PSP (Programmable Signal Processor) Development

by Les Nelson

INTRODUCTION

My involvement in NEXRAD[1] was from November 1982 through June 1993 participating during the National Weather Service's (NWS) down select from three companies to two companies: resulting in the selection of Unisys for full scale development. The following paragraphs discuss details of the Unisys-Eagan involvement and the engineering accomplishments which led to a very successful engineering development, as well as a perspective of weather information presented to the public.

Contents

STORY

Hal Pyle had identified Eagan's expertise to create a PSP to the NEXRAD Systems Development group in Great Neck, NY which led to Eagan's participation in the NEXRAD program. The NEXRAD contract required the use of a PSP. The requirements for NEXRAD radar processing required re-architecting a Signal Processor Element (SPE) into a PSP. Eagan's expertise in this area was based on development of a programmable SPE funded via IR&D which was slated for a military program. The lead engineer for this effort was Dave Bondurant. My involvement was writing the microcode for the SPE including the Fast Fourier Transform (FFT). The microcode listing is archived at the Charles Babbage Institute in Minneapolis.

NEXRAD radar processing requirements

NEXRAD scans 360 degrees at pre-determined elevations starting at 0.5 degrees with subsequent ascending elevations. Multiple radar pulses are transmitted within each one degree in azimuth out to 100^{+} miles. The returns from each pulse are sampled in time at 250 meters forming a time-series of data. When viewing the weather reports in electronic media (TV, smart phone, etc.), the viewer is seeing a top-down perspective with the 250 m (summed to one kilometer resolution) by one degree azimuth with these values summed for all elevation cuts for the geographic space. The product displayed most often in the electronic media is *Reflectivity*, which is the amplitude of a reflected pulse in contact with water droplets and other objects in the air (birds, airplanes, leaves, etc. which have been removed from the data.)

[1] Next generation weather Radar, www.vipclubmn.org/sysgovernment.html.

The product used during severe weather conditions is *Doppler Velocity* for tornadic activity detection. The third product provided is *Spectrum Width*. The PSP generates the three products per one km and one degree in azimuth and sends the information to the Product Generation Computer (PGC) located at each National Weather Service (NWS) location. The PGC creates a composite from the PSP data (Reflectivity, Doppler Velocity, Spectrum Width referred to as "base data") for each 360-degree elevation cut and for each elevation comprising the Volume Coverage Pattern (VCP) seen in the electronic media. The PGC also generates products such as Vertically Indicated Liquid (VIL) which may be rainfall or snowfall totals, moisture types, etc. (Note: Searching the Cloud, one can find an abundance of information on the three base products as well as the products generated by the PGC.)

From a viewer perspective, each NWS location controls its adjacent radar by the Radar Data Acquisition System Control (RDASC) and provides local geographic weather data and forecasts to the media via the PGC. The digitized radar data from each of the NWS sites is sent to the NWS in Oklahoma to form the composite for the entire United States.

Programmable Signal Processor Details

The PSP was uniquely designed to process time-series radar returns using Single Instruction Multiple Data (SIMD) architecture consisting of one Arithmetic Control Unit (ACU) and three Arithmetic Units (AUs). Three AUs are necessary to satisfy timing requirements to process all time-series data for the range of the radar per one degree in azimuth before the adjacent one degree of data is available. Each AU processes 1/3 of the time-series data received from the radar receiver for each one degree in azimuth for the range of the radar. There are instances where the work of one AU has to be unique so an AU can deactivate its adjacent AU. (Vince Splett designed the AUs and has a patent for the selective deactivation of an AU).

At the microcode level, the ACU requires a longer clock cycle for some operations (150 ns to 180 ns) and is programmable. The software in the PSP is microcode requiring 7 clock cycles for an operation completion. Each microcode instruction word is 128 bits (ACU is 72 bits and the AUs are 56 bits). The radar time-series values are complex numbers (real and imaginary parts) to accommodate the dynamic range of the time-series data. The basic architecture in the AUs is a multiplier followed by an accumulator. Digital Signal Processor (DSP) chips did not exist at the time of NEXRAD development so the multiplier was designed by an Eagan engineer and the accumulator was one chip built by TRW Corporation (Rick Martin located this chip which had just become available). The multipliers brought in two complex numbers and funneled the result to the accumulators.

The three PSP base products are generated after the removal of airplanes and the algorithms which perform range unfolding and velocity de-aliasing in the time-series data are performed.

Note that Fourier transforms would have been useful but because of processing time limits the Pulse-Pair algorithm was implemented in the PSP (which was complex code).

Additionally, ground clutter is removed in the Hardwired Signal Processor (HSP) which occurs prior to the PSP processing. At 0.5 degrees elevation the radar receives reflectivity time-series values from trees. These reflectivity values would distort valid weather values. During clear weather in the spring (no clouds) the radar records reflectivity values and builds maps which are installed in the HSP clutter maps memories used to eliminate this clutter from the valid time-series data.

