WFCAM SCIENCE ARCHIVE

DATA FLOW DOCUMENT

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Modification history:

Version	Date	Comments
Draft	Oct 2002	Original version (NCH, AL & IAB)
V1.0	Jan 2003	Revised (NCH)

1 INTRODUCTION

The purpose of this data flow document (DFD) is to examine data transfer rates, accumulating data volumes, data formats and data curation issues for the WFCAM Science Archive (WSA) project. This, in turn, is intended to inform the hardware and software design of the WSA. Issues to be considered include import/export rates/volumes/formats; post–processing; DBMS ingest and processing (eg. indexing); and backup/update/releases. The major goal of this document is to inform decisions concerning storage hardware and investigation of network connectivity.

In this context, we consider the 'flow' in data flow as encompassing i) *import*, ii) *curation*, and iii) *use* (including export); where 'data' encompasses pixels/catalogues/housekeeping information for both WFCAM and complementary datasets (see the SRD). The DFD is organised into Sections following these three broad categories.

An overview of the end–to–end data flow, including data rates and accumulation volumes, is given in Appendix A.

2 IMPORT

2.1 Import data volumes and rates

2.2 Import procedure

2.3 Import formats

3 CURATION

3.1 Additional processing

3.2 DBMS ingest (catalogues and housekeeping data)

3.3 Additional processing in DBMS

- indexing
- sorting
- spatial index computation

3.4 Storage of pixel data

- Compression
- 'Unit' of storage

3.5 Backup

3.6 Updates/releases/reruns

4 USE

4.1 Workspace

4.2 Access restrictions

4.3 Export formats

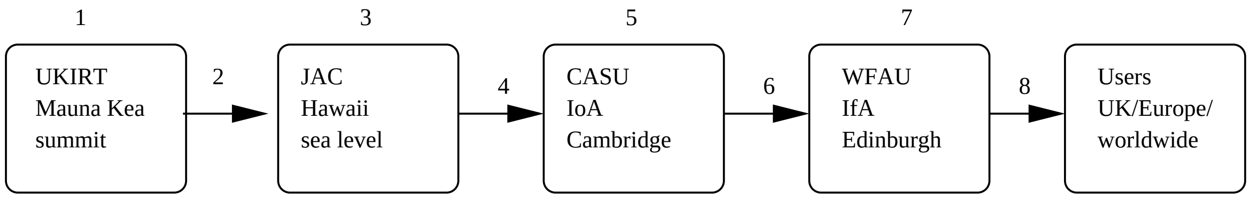
4.4 Export rates

A End–to–end Overview

This section examines the end–to–end data flow for the UKIRT WFCAM project in order to estimate

- online storage requirements
- offline storage requirements
- network bandwidth/media requirements for data transmission
- backup media/frequency requirements

In schematic outline, the putative data flow will be along the following lines:



A.1 Assumptions

The following assumtions can be made about WFCAM; these are unlikely to change:

- the maximum data rate from the DAS is one 4–device 'footprint' per 10s;
- the DAS will output 4 bytes per pixel;
- the DAS will co–add sky limited sub–exposures when a single demand exposure (specified for observing efficiency reasons for example) would saturate in the sky (eg. 40s demand integration at K);

Here, the 'DAS' ($\equiv$Data Acquisition System) consists of the device itself, the device controller, and ADC and a PC system that processes the 16 bit/pixel reads from the ADC. There will be four such subsystems operating in parallel, one per WFCAM device. The PC will coadd individual 16–bit reads, or process non–destructive reads etc., and for generality will always output 32 bit values $\equiv$4 bytes/pixel (note: these PCs should *not* be confused with those that will operate the summit pipeline). We further assume that the individual sky–limited sub–exposures will not be kept. For the purposes of estimating both the maximum and typical data volumes/rates, the following further assumptions can be made:

