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Research in computer science: an empirical study

V. Ramesh [a,*], Robert L. Glass [b,1], Iris Vessey [a,2]

[a] Department of Information Systems, Kelley School of Business, Indiana University, Bloomington, IN 47405, USA
[b] Computing Trends, 1416 Sare Rd., Bloomington, IN 47401, USA

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Abstract

In this paper, we examine the state of computer science (CS) research from the point of view of the following research questions:

1. What topics do CS researchers address?
2. What research approaches do CS researchers use?
3. What research methods do CS researchers use?
4. On what reference disciplines does CS research depend?
5. At what levels of analysis do CS researchers conduct research?

To answer these questions, we examined 628 papers published between 1995 and 1999 in 13 leading research journals in the CS field. Our results suggest that while CS research examines a variety of technical topics it is relatively focused in terms of the level at which research is conducted as well as the research techniques used. Further, CS research seldom relies on work outside the discipline for its theoretical foundations. We present our findings as an evaluation of the state of current research and as groundwork for future CS research efforts.

Keywords: Topic = Computing research; Research Approach = Evaluative-Other; Research Method = Literature analysis; Reference Discipline = Not applicable; Level of Analysis = Profession

1. Introduction

Computer science is a well-established discipline that is represented in almost all institutions of higher education. [3] As part of their faculty responsibilities, computer scientists conduct research in several different areas, such as artificial intelligence, databases, distributed systems, etc. Research is published in journals dedicated to fostering research in those specific areas. Thus, it is not surprising that most papers that examine the nature of research within computer science tend to focus on specific areas of computer science (see, for example, Gruman, 1990; Rice, 1995; Wegner and Doyle, 1996; Gallopoulous and Sameh, 1997) or even subareas, for example, heterogeneous databases (Sheth and Larson, 1990) or data modeling (Hull and King, 1987), rather than on the discipline as a whole. From a broader perspective, we also find articles that address the nature of computer science research at a country level, e.g., Ramamritham (1997) on India and Estivili-Castro (1995) on Mexico. With the exception of studies by Glass (1995) and Tichy et al. (1995), however, very few studies have examined the nature of research in the field as *a whole*. And even these studies have a relatively narrow focus in that they examine only commonly researched topics and/or the research methods used.

Our objective in this study is to provide a detailed characterization of computer science research, along the

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[*] Corresponding author. Tel.: +1-812-855-2641; fax: +1-812-855-4985.

E-mail addresses: venkat@indiana.edu (V. Ramesh), rlglass@acm.org (R.L. Glass), ivessey@indiana.edu (I. Vessey).

[1] Tel.: +1-812-337-8047.

[2] Tel.: +1-812-855-3485.

[3] Throughout this paper, CS is an abbreviation for Computer Science unless the context explicitly states otherwise (e.g., where CS is used to represent Computer System (in Unit/Level of Analysis) or Case Study (under Research Methods)).

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dimensions identified above, by examining articles published in major computer science journals from 1995–1999. Our interest in this study goes beyond topic and research methods and includes other ways of characterizing research such as research approach, which identifies the way in which a research study is conducted, the level of analysis, which identifies the object that is studied, and reference discipline, which identifies the theoretical foundation of the research.

2. The current study

This section describes the classification scheme used to characterize CS research in this study. It also presents details regarding the journals examined and the classification process.

2.1. Classification scheme

Given that our objective was to characterize research in computer science, our first task was to identify a classification scheme that would enable us to capture the richness of CS research. We found that traditional classification schemes such as the ACM computing classification scheme (ACM CCS, 1998) characterize research only along one dimension, i.e., topic. Classification schemes in related disciplines such as information systems, e.g., ISRL categories (Barki et al., 1988), also tend to focus on topic with research method as a secondary consideration. However, researchers often wish to know how the findings of studies of interest were obtained (i.e., the research approach and research method used). In addition, the level at which a study is conducted is also of interest to researchers; a study might, for example, focus on an abstract concept (AC) such as a data model, or a computing element (CE) such as an algorithm, or it might focus on a system, a project, or an organization. Finally, the origin of the study's theoretical base, the reference discipline, is also interesting to researchers because it may suggest richer conceptualizations of the phenomena of interest.

Because none of the existing classification schemes was sufficiently rich in the desired dimensions, we developed a multi-faceted classification system that characterizes research along the five dimensions outlined above. The classification system was comprehensive in a further way; it was developed to describe research in three computing-related disciplines: computer science, software engineering, and information systems (see Vessey et al., 2001). Thus, some of the categories in our scheme may be less relevant to mainstream CS research. For brevity, the classification system is presented with the results of our study in Tables 3–7. Below, we present a brief description of how the classification system was developed.

2.1.1. Classifying topic

To ensure that our list of topics was sufficiently broad to include all areas of computing research, we used several sources of topics from the general discipline of computing, viz., the ACM computing reviews classification scheme (ACM CCS, 1998), the categories in Barki et al. (1988), and the topic areas identified by Glass (1992). In particular, we used the classification scheme proposed by Glass (1992) as the starting point for arriving at the high-level categories shown in Table 3 because its stated objective of presenting a comprehensive set of topics in the fields of computer science, software engineering, and information systems best fit our completeness criterion.

