User Interface Design for Searching Biomedical Literature

Carlos Iñiguez-Jarrín   *carlos.iniguez@epn.edu.ec*
Departamento de Informática y Ciencias de la Computación, Escuela Politécnica Nacional
Quito, Ecuador

José Ignacio Panach   *joigpana @uv.es*
Universitat de València, Departament d'Informàtica, Escola Tècnica Superior d'Enginyeria
Valencia, Spain

Oscar Pastor López   *opastor@pros.upv.es*
Universitat Politècnica de València, Centro de Métodos de Producción de Software
Valencia, Spain

Abstract

Biomedical bibliographic sources are crucial resources for the work of physicians, biologists, and bioinformatics. Many of the genetic-medical diagnoses depend on the findings in these bibliographic sources. Despite the importance and value of the information stored in these repositories, the user interface (UI) of these resources does not provide the adequate mechanisms to interact with the content, converting the query and interpretation of the information into complex and time-consuming tasks. In this sense, improving the usability of these UIs becomes a challenge since this means facilitating the interaction, analysis and comparison of biomedical information, and, consequently, improving the productivity of professionals in this domain. This paper presents a UI design for the search of biomedical bibliography that incorporates solutions to the usability problems documented and detected by a study of the literature. The proposed design becomes a usability heuristic for UI designers facing the development of UIs in this domain.

Keywords: User interface design, bioinformatics, usability.

1.   Introduction

Bibliographic search tools are crucial for the work of biomedical researchers (i.e., physicians, bioinformatics, biologists) since they are the means used to justify medical and genetic diagnoses of diseases, as well as to keep updated with the advances in their research. Among the biomedical bibliographic search tools most frequently used by researchers is the PubMed database [1] web portal as well as the Google Scholar search engine. PubMed is one of the databases administered by the National Center for Biotechnology Information (NCBI[1]) containing to date (April 2018) more than 20 million citations of complete scientific-medical articles stored in the MEDLINE database, one of the most important bases of the National Library of Medicine of the United States.

Behind these web search tools are not only machine learning algorithms, but also the user interface (UI) that support the user to interact with the bibliographic data sources. At the level of interaction, there are several problems that the researcher faces, especially those related to the *querying* and *results interpretation* tasks. These problems have a negative impact on the researchers' work productivity and, even worse, the problems reduce the possibility of finding accurate and adequate results to support the medical-genetic diagnosis of a disease; a very delicate and decisive aspect when it comes to identifying the health status of a person.

---

[1] https://www.ncbi.nlm.nih.gov/

For this reason, the scientific community has expressed its growing need to improve the usability of the UIs of these tools [2][3][4]. A log-based study [5] of the search behavior of PubMed users provides relevant information for improving the biomedical information recovery. NCBI Insights[2], an NCBI blog dedicated to facilitating the use of its NCBI search resources for users, specifically invites readers through a post titled *"Try Our New, Experimental PubMed Search and User Interface in PubMed Labs"*[3] to experience the improvements and new functionalities at UI level and search algorithms added to a PubMed prototype. The NCBI goal is to test the functionalities and eventually incorporate them into the PubMed real site. Among the characteristics to be experienced are "Best match" (i.e., a search algorithm to rank the search results with respect to the degree of concordance of the content of the article with the search terms), "Responsive design" (i.e., a new look and feel of the site that follows the "mobile-first" design principle to adapt the UI to other deployment devices, "Snippets" (i.e., highlighting the searched terms and their synonyms). Seen in another way, searching for findings in the biomedical literature involves tracing the relationships immersed in the content of literature sources. A complex task due to usability problems at the UI level.

In this paper, we propose a simple and functional UI design that incorporates solutions to the usability problems found from a study of the literature. To achieve this, we a) define the profile of users in this domain and the search behavior characteristics b) analyze, identify, collect and categorize usability problems related to the biomedical literature search, and c) propose the design of a UI for searching for biomedical-scientific bibliography by incorporating the solutions to the identified usability problems.

The main contribution of this work is to propose solutions to the concrete usability problems found in the biomedical-scientific bibliography search. To explain the solutions, we have incorporated them into a design of a simple and generic UI which focuses on improving the user experience in the search and exploration of large collections of documents. The benefit of such solutions is that they can be re-used by UI designers when designing UIs not only for biological bibliography search systems but also for designing UIs of general-purpose bibliography search systems in different domains. Therefore, the proposed UI design becomes a usability heuristic that can be used as a reference to solve interaction design problems in further UI developments.

This work is structured as follows. Section 2 details some UIs of scientific and biomedical literature search applications. Section 3 presents the user's profile in this domain. Section 4 presents the usability problems detected in the literature. Section 5 presents the proposed UI design and describes its interaction. Section 6 describes future work, especially those related to the feasibility of the UI's technological implementation. Section 7 presents the conclusions.

