National Optical Astronomy Observatory

NEWFIRM Data Handling System

Quick Reduce Functionality

Lindsey Davis

Introduction

The primary function of the NEWFIRM quick reduce software is to:

- Evaluate the observing protocol
- Check that sufficient data has been taken
- Check that the data set is complete

The quick reduce software will operate at a slower cadence than the quick look software. Its task is to evaluate an "observation" where an observation may be a dither set or a set of dither sets and provide feedback to the observer on timescales of one to several hours.

In the ideal case the essential functions of the quick reduce software will be performed automatically when an "observation" is complete. In practice it may be the observer who invokes the quick reduce software for each complete observation. If the quick reduce software is invoked automatically, the observer must be able to disable it at any time.

The quick reduce software will run the "standard" reduction software. However some "standard" pipeline steps will be skipped or streamlined as suggested below.

- Elimination of reduction steps not required to fulfill primary quick reduce mission
    - Cross talk correction
    - Cosmic ray detection
    - Other

- Optimization of steps where feasible
    - Simple background subtraction
    - Simple resampling algorithm
    - Simple combining algorithm
    - Other

- Use of default or precomputed calibration files where feasible
    - Default bad pixel masks
    - Precomputed darks
    - Default sky flats
    - Other

The final set of quick reduce reduction steps will be selected based on actual experience at the telescope,

The quick reduce software will explore selected multiple calibration options where these are required to fulfill the primary quick reduce software mission, including but not limited to the following.

- Different flat fielding options
- Different sky subtraction options
    - Observer specified sky image
    - Combination / sliding median of data images (object or sky)
    - Combination / sliding median of sky images
    - Other

This type of requirement does complicate the reduction process and needs careful consideration.

The quick reduce software will not overwrite the raw images on disk. Instead the processed images will be created in a separate output directory. How this overlaps with observers who want to run their own version of the standard reduction software or their own personal software is a TBD. Obviously if an observer alters a raw image by performing some operation then the standard reduction software may not behave as expected.

The quick reduced images are used only at the telescope. They are not archived.

The quick reduce software will produce a log of the actions performed by the quick reduce tasks.

Quick Reduce Functions

Evaluate The Observing Protocol

1. How well is the flat fielding working?

Accurate flat fielding is crucial to doing accurate stellar and surface photometry. IR flats are normally computed by combining large numbers of sparsely populated dark subtracted object and sky images that are well separated in space and time. However accumulating the necessary image stack may be difficult to do in the context of the quick reduce tasks where quick feedback is required. Fortunately under normal illumination conditions sky flats are stable to a few percent over a typical observing run and precomputed sky flats can be used. Precomputed dome flats may be acceptable. By default the quick reduce software will use precomputed sky flats.

Initial evaluation of the flat fielding process will be done by direct inspection of the individual quick reduced images on the image display. The sky backgrounds should be flat, with a mean value of zero, a standard deviation of the background predicted by the noise, and negligible skew. If the sky backgrounds are not flat then the default flat may not represent the current illumination conditions and further investigation is warranted.

The quick reduce software should generate a flatness statistic for both the object and sky background images. For some object images this may be difficult to do in a robust manner without object masking. For the sky background images it should be relatively easy to do. Possible flatness metrics including: comparing the observed standard deviation to the predicted standard deviation, computing the skew, or performing a low order surface fit checking for significant spatial terms.

The quick reduce software should include a task for constructing a new sky flat automatically by combining dark subtracted sparse object or sky images from the current observation and comparing the result to the default sky flat. This check is not optimal, as these object and sky images will not span sufficient space and time to enable smoothing out the high frequency spatial and temporal variations. However displaying the ratio of the new / default sky flat would provide a quick visual and statistical consistency check.

Changes in flat field behavior from night to night, but especially during the course of a single night, are a flag to the observer that the observing conditions are unstable. This may due to any number of reasons including proximity to the moon or a bright source. Given such a flag observers can decide, whether to proceed with the current observing protocol (while recognizing that required processing may be non-standard), whether to adjust the protocol (i.e. take more frequent sky images), or whether to reschedule the target.

2. How well is the sky subtraction working?

Accurate sky subtraction is crucial to doing accurate photometry of faint sources. Sky images are normally constructed by combining sparse object or sky images taken close in space and time to the observation. A major concern is whether or not the sky background is changing faster than the time intervals between sky images. Although the quick look software can flag this condition, its effect on the observations can only be fully evaluated by performing the sky subtraction and examining the resulting images.

