User-Computer Interfaces for Scientific Communication: the Concept of Habitable Interfaces

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Introduction

Developments in computer technology have changed the way we communicate in general and in science in particular. These developments enable the increase in the effectiveness and efficiency of the communication. The actual increase will depend also on the fit between technology and people who are communicating.

Proliferation of the digital archives alone does not solve the problem of seeming abundance of scientific information. There are at least two issues that contribute to this. Firstly, more information resources require more attention and time to find those that are needed. Secondly, information or access to information is structured based on some rationale that does not necessarily fit the rationale of a scientist accessing the information.

We are primarily interested in the design of interfaces for accessing scientific archives. To design the interfaces such as to improve effectiveness and efficiency of scientific communication, we consider scientific communication as a context within which the technology is applied.

Scientific Communication as Context of Use

The Driving Forces and Functions of Scientific Communication

Scientific communication is to serve the progress of research and education. The overall objective of scientific communication is growth of knowledge. In general, scientific communication takes place between researchers. The researchers act as authors and readers. Their objective is to exchange scientific information. Roosendaal and Geurts (1997) point that *"… authors want to publish **more** and have their product widely available, while readers want to read **less**, but want to be informed of all that is relevant for their research …"* Thus, the generic stakeholders of scientific communication are authors and readers. They require availability of scientific information. The objective of the stakeholders is to generate questions and to provide answers in order to apply them in their research. This sums up in four main driving forces of the scientific communication: actors, content, accessibility and applicability.

The forces can be represented (Roosendaal and Geurts 1997) on a two-dimensional diagram Figure 1.

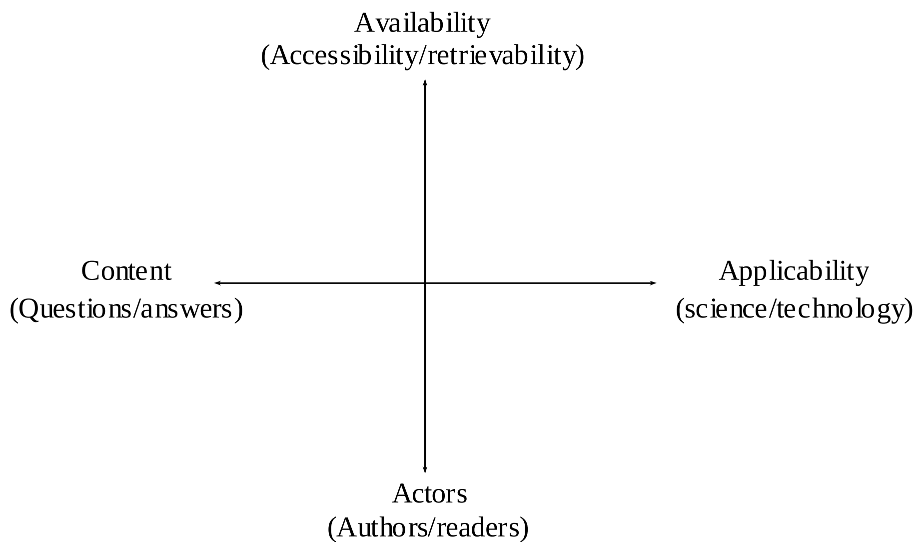

Figure 1 Forces of the scientific communication market

> "*Any scientific information and communication system will have to be in equilibrium with at least these four forces*"
>
> (Roosendaal & Geurts 2001, p. 412)

From the actors, primarily the readers are of interest to our research. However, simply taking authors out of consideration would make our analysis incomplete.Let us consider the plane with actors, applicability and content forces.

Physical content by itself (without interpreter) has no intrinsic applicability. Applicability of physical content may be considered only in relation with actors. Consequently, the applicability may vary depending on actors that interact with content. Two vectors (from the author to the applicability and from the reader to the applicability) in Figure 2 depict, possibly, different applicability of the content if authors and readers are considered separately in the analysis of scientific communication market.

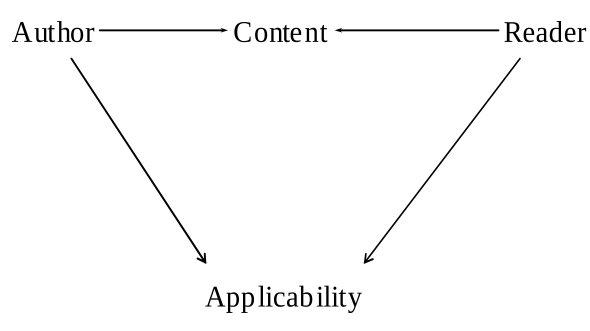

Figure 2

Further, we can simplify the diagram by assigning to content the applicability that is intended by the author (Figure 3). It is important to make this assignment explicit. Not always the applicability is fully expressed in a particular entity of content (like an article), but it may also be expressed in relation with other entities. In addition, there may be some shared (by author and prospective reader) knowledge that may be excluded (intentionally or unintentionally) from the content.

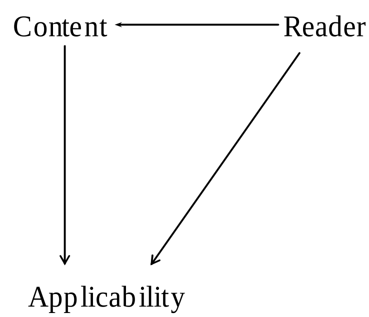

Figure 3

The possible differences in applicability of content and applicability demanded by reader have important consequences for communication. We will consider these consequences in the chapter on high level model of communication.

Functions of scientific communication fulfil the demands of the forces. Roosendaal and Geurts (1997) identify the main functions of scientific communication as: registration, awareness, certification and archiving. These functions constitute the product market. The four functions can be characterised by some operational characteristic issues, such as e.g.:

- Registration: (submission, speed, copy right, property rights ...)
- Archiving: (archive, access library ...)
- Certification: (peer review, quality ...)
- Awareness: (disclosure, browsing / search capabilities ...)

(Roosendaal & Geurts 2001, p. 414)

Similarly to the forces, the functions of scientific communication can be represented on a two-dimensional diagram Figure 4. Ultimately and may be indirectly "… the interests of the stakeholders are[1] expressed in the *awareness* of an article that is *archived, registered and certified*" (Roosendaal & Geurts 2001, p.414). Functions can be classified by their relation to the research and education process as internal or external. Furthermore, there are author and reader functions.

Classification on external and internal functions reflects the situation within the scientific communication market at present and in general. The elements of the functions that are externalised may vary depending on a particular configuration of the scientific communication system. For example, a particular configuration may include librarians (or other intermediaries in information seeking activities), helping the reader to find information. This is an example of externalising part of the internal reader functions. Similarly, functionality of the new technological systems for scientific communication can include some of the elements of internal functions.

[1] It does not necessarily mean that all the stakeholders have to recognise this. However, for scientists as readers it is direct and clear interest.

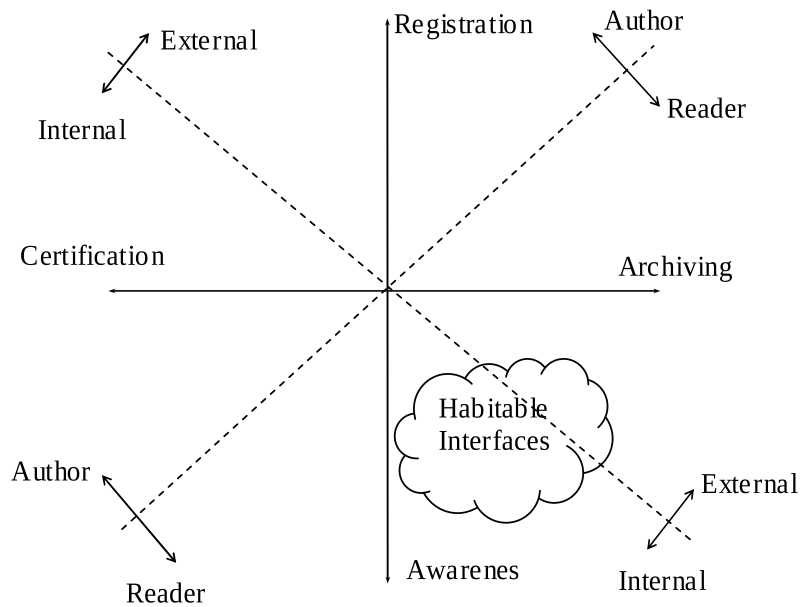

Figure 4 Functions of scientific communication. Habitable Interfaces are based on the archiving function and aiming at implementing new elements in the awareness function.

The functions discussed above are strategic for scientific communication. In the development of Habitable Interfaces, we concentrate on the reader functions archiving and awareness. Currently, there are many different organisations providing digital archives. Though many of these archives are connected to the Internet, for the users they remain separate resources. First attempts are being made to connect these archives into systems that can be seen as distributed archives. Distributed archives provide integrated (at the level of the user inquiry of the content) access to digital archives that may belong to different organisations, may have different accessibility and may physically be in remote locations. Major challenges to achieve such integration are the organisation of the distributed archive and its communication with personal archives of researchers. Figure 5 presents the archive as a "sluice" between the author submitting to an archive and the reader desiring the awareness of the archive's content.