The overall classification scheme, which is shown in Table 3, divides the topics of the computing research field into several major categories:

- Problem-solving concepts
- Computer concepts
- Systems/software concepts
- Data/information concepts
- Problem-domain-specific concepts
- Systems/software management concepts
- Organizational concepts
- Societal concepts
- Disciplinary issues

Each of these categories, is further divided into several subordinate categories.

2.1.2. Classifying research approach

We also categorized the research techniques used. We divided those techniques into research approach, the overall approach undertaken in performing the research, and research method, the more detailed techniques used. In this section, we discuss research approach.

Surprisingly, there is very little information in the field to aid in the classification of research techniques. We used Morrison and George's (1995) categorization of research approaches as a starting point for determining the research approaches to be examined in this study. Based on an analysis of articles in both software engineering and information systems between 1986 and 1991, they characterized the four major research approaches as descriptive, developmental, formulative, and evaluative. These correspond roughly to the scientific method categories of: observe, formulate, and evaluate (Glass, 1995). We included developmental in the descriptive category because such research primarily involved describing systems.

We further subdivided these categories to reflect a rich set of research approaches. Table 4 shows the categories used to classify research approach in this study. The descriptive approach has three subcategories. Subcategory descriptive-system (DS) is based on Morrison and George's descriptive category and is used to capture papers whose primary focus is describing a system. Descriptive-other (DO) was added to capture those papers that used a descriptive approach for describing something other than a system, for example, an opinion piece. We added descriptive-review (DR) as a subcategory into which we categorized papers whose primary content was a review of the literature.

The formulative research approach was subcategorized into a rich set of possible entities being formulated, including processes/procedures/methods/algorithms (all categorized under FP), and frameworks and guidelines/standards (FF and FG, respectively). In all, there are six subcategories of the formulative research approach.

Our evaluative categories are based on the three alternative "evaluative" epistemologies identified by Orlikowski and Baroudi (1991): positivist (evaluative-deductive in our system), interpretive (evaluative-interpretive), and critical (evaluative-critical). We added an "Other" category here to characterize those papers that have an evaluative component but that did not use any of the three approaches identified above. For example, we classified papers that used opinion surveys to gather data (as opposed to questionnaires that used established research instruments) under evaluative-other.

2.1.3. Classifying research method

Research method describes the specific technique used in a given study. While the choice of research approach narrows the set of possible applicable research methods, there is typically a one-to-many relationship between a given research approach and method. Hence, in addition to research approach, we also coded the detailed technique used by a study.

Unlike research approach, where there were few candidate categories from which to choose, in the case of research method, there were numerous classifications from which to choose. Recall that, while the objective of this paper is to characterize the nature of research in computer science, the categories and taxonomies used in this paper were intended to cover the whole of the computing field, including computer science.

Arguably, the computing discipline most concerned with research method is Information Systems where many prior publications have identified a number of commonly used methods (see, for example, Alavi and Carlson, 1992; Farhoomand and Drury, 2000). These articles identify, for example, laboratory experiments (using human subjects), field studies, case studies, and field experiment. Several other research methods have also been identified; for example, conceptual analysis (or conceptual study), literature review (Lai and Mahapatra, 1997), instrument development (Alavi and Carlson, 1992), and exploratory survey (Cheon et al., 1993).

Some studies have examined research methods specific to a software engineering context. Both Zelkowitz and Wallace (1997) and Harrison and Wells (2000) proposed a number of research methods similar to those identified in the information systems studies cited above. In addition, we are aware of two papers that address research methods in both computer science and software engineering. Glass (1995), for example, suggested a fairly simplistic approach, derived from prior literature, which categorized methods as scientific, engineering, empirical, and analytical. Tichy et al. (1995) conducted a more general survey of articles in CS journal and conferences and found that CS research was lacking in its use of experimental methods.

To assist in the categorization of the CS component of computing research, we added the following categories to the above list: conceptual analysis/mathematical (CA/M) and mathematical proof to facilitate the classification of papers that utilize mathematical techniques; Simulation, to allow categorization of papers that utilized simulation as their primary research method; and concept implementation for papers whose prime research method was to demonstrate proof of a concept by building a prototype system. We also added the category laboratory experiment (software) to characterize those papers that, for example, compare the performance of a newly-proposed system with other (existing) systems. It is important to note that not all of the research methods included in Table 5 are appropriate for computer science research.

2.1.4. Classifying unit/level of analysis

Level of analysis refers to the notion that research work may be conducted at one or more of several levels; for example, at a high level, the research may be technical or behavioral in nature. Example of technical research would be focused on the computing system (CS), computing element (CE, representing a program, component, algorithm, or object) or abstract concept level (AC, e.g., graph-based representations). An example of behavioral research is the Watts Humphrey work on Team Software Process (http://www.sei.cmu.edu/tsp/tsp.html), which would be categorized as GP for Group/Team, and his Personal Software Process work, which would be categorized as IN for individual (http://www.sei.cmu.edu/tsp/psp.html). Some research work is done at the level of the profession (PRO), of which this paper is an example, as are those papers referenced in the introduction that address CS research in a particular country, while others may be conducted within an enterprise at the organizational (OC) level. Table 6 presents the levels of analysis used in this study.

