D5.2– Data Fusion, Situation assessment, Context catching and serving – Final

Deliverable D5.2		
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CO	Confidential, restricted under conditions set out in Model Grant Agreement	
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Disclaimer

[Full project title] e-VITA – European-Japanese Virtual Coach for Smart Ageing

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[Document title] D5.2 – Data Fusion, Situation assessment, Context catching and serving – Final

[Editor: Name, Partner] K. Homma (AIST) & J. Boudy (IMT)

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Executive Summary

Deliverable D5.2, classified as “Demonstrator”, is concerned with the delivery of the final versions of Software modules specific to the data fusion stages for the user’s situation and environment assessment developed in task 5.1. Its main goal is to provide relevant information to the different dialog scenarios needed by the virtual coach. So, as also recalled in the first version of this deliverable (D5.1 at M15), the data fusion, by providing specific user’s situation labels, aims at smartly interacting with the Knowledge Graphs (KG) and Dialog Management (DG) stages of the e-VITA prototype for wave 2 of field test with the Users. Details on these data fusion SW modules and related architectures are provided, but also useful implementation details and user guides.

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Acronyms and Abbreviations

WP	Work Package
TBD	To be defined
KG	Knowledge Graphs
DM	Dialog Management
BT	Belief Theory
DE	Digital Enabler
ADL	Activities of Daily Life
DNN	Deep Neural Network
CNN	Convolutional Neural Network
RNN	Recursive Neural Network
LSTM	Long Short-Term Memory Network
BPM	Beats per Minute for measuring the Heart rate
LAN	Local Area Network
DFP	Data Fusion Platform
HAR	Human Activity Recognition
UCI	University of California, Irvine
EP	Event Processor
NM	Notification Manager
SQL	Structured Query Language
WSGI	Web Server Gateway Interface
ASGI	Asynchronous Server Gateway Interface
CEP	Complexe Event Processing
CB	Context Broker
API	Application Programming Interface
REST	RESTful API
HMI	Human Machine Interaction

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1 Introduction

Deliverable D5.2 on Data Fusion is concerned with the delivery of the final versions of Software modules specific to the data fusion stages for the user's situation and environment assessment developed in task 5.1. Its main goal is to provide relevant information to the different dialog scenarios needed by the virtual coach. So, as also recalled in the first version of this deliverable (D5.1 at M15), the data fusion, by providing specific user's situation labels, aims at smartly interacting with the Knowledge Graphs (KG) and Dialog Management (DM) stages of the e-VITA prototype for wave 2 of field test with the Users.

To this aim the report is organized in six sections: first an introduction (section 1), then two main technical sections (2 and 3), one conclusion with perspectives (section 4), references (section 5) and annexes (section 6).

Section 2 is devoted to the general architecture of the proposed Data Fusion Platform (DFP) and it considers successively the DF concept elaboration through an adapted architecture to modalities in presence (taking into account heterogeneity in a wide sense) and also the set-up of the different user's situations labels to be generated by the DFP in complement of those already established in previous deliverable D5.1. It also sketches up a first scheme of interaction between the DFP with its labels as output and the Dialog Manager stage through a triggering strategy proposed by ENG and INFAI.

Section 3 is completely devoted to the Data Fusion Platform implementation within the e-VITA ecosystem and describes successively its detailed architecture, Machine Learning so far evaluated and implemented, technical and demonstrating programs.

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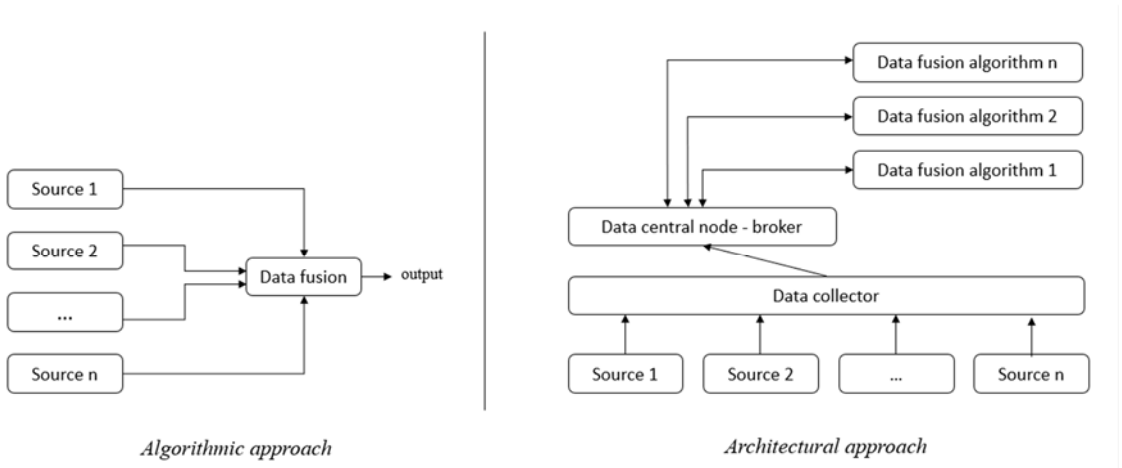
2 General architecture of the Data Fusion Platform (DFP)

2.1 Concept and Principle

Data fusion is a concept that is easily represented and difficult to define. In view of this duality, many research works have been interested in determining a definition. In the rest of this document, we will deal with data fusion in the sense of Buchroithner and Wald (1998): data fusion constitutes a formal framework in which the means and techniques allowing the combination of data from various sources are expressed. It aims at obtaining higher quality information; the exact definition of "higher quality" will depend on the application. Thus, it appears that data fusion is not only an algorithmic process (referring to the techniques) but can also be an entity offering support to these same techniques (referring to the means).

