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Current Comments®

The Multidisciplinary Impact of Math and Computer Science Is Reflected in the 100 Most-Cited Articles in *CompuMath Citation Index*, 1976-1980

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In citation studies of high-impact articles based on data from *Science Citation Index*® (*SCI*®), some fields consistently dominate—biochemistry, immunology, molecular biology, etc. Other fields, such as mathematics or geosciences, usually are underrepresented. One reason is that the average biochemistry paper cites about twice as many references as the average mathematics paper. Thus, the average biochemist will tend to be more highly cited than the average mathematician. Also, biochemists are more prolific than mathematicians in the number of papers they publish. The size of a field's literature will affect the *range* of citation frequencies, but not the *impact* of the average paper. For example, if a body of literature is ten times greater than that of another, it will have a greater chance of producing "superstar" papers.

By focusing on selected portions of ISI®'s data base, we can identify the most-cited publications and authors from the "smaller" sciences that tend to be suppressed in large-scale citation studies. In 1973, we identified 150 books and articles from math journals that were most cited in *SCI* from 1961 to 1972.[1] We also analyzed about 100 pure and applied math journals indexed in the 1980 *SCI* to see what they cited and what cited them.[2] In another study, we identified the 200 mathematicians most cited during 1978-1979 in about 65 *SCI* math journals.[3]

In this essay, we present the 100 articles most cited from 1976 to 1980 in *CompuMath Citation Index*® (*CMCI*®).[4] *CMCI* was launched in 1982 to serve the information needs of pure and applied mathematicians, computer scientists, statisticians, systems analysts, and researchers in related fields. *CMCI* is published every four months and cumulated in annual editions from 1981 onward. The literature from 1976 to 1980 is covered in a five-year cumulation. The *CompuMath* "system" consists of a *Source Index*, *Citation Index*, and *Permuterm*® *Subject Index*. The organization and uses of these indexes were recently reviewed for *SCI*[5] and *Social Sciences Citation Index*® (*SSCI*®).[6] These essays can serve as "primers" for *CMCI* as well.

Each year, *CMCI* indexes every significant article in about 390 "core" math journals. *CMCI* also selectively covers another 1,800 journals in ISI's data bases. Articles from these journals are *automatically* indexed if they meet the requirements of the selection algorithm. For example, an article is selected for indexing if one or more keywords and phrases in its title matches a dictionary of terms created for *CMCI*. Independent of the title, the algorithm also searches the article's reference list. If it cited two "pure" math journals fully covered in *CMCI*, or one pure *and* two applied math core journals, the article is selected for indexing in *CMCI*. *CompuMath* now provides direct access to 280,000 source articles from 1976 to date and the three million references they cited. This is in addition to coverage of mathematics and computer science in *SCI* from 1955 to 1975.

The present study is based on citation data from the five-year *CMCI* cumulation. The *CMCI* cumulation includes 160,000 articles published from 1976 to 1980 and the two million references they cited. Of these 160,000 articles, about 70 percent were published in 300 "core" math journals fully indexed in *CMCI*. The remaining 50,000 articles were from more than 3,000 journals selectively covered in *CMCI*. Many of these *non*-core articles were from applied physics journals. Thus, we will find that a large number of physics papers are among the most-cited articles in the *CMCI* cumulation. But you should keep in mind that these papers apparently are *of high interest to* math and computer scientists.

Table 1 lists the 100 articles most cited from 1976 to 1980 in *CMCI*. The number of citations each received is shown, followed by full bibliographic information, including the institutional affiliations of the authors. Nineteen of these articles were discussed in *Citation Classics*™ [7] commentaries. They are indicated by asterisks. The issue, year, and edition of *Current Contents*® (*CC*®) in which these commentaries were published follow the reference. A number symbol indicates that the paper was one of the most-cited math articles from 1961 to 1972.[1] The average paper in Table 1 received about 116 citations in the five-year period 1976-1980. Each article was cited at least 77 times. The most-cited paper received 245 citations.

