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Information Systems in Interdisciplinary Research: Analytic and Holistic Ways to Access Information Science Knowledge

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ABSTRACT

The paper explores how information science knowledge can be used systematically in digital, interdisciplinary research settings and gives a conceptual analysis of the relationship between information science knowledge as donor and other research as receiver in an interdisciplinary project environment. The validity of the approach is demonstrated by the author's work on the project "The Primacy of Tense: A. N. Prior Now and Then." The study proposes a hybrid approach, combining analysis and synthesis. The analytical component identifies information systems, assigns an information system type to them, and accesses the information science knowledge associated with that type. The synthetic part focuses on the connections between information systems according to the receiver discipline's practices. The paper makes explicit the actions of experienced information professionals, thereby making their expertise accessible to others. The analytical and synthetic strategies are explained by linking them to two modes of researchers in the receiver discipline, how they act as researchers and what they know about it. The paper offers information professionals concrete assistance with identification of the appropriate strategy for accessing professional knowledge and taking appropriate actions and development decisions.

Keywords: interdisciplinarity, project collaboration, information system, research communication, digital research environment, Arthur N. Prior

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1. INTRODUCTION

How can information science inform research communication and, in particular, the development of systems for research communication? This question arose from the author's engagement in a research project with which he is currently affiliated. The funded, Denmark-based research project "The Primacy of Tense: A. N. Prior Now and Then" (Prior Project Group, 2017) involves researchers interested in the New Zealand philosopher and logician Arthur Norman Prior, collaborating with information scientists affiliated with the Department of Information Studies, University of Copenhagen. The main tasks of the information science group, to which the author of this paper belongs, include development of Danish Prior websites associated with the project in order to enhance communication and collaboration between Prior researchers throughout the world, and to make Prior's unpublished manuscripts accessible in transcribed, digitised form. In 2017 the focus was on modernising the Danish Prior websites, accelerating the Prior Virtual Lab's production of transcribed manuscripts and making them more accessible via the Internet. The project group has reported elsewhere on some of the information science issues raised by the project (Engerer, Roued-Cunliffe, Albretsen, & Hasle, 2017; Engerer & Sabir, 2018) and more visions for the development of the digital Prior resources along information science lines can be found in Engerer and Albretsen (2017). This paper draws frequently on the author's practical work in the project to illustrate its main points.

Online research communication and collaboration (and their scientific study) are relatively recent phenomena and are strongly connected to the rise of the networked personal computer and the World Wide Web (Tredinnick, 2007). Internet-based systems for research communication include, for example, research portals (Becker et al., 2012), digital platforms for scientific collaboration ('collaboratories,' cf. Finholt, 2002; Olson et al., 2008) and, more recently, 'cyber-infrastructures' in e-science (Borgman, 2007; Elsayed, Madey, & Brezany, 2011). All of these types of system are well-researched interdisciplinary objects that are explored by researchers with very diverse research interests and theoretical backgrounds. For example, socio-constructivist learning theory and the concept of co-evolution from Luhmann's system theory have been combined in order to shed light on learning and knowledge building in online communities (Kimmerle, Cress, & Moskaliuk, 2012; Notari & Honegger, 2012) and complexity theory has been used to model research teams as complex systems interacting on several levels (Vasileiadou, 2012).

Thus from a science-sociological perspective, it does not seem surprising that applied and technological perspectives dominate research on communication and collaboration in research. Typical practical endeavours include research into taxonomies and types of research collaboration infrastructures (Bos et al., 2008), lists of success criteria for online collaboration (Olson et al., 2008), designs for evaluation procedures for collaboration projects (Ramage, 2010), and research into related issues such as ways of managing interdisciplinary digital communication and collaboration (Cummings & Kiesler, 2008). More technological issues are grid computing, big science, data mining and dataspace (Elsayed, Madey, & Brezany, 2011; Finholt, 2002), coding, standards and mark-up techniques (Eggert, 2009; Flanders, 2012), digital collaboration tools (Zaugg, West, Tateishi, & Randall, 2011), and others.

Sometimes it is somewhat unclear how the results of these various strands of research connect with each other and what consequences they have for a broader and more general perspective on digital research communication and collaboration; nevertheless this is a promising and exciting interdisciplinary field of real substance. Investigations into research communication can improve our understanding of how researchers interact with technology, with other researchers and the public, and with information—often all at the same time. The proposals presented in this paper concern work in an interdisciplinary project setting, in which the integration of information science knowledge into the development of digital research communication and collaboration systems plays a crucial role.

Some of the studies cited draw on specialised, sometimes fragmentary, theoretical frameworks, whereas others prefer more coherent, discipline-specific approaches to research communication and collaboration involving 'packages' of knowledge accrued by a discipline over the course of its history. Examples of this latter strategy include the use of a system of interconnected psychological concepts and theories such as 'impersonality' or 'being one's self' in a psychological analysis of blogging (Gurak & Antonijevic, 2012; for a more general account see Wallace, 2001) and a discussion of 'cyber-ethnography,' which redefines sociological inquiry and traditional ethnographic methodology (field work, participant observation, and text-as-data) for the new online environments (Robinson & Schulz, 2012).

It is not easy to find discipline-based studies of information science that deal specifically with research collaboration communication and research into it. It is true that much work in this field appeals to the importance and ubiquity of information, information behaviour, and other related informational concepts in relation to researchers' learning, collaboration, and research practices;[1] yet despite the numerous references to informational concepts, scholars only occasionally address information science knowledge directly.[2] This suggests a discrepancy between the widespread acceptance of the relevance of information science concepts to research communication and the application of disciplinary knowledge from the field of information science by those studying research communication.

This paper attempts to address this gap and so it presents some methodological and theoretical insights which should be useful both in research on scholarly collaboration and to those in the field of information science who are supporting the development of research collaborations. In a support setting information science is not expected to make a direct, disciplinary contribution to answering a project's research questions (hereinafter referred to as the 'domain,' 'domain research,' etc.). Instead, it contributes as a 'support discipline,' being used to explore and enhance the digital resources of a research project in another discipline, the domain. On the other hand, the 'constitutive' role of information science in interdisciplinary collaboration means that as a disciplinary field information science contributes to the project's research on the same footing as the other project disciplines (for example philosophy, history, or logic) (Engerer & Sabir, 2018). This paper is exclusively concerned with information science in a supporting role.

