The Birth of Multiple Hypothesis Tracking

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DONALD REID, INTERVIEWED BY CHEE-YEE CHONG, MARCH 2024

Reid's 1979 seminal paper "An algorithm for tracking multiple targets"[1] presents multiple hypothesis tracking (MHT), which has become a significantly popular tracking approach implemented in many systems. Since he left the tracking community shortly after publishing the paper, very few people know about the inventor of this valuable algorithm. This interview provides some missing information.

CC: *You joined the U.S. Air Force after graduating from the U.S. Military Academy at West Point, NY, in 1963. West Point trains mostly future Army officers. How did you end up in the Air Force?*

DR: Way back when I graduated, 1/8 of the class could go into another service. So, I decided to join the Air Force.

CC: *You must have done very well at West Point. How did you get to go to Stanford to get a master's degree as your first assignment?*

DR: I have no idea; those decisions were beyond my pay grade. I was in the top 5% of my class in my junior year, and I was sent to Stanford to get my master's degree in aero- and astronautics. That was during the Vietnam War. I was lucky because some of my West Point classmates were sent to Vietnam and died in action. After graduation I was first assigned to Vandenburg Air Force Base (VFAB), CA, to work on the then classified KH-8/ Gambit program, which launched spy satellites that took images of the Earth using film.

CC: *Can you say what you did on the program?*

DR: First some background. On previous camera spy satellite programs, the contractor (Lockheed Missiles and Space Company) was paid more for meeting the schedule than on how well the satellite was tested to meet performance. So, the satellite was shipped to VAFB before it was completely tested, and then technicians at VAFB (who were not as experienced as those at the factory) would have to retest and fix any technical problems. The new head of the National Reconnaissance Office thought this was a bad idea and decided that the satellites should be completely tested at the factory and then sent directly to the launch pad and mated on top of the booster (a Titan III Rocket). However, just to make sure, he wanted those of us at the base to monitor testing of the satellites at Lockheed before they were shipped to the base. I had the good fortune to be one of those.

CC: *Why did you decide to return to Stanford in 1969?*

DR: One reason I left the Air Force was my boss's boss. For some reason he didn't like me. I didn't know why. Perhaps it was because I was an Academy graduate. My boss was great and gave me a good performance report, but his boss—the endorsing official—put me right in the middle. Right in the middle means I would never get beyond the grade Major if I had stayed in the Air Force. That's when I decided it was time to go back to Stanford and get my PhD.

CC: *You received your PhD in aeronautic and astronautic engineering from Professor Art Bryson in 1972, when the aerospace industry in California was doing very well. Why did you go to the Institute for Defense Analysis (IDA) in the Washington D.C. area and not join Lockheed, Northrop, or other small R&D companies in the San Francisco Bay are,a such as Systems Control?*

DR: Stanford University is very good about inviting potential employers of its new graduates to come to the campus and recruit. I interviewed several companies, and IDA was one of them. I grew up in northern Virginia not far from IDA, and I thought it would be a good time to go back to my roots, but now with a wife and two children. We arrived in the early morning during the middle of a hurricane and got inside our "new" home, which my dad still owned at that time. The home had no furniture or anything. My wife broke down and started crying.

CC: *What did you do at IDA?*

DR: I was in the division of IDA that supported the Weapon Systems Evaluation Group; it was across Shirly Highway from the Pentagon, which was headed by a (three stars) lieutenant general. My job involved lots of travel around different military bases evaluating the status of the weapons, how they were employed, and their sensors. One interesting study was something called target engagement. You started with the sensors on one end and the weapons on the other end, with processing in between.

CC: *Why did you move back to Lockheed Palo Alto Research Lab in 1976?*

DR: I was getting a bit bored with studies. At a conference in San Diego, Herb Rauch (co-inventor of the Rauch, Tung, Strebel smoother) suggested I join him at Lockheed. I decided it's time for us to go back to California. My wife and two little kids left first to find a house. I wanted to live in Palo Alto, near Stanford University. The house that we could have bought for $30,000 when we left in 1972 was now $120,000. I could afford one for only $60,000, so we ended up in San Jose, CA.

[1] Reid, D. B. An algorithm for tracking multiple targets. *IEEE Trans. Auto. Control*, Vol. 24, 6 (1979), 843–854.