The papers in this study were published in 54 journals. Table 2 lists the journals that published at least two of these papers. The top eight journals account for 38 articles, and they received 4,300 citations. This represents 37 percent of all 12,000 citations to the 100 most-cited *CMCI* articles. Thus, as expected, a small number of journals accounts for the majority of high-impact papers and citations.

It is significant that the *Computer Journal* heads the list in Table 2, accounting for six of the most-cited articles. While *SCI* has always extensively covered the math literature, a systematic effort was made to expand coverage of the computer sciences literature in *CMCI*. About 165 journals and book series never covered in *SCI* are fully indexed in *CMCI*. Most of these newly indexed publications are in the computer sciences. Of the 100 most-cited *CMCI* articles identified here, about 20 are related to various problems in computer science research—algorithms for automatic computation, programming languages, system design, etc.

About 35 physics papers are included in this study. Most of these deal with gauge theories, a mathematical system for describing the four known forces of nature. As explained above, *CMCI* selectively covers many math-dependent journals. The selection algorithm expands *CMCI*'s coverage of the literature *of interest to* math and computer scientists. This includes not only physics but also engineering, psychology, economics, and medical journals.

For example, A.L. Hodgkin and A.F. Huxley, University of Cambridge and University College, London, England, respectively, coauthored a method for measuring current, conduction, and excitation in squid nerves. The paper was published in 1952 in the *Journal of Physiology—London* and was cited 2,400 times in *SCI* from 1961 to 1983. It received about 120 citations between 1976 and 1980 in *CMCI*. Five journals account for half of these *CMCI* citations: *Biological Cybernetics*, *Bulletin of Mathematical Biology*, *Journal of Mathematical Biology*, *Mathematical Biosciences*, and *Biophysical Journal*. Except for the last journal, all of these publica-

Table 1: The 100 articles most cited in 1976-1980 *CMCI*®, in alphabetic order by first author. A number symbol (#) indicates that the article also was one of the most-cited math publications in 1961-1972. An asterisk (*) indicates that the article was the subject of a *Citation Classic*™ commentary.

