Hybrid-dimensional Visualization and Interaction

Integrating 2D and 3D Visualization with Semi-Immersive Navigation Techniques

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Abstract—The integration of 2D visualization and navigation techniques has reached a state where the potential for improvements is relatively low. With 3D-stereoscopy-compatible technology now commonplace not only in research but also in many households, the need for better 3D visualization and navigation techniques has increased. Nevertheless, for the representation of many abstract data such as networks, 2D visualization remains the primary choice. However, often such abstract data is associated with spatial data, thereby increasing the need for combining both 2D and 3D visualization and navigation techniques.

We discuss a new hybrid-dimensional approach integrating 2D and 3D (stereoscopic) visualization as well as navigation into a semi-immersive virtual environment. This approach is compared to classical 6DOF navigation techniques. Three scientific as well as educational applications are presented: an educational car model, a plant simulation data exploration, and a cellular model with network exploration, each of these combining spatial with associated abstract data.

Keywords—Visualization; Stereo Vision; Human Computer Interaction; Systems Engineering Education; Data Visualization; Biomedical Engineering Education; Biological System Modeling; Biological Cells; Bioinformatics; Systems Biology

I. Introduction

Interactivity is one of the major aspects in software application design. Lots of research has been done for both, visualization and interaction in 2D as well as increasingly in 3D, covering applications in many areas from astrophysics to biology [1]–[3]. Especially interactive 2D visualization and navigation has reached a state where the potential for improvements is relatively low. The fact that already babies and toddlers start to use tablets and smartphones using multi-touch gestures underpins this statement [4]. Nevertheless, there are specific areas where the development of new approaches is still very important. One of these areas covers applications combining 2D and 3D visualization, in particular interaction within and between them. For this purpose, special interaction and navigation techniques are required.

Several hybrid-dimensional approaches combining 2D and 3D visualization techniques exist [5], [6]. An important application area is molecular visualization [7]. For example, RiboVision is focusing at the analysis of ribosomes: a 1D panel is used to visualize the nucleotide number in comparison to different aspects such as domains, the 2D panel shows the abstract visualization of the ribosome's secondary structure and the 3D view enables the exploration of the 3D structure by using Jmol [8], [9]. Aquaria can be used to analyze secondary structures of PDB files in direct comparison to the 3D structures [10], [11]. This tool is especially interesting as it makes use of the Leap Motion which can be used for 3D navigation in this environment [12].

Another application area of hybrid-dimensional exploration is the network visualization. The software used here is based on the previous version 4.1 of CELLmicrocosmos PathwayIntegration (CmPI) which integrated traditional 6DOF navigation techniques (see below for the explanation) [13]. A similar approach is HIVE which is based on VANTED [14], [15]. However, the major focus of HIVE was not an intuitive navigation but the integration of a large variety of different data sets. BioLayout Express 3D is a tool which is able to map between two- and three-dimensional networks [16]. In addition,

in certain other application areas the combination of 2D and 3D visualization is also reasonable [17].

Here we will discuss methods developed for integrating 2D and 3D visualization and interaction in the framework of the CELLmicrocosmos project. These methods are optimized for representing the following purposes:

- 3D objects representing single planet-like instances in a larger cosmos – it is possible to freely float through the cosmos, as well as to focus on/orbiting around single objects,

- abstract data, such as terms, attributes and/or networks, which are associated with these 3D objects and which are presented as a 2D visualization.

Three application cases will be discussed, combining spatial objects in 3D with abstract data presented in 2D, and partly also in 3D (see 6666C. Cytological Network Exploration).

II. Methods

A. Hybrid-dimensional Visualization and Interaction

One reason why 2D visualization is omnipresent nowadays is the simple navigation opportunities. Because only the coordinates *(X,Y)* are used, every simple two-dimensional plane-like object can be used to map the position of pointer devices (such as the finger or the mouse) to a 2D canvas of the computer. A 2D visualization features two to three *degrees of freedom (DOF):* movement along X/Y axis (*2DOF)*, and optionally additional rotation (*3DOF*) [2].

In 3D space, having the coordinates *(X,Y,Z)*, the position mapping is way more complex. For an adequate navigation, up to six degrees of freedom (*6DOF*) have to be taken into account: movement along the X/Y/Z axes (up/down, forward/back, left/right), and rotation along these axes (roll, yaw and pitch).

