MIT Kavli Institute **Chandra X-Ray Center**

MEMORANDUM
September 30, 2013

To:	Jonathan McDowell, SDS Group Leader
From:	Glenn E. Allen, SDS
Subject:	Sub-pixel event-positioning and pixel randomization spec
Revision:	2.4
URL:	http://space.mit.edu/CXC/docs/docs.html#subpix
File:	/nfs/inconceivable/d0/SDS/SPECS/SUBPIX/subpix_spec_2.4.tex

1 Sub-pixel event positioning

1.1 Description

The size of the point spread function of a point source observed with the ACIS detectors is determined by several factors: (1) the size of the point spread function of the mirrors, (2) the accuracy to which the pointing direction can be reconstructed, (3) the size of the pixels on the ACIS CCDs, and (4) "pixel randomization." The randomization is performed by adding a uniform random deviate in the interval $[-0.5, +0.5)$ pixel[*] to the coordinates `CHIPX` and `CHIPY` before the detector coordinates `DETX` and `DETY` and the sky coordinates `X` and `Y` are calculated. This randomization was introduced to avoid aliasing effects that can produce unusual features in the shape of the image of a point source for some observations. The randomization is automatically disabled if a sub-pixel event-positioning algorithm is used.

The size of an ACIS pixel undersamples the point spread function of an on-axis point source. As a result, the use of the ACIS detectors can degrade the quality of an image of a source if events are assumed to occur only at the centers of the pixels for which they are reported. Tsunemi et al. (2001), Mori et al. (2001), Li et al. (2003), and Li et al. (2004) describe algorithms that can be used to more accurately localize the centroids of certain events based upon the distribution of charge in the "event islands.[†]"

This spec describes the implementation of the energy- and `FLTGRADE`-dependent sub-pixel event-positioning algorithm ("EDSER") of Li et al. (2004) in the tool `acis_process_events`. Of the algorithms described by Li et al. (2004), EDSER is the one that works best for GRADED mode event data. It is also very good for non-GRADED mode data. The spec also describes the `PHAS`-dependent algorithm "CENTROID" and the processes to follow if `pix_adj=NONE` or `RANDOMIZE`.

[*] The range used to be controlled by the parameter `rand_pix_size`, with the default range being $[-0.5, +0.5)$ pixel. With the implementation of the sub-pixel event-positioning algorithm `EDSER`, the use of the parameter `rand_pix_size` has been discontinued. While it is still possible to apply a pixel randomization, it is no longer possible to control the range of the randomization.

[†] An event island, the quantity named `PHAS` in a Level 1 event-data file, contains the pulse-height distribution in a 3 pixel $\times$ 3 pixel region centered upon the pixel in which an event is reported. In `VFAINT` mode, `PHAS` is a 5×5 array instead of a 3×3. While the `PHAS` information is not telemetered for `GRADED` mode data, the `FLTGRADE`, a scalar representation of the distribution of charge in the central 3×3, is telemetered for `GRADED` (and non-`GRADED`) mode observations. The sub-pixel event-positioning algorithms "CSDSER" (Li et al. 2004) and `CENTROID` (see sec. 1.5.1) require `PHAS`. The rest of the algorithms use `FLTGRADE`.

1.2 Input

1. A Level 1 or Level 2 event-data file (acis*evt1.fits, acis*evt1a.fits, acis*evt2.fits)

2. If `pix_adj=EDSER`, then a sub-pixel ARD file (acisD*subpix*.fits)

1.3 Output

1. An event-data file in which the coordinates `DETX` and `DETY` and `X` and `Y` have been updated. The coordinates `CHIPX`, `CHIPY`, `TDETX`, and `TDETY` remain unchanged.

