Some Methodological Issues for Intelligent Information Systems

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Abstract. The paper discusses some methodological issues concerned with information systems, especially intelligent information systems (for short: IIS) such as arise in various areas of artificial intelligence and computer science. To make the discussion as broad as possible we consider not only software engineering issues but also more theoretical aspects of system modelling. The main thesis we defend is that to develop adequate methodological tools for IIS, we need to consider the many and possibly varied contexts in which some piece of R&D may be embedded. We look in particular at contexts related to three areas: philosophy, science and technology. We argue that each of these areas may provide useful tools for the methodology of IIS, including instruments for analysing and evaluating success and progress.

1 Introduction

This paper deals with the question to what extent models and instruments drawn from philosophy of science, philosophy of technology, economics, or other fields may be of use in developing a methodology or methodologies for information systems. We shall consider in particular what one might term intelligent information systems, for short: IIS, of the kind that arise in many areas of computer science and artificial intelligence. And, to keep the discussion as broad as possible, we shall not limit ourselves to software engineering issues only but also consider the more theoretical aspects of system modelling. We are therefore adopting a somewhat wider view of information system than is typically found in discussions of the foundations of IS, where one is often concerned with IT systems as they arise in business and industry. The main thesis we want to defend is that to develop adequate methodological tools for IIS, we need to consider the many and possibly varied contexts in which some piece of R&D may be embedded. We look in particular at contexts related to three types of area: philosophy, science and technology. We argue that each of these areas may provide useful tools for the methodology of IIS, including instruments for analysing and evaluating success and progress.
2 Philosophy and the Social Theory of Information Systems

Much of mainstream work in information systems (IS) conceives IS largely in terms of IT systems as applied in the everyday workplace in business and industry.\(^1\) As a consequence the theory of IS is often regarded as belonging to management science, and the social character of IS is highlighted above all others. It follows from this view that the kind of philosophy that can and should be applied in the foundations of IS is social philosophy and, so far as IS can be regarded as a science, it is a branch of social science. This kind of view is well represented by Rudy Hirschheim [8]:

> It is my contention that IS epistemology draws heavily from the social sciences because information systems are, fundamentally, social rather than technical systems. Thus, the scientific paradigm adopted by the natural sciences is appropriate to information systems only insofar as it is appropriate for the social sciences.

In fact Hirschheim goes on to argue against the view that the natural and social sciences have the same aims and methods. His position is accordingly that of antinaturalism, a view found in writers such as Dilthey, Winch, von Wright and many others.

A similar picture can be found in a recent collection of papers [14] devoted to philosophy and IS. The focus is on social theory and social philosophy, and special emphasis is placed on the antipositivist, antinaturalist tradition, including phenomenology and hermeneutics as developed by writers such as Husserl, Adorno and Habermas.

The above conception of IS in terms of applied IT systems places the main emphasis of IS methodology on tools and methods for system development. Iivari, Hirschheim and Klein [9] propose a framework for classifying what they call information system design methodologies, or ISDMs. Their framework identifies no fewer than 11 IS design approaches and 16 different ISDMs. Their classification scheme distinguishes between functionalist and non-functionalist approaches and provides an interesting picture of the IS landscape that is particularly relevant for system developers and management scientists. However, even among the six so-called functional approaches to IS design only two might be said to involve cognitive standards such as truth or correctness of modelling a certain domain.\(^2\)

If we adopt a somewhat broader view of IS, we may also consider information systems (software or otherwise) as they arise in computer science, artificial intelligence, bioinformatics, complex systems and other areas of basic and applied research. In this

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\(^1\) In their recent detailed analysis of the nature of IS as a discipline, Khazanchi and Munkvold [10] define IS as “The study of the effective use of information and the potential impact of software systems and enabling information technologies on the human, organizational and social world.” The core fields relevant for IS are listed as computer science, management science, organizational science, cognitive science and economics.

\(^2\) ‘Might’ is the key word here. Actually the approach called information modelling is said to involve developing a theory of a given domain, but the correctness of that theory is not listed as a guiding principle. On the other hand, the so-called structured approach to system design is said to have the goal to produce reliable and maintainable software, but program correctness is not listed as a guiding principle. It is not clear whether these kinds of unwritten cognitive standards are implicit or not.
case, the view that the theory of IS is part of management science and that its philosophical foundations belong to social theory and philosophy no longer seems persuasive. Accordingly we may also consider other aspects of methodology than merely those of software system design and development in a particular IT setting. In particular, to the extent that we can relate IS to (natural and applied) science or technology, we may be able to apply methods and models from the philosophy of science or of technology to the philosophical foundations of IS. I want to focus here on (or at least include) what might be called intelligent information systems (IIS) in order to embrace systems that are not only functionalist in the terminology of [9], but that additionally have a clearly cognitive component. There are many examples to be found in areas such as knowledge-based systems, decision support systems, knowledge discovery, cognitive robotics, information retrieval, machine translation, smart adaptive systems, and others. Some illustrative examples are mentioned below.