No. of Cites	Bibliographic Data
128	**Abers E S & Lee B W.** Gauge theories. *Physics Reports C* 9:1-141, 1973. SUNY, Inst. Theor. Phys., Stony Brook, NY.
170	***Ablowitz M J, Kaup D J, Newell A C & Segur H.** The inverse scattering transform-Fourier analysis for nonlinear problems. *Stud. Appl. Math.* 53:249-315, 1974. Clarkson Coll. Technol., Dept. Math. Comput. Sci., Potsdam, NY. 23/82/ET&AS
134	**#Agmon S, Douglis A & Nirenberg L.** Estimates near the boundary for solutions of elliptic partial differential equations satisfying general boundary conditions. I. *Commun. Pure Appl. Math.* 12:623-727, 1959. Hebrew Univ., Inst. Math., Jerusalem, Israel; Univ. Maryland, College Park, MD; New York Univ., New York, NY.
93	***Akaike H.** A new look at the statistical model identification. *IEEE Trans. Automat. Contr.* AC-19:716-23, 1974. Inst. Statist. Math., Tokyo, Japan. 51/81/ET&AS
104	***Astrom K J & Eykhoff P.** System identification—a survey. *Automatica* 7:123-62, 1971. Lund Inst. Technol., Div. Automat. Contr., Lund, Sweden; Eindhoven Univ. Technol., Dept. Elec. Eng., Eindhoven, the Netherlands. 12/80/ET&AS
85	**Atiyah M F & Singer I M.** The index of elliptic operators: III. *Ann. Math.* 87:546-603, 1968. Oxford Univ., Math. Inst., Oxford, UK; Mass. Inst. Technol., Cambridge, MA.
88	**Baskett F, Chandy K M, Muntz R R & Palacios F G.** Open, closed, and mixed networks of queues with different classes of customers. *J. Assn. Comput. Mach.* 22:248-60, 1975. Stanford Univ., Stanford; Univ. California, Los Angeles, CA; Univ. Texas, Austin, TX.
85	**#Bass H.** Finitistic dimension and a homological generalization of semi-primary rings. *Trans. Amer. Math. Soc.* 95:466-88, 1960. Univ. Chicago, Chicago, IL.
216	**Belavin A A, Polyakov A M, Schwartz A S & Tyupkin Yu S.** Pseudoparticle solutions of the Yang-Mills equations. *Phys. Lett. B* 59:85-7, 1975. Acad. Sci., Landau Inst. Theor. Phys., Moscow, USSR.
141	**Box G E P & Cox D R.** An analysis of transformations. *J. Roy. Statist. Soc. Ser. B Metho.* 26:211-43, 1964. Univ. Wisconsin, Madison, WI; Univ. London, Birkbeck Coll., London, UK.
77	**Box G E P & Muller M E.** A note on the generation of random normal deviates. *Ann. Math. Statist.* 29:610-1, 1958. Princeton Univ., Princeton, NJ.
96	**Callan C G, Dashen R F & Gross D J.** The structure of the gauge theory vacuum. *Phys. Lett. B* 63:334-40, 1976. Princeton Univ., Joseph Henry Labs.; Inst. Adv. Study, Princeton, NJ.
93	**Carroll J D & Chang J-J.** Analysis of individual differences in multidimensional scaling via an N-way generalization of "Eckart-Young" decomposition. *Psychometrika* 35:283-319, 1970. Bell Tel. Labs., Murray Hill, NJ.
123	**Chandrasekhar S.** Stochastic problems in physics and astronomy. *Rev. Mod. Phys.* 15:1-89, 1943. Univ. Chicago, Yerkes Observ., Williams Bay, WI.
80	**Ciarlet P G & Raviart P A.** General Lagrange and Hermite interpolation in R^n with applications to finite element methods. *Arch. Ration. Mech. Anal.* 46:177-99, 1972. Road Bridge Central Lab., Serv. Math.; Univ. Paris VI, Dept. Math., Paris, France.
232	**Codd E F.** A relational model of data for large shared data banks. *Commun. ACM* 13:377-87, 1970. IBM Res. Lab., San Jose, CA.
86	**Coleman S.** Quantum sine-Gordon equation as the massive Thirring model. *Phys. Rev. D—Part. Fields* 11:2088-97, 1975. Harvard Univ., Lyman Lab. Phys., Cambridge, MA.
82	**Connes A.** Une classification des facteurs de type III. (A classification of type III factors.) *Ann. Sci. Ecole Norm. Super.* 6:133-252, 1973. CNRS, Ctr. Phys. Theor., Marseille, France.
245	**#Cooley J W & Tukey J W.** An algorithm for the machine calculation of complex Fourier series. *Math. Comput.* 19:297-301, 1965. IBM Watson Res. Ctr., Yorktown Heights, NY; Bell Tel. Labs., Murray Hill; Princeton Univ., Princeton, NJ.
148	**Cox D R.** Regression models and life-tables. *J. Roy. Statist. Soc. Ser. B Metho.* 34:187-202, 1972. Imperial Coll., London, UK.
78	**Dahlquist G G.** A special stability problem for linear multistep methods. *BIT* 3:27-43, 1963. Roy. Inst. Technol., Stockholm, Sweden.
77	**Deser S & Zumino B.** Consistent supergravity. *Phys. Lett. B* 62:335-7, 1976. CERN, Geneva, Switzerland.
88	***Dijkstra E W.** A note on two problems in connexion with graphs. *Numer. Math.* 1:269-71, 1959. Fdn. Math. Ctr., Amsterdam, the Netherlands. 7/83/ET&AS
83	**Durbin J.** Testing for serial correlation in least-squares regression when some of the regressors are lagged dependent variables. *Econometrica* 38:410-21, 1970. London Sch. Econ. Polit. Sci., London, UK.

