Some of Dick Garwin's IBM-related Work 1952-1993

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Some background perhaps. I graduated from what is now Case Western Reserve University in April 1947 with a B.S. in Physics and moved to graduate work at the University of Chicago where I received my Ph.D. with Enrico Fermi in December 1949. I was hired to the Physics Department faculty there and worked with the 100-MeV betatron and 450-MeV synchrocyclotron until I left for IBM in December 1952.

I had three summers at the Los Alamos Scientific Laboratory 1950-52 where I worked on nuclear weapon design, test and such things.

I left for IBM for two reasons—Chicago was too dangerous a neighborhood, and I didn't like the sociology of high-energy physics, where I had to specify six weeks in advance what I wanted to do with the cyclotron and preferably work with six people. Now 6 years and 600 or 6000 people.

I preferred deciding each night what I was going to do the next day, and working by myself or with a partner or/and technician. So here is what I am <u>not</u> going to talk about.

I spent many more summers at Los Alamos with my family after I joined IBM by virtue of a unique clause in my 1952 IBM employment agreement, which allowed me to spend "one-third of my IBM time" working with the U.S. government on matters of national security. Initially this was nuclear weapons and other work at Los Alamos during the summers, but later expanded to consulting in Washington with the President's Science Advisory Committee, the Office of Science and Technology, service on the Defense Science Board, and consulting with elements of the intelligence community. In all, considering that I used weekends and IBM vacation, I estimate that I spent about one-half of my time working with the U.S. government. My wife, Lois Garwin, who attended this presentation, continues to extol IBM for its contribution in this regard.

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Nothing about:

Science

Non-conservation of parity,

Liquid and solid He-3,

Gravity-wave detection experiments,

Non-IBM applications

First hydrogen bomb, 1951-2

Arms control such as ABM Treaty of 1972 and Comprehensive Test Ban Treaty of 1996,

Nuclear power

Near-real-time imagery from space,

Putting out the 500 burning wells in Kuwait in 1991,

BP oil spill of 2010,

Fukushima Daiichi reactor meltdowns of 2011, etc

-- all but the first of which were done after I joined IBM in December 1952

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And here is the sort of thing I will talk about, but there are too many, so I have chosen six.

Computer technology

Spin-echo serial data storage, 1954

Thin-film cryotron computer technology and the (first)

.. **IBM superconducting computer project, 1956-**

Carrier-current remote answer-back in Lever House, 1955

Copying and printing technology

Choice of organic photoconductor technology for the IBM

.. **copier, 1965**

IBM 3800 240-page-per-minute computer-room printer, 1970-

Misalignment-tolerant (book-mirror) optics for laser printers, 1980

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Human-computer interaction

Gaze-controlled computers, 1981

Nose/head-controlled computer, 1982?

Touch input for color monitor on original IBM PC, 1980 and **Touch-input smart lecterns, 1982**

"Air bag protection" for laptops, 1993

Algorithmic innovation

Fast Fourier Transform (FFT—Cooley-Tukey algorithm), 1963

-- since 1970, mostly joint work with Jim Levine and Mike Schappert.

Questions welcomed, also by email or in small meetings later. Dick is RLG2@us.ibm.com

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In 1956 I was still at the IBM Watson Scientific Laboratory at Columbia University, directed by Wallace J. Eckert, the astronomer who introduced the punched card into scientific computing in the 1930s. The Laboratory had about 60 people altogether, of whom perhaps 15 were senior scientific or engineering staff. I introduced a practice of reporting on scientific meetings, and, as I recall, one of our engineers reported on a meeting at which he had heard a graduate student at MIT, Dudley Buck, present his invention of cryotron logic—a cross-connected pair of helical control wires and cylindrical gates that would carry a supercurrent stably on the left or on the right, with no dissipation. These could be series-interconnected in large systems and were very interesting, although slow because of the time taken for penetration of magnetic field into the high-conductivity normal state of the tantalum (Ta) "gate."

My own work at the Laboratory was with liquid and solid He-3, using the technique of spin echoes and a copper coil for producing the rf magnetic field to precess the spins in our little sample of 3cc STP of He-3 gas, condensed in the cryostat cell.

