



# The Collective Experience of Empathic Data Systems

ICT-258749

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## Deliverable 6.1

# Conceptualization and Design of CEEDs System Architecture for Applications

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## Executive Summary

This deliverable of WP6 focuses on the conceptualization and design of CEEDs applications. During the reporting period WP3 and WP8 have conceptualized the architecture of the project and have specified as set of features common to all CEEDs applications , and referred to as "core features". WP6 worked in close collaboration with the work packages WP3 and WP8 to conceptualize the CEEDs applications based on these definitions while providing inputs to their work. Following an iterative development approach WP6 started to develop prototypes of the applications. This approach is characterized by several cycles of specification, design, implementation, and testing, and is well suited for the development of scientific applications where not all specifications are known from the beginning.

In the present document each of the four CEEDs applications geared towards archaeology, retail, history and science are described conceptually and details of the prototypes under development are provide.

# Table of Contents

<b>EXECUTIVE SUMMARY .....</b>	<b>4</b>
<b>1 THE CEEDS ENGINE AND CORE FEATURES .....</b>	<b>8</b>
<b>2 CONCEPTUALIZATION AND DESIGN OF CEEDS SYSTEM ARCHITECTURE FOR APPLICATIONS .....</b>	<b>10</b>
<b>2.1 ARCHAEOLOGY: INTUITIVE AND EXPLICIT REACTIONS TO ARCHAEOLOGICAL DATA .....</b>	<b>11</b>
2.1.1 <i>Context and Goals</i> .....	11
2.1.2 <i>Implicit Response Analysis</i> .....	11
2.1.3 <i>Use Cases</i> .....	12
2.1.3.1 Scenario .....	12
2.2 <i>System overview</i> .....	14
2.2.1 <i>From sherds to 3D pottery reconstructions</i> .....	14
2.2.1.1 Sherd classification .....	14
2.2.1.2 Partial matching: from sherd to 3D object .....	14
2.2.2 <i>Ceramic &amp; pottery identification using 2D profiles</i> .....	16
2.2.3 <i>Data mining of complex archaeological databases</i> .....	17
2.2.4 <i>Geo-tagged augmented reality application</i> .....	19
2.2.4.1 3D visualisation and augmented reality application .....	19
2.2.4.2 Narratology .....	20
<b>2.3 RETAIL: COMMERCIAL PRODUCT DESIGN .....</b>	<b>22</b>
2.3.1 <i>Context and Goals</i> .....	22
2.3.2 <i>Use Cases</i> .....	23
2.3.2.1 Scenario .....	23
2.3.3 <i>System Overview</i> .....	25
2.3.3.1 Software Platform .....	25
2.3.3.2 Architecture and Components .....	25
2.3.3.2.1 Kitchen configurator component .....	26
2.3.3.2.2 Product category viewer component .....	27
2.3.3.2.3 Similarity search engine component .....	27
2.3.3.2.4 Narrative generator component .....	28
<b>2.4 HISTORY: BERGEN-BELSEN MEMORIAL .....</b>	<b>32</b>
2.4.1 <i>Context and Goals</i> .....	32
2.4.2 <i>Scenarios and relation to Core Features</i> .....	32
2.4.2.1 Scenarios .....	32
2.4.3 <i>Implementation of prototypes</i> .....	33
2.4.3.1 Description .....	33
2.4.3.2 Navigation modes .....	34
2.4.3.3 Information Data .....	35
2.4.3.4 Prototypes .....	36
2.4.3.4.1 Prototype 1: Navigation in a 3D world with geo-tagged data retrieval .....	36
2.4.3.4.2 Prototype 2: Real-time story-related data retrieval .....	38
2.4.3.5 Technologies .....	39
2.4.4 <i>Future steps</i> .....	39
<b>2.5 SCIENCE APPLICATION: NEUROSCIENCE AND ASTRONOMY .....</b>	<b>41</b>
2.5.1 <i>Introduction</i> .....	41
2.5.2 <i>Neuroscience application</i> .....	41
2.5.3 <i>Prototype: 3D visualization and interaction framework for iqr neuronal systems</i> .....	42
2.5.3.1 <i>Interaction Design</i> .....	42
2.5.3.2 <i>iqr, a multi-level neuronal simulation environment</i> .....	44
2.5.3.3 <i>Creating the 3D representation of the neuronal system</i> .....	45
2.5.4 <i>Next steps neuroscience application</i> .....	46
2.5.5 <i>Integration into the CEEDs Engine</i> .....	47

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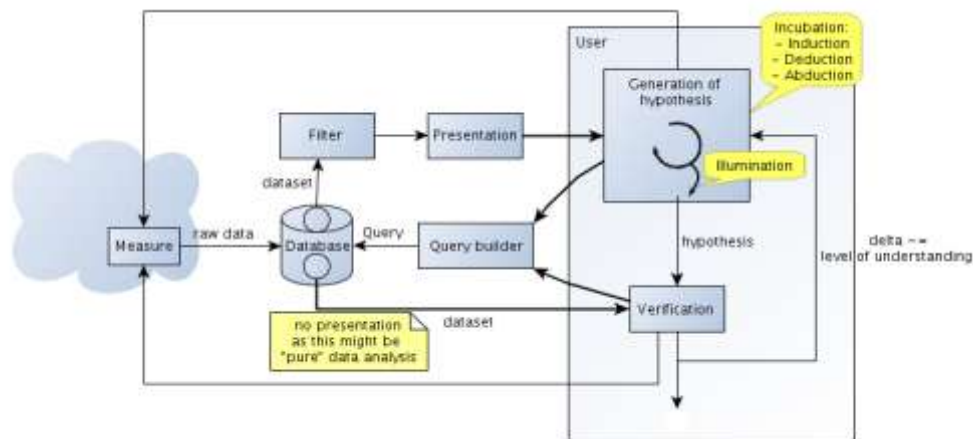
**3 REFERENCES.....49**

# List of Figures

<b>FIG. 1 -</b>	SYSTEMATIC VIEW OF HUMAN DATA EXPLORATION AND DISCOVERY .....	8
<b>FIG. 2 -</b>	ARCHITECTURE OF THE CEEDs ENGINE .....	8
<b>FIG. 3 -</b>	IMPLICIT RESPONSE ANALYSIS .....	12
<b>FIG. 4 -</b>	ARCHAEOLOGY SCENARIO: FROM SHERDS TO 3D POTTERY RECONSTRUCTIONS.....	13
<b>FIG. 5 -</b>	SHERDS SAMPLES.....	14
<b>FIG. 6 -</b>	FROM A SHERD VIEW TO A LIKELY 3D RECONSTRUCTION .....	15
<b>FIG. 7 -</b>	PROFILE’S SEGMENTATION AND MATCHING WITH PROFILES IN REFERENCE BOOKS .....	17
<b>FIG. 8 -</b>	MAP OF THE GRID UNITS AND THEIR INTUITIVELY CLASSIFIED FUNCTIONS.....	18
<b>FIG. 9 -</b>	WORK IN PROGRESS ON THE VIRTUAL MODEL: KORONEIA’S.....	20
<b>FIG. 10 -</b>	WORK IN PROGRESS ON THE VIRTUAL MODEL: PROVISIONAL RECONSTRUCTION OF KORONEIA’S THEATRE.....	21
<b>FIG. 11 -</b>	VISION CREATED BY UNIPD AT ELECTROLUX PREMISES OF THE “APPLIANCE” SCENARIO .....	22
<b>FIG. 12 -</b>	ARCHITECTURE DIAGRAM OF “APPLIANCE” SCENARIO .....	25
<b>FIG. 13 -</b>	VIRTUAL KITCHEN DESIGNED BY USER.....	26
<b>FIG. 14 -</b>	MAIN COMPONENTS CONNECTED TO KITCHEN CONFIGURATOR.....	26
<b>FIG. 15 -</b>	MAIN COMPONENTS CONNECTED TO PRODUCT CATEGORY VIEWER .....	27
<b>FIG. 16 -</b>	A TYPICAL MULTIMEDIA SEARCH ENGINE DIAGRAM .....	28
<b>FIG. 17 -</b>	FIRST STEP OF “APPLIANCE” SCENARIO.....	29
<b>FIG. 18 -</b>	SECOND STEP OF “APPLIANCE” SCENARIO.....	29
<b>FIG. 19 -</b>	THIRD STEP OF “APPLIANCE” SCENARIO.....	30
<b>FIG. 20 -</b>	FOURTH STEP OF “APPLIANCE” SCENARIO.....	31
<b>FIG. 21 -</b>	ILLUSTRATION (IN BLUE) OF THE PARTS OF THE CEEDs ENGINE ARE SO FAR IMPLEMENTED FOR THE BERGEN BELSEN SCENARIO.....	33
<b>FIG. 22 -</b>	“BERGEN-BELSEN MEMORIAL” APPLICATION-MAIN MENU SCREEN .....	34
<b>FIG. 23 -</b>	STAR-CAMP LANDSCAPE- APPLICATION USING GPS TRACKING SYSTEM .....	34
<b>FIG. 24 -</b>	STAR-CAMP LANDSCAPE- APPLICATION USING CONTROLS SYSTEM .....	35
<b>FIG. 25 -</b>	DATA REPRESENTATION INSIDE BARRACKS .....	35
<b>FIG. 26 -</b>	TRIGGERING TEXTUAL DATA .....	35
<b>FIG. 27 -</b>	WIKI- WALK PROTOTYPE .....	36
<b>FIG. 28 -</b>	WIKI- WALK IN A 3D WORLD .....	36
<b>FIG. 29 -</b>	SCHEME OF THE DATA RETRIEVAL METHODS IN THE BERGEN-BELSEN APPLICATION.....	38
<b>FIG. 30 -</b>	AN OFFLINE FRAMEWORK FOR REAL-TIME STORY-RELATED DATA RETRIEVAL AND PRESENTATION. ....	39
<b>FIG. 31 -</b>	GOAL OF PROTOTYPE 2: CONNECTION TO THE CEEDs ENGINE.....	40
<b>FIG. 32 -</b>	MAPPING BETWEEN THE USER’S POSITION IN XIM AND 3D VISUALIZATION .....	43
<b>FIG. 33 -</b>	SCHEME OF THE NEUROSCIENCE APPLICATION.....	45
<b>FIG. 34 -</b>	ON TOP THE CEREBELLUM MODEL IN IQR AND THE 3D VISUAL REPRESENTATION ON THE BOTTOM.....	46

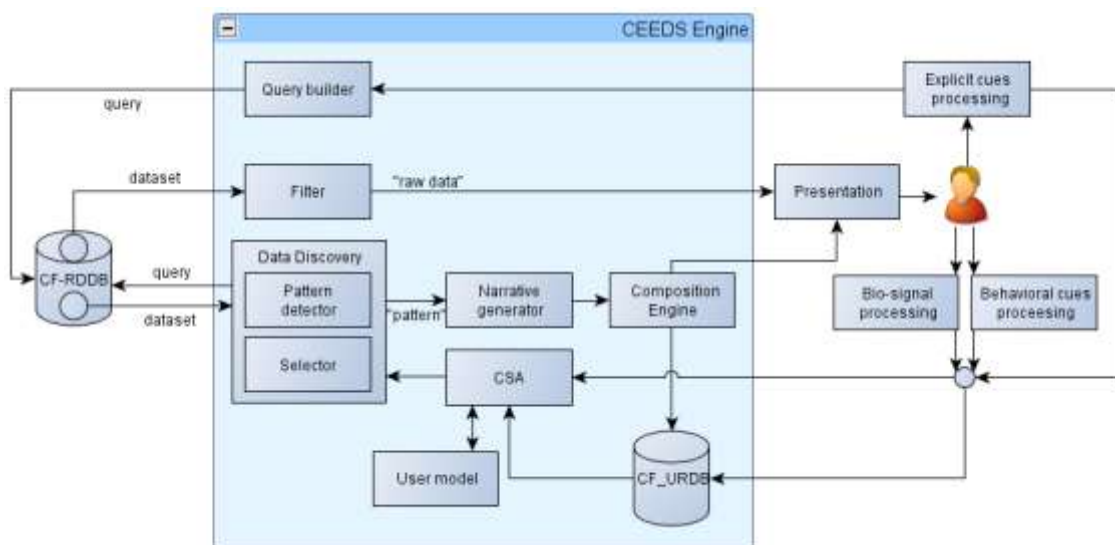
# 1 The CEEDs Engine and Core Features

This document provides a report on the specific architecture of the applications developed by WP6. However, these applications are integral part of the CEEDs project since not only they follow the goals of CEEDs, but are designed on the basis of the CEEDs Engine and correspond to the Core Features of said engine. To be able to subsequently relate the description of the applications to the components of the CEEDs engine, we start this introductory section with a brief description of the architecture of the CEEDs Engine (for a complete description see D3.1).



**Fig. 1 - Systematic view of human data exploration and discovery.**

The CEEDs Engine is designed to support the process of human data exploration and discovery (figure 1). To do so, the CEEDs user is stimulated with content, presented in a contextual and narrative form. The user reaction to the content is collected by the engine and new stimuli are presented to the user following his reactions.



**Fig. 2 - Architecture of the CEEDs engine**



Figure 2 describes the reference architecture for CEEDs applications. It contains the main components and interactions that will be implemented. The architecture described in this document is based on this conceptualization diagram.

For CEEDs a number of core features are defined that supports the discovery process, and that are requirements for any CEEDs applications. Hence the CEEDs engine has to be designed such that all core features are supported. The development of the core features was done by WP8 and is describes in the corresponding document (D8.1). In the present document the CEEDs engine and applications are described referencing these core features.

