A formal model for supporting the adaptive access to virtual museums

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Abstract Zz-structures are particular data structures capable of representing both hypertext data information and contextual interconnections among different information. We consider an extension of the standard zz-structure model in terms of computational agents. In particular, we propose a multi-agent adaptive system in which users store their personal information inside a zz-structure and agents collaborate in order to support them in the extraction of personalized navigational views, thus creating personalized tours of virtual museums. The strength of this new model resides in the level of freedom users have for the dynamical choice, based on some present interest or necessity, of their navigational path inside the virtual museum.

1 Introduction

In the past, culture was strictly related to a face-to-face model of interaction. With the diffusion of the Web this approach has deeply changed: while previously people would physically visit a museum, now the increased use of hypermedia to support access to museum information has modified this approach, thus allowing users to virtually navigate inside virtual museums. Users may have, however, different backgrounds, goals, preferences, hyperspace experiences, knowledge, thus the system has to adapt to their needs and support them during navigation [1]. Virtual marketing museums, have been developed to promote real physical museums. On the other hand, learning museums are accessed by users that want to "learn" something while exploring the structured hyperspace with context-adapted narration, i.e., users that aim at interacting with a system that recreates a real life museum tour guided by a real museum guide [2]. However, virtual museums usually provide only very standard and impersonal guided tours by offering , e.g., replicas of the exhibition experience on-line (see, e.g., the open source toolkits created by Omeka [3]).

The creation of the so called "personalized views", i.e., the displaying of a limited and well defined and personalized sub-portion of the entire hyperspace is something that has already been considered in different settings. Traditional web browsers implement this strategy through bookmarks or personalized site views such as, e.g., in My Yahoo and My Netscape. An extension to this are the adaptive bookmarking systems such as WebTagger [4], Siteseer [5], and PowerBookmarks [6]. Finally, other solutions which use Information Retrieval techniques to collect information on different users so to provide them useful suggestions based on their needs, are Web-based information services [7, 8].

Some work towards the development of different techniques to design adaptable interfaces for museum web sites has been done, e.g., in [1] where changes on the visitor user profile and thus on the type of presentation, of information, and of navigation are allowed. In [9] the authors present Flamenco, an interface for browsing and searching a large amount of information using similarities to sample images. Recently, the Delphi framework of semantic tools and community annotation for museum collections has been presented [10]. Delphi is an Open Source toolkit, that inherits some ideas of [9] and it is based on linguistic analysis tools, that can be used for browsing and searching in diverse museum collections.

Creating personalized views for the navigation inside virtual museum is thus a very interesting issue. In this paper we propose a formal structure for the visualization of these views. The proposed visualization technique, supported by an agent-based technology, gives a certain level of freedom to the users by allowing them to interact with the system in order to (partially) choose the path to follow during their navigation.

Our system assumes the storage of the views inside zz-structures [11], particular data structures that store both hypertext data information and the contextual interconnections among different information. These structures are very flexible and have been used in different kind of applications, such as modeling, e.g., an information manager for mobile phones [12], bioinformatics workspaces [12, 13], and many others [14, 15]. Zz-structures have also been applied to the creation of an EAD (Encoded Archival Description) a hierarchical organization of archival collections, typically implemented in XML. This EAD finding aid has been transformed into a zz-structure for visualizing archival information [16].

Observe that, good navigational tools have to: 1) limit the navigational material by identifying a subset of "interesting" pages; 2) define adequate structures for the items' storage and create personalized user views; 3) define personalized and adaptive navigational paths for the users.

The paper is organized as follows: in Section 2 we first concentrate on point 2, i.e., we first provide a formal description of the structures and views (in particular n-dimensional views) and we show how to use them to create personalized user views in the context of virtual museum tours. In Section 3, we show how to extend this new concept of views in a dynamically changing setting (point 3), i.e., in a setting where users may dynamically interact with the system in order to decide the path to be followed (limited to a restricted neighborhood of their actual posi-

tion). We conclude in Section 4 where we mention that point 1 is the topic of our on-going research (we leave its handling to other techniques, see, e.g., [10]).