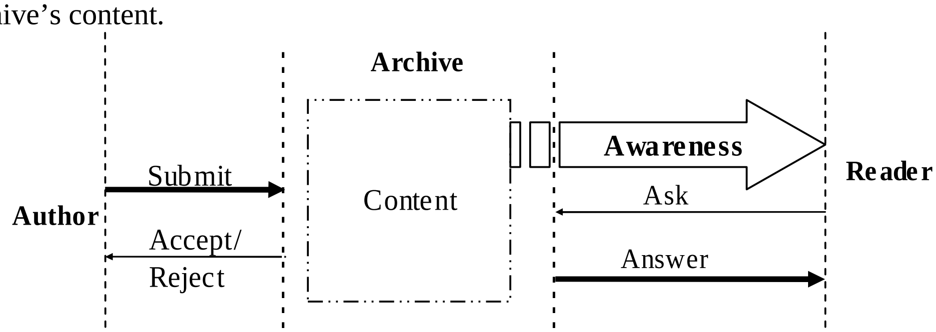

Figure 5 Archiving function

Organising a distributed archive requires a design that would allow researchers to communicate effectively and efficiently. Existing approaches to the design of Web resources may not fit the scale of the distributed archive. Below we present several considerations relevant for designing the distributed archives.

When it comes to collecting what one is looking for from Web resources the question of deciding between different information retrieval approaches is traditionally discussed (Roosendaal, Geurts & van der Vet 2001). Traditionally this discussion deals with trade-offs between precision and recall. For instance, improving recall only pays when the costs are lower than the costs likely to be incurred by missing relevant documents. Dealing with the problem this way requires knowledge of the costs involved: costs of indexing, of searching, of low precision, of low recall. Costs of indexing and searching can usually be determined relatively easy. Costs incurred by missing documents seem to depend on a particular set of tasks in which the information retrieval system is used. These costs may be difficult to determine before tasks have been completed. After the set of tasks is completed the consequences and costs of missing relevant documents can, possibly, be assessed.

Full-text search methods allow indexing the corpus without involving human experts. This decreases costs of indexing dramatically and makes full-text search attractive for some applications despite the necessary trade-off between precision and recall. The weakness of applying full-text search in scientific communication does not arise from method itself, but from the fact that the proportion of text in scientific publications is expected to decrease. Full-text search is unable to find equations, figures, sounds or videos. Current systems for searching non-textual material mimic full-text search. There are two main approaches. One is based on finding non-textual material by its textual description to which material is directly attached. Another approach attempts finding pictures or sounds based on similarity with a query picture or a query sound. To make use of such systems the user has to decide beforehand on which medium the information is expressed. It is expected that modes of non-textual publication will be rather divers. Therefore it is unlikely that the user knows this in all or even most cases.

Scientists may be interested in finding most or all relevant documents. Unfortunately, there is no known, cheap technological solution. Employing metadata to describe content of Web resources in fact returns to the expensive practice of manual indexing using predefined search terms. There has been work on automating this process, but so far no working systems suitable for real-life employment have been demonstrated. Another development in this direction is the design of structured index terms that are more expressive than the customary flat terms.

Integrating retrieved information into work of a research group may require “wiring together” a set of distributed resources, both in-house and remote. The work of research group may consist, for example, of predicting the outcome of an experiment, interpreting a new finding, or comparing own findings with findings reported by other groups. Clearly, there will be different requirements towards both flexibility and persistence of such configurations. Some configurations will exist just for hours and others will be needed during the lifetime of a scientific project that can be up to several years. The obstacle currently in the way of routine configurations is a multiplicity of formats. As we noted above, there are many organisations maintaining digital archives, and their number grows by the day. These organisations have different internal standard formats of information. In a situation when it is difficult to predict what resources will be useful, keeping up-to-date with changes in all the standards and data is a luxury accessible only for a few. Individual research groups generally will want to leave maintenance of these resources to the groups who created them. The organisation of the distributed archive should better be based on federating existing resources rather than on integrating them into monolithic systems.

As the interests of the readers are primarily expressed in the awareness function, the most important change should be in the awareness function too. A good historical example is the Web. The powerful combination of search engines and hypertext technologies greatly improved the awareness about digital journals and libraries and their content. The hypertexts enable[2] to externalise parts of the internal element of 'chaining' different documents, while search engines attempt to externalise extraction (retrieval) of information.

The design of computer interface for the reader (Habitable Interface) is part of implementing new elements in the awareness function. However, the awareness function is unfeasible without the archiving function. Clearly, interface should fit with the implementation of the archiving function.

We position Habitable Interfaces at the level of functions of scientific communication as directed towards awareness function. Habitable Interfaces are aimed at providing scientists with access to digital archives in such a way as to "bring content of digital archives directly to the 'minds' of scientists". It is equally important that Habitable Interface should be easy for scientists to adapt to. If the structure of access to information can be tailored for the internal reader's structure (more cognitive, but also physical) then such an access becomes part of the reader's awareness – a part of the reader.

The awareness function is an internal reader function. As such it may be difficult to directly measure the quality of implementing the awareness function. Therefore we need criteria to judge about the readers' awareness and these criteria should be measurable.

Trust in Scientific Communication

The process of scientific communication has characteristics of both a temporary system and a continuous process. Scientists searching for information might well use resources known to them (long-term system) as well as new sources of information (temporary system), for example, a new article in a proceedings of a recent conference that was referred to by a colleague.

The process requires a getting together of at least the following actors: an author, an editor, reviewers, a publishing company, a library and finally readers in research who are members of scientific communities. Typically, a scientist keeps on communicating within several different configurations. Some of these are temporary and some are long-term lines of communication.

Paper-based communications will increasingly be replaced by electronic communications which will polarise the character of the process as temporary, on the one hand, and more long-term systems, on the other hand. In an electronic environment it is easy to surf from one system to another in search for momentary desired information, but, on the other hand, creating, learning and integrating their information into one's own research may require more effort. Electronic systems are not more difficult to create then paper based archives, but amounts of information typically expected within electronic systems are much more voluminous then those of paper-based systems.

Contracts and control devices are hardly effective when dealing with a temporary co-operation since there are little opportunities to effectuate compliance. In a temporary

[2] Here we refer, also, to the technologies associated with hypertext. It is the software browser that actually extracts a document based on some pointer, such as URL. Hypertext specifies the pointer in such a way as to enable a software browser to process the pointer and to extract the document that was referred to by the author. This is in distinction to somewhat arbitrary style of references in plain texts that, in many cases, only human reader can follow as yet.

system that heavily relies on the use of information and communication technology there are hardly means to make a partner comply and to retaliate when he fails to meet his obligations. Also, contracts and control are hardly effective within scientific communication systems that traditionally rely on trust. Electronic communication therefore strengthens the need to build trust for both long-term and temporary configurations.

Trust is a necessary condition for scientific communication to take place. There are several perspectives from which trust in scientific communication can be considered.
The issue of trust is important as a means to reduce the complexity of reasoning about information. If the trustworthiness of information resources is not clear then the reader has to keep in mind several explicit assumptions about these resources. This may require a considerable effort. For example, if scientists do not trust a retrieval system in retrieving all the relevant documents then making important decisions (for example about direction of further research) may be more difficult and in some cases scientists may decide to do retrieval manually.
Also, externalizing elements of functions of scientific communication requires that there is some level of trust between parties involved. And other way around, the experience from cooperation will influence trust in its turn. Trust in this case is understood as willingness to delegate part of ones work to other party. This willingness is based on some features of the other party and own propensity to trust (Mayer et. al 1995). Both authors and readers delegate external functions (registration and archiving). The level of trust of the scientists towards the communication system will depend, among other parameters, on the importance of a particular activity. For example, for a brief preliminary investigation finding most relevant information in shortest time is of great value. This refers to the precision of the retrieval system. In another study, scientists may be interested to find all known facts about some phenomenon. In the later case recall of the retrieval system seems to be more prominent in decision to delegate.

Given the above, it is clear that the way how trust develops matters for effectiveness and efficiency of scientific communication. Hummels and Roosendaal (Hummels & Roosendaal 2001) proposed mapping between functions of scientific communication and levels of trust (Figure 6). The mapping shows level of trust required for implementing the functions of scientific communication. The levels of trust used in this mapping are based on a framework proposed by Zucker (Zucker 1986). Zucker distinguishes three types of trust: process-based trust, institutional-based trust and characteristic-based trust. Hummels and Roosendaal add a fourth type of trust which they call values-based trust. These four types of trust are considered in more detail in the chapter on criteria for evaluation (below). The types of trust can be classified by the relation of membership between trustor and trustee. That is whether both are members of the same community. Another classification is based on the nature of the relationship – either direct or indirect. These classifications seem to be similar to classification of the functions of scientific communication. Hummels and Roosendaal discuss these similarities in detail. Here we would like to stress that the mapping points towards levels of trust *required* as a necessary condition by the communication functions.