Thin-film-cryotron technology

I immediately produced some invention disclosures, revealing that the cryotron did not need to be slow (millisecond range) because the Ta could be in the form of a thin film around a passive Nb core, still wound with a finer Nb-wire control. But the idea of cylindrical interconnected objects did not appeal to me, and so I devised some thin-film planar cryotrons, in which a "meander-line" of thin Nb film would be printed by photolithography or other means over an insulated thin Ta gate, the whole over an Nb ground plane.

Pretty soon I was talking with IBM engineering vice presidents and we had organized an 80-person effort at three laboratories including NYC and the Hudson Valley, to pursue a thin-film cryotron computer. I led this effort until January 1957, when Leon Lederman and I were swept up into our non-conservation of parity discovery, and I resigned from the leadership of the planar cryotron effort. We had solved the problem of speed increase by moving to thin films, and this allowed large-scale integration (LSI) and was the origin of all of the IBM work on silicon LSI, after the planar cryotron effort wound down. The remaining problem was that the transition between superconducting and normal state in a magnetic field was first order and accompanied by the evolution of heat—not so much from the phase change within the material itself, but from the dissipation of inductive energy in the gate of the cryotron pair. So this seemed to limit the cycle time of a cryotron system to about 10 nanoseconds, and it was clear that silicon was going to be faster than that.

I really enjoyed the experimental work. We involved not only researchers at the other labs, but graduate students at the Watson Lab, including Myriam Sarachik, who received her Ph.D. with me and who was to become president of the American Physical Society.

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In 1965 I was asked by Gardiner Tucker, IBM Director of Research at the time, to move to Yorktown to direct Physical Sciences Research, but when I arrived, with my office adjacent to Rolf Landauer, who was newly named director of Applied Research, I realized that I was much more interested in applied research than in physical sciences, and we switched roles on the spot. As I recall, I was responsible for about 600 people, not only at Yorktown, but at the IBM San Jose Laboratory and maybe even Zurich, and there was a lot of catching up to do. I made three major investment decisions, each of about $0.5 million, for an ion-beam fabrication system, an electron microscope, and for the purchase of a 500 kilobit magnetic-core memory, to be shared by the entire Research Division; even $100,000 would now buy 10^8 megabits of much faster memory!

Choice of organic photoconducting film for copiers and printers

I was also on the Defense Department's Defense Science Board and the President's Science Advisory Committee—PSAC—and so had my plate full. I recall that at Christmas 1965, one of my tasks was to see how IBM could move into the office copier field to compete with Xerox, and I received from Cliff Herrick of the San Jose Research Lab a whole range of competing technologies that might be exploited in an IBM office copier.

I chose the organic photoconductor to replace the selenium drum Xerox used, not so much to avoid patents, but because I wanted quickly to demonstrate the technology and to move to production. The idea was to have at least 20,000 copies, and preferably 200,000 before the photoconductor needed to be replaced, and I couldn't see how to demonstrate that on an expedited basis. However, the physical form of the organic photoconductor (OPC) was similar to that of a roll of Saran household wrap, and the great virtue, to me, was that a supply spool could be housed within the photocopying drum, emerging through a slit in the surface, and wrapping around the drum to a take-up roll, also within the drum. So if only 20 K images had been achieved, the copier could stop for a few seconds, index the OPC around the drum, and resume, with the operator unaware of what was happening.

This was leveraged into laser printers-- the IBM 6670 Office Products printer and to the IBM 3800 240-page per minute computer-room printer.

In 1966, I resigned my position as Director of Applied Research to return to the IBM Watson Laboratory, because I could devote only about half my time to that management job, and I felt that others could do at least as well without the outside distractions that I had.

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The 1970s were not without accomplishment, as indicated by my patent file and invention disclosures. But the next thing I want to mention is touch input for the color monitor on the original IBM PC, together with touch-input for Smart Lecterns of which we built and provided to IBM more than 100 for internal education purposes.

By the time IBM entered the PC business with our new team from Boca Raton, the mouse was well established as an input device, but it has its shortcomings, as is evident by comparison with the touch-input ATM in banks.

Levine and I and Mike Schappert early-on wanted to provide touch-input ATMs because IBM was already in the ATM business.

We obtained a commitment from IBM Charlotte that the next version of ATM they brought out would be with our demonstrated touch capability, but they didn't put in the development effort to have it ready when they got the go ahead, and so brought out yet another keyboard-input device and were scooped by competitors.

