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Historiographs, Librarianship and the History of Science

by

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The study of the history of science has recently taken on new importance as an academic discipline. It's easy to see why. With the pace and complexity of scientific developments accelerating, the need for improved guidelines for scientific research becomes more obvious each day. As critical as today's dilemmas of pesticides, pollution, and nuclear weapons are, applications of current scientific research could produce far more serious problems in the future. For example, the work of molecular biologists could produce a happier, healthier world population or, as suggested by some, it could produce some horrible new weapon of war.[1]

Guidelines for scientific research, however, do not simply materialize from thin air. A solid understanding of past developments and the present nature of science itself is required first. Professor Derek de Solla Price claims, "We are getting to the point where there must arise a fairly hard academic discipline to help understand the machinery that makes science act the way it does and grow the way it grows."[2]

By studying the history of science in a more intensive and accurate fashion, we may obtain badly needed insight into such problems as:

a. The role of science in war and peace.
b. The use and misuse of research.
c. The inter-relations of science and technology.
d. The reciprocal responsibilities of scientists and society.
e. The funding and control of science.
f. The determination of future policies on scientific education.
g. The formulation of a public policy on science in general.

With such important questions to be answered, writing the history of science can no longer be looked on as an exercise to satisfy one's curiosity. This endeavor is too important to be fulfilled, as it has been in the past, as an avocation of scientists. What is needed, as in any other complex activity, is a highly trained specialist.

There have been some beginnings towards this objective. In 1950 there were only a handful of professional science historians in North America, and few schools offered doctoral programs. Today we can count at least 500 scholars in the field, while at least 25 major universities offer degree programs in the history of science.

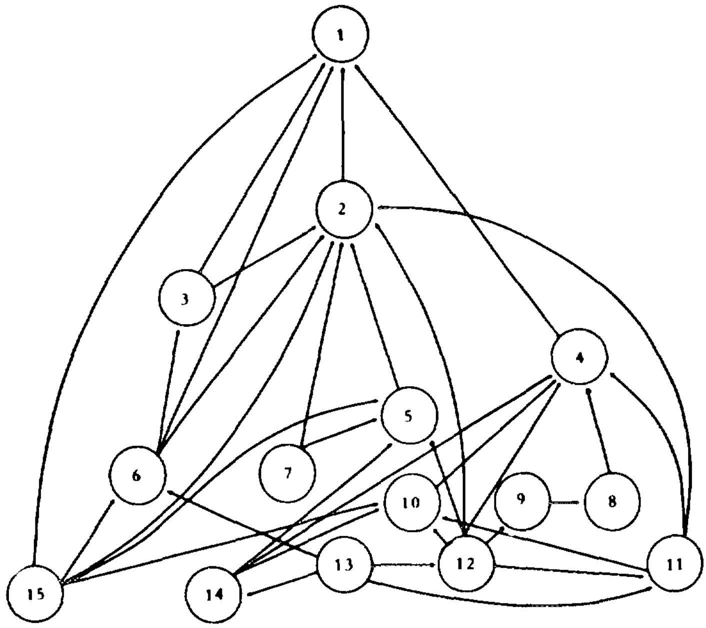
Probably the first full-time historian of science was George Sarton of Harvard who founded *Isis*, the chief journal of the field. In his early work, Sarton was primarily concerned with precise chronological reconstructions of events. In his subsequent work, he used more of a narrative approach and began to analyze and interpret cause and effect relationships. Later, Alexandre Koyré of Princeton attempted to explain the development of a new scientific concept by examining the work of the scientist against the prevailing philosophical and intellectual assumptions of his time. Koyré, however, did not regard a scientist's outer social milieu as an important factor in shaping his work. More recently, historians of science have begun to stress the relationship between new ideas and the outer social order in which they develop.[3]

Whatever the approach, the historian of science will produce useful results only in direct proportion to the investigative and evaluative tools at his disposal. The difficulty of amassing the facts of history is well known. Much human error is injected on the part of the historian despite his dedication and rigorous standards. Even with an event like the assassination of President Kennedy, which was observed by countless persons, there still remains doubt as to precisely what occurred. Writing the history of science has its own particular difficulties. The motivation and evolution of ideas are frequently omitted from scientific writings. Usually, major achievements in science are easily recognized; minor or less heralded contributions are difficult to identify and are often overlooked. Even relatively important events may be missed in the plethora of data to be evaluated. It is not surprising, therefore, that there are always numerous uncertainties in writing even a fragment of the history of science.

Historiographs

A new tool that promises to help the historian of science out of this predicament is the "historiograph," a term coined by the Institute for Scientific Information to describe a graphic display of citation data that shows key scientific events, their chronology, their inter-relationships, and their relative importance. Although the technical feasibility of this tool has been established, and a good portion of the required citation data base is available, much work remains to acquaint the historian of science with its availability and its applications. I feel that this is a role that is most properly filled by the librarian. I also feel that if librarians take advantage of this opportunity, they will be actively participating in a field of growing social significance and will have taken one more step towards achieving the dynamic professional image they desire.