Now that we have defined the general concept of data fusion, we need to determine a paradigm related to the principle. We then propose two possible paradigms in accordance with the previous conceptualization, namely the algorithmic principle or approach and the architectural principle or approach.

The algorithmic principle is defined by the use of a single algorithm allowing the ingestion of different data sources in order to produce new information. This approach has the advantage of being inexpensive to develop and to obtain a result in a short time. Nevertheless, it assumes a perfect data ingestion framework, i.e. availability (the data is really present) and synchronicity (all sources are synchronous). Although interesting, this principle does not allow to satisfy a real specification. In order to overcome this drawback, we propose the architectural principle. Its construction is based on the assimilation of the algorithmic principle as a module of this new approach. Thus, we obtain multiple algorithmic principles communicating with a kernel allowing the management of the various sources. Finally, we manage to get away from the problem of perfect ingestion but paradoxically the development costs are more ambitious. We can illustrate this with the figure below:



Tab 1: Algorithmic or architectural data fusion

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To conclude, the data fusion platform is a digital construction that puts into practice the architectural principle respecting the conceptualization of data fusion. In section 3 we will detail the technical aspects related to the development of the platform.

2.2 Recall of the Labels dataset produced by the DFP stage

The main objective of the DFP is to provide higher quality information (accuracy, specificity...) according to the different multimodal data sources. In our specific case the objective is to provide human activity recognition (HAR). And our data sources are, inertial information (accelerometer, gyroscope and magnetometer) from smartphone, location (latitude, longitude, altitude and speed) from smartphone, motion or intrusion detection with Delta Dore (EU) / EnOcean (JP) sensors, indoor climate with NetAtmo, inertial with smartwatch (we are waiting for Huawei developer access) and health information (bpm) with smartwatch (we are waiting for Huawei developer access).

In order to provide information from smartphone inertial or motion/intrusion sensors we use two public datasets:

- Ambient sensors: “Human Activity Recognition from Continuous Ambient Sensor Data” from the University of California, Irvine (UCI)
- Smartphone: “KU-HAR: An Open Dataset for Human Activity Recognition” from Medeley data

Each dataset gives us a set of labels, first for ambient sensors:

- Step Out
- Other Activity
- Toilet
- Phone
- Personal Hygiene
- Leave Home
- Enter Home
- Relax
- Sleep Out Of Bed
- Drink
- Watch TV
- Dress
- Evening Meds
- Wake Up
- Read
- Morning Meds
- Cook Breakfast
- Bath
- Cook Lunch
- Eat Lunch
- Wash Lunch Dishes
- Go To Sleep
- Sleep
- Bed Toilet Transition
- Wash Breakfast Dishes
- Work at Table
- Groom
- Cook
- Eat
- Cook Dinner
- Eat Dinner
- Wash Dinner Dishes
- Wash Dishes
- Entertain Guest
- Take Medicine
- Work
- Exercise
- Work On Computer
- Nap
- Work At Desk
- Laundry

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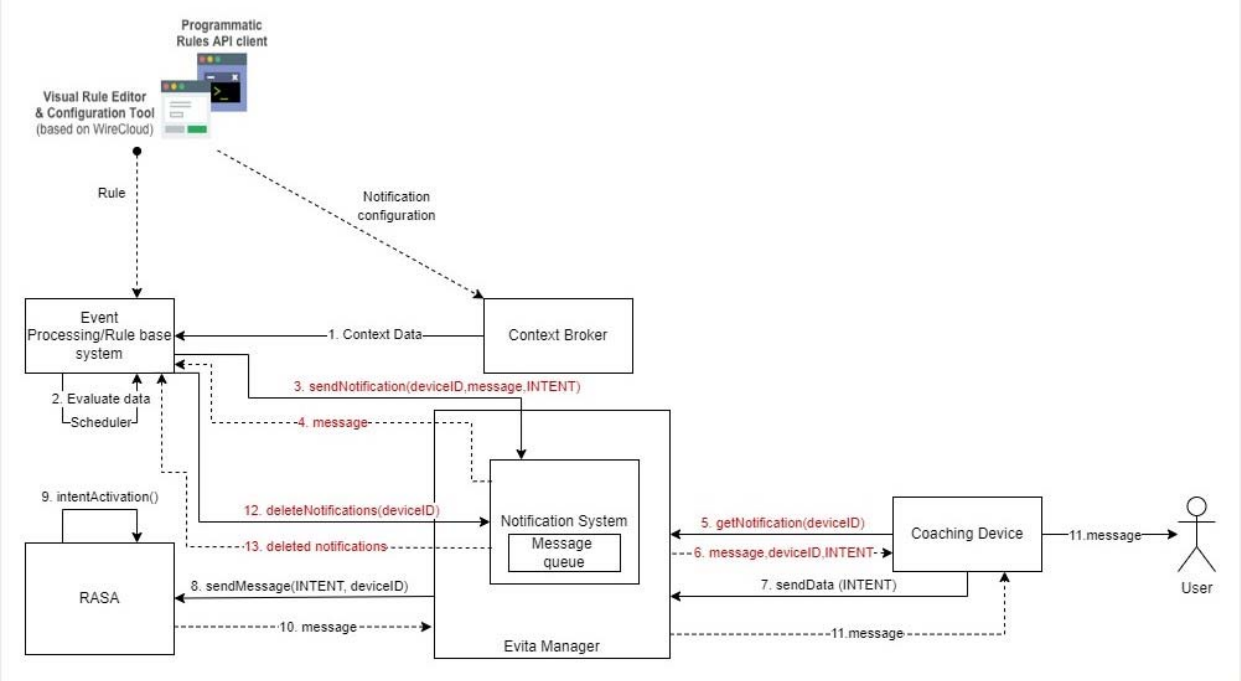
Second, smartphone sensors rely on these labels:

- Jump
- Lay
- Lay-stand
- Pick
- Push-up
- Run
- Sit
- Sit-up
- Stair-down
- Stair-up
- Stand
- stand-sit
- Table-tennis
- Talk-sit
- Talk-stand
- Walk
- Walk-backwards
- Walk-circle

2.3 Interaction with the Dialog Management stage through the Digital Enabler (DE)

2.3.1 Notification system

In order to deliver proactive dialog according to the predicted labels of User's situation and localization we used an Event Processing Rule based system to trigger dialogs. The communication scheme between the different components of the e-VITA system was updated and a new notification system is implemented. The architecture is presented in figure 2.



Tab 2: Rules-based decision for triggering specific dialog scenarios based on Vital state of the person

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Components involved in the Notification System:

- **Event Processing (EP)/Rule based component**: this component will be in charge to identify specific data patterns using sensors data or any other type of event based on rule to be notified to trigger a specific dialog. It could be also used to send only textual advice to the user without the aim of triggering a dialog.
- **RASA**: responsible for dialogs to be activated by specific intents.
- **Notification manager (NM)**: specific component of the DE, in particular of the *e-VITA Manager* component detailed described within *D7.4 on e-VITA Platform Architecture*, to manage the notification flow and message queues
- **Device** used by the user to dialog with e-VITA after a specific event happens.

General flow:

1. **EP** identify a specific event related to specific data pattern (e.g. temperature high) or to a schedule (it is time for exercise).
2. **EP** create a notification message that includes in the text the specific **RASA** keyword for that specific intent (e.g. EXERCISE_1200) and send the notification to the **NM**.
3. **NM** put the message in the message queue.
4. **Device** call the *getNotification* API.
5. **NM** receives the request, checks the queue and sends the notification as response to the device.
6. The **device** receives the notification and send back to e-VITA (**DE**) via the *send_data* API the message that includes in the text the intent keyword. The device won't show any message to the user at this stage.
7. The message will be sent to **RASA** as the usual flow. **RASA** will activate the intent and replay with another message to the request. The dialog flow will continue as usual.

In the following part we introduce the Event Processing component that we use in the e-VITA project.

2.3.2 Perseo

We use Perseo as an Esper-based[i] Complex Event Processing (CEP) software, developed by FIWARE and also provided by the Digital Enabler. Esper offers a language by name Event Processing Language (EPL) that implements, extends the SQL-standard, and enables rich expressions over events and time.

Perseo is designed to be fully NGSI-v2-compliant. It uses NGSI-v2 as the communication protocol for events, and thus, Perseo is able to seamless and jointly work with context brokers (CB), as Orion.

Perseo follows a straightforward idea: listening to events coming from context information to identify patterns described by rules, in order to immediately react upon them by triggering actions.

By leveraging on the notification's mechanism, clients instruct Orion CB to notify Perseo of the changes in the entities they care about (Event API). Then, rules to the CORE Rule Engine can be

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easily managed using any of the REST clients (Postman, curl, etc.) able to programmatically use the Perseo's Rule API. These rules will identify patterns that will trigger actions with Orion to create or update entities, or to communicate with RASA to trigger dialogues.
Perseo allows us to create/edit/delete rules through its API.

2.3.3 Perseo Rules

Perseo rules follow a simple JSON structure made up of three mandatory key-value fields: ***name***, ***text***, and ***action***. The structure of these rules is sketched in the following JSON code:

```
{
   "name":"<The name of the rule>",
   "text":"<Insert here a valid EPL statement>",
   "action":{
      "type":"[update|sms|email|post|twitter]",
      "parameters":{
         ...
      }
   }
}
```

Tab 3: Perseo rule example

The ***name*** field refers to the name of the rule, and it is used as rule identifier. It must start by a letter, and can contain digits (0-9), underscores (_) and dashes (-). Their maximum length is set to 50 characters.
The ***action*** field states the action to be performed by Perseo when the rule triggers. We can also use an array of action objects if needed. Each of those actions will be executed when the rule is fired, avoiding to duplicate a rule only for getting several actions executed.
The ***text*** field contains the valid EPL statement to be send to the Esper-based core rule engine. The value of this field must follow the EPL syntax.
Following there is an example of a valid EPL simple clause ready to be used with Perseo:

```
select *, bloodPressure? as Pressure
from iotEvent
   where (cast(cast(bloodPressure?,String),double)>1.5 and type="BloodMeter")]
```

Tab 4: Perseo query condition

The above Rule monitors the value of the blood Pressure and will trigger an action if the pressure excides 1.5.

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The rules can be also time based; in that case we can use the following template for example:

Timer:at(minutes,hours,days of month,months,days of week [, seconds [, time zone]]).