We had been experimenting with different approaches to touch input and could buy Elographic and other touch-sensitive panels, but we wanted to be able to touch the actual display surface or, in some cases a transparent panel on top of it.

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Touch-input for color monitor of original IBM PC
We had invented a laser-scan input device, which used a diode laser and a PC fan motor with the fan removed, spinning at 60 rps a mirror flake, so that it scanned the plane just above the display 60 times per second. A retroreflective (glass-beaded fabric) cot on the fingertip or stylus would return to the laser a large optical signal when the laser beam was crossing the finger, and this could serve not only to determine the angular position but also the angular breadth (diameter) of the finger in the field of view of the spinning laser.

Initially we had such a laser-scanner in the upper left and in the upper right portion of the display, but soon realized that by replacing a portion of the sheet-aluminum rim of the display mount with a mirror (or better, a 2-D V-groove mirror), one could use a single scanner and its virtual image. We provided such a device also for the assembly floor of a large aerospace firm.

We designed the electronics for a card to plug into the open-architecture data bus of the IBM PC, and demonstrated that we had the ability to input 60 points per second, with an accuracy of about 0.1 pixels. How do you measure 0.1 pixels? By holding the finger firmly in place and tilting it a little bit until the illuminated pixel jumps from one to the next. And, of course, not only are the x- and y- coordinates determined by simple trigonometry from the angle-angle measurements, but also the time of the input point, so that the two angles, measured a few milliseconds apart, can be interpolated to identical time for high-precision needs.

Jim Levine programmed various mock applications for the IBM PC, demonstrating cash-issuing terminals, airline ticket-issuing terminals, and a kiosk that would provide selection for framing and matting a picture that you scanned into the system. We thought this was pretty much the cat's meow and named our various iterations of these touch-input devices after various felines—one of them being "Topcat."

To say that IBM Research and IBM business were lukewarm about this concept would be an overstatement. In fact, for an IBM internal technology show, the Deputy Director of Research told me that I could not show this device, and it took my invoking my rank as IBM Fellow and threatening to resign to enable me to get a place at the show. This was also a time when the TrackPoint (eraser head) was being enthusiastically proposed by IBM Researchers in Almaden, and we helped them with their technology, but we got mostly grief and criticism from IBM in regard to touch input.

Among the criticisms were that people would not tolerate smudges on their screens (answer, fade to gray instead of black if you care), but do people now tolerate smudges on their Smartphones? Another criticism was that of rotating equipment (your PC and laptop probably still have a fan).

In any case, we were having fun and went on to other things, helping Hursley commercialize a touch-input monitor, although we argued that an add-on facility would be more profitable and more flexible.

We did, as I indicated, commercialize the Smart Lectern, together with a suite of software created by Jim Levine for creating and calling up slides and the like.

In addition, IBM sold an add-on touch-sensitive plate for the rack-mounted IBM industrial PC monitor, including one of several touch-sensitive devices that used either piezoelectric pills or strain gauges.

At the time of the collapse of the Soviet Union, I got IBM Research management to authorize any IBM researcher to spend 10% of her or his budget on work done in Russia, in order to take advantage of the low cost and potentially high quality of such work, and I tried to obtain integrated strain-gauge sensors for our touch-input project along these lines. Russian researchers, for the most part, though, preferred to work on what interested them rather than on what could make money for themselves and their institutions.

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We had other means in mind for interacting with computers, and having computers interact with us. One arose in the mid-1960s, when I chaired the Military Aircraft Panel of the President's Science Advisory Committee and flew in helicopters and fighter aircraft, in which display space was both costly and limited. So people wanted to have as large as possible a "horizontal situation indicator" (HSI) and "vertical situation indicator" (VSI), at a time when it was clearly possible to have these various displays all shown on the same physical indicator, in sequence. This before the flat-panel display, so you can imagine how much room and weight was needed in the cockpit.

As for input, we noted that the AH-65 Army helicopter had a helmet-mounted pointing device, and advocated that this be used more broadly in fighter aircraft, for instance in communication between the pilot and the navigation/gunnery officer, so that the gunnery officer could move her or his head to move a blip on the common display, to call attention to the particular item to be highlighted. This could enable automatic steering of the aircraft to that point, and the like.