1.4 Parameters

1. `infile,s,a,"",,,"Name of input event-data file"`

2. `outfile,s,a"",,,"Name of output event-data file"`

3. `subpixfile,s,h,"CALDB",,,"Name of input sub-pixel file (CALDB | NONE | none | <filename>)"`

4. `pix_adj,s,h,"EDSER",,,"Sub-pixel adjustment algorithm (EDSER | CENTROID | NONE | RANDOMIZE)"`

1.5 Processing

Perform the following tests before processing begins.

- Verify that the `infile` exists. If it does not, then exit with an error message.

- If `pix_adj=EDSER`, then verify that the `subpixfile` exists. If it does not, then exit with an error message.

- If `clobber=no`, then verify that the `outfile` does not exist. If it does, then exit with an error message.

- If `pix_adj=EDSER`, then verify that `DATAMODE=FAINT`, `FAINT_BIAS`, `GRADED`, or `VFAINT`. If it does not (e.g. if `DATAMODE=CC33_FAINT` or `CC33_GRADED`), then exit with an error message.

- If `pix_adj=CENTROID`, then verify that `DATAMODE=FAINT`, `FAINT_BIAS`, or `VFAINT`. If it does not (e.g. if `DATAMODE=CC33_FAINT`, `CC33_GRADED` or `GRADED`), then exit with an error message.

- If `pix_adj=EDSER`, `CENTROID`, or `RANDOMIZE`, then verify that `stop=sky`. If it does not, then exit with an error message.

1.5.1 `pix_adj=CENTROID`

If `pix_adj=CENTROID`, then the sub-pixel event-positioning algorithm described in this section is used after the CTI and time-dependent gain adjustments (if any) have been applied.[‡] The following steps are performed in sequence for each event.

1. The unnormalized weights w_i are calculated for each one of the nine pixels in the 3 pixel × 3 pixel event island. Here,

$$w_i = \begin{cases} \mathtt{PHAS}_i & \text{if the pixel is valid} \\ 0 & \text{if the pixel is invalid} \end{cases} \quad (1)$$

   If the CTI adjustment has been performed, then `PHAS_ADJ` is used instead of `PHAS`. For `FAINT` and `FAINT_BIAS` mode observations, the index i runs from 0 to 8, with $i = 4$ being the central pixel of an event island (Fig. 1 left). For `VFAINT` mode observations, i runs from 0 to 24. However, only the

[‡]With the implementation of the sub-pixel event-positioning algorithm `EDSER`, the use of the parameter `docentroid` has been discontinued and replaced by `pix_adj=CENTROID`.

