An Easy Approach to Epistemology and Ontology in Computing Theses

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ABSTRACT

In many research fields—notably social sciences but also in those fields where design, experiment-based science, and social sciences are mixed—researchers must often describe their epistemological and ontological commitments in research reports. The research literature describes those commitments in various ways, often grouped under research paradigms such as positivism, post-positivism, and constructivism, and described as "world views." This paper presents the bare bones of the ontological and epistemological questions in scientific practice. Ontologically speaking, subject matters can be mind-dependent or mind-independent. Epistemologically speaking, elements of research may be more or less open to interpretation. This paper introduces a simplified approach to standard research terminology for computing and engineering students by offering a rough-and-ready way for resolving ontological and epistemological questions.

Categories and Subject Descriptors

K.3.2 [**Computers and Education**]: Computer and Information Science Education—*computer science education*

General Terms

Theory

Keywords

Thesis work, computing education, computer science education, philosophy, epistemology, ontology, research paradigms

1. INTRODUCTION

Computing combines a number of very different subjects under the same disciplinary umbrella (e.g., [4]). A look at the six research areas of computing [5] reveals a broad variety of subjects of study. In electrical and electronic engineering we study things like semiconductors and electromagnetic radiation. In computer engineering we study things like microprocessors and sensors. In computer science we study things like algorithms and computability theory. In software engineering, we study things like software development processes and formal methods. In information technology we study things like network design and lifecycle analysis. And in information systems we study things like organizational processes and decision support systems. Many computing fields, such as human-computer interaction and artificial intelligence, span across several computing fields and also intertwine with fields other than computing.

The variety of research topics in computing makes it nigh impossible to formulate an overarching prescription on how computing research should properly be done [24, 25]. Researchers in each computing subfield prefer a different set of methods. Analytical methods dominate in the theoretical fields, varieties of the scientific method are common in the quantitatively oriented empirical fields, methods from social sciences and the humanities dominate in the qualitatively oriented empirical fields, and engineering methods are often found in the design-oriented fields [23, 24]. It is uncommon to find pure engineering, pure science, or pure theory in computing disciplines, and some may consider it undesirable, too [12].

In computing literature, ontological and epistemological questions have received their most covering treatment in the field of information systems (e.g., [11, 16]). The lack of field-specific philosophical foundations is often not much of a concern, but as methodological literature often discusses research philosophy too, it is hard to completely ignore them. Most importantly, many students face, at some point of their thesis work, two grand words in the research literature: epistemology and ontology.

Research textbooks typically introduce the epistemological question as "What is the nature of the relationship between the knower ... and what can be known?" [8, p.108] and the ontological question as "What is the form and nature of reality and, therefore, what is there that can be known about it?" [8, p.108]. Methodology literature presents a variety of answers to these two questions, ranging from clear and simplified to abstract and vague. Guba and Lincoln [8, p.107] wrote that a research paradigm, which entails ontological, epistemological, and methodological assumptions, represents a "world view" that defines the researcher's view of the nature of the world, the individual's place in it, and the range of possible relationships to that world and its parts. On a more basic level, what the ontological and epistemological questions do in a research report is specify some basic facts about one's subject of study. Those questions, when properly formulated, can help students with

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their framing of research, their method choice, and their research questions.

The classic definitions and treatments of research paradigms, as accurate and deep as they may be, are not always very useful for students in computing fields. Consider, for example, a student who does a quantitative study on users' perceptions on usability of a new tool. Should that student adopt the positivist viewpoint which entails naïve realist ontology and objectivist epistemology; or should that student adopt the constructivist viewpoint which entails relativist ontology and subjectivist epistemology [8]? Too many new and difficult concepts may unnecessarily complicate a discussion that is aimed at clarifying the thesis. The research paradigms are rooted in a number of fundamental ontological, epistemological, and methodological positions, and choosing between them requires quite a lot of knowledge of philosophy. It would be hard to argue that in-depth knowledge of such debates would or should play a very important role in computing students' training.