2. Related Works

The list of web search tools for biomedical literature sources is varied [6]. However, PubMed is the tool most often used by researchers in this domain. The type of search and exploration that the UIs of these tools support is "*query-focused*" search, that is, the researcher defines a query as a starting point to start the exploration. In PubMed, for example, the user enters the name of a disease as a search term and the records of biomedical literature obtained from the consultation become the starting point to navigate and explore the issues related to the disease.

From a general perspective, the UIs of search and analysis of scientific literature has made a great leap from text UIs to UIs that allow the exploration and visual analysis of the global properties of the literature collection (e.g., authors, locations, publication dates) [7], as well as, the properties of each of the items in the collection (e.g., co-citation relationships, co-authorship). Tools such as VOSviewer [8] or PubNet [9], for example, show powerful

---

visualizations about bibliometric networks allowing visualizing publications, authors or journals from the point of view of citation relationships, co-citations or bibliographic coupling.

There are also applications that aim to integrate the various bibliographical sources to avoid the researcher visiting each of the sources of bibliography in search of useful information. The UIs of these systems incorporate global and detailed visualizations of the bibliography collection.

Mastermind [10] is a specialized search engine to find the relationships between documented diseases and genetic aspects (genetic variations and genes). To achieve this, the application integrates the content of several biomedical repositories from which the researcher interacts mainly through two UIs: search parameters and data exploration. The first one allows the researcher to enter any of the three search parameters supported by the application such as the name of a disease, the identifier of a genetic variation or the name of a gene. The query results are presented in the second UI that includes textual and statistical graph information about the medical-scientific articles found, as well as the genetic information (genetic variants and genes) referenced in the articles. The graphic representation of the articles is well achieved through a zoomable scatter plot where each point becomes a circle of a variable area that represents each of the items in the set. This graphic representation allows visualizing the set of articles from 3 dimensions. The 2 scatter plot axes (XY) represent the *date of publication* and *number of citations* dimensions. The third dimension, *% match search term in the article*, is represented by the variable area of each circle in the graph. The objective of the authors to include functionalities and improvements in the UI is to obtain faster, clinically relevant search results and achieve comprehensive diagnoses. Unlike databases such as PubMed, Mastermind provides full indexing of articles, which makes it possible to match full-text statements in the content of biomedical articles.

Dimensions [11] is a discovery platform with nearly 90 million publications, full-text search, and contextualization of information through links to publications, patents, clinical trials, authors, appointments, among others. Its UI is distributed in four sectors (i.e., search term, list of publications found, fixed area of filters and the view of analytics) fairly similar to other search engines of scientific-academic literature such as Scopus except that the Dimensions' UI facilitates the segregation of results through filters related to the fields of research (e.g., genetics, clinical sciences, immunology), relevant authors, sources of titles (e.g., Plos One) and makes possible, through a 2D chart, the interactive analysis of publication metrics over the years.

Other systems set their UI with visual components that retrieve information from different bibliographic sources. BioGPS [12] is a portal for querying and reporting genes where the UI is built from the combination of plugins which present data retrieved from data sources focused on genes external to BioGP. For example, among the plugins available in the portal that support the literature search about genes include plugins to search on Google Scholar, PubMed full-text search, Gene Wiki[4], NextBio[5], among others. The plugins mechanism makes this application configurable (customizable) and extensible.

The tools described in this section present UIs that allow exploring the bibliography in several ways. Specifically, the type of exploration that we pursue is the *exploratory visual search* that supports tasks such as analyzing, comparing and evaluating the content. The proposed UI design considers the exploratory visual search and the best usability practices of the tools described in this section.

3. User Profile

Knowing the users is critical to design successfully the interaction. In this sense, defining a *user profile* helps the interaction designer to know the users to whom the product is being designed. The definition of a user profile contains, among other things, the information about demography

---

[4] https://en.wikipedia.org/wiki/Portal:Gene_Wiki

[5] http://www.nextbio.com/b/nextbio.nb

(e.g., gender, age, economic level, custom preferences), education, tasks performed by the user, however, for our study purposes, we have focused specifically on defining the information about *user's search behavior* in this domain. To do that, we have collected and analyzed both several works existing in the literature [5],[13] and conducted surveys and interviews with genetic laboratory researchers and bioinformatics students.

In this section, we define the user's search behavior by describing the search characteristics from various perspectives such as query size, query intent frequency, revision trend, among others and, for a better organization, we classify the characteristics in relation to the typical search tasks of this environment: *query* and *results review*.

Considering the query task, the user search behaviour characteristics are:

Query size. - Users make short queries that have on average 3.4 tokens (words), which produce more than 10,000 results.