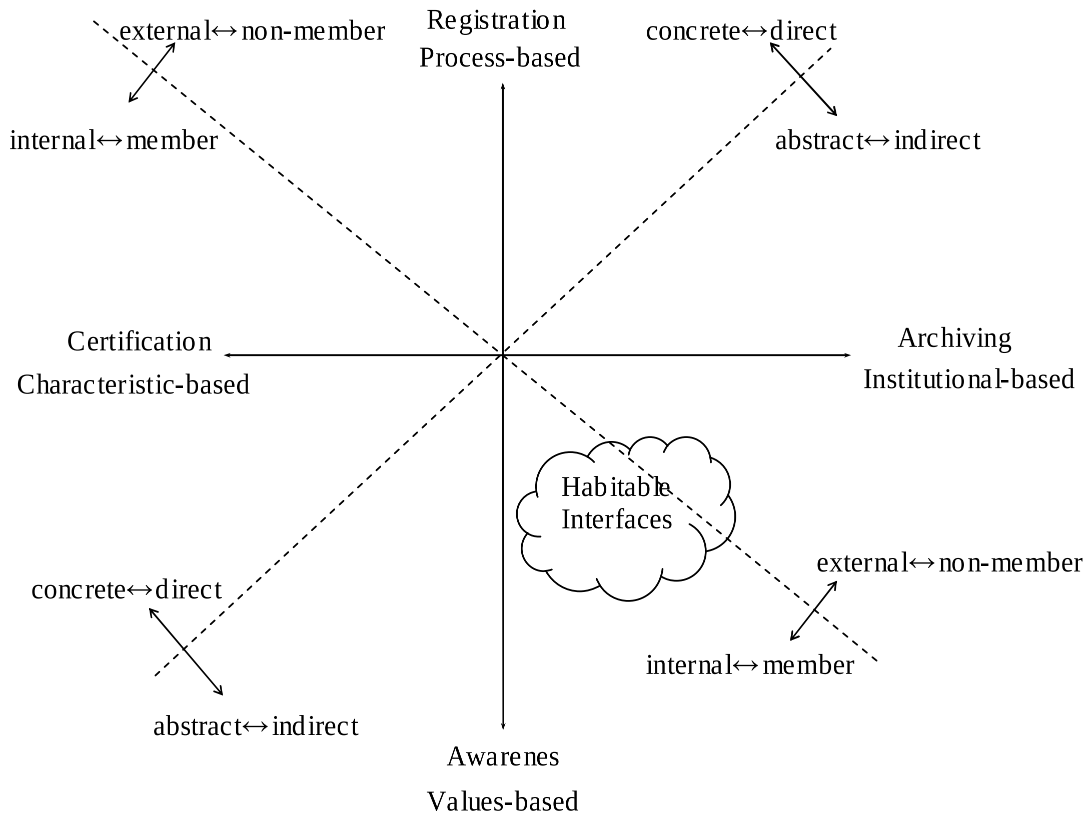

Figure 6

The awareness function is a reader function. Externalising elements of the awareness function requires values-based trust (Figure 6). The archiving function, on the other hand, is external to the reader. Reader should have a choice on whether to use a particular archive or not. This choice, we assume, will also depend on the level of trust of a reader towards a particular archive as an institution. The mapping in Figure 6 shows that the archiving function requires institutional-based trust.

Analysing functions of scientific communication we positioned Habitable Interfaces as part of the implementation of awareness function. Given the mapping between the functions of scientific communication and the levels of trust it is evident that the design of a Habitable Interface should allow a values-based level of trust. But, not all archives are members of the reader's community. Therefore, Habitable Interfaces should be transparent on the institution the data is supplied by.

But assessment of trust towards a communication line says nothing about a particular component of this line unless an appropriate testing procedure is utilised so that only a particular set of factors is varied while others are kept the same. This requires finding independent factors. In the case of Habitable Interfaces elements of the awareness function and ways to implement these elements are of primary concern. Elements of the awareness function which are likely to be externalised need to be identified and ways to implement these elements should be proposed.

High Level Model of Communication: the Knowledge Gap

Defining Habitable Interfaces needs a model of interaction between reader and content. This model should take into account differences in the applicability of the content and the applicability the reader has in mind.

The Mismatch Between Data Models of the Reader and the Archive

Scientists are engaged in a knowledge discovery process. Knowledge is accumulated by collecting information and data. Collecting data requires a model that serves the purpose of practical guidance. Knowledge discovery is a collective effort, and a collective effort needs communication. In communication, researchers have generally different roles of authors and readers. Given the variety of purposes that knowledge can be applied to, and the variety of the data models, it is next to inevitable that there is a mismatch between the reader's and the author's data models. The situation worsens, when there are many readers and many authors who are trying to communicate on similar issues.

The archive can be perceived as an intermediary between authors and readers. Building an archive requires yet another data model (Figure 7). The data models of authors and archives are known and can be communicated.

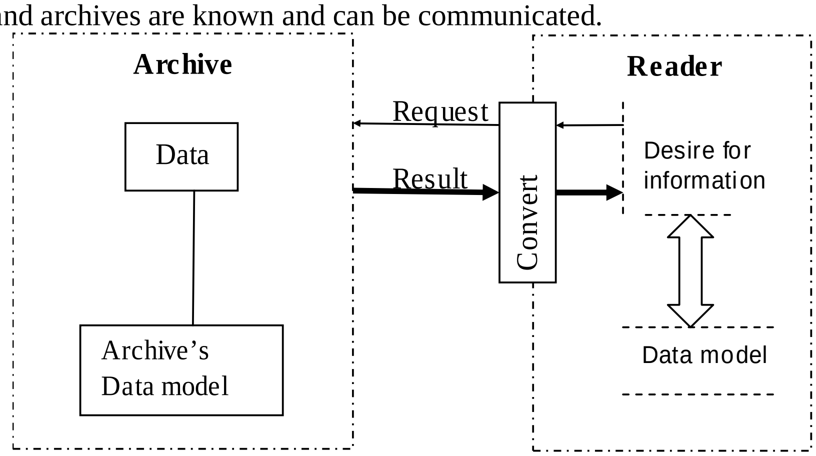

Figure 7 Communication between archive and reader

But for readers the situation is different. Readers do not need to know the archive data model and they even may not want to know the archive data model, as it does not fit their mental frame. As a consequence, there is a gap between what we call desire (expressing what information the reader wants to know) on the one hand, and need (referring to the information in the archive's terms) on the other hand.

To fill the gap, an archive could convert data into a form required by the readers. Multiplicity and dynamics of the readers' interests present too great a challenge for designers of archives and in principle, even the best study of requirements would not provide a uniform representation of the readers' interests. Indeed, there is no average reader and there are many different archives.

The Distinction Between Desires and Needs

To illustrate the distinction between desires and needs that was introduced above let us turn to the familiar and rather simple domain of vacations and travelling. Though looking for information on travelling (like time tables) may be different from searching scientific archives, the complexities, which a particular research field might present to a reader, could possibly obstruct our explanation.

Furthermore, the domain of travelling resembles a scientific domain as there are many agencies (including railroads and airlines) advertising their services for travellers. These agencies have different schemas of their services and also different, sometimes overlapping areas of interest in travelling and vacations. Travellers, especially those looking for new (may be also non-existent) ways to travel and having different situations at hand can be considered as researchers.

Clearly, the differences between travellers and scientists should be stressed. Firstly, criteria of a successful search for travellers and scientists can be different. Secondly, travellers do not integrate the results of their search into their activity at the level scientists usually do (although travellers may fill their agendas based on results of their search). Thirdly, travellers may be less knowledgeable in the domain of travelling than scientists in their own field of research. Fourthly, there are many services or intermediaries in travelling business fulfilling the gap between what the user wants and what is proposed on the market. In science, this is less common.

Despite all the differences, for explaining the distinction between desires and needs, and only for this purpose, our simplification seems adequate.

> *Let us consider some fictitious travellers planning their vacation. They have planned to visit Italy, but are yet inconclusive on their return trip. A possibility is to go through Germany travelling along the Rhine with short stops in a number of cities. They decided to limit their travelling time and visit no more than five cities possibly with over-night stops. The travellers will go on vacation by train, because of the special summer offer, but they have not yet decided on what transportation to use on the way back.*

In the terms of our model, the brief description above outlines the desire for information of the user, our travellers. Though for reasons of clarity we described the situation as the travellers see it, the way it can be expressed in a dialog (with the travelling agency, for example) might look like this:

"…

- *We would like to get some information to plan our vacation tour.*
- *So, where do you want to go?*
- *We would like to go from Italy to Great Britain through Germany and we would like to go along the Rhine. Something like the Grand Tour people used to make in the old days.*
- *Ok. Would you like to consider a cruise on a ship?*
- *Aren't there any other options like travelling by train?*

…"

From this example, we can see that users can easily describe their desire for information, i.e. "We need information to plan our tour from … ". Travelling agents have to ask additional questions such as "Where would you like to go" because they do not know the specific situation of the customer, but travelling agents do know that they need to name a destination to plan the route. In addition, the travelling agent immediately suggests an option based on the information that was presented. In this example, it turned out that what the customer wants is different from the anticipated case, and the suggestion is rejected.