Initial evaluation of the sky subtraction process is done by direct inspection of the individual quick reduced images. The sky backgrounds should have a median value of zero, a standard deviation consistent with the predicted value, negligible skew, and be pattern free. If these conditions are not met then the sky may be changing more rapidly than the frequency of the sky observations and further investigation is warranted.

The quick reduce software should generate a sky subtraction statistic which measures the quality of the sky subtraction, including the mean, standard deviation, skew, and a flatness statistic. The mean should be around zero, the standard deviation approximately equal to that expected from the noise in the background, the skew negligible, and the flatness statistics negligible. See suggestions in the previous section on how to define the flatness statistic.

The quick reduce software should include an option for performing the sky background subtraction in two ways: first a sliding median sky subtraction, and second a median of the designated sky images subtraction. Visual and statistical comparison of the data reduced in both ways should produce the same result to within the expected noise effects.

Changes in sky subtraction behavior during the course of a single night or even a single observation are a flag to the observer that the observing conditions are unstable. This may due to any number of reasons including changes in the weather. Given such a flag observers must decide on whether to proceed with the current observing protocol (while recognizing that processing may be non-standard), whether to adjust the protocol (i.e. take more frequent sky images), or reschedule the target.

3. Is the WCS calibration adequate?

Accurate astrometry is essential for resampling and combining images. All images will be provided with a precomputed filter specific default WCS adjusted at observing time for the current pointing of the telescope. If the telescope pointing is sufficiently accurate the precomputed WCS can be adjusted for local conditions, such as small focus changes, differential refraction effects, etc using on-line catalog data (2MASS?).

The quick reduce software should include an option for recalibrating the WCS and provide an estimate of the recalibration error. Observers can use this statistic to decide whether or not the default astrometry is sufficiently accurate for their purposes, whether the error is consistent with the know accuracy of the input catalog, etc.

4. How Photometric is it?

Some programs require photometric or near photometric conditions and others do not. The quick look software can provide an assessment of how rapidly the sky background is changing but until some preliminary reductions are performed it is hard to evaluate if or how photometric it is.

The quick reduce software should compute a photometric quality metric. One way to do this is to compute the magnitude zero point and compare it to the known standard zero point in the appropriate waveband. Given an initial WCS (one accurate enough to locate catalog stars) and an on-line catalog (e.g. 2MASS) it is easy to estimate a magnitude zero point. Given the zero point simple observing utilities can examine the distribution of the zero points with time, air mass, etc. Observers can use this information to assess the local observing conditions.

5. Is the dither pattern appropriate?

Dithering is required to provide coverage for gaps in mosaics and bad pixels in both mosaics and single detector images. The image display and image examining tools can be used to quickly check the individual flat fielded and sky subtracted images in a dither stack for gap and bad pixel region coverage.

The quick reduce software will be able to quickly combine dither stacks by tweaking the existing WCS, resampling, and stacking the images. Displaying and examining the resulting mosaic on the image display will quickly demonstrate any lack of gap and bad pixel region coverage.

6. Is the mapping pattern appropriate?

Sky mapping is used to provide large area sky coverage by combining individual images or dither stacks into a larger mosaic. The image display and image examining tools can be used to quickly check the mapped observations in order to see whether the offsets are large enough to support intensity matching if that is required.

The quick reduce software will be able to quickly mosaic mapped image stacks by using the existing WCS, resampling, and combining the images. Displaying and examining the resulting mosaic on the image display will quickly demonstrate any lack of sky coverage.

7. Other?

Determine When Sufficient Data Has Been Taken

1. Has the target S/N for the faintest objects been achieved?

Many programs have a target depth and S/N. Observers need to know if they have achieved this target for a given observation.

The quick reduce software should provide a signal to noise versus magnitude metric. Aperture photometry of known catalog (2MASS) objects can provide one S/N metric for either single or combined images. The functionality is essentially the same as that required for photometric calibration so the same code can be used for both purposes. Given the photometric calibration aperture photometry of faint point sources can provide another estimate. Given the variety of program NEWFIRM is likely to encounter other metrics (TBD) may be more appropriate.

2. Are there variations / discontinuities in the background?

For many programs basic sky subtraction will remove the local sky background gradients and patterns. However for others especially those involving surface photometry or surface photometry of objects embedded in complex backgrounds good sky subtraction may be difficult to achieve.

Initial assessment of the existence of large scale variations and / or discontinuities in the sky background will be made by displaying and examining the individual or combined images.