Yet, it is still important to recognize assumptions about one's research. Clarity about ontological, epistemological, and methodological stands in a research study is especially important in a field that has to maneuver between and across disciplines that deal with essentially different kinds of things. In computing, the same research study may involve mathematical and formal objects, artifacts made by people, and social or other kinds of conventions. This paper is primarily aimed at educators in the field of computing, and it proposes a practical, hopefully student-friendly approach to talking about ontology, epistemology, and methodology in computing disciplines. This article is intended to be short and to-the-point; there are only four crucial concepts: mind-dependence and independence, epistemological objectivity, and epistemological subjectivity. Those interested in deeper discussions on the topic will easily find plenty of good reading on the philosophy of science.

2. ONTOLOGY

Ontology is concerned with the most fundamental level of the world: what are the ultimate constituents of the world, "how" do those constituents exist, and what kinds of relations are there between those constituents. Some classical questions about ontology have occupied philosophers for ages. One set of such questions includes questions on substances: what are they like, and how many kinds of substances are there. Philosophers have proposed numerous answers to such questions, and some of those answers seem downright counterintuitive. A full appreciation of all possible positions would take us too far away from practical work, and we discuss only positions that we take to be relevant to the field, but we mention points of potential disagreement. We attempt to approach these difficult issues from an intuitive, common-sense point of view.

One of the major disputes in philosophy is concerned with existence of things, and their mode of existence. Existence of material things (such as processors and copper wires) seems unproblematic to common sense. Similar, for computer scientist the existence of things that we manipulate daily (such as electromagnetic radiation and electrons) often seems unproblematic. How mental things (such as wishes, emotions, thoughts, and feelings) exist might be slightly more problematic. And how social things (such as laws, conventions, first names, ideas, ideologies, and theoretical entities) exist may be the least certain to common sense. Some philosophers argue that all the examples above exist only in people's minds, but that point of view, one kind of anti-realism, is rare. For the common sense, a realist position is often taken for granted when it comes to material things, but mental and social spheres can lead to problems.

Table 1: Examples of mind-dependent and mind-independent things in computing disciplines

Mind-dependent	Mind-independent
Preferences, attitudes, programming languages, values, worth, standards, processes, procedures, models	Electromagnetic radiation, material properties, semiconductors, thermal noise

The realist standpoint typically says that on the one hand, there are things and forces in the world that exist regardless of our thoughts and feelings—things such as silicon, electrons, copper, and electromagnetic radiation. We may not know everything about those things, but they nevertheless exist independently of us. Their existence is *mind-independent*: They would continue to exist even if there were no humans left on the planet. One must be careful to distinguish a term, say "copper" (which is a name we give to a thing), and the things that the term refers to (the actual thing, such as pieces of copper). Terms are mind-dependent but they may refer to mind-independent things.

On the other hand, there are things whose existence depends on people's states of mind, thoughts, or feelings about those things; take, for instance, first names, users' preferences, computer brands, organizational cultures, syntaxes, and agreements. The existence of those things is *mind-dependent*. They exist by virtue of people individually or collectively making them exist. Those things are created, maintained, and discarded by individual cognition or by collective agreements, and they cease to exist if there is no-one left to maintain them. Table 1 presents examples of mind-dependent and mind-independent objects. In Table 1 on the right hand side there are things whose existence is not at all relative to what people think about them, and on the left hand side there are things whose existence depends on us making them exist. It is along this dimension of ontology where people in a technical field usually face the ontological question. The reason is that many interdisciplinary fields, such as computing, deal with physical, mental, and social aspects—sometimes even within a single project.

In general there is a good understanding of the mind-independent mechanisms underlying physical systems (especially systems relevant to computing, such as electrical circuits), but the situation is not so good with minds and societies. In many sciences of the mind and societies, there is less understanding of how things work and why—and sometimes even no vision of how such consensus could even look like. Mind-dependent and -independent things are also studied differently: while mind-independent phenomena do not on the macro level care much about instruments used for studying them, mind-dependent phenomena may be irreversibly changed by the act of studying them. For instance, putting a person in usability lab probably affects that person's behavior. Similar, doing the same experiment on semiconductors in the 1970s and in the 2010s should yield the same results, but one does not even expect interview results to be the same between the 1970s and the 2010s.