And with the following example of use:

Rule example: only fires 1 time at 5:00 pm Pacific Standard Time

```
{
  "name":"17_PST",
  "text":"select * from pattern [timer:at (0, 17, *, *, *, *, 'PST')]",
  "action":{...}
}
```

Tab 5: Perseo rule example 2

More details are available on the official website of PERSEO [i].

[i] https://www.espertech.com/esper/

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3. Implementation of the Data Fusion Platform for e-VITA

This section will resume technical aspect of the DFP. It will discuss technical description before showing some results and then recommendation for the future or limitation. For a complete documentation on DFP we invite readers referring to the annex section.

3.1 Technical description of the Data Fusion Platform

The DFP is a web-based platform, Fiware standard, which aims to collect and process several data sources. It has to be able to work on batch or real time workflow. In this study w define real-time processing as: “Process data faster than a significant change in the input data”. However, this system is not a single hosted system it has to be transferable and customizable in order to fit to all data ingestion problematic. Thus, the DFP is fully deployed under docker to ensure OS compatibility (Windows 10 Pro with WSL for development).

Before tackling components explanation, we want to attract reader attention on the fact that the platform possesses two level of security. The first level is an architectural protection, it avoids not desire user to reach the system. This part runs under OAuth2 protocol. The second level is a data protection in case of failure of level 1. This is a data encryption on sensible information on databases, it runs with RSA mechanism. A level 0 is in reflexion and will be discussed on the last chapter of this section.

Components can be sorted through some categories:

- Core: Data centralization and knowledge propagation
- Dispatcher: Open ports reduction – it redirects to specific service according to the user request.
- Central security: Manage security at a global stage (all the platform)
- Agent security: Manage security at a local stage (dedicated to a specific component)
- Backend: Customizable component.
    - Collector: Collect data from sources
    - Compute: Process data (GPU capabilities)
    - Connector: Login provider
- Persistent: Data persistence
    - Database: Store data on SQL or noSQL logic
    - Object storage: Store data as an object
- Visualization: Human machine interaction

Previously we state that the platform follows Fiware standard. This aspect comes from core, central security and agent security components. In fact, it uses Fiware Orion context broker, Fiware Cygnus data historization and Fiware STH-Comet time series query, Fiware Keyrock and Fiware pep-Proxy. This technology has double advantages; on the first hand it directly manages interoperability between data sources. On the second hand, it ensures compatibility with the Digital Enabler.

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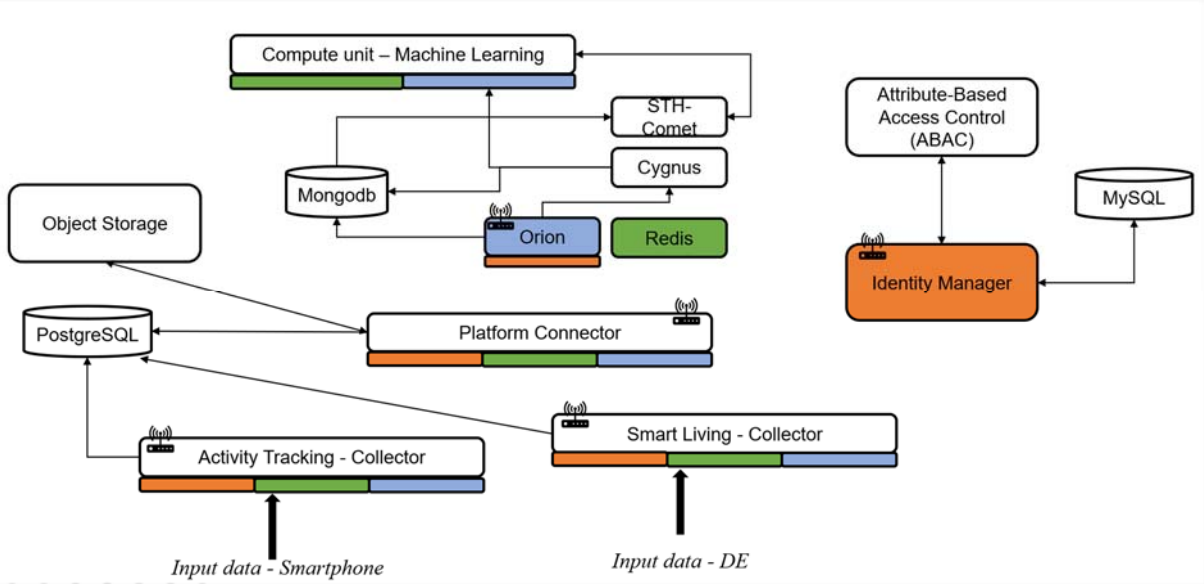
Then another key component is the backend. The main difference with other components is that backends is the only service which is dedicated to several contexts. For example, Orion is dedicated to data or a security agent is dedicated to ensure the security of an entity. Backends can be deployed as data collector, data processor or even login portal. The only specification is about communication, and we refer to Web Server Gateway Interface (WSGI) or Asynchronous Server Gateway Interface (ASGI). Obviously according to these specifications backends are developed with Python. Thus, with WSGI we can achieve REST API and with ASGI we can achieve websocket communication. Another aspect is that backend can easily access GPU from the host. In the next chapter we will see machine learning (ML), the entity in charge of running ML is also backend. To conclude, if we say that core is the keystone of the architecture, backend is the bearing walls.