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187	**Smale S.** Differentiable dynamical systems. *Bull. Amer. Math. Soc.* 73:747-817, 1967. Univ. California, Dept. Math., Berkeley, CA.
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97	**'t Hooft G.** Computation of the quantum effects due to a four-dimensional pseudoparticle. *Phys. Rev. D—Part. Fields* 14:3432-50, 1976. Harvard Univ., Phys. Labs., Cambridge, MA.
79	**'t Hooft G.** Dimensional regularization and the renormalization group. *Nucl. Phys. B* 61:455-68, 1973. CERN, Geneva, Switzerland.
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105	**'t Hooft G.** Symmetry breaking through Bell-Jackiw anomalies. *Phys. Rev. Lett.* 37:8-11, 1976. Harvard Univ., Dept. Phys., Cambridge, MA.
118	**'t Hooft G & Veltman M.** Regularization and renormalization of gauge fields. *Nucl. Phys. B* 44:189-213, 1972. Univ. Utrecht, Inst. Theor. Phys., Utrecht, the Netherlands.
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173	**Weinberg S.** A model of leptons. *Phys. Rev. Lett.* 19:1264-6, 1967. Mass. Inst. Technol., Lab. Nucl. Sci. & Phys. Dept., Cambridge, MA.
89	**Wess J & Zumino B.** Supergauge transformations in four dimensions. *Nucl. Phys. B* 70:39-50, 1974. Karlsruhe Univ., Karlsruhe, FRG; CERN, Geneva, Switzerland.
162	**Wilson K G.** Confinement of quarks. *Phys. Rev. D—Part. Fields* 10:2445-59, 1974. Cornell Univ., Lab. Nucl. Stud., Ithaca, NY.
105	**Wilson K G & Kogut J.** The renormalization group and the ε expansion. *Physics Reports C* 12:75-199, 1974. Inst. Adv. Study, Princeton, NJ; Cornell Univ., Lab. Nucl. Stud., Ithaca, NY.
82	**Wirth N.** The programming language Pascal. *Acta Inform.* 1:35-63, 1971. Swiss Fed. Inst. Technol., Zurich, Switzerland.
145	**Yang C N & Mills R L.** Conservation of isotopic spin and isotopic gauge invariance. *Phys. Rev.* 96:191-5, 1954. Brookhaven Natl. Lab., Upton, NY.
224	***Zadeh L A.** Fuzzy sets. *Inform. Contr.* 8:338-53, 1965. Univ. California, Dept. Elec. Eng. Comput. Sci., Berkeley, CA. 47/80/ET&AS
151	**Zakharov V E & Shabat A B.** Exact theory of two-dimensional self-focusing and one-dimensional self-modulation of waves in nonlinear media. *Sov. Phys. JETP—Engl. Tr.* 34:62-9, 1972. USSR Acad. Sci., Inst. Hydrodynam., Siberian Div., Novosibirsk, USSR.
112	***Zellner A.** An efficient method of estimating seemingly unrelated regressions and tests for aggregation bias. *J. Amer. Statist. Assn.* 57:348-68, 1962. Univ. Wisconsin, Madison, WI. 38/82/S&BS

tions are fully indexed in *CMCI*. *Biophysical Journal* is selectively covered in *CMCI*, as is *Journal of Physiology—London*. Clearly, math is a universal language used by researchers in all fields of science and the social sciences—physics, chemistry, biology, psychology, economics, etc. *CMCI*'s multidisciplinary coverage reflects the extensive application of mathematical and computer methods in many fields.

Pure and applied math papers are also well represented in Table 1, accounting for about 45 of the papers listed. Interestingly, the authors of these math papers reiterate the point made here that researchers in other fields find their research very useful. For example, D.W. Marquardt, E.I. du Pont de Nemours & Co., Wilmington, Delaware, described an algorithm for least-squares estimation of nonlinear parameters. In a *Citation Classic* commentary, Marquardt said, "The growing use of nonlinear models in both the sciences and social sciences...must be a factor in the citation history of this paper."[8] E.L. Kaplan, now at Oregon State University, Corvallis, and Paul Meier, University of Chicago, devised a formula for nonpara-

Table 2: Journals that published two or more of the articles most cited from 1976-1980 in *CMCI*®.

