

# Information Search in Ontology Visualization – An Eyetracking User Study of Indented List on Desktop and Tablet Computers

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**Abstract:** A large amount of research efforts have focused on designing and developing ontology visualization methods over the years, but less effort in comparison has been put on evaluating usability support of these existing ontology visualization techniques particularly in rising interaction mediums such as touchscreen devices. This paper investigates the visual support of indented list visualization - traditionally designed for desktop computers - in the context of class search activities using traditional desktop computers as well as tablet computers. Using task-based user studies conducted on desktop and tablet computers, we analysed the difference between task success, task speed, eye gaze, as well as qualitative data collected from usability questionnaires, we found that the indented list visualization is not as effective on tablet computers with increased gaze activities, where many users preferred using it on desktop computers.

## 1 INTRODUCTION

Traditional desktop computers (configured with mouse and keyboard) have provided a main platform for human computer interaction for several decades. In recent years, the increased usage<sup>1</sup> of tablet computers brings a much needed examination of the effectiveness of touchscreen interactions in supporting information search activities in comparison to traditional desktop computers.

Ontology visualization typically assumes that the users are interacting with these visualizations using traditional desktop computers. With an ever-increasing number of users accessing the web via mobile and tablet devices instead of personal computers, this assumption may no longer be representative of the vast amount of users today.

Given this current user characteristic, there is a pressing need to investigate whether established ontology visualization techniques such as indented lists are providing the desired interactive support to users using tablet computers. More specifically, this paper investigates whether touch screen interactions change how users browse pertinent information, and whether

search accuracy and efficiency differ from that of desktop computer interactions.

Through user studies with tasks focusing on searching for specific ontology classes using indented list visualizations, we measure user success and task speed using desktop and tablet computers. In addition, eye tracking is used to supplement observations of search behaviours, such as gaze efficiency and navigation. Furthermore, participants are asked to complete the System Usability Scale (SUS) questionnaire as described by (Brook., 1996) to evaluate “the effectiveness (ability to complete tasks), efficiency (the level of resource consumed by tasks), and satisfaction (user’s subjective reactions to the system) of the interfaces”.

## 2 RELATED WORK

Visualizations are used to convey various different kinds of data in the real world, from health related data (Brown et al., 2016), genetic sequencing data (Kearse et al., 2012), to database information (Stolte, Tang and Hanrahan, 2012). Visualizations that are originally designed for desktop computers are often transferred to tablet computers with little modification. Previous research (Chittaro, 2006) has found that mobile visualization is significantly different from desktop visualizations due to physical limitations such as

<sup>1</sup> The Pew Research Center reported in 2015, the number of adults who own a tablet computer increased from 3% to 45% between 2010 and 2015, see: [http://www.pewinternet.org/2015/10/29/technologydevice-ownership-2015/pi\\_2015-10-29\\_device-ownership\\_0-01/](http://www.pewinternet.org/2015/10/29/technologydevice-ownership-2015/pi_2015-10-29_device-ownership_0-01/)

Table 1: Characteristics of Anatomy and Disease Ontology.

Ontology	Classes	Maximum Subclasses	Longest Path	Object Property	Data Property	Multiple inheritance
Disease	46	6	6	15	-	1
Anatomy	76	7	12	140	30	1

smaller screen size, less powerful hardware to render visualizations, and different inputs methods (e.g. finger tap, stylus). It is thus of interest for us to evaluate established ontology visualization techniques such as indented lists, whether they remain effective on tablet computers.

A significant amount of research effort has focused on comparing different visualization techniques on desktop interfaces (Katifori et al., 2007). In comparison, less attention has been placed on examining whether visualization techniques primarily designed for desktop computers are transferable to tablet interfaces. Prior research in (Rivadeneira and Bederson, 2003), (Plaisant, Grosjean and Bederson, 2002) and (Katifori et al., 2006), suggests indented list visualization as an efficient method for searching ontology class information, with dominant user preferences as stated by (Fu, Noy and Storey, 2013) and (Golemati, 2008), and (Fu, Noy and Storey, 2015) claims it is more effective at supporting information search activities. A related question naturally arises as to whether the indented list visualization remains effective for information search activities carried out on tablet computers.

### 3 EXPERIMENT

To investigate the aforementioned research question, we carried out task-based user studies using biomedical ontologies. Participants are asked to search for specific classes of the given ontologies using indented lists visualizations. The remainder of this section discusses further details of the ontologies, the visualizations, eye tracking, and the experiment protocol used in our study.