2.1.5. Classifying reference discipline

By reference discipline, we mean any discipline outside the CS field that CS researchers have relied upon for theory and/or concepts. Generally, a reference discipline is one that provides an important basis, such as theory, for the research work being conducted. Various researchers have characterized the reference disciplines used in research (see, for example, Swanson and Ramiller, 1993; Westin et al., 1994). Swanson and Ramiller (1993) identified computer science, management science, and cognitive science, organizational science, and economics as four key reference disciplines for information systems. Barki et al. (1988) also include behavioral science, organizational theory, management theory, language theories, artificial intelligence, ergonomics, political science, and psychology, while Westin et al. (1994) further identified mathematics/statistics and engineering. The reference discipline categories presented in Table 7 represent a comprehensive aggregation of the categories addressed in prior research, i.e., some of our categories subsumed one or more of the categories outlined above. The management category, for example, subsumes organizational theory and management theory. Similarly, artificial intelligence is subsumed within computer science.

2.2. Journal and article selection

For our study to truly reflect the field of computer science, we needed to ensure that we evaluated a representative sample of research articles. We began with the ACM and IEEE journals that Geist et al. used in their 1996 study of faculty productivity and eliminated two software engineering journals (*ACM Transactions on Software Engineering and Methodology and IEEE Transactions on Software Engineering*) as well as *IEEE Transactions on VLSI*, which does not appear in the list of IEEE Computer Society publications. [4] Table 1 presents the 13 journals examined.

Table 1
The journals examined

Journal title	Abbreviation
IEEE Transactions on Computers	COMP
Journal of the ACM	JACM
IEEE Transactions on Knowledge and Data Engineering	KDE
IEEE Transactions on Pattern Analysis and Machine Intelligence	PAMI
IEEE Transactions on Parallel and Distributed Systems	PDS
ACM Transactions on Human–Computer Interaction	TOCHI
ACM Transactions on Database Systems	TODS
ACM Transactions on Graphics	TOG
ACM Transactions on Information Systems	TOIS
ACM Transactions on Modeling and Computer Simulation	TOMCS
IEEE/ACM Transactions on Networking	TON
ACM Transactions on Programming Languages and Systems	TOPLAS
IEEE Transactions on Visualization and Computer Graphics	VCG

We used a sampling approach that enabled us to select approximately 500 articles for evaluation. We wanted to ensure that, as a group, the two primary publication outlets, IEEE and ACM Transactions were reflected equally in the sample set. [5] Based on the number of articles published during the years 1995–1999, inclusive, we selected 1 in 10 articles from the IEEE journals and 1 in 3 articles from ACM journals. This approach resulted in approximately 309 articles in IEEE journals and 286 articles in ACM journals, as well as 33 articles from a joint IEEE/ACM publication (*Transactions on Networking*). Table 2 presents raw data for the number of articles examined in each of the journals during the five-year period.

2.3. The classification process

Two of the three authors of this paper independently classified each article using just one category in each of the five characteristics. Hence the coding reflected the primary focus of the research. Following the individual codings, the first author resolved differences by reexamining the article and choosing a final coding that was typically one of the two original codings.

Agreement varied among categories. For example, high levels of agreement were achieved for research method and reference discipline coding (close to 90%), while coding of level of analysis and topic was somewhat more problematic (70% and 75% agreement, respectively). Disagreement occurred most often when a paper could legitimately have been coded in more than one way. Original agreements across all categories averaged around 80%.

3. Findings

In the following section the study findings are presented by research question; that is, we address the topics, research approaches, research methods, levels of analysis, and reference disciplines that CS researchers use, in turn. Tables 3–7 summarize the findings. Although this study was designed to characterize research in the CS *discipline*, it is also interesting to examine differences in the journals themselves. Hence, in each of the sections, we also highlight the findings by journal.

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[4] *ACM Transactions on Software Engineering and Methodology* (TOSEM) and *IEEE Transactions on Software Engineering* (TSE) were not included in this study because they are primarily software engineering journals and were therefore examined in our analysis of the software engineering literature. This analysis is reported in Glass et al. (2002).

[5] An alternative distribution scheme based on the amount of research published could also have been used here. However, we did not want our sample to be overwhelmed by publications in IEEE Transactions, which publish more issues per year and more articles per issue than ACM Transactions.

Table 2
Numbers of publications examined by journal and year

	Overall	COMP	JACM	KDE	PAMI	PDS	TOCHI	TODS	TOG	TOIS	TOMCS	TON	TOPLAS	VCG
1995	141	21	20	10	17	16	4	10	7	9	6	4	13	4
1996	128	20	16	10	17	14	7	3	7	7	6	8	9	4
1997	135	18	16	10	19	14	6	7	7	6	9	9	11	3
1998	122	17	15	8	19	12	5	5	6	7	8	6	11	3
1999	102	15	11	8	17	10	3	3	4	6	8	6	8	3
Totals	628	91	78	46	89	66	25	28	31	35	37	33	52	17

Table 8 presents the data by journal for each of the categories examined. While some of the results for the discipline as a whole and the journals are somewhat predictable, some are fairly surprising.

3.1. Findings for topic

Table 3 shows that research in computer science is spread evenly among the five categories: computer concepts (28.67%), problem-domain-specific concepts (21.50%), systems/software concepts (19.11%), data/information concepts (15.45%), and problem-solving concepts (14.65%). Two other categories, systems/software management concepts, and organizational concepts, are represented minimally, while two categories, societal concepts and disciplinary issues are not represented at all.