When dealing with complex objects a situation may arise where one aspect of the object may belong to the sphere of mind-independent things and another to the sphere of mind-dependent things. In such a case we may say that the object of study is mind-involving. A relevant question then is: what kind of involvement is it? Artifacts are trivially mind-involving, because the very meaning of term artifact includes a mind (an artifact is made by humans and it has uses and functions that are mind-dependent). But artifacts have also physical properties that are mind-independent, and even though people have made them, their continuing existence does not depend on human minds. Artifacts have properties that are non-trivially mind-involving or not-mind-involving.

Ontology: Why?

Distinction between mind-independent things and mind-dependent things is important because there are remarkable differences between their properties. Consider, for instance, how persistent those properties are. Mind-dependent things, such as values, standards, opinions, and preferences may change radically over time, whereas many properties of mind-independent things are relatively stable: how semiconductors behave does not change over time. For example, a computer system for commercial purposes may have been effective in the 1960s economy and user base, but ceased to be so in the 2010s; even though the mind-independent parts (the computer system) have not changed, the mind-dependent parts (users and the economy) have changed.

Sciences, including many social sciences and humanities, are not directly concerned with ontological questions, yet every research study involves, implicitly or explicitly, ontological assumptions. In empirical research studies, ontology describes the most general background assumptions of the study: what sorts of things is the researcher dealing with. In natural sciences ontological issues are often not treated in university curricula or discussed in research papers, as there often is no controversy about those issues and many would consider them to be a waste of time [13]. Especially in natural sciences [13] it is a common view that there is no need to delve into philosophical discussions, as they would only slow down research. However, the situation is different in social sciences and humanities, where there is much less consensus about many fundamental philosophical issues.

Similar to many natural sciences, ontological issues are not explicitly treated in computing curricula and it is rare to see them discussed in research papers in computing. But only some parts of computing are similar to natural sciences. Much of computing research is directly concerned with mind-dependent things, which situates it closer to social sciences than natural sciences. In some clearly human-oriented branches of computing, especially information systems, ontological descriptions are more common than in branches that are associated more closely with formal or natural sciences. Yet, in all research ontological commitments have more or less direct ramifications on the epistemological and methodological aspects of the study. Especially in cross-disciplinary collaboration, computing researchers should be able to state their general ontological position in clear terms.

Ontology: How?

A crude but effective way of thinking about ontology in computing research is to ask whether the existence of the subject of study has anything to do with people's mental states—thoughts, feelings, anxieties, and so forth. Examples of subjects of study that have nothing to do with people's mental states are plenty in electrical engineering, computer engineering, and information technology. If a study is about things like wireless network signals or semiconductors, the study is concerned with things that are mind-independent. Neither the existence nor the properties of those things depend on what anyone thinks about those things.

Alternatively, if a research subject exists by virtue of people's feelings, agreements, thoughts, or other mental states, the study is concerned with things that are mind-dependent. Examples of such topics can easily be found in the fields of information systems, computer science, and software engineering. If a study is about, say, IEEE standards, OSI layers, programming languages, or users' preferences, it studies things that are mind-dependent. Those things exist because humans individually or collectively make them exist, they may be changed in the course of time, and they cease to exist if there is no-one left to hold them. Often research projects do not, however, concern objects as much as features or properties of objects—and those too can be mind-dependent or -independent.

It is important to note that mind-independent subjects of study, take a computer mouse, for example, can have both mind-dependent and -independent properties [19]. Firstly, the existence of a specific mouse does not depend on our feelings about it. Secondly, there are several features of that mouse that are mind-independent: for instance, that it has a certain mass, form, location, and chemical and physical composition. Thirdly, many other features of the mouse are mind-dependent: for instance, that we call it a mouse, that it is meant for controlling a computer, that this is Mary's mouse, and that Mary's mouse is a particularly good mouse.

Resolving the Ontological Status of a Subject of Study

Figure 1 presents two simple questions for resolving the ontological status of one's research subject. The first question resolves whether the subject of study is mind-dependent or -independent. In the case of mind-independent subjects, many studies still focus on their mind-dependent features, functions, or properties. Hence, the second question finds out whether the features studied are observer relative (mind-dependent) or intrinsic (mind-independent). That distinction is—much of the time—enough to frame ontology for a study.

