Research in Computing and the nature of the discipline

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1

Presentation for Trinity CS post-grads,
April 2011, Dublin

Computing a professional discipline criss-crossing many subjects?

Many of the modern sciences are of interdisciplinary, "eclectic" type. It is a trend for new sciences to search their methods and even questions in very broad areas. It can be seen as a result of the fact that the communications across the borders of different scientific fields are nowadays much easier and more intense than before.

Gordana DODIG-CRNKOVIC (2005). Scientific Methods in Computer Science

Computing?

- Computing is the action of calculating or counting; the activity or operation of a computer; the action or practice of using a computer, esp. as a professional or expert.

Oxford English Dictionary Online (accessed 11/04/2007)

Computing?

- Computing 'is decidedly a new kind of discipline one in which, for example, theory is not concerned with explaining extant (physical) phenomena, and experimentation is not necessarily concerned with testing whether theory predicts reality.'

- International Review of Research in Computer Science in the UK (2001)

Alan Turing and his Legacy

ALAN MATHISON TURING (born London, 23 June 1912, died Manchester, 7 June 1954)

Mathematician, cryptanalyst, **pioneering** theoretical computer scientist and first of the computer professionals, amongst the founders of computational biology. And an amateur athlete (Walton Athletic Club, Surrey).

All in a brief life of 41 years, 11 months and approximately 15 days.

www.turing.net

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Computing: a Professional Discipline

- Computing is a professional subject much like medicine, the law, or accountancy:
  - The intellectual challenge in a professional subject is always there and inextricably linked with the application.
  - Only in dead subjects there is only theory and no application.
  - Only in mundane branches of human endeavour there is only application and no theory.

Computing: Research in an interdisciplinary enterprise

The diversity of research paradigms within Computer Science may be responsible for the divergences of opinion concerning the nature of Computer Science research.

The fundamental question underlying all computing is:

What can be (efficiently) automated?

Gordana DODIG-CRNKOVIC (2005). Scientific Methods in Computer Science

Computing: a Professional Discipline

- Computing is a professional subject much like medicine, the law, or accountancy:
  - There are theoretical advances in a professional subject (theory of infection in medicine, equality of all before the law, or the concept of limited company);
  - There are experimentations that help the profession to progress (micro-surgery, electronic tagging and 'war crimes', compliance schemes)

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Computing: a Professional Discipline

- Computing is a professional subject much like medicine, the law, or accountancy:
- **Rational Computing**: There are theoretical advances in a professional subject (assemblers, compilers);
- **Empirical Computing**: There are experimentations that help the profession to progress (the personal computer, the Internet, the Grid, programming paradigms)

Computing: Research in an interdisciplinary enterprise

Science Foundation Ireland suggests that research in computing is 'Bold research in numerous disciplines continues to transform the potential of information and communications technologies. Fields that have already contributed to ICT's evolution include the fundamental sciences, the engineering of complex systems and software, low-cost manufacturing technologies, and end-user applications.'

http://www.sfi.ie/home

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Two SFI Projects in the Department – AMAS under Vinny Wade/Owen Conlan and Metropolis under Carol O’Sullivan, are amongst the best examples of interdisciplinary research in Computing

http://www.sfi.ie/home

Computing – the new metaphor

We should, by the way, be prepared for some radical, and perhaps surprising, transformations of the disciplinary structure of science (technology included) as information processing pervades it.

Allen Newell, Artificial Intelligence 25 (1985) 3

Computing – the new metaphor

Initially, c. 1940, Computer Science was net recipient of intellectual input from mathematics, logic, electronics, psychology, organisation theory and human factors (sociology) and (neuro-)biology;

Now, c. 2000, Computer Science is providing intellectual input to other disciplines, notably communications engineering, neuro-biology, molecular genetics, economics and econometrics

Computing – the new metaphor

- Jan 08/Nov 2009 'hot paper' in Computer Science

Article Title: Neural networks based system identification techniques for model based fault detection of nonlinear systems
Authors: Fekih, A;Xu, H;Chowdhury, FN
Journal: INT J INNOV COMPUT INF CONTRO
Volume: 3
Issue: 5
Page: 1073-1085
Year: OCT 2007
* Univ SW Louisiana, Dept Elect & Comp Engn, POB 43890, Lafayette, LA 70504 USA.