2 Concept Space and Map

In order to define the concept space and map, we need some preliminary definitions of zz-structures and related views.

2.1 Zz-structures

Zz-structures [11] introduce a new, graph-centric system of conventions for data and computing. A zz-structure can be thought of as a space filled with cells.

Cells are connected together with links of the same color into linear sequences called *dimensions*. A single series of cells connected in the same dimension is called *rank*, i.e., a rank is in a particular dimension. Moreover, a dimension may contain many different ranks. The starting and an ending cell of a rank are called, *headcell* and *tailcell*, respectively, and the direction from the starting (ending) to the ending (starting) cell is called *posward* (respectively, *negward*). For any dimension, a cell can only have one connection in the posward direction, and one in the negward direction. This ensures that all paths are non-branching, and thus embodies the simplest possible mechanism for traversing links.

Formally a zz-structure is defined as follows (see, [15]). Consider an *edge-colored multigraph* $ECMG = (MG, C, c)$ where: $MG = (V, E, f)$ is a multigraph composed of a set of *vertices* V, a set of *edges* E and a surjective function $f : E \rightarrow \{\{u, v\} \mid u, v \in V, u \neq v\}$. C is a set of colors, and $c : E \rightarrow C$ is an assignment of colors to edges of the multigraph. Finally, $deg(x)$ (respectively, $deg_k(x)$) denotes the number of edges incident to x, (respectively, of color c_k).

Definition 1. *A* **zz-structure** *is an edge-colored multigraph* $S = (MG, C, c)$, *where* $MG = (V, E, f)$, *and* $\forall x \in V$, $\forall k = 1,...,|C|$, $deg_k(x) = 0,1,2$. *Each vertex of a zz-structure is called* zz-cell *and each edge a* zz-link. *The set of isolated vertices is* $V_0 = \{x \in V : deg(x) = 0\}$.

An example of a zz-structure related to an art museum is given in Fig. 1. Vertices are paintings, in particular portraits. Normal (red), dashed (green) and thick (blue) lines group, respectively, operas of the same artist: in particular, $\{v_1, ..., v_{11}\}$ and $\{v_{12}, ..., v_{18}\}$ identify, respectively, Van Gogh's and Gauguin's portraits; dashed lines group self-portraits of the two artists ($\{v_1, ..., v_7\}$ of Van Gogh and $\{v_9, ..., v_{15}\}$ of Gauguin); finally thick lines group operas of the same museum: v_{12}, v_1, v_3 and v_6, are in the Van Gogh Museum of Amsterdam, while v_2, v_4, v_8, v_9, v_{10}, v_{11}, v_{15}, v_{17} and v_{18} are in Musée d'Orsay of Paris.
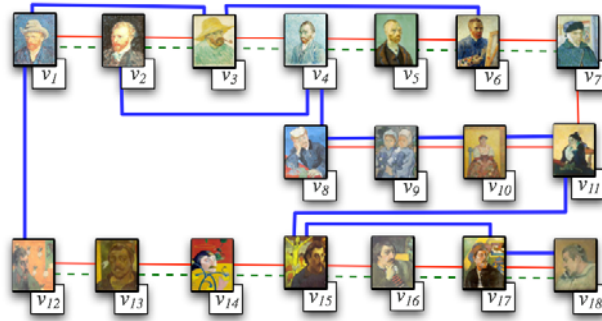
Fig. 1. Van Gogh - Gauguin: self-portraits.

Dimensions

An alternative way of viewing a zz-structure is a union of subgraphs, each of which contains edges of a unique color.

