To appear in the proceedings of the conference AICA'96, Rome, 24-27 September 1996.

On the Foundations of Information Retrieval

Stefano Mizzaro

Dipartimento di Matematica e Informatica
Università di Udine
Via delle Scienze, 206 –Loc. Rizzi –Udine –Italy
Ph: +39 (432) 55.8456 –Fax: +39 (432) 55.8499
e-mail: mizzaro@dimi.uniud.it
Tipo: Lavoro completo
Classificazione: Internet e servizi Internet

Abstract

Information overloading is one of the major problems of the Information Society, and it is experienced by many people. Information retrieval is aimed at solving such problem, and hence it is a crucial discipline of this new era. Despite its centrality, information retrieval has its own shortcomings: for instance, most of Internet users have discovered with excitement the information retrieval systems available on Internet (the so called 'search engines'), but they have also experienced how often the performance of such services is too low, very far from an ideal 100%. The lackness of a formal account is probably one of the most evident of these shortcomings: concepts like information, information need and relevance are neither well understood nor formally defined. This paper sketches a cognitive framework that permits to analyze these central concepts of the information retrieval scenario.

The cognitive framework consists of concepts as cognitive agents acting in the world, knowledge states possessed by the cognitive agents, transitions among knowledge states, and inferences. On the basis of such framework, information is formally defined as an ordered pair representing the difference between two knowledge states; this definition permits to clarify the distinction among data, knowledge and information and to discuss the issue of the subjectiveness of information. On this ground, the concept of information need is examined: it is defined, it is studied in the context of the interaction between an information retrieval system and a user, and the well known classification in verificative, conscious topical and muddled needs is analyzed. On the basis of the above definitions of information and information need, relevance is formally defined, and some critical features of this concept are discussed.

1 Introduction

Information Society is here: Internet (e-mail, usenet news, BBS, gopher, World Wide Web, and so on) and CD-Roms are among its most manifest aspects. One of major problems of this new era is *too much information*: people are often overloaded with information and too much information usually means no information. The discipline of information retrieval [20, 34], born about half a century ago, is trying to solve this problem: the aim is to build computer systems that help the user to express his *need of information* in order to retrieve only the *information* that is *relevant* to his need. The so called *search engines* (Archie, Veronica, WebCrawler, Yahoo, Lycos, and so on) that can be found on Internet are nothing else than information retrieval systems of such kind, and they are necessary tools for avoiding the aforesaid information overloading.

The concepts of information, information need and relevance, central ones in information retrieval (as demonstrated by the emphasized terms in the above sentence), are not well understood. This is perhaps the most evident manifestation of the lackness of a comprehensive theory of information retrieval, looked for by many researchers. In this paper I propose a cognitive framework on which basis such a comprehensive theory of information retrieval might be developed. The adequacy of such framework is then evaluated by using it for better understanding the three above mentioned central concepts of information retrieval (information, information need and relevance).

The paper is structured as follows: in Section 2 a cognitive scenario is presented; on this basis, information (Section 3), information need (in Section 4) and relevance (in Section 5) are defined and analyzed. The last section summarizes the work done so far and sketches the future developments of this line of research.

2 A cognitive scenario

The importance of the cognitive view in information retrieval, and the powerful and adequacy of using cognitive instruments in the information retrieval field are largely recognized, and witnessed, for instance, by accomplishments like the MEDIATOR and MONSTRAT models. I have not enough space to discuss here such issues, that are anyway well analyzed in [20].

This section describes in an intuitive way some cognitive concepts: cognitive agents, knowledge states, knowledge items, transitions among knowledge states, and inferences.

2.1 Agents, knowledge states and knowledge items

I assume that the world is populated by *Cognitive Agents* (henceforth simply *agents*), that each agent possesses a *Knowledge State* (KS), and that it is possible to separate an agent and his (her, its) KS from the *'External' World* (henceforth simply *world*), whatever it may be. Through his perception system, an agent *perceives* (a portion of) the world and *represents* it into his KS. The portion of the KS that corresponds to a portion of the world is said the *representation* of that portion of the world into the KS. Such representation of the world can be more or less correct (i.e. corresponding to the world) and complete (i.e. taking into account every aspect of the world). An agent, on the basis of his KS, can *act* in the world.

Each KS is a collection of "atomic" components, that I call *Knowledge Items* (KI). Each KS is thus a set of KIs, and in the following I use some of the usual symbology of set theory, as $\in$ (belong), $\subseteq$ (subset), \ (set difference), $\varnothing$ (empty set), $\cup$ (union), $\cap$ (intersection), and so on, with the usual meaning extended to KSs and KIs.

Figure 1 illustrates intuitively the scenario presented so far: an agent perceives a portion of the world and represents it in K', a subKS of his whole KS K.

The reader can imagine many alternatives for having a more concrete picture of KSs (and KIs), for instance: logical theories (i.e. sets of logical formulas) [17]; semantic nets [38]; sets of beliefs [17]; situations [2, 12, 14], see also [11, 22]; recursive models [26, 29]; minds and ideas [4]; and so on. I do not take position among these (and many others) alternatives in this paper, and I try to remain at a level of abstraction enough general for comprising all of them.

Let us go more deeply inside a KS. Whatever KSs and KIs are, I suppose that some *links* exist among the KIs and the KSs. This means that a KS can be partitioned into subKS, each

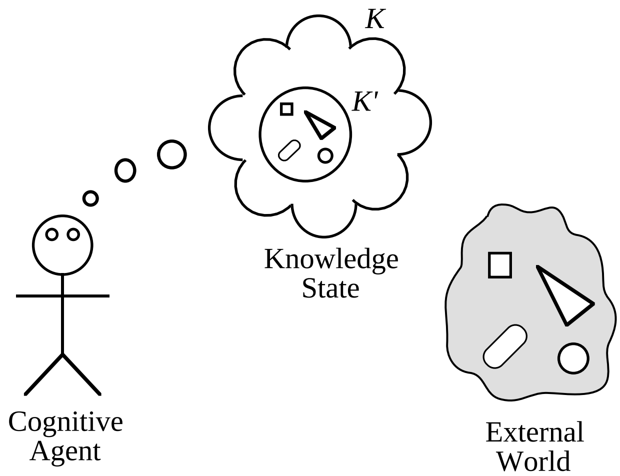

Figure 1: An agent, his KS, a part of the world and its representation.

partition containing the KIs more strongly linked. See for instance Figure 2: the KIs regarding, say, Euclidean Geometry (as the concepts of triangle, square, Pitagora's Theorem, and so on) belong to one partition, while the KIs regarding, say, mammals belong to another partition. Such partitions, besides being subjective, are neither absolute nor clear-cut: it is (almost?) always possible to find a link chain among two KIs or KSs. It is a fuzzy, or perhaps fractal, situation. For instance, it is possible to link, say, a mammal with a square through the KSs about mice and cages. Furthermore, the links themselves are a kind of KIs, in order to, for instance, have links among links (and so on), as the dashed one in Figure 2 (that links two "IsA" links).