The dialog shows furthermore how the travelling agent is trying to construct a mapping of the desires of the customers onto the needs that the travelling agency knows how to address.

A dialog like the one above is not to everyone's liking. Also, not everyone would want to go or can go to a travelling agency. Alternatively one can use the Internet that is nowadays, for many, a universal source of information.

> *An option is to start from the www.startpage.com. There one finds a category travel and can try different links. Unfortunately, travelling agencies on the web ask them to name a destination and not a route. Browsing through thousands of non-relevant, though highly attractive offers distracts quickly. After some time one returns to the starting page. There is a search engine and the search terms 'Rhine' and 'travel' are entered. At last, there are some relevant links to sites offering tours along the Rhine. There are even maps showing the locations of hotels and castles along the river. Still, the travelling plan is not complete without a transport connection. They could decide which cities to visit, but this choice depends among other things on the travelling times between cities. To make their choice easier travellers can decide to go by train and open the train planner Web site like www.db.de. Doing so, one has to work iteratively by requesting information from the train planner site and matching this information with information about hotel accommodations acquired from another site. Finally, the travellers complete the plan and book hotels and train tickets. The task is accomplished, but getting this far requires quite a bit of discussions, browsing and thinking, and all this despite the fact that the required data are all easily available.*

With this simple example, we show that mapping one's desires for information onto information needs can be non-trivial. We have to take into account that our travellers are not knowledgeable about the availability and the content of the information resources, given the number of information resources and the variety of questions the travellers might have. Our travellers have to explore the information space and the desired information can be extracted only when at least some of the relevant resources are known to the travellers. If such an exploration takes too much effort, the travellers of our example will consider other options and will compromise some of their initial goals. Furthermore, regardless of whether travellers know about the content of the resources or not, they have to combine the information from all relevant resources into a form they actually need and this is not supported by present interfaces.
In addition, the example shows that there is a need for an intermediary guiding the customers with their desires for information to the relevant information services. While a search engine can be seen as an intermediary, its efficiency depends on the user's query. For example, a query on travelling to Rome would return many irrelevant links just because Rome is often mentioned in all sorts of documents and web sites. Moreover, many search engines would not consider the search term 'Rome' a relevant term to access a site with a database on airlines' timetables that contains records about flights to Rome.

First, before starting the communication process, the reader has a certain desire for information. The word 'desire' implies a strong intention or aim. It is in contrast with the 'need' that is in general defined as a lack of something requisite or useful. Figure 8 shows this distinction from a number of viewpoints.

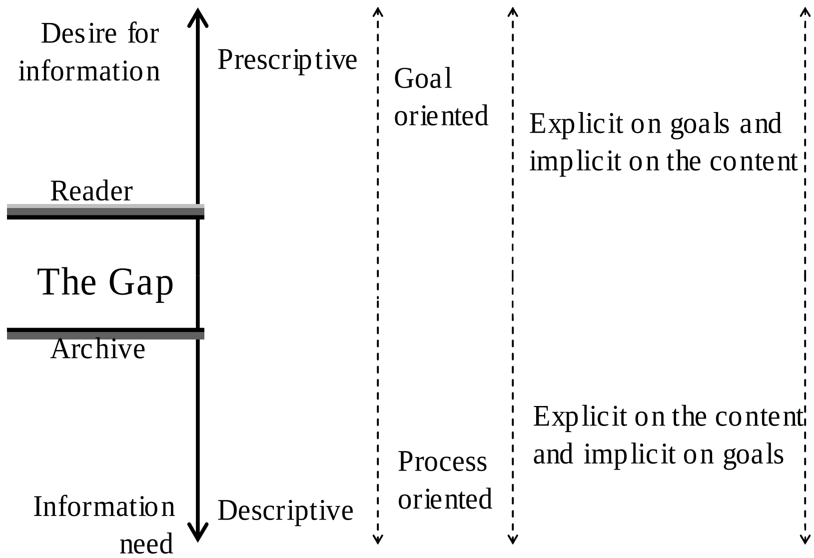

Figure 8 Distinction between desires and needs. There is a gap if the reader and the archive are at the different levels.

Returning to our example, the desire of the travellers is to make a plan for their tour. Unravelling this desire in more detail would give us the route they would like to follow (along the Rhine), the time they want to spend (less than five days) and some specific interests such as visiting museums, natural sites or cities. However, to make the plan realistic it needs to be mapped onto existing services. These services are built around information needs that are defined by the maintainers of archives and based on user studies or just preferences of the maintainers of archives. Travelling agencies, railways and airlines usually require naming the destination and plan the route based on criteria such as minimal number of stops, shortest or fastest route, minimal cost or some combination. Table 1 gives examples of desires that travellers might have and needs that are supported by different information resources.

Both the desires and the needs are multidimensional and different partial overlaps can be found, so in reality the mapping is not binary (either useful or not), but rather the degree to which the resource can be useful and in what quality it can be useful to address a particular desire for information.

Table 1 An example of mapping desires onto needs

Need / Desire	Railways timetable (planner)	Airlines timetable (planner)	Web-site about the city	Travelling agency web-site	Web-site on skiing
Where to spend summer holiday?				X	
How to visit the Pisa tower?			X	X	
What are the ‘nearby’ locations for skiing?				X	X
How to get to Rome?	X	X			
Plan a tour along the Rhine.	X		X	X	

The Knowledge Gap: High Level Model of Communication

To arrive at an approach to designing Habitable Interfaces we start from a high-level model of communication between the reader and the archive. This model is rooted in other models proposed in the literature on Information Seeking and Information Retrieval. There are several overviews of the models and the concept of information in general (see for example Ingwersen 1992; Capurro & Hjørland 2003). Here we would like to briefly consider the most influential models.

We start from the simple Information Retrieval model Figure 9.

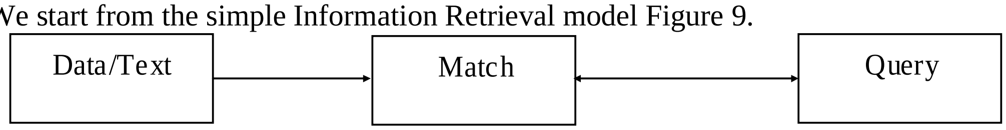

Figure 9 Simple Information Retrieval model

In this model, a query is matched against all available data (that can be in a variety of forms, like text, tables, graphics and other). The match function can also be adjusted based on a query that is presented to the system. Depending on the implementation of the match function and its interaction with the query, this model can describe any Information Retrieval system.

Belkin has put forward a hypothesis about the Anomalous State of Knowledge (ASK) (Belkin et al. 1982). Figure 10 represents Belkin’s model. There are several significant advances in comparison with the simple Information Retrieval model. Firstly, Belkin includes the recipient and knowledge of this recipient in his model. Secondly, there is a division on two levels of communication: the linguistic level and the cognitive level. Thirdly, the model points towards ASK as a prompt for a “recipient-controlled” communication, that suggests that recipients may not know what information can be useful for them. In other words, recipients get to know about what information they need during the search process. Such a view is similar to the distinction between desires and needs that we discussed above.

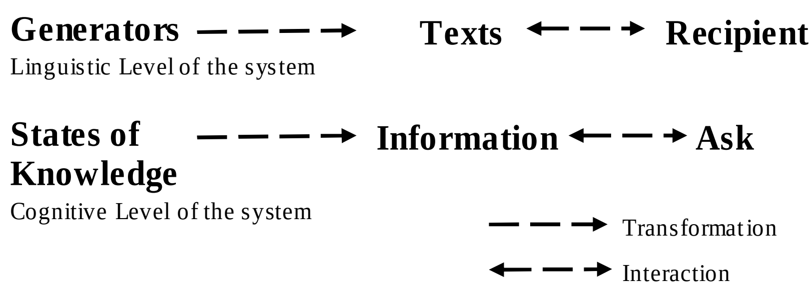

Figure 10 The communication system of information science (Belkin, 1978, p.81)

Following his model, Belkin states that "... the effect of the information associated with any particular text can be predicted, *given some idea of the recipient's state of knowledge, and some means for representing states of knowledge*" (Belkin, 1978). In respect to designing the interaction with an information system several open questions remain, like for example: "is it possible to have an idea of an anomalous state of knowledge (within a formal system) and representative means that would help the user to 'correct' her 'anomalous' state of knowledge?" Does the model imply that any ASK can be addressed by interacting with a system or the ASK should be within the States of Knowledge? How can the States of Knowledge be represented as to help the readers to resolve their ASK? Furthermore, although Belkin refers to the desire for information in his text, it remains implicit in his model just as the notion of a topic of communication.