The leading sub-category was computer graphics/pattern analysis within the problem-domain-specific concepts category. Twenty percent of articles were devoted to this category, while 17.68% were devoted to inter-computer communication (part of computer concepts), which includes such topics as networking and distributed systems. Other notable topics were computer/hardware principles/architecture at 10.19% (again part of computer concepts) and database/warehouse/mart organization at 8.44% (part of data/information concepts), while papers focusing on mathematics/computational science (part of problem-solving concepts) were next at 6.69%.

Table 8 (Panel A) presents the topics by journal. The results show that most journals tended to have a single dominant topic as suggested by their title. These topics, then, broadly define the sub-fields that make up the discipline of computer science. We found that 2 or 3 of the 13 journals typically focused on the same topic area. For example, the principal topic category in *Journal of the ACM* and *ACM Transactions on Modeling and Computer Simulation* was problem-solving concepts; in *IEEE Transactions on Computers*, *IEEE Transactions on Parallel and Distributed Systems*, and *IEEE/ACM Transactions on Networking* it was computer concepts; in *ACM Transactions on Computer–Human Interaction* and *ACM Transactions on Programming Languages and Systems*, it was systems/software concepts, in *IEEE Transactions on Knowledge and Data Engineering*, *ACM Transactions on Database Systems*, and *ACM Transactions on Information Systems*, it was data/information concepts, and in *IEEE Transactions on Pattern Analysis and Machine Intelligence*, *ACM Transactions on Graphics*, and *IEEE Transactions on Visualization and Computer Graphics*, it was problem-domain-specific concepts.

3.2. Findings for research approach

Table 4 shows the primary research approaches used by CS researchers. Formulative was by far the dominant research approach representing 79.15% of the papers assessed, followed by evaluative and descriptive approaches, which were virtually equivalent at 10.98% and 9.88%, respectively.

Examination of the sub-categories of research approach shows that FP, a multifaceted subcategory that includes formulating processes, procedures, methods, or algorithms is the most important of the formulative subcategories. Approximately half of computer science research (50.55%) fell into this category. The next largest category was FC (e.g., formulating a concept such as a data model), at 17.04%. Papers whose primary focus was evaluation using techniques other than deductive, interpretive, or critical approaches (evaluative-other) were third at 9.87%.

Table 8 (Panel B) shows the primary research approaches by journal. The data shows that FP (formulate-process, method, or algorithm) was the most important research approach in 12 of the 13 journals examined while formulate-concept (FC) was the second most important approach (in 8 out of those 12 journals). *ACM Transactions on Computer–Human Interaction* was the only journal in which the formulative research category did not dominate. Instead, 40% of the papers in that journal were devoted to evaluative studies (evaluative-deductive and evaluative-other at 20% each), with a further 20% devoted to system descriptions (DS). Other journals with significant numbers of evaluative studies were *ACM Transactions on Programming Languages and Systems* (21.15%) and *Journal of the ACM* (20.51%).

Our results suggest, therefore, that the focus in most areas of computer science research is primarily on formulating things.

Table 3
Findings for computing topics

1.0	*Problem-solving concepts*	14.65%
1.1	Algorithms	5.57%
1.2	Mathematics/computational science	6.69%
1.3	Methodologies (object, function/process, information/data, event, business rules,...)	–
1.4	Artificial intelligence	2.39%
2.0	*Computer concepts*	28.67%
2.1	Computer/hardware principles/architecture	10.19%
2.2	Inter-computer communication (networks, distributed systems)	17.68%
2.3	Operating systems (as an augmentation of hardware)	0.80%
2.4	Machine/assembler-level data/instructions	–
3.0	*Systems/software concepts*	19.11%
3.1	System architecture/engineering	0.48%
3.2	Software life-cycle/engineering (including requirements, design, coding, testing, maintenance)	–
3.3	Programming languages	3.82%
3.4	Methods/techniques (including reuse, patterns, parallel processing, process models, data models...)	3.82%
3.5	Tools (including compilers, debuggers)	5.25%
3.6	Product quality (including performance, fault tolerance)	1.75%
3.7	Human–computer interaction	3.18%
3.8	System security	0.80%
4.0	*Data/information concepts*	15.45%
4.1	Data/file structures	1.91%
4.2	Data base/warehouse/mart organization	8.44%
4.3	Information retrieval	3.98%
4.4	Data analysis	0.64%
4.5	Data security	0.48%
5.0	*Problem-domain-specific concepts (use as a secondary subject, if applicable, or as a primary subject if there is no other choice)*	21.50%
5.1	Scientific/engineering (including bio-informatics)	0.48%
5.2	Information systems (including decision support, group support systems, expert systems)	0.64%
5.3	Systems programming	–
5.4	Real-time (including robotics)	0.16%
5.5	Computer graphics/pattern analysis	20.22%
6.0	*Systems/software management concepts*	0.32%
6.1	Project/product management (including risk management)	0.32%
6.2	Process management	–
6.3	Measurement/metrics (development and use)	–
6.4	Personnel issues	–
7.0	*Organizational concepts*	0.32%
7.1	Organizational structure	–
7.2	Strategy	–
7.3	Alignment (including business process reengineering)	–
7.4	Organizational learning /knowledge management	–
7.5	Technology transfer (including innovation, acceptance, adoption, diffusion)	0.16%
7.6	Change management	–
7.7	Information technology implementation	–
7.8	Information technology usage/operation	–
7.9	Management of "computing" function	0.16%
7.11	IT impact	–
7.11	Computing/information as a business	–
7.12	Legal/ethical/cultural/political (organizational) implications	–
8.0	*Societal concepts*	–
8.1	Cultural implications	–
8.2	Legal implications	–
8.3	Ethical implications	–
8.4	Political implications	–
9.0	*Disciplinary issues*	–
9.1	"Computing" research	–
9.2	"Computing" curriculum/teaching	–