2. RELATING INFORMATION SCIENCE TO OTHER RESEARCH

To clarify how information science links up with other research in a project environment, in our case the 'logical/philosophical' component of the Prior project, information science knowledge is related to three aspects of domain research:

a) conceptual knowledge in the domain (e.g., logic, philosophy)
b) research activities in the domain (e.g., discussing a logical/philosophical argument, applying for funding) and
c) practical knowledge about these domain research activities (b) that is held by domain researchers (e.g., logicians, philosophers).

These three related aspects can be interpreted as distinct forms of domain knowledge, conceptual and practical (in the cases of [a] and [c]) (Krohn, 2010), and types of communicative and non-communicative activity carried out by a professional agent in an academic domain for intellectual or coordination purposes (in the case of [b]) (this distinction is explained in more detail below) (Erkens, Prangsma, & Jaspers, 2006). The semantic relationship between these two dimensions, information science and domain research, is one of 'transfer,' where the academic 'donor' is information science and the academic 'recipient' the research domain.

The first part of this section describes the three knowledge/activity components a)-c) in more detail. The second part discusses three ways in which information science can be related to each of the three aspects of domain knowledge/activity.

2.1. The Domain Knowledge/Activity Dimension

On the most basic level 'conceptual domain knowledge' (a) is internalised knowledge of a discipline's research objects (logical entities and concepts, philosophical arguments, proofs, etc.), as found in, for example, books, articles or other media from the domain (Goldsmith, Johnson, & Acton, 1991).

'Domain activities' (b) are the communicative and non-communicative acts ('doings,' cf. Schatzki, 1996) of logicians and philosophers within their domain. These activities can serve intellectual or coordinating functions. Where they serve an intellectual function they are directed at joint knowledge building (Cress & Kimmerle, 2008) and addressing the research questions of the domain or project, and are therefore closely related to conceptual domain-specific knowledge (a). The coordinating functions include all the practical, research-related questions in a domain that require communication, for example, project coordination, research dissemination, funding and cooperation over publishing projects, and organisation of meetings and conferences (Rolland & Potter, 2017). Coordinating labour is only indirectly linked to research questions and domain knowledge, and there is a clear hierarchy of research activities, with intellectual labour regarded as proper

[1] Informational concepts referred to in collaborative research include information needs, accessibility of information, and access points of collaboration platforms (Borgman, 2007, p. 2; Elsayed et al., 2011, p. 270), questions of content and mark-up in digital information and websites (Eggert, 2009, p. 75), the idea of information as a shared, accessible, and created commodity in knowledge collaboration (Kimmerle et al., 2012), the buzzword 'information overload' (Cummings & Kiesler, 2008, p. 113), digital libraries for research (Finholt, 2002, p. 79), and Borgman's notion of 'information infrastructure,' which emphasises the information/data dichotomy in relation to modern research collaborations (Borgman, 2007, ch. 3). Furthermore, references to the importance of tacit and presupposed knowledge in digital communication (Finholt, 2002, p. 96) and the conceptual value of distinguishing between 'information' and 'knowledge' when studying research communication (information is easier to mediate than knowledge) (Bos et al., 2008, p. 54) are often supported by citing information science theory.

[2] Cf. Hockey who emphasises the positive role that 'information specialists' (a kind of practising information scientist) play in collaborations with researchers on digital humanities projects, but does not directly refer to information science sources (Hockey, 2012, p. 87). An exception is Christine Borgman, who is exploring in great detail how information science concepts can be used to understand digital research communication and collaboration, a topic she treats in her book *Scholarship in the digital age* (Borgman, 2007).

research and coordinating labour as merely facilitative.

'Domain community knowledge' (c) highlights that a domain researcher is part of a disciplinary community of researchers, with a collective history, norms, quality standards, criteria for good arguments and good research, and academic motivational systems (Elsayed et al., 2011; Tompkins, Perry, & Lippincott, 1998). This set of norms, criteria, and standards guides researchers' activities in the domain (b), whether intellectual (e.g., discussion about a research paper) or coordinating (e.g., department meetings, discussing funding possibilities, etc.).

Domain-specific procedural knowledge typically consists of sequences of activities which 'make sense' (Dervin, Foreman-Wernet, & Lauterbach, 2003) in the context of the domain concerned. Thus, domain community knowledge determines the order in which tasks are executed and the nature of communicative activities in the context of the domain concerned. One example would be the structuring of processes a domain uses for information seeking (Case, 2012; Engerer & Gudiksen, 2016), from seeking a reference and accessing the full text document to checking its relevance to the researcher's interests, downloading the reference into the researcher's reference-managing program and relating it to other references therein, downloading the full-text document to a target destination with accepted ordering principles (for example a list in a Dropbox folder that is ordered alphabetically by author), and so on. This also demonstrates that not all activities in the domain are necessarily communicative; an activity such as downloading a document makes sense for the agent alone by virtue of being preceded by saving the corresponding reference (a prerequisite for subsequent citation) and succeeded by the naming of the document file according to the ordering principle of the researcher's private repository (to ensure it is easily retrievable) (Østerlund, Snyder, Sawyer, Sharma, & Willis, 2015). These three aspects of domain research are linked as Fig. 1.

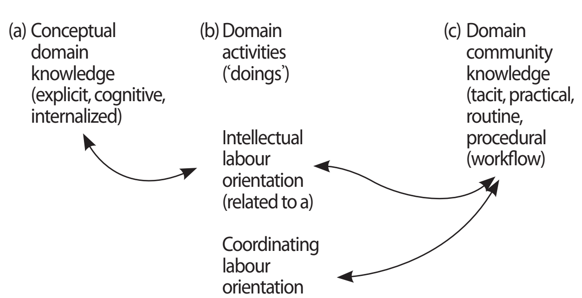

Fig. 1. Relationships between conceptual domain knowledge (a), activities in the domain (b), and a community's tacit, practical knowledge how to do things in the domain (c).

A community's tacit, practical domain knowledge (c) organises the activity within the domain (b) and structures activities having directly to do with the domain's disciplinary objects of knowledge (intellectual labour) and other more practical research-related communications (coordinating labour). At the same time, these communicative activities instantiate and externalise the tacit, procedural knowledge of the research community (c). There is also a two-way relationship between intellectual labour-related communication and cognitive knowledge-building (a). This connection highlights that research is not an isolated, individual process of cognitive knowledge-building, but, like all learning (Wenger, 1998), is a social and communicative activity as well.

2.2. Information Science Perspectives on the Domain

These three knowledge/activity aspects of researchers in a domain yield three distinct perspectives on information science knowledge and how it is brought into play in an interdisciplinary project where information science is the supporting discipline.