As early as 1922 E. Wyndham Hulme used the term "statistical bibliography" in his lectures at the University of Cambridge. Hulme used the term to describe the process of illuminating the history of science and technology by counting documents. In later years, Pritchard used the word "bibliometrics" to describe the quantitative analysis of citations. Russian historians of science have suggested the use of the term "scientometrics" for this type of study.[4]



Key:

1.	Rabinowitch. 1941	6.	Lawley. 1956.	11.	Steiner. 1959.
2.	Michaelis. 1947.	7.	Peacocke. 1956.	12.	Bradley. 1959.
3.	Michaelis. 1950.	8.	Appel. 1958.	13.	Bradley. 1959.
4.	Zanker. 1952.	9.	Appel. 1958.	14.	Bradley. 1960.
5.	Northland. 1954.	10.	Steiner. 1958.	15.	Loeser. 1960.

Figure 1. Citation Relationships of a Bibliography on Staining Nucleic Acid.

It was almost by accident, however, that Dr. Gordon Allen triggered the activities that led to the development of the historiograph. In a private communication to me in 1960, Dr. Allen diagrammed the relationships between the citations of a bibliography on the staining of nucleic acid as shown in Figure 1. Although Dr. Allen did not think of this diagram in the context of a historical tool, my examination of it lead me to form the hypothesis that, in most cases, a network diagram of citation relationships would, in fact, constitute a fairly reliable "outline" for writing the history of a field of science. This belief was further reinforced in discussions with Bernal,[5] Price,[6] Leake,[7] and Shryock.[8] I then published an article in *American Documentation*[9] in 1963 which summarized my thoughts on the subject and proposed some specific applications.

Testing the Validity of Historiographs

In 1964, the Institute for Scientific Information began work on Air Force Office of Scientific Research Contract AF49(638)-1256 to verify whether citation data are useful heuristic tools for the historian.[10] Essentially, the plan of the study was to construct two network diagrams of the history of a field of science: one based on the traditional historical account, and one based on a reconstruction of the same history by using citation relationships. If the two diagrams coincided to any significant degree, it could be concluded that citation data was, in fact, useful in writing the history of science.

To conduct the study it was necessary to select a recent important scientific break-through which was based on the cumulation of years of diverse scientific achievement. The discovery of the DNA code was selected as this event. The basis for this choice was: (1) the publication in 1963 of Dr. Isaac Asimov's book, *The Genetic Code*,[11] which describes the major scientific developments that led to the laboratory duplication of the process of protein synthesis under control of DNA, and (2) the availability of the *Genetics Citation Index* and the 1961 *Science Citation Index*® to provide the required citation data.

In our study, Dr. Asimov's book was construed as the historian's account of the discovery of the DNA code. The *GCI* and the *SCI*® provided most of the data by which we would attempt to construct a history of the same topic by other than expository accounts.

To construct the two historiographs, we proceeded as follows: first we carefully identified the specific papers involved in the discoveries described by Asimov in his history of DNA. These included events explicitly named by Asimov, as well as events not explicitly named but easily identified by his mention of such things as date or place of investigation. Forty key events (called nodes) were identified (36 explicit, 4 implied) which spanned a period of about 140 years (1820 to 1962). The 40 nodes were then plotted chronologically and grouped in broad subject classifications such as nucleic acid chemistry, protein chemistry, genetics, and microbiology. Asimov's book was then examined to determine the historical relationships between these 40 nodes. The explicit and implicit relationships were then diagramed as shown in Figure 2.

An extensive literature search was then conducted to identify the specific published works related to each node described by Asimov. The strictest criteria were adopted to insure that the reference citations chosen were the ones which most definitely corresponded to the discovery in question. It turned out that 17 of the 40 nodes represented more than one paper. Thus, 65 articles were required to cover the 40 nodes.

The bibliography of each node article was examined to determine the connections between it and other node articles. The 40 nodes were then redrawn in exactly the same positions and lines drawn to show the direct and indirect citation connections as shown in Figure 3. Finally, the two diagrams were superimposed and the degree of coincidence determined. Figure 4 is a summary of the relationships observed from the superimposition of the two diagrams.

From this comparison it was determined that: (a) enough of the network diagrams were coincident so that it could be concluded that citation data could be used to develop the history of a field; and (b) significant new relationships between nodes were identified by citation linkages which did not coincide with Asimov's linkages.