We call the combination of a 3D canvas plus a 2D canvas a *hybrid-dimensional visualization*. In this case, both canvas have to be interactive, i.e., changing or interacting with the 2D canvas must also lead to a change in the 3D canvas, and vice versa. Moreover, structures such as networks shown in the 2D canvas can be mapped onto 3D objects, using, e.g., polar coordinates.

B. Test System Configuration: A half-immersive Environment

For 3D visualization and interaction, several new approaches have been recently developed. There are fully-immersive setups using head-mounted displays (HMDs) – such as the Oculus Rift – which provide a 100 degree view but come with strong side effects such as motion sickness [18]. Especially their use in education should be limited to certain ages and to short time periods [19].

In contrast to HMD setups, we required a working environment suitable for the daily long-term use. Therefore, we developed a new 3D navigation and interaction technique based on the semi-immersive *zSpace* 200 monitor [20]. The zSpace was chosen because it covers the following aspects: an easy set up, transportability, suitability for daily work, the integrated interaction pen *Stylus* for 3D navigation, head-tracking support, as well as passive 3D-stereoscopic visualization which allows the use of an additional 2D monitor without changing glasses.

Fig. 1. This image illustrates the test system setup. On the left side, the zSpace 200 3D-stereoscopic monitor, on the right side, the 2D monitor. The user holds the Stylus pen for 3D interaction and navigation. On the right side of the table, the mouse is located, to be used with the 2D monitor.

Fig. 1 shows the test system setup. The 2D monitor is used in combination with a mouse for 2D interaction, whereas the zSpace is equipped with a Stylus pen, supporting a 6DOF navigation. Moreover, a user wears head-tracked 3D glasses which can be used to look around objects shown on the zSpace.

C. 2D Navigation

The 2D navigation used in combination with the mouse and the standard monitor supports 3DOF. The view can be dragged by holding the right mouse button, elements (such as nodes of a network) can be selected by just clicking on corresponding nodes, a double-click initiates a movement in 3D space to the corresponding object.

D. Classical 3D Navigation with Mouse and Keyboard

First, the classical navigation modes are discussed. To work with these modes, only a standard mouse operating in two dimensions and a keyboard are required. Three navigation modes are supported, which allow full 6DOF movement [13].

- *Floating Mode (FOM):* In this mode the user 'floats' through the 3D scene and can select different objects, highlight them or initiate the *Object Bound Mode* via double click. To navigate the standard WASD-keys as well as the arrow keys can be used. Therefore, users familiar with first person computer games will adapt quickly to this navigation mode.

- *Flight Mode (FIM):* If the user wants to fly in airplane-style through the 3D environment, he should use this mode. By holding the SHIFT key down, he can freely move forward by using the left mouse button, and move backward, by using the right mouse button. The movement of the mouse changes the direction.

- *Object-Bound Mode (OBM):* Here, the object of interest is centered and all movement occurs around this specific object. All three mouse buttons can be used: with the left mouse button the user can move around the object, with center mouse button the object is approached, and with the right mouse button the perspective is shifted.

Although these modes provide all required functionality to navigate through 3D space, it requires some time to adapt to it, as they are not that intuitive. Therefore, a preferable solution would be to use a single navigation device which operates in three dimensions.

E. Advanced 3D Navigation with Stylus pen

To achieve a fluent 3D interaction, all previously discussed navigation modes were combined, condensed and simplified. Whereas the Classical 3D Navigation Mode requires a mouse plus a keyboard for navigation, the following methods can be completely realized by using only the Stylus pen.

First, a *3D mouse pointer* is introduced which can be used to select single objects directly. This pointer moves inside the 3D environment and is connected with a virtual line to the Stylus pen, as suggested by the design instructions of zSpace, Inc. (Fig. 2 Top) [21].

TABLE I. Navigation Modes

Navigation		6DOF[a]					
Types[b]	Modes[c]	XT	YT	ZT	XR	YR	ZR
C3D NAV	FOM	X	X	X			
	FIM			X	X	X	
	OBM			X	X	X	(X)
A3D NAV	FOM	X	X	X	X	X	
	OBM			X	X	X	(X)

[a.] 6 **D**egrees **O**f **F**reedom: X/Y/Z translation and rotation along the X/Y/Z axes

[b.] Navigation Types: **C**lassical and **A**dvanced **N**avigation

[c.] Navigation Modes: **Fl**oating **M**ode, **Fl**ight **M**ode, **O**bject-**B**ound **M**ode

