3D Vizualization of Large Scale Data Centres

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Abstract: This paper reports on ongoing work regarding interactive 3D visualization of large scale data centres in the context of Big Data and data centre infrastructure management. The proposed approach renders a virtual area of real data centres preserving the actual arrangement of their servers and visualizes their current state while it notifies users for potential server anomalies. The visualization includes several condition indicators, updated in real time, as well as a color-coding scheme for the current servers' condition referring to a scale from normal to critical. Furthermore, the system supports on demand exploration of an individual server providing detailed information about its condition, for a specific timespan, combining historical analysis of previous values and the prediction of potential future state. Additionally, natural interaction through hand-gestures is supported for 3D navigation and item selection, based on a computer-vision approach.

1 INTRODUCTION

Big data analysis is at the centre of modern science and business (Eaton et al. 2012). On the other hand, the need for additional storage space due to the massive growth of the data volume (Schneider 2012) has resulted into the expansion of existing data centres.

High quality and reliable services are essential for the data centres. Any potential issues that may arise should be dealt with as soon as possible in order to eliminate, or at least minimize, the downtime of servers. The increasing dependency on the reliability and responsiveness of systems and services requires continuous and real-time monitoring, creating the need for real-time rich interactive visualizations that assist data centre experts.

Additionally, several approaches successfully manage to not only identify problems, but also to reason on the cause of the issues and predict future behaviours. Such examples include Root Cause Analysis, comprising many different tools, processes and philosophies, and Data Centre Predictive Modelling (Moore, Chase and Ranganathan, 2006), forecasting the performance of a data centre into the future respectively.

Data centre infrastructure management consists an integral part of Big Data, as this sector provides the means for supporting Big Data storage, retrieval and monitoring as a whole. Although much work exists in literature regarding both Big Data visualization (LaValle et al., 2011) and (Keim et al., 2013) and data centre infrastructure management (Moore et al., 2005), (Moore et al.,2006) and (Harris and Genq, 2015), limited research targets the direction of visualizing the state of the data centres. Several indicators exist that can provide insights of the current state of each server, such as CPU usage, power consumption, network load, etc. A major issue for data centre infrastructure management involves real-time monitoring of the existing facilities. In this context, this paper addresses the need for an intuitive, rich and adaptable visualization of all the hardware and software components that exist in a data centre.

Maintenance of Big Data infrastructure involves providing continuous monitoring and troubleshooting any potential issues that may arise (such as hardware inefficiencies) as soon as possible. The growth of data volumes results into the further expansion of data centres, and consequently, the addition of further data servers. Potential issues may either be resolved remotely or physically on site; in any case, the first

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step of solving a problem is identifying it. This fact adds up to the complexity of locating the area of interest instantly, a process which is solved within minutes only in 26% of the cases (Cole, 2012).

The proposed approach aims at creating an adaptive, multi-purpose system which is able to allow database experts to manage a data centre effectively and efficiently. To this end, the system employs a three-dimensional virtual environment to visualize the data centre and supports gesture-based interaction. The innovative aspects that enhance the visualization of the data centre layout include the notification of problematic units, the on-demand exploration of server details and the historical overview of past values.

Furthermore, this approach aims at generating a self-explanatory environment which will minimize the need for training users. To achieve this goal, the proposed approach focuses on providing a virtual environment of large-scale data centres that is very close to the real ones, realising in this way procedures for identifying and addressing a problem similar to those procedures that are followed by the experts on site. Moreover, it introduces alternative ways of interaction, based on hand gestures, facilitating thus different scales of installations, from a desktop monitor to the very large screens of a situation room.

In this context, the proposed work aims to fill-in the gap of innovative real-time data centre infrastructure visualization and management in the context of Big Data. Furthermore, the method combines state-of-the-art 3D visualization techniques and gestural interaction. In the following sections, this paper reports on the work presented in literature in the related areas of research, presents the proposed approach in terms of system design, interaction and data storage/retrieval, gesture-based interaction and finally outlines conclusions and potential future directions of interest.