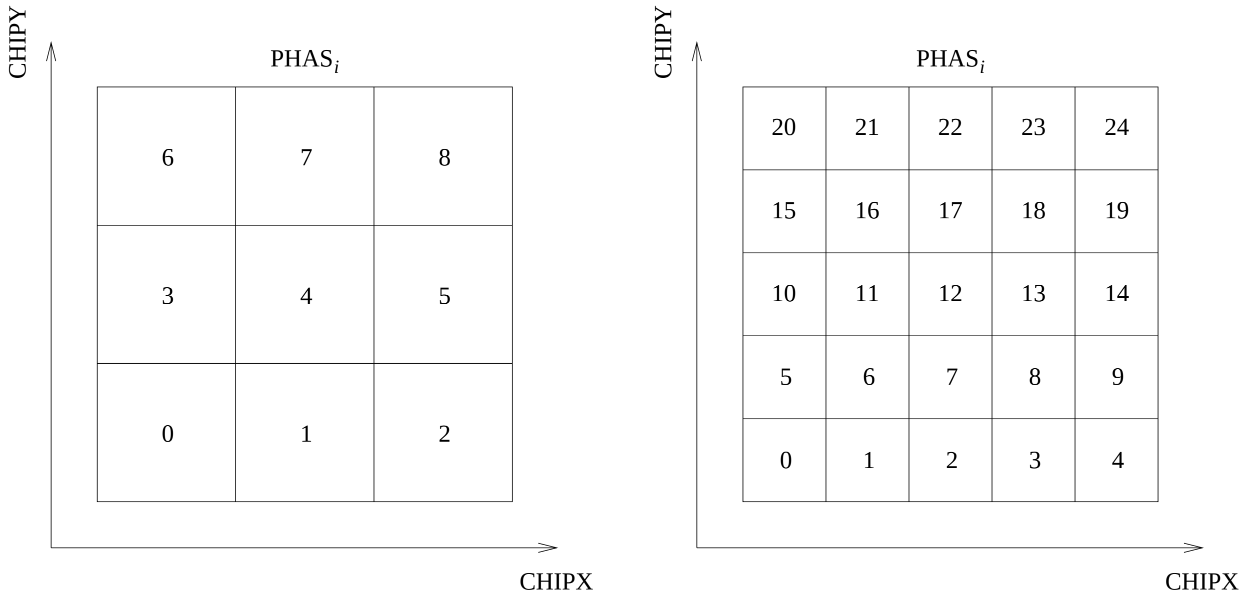

Figure 1: *Left:* The relative `CHIPX` and `CHIPY` coordinates of the nine pixels ($i = 0, \ldots, 8$) in a 3 pixel × 3 pixel event island ($\texttt{PHAS}_i$). *Right:* The relative `CHIPX` and `CHIPY` coordinates of the twenty-five pixels in a 5 pixel × 5 pixel event island.

central nine pixels are used (i.e. i = 6, 7, 8, 11, 12, 13, 16, 17, and 18 instead of i = 0, 1, 2, 3, 4, 5, 6, 7, and 8, respectively [Fig. 1 right]). Invalid pixels are those that are not included in the summed pulse height PHA (see the spec http://space.mit.edu/CXC/docs/docs.html#grades) and those that have one or more of the bad-pixel `STATUS` bits 0, 1, 2 (only during the bias-parity error), 3, 4, 11, 13 (only during the "FEP0" error), 14, 15 (only during the afterglow), or 16 set to one.

2. The normalized weights
$$w_i' = \frac{w_i}{\sum_{i=0}^{8} w_i} \tag{2}$$
are defined such that $\sum_{i=0}^{8} w_i' = 1$.

3. The expressions
$$\texttt{CHIPX}' = \texttt{CHIPX} - w_0' + w_2' - w_3' + w_5' - w_6' + w_8' \tag{3}$$
and
$$\texttt{CHIPY}' = \texttt{CHIPY} - w_0' - w_1' - w_2' + w_6' + w_7' + w_8' \tag{4}$$
are used to calculate the real-valued, sub-pixel coordinates `CHIPX′` and `CHIPY′`, respectively.[§] If the central pixel of an event island is identified as bad, then `CHIPX′` = `CHIPX` and `CHIPY′` = `CHIPY`.

4. The values of `CHIPX′` and `CHIPY′` are used to calculate the detector coordinates `DETX` and `DETY` and the sky coordinates `X` and `Y`.

5. If the parameter `eventdef` includes `f:chipx_adj` and/or `f:chipy_adj`, then the coordinates `CHIPX′` and/or `CHIPY′` are written to the `outfile`. Although `chipx_adj` and `chipy_adj` are excluded from `eventdef` by default, the data in these columns are valuable for testing purposes and may be of interest to some users.

6. The header keyword `PIX_ADJ` is created (or updated) in the `outfile`. The value of this keyword is `CENTROID`.

[§]If `pix_adj=CENTROID`, then |`CHIPX′` − `CHIPX`| and |`CHIPY′` − `CHIPY`| can exceed 0.5 pixels, but must be less than 1.

7. The header keyword RAND_SKY is created (or updated) in the outfile. The value of this keyword is 0.0.

1.5.2 pix_adj=EDSER

If pix_adj=EDSER, then use the sub-pixel, event-positioning algorithm described in this section. This algorithm should be used after the CTI and time-dependent gain adjustments (if any) have been applied and after the ENERGY and FLTGRADE have been computed, since the algorithm depends upon the values of ENERGY and FLTGRADE. Perform the following steps, in sequence, for each event.