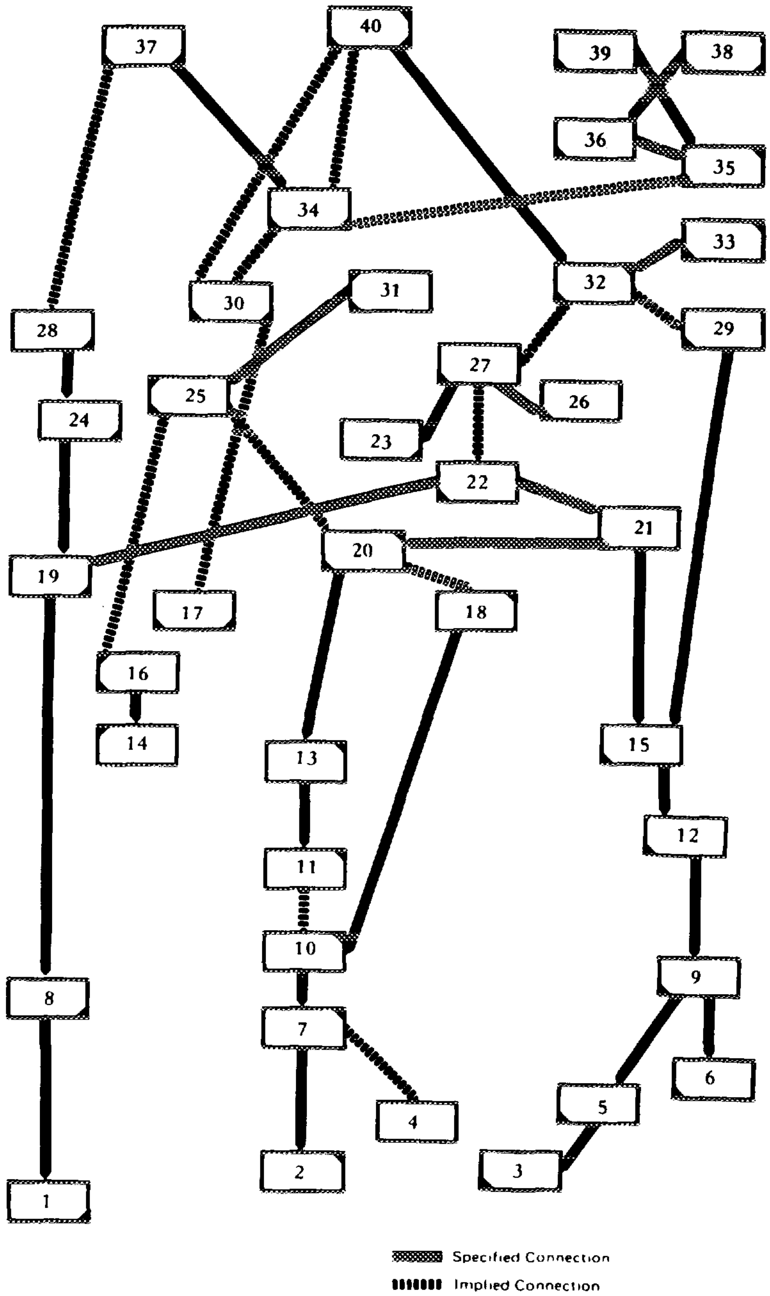


Figure 2. Asimov's Specified and Implied Relationships in the History of DNA

Key for Figures 2 and 3

1. Braconnot. 1820.
2. Mendel. 1865.
3. Miescher. 1871.
4. Flemming . 1879.
5. Kossel. 1886.
6. Fischer, Piloty. 1891.
7. De Vries. 1900.
8. Fisher. 1907.
9. Levene, Jacobs. 1909.
10. Muller. 1926.
11. Griffith. 1928.
12. Levene, Mori, London. 1929.
13. Alloway. 1932.
14. Stanley. 1935.
15. Levene, Tipson. 1935.
16. Bawden, Pirie. 1936/37.
17. Caspersson, Schultz. 1938/39.
18. Beadle, Tatum. 1941.
19. Martin, Synge. 1943/44.
20. Avery, MacLeod, McCarty. 1944.
21. Chargaff. 1947.
22. Chargaff. 1950.
23. Pauling, Corey. 1950/51.
24. Sanger. 1951-53.
25. Hershey, Chase. 1952.
26. Wilkins. 1953.
27. Watson, Crick. 1953.
28. Du Vigneaud. 1953.
29. Todd. 1955.
30. Palade. 1954-56.
31. Fraenkel, Conrat. 1955-57.
32. Ochoa. 1955/56.
33. Kornberg. 1956/57.
34. Hoagland. 1957/58.
35. Jacob, Monod. 1960/61.
36. Hurwitz. 1960.
37. Dintzis. 1961.
38. Novelli. 1961/62.
39. Allfrey, Mirsky. 1962.
40. Nirenberg, Matthaei. 1961/62.