But displays were capable of perhaps 400-1000 line resolution, and the human eye of 4000-line resolution (at least, that is the resolution in the fovea, corresponding only to about 0.01% of the visual field). Nevertheless, I wanted to provide a "perfect-resolution display" by tracking the gaze—not just the head, and we decided we would implement the elements of such a display in our Lab, since there were no takers among the military services or their contractors, including IBM Federal Systems Division.

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I won't go into the laser-scanned system that we proposed for a perfect-resolution single-user display, but I do talk here about the gaze-tracker that we implemented in the office environment (no helmet) and published. Here are a couple of illustrations from the paper, showing the infrared illuminator and the real-time TV representation of the eye that is used for tracking the gaze.

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In the Figure you see the retro-reflective, uniformly bright image of the pupil, shining by "cat's eye" reflection from the retina returning to the illuminator and separated by a beam splitter onto a TV imaging device. In addition to the elliptical boundary of the pupil, you can see the highlight on the (more or less spherical) cornea of the illuminating beam.

Gaze-controlled computer

In the approximation of a spherical cornea, that highlight doesn't move as the gaze shifts, but the boundary of the pupil does move, and when you sat down at the console, you were provided with a set of 16 sequential crosses, unavoidably looked at and providing a calibration of the gaze field.

But there are many ways still to go wrong, and we worked to provide a useful and convenient means for demonstrating office tasks such as editing.

For instance, we realized that one could have "landing patches" for the gaze—even outside the display area—some of which were replicated and much larger than others—something that could usefully be transferred, even now, to many touch applications on the Smartphone!

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Still, for people with full use of their hands, our original touch-input system was very convenient. Not the case for people with cerebral palsy or those afflicted with trauma-induced paralysis, such as quadriplegics.

We gave a try to experiments with such clients, but found this was too much for our little research group, and we transferred the technology—based on an IBM minicomputer at the time—to the University of Virginia and encouraged that group to travel to England to see whether Stephen Hawking could use the gaze-controlled speech-output device better than his switch-choice words selector.

Ultimately Mike Schappert transferred a version of the technology to the IBM PC from the minicomputer, making it very much more practical, but so far as I know the work has still not been done to make it widely available to the community that could benefit from it. This includes a large number of veterans, and the need and the opportunity seems to fall between the technological challenges addressed by DARPA and what can be procured on the mass market and adapted for veterans and others with special needs.

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My final topic—the Fast Fourier Transform of 1963—54 years ago
This is an example of innovation on my part—not invention. I had a minor problem—to find the periodicity in a computer model of some 20,000 spins on a hexagonal close-packed lattice, in which computer experiments showed me there was regular periodicity, but it wasn't apparent.

I knew statistician John W. Tukey (Princeton and Bell Labs) very well from my government work and usually sat next to him at monthly meetings of the President's Science Advisory Committee (PSAC), and this time I saw him writing Fourier sums. Curious, I asked him whether he knew something I didn't, and he told me that a colleague, I.J. Good of GCHQ in Britain, had a way to double the number of points in a Fourier series without multiplying the number of operations by four. Or, more generally, without the work expanding as the square of the number of points. Never mind my own little problem! I knew of many applications ranging from undersea warfare to design of spacecraft, to digital transformation of photographs that were infeasible with "modern" computers because of the accepted "N-squared" behavior of the Fourier Transform.

To make a short story shorter, the next day I asked Herman H. Goldstine, Director of Mathematics in IBM Research, to find a "numerical analyst" who would work with John Tukey to program this algorithm. Once he was dragooned into doing this, Jim Cooley did a bang-up job, providing a Fortran program that used no more computer memory than the initial data points—no small merit at a time when each bit of computer memory cost a dollar!

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I doubt that John Tukey was particularly happy with this accelerated pace, but I wrote dozens of letters to people I knew personally or whose work in the literature would clearly benefit from the newly born FFT, and the rest is history. Although it is not necessarily done this way, to transform the roughly 10^6 points of a single high-resolution TV frame in order to modify the picture quality by multiplying in the spatial-frequency domain by a given weighting function, would have required some 10^{12} multiplications, and with the FFT requires some 100,000 times less. This was apparently the first of the "fast" algorithms, and perhaps the most important.

I hope this talk gives you some feel for some of the interesting work done by your colleagues at IBM in a few of the fields with which you may not be intimately familiar.