The above assumptions are widely spread in many fields, for instance: artificial intelligence (under the label "logicism" [17, 32]), situation semantics [12], cognitive science [16], and human-computer interaction [13]. They are criticizable from many points of view (see for instance [7, 25, 27]), but they will be useful in the following of this paper for describing the interaction between a user and an information retrieval system. Thus, I do not take them as established truths, but as useful work hypotheses: for the sake of brevity, I avoid to analyze the (many) philosophical implications of these issues. In the same way, being the KS the only component of an agent that is analyzed here, I assume that the perceptual systems of different agents are similar, though this is obviously a rough abstraction.

2.2 Transitions among KS

The KS of an agent may change as time goes on: when this happens, I say that a *transition* between an initial KS K^I and a final KS K^F takes place. Such transitions can take place for two different reasons:

- by (internal) inference: the agent reasons, reflects, and modifies his KS without any input from the world. This will be called *inferential transition*; it is the only kind of transition that can take place for an agent without a perception system;
- by receiving information: through his perception system, the agent perceives something (a datum) from the world and this leads to the modification of his KS (a transition into another KS). This will be called *noninferential transition*. If the datum leads to a change of the KS then the datum is said to *carry* information. Note that everything can be a datum, also nothing (i.e. no receiving from the world), because nothing is different from something, and so it can carry information [4]. This is the reason for distinguishing between an inference and a null datum.

Let us analyze in more detail a single transition. The modification that takes place in the KS can be expressed by what is added (a subKS indicated by K^+) and what is removed (K^-). In Figure 3 the two KSs K^I and K^F are represented by circles, the subKS K^+ added to the KS by the little white semicircle on the border of the KS, and the removed subKS K^- by the little black

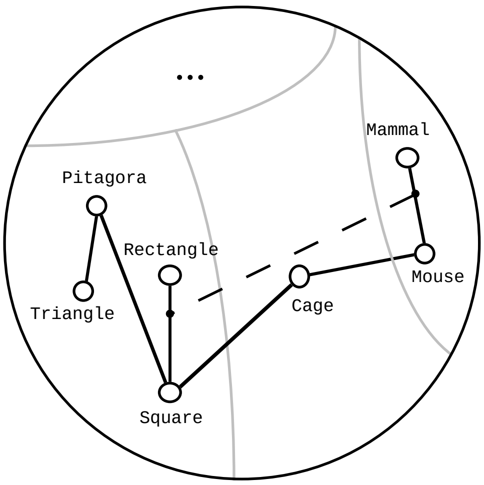

Figure 2: Links among and partitions of KSs.

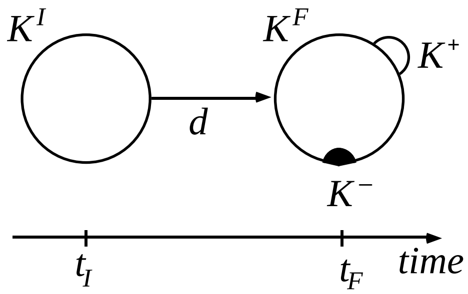

Figure 3: Initial and final KS of a transition.

semicircle. The transition between the two KSs is represented by an arrow labelled by the corresponding datum (or by 'infer' if it is an inferential transition). Finally, at each KS can be associated a time instant (in figure, t_I and t_F are the time instants of K^I and K^F, respectively).

Note that, besides adding new KIs (K^+), a datum can also lead to the removal of some subKS (K^-). This happens, for instance, when a fact is believed true in the KS before a transition and false later: the KIs representing the truthness are removed and the KIs representing the falsehood are added. Furthermore, the addition and removal of KIs can be very complex operations, because the KIs linked to the added or removed KIs are affected too, in a recursive way.

It is possible to imagine a *network* (a la Kripke [18]) of possible KSs of an agent: the nodes of such network are KSs, among which some are 'real' KSs (i.e. KSs before or later actually possessed by the agent) while other ones are possible KSs that do not become 'real' ones (i.e. the agent does not possess them, though he could); the arcs of this network are the transitions from one KS to another one. In Figure 4 some transitions among plausible KS are represented. The KS and transitions in the figure are the possible ones, but only one path from K_1 to K_7 is followed in the reality, for instance the one with the thickest lines, while the other KSs remain only plausible ones.

In the next three sections, the above introduced concepts (KS, KI, link, transition, K^+, K^-, and network of KSs) are applied to the *Information Retrieval* (IR) field, in order to analyze and better understand three central concepts of IR: information, information need and relevance.

3 Information

In this section I propose a definition of information on the basis of the above introduced concepts. This definition leads to distinguish among data, knowledge and information, to analyze the subjectiveness of information, and to go more deeply inside the KSs.

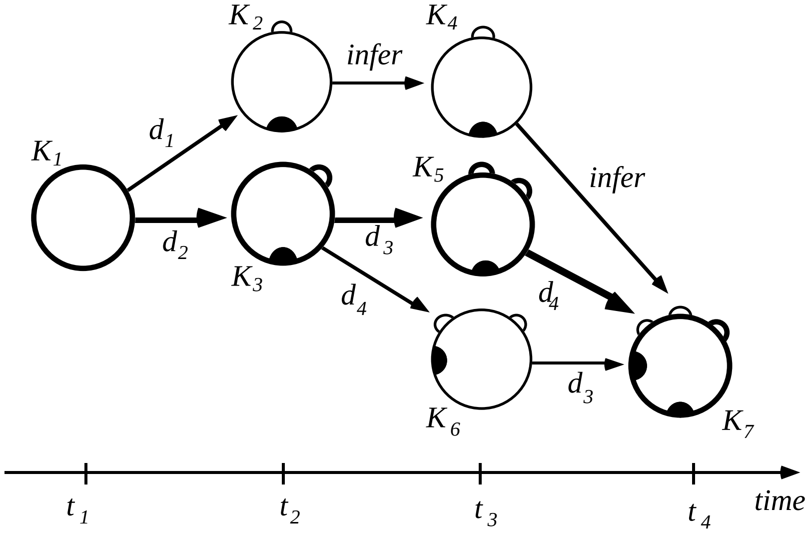

Figure 4: KS and transitions among them.