Type of search. - In contrast to the "Web search", the search need is specific and related to the biomedical domain.

Search strategy. – To build the query string, the users frequently use abbreviations (e.g., DNA) and terms intrinsically related to fields of the literature (e.g., author) followed by non-bibliographic terms (e.g., terms related to "genes/proteins" and "diseases").

The time between queries. - There are short periods between subsequent queries (72% of all queries are sent within 1 minute after the initial query).

Reformulation. - The query string is modified continuously.

Persistence. - Regardless of whether the results are many or none, the search is persistent; new queries are sent to obtain significant results.

Considering the results review task, the user behaviour characteristics are:

Interpretation scope. - The interpretation depends strongly on the repository used. For example, the results retrieved by PubMed are limited to the fields that it indexes (e.g., titles and abstracts) since it does not index full-text articles. On the contrary, Google Scholar indexes millions of articles from various domains including the biomedical domain. However, Google Scholar is not focused on human diseases searches, therefore, the results obtained overload valuable information.

Review trend. - Users tend to select search results located in the top positions. The number of clicks in the documents located in the last pages decreases exponentially. In addition, the user accesses frequently the abstracts instead of the full-text article.

Selection probability. - There is a low probability of selection of results when the result set increases in size. The greater the set of results, the user tends not to review the results.

The user profile, comprised of the behavior characteristics described, becomes a distinctive model of the search behavior of the user population in this domain. The importance of the user profile lies in its role as a support instrument for making user interface design decisions. In effect, to achieve a customized user interface design that meets the real needs of biomedical bibliographic search, it is essential to consider the characteristics of the end user's search behavior.

4.   Usability Problems

In this section, we identify and collect seven (7) usability problems in the biomedical literature search UIs from the literature analysis [5],[14]. In addition, usability problems were categorized into two general lines: *query* and *result interpretation*. Within each category, each usability problem is identified with the prefix UP (usability problem), the assigned number and its distinctive name, as detailed in the following subsections.

4.1.   Query Usability Problems

Regarding the query task, we have identified two usability problems.

UP1-Correct query terms. - Users experience problems when building the query string. These problems are caused mainly by the lack of the information and the support mechanisms to structure and build the query string. From a practical view, these problems can be outlined

in two specific usability sub-problems: "*finding the correct term*" (the search mechanisms provided by the repositories do not support searches by synonyms, but exact and well-written terms which usually produces 0 results) and "*search by object ID*" (object ID[6] is a univocal and exclusive identifier number assigned to each article indexed in the bibliography database which is used to yield accurate results, however, in most cases, it is not used because the users do not know where or how to include it in the query).

UP2-Complex generation of the query string. - The mechanisms used for building query strings are extremely simple or difficult to use. While the "standard search" mechanism becomes a solution relatively simple that often produces a lot of noise in the results, the "advanced search" becomes a difficult-to-use mechanism and requires special skills on the part of the user. For building complex queries, for example, the user must have an in-depth knowledge of the possible data fields to filter and deal with the logical operators. Especially, the syntax and semantics of the operators cause many problems among the users; users must deal with the order and combination of operators as well as their meaning (for example, some use "AND" another "+"), without obtaining any results. In that sense, the existing query mechanisms do not allow to correctly express the semantics of the query string.

4.2.   Result Interpretation Usability Problems

Regarding the result interpretation task, we have identified five usability problems.

UP3-Lack of the vision of the "big picture". - Given the numerous query results, perceiving the trends in the result set is difficult. The user requires an entire visualization of the results that allow understanding the result set in a glance.

UP4-Manual Annotations. – Users frequently use Microsoft Excel to manually document the findings found in the literature. This is a time-consuming task since, for each comment, the user must fill a row with several columns including the bibliographic reference to locate the source of the comment in the future.

UP5-Handling long lists of results. - Users have difficulty handling long lists of results. With more than 100 records, users behave in two ways: a) Do not explore the results and reformulate the query string or b) Focus on the first three results expecting them to be the most relevant (something that is not fulfilled in most cases).

UP6- Non-understandable ranking criteria. - Several sorting criteria are used in lists of options or in data charts, however, many of them are not well explained leaving to the user's imagination the meaning of them.

UP7- Extract of the document does not allow understanding its content. - The title and the abstract are not helpful to understand the document.

From these usability problems detected, in the next section we propose design solutions to the UI of biomedical bibliography search to facilitate the search for information and obtain relevant results.

5.   UI Design

To address the detected UPs, we have designed two UIs (one for "*query task*" and another for the "*result interpretation task*"). In this section, we describe the design of each UI and its functionality, emphasizing how the usability problems described in the previous section have been addressed. For a better understanding of the UI functionality, we will begin by describing the UI for the result interpretation task and then the UI for the query task.