http://sciencewatch.com/dr/nhp/2009/09jannhp/09jannhpFeki/

Computing – the new metaphor

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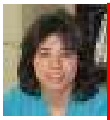

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Why do you think your paper is highly cited?
I think the paper is highly cited because it describes the development and application of a new structure of a neural networks-based system identification technique for nonlinear systems with the specific goal of real-time residual generation for fault detection purposes. The technology was tested on a Boeing 747 model but is of general interest to several complex technological systems.

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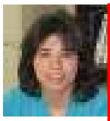

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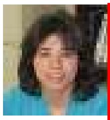

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Does it describe a new discovery, methodology, or synthesis of knowledge?
This paper describes a new structure of partially connected neural networks for real–time residual generation in nonlinear systems. For nonlinear systems, the task of residual generation is sometimes complicated by the size of the problem, or by the lack of a suitable model from where the residual can be generated.

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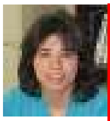

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Does it describe a new discovery, methodology, or synthesis of knowledge?
[.....]
This paper develops and implements a **new structure of partially connected neural networks** for such systems and successfully implements it on a Boeing 747 aircraft model. It also provides a comparison between the **performance of the proposed partially connected neural networks structures and the fully connected one.**

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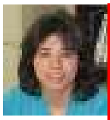

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Would you summarize the significance of your paper in layman's terms?
Residual generation is an essential part of model-based fault detection schemes. This paper presents a new tool for residual generation in nonlinear systems and its application to aircraft systems.

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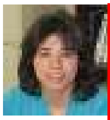
Computing – the new metaphor



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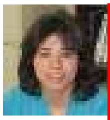
Where do you see your research leading in the future?
Fault detection and identification [FDI] technology is fast becoming an issue of primary significance in intelligent and autonomous control system design since it provides the prerequisites for increased reliability, safety, and system availability, automation of inspection procedures, and minimization and maintenance activities and cost. **Real-time FDI** would insure high performance of technological systems even with impairments to the actuators, sensors, or control surface, and thus increase the system's survivability, and probability of mission success.

http://sciencewatch.com/dr/nhp/2009/09jannhp/09jannhpFeki/

Computing – the new metaphor



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Do you foresee any social or political implications for your research?
Yes. This research is going to change the way we design technological systems in the future. Research into FDI technology is going to grow in importance with the increased complexity of engineering systems along with the stringent requirements on reliability, safety, and performance.

http://sciencewatch.com/dr/nhp/2009/09jannhp/09jannhpFeki/

Computing – the new metaphor

- April 2009 'hot paper' in Computer Science

Article Title: Multi-antenna downlink channels with limited feedback and user selection
Authors: Yoo, T;Jindal, N;Goldsmith, A
Journal: IEEE J SEL AREA COMMUN
Volume: 25
Issue: 7
Page: 1478-1491
Year: SEP 2007
*** Stanford Univ, Dept Elect Engn, Stanford, CA 94305 USA.**
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*** Univ Minnesota, Dept Elect & Comp Engn, Minneapolis, MN 55455 US.**

http://sciencewatch.com/dr/fbp/2009/09aprfbp/09aprfbpYoo//

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Why do you think your paper is highly cited?

Our paper has both theoretical and practical significance. In the communications and information theory community, multiple-input multiple-output (MIMO) systems and multiuser diversity have been among major research topics which have drawn lots of attention and been extensively developed during the past decade. Those are two among several key concepts that will enable higher data rates and/or reliability in the near future for wireless communication systems.

