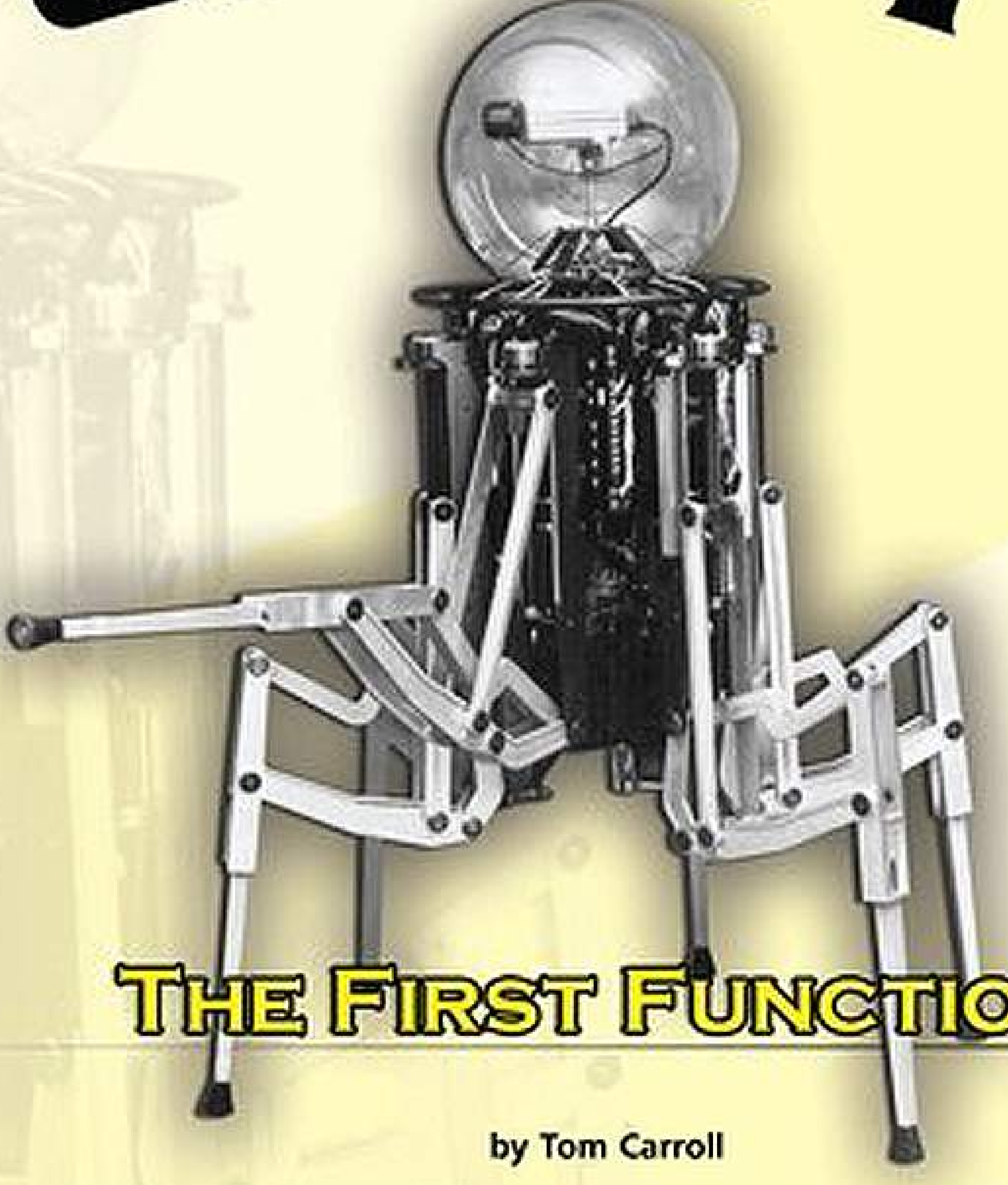
ODEX 1



The First Functionoid

by Tom Carroll

Several *SERVO* readers have asked about the Odex 1 robot. In talking with *SERVO* editor Dan Danknick, we felt that an article about the development of the Odex was timely and would prove to be quite interesting. With the okay to write the article, I felt that there would be ample information available on the Internet through Google. Wow, was I surprised. There are many references, but only one good article from *Robotics Age* magazine, circa 1983.

My next step was to go to Odetics, which is now called Iteris Holdings. In changing names and changing to a vastly different product line from that of the early 80s, I learned that most of the early technical data had been thrown away just weeks before — including photos and documentation on Odex. Thanks to some great people from Iteris, I was able to find the information for this article.