#### 3.1 Ontologies

To minimize potential bias that may be a result of domain expertise, we chose two domains such as the disease and the anatomy ontology, which are taken from BioPortal (Whetzel et al., 2014). The disease

ontology<sup>2</sup> has 9247 classes, the maximum number of children 88 and the maximum depth of 12; the anatomy ontology<sup>3</sup> contains 104145 classes, the maximum number of children 225 and the maximum depth of 23. In our experiment, we used a subset of the aforementioned ontologies. As shown in table 1, the disease ontology<sup>4</sup> used in our study contains 46 classes with a maximum of 6 subclasses for a class, 15 object properties, no data property and 1 occurrence of multiple inheritance. The anatomy ontology<sup>5</sup> used in our study contains 76 classes with a maximum of 7 subclasses for a class, 140 object properties, 30 data property, and 1 occurrence of multiple inheritance.

The anatomy ontology is relatively more complex than the disease ontology, with more classes, a higher number of subclasses per class, and longer paths to

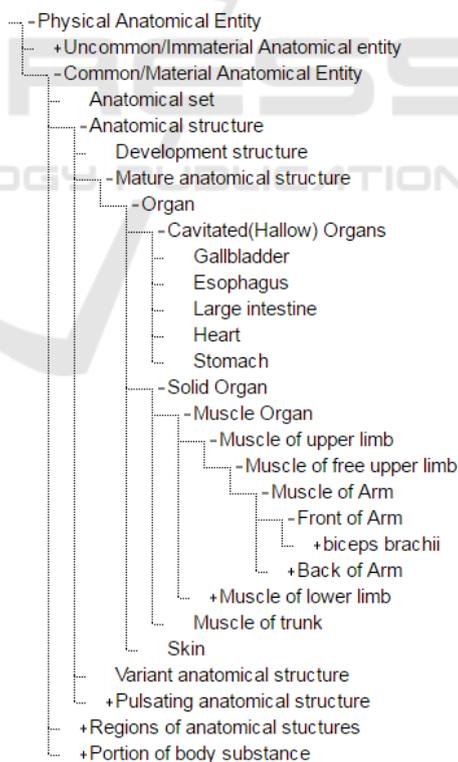


Figure 1: Example Indented List Visualization.

<sup>2</sup> <http://bioportal.bioontology.org/ontologies/DOID/?p=summary>

<sup>3</sup> <http://bioportal.bioontology.org/ontologies/FMA/?p=summary>

<sup>4</sup> <https://aqueous-spire-79089.herokuapp.com/>

<sup>5</sup> <https://infinite-brushlands-54265.herokuapp.com/>

root. To ensure the ontologies are comprehensible to a wide range of participants, we used novice terminologies as opposed of scientific terminologies where appropriate. For example, for the purpose of our experiment, the class: *Cavitated Organs* is renamed to *Hallow Organs*, and the class *Material Anatomical Entity* is renamed as *Common/Material Anatomical Entity* in the anatomy ontology.

### 3.2 Indented List Visualization

The indented list visualizations are implemented using the D3.js library and presented in a web browser. Figure 1 shows an example visualization of the anatomy ontology. Classes are presented in a vertical list, and indentations are used to illustrate *is-a* relationships. The dotted lines illustrate superclass-subclass relationships and siblings. The + icon expands a class and reveals its subclasses. The – icon collapses a class and hides its subclasses. The absence of an + or – indicates a class has no subclasses.

### 3.3 Equipment and Setup



Figure 2: Tablet Setup.

We used a Tobii Pro X3-120 eye tracker to capture gaze data. For the tablet interface, an Apple iPad Air 2 is placed upon the Tobii Mobile Stand X2. The tablet has a dimension of 16.95 x 24 cm and uses a 2048 x 1536 pixel resolution. For the desktop configuration, a Dell Precision Tower 5810 workstation with a 24" monitor, mouse, peg-leg chair are used. The monitor has a dimension of 56.5 x 49.9 cm, and a resolution of 1920 x 1080 pixels.