From the theoretical side, information theorists have successfully characterized performance limits of multiuser MIMO channels. In particular, they have shown that the sum capacity of the channel grows in proportion to the number of antennas (multiplexing gain) and double-logarithmically in the number of users (multiuser diversity gain).

http://sciencewatch.com/dr/fbp/2009/09aprfbp/09aprfbpYoo//

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- **Does it describe a new discovery, methodology, or synthesis of knowledge?**
- To our knowledge, ours was the first paper to address and successfully analyze the sum-capacity of large-user MIMO channels with limited feedback. Our paper put together such previous discoveries as MIMO broadcast channel capacity, multiuser diversity, and limited feedback MIMO systems, into a unified mathematical framework.

http://sciencewatch.com/dr/fbp/2009/09aprfbp/09aprfbpYoo//

Novelty in Computing Research

DEVELOP	GENERIC APPLICATION	ELABORATION	SPECIFIC APPLICATION	IMPROVEMENT TO EXISTING PRODUCTS/ SERVICES
MODELS				
ALGORITHMS				

http://www2.smumn.edu/deptpages/~tcwritingcenter/Forms_of_Writing/ResearchProposal.htm

Research in Computer Science

The discipline of Computing is the systematic study of algorithmic processes that describe and transform information: their theory, analysis, design, efficiency, implementation, and application

Gordana DODIG-CRNKOVIC (2005). Scientific Methods in Computer Science

Research in Computer Science

The discipline of Computing is the systematic study of algorithmic processes that describe and transform information: their theory, analysis, design, efficiency, implementation, and application

1. Computer Science is the study of phenomena related to computers.
2. **Computer Science is the study of information structures**
3. Computer Science is the study and management of complexity.
4. **Computer Science is the mechanization of abstraction**

Research in Computer Science

The discipline of Computing is the systematic study of algorithmic processes that describe and transform information: their theory, analysis, design, efficiency, implementation, and application

1. Computer Science is the study of phenomena related to computers.
2. **Computer Science is the study of information structures**
3. Computer Science is the study and management of complexity.
4. **Computer Science is the mechanization of abstraction**
5. Computer Science is a field of study that is concerned with theoretical and applied disciplines in the development and use of computers for information storage and processing, mathematics, logic, science, and many other areas

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Computer Science and shifts in meaning

It is interesting to note that the British/American/Irish term "Computer Science" has an empirical orientation, while the corresponding German and French terms "Informatics" have an abstract orientation.

Gordana DODIG-CRNKOVIC (2005). Scientific Methods in Computer Science

Computer Science: Key Areas

What can be (efficiently) automated?

Three broad areas of inquiry:
Experimental Computer Science;
Theoretical Computer Science;
Simulation and Modeling

Gordana DODIG-CRNKOVIC (2005). Scientific Methods in Computer Science;
www.idt.mdh.se/personal/work/cs_method.pdf

Computing: a Professional Discipline

- **Theoretical research in computer science concerns the power, limits, and costs of computation independent of hardware systems.**
- **A theorem might, for example, characterise a class of problems that cannot be computed by a digital computer, thereby making a statement not only about present-day hardware but also about any digital computing device that might ever be built or conceived.**
- **Theoreticians also derive bounds on the time or memory required by any program that solves problems from a given class (such as searching, sorting, or scheduling).**

Computing: a Professional Discipline

- Sometimes the cost or intractability of a problem is reason for dismay; sometimes not --- the premise of modern cryptography is that reversing certain methods of encryption would be intractable.
- Much of the work in theoretical computer science is mathematical in character. And formal logic is central. By definition, each step in a formal proof must be mechanisable, creating an intimate connection between proof and computation.
- **The study of programming languages, like the study of logic, is concerned with the expressive power of formal notations, with correspondences between syntax (programs) and semantics (what they mean), and with the means by which texts in a formal language can be analysed (automatically or manually) in order to extract truths.**

Computing: a Professional Discipline

- **Experimental work plays a very different role in computer science research from the part it plays in the natural sciences.**
  - Rather than attempting to understand an existing reality, experiments in computer science are often intended to explore new approaches or abstractions.
  - Here, a research prototype might be built, instrumented, deployed, and measured in order to evaluate the strengths and weaknesses of something that the prototype embodies.