Another way of considering communication between a reader and an archive is by describing the behaviour of the reader in interaction with the archive. Clearly, to be applicable for designing interfaces of archives this model should be generalised over a set of possible designs and also over a set of potential readers and their questions.
Taylor (1968) describes the process of asking questions as starting from the 'visceral need':

- Visceral need – a vague dissatisfaction with the current knowledge about some topic;
- Conscious need – conscious understanding of what kind of information (knowledge) is missing;
- Formalised need – the formal statement of the need;
- Compromised need – the query that is presented to the archive

The model suggests that readers formulate a query in several steps. In later experiments, (Chen & Dhar 1990) the last three steps were reportedly observed. But Taylor's model does not explain how the visceral need is being converted into a compromised need. We believe that this conversion depends on the design of the retrieval system. An experimental investigation on such models has to generalize beyond the design of the system used in the investigation. In other words, if the system design implies a certain behaviour of the reader, it is likely to induce such a behaviour. For example with some interfaces, the readers have to explore the archive, with others they have to know the terms used in the archive before they can search for the desired information. The example from the previous chapter shows differences in interacting with a human intermediary (travelling agent), a computer system with hypertext (web sites) and a search engine. The first interaction is based on a dialog and negotiation, the second is sort of navigation or browsing and the third one is a combination of a simple dialog (entering keywords) and browsing (through results).

The significance of the Taylor's model for Habitable Interfaces is that it postulates that a request to the archive is a result of converting a particular 'inadequacy' in reader's knowledge about some topic.

We take also a model of the system into account into the model of communication. This allows stating a hypothesis about the system design that can be validated against empirical data.

Based on the above, we arrive at the following characteristics of the Habitable Interface model:

- The readers have knowledge that can be divided into classes serving the purpose of building a model.
    - Domain knowledge is a set of facts and rules that are known within a certain research domain. In a federated archive, this knowledge can form a basis to organise disparate resources.
    - We refer to the knowledge about the current situation as the situation perceived by the reader. It may be not an adequate understanding of the situation by the reader, but for our purposes, this is not relevant. Situations can be rather divers. If we add to this an individual interpretation of the situation, it is clear that this knowledge will be specific for an individual reader. The knowledge about the current situation will set the context, within the domain, for the information being communicated.
    - The knowledge about the system or the language of the system is needed for converting the desire for information into a query that is comprehensible for the system and for converting results returned by the system into a form that the reader understands. The knowledge about the system, as any knowledge on communication, can be considered at four levels: lexical, syntactic, semantic and pragmatic. The fourth level in this classification is the pragmatic level at which the desire for information is communicated.
- The desire for information stems from the current situation and it is based on domain knowledge. The desire also indicates some lack of domain knowledge;
- Readers do not need to know the language of an archive and many readers will lack knowledge about the archive and its language;
- The gap between the desires for information of the readers and the information needs supported by archives can be viewed as the combined effect of lack of domain knowledge and lack of knowledge about archives;
- Converting this lack of knowledge into communication requests generates different sorts of behaviour, that, in general, depend also on the design of the archive;
- The communication process stops when the reader is satisfied (of course, a reader can feel bored and frustrated, but what we point at are internal conditions when in response to external events and, possibly, other factors the decision is taken or forced to be taken to stop interacting. In this sense we can say that in the given circumstances the desire, not the reader was satisfied at certain point. In other words, searching is not limited to one resource only and continues until the desire is satisfied).

This model is depicted in Figure 11. The content on Figure 11 may be heterogeneous and also distributed across a computer network like Internet. The issue of accessing the content and combining it into a uniform information space should be addressed. An important question to be answered based on this model is the design of the Interface. The Interface presents to the reader what is available in the archive and allows building a comprehensive set of queries (a set of queries may be needed because content may be heterogeneous in form and distributed over a computer network). The results of querying must be combined into a single representation for the reader. However, the particular implementation would require answers to questions such as:

- What are the principles to organise the representations of the information sent to and retrieved from the different resources?
- What sorts of interaction with the representations are useful and adequate for the reader?

Our model suggests that the representations should be based on domain knowledge and the interaction with these representations should be designed in order to require a minimal knowledge of the system.

The design of the interface serves to reduce the requirements on the reader's knowledge about the system, and to improve the effectiveness and efficiency of the communication.

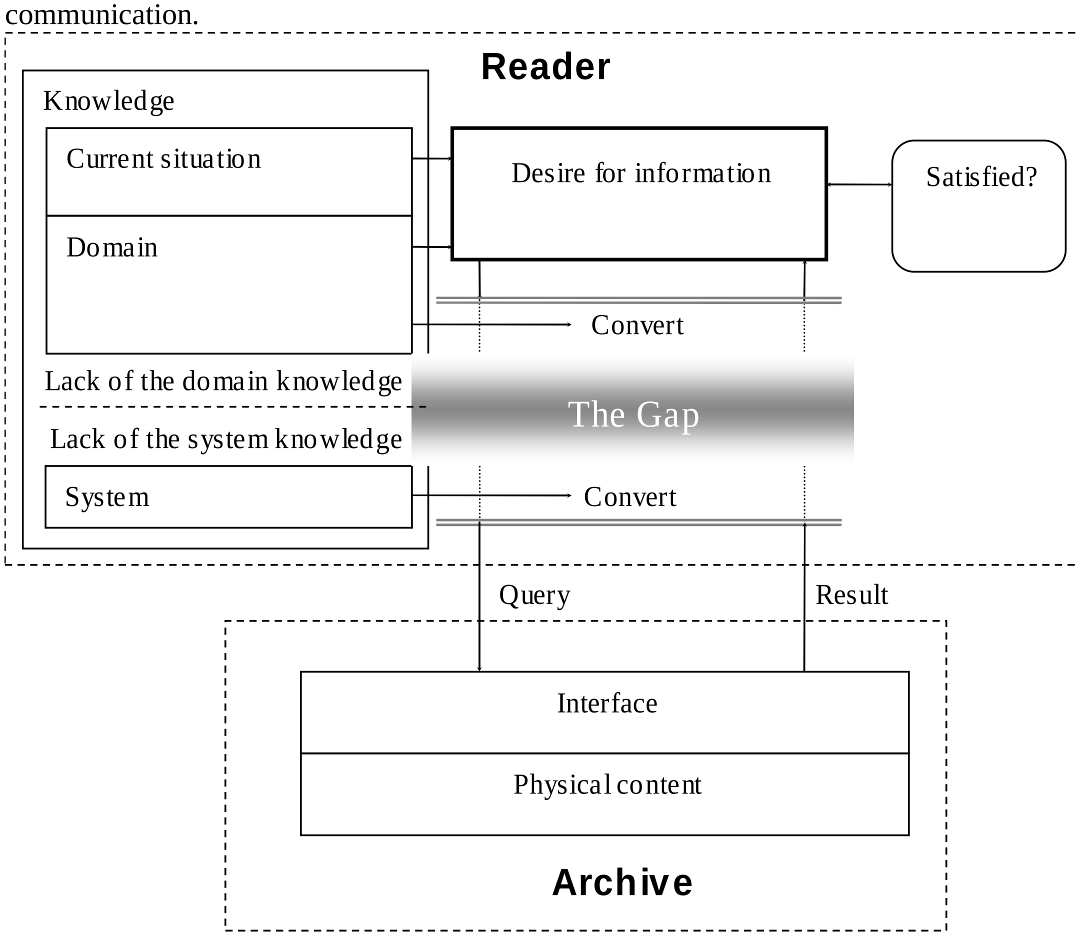

Figure 11 High level model of communication

It is clear that for the interface to perform its functions, in particular functions related to the awareness of the reader, it should be able to interpret the physical content at a level that would help the reader to bridge the knowledge gap. The level at which content can be interpreted by the interface will be determined by available technologies (like statistical analysis, for example, allows to interpret physical content at the lexical level based on a user query). In principle, the system should be able to communicate at the level of the situation. Not a situation as such, but what the inference of the situation is at least in a particular domain. This can only be done when interpretations of the lower levels are available.

An interface provides interaction of the reader with the content of the archive. For designing an interface, the dynamics of this interaction should be considered. In general, both content and reader are changing over time. In such conditions relatively stable domain knowledge can help in the communication by providing a bridge between the reader and the content. In a situation when the content changes rapidly in comparison with the changes in the desires of the reader an information filtering approach can be utilised. Information filtering allows users to specify their desires in some formal way. The archive, then, can notify the reader about relevant changes in its content. Also, the archive can suggest to the reader those topics that seem to be relevant. The input for such filtering can include both the current point of interest as well as a navigation path or interaction history with the reader (also, the interaction with the other, collaborating, readers can be considered).

Specifying the desire of the reader will require representing the domain knowledge and the possibility to browse through domain knowledge.

The domain knowledge is never complete, but it is (at least should be in theory) consistent. In, practice, however, one can find well known and less well known inconsistencies and gaps in the domain knowledge. Taking all this into account, while reasoning, may be too high of a load. In addition, people usually operate (mentally) with a limited number of items. Pictorial and schematic representations of domain knowledge seem to be useful to facilitate the access to an archive.