Back in the early 80s, I first became acquainted with this very unique Odetics robot. With my ocean engineering education and antenna testing background, my work involved almost everything but robotics. It was my interest in hobby and experimental robotics that caught the interest of our Rockwell division's chief engineer. He had seen a few articles written by me about the field and wanted to know what the state-of-the-art in robotics was at the time and how we could use this new technology in our space businesses. He figured that, if one of his engineers liked to "play" with robots, maybe he could also help the company get into this

Figure 1

new technical field in a more serious way.

Even though I knew nothing about industrial robotics, I was tasked with exploring implementations of robotics for use in our manufacturing processes, as well as space applications for our customer, NASA. These were the days when many companies wanted to be part of the new "robotics revolution." I quickly discovered that writing and delivering a paper at a conference not only granted me free entrance to the conferences, but also coaxed Rockwell into sending me there. As a result, I was sent on yearly trips to the annual RI/SME (Robotics International of the Society of Manufacturing Engineers) conferences that alternated between Detroit, MI and Chicago, IL each year to deliver papers on my space robotics projects and to gather information about other developments by other companies and universities. The most enjoyable trips were to all the university and government labs that I visited on the side, but I met the most diverse and interesting groups of people at these conferences.

I remember well the moment when I first saw the Odex robot in the spring of 1983. I saw the conference session title on the program and decided that it sounded interesting. The picture showed Odex standing tall, like a metal, six-legged octopus (or would that make it a sextapus?). I worked my way into the room along with about a hundred other people — most of whom had manufacturing backgrounds.

After a short introduction by an Odetics spokesperson, the room darkened and the presentation began. This is quite often a signal for some people to begin to nod off after getting a good meal below the hatches, but not this time. I still remember the images of this human-sized, giant spider walking off the back of a small pick-up truck. A few minutes later — with the help of an L-shaped bracket attached to the truck's bed — it actually lifted the back end of the 2,100 pound truck off the floor by pressing its head against the outstretched arm of the bracket (Figure 1).

Holy Cow! No one nodded off during this session. Other views showed the robot striding across the floor at a man's pace. The Odex could change the arrangement of its six legs and easily pass through a door. It could climb into and out of a truck bed and walk up inclined ramps. There was no tether; it was all self-contained. Most of the attendees were familiar with one ton industrial robots that could maneuver a 40 pound welding head around a car's frame, but not a 370 pound robot that can easily lift four times its weight.

Figure 2 shows one of Odex's developers, Robert Drap, holding one of Odex's arms.

Figure 2

A Little Background

Robot experimenters have long been fascinated with walking machines. Many of the robot kits available today are based on hexapod — six legged — platforms. These six legs are usually arranged on two sides of a rectangular base, not equally spaced about a circular base. This seems to be an odd means of movement to us; when we think of ways to get from one point to another, we naturally think of the way that we humans and animals traverse the surface of the earth. The early robots of science fiction movies were always walkers, even though the "walking" was accomplished by a person in a "robot suit."

Several major corporations developed walking robots, such as the huge, four-legged, gasoline engine-powered "robot walking truck" built by General Electric. Sony's AIBO series and the i-Cybie are very popular four-legged robot dogs. Yes, there are some very unique bipedal robots made by Honda, Sony, and other Japanese manufacturers, but very few large walking robots have ever made such a technological "splash" as Odetics' Odex.

Odetics, formed in 1969, became well-known and respected for quality audio, digital, and video recording equipment. They were particularly proud of the fact that they had captured over 70% of the world's market for space-borne magnetic digital tape recorders. This market dried up after the advent of solid state, Flash, and other memory devices, but Odetics turned to other ventures, such as large, automatic tape retrieval libraries. These machines reminded me of a huge X-Y chart recorder where a robotic "hand" could be programmed to rapidly go to a specific compartment and retrieve a video tape cassette and then go to a commercial VCR and place the tape in the VCR for playback. This and many other Odetics products are an offshoot of the Odex development.

Odetics intended this robot to be part of a new era in the growing robotics industry in the early 1980s. Not a bit similar to Unimation's early "tank turret" manipulators that were used in many automotive and other types of factories, the Odex was intended to serve another purpose. Odetics management saw the unit as a robot that could perform the typical tasks ascribed to industry, yet walk away from the job site and do tasks in another area of the factory. Later versions of the Odex were configured to perform tasks in areas that were hazardous to humans or inaccessible to conventional tracked or wheeled vehicles. The debut of such a unique robot caught industry analysts by surprise, as no one in the robotics field had ever heard of Odetics.