Computing: a Professional Discipline

- Experiments are pivotal in the natural sciences when they demonstrate aspects of reality that depart from what current theory predicts and thus defy our understanding; in computer science, it is prototypes that launch paradigm shifts.
  - Building a prototype might expose implicit assumptions,
  - prevent key sub-problems from being ignored by its builders,
  - or allow its users to discover synergies and unanticipated uses issues that would not be addressed if analytical techniques were applied to a paper design.

Computing: a Professional Discipline

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- Timeshared computing, the personal computer (with all its productivity-enhancing software), and the Internet itself, all started as experimental prototypes.

Computing: a Professional Discipline

The PageRank Citation Ranking: Bringing Order to the Web

January 29, 1998

Abstract

The importance of a Web page is an inherently subjective matter, which depends on the readers interests, knowledge and attitudes. But there is still much that can be said objectively about the relative importance of Web pages. This paper describes PageRank, a method for rating Web pages objectively and mechanically, effectively measuring the human interest and attention devoted to them.

We compare PageRank to an idealized random Web surfer. We show how to efficiently compute PageRank for large numbers of pages. And, we show how to apply PageRank to search and to user navigation.

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'Measuring' Research Performance in Computer Science?

The Most-Cited Institutions in Computer Science,1998-2008

Rank	Institutions	Papers	Citations	Cites per paper
1	AT&T	1963	22271	11.35
2	IBM CORP	3210	18663	5.81
3	MIT	2105	16079	7.64
4	UNIV CALIF BERKELEY	1734	16028	9.24
5	STANFORD UNIV	1773	15458	8.72
6	UNIV ILLINOIS	2108	10549	5
7	PENN STATE UNIV	880	10182	11.57
8	ARIZONA STATE UNIV	595	9149	15.38
9	UNIV CALIF SAN	1230	9099	7.4
10	UNIV UPPSALA	439	7832	17.84
11	TOKYO METROPOLITAN UNIV	67	7204	107.52

http://sciencewatch.com/inter/ins/pdf/08octTOP20COM.pdf

'Measuring' Research Performance in Computer Science?

The Most-Cited Institutions in Computer Science,1998-2008

The Computer Science field includes journals that cover the following specific areas of study:

- computer hardware and architecture
- computer software
- software engineering and design
- computer graphics
- programming languages
- theoretical computing
- computing methodologies
- broad computing topics
- interdisciplinary computer applications
- information systems and information technology
- acquisition, processing, storage, management, and dissemination of information
- communications via various devices and systems
- bioinformatics and biostatistics

http://sciencewatch.com/inter/ins/pdf/08octTOP20COM.pdf

'Measuring' Research Performance in Computer Science?

Most cited articles in Computer Science → 1990-2006

Rank	Title	Authors	Citations
1	*Computers and Intractability: A Guide to the Theory of NP-Completeness (1979)*	Garey & Johnson	4137
2	*Introduction to algorithms.* (1991)	Cormen et al	3803
3	*Communicating Sequential Processes (1985)*	Hoare	2697
4	Maximum Likelihood from Incomplete Data via the EM Algorithm. *J. Royal Stats. Soc*	Dempster, Laird, Rubin	2321
5	*Elements of Information Theory (1991)*	Cover & Thomas	2220

http://citeseer.ist.psu.edu/articles.html

'Measuring' Research Performance in Computer Science?

Most cited articles in Computer Science → 1999-2010

Rank	Author	Title of Paper	Title of Publication	Year of Pub.	Total Citations
1	A Dempster, N Laird, Rubin. D.	Maximum likelihood from incomplete data via the EM algorithm.	J Royal Statistical Society	1977	5204
2	S Brookes, C Hoare, A Roscoe.	A theory of communicating sequential processes.	J. ACM	1984	2900
3	J R Quinlan	Induction of decision trees.	Machine Learning	1986	2668
4	I Stoica, R Morris, D Karger, M Kaashoek, H Balakrishnan.	Chord: A scalable peer-to-peer lookup service for Internet applications.	Proc. of the ACM SIGCOMM	2001	2644
5	L R Rabiner.	A tutorial on hidden Markov models and selected applications in speech recognition.	Proc. of the IEEE	1989	2611

http://citeseer.ist.psu.edu/articles.html

'Measuring' Research Performance in Computer Science?