Second, the three navigation modes of the Classical 3D Navigation (C3D NAV) are reduced to the use of a Floating Mode and Object-Bound Mode for the Advanced 3D Navigation (A3D NAV). Table I. shows an overview. The dashed line in the A3D NAV row indicates an important aspect: the transition between FOM and OBM is now floating. Fig. 2 top shows the FOM, Fig 2. bottom the OBM. The Stylus pen has three buttons (Fig. 3). To keep the basic navigation as simple as possible, all basic movement as well as selection methods can be performed with the center button A. Keeping the center mouse button pressed (without selecting an object), the movement of the viewport follows the arm movements. The direction of the movement is automatically represented by the direction of the 3D mouse pointer. If the 3D mouse pointer touches an object, a vibrating feedback is provided as well as a label of the selected object. Then, this object can be focused by pressing the center mouse button during a short period of a few seconds after the collision between 3D mouse pointer and object occurred. In this case, the navigation is automatically switched to OBM. By moving the Stylus along the horizontal and vertical axes, the viewport moves around the center of the object in focus (Fig. 2 bottom left). By changing the distance towards the screen with the Stylus, also the distance to the object changes (Fig. 2 bottom right). In this way, the object can be freely explored from every perspective while maintaining the overview of the whole environment, because the user can always zoom out completely

without losing the contact to the selected object, even if the differences in size are quite huge.
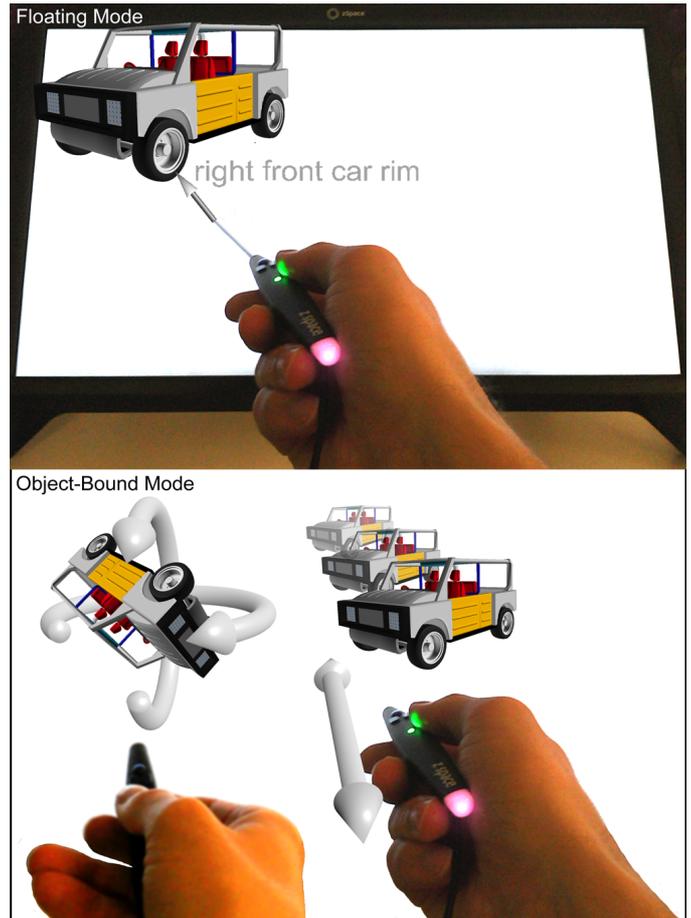

Fig. 2. Floating and Object-Bound Mode with the zSpace Stylus pen. Top: The image shows how the user can interact with a model. In Floating Mode (FOM), the Stylus is visually connected by a line to the 3D navigation arrow which is used to select the different 3D models. The direction of the 3D arrow follows the direction of the Stylus pen. If it touches an object, the Stylus vibrates. Bottom: In Object-Bound Mode (OBM), the user's view rotates around the object by moving the Stylus pen along the X/Y axes (left image). Stylus movement along the Z axis drags the user closer to the centered object (right image).
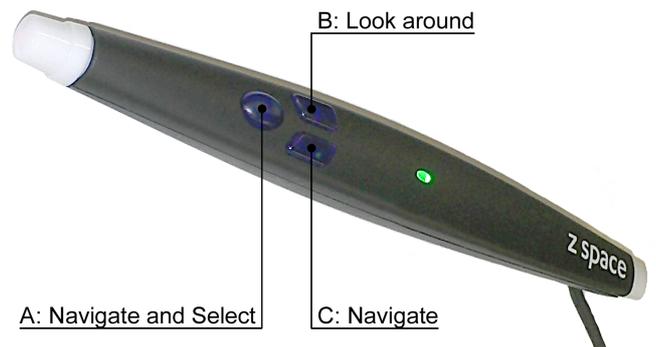

Fig. 3. zSpace Stylus pen buttons. Button A is used to change between the Floating Mode and the Object Bound Mode. Button B moves the user's view along the X and Z axes. Button C can be used for simple navigation without selecting a 3D object by accident (see also Fig. 2).