Query and Result Interpretation UI

This UI has been designed to provide a global and detailed view of the results and allows the user to freely explore the bibliography through different connected views of the content. Figure 1 shows the design of this UI stating the four panels that make it up.

---

[6] https://www.ncbi.nlm.nih.gov/pmc/pmctopmid/

Search panel. - It contains the text box to enter the search terms, a link to the Query UI (showed in Figure 4) that allows refining the query string and, additionally, the link to the "annotations form" to make notes about the content of the articles.

Menu panel. - It is a menu bar with the links to navigate to the different parts of the website. The user can navigate to the data filter panel, the list of the notes made in the articles, the alerts configured by the user, the list of saved citations and the user account configuration.

Literature panel. - This panel, next to the menu panel, lists the literature found based on the search term. The panel header shows the number of results retrieved, as well as the estimated time the system took to retrieve the results. The list can be ordered by several options such as the number of citations, the number of occurrences of the search term in the article, among others.

Exploration panel. - This is the largest panel of the UI and contains two zones. The first presents a scatter plot of the set of articles showed in the literature panel. The latter presents the full-text content of the article that has been previously selected in the scatter plot or in the list of articles in the literature panel.
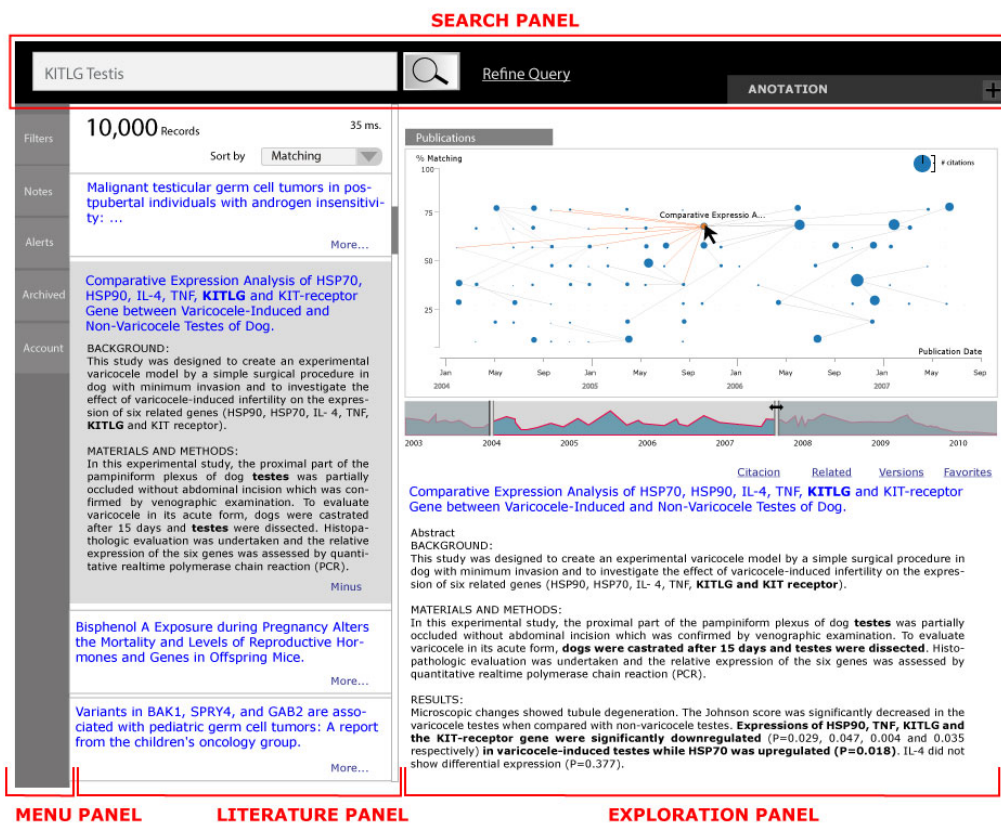

Figure 1. UI design for exploring and interpreting the biomedical literature.

The operation of the UI starts when the user enters a term in the search text box. To help the user find the appropriate terms for searching and querying the heterogeneous biomedical data, each term entered by the user is compared internally with terms of an underlying ontology [15] that contains the concepts of the domain and the relationships between them. Thus, even when the user commits a writing error, the system suggests the user correctly written terms related to the entered term. This achieves a query string with a high probability of obtaining accurate results. This solution is related to UP1.

Once the user has requested to retrieve the results from the query string, the set of literature records is listed in the literature panel and mapped in the scatter plot (exploration panel in Figure 1).