As described above the schedule was very tight through all phases of the NEXRAD development. To deal with the schedule, two decisions were made that were instrumental in schedule compression: 1) development of a software program that supported PSP microcode checkout and 2) development of test hardware that provided a known radar time-series input.

There was only one PSP hardware system under development which meant that the microcode checkout was also dependent on this one PSP. To buy schedule time, Bob Ellingrod wrote an emulation program in six weeks (in Pascal) running on an 1100 series computer. This emulation program very accurately reflected the PSP architecture including complex numbers with overflow and underflow. My PSP microcode running on the emulator provided a printout of the output of each register in the ACU and AUs at the end of each of the seven clock cycles. When the microcode was installed in the PSP hardware, very few bugs were found. Kudos to Bob for his work.

The input test hardware consisted of one 6”x9” VME card programmable with radar time-series data sets for every 0.25 meters from the radar out to 100+ miles. In addition to a range of values simulating what would be expected from the radar, the data sets contained simulated aircraft, range folded data and velocity aliased data.

A word or two needs to be said about the macrocode written by Jerry Murphy in Eagan. The macrocode was written in Fortran and executed on the Radar Data Acquisition System Controller (RDASC) computer with the purpose of loading the list of microcode primitives to be executed in the PSP into one of the two Command Banks. The Command Banks are then toggled allowing the PSP access to the microcode primitive sequence while allowing filling of the other Command Bank with another set of microcode primitives.

The software deliverables consisted of the following: 1) PSP microcode, 2) macrocode software written in Fortran executable on the RDASC, 3) diagnostic software for the PSP, and 4) the PSP microcode assembler which ran on a Unisys 1100 series computer.

The PSP microcode listing is 457 pages on 8.5"x11" paper –attached are a few pages of the *Reflectivity* primitive for reference. The description of each ACU and AU field is in a document at the Charles Babbage Institute at the University of Minnesota.

Others who contributed to the success of PSP development:

1) Dr. Ray Artz who was the PSP software architect mapping the NWS algorithms into the PSP available hardware which required lookup tables to minimize execution time. The PSP had to complete all processing for a one degree radial in the time the radar transmits and receives the data for the next one degree radial.
2) Frank Amodeo of MITRE Corporation who spent weeks in Eagan reviewing all test data for the diagnostic software, macrocode, and microcode.
3) The 5 people who wrote the PSP diagnostic software (names not available) and to Beth Henry who did all the testing of the PSP diagnostic software.

Leslie Nelson's micro-biography:

My degree is Bachelor of Electrical Engineering (BEE) from the University of Minnesota in 1969. I started work at Sperry Univac in June 1969 in Field Engineering supporting the CP-901 Computer during development of the Tactical Support Center (TSC). I returned to MN in May 1972 working for Curt Nelson in CP-901 system support. Through subsequent years I worked on numerous proposals including two years in the black world. Subsequently, my work was in signal processing which included NEXRAD activities described above. Post NEXRAD I worked in Japan P-3C programs for Art Francis then when Art retired I became project engineer leading the effort to participate in the Japan P-3C replacement aircraft, their P-1. After Japan projects, I had the following roles as Technical Director for P-3C activities until retirement in January 2010:

1. New Zealand proposal to update their five aircraft with mission systems, sensors, radios, navigation, COMINT, cockpit upgrades as well as a trainer and software maintenance system. We lost the $200M effort.
2. Pakistan acquisition of 7 aircraft with our proposal for the mission system, sensors, radios, navigation, and cockpit upgrades. We won the contract which became $260M.
3. Contract to update the P-3C trainer acquired by Germany from the Netherlands.
4. Quick reaction successful program for German Navy to install a new EO/IR system on one of their P-3Cs in six weeks for deployment to Djibouti.

I retired in January 2010, joined the VIP Club, then in 2013 began volunteering at the Lawshe Memorial Museum.