In addition the Stylus pen has two other buttons (Fig. 3). The right button B can be used to move the viewport around the center of the user's view, emulating 360° head movement. The left one, button C, has the same functionality as the center button. The only difference is that objects cannot be selected/focused. Therefore, a free navigation is possible, ignoring objects colliding with the 3D mouse pointer.

Moreover, it is possible to switch completely to OBM by double-clicking the center mouse button 1. Again the right and left mouse button can be used for navigation, whereas the center mouse button returns to the FOM.

The head tracking of the passive stereoscopic glasses performed by the zSpace also differentiates between the two navigation modes FOM and OBM. In OBM, the viewport just rotates around the actually selected object's center. In FOM, the rotation center is dynamically computed based on the closest intersection point. This intersection point has to be acquired for the stereoscopic perspective optimization to be discussed in the following section. Moreover, if the user's viewport is in the standard position, then the user's view rotates around the center of the complete environment.

F. 3D Stereoscopy and Navigation

An important factor of *Stereoscopic 3D (S3D)* visualization is the optimized projection of three-dimensional objects in 3D space. Recently, we have evaluated methods to use 3D stereoscopy in combination with cellular environments featuring large differences in size and structure [22]. For example, whereas some cellular component are as small as 23 nm (ribosomes), others are as large as 10,000 nm (plasma membrane). Here, the basic problem is that large size differences have to be bridged. Therefore, the distance d_e between both eye positions has to be optimized with respect to the distance to the actual point of interest (POI) represented by a 3D object [22]. As previously mentioned, this distance is also used to compute the center point for the rotation.

G. Object Selection in 3D Space

In contrast to a regular 2D visualization, in 3D space objects in the foreground may cover those ones in the background (Fig. 4).

Fig 4 bottom shows the intuitive selection technique as previously discussed for the Advanced 3D Navigation. The 3D mouse pointer has to be moved in FOM towards the object to be selected. If the mouse pointer touches the object, it is highlighted and can be selected to toggle OBM.

As the Classical 3D Navigation mode does not provide a 3D mouse pointer, the mouse wheel is used to select covered objects (Fig. 4 top). In FOM, the left mouse button has to be pressed and then the mouse wheel is used to select step-by-step different objects: first the object in the foreground (1), then in the center (2), and finally in the background (3). If the mouse button is released, the last selected object is chosen as the active one.

Another drawback of the standard 2D mouse pointer should also be mentioned. In Fig. 4 top the objects lie all behind the zero parallax plane [22], because the 2D mouse pointer will always be located in this area, physically represented by the monitor screen. Therefore, if S3D techniques are used, this might lead to unintended side effects, because the 2D mouse pointer might lie

behind objects popping out of the screen, such as shown in Fig. 4 bottom.