The quick reduce software should produce some sort of flatness statistic as discussed in previous sections although it may be quite difficult to compute this in a robust fashion as discussed previously.

The only solution to this problem may be to fit and subtract a surface from the problem images. At present there are no plans to deal with this issue in the quick reduce software, although it should be an option in the full reduction software.

3. Is the signal to noise in the background variable?

If the variations or discontinuities in the background are significant they can cause patterns in the background noise across an image or a combined image. Varying exposure times in different parts of an image or mosaic can produce the same effect. Programs that depend on uniform object detection criteria may need to evaluate this condition to see how serious it is for their program.

Initial assessment of the existence of significant background variations can be made by displaying and examining the individual or combined reduced images. Facilities for creating and maintaining error arrays are planned but my not be part of the quick reduce software or part of the initial version of the standard reduction software.

4. Is the seeing variable?

Seeing variations may be present across the combined image and the variations may be discontinuous unlike most PSF variations produced by the instrument optics. This condition may cause problems for some kinds of faint object detection and photometry programs.

Initial assessment of variable seeing across the mosaic can be made by displaying an image and examining it. The PSF statistics written by the quick-look software can also be accessed checked for consistency with the visual display. Facilities for doing PSF matching are planned but they will not be part of the quick reduce software or the standard processing software.

5. Is the observation complete?

If all the components of the observation are not present, the calibrations are incomplete, or the WCS is incorrect, then the "correct" combined image will not be created.

Initial assessment of observation completeness will be made by monitoring the quick reduce output and by visual inspection of the mosaiced image or sub image.

6. Other?

In all these cases the observer must assess the situation and decide whether the current data is good enough, whether more data under the current conditions is required, or whether a new data set is required.

Determining That The Data Set Is Complete

The quick reduce software will run a subset of the full reduction software including the basic reduction and image combining steps but eliminating iterative and fine-tuning steps. The quick reduce software will confirm that each observation to be reduced is complete, that the required calibration data is present, and that the headers of each image component observation are complete and correct. In effect the quick reduce software will confirm that the initial check that the data is ready for "serious" processing.

Basic Processing Steps: Individual Object Exposures

The basic processing steps for single object exposures are listed below in the order they would "normally" be performed in a standard pipeline. The steps labeled "qr function" define one possible quick reduce function set. Other steps may be added or subtracted in the future. In some cases simple optimizations are possible should certain steps, e.g. linearity corrections, prove to be unnecessary. In other cases these same optimizations may not be desirable because of the need to retain intermediate data products.

Given the appropriate calibration information all the following reduction steps can be performed independently for each NEWFIRM exposure. Most reduction steps can also be performed independently for each imager in the NEWFIRM mosaic. This means that the majority of the reduction steps are highly parallel. Exceptions include cross talk correction and some cosmic ray detection techniques.

- Trim bad edge rows and columns
- Initialize the bad pixel mask (qr function)
- Apply cross talk correction
- Detect saturated pixels
- Detect bleed trails
- Apply bias correction
- Either
  - Apply dark current correction (qr function)
  - Apply linearity correction (qr function)
  - Apply flat field correction (qr function)
  - Do sky subtraction (qr function)
- Or
  - Do background (sky + dark) subtraction (qr function)
  - Apply flat field correction (qr function)
- Merge channels (qr function)
- Do pattern removal
- Detect cosmic rays
- Detect some kinds of ghosts
- Interpolate over bad pixels (qr function)
- Do WCS calibration (qr function)
- If image is to be resampled (qr function)
  - Specify reference WCS
  - Resample image and create single FITS image
- Else (qr function)
  - Correct for pixel scale change effects
- Do photometric calibration (qr function)

The above processing steps are described in a bit more detail below.

Trim Bad Boundary Rows And Columns

Trim bad boundary rows and columns from the raw image. This avoids processing known bad data to no purpose.

Note: If the number of bad boundary pixels is small it might be simpler to use the bad pixel mask to define the bad pixels and remove them from later processing steps rather than use the TRIMSEC keyword.

Initialize The Bad Pixel Mask (Qr Function)

Initialize the exposure bad pixel mask to the default instrumental bad pixel mask stored in the instrument calibration directory. Adjusting the mask for trimming done in the previous step. The instrumental bad pixel masks specify known bad pixels in each imager.

Note: Not performed on calibration images.

Apply Cross Talk Corrections

Apply the cross talk corrections to the raw data. The nature of the cross talk correction will depend on the controller electronics. If cross talk is known to be significant but its functional form cannot be determined no correction will be applied. Instead the affected pixels will be added to the bad pixel mask with the appropriate error code.

