The Design of the User Interface of a Scientific DLS in the Context of the Data, Information, Knowledge, and Wisdom Hierarchy

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***Abstract*— This paper describes the study made to design and develop a digital library system able to manage the different types of information resources produced during a large-scale evaluation campaign and to support the different stages of it. In particular we present how the use of the Data, Information, Knowledge, and Wisdom (DIKW) hierarchy as a model helped us in the design of the user interface of DIRECT, a digital library system developed to assist the users and the stages of the CLEF campaigns from 2005 to 2007. DIRECT provides management, access, exchange, visualization, interpretation, re-use, and enrichment of the information resources produced during an evaluation campaign. This study contributes to create awareness about the different levels of the hierarchy and increasing complexity of the information resources produced during a campaign.**

I. Introduction

This paper reports the effort of designing and developing a *User Interface (UI)* for a digital library system able to support the stages of a large-scale evaluation campaign for *Information Retrieval Systems (IRSs)* in the context of the *Data, Information, Knowledge, Wisdom (DIKW)* hierarchy [1], [16], according to the approach proposed by [3], [5].

A large-scale evaluation campaign – such as the *Text REtrieval Conference (TREC)*[1] and the *Cross-Language Evaluation Forum (CLEF)*[2] – or the *TrebleCLEF Coordination Action*[3], promotes and stimulates the research and development of IRS by:

- the creation of an evaluation infrastructure and the organisation of regular evaluation campaigns for system testing;
- the building of a strong multidisciplinary research community where ideas can be exchanged and different approaches can be discussed, and where problems are faced from different points of view - e.g. information retrieval, question answering, natural language processing - and multiple techniques are merged and harmonized together;
- the support for the development and the consolidation of expertise, and the dissemination of this know-how to involved and interested communities, such as the digital library one;
- the construction of publicly available test-suites which can also be used outside the evaluation campaigns for system benchmarking.

Furthermore, large-scale evaluation campaigns impact not only the *Information Retrieval (IR)* field but also other research fields which adopt and apply results from it, such as the *Digital Library (DL)* field. Indeed, information access and extraction components of a *Digital Library System (DLS)*, which deal with the indexing, search and retrieval of documents in response to a user's query, rely on methods and techniques taken from the IR field. In this context, large-scale evaluation campaigns provide qualitative and quantitative evidence over the years as to which methods give the best results in certain key areas, such as indexing techniques, relevance feedback, multilingual querying, and results merging, and contribute to the overall problem of evaluating a DLS [12].

On account of this, during the workshop on "The Future of Large-scale Evaluation Campaigns"[4] [4], held in Padua, Italy, March 2007, and organised jointly by the University of Padua and the DELOS Network of Excellence on Digital Libraries[5], TrebleCLEF[6] was made, a coordination and support action funded by the European Community within the Seventh Framework Programme.

TrebleCLEF is the result of a critical assessment of the scientific results of the CLEF initiative and intends to promote research, development, implementation and industrial take-up of multilingual, multimodal information access functionality by continuing to support the annual CLEF system evaluation campaigns, by constituting a scientific forum for the *MultiLingual Information Access (MLIA)* community of researchers to enable them to meet and discuss results, emerging trends, and new directions, and by acting as a virtual centre of competence providing a central reference point for anyone interested in studying or implementing MLIA functionality and encouraging the dissemination of information [6].

However, the current approach to experimental evaluation, which is based on the Cranfield methodology, is mainly focused on creating comparable experiments and evaluating their performances. As pointed out in [5], researchers would

[1] http://trec.nist.gov/
[2] http://www.clef-campaign.org/
[3] http://www.trebleclef.eu/
[4] http://ims.dei.unipd.it/events/2007/future-evaluation-campaigns/future-eval-index.html
[5] http://www.delos.info/
[6] http://www.trebleclef.eu/

also greatly benefit from an integrated vision of the scientific data produced, their analyses and their interpretations, and from the possibility of keeping, re-using, and enriching them with further information. The way in which the experimental results are managed, made accessible, exchanged, visualized, interpreted, enriched and referenced is an integral part of the process of knowledge transfer and sharing towards relevant application communities, such as the DL one.

Therefore, we have started to design and develop a DLS for scientific data able to support the course of an evaluation initiative and to promote the dissemination and sharing of the experimental results. In order to achieve this goal, we need to:

- introduce a conceptual model making clear what the entities implied by the information space, their features and their relationships are;
- develop common metadata formats, which provide meaning to the data, enable their sharing and re-use, and keep track of their lineage;
- adopt a unique identification mechanism, which allows the citation of and easy access to the scientific data and supports their enrichment;
- manage the different needs of the actors involved in the evaluation campaign and provide an access strategy to the relevant information resources tailored to their needs;
- manage all the aspects of the campaign, such as track set-up, management of document collections, topic creation, experiment submission, relevance assessments, computation of statistical analyses, visualization of and access to the managed scientific data, data exchange, and so on.