Journal	Articles	Journal	Articles
Comput. J.	6	Bell Syst. Tech. J.	2
Phys. Rev. Lett.	6	Econometrica	2
Phys. Lett. B	5	IEEE Trans. Automat. Contr.	2
Phys. Rev. D—Part. Fields	5	J. Amer. Statist. Assn.	2
Ann. Math.	4	J. Chem. Phys.	2
Ann. Math. Statist.	4	J. Roy. Statist. Soc. Ser. B Metho.	2
Nucl. Phys. B	4		
Psychometrika	4	Physics Reports C	2
Acta Math.	3	Proc. IEEE	2
Comm. ACM	3	Rev. Mod. Phys.	2
Comm. Pure Appl. Math.	3	Technometrics	2

metric estimation from incomplete observations. Kaplan commented that the formula can be applied to problems as diverse as the duration of cancer cells and the lifetimes of vacuum tubes.[9] A.E. Hoerl, University of Delaware, Newark, and R.W. Kennard, formerly of E.I. du Pont de Nemours & Co., explained that their procedure of ridge regression in biased estimation for nonorthogonal problems "pointed out and gave reasons for difficulties in multiple linear regression, a data analysis used in many fields."[10]

Sixty-four institutions were listed in the 100 most-cited *CMCI* articles. They are shown in Table 3. Authors based at US institutions were listed in 62 papers. UK researchers contributed 13 articles. Switzerland and the USSR were listed in five papers each. France, Japan, and the Netherlands follow with four papers each; Federal Republic of Germany, Israel, and Sweden, three each; and Belgium, Czechoslovakia, and Poland, one each.

In a larger population of papers, a number of interesting variables could be analyzed and compared for institutions—impact, or average number of times a given institution's articles were cited; efficiency, or the percentage of its output that was cited and uncited; degree of self-citation, etc. In the future, we'll present a series of institutional citation analyses based on *SCI* data.

Table 4 gives the publication year distribution for the 100 articles in this study. Almost half were published in the

Table 3: The institutional affiliations of authors in descending order.

Institution		Frequency
Princeton Univ., NJ		10
Univ. California, CA		8
Berkeley (Incl. Los Alamos)	5	
Davis	1	
Los Angeles	1	
San Diego at La Jolla	1	
Bell Tel. Labs., Murray Hill, NJ		7
Massachusetts Inst. Technol., Cambridge, MA		6
Univ. Chicago, IL		6
Chicago	5	
Yerkes Observ., Williams Bay, WI	1	
Inst. Adv. Study, Princeton, NJ		5
Acad. Sci. USSR		4
L.D. Landau Inst. Theor. Phys., Moscow	3	
Inst. Hydrodynam., Novosibirsk	1	
CERN, Geneva, Switzerland		4
Cornell Univ., Ithaca, NY		4
Harvard Univ., Cambridge, MA		4
E.I. du Pont de Nemours, Wilmington, DE		3
IBM		3
San Jose Res. Lab., CA	2	
Watson Res. Ctr., Yorktown Heights, NY	1	
Stanford Univ., CA		3
UK Atomic Energy Authority, Atomic Energy Res. Establ. (AERE), Harwell, UK		3
Univ. London, UK		3
Birkbeck Coll.	1	
Imperial Coll. Sci. Technol.	1	
London Sch. Econ. Polit. Sci.	1	
Univ. Wisconsin, Madison, WI		3
Hebrew Univ., Jerusalem, Israel		2
Lund Univ., Sweden		2
New York Univ., NY		2
Queen's Univ. Belfast, Northern Ireland		2
Univ. Delaware, Newark, DE		2
Univ. Leeds, UK		2
Univ. Maryland, College Park, MD		2
Univ. North Carolina, Chapel Hill, NC		2
Univ. Texas, Austin, TX		2
Univ. Tokyo, Japan		2
Bolt Beranek and Newman, Inc., Cambridge, MA		1
Brookhaven Natl. Lab., Upton, NY		1
Carnegie Inst. Technol., Pittsburgh, PA		1
Clarkson Coll. Technol., Potsdam, NY		1
CNRS, Ctr. Phys. Theor., Marseille, France		1
Constructors John Brown Ltd., Leatherhead, UK		1
Czechoslovak Acad. Sci., Prague, Czechoslovakia		1
Eindhoven Univ. Technol., the Netherlands		1
Fdn. Math. Ctr., Amsterdam, the Netherlands		1
Fermi Natl. Accelerator Lab., Batavia, IL		1
Free Univ. Brussels, Belgium		1
Inst. Math., Leningrad, USSR		1
Inst. Statist. Math., Tokyo, Japan		1
Iowa State Univ., Ames, IA		1
Karlsruhe Univ., FRG		1
Kyoto Univ., Japan		1
Math. Soc. France, Paris, France		1
Natl. Veget. Res. Station, Warwick, UK		1
Oxford Univ., UK		1
Poland Acad. Sci., Warsaw, Poland		1

