Notion of Semantics in Computer Science A Systematic Literature Review

by

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A Systematic Literature Review

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Abstract

In this paper we report on a Systematic Literature Review where we explored the notion of semantics in Computer Science (CSE) literature. Our goal was 1) to surface how the idea of semantics has been used and represented, and 2) to surface its publication pattern in CSE. Our automated search in 5 CSE repositories yielded 653 relevant papers, emerging from multiple disciplines and geographies, spanning a period from year 1967 to 2017. We shortlisted 50 representative samples to study. This literature review was motivated by an external Web Accessibility effort in which we wanted to understand how to influence the various meanings that a variety of human end-user could derive by varying the computer rendering of a given content. The results of the SLR indicate that 44% of papers do have their own definition, almost all are formal in their presentation, and 94% of them have a notion of semantics that favors the computer as a processor. We observe the limited human oriented focus on semantics in CSE, and suggest such semantics focus as an area of potential study.

1 Introduction

In the scenario of a human interacting with a computer, meaning is getting produced and processed. We are interested in impacting the notion of this *meaning* that is getting created in the human.

Philosophers and Linguists have routinely used the term ”Semantics” to represent the notion of meaning. Now, this notion of semantics has been carried over to Computer Sciences where it has been applied in Natural Language Processing, Programming Languages, Web, Software Engineering etc.

Motivated by impacting human meaning and human sense-making, we are therefore transitively interested in the notion of semantics. However, even for a contained area like Computer Science (CSE), this term has not been unambiguously defined for similar and consistent use universally. Many disciplines within CSE have all made use of this notion of Semantics, but in their own way.

1.1 Goal of this Paper

The goal of this paper is to conduct a Systematic Literature Review on the notion of semantics in CSE. In particular we aim to study the use of this term in the CSE, at least in such disciplines as Programming Languages (PL), Software Engineering (SE), Compilers, Web and NLP. The overall goal being, 1) to surface how the term of semantics has been used and represented in these said disciplines, and 2) to surface the publication pattern on this topic.

1.2 Background, Context & Motivation

In human computer interaction, there is obviously 1) a human, 2) a computing system and 3) an engagement or interaction between the two. The engagement could either be passive (as in browsing or viewing), or active, as in querying or selecting something on the system. In such scenarios, humans are said to be deriving meaning from the representation presented by the computer. The modality for representation can be text, image, audio, video etc. More interactive representation(al experiences) can be animation, video, user interfaces etc. In the case of interaction (as in inputting or programming by the human), the computing system is also processing data to derive meaning. Apparently, both the human and the system can be seen as two processing agents.

The notion of meaning and semantics can, therefore, be applied to either of the two agents. Our interest, however, is on the human formulating meaning. From an information delivery point-of-view, the idea of how meaning is extracted, constructed or possessed by the human is studied by Psychologists, Cognitive Scientists and Information Processing researchers. On this side, topics like Sense-making (Russell et al., 1993), User Experience, Semantic Interaction (Endert et al., 2012) etc. emerge.

As a compliment to the human sense making experience, on the computing side, we may also look at how something can be constructed to deliver a particular meaning. Web Accessibility researchers, claim that currently web content is primarily designed for a majority in mind (Prasad et al., 2014). And that it may not suffice for the individualized needs of a minority of users (Prasad, 2017).

A color blind person, for example, may not benefit in the same way as a non-body disabled user. So, in this regard, on the computing system side of the human computer interaction, does there exist a platform that would enable the creation and simultaneous co-existence of multiple representations for the varying needs of a diverse human end users? Is there sufficient motivation for a system that can *renarrate* and simultaneously have multiple representations of some source text (Prasad, 2017)? That is, a system equally being able to produce colorful content for the majority of users, high contrast and appropriately rendered visuals for the color blind, braille for the visually impaired, in vernacular for the non-English speakers, in tables, diagrams and scientific explanations for the learned etc. These questions form the background context and motivation for our study of semantics in CSE.