Odex 1 began as a vision of robot experimenter Steve Bartholet, who happened to work for Odetics as a mechanical engineer. With a degree in mechanical engineering from Washington State University, it was a natural tendency for Steve to become interested in robotics as a hobby. He had seen many of the "typical" wheeled robots that had been built by others, but he longed for a robot that could traverse uneven ground and carry a very large load. The robot had to have the ability to change its profile (to be able to climb stairs or go through narrow openings), in addition to agility in its movements, strength, stability, and a self-contained power source. Walking robots seemed to be the answer. He worked through several leg configurations before deciding upon the final design used in the Odex 1. Figure 3 shows the plywood mock-up of the "articulators" — or legs — on the Odex.

Steve's robot design ideas reached Odetics management, particularly Joel Slutzky, the company president. The two talked about the possibility of Odetics actually constructing Steve's design. Unlike most companies that take an existing or potential customer's request and present a proposal, Odetics decided to "go it alone." Odex 1 was designed and built without specific applications or customer requirements — a major gamble for a small company. Slutzky wanted to protect the company's competitiveness and long-term growth.

Steve sat down to determine just what attributes he wanted to incorporate into his unique robot. It was a major departure from any existing industrial machine in existence at that time — or even today. Instead of being mounted in a fixed position in an automated assembly line or even being a mobile AGV (Automated Guided Vehicle) that was programmed to follow a specific path to deliver parts or mail, this robot had to be flexible in many environments. Odetics gave it the moniker of "Functionoid" due to its many functions. The Odex also had to have unprecedented strength-to-weight capability, as well as extreme agility. These were tall orders.

Let's get into the design of Odex. Figure 4 shows the configuration of each of the six "articulators." These are the keys to the overall design of the Odex. It is a great mechanical design of basic simplicity. The Z-shaped horizontal arm piece swivels from a fixed point below the structure and is fastened to the top of the leg. The second L-shaped piece is fastened to the same point and is connected to the extension actuator to cause the leg to move outward and inward. The third leg element is the horizontal piece that takes most of the force and is connected to the leg a bit below the top.

The largest of the three motors on each leg is the vertical motor. It is connected to a leadscrew/nut assembly to create the lifting force. A quick look at the drawing shows the end of the vertical actuator arm fastened about one-fifth of the way out from the pivot point. To create a force of 300 pounds at the end of the swivel arm holding the leg, the actuator must exert 5 x 300 — or 1,500 pounds — of force and that is with the end of the leg directly below the end of the swivel arm. That is a great deal of force for a small linear actuator, even with what appears to be a 3:7 gear ratio. A much higher ratio would not have allowed the quick movements required of the articulators.

The second of the leg actuator motors is the extension motor that is a self-contained gearmotor/lead screw