In summary the core features are:

[CF-RDDB] 'Raw Data Database': the existing raw dataset to be displayed

[CF1] The display of a CSA-independent filtered view, perspective or flow of CF-RDDB;

[CF2] The collection and storage of users' (a) explicit and/or (b) implicit responses to a dataset that is based on the output of CF1 [raw] or CF4 [tagged];

[CF3] The interpretation and storage of the output of CF2

[CF-URDB (user response database)] Database that stores outputs of CF2 and CF3, in relation to raw data [input to CF1]

[CF4] The display based on a user model of a CSA-dependent view, perspective or flow of a raw dataset;

[CF5] The display of users' responses and/or the data on which the CSA is making decisions as an overlay to the output of CF1 or CF4

## **2 Conceptualization and Design of CEEDs system architecture for Applications**

This section describes the CEEDs applications providing details of their context and functional requirements. It also describes the applications based on the reference architecture defined both WP3 and the core features defined in WP8.

The applications developed in the CEEDs project are representative of the concepts that CEEDs employs to address the identified issues. All of the applications have in common requirements for visualization of large volumes of data and the necessity to use explicit and implicit user responses in order to improve the user experience.

As part of the conceptualization and design process, development of early prototypes of the applications have already started, assuring that the design is based on the experience gathered during the creation of prototypes. This is a general approach for all CEEDs applications to build the software following an iterative development process. This work is also part of task 6.2 and 6.3 of the WP and grounds the work for the developments of the prototypes in year 2.

For each of the applications a responsible partner has been identified, and a group of partners are jointly developing the application. This way the applications are used as driver of the task which are transversal to the application across WP6 and other work packages.

## 2.1 Archaeology: Intuitive and explicit reactions to archaeological data

### 2.1.1 Context and Goals

*Leiden University in collaboration primarily with Comp/GOLD, CERTH/ITI, MPG/MPI and TEESIDE*

#### **Sherd classification**

A major problem of archaeologists is the classification of pottery sherds found in the field. During an archaeology dig numerous sherds can be discovered referring to various objects or even historical periods. These sherds are typically cleaned (washed-up) and then classified into similar sherd-groups. Each such group can contain sherds from various objects that have similar characteristics, e.g. pottery of the Byzantine era.

This process is very difficult for archaeologists, because it is extremely time and energy consuming. It is not unusual for a specialist to spend days of effort to identify sherds of a certain object, in order to reconstruct the 3D object or create a corresponding approximate model. On a typical large site, such as the ones we are concerned in CEEDs, millions of sherds end-up in storage areas and may remain unexploited.

#### **Novice users: educational tool**

In the case of the student archaeologist (novice user) the CEEDs engine acts as an educational teaching tool. The concept with the novice user is to learn from the experts implicit as well as explicit reactions during the whole procedure. Novice users may perform the same actions as expert ones, however their responses will be compared with the expert's ones' [CF5]. CEEDs archaeology teaching feature will also guide the novice user (through narratives) to track the decisions of expert and reactions on various stimuli.

### 2.1.2 Implicit Response Analysis

The CEEDs engine supports a mechanism for retrieving items (CAD objects, images, etc.) from a database. The retrieval process starts when a query item is posed (uploaded) by a user such as an archaeologist, expert, and student. Then, the  $M$  most similar items to the query are retrieved, based on content similarity (in various scenarios detailed below) and user's explicit and implicit responses. The CEEDs engine's mechanism captures  $K$  user's implicit responses when each retrieved item is presented to them ( $M$  retrieved items lead to  $M$  presentations per query).

CEEDs experts (e.g. psychologists) should define the  $K$  most prominent implicit responses for capturing user's satisfaction degree per item. Some level of explicit inputs may be considered too in some stages of CEEDs development (like naming, or audio recordings for documentation purpose). Given a query, satisfaction degree corresponds to user's acceptance for a certain retrieved item. The set of  $K$  implicit responses should be mapped to a satisfaction degree axis, e.g. 10 levels, from 1 to 10 (mapping could be also performed to

additional emotions degree axis). The satisfaction degree axis should be divided based on the satisfaction threshold into two separate areas (the satisfaction threshold should be also defined by the experts). These two areas are: (i) the positive response area and (ii) the indifferent or negative response area<sup>1</sup>, each corresponding to the acceptance degree of a retrieved item or disapproval degree respectively. The process of capturing and mapping CEEDs user's responses to satisfaction degree axis is depicted in **Error! Reference source not found.** (note that the proper emotion and its respective threshold are case dependent and experts should decide for alternative emotions to satisfaction). The procedure of capturing and mapping CEED's responses to satisfaction degree axis is called 'Implicit Response Analysis'.

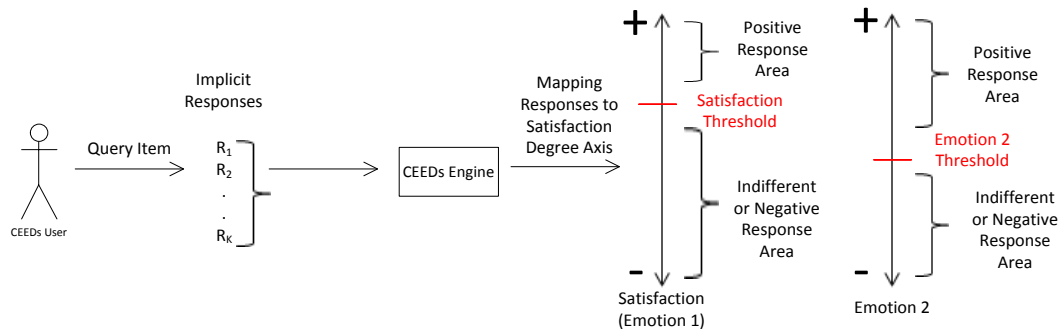


Fig. 3 - Implicit Response Analysis

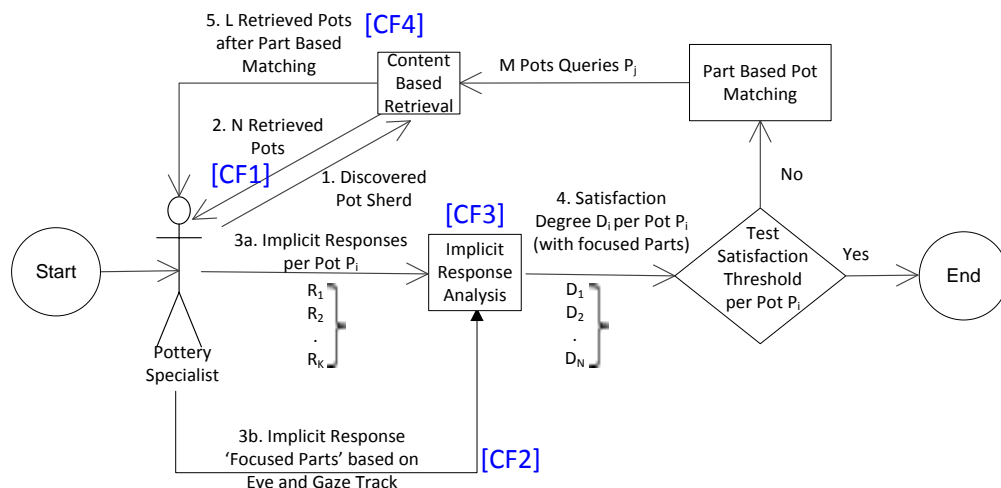
## 2.1.3 Use Cases

### 2.1.3.1 Scenario

- 1) Specialists define the number of classes of the newly discovered sherds.
- 2) [CF1] 2D images of the discovered pot sherds are posed as input in the sherd classification system (to be developed by CERTH).
- 3) Class centers are refined [CF3] using specialists' explicit [CF2] reaction and sherds are re-classified based on new centres [CF4].
- 4) A 2D image of a classified pot sherd is posed as query in the content based retrieval method (to be developed by CERTH).

<sup>1</sup> There could be more areas in the satisfaction axis, i.e. positive, neutral, and negative. It's up to the psychologists to decide.

- 5) **[CF1]** The query is matched based on shape and texture to 3D representations. Thus, the  $N$  most similar pots are retrieved and returned to pottery specialist. In figure 4, a retrieved pot is noted as  $P_i$ .
- 6) (a) **[CF2] [CF3]** In this step the Implicit Response Analysis starts (as described in section above). A satisfaction degree value  $D_i$  is calculated per pot  $P_i$ . The satisfaction degree value  $D_i$  is tested, using the satisfaction threshold. In case the satisfaction degree value of pot  $P_i$  is within the positive area then it passes the test. If all pots pass the test, then the procedure ends.
  - (b) **[CF2]** simultaneously, the parts of the  $N$  pots, which gained most of pottery specialist attention, are recognized, using eye and gaze tracking. In figure 4, these parts are named as 'focused' and they are current's step implicit information.
- 7) **[CF4]** In case  $M$  retrieved pots ( $M \leq N$ ) have satisfaction degree below threshold, the procedure must continue. Thus, a part based pot matching is performed. The implicit information (obtained at step 3b) is used to guide the shape matching. This results to  $M$  new pots  $P_j$ . Each pot  $P_j$  is posed as query in the content based search method ( $M$  queries totally). This way,  $L$  pots are retrieved, posing  $M$  queries totally (results per query are aggregated).
- 8) The  $L$  retrieved pots are depicted to the pottery specialist and procedure starts over at step 3.
- 9) In the case of student archaeologist (novice user) the same steps are being performed but also the experts responses and decisions are also displayed **[CF5]**.



**Fig. 4 - Archaeology scenario: From sherds to 3D pottery reconstructions**

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## 2.2 System overview

### 2.2.1 From sherds to 3D pottery reconstructions

*Lead: CETH/ITI, with expertise from Leiden, in collaboration with Teesside, MIS/MPG and Gold/Comp.*

The scenario is formed as a two step process aiming to address different needs as well as to combine them in an overall archaeology scenario. Experts and novice users may benefit from different features of CEEDs archaeology framework.

#### 2.2.1.1 Sherd classification

CEEDs will make use of specialist's explicit and implicit responses to classify sherds into predefined classes (sherd-groups). These classes will reveal general characteristics about sherds such as location, era, etc.

Based on 2D photographic pictures of sherds CEEDs will assign a similarity measure to each pair of sherds, based on color and/or texture features.

Archaeologists through a sampling method will define the total number of classes for the whole sherd-group. Based on a similarity measure and the total number of classes, CEEDs will then classify each sherd into a corresponding class. A ranked list of detected class centres (representatives of the class) will be presented to the specialist user and finally a refinement will be achieved through explicit and/or implicit specialists' reactions. Each sherd of a class will be available for a user to set it as input for the next stage.



**Fig. 5 - Sherds samples**

#### 2.2.1.2 Partial matching: from sherd to 3D object

Pottery specialists are trained to be able to assign intuitively a newly found pottery sherd to an existing pottery typology. This gives indications about the sherd's period of production and its provenance. To do so, pottery specialists need to study and memorise existing typologies of pottery. When they are confronted with a newly found pot sherd, they activate in their minds implicit reactions and explicit knowledge, which leads them to assign the sherd to its category within the already existing typological classification. CEEDs will make explicit the pottery specialists implicit mental processes by creating an algorithm that is able to match the properties of the sherd with the existing body of 2D/3D pottery shapes.

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Based on a 2D photographic picture of the sherd, the CEEDs engine will search its database for similar objects in order to link the sherd with a body of similar objects (and their related metadata regarding place of finding, chronology, bibliography in which they are discussed) in an effort to classify it in a certain typology (e.g. amphorae, alabastron, etc.). During this procedure the 2D image of the sherd will be matched based on shape and texture to 3D representations of master class objects.



**Fig. 6 - From a sherd view to a likely 3D reconstruction**

Since the pottery sherds may be eroded and/or chipped (due to exposure to elements) a perfect match will not be easily found. Thus, the CEEDs engine will first show a few possibly relevant potteries (either synthetic master class 3D representations or previously found potteries of the same or other area, period etc, chronological and geographical information about the dig may also be used as extra constraints for the search process). The system will then capture and analyze the implicit feedback of the expert user. It will recognize which object(s) has gained most of his attention, to show more such representatives.

Further, it will understand on which specific part of the complete pot the user is focusing on and will use it as an indication on sherds position in the object (capturing the experts' estimation of the sherds alignment to the object). This way it will use this implicit information to guide the shape matching of the picture to the 3D representations.

The system will then iteratively show estimates of the sherd's reconstructed pottery, until it realizes from the expert's implicit reactions that he is satisfied. The responses and the expert's procedure to find the result will get recorded in order to train the system for future findings.

This way the expert users will train the CEEDs system in order to make it able to guide and teach a non expert user through the implicit steps that pottery specialists usually take in order to assign a pot sherd to a certain typology. Also this will allow an independent comparison of 'expert system' classification by intuition and experience with formal properties defined explicitly.

The master 3D potteries retrieved from the search process will be used as building blocks of the ultimate augmented reality (or virtual reality) reconstructed city of Koroneia in Greece.

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## 2.2.2 Ceramic & pottery identification using 2D profiles

*Lead: GOLD/Comp., with expertise from Leiden, in collaboration with Teesside, MIS/MPG and CERTH/ITI*

Testing the reactions of specialists to fragmentary pieces of ancient pottery and ceramics<sup>2</sup> focusing on profiles. It consists of two interrelated parts:

1- Leiden supplies a series of already classified archaeological finds to GOLD who will compare this intuitive classification with published master types of pottery to examine variability between the implicit and explicit typologies.