Table 4
Findings for research approach

Descriptive:		9.88%
DS	Descriptive-system	4.14%
DO	Descriptive-other	5.10%
DR	Review of literature	0.64%
Evaluative:		10.98%
ED	Evaluative-deductive	1.11%
EI	Evaluative-interpretive	–
EC	Evaluative-critical	–
EO	Evaluative-other	9.87%
Formulative:		79.15%
FF	Formulative-framework	2.39%
FG	Formulative-guidelines/standards	0.64%
FM	Formulative-model	5.73%
FP	Formulative-process, method, algorithm	52.55%
FT	Formulative-classification/taxonomy	0.80%
FC	Formulative-concept	17.04%

Table 5
Findings for research method

AR	Action research	–
CA	Conceptual analysis	15.13%
CAM	Conceptual analysis/mathematical	73.41%
CI	Concept implementation (proof of concept)	2.87%
CS	Case study	0.16%
DA	Data analysis	0.16%
DI	Discourse analysis	–
ET	Ethnography	–
FE	Field experiment	–
FS	Field study	0.16%
GT	Grounded theory	–
HE	Hermeneutics	–
ID	Instrument development	–
LH	Laboratory experiment (human subjects)	1.75%
LR	Literature review/analysis	0.32%
LS	Laboratory experiment (software)	1.91%
MA	Meta-analysis	–
MP	Mathematical proof	2.39%
PA	Protocol analysis	–
PH	Phenomenology	–
SI	Simulation	1.75%
SU	Descriptive/exploratory survey	–

Table 6
Findings for level of analysis

SOC	Society	–
PRO	Profession	0.32%
EXT	External business context	–
OC	Organizational context	–
PR	Project	–
GP	Group/team	–
IN	Individual	1.91%
CS	Computing system	5.57%
CE	Computing element—program, component, algorithm	53.34%
AC	Abstract concept	38.85%

Table 7
Findings for reference discipline

CP	Cognitive psychology	0.80%
SB	Social and behavioral science	–
CS	Computer science	89.33%
SC	Science	0.96%
EN	Engineering	–
EC	Economics	–
LS	Library science	–
MG	Management	–
MS	Management science	–
PA	Public administration	–
PS	Political science	–
MA	Mathematics	8.60%
OT	Other	0.32%

3.3. Findings for research method

Table 5 presents the primary research methods used by CS researchers. Conceptual Analysis/Mathematical (CA/M) (73.41%) was the primary research method with conceptual analysis (not using mathematical techniques) next at 15.13%. Categories such as laboratory experiment (using human subjects), laboratory experiment (software), simulation, and concept implementation are also represented, although none reached double-digits.

Table 8 (Panel C) shows the findings for research method by journal. CA/M was the most important research method in all journals except *ACM Transactions on Computer–Human Interaction (TOCHI)*. The figures ranged from a low of 37.14% in *ACM Transactions on Information Systems (TOIS)* to a high of 90.32% in *ACM Transactions on Graphics* (TOG). In *TOCHI*, which published no studies using CA/M, the leading research methods were conceptual analysis (40%) and laboratory experiment (36%). Concept implementation as a research method was primarily used in TOCHI (16%) and TOIS (11.43%). *TOIS* was also the only journal in which comparative studies of systems (laboratory experiment (software)) was used as the primary research method (14.29%).

3.4. Findings for level of analysis

Table 6 presents the levels of analysis used by CS researchers. It shows that, similar to research approach and research method, CS research was also relatively focused in terms of levels of analysis. The most dominant level of analysis was the Computing Element (CE) category (53.34%), which relates to algorithms, methods, and techniques, e.g., a scheduling algorithm for a crossbar switch. The Abstract Concept (AC) category, which relates to concepts such as the definition of global predicates in the context of distributed computations, was the next largest at 38.85%. Finally, 5.57% of the papers focused on the computing system (CS) level. Two other categories (individual (IN) and profession (PRO))

Table 8
Representation by topic (Panel A), representation by reasearch approach (Panel B), representation by research method (Panel C); representation by level of analysis (Panel D), representation by reference discipline (Panel E)