The result of our work is *Distributed Information Retrieval Evaluation Campaign Tool (DIRECT)*, a DLS which has been developed, adopted and tested in the CLEF campaigns from 2005 to 2007 [8], [9], [10].

This paper presents the study made to design DIRECT, in particular its UI according to the proposed methodology, and the results achieved, and is organized as follows: Section II describes how the DIKW hierarchy has been adopted to design a user interface able to support the different levels of interaction and abstraction needed by the user; Section III explains the architecture of the user interface of DIRECT, Section IV provides some examples of the developed interfaces for the different levels in the hierarchy; finally, Section V wraps up the discussion and presents some conclusions.

II. DIKW as a Conceptual Model for Designing a User Interface

The DIKW hierarchy can be used to structure the managed scientific data, the cognitive process of the users, and the way they interact with the UI over four layers [1], [16]:

- at the *data* layer are raw, basic elements, partial and atomized, having little meaning and no significance by themselves. Despite the possibility of manipulation, a limited amount of actions can be performed with data, which are created with facts and can be viewed as the building blocks of the other layers. Since *experimental collections* and *experiments* are the basis for any subsequent computation, and can be measured, we can consider them at this level of the hierarchy;
- the *information* layer is the result of computations and processing of the data. In*form*ation is created giving data *a new form, a new shape* by relating them. For example, the *relevance judgements* are at the "information level", creating a relationship between topics and documents of an experiment;
- the *knowledge* layer is related to the generation of appropriate actions, by using the appropriate collection of information gathered at the previous level of the DIKW hierarchy. Knowledge can be articulated into a language, such as numbers, words, expressions and so on, and transmitted to others or embedded in individual experience (like beliefs or intuitions). *Descriptive statistics* and *hypothesis tests* are at this level of hierarchy, since they are a further elaboration of the information carried by the performance measurements and provide us with some insights into the experiments;
- the *wisdom* level provides interpretation, explanation, and formalization of the content of the previous levels. Wisdom is not one thing, but uniquely a human state, at the highest level of understanding. Using wisdom, people can strive for the future. *Theories*, *models*, *algorithms*, *techniques*, and *observations*, which are usually communicated by means of papers, talks, and seminars, correspond to this level.

To better understand the relationships between the four levels, we can use a metaphor provided by Zeleny [16, pp. 59–60]: he considers the task of baking bread: "*data* are like basic elements: atoms and molecules of starch, H_2O, bacteria of yeast, etc.; no trace of bread anywhere. *Information* is like ingredients: flour, sugar, water, spices; still no trace of the intended outcome (but one cannot make a beer out of it anymore). Having all such ingredients does not imply that *knowledge* of how to make bread exists: one can still end up with a tasty crust, black cinder or gluey mush. Knowledge involves relations: recipes and their contextual interpretations. Further, having the know-how for making bread does not imply that one actually *should* make bread and why. *Wisdom*, goes beyond knowledge because it allows comparisons (judgments) with regard to know-what and know-why. It is a long way from data to wisdom".

The four levels can be graphically represented as a continuum linear chain or as the *knowledge pyramid*, and some transitions between each level in both directions can be seen [13].

Figure 1 frames the scientific data produced during a campaign into the four levels of the hierarchy, represented as a pyramid, with respect to the metaphor of baking bread.

The actors involved in an evaluation campaign (participants, assessors, visitors, and organizers) interact together in various ways during the course of the campaign and contribute differently to the DIKW hierarchy discussed above.

- the *participant* needs a forum to test and validate his algorithms and techniques, compare their effectiveness and results, and to discuss and share his proposals with the other participants. He needs to submit and validate his experiments, and then expects to receive measurements and indicators about their performance, compared with

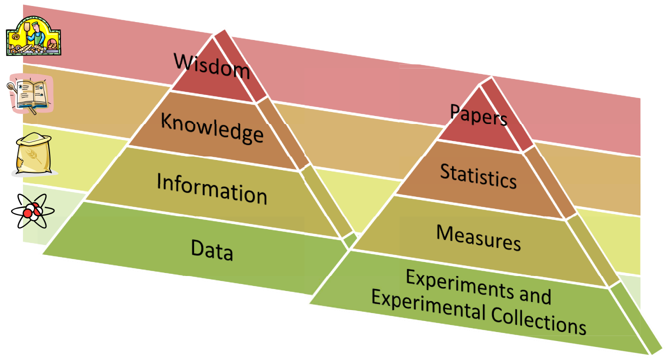


Fig. 1. DIKW knowledge pyramid representation with respect to IR experimental evaluation and the metaphor of baking bread.

the ones submitted by the other participants. Moreover, he should have the possibility of properly citing his experiments and other information resources and to get a citation correctly resolved to the corresponding information resource;

- the *assessor*, proposing the topics and assessing the relevance of the documents with respect to those topics, contributes to the creation of the experimental collections. His tasks are labour-intensive and require the management of great amounts of data;
- the *visitor* needs to consult, browse, and access the resources produced during the campaign. He should have the possibility of properly citing the accessed information resources, and getting a citation correctly resolved by the system;
- the *organizer* manages the different aspects of an evaluation forum, contributing to the creation of the experimental collections and providing the framework for the participants to conduct their experiments. He computes the different measures of performance, and he provides the visitors with the means for accessing all the resources they are looking for.