Ontological status of research subject says nothing about how difficult is the science involved; it only denotes the subject's mode of existence. Research on both kinds of subjects can reveal interesting and important facts about the world, but those facts are of different types. Those facts that concern mind-independent aspects of the world have been called *brute facts*, and those facts that concern mind-dependent aspects of the world have been called *institutional facts* [19]. For example, it is a brute fact that transistors switching in processors cause heat. They cause heat no matter what we think about semiconductors, processors, current, and resistance. There again, it is an institutional fact that 8 bits

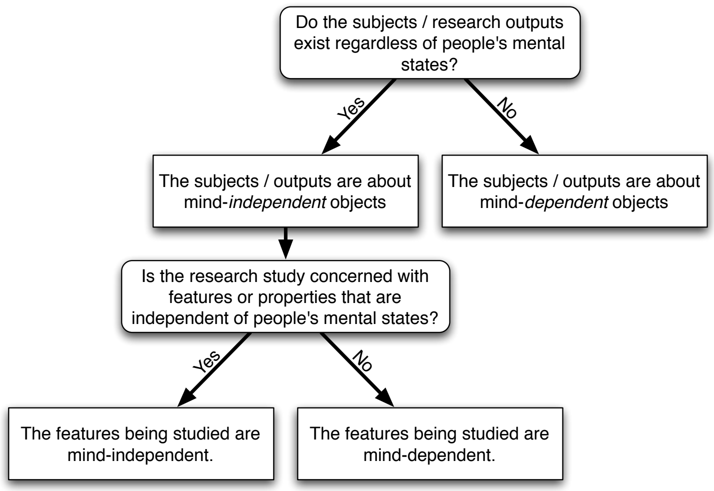

Figure 1: Resolving the ontological status of elements of study.

make a byte: That fact is created and collectively maintained by people, and it is a fact due to people's collective agreement.

3. EPISTEMOLOGY

Epistemology refers to the theory of knowledge and is concerned with, for example, what knowledge is and how one may gain knowledge. Historically speaking, two major schools of epistemology have been empiricism, which emphasizes perception (such as research based on empirical data collection), and rationalism, which emphasizes reason (such as any logical or mathematical reasoning). The old philosophical dispute between empiricism and rationalism is often not a concern for computing students, although ignoring the fundamental differences between the two modes of knowledge creation risks some critical misunderstandings.

All scientific disciplines have some traditions and conventions concerning credible ways of acquiring and justifying knowledge claims. But computing is a diverse discipline, and spans from highly abstract topics, such as computability theory, to quite practical topics, such as information technology. Hence, understanding epistemological issues plays an important role in clarifying research studies in computing, too.

Epistemology: Why?

There are various kinds of reasoning in different branches of science. Different kinds of reasoning and different kinds of information all have their own limitations and pitfalls. For instance, mathematical and formal models are precise and unambiguous, yet they are confined to the world of abstractions and they fail to capture the unbounded richness of the physical and social world. Narratives and ethnographies are rich in dimensions and sensitive to detail, yet they are equivocal and context-dependent. Scientific experiments enable accurate prediction and statistical description, but cannot capture things like meaning and significance. Narratives have little predictive power, and formal proofs have little explanatory power regarding things like usability preferences and much of the human experience in general. There again, the predictive power of mathematical and computational formulations is uncanny: Computational models have a miraculous, "unreasonably effective" capability of accurately predicting things in seemingly unrelated domains [9]. Confusing the limits of different intellectual traditions undermines the credibility of a research study, and credibility in part involves the recognition of known pitfalls and problems related to each source of knowledge.

Although scientific experiments and empirical research are able to produce new knowledge about the world, they both entail various epistemological issues. For example, perception is limited as a source of knowledge, and it is not always trustworthy: dip a straight stick in water, and it looks like it is bent. Measurement tools may offer a very limited picture of the phenomenon they measure. Existing theories, experiences, memory, and presuppositions affect how people interpret what they perceive. However, not only empirical work, but also theoretical reasoning entails problematic issues ranging from affirming the consequent, to hasty generalizations, to equivocation, and beyond. Even introspection (examining one's own mental states) is fallible—memories fade, change, and some 'memories' never happened. In any research study that involves things like observational, reflective, or reflexive practices, one needs to be cognizant of the epistemological issues involved, so that one can take into account the possible errors and try to work out the research design to accommodate biases, misrepresentations, misunderstanding, and other kinds of problems.