3.1 Data, knowledge, and information

I assume that *knowledge* exists only inside the agents' KSs (thus a book does not contain knowledge). A *datum* is an entity of the physical world that, once perceived by an agent, leads to a noninferential transition of a KS, changing, say, from K^I to K^F. When this happens, the datum is said to carry *information*.

On this ground, it is possible to define the information carried by the datum in (at least) two ways: (i) something that *causes* a transition, or a difference between two KSs (and so is in some way inherent in the datum); or (ii) something that *is* the difference between the two KSs. Here I follow the latter choice: referring to Figure 3, the information carried by the datum *d* in the transition from K^I to K^F is defined as an ordered pair

$$Information\ (d, K^I,K^F) = \langle K^+,K^- \rangle = \langle K^F \setminus K^I, K^I \setminus K^F \rangle;$$

a way of expressing the *difference* among the two (final and initial) KSs.

Also Bateson [3, 4] and Brookes [10] define information as a difference, but in ways that are different from the one proposed here. Following Bateson, an item of information is a difference in the world: on the basis of the above definitions, Bateson's difference is a datum. Brookes proposes in his "fundamental equation" $K[S] + \Delta I = K[S + \Delta S]$, that "information is a small bit of knowledge": a "knowledge structure" $K[S]$ is changed to a new knowledge structure $K[S + \Delta S]$ by the information ΔI. Brookes's view is more similar to the one proposed here than Bateson's one, but is anyway different: Brookes's knowledge and information are measured in the same units, while this does not hold for information as defined above.

With this definition of information, the following two features hold:

- The same datum can carry different information. For instance, if the datum is an utterance in some language, an agent understanding such language can obtain information, while an agent not understanding the language cannot. A single 'bit' (i.e. an atomic datum, as 0/1, true/false, on/off) can carry an huge amount of information to an agent in an opportune KS, i.e. a KS with a high 'potential' (borrowing the term from physics) knowledge, in which a single bit triggers some transitions with a high difference between the initial KS and the final KS. The same datum can carry different information to two different agents or even to the same agent in different time instants: this can happen if the KSs of the two agents are different or if the KSs of the same agent in the two time instants are different.
- Two different data can carry the same information. For instance, an utterance uttered in two different languages carries the same information to an agent understanding both of the languages (and already knowing that the speaker knows both languages!). A number expressed through different 'formats' (8, VIII, 10_8, 1000_2, 20_4) carries the same information to an agent not 'sensible' to the difference of the base.

Hence, the KS plays a fundamental role in an agent receiving data: the information carried depends on the KS of the agent. It should be said that a datum is 'interpreted' (not 'received') by an agent on the basis of his KS. It is possible to define an *interpretation* function

$$int: Data \times KS \rightarrow KS$$

that, given as argument a datum and a KS, assumes as value the KS resulting from the transition.

Despite of this evident subjectiveness of information, in everyday life the same datum sometimes (if not often) brings the same information to different agents. This may be explained assuming that the differencies among the KSs of the agents that populate the real world (mostly human beings) are low enough for having a good accordance between them, and this can in turn be justified by the fact that the KSs of the agents of the real world are similar for genetical and

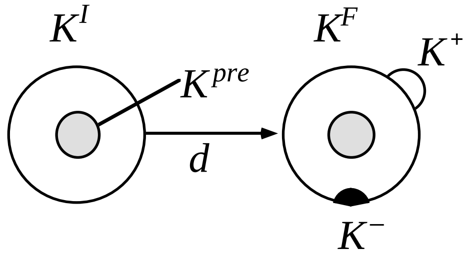

Figure 5: The interpretation of a datum does not depend on the whole KS.

social factors.[1] In this way, it becomes possible to speak of "potential" information, and this is probably the reason for having an *Information Theory* [37], that should perhaps be called 'data' theory, in which the information is *objective*.

3.2 Prerequisite knowledge state

Supporting this view, note that the information received through a particular datum does not depend on the whole initial KS, but only on a *prerequisite* subKS (and thus the subjectiveness of information is less evident). Such subKS, indicated by K^{pre}, must be such that the information received by the agent would not change if the initial KS of the agent were just K^{pre} instead of the whole KS. Let us see an example. An agent believes a wrong version of Pitagora's Theorem (for instance $a^2 + b^2 > c^2$, instead of the well known correct version $a^2 + b^2 = c^2$). When the agent receives the proof of the right version of the theorem (a datum), his KS changes accordingly. Referring to Figure 5, we have: K^I is the initial KS of the agent; d is the proof of the right version of the theorem; K^{pre} is the prerequisite KS and represents the notions of triangle, square, and so on, necessary for understanding the theorem; K^F is the final KS of the agent; K^+ is the subKS representing the right version of the theorem; and K^- is the subKS representing the wrong version of the theorem. Obviously, the KS of the agent may contain something more than K^+, K^- and K^{pre}, but this is absolutely not relevant in this example.

In order to better understand the prerequisite KS, let us analyze more formally the situation. Given an initial KS K^I, a final KS K^F, and a transition labelled with a datum d, K^{pre} is defined as a KS such that:

(i) $K^{pre} \subseteq K^I$;

(ii) $\langle int(d,K^I) \backslash K^I, K^I \backslash int(d,K^I) \rangle = \langle int(d,K^{pre}) \backslash K^{pre}, K^{pre} \backslash int(d,K^{pre}) \rangle$;

(iii) K^{pre} is minimal, i.e. $\neg \exists K' \subseteq K^{pre}$ such that holds the previous property (ii).

Note that on the basis of this definition we obtain a restriction on K^- and K^{pre}: $K^- \subseteq K^{pre}$ (a particular case being $K^- = \emptyset$). This means that the subKS removed must be a part of the prerequisite KS, and this is quite reasonable. Figure 5 should be modified in this sense, and this will be taken into account in the following.