Most cited articles in Computer Science → 1999-2010

Rank	Author	Title of Paper	Title of Publication	Year of Pub.	Total Citations
6	S Kirkpatrick, C D Gelatt, M P Vecchi.	Optimization by Simulated Annealing.	Science	1983	2503
7	R E Bryant.	Graph-based algorithms for boolean function manipulation.	IEEE Transactions on Computers	1986	2471
8	C L Lui, J W Layland.	Scheduling Algorithms for multiprogramming in a hard realtime environment.	J. of the ACM	1973	2357
9	R Sutton, A. Barto.		Reinforcement Learning: An Introduction.	1998	2265
10	R L Rivest, A Shamir, L Adleman.	A method for obtaining digital signatures and public-key cryptosystems,	Comm of the ACM	1978	2230

http://citeseer.ist.psu.edu/articles.html

'Measuring' Research Performance in Computer Science?

Most cited articles in Computer Science → 1999-2010

The publication outlet of the 10 most cited papers between 1999 and 2010 is as follows:

Journal Articles	**70%**
Conference Proceedings	**20%**
Book	**10%**

http://citeseer.ist.psu.edu/articles.html

‘Measuring’ Research Performance in Computer Science?

Most cited articles in Computer Science → 1999-2010

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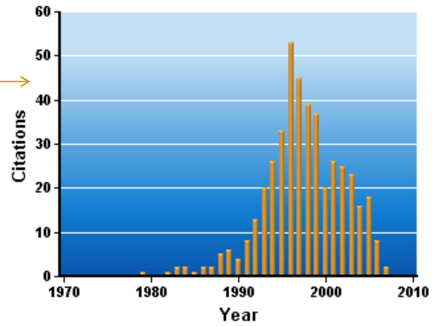
The rise and saturation citations of a research paper → Rivest, Shamir and Adelman.

Cited also because of the free software associated with the paper.



http://citeseer.ist.psu.edu/articles.html

‘Measuring’ Research Performance in Computer Science?

Most cited articles in Computer Science → 1999-2010

11. ***2195*** M Kass, A Witkin, D Terzopolous. *Snakes: Active contour models*. Inter. J. Computer Vision, , 1988.
12. ***2114*** S Ratnasamy, P Francis, M Handley, R Karp, S Shenker. *A scalable content-addressable network*. in Proceedings of the ACM SIGCOMM 2001 Conference, , 2001.
13. ***2092*** S Brin, L Page. *The anatomy of a large-scale hypertextual web search engine*. In WWW7: Proceedings of the 7th International Conference on World Wide Web 7, , 1998.
14. ***2008*** W Diffie, M E Hellman. *New directions in cryptography*. IEEE Transactions on Information Theory, , 1976.
15. ***1955*** M Turk, A Pentland. *Eigenfaces for recognition*. Journal of Cognitive Neuroscience, , 1991.
16. ***1881*** R Agrawal, Srikant. *R.: Fast algorithms for mining association rules*. In: 20th VLDB Conf, , 1994.
17. ***1852*** J M Kleinberg. *Authoritative sources in a hyperlinked environment*. J. ACM, , 1999.
18. ***1834*** S C Deerwester, S T Dumais, T K Landauer, G W Furnas, R A Harshman. *Indexing by latent semantic analysis*. J. of the American Society for Information Science, , 1990.
19. ***1823*** D G Lowe. *Distinctive image features from scale-invariant keypoints*. , 0.
20. ***1816*** D Harel. *Statecharts: a visual formalism for complex systems*. Sci. Comput. Prog, , 1987.

http://citeseer.ist.psu.edu/articles.html

‘Measuring’ Research Performance in Computer Science?