Proposition 1 *Consider a set of colors* $C = \{ c_1, c_2, ..., c_{|C|} \}$ *and a family of indirect edge-colored graphs* $\{ D^1, D^2, ..., D^{|C|} \}$, *where* $D^k = (V, E^k, f, \{ c_k \}, c)$, *with* $k = 1, ..., |C|$, *is a graph such that: 1)* $E^k \neq \emptyset$; *2)* $x \in V$, $deg_k(x) = 0, 1, 2$. *Then* $S = \bigcup_{k=1}^{|C|} D^k$ *is a zz-structure.*

Definition 2. *Given a zz-structure* $S = \bigcup_{k=1}^{|C|} D^k$, *then each graph* D^k, $k = 1, ..., |C|$ *is a distinct* **dimension** *of* S.

In Fig. 1, we may identify three dimensions: *artist*, *self-portraits* and *museum*, respectively represented by normal, dashed and thick lines.

Ranks

A rank is in a particular dimension and it must be a *connected* component.

Definition 3. *Consider a dimension* $D^k = (V, E^k, f, \{ c_k \}, c)$, $k = 1, ..., |C|$ *of a zz-structure* $S = \bigcup_{k=1}^{|C|} D^k$. *Then, each of the* l_k *connected components of* D^k *is called a* **rank**.

A dimension can contain one (if $l_k = 1$) or more ranks. Moreover, the number l_k of ranks differs in each dimension D^k. In Fig. 1, each of the three dimensions contains two ranks; in particular, the dimension *artist* contains *van-gogh*, and

g*auguin*. We note that the example in Fig. 1 is only a fragment of a larger zz-structure; for this reason, for example, in the dimension *museum* we identify only two ranks (related to the *Van Gogh Museum of Amsterdam* and to the *Musée d'Orsay of Paris*). In reality, this dimension contains all the ranks related to the museums in which the paintings are exhibited (such as the *National Gallery of Art of Washington*, the *MacNay Art Museum of San Antonio, Texas*, the *Fogg Art Museum of Cambridge*, etc.).

Given a rank R_i^k, an alternative way of viewing a dimension is a union of ranks:

$$D^k = \bigcup_{i=1}^{l_k} R_i^k \bigcup V_0^k .$$

Head and tail cells

If we focus on a vertex x, $R_i^k = ...x^{-2}x^{-1}xx^{+1}x^{+2}...$ is expressed in terms of negward and posward cells of x: x^{-1} is the negward cell of x and x^{+1} the posward cell. We also assume $x^0 = x$. In general $x^{-i}(x^{+i})$ is a cell at distance i in the negward (posward) direction.

Definition 4. *Given a rank $R_i^k = (V_i^k, E_i^k, f, \{c_k\}, c)$, a cell x is the **headcell** of R_i^k iff exists its posward cell x^{+1} and it does not exist its negward cell x^{-1}. Analogously, a cell x is the **tailcell** of R_i^k iff exists its negward cell x^{-1} and it does not exist its posward cell x^{+1}.*

Views.

Personalized views are shown to the users, when they choose a vertex as a focus and a set of preferred topics, e.g., type of operas, artists and so on.

The classical **guided tour** is a suggested linear path, defined in terms of a specific dimension.

An example of guided tour on dimension *museum* is proposed in Fig. 2; in this case, a user is interested to view the portraits, accessing them museum by museum.

The focus is the Musée d'Orsay, and the related rank, composed by 9 cells, is visualized; referring to Fig. 1, the portraits contained in Fig. 2 are v_2, v_4, v_8, v_9, v_{10}, and v_{11} collocated in the room 35, v_{15} in the room 43, while v_{17} and v_{18} in the room 44. The user can choose to continue his/her tour by clicking on the forward button, or directly selecting one museum among the ranks present in the current dimension (*Van Gogh Museum of Amsterdam*, *National Gallery of Art of Washington*, *MacNay Art Museum of San Antonio, Texas*); in this case, the zoomed cell related to the Musée d'Orsay will substituted by the cell related to new museum, selected by the user.

Fig. 2. A guided tour.