	Overall	COMP	JACM	KDE	PAMI	PDS	TOCHI	TODS	TOG	TOIS	TOMCS	TON	TOPLAS	VCG
Panel A:														
Prob-solving	14.65%	12.09%	44.87%	28.26%	5.62%	6.06%	–	–	3.23%	2.86%	51.35%	–	1.92%	11.76%
Computer	28.66%	69.23%	26.92%	2.17%	–	68.18%	–	–	–	–	37.84%	96.97%	7.69%	–
Systs/SW	19.11%	16.48%	11.54%	6.52%	–	22.73%	80.00%	3.57%	6.45%	17.14%	5.41%	3.03%	88.46%	–
Data/Info	15.45%	1.10%	16.67%	60.87%	4.49%	1.51%	8.00%	96.43%	–	54.29%	2.70%	–	1.92%	–
Prob-domain	21.50%	1.10%	–	2.17%	89.89%	1.52%	8.00%	–	90.32%	17.14%	2.70%	–	–	88.24
Sys/SW Mgt	0.32%	–	–	–	–	–	–	–	–	5.71%	–	–	–	–
Org'al	0.32%	–	–	–	–	–	4.00%	–	–	2.86%	–	–	–	–
Societal	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Disc issues	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Panel B:														
DO	5.10%	5.49%	–	2.17%	5.62%	–	–	7.14%	3.23%	8.57%	24.32%	3.03%	7.69%	5.88%
DR	0.64%	–	–	4.35%	1.12%	–	4.00%	–	–	–	–	–	–	–
DS	4.14%	3.30%	–	6.52%	2.25%	1.52%	20.00%	3.57%	–	11.43%	10.81%	–	1.92%	11.76%
ED	1.11%	–	–	–	–	–	20.00%	–	6.45%	–	–	–	–	–
EI	–	–	–	–	–	–	–	–	–	–	–	–	–	–
EO	9.87%	7.69%	20.51%	6.52%	6.74%	3.03%	20.00%	7.14%	–	8.57%	10.81%	9.09%	21.15%	–
EC	–	–	–	–	–	–	–	–	–	–	–	–	–	–
FC	17.04%	23.08%	29.49%	17.39%	13.48%	7.58%	8.00%	17.86%	16.13%	8.57%	18.92%	3.03%	28.85%	–
FF	2.39%	–	1.28%	2.17%	8.99%	–	–	3.57%	–	8.57%	–	–	1.92%	–
FG	0.64%	3.30%	–	–	–	–	4.00%	–	–	–	–	–	–	–
FM	5.73%	6.59%	1.28%	13.04%	5.62%	7.58%	4.00%	–	3.23%	17.14%	2.70%	12.12%	–	–
FP	52.55%	50.55%	46.15%	47.83%	56.18%	80.30%	16.00%	50.00%	70.97%	37.14%	32.43%	72.73%	38.46%	82.35%
FT	0.80%	–	1.28%	–	–	–	4.00%	10.71%	–	–	–	–	–	–
Panel C:														
AR	–	–	–	–	–	–	–	–	–	–	–	–	–	–
CA	15.13%	19.78%	–	36.96%	4.49%	12.12%	40.00%	10.71%	3.23%	34.29%	16.22%	24.24%	7.69%	23.53%
CAM	73.41%	69.23%	89.74%	52.17%	89.89%	81.82%	–	78.57%	90.32%	37.14%	72.97%	69.70%	86.54%	70.59%
CI	2.87%	2.20%	–	4.35%	–	–	16.00%	3.57%	–	11.43%	5.41%	–	3.85%	5.88%
CS	0.16%	–	–	–	–	–	–	–	–	–	2.70%	–	–	–
DA	0.16%	–	–	–	–	–	–	–	–	2.86%	–	–	–	–
ET	–	–	–	–	–	–	–	–	–	–	–	–	–	–
FE	–	–	–	–	–	–	–	–	–	–	–	–	–	–
FS	0.16%	–	–	–	–	–	4.00%	–	–	–	–	–	–	–
GT	–	–	–	–	–	–	–	–	–	–	–	–	–	–
HE	–	–	–	–	–	–	–	–	–	–	–	–	–	–
ID	–	–	–	–	–	–	–	–	–	–	–	–	–	–
LH	1.75%	–	–	–	–	–	36.00%	–	6.45%	–	–	–	–	–
LR	0.32%	1.10%	–	–	1.12%	–	–	–	–	–	–	–	–	–
LS	1.91%	1.10%	–	–	1.12%	1.52%	4.00%	7.14%	–	14.29%	–	–	1.92%	–
MP	2.39%	4.40%	10.26%	–	3.37%	–	–	–	–	–	–	–	–	–
PA	–	–	–	–	–	–	–	–	–	–	–	–	–	–
SI	1.75%	2.20%	–	6.52%	–	4.55%	–	–	–	–	2.70%	6.06%	–	–
SU	–	–	–	–	–	–	–	–	–	–	–	–	–	–