1.3 Semantics as "Meaning"

Online dictionary[1] describes Semantics as "the meaning, or an interpretation of the meaning, of a word, sign, sentence, etc." From a linguistic point of view, it relates Semantics to "the study of meaning". Webster's dictionary[2] too shares a similar explanation, and calls semantics as "the study of meanings".

From a human computer interaction point view, the study of semantics can be related to the study of meaning for either the human or the computer. We are keen to uncover how semantics research in CSE has defined and explored this topic.

1.4 SLR - A Research Tool

As already stated, our larger goal is to understand how best to represent either information or data on the system so that it may create the right meaning to the human. To that end we wanted to conduct an exploratory Literature Review for such a social applicable, human oriented web application space.

SLRs have been popularized as a Evidence Based Software Engineering (EBSE) research tool by Kitchenham et al. in a seminal paper (Kitchenham et al., 2004) presented at ICSE 2004, which is a prominent conference for Software Engineers. In particular SLRs have been suggested as a systematic way of exploring a problem space and thus have been suggested as valuable first step in a PhD research effort (Kitchenham et al., 2004).

While SLRs have been popular in the fields of medical sciences, their use in CSE has been limited. However, we are now beginning to find SLRs in various areas of CSE. SLRs are now being published in Information Systems (Okoli and Schabram, 2010), Software Engineering (Kitchenham et al., 2009), Programming Languages (Major et al., 2012), Web (Doğan et al., 2014), Model Driven Engineering (Santiago et al., 2012) etc.

2 Research Method

This SLR follows the guidelines given in (Keele and others, 2007) and is also informed by DARE[3] criteria for SLR.

2.1 Research Questions

The research questions put forth for the documents surfaced by our search strategy (given in section 2.2) include:

RQ1: Was there a definition for semantics in the paper?

RQ2: Was the notion of semantics general, or did it have some sub categories? What where they?

RQ3: Is the notion of semantics oriented towards the human or the computer?

RQ4: What sort of precision did it have in its definitions?

[1] http://www.dictionary.com/browse/semantics?s=t

[2] https://www.merriam-webster.com/dictionary/semantics

[3] Database of Abstracts of Reviews of Effects (DARE): https://www.ncbi.nlm.nih.gov/pubmedhealth/about/DARE/

RQ5: Which research domain did the paper represent within CSE?

RQ6: When was the research published?

2.2 Search Strategy

For the SLR we conducted an automated search, which included five of the most commonly used CSE bibliography repositories. See Table 1. Each of the databases were searched, in the stated order of priority, on the following aspects: 1) the queried records must be CSE papers, 2) they must have the word "semantic" in their title, and 3) they must have the term "definition of semantics" in their body of text. Table 1 lists the exact string and the restrictions that were used for our automated search.

2.3 Paper Selection

Paper selection was based on a set of inclusion, exclusion and quality criteria. The **inclusion criteria** required the document to fulfill the search string, be a peer reviewed primary study, and be an accessible document on the web. Papers with zero citations, papers that were essentially Patents, papers that were on non-CSE topics (like biology/genome) were **excluded**. **Quality criteria** consisted of only selecting papers that were considered long publications (i.e. had to be more than 4 pages), had to be peer reviewed, and had to have some citations.

2.3.1 Selection Process

Once a paper fulfilled our inclusion, exclusion and quality criteria, it was entered into our initial corpus for individual selection. The initial corpus was maintained as Bibtex files in Microsoft Excel worksheet. We expected our initial corpus to be quite large, we planned on manually shortlisting it into a handlable size for evaluation. This shortlisting process was done on Excel by two outside judges. Our aim was to reduce the initial corpus into a more practical size of 50 representative samples. These set of shortlisted records were then to be fed into a document manager to surface the full length documents from the web. For PDF management we used Qiqqa tool[9], and for Bibtex management, we used JabRef tool. This set of 50 shortlisted records, complete with their full body content were then positioned on the Qiqqa tool for data collection.