- online archive will not utilise any 'lossy' compression to reduce pixel storage requirements;
- UKIDSS ($\sim$ 700 night combined science programme) is typical of the science that will be undertaken with WFCAM;
- assume 2×2 microstepping and WFCAM project scientist efficiency estimates for the purposes of time–average numbers (eg. the UKIDSS proposal);
- the PEAK data rate is that delivered by the DAS maximum and using a 2×2 microstep mode with efficiency 0.65. An interlaced frame will be produced in $\sim$ 1 minute comprising 4 detectors $\times$ 2048 $\times$ 2048 pixels $\times$ 4 bytes per pixel $\times$ 2×2 microsteps = 270 Mbyte or 230 Gbyte per perfect 14 hour winter night;

- Typical time–averaged data rate can be estimated by averaging over UKIDSS component surveys, assuming an average 10 hour night and scaling the data rate in the previous item by the relative survey efficiencies:

LAS	183.4 nights	160 Gbyte per night	= 29.3 Tbyte
GPS	130.2	92	12.0
GCS	58.8	160	9.4
DXS	123.9	52	6.4
UDS	130.2	52	10.8
Totals:	~ 700		~ 70.0

or an average over the science programme of ~ 100 Gbyte per full night.

- data volumes/rates will include a 10% overhead on pixel data alone, where appropriate, for the purposes of allowing for derived object catalogues, housekeeping and DBMS

This last item needs closer inspection. Appendix D lists the baseline set of parameters per detected object from CASU standard pipeline processing. Assuming 4 bytes per parameter (they will be mainly single precision floating point numbers) this is 66 parameters $\times$ 4 bytes = 264 bytes per detection. Further, for the purposes of list–driven co–located photometry (see the SRD; ie. given a detection in one passband, what are the object parameters at fixed positions using fixed apertures and profiles in all other passbands) this value should be scaled appropriately for ~ 4 UKIDSS passbands (and ultimately another 5 SDSS passbands for total generality; again, see the SRD). So, to order of magnitude, the catalogue records size is $\sim 10^3$ bytes per detected object. Now, the number of detected objects per frame will vary enormously. For example, in the UKIDSS GPS, towards the Galactic centre the surface density of sources is likely to be $> 10^6$ per sq. deg. (or $\sim 10^{-2}$ objects per pixel) while in the lowest surface density regions of the LAS this is likely to drop to $\sim 10^3$ per sq. deg. (or $\sim 10^{-5}$ objects per pixel). If we assume a typical surface density of sources as being $\sim 10^4$ per sq. deg., or $\sim 10^{-4}$ objects per pixel, then for a given amount of pixel data the object catalogue overhead is

$$\frac{10^3\text{bytes/obj} \times 10^{-4}\text{obj/pix}}{4\text{bytes/pix}} \times 100 \approx 3\%.$$

Allowing for housekeeping, other ancilliary data and DBMS overheads, a figure of 10% overhead on pixel data does indeed seem reasonable.

A.2 Details

Some relevant details on individual parts of the data flow scheme above:

1,2,3: JAC/ATC responsibility; JAC will likely make offline tape archive of raw pixel data; couple of weeks online buffer storage will probably be used; ATC proposes 4–way parallelisation of the DAS & summit pipeline data chains; output format will be Starlink NDF (JAC archive) and MEFs (multi-extension FITS files) for transport to CASU.

4: For ease of housekeeping/transport/handling, one disk or tape per night would be advantageous. Peak data rate is 230 Gbyte/night. One or two disks may be employed to ship the data; alternatively tapes may be used. Currently, the highest capacity system would appear to be ‘Linear Tape Open’ (LTO) which can store ~ 100 Gbyte native, and would probably manage a night’s worth of data (with a bit of lossless compression) on all but the most productive of nights. The transfer rate for LTO is reportedly 100 Gbyte/hour. By the time WFCAM becomes operational, there may be higher capacity in this system, or higher capacity alternatives.