2 RELATED WORK

Data centre infrastructure management heavily involves finding the optimal architecture by identifying imbalances in the existing setups. The work presented by (Moore et al. 2005) analyses existing facilities' performance data, as well as workload playback methods. Furthermore, data centres' impact to the environment is a subject of research in terms of energy consumption (Andrae and Edler, 2015), workload distribution and isolation (Sfakianakis et al., 2014) and data centre network virtualization.

3D visualizations exist in various forms in literature due to their ability to display increased information at a glance. The authors of (Reda et al., 2013) apply 3D visualization in hybrid-reality environments in order to visualize large heterogeneous data.

Regarding real space visualization, literature mainly contains work focusing on dissimilar simulated areas, such as architecture (Koutamanis, 2000), homes (Lozada and De la Rosa, 2014) and (Lazovik et al., 2009), and industrial setups (Lawler, 2010) and (Chen, 2012). Lawler focuses on creating a toolkit to improve performance using a packaging line as a case study, while Chen emphasises on floor area reduction and visual management. The technique of color-coding is widely adopted in literature (Ware, 2012) and especially in the case of visualizing complex information which can be categorised (Gölitz et al., 2013) and (Kriglstein et al., 2013).

As far as gestural interaction is concerned, hand gesturing is an approach widely adopted in literature as a straightforward, intuitive and easy to memorise interaction method. According to Aggarwal (Aggarwal and Ryoo, 2011) gestures are defined as elementary movements of a person's body part, most commonly involving the hands, arms, face, head, defining the expressive atomic components that describe the meaningful motion of a person. Gestural interaction is both applied in the air (Drossis et al., 2013) and (Ren et al., 2013) and using touch (Valdes et al., 2014). Computer vision based hand gesture tracking allows interaction in a similar manner to every day human to human communication without the burden of actually coming to physical contact with any object. Despite the considerable research efforts and advances, hand-based gesture recognition and incorporation in interaction remains a challenging task.

The presented work aims to address new aspects that have emerged with the vast inflation of data centres, as a result of the need for very large scale infrastructures accommodating big data and cloud services. To this end, the proposed approach extends existing approaches for data centres' monitoring, by providing a more realistic visualization combined with natural interaction.

3 SYSTEM DESIGN

The Data Centre 3D Visualization application aims at helping data centre experts to get an intuitive overview of a specific data centre room, regarding its current condition. Additionally, the application facilitates inspection of the racks and servers by the users and warns them, in an intuitive manner, about situations that need further investigation, such as an anomaly regarding a particular set of servers that may bring to surface malfunctions or degraded operation. Taking into account the various potential contexts of use, ranging from an office to a control room, the application is able to be deployed in a laptop or a PC, featuring interaction with the mouse, as well as in large displays, with gestures.

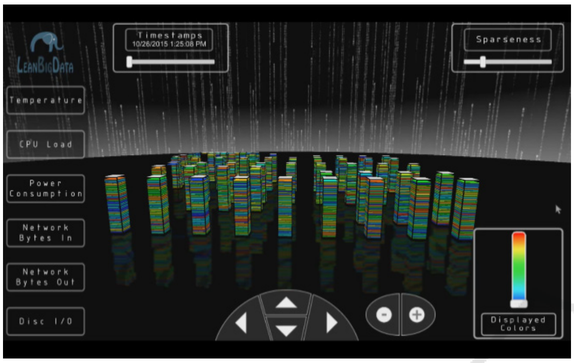

Figure 1: Main Scene view.

3.1 3D Overview

The main screen of the Data Centre 3D Visualization application, which comprises a virtual representation of a data centre room and the basic interactive UI components (e.g., navigation buttons) is depicted in Figure 1. All the servers of the room are grouped and displayed as 3D racks according to their physical location in space. Each rack may contain at most 40 units, each displayed as a slice with a specific colour, annotating its current condition [Figure 6Figure 3]. Overall, the virtual data centre room is constructed as a grid in the 3D space. The virtual environment that encloses the scene is spherical and the servers' grid is placed in the centre, so that users can have a 360 degrees overview.