On the most basic level, many research studies follow a question–answer structure, where the answer makes a claim or a statement about how things are. One of the central meanings of epistemology refers to the *objectivity or subjectivity of judgments or statements* [19]. Whereas in the ontology above things are either mind-dependent or -independent, in epistemology objectivity or subjectivity is a *matter of degree*: judgments can be between subjective and objective [19]. In everyday language, *objective* judgments are those that are independent of single people's attitudes towards them; often those shared judgments are called intersubjective. Respectively, *subjective* judgments are those

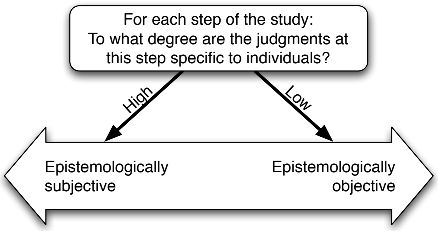

Figure 2: Evaluating the epistemological status of elements of study.

that depend on people's attitudes or feelings. Objective judgments are often called facts or knowledge, whereas subjective judgments are often called opinions, preferences, or beliefs.

Research studies on both mind-dependent and mind-independent subjects face similar epistemological questions, often discussed in different terms. There is the question of how closely does the data represent reality. There is the question of how strongly do the data support conclusions. There is the question of how certain the results are. There is the question of how well does the tool measure what it is supposed to measure. There are questions about the generalizability of results, and many more.

Epistemology: How?

One approach for reflecting on epistemological dimensions of a research study is to try to map in the same picture the question, a tentative (imagined) answer, and all the steps in between. Different steps may involve different kinds of epistemological stances: To what degree are the data epistemologically subjective or objective? Studies can be about things like people's preferences (more subjective), as well as about things like people's religious nominations (more objective, ascertainable from the population register). To what degree does the data collection itself involve interpretation versus recording of data? To what degree does the analysis involve interpretation versus mechanical processing? For instance, considering results, one can ask, "how much do these results depend on the researcher's and the reader's interpretation, attitudes, or preferences?" The more objective the results, the less they depend on any kind of interpretation.

The formulation of the research problem, aims, and research questions rely on existing research studies and researchers' interpretations of valuable and worthwhile questions, and the question could be about previously unknown things or conflicting views. Data is not collected randomly, and in the data collection process, only a minor part of infinite available data is collected, based on what is already known about the domain. The data is collected using formal or informal data structures that are created to record or model some aspects of the phenomenon as well as possible. Because data structures are built according to what one already knows about the domain, data cannot be independent of one's previous knowledge. Treating such data as if they were 'independent' empirical discoveries or theoretical results has been called 'inscription error' [22, p.52]. All results are also interpreted, often on multiple levels. Raw data are often interpreted for reporting results, and results are interpreted for discussion of findings—and in the end the critical reader and the scientific community are the final interpreters of the research report. There is no research without interpretation somewhere.

Epistemology: From Subjective to Objective

Many judgments depend on individual preferences. For example, the judgment that OS X is a good operating system is a matter of viewpoint, and that judgment varies by people's feelings about aesthetics, user experience, proprietary products, and various other things. So, the judgment that OS X is a good operating system is *epistemologically subjective* to some degree, and many may disagree with the judgment. There are many types of research studies that study epistemologically subjective matters (such as preferences and attitudes). Some interpretive research looks at things that rely heavily on individuals' personal states of mind—take, for instance, aesthetics or users' emotions regarding interface design. Many studies that try to understand individuals' meanings, interpretations, or feelings study epistemologically subjective matters.

There again, there are some judgments that are considered to be more than mere opinions. Many people may hold the same judgments (sometimes called intersubjectivity), or those judgments may form a part of a coherent structure of statements. For example, the statement that there are 7 OSI layers is an objectively ascertainable fact. That judgment is *epistemologically objective* [19] or *intersubjective* to a high degree. Note that although the OSI model—as a standard created by networking professionals—exists mind-dependently, statements about the OSI model can be objective in a sense that those statements cohere with commonly accepted standards or definitions; they are not only subjective opinions.