The data that was used for filtering was Title, Keywords, publication meta-data (like the publisher, journal name, issue details etc), and in some cases Abstracts as well.

2.4 Data Extraction

The intent of this phase is to ensure that we collect appropriate data from each earmarked paper to answer our earlier stated SLR research questions. Here is the criteria that was used for each questions:

RQ1: We used the document management tools[10] to search for various definitions found in the papers. If there were any definitions on the topic related to semantics then we took it as a *YES* count. Else, it was counted as a *NO*.

RQ2: We searched the surfaced papers to uncover the various contexts[11] in which the word semantic was used. If there were any repeatedly used *sub-concepts* of semantics then we recorded it. At the end we expected to have a bag of semantics related concepts and ideas that would form the base for where the CSE research was headed.

RQ3: One key differentiation we wanted to make was to whom the semantics was being made relevant to. Was it the *human* (as a processor of rendered information), or was it the *computer*[12] (as a processor of the input information)? We scanned papers to see how the definitions of semantics were oriented, and incremented the relevant "H" or "C" count as appropriate.

RQ4: Through this question we wanted to see if the papers presumed an earlier (elsewhere) defined notion, or if they took the trouble to define their own working definition. In some cases we expected to also have some loosely defined terminology. So, our measure was on the precision: Was the definition *formal* (with logic and mathematics)? Or, was it *informal* - as in just by English text? Or (as in RQ1) was there *no* definition at all? This was checked and recorded.

RQ5,6: For the last two questions we collected meta data on the publications. Here we wanted to see where the research was emerging from. We wanted to understand which *domains* were active in this research and the *year* of publication.

In addition to the above highlighted data, we

[9]Desktop v.79s for Windows; source:`http://www.qiqqa.com/`

[10]which, in our case, was Qiqqa Desktop

[11]The word context is refers to the research narrative and not the context of corpus within some research.

[12]We treated these two as mutually exclusive even though they need not be.

Databases	Search String	Restrictions	Hits
ACM Digital Library[4]	acmdlTitle:(+semantics) AND content.ftsec:(+"definition of semantics")		282
IEEE Xplore[5]	((definition of semantics) AND "Publication Title":semantics)		67
Science Direct[6]	TITLE(semantics) and (definition of semantics) AND LIMIT-TO(topics, "theoretical computer,logic program,program,definition").	Advanced Search/Expert Search tag; used no theoretical, no books filters	342
SpringerLink[7]	"definition of semantics"	"definition of semantics" anywhere and "semantics" in title; used Articles, Computer Science, English filters	61
Wiley Inter Science[8]	definition of semantics in All Fields AND semantics in Publication Titles	Advanced Search	33
		total	790

Table 1: The CSE bibliographic repositories that were used in the automated search.

also collected such publication related meta data as: Title, Keywords, Author names, Publication, Year, and in some cases, even the Abstract. We used Bibtex for the extraction of this information from the online bibliographies.

Essentially, through this data collection, we sought to surface how computer science research viewed semantics with respect to their own work, and to see how these ideas tallied with our idea of influencing meaning in the minds of an end user.

3 Results

Our initial automated search extracted 790 records, of which 5 records were malformed and irretrievable. In this initial corpus we were able to identify 21 repeat records, 87 with no "semantics", and 32 short papers. That is, overall 140 were eliminated from this initial corpus, resulting in 653 retrievable pruned set of records.

In studying the initial corpus we found that our collection was indeed quite diverse: For example, the publication dates ranged from 1967 to 2017. The locations of publications at least included USA, UK, Germany, Australia, South Africa, Netherlands, Switzerland and Canada. The covered disciplines included Theoretical CSE, Knowledge Engineering, Formal Methods, Programming Languages, Logic Programming, Semantics, Web, Linguistics, Systems, Multimedia, Software Engineering, Artificial Intelligence etc. Even Biology/genome related publications were captured.