Perspective 1, which relates to conceptual domain knowledge (a), entails interdisciplinary interaction in which information science concepts such as 'information' and 'knowledge' are integrated into logical and philosophical reasoning and research (Floridi, 2011). Today interdisciplinarity is a research discipline in its own right (Frodeman, Klein, & Mitcham, 2010; Klein, 2010; Krohn, 2010) and it has already provided fruitful concepts and a theoretical background for the analysis of information science's relationships with other disciplines (for a study exploring the interdisciplinary relationships between information science and linguistics see Engerer, 2017b). As this paper is concerned with information science in a supportive, rather than constitutive, role in collaborations the interdisciplinarity perspective will not be discussed further.

Perspective 2 is connected with the activities in a domain (b) and relates information science knowledge to that domain's digitally mediated activities in a project context. From perspective 2, digital communication tools are typically conceptualised as information systems (Boell & Cecez-Kecmanovic, 2015; Urquhart, 2018), distinguished from other system components by their high degree of functional autonomy, input/output features, and knowledge-organising properties (Hjørland, 2003, 2008, 2013) and interactivity (Borlund, 2013; Kiousis, 2002; Ruthven & Kelly, 2011), as well as by their typically dichotomous functional structure. In this structure 'content' is linked to (or 'mediated by') an interpreting receiver, either a human user or a machine (Engerer, 2017a). Under perspective 2 information systems are often regarded as analytically closed systems which can be studied in isolation.

In the following section this line of thought is elaborated and illustrated by an analysis of the Prior website's information systems.

Under perspective 2 the concept of self-contained information systems relates to both intellectual and coordinating labour. Expertise for coordinating functions includes informing the development of project platforms, customising of wikis for information-sharing, integrating conference programmes into a researcher's work desk, embedding tools for announcing project activities into a project website, and developing and maintaining other information systems that directly or indirectly facilitate coordination of a project.

An intellectual labour orientation implies a focus on the knowledge aspect of digital information systems, which serve as media for domain researchers in their cognitive and joint knowledge-building. Information science has a much richer tradition of studying systems for intellectual labour rather than coordinating labour and emphasises that distributed and equal access to domain-relevant information resources and joint terminology are important to the sharing of domain knowledge. One of the characteristics of these systems is a special type of dichotomous functional structure, a nexus linking indexing/metadata and user queries. In the context of intellectual labour information systems deal with both the metadata and representational properties of items of information (Chowdhury, 2010, p. 1; Frohmann, 1990; Lancaster, 2003; Mai, 1999; Svenonius, 2000), typically documents and their retrieval (Baeza-Yates & Ribeiro-Neto, 2011; Pandey, 2003; Ruthven & Kelly, 2011; Warner, 2010). Examples of this kind of dichotomous information system are digital full text repositories, bibliographies, library catalogues, directories of domain-relevant sources, and other digital aids which help researchers to access the information they need directly.

Perspective 3 relates information science knowledge to another kind of knowledge, i.e. practical domain community knowledge (c) about the domain activities (both intellectual and coordinating) of logic and philosophy specialists (b). Practical knowledge of the type c) specifies how things are done in the domain, why they are done this way, and which digital tools are typically used (Wenger, 1998). The first step in connecting information science knowledge with a domain community's practical knowledge is to elicit and externalise tacit domain knowledge, and the second is to map it onto complexes of related information systems in the domain. Hence the question which information science knowledge can be drawn upon has a less straightforward answer than under perspective 2. It is not simply a matter of information systems typology. Faced with the task of eliciting tacit practical knowledge (Nonaka, Toyama, & Konno, 2000), information science can fall back on methods such as domain analysis (Hjørland, 2002), ontology building, user studies, and other qualitative, ethnomethodological techniques (Boaduo, 2011; Daniel, 2011; Pickard, 2013), which can be used to help establish the practical understanding that domain researchers have of their own and their peers' activities. From these approaches we will in the following paragraph elaborate in more detail on domain analysis and ontologies.

As highlighted above, a perspective 3 approach to designing, evaluating, and improving scholarly digital resources builds basically on a correspondence of research community features on the one hand and the structure and design of the information systems used in that community on the other. The more general postulate of a close relationship between user features (e.g., linguistic, social, situational, professional) and the structural makeup of the knowledge systems for these users is in information scientific terms described by the notion of the "domain" (here used in a somewhat narrower sense than in the remainder of this article). A domain from an information science view captures the dependency between knowledge of a specific subject field (such as time logic) and skills in managing and organizing the information resources specifically of that field (such as the Prior Internet Resources [PIR]). Domain analysis takes the view that managing information resources and information systems (databases and websites) in a specific field demands knowledge of this field including its traditions, terminologies, norms, and practices (Albrechtsen, 2015; Bawden & Robinson, 2012; Hjørland, 2002, 2017; López-Huertas, 2015; Robinson, 2009; Tennis, 2003). Birger Hjørland devised a rude but useful and pragmatic methodology (better: systematics) for producing domain-specific knowledge necessary for information scientists in solving their tasks. This methodology includes approaches such as subject gateways, specialist classifications and thesauri, disciplinary peculiars of indexing and retrieving practices, user studies, bibliometrical studies, document and genre studies, terminological studies, historical studies, and more (Hjørland, 2002). Domain-analysis is a practical approach and thus appears as a good starting point for information specialists to systematically collect knowledge about the practices, modes of information seeking, language and communication conventions, and the more in the domains of other disciplines.

A further refinement from a perspective 3 standpoint is ontologies. The information scientific concept of an ontology encompasses the sphere of indexing terms and related search terminology at the same time, and therefore regards index terms as closely linked to (if not identical with) the vocabulary used by specialists in their domain. The step from traditional thesauri and classification schemes to ontologies of knowledge domains demarcates not only the integration of semantic web principles into the description of data (Berners-Lee, Hendler, & Lassila, 2001), but is foremost a move from barely developing a search terminology towards a controlled language for knowledge representation (Engerer et al., 2017). This step from the lexical-terminological component to a whole language with a built-in logic, a syntax, and inference rules makes it possible to derive information which is not explicitly contained in the descriptive terms themselves (Antoniou, Groth, van Harmelen, & Hoekstra, 2012, p. 4). Knowledge is therefore no longer just named, as it is the case in traditional controlled vocabularies, but it can be described and "confirmed" via ontology languages through constructing sentence-like complex formulas operating with linguistically-informed components such as subjects, verbs (relations), and objects.