The application provides details and insights of the displayed data centre room through its intuitive user interface. In more details, at the left side of the application's viewport a menu of five components is displayed, highlighting elementary values of the data centre's servers such as temperature, CPU load, power consumption, network Bytes In/Out, Disk I/O [Figure 1]. Upon the selection of one of these values, the visualized information of the data centre is updated accordingly, representing the current status for the selected characteristic. This way, the users are able to instantly switch between different server characteristics and correlate the displayed state of the data centre with specific server characteristics (e.g., CPU Load and Power Consumption: usually, a high CPU Load is expected to result into a higher power consumption).

Furthermore, the application provides historic information of the data centre state by allowing users to select the date and time of the information that is visualized. Upon the selection of a time frame, all the servers update their values accordingly. If the selection is performed in the close-up view of a rack, then additional options are provided in order to present the history of the selected unit [Figure 3].

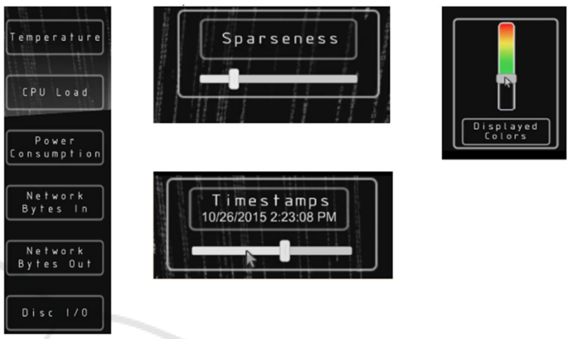

Figure 2: [Left] Visualization Menu Options, [Middle-Up] Scene Sparseness Filtering, [Middle-Down] Date Time Filtering, [Right] Displayed Unit Colours Filtering.

In addition, the system offers filtering and arrangement options [Figure 2], allowing users to manipulate the information provided and focus on specific aspects of the data centre. In more details, filtering according to the state of the displayed servers (color-coded) allows exclusion of elements which are not in the field of the user's interest, resulting in a comprehensible and clear view of the available information (e.g., the user can easily view all the servers in critical state). On the other hand, arrangement according to the level of sparseness of

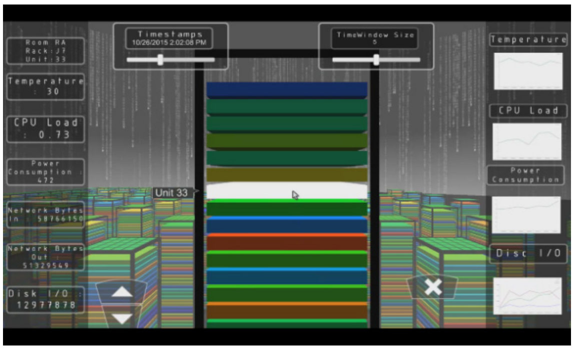

Figure 3: Close-up state shows the units of the selected rack and focuses on the "worst" one, with number 33. On the left the UI-information for this unit and on the right the line charts for the specified history.

the data centre, aids in defining the view of the data centre (e.g., the servers can be densely placed in order to provide an overview of the data centre or sparsely so as to facilitate inspection of server values in detail over specific areas of the data centre room).

3.2 Navigation

Navigation in the scene is accomplished through an orbit virtual camera providing, in this way, different levels of details. For example, if the camera moves forward then the scene focuses towards a particular server (zoom in) and the user gets a closer and detailed view of the server details and its units. On the other hand, if the camera moves away (zoom out) then the user gets the whole picture of the data centre. Furthermore, the camera can also move left and right to provide a better view of all the sides of the data centre. Upon the selection of a specific rack, the camera zooms into it, allows moving up or down to focus on a specific unit, and explore the provided information.