Finally, we study the visualization component. The objective of this component is to display or communicate with the users, it means Human Machine Interaction (HMI). HMI has different forms in e-VITA, as none exhaustive reminder: gatebox, google nest, nao robot, etc. We can refer to D4.6 for complete details. But in D4.6, you may see information related to data fusion application. This application turns smartphone as sensor but it's also an HMI, thus it's the visualization component of the DFP.

In order to visualize the architecture, we propose we simplified schema below. To guarantee readability we use a colour code. Each service with a colour indication on the bottom is linked to the service with the same colour. As explained on introduction a complete technical specification is available on annex.



Tab 6: Basic DFP architecture

In conclusion, we have seen all the different components of the DFP and their role and objectives. Furthermore, with the architectural schema we can understand the dependence between components.

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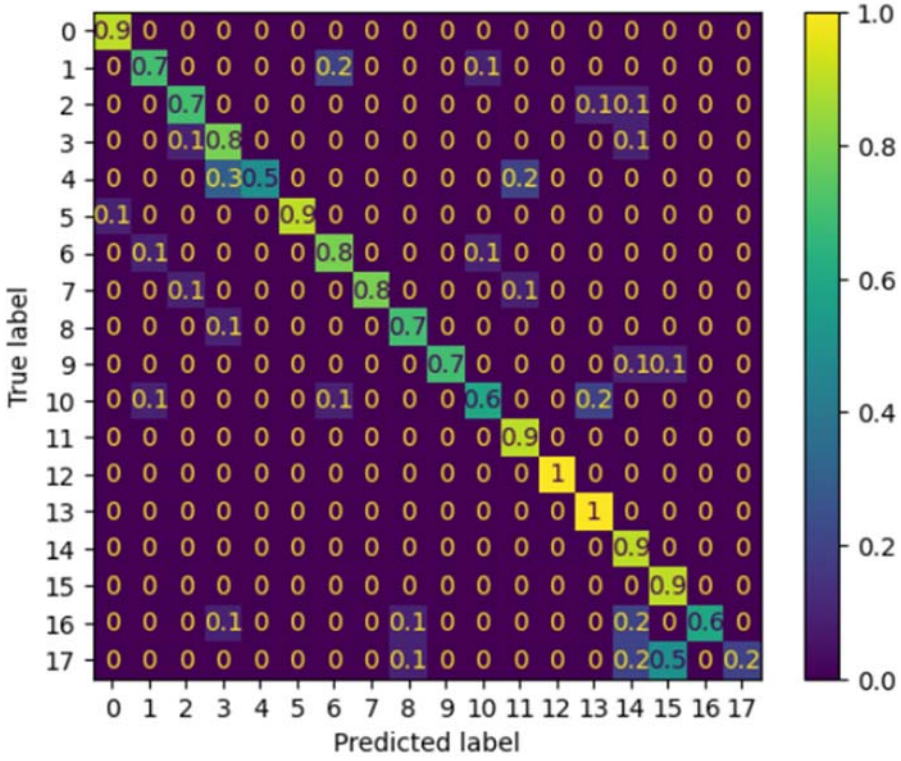
3.2 Machine Learning specifications

To create more valuable information, we focus on two subjects. The first one is gait analysis based on the smartphone. The second is human activity recognition from PIR and contact sensors. Except data type the requirements for each dataflow are different. For the smartphone we need a high velocity model but for the habitation we need a model to fit more parameters.

For gait analysis we investigate on different models such as k-Nearest Neighbours, Long-Short Term history (LSTM) Model and Random Forest (RF). Then motivate by literature which have tackled the same problematic such as "The Opportunity challenge: A benchmark database for on-body sensor-based activity recognition" Chavarriaga & al or "KU-HAR: An open dataset for heterogeneous human activity recognition" Sikder & Nyler we choose random forest. Furthermore, it permits us to use efficiently Nvidia Rapids. Referring to rapids documentation this software is described as: "*The RAPIDS suite of software libraries, built on CUDA-X-AI, gives you the freedom to execute end-to-end data science and analytics pipelines entirely on GPUs. It relies on NVIDIA® CUDA® primitives for low-level compute optimization, but exposes that GPU parallelism and high-bandwidth memory speed through user-friendly Python interfaces.*". Thanks to this software it is possible to efficiency run data pre-processing and processing during training and on real time processing even for a great amount of data. Here you can find a confusion matrix result training of a random forest. For training we use an input dataset of shape 45765x600 (16675x600 for testing) on a random forest with 400 estimators and 20 as max depth (training phase: around 3 min).



Tab 7: Confusion Matrix - Decision Tree - RAPIDS

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Labels in same order: jump, lay, lay-stand, pick, push-up, run, sit, sit-up, stair-down, stair-up, stand, stand-sit, table-tennis, talk-sit, talk-stand, walk, walk-backwards, walk-circle

About dataset, for gait analysis we focus on a public one "KU-HAR: An Open Dataset for Human Activity Recognition" from Medeley data.