4 Information need

The concept of *information need* has been studied for years by many researchers, among which:

---

[1] This is less true if we consider people from different cultures, e.g. European vs. Asiatic, or different kinds of agent, e.g. human beings vs. computers. By the way, this might be an explanation of all the difficulties encountered in computer science, especially in artificial intelligence: a high difference between the KSs of the two kinds of agents, human beings and computers.

- Mackay [23] speaks of "incompleteness of the picture of the world", "inadequacy in what we may call his [the agent's] 'state of readiness' to interact purposefully with the world around him in a particular area of interest";
- Taylor [39] speaks of visceral, conscious, formalized and compromised information need, individuating four levels of question formation;
- O'Connor [33] notes the ambiguous nature of the concept of information need;
- Belkin, Oddy and Brooks [5, 6] speak of "Anomalous State of Knowledge", the well known 'ASK';
- Ingwersen [19, 20] conies the ASK-like acronyms ISK (Incomplete State of Knowledge) and USK (Uncertain State of Knowledge) unifying these three acronyms in a common concept. He also proposes three fundamental types of information need (verificative, conscious topical and muddled).

Notwithstanding these and many other studies, and the common usage of the term "information need" in the field of IR, still today the concept is neither understood nor defined. In this section it is analyzed on the basis of the above introduced cognitive scenario and definition of information: I afford definitional issues, illustrate the activity of the user of an IR system, and describe the differencies among the above mentioned three types of information need proposed by Ingwersen.

4.1 Definition of information need

What is an information need? Well, it is (obviously!) a *need* of *information*, and information is the "difference" between two KSs. A first attempt of graphically representing the situation is illustrated in Figure 6: an agent with an initial KS K^I does not posses the 'right' knowledge for solving a problem (or reaching an aim), and thus needs some additional information for reaching an adequate KS K^F, perhaps through some intermediate KSs (here and in the following figures an arrow containing three dots stands for a chain of transitions). The pair

$$\langle K^F \setminus K^I, K^I \setminus K^F \rangle = \langle \bigcup_i K^+{}_i,\ \bigcup_i K^-{}_i \rangle$$

is the information needed by the agent, in which the union of more K^+ and K^- indicates that the information may be obtained through subsequent steps.

But this is an uncomplete representation, because an information need can, in general, be satisfied in different ways: there is not a unique KS K^F that satisfies the need, but there can exist different final KSs and different paths for reaching each of them. Figure 7 represents this more complete view: the dashed circles represent the KSs that satisfy the information need.

Some of the final KSs of Figure 7 may be redundant: they do satisfy the need, but they contain also unuseful, or not used, additional knowledge. Only the minimal KSs among the dashed ones should be taken into account. In a more formal way, given the set

$$\boldsymbol{K} = \{K^F{}_1, K^F{}_2, K^F{}_3, \ldots\}$$

of all the KSs satisfying the need, the redundant KSs can be eliminated normalizing $\boldsymbol{K}$ in the following way:

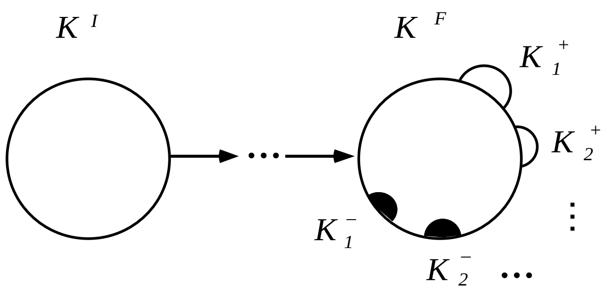

Figure 6: An information need as a difference of KSs.

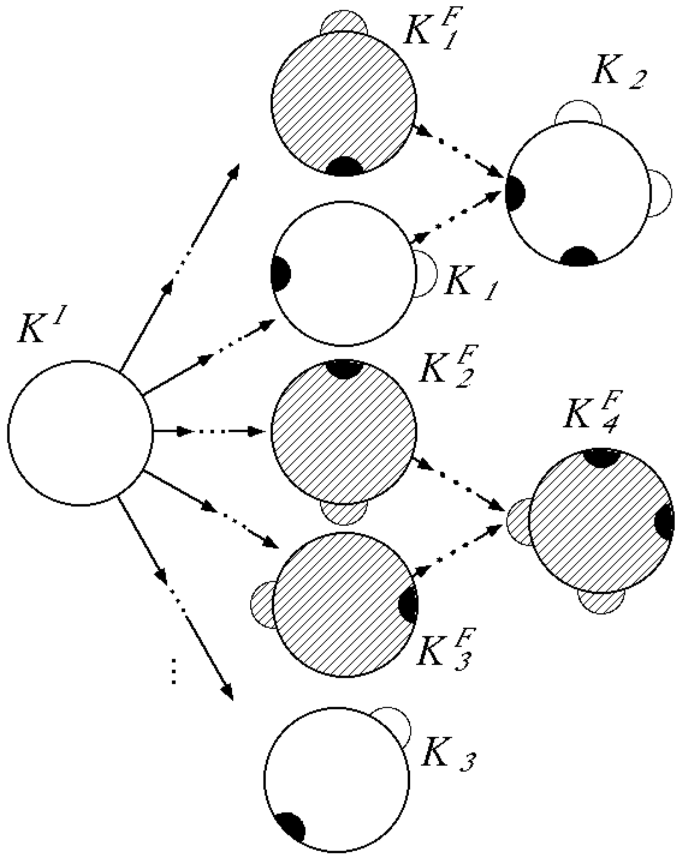

Figure 7: A more complete representation of an information need.

$$\boldsymbol{K}^* = \{K \mid K \in \boldsymbol{K} \ \& \ \forall K' \in \boldsymbol{K} \ (\neg \ \exists (K' \rightarrow K))\}$$

(where $K' \rightarrow K$ stands for a transition from K' to K). In Figure 7 we have $\boldsymbol{K} = \{K^F{}_1, K^F{}_2, K^F{}_3, K^F{}_4\}$ and $\boldsymbol{K}^* = \{K^F{}_1, K^F{}_2, K^F{}_3\}$.

Now it is possible to define the information need in a KS K as a set of pairs, the set of the information items needed:

$$Need(K) = \{\langle K^* \setminus K, K \setminus K^* \rangle \mid K^* \in \boldsymbol{K}^*\},$$

so that the information needed in a KS K is the set of information items that permit to change the KS in a minimal final KS. Thus, 'to satisfy the information need of an agent in a KS K'' means 'to give him one of the information items of the set *Need (K)*'.