3.3 Close-up View

Investigation of a rack is achieved by either using the controls at the bottom of the screen or performing appropriate hand gestures. This view [Figure 3] is used for inspecting information on a per-server level, displaying the current values of the server's attributes (e.g., temperature, CPU load, etc.) along with line charts. Any of these charts can be enlarged on users' request, in order to provide a more detailed view. The close-up view of a rack provides up-down navigation to the user for selecting a particular unit. When the user does so, the current values of the selected unit are illustrated on the left side of the screen, while history values are depicted as line charts on the right side. On top of the screen, there are two sliders: the displayed timestamp slider and the time window slider. The first slider provides the ability to the user to select a past time value for the selected unit in order to investigate its previous states. The time window slide sets the size of the time frame used for the calculation of the visualization of the mean values illustrated by the charts. For instance, if a user increases the value of the time window slider then he/she increases the timespan over the means of previous unit's values are estimated and displayed, getting in this way a broader view of the unit's history.

3.4 Anomaly Detection Visualization

The purpose of the 3D data centre visualization is to provide a real-time view of a data centre and to facilitate the efficient handling of a critical situation when it is turned up. Therefore, the system provides a mechanism that supports the representation of anomaly detections regarding the temperature or power consumption. When a problematic unit is detected, then the colour of the rack that contains this unit changes to red and a notification message pops-up above it, displaying a short description of the problem and the unit's number [Figure 4].

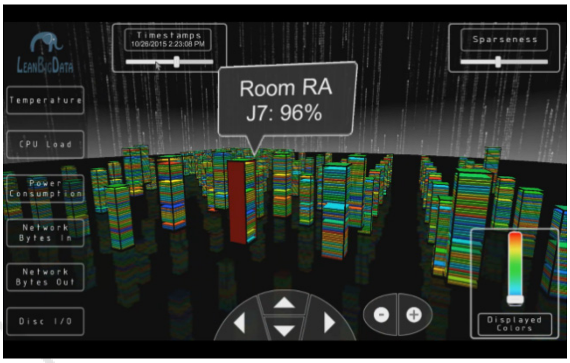

Figure 4: Upon anomaly detection, the server has changes colour accordingly (red).

3.5 Interaction Techniques

The application supports mouse-based and gesture-based interaction, aiming to address the potential contexts of use, i.e., a typical desktop environment and a control room.

3.5.1 Mouse-based Interaction

The interactive elements of the scene include both the server racks and the server units. Upon mouse hovering a server rack, a notification pops-up presenting basic information (i.e., the rack's id, the room it is located in, and its coordinates in the room, if the unit is in critical state). If the user clicks on a specific rack, the scene changes to a close-up view, the camera zooms in towards the selected rack and specifically displays the unit of the rack which is in the "worst situation", and which defines the criticality level of the server [Figure 3]. While in close-up view, the user can select a specific unit of a rack, through a mouse click. Then, at the right side of the rack, four different line charts are displayed, illustrating the history of the selected unit, as already discussed in section "Close-up View". If the user hovers the mouse pointer over a specific chart, then the chart expands in order to display a better view of the unit's history and its temporal evolution [Figure 5].

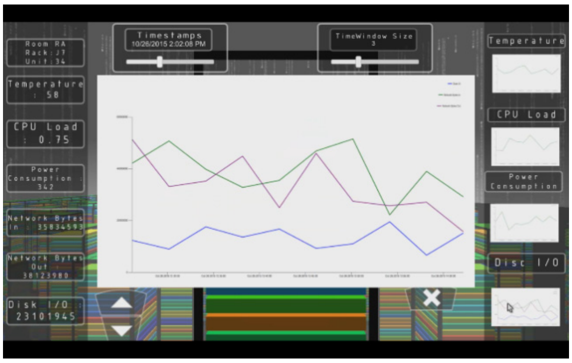

Figure 5: Maximized chart on mouse over the interactive item at the right screen side.

In addition, aiming to facilitate users' navigation in the 3D environment, a navigation tool has been developed, through which the view of the camera is controlled [Figure 6]. This component comprises four navigation buttons for moving the camera forward, backward, left and right, as well as a minus and a plus button for camera zoom out and in accordingly. These buttons are triggered on hover. For example, as long as the mouse pointer hovers the up arrow button the camera moves forward. The navigation component changes when a rack is selected and the scene switches to the close-up view. In this state, the navigation buttons provide only the up or down functionality since the server's units are stacked vertically on the rack. Furthermore, there is an exit button in order allowing users to return to the full scene view.