Fig. 2 summarizes the relationships between the main steps of an evaluation campaign, shown in chronological order on the horizontal axis, the elements of the DIKW hierarchy, shown on the vertical axis, and the main actors involved in an evaluation campaign. As time goes on and the campaign comes into full swing, there is a progressive movement from data to wisdom, and the number of involved actors and their interactions grow. The result is a representation similar to the linear chain found in [13], where a lot of transitions between the levels can be studied.

In the following, we discuss how the results of this study and analysis have been applied in designing and developing the architecture of the UI of DIRECT.

III. The Architecture of the User Interface of DIRECT

The DIRECT user interface is designed to go along with the requirements and needs of the users, meeting the following goals:

- to be cross-platform and easily deployable to end users;
- to be as modular as possible, clearly separating the application logic from the interface logic;
- to be intuitive and capable of providing support for the various user tasks, such as experiment submission, consultation of metrics and plots about experiment performances, relevance assessment, and so on;
- to support different types of users, i.e. participants, assessors, organizers, and visitors, who need to have access to different kinds of features and capabilities;
- to support internationalization and localization: the application needs to be able to adapt to the language of the user and his country or culturally-dependent data, such as dates and currencies.

The modularity of the components has enormous benefits when building interactive applications, since it helps the designer to better understand and develop each component and modify it without affecting the others. Therefore, we used the *Model-View-Controller (MVC)* [14] approach as provided by Apache STRUTS[7] framework to clearly separate the following three layers:

- *model layer*: contains the underlying data structures of the application and keeps the state of the application;
- *view layer*: the way the model is presented to the user;
- *controller layer*: manages the interaction between the view and the input devices, such as the keyboard or the mouse, and updates the model accordingly.

Figure 3 shows the architecture of the DIRECT user interface which is Web-based in order to be cross-platform and easily deployable and accessible without the need of installing any software on the end-user machines.

The user interface is based on the *JavaServer Pages (JSP)* technology[8]; in addition, we developed a JavaScript[9] library which provides event listeners, manipulation of the *Document Object Model (DOM)*[10] , and *Asynchronous JavaScript and XML (AJAX)*[11] support in order to make the user interaction more successful and responsive. In particular, AJAX allows us to make asynchronous calls to the server and to speed up the user interaction by loading only the requested portion of the data without requiring to download huge amounts of data in one time or to completely refresh a page when only a part of it has changed.

Moreover, the user interface is made more modular by using the STRUTS TILES[12] templating framework, which allows for a rapid development and reuse of components. As shown in Figure 3, when the browser requests a page, the STRUTS engine asks the TILES engine to put together the page components, according to instructions provided by an *eXtensible Markup Language (XML)*[13] configuration file. Then, TILES loads the JSP reusable code segments to create

[7] `http://struts.apache.org/`
[8] `http://java.sun.com/products/jsp/`
[9] `http://www.ecma-international.org/publications/standards/Ecma-262.htm`
[10] `http://www.w3.org/DOM/`
[11] `http://www.w3.org/TR/XMLHttpRequest/`
[12] `http://struts.apache.org/1.x/struts-tiles/`
[13] `http://www.w3.org/XML/`