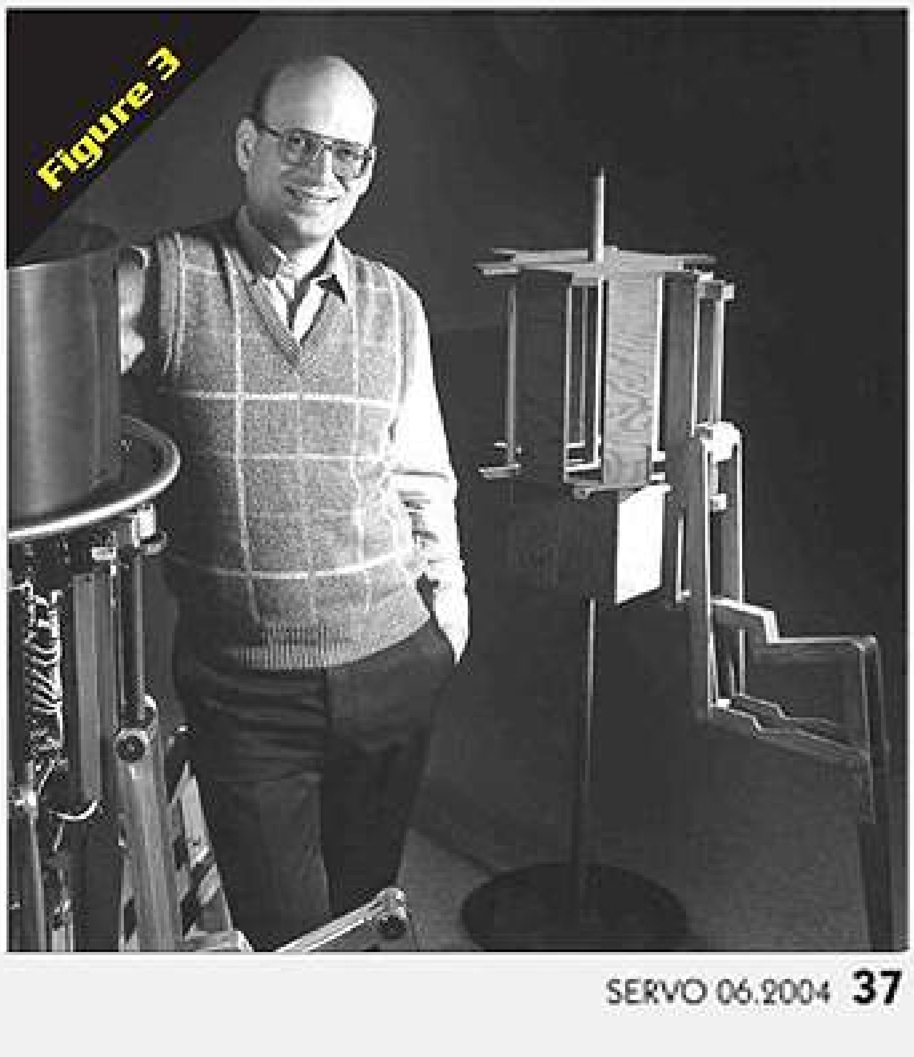


Figure 3

assembly. This motor does not need to be as large as the vertical motor, as it only needs to move the leg in and out. Of course, the approximately 2:1 ratio in the L-bracket requires twice as much force from the actuator, but the horizontal movement is also twice as much. When the actuator is at full extension, the longest part of the L-arm is forced horizontal and allows the V actuator to draw the leg upward to a compact stowage configuration. That is the reason for the Z in the horizontal piece — to allow the top of the leg to be pulled close to the robot's body.

The third of the Odex's actuator motors is the swing actuator. Since the Odex has a circular arrangement for its six legs, each of the legs cannot swing fore and aft at the same rate or amount as is done by the legs in a typical hexapod robot with a rectangular leg arrangement— three by three. It depends on which direction the robot is commanded to go and where the legs are oriented at the point of the command. Again, this is a smaller motor than the vertical motor, as it does not confront forces as great as the lifting forces and, in fact, is the same type of motor used in the extension actuator. From an informational drawing, it also appears to have a 3:7 gear arrangement.

The initial prototypes used external power through a tether, but the design team desired self-contained power in the final model. With some of the lifting capacities in mind and the motors selected, Steve decided to use a 24 volt, 25 AHr aircraft battery to cut down on wire sizes and be able to use lower current driver circuitry. Placed low down in the central cavity, the battery added little weight relative to its power capacity. With the great force capabilities of the Odex in mind, it is amazing that the robot only required 450 watts in active mode and 2 watts in the stand-by mode. For the initial concept demonstrator, the aircraft battery supplied all the power Steve required. Even so, the battery had to be recharged after an hour's use. Later versions used different batteries and these different chemistries brought greater capacities.

Figure 4

With the physical characteristics and overall leg design completed, Steve was now faced with an even larger problem. There was no way that an operator could toggle 18 DPDT polarity reversing switches quickly or accurately enough to be able to control the Odex through a simple series of movements. Just for a leg to move forward for a single step, all three motors must be used. Even for the Odex to turn on its axis, every leg cannot just turn on its swing motor; as the length of each leg changes from a radii to a tangential distance, all of the legs would have to extend a bit just to keep the feet at the same points.

Computer control was required with accurate encoder feedback. This was in the days before microcontrollers existed and only 8- and 16-bit microprocessors were available. As a mechanical engineer, Steve enlisted the help of Robert Drap (Figure 2) to develop the software required and to select the computer hardware. Robert chose the Intel 8086 processor used in the first IBM PCs. The "Odex Operating System," as it was later called, was an embedded type of real time processing package.

Robert had been in charge of software development at NASA's Johnson Space Center (JSC) in Houston, TX. Much of his background had to do with mechanism control — great experience for a new style of walking robot. After a stint at JSC, he did some contract software engineering for Hughes and other clients before making the move to Odetics in 1982. He immediately began working with Steve on the Odex project to develop the gaits and walking algorithms.