Intersubjective matters can also be studied in many different ways. Many mind-dependent subjects can be studied in a way that does not leave much room for idiosyncratic interpretation—take, for instance, studies on IEEE standards or commonly agreed models. Other research studies try to understand and interpret the subjective meanings and mechanisms between intersubjective things—take, for instance, studies on groupware or computer-supported collaborative learning. Many such subjects are an outcome of negotiation, common making of meaning, and social processes. Indeed, there is a continuum that ranges from intersubjective agreements that are fixed to a high degree (statements like "eight bits make a byte") to subjective preferences (statements like "pair-programming works well for me"). At the highly objective end of the spectrum, with very strong intersubjective agreement, are things like axioms in mathematics and transformation rules in logic.

Objective out of Subjective

If one's research data lies at the subjective end of the spectrum, that does not mean that results could not be at the opposite, objective, end of the spectrum. For instance, a presidential poll is essentially a survey on subjective preferences ("X would make a better president than Y would"). The results are highly objective facts, such as the fact that Barack Obama won 52.92% of votes in the American 2008 presidential elections. Surely such survey has various limitations, such as the fact that the respondents are not a representative sample of the population, but those limitations do not change the vote count, which is highly objective: the

Table 2: Example statements with various ontological and epistemological aspects of research.

	Epistemologically Subjective	Epistemologically Objective
Mind-dependent	1. *It's more fun to learn Python than it is to learn Java*	2. *The Java language has fewer reserved words than the Cobol language has*
Mind-independent	3. *Thermal noise in conductors is an undesirable phenomenon*	4. *The speed of electromagnetic radiation in vacuum is about* $3 \times 10^8 m/s$

election results are not an interpretation but as long as the rules of counting remain the same, any new count of the votes would come up with roughly the same result.

Epistemological standpoints affect, in many ways, what a research study can achieve. Research studies that deal with epistemologically objective matters (such as standards, theoretical constructions, or procedures) often yield results that can be right or wrong. Studies on epistemologically objective as well as subjective matters can yield statistics or empirically testable models. Studies on epistemologically subjective matters (such as opinions, preferences, or attitudes) can have a lot of variety in their results. Some of those studies come up with objective facts whereas others come up with interpretive, subjective results, such as case studies, ethnographies, or other types of rich description. The latter type of studies are often judged by their credibility, transferability, coherence, or confirmability.

The strength of many kinds of research is in the rich description they can provide of subjective things—of people's reasoning, motivations, fears, hopes, anxieties, expectations and so forth. In some other kinds of research, subjectivity is considered to be negative. All in all, many subjective aspects in research are unavoidable—from interpretation and communication of results to the choice of axioms—yet those often do not undermine the study's credibility much. Other subjective aspects can be avoided, and avoiding them may improve the credibility of results. For example, in research with human subjects, the individual researcher can make a sharp distinction between the beliefs and knowledge of researchers and beliefs and knowledge of the research subjects. Various techniques (multiple reviewers, coding books, etc.) can be employed to measure the level of intersubjectivity of results. Statistics provides a multiplicity of tools for establishing confidence on results.

It is important that researchers are aware of the epistemological aspects of their research; false assumptions may lead to decreased credibility of a research study. A researcher should have an understanding of the human condition and epistemic condition of the research subject. It is also important to separate between subjects, data, and results of the research—those are very different things.

4. DISCUSSION

All combinations of the ontological and epistemological aspects of research can be found in computing research. Table 2 presents examples of each combination. Sentences 1 and 2 on the first row concern mind-dependent things (programming languages), while sentences 3 and 4 on the second row concern mind-independent things (thermal noise and speed of light). Epistemologically speaking, statements in the first column are more subjective whereas statements in the second column are more objective.

In Table 2, the first statement concerns learning programming languages. Both learning as well as programming languages exist by virtue of our thinking, and are hence mind-dependent. As judgment 1 is highly contextual and dependent on one's opinion, it is epistemologically subjective. The second statement is also concerned with programming languages, which are mind-dependent. But judgment 2 is not a matter of anyone's opinion. Statement 2 is an epistemologically objective judgment about a mind-dependent thing, so statement 2 is an institutional fact.