H. Interaction between 2D and 3D Navigation

Another very important aspect for a fluent interaction is the combination of 2D and 3D visualization. For example, if a user selects an object in 2D space (Fig 1, right monitor), the associated object in 3D space (Fig 1, left monitor) should be highlighted, and vice versa. If an object in 2D space is double-clicked, the view in the 3D space should automatically navigate to the corresponding 3D object. Following the focus+context paradigm, the 2D view can be used to maintain the overview, whereas the 3D view can be used to explore a specific point in the 3D universe [23].
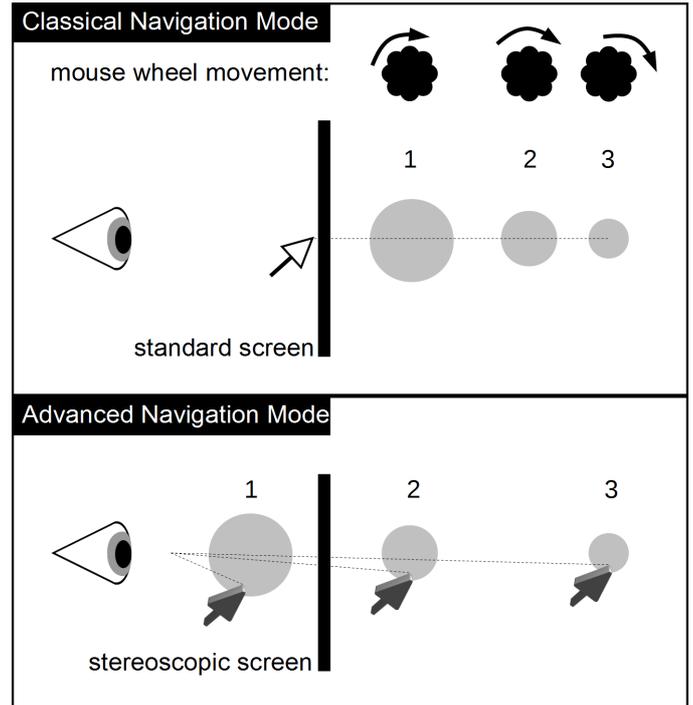

Fig. 4. Object selection in 3D Space: The Classical Navigation Mode uses the 2D mouse pointer in combination with the mouse wheel to toggle between different 3D objects which are covered. The Advance Navigation Mode uses a 3D mouse pointer and enables the direct selection of components in 3D space.

I. Test System Setup and Implementation

The Test system consists of a zSpace 200 monitor for stereoscopic 3D visualization and interaction [20], and a standard monitor for 2D visualization (each with Full HD resolution), a desktop computer i7 equipped with an NVIDIA Quadro K4100 card.

The methods presented in the reminder of this article have been implemented in a Java-based framework. Although 3D applications are nowadays often developed to run within web browsers [8], [10], they all have the problem that they do not support hardware-accelerated stereoscopic 3D visualization. Therefore, a standalone Java application was chosen. The software used for the test setup was the CELLmicrocosmos 4.2 PathwayIntegration (http://Cm4.CELLmicrocosmos.org) [13]. The 3D visualization is based on Java3D 1.6.0-pre11 (Jogamp JOGL 2.2 implementation) extended by special JOGL-based

libraries for zSpace support [24]. The 2D visualization and navigation in CmPI is based on the Java Universal Network/Graph Framework (JUNG) 2.0.1 environment [25].

III. Applications

Here, three application cases are presented which are able to make full use of the proposed methodology.

A. Educational Model Exploration

First, a simple application case is shown. The basic idea is to support the spatial and linguistic understanding of children. The practical use of this approach is that young children could use similar approaches – e.g., in the kindergarten – to learn a) the vocabulary of different everyday life objects, plus b) experience their spatial properties.
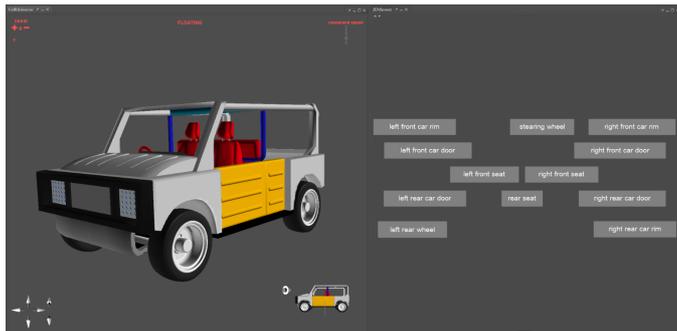

Fig. 5. Car model: Left: 3D view of the complete car, Right: terms associated with specific car parts
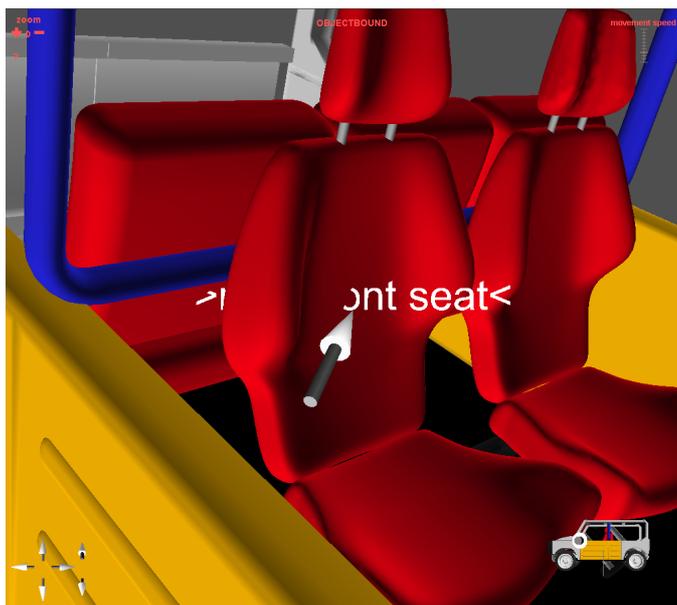