CC: *Housing prices have increased a lot since the 1970s. The same house in Palo Alto today will be worth $2 million because of the growth of Silicon Valley companies such as Apple, Oracle, Google, Facebook, etc. What did you work on at Lockheed Palo Alto Research Lab?*

DR: I was expecting when I got there that they would have a job for me. Well, their job for me was to create new jobs for other people in the lab. Specifically, I had to start writing proposals for the internal research and development (IRAD) program, which was funded by the overhead that we charged the government on contracts.

CC: *How did you get into target tracking? What about MHT?*

DR: My boss wanted me to create proposals that we could present to the government for the IRAD program. I had attended conferences that had target tracking and that sounded like an interesting area for me. In fact, I had discussions with Yaakov Bar-Shalom, who worked for a small company (Systems Control) that was about half a mile from where I worked in Palo Alto. This was before he went to the University of Connecticut. I told him about my ideas on delaying association decisions by maintaining multiple hypotheses. He said it was a reasonable idea.

CC: *Bar-Shalom called it "time depth" with revision of probabilistic associations as new data are received. Your 1979 paper had some simulation results. Did you write the program to generate those results?*

DR: The programming language I used was FORTRAN 4. There was an IBM computer card for each line of code. Each computer card was created by me on a key punch machine. In theory, I could have printed the code neatly by hand for a secretary to punch up the cards, but that would have taken two or three times longer than just punching them myself. Also back then, you would draw a long, black line diagonally across the box of cards so that if by some accident you dropped the deck, you could easily get them back in the right order. At this point I should confess that I didn't have a complete target tracking program, but only enough code to create the figures in the paper.

Donald Reid (center) with Yaakov Bar-Shalom (left) and Chee-Yee Chong (right) at FUSION 2018 in Cambridge, UK.

CC: *Getting company approval to publish a paper is quite difficult these days, especially on research supported by an IRAD program. How did you get approval to publish your paper?*

DR: Approval was easy in those days. After completing the Lockheed report that documented the algorithm, I asked my friend Herb Rauch whether he thought it was good enough to publish. He said yes, and I presented the paper at the 1978 IEEE Conference on Decision and Control. The Transactions on Automatic Control version of the paper was published in 1979.

CC: *I have the Lockheed report. The external distribution list includes researchers in other companies that were potential competitors. This type of technical exchange is quite rare today. Your paper has a very simple title but got everyone's attention right away. Why did you leave the tracking field?*

DR: I've often been asked why I didn't continue in the field. The short explanation is a short story. I was in charge of a small group working on an IRAD project that included my brother, Malcolm, and an older gentleman named Robert (Bob) Bryson (no relation to Art Bryson, my PhD advisor at Stanford). These IRAD projects had to be justified every year to Lockheed management. In 1980 I did so to Lockheed's chief scientist from Sunnyvale. In the course of the presentation, I proposed development of a Fusion Center. I had previously worked at IDA on a target engagement task force. In this study, we examined the three areas of reconnaissance, weapons, and command and control, so, I knew that the current buzzword for integrating sensor data was called fusion. Therefore, in my presentation to said chief scientist, I proposed that we work on a Fusion Center. His background, however, was in nuclear engineering, and he objected to my use of the word fusion.

A few weeks later a friend of mine from my Stanford days, Dave Klinger, was in Palo Alto looking for engineers to work for him at Lockheed Missiles and Space in Sunnyvale. Considering the previous information, I told him, "Now might be a good time". I also asked for a raise, which he was able to get for me. I then went to my boss in Palo Alto, told him of Dave's offer, and asked him whether he would give me a raise. He said, "I never stop someone from improving themselves".

CC: *Can you say what you worked on?*

DR: Over the years, I've worked on a number of different satellite programs for Lockheed (and later Lockheed Martin). These usually included work on the attitude determination and attitude control systems, but also included satellite operations. In addition, I've had the pleasure of working in West Germany on two separate 3-year periods in the 1980s and later in England in the 2000s, also on two separate 3-year periods.

CC: *Did you ever regret not continuing on MHT? You could have joined companies such as ORINCON or ALPHATECH, which developed MHT used in real systems, and made a lot of money when they were sold.*

DR: Not until now. Until this moment I didn't think you could make money doing research on MHT.