The desire for information is not necessarily mapped on a continuous area in domain knowledge. A possibility of selecting and integrating several relevant topics from the domain knowledge should be realised in interface.

The Concept of Habitable Interfaces

An interface can be categorised by, at least, three main characteristics:

- Functionality;
- Representation of functionality and results (visual or/and other modalities such as audio, tactile, etc.);
- Interaction;

Functionality in general is determined by specifying a set of goals that a user can achieve by using the system (for example a text editor can be used for typing, formatting, printing, saving texts and so on). Functionality is usually a hierarchical set. It is important to compare systems based on a precise specification of their functionality (down to the most elementary functions). For example, with a key one can unlock a door of a car. If a car has a central lock, one can unlock all the doors of a car from one location (but, usually, the user will not be able to unlock only one door from the outside). Another example is the steering of a car. When an electrical steering system was proposed the feedback from the steering wheel was not immediately recognised as an important function. As a result, steering with those systems without feedback was more difficult and even more dangerous then with the traditional mechanical or hydraulic systems.

Some functions are difficult to associate directly with goals of user. These functions usually are either informative, error preventing or error handling. For example, a driver cannot switch to reverse unless the wheels of a car are not rotating. There are also informative functions, like an indicator of the battery state in mobile electronic devices such as notebook computers.

Representation of functionality and results can be trivial as in the case with the opening doors of a car. The function of opening a door is represented by a key, a door lock and a door handle. If the door lock is invisible one may conclude that the functionality of locking a car doors is absent. A button on a key can represent the function of unlocking car doors remotely. In addition, special symbols or text are used to represent the available functionality for the users. In many cases, functionality is also localised (normally, one would hardly need to steer a car while being outside of it or in a passenger seat).

The representation of functionality and results can be multimodal. For example, the feedback from the steering wheel is tactile. Some cars give an audio signal when the driver takes the key from the ignition and opens a door while leaving the lights on.

For designing computer systems the design of representations is not as “trivial” as in the car examples above. This stems partially from the abstract nature of the concepts that are usually manipulated with. In computer systems metaphors are widely used. Metaphors usually resemble familiar things from everyday life, like the office desktop. There are two main issues with metaphors. Firstly, the correspondence of the computer model with the original (real world) prototype is only partial and it is sometimes difficult for users to give up an attractive metaphor when it does not correspond anymore to the system they work with. Secondly, metaphors have to be familiar for a user which cannot be expected for a wide audience with different cultural and professional backgrounds. What is familiar for one user may be completely new for another.

Interaction is needed for a user to instruct a system to perform certain functions. Examples of elementary interactions are pushing a button or shifting a gear in a car.

The example of shifting a gear is interesting as it requires some additional functionality and interaction in the form of pressing and releasing a clutch pedal. It is not immediately clear for a naive person that there is a connection between a clutch pedal and shifting of gears. This interaction requires users to learn this special skill.

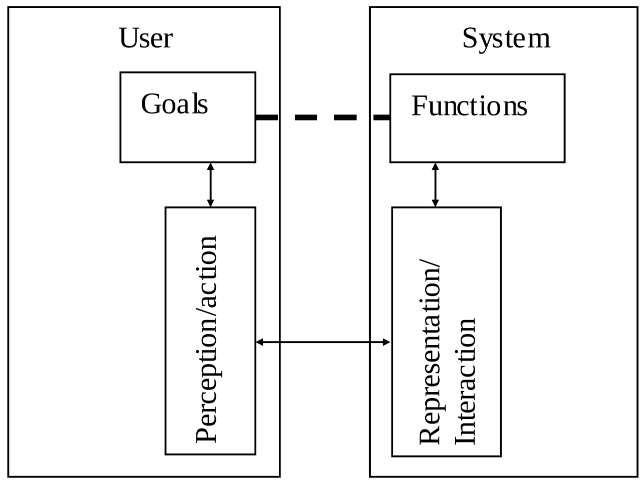

Figure 12 Correspondence between user's goals and system functions

Figure 12 presents the correspondence between the user goals and the functions of a system. This correspondence can be incomplete. Not every goal is supported by the system and the system sometimes has excessive functionality. The latest does not seem to be of a problem, however it requires more 'space' to represent all the functions and can distract the user's attention. Users perceive a system and an environment and act upon the system according to their goals. This is a very rough simplification as users have emotions, feelings, they make mistakes and they are not always clear on their goals if there are explicit goals at all. Also, there can be a mixed initiative in interacting when the user reacts on something presented by the system or otherwise the user issues commands for the system based on some external (to interaction with a system) goals. However, we do not attempt to match a user model with a system model. An example of a more detailed correspondence between the user goals and the system functions is presented in Table 2. The first row represents the top goal of the user that is directly relevant to the system under consideration. The next rows represent sub goals of the top goal. The goal can, usually, be reached by using the functionality of the system. To use the functionality, the user must be aware of it. The awareness of the user about the available functionality is achieved through learning and/or representations. Access to the functionality of a system is expressed in the design of interaction with the system.

Table 2 An example of hierarchy of goals

Goals	Functions (of a computer)	Representations	Interactions
Write a report	Text editor	A computer	Using a computer with text editor
Using a computer with text editor	Switching on and off	Power switch	Pressing power switch
	Input and output of information	Input devices such as keyboard, mouse and microphone and output devices such as computer display and speakers	Typing on a keyboard, clicking on and moving the mouse, reading information from the screen, listening
…	…	…	…
Edit a document	Create new document, open existing document, saving document, type in text, delete text and insert text	Menus, toolbars, cursor (indicates place where text will be inserted), background, written text	Selecting menu items, pressing toolbar buttons, moving cursor, selecting text

The quality of an interface design can be expressed in criteria such as naturalness, transparency or more specific like usability or user satisfaction[3]. We will discuss these criteria in the chapter on evaluation criteria (below).

The interface design is facilitated and consequently constrained by the available technology. It means that there is a balance to be found between functionality, representation and interaction. This balance can be indicated in terms of chosen criteria. The criteria may be a set of components. Some combination of these components gives overall assessment of the design. In general, criteria can be divers, and optimisation for the different criteria may require different combinations of functionality, representations and interaction.
The constraints of technology are not always clear, so it is difficult to predict where the maximum can be found. To improve the quality of an interface, the interface can be compared with other interfaces and also subsequently refined.

To decide which functionality should be included in an interface, which representations and kinds of interaction should be employed we use criteria. By varying different aspects of an interface, such as adding or removing functions, changing representations and interactions we will consequently improve the interface. The concept of Habitable Interfaces, then, can direct such an improvement.

[3] Most definitions of usability in the literature include satisfaction as one of the components of usability. This implies that there are several stakeholders each interested in particular components (but not all) of the usability. Considering readers as the main stakeholders, we could assume, for example, the satisfaction of readers to be the central issue and the effectiveness and the efficiency to be the factors that influence the satisfaction.

Habitable Interfaces can help users to convert their desires for information into information needs that are then being communicated to the existing information resources. Using Habitable Interfaces would change the example about planning a tour along the Rhine significantly.

> *By interacting with a visual representation, one would select on a map cities one wants to visit or select a route one likes to follow. Adding the concept of hotels or attractions would visualise these on a map enabling the user to request information on these accommodations and 'glue' selected information to the selected route. Further, one can play with the selection to arrive at a planning of the trip one likes most. Because all communication between the resources is done transparently for the user, there is no need to know all sources of information and their interfaces.*

The above illustrates the basic concept of Habitable Interfaces. The concept of Habitable Interfaces builds on values-based trust.

The most important feature of Habitable Interfaces is manipulating with graphical representations of concepts and relations from a specific domain of scientific knowledge.
For molecular biology, for example, knowledge about a cell and its components can be used. Obvious graphical representations for this knowledge are stylised pictures of a biological cell and its components. In addition, well known metaphors such as biological pathways (Figure 13), structures of proteins or genome maps (Figure 14) will be used. These pictorial representations will be related within an interface to the concepts and the relations of ontologies and further to the information resources.

Based on this feature the whole set of functionality will be implemented. The use of the domain knowledge for browsing and collecting information seems to be rather direct. For the other three functions, this feature will serve as a way to provide input such as setting the parameters for filtering. While browsing through concepts a user can, for example, ask to notify when new data about a certain concept will be or have become available.