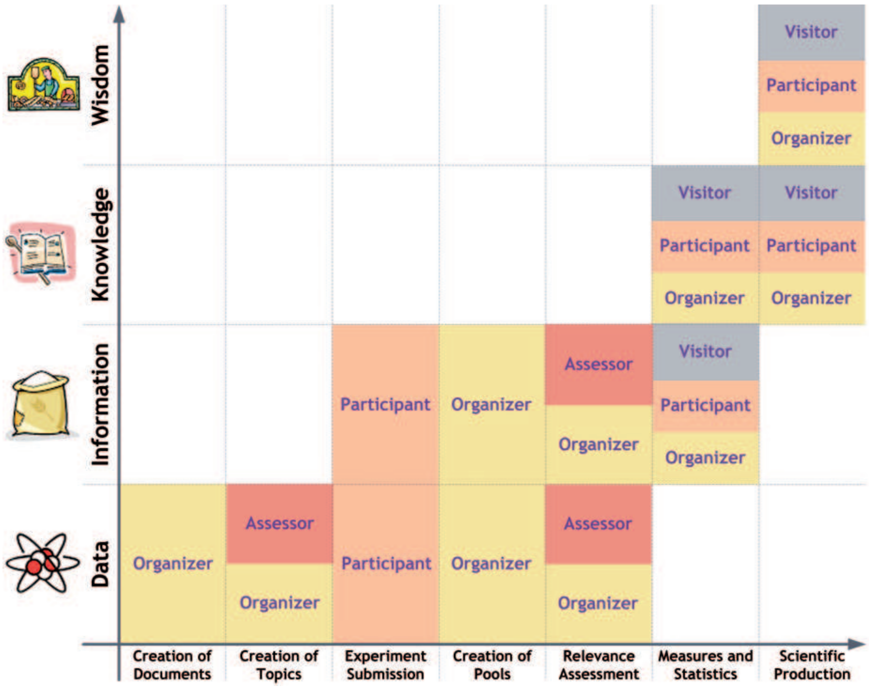


Fig. 2. Relationships between the DIKW hierarchy, the different types of actors and the main steps of an evaluation campaign.

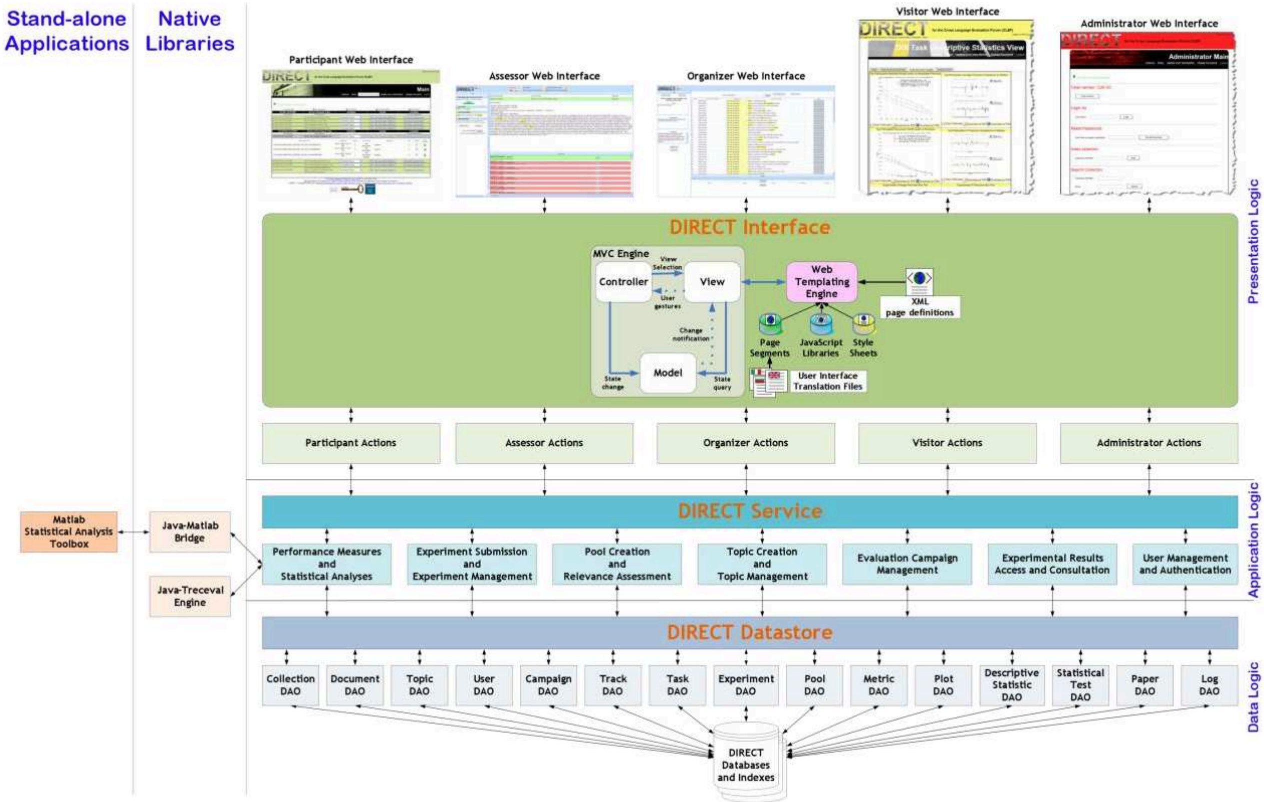


Fig. 3. Architecture of the DIRECT user interface.

the page skeleton, adds the JavaScript libraries needed for enhancing the user interaction, fills the page with the contents provided by the STRUTS controller, applies the necessary *Cascading Style Sheets (CSS)*[14] for formatting the page, and returns the dynamically created page to the View layer of STRUTS, which, in turn, sends it to the browser. Finally,

[14] `http://www.w3.org/Style/CSS/`

we also support the internationalization and localization of the user interface by adapting it to the language and country of the user. As shown in Figure 3, this is implemented by using translation files according to the Java internationalization capabilities[15]. The correct language and country are initially loaded according to the browser settings and, in the case of not supported locales, it falls back to a default configuration. The user interface has been translated in the following languages: Bulgarian, Czech, English, French, German, Farsi, Indonesian, Italian, Portuguese, and Spanish.