The state of the panels (literature and exploration in Fig. 1) changes according to the user's behavior in any of them, it means that the actions performed by the user in a panel change automatically the state of the other panel. In Figure 1, for instance, when the user selects a circle

that represents one of the articles published between 2004 and the last months of 2007 (as shown by the timeline bar), several things happen at the same time: a) in the scatter plot, the lines that connect the selected article with referenced articles are highlighted, b) in the literature panel, the corresponding publication (second publication of the list) in the literature panel is highlighted, c) in the exploration panel, the full-text article is displayed.

In the full-text article, the user can see highlighted not only the exact words that match with the search terms, but also the synonymous and the complete sentences that make the context of the document more understandable. This functionality, inspired by the functionalities in [10] and [1], addresses the UP7.

The scatter plot is inspired by the Mastermind's scatter plot where the scientific-clinic articles are represented by circles of a variable area which are located regarding *the publication date* (X-axis), *% match of the search terms within the article content* (Y-axis), *number of citations* (variable area of each circle). However, we have adapted the Mastermind's scatter plot to show an additional dimension: *the citation relationships between articles* (lines that join the circles) to show the articles that have been referenced by a selected article, as shown by the enlarged image of the scatter plot in Figure 2. The spatiotemporal relationships between articles facilitate a global perspective of the entire result set. Therefore, this improvement is related to UP3. The UP5 is also addressed since the user can use the scatter plot to select the subset of results to review, thus reducing automatically the long list of results displayed in the literature panel. The legend located at the upper right corner of the diagram indicates the user the meaning of the circle area: *the number of citations of the article*, an important detail mentioned in the UP6. Therefore, each circle varies its area depending on the number of citations of the article.
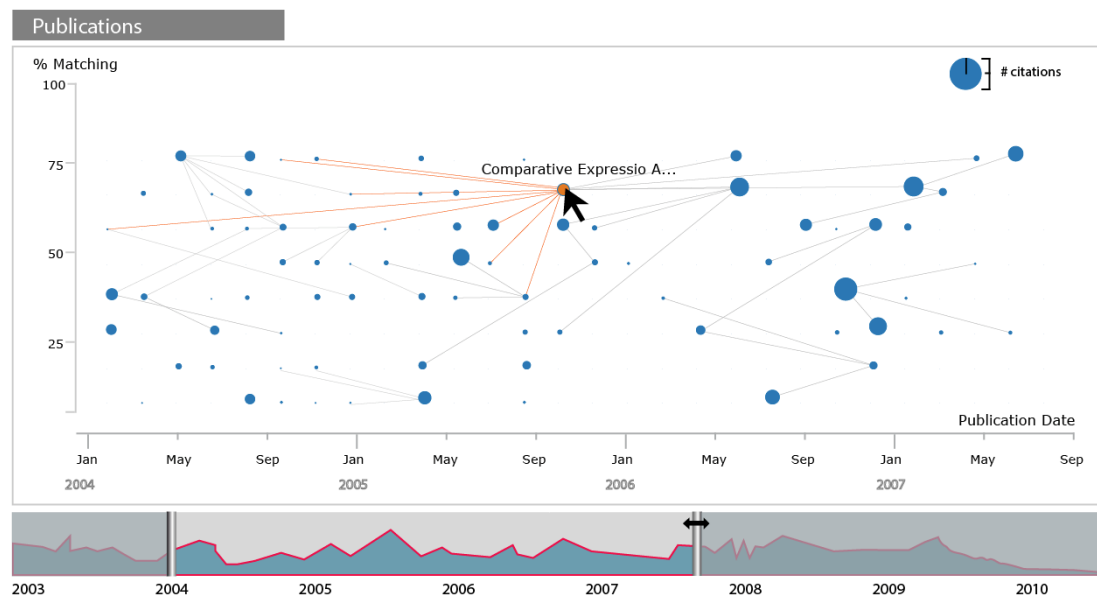

Figure 2. Scatter plot chart showing four dimensions for publications.