The Tobii Pro X3-120 eye tracker is situated at the bottom of the monitor in the desktop interface (shown in Figure 2), and below the tablet in the mobile interface (shown in Figure 3). The eye tracker has a sampling rate of 120Hz, with operating distance at 50-90cm. The eye tracker verifies the data recorded by assigning validity codes (a number from 0-4) to every row of data throughout a recording. In this

study, only data with 0 validity codes (meaning both eyes are found and tracked by the eye tracker) are used in the analysis to reduced bias. The data parsing and cleaning code used in this study can be found online<sup>6</sup>. Calibration is carried out before each recording. Subtle head movements are tolerated by the Tobii Pro X3-120 eye tracker, and participants were instructed to refrain from large movements after successful calibration. This setup simulates a typical usage and common interaction with desktop monitors and tablet screens.

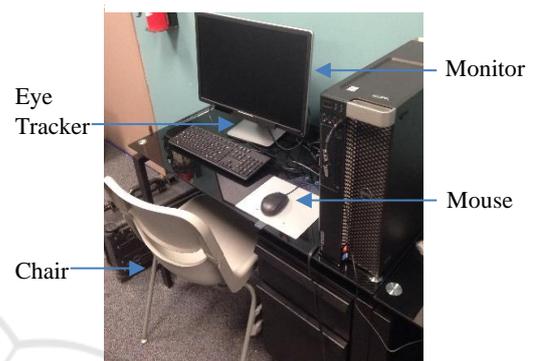


Figure 3: Desktop Setup.

### 3.4 Eye Tracking Metrics

In the context of information search, shorter scan path may be considered as an indication of an optimal route of navigation when the search is completely directed to the required information (Goldberg, 1999). Scan path gives insight to gaze behaviour by examining the physical trace of alternating fixations and saccades sequences. By treating fixations as gaze points and saccades as edges between these points, scan path measures the visual distance a participant's gaze travel on a screen by summing the distance between gaze points, or the total length of the saccades measured in pixels. In other words, scan path is an eye productivity measurement in the sense that it measures eye activity. Goldberg claims a small scan path typically means the search is directed and methodological, and a large scan path indicates undirected or possibly exhaustive search behaviour. In contrary, exhaustive search behaviours tend to systematically visit all possible candidates for the solution. Ideal search behaviours may be understood as those that produce smaller task time and shorter scan path, suggesting that the task was completed faster with fewer eye movements. In other words, time was used efficiently and eye gazes were used strategically.

<sup>6</sup> <https://github.com/HDSCLabSource/Source>

### 3.5 Participant Recruitment and Experiment Protocol

Undergraduate and graduate students from the Department of Computer Engineering and Computer Science with background in ontologies and interactive visualization were asked to participate in this experiment.

Each participant was given an overview on the interactive features, such as zooming and selecting for the tablet interface, and mouse control and clicking for the desktop interface. Note that font sizes were set to the same zoom level on both the desktop and tablet interface before each recording. Additionally, participants were given instructions on the tasks to be accomplished. They are encouraged to be as fast as they can to complete the given tasks and once the eye tracking recording begins, they can no longer ask questions or interact with the researcher. Table 2 shows a list of the tasks used in our study.

Table 2: Anatomy and Disease Ontology Tasks.

Anatomy Ontology Tasks
1. Name three muscle in the 'Leg'.
2. What are the two parents of 'Heart'?
3. Find the parent of 'Left Triceps'.
4. What is the parent of 'Fissure of Tooth'?
Disease Ontology Tasks
1. Find parent of 'Down Syndrome'.
2. What are the two parents of 'Diabetes'?
3. What is the child of 'Obesity'?
4. What is the parent of 'sleep disorder'?

To reduce potential bias that may be a result of increased familiarity with a given domain, each participant is shown two ontologies. Also, to minimize potential bias caused by whether a participant was given the tablet or desktop interface first, we alternated the following 4 combinations between experimental runs and participants, e.g. disease/tablet, disease/desktop, anatomy/tablet, and anatomy/desktop. After completing one of these four combinations, participants partake in a second combination being the other ontology and the other interface, e.g. a participant would answer questions about the disease ontology using the tablet interface, and then answer questions about the anatomy ontology using the desktop interface.

The time a participant takes to complete all the questions is recorded. Task accuracy (e.g. a success score about how many questions were answered correctly) and gaze data are also collected from each participant. In addition, participants also completed

the SUS questionnaire for each interface, having questions rated on a scale of 1-5. These scores are normalized in the range of 0-100, higher scores indicate more favourable perception of that interface. Furthermore, we asked each participant's overall preference between desktop and tablet computers, with the goal of eliciting qualitative feedback.