Detect Saturated Pixels

Detect saturated pixels and pixels for which the non-linearity cannot be corrected with sufficient accuracy in the raw data. Exclude pixels already defined as bad. Add the saturated pixels to the bad pixel mask.

Note: Not performed on calibration images.

Note: For IR data is may also be necessary to define a low bad pixel that signifies an overflow.

Detect Bleed Trails

Detect bleed trails along columns and rows in the bad data. Exclude pixels already defined as bad. Add the bleed trail pixels to the bad pixel mask.

Note: Consider whether or not to detect bleed trails in a later stage of processing, e.g. after sky subtraction when the background threshold is 0.0. This may be useful if using a detection threshold defined in terms of a mean, e.g. mean + threshold or mean * threshold to define the bleed trails. On the other hand if the threshold is defined as saturation + threshold or saturation / threshold working with raw pixels is better. The important thing is to distinguish bleed trails from bad columns and rows.

Note: Because of the way NEWFIRM works the instrument may not suffer from bleed trails. However include the option for completeness.

Note: Not performed on calibration images.

Apply Bias Subtraction

Subtract an offset from the raw data where the offsets are derived from unexposed pixels written to raw data for that purpose. For IR imagers this step is normally performed by the instrument software (?) but is included here for completeness.

Note: The NEWFIRM CODR makes mention of bias corrections but it is not yet clear what form they will take or if present whether they will be handled internally by the instrument software or dealt with by the DHS.

Apply Dark Subtraction (Qr Function)

Subtract the dark current from the raw data using dark calibration images taken for that purpose. Normally the individual darks must match the exposure time and number of co adds of the raw image. Many darks may be combined to reduce the impact on the signal to noise of the reduced image. Permit scaling the dark image by the ratio of the raw image exposure time to the dark image exposure time (CCD mode) as an exception.

Note: Defer the issue of selecting the correct dark from a list of darks to a later section.

Note: Not performed on zero images, i.e. images with zero exposure time, or on dark images.

Note: In some case, i.e. linearity corrections are not required; a separate dark subtraction may not be required as the dark current can be considered to be part of the sky background. Darks must be subtracted from flat field images.

Apply Linearity Correction (Qr Function)

Correct the dark subtracted images for non-linearity effects using information stored in the instrumental calibration directory. The form of the correction is TBD.

Note: The linearity correction may be imager dependent. Is there any possibility it is channel dependent?

Note: Not performed on zero or dark images.

Apply Flat Field Correction (Qr Function)

Divide the dark and linearity corrected data by the flat field calibration images stored in the instrumental calibration directory or taken for that purpose. The flat field calibration images must match the filter of the observation.

Note: Selecting the correct flat from a list of flats is normally done by filter.

Note: Not performed on zeros, darks, and flats.

Note: For the purpose of the quick reduce pipeline assume that the appropriate flats already exist, but include the option of creating one as a check on the observing protocol. In the case of the standard reduction it may be necessary to create flats from the data itself.

Do Sky Subtraction (Qr Function)

Subtract the sky background from the dark subtracted, linearity corrected, and flat fielded data. For the quick reduce software the sky background images must be determined from the data in the observation or precomputed by the observer.

Note: The background images must normally be taken near in time and space and through the same filter as the raw images. Details of how the sky background images are computed and selected are deferred to a later section.

Note: In the case that linearity corrections are not required a separate dark subtraction is not required as the dark current can be considered part of the sky background.

Note: The sky background image should have the same effective exposure time as the data.

Note: The mean level of image before sky subtraction should be preserved in the image header.

Note: It is possible that sky background images may contain undefined bad pixels. These should be added to the appropriate image bad pixel mask when the sky background images are created.

Note: Although the process of sky subtraction is highly parallel the process of creating the sky background image is not.

Note: Not performed on dark images or flats. For the flats the appropriate dark becomes the background image.

Merge Channels (Qr Function)

Merge data taken in different channels and stored in different extensions into a single image extension.

Note: This step is only necessary if data in different channels of the same imager are stored in separate extensions. Reasons for separating data in different channels include ease of dealing with cross talk corrections, possible gain differences between channels, etc.

Note: The first point where this step can occur in the processing sequence depends on the nature of the corrections that are required.

Do Pattern Removal

Subtract high frequency low-level non-static patterns from the background. Typical patterns are: line or column striping patterns and fringe patterns. Pattern removal involves scaling a pattern template and subtracting it from the image.