Obviously, Figure 7 represents (some of) the plausible KSs of an agent, but only a few of them are real ones: the agent follows a single path. Moreover, it should be evident that it is impossible to know 'a priori' which is the information needed.

This is not the whole story. An agent represents the world, and also himself in the world. Thus, an agent represents in his KS also his (perception of his) KSs: a part of each KS of Figure 7 represents the whole scenario illustrated in Figure 7. Thus, we have two kinds of information need: the *Observer's Information Need* (ONeed), corresponding to Taylor's 'visceral need' [39], about which I have discussed so far, and the *Agent's Information Need* (ANeed), corresponding to Taylor's 'conscious need', perceived by the agent.[2] The new

2 I am implicitly assuming that the external observer is a sort of oracle, that has a correct image of the situation and can "see" inside the KS of an agent without affecting him.

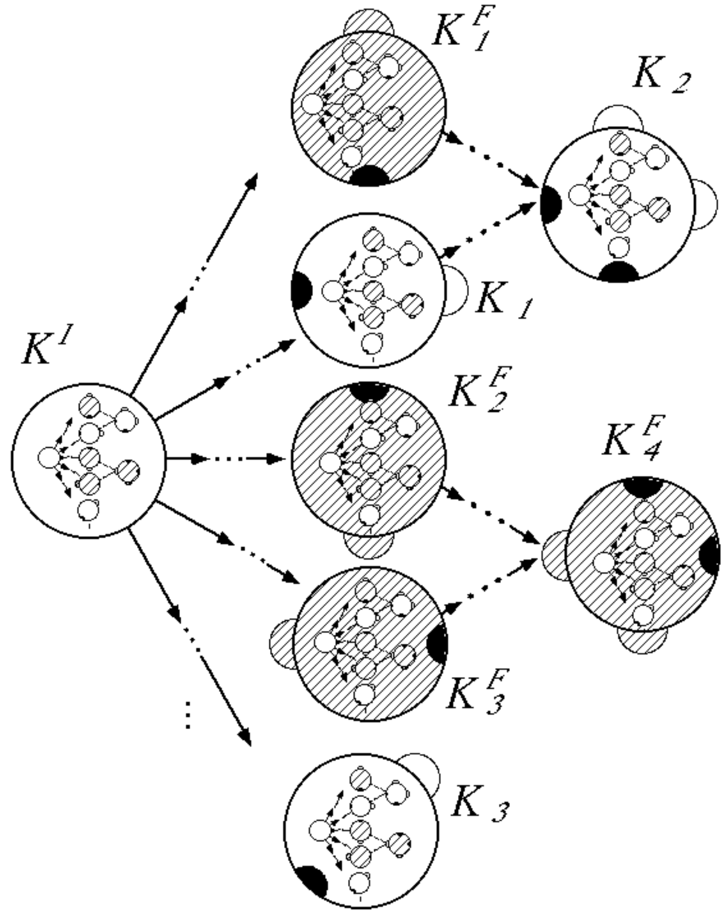

Figure 8: Representation of the information need inside the KSs.

situation is sketched in Figure 8, in which the representations inside the KSs and thus the ANeed are added.[3]

In order to formally define the ANeed, a *representation* function

$$repr: KS \times World \rightarrow KS$$

is needed. This function, given a KS and an object of the world, assumes as value the representation of such object in such KS: $repr_K(x)$ is the representation of the object x inside the KS K. Using such function, the ANeed in a KS K as seen by an agent with a KS $\overline{K}$ can be defined as:

$$ANeed_{\overline{K}}(K)=\{\langle repr_{\overline{K}}(K^*) \setminus repr_{\overline{K}}(K), repr_{\overline{K}}(K) \setminus repr_{\overline{K}}(K^*)\rangle | K^* \in repr_{\overline{K}}(\mathbf{K}^*)\}.$$

Also $ANeed_{\overline{K}}(K)$ is a set of pairs, and it is in general different from $ONeed(K)$. As the representation function is more correct and complete, $ANeed_{\overline{K}}(K)$ becomes more similar to $ONeed(K)$. Anyway, correctness and completeness of the representation function $repr_{\overline{K}}$ are sufficient but not necessary for having $ANeed_{\overline{K}} = ONeed$.

The ONeed changes as time goes on: at time t_I, in KS K^I, the ONeed is the initial one, and changes during the receiving of information. The ANeed is a representation of the ONeed, and

3 If inside the KS there is the representation of the KS, then there will be also the representation of the representation and so on. This leads to an infinite (if no fixed points are found) recursion, that should be handled in an opportune way.

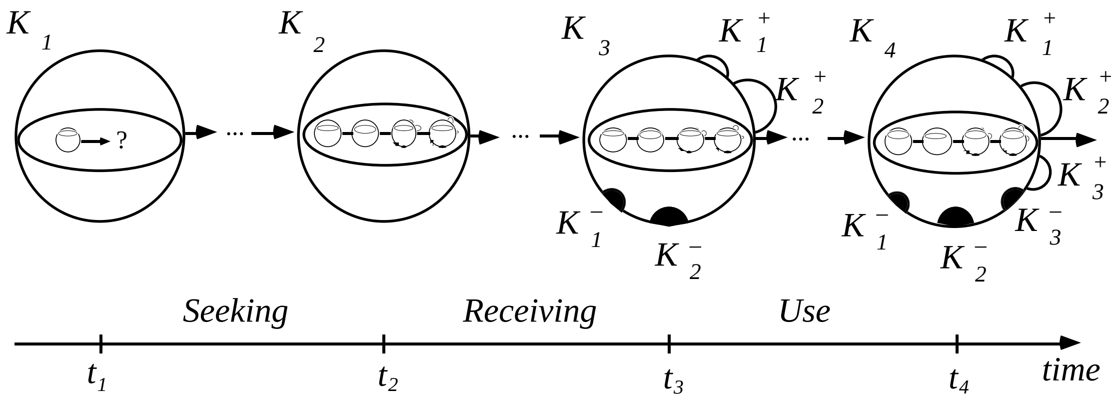

Figure 9: KSs in information seeking, retrieving and use.

thus it is time dependent too. Moreover, remember that a representation inside a KS is by no means correct and complete: an agent might need some information and not notice it, while another agent might not need information and believe that he needs it. Thus, it is likely that the ANeed is more adherent to the ONeed as the time goes on (more appropriately, as new data are being received), because the agent can perceive in a more correct and complete way his ONeed.