3 IIS: What versus When

Asking of IS the typical philosophical question: ‘What kind of object is X?’ will lead us back to the issue whether or not IS is part of management science. In fact, where intelligent information systems are concerned we might well point to any of the following fields as relevant:

- Technology
- Engineering science
- Applied science
- Social science
- Empirical science
- Philosophy

The first three categories are seemingly uncontroversial, the fourth we have already dealt with and the last two will be considered below. The point to make here is that evidently IIS defies straightforward and easy categorisation and can be better construed as a hybrid of different disciplines. For this reason it seems preferable to replace the question ‘What is IIS?’ by a whole series of questions of the sort ‘When is IIS X?’, where X is any of the categories of science, technology, and so forth on our list above. Why does this matter? The simple answer is that knowing in what circumstances IIS is being perceived as X allows us to use models of X to evaluate such things as

- Success
- Progress
- Effectiveness

For the remainder of the paper we shall examine ways in which IIS can be perceived as philosophy, as science or as technology, and how these three areas may provide useful methodological tools.

3 Some authors would disagree. For instance, Dirk Siefkes takes the view that all informatics and computer science is of a social and cultural nature. See eg. [21].
4 IIS as philosophy

At first sight it might seem odd to regard the theory or practice of information systems as a sub-field of philosophy. However if we look at that part of R&D in intelligent systems that can be seen as belonging roughly to the field of artificial intelligence then it is not hard to identify commonalities with philosophy. In particular we can say that intelligent systems research acts like theoretical philosophy when it deals with the rational reconstruction of concepts like knowledge, causality, induction, explanation and discovery that are clearly of an epistemological nature. On the other hand it acts like practical philosophy when dealing with notions like beliefs, goals, intentions, actions, agency, emotions, norms, social choice, societies and organisations, control, communication, ethics, etc, as well as with associated problems of practical reasoning.

What are the aims and methods of rational reconstruction in philosophy? The classical position in analytical philosophy was developed by Rudolf Carnap (see for example Chapter 1 of [1]) and is called the method of explication. An (informal) concept, known as the explicandum, is analysed by providing an exact, formal concept or explicatum. Carnap lists four requirements for an adequate explicatum: it must be (i) similar to the explicandum, (ii) exact, via explicit rules for use (eg by definition in a formal system), (iii) fruitful and (iv) simple. The first three conditions take precedence over the fourth.

Rational reconstruction or explication in philosophy usually proceeds by defining a formal system in some suitable logical language accompanied by an analysis of desired properties to be displayed by the explicatum. That is, precise desiderata or criteria of adequacy for the explicatum are proposed, a rational reconstruction is described and analysed, and its properties are compared with the stated criteria of adequacy.

The procedure in IIS is not dissimilar. For instance, concepts may be defined within a logical language; rules for use are provided, which may for example be logical, axiomatic, etc. Algorithms are provided to compute solutions to problems, leading to a (re)formulation and implementation of the explicatum in a programming language. As to the methodological constraints on conceptual analysis, IIS typically requires:

- Effectively computable concepts
- Efficient implementations
- Various idealisations built-in to make systems applicable, user-friendly, etc.

In philosophy, especially in the Carnapian tradition, choice of language is typically regarded as conventional. However constraints may occur. For instance in the case of nominalism no abstract entities are permitted, or, for a constructivist, only effectively constructible entities are allowed. In the case of IIS choice of language is also often seen as conventional, but within the constraint of leading where possible to computationally feasible solutions. For the purposes of evaluation both IIS and philosophy use thought experiments and test-case problem scenarios as proving grounds. IIS additionally makes use of experimental testing by programs, benchmarks, etc. But one should take care not to use implementation as a substitute for meta-studies of properties of systems and their comparison with desiderata or criteria of adequacy. In summary
when IIS is acting as philosophy, it should be also subjected to accepted philosophical standards of evaluation.4

5 IIS as (engineering, applied) science and as technology

Research in the field of intelligent information systems can be science-like in several different ways. For example it may act like natural science when discovering chemical laws through machine learning; it may act like engineering science, for instance when activating and controlling mechanical robots; and it may perform functions of cognitive/information science, eg. when designing and applying multi-agent system architectures.