From this diverse sample set of 653 records, as per our selection process, we then needed to shortlist a smaller sample size of just 50 records. We used two external judges to help us identify 50 representative samples from the original list of 653. While the choice was somewhat arbitrary, it was still ensured that the reduced set too was sufficiently diverse and indicative of the larger set of 653. Tables 2 and 3 provide a listing of these finalized studies.

The earmarked 50 records were converted into a shortlisted bib file by use of the JabRef tool[13]. The bib file was used by our document manager, Qiqqa, to import the full content. The files were imported from online document repositories given by Table 1. Finally, for subsequent steps involving data extraction, the same Qiqqa tool was then used to manage the 50 uploaded PDFs.

Here is a brief summary of what was uncovered through our data collection process:

3.1 RQ1: Definition

In the first RQ1 we wanted to understand how many, if any, actually even bothered to define the notion of semantics in their research. Our initial presumption was that while the idea of semantics and usage of the term was rampant, the definition was most likely ambiguous and perhaps not sufficiently formal.

The results of our SLR contradicted our assumptions. The data informed us that while 56% (that is, 28 out of 50) papers were indeed assuming a pre-existing notion and definition of semantics, there were also the other 44% that indeed contained definitions. That is, 22 of the 50 samples actually had expressed their notion of semantics.

Upon investigation we found that most of them were either having special applications or were defining niche terms related to semantics. For example, S5[14] for these references. defined the notion of "meaningfulness", S6 had Context Free Grammar (CFG) related semantics, S16 had defi-

[13]Our JabRef tool was part of our TexStudio Latex document editor, and was supported by Qiqqa.

[14]See Tables 2, 3 for listing of 50 sample studies we used in our SLR. Due to the long length, it has been divided into two parts.

ID	Author	Formal Definition Present	hum/com	subtypes	domains
S1	(Ray et al., 1998)	none	comp	correctness	database
S2	(Haghverdi and Scott, 2005)	none	comp	denotational	prog lang
S3	(Hans Bruun, 1991)	none	comp	static	prog lang
S4	(Alexandre Rademaker, 2005)	none	comp	logic	software eng
S5	(Lavelli et al., 1992)	yes - meaningfulness	comp	multilevel	systems
S6	(Vykhovanets, 2008)	yes - CFG related	comp	general	prog lang
S7	(Schwarcz, 1969)	yes	comp	general	nlp
S8	(Juba and Sudan, 2008)	none	comp	universal	nlp
S9	(Winsborough, 1992)	none	comp	graph	compiler
S10	(Andrew Butterfield, 2006)	none	comp	general	compiler
S11	(Glesner, 2005)	none	comp	general	compiler
S12	(Dan R Ghica, 2012)	none	comp	game, denotational	game
S13	(Matos et al., 2010)	none	hum	general	web services
S14	(Pittarello and De Faveri, 2006)	none	comp	general	web
S15	(Yong et al., 2004)	none	hum	general	urban planning
S16	(Alexey L. Lastovetsky, 2001)	yes - abstract lang	comp	general	prog lang
S17	(Benveniste et al., 1991)	none	comp	general	prog lang
S18	(Perdrix, 2008)	yes - for a quantum program	comp	quantum	theoretical, logic
S19	(Bochman, 1998)	yes- for logic programs	comp	stationary and stable class	theoretical, logic
S20	(Blair, 1982)	none	comp	general	theoretical, logic
S21	(Cox and Dang, 2010)	none	comp	general	prog lang
S22	(Velbitskiy, 1977)	yes - a meta lang	comp		prog lang
S23	(Menezes, 2008)	yes - for aspect oriented	comp	denotational, operational, action	prog lang
S24	(Zhou and Zhang, 2017)	none	comp	stable model	theoretical, logic
S25	(Toch et al., 2007)	yes - narrow web service semantics	comp		web services

Table 2: Listing of 50 sample studies we used in our SLR. Due to the long length, it has been divided into two parts. This represents the first part.

nitions to be used in an abstract language, S23 applied semantics to Aspect Oriented Programming concepts etc. Again, the existence of such definitions confirmed to us that work with semantics is not as arbitrary as we had initially presumed.