In Table 2, the third statement concerns thermal noise, which is an intrinsic feature of conductors. Both conductors and thermal noise are mind-independent, for both exist independent of any observers or mental states. Statement 3 is, however, epistemologically subjective, as it is contingent on observers' preferences. Physicists, for one, do not consider thermal noise as desirable or undesirable—"it just is"—whereas for many engineers thermal noise is an unwanted phenomenon. In the fourth statement of Table 2, speed is an intrinsic feature of electromagnetic radiation, which does not know or care about any observers or anyone's feelings towards it. The statement 4 is not, however, anyone's subjective opinion, but an objectively ascertainable fact, and hence epistemologically objective. Being an epistemologically objective statement about an ontologically objective thing, statement 4 is a brute fact.

Some Difficulties and Relationships to Other Research

There are topics in computing that are difficult to classify in the categories presented above. Take theoretical topics, for instance. Ontology of mathematics is a notoriously tricky issue. For instance, Gödel [7, 8,§1] argued that mathematical objects exist in the very same manner as tables and screwdrivers do. In mathematics, ontological realists argue that there are mathematical objects that exist independently of people; ontological idealists argue that mathematical objects exist by virtue of our minds; and nominalists argue that mathematical objects do not quite "exist" [21, 25,226–227]. The image of mind-independence of mathematics was questioned by, for example, Lakatos [14] and Bloor [1]. In computing fields, De Millo et al. [3] discussed the social processes of knowledge creation in the discipline.

In computing fields, one bone of contention is the ontological and epistemological status of algorithms [6, 22]. Some argue that we find computations (and apparently algorithms) in the nature—that is, they are mind-independent [20, 15, 26]. Others argue that algorithms as well as properties of algorithms are mind-dependent (cf. [18]). However, in theoretical branches of computing epistemological and ontological positions in research are rarely debated, and epistemological and ontological positions do not affect method choice or research frameworks in theoretical fields. Cognitive science, with which computer science is often linked, poses another set of epistemological and ontological difficulties [19].

This article partly coheres with some research framework descriptions in computing fields. For example, Hirschheim & Klein [10] and Roode [17] adapted Burrell & Morgan's [2] four quadrants of sociological research to the field of information systems: those quadrants are the functionalist paradigm, the interpretive paradigm, the radical humanist paradigm, and the radical structuralist paradigm. The axes that cut through the four paradigms are, however, only partly the same as the axes in this study: As the study of Burrell and Morgan [2] was fully focused on sociological subjects, it did not touch on mind-independent matters at all.

Hence, the "subjective–objective" dimension presented by Hirschheim & Klein [10] and Roode [17] is the same as the epistemological dimension in this article, but the "order–conflict" dimension in those studies is specific to sociological research. Hirschheim & Klein [10] and Roode [17] divided ontology into realism—where "an empirical organizational reality that is independent of its perceiver or observer is believed to exist" [10]—and nominalism, where "reality is not given, immutable "out there," but is socially constructed" (*ibid.*). The problem with the type of "ontological realism" presented by those authors is that it argues for an independent social reality that would continue to exist even if all observers would cease to exist, and hence faces difficulties with metaphysics.

Conclusions

Computing's interdisciplinary linkages and computing researchers' increasing collaboration with people from other fields has led to a point where computing researchers too need to be able to understand and use some standard research terminology. In many research projects it is important that the authors can describe the mode of existence of their research subject and some epistemological aspects of their research data and results. Those questions—the ontological and the epistemological question—are in the research literature explained in various ways.

This paper proposes a simple way of framing the ontological and epistemological questions. The paper proposes that a computing research study's ontological and epistemological linkages can be determined through a few simple questions. Firstly, in many cases the ontological status of a study's subjects can be resolved by asking whether the subjects, their properties, or their features exist regardless of people's mental states. That question creates a division into mind-dependent and mind-independent subjects, which lead to very different sets of methods applicable. Secondly, the epistemological status of data, research results, and other judgments can be evaluated by considering the degree to which they depend on particular individuals' judgments. The ontological distinction is a clear "either/or" juxtaposition, whereas the epistemological dimension is a continuum; a "more-or-less" type of a question. These two dimensions offer a rough-and-ready starting point for discussing ontology and epistemology in computing theses.