Ontologies reflect a common understanding of a domain (Antoniou et al., 2012, p. 11) by expanding the restricted repertoire of thesaural relations between terms (e.g., broader/narrower terms, related terms) to an unrestricted range of semantic relationships realized and acknowledged in the domain idiom. Ontologies must therefore be constructed for each specific domain in order to reflect the language use practiced in the domain in question (Stuart, 2015). Generally, an ontology models the expert user's view on information in his/her domain. More practically, in the case of PIR, the information scientist collects terms, their definitions, and mutual semantic relationships and builds a formal vocabulary system, including syntactical and inference rules. The advantages of ontologies for specialist users are, among others, improved possibilities for exploring data, "semantic search" (King & Reinold, 2008, p. 22), enhanced serendipity, and optimized search results by using ontology-based search techniques including Natural Language Processing (King & Reinold, 2008, p. 12).

Not unlike domain analysis, a complete methodology is linked to the creation of ontologies in specific domains, including steps such as collecting the vocabulary, defining and classifying the vocabulary terms, and indicating the semantic relationships between the established classes (King & Reinold, 2008, ch. 3; Stuart, 2015). Building an ontology is therefore in a way similar to doing a domain analysis as described in Hjørland (2002); both methodologies aim at transferring expert knowledge, often in tacit form, into the realm of explicit knowledge organization, and both respect the linguistic form of this knowledge when modeling it in a knowledge system. Domain analysis and the development of expert ontologies can therefore be regarded as two sides of the same coin, though ontology building is a more specialized activity and part of the broader theoretical endeavors and coverage of domain analysis. The three perspectives are mapped to their respective domain categories a) to c) in Fig. 2.

The illustration highlights two opposite, yet complementary and necessary strands of the process of bringing information science knowledge together with research in other domains (marked with grey). Setting the interdisciplinary perspective (1) aside, we can see that perspective 2 takes an analytical, isolationist approach to information systems, viewing them as self-contained units that are studied by information science in a rather straightforward way, in particular with respect to information systems for intellectual labour. In contrast perspective 3 takes a synthesising, holistic, and integrative approach to information systems, prompted by the tacit, procedural nature of domain communities' knowledge, which

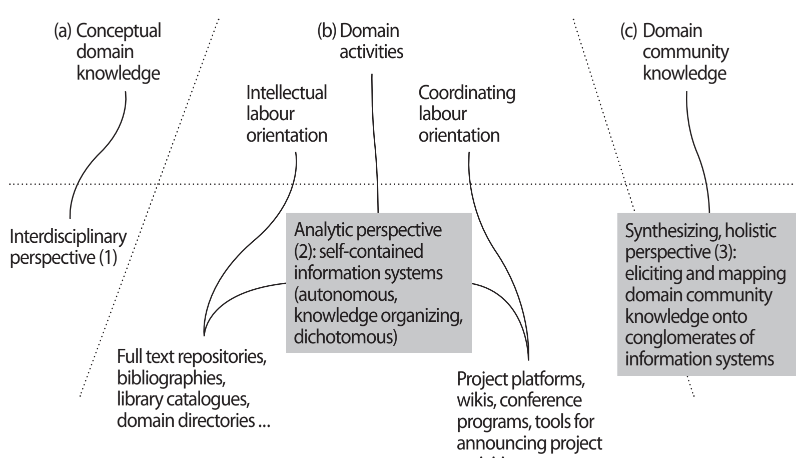

Fig. 2. Three information science perspectives assigned to three knowledge/activity modes of domain researchers.

means that existing practices and workflows must be reflected in the interplay between different information systems (Nicolini, 2013).

Below these two perspectives on information systems, the analytic-isolationist and the synthesising-holistic, are elaborated. It is demonstrated that information scientists need to use both approaches in order to access relevant professional knowledge and respond to domain researchers' two essential ways of constructing their disciplinary domain, namely in terms of what they do (b) and what they know ([a] and [c]).

3. AN ANALYTICAL APPROACH TO INFORMATION SYSTEMS

How is information science knowledge accessed when working with digital research resources? To address this question it is necessary to identify the proper objects for information scientific analysis. The task is, in general terms, to move from functionally unspecified, barely formal organisation units (Internet domains, websites, etc.) (Borgman, 2007) to functionally specialised information systems, which are the appropriate objects of study from an information science point of view (Urquhart, 2018). Once identified these information systems are categorised by type and this typing then serves as a pointer to the disciplinary knowledge that information science has accrued on each. The knowledge associated with each information system type guides analysis of the information system in question and in consequence interventions, improvements in functionality, and other development initiatives can be undertaken in a controlled manner, based on information science analysis.

As one reviewer rightly noted, the dynamic, spatial jargon used here ('move from X to Y') and the arrows in Fig. 3 are based on metaphors with another, grounding concept behind it. In fact, there are four. Firstly the 'moving' metaphor can target the ontology of the information specialist's professional 'world' where he/she starts with given websites, puts focus on the information components in it, names the relevant disciplinary knowledge areas, and accesses them. The 'moving' metaphor is here grounded in a certain chronological concept of professional workflow. Secondly, moving from left to right in the topology represented in Fig. 3 can mean adding accumulatively specificity to digital objects (from websites in general to partial systems with information functions), and cognitive objects (from generic representations of our knowledge of these systems to the knowledge itself). Thirdly, the path from left to right, and, thus, the movement along this path, can be connected and directed by semantic relations represented as arrows in Fig. 3. The arrow from website to information systems connects the two domains by the is-part-of /include relation; knowledge type and knowledge concepts are related by a semiotic reference function, where the type represents, or is a pointer for an information science concept. The transgression from information system to type is more intricate (see the arrow in the middle), as it demarcates the line between two very different spheres, the digital and the cognitive. The assignment of a cognitive knowledge type to a given digital information system is obviously a matter of experience and expertise of practising information specialists; in this sense the assignment of a knowledge representing term to a given information system by an information specialist presupposes an analysis of the latter. Fourthly the outer left and right components in Fig. 3, formal organization and conceptual domain knowledge, can be interpreted as the two sides of the semiotic sign, form and meaning. Accordingly, the movement from formal organization to conceptual knowledge can be interpreted as the systematic assignment of cognitive meanings to formal digital structure. To sum up, moving from left to right can then mean following a workflow, becoming more specific, navigating along semantic relations, or getting closer to the meaning of a digital object. The 'moving' metaphor itself, as used here, is ambiguous with respect to these options.

The first part of this section discusses the theoretical aspects of moving from websites to information systems, and thence to subtypes and the corresponding information science knowledge. The second part illustrates these moves with examples from the PIR. The third part analyses the information systems embedded in the PIR using the theoretical framework set out here.

3.1. From Websites to Domain Knowledge

The path from websites to knowledge via information systems and knowledge types is illustrated in Fig. 3. Below the individual steps are justified and discussed in greater detail.