Over and above these findings, it became clear that one picture was indeed worth a thousand words. The graphic displays of the history made it easier and quicker to grasp the total flow of the development of the field. Further, they made it possible to tie-in seemingly unrelated events. It was at this point that we became convinced that the historiograph would be a boon to the historian.

Need for Automatic Diagraming

It soon became obvious, however, that the manual production of historiographs would severely limit the usefulness of this tool. As the number of nodes increased in a history, it soon became almost physically impossible to draw all the connecting lines. Also, as the lines increased, the clarity of the diagram decreased.

In 1967 ISI® began an investigation of the problem of the automatic drawing of network diagrams containing nodes with many interconnections. This work was performed under Air Force Office of Scientific Research Contract AF49(638)-1547 and its objective was to identify an existing method of automatic diagraming or develop a new one that would:

a. Allow algorithmic generation and manipulation of the diagram.
b. Allow the display of 100 or more nodes.
c. Allow the display of an unrestricted number of connections between nodes.
d. Be simple to understand and aesthetically pleasing.
e. Allow direct printout from a digital computer or plotter.

All known methods of automatic diagraming were investigated. These included methods used for:

1. Flow charts and PERT charts[12-26]
2. Organization charts[27]
3. Electronic circuits[28-38]
4. Tree systems[39,40]
5. Routing systems[41-44]

The investigation of previous work uncovered no method that satisfied all specified criteria. Even if all other criteria were met, the displays became inordinately complicated when more than 10 nodes were involved. It was then felt that the solution to this problem was in developing a unique way

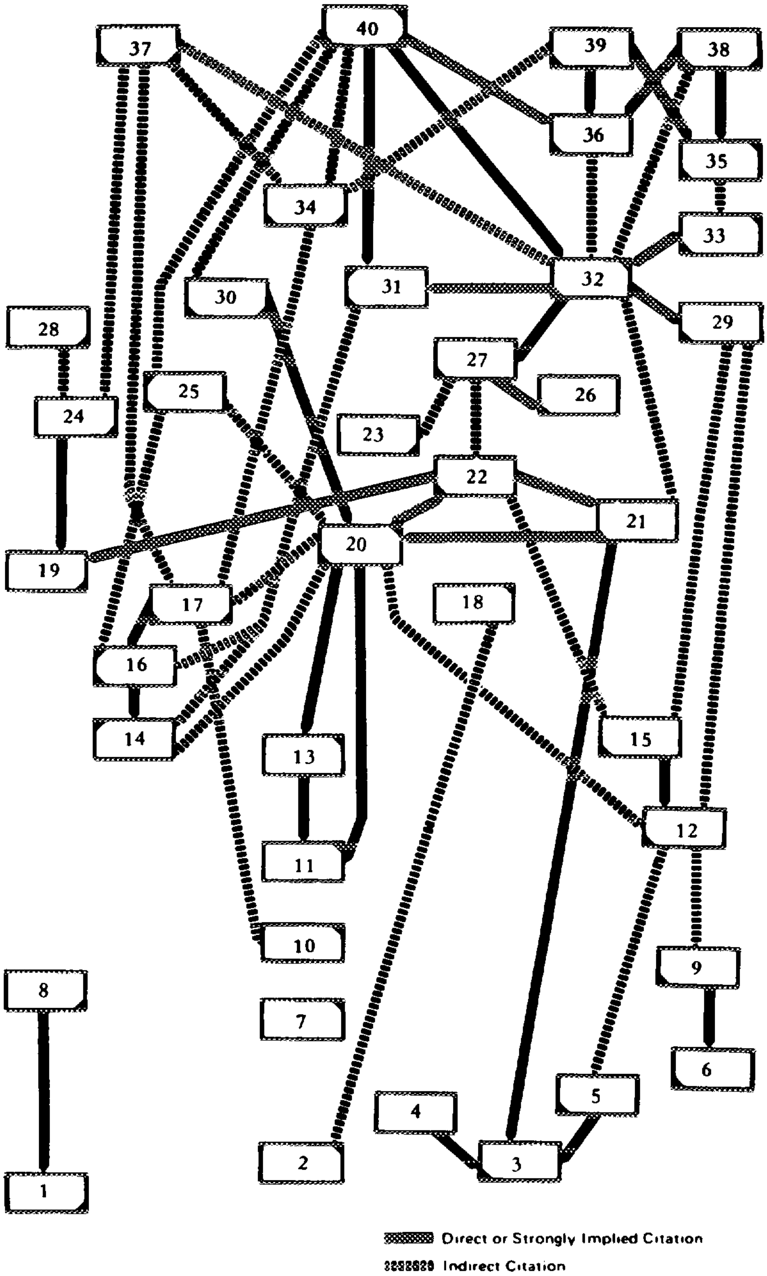


Figure 3. Direct and Indirect Citation Relationships in the History of DNA

of ordering nodes and/or interconnecting lines. Some of the display formats evaluated and rejected included:

a. Linear Array (see Figure 5)
b. Cascade Display (see Figure 6)
c. Waterfall Display (see Figure 7)
d. Rectangular-Node Cascade Display (see Figure 8)
e. Fountain Display (see Figure 9)

Diagonal Display

Finally, the concept of "Diagonal Display" was evolved and refined.[45,46] As shown in Figure 10, Diagonal Display involves arranging the nodes on a diagonal with interconnections shown by lines in the areas adjacent to the nodes. In this original conceptual drawing, the dots indicate a connection between nodes.