Focusing on four interesting interfaces, next section provides some examples of the interfaces developed for DIRECT for the different levels in the DIKW hierarchy.

IV. DIKW LEVELS AND UI SUPPORT

In this section, we use Fig. 2 as a map to present some of the interfaces developed at each level of the hierarchy. We will highlight:

- at the *data* level, the interface developed to manage the experiment submission by the participants, and how a logical structure is suggested by the system to support the user's actions;
- at the *information* level, the interface enabling assessors to do relevance assessments, and how information can be created by the user over existing data;
- at the *knowledge* level, how the system helps the creation of relations between different information on the visitor's metrics and statistics page, and some plan for future investigations to allow the user to create of his own scenario of knowledge;
- finally, at the *wisdom* level, we point out some possible future directions which discuss how the DIRECT system may support the scientific production.

A. Data level interfaces

At the data level, the main goal of the UI is to to manage a large amount of data, and to present them in a coherent and compact way.

Fig. 4 presents the main page for the experiment management, and it is a good example of data management and presentation. The interface allows the participant to access all the relevant information about a track, related tasks, topics, and experiments. It is based on a set of folding tables, allowing access to the data produced by the participant itself by structuring them in different levels based on a hierarchy - tracks, tasks, and experiments - well known by the user. All this enables the exploration of the data by simply selecting and expanding the right level, and the submission, editing, or deletion of an experiment by looking for its level in the hierarchy.

The UI, moreover, can logically associate further *data* at each level of the hierarchy to support the participant's actions. Since data could have little meaning by themselves, this system-aided work is fundamental for allowing the user to find the right data, at the right level, in the right format, and at the right moment. As an example, DIRECT can suggest the download of the topics, that is data produced by the assessor, by proposing only those that are pertinent for the task currently selected by the user.

We can find the relationships between the different levels of the hierarchy, and also between the different actors, looking at the buttons that enable the participant to view the metrics about an experiment, which are *information* provided by the organizer, and to view the descriptive statistics about a task, information resources at the *knowledge* level of our hierarchy and provided by the organizer of the campaign. There is, as mentioned in II, a lot of transitions between levels and actors that the study made on the design of the interface has made natural and simple.

B. Information level interfaces

Fig. 5 shows the interface for relevance assessments. Pools are *data*, since they are a sampling of the submitted experiments and suggest possible relations among topics and documents in terms of which documents have been retrieved in response to a given topic. On the other hand, relevance judgments are human-added information, since they set the actual relation between a topic and a document, specifying whether a document is relevant or not for a given topic. The outcome of the relevance assessment step is thus the passing from the *data* contained in the pool to the *information* contained in the relevance judgments.

The aim of the UI presented is to support the creation of this *information*: in the top left corner it is possible at a glance to read *data* about the topic produced previously by the assessor: title, description, and narrative are reported, and the status of the assessment task is shown as a progress bar, which reports the percentage of assessments already done. Moreover, a search form is provided to find terms occurrences in both the topic and the selected document. In particular, it is possible to save the last submitted query, and automatically repeat it on subsequent document selections. Found occurrences are highlighted in yellow.

The navigation through the documents is facilitated by a set of buttons in the top bar allowing the user to quickly find the next non assessed, relevant or not relevant document. The selected document is shown at the center of the page, reporting its identifier, title, and content. *Information* about its relevance status is provided alongside of the *data* shown. In addition, a highlighting frame flowing up and down over the list of the documents at the bottom of the page shows at any time which document the user is reading in relation to all the documents pooled for that topic, providing *data* on documents produced by the organizer in relation to the *information* about the assessment status of the document.

Specific sets of buttons are also provided at the top of the page to help the assessor make the assessment task in an intuitive, quick, and useful way, creating in this way *information*. They are characterized by the use of two colors: green to set the *relevant* status, and red for *not relevant*. When an assessment is performed, instantly the row at the bottom