Inspecting the illustration from left to right we can see that the relationships between formal websites and information systems are not necessarily one-to-one; an information system (in this example information system 3) can formally be distributed over two or more web domains (indicated by a circle overlapping with two websites) and, perhaps trivially, one website can contain more than one information system, as it is the case with website 1, in which information systems 1 and 2 are embedded. The relationships between websites and information systems connect the digital, formal organisational level with the information systems level, marking the transition from a rather non-specific domain of communication to a functionally more

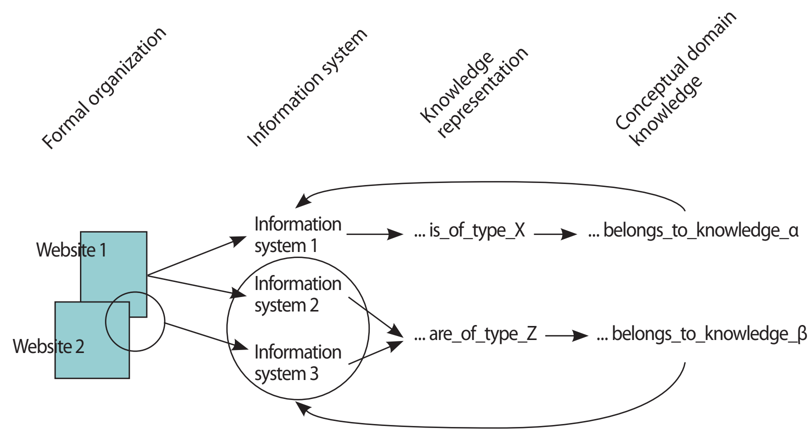

Fig. 3. From websites to information systems, to types of information systems, to type-specific knowledge, and back to the information system.

specific domain, in our case the informational domain.

Looking further to the right of the illustration we reach the knowledge representation level (Blair, 1990; Stock & Stock, 2013), where the type of information system is specified. Again, a non-unique relationship connects knowledge types with information systems. One information system can be related to just one type of knowledge (in this example information system 1 is connected only with knowledge type X), or two information systems (here, 2 and 3) may be instantiations of the same knowledge type (here, type Z). Note that under perspective 2 the knowledge types (and hence also the domain knowledge) are assigned to the information systems regardless of 1) how many instantiations they possess on the level of information systems and 2) their formal organisational properties, which is the level at which the context of these systems is determined (in other words, the context in which an information system is embedded is irrelevant to the assignment of knowledge types). Clearly, therefore, perspective 2 is unsatisfactory, and perspective 3, which is complementary, compensates for this, as shown below.

Moving from information systems to knowledge representations is a step towards domain specialisation. This specialisation is achieved by mapping non-specific information systems onto an information scientific nomenclature for domain terms. This acknowledgement of the disciplinary terminology of a knowledge-organising system (Temmerman, 2000), not unlike a thesaurus system (Broughton, 2006; Foskett, 1994; Lykke Nielsen, 2001), is the key to the conceptual domain-specific knowledge.

The right side of Fig. 3 shows the linking of conceptual domain-specific knowledge (more commonly termed 'expert knowledge' or 'expertise') and information system types. Relationships between knowledge-type terms and the knowledge system itself are also not unambiguous (although this is not indicated in the illustration). In practice an information system type can map to more than one knowledge system or concept; similarly, two or more different information system types can relate to the same kind of knowledge system or concept. Theories of knowledge organisation treat these relationships as ambiguous descriptor terms in a thesaurus system (our knowledge types) with several, often incompatible 'meanings,' 'definitions,' 'referents,' 'semantics,' etc. (our conceptual domain-specific knowledge). In traditional information organisation, ambiguities like the ones mentioned above are treated as mismatches and undesirable drawbacks (Svenonius, 2000). In our very different context we might simply conclude that the information professional faces the challenge of identifying the most appropriate domain knowledge for the information system type under inquiry.

Once the relevant information science knowledge is identified, it must be projected into the realm of information systems where it guides analysis and, eventually, prompts interventions. In our illustration, the transfer of partial information science knowledge into information systems is indicated by backwards arrows.

3.2. Illustration of Moves Using the PIR

In this section the abstract moves presented in the previous section are illustrated using cases taken from the PIR. The numbers 1-6 designate the six information systems in the PIR, as illustrated in Fig. 4. Methodologically, the identification of information systems (3.2.1) differs from the identification of knowledge types (3.2.2) and conceptual knowledge (3.2.3). While the status of an information system is mainly a matter of design affordances, web site architecture and, most importantly, the way user practices apply to these affordances, the identification of knowledge types and concepts in relation to these systems is guided by disciplinary, information science meta knowledge regarding how to assign a knowledge type to an existing information system and connect this type with the relevant knowledge domains of the discipline. Thus, on the one hand, whether a website facility functions as an information system or not is to a high degree dependent on the user practices, here the uses that time logicians (logicians working on time as a philosophical subject), philosophers, historians, and more make of a website. On the other hand, assigning information science knowledge types to digital systems and accessing the corresponding information science concepts is solely based on information science practice and method.

We can therefore methodologically ground the move from websites to information systems (3.2.1) by addressing design features, website architecture characteristics, and the information practices of the website's user group. Decisions concerning types and concepts (3.2.2 and 3.2.3), however, must methodologically be based on information science practice, i.e. the ways how information specialists draw on their professional knowledge in developing information systems. With regard to the former, knowledge from interaction design (for example, Preece, Sharp, & Rogers, 2015) and information architecture (for instance, Ding, Lin, Zarro, & Marchionini, 2017) is coupled with informal assessments of the website and its information systems by members of the domain group (collected in informal conversations). With regard to the latter case, in which information professionals access the relevant disciplinary knowledge they need to apply to a digital system, only introspective reflection into their own professional practices reveals their competencies and practical skills. These reflections have been discussed in the information science group of the project and have been discussed by the information science group in several publications (Engerer et al., 2017; Engerer & Albretsen, 2017; Engerer & Sabir, 2018). What we do here, in a nutshell, is to make explicit *a posteriori* our own tacit model of accessing and applying information science disciplinary knowledge in our concrete practice of website development. In this sense, other researchers may arrive at other 'models' in their own practice, but it is finally this awareness and explicitness that is the basis for development and improvement in professional environments.