1. Use the value of CCD_ID to select the appropriate HDU in the sub-pixel ARD file and use the value of FLTGRADE to select the appropriate row in that HDU (see sec. 2).

2. Use the expressions

$$\mathtt{CHIPX}' = \mathtt{CHIPX} + (\Delta X_{i+1} - \Delta X_i)\left(\frac{E - E_i}{E_{i+1} - E_i}\right) + \Delta X_i \quad (5)$$

   and

$$\mathtt{CHIPY}' = \mathtt{CHIPY} + (\Delta Y_{i+1} - \Delta Y_i)\left(\frac{E - E_i}{E_{i+1} - E_i}\right) + \Delta Y_i \quad (6)$$

   to calculate the real-valued, sub-pixel coordinates CHIPX′ and CHIPY′, respectively.[¶] Here E is the ENERGY of the event and

$$\begin{aligned} E_i &= \mathtt{ENERGY}_i, & (7)\\ E_{i+1} &= \mathtt{ENERGY}_{i+1}, & (8)\\ \Delta X_i &= \mathtt{CHIPX\_OFFSET}_i, & (9)\\ \Delta X_{i+1} &= \mathtt{CHIPX\_OFFSET}_{i+1}, & (10)\\ \Delta Y_i &= \mathtt{CHIPY\_OFFSET}_i, \text{ and} & (11)\\ \Delta Y_{i+1} &= \mathtt{CHIPY\_OFFSET}_{i+1}, & (12) \end{aligned}$$

   where the quantities on the right-hand sides of equations 7–12 are from vectors in the ARD file (see sec. 2). The values of i and $i+1$ are the ones that satisfy the relationship

$$E_i \leq E < E_{i+1}. \quad (13)$$

   The valid ranges for i and $i+1$ are from 0 to $\mathtt{NPOINTS} - 2$ and from 1 to $\mathtt{NPOINTS} - 1$, respectively.[‖] If $E > E_{\mathtt{NPOINTS}-1}$, then use $i = \mathtt{NPOINTS} - 2$ and $i + 1 = \mathtt{NPOINTS} - 1$ (i.e. extrapolate instead of interpolate). Since E should always be greater than zero and since $E_0 = 0$, in no case should $i < 0$.

3. Use the values of CHIPX′ and CHIPY′ to calculate the detector coordinates DETX and DETY and the sky coordinates X and Y.

4. If the parameter eventdef includes f:chipx_adj and/or f:chipy_adj, then write the coordinates CHIPX′ and/or CHIPY′ to the outfile. Although chipx_adj and chipy_adj are excluded from eventdef by default, the data in these columns are valuable for testing purposes and may be of interest to some users.

5. Create or update the header keyword PIX_ADJ in the outfile. The value of this keyword should be EDSER.

6. Create or update the header keyword RAND_SKY in the outfile. The value of this keyword should be 0.0.

[¶] If pix_adj=EDSER, then $|\mathtt{CHIPX}' - \mathtt{CHIPX}|$ and $|\mathtt{CHIPY}' - \mathtt{CHIPY}|$ cannot exceed 0.5 pixels.

[‖] NPOINTS is the name of a column in the ARD file (see sec. 2).

1.5.3 pix_adj=NONE

If pix_adj=NONE, then perform the following steps, in sequence, for each event.

1. Use the integer-valued, read-out coordinates CHIPX and CHIPY to calculate the detector coordinates DETX and DETY and the sky coordinates X and Y.

2. If the parameter eventdef includes f:chipx_adj and/or f:chipy_adj, then write the coordinates CHIPX and/or CHIPY to the outfile.

3. Create or update the header keyword PIX_ADJ in the outfile. The value of this keyword should be NONE.

4. Create or update the header keyword RAND_SKY in the outfile. The value of this keyword should be 0.0.

1.5.4 pix_adj=RANDOMIZE

If pix_adj=RANDOMIZE, then perform the following steps, in sequence, for each event.