[15] `http://java.sun.com/javase/technologies/core/basic/intl/`

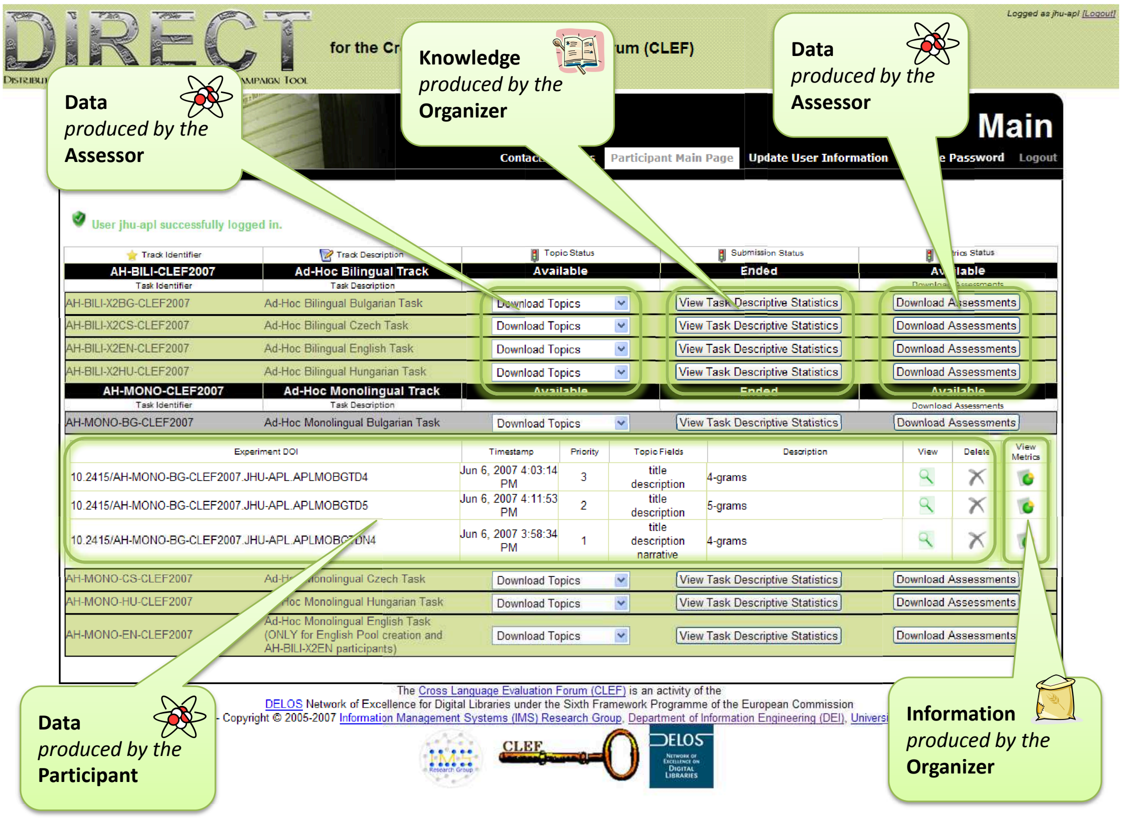


Fig. 4. Main page for the experiment management.

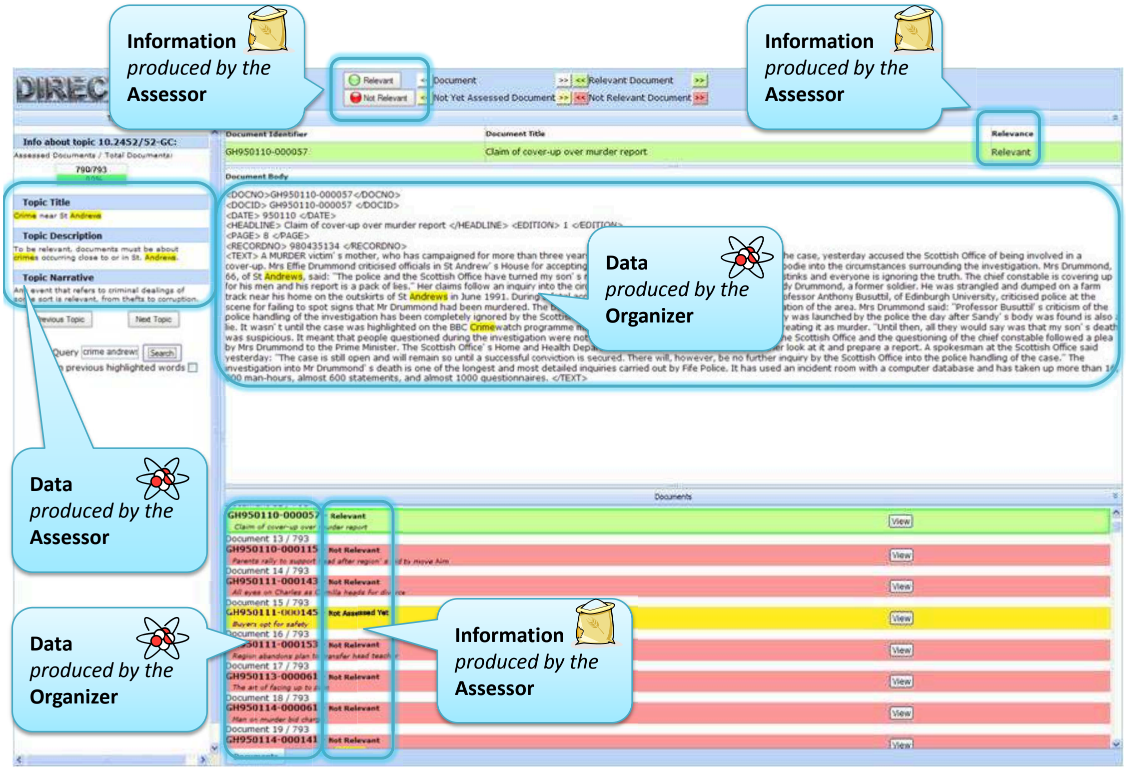


Fig. 5. Relevance assessments interface.

of the page concerning the assessed document changes color as above explained, and the highlighting frame automatically moves to the next document to assess.