Panel D:														
SOC	–	–	–	–	–	–	–	–	–	–	–	–	–	–
PRO	0.32%	–	–	2.17%	1.12%	–	–	–	–	–	–	–	–	–
EXT	–	–	–	–	–	–	–	–	–	–	–	–	–	–
OC	–	–	–	–	–	–	–	–	–	–	–	–	–	–
PR	–	–	–	–	–	–	–	–	–	–	–	–	–	–
GP	–	–	–	–	–	–	–	–	–	–	–	–	–	–
IN	1.91%	–	–	–	–	–	40.00%	–	6.45%	–	–	–	–	–
AC	38.85%	56.04%	42.31%	34.78%	44.94%	12.12%	24.00%	35.71%	22.58%	42.86%	45.95%	36.36%	55.77%	–
CS	5.57%	4.40%	–	10.87%	2.25%	–	20.00%	3.57%	–	17.14%	16.22%	–	7.69%	11.76%
CE	53.34%	39.56%	57.69%	52.17%	51.69%	87.88%	16.00%	60.71%	70.97%	40.00%	37.84%	63.84%	36.54%	88.24%
Panel E:														
CP	0.80%	–	–	–	–	–	20.00%	–	–	–	–	–	–	–
MA	8.60%	1.10%	41.03%	–	7.87%	–	–	–	6.45%	2.86%	18.92%	3.03%	5.77%	–
SB	–	–	–	–	–	–	–	–	–	–	–	–	–	–
CS	89.33%	98.90%	57.69%	97.83%	92.13%	100.00%	72.00%	100.00%	90.32%	97.14%	81.08%	96.97%	94.23%	82.35%
EC	–	–	–	–	–	–	–	–	–	–	–	–	–	–
IS	–	–	–	–	–	–	–	–	–	–	–	–	–	–
MG	–	–	–	–	–	–	–	–	–	–	–	–	–	–
MS	–	–	–	–	–	–	–	–	–	–	–	–	–	–
OT	0.32%	–	–	–	–	–	8.00%	–	–	–	–	–	–	–
SC	0.96%	–	1.28%	2.17%	–	–	–	–	3.23%	–	–	–	–	17.65%

Table 1 presents the journal titles; The shaded areas represent the highest percentage and 2nd highest percentage, respectively.

were below 2%, while the five categories of societal, organizational context, external business context, project, and group/team were not represented.

Table 8 (Panel D) presents level of analysis by journal. The data shows that CE was the primary level of analysis in 8 of the 13 journals. The figures ranged from a low of 51.69% in *IEEE Transactions on Pattern Analysis and Machine Intelligence* to a high of 88.24% in *IEEE Transactions on Visualization and Computer Graphics (VCG)*. Further, AC was the primary level of analysis in four journals ranging from 42.86% to 56.04%, while Individual was the primary level of analysis in *ACM Transactions on Computer–Human Interaction (TOCHI)*. In addition, *TOCHI* and *ACM Transactions on Graphics (TOG)* were the only journals to publish articles that used a non-technical level of analysis (i.e., levels of analysis other than AC, CS [6] or CE) with 40% of the articles in *TOCHI* and 6.45% of the articles in *TOG* focusing on the individual level.

3.5. Findings for reference discipline

Table 7 presents the reference disciplines used by CS researchers. The results suggest that, for the most part, CS research does not rely on other fields for its fundamental theories and/or concepts. Of the papers examined, Computer Science itself was the reference discipline in 89.33% of the cases. The only other discipline that emerged was mathematics (8.60%). There were trivial instances of papers that relied on cognitive psychology (0.80%) and science (0.96%).

Table 8 (Panel E) presents the breakdown of reference discipline by journal. Not surprisingly, computer science was the primary reference discipline in all journals, ranging from a low of 57.69% in *Journal of the ACM (JACM)* to a high of 100% in *IEEE Transactions on Parallel and Distributed Systems*. Mathematics was a major reference discipline in *JACM* with 41% of the articles using concepts directly from that discipline. Only two journals did not have mathematics as their second most important reference discipline (*TOCHI* and *VCG*). Cognitive psychology emerged as a major reference discipline in *TOCHI* (20%) and Science in *VCG* (17.65%).

4. Discussion and implications

In this study, we sought to analyze the characteristics of computer science research according to five research characteristics all of which are recorded in the literature as being important aspects of any research study. We first provide a brief summary of the key findings, followed by a discussion of the some of the limitations of our study.

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[6] Computer System.

CS research is fairly evenly distributed across five major topic areas: problem-solving concepts, computer concepts, systems/software concepts, data/information concepts and problem-domain-specific concepts. The leading category is computer concepts, with problem-domain-specific concepts (principally computer graphics and pattern analysis) second. As would be expected, there is very little work in the area of systems/software management concepts (two papers), one paper on organizational concepts, and no papers that examined societal concepts or disciplinary issues.

In terms of both research approach and research method, CS research tends to be quite focused. The "formulate" research approach category accounts for almost 80% of the research with a majority of papers being devoted to formulating a process, method, or algorithm. The preferred research method is conceptual analysis based on mathematical techniques.

With regard to levels of analysis, CS research falls primarily into the CE or AC categories confirming that the mission of CS is to conduct research that is focused on technical levels of analysis. As would be expected, very little research focused on the society or profession categories.

With respect to reference disciplines, our data shows that CS research seldom relies on research in other disciplines and in the rare instances that it does, it relies primarily on mathematics.

Table 9 presents a summary of the most important research characteristics in each of the 13 journals. The data indicate that while CS research addresses a diverse range of topics, there is a high degree of consistency in terms of the research approaches, research methods, and levels of analysis used to study these topics. Further, across the 13 journals studied, *ACM Transactions on Computer–Human Interaction* is a clear outlier. It is, for example, the only journal not to have FP (formulate process, method or algorithm) as the predominant research approach and CA/M as the predominant research method. From the viewpoint of level of analysis, CE dominates AC by eight journals to four. It is, however, interesting to note that each of the four journals in which AC is dominant focuses on one of the major topic categories; the only topic category that is not the focus of one or more of the journals we studied is problem-domain-specific concepts.