Note also that in order to define the ANeed, I have supposed that an agent represents his possible KSs (and the set ***K****). There are three very strong assumptions here: (i) the KSs (and ***K****) are objects of the world; (ii) an agent thinks in terms of KSs and transitions among them (while probably he does not); (iii) the agent represents all the possible KSs.

4.2 Information seeking, receiving, and use

Let us go more deeply into the details of the KS of an agent that tries to satisfy his information need using an IR system. His activity can be divided into three phases, graphically represented in Figure 9 (in which only the 'real' KSs, not the plausible ones, are reported):[4]

- *Information seeking* in which the agent tries to understand *how* (i.e. which are the steps to take) to satisfy his information need. At the end of this phase (K_2), the ANeed is very different from the initial one (in K_1), while the rest of the KS is practically unchanged. Let us suppose that in this phase the agent interacts with an IR system. Then, at the end of the phase, the user knows which documents to read and how he will try to satisfy his information need (obviously, only in an approximate way, as nobody can know the future with certainty).
  In this phase the user of the IR system is not interested in information, but rather in *metainformation*, i.e. in information about the information that he will obtain in the next phases. In the case of a bibliographic IR system, such metainformation is extracted from the surrogates of the documents.
- *Information receiving* in which the agent receives the data (in this case, documents) individuated in the previous phase, reads and studies such documents in order to reach the adequate KS K^F that permits him to start the following phase. In this phase, the KS of the agent is largely modified.
- *Information use* in which the agent uses the information received for acting (for instance, he writes something, or speaks about it to other people, or infers some other facts, or just do nothing). In this last phase, the KS of the agent is modified only by inferential transitions.

Usually, the IR researchers study only the first phase, guiltily neglecting the other two that should instead be taken into account. Summarizing, one should write:

---

4 Note that the situation is not so linear, because not all the transitions are "good" ones: there might be some transitions that take the user away from the satisfaction of his information need (instead of bringing him near to it). Anyway, the user, before or later, perceives this fact, and accordingly modifies his behavior: there is a sort of *feedback*.

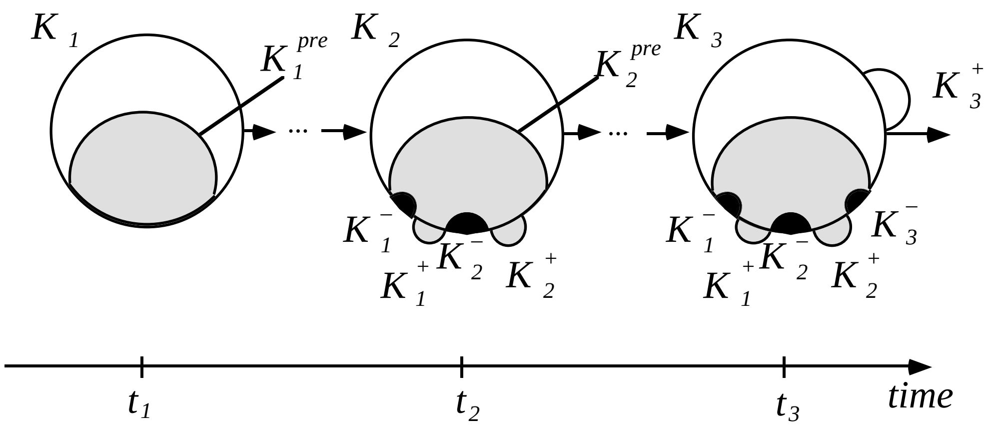

Figure 10: Modification of K^{pre} in a muddled need situation.

IR = Information seeking + Information receiving + Information use.

4.3 Information need types

On the basis of empirical data, Ingwersen [19, 20] proposes three "fundamental types of information needs in IR": *Verificative need* (the user knows the bibliographic data of the needed documents. It is more a database problem than an IR problem); *Conscious topical need* (the user needs information about a topic that he knows well); and *Muddled topical need* (the user needs information about a topic that he does not know well. This is an ill-defined information need).

The information receiving phase of these three types of needs can be described on the basis of the above proposed cognitive scenario. The first two kinds of information need are nothing special: one or more transitions take place in order to modify the KS of the user. In the more interesting case of a muddled need (Figure 10), some transitions take place, with the characteristics that the prerequisite KS (the gray area in figure) changes along the transitions chain: the user has to learn something (i.e. to receive some information) in order to be able to learn something else (i.e. to receive the information properly needed). Coming back to the Pitagora's Theorem example (Section 3.1), a muddled need would be one in which the user does not know the basics of Euclidean geometry (triangle, square, and so on): he has to learn those concepts before understanding the theorem.[5] Thus, in the case of a muddled need, the standard so called *Automatic Query Expansion* techniques [24] (based on the assumption that the first expression of the user need is a correct one) seem not adequate, and *Interactive Query Expansion* ones (see for instance [8, 9]) seem mandatory.

5 Relevance

Relevance [15, 35, 36] is another concept, crucial in IR (and information science in general) and lacking a final definition, that can be defined and analyzed on the basis of the scenario presented in the previous sections.

The term 'relevance' has already been used in Section 3.1, for emphasizing that a part of the initial KS of an agent receiving some data can be not relevant for the interpretation of such data. But this relevance is not the only one, and is not the one studied in IR. In IR, one speaks of information (or data, i.e. documents) relevant to an information need (or to one of its expressions, i.e. request or query; see [28, 30] for a detailed discussion of this issue).

Figure 11 illustrates a network of KSs. From the initial KS K^I, two transitions can take place, through receiving one of two data (d_a or d_b). Let us consider by now only the two possible KSs at time t_2 ($K^2{}_a$ and $K^2{}_b$): if only $K^2{}_b$ is a final (i.e. satisfying the information

[5] Note that the prerequisite KSs used in the chain will belong to the final KS satisfying the need.