C. Knowledge level interfaces

[16] points out that knowledge is the process through which "individual pieces of data and information (components, concepts) become connected with one another (i.e. organized) in a network of relations". Therefore, we need to design and develop interfaces which allow users to benefit from this "network of relations", to navigate it, and possibly to be able to add new relations. As an example, Fig. 6 shows the interface used to access the information resources about a task.

In particular, Fig. 6(a) shows some of the plots used for summarizing the overall performances achieved in the task and comparing the performances of the top participants with respect to the median performances in the task; all these plots can be downloaded and used by participants and visitors, while the numerical data needed to create this plots can be accessed and downloaded by selecting "Task Overview Results" tab. *Data* and *information* become *knowledge* through a further elaboration and the articulation into the expressive power of the language of a plot.

Fig. 6(b) shows the navigation possibilities provided starting from a task: the user can select the topics, experiments, and collections related to the given task. In particular, Fig. 6(b) shows the list of topics used in the task and to which the performance measures and plots reported in Fig. 6(a) refer. This is *information* produced by the organizer, but using this information it is possible to compare the *knowledge* produced about the same topic into different tasks. The UI itself makes clear relationships and a very large set of possible paths to improve the cognitive process of the user.

Finally, more information about each topic can be obtained by navigating the corresponding link displayed in Fig. 6(b). The results of the navigation are shown in Fig. 7, where the contents of a topic are displayed in the different languages selected by the user and accessible for download. This is another example of the relationships between the different levels of the hierarchy, since the contents shown are *data*, but it is also the creation of relationships between them made to draw the plots that provides the *knowledge*.

Moreover, on the right, links to the tasks where the topic is used are reported, so that the user can continue the navigation to other tasks using this *information*. It is therefore possible, for example:

1) to compare the performances achieved for a given topic in different tasks by simply accessing a task,
2) consulting the performances related to it, selecting the topics used in that task,
3) from the topics choosing another task that uses the same topics,
4) consulting the performances related to the new selected task.

D. Wisdom level interfaces

Organizers and participants usually prepare reports which provide an overview for the evaluation campaign and which explain techniques that have been adopted and the findings achieved. This work continues even after the conclusion of the campaign, taking the form of conference papers, journals, articles, talks, and discussion among researchers. The outcomes of this process are what is conventionally indicated as *wisdom*, and organizers, participants, and visitors need a system and a user interface which provides easy access and meaningful interaction with the managed information resources, allowing them to cite and reference the information resources relevant for their work.

In particular, we adopted the *Digital Object Identifier (DOI)* [15] as unique identification mechanism for experiments, collections, topics, pools, and statistical tests. The DOI assigned to each of these entities can be resolved to the corresponding information resource which can be easily accessed, as discussed in the previous sections. Moreover, the DOI allows the *citation* of the identified information resources, intended as the possibility of explicitly mentioning and making references in the papers to desired experiments, topics, and so on. In this way, it is possible to directly access the data, information, and knowledge which are part of each written production and to better couple them to it.

In addition, we are planning to add to DIRECT the support for managing the talks, papers, and articles produced by the research community by using the scientific data managed by the system to link these scientific productions to the related experiments, metrics, and statistical analyses.

Finally, we are planning to investigate new features for the UI and more effective ways to provide access to the managed information resources. For example, adding search functionalities for the different kinds of managed information resources can provide better support to the scientific production, since this would allow access to relevant content by new and unexpected ways different than only navigation or browsing.

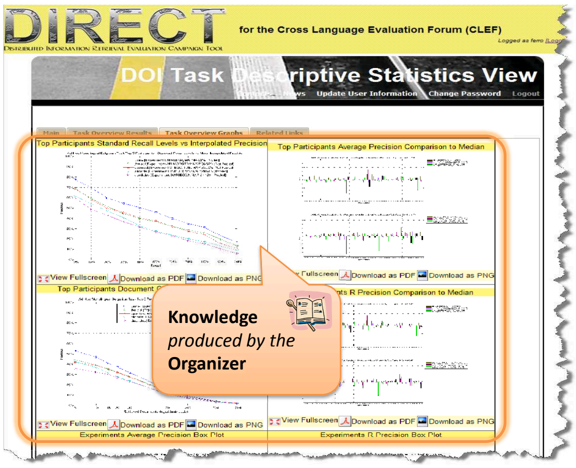
V. Conclusions

We have discussed the development of a UI for a DLS according to the DIKW hierarchy. In particular, we focused our attention on the design of the distinctive features specifically developed to better assist the user through the four levels of the hierarchy, showing some of the interfaces to give the reader a taste of the approach adopted and the results achieved.