Figure 6: Camera navigation tools.

3.5.2 Gesture-based Interaction

In order to make the interaction more natural and friendly to the user, especially when the system is deployed in a large-screen setting, gesture-based interaction is supported. The current version supports a small vocabulary of gestures that enable users' interaction with the 3D scene using a cursor metaphor (hand-mouse).

In more details, through a hand tracking mechanism, the user's movements are filtered and a mouse event emulator is raised and listens to the incoming events that correspond to the user's moves. As a result, when the user moves his right hand in the space in front of him, the mouse moves accordingly in the scene [Figure 7]. In order to select an interactive element the user has to raise his left hand and open the palm, showing at the same time with his right hand the component that he wants to select.

Figure 7: Gesture-based interaction.

Future versions of the application will support gesture-based interaction through a larger vocabulary of intuitive gestures (e.g., move hands apart for zooming in). Nevertheless, the hand-mouse metaphor will continue to be supported, as it is an easy-to-learn interaction modality for first-time users of gesture-based interaction.

4 DATA STORAGE AND RETRIEVAL

4.1 Input Data and Analysis

In order to create the scene layout and fill in the server racks and the corresponding units with their values, a mechanism has been implemented to parse an input file (.csv format) and to retrieve all the data written in it, analyse it - if needed - and create the necessary data structures in memory for information representation of the scene data elements.

```
1410768000,RA_A24_8,0.83,48180,34080,810180,64.6,344
1410768000,RA_A24_10,0.01,32160,23520,491520,27.4,160
1410768000,RA_A24_11,0.71,27780,0,0,60.5,242
1410768000,RA_A24_12,0.76,3850320,2757480,7180140,62.1,343
1410768000,RA_A24_13,0.51,8940,92220,568500,51.2,244
```

Figure 8: Input CSV file format.

Each line of the file features comma-separated values providing information for a specific unit of a server of a room in a specific Date and Time. The comma-separated values represent information regarding the temperature of the server, its CPU load, power consumption, network bytes in/out and Disk I/O. The parsing of the file is based on the specific format of each line, as shown in Figure 8. For example, “1410768000, RA_A24_8, 0.83,48180, 34080, 810180, 64.6, 344” reports that:

- 1410768000 is the Date Time (long)
- RA_A24_8 the information refers to Room A, for the server which is located in Row A, Column 24 and the unit for which the data in this line refer to is the 8th.
- 0.83 is the CPU load in the specific timestamp (float)
- 48180 are the Network Bytes In for the specific timestamp (long)
- 34080 are the Network Bytes Out for the specific timestamp (long)
- 810180 is the Disk Input/Output for the specific timestamp (long)
- 64.6 is the temperature load for the specific timestamp (float)
- 344 is the power consumption for the specific timestamp (integer)

The data provided in the input file is used to populate the data structures that are required to visually represent the aforementioned information in the 3D scene. In more details, the following data structures are used: (a) a server-description structure, featuring the room in which the server is stored, the position of the server in the grid layout, and the units of the server, (b) a unit-description structure, which involves all the unit values that have been explained above (CPU load, network bytes in, network bytes out, disk I/O, temperature, power consumption), as well as the timestamp information.

4.2 Scene Creation

Apart from the data structures needed, a scene generator has been created in order to visualize the data according to the information stored in the file. The scene generator asynchronously creates all the 3D racks with their units and all the coloured values in them and places them according to their positions given in the input file for the specific room. As illustrated in Figure 1 and explained in section “Input Data and Analysis”, positions are defined by rows and columns, which is an easy to understand and effective way to visually map them in the scene as a grid with the corresponding rows and columns.