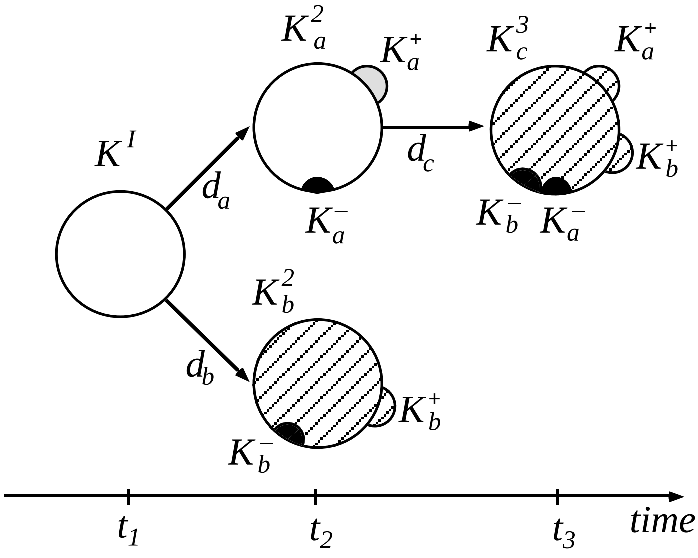

Figure 11: Relevance of information to information need.

need) KS, then the information $\langle K^+{}_b,K^-{}_b\rangle$ carried by d_b is relevant, while the information $\langle K^+{}_a,K^-{}_a\rangle$ carried by d_a is not relevant.

More generally and formally, given an information need

$$ONeed = \{\langle K^+{}_1,K^-{}_1\rangle,\langle K^+{}_2,K^-{}_2\rangle, \ldots\},$$

an item of information $\langle K^+;K^-\rangle$ is relevant to such information need if and only if there is an 'intersection' between the two:

$$relevant(\langle K^+,K^-\rangle,ONeed) \textbf{ iff } \exists i(K^+{}_i \cap K^+ \neq \emptyset \vee K^-{}_i \cap K^- \neq \emptyset).$$

This means that an information item is relevant to an information need if such information item helps to reach a KS satisfying the need.[6]

The situation is anyway not so simple. A datum might seem not relevant to an ONeed at the end of a particular transition, and become relevant on the basis of a successive transition: relevance depends on the future. In order to illustrate this issue, let us consider the KS $K^3{}_c$ of Figure 11 and suppose that: (i) a successive transition from $K^2{}_a$, caused by another datum d_c, could take place; (ii) the KS $K^+{}_a$ of $K^2{}_a$ (obtained from d_a) is a part of the prerequisite subKS for this transition; and (iii) this transition leads to a KS $K^3{}_c$ that differs from $K^2{}_a$ because contains $K^+{}_b$ and does not contain $K^-{}_b$ (and so is a sort of "union" of $K^2{}_b$ and $K^2{}_a$). Then, d_a is relevant: more specifically, d_a seems not relevant at time t_2 (after he has been perceived), while its relevance appears at time t_3 (an arbitrary time later). In a similar way, a datum might seem relevant before and become not relevant after. Note furthermore that the datum d_c carries the same information $\langle K^+{}_b,K^-{}_b\rangle$ of the (different) datum d_b, starting from different KSs.

Anyway, the above definition of relevance can be extended. The extension from information to data (i.e., in the IR case, documents or surrogates) is straightforward: a datum is relevant if and only if the information carried is relevant; the problem is that the information carried by a datum is not univocal, as illustrated in Section 3.1. Also the extension from ONeed to ANeed is simple. Being the ANeed a set of pairs analogously to the ONeed (see Section 4.1), the relevance of information to the ANeed is defined in a way similar to the relevance to the ONeed. Remember that the ONeed is different from the ANeed, so it is possible that an item of information is relevant to the ONeed and not relevant to the ANeed (or vice-versa). This

6 Remember that (relevant) prerequisite KS have to belong to the final KS (see the footnote 5 at the end of Section 4.3).

difference is likely to decrease as the agent, receiving data, approaches to a KS in which his ONeed is satisfied.

6 Conclusions and future work

This paper proposes a cognitive framework for analyzing the information retrieval scenario in a formal way. In Section 2 some cognitive prerequisites are illustrated (KS, KI, link, K^+, and K^-). On this ground, three crucial concepts of information retrieval are analyzed: in Section 3 information is defined as a pair representing the difference between two KSs; in Section 4, information need is defined as a set of information items; in Section 5, relevance of information to information need is defined as a set intersection operation. Besides clarifying these three concepts, the adequacy of the above proposed cognitive framework is thus assessed.

There are many promising future developments of this work. First of all, the cognitive scenario should be enriched in order include into the description:

- A more detailed analysis of what is inside the KSs. The dichotomies knowledge vs. metaknowledge [17], implicit vs. explicit knowledge [31], actual vs. potential knowledge (if an agent knows the axioms of a theory, does he know all the theorems of the theory?), and other ones should be taken into account. Also the links should be analyzed more in depth, as they seem to play an important role in the transitions between KSs.
- A more dynamic vision of KSs. In this paper, I have preferred to define static KSs in order to avoid the problems related to logical omniscience [17]. This is the reason for putting the inferences outside the KSs. The alternative way of including the inferences inside the KSs (and thus take into account the area of belief revision [1, 21]) should be considered.
- The intention of an agent [12]. The aims and goals play a crucial role in the interpretation of a datum, and they can change when a transition between KSs takes place.

When such an enriched cognitive scenario is available, the analysis of information need and relevance should be reconsidered, taking into account also the relevance to a request expressed by an agent: the relevance to a request is different from the relevance to ONeed and ANeed. Also other concepts of the IR field should be studied, as the *task* of the user of an IR system (i.e. what the user has to do with the retrieved documents) that should be included once introduced the aims and goals of the agent. Moreover, the topic-task-context trichotomy [28, 30] should consequently be clarified.

Finally, it could be interesting to fully formalize this work, looking for an axiomatic theory.

Acknowledgements

I am indebted to Paolo Giangrandi and Carlo Tasso for having read a previous version of this paper and provided useful suggestions, and to Giuseppe O. Longo for his wise advices.