Note: The issue of generating the pattern template and computing the scale factor is left till later.

Note: Ask people about their experience with fringing and fringe removal in the IR. How much of a problem is it? Does sky subtraction remove "most", or "all" of it? What about narrow band fringes?

Detect Cosmic Rays

Detect cosmic rays in the sky-subtracted images ignoring any pixels previously defined as bad. Record the cosmic ray in the bad pixel mask using the appropriate error code.

Note: It can be difficult to robustly detect cosmic rays on single images especially if they are difficult to distinguish from stars. For many programs this step may be better performed by combining short exposures at the telescope pointing, i.e. cosmic ray splits. Ask astronomers whether or not cosmic ray splits should be considered part of the supported observing modes. The alternative is to try and detect them in dither sets, or after the images have been registered and resampled.

Detect Ghosts

Detect ghosts and add to the bad pixel mask? The question mark indicates that this is a speculative processing step that assumes that it is possible to automatically detect and remove ghosts from single images.

Note: Mike Merrill indicated that the location some kinds of ghosts can be predicted from the positions of bright objects in the field. It was not so obvious that their sizes and shapes could be determined given that they are unfocused objects.

Interpolate Over Bad Pixels (Qr Function)

Interpolate over bad pixels in the sky subtracted and flat-fielded data using information in the bad pixel mask. The reason for doing this is to minimize their effects in the later resampling step. Error codes in the bad pixel mask permit selectively choosing which types of images pixels to interpolate over. The bad pixel mask ensures that bad pixels of any type will not be used in any image-combining step.

Note: In the optical CCD code bad pixel removal is done separately at various stages, e.g. bad detector pixels are fixed immediately, saturated and bleed trail pixels after flat fielding, cosmic rays later etc. Would prefer to do the replacement all at once but there may be advantages and disadvantages to dividing things up. Consult on this issue.

Do WCS Calibration (Qr Function)

Correct the WCS calibration in the calibrated image using the existing WCS in the image header and astrometric information derived from an online preferably local catalog. The initial WCS must be accurate enough to locate stars in the image. The catalog must be rich enough to contain on average sufficient stars in a field to derive linear corrections to the existing transformations. The WCS calibration is vital to later combining steps

Note: If would get a local copy of the 2MASS survey or a reliable remote connection to IPAC that would be ideal.

Specify The Reference WCS (Qr Function)

Specify the reference center, pixel scale, and orientation of the resampled image. The reference center is the center of the final combined image not the image center or a sub field center.

Note: In order to automate the resampling process at a minimum the reference center must be defined in the image headers. This means that when an "observation" is initiated the reference position must be part of the observation specification. Other quantities such as pixel scale can default to the pixel scale at the center of the image. Orientation can default to the usual north up and east left orientation.

Resample The Image (Qr Function)

Resample the images to the reference WCS using the appropriate resampling technique and output a single resampled image. If the standard IRAF interpolants are used this automatically corrects for the pixel scale effects. Correct the bad pixel mask appropriately.

Do Photometric Calibration (Qr Function)

Perform a quick photometric calibration on the data using catalog information. Determine the zero point of the transformation and compare to nominal values. This zero point includes the effects of air mass. This photometric calibration can be used to flag deviant data.

Note: Again if we could get local copy of the 2MASS survey or a reliable remote connection to IPAC that would be ideal.

Note: Must be able to match image and catalog filter information for reasonable results.

Note: If the images are not resampled a correction for scale change effects must be made to the image.

Basic Processing Steps: Combining Exposures

The basic processing steps for combining multiple exposures are listed below in the order they would "normally" be performed by the standard reduction software. The steps labeled "qr function" define one possible quick reduce function set.

The first two steps below are the same as the next to last two steps from the previous section. They are repeated here because: 1) resampling to a common WCS must be performed before the images can be combined, 2) it may be possible to resample and PSF match the images in a single step in the future.

- Specify the reference WCS (qr function)
- Resample the images (qr function)
- Specify the reference PSF

- Match the image PSF to the reference PSF
- Match the background levels
- Match the intensity scales (qr function)
- Combine the images (qr function)
- Detect transients and update bad pixel masks
- Recombine the images
- Check WCS calibration of combined image
- Do photometric calibration of combined image (qr function)

The above processing steps are briefly outlined below.

Specify The Reference WCS (Qr Function)

Specify the reference center, pixel scale, and orientation of the resampled image. The reference center is the center of the final combined image not the image center or a sub field center.