Notice that IIS may provide (descriptive) models or theories to explain, predict or control given natural, social or artificial phenomena. In this capacity it clearly acts in a more theoretical, science-like fashion. On the other hand IIS may apply models or theories (drawn from any suitable source) to provide design recipes for building systems and applications. In this case it is clearly more technology-like. This leads us naturally to consider some of the similarities and differences between science and technology and how models of each may be applied in the area.

5.1 science vs. technology

One of the major differences between science and technology is succinctly expressed by Skolomowski’s phrase that “science concerns itself with what is, technology with what is to be”, [22]. Science primarily produces knowledge-that (or knowledge-why), typically expressed via propositions. Technology tends to produce knowledge-how which is more dynamic in nature and may be embodied both in software (skills, programs) and hardware (machines, production processes).

Since science is primarily concerned with knowledge-that, it admits 'internal', cognitive models of progress based on measures of semantic content, empirical adequacy, explanatory power, problem-solving ability, and so forth. There are of course also 'external', indicators such as research spending, publications, citation counts, and the like. But these are 'noncognitive' with respect to the main goals of truth-seeking or problem-solving. Since technology deals with knowledge-how, its embodiment in techniques and skills does not carry truth-value or explanatory power. Where technology is concerned there is accordingly no rigid distinction to be found between internal and external indicators of progress. In fact all technological change needs to be analysed in the socio-economic context. Several writers, including Skolimowski, have attempted to identify internal measures of effectiveness for technology and thereby model a cognitive dimension of technological progress, often adapting approaches developed within the philosophy of science. Elsewhere [3] I have argued at length that this path amounts to a cognitive fallacy and is untenable. In particular, where technology is concerned it

4 This point is worth emphasising because in my view some areas of theoretical research in IIS lack a systematic methodology, including clear criteria for evaluation. Solutions proposed are often piecemeal and ad hoc.
is not that the distinction between internal and external indicators is a blurred or inexact one, it is simply that there is no distinction to be made. In the case of science, however, the distinction is a valuable and indeed a vital one. The internal, cognitive models best-known in the philosophy of science include:

- **Realism**, where truth, or truthlikeness (verisimilitude), is the main regulatory principle governing scientific progress (Popper [17, 18], Niiniluoto [16]);
- **Empiricism**, involving say predictive/explanatory adequacy, conformity with experiment, etc (van Fraassen [6, 7]);
- **Instrumentalism**, replacing truth by other indicators such as problem-solving effectiveness (Laudan [13])

Alongside these different indicators, scientific progress is customarily modelled with the help of concepts like research tradition (Laudan [13]), research programme (Lakatos [12]) or paradigm (Kuhn [11]). In each case, theories are not considered in isolation but as part of a knowledge environment (especially in the case of Kuhnian paradigms it is also a social environment) which helps to guide and focus research. It also helps to define adequate solutions and therefore acts as a guideline for assessing success. These different concepts of knowledge or research environment offer different models of progress, however. For Laudan, for example, progress is always a comparative measure of the success of one research tradition with respect to another; a yardstick that assumes the existence of a pool of shared problems and success criteria. For Kuhn, on the other hand, in many cases only a limited cognitive comparison of competing theories may be possible, since rival paradigms may be incommensurable.

When research in IIS acts in a science-like capacity, any of these approaches might provide useful tools for analysis. Where truth and explanatory power are not the main concerns one might for example look at more neutral measures such as problem-solving effectiveness (PSE) [13]. This would involve, say, identifying research traditions within IIS (planning, machine learning, robotics, neural nets,...) characterising and weighing their major achievements (solved problems) and anomalies (recalcitrant problems) and assessing their progressiveness, especially the relative progressiveness of rival traditions. Generally speaking, research traditions will not be rivals in an absolute sense, but may be considered rivals with respect to some domain of investigation. For instance in the domain of learning and adaptive systems one would typically regard neural networks, evolutionary computing, fuzzy logic and machine learning as offering competing methodologies or perhaps even ‘paradigms’.

### 5.2 Technology Models

For technology, as we have seen, there is no precise distinction to be drawn between cognitive and noncognitive models of progress. Technological change (TC) has been

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5 Note that this is not the case for the technological or engineering sciences which may well deal with truth, knowledge-that, etc.