## 4 RESULTS

A total of 24 participants took part in our study. A total of 463.1 megabyte of text file eye tracking data were collected, and 1,281,271 valid gaze points were analysed after data cleaning. Unpaired two-tailed t-tests with the standard confidence level of .95, or significance level,  $\alpha$  of .05 were applied to verify statistical differences (if any).

### 4.1 Task Time Vs Scan Path Correlation

Since task time typically represents search efficiency and scan path typically is an indication of search productivity, together they may give a holistic view. Figure 4 shows a positive correlating relationship between the two, with r-values: .4218 (disease/desktop), .6989 (disease/tablet), .5847 (anatomy/desktop), .4549 (anatomy/tablet). Generally, when task time increases, scan path also increases. Interestingly, we observed some participants have comparable task time but noticeably longer scan path, most notable in the anatomy/tablet group (blue squares in Figure 4). Specifically, these are data points within their respective group that lies in the lower and further right region of Figure 4, meaning shorter task time and longer scan path. This result suggests an exhaustive search method in which participants systematically visit all possible candidates to find the solution.

However, our data also shows a lengthy scan path does not always lead to a shorter task time. In fact, lengthier scan path does not predict a long or short task time, as seen by points being high on the scan path axis, and low (efficient exhaustive search) or high (inefficient exhaustive search) on the time axis. Another possible search method is a directed search. Likewise, this sort of directed search behaviour, typically having shorter scan path, could have low (efficient methodological search) or high (inefficient methodological) task times. Our results exhibits a little of each of these behaviours, and it suggest any difference, if any, found in our

experiment between desktop and tablets, will not be task time. In other words, indented list visualization on the tablet does not encourage an approach that reduces task time, and there are no statistically significant differences in task time between desktop and tablet interfaces. This does not mean the two interfaces are equal in terms of usability since scan path is another important metric that affects usability.

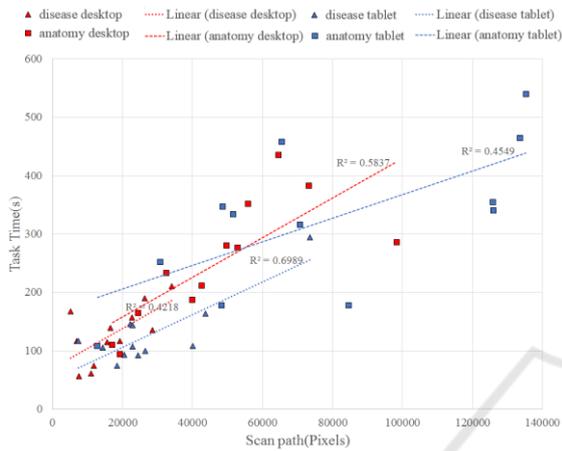


Figure 4: Scatter plot of task time versus scan path.

#### 4.2 Scan Path Length

We found the anatomy ontology has statistically significant scan path difference when comparing the desktop and tablet interfaces. In Figure 5, for the desktop interface, participants’ average scan path is  $47540 \pm 23755$  pixels (blue bar), and for the tablet interface, average scan path is  $77806 \pm 42766$  pixels (red bar); a statistically mean defence of  $-7566$  (95% CI,  $-15015, -18$ ) pixels,  $t(12) = -2.14$  and  $p\text{-value} < 0.047$ . Also, we found that the disease ontology has no significant scan path difference between desktop and tablet interfaces at  $p\text{-value} = 0.072$ ; nevertheless, the scan path length is  $17148 \pm 9269$  (red bar) and  $28086 \pm 17382$  (blue bar) pixels respectively. We speculate that the simple nature of the disease ontology did not sufficiently augment the difference between desktop and tablet computers. For example, the entirety of the disease ontology can be fitted on the tablet and desktop monitor, but the entirety of the anatomy ontology cannot fit on the tablet.

In comparison to desktop monitor, on the tablet interface, participants’ average scan path increased by a factor of 1.64 for both ontologies, and scan paths exhibit a factor of 1.80 and 1.86 increase in variance for anatomy and disease ontology respectively. In relation to average scan path, it may be expected that mobile devices have larger fonts than desktop

computers using the zoom feature of tablet interface and this may be the obvious reason for longer scan path. In relation to scan path variance, this may be a result of uncertainty caused by frequent scrolling back and forth, which leads the eyes to acutely travel more (i.e. increased scan paths), and some participants may scroll more than others to comprehend the task at hand. This result suggests that indented list visualizations on tablet computers may have led to confusion for some participants, as reflected by additional gaze activities in the process of information search.