Since the Diagonal Display concept had been entirely hand-drawn up to this point, it was now necessary to determine how this type of plot could be drawn automatically. The first attempts involved the use of a standard computer printer. Although this was quite satisfactory for many applications, it was felt that even the addition of special characters to the printer would not give the printout the overall visual clarity desired.

With particular concern for improving the clarity of line junctions and crossovers, we then considered several other types of output devices. Included in these were:

a. Electric lamp display
b. Cathode ray tube (CRT) direct display
c. CRT plotter
d. Incremental pen plotter

It soon became obvious that although each device could be used in the system, the best choice for the type of printout desired would be an incremental pen plotter. Typically, with such a device, digital signals cause the pen to move in increments in linear directions to any point on a sheet of paper. By drawing very small, consecutive increments, the pen can also produce curved lines.

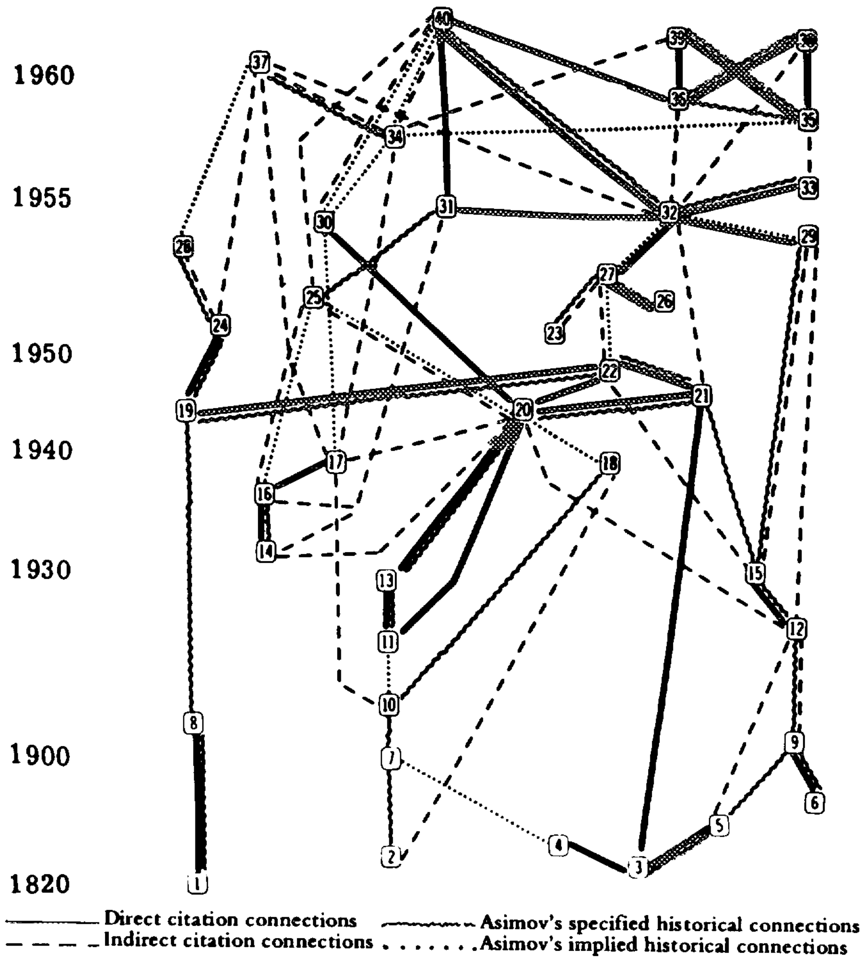
A number of commercially available incremental pen plotters were considered, and a CalComp 563 was selected as the most suitable. An appropriate program was written and several variations of the basic Diagonal Display format shown in Figure 10 were developed, with the most significant modifications being the way connections and crossovers of lines were handled. Most improvements in the selected display format involved the use of gaps in vertical lines to indicate crossovers, rounded elbows to show connections, and the addition of numbers at each elbow to show what nodes were connected at that point.