Then for human activity recognition we worked on dataset "Human Activity Recognition from Continuous Ambient Sensor Data" from the University of California, Irvine (UCI). Related to this dataset we investigate first the paper "Human Activity Recognition from Continuous Ambient Sensor Data Data Set" Cook & al. Thanks to that paper we have seen that machine-learning algorithms can go up to 90 % of Accuracy. However, the approach of D. Bouchabou in the paper "Using Language Model to Bootstrap Human Activity Recognition Ambient Sensors Based in Smart Homes" demonstrated that with deep learning algorithms we can go further than 90% (mostly LSTM). Furthermore, velocity in this case is not an issue (compare to gait analysis for example). To that extent it's possible to use TensorFlow models in production even on real time processing. We remind that produced labels of these models are:

- Step Out
- Other Activity
- Toilet
- Phone
- Personal Hygiene
- Leave Home
- Enter Home
- Relax
- Sleep Out Of Bed
- Drink
- Watch TV
- Dress
- Evening Meds
- Wake Up
- Read
- Morning Meds
- Cook Breakfast
- Bath
- Cook Lunch
- Eat Lunch
- Wash Lunch Dishes
- Go To Sleep
- Sleep
- Bed Toilet Transition
- Wash Breakfast Dishes
- Work at Table
- Groom
- Cook
- Eat
- Cook Dinner
- Eat Dinner
- Wash Dinner Dishes
- Wash Dishes
- Entertain Guest
- Take Medicine
- Work
- Exercise
- Work On Computer
- Nap
- Work At Desk
- Laundry

However, we have to qualify about this set of labels. In fact, it depends on the sensor's installation, it means if the installation fits one of the installation's dataset it is possible to get all these labels. But, in reality some labels will disappear for users because of the configuration. Even more, it is not possible to "Work At Desk" if there is no desk, same thing for "Watch TV".

To conclude, for the machine learning specification we rely on deep learning model on TensorFlow for human activity recognition. And, for gait analysis we rely on random forest model on Nvidia Rapids. Thanks to that frameworks we can achieve to run AI on batch pipeline or on real time pipeline.

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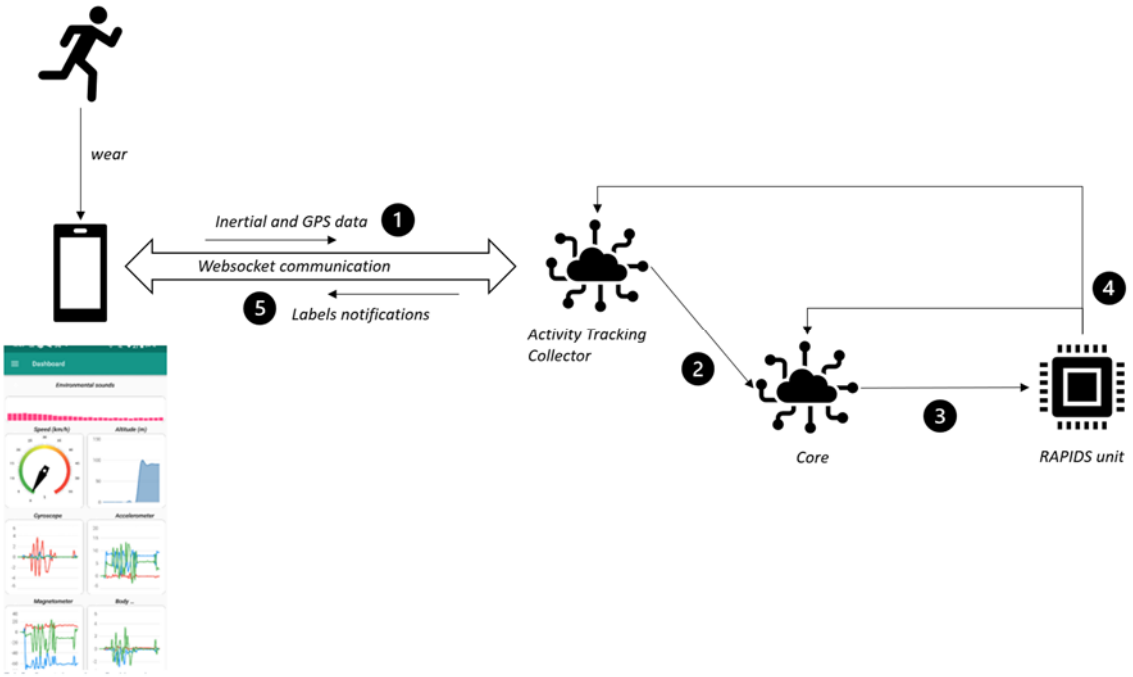
3.3 Demonstrating programs

In this section we are going to demonstrate how the platform works in order to retrieve labels. Obviously, it's a dynamic procedure, to illustrate it we propose this dataflow schema. We split the complete mechanism into two branches. The first one, is for smartphone acquisitions and gait analysis. The second, is for habitation's ambient sensors acquisitions and activity analysis. Even if in the schema it seems to be two different processes, it runs at the time for multiple habitations and smartphones.

3.3.1 Smartphone acquisitions and gait analysis



Tab 8: DFP - gait analysis dataflow

1. The user is connected to the DFP with the smartphone app. He is currently running, data are sent. The connection is achieved by WebSocket.
2. The backend "Activity Tracking Collector" received information from the smartphone and send it to the core.
3. The core received information, then it updates current value and historize data. Then it notifies RAPIDS Unit.
4. RAPIDS Unit received signal for label computing. Then it computes label. Label is sent back to the core in order to keep the last value and to Activity Tracking Collector.
5. Activity Tracking Collector received label from RAPIDS Unit. Finally, it notifies client through WebSocket. Actually, user is running, for example.