A guided tour shows one dimension; now we formally present the concept of a 2-dimensional view. $x \in R_{(x)}^a$ denotes that $R_{(x)}^a$ is the rank related to x of color c_a.

Definition 5. *Given a zz-structure* $S = \bigcup_{k=1}^{|C|} D^k$, *where* $D^k = \bigcup_{i=1}^{l_k} R_i^k \bigcup V_0^k$, *and where* $R_i^k = (V_i^k, E_i^k, f, \{c_k\}, c)$, *the* **H-view** *of size* $l = 2m+1$ *and of focus* $x \in V = \bigcup_{i=0}^{l_k} V_i^k$, *on main vertical dimension* D^a *and secondary horizontal dimension* D^b *(($a,b \in \{1,...,l_k\}$), is defined as a tree whose embedding in the plane is a partially connected colored* $l \times l$ *mesh in which:*

- *the central vertex, in position* $((m+1),(m+1))$*, is the focus* x*;*
- *the horizontal central path (the* $m+1$*-th row) from left to right, focused in vertex* $x \in R_{(x)}^b$ *is:* $x^{-g}...x^{-1}xx^{+1}...x^{+p}$ *where* $x^s \in R_{(x)}^b$*, for*

  $s = -g,...+p(\, g,p \leq m \,)$.

- *for each cell* x^s*,* $s = -g,...+p$*, the related vertical path, from top to bottom, is:* $(x^s)^{-g_s}...(x^s)^{-1}x^s(x^s)^{+1}...(x^s)^{-p_s}$*, where* $(x^s)^t \in R_{(x^s)}^a$*, for*

  $t = -g_s,...,+p_s\ (\, g_s, p_s \leq m \,)$.

Intuitively, the *H*-view extracts ranks along the two chosen dimensions. Note that, the name *H*-view comes from the fact that the columns remind the vertical bars in a capital letter H. As example, consider Fig. 3 that refers to the zz-structure of Fig. 1. The chosen dimensions are *self-portraits* and *museum*. The view has size $l=2m+1=5$, the focus is v_3, the horizontal central path is $v_3^{-2}v_3^{-1}v_3v_3^{+1}v_3^{+2} = v_1v_2v_3v_4v_5(\, g,p=2 \,)$. The vertical path related to $v_3^{-1} = v_2$ is $(v_3^{-1})(v_3^{-1})^{+1}(v_3^{-1})^{+2} = v_2v_4v_8(\, g_s=0, p_s=2 \,)$, that is $v_3^{-1} = v_2$ is the headcell of the rank as $g_s = 0 < m = 2$.
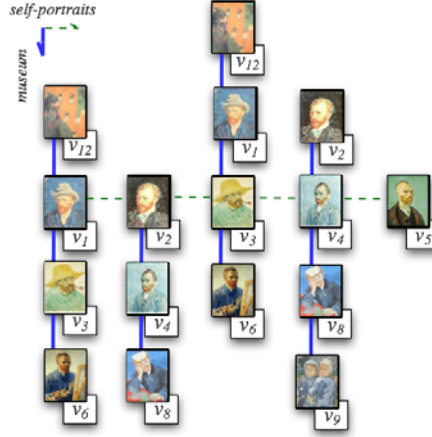
Fig. 3. An *H*-view related to Fig. 1.

We now extend the known definition of H to a number $n > 2$ of dimensions. Intuitively, we will build $n-1$ different *H*-views, centered in the same focus, with a fixed main dimension and a secondary dimension chosen among the other $n-1$ dimensions. Formally:

Definition 6. *Given a zz-structure* $S = \bigcup_{k=1}^{|C|} D^k$ *, where* $D^k = \bigcup_{i=1}^{l_k} R_i^k \bigcup V_0^k$ *, and where* $R_i^k = (V_i^k, E_i^k, f, \{c_k\}, c)$ *, the* **n-dimensions *H*-view** *of size* $l=2m+1$ *and of focus* $x \in V = \bigcup_{i=0}^{l_k} V_i^k$ *, on dimensions* $D^1, D^2, ..., D^n$ *is composed of* $n-1$ *rectangular H-views, of main dimension* D^1 *,* $i = 1, ..., n$ *, all centered in focus x.*

2.2 A-Space and a-Map

A concept space provides an ontology for a given knowledge domain.