3.2 RQ2: Subcategories

The intent here was to understand how generic was the application of semantics. Our results suggest that there are indeed many research works and disciplines that discuss semantics at a very high level, but there are also those that sufficiently focused in on the sub topics within semantics.

In our collection, the subtopics that were explored included: denotational semantic (S2), static semantic (S3), logic semantics (S4), multilevel semantics (S5), universal semantics (S8), graph semantics (S9), game semantics (S46), quantum semantic (S18), stationary semantic (S19), stable class (S19), operational semantics (S23), action semantics, stable model semantics (S24), trace semantics (S37) etc. Other notion of semantics include: semantic correctness (S1), semantic relatedness (S27), semantic distance (S27), semantic forgetting, semantic compatibility (S42,44), timed semantics, semantic spaces, semantic models, semantic similarity etc.

3.3 RQ3: Human Vs. Computer Semantics

Through this RQ3 we wanted to uncover a presumption that most of the notion of semantics in CSE was computer oriented and not human oriented. The SLR results confirmed this. We found that 47 out of 50 papers were indeed meant for computers as the processing agent. Only 3 out of the 50 were designed for human as the processing

ID	Author	Formal Definition Present	hum/com	subtypes	domains
S26	(Kravicik and Gasevic, 2006)	none	comp	general	web services
S27	(Xu et al., 2006)	yes - for relatedness of keywords	comp	relatedness, distance	ontology
S28	(Emmon Bach, 2008)	none	comp	general	linguistics
S29	(Bergmann and Gil, 2014)	none	comp	general	workflows
S30	(Dasiopoulou et al., 2010)	none	comp	general	image analysis
S31	(Biancalana et al., 2013)	none	comp	general	social web
S32	(Paolini, 2009)	none	comp	general	theoretical, logic
S33	(Boute, 1988)	yes -for SDL	comp	denotational	systems
S34	(Papaspyrou, 2001)	yes - for C	comp	denotational	prog lang
S35	(Lobo et al., 1991)	yes - Logic	comp		logic
S36	(Broy and Lengauer, 1991)	yes - Logic	comp	predicative, denotational	theoretical, logic
S37	(Puntigam, 1997)	none	comp	trace	prog lang
S38	(Jasmin Christian Blanchette, 2008)	yes - alternatives presented	comp	operational	prog lang
S39	(Thomas Eiter, 2008)	yes - for answer sets	comp	forgetting, stable model	theoretical, logic
S40	(Ouksel and Sheth, 1999)	none	comp	general	Global Info Systems (GIS)
S41	(Millard et al., 2005)	yes- for hypertext	comp	general	hypertext, logic
S42	(Zeng et al., 2006)	yes - compatibility	comp	compatibility	prog lang
S43	(Wehrman et al., 2008)	yes - for ORC	comp	operational, denotational, timed	theoretical; logic
S44	(Zeng et al., 2005)	yes - compatibility	comp	compatibility	web services
S45	(Benthem, 2005)	none	comp	general	logic
S46	(Kessing et al., 2012)	none	hum	general	game
S47	(Baroni and Lenci, 2010)	none	comp	spaces, models, similarity	distributed memory; database
S48	(Abiteboul and Hull, 1987)	yes - IFO database model	comp	general	database
S49	(da Silva et al., 2012)	none	comp	general	workflows; web services
S50	(Titov and Klementiev, 2011)	yes- bayesian parsing	comp	general	nlp

Table 3: Part two, or the remaining listing of 50 sample studies we used in our SLR.

agent.

Upon further investigation, these 3 were either using a specialized concept of semantics or were geared towards a social application. For example S15 had to use human understandable terms like Roof, Window, Gate, Shell, Wall etc to link the graphics to urban planning. S13 used a cell component ontology, and S46 focused on real world physics on game word entities.