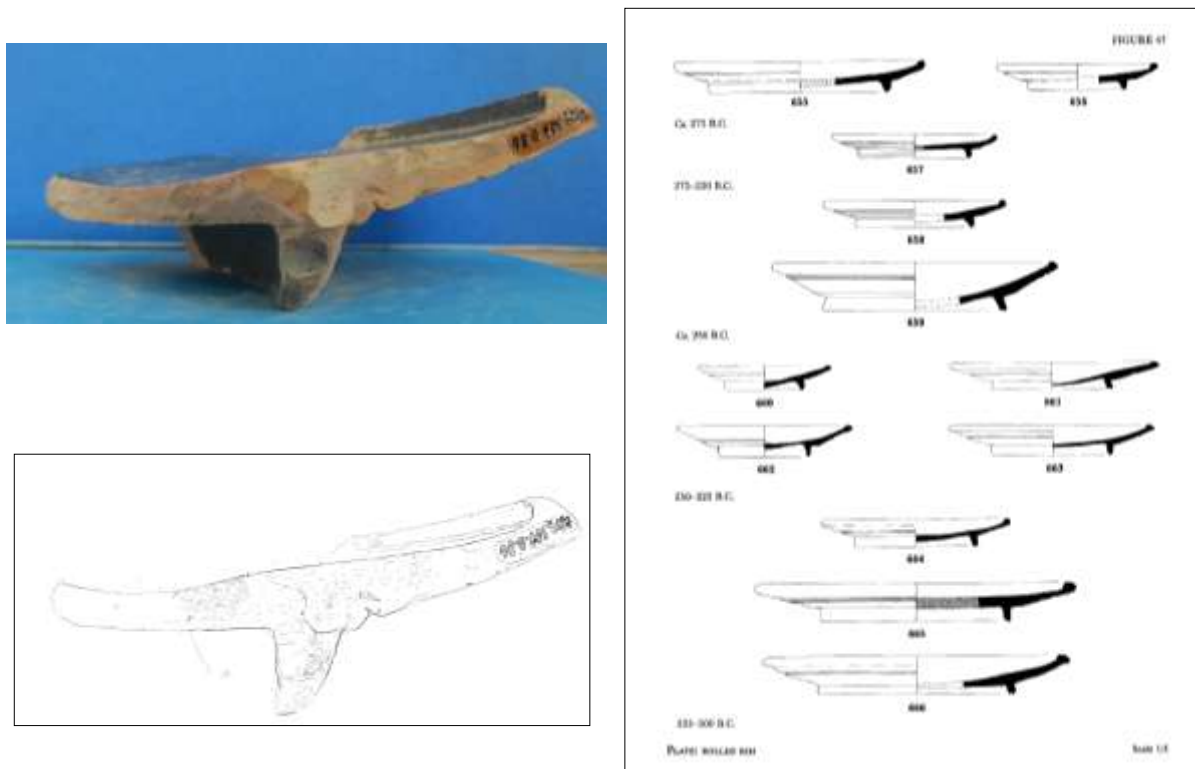
2- GOLD will carry out experiments with archaeologists to measure their responses in the CEEDs system to the classification of archaeological finds.

In step 1, a method to automatically segment profiles out of images taken by the archaeologist (or some other user) properly positioned with a good background contrast (such as a blue or white screen), will be developed by GOLD/Comp. A shape-based retrieval method will also be developed which will exploit the availability of corresponding idealised profiles in references (books) provided by the archaeology experts. This implies some a priori DB of profile features will be constructed out of the references, this to speed-up the retrieval stage. The shape representation will (at least initially) be based on shock graphs.

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<sup>2</sup> Ceramics and pottery are near synonyms. Pottery usually implies a "container made from clay", while a ceramic is as "object made from materials permanently set via heating".





**Fig. 7 - Profile's segmentation and matching with profiles in reference books**

In step 2, one or a likely set of matches will then be presented to the user and their responses measured within the CEEDs engine. Implicit and explicit responses will be used to refine the identification of an image of a profile with its likely reference match. This type of knowledge is then exploited later by the CEEDs agent to engage in "conversations" with the user (novice or not) when presented new data and retrieval results.

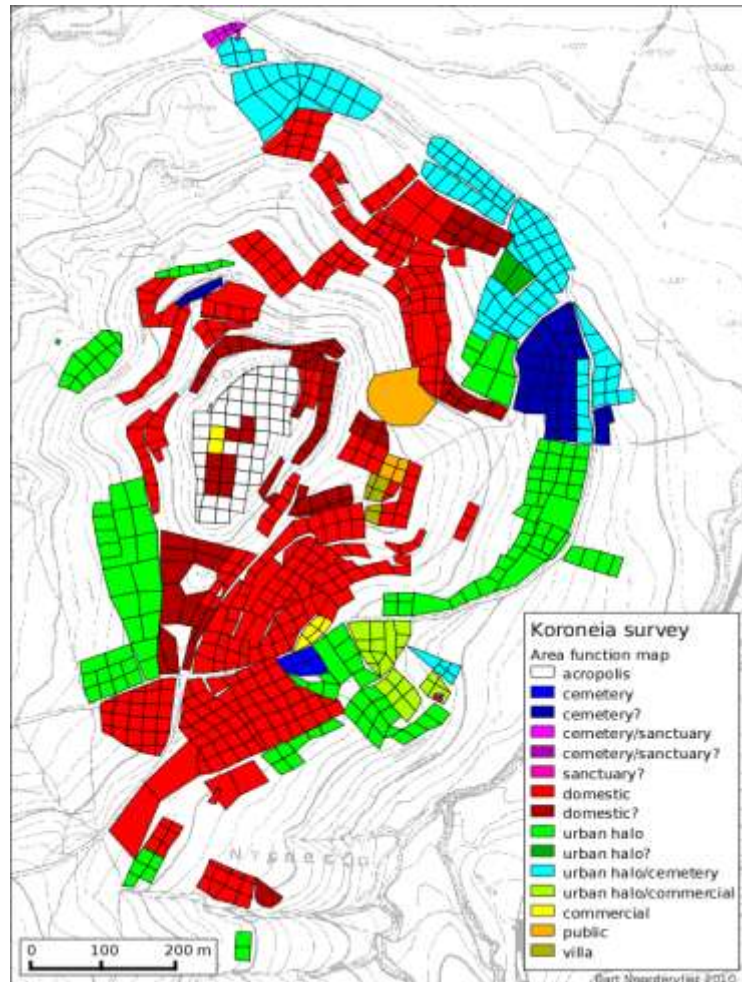
An additional application will be to produce likely 3D ceramics reconstructions by exploiting identified references and the rotational symmetry of outlines from profiles. Alike in the first scenario, implicit responses of users to the proposed 3D approximate reconstruction will be studied in CEEDs.

### 2.2.3 Data mining of complex archaeological databases

*Lead: MIS/MPG, with expertise from Leiden, and in collaboration with Gold/Comp, CETH/ITI, Teesside*

Archaeologists have already made functional maps of ancient cities made of intuitive classification during fieldwork and secondarily during the analysis of finds from the individual grid unit into which these sites are divided. The Leipzig team will independently search the archaeological database of these cities [CF-RDDB] and, using data mining procedures (the Data Discovery component of the CEEDs engine), will test the strength of intuitive structures of associations not apparent to the archaeologists. The results of the data mining will suggest new associations or structures in the data not revealed by the intuitive and implicit procedures of the archaeologists, this information will feed the user response database [CF-URDB] and will be used by the CSA [CF4].

Patterns to be looked for in the database are (a) the spatial distribution of different types of pottery (e.g. tableware, production waste, funerary pottery) and the spatial distribution of pottery from different periods. These observations generate archaeologists' hypotheses on (a) the functional areas of the ancient city and (b) the development of the settlement over time.



**Fig. 8 -** *Map of the grid units and their intuitively classified functions*

The data mining is based on building a statistical model of the pottery data base. Each classified sherd corresponds to one entry in the data base containing the:

- (1) location, i.e. the cell in the grid, where it was found;
- (2) type of pottery, such as cup, plate, amphora;
- (3) time period, such Hellenistic, early Roman;
- (4) function, such as storage, transport, architecture (not used so far);
- (5) further entries that will be not considered in the first analysis.

For the statistical analysis we assume that each entry is a sample randomly drawn from a joint probability distribution. As a starting point we restrict ourselves to joint probability distribution  $p(y,x,t)$  of the random variables Location (X), Type (Y) and Time (T). This distribution quantifies how likely it is that a randomly chosen sherd of type  $y$  was found in location  $x$  and is assigned to the time  $t$ .

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The intuitively classified functions of areas of the ancient city shown in Figure 8 will be represented by a hidden random variable  $F$  that has to be inferred from the observations<sup>3</sup>. The basic idea is that a certain function of an area at a certain time generates a specific distribution of types of pottery,  $p(y|f)$  in that area. In the general case this distribution is time dependent, i.e.  $p(y|f,t)$ . The joint probability distribution  $p(y,x,t)$  is then modelled as  $p(x,y,t)=\sum_f p(y|f,t)p(f|x,t)$ . For a fixed time statistical models of this form are known as "Topic models" in the context of text analysis. There  $X$ , our location, corresponds to the texts and  $Y$  (type of pottery) to the words, while  $F$ , the area function in our case, represents the different topics. The aim of the statistical analysis is to infer the conditional probabilities  $p(y|f,t)$  and  $p(f|x,t)$  from the data. Here  $p(y|f,t)$  quantifies the pottery pattern corresponding to some function and  $p(f|x,t)$  would allow us to draw functional maps such as shown in figure 8<sup>4</sup>. In a later stage we will also take into account the function of neighbouring cells, i.e. that it is more likely that adjacent cells have the same function and also temporal correlations. The corresponding class of statistical models is called "Markov random fields".

Visualisations of the pottery type patterns and the functional maps within CEEDs can be used for Implicit Response Analysis to judge the quality of the inferred statistical model for different model classes. For instance, we can vary the number of functions in the "Topic model" or we can assess the effect of different prior distributions for the model parameters. The model evaluation by experts using CEEDs can be compared to model selection schemes used in machine learning.

## **2.2.4 Geo-tagged augmented reality application**

*Lead: Leiden, in collaboration with UPF, TEESIDE, Gold/Comp*

### **2.2.4.1 3D visualisation and augmented reality application**

A challenge in archaeology is to present the huge amount of data that we collect during surveys to the general public in an immediately comprehensible way. The data that we've collected on the field take shape in our mind in such a way that we can picture the image of the ancient city as it used to be. Our reconstructive hypotheses (e.g. what this ancient city looked like?) are based on the combination of all the available data that are visualised in our mind as combined in a coherent structure (e.g. pottery and architectural fragments indicate functional areas of the city and evolution of the settlement in a diachronic dimension; the shape of the landscape gives us hints about the use of the terrain for laying out house-blocks, public squares, temples and cemeteries, or defence walls). These data, however,

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<sup>3</sup> Note that this "function" is a function of area, while the entry named "function" in the pottery data base, assigns the function to a piece of pottery.

<sup>4</sup> This model allows more than one function in one location. One possibility to contain a functional map would be to show the function with the highest probability. Alternatively one could restrict the probability to 0 or 1 thus allowing only a single function for one location.

seem to a non-expert eye only a scattered and incoherent amount of meaningless material. The application will guide a non-expert user through the discovery/understanding path that has been reconstructed based on expert's experiences and knowledge [CF4]. This will help novice users to make explicit the vision expert users and raise the interest of a non-expert audience to make them realise the cultural value of the work.



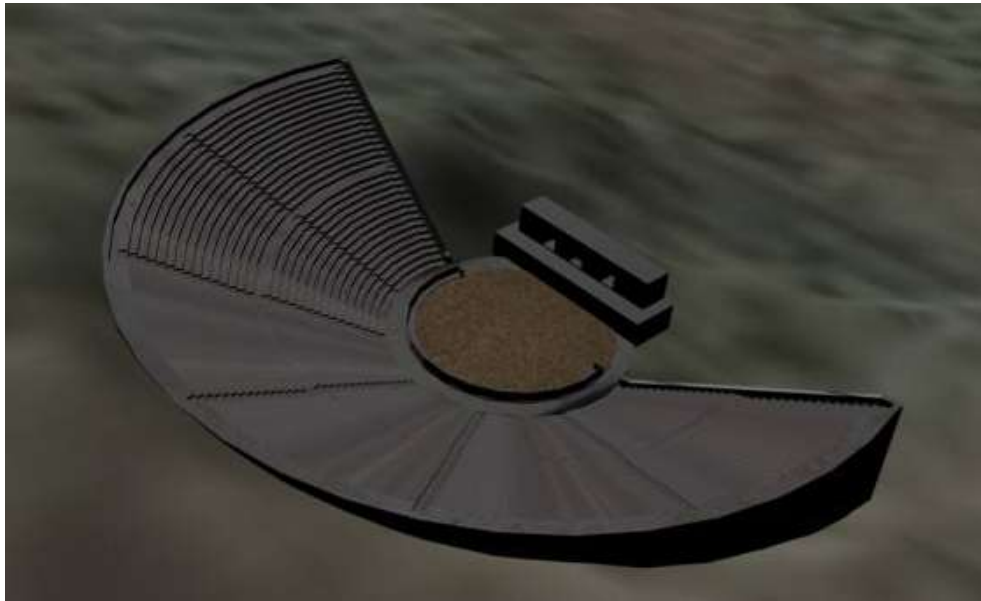
**Fig. 9** - *Work in progress on the virtual model: Koroneia's*

This application will benefit from the geo-tagged augmented reality framework that UPF is developing for the History application (Bergen-Belsen Memorial). CEEDs will make archaeologists reconstructive hypotheses visible that organise all the available data. Moreover, the application will direct the user's attention to particular meaningful areas of the city (e.g a reconstructed household; the town centre or Agorà).

Leiden will create the virtual reconstruction of the ancient cities that will include both buildings and artefacts that represent the functional use of space tied to real coordinates and the content of a typical household to allow the navigation across real and augmented reality landscapes. This will be done by integrating the results of the improved classification of finds and the results of the data mining on the functional areas of the city.