1. Use the expressions
$$\mathtt{CHIPX}' = \mathtt{CHIPX} + a_x \tag{14}$$
and
$$\mathtt{CHIPY}' = \mathtt{CHIPY} + a_y \tag{15}$$
to calculate the real-valued coordinates $\mathtt{CHIPX}'$ and $\mathtt{CHIPY}'$, respectively. Here a_x and a_y are uniform random deviates in the interval $[-0.5, +0.5)$.

2. Use the values of $\mathtt{CHIPX}'$ and $\mathtt{CHIPY}'$ to calculate the detector coordinates DETX and DETY and the sky coordinates X and Y.

3. If the parameter eventdef includes f:chipx_adj and/or f:chipy_adj, then write the coordinates $\mathtt{CHIPX}'$ and/or $\mathtt{CHIPY}'$ to the outfile. Although chipx_adj and chipy_adj are excluded from eventdef by default, the data in these columns are valuable for testing purposes and may be of interest to some users.

4. Create or update the header keyword PIX_ADJ in the outfile. The value of this keyword should be RANDOMIZE.

5. Create or update the header keyword RAND_SKY in the outfile. The value of this keyword should be 0.5.

1.6 Caveats

1. The sub-pixel, event-positioning algorithms EDSER and CENTROID cannot produce a point spread function that is better than the point spread function produced by the mirrors and by the accuracy of the reconstruction of the pointing direction of the telescope. They are not deconvolution algorithms.

2. At this time, the effects of this sub-pixel algorithms EDSER and CENTROID on the point spread function of an astrophysical source are not calibrated.

3. The use of a sub-pixel, event-positioning algorithm can influence the fraction of the events inside a source extraction region. At present, this effect is not included in the response files.

4. The algorithm CENTROID can introduce a systematic offset in the coordinates of events.

5. The CENTROID and EDSER sub-pixel event-repositioning algorithms are not, at present, used for continuous-clocking mode data because the coordinate CHIPY is not a spatial coordinate, but a time coordinate. Therefore, adjustments to the coordinate CHIPY should affect the values of TIME, not the values of DETY, X, and Y.

2 Sub-pixel positioning ARD

The sub-pixel, event-positioning algorithm EDSER requires input that is specified in an ARD file. Aside from a null primary header, the ARD file includes ten separate HDUs (one HDU for each CCD). Each HDU contains one binary table with the following columns.

- FLTGRADE
- NPOINTS
- ENERGY
- CHIPX_OFFSET
- CHIPY_OFFSET

There is one row for each FLTGRADE. The columns ENERGY, CHIPX_OFFSET, and CHIPY_OFFSET contain vectors for each row. These vectors are used to perform the linear interpolation and extrapolation described in section 1.5.2. Only the first NPOINTS elements in the vectors should be used for this process. The remaining elements, if any, are zero. The information in the ARD file is based on the data in Figure 4 of Li et al. (2004).

3 TBD

- Should a sub-pixel algorithm be incorporated into the tool tg_resolve_events?

References

Li, J., Kastner, J. H., Prigozhin, G. Y., & Schulz, N. S., 2003, ApJ, 590, 586

Li, J., Kastner, J. H., Prigozhin, G. Y., Schulz, N. S., Feigelson, E. D., & Getman, K. V., 2004, ApJ, 610, 1204

Mori, K., Tsunemi, H., Miyata, E., Baluta, C. J., Burrows, D. N., Garmire, G. P., & Chartas, G., 2001, in New Century of X-ray Astronomy, ed. H. Inoue & H. Kunieda, Vol. 251, 576

Tsunemi, H., Mori, K., Miyata, E., Baluta, C., Burrows, D. N., Garmire, G. P., & Chartas, G., 2001, ApJ, 554, 496