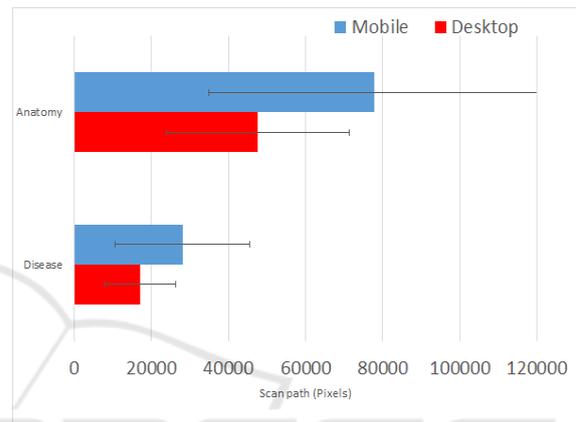


Figure 5: Scan path length (pixels). For the both the anatomy and disease ontology, the tablet interface has a much larger scan path, and a significant amount of variance.

#### 4.3 User Preference

For the desktop and tablet interface, shown in Figure 6, the SUS score is  $86.4 \pm 10.2$  and  $79.2 \pm 11.2$  points respectively with a statistical mean difference of 7.17 (95% CI,  $(.80, 13.55)$ ,  $t(24) = 2.27$  and  $p\text{-value} < 0.028$ . This finding suggests that participants preferred the desktop interface, because it is easier to use and they find it familiar. For example, one participant says, “Despite, having experience with both interface, the tablet was difficult to use”, another says, “The desktop is less cumbersome and easier to use”, and a third says, “The desktop mouse is handier to use than the touch screen, and manipulation with the tablet was harder. Touching sometimes need to tap twice, and it is not as responsive as I would like. You have to be accurate with your hand”. Overall user preference also showed a significant difference in favour of the desktop interface, with 16 out of 24 participants stated they preferred the desktop interface.

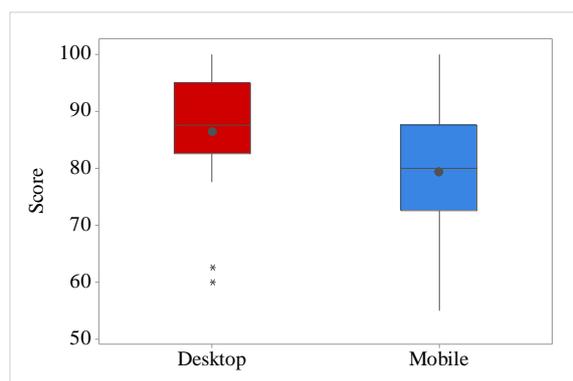


Figure 6: Box Plot of SUS of desktop and mobile scores. \* are outliers. The square contains 50% of all data points. Horizontal line inside the square is the median, and the dot is the mean.

## 5 CONCLUSIONS AND FUTURE WORK

Although we did not find statistically significant difference in task time or task accuracy, we have found some evidence suggesting that the indented list visualization is more effective on desktop computers than tablet computers, such as overall user preference, scan path discrepancy, e.g. more consistent scan path for desktop, and shorter scan paths when using desktop computers. Although our statistical tests did not show any significant in task accuracy or speed, this does not imply desktop and tablets are the same in supporting the given tasks. For example, perhaps increased user engagement or mental processing power on the tablet may have equalized speed and accuracy and offset the advantages otherwise gained on a desktop. Potential future research could investigate exclusively whether this speculation is true.

Secondly, there may be a critical point where an exhaustive search (large scan path) may outperform directed search (small scan path), and vice versa. If an ontology is relatively but not overly simple, it may be more efficient to engage users in exhaustive searches simply because it will not take a long period of time to traverse the entire ontology. On a tablet device, it may also be more efficient to encourage participants to conduct an exhaustive search, going through the expanded portions and then collapsing after traversing them to allow greater focus on a single section. For example, the ontology visualizations on the tablet computer may not be seen in its entirety, and it may be frustrating to use a directed search method because of the limited view. On the other

hand, if the ontology is very complex and contains a lot of classes, an exhaustive search approach can produce long task time if some classes are missed by the participant and needs many more rounds of searching. Depending on the characteristics of the ontologies, interaction designs may focus on guiding users in either exhaustive or directed search.