Definition 7. *An* **a-space** *a-CS is the representation of a concept space in terms of a multi-agent system composed of five types of agents: concept maps, dimensions, ranks, composite and atomic cells.*

These five agent classes represent five abstraction levels of the concept space. Concept maps know and directly manipulate dimensions and isolated cells; they include concepts and relationships between concepts, that are organized in dimensions. Dimensions, uniquely identified by their colors, know and manipulate their connected components, i.e., their ranks. Ranks know and coordinate the cells and the links that connect them; composite cells contain concept maps related to more specific topics, and finally atomic cells are primary entities and directly refer to documents.

Agents can be used in order to model concurrent computations. They are organized as a universe of inherently autonomous computational entities, which interact with each other by sending messages and reacting to external stimuli by executing some predefined procedural skills. Various authors have proposed different definitions of agents. In our setting an agent is defined as follows:

Definition 8. *An **agent** is denoted A = (Ts, En, Re, Ac) where*

- *Ts represents its **topological structure**;*
- *En={η_1,η_2,…} defines its local **environment**;*
- *Re={ϱ_1,ϱ_2,…} is the finite set of incoming **requests**;*
- *Ac={α_1,α_2,…} is the discrete, finite set of possible **actions**.*

Ts and *En* represent the passive part of the agent, while *Re* and *Ac* its active part. To give an idea of our agent classes, we define the concept map agent.

Definition 9. *An a-map is a **concept map** agent a-map=(Ts,En,Re,Ac) where*

- *Ts=S (see Definition 2.1 and Proposition 1);*
- *En= {dimensions, isolated-cells, colors, ranks, cells, links, …};*
- *Re={$\varnothing$}, initially;*
- *Ac={return-colors, return-ranks, return-cells, return-links, check-global-orientation, delete(cell$_1$,…,cell$_n$), …}.*

dimensions, isolated-cells and the other data of *En* contain information on the structure. The first four actions of *Ac* are internal to the agent and enable it to derive the colors, ranks, cells and links of the zz-structure. These actions are performed by sending querying messages to dimensions and isolated-cells; ranks and used colors are obtained sending a request to the dimension agents, while cells and links references are requested from the dimensions to the rank agents. Other scripts, such as *check-global-orientation* that checks whether local orientation of neighboring cells are consistent, and *delete(cell$_1$, …, cell$_n$)*, that deletes a chosen set of cells, are used in dynamic operations illustrated in the next section.

3 Displaying and Changing Views

In this section we will show how a session agent may interact with the users in order to first create and display *H*-views, and then neighboring views, i.e., views where the focus is at distance one from the previous one. While displaying these personalized views, the users will also be able to personalize their paths, by deciding to what neighboring view they will move, what dimension they would like to add/remove and so on. During this navigation process, the users can recreate a setting similar, e.g., to the one of [17], by storing the information they find interesting in an album, in order to create a personal, re-usable workspace.

More precisely, assume that A is the user-author, SA the session agent of Z, D^k is the dimension with color c_k, and for simplicity, $R^k_{(x)}$ is the rank cell x belongs to. Whenever SA receives from A the message *h-view(x, l, D^a, D^b)*, regarding the displaying of an *H*-view, centered at x, of size l, using main vertical dimension D^a and secondary horizontal dimension D^b, it sends to x the message *focus(h-view, l, D^a, D^b)*, asking x to assume the role of the focus in the visualization of the *H*-view. The visualization operation may be divided into two different steps.