A printout was generated for the 40 nodes contained in the previously discussed history of the genetic code. This printout is shown in Figure 11. A comparison of Figure 11 with Figure 3 (the hand-drawn network of the DNA history) will make obvious the increased clarity provided by the automatic Diagonal Display.

Another test was conducted to produce a printout for a network with 80 nodes. It was concluded that this was as visually clear as the 40-node printout. In fact, it is now felt that even printouts containing 250 nodes would be equally clear.

To summarize all this, ISI's work has shown:

1. That citation relationships can be of great use in writing the history of a field of science.



DATES, NAMES & NODES

1820	Braconnot-1	1935	Stanley-14	1953	Watson, Crick-27
1865	Mendel-2	1935	Levene, Tipson-15	1953	DuVigneaud-28
1871	Miescher-3	1936-37	Bawden, Pirie-16	1955	Todd-29
1879	Flemming-4	1938-39	Caspersson, Schultz-17	1954-56	Palade-30
1886	Kossel-5	1941	Beadle, Tatum-18	1955-57	Fraenkel-Conrat-31
1891	Fischer, Piloty-6	1943-44	Martin, Synge-19	1955-56	Ochoa-32
1900	DeVries-7	1944	Avery, MacLeod, McCarty-20	1956-57	Kornberg-33
1907	Fischer-8	1947	Chargaff-21	1957-58	Hoagland-34
1909	Levene, Jacobs-9	1950	Chargaff-22	1960-61	Jacob, Monod-35
1926	Muller-10	1950-51	Pauling, Corey-23	1960	Hurwitz-36
1928	Griffith-11	1951-53	Sanger-24	1961	Dintzis-37
1929	Levene, Mori, London-12	1952	Hershey, Chase-25	1961-62	Novelli-38
1932	Alloway-13	1953	Wilkins-26	1962	Allfrey, Mirsky-39
				1961-62	Nirenberg, Matthaei-40

Figure 4. A summary of the relationships observed from superimposition of Figures 2 and 3

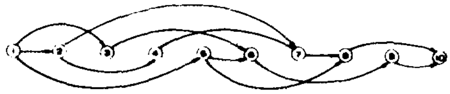


Figure 5. Linear Display

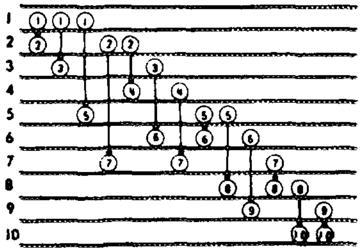


Figure 6. Cascade Display

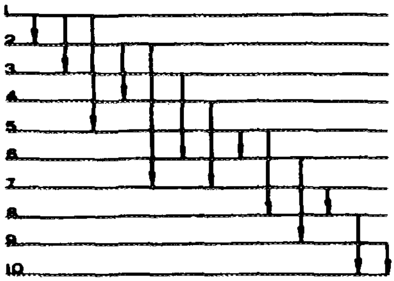


Figure 7. Waterfall Display

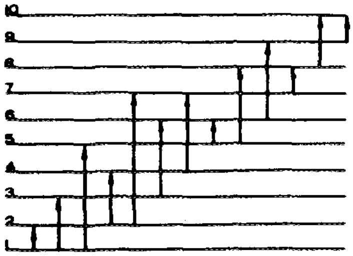


Figure 9. Fountain Display

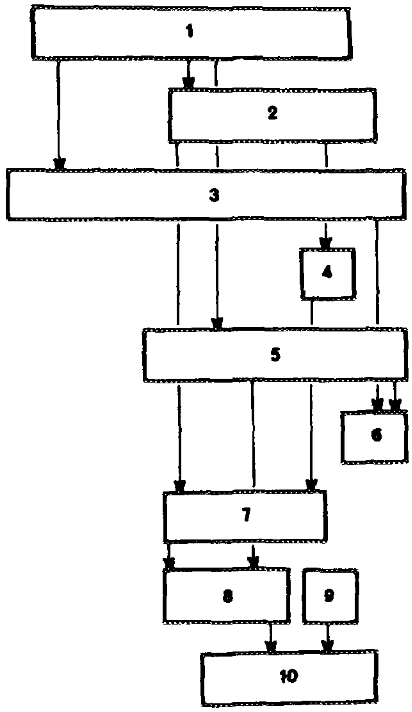


Figure 8. Rectangular-Node Cascade Display

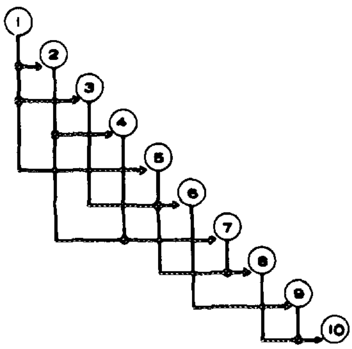


Figure 10. Original Diagonal Display Concept

2. That a graphic representation (historiograph) helps to clarify the relationships and give a quick, over-all view of the development of the field.
3. That relatively large-scale historiographs can be automatically produced on a practical basis.