Wireless/Mobile Networks top 5 cited papers 2004-2005

Journal	Title	Authors	Citations
IEEE SIGNAL PROC MAG, Vol 14, pp 49-83, 1997	Space-time processing for wireless communications - Improving capacity, coverage, and quality in wireless networks by exploiting the spatial dimension	Paulraj &Papadis	173
IEEE Trans Inf. Theory, Vol 46, pp388-404, 2000	The capacity of wireless networks	Kumar	161
Proc. IEEE, Vol 86, pp 974-977	Error control and concealment fro video comms – A Review	Wang & Zhu	150
IEEE/ACM Trans of Networks, Vol 5, pp 756-769	A comparison of mechanisms for improving TCP performance over wireless links	Balakrishnan et al	126
IEEE/ACM Trans of Networks, Vol 5, pp 38729	A resource estimation and call admission algorithm for wireless multimedia using shadow clusters	Levine et al	113

http://www.esi-topics.com/wireless/papers/a1.html

‘Measuring’ Research Performance in Computer Science?

Interview with one of the authors of the 2nd most cited paper, Dr. Kumar

- **Your most-cited paper is on the capacity of wireless networks. How did you approach the problem of capacity, and what made it interesting to you?**
- The excitement of wireless, obviously, is that you can dispense with all these wires. You don’t need them to communicate. If you have a laptop and some kind of wireless modem, you can open up your laptop and spontaneously, at any given time, form a network with maybe 1,000 people on your campus or 100 people in your office building. This is what’s called an ad hoc wireless network. There’s no prior infrastructure. What makes them interesting is that they need to be very adaptive. For instance, in the morning there may only be 50 people in this building; in the afternoon, 100. So the number of nodes may change. The position of the nodes changes. But the network itself has to keep functioning.

http://www.esi-topics.com/wireless/interviews/PRKumar.html

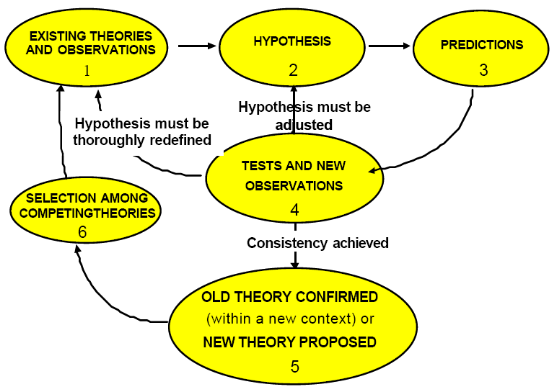
Computer Science: Key Areas

What can be (efficiently) automated?

Theoretical CS	Logic + Mathematics: limits of computation and the power of computational paradigms; formal/conceptual models
Experimental CS: Experiments are:	(a) Used both for theory testing and for exploration (b) Used for testing theoretical predictions against reality. (c)Designed to test the presence of bugs in a theory; not their absence (d) The basis of in search, automatic theorem proving, planning, NP-complete problems, natural language, vision, games, neural nets/connectionism, and machine learning. (e) Conducted to simulate the human brain (neural networks), but were initially rejected on theoretical grounds, but the theory under-reported the salience of NN
Simulation/ Modelling	Applied Maths/Numerical Analysis & input from application discipline. Key areas here include *artificial life, virtual reality, computer games with 'built-in' physics, chaos and non-linear dynamical systems*

Gordana DODIG-CRNKOVIC (2005). Scientific Methods in Computer Science; www.idt.mdh.se/personal/work/cs_method.pdf

A commonly used research model in CS: Hypothetico-deductive method



THE SCIENTIFIC METHOD

Gordana DODIG-CRNKOVIC (2005). Scientific Methods in Computer Science

Computing – the new metaphor

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Allen Newell, Artificial Intelligence 25 (1985) 3

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In particular, as we become more aware of the detailed information processes that go on in doing science, the sciences will find themselves increasingly taking a meta-position, in which doing science (observing, experimenting, theorizing, testing, archiving,) will involve understanding these information processes, and building systems that do the object-level science.

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Then the boundaries between the enterprise of science as a whole (the acquisition and organization of knowledge of the world) and [Soft Computing] AI (the understanding of how knowledge is acquired and organized) will become increasingly fuzzy.

Allen Newell, Artificial Intelligence 25 (1985) 3