Step 1. *Wake-up of vertices in the horizontal m+1-th row, i.e., $x^{-g},...,x^{-1},x^o = x,x^{+1}...x^{+p}$. The focus activates rank $R^b_{(x)}$ that propagates the request to the vertices in the m+1-th row. These vertices are woken-up and are visualized horizontally, i.e., as* horiz *(see Fig. 4).*
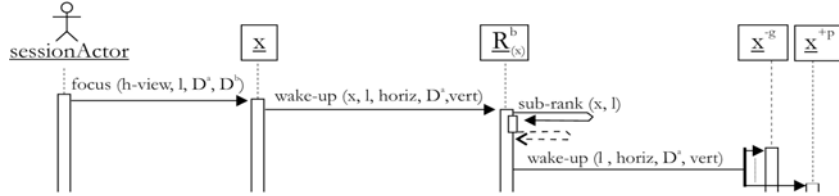

Fig. 4. Computation related to D^b.

Step 2. *Propagate the wake-up request from the vertices in the m+1-th row, to their rank of color c_a, and from the rank to its vertices at distance at most m from $x^{-g},...,x^{-1},x^o = x,x^{+1}...x^{+p}$, respectively. These vertices are visualized vertically, i.e., as* vert *(see Fig. 5).*
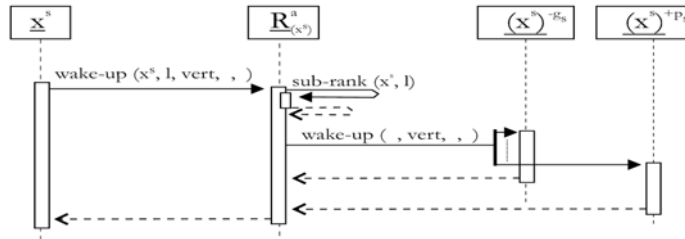

Fig. 5. Computation related to D^a.

Another interesting issue is the visualization of a neighboring view, e.g., a view where the focus shifts by one position.

Agents may either apply the *sleep* procedure that turns off all the cells that have been woken up, and then start from scratch a new *wake-up* procedure, or try to optimize the computation and turn off only part of the cells and turn on part of oth-

ers. E.g., whenever the focus moves vertically, the simplest procedure consists of turning off the whole old view and turning on the new one as it follows:

Posward-Vert-Shift-h-view$((x^0), (x^0)^{+1}, l, D^a, D^b)$
1. <u>send-now</u>($sleep((x^0), l, horiz, D^a, vert)$) <u>to</u> $R^b_{(x^0)}$
2. <u>send-now</u>($focus(\text{h-view}, l, D^a, D^b)$) <u>to</u> $(x^0)^{+1}$

Note that the focus is shifted from x^o to $(x^o)^{+1}$: the cells that do not change are the *(l-1)* placed vertically.

Now, we assume that the focus moves horizontally, i.e., from x to x^{+1}, as, e.g., in Fig. 3 from $x = v_3$ to $x^{+1} = v_4$ thus obtaining the new view of Fig. 6.
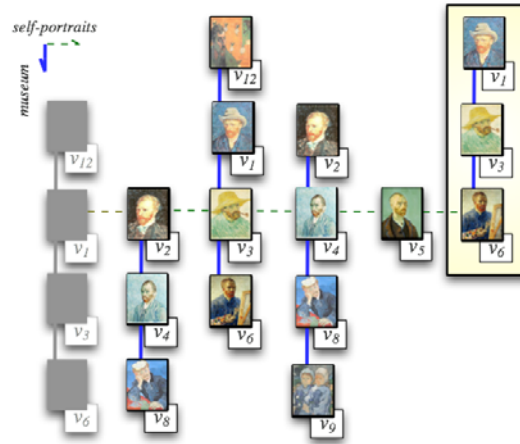

Fig. 6. Horizontal shift of focus.