4.3 Real-time Communication

Information regarding the servers’ state is acquired in real time, both in terms of raw data (such as temperature, CPU usage, etc.) and in terms of anomalies. Information retrieval is accomplished by automatic anomaly detection and root cause analysis CEP Operators, which is part of a system developed in the context of the LeanBigData FP7 project [LeanBigData, 2014-2017]. The data currently provided comes from recorded datasets, while ongoing work involves the provision of real-time information. The communication is implemented using REST API endpoints and provides both current and previous values for any given server.

5 GESTURE-BASED INTERACTION

For supporting gesture based interaction a framework has been implemented based on the approach discussed in (Michel et al., 2014). The adopted framework encompasses a collection of techniques that enable robust, real-time and efficient gesture recognition based on visual information acquired by an RGBD camera. The framework encompasses hand detection, hand tracking, hand posture recognition and hand gesture recognition processes and interprets the recognized hand gestures to windows native mouse events, acting as a Human Interface Device (HID). To this end, it can be installed on any computer with windows operating system, providing, in a transparent way, gesture – based interaction to any windows application.

The employed gestural vocabulary is composed of three different classes of physical hand-arm actions.

Mouse Button Press: The case of a mouse button press is recognised if the posture of a tracked hand changes from “closed hand” to “open hand” and the “open hand” posture is maintained for a number of consecutive frames.

Mouse Button Release: The case of a mouse button release is recognized if the posture of a tracked hand changes from “open hand” to “close hand” and the “closed hand” posture is maintained for a number of consecutive frames.

Cursor Move: A hand has a posture that is classified as “index up”. Then, the 2D projection of its centroid in the image plane as it moves around, defines the x-y coordinates of the mouse cursor in the application area.

6 CONCLUSIONS AND FUTURE DIRECTIONS

The work presented in this paper attempts to combine innovative, state-of-the-art technologies in the fields of Big Data anomaly detection, information visualization and computer vision gesture recognition, in order to deal with visualization needs for Big Data and data centre infrastructure management.

The proposed approach primarily deals with the monitoring and the intuitive display of existing data centres' information, using their actual layout, in order to inform data centre experts about the servers' current state and assist navigation in actual space. The proposed approach takes advantage of 3D rendering, providing seamless transition from the data centre's overview to on-demand specific server information.

Finally, the presented work is designed not only to suit traditional desktop interaction but also to support natural interaction by employing gesture-based interaction.

Future work involves enriching the gestural vocabulary and conducting an in-depth qualitative and quantitative evaluation, in order to assess the system's usability, scalability and the overall user experience. Another challenging issue upon which further research can be directed is the ability to incorporate the visualization of relationships between servers in the system.

Finally, this work aims to act as a starting point for developing a complete framework for Big Data Infrastructure Management. Due to the nature of Big Data, a plethora of information exists that is significant and meaningful for data centre experts, constituting a very demanding area in the interdisciplinary domain of 3D Graphics, Human-Computer Interaction and Visual Big Data Analytics.

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REFERENCES

Aggarwal, J., Ryoo, M., 2011. Human activity analysis: A review. ACM Comput. Surveys. 43.

Andrae, A. S., & Edler, T. (2015). On Global Electricity Usage of Communication Technology: Trends to 2030. *Challenges*, *6*(1), 117-157.

Chen, C. P., & Zhang, C. Y. (2014). Data-intensive applications, challenges, techniques and technologies: A survey on Big Data. *Information Sciences*, *275*, 314-347.

Chen, Z. (2012). *Production system improvement: floor area reduction and visual management* (Doctoral dissertation, Massachusetts Institute of Technology).

Cole, D. (2012). Data center infrastructure management. *Data Center Knowledge*.

Drossis, G., Grammenos, D., Birliraki, C., & Stephanidis, C. (2013). MAGIC: Developing a Multimedia Gallery Supporting mid-Air Gesture-Based Interaction and Control. In *HCI International 2013-Posters' Extended Abstracts* (pp. 303-307). Springer Berlin Heidelberg.

Eaton C., Deroos D., Deutsch T., Lapis G. and Zikopoulos P. (2012), Understanding Big Data: Analytics for Enterprise Class Hadoop and Streaming Data.