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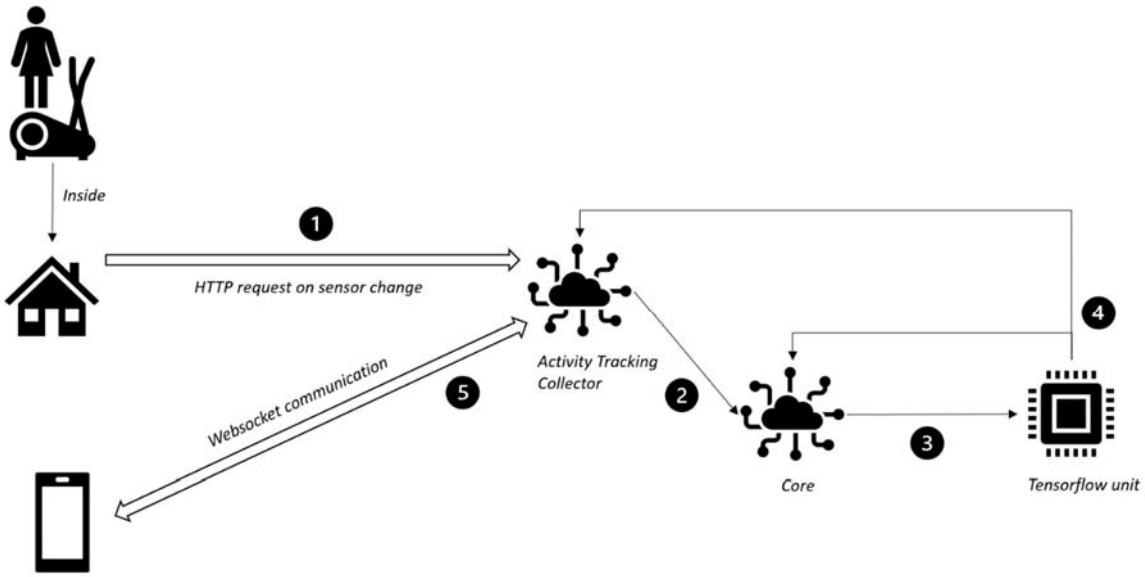
3.3.2 Ambient sensors acquisitions and activity analysis



Tab 9: DFP - activity analysis dataflow

1. The user is in the habitation. Ambient sensors send information to Activity Tracking Collector.
2. Activity Tracking Collector backend received information and sends it to Core.
3. Core received signal for label computing. Then it computes label. Label is sent back to the core in order to keep the last value and to Activity Tracking Collector.
4. TensorFlow Unit received signal for label computing. Then it computes label. Label is sent back to the core in order to keep the last value and to Activity Tracking Collector
5. If the user is using the smartphone app it notifies activity through WebSocket channel. Actually, the user is doing exercise.

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3.4 Discussion and recommendations

On this chapter we have seen the architecture and global mechanism of the DFP. We have focused about data flow, on real time processing on smartphone and ambient sensors. However, as explained on section 2.2 there are more data sources than these two. But over data sources depends on batch processing, which has not been treated in this deliverable.

Opposite to real time, which computes when data come. Batch processing is a scheduled mechanism. Let us consider the smartwatch device as example. Even with the Huawei developer access is not possible to ask thousands of times information on Huawei cloud. Then, we only take data at scheduled moments such as: wake up time (around 8 am), afternoon time (around 4pm) and evening time (around 10 pm). Then, when we take data at afternoon time, we can compute information from 8 am to 4 pm. Information can be abnormality in bpm on a precise time period.

Furthermore, this mechanism can be a second stage data fusion. For example, it permits to agglomerate ambient sensors labels results for a certain time period and retrieve the labels repartition. For example, during 8 am to 4 pm you have spent 20% of time cooking and 80% watching TV. At least, it can trigger dialog manager or DE (with Perseo) in order to notify user that he should do some exercise or go to a walk. Actually, is not only a second stage data fusion, with this mechanism: agglomerate data, batch compute, new valuable information, we can proceed with multi stage data fusion. The main objective behind this is to create personalisation behaviour based on general observations.

Another subject which has not been discussed is the dataflow optimisation. Now, smartphone app sends real time data to the DFP at 50Hz (it represents around 45 Mb/h). But it could be a problem in case of multiple users (more than 60). An optimisation solution could be to create an accumulator on the client in order to send every 10 seconds (for example) the last 10 seconds. However, this solution can decrease the computer charge during communication but it will be real time with an offset delay.

Last not least, if you want to deploy the DFP yourself. First you need to have access to the E-Vita GitHub. Then we strongly recommend to use windows 10 OS, it should work for Ubuntu or other Linux distribution but the DFP has been developed on windows 10, it means control commands are for windows OS. And we strongly recommend to use WSL 2 with Cuda support in order to let the DFP access your local GPU(s).