5: CASU pipeline will derive/add data to the images ingested from JAC: i) housekeeping info; ii) object catalogues; iii) confidence arrays. As stated in the assumptions above, a 10% increase on pixel data volume will allow for housekeeping, object catalogues and DBMS overheads; however iii) is potentially a large increase on raw pixel volume/rates. For example, if a 2–byte confidence value per 4–byte pixel is added for any image that is likely to be stacked (cf. current CIRSI pipeline processing) then volumes/rates increase by 50%. The greater fraction of the UKIDSS science program will be stacked to increase depth, so a conservative assumption would be to increase ALL pixel data volumes/rates by a factor 1.5; however it is unlikely that confidence values will be needed on a pixel–by–pixel basis; rather nightly library confidence frames will suffice. In this case the overhead will be small and can be subsumed into the existing 10% overhead.

7: An estimate of the yearly rate can be made as follows. Nights per year are likely to be $365\times$ 80% UK time on UKIRT $\times f_{\rm WFCAM}$, the fraction of all UK time given over to WFCAM. Assume 110 Gbytes per night average, and for the likely range assume $0.6 < f_{\rm WFCAM} < 0.8$. Then, the average yearly data accumulation rate will be between 19 and 26 Tbytes.

For science archiving, it is important to distinguish between storage requirements for 'immediate' access (or 'as fast as possible' access) and storage for less time critical usages. An examples of the former is where an astronomer wishes to trawl object catalogues for rare objects, where data exploration (ie. interaction in real time) is important. An example of the later is where a 'power user' wishes to reprocess a large fraction of survey data to look for objects that they believe were missed in the standard pixel processing pipeline (eg. large–scale, low surface brightness objects). The split in usages requiring fast/slower (real–time/offline) response times is a split between catalogue usage and pixel data usages, broadly speaking.

An estimate of the final pixel storage requirement for UKIDSS at least is straightforward: assuming 4 bytes per pixel and 2×2 microstepping (ie. 0.2 arcsec pixels); the areas of the LAS, GPS, GCS, are respectively 4000 sq. deg. $\times 5$ filters; 1800×5; 1600×4 (stacked pixel data for the DXS and UDS are negligible for these purposes). This adds up to ~ 50 Tbytes; the final UKIDSS object catalogues and associated data will be ~ 5 Tbytes.

At each point in the end–to–end system, the data flow volumes/rates and some hardware requirements can be roughly stated as follows:

1,2,3:

- Peak data rate 230 Gbyte/night
- Average data rate 100 Gbyte/night for ~ 200 nights each year
- Accumulation of data: ~ 20 Tbyte/year
- Online storage requirements (summit): a few Tbytes

Nightly backups required; these should be able to cope with 230 Gb/night; one backup tape per night if possible; $\sim 200\times$ N tapes needed per year for JAC offline raw data archive, where N = no. of tapes per night.

4:

- Peak data rate: 230 Gbyte/night
- Average data rate 100 Gbyte/night for ~ 200 nights each year

- One disk or tape per night if possible

If a tape solution were to be employed, and furthermore those tapes were used as an offline backup at CASU (as opposed to being recycled) then $\sim 200 \times$ N tapes would be needed per year for data transfer to CASU and subsequent shelving in CASU UKIRT data archive, where N = average no. of tapes per night.

5:

- Peak data ingest rate: 230 Gbyte/night
- Average data ingest: 100 Gbyte/night for ~ 200 nights per year

from here on, data volumes/rates multiplied by 1.1 to account for housekeeping/catalogue overheads:

- Typical rate of accumulation of processed data: 22 Tb/year

6: If network, then need to be able to transfer 250/110 Gbyte/day (peak/average). Note: a 1 Gbit/s continuous link would enable 450 Gbyte/hr to be transfered.

7:

- Data ingest: 250/110 Gbyte/day (peak/average)
- Accumulation of data: 22 Tb/yr

Archive backup frequency: every few months probably sufficient; speed not critical but clearly 1 Tb/day may eventually become impractical as archive size increases beyond 100 Tb while 10 Tb/day may be overkill.

8: User access: SSS is Gbyte/week; suggest it is likely that WFCAM archive is likely to be 10x more, hence Gbytes/day.