3.2.1. From Websites to Information Systems

As stated above, one information system can be distributed over two or more web domains and vice versa, i.e. one website

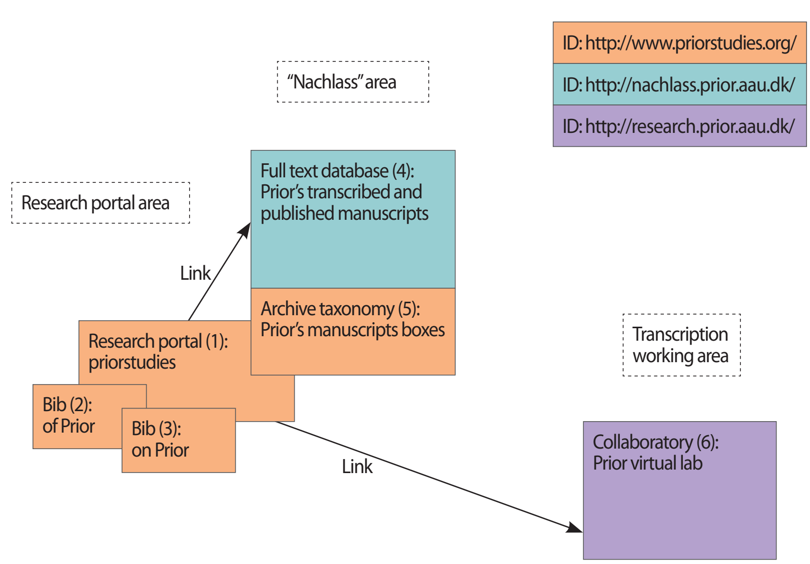

Fig. 4. General structure of Prior Internet Resources (as of summer 2017): six information systems representing five distinct information system types, implemented on three Internet domains functioning in three areas.

can contain more than one information system. An example of the latter situation is the Prior Studies website,[3] which embeds two bibliographies (Of Prior, On Prior, no. 2 and 3) and also contains the archive taxonomy as a functional part of the Nachlass area (no. 5). An interesting illustration of the former situation is the complex Nachlass area (depicted in Fig. 4), which covers handwritten material by Prior from the Bodleian Library archives and is, as seen from perspective 3 and through the lens of the research community's practices, one information system unit. From perspective 2 however, it encompasses three information systems: the archive taxonomy (no. 5, a classificatory entrance to the material), the full text database containing manuscripts which have already been transcribed and published (no. 4), and the Prior Virtual Lab (no. 6), which contains photographic images of unpublished handwritten material. All three systems are distributed over three different Internet domains and embedded in completely different websites and contexts. This makes it difficult for users to recognise the Nachlass area's functional coherence.

There is an obvious discrepancy between larger, functional units such as the Nachlass area and the rather isolationist construct of the information systems that constitute them. The latter focuses on single information systems and their input and output characteristics, whereas the former highlights the interplay between the systems and how, collectively, they serve the research practices of the users.

3.2.2. From Information Systems to Knowledge Types

The relationship between information systems and knowledge types is also variable. One information system can be related to one knowledge type and two information systems can instantiate a single knowledge type. An example of the former, straightforward case is provided by the full-text repository of transcribed and published Prior manuscripts (no. 4), which can be classed unequivocally as a full-text database. One example of the latter case would be two information systems Of Prior and On Prior (no. 2 and 3), which are lists of Prior's writings and secondary literature which has Prior as its subject. Clearly, in the light of our subjective, introspective methodology, one can express doubt about the status of the two bibliographies. Could users, as one reviewer asked, not conceptualize these as one composite information system or maybe not even consider them separate at all? In our conversations with Prior scholars, however, we realized that access to the original writings by Arthur Prior was very differently conceptualized and had very different status for the project participants than access to secondary literature about Prior. This has, among other things, to do with a speciality in the project research practices, namely regarding Prior's writings as, in a sense, primary objects of research and interpretation *per se*, while research and interpretation is documented in 'secondary' publications. We also want to mention the pivotal role of Arthur Prior as a person in general for the project. Thus, in spite of these user-related, practice-based distinctions between Of Prior and On Prior, these two information systems are of the same information science knowledge type, namely bibliography.

3.2.3. From Knowledge Types to Conceptual Knowledge

As already noted, one information system type can correspond to more than one knowledge system or concept as, for example, in the case of the Prior Virtual Lab (no. 6), where the information system type 'collaboratory' (Bos et al., 2008; Finholt, 2002) points at several complementary theories or approaches, depending on whether the focus is on transcription labour, communication, and knowledge sharing among the participants or the organisation and availability of the photographed manuscripts. On the other hand, two or more different information system types can be related to the same kind of knowledge system or concept. This kind of ambiguity is illustrated by the information system types bibliography (no. 2 and 3), full-text database (no. 4), and archive taxonomy (no. 5), which all draw on concepts such as metadata (Hider, 2012), indexing categories (Lancaster, 2003; Weinberg, 2009), classification (Batley, 2005), and taxonomic principles (Bawden & Robinson, 2012).

3.3. Information Systems in the PIR

The analytic approach will now be illustrated using the PIR, which comprise the Internet resources on Arthur Prior that are associated with the Prior project. The term PIR encompasses both formal digital elements such as websites, knowledge-organising units such as bibliographies, and other information systems, which will be presented in further detail below. The overall structure of the PIR, depicted in Fig. 4, consists of three main components, i.e. 'content areas' (these do not strictly coincide with particular Internet domains). 'Foundations of Temporal Logic—The WWW-site for Prior-studies' (Hasle & Øhrstrøm, 2016), hereafter 'Priorstudies,' is the main entry point (research portal) for scholars interested in Arthur Prior's work and life. The related 'Virtual Lab for Prior Studies'

[3] The Danish Prior Internet representation has been revised several times in the years 2018/19, and the result of this development process can be accessed under http://www.priorstudies.org. Our own analysis refers to the website as it was before these improvements (which are connected with the work done by the author) until 2017. This 'historical' website can be accessed through http://web.archive.org/web/20070609124540/http://www.kommunikation.aau.dk/prior/index2.htm, which is an archived version.

(Albretsen, 2016), hereafter Prior Virtual Lab (PVL), is the virtual platform used by researchers transcribing handwritten documents by Prior. Finally, we have the so-called 'Nachlass,' a full-text archive of transcribed and published Prior manuscripts (Nachlass area). As already mentioned, our analysis refers to the Prior sites as they were until 2017, not taking into account subsequent changes and design modifications. This older version is accessible and archived at http://web.archive.org/web/20070609124540/http://www.kommunikation.aau.dk/prior/index2.htm.