ATTACHMENT, PSP *Reflectivity* microcode:

```
KRAD/PSP  MACRO ASSEMBLER VERSION 18 REVISION 00.00 DATE 03/14/91 TIME 17.27.56 PAGE   276
   CRDNO LABEL     OPERATOR  OPERAND            . COMMENTS                          SEQUENCE

         / .
         . *************************************************************************
         . *                                                                       *
         . *                  M O D U L E   P R O L O G U E                        *
         . *                                                                       *
         . *  MODULE NAME: A20501 (COMPUTE REFLECTIVITY)                           *
         . *                                                                       *
         . *  MODULE VERSION: 0002                                                 *
         . *                                                                       *
         . *  MODULE LANGUAGE:  ASSEMBLER MICROCODE                                *
         . *                                                                       *
         . *  CHANGE HISTORY:   DATE       VERSION    PROGRAMMER         NOTES     *
         . *                    2.84        0000A     NELSON                       *
         . *                    1.85        0000B     NELSON                       *
         . *                    8/11/88     0001      NELSON             SPR 80237 *
         . *                    9/24/90     0002      NELSON             SPR 91038 *
         . *                                                                       *
         . *  CALLING SEQUENCE: A20501,K1.EXP,K1.SIG,K2.EXP,K2.SIG,K31.EXP,K31.SIG  *
         . *                    K32.EXP,K32.SIG,K4.EXP,K4.SIG,N,A,B1,B2,C          *
         . *                                                                       *
         . *  MODULE FUNCTION: THIS ROUTINE SCALES ECHO POWER TO COMPENSATE FOR    *
         . *                   RANGE SQUARED ATTENTUATION, ATMOSPHERIC ATTENTUATION,*
         . *                   AND SYSTEM CALIBRATION TO PRODUCE REFLECTIVITY.     *
         . *                                                                       *
         . *  MODULES CALLED:  A21001                                              *
         . *                                                                       *
         . *  PARAMETERS:  (*: G=GLOBAL, C=COMMON, P=PASSED)                       *
         . *                                                                       *
         . *    *    INPUT               TYPE            DESCRIPTION               *
         . *                                                                       *
         . *    P    K1.EXP,K1.SIG       FLOATING POINT  RANGE OF FIRST CELL(CELL = 0)*
         . *                              ACU             OF FIRST AU  (AU = 0)    *
         . *                                                                       *
         . *    P    K2.EXP,K2.SIG       FLOATING POINT  ATMOSPHERIC ATTENUATION   *
         . *                              ACU             CONSTANT                 *
         . *                                                                       *
         . *    P    K31.EXP,K31.SIG     FLOATING POINT  SYSTEM CALIBRATION CONSTANT *
         . *                              ACU             FOR ARRAY B1             *
         . *                                                                       *
         . *    P    K32.EXP,K32.SIG     FLOATING POINT  SYSTEM CALIBRATION CONSTANT *
         . *                              ACU             FOR ARRAY B2             *
         . *                                                                       *
         . *    P    K4.EXP,K4.SIG       FLOATING POINT  NUMBER OF CELLS IN ARRAYS *
         . *                              ACU             A,B1,B2, AND C           *
         . *                                                                       *
         . *    P    N                   INTEGER         NUMBER OF CELLS IN ARRAYS *
```

```
NEXRAD/PSP  MACRO ASSEMBLER VERSION 18 REVISION 00.00 DATE 03/14/91 TIME 17.27.56 PAGE   277
       CRDNO LABEL     OPERATOR  OPERAND            . COMMENTS                          SEQUENCE

 . *                                                      A,B1,B2,C                          *
 . *                                                                                         *
 . *    P    A                        INTEGER            COLLATION CONTROL WORD(IMAG)        *
 . *                                                                                         *
 . *    P    B1                       ADDRESS            FIRST ALTERNATIVE ECHO POWER        *
 . *                                                      SOURCE ARRAY BASE ADDRESS          *
 . *                                                                                         *
 . *    P    B2                       ADDRESS            SECOND ALTERNATIVE ECHO POWER*
 . *                                                      SOURCE ARRAY BASE ADDRESS          *
 . *                                                                                         *
 . *    P    C                        ADDRESS            REFLECTIVITY DESTINATION            *
 . *                                                      ARRAY BASE ADDRESS                 *
 . *                                                                                         *
 . *         OUTPUT                                                                          *
 . *                                                                                         *
 . *    P    C                        FLOATING POINT      DATA AT ARRAY ADDRESSES            *
 . *                                   ACU                 C(0) THROUGH C(2*N-1)             *
 . *                                                                                         *
 . *  DATABASE/FILE REFERENCE:  NONE                                                         *
 . *                                                                                         *
 . *  INTERNAL TABLES/WORK AREA:                                                             *
 . *                                                                                         *
 . *      NAME                 TYPE                  DESCRIPTION                             *
 . *                                                                                         *
 . *       T0                  FLOATING POINT        AU IDENTIFICATION NUMBER                *
 . *                            REAL                                                         *
 . *                                                                                         *
 . *  GLOBAL BLOCKS REFERENCED:  NONE                                                        *
 . *                                                                                         *
 . *  COMMON BLOCKS REFERENCED:  NONE                                                        *
 . *                                                                                         *
 . *  ERROR CONDITIONS REFERENCED FROM THIS MODULE:  NONE                                    *
 . *                                                                                         *
 . *  ASSUMPTIONS/RESTRICTIONS:  NONE                                                        *
 . *                                                                                         *
 . *  DEVIATIONS FROM STANDARDS:  NONE                                                       *
 . *                                                                                         *
 . *  COMPILATION/LINKAGE:  THIS MODULE IS ASSEMBLED USING NEXRAD PSP                        *
 . *                        MACRO ASSEMBLER.                                                 *
 . *                                                                                         *
 . *  MISC:                                                                                  *
 . *                                                                                         *
 . *      COEFFICIENT MEMORY:                                                                *
 . *                                                                                         *
 . *         NAME              TYPE                  DESCRIPTION                             *
 . *                                                                                         *
```