References

[1] C. E. Alchourron, P. Gärdenfors, and D. Makinson. On the logic of the theory of change: partial meet functions for contraction and revision. *Journal of Symbolic Logic*, 50:510-530, 1985.
[2] J. Barwise and J. Perry. *Situations and attitudes*. MIT Press, Cambridge, MA, 1983.
[3] G. Bateson. *Steps to an Ecology of Mind*. Chandler Publishing Company, 1972.
[4] G. Bateson. *Mind and Nature*. E. P. Dutton, 1979.
[5] N. J. Belkin, R. N. Oddy, and H. M. Brooks. ASK for information retrieval: Part I. Background and theory. *Journal of Documentation*, 38(2):61-71, 1982.
[6] N. J. Belkin, R. N. Oddy, and H. M. Brooks. ASK for information retrieval: Part II. Results of a design study. *Journal of Documentation*, 38(3):145-164, 1982.
[7] L. Birnbaum. Rigor mortis: a response to Nilsson's "Logic and artificial intelligence". *Artificial Intelligence*, 47:57-77, 1991.

[8] G. Brajnik, S. Mizzaro, and C. Tasso. Interfacce intelligenti a banche di dati bibliografici. In D. Sacca, editor, *Sistemi evoluti per basi di dati*, pages 95-128. Franco Angeli, Milano, 1995.
[9] G. Brajnik, S. Mizzaro, and C. Tasso. Evaluating user interfaces to information retrieval systems: A case study on user support. To appear, accepted for the publication in *ACM SIGIR'96*, 1996.
[10] B. C. Brookes. The foundations of information science. Part I. Philosophical aspects. *Journal of Information Science*, 2:125-133, 1980.
[11] P. D. Bruza. Stratified Information Disclosure: A Synthesis between Hypermedia and Information Retrieval. Ph.D. Thesis, Katholieke Universiteit Nijmegen, The Netherlands, 1993.
[12] K. Devlin. *Logic and Information*. Cambridge University Press, Cambridge, England, 1991.
[13] A. Dix, J. Finlay, G. Abowd, and R. Beale. *Human-computer interaction*. Prentice-Hall, New York, 1993.
[14] F. Dretske. *Knowledge and the Flow of Information*. Bradford Books, MIT Press, 1981.
[15] T. J. Froehlich. Relevance reconsidered – Towards an agenda for the 21st century: Introduction to special topic issue on relevance research. *Journal of the American Society for Information Science*, 45(3):124-133, April 1994.
[16] H. Gardner. *The mind's new science: A history of the cognitive revolution. With a new epilogue by the author: Cognitive science after 1984*. Basic Books, New York, 1987.
[17] M. R. Genesereth and N. J. Nilsson. *Logical Foundations of Artificial Intelligence*. Morgan Kaufmann Publishers, Los Altos, California, 1987.
[18] G. E. Hughes and M. J. Cresswell. *An Introduction to Modal Logic*. Methuen and Co. Ltd., London, 1968.
[19] P. Ingwersen. Cognitive analysis and the role of the intermediary in information retrieval. In R. Davies, editor, *Intelligent Information Systems*, pages 206-237. Horwood, Chichester, England, 1986.
[20] P. Ingwersen. *Information Retrieval Interaction*. Taylor Graham, London, 1992.
[21] H. Katsuno and A. O. Mendelzon. Propositional knowledge base revision and minimal change. *Artificial Intelligence*, 52:263-294, 1991.
[22] M. Lalmas and C. J. van Rijsbergen. Information calculus for information retrieval. *Journal of the American Society for Information Science*, 47(5):385-398, 1996.
[23] D. M. Mackay. What makes the question. *The Listener*, 63(5):789-790, 1960.
[24] M. Magennis. Expert rule-based query expansion. In *British Computer Society Information Retrieval Specialist Interest Group Colloquium*, Crewe, England, April 1995.
[25] H. R. Maturana and F. J. Varela. *The tree of knowledge*. Shambala, Boston and London, 1992. ISBN 0-87773-642-1.
[26] S. Mizzaro. TOBI - An Ontological Based Interpreter for Temporal Presuppositions and Counterfactuals. In R. Trappl, editor, *Cybernetics and Systems '94*, volume 2, pages 1879-1886, Singapore, 1994. World Scientific. Proceedings of the Twelfth European Meeting on Cybernetics and System Research, organized by the Austrian Society for Cybernetics Studies, held at the University of Vienna, Austria, 5-8 April 1994.
[27] S. Mizzaro. La conoscenza in intelligenza artificiale. In *Atti del Congresso Annuale AICA'95*, volume II, pages 1066-1073, 1995.
[28] S. Mizzaro. Le differenti relevance in information retrieval: una classificazione. In *Atti del Congresso Annuale AICA'95*, volume I, pages 361-368, 1995.
[29] S. Mizzaro. Recursive models: A computational tool for the semantics of temporal presuppositions and counterfactuals in natural language. Research Report UDMI/11/96/RR, University of Udine, Department of Mathematics and Computer Science, Via delle Scienze, 206 – Loc. Rizzi – Udine, Italy, 1996.
[30] S. Mizzaro. Relevance: The whole (hi)story. Research Report UDMI/12/96/RR, University of Udine, Department of Mathematics and Computer Science, Via delle Scienze, 206 – Loc. Rizzi – Udine, Italy, 1996. Submitted to 'Journal of the American Society for Information Science'.
[31] B. Nebel. Reasoning and Revision in Hybrid Representation Systems, volume 422 of *Lecture Notes in Artificial Intelligence*. Springer-Verlag, Berlin, 1990.
[32] N. J. Nilsson. Logic and artificial intelligence. *Artificial Intelligence*, 47:31-56, 1991.

[33] J. O'Connor. Some questions concerning "information need". *American Documentation*, 19(2):200-203, 1968.
[34] G. Salton. *Automatic Text Processing - The transformation, Analysis, and Retrieval of Information by Computer*. Addison-Wesley, Reading, MA, 1989.
[35] T. Saracevic. Relevance: A review of and a framework for the thinking on the notion in information science. *Journal of the American Society for Information Science*, 26(6):321343, 1975.
[36] L. Schamber, M. B. Eisenberg, and M. S. Nilan. A re-examination of relevance: Toward a dynamic, situational definition. *Information Processing & Management*, 26(6):755-776, 1990.
[37] C. E. Shannon and W. Weaver. *The Mathematical Theory of Communication*. University of Illinois Press, Urbana, 1949.
[38] J. F. Sowa, editor. *Principles of semantic networks*, San Mateo, CA, 1991. Morgan Kaufmann.
[39] R. S. Taylor. Question-negotiation and information seeking in libraries. *College and Research Libraries*, 29:178-194, 1968.