## **2.2.4.2 Narratology**

The exploration of abandoned cities by archaeologists can be repeated in a controlled way for local schools and villagers who can see their nearest ancient town through the innovative experience of a real space augmented reality reconstruction trail. Narratology theory allows us to create pathways of exploration for non-specialists that illustrate in an entertaining, informative and empathic way how an ancient city looked, worked, and the kind of experience one might have had when walking through it. Leiden will provide the historical and archaeological information and topographical detail of Koroneia which are necessary for creating a heritage navigation of an interactive kind for the regional population around ancient Koroneia. To assist a stimulating navigation in these digital tours, collaboration with TEESIDE will allow the most suitable narrative structure to be incorporated into this heritage presentation in order to achieve an emphatic experience of the ancient site.



**Fig. 10** - *Work in progress on the virtual model: provisional reconstruction of Koroneia's theatre*

## 2.3 Retail: Commercial product design

### 2.3.1 Context and Goals

The scenario provides an immersive and empathic environment for experiencing and manipulating 3D objects of appliances. This is aimed at a variety of actors in the product design lifecycle: designers, engineers, prospective users and consumers.



**Fig. 11** - *Vision created by UNIPD at Electrolux premises of the "Appliance" Scenario.*

The scenario provides an immersive manipulation of virtual appliance products including:

- Experiencing different selections, configuration and combinations into complex data visualisations such as a interior design composite (e.g. a kitchen).
- Eliciting "active" experiences and perception of virtual objects
- Based on multimodal interaction using natural intuitive 3D gestures and input techniques and stereoscopic life size environments.
- Adaptively retrieves related visualisation or proposes relevant narrative paths

The complex data aspect is given by the virtual models, their combination (in a kitchen) resulting in rich and complex data.

The empathic experience aspects are relevant considering the user experience, understanding and emotions while manipulating objects. CEEDs can perform empathic annotation, find similar views of other products, and suggest narrative paths in composition and manipulation.

Moreover interaction and user status can be recorded while manipulating objects in immersive platform as compared to surface or desktop computing interaction. Record of experiences of navigation with virtual objects can be used when another user uses the system. In particular potential scenarios include support for alternative views to and animations of virtual objects as adaptive narrative paths. This includes for example navigating an appliance starting from different parts or having different sequences in the presentation, expanding or deepening narration of specific aspects given the profile and feedback of the user.

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## 2.3.2 Use Cases

### 2.3.2.1 Scenario

Overall purpose is to support “customers” in exploring products in a novel way and developing a custom kitchen replete with appliances.

Potential primary end users will be,

- Business to Business customers
- Customers from general public

Potential secondary end users will be,

- Designers
- Marketeers

#### **Step 1: Choose an initial product category to explore (Cat A)**

The user enters the virtual show room environment and is presented with product category options derived from all product categories in the CF-RDDB [CF1]. The CF-RDDB contains a large number of virtual models. The user makes an explicit selection (“I’d like to see the washing machines” or navigates in the environment towards their selected product category).

#### **Step 2: Within product category, infer a user’s preferred appliance (model A)**

The user is presented with a/the selection of chosen appliances with the product category selected in Step 1. The step 2 can be simple or extended depends on the number of appliances available in the selected product category. Steps 2a and 2b will describe the different approaches taken depending on the number of items in the scenario.

#### **Step 2a: Assuming the total number of appliances available within a category (e.g., washing machines) is small ( $n < 5$ )**

All available (washing machines) from the CF-RDDB are represented to the user (*washing machines: a, b, c, d, e...*). The user will get a chance to explore the washing machines in a basic visual level. Since there are small number of appliances presented in the selection environment user can explore visual details of every appliance.

Throughout their exploration, the user’s responses are recorded [CF2] and interpreted [CF3]. The relationships between the user’s responses (relating to relevant constructs such as preference, interest, likeability etc.) and characteristics/parts of the appliance (e.g., control panel, handle, door, surface/finish) are stored in [CF-URDB].

Using the user’s response data (raw and interpreted), the CSA infers the most desirable model of washing machine for that user [CF4].

Its inference could take account of how the user responds to different features of the appliance (e.g., control panel, handle, door, surface/finish) so that the CSA understands what characteristics the user is most focused on and how much they like/dislike each component. This could produce a weighted average for any product. CEEDs could use this information (e.g., high preference for handles of a particular shape) for prioritising the types of stimuli to present.

#### **Step 2b: Assuming the total number of appliances available within a category (e.g., dishwashers) is large ( $n > 5$ )**

A selection of all available [washing machines] from the CF-RDDB are represented to the user. This initial selection is based on those washing machines that are most contrasting (determined by CERTH’s search algorithm). The user is free to explore and interact with the washing machines.



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Throughout their exploration, the user's responses are recorded [CF2] and interpreted [CF3]. The relationships between the user's responses (relating to relevant constructs such as preference, interest, likeability etc.) and characteristics/parts of the appliance (e.g., control panel, handle, door, surface/finish) are stored in [CF-URDB].

The CSA uses information derived from the CF-URDB to understand what characteristics of the appliance that the user is most focused on (e.g., control panel, handle, door, surface/finish) and how much they like/dislike each component. Using the CF-URDB (and CERTH's search algorithm for similar objects), the CSA changes the selection of products displayed to the user [CF4] with the goal of presenting washing machine models that most appeal to the user.

The user's implicitly preferred washing machine is chosen and presented to the user for verification (explicit response).

### **Step 3: Feasibility and placement of appliance/model A in Custom Kitchen**

Once user selects an appliance/model A (selected in Step 2 above), he/she places it into his/her Custom Kitchen plan. The size and position of the appliance in the Custom Kitchen is checked for feasibility by the user and its position can be manipulated using explicit interaction to meet functional requirements of the user. Its dimensions are checked to ensure suitability of fit.

### **Step 4: Choose a second product category to explore (Cat B)**

The user returns to the virtual show room environment and is presented with the remaining product category options derived from the CF-RDDB [CF1].

The user makes an explicit selection ("I'd now like to see the dishwashers" or navigates in the environment towards their selected product category).

### **Step 5: Infer a user's preferred appliance/model B from Cat B**

The user is presented with the option of

- (a) being shown a product from Cat B that is in the same 'range' as that selected in Cat A or
- (b) being shown the/a selection of products from Cat B (see Step 2).

*If (a):*

The user makes an explicit decision about whether to select for the Custom Kitchen this dishwasher in the same range as the washing machine, or if they would like to view the other possibilities. If they choose other possibilities, they continue as per (b) below

*If (b):*

If the user chooses to view alternative models from Cat B, the CSA using the CF-URDB suggests models that have similar features (based on CERTH's similarity search algorithm) to those previously considered desirable by the user.

The user interacts with other dishwasher models whilst their responses are collected and interpreted in order to update the CF-URDB.

Once the user's implicitly preferred washing machine is identified, it is presented to the user for verification (explicit response).

### **Step 6: Feasibility and placement of appliance/model B in Custom Kitchen**

The user places the appliance/model B (selected in Step 5 above) into his/her Custom Kitchen plan. The size and position of the appliance in the Custom Kitchen is checked for feasibility by the user and its position can be manipulated using explicit interaction to meet functional requirements of the user. Its dimensions are checked to ensure suitability of fit.

Steps 5 to 6 are repeated until all appliances from each product category have been placed in the Custom Kitchen.



### Step 7: Construct CEEDs User Preference Profile (CUPP)

Data specific to the user is stored (onto portable device/cloud) for the user to use in other settings.

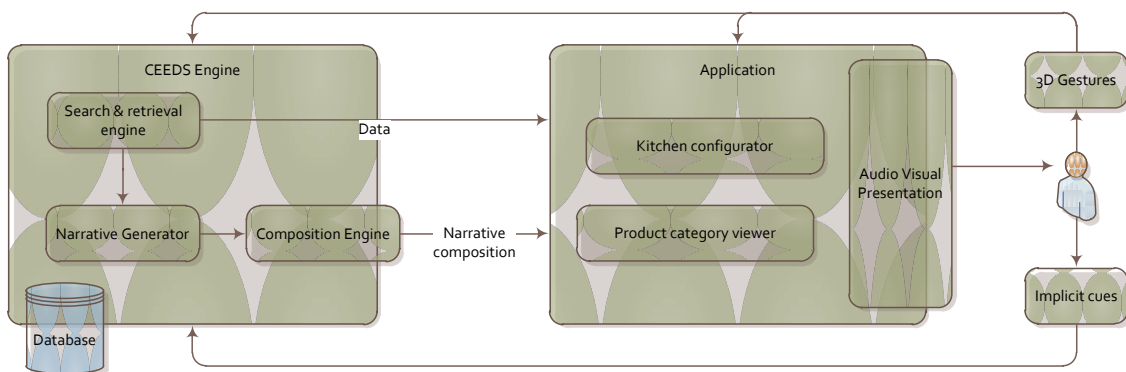
## 2.3.3 System Overview

### 2.3.3.1 Software Platform

The proposed development platform is Unity 3D (<http://unity3d.com>). The choice has been made after carefully evaluating inside the consortium available alternatives. Unity3D offers a cross platform, versatile and open development platform at limited costs for academic work. Appliance models will be designed in other facilities and will be imported to Unity 3D for further development. Final result will be compiled as a desktop application to run on either Windows or Mac based operating system on CXIM 2.0 or the portable CXIM.

### 2.3.3.2 Architecture and Components

In this development scenario we will be mainly focusing on the presentation unit of the CEEDs system (as reflected in figure 2 on the introduction). The presentation unit has two data input channels. One of them will contain the raw data fetched from database and the other channel will provide much abstract data after processing. For this scenario the presentation unit will have larger display screens, sound systems and haptic feed generators. The system will keep collecting user interactions made implicitly and explicitly. The implicit data is used in presentation unit as user controls.



**Fig. 12 - Architecture diagram of "Appliance" scenario.**

In "Appliance" Scenario the target implementation takes place at the Application unit. Rest of the CEEDs engine supports this scenario by providing information. There are five key entities in system. They are "Search and retrieval engine", "Narrative Generator", "Kitchen configurator", "product category viewer" and "audio visual presentation system". The system will present user in two different modes. Kitchen configurator is a one mode where user can move the selected appliance around a virtual kitchen environment. Other mode is the product category viewing mode. There user can select the products from catalogues and also the system will suggest related products by user feedbacks.

The user's gestures will be computed through the CEEDs engine and they will be stored for later use. As it is discussed in section 2.2 step 2.a, the collected cue and gesture data will be processed through the CEEDs engine and forwarded into "Application" unit. At the same time data will be used by "Search and retrieval engine" to generate similarity rankings of other products. The data processed inside the CEEDs engine will be forwarded to "Product category viewer". The 3D gestures are directly computed by presentation layer since 3d gestures play a role in controlling elements.

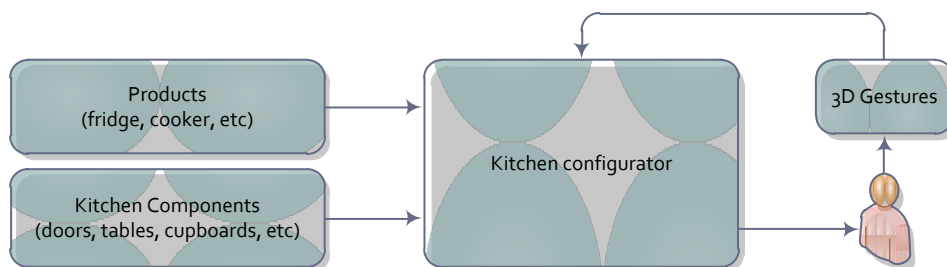
### 2.3.3.2.1 Kitchen configurator component

Kitchen configurator is the key visible component for the user. This will mainly create a virtual environment and allow user to feel like staying in a real kitchen.



**Fig. 13** - Virtual kitchen designed by user.

The task of this scenario is to move the kitchen components around the created virtual kitchen and feel how well the component fits to the real environment. The basic functionalities of this unit are selecting objects (refrigerator, oven, dishwasher, etc.), moving the selected objects to feasible locations and to walk around the virtual environment. The large display screens connected to the system will allow users to feel like they are in a real size kitchen with real size appliances. Moving around the area will be computed by this unit by considering the user movements and 3D gestures. In the same time the areas that person cannot walk (geometry constraints such as a table or a wall) will be notified to the user not only visually but also by haptic feedbacks.

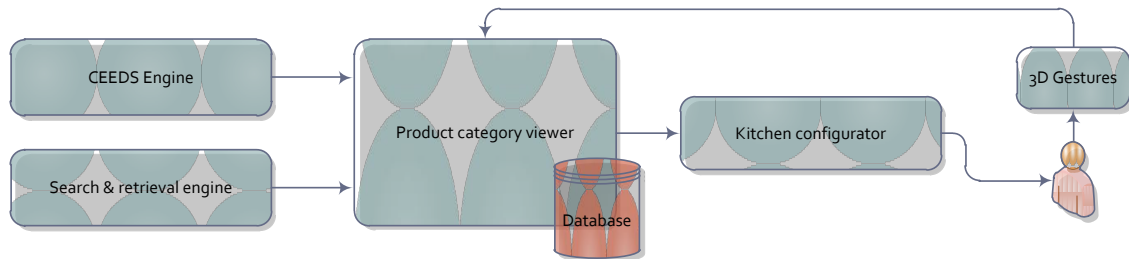


**Fig. 14** - Main components connected to Kitchen configurator

Kitchen configurator (KC) will be creating the virtual environment by using kitchen components and products. The direct input from user gestures is computed and gives the result to the user by the KC. Kitchen components are also selected from database by considering user's direct choices and also by the implicit cues given.