Fig. 6. Car model: a single part of the car shown after the user clicked on the corresponding term in the 2D view. The screen shot shows the arrow attached to the right front seat which is used to navigate around a selected object

This educational application case shows a car model. The vehicle (Fig. 5 left) is modeled in 3ds max [26], and it references to the design by Selby Coxon as part of a compact mining vehicle project [27]. Due to the regular clashing and damage characteristic of a tunnel vehicle under coal mining environment, most of the components on the vehicle body are designed to be made by durable plastic material such as polypropylene or PVC, which provides light weight, easy installation and cross-share design features. Fig. 5 left shows the three-dimensional simplified model of an off-road vehicle featuring all relevant car parts. The right part of this figure shows the different terms of the car parts. If one of these names is clicked by the user, the view automatically centers the chosen car part and moves towards it, as shown in Fig. 6.

The combined 2D-3D visualization method provides an efficient tool for group viewing and interactive discussions (Fig 5). In the future, this setup may provide multi-dimensional and innovative interactions between novel system/product designs and group users [24]. There are a number of benefits for using such a system, especially the overall understanding is improved.
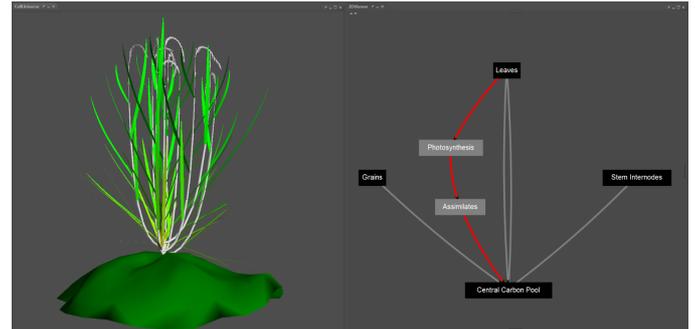

Fig. 7. Rice Plant Model: Left: the 3D view showing the complete model, Right: a simplified visualization of the simulation workflow
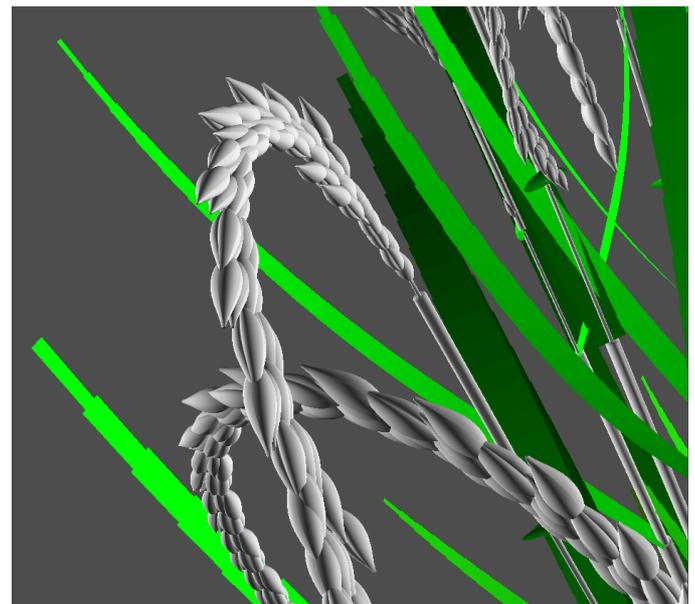

Fig. 8. Rice Plant Model: Detail shown after clicking on the corresponding term in the simulation workflow. Each of the grains and leaf segments shown here are relevant for the functional structural simulation process.

The 2D diagram enables first-time viewers to easily grasp the overall big picture and the interrelationships of various vehicle components. Users may also intuitively focus on a certain vehicle part by simply clicking the corresponding tag on the 2D diagram (Fig. 5 right). For instance, when a client asks to show a certain part – e.g. the right front seat (Fig. 6) – the virtual camera will swiftly zoom in to view the component.