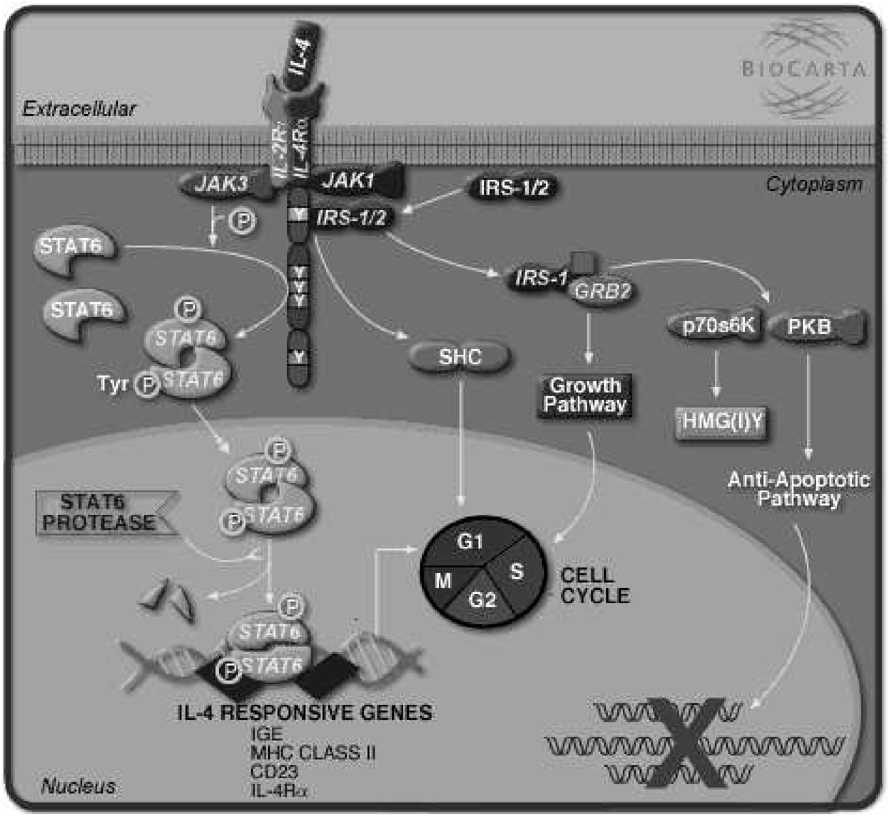

Figure 13 An example of graphical representation of a pathway (IL 4 signalling pathway. Downloaded from BioCarta **http://www.biocarta.com/**). Users can access information about different components of a pathway by clicking on representations of these components on the pathway.

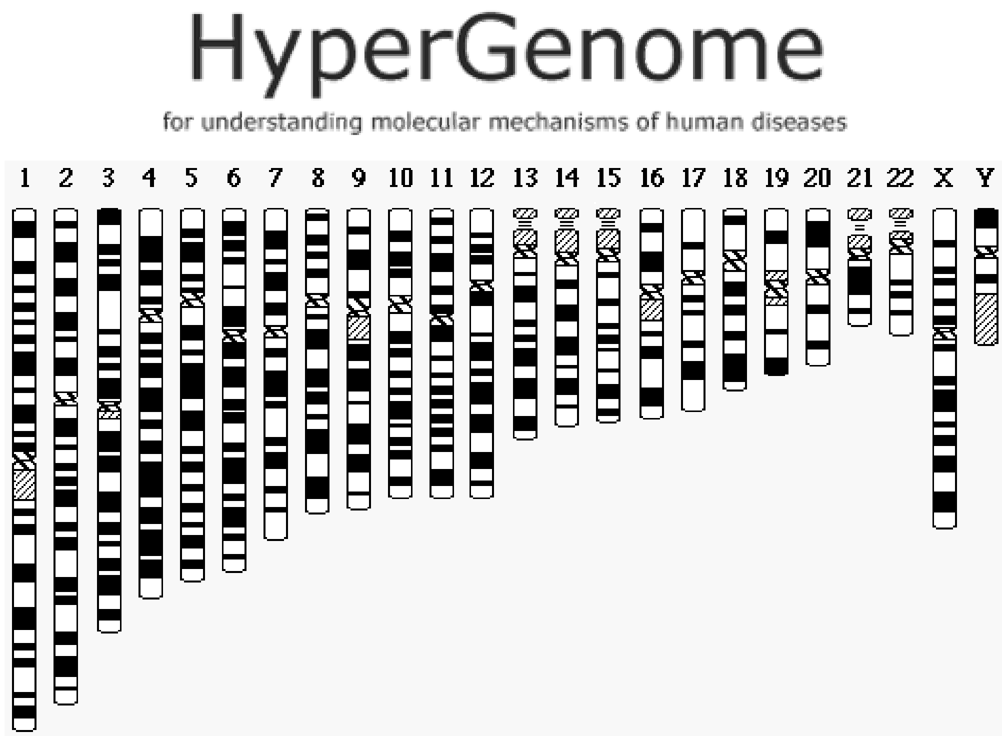

Figure 14 An example of representation of human genome (from **http://www.genome.ad.jp/hypergenome/**). By clicking on different parts of the chromosomes represented, users can fetch information related to the selected part of a chromosome and in context of understanding mechanisms of human diseases. The same picture may be used in other contexts where it will refer to different information and/or information resources.

The concept of Habitable Interfaces in terms of functionality, representations and interaction can then be specified as follow:

- Functionality:
    - Browsing (Allowing the user to browse through available information by means of representations and interaction based on navigating through these representations)
    - Retrieving (Finding relevant information from all the available resources based on a query specified by the user [by typing text, using speech or navigating through some representations of available information])
    - Filtering (Finding relevant information within a collection of information sources, based on a priori parameters of a filter specified by the user)
    - Chaining (relating objects, concepts or resources from the domain in a way suitable for the user)
    - Collecting (allowing user to systematically or randomly collect data or other objects [like concepts] from a representation or results of a query)

- Representations:
  - Graphical representations that are built based on concepts of scientific knowledge from a particular domain (such as maps, charts, tables or complex objects like biological cell)
  - Make use of domain knowledge for building, manipulating with (or on) representations and relating representations to information resources and data

At the level of physical input the interaction can be based on standard input devices (keyboard and mouse). Later speech and other modalities (such as force feedback) can be tested on how far they can improve the habitable aspects of such an interface. At the level of manipulating with graphical representations on a computer screen we have to decide on a set of virtual tools (such as rotating, collecting, chaining) to facilitate such manipulation.

Evaluation

To be applicable in a design, a concept needs validation. In validating the concept of the Habitable Interfaces we follow, in general, the empirical validation approach. The concept, such as the concept of Habitable Interfaces, can be empirically validated by building a number of prototypes and evaluating these prototypes under realistic conditions. Such evaluation is, usually, based on a priori agreed criteria and a method for evaluation (the design of the evaluation).

Criteria

As we mentioned in the previous chapter, there are several different (and sometimes overlapping) criteria that are advocated in the literature on interface design and used in evaluation of information systems. Some of these criteria are standardised. For example, ISO standard ISO 9241 part 11 gives guidance on the usability requirements for office work with visual display terminals. Here, usability is defined as the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use. However, the standard itself is formulated as “ergonomic requirements” rather then criteria. Furthermore, the term “office work” is not specific enough for our purposes as we put a clear emphasis on scientific communication. Nevertheless, the general ideas behind the usability can be reapplied in shaping-up criteria for evaluating Habitable Interfaces.

As we discussed in the previous chapters the main stakeholders considered in the concept of Habitable Interfaces are the readers. Following other authors, we asserted the importance of trust in scientific communication. Of course, trust is not the only criterion that is important for scientific communication. In addition, criteria such as effectiveness, efficiency and satisfaction (in a sense of feeling in comfort) have to be evaluated on. These criteria need to be operationalised in a set of measurable parameters. The set of parameters as it is planned now is presented in the next section of this chapter. Here we consider one of the measurements – the level of trust in more detail.

Zucker (1986) distinguishes three central mechanisms of trust-production that offer a framework for analysing real-life situations: process-based trust, institutional-based trust and characteristic-based trust. Hummels and Roosendaal added a fourth type of trust: values-based trust. They explain and elaborated on these types of trust using the notions of ability, benevolence and integrity. Below we present a summary of the discussion. The four mechanisms of trust production are presented in Figure 15.