Posward-Horiz-Shift-h-view(x, x^{+1}, l, D^a, D^b)

1. <u>if</u> $g=(l\text{-}1)/2$ *<vertex $x^{-((l-1)/2)}$ exists>*
2. <u>then</u> <u>send-now</u>($sleep((l, horiz, D^a, vert))$ <u>to</u> x^{-g} *<the (l-1)/2 -th column on the left is turned off>*
3. <u>if</u> $p=(l\text{-}1)/2$ *<vertex $x^{+((l-1)/2)}$ exists>*
4. <u>then</u> <u>send-now</u>($wake\text{-}up((l, horiz, D^a, vert))$ <u>to</u> $x^{+(p+1)}$ *<the ((l-1)/2)+1-th column on the right is turned on>*
5. *update-view*

In this case, an optimized procedure, called Posward-Horiz-Shift-h-view(x, x^{+1}, l, D^a, D^b), is activated by *SA*. The procedure has to turn off the vertical column related to vertex $x^{-(l-1)/2}$ (lines 1-2), if it exists, and has to turn on the column related to vertex $x^{+((l-1)/2)+1}$, given that vertex $x^{+((l-1)/2)}$ exists (lines 3-4). The first operation is analogous to the one of Fig. 5 with vertex x^s substituted by vertex x^{-g} and the

script *wake-up* with the script *sleep*, with the same arguments. The second operation (lines 3-4) is similar but it has to be applied to vertex $x^{+(p+1)}$ using the script *wake-up*. Finally, *SA* has to update its view (line 5).

Displaying n-dimensions H-views.

In this section we will show how to extend the technique of the previous section and thus how the *SA* may display n-dimensions *H*-views.

The technique is very similar. For example, for the *n*-dimensions *H*-view the *SA* contacts the focus *x* with message *focus(n-dim-h-view,l,D¹,...,Dⁿ)*. Since an n-dimensions *H-view* on main dimension D^1 and secondary dimensions $D^2, D^3, ..., D^n$ is composed of $n-1$ different *H-views* on main dimension D^1 and secondary dimension D^i, for *i=2,...,n*, the visualization operation is divided into two different steps.

Step 1. *Wake-up the vertices in the secondary dimensions of each H-view centered in x, i.e., of dimensions* $D^2, D^3, ..., D^n$ *. Focus x multicasts message wake-up(x,l,plane,D¹,vert) to ranks* $R^i_{(x)}$ *(i=2,...,n). The output of this script is the computation of sub-ranks (x, l), i.e., the sub-ranks of size l centered in x in dimension* $D^i(x)$*, for i=2,3,...,n. Then, each* $R^i_{(x)}$*, i=2, 3, ..., n sends message wake-up(x, l, plane,* D^1*, vert), to all its vertices.*
Step 2. *Similar to the one of the 2-dimensions case respectively applied to the vertices in ranks* $R^i_{(x)}$ *, for i=2,3,..., n.*

The technique for the *n*-dimensions *I*-view is very similar. In the case of the *3*-dimensions extended *H*-view the SA contacts the focus x with message *focus(3-ext-h-view, l, D¹, D², D³)*. The focus, as in a *2*-dimensions H-view, activates rank $R^3_{(x)}$ in order to compute a 2-dimensions H-view with main dimension D^2 and secondary dimension D^3. The activated vertices $x^{-g},...,x^{+p}$ of $R^3_{(x)}$, while executing the standard second step of the *H*-view wake-up procedure, will also act as focus and activate a new procedure for a new *2*-dimensions *H*-view of size *l* on main dimension D^1 and secondary dimension D^2.

4 Conclusion

In this paper we have proposed a multi-agent adaptive system to support tours of virtual museums. We have proposed an extended zz-structure model and we have shown how this new system can be used to display personalized user views and to

create personalized and navigational adaptive paths for users. As future work we want to concentrate on the study of good techniques to identify the collection of "interesting" pages for specific users, based on their preferences and needs.

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