### 2.3.3.2.2 Product category viewer component

The product category viewer (PCV) is a backend unit in the presentation unit. PCV mainly works as the shop assistant. The task of PCV is to identify the user needs and push related products to user environment. The identification of user needs works in two different ways. One is identifying the explicit cues given by the user (customer). When customer asks for a fridge the PCV should guide him/her to a product catalogue with fridges. In the same time computing of implicit cues will allow seller to reach the customer needs precisely.



**Fig. 15** - Main components connected to product category viewer

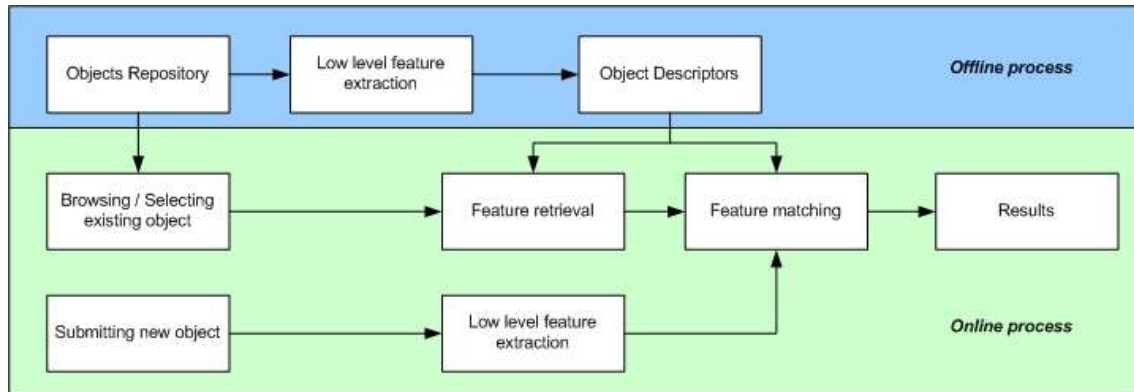
PCV is getting data from CEEDs engine and also from the "Search & retrieval engine". Both of these engines are supporting the PCV to select a subset of products from whole catalogue. 3D gestures captured are also used as explicit cues from the user. By considering all these inputs system selects the best subset of items from its database. This database is mainly holding the product catalogue of the company who is providing products.

### 2.3.3.2.3 Similarity search engine component

The 3D model similarity search engine will be responsible to provide similarity/dissimilarity ranked lists based on user/system queries. The queries will be descriptors of visual features as well as implicit user responses during the querying procedure. The combination of implicit user responses with the explicit information (visual features) will provide personalized search results for each user.

#### Feature extraction

The first step for the search engine to work is to extract visual features descriptors for all the 3D models in the database. A typical multimedia search engine workflow is shown in **Error! Reference source not found.**



**Fig. 16 - A typical multimedia search engine diagram**

Local visual (2D/3D) features descriptors will be developed and tested to evaluate their performance in partial matching of different appliances parts (handles, control panels etc.). The local visual features descriptors may be extracted directly from the 3D data both in the offline part (database pre-processing) as well as in the online part (query construction), or indirectly by using 2D snapshots of the appliances from the viewpoint of the user along with some implicit responses information in order to locate the user's interest points. This information may be eye gaze information that will provide x,y,z coordinates of the interest point on the object the user is viewing and/or manipulating. Other implicit user responses may also be used to drive relevance feedback of the search engine.

Different matching algorithms should also be tested for their performance on the actual dataset for the specific needs of the application.

### 2.3.3.2.4 Narrative generator component

#### Overview and integration

The narrative generation component is responsible of presenting and suggesting appliances using cues of actions that will be executed within the presentation unit. It uses heuristic search planning to generate sequences of actions by exploring the corresponding state space using a real time search. The search is able to perform look ahead and sampling in order to tackle combinatory explosion resulting from the large set of appliance and the possibility of anytime user interaction.

In a similar fashion than the search engine component, the narrative generator could communicate via Unity3D either through TCP communication or by being directly integrated within as Unity3D it allows to use .NET C# scripts and Dynamic-Link Library (DLL) which is the language the narrative generator have been implemented.

#### Scenarios examples

The following figures illustrate through a simple example how the narrative generator will help suggesting appliances to the user by taking into account implicit and explicit feedbacks.

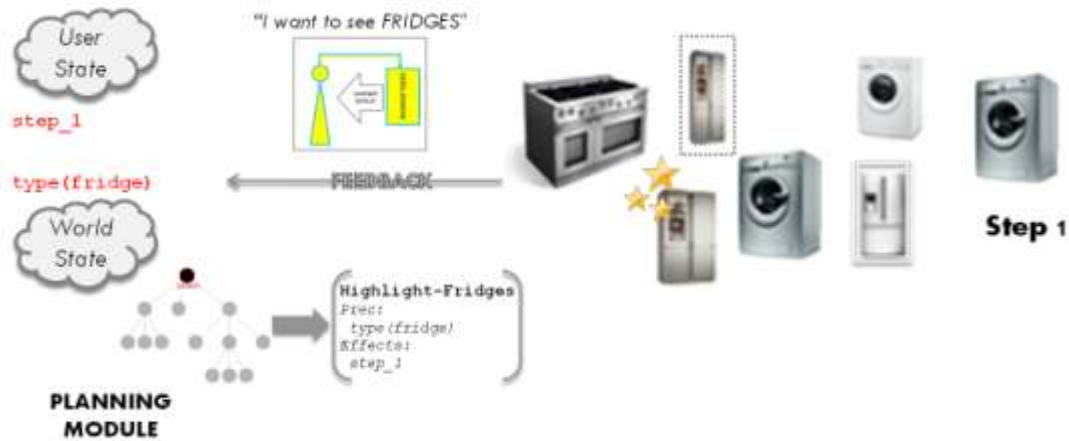


Fig. 17 - First step of "Appliance" scenario.

The first part of the scenario (illustrated here by Figure 17) is responsible of the selection of the appliance. The suggestion of the user to select a fridge for example will result in the modification of the user state by adding the proposition type (fridge). This in return will allow the narrative generator to trigger an operator like Highlight-Fridges. This action could then correspond to a sequence of actions that will make the fridge appliances more obvious to the user. Each type of fridges could present a different highlighting depending on the style (e.g. luxe, economic or efficient).

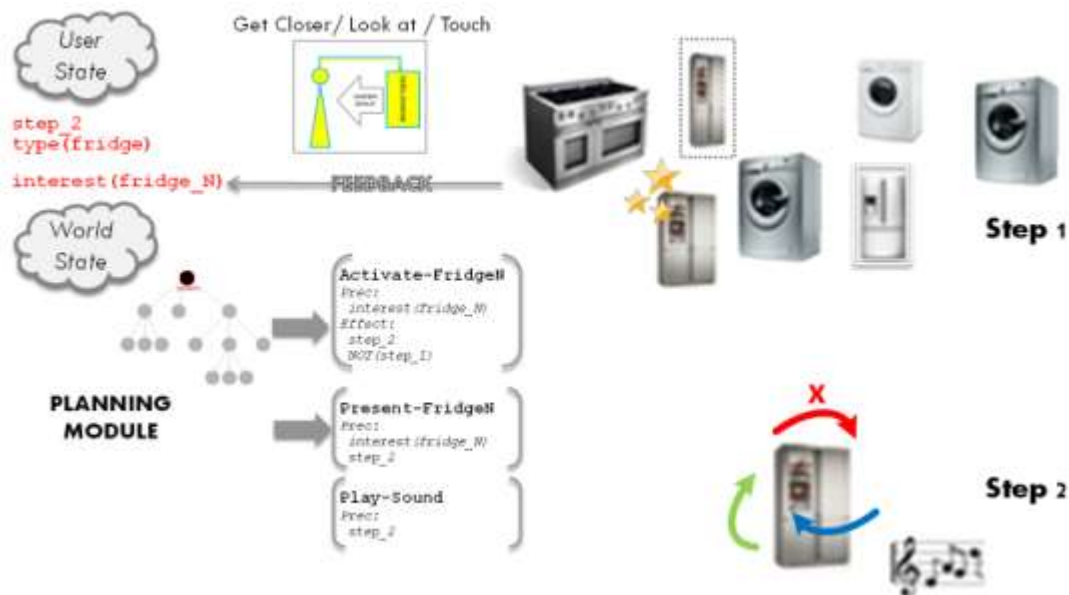
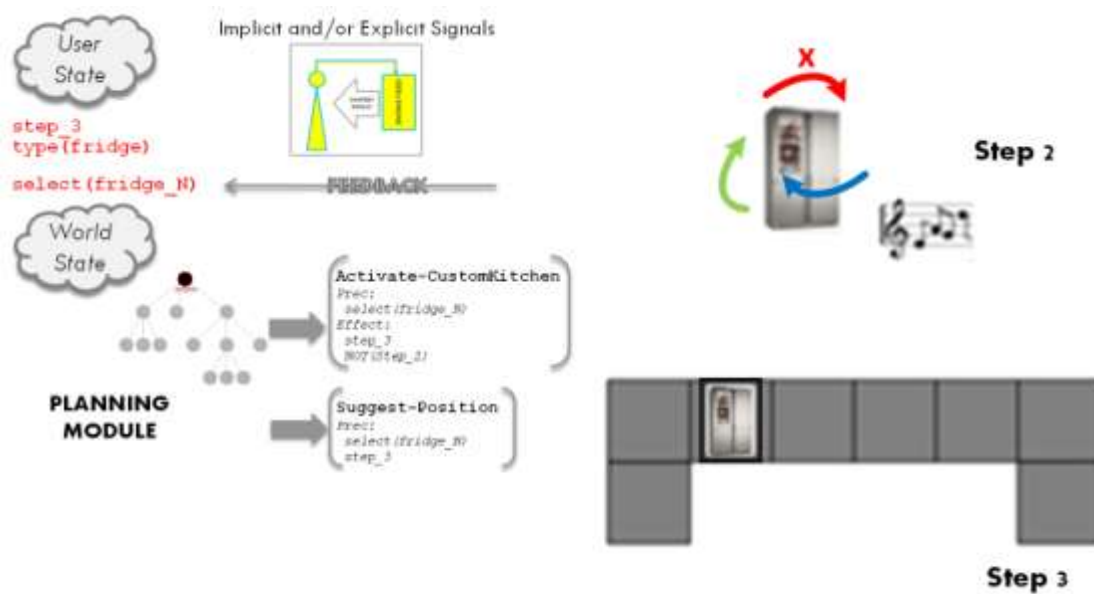


Fig. 18 - Second step of "Appliance" scenario.

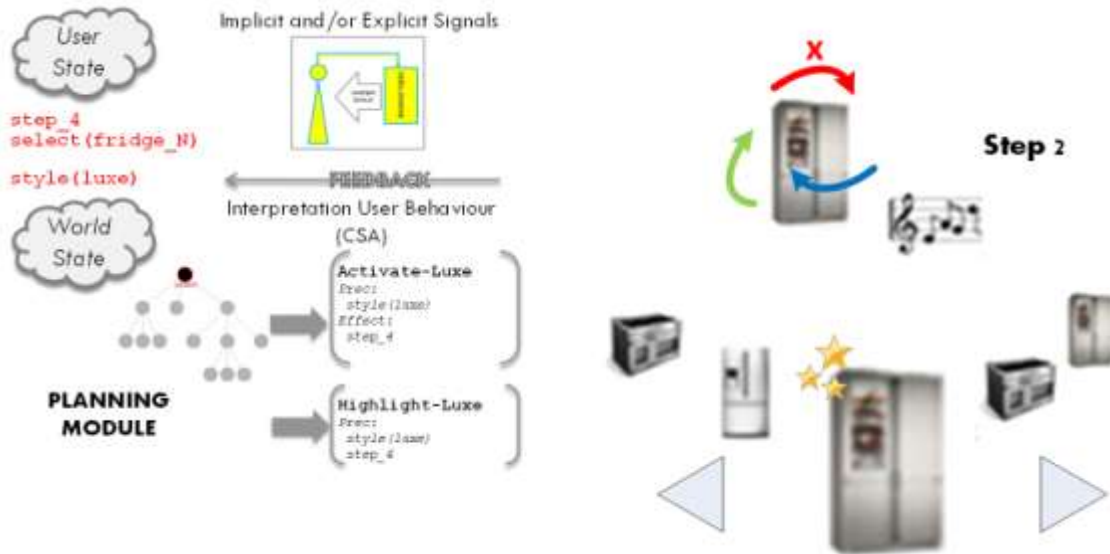
The second step of the scenario is the suggestion of a particular appliance as well as its presentation (Figure 18). This could results from explicit interaction from the user such as getting closer, looking at or touching the appliance. This would in feedback be represented in the user by the proposition interested (fridge\_N). The activation of the appliance by the narrative generator (here done by the Activate-Fridge operator) will allow the further generation the presentation of its features (here done by the Present-FridgeN operator) as well as the playing of sound for example. Here the presentation of the fridge is only represented by one simple operator for simplicity but in the final scenarios this can

constitutes of course a complete sequence of actions composed of different animations illustrating the appliance features.



**Fig. 19** - Third step of "Appliance" scenario.

The third step of the scenario is placing the appliance in the virtual kitchen (Figure 19). The selection of the appliance could either be triggered by implicit or explicit interaction of the user. This will change the proposition interested (fridge\_N) into select (fridge\_N) which in return will allow the activation of the virtual kitchen (Activate-CustomKitchen) and a suggestion of a possible position (Suggest-Position).



**Fig. 20** - Fourth step of "Appliance" scenario.

Finally, interpreted from implicit/explicit signals, the CSA can infer user preferences. For instance here in Figure 20, the proposition `style(luxe)` is added into the user state which in return will allow the activation of the appliances with similar features (Activate-Luxe). In a similar fashion that step one, the luxe nature of the appliances can be reinforced (Highlight-Luxe).