Furthermore, this method also enables users to observe how the changes on selected component could potentially affect the overall system to provide understanding on interrelated impacts.

B. Plant Simulation Data Exploration

Here, CmPI is used to visualize the final stage of a simulation. In case of molecular dynamic simulation, tools such as VMD [28] are frequently used to visualize simulation results. Usually, the result is shown as a static image in the publication. But in terms of complex 3D models it would be preferable to provide a tool which can be used to directly explore and experience the spatial structure of the model. Moreover, simulations based on, for example, Petri nets or Bayesian networks are often represented as network structures.

In Fig. 7 left, a functional structural model of a fully grown rice plant is shown. It represents the final stage of a simulation, integrating major physiological processes and morphological developments, as well as quantitative genetic information which in return regulates the morphological dynamics [29]. The plant simulation was performed with the simulation platform GroImp [30].

Fig. 7 left shows the complete plant model, whereas Fig. 7 right illustrates the simulation workflow. The grains, stem-intermediate nodes, as well as the leaves acquire the energy from a central carbon pool. In addition, details of the bidirectional association between source and leaves are shown: the photosynthesis and its assimilates. Clicking now at the different terms in the network, such as "grains", leads the user directly to the corresponding location in the 3D structure, as shown in Fig. 8.

Therefore, it would be preferable to enable an easy combined exploration of the simulation workflow structure in 2D and the associated spatial model in 3D.

C. Cytological Network Exploration

This life science application case shows a virtual hepatic cell which was modeled based on a number of microscopic images. The cell model is associated with two metabolic pathways (Fig. 9 and 10); the Citrate cycle and the Glycolysis. Both pathways were obtained from the KEGG database and localized into the correct spatial areas (compartments) using CmPI [13], [31]. By integrating the virtual cell with specific intracellular biological processes (pathways) it is possible to focus and explore network nodes as well as cellular components. Fig. 9 shows on the left side the 3D cell. Clicking on a node of the pathway highlights the corresponding node in the 2D representation on the right side of Fig. 9. And vice versa, double clicking on a node in the 2D representation highlights the node and navigates the view to the corresponding position in 3D space. Then, the final position might look like shown in Fig. 10. Here it can be seen, that – in contrast to previous application cases – the network is also mapped onto the three-dimensional surface of the mitochondrion and its surrounding environment. The exploration of such a network requires 3D-supported navigation. Moreover, following the Focus+Context paradigm, the 2D visualization can be used to maintain the overview in networks with complex structures.

This approach is especially relevant if spatial/topological data has to be combined with abstract information with the purpose to analyze their validity. For example, if two metabolic reaction partners are located in two too distant domains of the cell, the underlying information has to be re-evaluated.
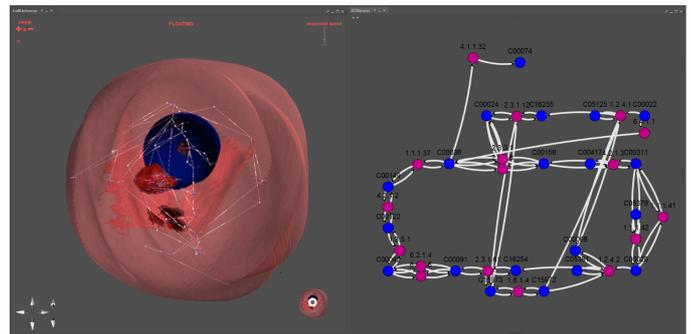

Fig. 9. Cell Model: Left: 3D View of the complete cell, Right: 2D visualization of a metabolic pathway
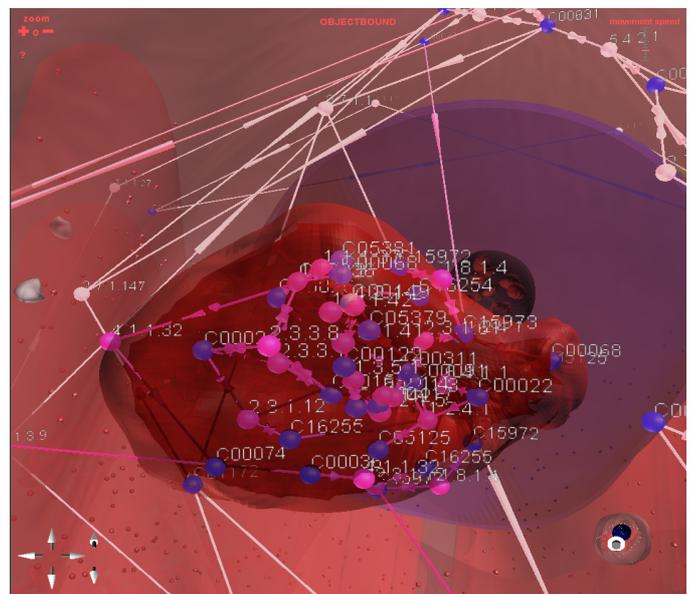