As indicated in the preceding section, the information systems have to be identified first. The term 'information system,' which has its roots in the world of management and business (Burton Swanson, 2009), refers by default to IT-based support to enable organisations to accomplish specific tasks (cf. Wallace, 2015), but definitions and conceptions of information systems vary considerably according to whether the perspective is technological, social, sociotechnical, or process-oriented, as a thorough review of information systems' definitions (Boell & Cecez-Kecmanovic, 2015) demonstrated. Perhaps the broadest definition of an information system—but still meaningful in the context of this paper—is the one that comes from Wikipedia; it is widely cited in textbooks (for example, Bourgeois, 2014) and on conference websites (in the Wikipedia article itself no references are given). According to this definition "[a]n information system […] is an organised system for the collection, organisation, storage and communication of information. More specifically, it is the study of complementary networks that people and organisations use to collect, filter, process, create and distribute data." (Wikipedia, 21 April 2017, https://en.wikipedia.org/wiki/Information_system, link marking and bold type removed).

This broad definition of information systems is practical and allows the approximate identification of six information systems embedded in the PIR.[4] Each information system in the PIR has been glossed in the list below with the specific information-related action associated with it, taken from the definition above:

1) 'Foundations of Temporal Logic—The WWW-site for Prior-studies': e.g., communication of information
2) Works written by Prior, primary literature: e.g., collection, organisation of information
3) Works written on Prior, secondary literature: same as 2)
4) 'Nachlass' (full-text): e.g., organised system for the collection, organisation, storage and communication of information
5) 'Nachlass' in the archive boxes: e.g., organisation of information
6) Prior Virtual Lab: e.g. complementary networks that people and organisations use to collect, filter, process, create and distribute data

In information science, information systems are of several types—most prominently documentary languages implemented in knowledge organisation systems such as classification systems, thesauri, and ontologies (Hjørland, 2003, 2013; Stock & Stock, 2013, sect. L); information services such as bibliographies, retrievable databases, and text repositories; and, last but not least, research portals and collaborative academic platforms in general. In order to identify the information science knowledge relevant to the six PIR-embedded information systems, these systems have to be mapped onto specific types of information systems, such as the ones mentioned. The goal of this exercise is to enable systematic access to relevant and useful scientific disciplinary knowledge, which improves our understanding of the PIR and can be a starting point for professionals seeking to develop and improve the existing digital resources.

The PIR, defined as the virtual space delimited by the three abovementioned content areas and Internet domains (Priorstudies, PVL, and Nachlass), contains, on first inspection,[5] six information systems of five distinct types. All information systems types are well-known and acknowledged in the information science research tradition, and disciplinary knowledge relevant to each type is readily accessible:

- Information system 1: 'Foundations of Temporal Logic—The WWW-site for Prior-studies' (part of the Priorstudies Internet domain); type: research portal; exemplary domain knowledge (Becker et al., 2012; Elsayed et al., 2011)
- Information system 2: 'Of Prior,' works written by Prior, primary literature (part of the Priorstudies Internet

[4] It has to be emphasised that the Wikipedia definition is by no means sufficient as an operational definition, nor does it really explain what information systems are. Clearly, there is much heuristic supposition involved in the identifications given above, but if these six objects can be mapped onto significant information systems types and thus be meaningfully and instructively linked to information science knowledge they should provide a better understanding of these systems and thus provide practical confirmation of the plausibility of the initial decisions.

[5] Again, it has to be emphasised that there is a great deal of heuristic assumption involved in specifying the types of knowledge systems that exist in the information science domain and how they can be recognised in a variety of instantiations of digital information systems. The same can be said about the assignment of information science concepts to information system types. Clearly, professional background, professional experience, and theoretical inclinations play a crucial role in determining the theories and works an information scientist draws upon when he/she describes a specific type of information system.

domain); type: bibliographical database; exemplary domain knowledge (Chowdhury, 2010, p. 17; Hider, 2012)
- Information system 3: 'On Prior,' works on Prior, secondary literature (part of the Priorstudies Internet domain); type and exemplary domain knowledge is the same as in information system 2
- Information system 4: 'Nachlass' in its narrow meaning (Nachlass Internet domain); type: full-text database, text repository; exemplary domain knowledge (Borgman, 2007; Eggert, 2009; Lin, Fan, & Zhang, 2009; Littlejohn, 2005)
- Information system 5: 'Nachlass' in the archive boxes (part of the Priorstudies Internet domain); type: taxonomic entry for archival metadata; exemplary domain knowledge (Batley, 2005; Bawden & Robinson, 2012; Broughton, 2006; Millar, 2017; Thomas, Fowler, & Johnson, 2017)
- Information system 6: Prior Virtual Lab (Prior Virtual Lab Internet domain); type: collaboratory, research platform; exemplary domain knowledge (Becker et al., 2012; Bos et al., 2008; Elsayed et al., 2011; Finholt, 2002)

At the 2017 stage of the Prior project the digital information structure of the PIR consists of four theoretical levels: formal organisation (three Internet domains), information systems (six partial systems), knowledge representation (five information science subtypes), and conceptual domain-specific knowledge (five partial knowledge domains, corresponding to five information science subtypes). At the time of writing a complete restructuring of the website is in progress; some preliminary results are presented in Engerer and Albretsen (2017). Fig. 4 sketches the general structure of PIR in summer 2017.

4. A SYNTHETIC APPROACH TO INFORMATION SYSTEMS: THE 'TRANSCRIBER LOOP'

In this final section the perspective 3 standpoint is explored further (although rather informally and in less detail than for perspective 2). This discussion 'corrects' the flaws of the analytical view of information systems and emphasises the fact that such systems are always part of a larger system which must support existing practices and workflow in the domain (Nicolini, 2013).

From the perspective of domain users there are substantial functional connections between the three information systems making up the PIR as constituted at the time of writing. The dynamics of the relationship between the archive taxonomy (no. 5, Prior's archive boxes), the PVL (no. 6), and the Nachlass full-text database (no. 4, transcribed and published manuscripts by Prior) is crucial to the work of the PVL (a collaboratory, no. 6), i.e., transcribing, digitising, and making accessible via the Internet as many unpublished manuscripts by Prior as possible. The role of the box taxonomy from the Nachlass section is particularly important, as it is the only point of departure for Prior scholars seeking to match topics in the original handwritten material with their own research questions and research interests.

It is important to note that at that point of their inquiry researchers do not have the opportunity to verify documents' relevance by consulting an electronic copy of the original paper in the archive (Blair & Kimbrough, 2002). They only have access to documents' metadata, their representations, which the researcher has to treat as reliable surrogates for the original document. A preliminary match should give a scholar an incentive to sign up to use the PVL, request a copy, and then determine whether the text is worth transcribing. In other words, if Prior scholars cannot reliably ascertain whether the archive boxes contain documents relevant to their research questions, it is highly unlikely that they will register to use the PVL.