## 2.4 History: Bergen-Belsen Memorial

### 2.4.1 Context and Goals

The Bergen-Belsen concentration camp was built in May 1940. It was called at the time POW (prisoner-of-war) camp and was located in north-western Germany, between the villages of Bergen and Belsen. In 1945, 60.000 prisoners were liberated from the camp and 10.000 were found dead. The camp was divided in eight different sub-camps, each sub-camp holding different types of prisoners.

Nowadays almost nothing of the old concentration camp remains: just a few rests and a documentation centre that illustrates the history of the camp and its victims. An virtual reconstruction of the camp is now being built in order to enhance the visitors' experience.

For the users of the application, the aims are:

- To understand the importance of Holocaust
- Identify with the victims
- Assign meaning to the information acquired with respect to their lives.

In order to produce an enhanced, meaningful, informative and emotive story about Bergen-Belsen, we are developing a mobile application through the use of a handheld device displaying a virtual reconstruction of the space.

### 2.4.2 Scenarios and relation to Core Features

#### 2.4.2.1 Scenarios

The aim of this scenario is:

- To provide empathic and factual specialised experiences of historic events from different viewpoints (e.g., survivor, victim, camp liberator, guard) in order to support awareness and understanding about the significance of Bergen Belsen.
- To support, verify and enhance understanding of historic events through an empathic and factual specialised experience.
- To provide an empathic and factual spatialised experience of historic events in which the user can moderate their own emotion by selecting a guide path tagged for emotional intensity and valence.

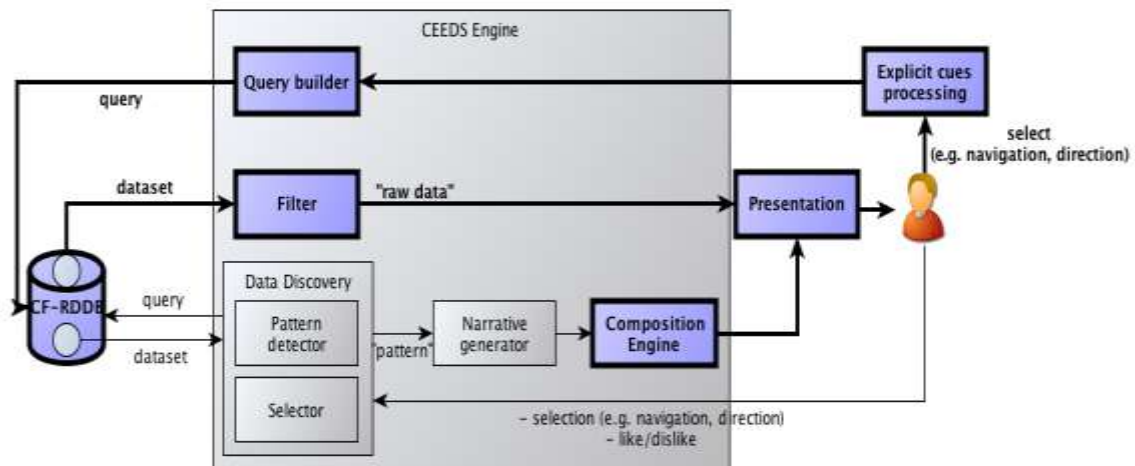
The Bergen-Belsen scenario will implement the core features through the following characteristics:

- [CF-RDDB] Raw database  
Text, images, audio, 3D objects from different sources: Bergen Belsen Memorial, Yad Vashem, Imperial War Museum are stored in the CF-RDDB.
- [CF1]: an informative experience



A 3D rendering of the environment and reconstructing experience from different viewpoints (survivor, historian, guard, liberator...) will be implemented.

- [CF2]: user input  
Recording of user responses (implicit and explicit): real-time (e.g. Navigation) and off-line (e.g. post-experience questionnaires)
- [CF3]: analysis and interpretation of user responses  
Experimenting with user responses and defining behaviour patterns in order to categorize the response database (emotional arousal, understanding of data, and memorization of events).
- [CF-URDB]: relating Raw data and User Responses
- [CF4]: an empathic experience  
Understanding and empathy: provide each user with a custom presentation according to her current affective state



**Fig. 21** - Illustration (in blue) of the parts of the CEEDs engine are so far implemented for the Bergen Belsen scenario.

## 2.4.3 Implementation of prototypes

### 2.4.3.1 Description

The “Bergen-Belsen Memorial” application prototype it is being developed using Unity3D and tested in an iPad<sup>5</sup>. It is basically a framework for real-time story-related data retrieval and presentation. The application can be used for a guided tour where the user can navigate through a virtual representation of the Bergen-Belsen concentration camp and retrieve

<sup>5</sup> <http://www.apple.com/ipad/>

information about the history of the camp. It can also be deployed as a desktop application or in the CXIM 2.0 environment with different navigation modes.



**Fig. 22** - "Bergen-Belsen Memorial" application-Main menu screen

### 2.4.3.2 Navigation modes

The main goal of the application is to be used in the open space of the now empty field of the Bergen-Belsen concentration camp. Hence, the user is able to move around in the physical world, holding the iPad, and explore the virtual representation of the camp through the device's screen. The system tracks the user's position and orientation through the iPad's GPS and gyroscope sensors respectively. The sensors' incoming data are used to update the virtual world camera placement depending on the user's movements. When the application opens, the user needs to initially calibrate the camera's orientation by keeping the device towards the north and vertical to the ground.



**Fig. 23** - Star-camp landscape- Application using GPS tracking system

However, an indoors version of the application allows the users to explore the virtual space using controllers(joysticks) that are placed on the bottom of the screen in order to change the camera's position or/and orientation by hand (Figure 24). Moreover, on the top right corner of the screen, a map is placed that shows the user's current position with respect to the information points.



**Fig. 24 - Star-camp landscape- Application using controls system**

### 2.4.3.3 Information Data

Along the path users can find different unities of information about the camp. The application incorporates a database where the data can be stored in the form of text, picture or audio. Additionally, this data can be grouped in categories/stories. These information units can be retrieved from the database and represented in the virtual world in the form of picture frames, info objects and speakers respectively. The user can trigger these objects by tapping on them (Figure 25 and 26). The data of each story can be presented to the users in selected information spots. In this first step, the information spots have been chosen to be inside the space of the reconstructed barracks. In the future online version of the app, the data will additionally be geo-tagged so that they can be placed appropriately, depending on their content. The specific information material will be provided by the Bergen-Belsen Memorial historians.



**Fig. 25 - Data representation inside barracks**



**Fig. 26 - Triggering textual data**

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## 2.4.3.4 Prototypes

To develop the conceptual framework of the Bergen-Belsen application prototypes to test specific features were developed. Components of these prototypes will later be integrated in the Bergen-Belsen application, and are described in the following sections.

### 2.4.3.4.1 Prototype 1: Navigation in a 3D world with geo-tagged data retrieval

The first prototype is based on a web-framework which deals with the large amount of data produced by online web services such as Wikipedia (wikipedia.org) and Flickr (flickr.com) (Figure 27). The framework has been appended for custom geo-tagged 3D objects and implemented to incorporate 3d virtual world instead of 2D maps. The virtual world and the camera (avatar in Figure 28) location are mapped on coordinates of a real world location. With real-time queries we can retrieve geo-tagged 3D objects and information (text, pictures, etc.) depending on the camera's current location. Hence, we can define a radius around the user within which geo-tagged information will be retrieved.



**Fig. 27** - Wiki- walk prototype



**Fig. 28** - Wiki- Walk in a 3d world

This prototype was been integrated and adapted for the Bergen-Belsen application. Below, we analyse the system's logic and in Figure 30 there is an illustration of the architecture.

#### LAMP Server

The data is handled through a LAMP<sup>6</sup> (Linux<sup>7</sup>, Apache<sup>8</sup>, MySQL<sup>9</sup>, PHP<sup>10</sup>) Server. The MySQL database contains the raw data. The API that we developed in PHP handles the data

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<sup>6</sup> [http://en.wikipedia.org/wiki/LAMP\\_\(software\\_bundle\)](http://en.wikipedia.org/wiki/LAMP_(software_bundle))

<sup>7</sup> <http://en.wikipedia.org/wiki/Linux>

<sup>8</sup> <http://www.apache.org/>

<sup>9</sup> <http://www.mysql.com/>

<sup>10</sup> <http://www.php.net/>

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requests; the API analyses the request that has been sent through the web (e.g requests for geo-tagged data on a radius around a specific point in the world). Then a MySQL query makes a request for data to the database. The data returned is then organized in JSON<sup>11</sup> format, using the JSON composer, and sent back to the client that requested them. JSON formatted data contain information about the 3D objects that are stored in the database (object id, geo coordinates, object location in the server, etc.)

#### iPad App

The iPad application has been developed in Unity3D<sup>12</sup>, and integrates the user's input, the data retrieved from the database, and the rendering of the virtual world. User input is his/her placement in space. The iPad GPS sensor gives the approximate position in the real world and the gyroscope gives the orientation (pitch, yaw, roll) of the iPad. These data are used as a reference for the camera's position and orientation in the virtual world, so that we have the impression that the iPad screen is a window to the virtual world.

The virtual world can be mapped to a specific area of the real world (e.g. the Bergen-Belsen Memorial site). Accordingly, every time the system receives a new GPS position, the system maps the geo-coordinates (latitude, longitude) to the appropriate point (x, z) of the virtual world and the camera is then placed on that point. Due to late GPS updates, the camera's movement needs to be smoothed between two sequential positions so that we give a more natural effect.

Unity3D incorporates a web service (named WWW), which is used in our case to send web requests to the LAMP server. Given the GPS position update, a request for data that are geo-tagged around that position is created and constantly sent to the server. The result is sent to the application in JSON format and decomposed by the JSON decomposer (LitJson lib). The 3D objects can now be downloaded directly from the database and rendered in the appropriate location in the virtual world.

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<sup>11</sup> <http://www.json.org/>

<sup>12</sup> <http://unity3d.com/>

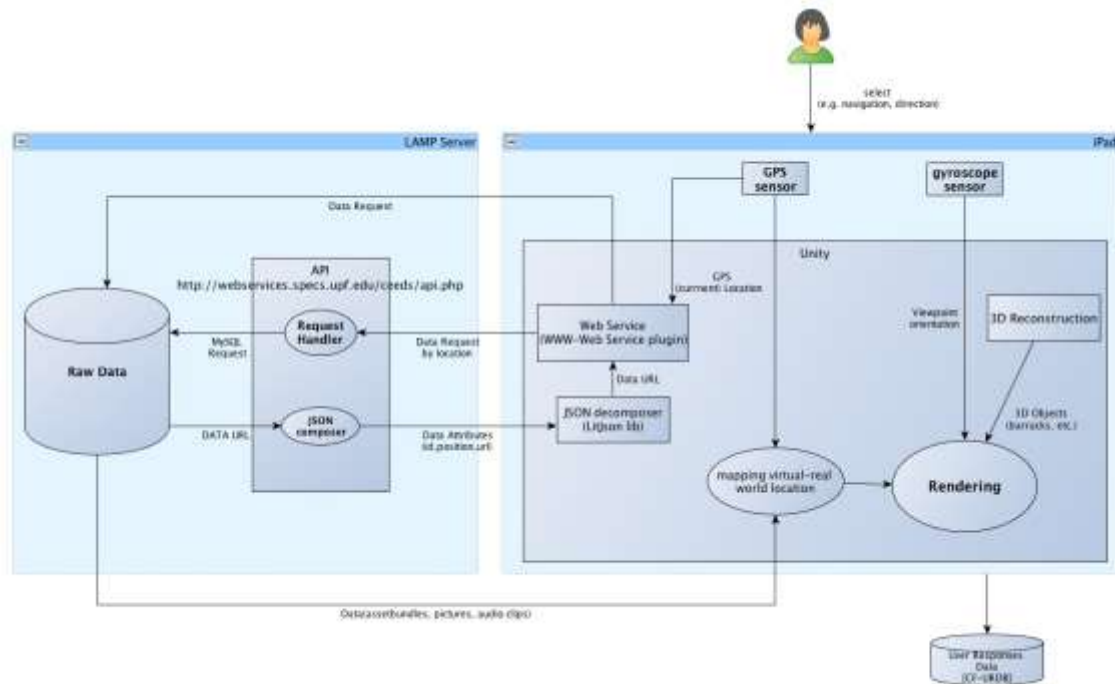
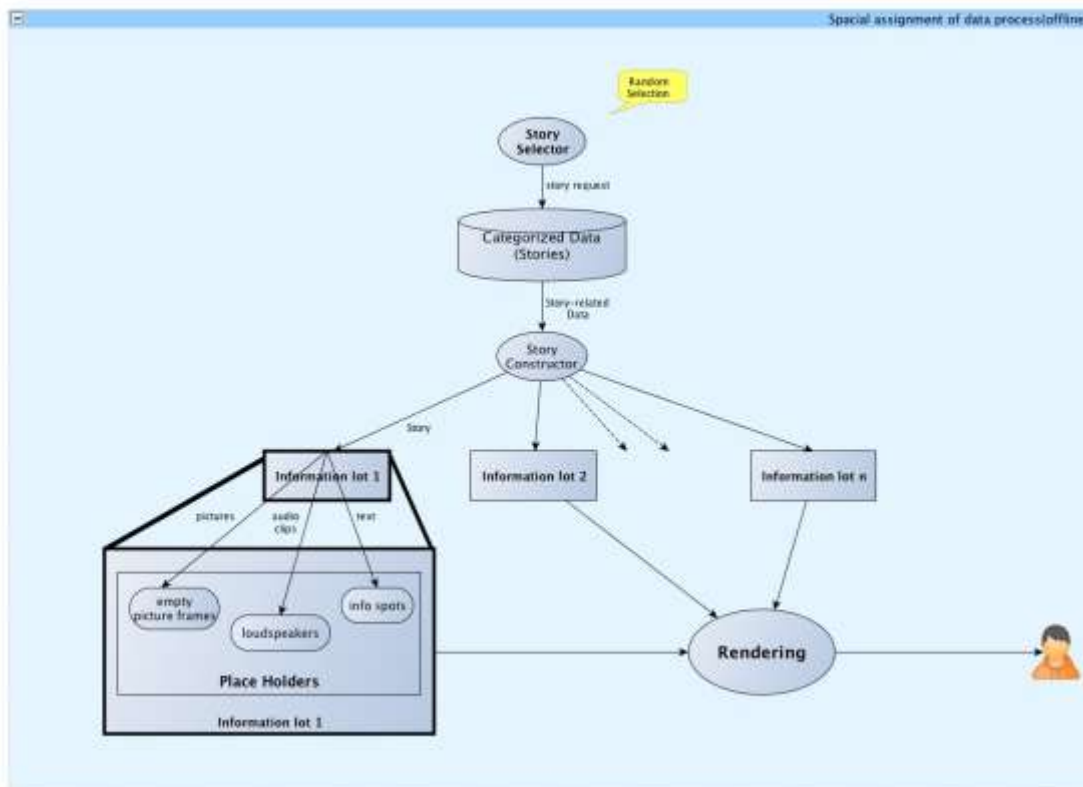


Fig. 29 - Scheme of the data retrieval methods in the Bergen-Belsen application.