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4. Conclusion and Outlook

Deliverable D5.2 on Data Fusion was devoted to the realisation of the final version of the data fusion platform (DFP), in particular to extend the previous DFP prototype formerly described in D5.1 to a secured one with connection with the Digital enabler (DE) and able to provide various user's situations labels to the Dialogue Manager (DM) through a dialogue scenario triggers mechanism. So, firstly were reported, on one side, the introduction of an adaptive concept of data fusion architecture modelling, in order to take into account data types (heterogeneity) as well as their sources, which serves to our DFP implementation, on the other side the specification of the DFP-DE-DM stages interaction scheme to provide relevant information to the different dialog scenarios needed by the virtual coach. Relative to this last item, triggers based on rules has been proposed to be implemented in the PERSEO framework, in particular by the Esper-based Complex Event Processing (CEP) software tool. Then a description of the DFP prototype as it was integrated so far in prevision of next Wave2 Filed Tests has been performed by putting a focus, first on the different technical components which compose the DFP, then on the Machine Learning algorithms which were retained and selected so far for the effective data fusion-based HAR labels prediction as expected output from the DFP. These latter ones were indeed based on smartphone-based actimetry sensors, presenting a satisfactory variety (accelerometer, gyroscope, magnetometer) and on ambient PIR presence detection sensors. However, the DFP prototype is open and configurated to receive other sensors like the smartwatch Huawei (underway) for the vital signals capture like PPG-based heartrate and HRV and eventually the Netatmo environmental station for temperature and humidity (see also D5.1 for details). It is expected to robustize and extend the generation of the user and environmental situation labels to improve a few, by giving more reliable contextualisation, the e-VITA coach interactiveness in its dialogue with the user.

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Francesca D'Agresti , Martino Maggio. D7.4 e-VITA Platform Architecture - Final Version

Perseo documentation: https://fiware-perseo-fe.readthedocs.io/en/latest/

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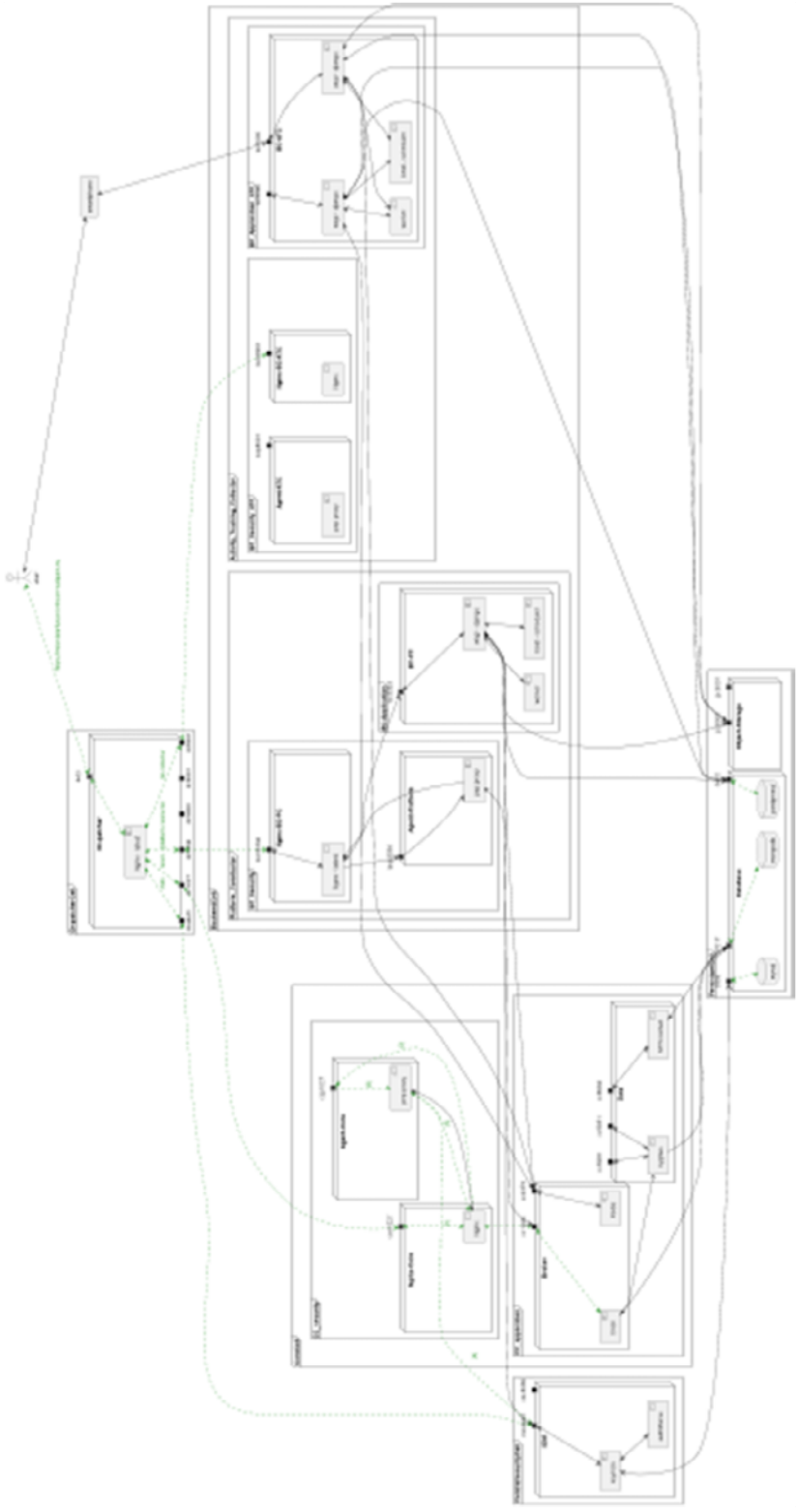
6. Annexes

6.1 Annex 1: Detailed Architecture of the DFP- Flow and Components



[i] https://fiware-perseo-fe.readthedocs.io/en/latest/

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