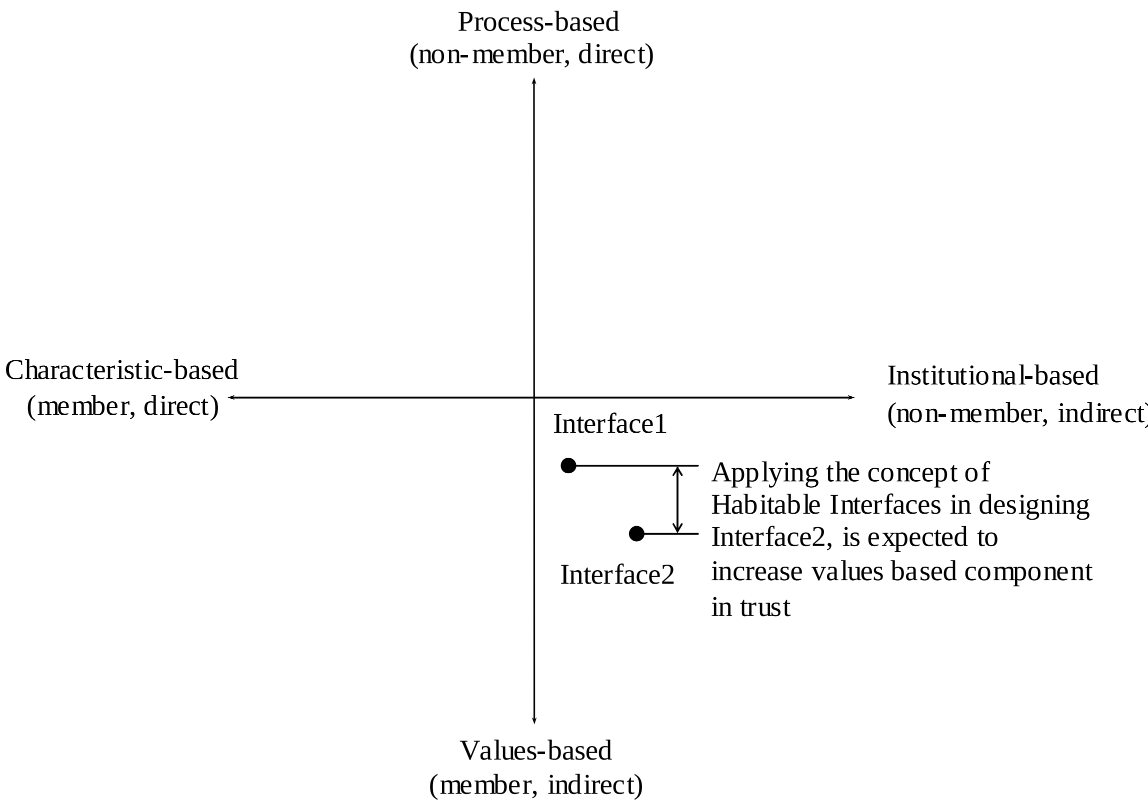

Figure 15 The four mechanisms of trust production

It is particularly the relationship, between (inter)dependent parties, which is relevant for trust in business relations. This relationship is determined by three characteristics of the trustee: *ability, benevolence* and *integrity***.**

Ability refers to the personal and functional competence of the trustee to perform according to the legitimate expectations of the trustor.
Benevolence is the extent to which a trustee is believed to want to do good to the trustor. It expresses a willingness to "care for the protection of others".
Integrity is defined as a "reputation for honesty" or – more in general – as the adherence to a set of principles.

Process-based trust stresses the need to be responsive to the needs of the trustor on the basis of successful cooperation in the past and a desire to continue the relationship.
This entails a strong orientation towards *ability* and *integrity* (or loyalty).
Ability is important since the focus is on achieving mutual benefit.
In a situation in which cost-reduction or (financial) benefits are strong motives to build process-based trust *integrity* also becomes important. If the other violates the basic notion of integrity by cheating or taking a free ride the collaboration is endangered. The notion of *benevolence* may but need not play a prominent role in the decision to trust the other.

Institutional-based trust stresses the need to be responsive to the needs of the trustor on the basis of an abstract duty to act professionally.

Institutional-based trust entails a strong orientation towards the *ability* of a "professional" who is expected to be capable and willing to act according to the standards of the "profession".
A person's *integrity* and *benevolence* are fine qualities but what really matters is his ability to, for example, diagnose a disease and to intervene effectively.

Characteristic-based trust stresses the need to be responsive to the needs of the trustor who appeals to a common background and a set of shared values or principles.
This entails a strong orientation towards *benevolence*. That is, one cares for the needs and interests of those one is closely related to.
The notion of *ability* may be important when someone wants to "become a member of the club" but once he or she is accepted ability plays a less prominent role in the decision to trust.

Values-based trust entails a positive attitude towards the trustee in a situation in which the trustor has no evidence that the trustee will be trustworthy. It rests on the expectation that the trustee will not act to the detriment of the trustor based on a sense of *benevolence*, decency, or good will.
Values-based trust entails a strong orientation towards *benevolence* and *integrity*, while the notion of *ability* may but need not play a prominent role in the decision to trust the other. Benevolence rests on the assumption that both the trustee and the trustor think through the possible outcomes of their interactions and come to the conclusion that it is in their best self-interest to be trustworthy.

The way trust develops in communication will also depend, we assume, on the way the information is communicated. It will depend on the interface between the scientist and content. Based on the mapping between the functions of scientific communication and the types of trust, different concepts towards the development of interfaces for scientific communication can be put forward. For example, the institutional-based type of trust can be related to branding (building trust towards well established brands). Interfaces that build on institutional-based trust can lead towards the development of in-house archives. The concept of Habitable Interfaces is built on values-based trust (see Figure 15). The level of trust is an important design criterion.

Design of evaluation

The design of evaluation, in a bird's-eye view, is presented on the Figure 16

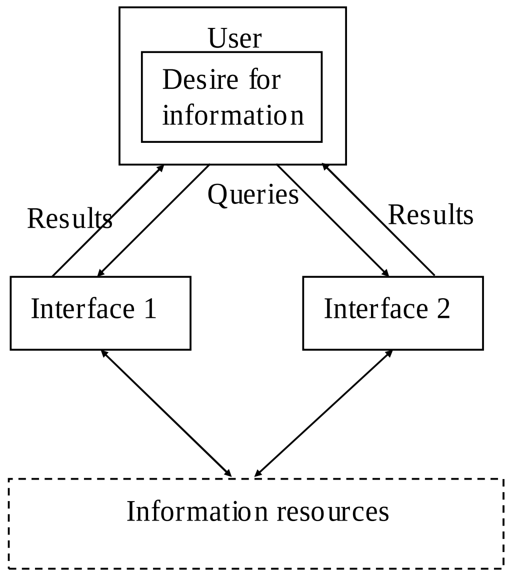

Figure 16 Comparison of two interfaces

Several interface designs will be compared. For this comparison the same set of resources and similar desires for information of the users will be applied. The main characteristics of an interface as discussed above are general criteria for evaluation.

For comparing interfaces we need to decide about operational measurements that can be made during evaluation. In deciding about operational measurements it is important to match between the goals of the evaluation and the measurements that will be used.

In the planned evaluation, both objective and subjective measurements will be collected. Objective measurements are taken by an experimenter and may include measurements on how much time users need to accomplish a task, how many errors they make, how many times they repeat the same error. Subjective measurements are based on participants' assessments. These measurements can be qualitative and quantitative. Quantitative measurements can be collected, for example, based on N-point scale ratings. The participants will be asked to state the level of their agreement or disagreement, for example, on a scale from one to five, with statements from a list. We also will collect the participants' comments that represent qualitative measurements.

We plan to collect the following measurements of differences between interfaces that will be evaluated:

- in data obtained in a search
- in time needed to obtain the same result
- in comfort to obtain the same result,

and

- in trust of users towards both: the information they will collect using the interface and the interface itself.

These measurements will be combined to judge about "habitable" aspects of interfaces.

Conclusions and Further Research

The proposed concept of Habitable Interfaces is an approach to design interfaces of scientific archives such as to improve effectiveness and efficiency of scientific communication. It rests on our analysis of scientific communication as a context of use. Particularly, the following relevant conclusions were drawn from the analysis:

- The applicability of an entity of content may be seen differently by a reader than applicability of this entity of content that was intended by the author. These differences are important for communication and should be taken into account when designing distributed archives. This is especially important; given the relatively large number of resources that a scientist may need to access.
- The four functions of scientific communication proposed in the literature are supposed to be invariant for different technologies that may be used in implementation of a communication system. If indeed true, this theoretical framework provides stable basis to analyse and build scientific communication systems.
- Trust is an important phenomenon in communication in general and it is a necessary condition for scientific communication to take place. The design of interfaces for scientific communication should enable a necessary for communication level of trust of the actors.

The differences in applicability of content were taken into account in the proposed high-level model of communication. The distinction between desires for information and information needs supported by information resources can be partially attributed to the differences in applicability of content. The model suggests that representing information resources to the reader using the domain knowledge may help to bridge the gap between the desire for information of the reader and the information needs supported by the information resources. The concept of Habitable Interfaces, that is proposed based on the high-level model and the analysis of scientific communication, if applied to the design, may improve effectiveness and efficiency of scientific communication.

Further research will be aimed at developing technologies for building Habitable Interfaces. Based on these technologies a number of prototypes will be built. These prototypes will be evaluated against proposed criteria and consequently improved. Several research questions remain open, such as:

- What are the suitable structure and form of the domain knowledge to use as the basis for building Habitable Interfaces?
- How to design different aspects of browsing, such as browsing to more generic or to more specific concepts and what are the starting points for browsing?
- What kind of dialog controls and visualisations are useful?
- How to combine graphical representations of individual concepts and resources to produce sensible integrated representations?
- How to represent concepts and models that do not have direct physical meaning? What kinds of metaphors are useful?

Answering these questions may require some preliminary testing. As mentioned above, after developing prototypes an empirical evaluation of the prototypes is planned. The concept of Habitable Interfaces will be validated based on results of this evaluation.

Acknowledgments

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