Note: In order to automate the resampling process at a minimum the reference center must be defined in the image headers. This means that when an "observation" is initiated the reference position must be part of the observation specification. Other quantities such as pixel scale can default to the pixel scale at the center of the image. Orientation can default to the usual north up and east left orientation.

Resample The Images (Qr Function)

Resample the images to the reference WCS using the appropriate resampling technique and output a single resampled image. If the standard IRAF interpolants are used this automatically corrects for the pixel scale effects. Correct the bad pixel masks appropriately as well.

Specify The Reference PSF

Specify the reference PSF by specifying a reference PSF model or a reference PSF image. This step should be performed only if the science requires it. This step will not be part of the quick reduce software and will probably not become part of the standard reduction software either.

Note: Matching the PSF is not required to detect transients such as cosmic rays, meteors, etc.

Note: Care must be taken to select an appropriate reference PSF. It is "relatively" straight forward to match image to the lowest common denominator image, e.g. the worst seeing image, more challenging to go the other way.

Note: PSF variations across the image must be dealt with.

Note: Poor seeing images can be rejected using the quality assessment statistics.

Match The Image PSF To The Reference PSF

Match the image PSF to the reference PSF by performing some sort of spatially variant (to account for PSF variations with position) convolution kernel.

Note: Investigate the Allard algorithm that combines registration and PSF matching.

Match The Backgrounds

Match the background levels to allow for the fact that the sky varies with time. This should not in general be necessary, as the sky subtraction process should have automatically matched all the background levels by setting them to zero. The mean level of the subtracted sky will be recorded in the image header.

In some cases it may be necessary to remove residual sky gradients. If necessary this can be done with a low order polynomial function.

Match The Intensity Levels (Qr Function)

Match the intensity levels to allow for the fact that the sky transparency varies with time. As long as the dither steps are small enough this can be done by measuring the intensities of regions common to one or more images and computing the relative scaling factors. If survey data is available then this can also be done by using the photometric zero points computed in an earlier step. Comparison of the two techniques might be a useful reality check.

Note: The first intensity matching method is probably the preferred one as it does not rely on any external data source?

Combine The Images (Qr Function)

Combine the images using the WCS information. The details of how the pixels are evaluated may depend on whether or not transient object detection is enabled, i.e. severe clipping may be optimal for creating a deep template image against which to detect transients, but no clipping is optimal for producing the final science image.

Detect Transients

Detect cosmic rays, ghosts, meteors, asteroids, etc by comparing the individual images against the combined image. Add the transients to the individual bad pixel masks.

Recombine The Images

Recombine the images eliminating the transients detected in the previous step.

Check The WCS Calibration

Check the WCS by locating catalog stars in the combined image and recomputing the WCS. The recomputed WCS should agree with the reference WCS to within the errors in the catalog, errors in the original solution, and object recentering errors.

Note: It may or may not be a good idea to overwrite the existing solution in the header at this point, but is a good idea to add some WCS error information to the header if such is not already present.

Note: This can be considered a quality assessment step.

Do Final Photometric Calibration (Qr Function)

Compute a "final" zero point for the image using catalog survey stars measured in an appropriate photometric band.

Basic Processing Steps: Generating The Required Calibration Data

In order to fulfill its mission of observing condition and protocol verification, the quick reduce software will exercise only a subset of the standard reduction software, and will make compromises on the quality of the calibration data.

The standard reduction software requires accurate and complete calibration data in order to function correctly and automatically. The required calibration data for the standard reduction steps are listed below. The calibration data labeled qr function are required to run the quick reduce software.

- Instrumental bad pixel mask (qr calibration)
- Cross talk corrections
- Saturation / non-linearity definition
- Bleed trail definition
- Bias corrections
- Dark calibration images (qr function)
- Linearity corrections (qr function)
- Flat field calibration images (qr function)
- Sky background calibration images (qr function)
- Cosmic ray (and other artifact) definition
- WCS calibration data (qr function)
- Transient object definition
- Photometric calibration data (qr function)

Each type of calibration is described briefly below along with a note about how the calibration will or will not be used by the quick reduce software.

The Instrumental Bad Pixel Mask (Qr Calibration)

The instrumental bad pixel mask specifies the known bad detector lines, columns and features. These masks are used to hide known bad pixels during image display, to replace bad pixels with some user defined value, and most importantly to remove bad pixels from the image combine step. The instrumental bad pixel masks should be ~constant over time.

Each exposure bad pixel mask is initialized to the instrumental bad pixel mask and used by both the quick reduce and standard reduction software.