### 2.4.3.4.2 Prototype 2: Real-time story-related data retrieval

The second prototype is related to the organisation and representation of the raw data of our system (pictures, audio, text) (Figure 30) and serves to develop the conceptualization of the Narrative Generator of the CEEDs Engine. The raw data are currently organised into story-related categories. Thus, a story might consist, for instance, of 10 pictures, 2 audio clips and 4 text fragments. Furthermore, the virtual space contains information lots (barracks). In each barrack are lying "place holders" (empty frames, speakers, and info buttons). Once we run the application, each story is randomly assigned to a specific info location (barrack) of the virtual world and the data are attached to the "place holders" in real-time.





**Fig. 30** - An offline framework for real-time story-related data retrieval and presentation.

### 2.4.3.5 Technologies

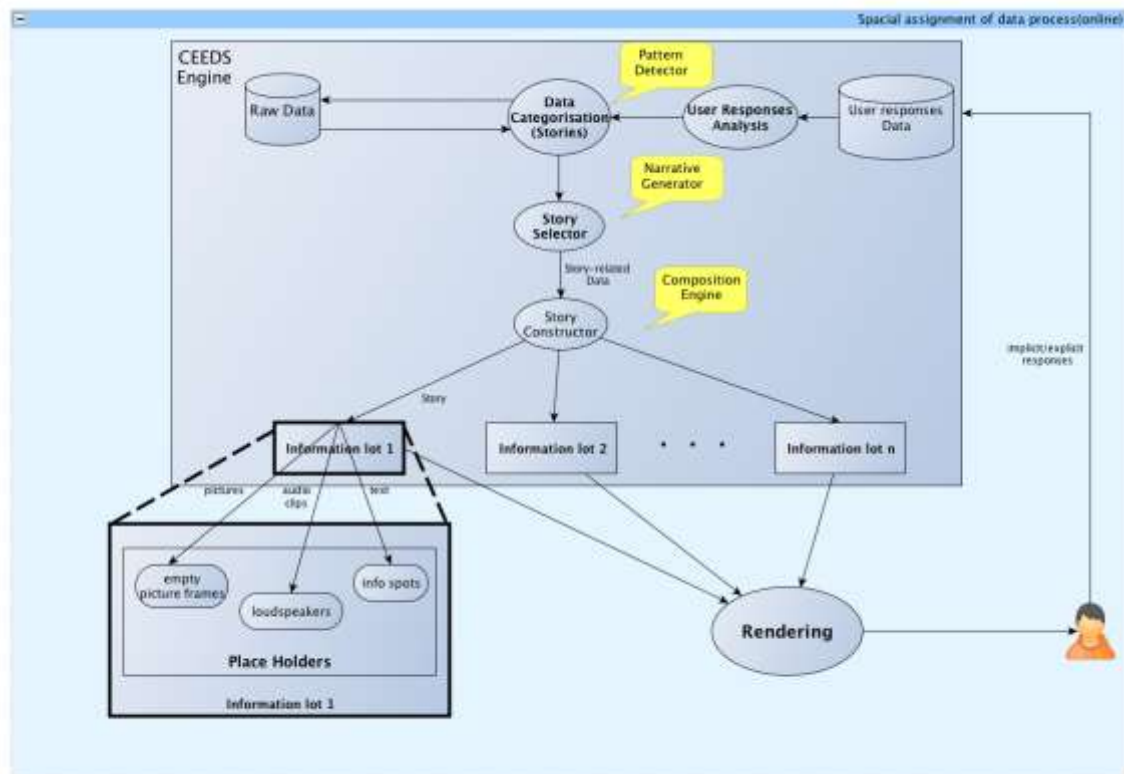
This section describes the technologies used for the development of the Bergen-Belsen application.

The application is developed for the iPad device built in with GPS sensor, gyroscope, accelerometer and compass. For retrieving the data from a web-service it uses a LAMP server to manage the web-service and JSON composer for encoding and de-encoding that are transmitted between the server and iPad. For the visualization it uses the Unity3D game engine and uses the *AssetBundles* feature (a format to store the 3D objects in an online database) and the web service support of unity (www module).

### 2.4.4 Future steps

- *Goal of prototype 2: Connection to the CEEDs engine*

Figure 31 depicts how prototype of the real time story-related data retrieval will be connected to the CEEDs engine. As it is shown in the figure we now have tested a part of the engine for the Bergen-Belsen Memorial application. However, as a future step a pattern detector will be responsible for the data categorization, given of course a big raw data collection. Moreover, instead of a random selection of stories that will be represented in each information lot, the goal will be to use the narrative generator for the stories selection. Finally, a concrete database of user’s implicit and explicit responses needs to be built and updated on run-time.



**Fig. 31 - Goal of prototype 2: Connection to the CEEDs engine**

This application is now ready to include a User-Response Data-Base (CF-URDB) which will be organized according to a specific ontology based on empirical experimentation. The interaction loop of the application needs however the implementation of implicit cues on part of the users (for example, physiological measurements assessing the affective states of the users).

These steps however call for a thorough design of a narrative structure that will take into account different criteria such as discourse structure (alternative timelines), data-specific design (e.g. sound design), or emotional modulation (offline and/or in real-time) (CF-4). Additionally, an extra-layer of information for debugging purposes but also as a possibility to present to the users feedback on their own reactions to the navigation is yet to be implemented (CF-5).



## 2.5 Science Application: Neuroscience and Astronomy

### 2.5.1 Introduction

The goals of exploring and discovering patterns in large datasets are the same in the application domains of Astrophysics and Neuroscience. For this reason, the two application areas are combined and termed "Science".

The "Science" application pursues the following goals:

- To support experts in the discovery of new patterns in datasets, e.g., via implicit responses indicating rule violation;
- To support experts in testing alternative hypotheses/models through visualisation of the data in different ways e.g., to use information about the strength, direction and number of independent confirmations ("known-ness") of relationships within and between a large set of variables. This could include algorithms and equations (e.g., explore implicit zones of interest in astrophysics, neuroscience);
- To provide students/visitors in classrooms/museums with an educational/learning tool to support better understanding of the significance of brain structure and its relationship to function.

In a first phase the efforts are concentrated on developing applications for the domain of neuroscience.

In this section we describe a first prototype for the visualization and interaction with neuronal systems that stem from the simulation environment *iqr*. This data comprises the static description of the system architecture as well as the real-time dynamics of the simulation of neurons and synapses. The prototype at the moment is using the user's explicit behaviour for navigation and triggering of dynamic displays.

The current plan for the further development of the "Science" application is on the one hand to include implicit responses from the user, and on the other hand to expand to other data sets such as multi-electrode recordings (see below).

### 2.5.2 Neuroscience application

Neuroscience is one of the scientific fields that contribute most to the generation of the extensive amount of data produced by multi-electrode recordings and magnetic resonance imaging. Within neuroscience one large set of data stems from the analysis of the connectivity of the brain (Sporns et al. 2005). This "connectome data" is composed of hundreds of thousands of neurons and their connections and is virtually impossible to understand without the aid of models and data analysis techniques.

Within CEEDs we will use neuronal "data" as [CF-RDDB] "Raw Data Database" stemming from tree sources:

1. Neuronal: Multi-electrode recording, which is derived from activity in snail brains (for detail see D8.1);
2. Connectome data: Structural and functional connection matrices for the cerebral cortex - more recent work also includes subcortical regions. The array "CIJ\_resampled..." contains the structural coupling coefficients ("anatomy");,

- 
3. Neuronal system descriptions of the simulator *iqr*. System architecture and dynamic properties (neuron and synapse update functions).

### **2.5.3 Prototype: 3D visualization and interaction framework for *iqr* neuronal systems**

The goal of this first prototype is to foster understanding of neuronal systems and neuronal data. This is achieved through the development of a 3D real-time visualization system that allows the graphical representation and interaction with the neuronal data such as the massive connectivity of neuronal network models designed with the multi-level neuronal system simulation software *iqr*. In this application domain *iqr* serves as a starting point for the development of a general data visualization system.

We built 3D real-time visualization system in the *eXperience Induction Machine* (XIM) (Bernardet et al. 2009) that allows the graphical representation of and interaction with the massive connectivity of neuronal network models designed with the multi-level neuronal systems simulation software *iqr*.

By transforming neuronal system designed with *iqr* into three-dimensional representations, and employing the sensors and effectors of XIM for the interaction, we allow the user to explore and interact with neuronal systems in real time, while physically navigating by walking through the system.

Such a transformation and interaction constitutes a first step towards a generalization of our system to be applied to other dataset in different fields. We aim at understanding which transformations can be achieved, what they entail, and by generalizing our model we can discover how different types of neuronal data can be transformed by means of different operations.

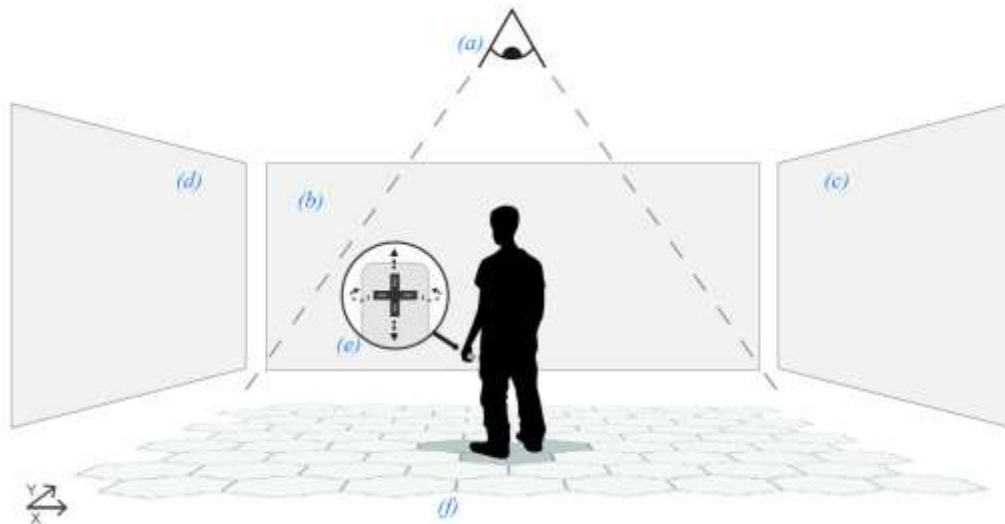
This prototype implements the following CEEDs core features:

- **[CF1]** The display of a CSA-independent filtered view, perspective or flow of CF-RDDB: Presenting data originating from neurobiological recordings generated using *iqr*
- **[CF2]** The collection and storage of users' explicit responses whilst they explicitly control their interaction with the data (e.g., navigation through a 3D representation)

#### **2.5.3.1 Interaction Design**

The system is rendered in real-time and constantly adapts to the neuronal network simulation activity, allowing live interaction with the user based on information from the CXIM 2.0 multi-modal tracking system. The right screen displays information and statistics about the system (number of processes, groups and connections) and about the closest neuronal groups (number of neurons, live activity). Additionally, the right screen displays the entire neuronal system from a wider and farther perspective, providing the user with a navigation map (Illustration 32c). The left screen shows the real-time activity plots of the

closer group that are triggered as the user approaches a group (Illustration 32f). The user can walk freely on the CXIM 2.0 floor and navigate through the system. To switch from one process to another, extra controls were implemented through the use of the Nintendo *WiiMote*<sup>13</sup>. The Nintendo *WiiMote* allows the user to change the process (i.e. move along the Z axis) and to control the display of information on the lateral screens (Illustration 32).



**Fig. 32 - Mapping between the user's position in XIM and 3D visualization**

Figure 32 shows the mapping between the user's position in XIM and 3D visualization. The main display (b) shows the 3D system according to the user perspective in a virtual world. The virtual camera represents the user's eyes, in a first-person viewpoint paradigm. The multi-modal tracking system captures the user's position using an overhead camera (a) and the pressure sensors in the floor (f). This information is sent to the virtual camera in Unity, and to the interactive floor (f) that lights a tile corresponding to the user's tracked position. The user starts the navigation in the centre of the XIM space and the virtual camera in Unity is fixed. When the user shifts forward or backward in the space, the camera moves along the Y axis. When the user shifts left or right, the camera moves along the X axis. To aid the user's orientation in the system, the projection on the left side shows a global view of the system (c). Additionally, this display provides statistics of the system as such total number of processes, neurons and connections, and report on activity in real-time. The activity plot display (d) shows the activity plots of *iqr*. *iqr* sends updates to Unity every 500ms through UDP packets that contain the real-time activity value of each group. To perform movements that are not easily mapped into movements in the plane such as moving along the Z axis and shifting from one process to another, the user is using a Nintendo *WiiMote* controller (e). Movements that are not easily mapped into movements in the plane such as moving along the Z axis and shifting from one process to another are controlled by a handheld Nintendo *WiiMote* controller (e).