If the user is interested in an extract of the content of an article, the user can comment it by clicking on the (+) sign in the annotation menu (located in the search panel). The annotation form (Figure 3b) loads automatically the selected content by the user, the article citation and provide a text box to add the respective comment. By accessing the "Notes" menu (menu panel), the user can see all the notes made. This built-in functionality allows automating the manual annotation process improving the productivity of the user. This solution is related to UP4.
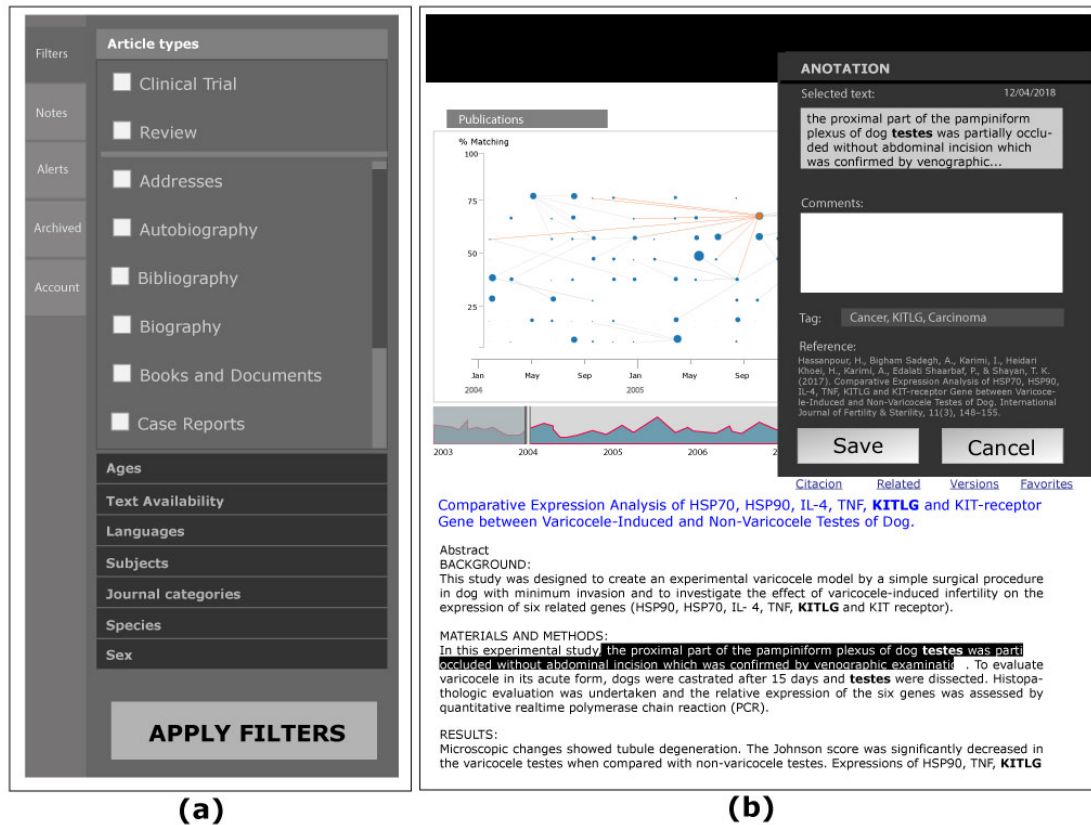
Figure 3. a) Filters b) Annotation form.

The filters tab (Figure 3a) shows the filter conditions that help segregate the set of articles by some themes and categories related to the article attributes. Although most of the search engines in this domain have already implemented this filter feature, in this paper, we highlight this functionality because we consider it a feature necessary and mandatory in this kind of applications. The filters address the UP5 since through the filters the information overload is avoided by segregating the result set to one or another filter condition.

Query UI

The Query UI deals with the tasks related to how to query and discover the data. The link "Refine Query" (located in the search panel in Figure 1) allows accessing to the Query UI. When clicking the link, the Query UI is displayed by showing a mechanism for building query strings, as shown in Figure 4. A *query string* is a set of terms related by logical operators (i.e., AND, OR, NOT). Building complex query strings can become a difficult task since it supposes to deal with nested logical operators and the order in which they must be executed. The proposed mechanism addresses the UP2 by facilitating the use of syntax and improving the semantic of logical operators.

The mechanism is composed of the "*Query String*" (Figure 4a) and the "*Query Builder*" (Figure 4b). The Query String is a read-only field that displays the "query string" formed automatically for each change made in the Query Builder. The Query Builder contains the "Search for" field, the first term of the query string, and the "matrix of terms" that contains the terms that are added to the first term by means of the syntax of logical operators AND, OR and NOT represented by the INCLUDE, OPTIONAL, EXCLUDE columns of the table, respectively.

Figure 4. Query builder settings to obtain 341989 results.

To explain how to operate the mechanism, we will assume that the researcher wants to search for "*the relationship between the KITLG gene and testicular cancer in humans or in dogs*". To build this query string, the researcher enters the first search term "*KITLG*" in the "Search for" field as shown in Figure 4b. Next, the researcher enters the "*testis*" and "human" terms in the INCLUDE column (using the corresponding text box at the top of the column) and the term "*dog*" in the OPTIONAL column since the researcher requirement states "*... in humans OR in dogs*". Note that, for each term entered, regardless of whether the term was entered in the INCLUDE, OPTIONAL or EXCLUDE column, the table creates a complete row to keep the term entry order, therefore, it is not possible to have two terms in the same row. For each term in the table, the researcher can use the drop-down lists from the FIELD column to specify the field within the article (e.g., title, affiliation, publication year, author) to perform the query. The "Up" and "Down" actions allow altering the order of the terms in the query. The checkboxes of the GROUP column serve to express groupings between the terms, which we will see later. The result of this operation is the query string "(((KITLG) AND testis) AND human) OR dog" that yields 341898 literature results.