Res. Inst. Adv. Study, Baltimore, MD	1
Road and Bridge Central Lab., Paris, France	1
Roy. Inst. Technol., Stockholm, Sweden	1
SUNY, Stony Brook, NY	1
Swiss Fed. Inst. Technol., Zurich, Switzerland	1
Syracuse Univ., NY	1
Tel Aviv Univ., Ramat Aviv, Israel	1
Univ. Amsterdam, the Netherlands	1
Univ. Bonn, FRG	1
Univ. Cambridge, UK	1
Univ. Montpellier II, France	1
Univ. Paris VI, France	1
Univ. Pittsburgh, PA	1
Univ. Stuttgart, FRG	1
Univ. Utah, Salt Lake City, UT	1
Univ. Utrecht, the Netherlands	1
Vanderbilt Univ., Nashville, TN	1
Yeshiva Univ., New York, NY	1

Table 4: Chronological distribution.

Years	Articles
1940s	3
1950s	9
1960s	40
1970s	48

1970s, all before 1977. Forty papers were published in the 1960s, nine in the 1950s, and three in the 1940s. Before we draw conclusions on the median age of the most-cited publications in *CMCI*, high-impact books also have to be considered. Mathematicians cite books very frequently. For example, the 100 books most cited from 1976 to 1980 in *CMCI* received more than 32,000 citations. In comparison, the 100 journal articles presented here received 12,000 citations. We'll identify and discuss the most-cited *CMCI* books in a separate essay.

Sixteen authors in Table 1 were among the 200 most-cited mathematicians in 1978-1979.[3] Seven of them received the Fields medal, an award comparable in prestige to the Nobel prize.[11] They are: M.F. Atiyah, A. Connes, C. Fefferman, A. Grothendieck, L. Hormander, J.W. Milnor, and S. Smale. The Fields medal is awarded every four years by the International Mathematical Union. The medal is intended to honor mathematicians under age 40 for their outstanding achievements. Only 27 mathematicians have won the Fields medal since the first two were awarded in 1936.

Six authors in Table 1 were also identified in a study of the 1,000 most-cited authors in the 1965-1978 *SCI*.[12] All six are physicists: D.J. Gross, R. Jackiw, B.W. Lee, S. Weinberg, K.G. Wilson, and B. Zumino. In addition to Weinberg and Wilson, four other authors on the list are Nobel laureates. S. Chandrasekhar and C.N. Yang won the prize for physics in 1983 and 1957, respectively. Hodgkin and Huxley were awarded the prize for physiology or medicine in 1963.

As stated earlier, 19 of the most-cited *CMCI* papers have been commented on by their authors. The majority of these papers qualify as *Citation Classics*. Pending a more comprehensive citation analysis of the math and computer science literature covering the 30-year period from 1955 to date, we will write to the authors and invite them to comment on their classic publications. In making these selections we can, and do, rely on data for individual journals. The most-cited articles for each journal may be chosen regardless of their absolute citation counts.

This concludes our discussion of the most-cited papers in the 1976-1980 *CMCI*. In a continuation of this study, we will analyze the most-cited *books* for the same period. In a few years, we'll follow up these studies by identifying a new crop of most-cited articles and books for 1981-1985.

* * * * *

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