6 The EU-funded project COIL - Computational Intelligence and Learning Cluster (1999-2001) - is an interesting example of an attempt to integrate aspects of these four traditions within a single network of researchers. See [23]
closely monitored within the field of macroeconomics and a variety of different but loosely related models has been proposed. Among them are notions like technological imperatives (Rosenberg [19]), technological guideposts (Sahal [20]), or selection environment (Nelson & Winter [15]). Although these models differ in detail, in each case it is claimed that a set of heuristics leads and constrains technological development along a natural path or trajectory (Nelson & Winter, Dosi [4, 5]). These models clearly invite comparison with concepts like research tradition and paradigm developed within the philosophy of science. Among the authors mentioned, Dosi [4] has attempted to forge the closest links between the two areas by describing an approach to TC based on a concept of technological paradigm. Again we would issue a strong warning here. What looks as first sight to be a promising set of analogies between scientific paradigms and technological paradigms in Dosi’s sense, turns out on closer inspection to be of no substance. In fact there are several disanalogies between the two concepts, one of the main ones being that technological development is more continuous in nature and does not exhibit the kinds of abrupt changes or ‘revolutions’ found in the Kuhnian model of science.\footnote{I have discussed this issue at much greater length in [2].}

Applying models of the above kind leads naturally to the following picture of Technology Assessment (TA): Characterise the nature of the technology; chart its historical development; assess its (degree of) progress at any time; use this as a basis for formulating technology policy. Notice that TA is not a part of the technological discipline in question but belongs to the methodology of the discipline. It therefore belongs to philosophy, as well as to economics. In addition, the history of technology, as well as organisation and management sciences, may be relevant.

To see how macroeconomic models of technology might apply to IIS, let us consider the well-known, three-phase model of Technical Change elaborated by Schumpeter. The following stages are envisaged by Schumpeter:

- **invention**: new techniques, designs, patents, prototypes are developed
- **innovation**: the adoption and commercialisation of new products, techniques, processes
- **diffusion**: marketing and distributing of new products

It is important to note that that on this view the centrepiece of technological change - innovation - already involves industrial production and commercialisation. TC cannot therefore be divorced from socio-economic and political environments.

Applying the three-phase model of TA to IIS suggests that it may be fruitful to consider the following categories or stages:

- implementation level (technical)
- software engineering level (technical & managerial)
- socio-economic level (markets)

The first of these is really a purely technical level and involves technical performance and support characteristics such as compilation speed, parallelism, distributed
computation, libraries, interfaces. The second, software engineering level, is both technical and managerial, involving such items as dependability, costs, verifiability, quality management etc. The third level involves social, cultural, political, organisational, economic structures, environments and markets.

At the software engineering level one can make further distinctions. For example dependability can be viewed in terms of software reliability, software reuse, safety-critical software, etc. Cost can be measured in terms of effort, time, facilities and other parameters. Verification and validation may involve logical or statistical vs. defect testing, debugging, etc. And quality management for software systems can be described via external attributes that are not directly measurable, and internal attributes that are measurable. In the case of external attributes, one may consider issues such as maintainability, reliability, portability, usability that are indirectly measured by software metrics based on internal attributes such as number of procedure parameters, cyclomatic complexity, program size in lines of code, number of error messages, length of user manual, and so forth.

At the socio-economic level it is important to note that market success does not necessarily equate to “most innovative”. This is due to several factors. For instance organisations and markets may exhibit barriers due to conservativeness and rigidities. External support for a technology may play a decisive role in its uptake, e.g. support from public agencies such as the EU or large corporations like Microsoft. Additionally a role is played by economic strength and marketing power, and furthermore by public perception in terms of “image” and “visibility” as seen e.g. in scientific standards and integrity, projects, workshops, seminars, conferences, training schemes, and university education.

6 Summary and Conclusions

The theory and practice of intelligent information systems does not readily fall into a single ‘scientific’ or ‘cultural’ category. For this reason we have argued that it makes little sense to study the nature of IIS in the absence of a specific R&D context. Once a clear R&D context is given, however, we can try to identify, select and eventually extend suitable models of development so that a methodological framework becomes available in which such factors as progress and effectiveness can be rigorously discussed and evaluated. In this note we have examined briefly three kinds of context that we can loosely label philosophy, empirical science and technology. However, these are large areas and within them we will almost certainly need to make further distinctions, as between theoretical and practical philosophy, pure and applied science, and different phases of technological change. In the latter case we suggested that macroeconomic models of technical change might be applied to IIS. However which of the models developed within macroeconomics and technology studies might be most suitable remains an issue for future work.

Given a workable technology model for information systems one will, in particular, need to investigate appropriate metrics to apply in level 2 (i.e. the software engineering level) and to study the structures, barriers and “forces” at work in level 3 (the socio-
economic level). This can be used as a basis for future technology policy recommendations and for promoting and diffusing the technology.

In conclusion, models of philosophy, science or technology can be applied to information systems providing that a suitable, clearly defined context can be identified. These in turn may be used to develop adequate methodologies.

References