Cross Talk Corrections

Cross talk corrections specify how to correct the counts in a given channel for any crossover effect of counts in a "neighboring" channel. The form of this correction if any is TBD, as is the issue of how constant it is over time.

Unless the corrections are "large" cross talk correction will not be part of the quick reduce software. It will be part of the standard reduction software.

Saturation / Non-Linearity Limit Definition

The saturation or non-linearity limit is a single number defining the maximum good pixel value in counts. Additional parameters such as a region growing box may also be defined. This number should be ~constant over time.

Saturation / non-linearity limit detection will not normally be part of the quick reduce software. It will be part of the standard reduction software.

Note: These numbers may be different for different imagers.

Note: It may be necessary to define a lower good data limit as well.

Bleed Trail Definition

Bleed trails are usually defined in terms of some number of consecutive pixels above a defined threshold. Additional parameters such as a region growing box may also be defined.

Bleed trail detection will not normally be part of the quick reduce software. It will be part of the standard reduction software.

Note: IR imagers may be relatively immune from bleed trails. ONIS was not.

Bias Corrections

Bias corrections are DC offsets, derived from unexposed image pixels devoted to that purpose, which are subtracted from the data before other reduction steps are performed, i.e. the CCD under scan or over scan pixels.

Note: This type of bias correction is not normally performed for IR imager data (?) but is included for completeness.

Dark Current Calibration Images

Dark current calibration images are images taken with the same exposure time and number of co adds as the data but with the "shutter" closed. In most cases several dark images are combined into a single dark calibration image. This can be done before actual observing begins.

Dark subtraction will be a standard part of the quick reduce software and the standard reduction software.

Note: In some cases a separate dark subtraction may not be required as it is included in the sky subtraction step.

Linearity Corrections

Linearity corrections are applied to the dark subtracted pixels. The form of this correction if any is TBD. The linearity corrections should be ~constant with time.

The linearity corrections will be a standard part of the quick reduce software and the standard reduction software.

Calibration Images Flat Field

Flat field calibration images may be dome / lamp flats (not usual in the IR...) or sky flats taken in the same filter as the data. In most cases several flat images are combined into a single flat with appropriate rejection.

Flat field corrections will be a standard part of the quick reduce software and the standard reduction software. In the former case precomputed library flats will be used. In the latter case the flats may be precomputed or computed as part of standard reductions.

Sky Background Calibration Images

Sky background images must be computed from data near in space and time to the observation being reduced. They are subtracted from the data.

Sky background subtraction is a crucial part of both the quick reduce and standard reduction software. Several options will be available for computing the sky background image and the quick reduce software shall for the purpose of comparison permit more than one to be exercised.

Cosmic Ray (And Other Artifact) Definition

Define how cosmic rays and other "recognizable" artifacts can be recognized and removed from single images.

Cosmic ray removal will be a part of the standard reduction software although it may turn out to be better handled by transient detection software than by pattern recognition software. It will not be part of the quick reduce software.

WCS Calibration Data

Accurate WCS data is critical for mosaic assembly. Each exposure will be assigned a precomputed WCS derived from a standard astrometric field or survey data. The built-in reference point will be replaced by the current telescope pointing. The WCS calibration data will tweak the WCS to account for small scale changes etc using the positions of known (2MASS?) stars.

WCS calibration will be a standard part of both the quick reduce and the standard reduction software.

Transient Object Definition

Define how transient objects will be detected. One possibility is to difference each individual image component of the observation against a heavily clipped version of the combined image and compare fluxes in the differenced image.

Transient object detection and removal will be part of the standard reduction software. It will not be part of the quick reduce software.

Photometric Calibration Data

The final photometric calibration step cannot rely on the observers program including observations of known IR standards. Instead an approximate zero point will be determined for each image using an on-line survey such as 2MASS.

Photometric calibration will be part of the quick reduce and standard reduction software.

Complications: Iterative Processing Steps

Despite the increasing casual use of the term pipeline, which implies a linear sequence of events, some steps in the reduction software may actually be iterative in nature rather than linear. A sample of some of these is shown below. Iterative steps be avoid in the quick reduce software if possible.

- Sky background determination
- Transient object detection
- Calibration image creation

Accurate Sky Subtraction

Accurate sky subtraction may require object detection and masking of the individual images composing a sky background image. This is normally an iterative process involving initial sky background image creation, initial sky subtraction, object detection, object mask creation, new sky background image creation, and final subtraction.