Harris, M., & Geng, H. (2015). Data Center Infrastructure Management. *Data Center Handbook*, 601-618.

Gölitz, P., Struffert, T., Lücking, H., Rösch, J., Knossalla, F., Ganslandt, O., & Doerfler, A. (2013). Parametric color coding of digital subtraction angiography in the evaluation of carotid cavernous fistulas. *Clinical neuroradiology*, *23*(2), 113-120.

Keim, D., Qu, H., & Ma, K. L. (2013). Big-data visualization. *Computer Graphics and Applications, IEEE*, *33*(4), 20-21.

Koutamanis, A. (2000). Digital architectural visualization. *Automation in Construction*, *9*(4), 347-360.

Kriglstein, S., Wallner, G., & Rinderle-Ma, S. (2013). A visualization approach for difference analysis of process models and instance traffic. In*Business Process Management* (pp. 219-226). Springer Berlin Heidelberg.

LaValle, S., Lesser, E., Shockley, R., Hopkins, M. S., & Kruschwitz, N. (2011). Big data, analytics and the path from insights to value. *MIT sloan management review*, *52*(2), 21.

Lawler, M. E. (2010). *Improving shop floor visualization and metrics* (Doctoral dissertation, Massachusetts Institute of Technology).

Lazovik, A., Kaldeli, E., Lazovik, E., & Aiello, M. (2009). Planning in a smart home: visualization and simulation. In *Application Showcase Proceedings of the 19th (ICAPS) Int. Conf. Automated Planning and Scheduling*.

LeanBigData - Ultra-Scalable and Ultra-Efficient Integrated and Visual Big Data Analytics, Funded by FP7 ICT 619606, 2014-2017, http://leanbigdata.eu/, http://cordis.europa.eu/project/rcn/191643_en.html (last accessed on 21/1/2016).

Lozada, C., & De la Rosa, R. (2014, June). Simulation platform for domotic systems. In *Communications and Computing (COLCOM), 2014 IEEE Colombian Conference on* (pp. 1-6). IEEE.

Michel, D., Papoutsakis, K., & Argyros, A. A. (2014). Gesture recognition supporting the interaction of humans with socially assistive robots. In Advances in Visual Computing (pp. 793-804). Springer International Publishing.

Moore, J., Chase, J., Farkas, K., & Ranganathan, P. (2005, February). Data center workload monitoring, analysis, and emulation. In *Eighth Workshop on Computer Architecture Evaluation using Commercial Workloads*.

Moore, J., Chase, J. S., & Ranganathan, P. (2006, June). Weatherman: Automated, online and predictive thermal mapping and management for data centers. In *Autonomic Computing, 2006. ICAC'06. IEEE International Conference on* (pp. 155-164). IEEE.

Reda, K., Febretti, A., Knoll, A., Aurisano, J., Leigh, J., Johnson, A., ... & Hereld, M. (2013). Visualizing large, heterogeneous data in hybrid-reality environments. *IEEE Computer Graphics and Applications*, (4), 38-48.

Ren, Z., Yuan, J., Meng, J., & Zhang, Z. (2013). Robust part-based hand gesture recognition using kinect sensor. *Multimedia, IEEE Transactions on*, *15*(5), 1110-1120.

Schneider, R.D. (2012), Hadoop for Dummies Special Edition, John Wiley&Sons Canada.

Sfakianakis, Y., Mavridis, S., Papagiannis, A., Papageorgiou, S., Fountoulakis, M., Marazakis, M., & Bilas, A. (2014, November). Vanguard: Increasing Server Efficiency via Workload Isolation in the Storage I/O Path. In *Proceedings of the ACM Symposium on Cloud Computing* (pp. 1-13). ACM.

Valdes C., Eastman D., Grote C., Thatte S., Shaer O., Mazalek A., Ullmer B., Konkel M. (2014). Exploring the design space of gestural interaction with active tokens through user-defined gestures. ACM.

Ware, C. (2012). *Information visualization: perception for design*. Elsevier.