5. REFERENCES

[1] D. Bloor. *Knowledge and Social Imagery.* Routledge & Kegan Paul, London, UK, 1976.

[2] G. Burrell and G. Morgan. *Sociological Paradigms and Organisational Analysis: Elements of the Sociology of Corporate Life.* Heinemann, London, UK, 1979.

[3] R. A. DeMillo, R. J. Lipton, and A. J. Perlis. Social processes and proofs of theorems and programs. *Communications of the ACM*, 22(5):271–280, 1979.

[4] P. J. Denning. Great principles of computing. *Communications of the ACM*, 46(11):15–20, 2003.

[5] J. J. Ekstrom, S. Gorka, R. Kamali, E. Lawson, B. Lunt, J. Miller, and H. Reichgelt. *Computing Curricula*, volume Information Technology. ACM, 2005.

[6] J. H. Fetzer. Program verification: the very idea. *Communications of the ACM*, 31(9):1048–1063, 1988.

[7] K. Gödel. Russell's mathematical logic. In S. Feferman, J. Dawson, S. Kleene, G. Moore, R. Solovay, and J. van Heijenoort, editors, *Kurt Gödel Collected Works (1990)*, volume II: Publications 1938–1974, pages 119–141. Oxford University Press, Oxford, UK, 1944.

[8] E. G. Guba and Y. S. Lincoln. Competing paradigms in qualitative research. In N. K. Denzin and Y. S. Lincoln, editors, *Handbook of Qualitative Research*, pages 105–117. SAGE, London, UK, 1994.

[9] R. W. Hamming. The unreasonable effectiveness of mathematics. *The American Mathematical Monthly*, 87(2):81–90, 1980.

[10] R. Hirschheim and H. K. Klein. Four paradigms of information system development. *Communications of the ACM*, 32(10):1199–1216, 1989.

[11] H. K. Klein and M. D. Myers. A set of principles for conducting and evaluating interpretive field studies in information systems. *MIS Quarterly*, 23(1):67–94, 1999.

[12] D. E. Knuth. Theory and practice. *Theoretical Computer Science*, 90(1991):1–15, 1991.

[13] T. S. Kuhn. *The Structure of Scientific Revolutions.* The University of Chicago Press, Chicago, USA, 3rd edition, 1996.

[14] I. Lakatos. *Proofs and Refutations: The Logic of Mathematical Discovery.* Cambridge University Press, Cambridge, UK, 1976.

[15] S. Lloyd. *Programming the Universe: A Quantum Computer Scientist Takes on the Cosmos.* Vintage Books, London, UK, 2007.

[16] M. D. Myers. Qualitative research in information systems. *MIS Quarterly*, 21(2):241–242, 1997.

[17] J. D. Roode. Implications for teaching of a process-based research framework for information systems. In *Proceedings of the International Academy for Information Management Conference*, Orlando, Florida, USA, 1993.

[18] J. R. Searle. Minds, brains, and programs. *The Behavioral And Brain Sciences*, 1980(3):417–457, 1980.

[19] J. R. Searle. *The Construction of Social Reality.* Penguin Press, England, 1996.

[20] C. Seife. *Decoding the Universe. How the New Science of Information is Explaining Everything in the*

Cosmos, from Our Brains to Black Holes. Penguin Books, London, UK, 2006.

[21] S. Shapiro. *Thinking About Mathematics: The Philosophy of Mathematics*. Oxford University Press, New York, NY, USA, 2000.

[22] B. C. Smith. *On the Origin of Objects*. MIT Press, Cambridge, Mass., USA, MIT paperback edition, 1998.

[23] M. Tedre. Computing as engineering. *Journal of Universal Computer Science*, 15(8):1642–1658, 2009.

[24] M. Tedre. Computing as a science: A survey of competing viewpoints. *Minds & Machines*, 21(3):361–387, 2011.

[25] M. Tedre and E. Sutinen. Three traditions of computing: What educators should know. *Computer Science Education*, 18(3):153–170, 2008.

[26] S. Wolfram. *A New Kind of Science*. Wolfram Media, Champaign, IL, 2002.