Applications

Manually *or* automatically drawn historiographs can be used to advantage by the historian of science to:

a. Reduce a large number of seemingly unrelated events to a coherent pattern.
b. Identify classic papers.
c. Identify break-through events within the development of a field.
d. Identify the descendant of a development.
e. Keep track of how often an event influences later events.

Contexts

By removing the vagaries of manual drawing, however, automatically produced historiographs provide additional depth of analysis. For example, because similar relationships will be consistently displayed in the same way, certain types of pattern analyses can be performed. The similarities or differences between the historiograph patterns of one field and those of another could lead to meaningful insights. This type of comparison could also apply to historiographs generated for sub-fields of a larger area of scientific endeavor. Pattern analysis could also be used to identify unusual chronological spacing between events and to determine how fields of science coalesce or fragment. Automatic manipulation also makes it easy to emphasize or leave out certain events in a given history. The historian can then determine if there were alternate paths to subsequent discoveries

Role of the Librarian

At this point, the librarian may legitimately ask, "What has all this to do with me? Of what use will historiographs be to me in my work? Where do I fit in?" Librarians should look on historiographs as tools that rightfully belong in their domain. Just as much as an index is a retrieval tool, so too is the historiograph. For example, what better way could there be for the librarian to select key papers for a newcomer to a field to read than by examining a pertinent historiograph? In the not too distant future I can envision a historian of science requesting information from the library on a specific development. The librarian will then, as he does now, compile an appropriate bibliography by manual or automatic means. However, another step will then take place that will add a new level of importance to the assistance a researcher can expect from a librarian. The librarian will then sit at a computer console (or some similar device) and use the bibliography as input data. He will ask the computer to print out or display all or part of the citation relationships existing in the input bibliography. The librarian will then assist the researcher in identifying key papers or obscure but important papers. The value of this type of service, especially with lengthy bibliographies, is self-evident.

Another important contribution that could be made by a librarian with a historiograph to analyze, would be the identification of a key paper from another field that had an impact on the field of interest. With experience, the librarian might also become skillful at recognizing certain "classic" historiograph patterns. Perhaps then, he will be able to help the historian identify the signs of declining or emerging disciplines.