It should be noted that there are several factors not explicitly tested in the design of this experiment. For instance, we discussed searching behaviours and patterns that participants engage in, but we did not confine them to searching in a particular way, i.e. exhaustive, or directed search. In addition, age, gender, and cognitive styles were not explicitly investigated. Future experimentation can include these factors to determine if any of the aforementioned variables could have a significant effect on user speed or accuracy, such as grouping participants by age or gender may show differences in user preference and gaze activities. In addition, future experiments could examine various screen size and whether an ideal size exists for the desktop or tablet environment. Furthermore, it may be useful to consider stylus versus finger tapping as another influential factor in touchscreen interaction design.

Lastly, participants have significantly rated the desktop interface to be superior, some have mentioned inconveniences using the tablet interface, such as “accidentally clicking interactive objects in the visualization”, “confusion from scrolling”, and “the smaller screen space made it harder than the desktop”. For these reasons, and increased gaze activities, we found that indented list visualization on tablets is less effective than on desktop machines.

## REFERENCES

- Brooke 1996. *SUS: A “Quick and Dirty” Usability Scale*, In: P.W. Jordan, B. Thomas, B.A. Weerdmeester, McClelland. *Usability Evaluation in Industry*, pp. 189–194.
- Brown B., Chetty M., Grimes A., and Harmon E 2006. *Reflecting on Health: A System for Students to Monitor Diet and Exercise*. In CHI '06 Extended Abstracts on Human Factors in Computing Systems ACM.
- Kearse M., Moir R., Wilson A., Stones-Havas S., Cheung M., Sturrock S., Buxton S., Cooper A., Markowitz S., Duran C., Thierer, T. Ashton B., Meintjes P., and Drummond Alexei 2012. *Geneious Basic: An Integrated and Extendable Desktop Software Platform for the Organization and Analysis of Sequence Data*. *Bioinformatics*, vol.28, no. 12, pp 1647-1649.
- Stolte C., Tang D., and Hanrahan P., 2002. *Polaris: a system for query, analysis, and visualization of multidimensional relational databases*. In IEEE

- Transactions on Visualization and Computer Graphics, vol. 8, no. 1, pp. 52-65.
- Chittaro L 2006. *Visualizing Information on Mobile Devices*, Computer, vol.39, no. 3, pp. 40-45.
- Katifori A., Halatsis C., Lepouras G., Vassilakis C. and Giannopoulou E 2007. *Ontology Visualization Methods - A Survey*. ACM Computing Surveys, vol.39, no.4, Article 10.
- Rivadeneira W. and Bederson B.B 2003. *A Study of Search Result Clustering Interfaces: Comparing Textual and Zoomable Interfaces*.
- Plaisant C., Grosjean J. and Bederson B.B. 2002. *SpaceTree: Supporting Exploration in Large Node Link Tree, Design Evolution and Empirical Evaluation*. Proceedings of IEEE INFOVIS '02, Boston, pp 57-64.
- Katifori A., Torou E., Halatsis C., Vassilakis C., Lepouras G 2006. *A Comparative Study of Four Ontology Visualization Techniques in Protégé: Experiment Setup and Preliminary Results*. Proceedings of IV'06.
- Fu, B., Noy, N.F., Storey, M.-A. 2013. *Indented tree or graph? A usability study of ontology visualization techniques in the context of class mapping evaluation*. In ISWC 2013, Part I. LNCS, vol. 8218, pp. 117–134. Springer, Heidelberg.
- Fu, B., Noy, N.F., Storey, M.-A. 2015. *Eye Tracking the User Experience - An Evaluation of Ontology Visualization Techniques*. Semantic Web Journal.
- Golemati M 2008. *An Interview-Based User Study on the use of Visualizations for Folder Browsing*. 12th International Conference Information Visualisation, London, pp. 106-112.
- Whetzel P.L., Noy N.F., Shah N.H., Alexander P.R., Nyulas C, Tudorache T, Musen M.A 2011. *BioPortal: enhanced functionality via new Web services from the National Center for Biomedical Ontology to access and use ontologies in software applications*. Nucleic Acids Res.
- Goldberg J 1999. *Computer Interface Evaluation using Eye Movement: Methods and Constructs*. International Journal of Industrial Ergonomics, vol.24, no.6, pp 631-645.