An additional complication is that it may be necessary to perform the object detection and masking on the combined images in order to detect fainter objects and then propagate the mask back to the individual images to redo the sky subtraction.

Transient Object Detection

Transient object detection may require differencing individual images against a heavily clipped master combined image, detecting and removing transients, and recombining the final image.

Calibration Image Creation

Creating good calibration images, e.g. sky flats, may also be an iterative process.

Existing Pipelines

Some sample pipelines are outlined below. Only the functionality is presented.

The NDFWS ONIS Pipeline

Given

- A header translation file
- An instrument bad pixel mask
- ~60-120 dark calibration images
- Linearity correction images
- ~60-120 on/off dome flat calibration images
- The reference WCS
- ~170 standard star observations
- ~250 program images in an RA strip

the ONIS pipeline performs the following steps:

- Header regularization
- Dark calibration image construction
- Dome flat calibration image construction
- Dark subtraction, linearity correction, flat fielding
- Updated bad pixel mask construction

- First pass sky subtraction
- First pass bad pixel correction
- First pass cosmic ray detection and removal
- First pass offset computation
- First pass image mosaic

- Object mask construction
- Object mask deregistration
- Mask pass sky subtraction
- Mask pass bad pixel correction
- Mask pass cosmic ray detection and removal
- Destriping
- Mask pass image mosaic

- WCS computation for combined image
- WCS transfer to single sky subtracted images
- Output image resampling to a common WCS
- Photometric calibration computation using standard stars
- Image stacking using intensity scaling factors

The Las Campanas Infrared Survey Carnegie Reduction Pipeline

Given

- Dark calibration images?
- Linearity corrections?
- Dome flat calibration images
- 3-5 sets of standard star observations per night
- Observations consisting of
    - 3-5 images per telescope pointing
    - 9 pointing dither set with offsets of 8-13 seconds (bad pixels)
    - 4 pointing dither set (tile) with offsets of ~190 seconds (gaps)
    - 4 tiles per field

the Carnegie pipeline does the following

- Dark calibration image construction?
- Dome flat calibration image construction ?
- Averages single pointing images simultaneously rejecting cosmic rays
- Dark subtracts?, linearity corrects?, and flat fields the images
- Constructs bad pixel mask from flats
- Initial sky image construction from single pointing images
- Initial sky subtraction
- Small dither set offset computation and image combination
- Object mask construction
- Mask pass sky image construction
- Mask pass sky subtraction
- Detector reset instability correction
- Pointing image combine using stars in the overlap regions
- WCS computation using standard stars

Details can be found in Chen et al. (2001), submitted to Ap.J., astro-ph/0108171

The Las Campanas Infrared Survey IoA Reduction Pipeline

The pipeline is the same in conceptual design as the Carnegie version but the ordering of some of the steps and the computational details vary.

Details can be found in Firth et al. (2001), submitted to MNRAS, astro-ph/0108182

The Florida Flamingos Pipeline

Add later.

Software Status

The NEWFIRM reduction software does not have to be built from scratch. Simple tools for creating dark calibration images, flat field calibration images, and bad pixel masks already exist in IRAF. IRAF software for automatically computing the WCS, storing it in the image header, and tweaking it to adjust for local conditions already exists, as does IRAF software for resampling and combining images into larger fields. IRAF Software for automatically computing photometric calibrations for images already exists as well. New IRAF software for detecting transients already exists and will undergo development in the future on a time scale suitable to meet the needs of NEWFIRM.

What does not currently exist in IRAF is a header driven, i/o efficient, package for doing basic IR reductions including dark subtraction, linearity correction, flat fielding, sky subtraction, bad pixel mask construction, etc along the lines of the optical IRAF ccdred package. Although many of the concepts embodied in the ccdred package can be borrowed for the development of the IR package a somewhat different infrastructure is required. Development of this infrastructure will be the major effort required to support NEWFIRM reductions.

Reality Checks

The CDR documented included some very crude processing time requirements, which ere extrapolated from our experience with the ONIS pipeline. The ONIS pipeline takes about 4 hours to process 0.7GB/night on a recent vintage Sun Ultrasparc computer. Assuming a NEWFIRM data rate of 32 GB per night, a factor of 2 is estimating the computational requirements, and a computer that is 8 times faster those currently in use it should require ~50 hours to process the data. A 5-processor cluster could easily handle the data rate. It should be emphasized that this estimate is actually quite conservative as the ONIS pipeline is built around simple scripts and does far more i/o than more sophisticated software would do.

Add MSCRED timings from Jenna and Buell when they are available.