This exposed a potential bias for us. It appears that in CSE, most of the ideas related to semantics have indeed been largely designed for computers, and not humans as the processing agent.

3.4 RQ4: Precision in Definition

In continuation of RQ1, we wanted to understand the level of definition precision one could expect out of these papers. For instance, if the papers were formal in their content, then we could expect to see formal term definitions for semantics as well.

Our results indicate that while 42 of the 50 were papers had lot of logic and formalisms in them, only 44% (or 22 papers) had definitions for (portions of) semantics. 5 were informal in their definitions. And 3 assumed that semantics were defined elsewhere. So, we could see the pattern that most of the Logic Programming, Formal Methods and Theoretical CSE works perhaps already had a notion of semantics formally defined elsewhere that they could leverage in these documents. And that there very few documents discussing semantics from scratch.

In the case of working with humans and their sense-making of content, no such formal definitions may exist. Therefore, such research would

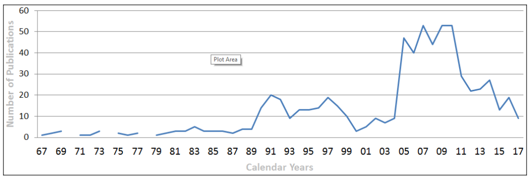

Figure 1: Year-wise histogram of all 653 published papers.

need a more formal definition of semantics – a human oriented semantics – in their publication.

3.5 RQ5: Computer Science Domains

Our goal in RQ5 was to understand which sub areas within Computer Science were actively discussing semantics. Our results indicate that semantics was discussed in multiple sub-areas including: NLP with 3 papers, Programming Languages with 13 papers, Workflows having 2, Databases having 3, Games having 2, Web Services having 5, Logic related papers having 11 and theoretical being 8. Of course, these topics were not mutually exclusive and did overlap. See Figure 2 for a distribution of topics.

The conclusion, therefore, is that notion of semantics is not just restricted to one or two niche areas – like Linguistics, or Programming Languages. There appear to be quite a few emerging areas where semantics – and that too human semantics – can be relevant. For example, mobile web and social web applications has a lot of scope for social and human related content.

3.6 RQ6: Publication History

In RQ6 we wanted to see how hot semantics research has been in the past. We wanted to look at the publication history to draw some context, and from that extrapolate the future outlook for this work.

When we look at the overall corpus of 653 papers, the publications on semantics started in 1967 and continued with just a few publications a year till early 80s. See Figure 1. In the decade of 90s there was a wave of publications for each year contributing to about 10-20 publications each. While 2001-5 was relatively low (with just less than 10 publications a year), the year starting 2005 saw a huge leap in publications: 2006-2011 saw 50-60 publications a year. Starting 2011 to date (2017) we again see a decline in number of papers focused on this topic.

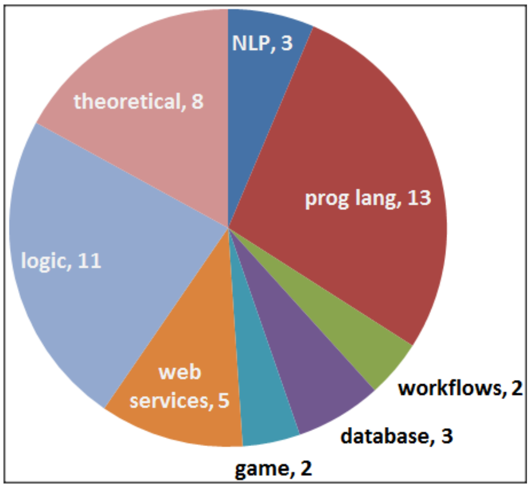

Figure 2: Sub-areas of CSE which published the 50 shortlisted papers.

It appears that semantics had its hayday in the second half of 2005. From 2007 to 20011, that is in the last decade, we could see over 222 publications in this space. However, this number has reduced considerably. In the past five years we could only see 45 publications in this space.