<sup>13</sup> [http://en.wikipedia.org/wiki/Wii\\_Remote](http://en.wikipedia.org/wiki/Wii_Remote)

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## 2.5.3.2 *iqr*, a multi-level neuronal simulation environment

*iqr* is a multi-level neuronal simulation environment which allows designing complex neuronal models graphically, and to visualize and analyze their properties on-line (Bernardet et al. 2010). The architecture of *iqr* is modular, providing the possibility to write new neuron and synapse types, as well as custom interfaces to other hardware systems. *iqr* can be connected to both sensors and effectors, and can simulate large neuronal systems of over 500000 elements (neurons and synapses). The code of *iqr* is publicly accessible under the GNU General Public License (GPL), and the software runs on the Linux, Apple's Mac OS X and Microsoft Windows platform<sup>14</sup>.

*iqr* provides a 2D graphical interface to design and manipulate the neuronal model. While the simulation is running, the user can visualize internal states and change the parameters of system elements.

Neuronal models in *iqr* are organized at three different levels:

1. The top (or system) level comprises an arbitrary number of processes, and connections.
2. The second level consists of processes which in turn contain an arbitrary number of groups. The process level allows to structure the model into logical units, and to interface groups to external devices.
3. At the third level are the groups that are an aggregation of neurons of identical type.

Connections are used to send information from neurons of one group to neuron of another group, and are made up of synapses of identical types.

Functional as it might be, the two-dimensional representation of a neuronal system that is effectively organized in three dimensions, can present a limitation to the understanding of the system the user is dealing with.

*iqr* stores the entire neuronal system description (systems, processes, groups, neurons, connections, and connection type) in a standard XML file. To create the 3D representation of a neuronal network we use Unity<sup>15</sup>. Within Unity we developed an engine to parse the XML files produced by *iqr* and extract the following data about the neuronal network:

- Processes: Number of process, name, position
- Groups: Name, id, number of groups, position, type, number of cells
- Connections: Origin and destination groups, type of connection

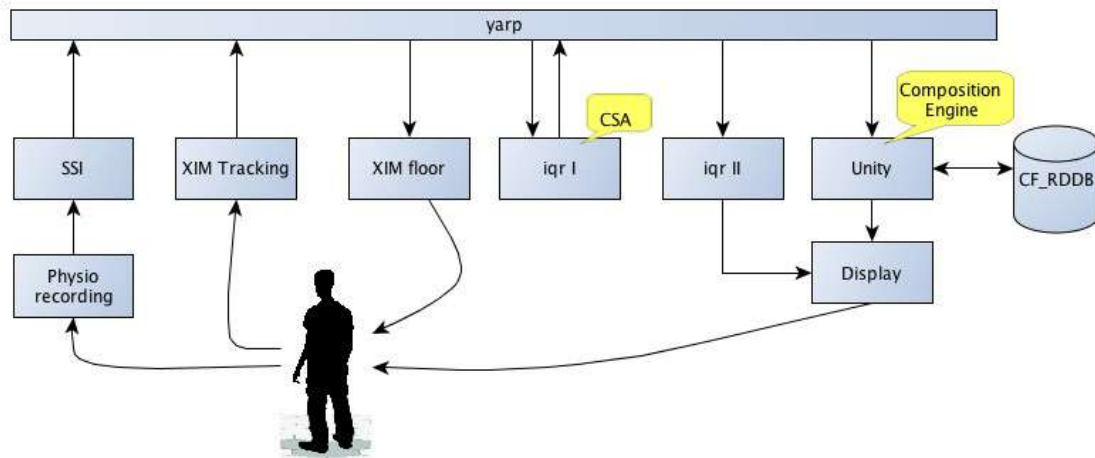
The figure below shows a schematic view of the Neuroscience application. Two instances of *iqr* run at the same time in our system. The first one (I) receives information from the XIM Tracking machine (user's X,Y coordinates in the space) and from Unity (proximity of the user to neuronal groups). On the other hand it sends back useful information to the XIM display (name of the processes and of the neuronal groups), to the XIM floor (real time feedback about position through light on the tiles) and to the second instance of *iqr* (II) which displays

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<sup>14</sup> <http://iqr.sourceforge.net>

<sup>15</sup> <http://unity3d.com/>

in the XIM screen the space plots (i.e. real time activity) of the selected neuronal groups. All the machines communicate through YARP.



**Fig. 33 - Scheme of the Neuroscience Application**

### 2.5.3.3 Creating the 3D representation of the neuronal system

#### Processes

The processes are rendered as horizontal 3D layers distributed on the Y axis with a common Z coordinate. The size and the position of the processes are fixed. Multiple processes are arranged vertically, following their original order in the iqr system. The layer of the active process, i.e. the one the user is navigating at that moment, has a low alpha level, while inactive layers are translucent (70% alpha level) to allow the visualization of the above and below processes. The user receives real-time feedback regarding his/her position within the layer of a process, and information about the closest groups (name, type, size, amount of activity) is displayed on the front screen.

#### Groups

The groups of neurons are represented as spheres. The size of a sphere is logarithmically scaled based on the number of neurons a group contains. The position of the spheres on the X and Y axes is determined by the original coordinates in the iqr system as specified in the XML file. The colors of the groups are determined according to the type of neurons they contain.

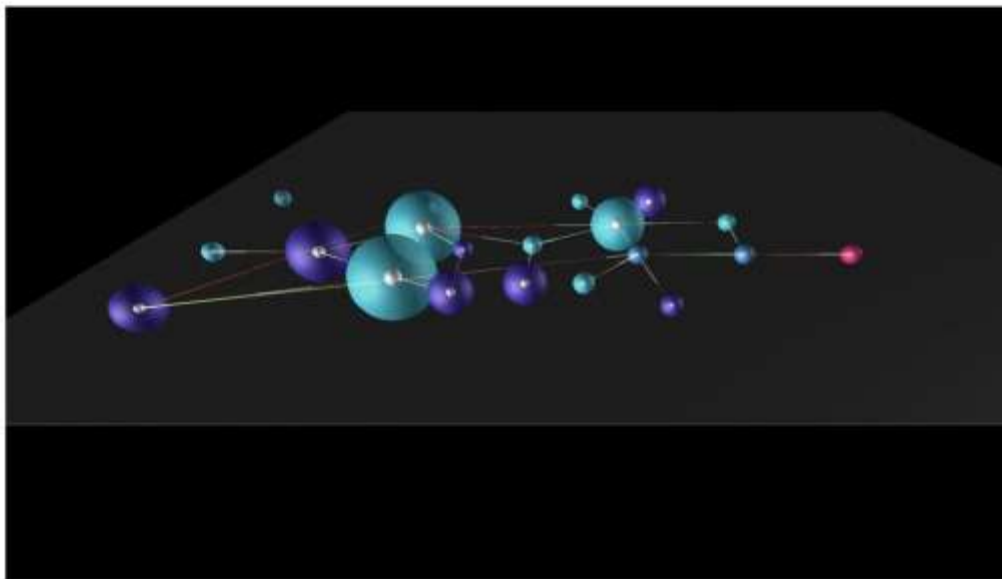
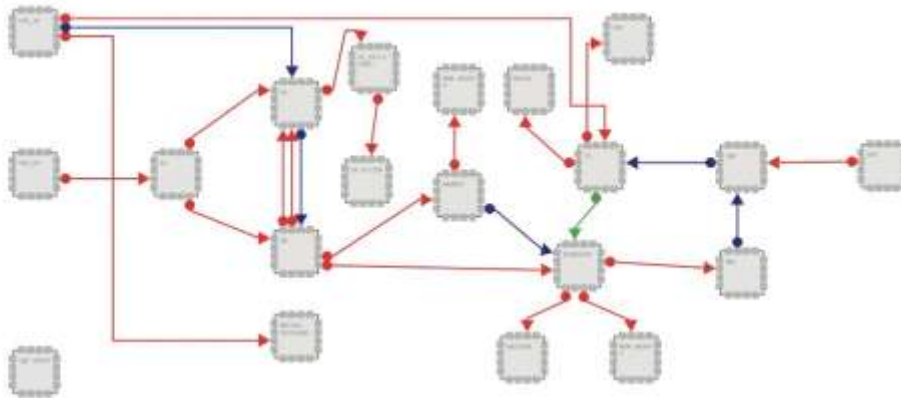
#### Connections

Each connection is represented as a tube and links the source group to the destination group. The colors of the connections are assigned according to their effect on the target neurons. The directionality of the connections is represented by animated visual effects which shoot towards the tube following a path which proceeds from the source to the destination group. This representation allows observing the exchange of information between groups in real-time, hence providing the user with the impression of a live and dynamic system.

#### Real time Activity

iqr and Unity communicate bi-directionally via UDP sockets. After starting the neuronal network simulation, iqr sends to Unity the average activity of each neuronal group via a UDP every 500ms. The activity is scaled between 0 and 1:00, and calculated as the average

activity per group. In Unity the activity is rendered as pulsating orbs inside each group, with a blinking frequency directly proportional to the amount of activity. In the opposite direction Unity sends triggers to iqr whenever the user moves near a group in the 3D representation. Upon reception of a trigger, iqr shows a real-time space plot of the corresponding group.



**Fig. 34** - On top the cerebellum model in iqr and the 3D visual representation on the bottom

## 2.5.4 Next steps neuroscience application

The next steps for the neuroscience application include the integration of implicit behaviour of the user, and the expansion to "real data" such as multi-electrode recording.

A potential scenario for the neuroscience application will be:

### **Step 1: Assessment of the user's level of expertise and prior knowledge**

In a first step the user's level of experience and prior knowledge is assessed and stored in the URDB

### **Step 2: Selection of the system of interest**

The user chooses what system he/she is interested in.

### **Step 3: Closed-loop interaction with the 3D data system**

The actual interaction with the data is a closed loop system where the CSA optimizes the level of understanding of the neuronal system the user has chosen.

During the interaction the system records and stores the user's implicit and explicit responses [CF2]. The off-line responses from the user include the level of understanding about the system. On-line responses from the user include markers of information processing load (physiological and behavioural), rule violation, spatial attention (via eye tracking), spatial navigation behaviour, direct commands through gestures and a wand (e.g. wii remote).

While the user is exploring the data space, the CSA will guide the user through the data based on his/her own implicit/explicit choices, experience or the experience of other users [CF4].

Output to the user [CF1] in CXIM comprises:

- Spatial organization of the data (layouts)
- Density of presented information (e.g. speed in the case of passive navigation)
- Switching between functional and structural information displays
- Change of interaction mode, i.e. the way in which the users behaviour is mapped onto navigation through the data
- Visualizations at varying levels of abstraction
- Sonification expression spatial structure and dynamics

## **2.5.5 Integration into the CEEDs Engine**

The Neuroscience application will be integrated into the CEEDS engine (Figure 35). Two instances of *iqr* run at the same time in our system. The first one (I) is running the simulation sending (and receiving) feedback to (and from) the CEEDs Sentient Agent. It also sends to Unity real time information about the running simulation (e.g. activity of the neuronal groups). The second instance of *iqr* (II) receives information from Unity (proximity of the user to neuronal groups) and sends back information to Unity (e.g. name of the processes and of the neuronal groups) and to the XIM display (real time *iqr* space plots). Unity receives from the composition engine arrangements for the final presentation and displays the results in the XIM (displays and floor).

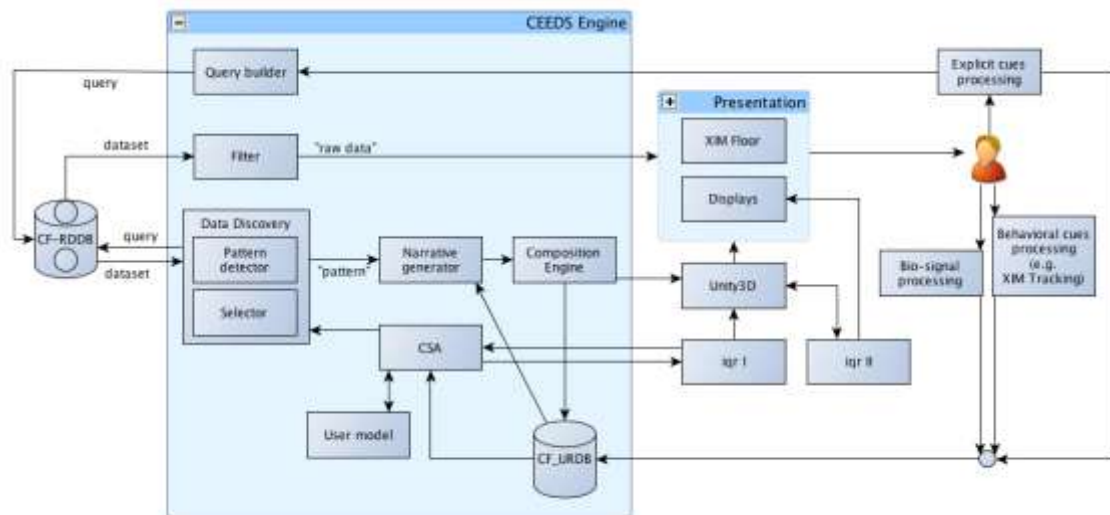


Fig. 35 - Schematic view of the Neuroscience



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