Note that we used our classification system to record the keywords describing this paper (following the abstract). The paper is classified as follows: (a) the topic is computing research (9.1); (b) the research approach is EO (evaluative-other) because our paper is about evaluating CS research; (c) the research method is LR (literature review/analysis); (d) the level of analysis is the profession (PRO); and (e) the reference discipline is none because we did not use concepts from other disciplines in performing the study. We encourage authors in the future to use our classification system not only to select keywords but also to write abstracts. Such a practice would aid researchers to assess the relevance of published research to their own endeavors.

A study of this nature is not without limitations. The first limitation stems from the choice of journals. The results of our study reflect the nature of computer science research to the extent that these journals are representative of the field. While there are many other magazines, and high-quality research conferences that publish CS research articles, we chose to analyze only articles published in journals because of the traditional and enduring role that journals play in the development of academic disciplines. A second potential limitation arises from the fact that we coded only a sample of the articles published in the selected journals. Given, however, that we used a systematic sampling procedure, we have no reason to believe that the results are biased. A final limitation arises from the subjective nature of the coding process. We attempted to reduce the subjectivity by using two independent coders who revisited the articles to resolve any disagreements. The relatively high-level of raw agreements suggests that articles were indeed coded in a consistent manner.

Table 9
Summary of characteristics of journals

Journal	Principal topic	Research approach	Research method	Level of analysis	Reference discipline
TOMCS	Problem-solving	FP	CA/M	AC	CS
JACM	Problem-solving	FP	CA/M	CE	CS
COMP	Computer	FP	CA/M	AC	CS
PDS	Computer	FP	CA/M	CE	CS
TON	Computer	FP	CA/M	CE	CS
TOIS	Data/information	FP	CA/M	AC	CS
TODS	Data/information	FP	CA/M	CE	CS
KDE	Data/information	FP	CA/M	CE	CS
PAMI	Problem-domain-specific	FP	CA/M	CE	CS
TOG	Problem-domain-specific	FP	CA/M	CE	CS
VCG	Problem-domain-specific	FP	CA/M	CE	CS
TOPLAS	Systems/software	FP	CA/M	AC	CS
TOCHI	Systems/software	DS, ED, EO	CA	IN	CS

5. Conclusion

We examined 628 papers (over a 5-year period) in 13 leading research journals in the CS field from 1995 to 1999 to answer questions regarding the nature of CS research. We characterized CS research in terms of the topics, research approaches, research methods, levels of analysis, and reference disciplines used. Our results suggest that CS research focuses on a variety of technical topics, using formulative approaches to study new entities that are either computing elements or abstract concepts, principally using mathematically-based research methods.

The results from our study should be of value to both researchers and doctoral students engaged in computer science research. For example, our study provides a characterization of the types of articles that computer science journals publish. Researchers can use this knowledge to make choices when deciding on a target journal for their research. Our results can also be used to provide insights into areas of CS research that are receiving little research attention. For example, in terms of research approaches, our results clearly suggest that insufficient emphasis is being placed on the use of evaluative methodologies. However, while our results clearly support Tichy et al.'s (1995) claim regarding the lack of focus on evaluation in CS research, Fletcher (1995) cautions that the use of experimental methods may not always be appropriate in computer science, a caveat that should be kept in mind.

Further, funding organizations such as NSF could use the findings of our research to provide focused calls for proposals aimed at fostering research in particular areas or using particular approaches/methods. It is important to note, however, that any interpretation of gaps represented in or findings must take into account the fact the classification scheme was developed to cover a broader scope than computer science, alone, by also including the disciplines of software engineering, and information systems. Hence, for example, while our results clearly show that there is a lack of emphasis on organizational aspects of computing, that is the focus of IS researchers (see Vessey et al., 2002) and does not necessarily represent opportunities for CS researchers.

We hope that our evaluation of the state of current CS research fosters future CS research efforts.

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Ramesh Venkataraman, Ph.D., is an Assistant Professor of Information Systems and Ford Motor Company Teaching Fellow in the Department of Accounting and Information Systems at Kelley School of Business, Indiana University. He has published over 25 papers in leading journals, books, and conferences. His areas of expertise are in database modeling and design, systems design and development, heterogeneous databases, and groupware systems.

Robert L. Glass is president of Computing Trends, publishers of *The Software Practitioner*. He has been active in the field of computing and software for over 45 years, largely in industry (1954–1982 and 1988–present), but also as an academic (1982–1988). He is the author of over 20 books and 70 papers on computing subjects, Editor Emeritus of Elsevier's *Journal of Systems and Software*, and a columnist for several periodicals including *Communications of the ACM* (the "Practical Programmer" column) and *IEEE Software* ("The Loyal Opposition"). He was for 15 years a Lecturer for the ACM, and was named a Fellow of the ACM in 1998. He received an honorary Ph.D. from Linkoping University in Sweden in 1995. He describes himself by saying "my head is in the academic area of computing, but my heart is in its practice."

Iris Vessey is Professor of Information Systems at Indiana University's Kelley School of Business, Bloomington. She received her M.Sc., MBA, and Ph.D. in MIS from the University of Queensland, Australia. Her research into evaluating emerging information technologies from both cognitive and analytical perspectives has been published in journals such as *Communications of the ACM*, *Information Systems Research*, *Journal of Management Information Systems*, and *MIS Quarterly*. In recent years, her interests have focused on managerial issues associated with the management and implementation of enterprise systems. She currently serves as Secretary of the Association for Information Systems and of the International Conference on Information Systems and is an AIS Fellow.