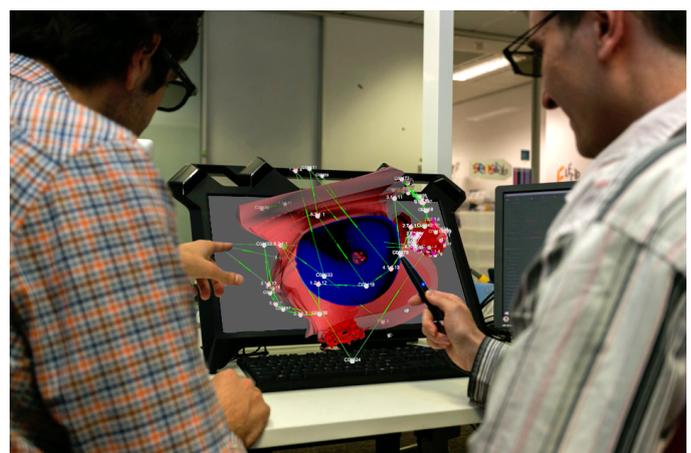Fig. 10. Cell Model: Detail showing the mitochondrion associated with the citrate cycle

Fig. 11. This image illustrates how the user interacts with the cell model in 3D by using the Stylus pen. Image © 2015 Monash University

IV. Results and Conclusions

We presented a new system combining the advantages of 2D and 3D visualization and navigation. We discussed general ways to navigate and interact in this environment, presented a setup using the zSpace 3D monitor with a 2D monitor. The zSpace is used to explore the 3D environment, a second standard monitor is used to visualize the network or other information (such as tables). An advantage of this system is the fact that the user can usually work with both monitors by using passive stereoscopic glasses. It should be mentioned that the used software system is also able to be run on only a single screen, including stereoscopic visualization.

Instead of changing between the different modes, it is now possible to directly select a node and to navigate through 3D space by using the Stylus pen. The change between the two modes is done now fluently. However, to select a node using a classical mouse and the mouse wheel technique might be not so intuitive, but in specific cases this may work faster than selecting it with the Stylus pen.

Three application cases from different domains were discussed: The first one showed that the discussed setup can be used for early educational purposes, combining spatial structures (vehicle) with key terms (car component terms). The second application case visualized the final stage of a plant simulation (rice plant) in combination with a simple network (basic simulation workflow). This approach might be used in the future to explore every substructure – such as a single grain – by using our new navigation techniques. Moreover, it would be possible to combine these structures with values representing the actual state in the simulation. For this purpose, again the 2D visualization could be (also) used. A cell model (animal hepatocyte cell) in combination with two networks (metabolic pathways) was the final application case. It showed how more complex topological data can be combined with associated abstract data for validation purposes. Moreover, this data was also mapped onto the 3D structures. Here, the 2D map can be used to maintain the overview if the three-dimensional representations become too complex.

There are a number of benefits of using hybrid-dimensional visualization and navigation. The overall understanding is improved, because the 2D diagram enables first-time viewers to easily grasp the overall big picture and the interrelationships of various components. Users may also intuitively focus on a specific component by clicking the corresponding tag on the 2D diagram. Furthermore, this method may also enable users to observe how the changes on selected component could potentially affect the overall system to provide understanding on interrelated impacts.

Moreover, the hybrid-dimensional visualization method provides an efficient tool for group viewing and interactive discussions. Because the discussed setup provides a 3D mouse pointer, as well as a standard mouse cursor, the system can be operated by one to two people, with additional participants joining the discussion. In the future, this setup may provide multi-dimensional and innovative interactions between novel system/product designs and group users [32].

Although initial evaluations using the zSpace have been already done [33], future work could include user studies, examining the combination of hybrid-dimensional visualization and navigation techniques.

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