Robert explained to me that the Odex Operating System consisted of a core of highly optimized 8086 assembly language primitives. These primitives were "threaded" together to function in a multi-tasking operating system in a single 8086 CPU to control the Odex robot. The core primitives provided the library for all aspects of the software environment, including multiple mains, interrupt servicing, algorithm processing, I/O device drivers, communication queues, as well as an embedded compiler and assembler. When the core primitives were threaded together, the operating system became layered into the application. The total object code size was 48K bytes. The communications link for the remote control was an FM telemetry radio that used FSK modulation with an Intel HDLC communications controller. They used 6809 processors in each leg servo and implemented PID servo loops for the actuator motors.

We have processors these days that are so fast and can address so much memory that designers of today do not have to squeeze every bit of processing power out of modern chips. It was a little bit different 20 years ago for the Odetics team. Much like the NASA Apollo command module and the lunar excursion module computers that operated with as little as 8K bytes of memory, Odex performed its algorithms with 48 KB of memory in real time on an 8 MHz 8086. There was no remote mainframe or minicomputer involved in algorithm processing, like there was with SRI's Shakey, which I wrote about in the April 2004 issue of *SERVO*. This software impressed many people of the 1980s, including the Smithsonian Institution.

To perfect the required gaits, the team decided to suspend the base and articulators above the floor for ease of observing the different motions. Just as with most hexapod robots built by experimenters today, the Odex uses a tripod gait. To move forward, the robot picks up three legs, which are arranged in a triangle, and moves them forward as the other three legs remain touching the floor and move in a triangle rearward. With computer graphics in color (not bad for 1980s XTs and ATs), it was easy to see if all the articulators were in sync and provided a great debugging tool. They called the three articulator legs that moved forward "translators" and the three load-carrying legs still on the floor "strokers."

When Odex was perfected, it was able to walk through openings as narrow as 21 inches. It could climb steps as high as 33 inches each. It could fold itself into a compact, "tucked" form only 48 inches high by 27 inches wide at the base. At full speed, it could walk as fast as a person's brisk pace. In the "tall" profile, it could raise itself to 78 inches in height. It could actually walk with its articulator legs spread out to 72 inches between leg tips and its height only 36 inches above the floor. It could lift 2,100 pounds with all legs on the floor or carry a load of 900 pounds at normal walking speed. We usually think of the typical industrial robot that I mentioned earlier as being fairly weak for its weight. It might have a light mass at the end effector, but it can move that weight — be it a welding head or paint sprayer — very quickly and accurately. Odex was fast, accurate, and capable of really carrying a very big load.

Needless to say, Odex didn't go up to a set of stairs or the back of a truck bed and just climb in like a giant spider. The operator at his control panel pedestal would enter an algorithm mode for the particular articulator, which was numbered from zero to five for operator identification from a distance. Many demonstration "feats" were choreographed ahead of time by having the operator examine distances, areas, and heights beforehand and dial in articulators and motions on thumb wheels on the control panel. A simple joystick on the control panel was all it took to control the Odex in traversing mode with the direction of the tilt of the joystick corresponding to Odex's motion.

After development and testing over a period of 18 months, Odetics put out feelers for potential users. After seeing demonstrations at various locations, many customers came to Odetics first. NASA was quite interested, as was the Department of Energy, who considered the Odex for hazardous nuclear power plant applications. The Savannah River Labs of the DOE made use of a second version — Odex 2 — and made several significant changes to it. An Odex 3 model that was significantly more powerful with extendible legs was sold to the French CEA — their version of our Atomic Energy Commission. This unit was cable-controlled and also derived its power through the cable.

In my opinion, nothing has yet to come close to the Odetics Odex series in terms of versatile walking robots. Yes, modern computers running 400 times as fast with 10,000 times the memory could allow the Odex to do even more amazing things. New accelerometers, tilt sensors, GPS, and gyros added to a modern package could do wonders. There is no doubt in my mind that these machines would create just as much awe today as they did two decades ago, without any modern additions. Odetics should be commended for striking out on its own to create such an amazing proof of concept machine as the Odexs. SV

A Special Thanks

I was particularly disheartened to find out that Steve Bartholet had passed away from brain cancer in 1999. I would like to dedicate this article to his memory. It was his inspiration that brought the Odex to life and he was very cordial to me when, in 1983, he gave his valuable time to show me the two Odexs and talk about their development. Marv Russell, who was Director of Engineering, and Joel Slutzky, then the President of Odetics, also spent a lot of time with me in 1983 and I thank them. I am also indebted to Joel, who is now President of Iteris, Robert Drap, co-developer of Odex (software), Ginny Taylor and Cathy Steger of Iteris, and Tom Bartholet (Steve's brother and also formerly with Odetics) for helping me on this project. These people combed through many files and helped me chase down the people I needed to speak with.