Figure 5. NCBI's advanced search UI.

So far, the query string formulation mechanism does not differ from those presented by the existing search repositories. In fact, the same query string can be built with the advanced NCBI search (Figure 5). However, the query string built by using our mechanism (Figure 4) or the

NCBI search (Figure 5) is incorrect since it does not express the correct semantics of the query. The end of the query string should be "*AND (human OR dog))*" instead of "*AND human) OR dog*". It is the reason for a large number of results.

What makes our mechanism different from existing mechanisms is the ability to allow expressing the correct semantics of the query string. For example, in Figure 5, the researcher would have no way of expressing the grouping between the terms "human" and "dog" and connect them by using the "OR" operator, as the correct query should be. Also, if the user wanted to modify the query string by adding a new term between the terms "testis" and "human", there would be no way to do it, except by making the query string again. This semantic error has caused an exorbitant number of results (341989).

Unlike the existing search mechanisms, our mechanism allows freely grouping the terms and order them. For instance, to group the "human" and "dog" terms, in Figure 4 the user check the checkboxes located next to the second-last and last rows corresponding to the "human" and "dog" terms and then clicks on the "*Group*" action link in the column header. Figure 6 shows the result of this actions. The broken lines state how the end of the query string has changed from "*AND human) OR dog*" to "*AND (human OR dog))*" by the grouping of the second-last and last rows and the number of results has reduced from 341989 to 9. These 9 results are appropriate for the researcher since they come from a semantically correct query string that expresses the researcher's need for knowledge.
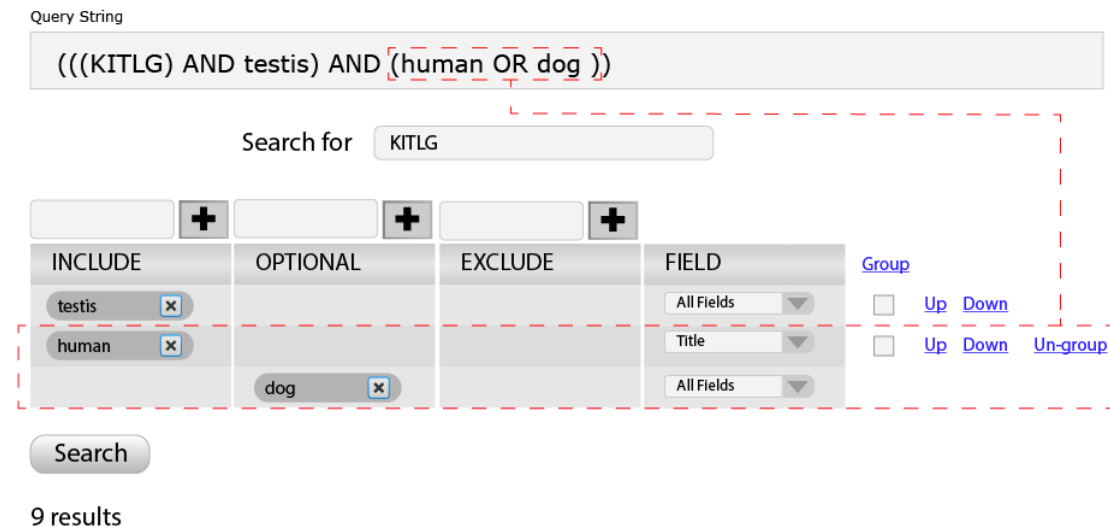

Figure 6. Query builder settings to obtain 9 results.

6.   Future Works

Our next goal is to perform the usability tests to the proposed UI, incorporate the improvements to the UI and implement it. The UI implementation is totally feasible thanks to the web platform technologies (i.e., HTML, CSS, JavaScript) and especially to the FIWARE [16] platform that allows not only to implement the UI but also to implement the data layer that will provide the data to the UI. FIWARE is an open source software platform that facilitates the development of intelligent applications through the combination of components called Generic Enablers. Our plan is to use a Generic Enabler that allows us to integrate the diverse and heterogeneous biomedical databases and implement the proposed UI for searching and exploring the biomedical data.