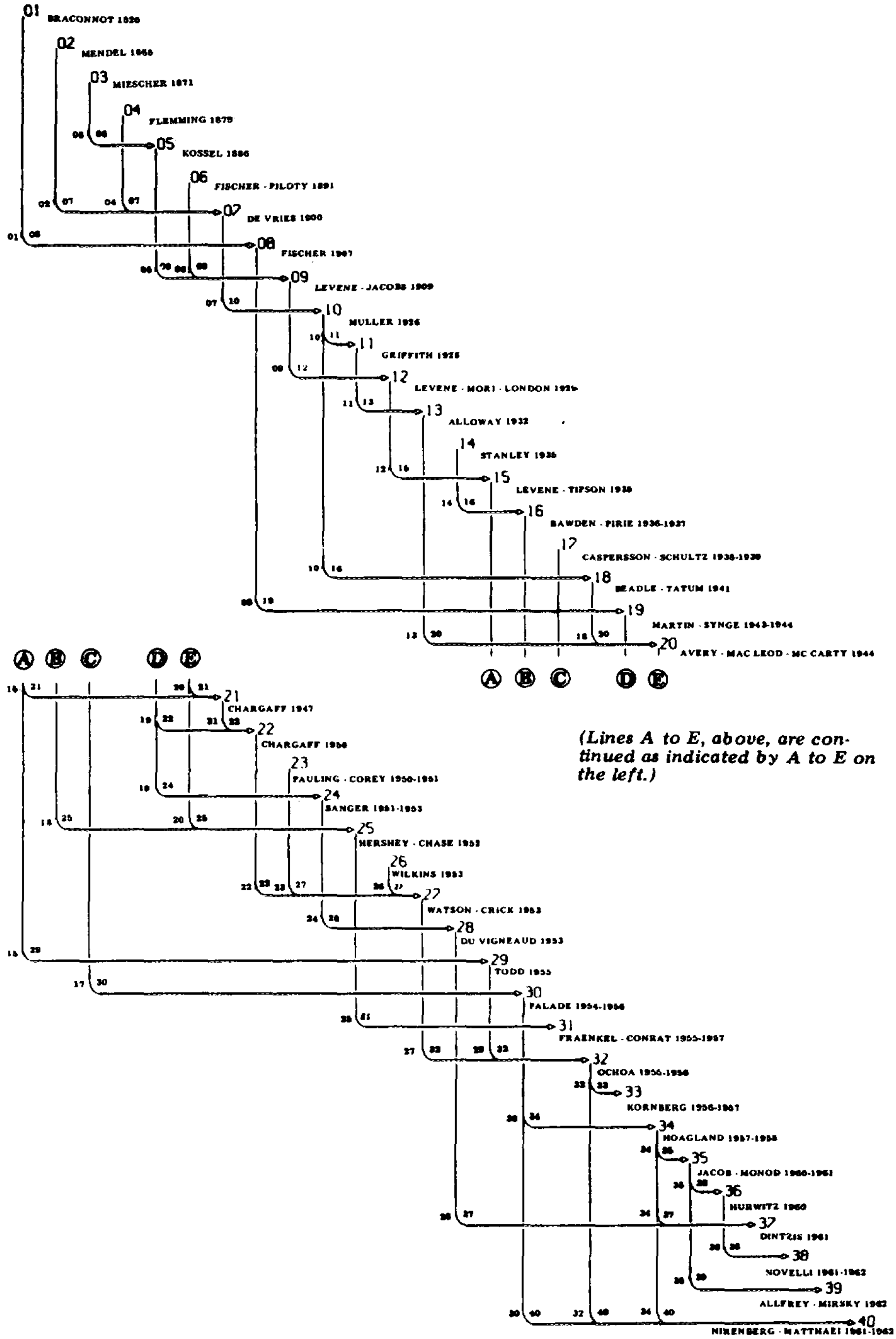


Figure 11. Printout of Computer Generated Diagonal Display

The types of analyses described above can be performed by using historiographs generated from citation data currently contained in the *Science Citation Index*. In the near future, ISI will publish, for the first time, the *Journal Citation Index*.[47] The *JCI* will be a statistical compilation that shows how often other journals cite each of over 2000 journals. The *JCI* will also show how often these 2000 journals cite any of over 25,000 other journals.With this type of data base available, it will be possible to draw historiographs that show relationships between journals rather than individual papers. This, in turn, will permit several additional types of analyses to be made.

For example, it would be possible to show the emergence and growth of a field of science by tracing the history of journals in that field, To do this, a number of journals could be used as nodes in a network. The nodes would be arranged chronologically according to when volume 1 of each particular journal appeared. The citation patterns between the journals over the years could then be drawn and the relationships observed. With this kind of display it would be possible to trace, in terms of journal development, how scientific fields branched out from older existing fields. You could literally tell which journals were the "parents" of other journals. Besides being an aid in writing the history of science, this would also be a useful tool for library science researchers.

Another use for network diagrams made from *Journal Citation Index* data would be to determine what disciplines make up a scientific field. For example, you could start with certain hard-core genetics journals (such as *The American Journal of Human Genetics, Annals of Human Genetics*, and *Genetics)* and have them represented as a kind of bulls-eye node in the center of a network diagram. Then, you could represent other journals which cite these journals or are cited by these journals as other nodes in the diagram. Those journals that had the highest number of inter-citations with the core journals would be positioned closest to the diagram bulls-eye. Those with a lesser number of inter-citations would be placed proportionately further away. Thus, with one diagram, you could get a quick, clear picture of all the disciplines involved in genetics and the extent of their involvement. Not only would this be a help to the historian of science, it would help the librarian in such things as advising the head of a science department on what journals he should receive. There is no need to emphasize the beneficial effect the ability to give such service will have on the professional status of librarians as a group.

A Project for Students

In conclusion, I would like to propose a project that would be quite appropriate for library school students. All the preceding discussion of historiographs and other types of network diagrams presupposes the existence of large-scale citation indexes to provide the data necessary to draw the historiographs. ISI has produced such indexes for all but two years of the 1960's and work is now in progress so that citation indexes for the missing years (1962 and 1963) will be available by the end of 1971. Our goal is to produce total citation index coverage for the literature of the 20th century, and steps are being taken in this direction.

ISI would like to establish a similar goal for the literature of the 19th century. In particular, we would like to start this project by creating citation indexes for the rather limited American scientific literature of that period. Unfortunately, 19th-century scientific authors had very poor citation practices--very few explicit citations were made, although implicit citations were common. Thus, before ISI's citation indexing techniques could be applied, explicit citations would have to be created from the implicit ones. It is the work of creating these explicit citations that I suggest be taken on by library students.

The value of this information to historians of science, and perhaps to civilization, would begin to approach the magnitude of the respect we all have for Jesse Shera.[48]

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48. For readers who may not know him, Jesse Hauk Shera, for many years Dean of the School of Library Science at Case Western Reserve University, has been not so much a legend in his own time, as a phenomenon in the science and art of librarianship. The title of the *Festschrift* in which the paper reprinted here appeared reflects the spirit and striving of his prodigiously productive professional life: *toward a theory of librarianship.*