computing** → **Ubiquitous and mobile computing**; • **Software and its engineering** → **Development frameworks and environments**; • **Applied computing** → Health informatics.

Additional Key Words and Phrases: mobile sensing, wearable sensing, context-aware computing, mobile health, mHealth, digital phenotyping, sensors, electrocardiography, ECG, eSense

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1 INTRODUCTION

Research in mobile sensing – i.e. the collection of data from sensors in mobile technologies – has shown that indicators of behavioral, social, psychological, and health status can be derived by collecting continuous and real-world data and applying advanced algorithms to it [21]. A significant body of research has been applying mobile sensing to health and wellness applications [5], including, for example, the EmotionSense [23], BeWell [22], and StudentLife [35] systems that classify physical activity, sleep, and social interaction based on sensor data. Studies in mental health have demonstrated correlations and predictive power between phone-based features on physical activity, mobility, social activity, phone usage, and voice data on the one hand, and mental health symptoms in e.g., depression [31], bipolar disorder [14, 17], and schizophrenia [7] on the other. In health sciences, mobile and wearable sensing has been defined as central to the 'Precision Medicine Initiative' [12]; genotypic information is

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The CAMS eSense Framework – Enabling Earable Computing for mHealth Apps and Digital Phenotyping

mCardia: A Context-Aware ECG Collection System for Ambulatory Arrhythmia Screening

CHI 2020 Paper

CHI 2020, April 25–30, 2020, Honolulu, HI, USA

MUBS: A Personalized Recommender System for Behavioral Activation in Mental Health

Paper 750

DiaFocus: A Personal Health Technology for Adaptive Assessment in Long-Term Management of Type 2 Diabetes

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Type 2 diabetes (T2D) is a large disease burden worldwide and represent an increasing and complex challenge for all societies. For the individual, T2D is a complex, multi-dimensional, and long-term challenge to manage, and it is challenging to establish and maintain good communication between the patient and healthcare professionals. This paper presents DiaFocus, which is a mobile health (mHealth) sensing application for long-term ambulatory management of T2D. DiaFocus supports an *adaptive* collection of physiological, behavioral and contextual data in combination with ecological assessments of psycho-social factors. This data is used for improving the patient-clinician communication during consultations. DiaFocus is build using a generic data collection framework for mobile and wearable sensing and is highly extensible and customizable. We deployed the DiaFocus system in a 6-week feasibility study involving 12 patients with T2D. The patients found the DiaFocus approach and system useful for diabetes management, especially for early diagnosed patients, and found the system easy to use. Most patients would use such a system, if available as part of their treatment with a physician. Analysis of the collected data shows that mobile sensing is feasible within diabetes, while also pointing to the need for taking into consideration different use patterns from especially elderly patients. Overall, the results demonstrate high usability and feasibility of mHealth technology like DiaFocus for longitudinal ambulatory assessment of T2D.

CCS Concepts: • **Human-centered computing** → **Ubiquitous and mobile computing**; • **Applied computing** → Health informatics.

*AJ was employed by Roche at the time of this research.

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