7.   Conclusions

In this paper, we propose the design of visual and interactive user interfaces for the efficient search of the biomedical literature. Our intention is to improve the productivity of professionals

in the biomedical domain by providing user interfaces designed to facilitate the visualization, analysis, and interpretation of relevant results. The strategy we have used to design the UI includes the identification and understanding of the problems in the context. In fact, the solutions incorporated in the proposed UI designs solve seven (7) current and concrete usability problems of the biomedical bibliography analysis, which have been detected and collected from the study and analysis of the available literature. The usability problems that are addressed include the lack of a global vision of the result set, the handling of long lists of results, problems in the generation of query strings, among others.

For a better understanding of the usability problems, the problems were grouped considering the typical tasks of information search. Some problems are related to the *query* task and other problems are related to the *result interpretation* task. Indeed, the two user interface designs presented correspond to each of the two mentioned tasks.

The proposed UI design has implications for both the UI developers and the end users who consume the information. On the one hand, the improvement of UI usability positively impacts the productivity of end users (i.e., medical, biology or bioinformatics professionals) allowing them to find more and better results either to generate diagnoses in their area or simply to keep updated with the advances in their research lines. On the other hand, the proposed improvements become heuristics of usability that can be applied by interface designers in the development of biomedical bibliography analysis and exploration software systems.

Although the usability problems analyzed in this paper are specific to the domain of the search of biomedical bibliography, the alternatives proposed to solve such problems can be extended to adapt to the usability problems in the UI of general bibliography search.

References

1. NCBI, "PubMed Homepage." https://www.ncbi.nlm.nih.gov/pubmed/.

2. M. Muin and P. Fontelo, "Technical development of PubMed interact: An improved interface for MEDLINE/PubMed searches," *BMC Med. Inform. Decis. Mak.*, vol. 6, p. 36, Nov. 2006, DOI: 10.1186/1472-6947-6-36.

3. G. Alexander, S. Hauser, K. Steely, G. Ford, and D. Demner-Fushman, "A usability study of the PubMed on Tap user interface for PDAs.," *Stud. Health Technol. Inform.*, vol. 107, no. Pt 2, pp. 1411–5, 2004.

4. J. L. Marill, N. Miller, and P. Kitendaugh, "The MedlinePlus public user interface: studies of design challenges and opportunities.," *J. Med. Libr. Assoc.*, vol. 94, no. 1, pp. 30–40, Jan. 2006.

5. R. Islamaj Dogan, G. C. Murray, A. Névéol, and Z. Lu, "Understanding PubMed® user search behavior through log analysis," *Database*, vol. 2009, no. 0, pp. bap018-bap018, Nov. 2009, DOI: 10.1093/database/bap018.

6. Z. Lu, "PubMed and beyond: A survey of web tools for searching biomedical literature," *Database*, vol. 2011, p. baq036, 2011, DOI: 10.1093/database/baq036.

7. "GoPubMed." http://www.gopubmed.org/web/gopubmed/.

8.   VOSviewer, "Visualizing scientific landscapes," *Centre for Science and Technology Studies, Leiden University*, 2015. http://www.vosviewer.com/.

9.   S. M. Douglas, G. T. Montelione, and M. Gerstein, "PubNet: a flexible system for visualizing literature derived networks.," *Genome Biol.*, vol. 6, no. 9, p. R80, 2005, DOI: 10.1186/gb-2005-6-9-r80.

10.   Genomenon, "Mastermind - Comprehensive Genomic Search Engine." https://mastermind.genomenon.com/.

11.   DigitalScience, "Dimensions." https://app.dimensions.ai/discover/publication.

12.   C. Wu, X. Jin, G. Tsueng, C. Afrasiabi, and A. I. Su, "BioGPS: building your own mash-up of gene annotations and expression profiles," *Nucleic Acids Res.*, vol. 44, no. D1, pp. D313–D316, 2016, DOI: 10.1093/nar/gkv1104.

13.   J. R. Herskovic, L. Y. Tanaka, W. Hersh, and E. V Bernstam, "A Day in the Life of PubMed: Analysis of a Typical Day's Query Log," *J. Am. Med. Inform. Assoc.*, vol. 14, no. 2, pp. 212–220, Jul. 2007, DOI: 10.1197/jamia.M2191.

14.   D. Bolchini, A. Finkelstein, V. Perrone, and S. Nagl, "Better bioinformatics through usability analysis," *Bioinformatics*, vol. 25, no. 3, pp. 406–412, Feb. 2009, DOI: 10.1093/bioinformatics/btn633.

15.   D. L. Rubin, N. H. Shah, and N. F. Noy, "Biomedical ontologies: a functional perspective," *Brief. Bioinform.*, vol. 9, no. 1, pp. 75–90, 2008, DOI: 10.1093/bib/bbm059.

16.   Fiware.org, "FIWARE," 2015. https://www.fiware.org/.