One may interpret this reduction trend to mean that interest in semantics is now waning. However, we take a different stand. We suggest that what is reducing is not interest in semantics, but rather reduction in publications with ”definitions of semantics” in them. This could mean two things for us: 1) There is considerable computer oriented, formal definition of semantics already out there that could be leveraged, and 2) there is an excellent opportunity ahead to further define more human oriented semantics for upcoming mobile and web applications.

3.7 Threats to Validity

We recognize that our study sample is (n=)50 and only represents 8% of our excavated corpus of (n=)653. This sample size does indeed effect our results. In addition, we realize that we only focused on papers that used the word ”semantic” in their title, or on those that had ”definition of semantics” in their body. This also reduces our input corpus.

Broadening our search to also include papers on other related terms could enrich our corpus and through that better inform similar research. But, such resources would come at a cost: They would potentially require more resources in time, effort and reporting. While they may provide more details, but it may only be marginally different information to the pattern of findings a smaller study could feasibly uncover.

4 Discussion & Insights

From our study we gather that semantics is not merely a study of meaning, but it is study of meaning for humans as well as computers (RQ3), both in natural language as well as in technical languages, both in context (as in usage by a human context) or in context-independent manner (as with lexical analysis in linguistics).

In a computing situation, it appears that there are both 1) theoretical studies that explore the formalism (RQ4), the logic – as in (S18-20,24,32,36 – and 2) application studies, that apply it to web (as in Semantic Web), or to Web Services (S13, 25-26,44), or to Work Flows (S29,49). The theoretical studies tend to be formal and use significant logic (RQ4). Apparently they have contributed to design and development of robust programming languages (S2-3,6,16-17, 21-23,34, 37-38,42) and compilers (S9-11).

In the context of Programming Languages, there is Denotational (S2,12,23,33-35,43), Operational (S23,38,43) and Axiomatic Semantics. Also, the Denotational work was supported with Action Semantics (RQ2).

We also saw that there was application of game theory principles to semantics (S12,46), and, on the other side, application of semantics to graphs (S), images (S30), urban planning (S15), genome studies, databases (S47-48), ontologies (S13), semantic web (S14), web services (S13,25-6,49), Hypertext (S41) etc. Semantics seems to have been used to study similarity (S42-44), distance (S27), tuples, stability. It was applied to systems (S5) as well as for forgetting (S39).

We realize that while the generic term is somewhat ambiguous, in CSE, the term is mostly related to the computer as an processing agent model. Only when it comes to social (as in, biological or urban studies) or web applications level (for example with Ontologies) we found a human interpretation to this term.

From a logic and formalism point of view, semantics has been receiving lot of research attention. However, going forward, there seems to be scope to interpret semantics from the point of view of a human processor. Cognitive Linguistics, Psychology, Information Processing might be able to address the emerging need to make processing as a tool to help the human manage and make sense of the information rendered for her.

5 Conclusions

We undertook the SLR study to systematically explore the notion of semantics, as it is applied in CSE. We presumed that the term Semantic was ambiguously or variedly defined in different subareas of CSE research. What we discovered instead is that the notion of semantics is not ill defined. But, however, it seems to be narrowly defined. Working definitions and application specific definitions seem to exist (S5-6,16,18-19,22-23,27,33-36,38-39,41-44,48-49). Moreover, we found that, in the human computer interaction relationship, most of the focus of the semantics is geared towards the computer being able to process the information(S34,50), to present the information (S41), to access the information (S1,47).

Human semantics (influenced by a computing system) has been, in our opinion, under emphasized (S13,15,46). We see this as an opportunity to develop systems, content and architectures to focus on enhancing *meaning* for the human. No doubt, semantic models and analysis is needed for the back-end computing processor agent. However, such models and analysis should also account for and accommodate a better semantic or easier sense-making ability for the human end user as well. That exploration will be our future work.

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