The box taxonomy must therefore be viewed as the hub of the transcription project. It is where the researcher initiates a document cycle, the starting point of which is an attempt to identify a document that is suitable for transcription; should the attempt be successful the document is transcribed and eventually returns to the Nachlass as a full-text, searchable electronic document, provided with a fully-fledged set of metadata. This dynamics of the relationship between information systems, under one system umbrella, and domain user properties is illustrated below in Fig. 5, which shows the pathways of researchers and manuscripts/documents between the three information systems schematically, in the form of a loop, the researcher-to-document loop or, more succinctly, the transcriber loop.

In the initial phase of the manuscript cycle, the 'manuscript-born' index fields, which have been derived from a specialist archiver's descriptions, act as a kind of 'beginner set,' attached to the handwritten text. They are extraordinarily valuable access points (Hjørland, 1998; Lancaster, 2003, p. 6) for advanced specialist searches. As the illustration shows, the researcher then assumes the role of a transcriber. In this transition the initial archiver's metadata accompany the manuscript. In this stage the researcher not only carries out the transcription, but also enriches the manuscript metadata from the archive with information drawn from his/her expert knowledge and

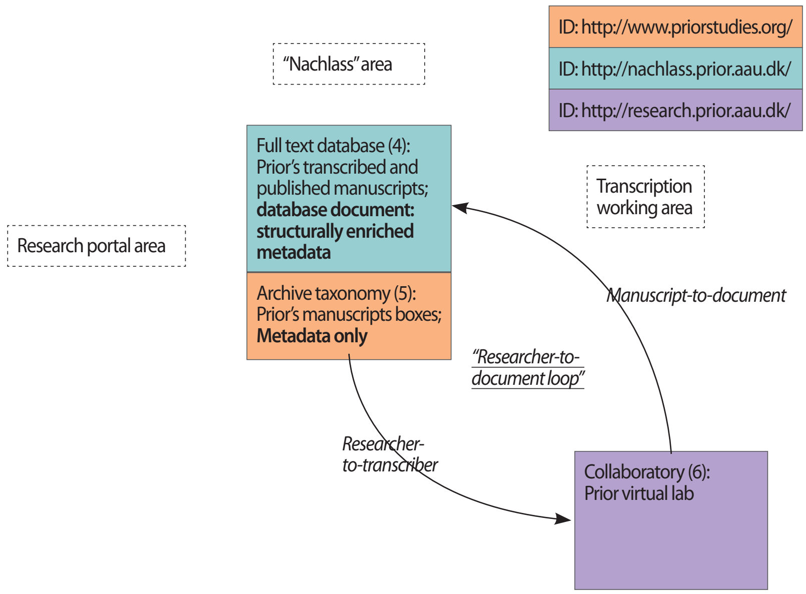

Fig. 5. The researcher-to-document loop connecting three information systems in the Prior Internet Resources.

textual or contextual knowledge arising from his/her deep intellectual engagement with the content of the manuscript during the transcription process. This is an important aspect of the manuscript-to-document process, indicated by the arrow from the PVL to the Nachlass full-text database. The sequential aggregation of metadata, as shown here, is a typical case of 'enrichment via information-added values,' whereby texts are formally described and indexed for content, resulting in fully-fledged surrogates, sometimes called 'documentary units' (Stock & Stock, 2013, p. 69).

The last step of the manuscript-to-document process is the formal adaptation of the documentary units to a database environment, a formally organised collection of surrogates which can be searched, retrieved, and explored. This makes them what often is called a 'record.' From this information science perspective, the manuscript-to-document arrow signifies a text's change of status from a more or less unstructured and informal piece of text to a standardised record in a formal, machine-readable, and searchable database in the full-text Nachlass. Processes such as these can only be understood when an account of the interactions of information systems, linked to profound knowledge of the domain group's practices and motivational factors, supplements the analytical approach to information systems as illustrated in the previous sections.

5. CONCLUSION

This paper explores how information science knowledge can contribute to research collaborations in which information scientists support colleagues from another discipline. Information science comes into contact with domain research in three forms: knowledge of the domain (conceptual knowledge), intellectual and coordinating functions (activities in the domain), and knowledge of how things are done in the domain and why (practical knowledge). These three forms engender three perspectives on information science knowledge: 1) the interdisciplinary view (not covered in this paper), 2) an analytical and isolationist perspective on information systems, and 3) a synthetic and holistic perspective, which sees information systems as interacting units responding to practices in the domain. From perspective 2, information science knowledge is accessed in three moves: from websites to information systems, from information systems to information system types, and finally from information system types to knowledge systems which can be used to develop the information systems in question. These moves have been illustrated through an analysis of the PIR. The synthetic perspective is exemplified by the transcriber loop, in which researchers move across three information systems, the box taxonomy, the PVL, and the full-text Nachlass, in order to execute a complex task, namely transcribing and commenting on a photographic image from the collection of handwritten manuscripts by Prior.

The paper makes the point that, in order to access the knowledge they need when working with information systems, it is important for information professionals to understand whether they react to activities in the domain (perspective 2) or to tacit knowledge of these activities, for example the structure and motivation of workflows (perspective 3). In the first case the path to professional knowledge is straightforward and flows from information system to information system type to information science knowledge. In the latter case an intermediate step, eliciting domain researchers' practical knowledge of their workflows, is required; this knowledge can then be mapped onto a more complex structure of interdependent information systems.

There are, therefore, two intended audiences for this paper. The first consists broadly of information professionals, i.e. research librarians, information specialists working with information systems in domain-specific settings, and computer scientists. The paper offers this audience concrete help in identifying the appropriate strategy for handling professional knowledge in order to take appropriate actions and development decisions. Defining one's own position towards researchers' doings and knowings in the domain makes it easier to determine what support one should offer. It helps to clarify an originally vague and ambiguous situation.

The paper's other target audience is senior researchers writing research proposals and principle investigators already engaged in research project management, including decisions about resource allocation. The paper provides this audience with criteria for describing precisely the nature of a digital project's resources, according to whether the priority is development of project-specific information and communication systems (perspective 2) or the mapping of larger tasks, such as manuscript transcription, onto conglomerates of digital systems (perspective 3). Knowledge of the distinctions presented here will support deliberate and selective allocation of project resources and could inform the decision about which types of information professional should be recruited to assist with the project. Such knowledge should help to define shared expectations and make collaboration smoother and more effective.

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