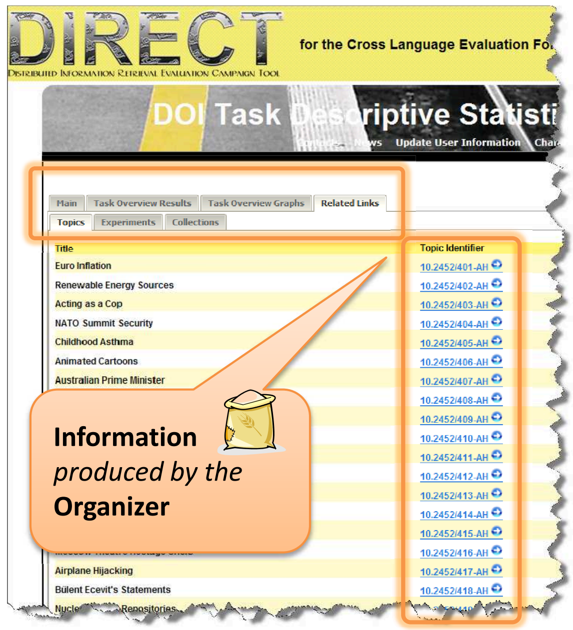
Furthermore, we have mentioned some of the features planned for the future of DIRECT, concerning a better support for the process of creation of knowledge and wisdom in a personalized way.

Acknowledgments

The work reported has been partially supported by the TrebleCLEF Coordination Action, as part of the Seventh Framework Programme of the European Commission, Theme ICT-1-4-1 Digital libraries and technology-enhanced learning (Contract 215231).



(a) Plots about task overall performances and statistics.



(b) Navigation to other resources: access to the topics related to a task.

Fig. 6. Interfaces for providing access to the information resources about a task.

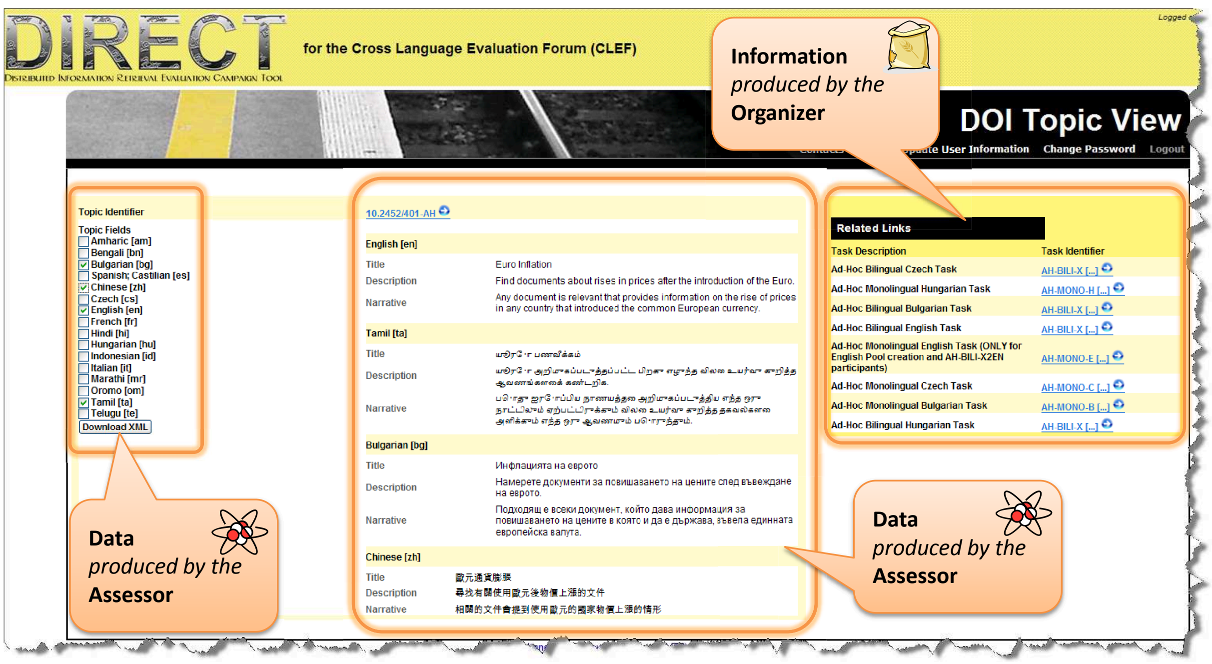


Fig. 7. A detail of the interface for resolving the DOI for a topic and showing related tasks.

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