A.3 Summary for the WSA

In summary, data flow for the WSA will be:

- Ingest: $\sim$ 250/110 Gbyte per day (peak/average) for ~ 200 days per year;
- Accumulation of data: ~ 20 Tbytes per year;
- Accumulation of catalogue, housekeeping and other ancilliary data: ~ 2 Tbytes per year.

The uncertainties above (eg. detected objects per pixel; the amount of confidence array information needed to be stored, etc.) should not prevent progress on hardware design and acquisition, since storage for the final data volume does not have to be purchased up front. Provided sufficient storage is acquired for the first year of operation, it will become clearer during that time what the precise long term requirements are. In any case, the lifetime of the WSA project is significantly longer than the typical timescale of leaps in computer hardware design, so it should be expected that the initial hardware solution will not be the final one, and a phased approach (as is required from the science exploitation point of view; see the SRD) is implied.

A.4 Descopes

Numbers above are of course dominated by the volume of pixel data. If it is decided that it is unnecessary to archive processed pixels in uncompressed form, then storage volumes & data rates can be reduced dramatically. For example, if the archive contains 10x H-compressed pixels, then all numbers from 6 onwards can be reduced by $\sim 90\%$. However, there is a very clear requirement in the SRD for online archiving of unadulterated pixel data.

In specifying the requirements, a chance could be taken on assumption of the average number of usable nights: eg. UKIDSS proposal suggests that on average, 70% of allocated nights will produce science data, so volumes/rates can be decreased by 30% (but note that on a daily basis the data flow system should still be able to cope with peak data rates produced by hopefully many perfect nights).

B FITS headers

C WFAU network connectivity

D Catalogue parameter list (standard CASU processing)

APM/SuperCOSMOS/INT WFC/CIRSI analysis produces 32 4-byte parameters per detected object. This has been enhanced to include extra parameters for flux estimation and error estimates. The following is the suggested list for the standard WFCAM pipeline:

No.	Name	Description
1	Seq. no.	Running number for ease of reference, in strict order of image detections
2	Isophotal flux	Standard definition of summed flux within detection isophote, apart from detection filter is used to define pixel connectivity and hence which pixels to include. This helps to reduce edge effects for all isophotally derived parameters.
3	X coord	Intensity–weighted isophotal centre–of–gravity in X
4	Error in X	estimate of centroid error
5	Y coord	Intensity–weighted isophotal centre–of–gravity in Y
6	Error in Y	estimate of centroid error
7	Gaussian sigma	These are derived from the three general intensity–weighted second moments.
8	Ellipticity	The equivalence between them and a generalised elliptical Gaussian distribution
9	Position angle	is used to derive Gaussian sigma $= (\sigma_a^2 + \sigma_b^2)^{1/2}$
		Ellipticity $= 1.0 - \sigma_a/\sigma_b$
		Position angle = angle of ellipse major axis wrt x axis
10	Areal profile 1	Number of pixels above a series of threshold levels relative to local sky.
11	Areal profile 2	Levels are set at T, 2T, 4T, 8T ... 128T where T is the threshold. These
12	Areal profile 3	can be thought of as a sort of poor man's radial profile. Note that for now
13	Areal profile 4	deblended, ie. overlapping images, only the first areal profile is computed
14	Areal profile 5	and the rest are set to −1 flagging the difficulty of computing accurate
15	Areal profile 6	profiles.
16	Areal profile 7	
17	Areal profile 8	
18	Peak height	in counts relative to local value of sky - also zeroth order core flux
19	Error in pkht	
20	Core flux	Best used if a single number is required to represent the flux for ALL objects. Basically aperture integration with radius rcore (in the FITS header) but modified to simultaneously fit 'cores' in case of overlapping images. Best scaled to $\approx$<FWHM> for site+instrument. Combined with later-derived aperture corrections for general photometry.
21	Error in flux	
22	Core 1 flux	A series of different radii core/aperture measures similar to parameter 20
23	Error in flux	
24	Core 2 flux	Together with parameter 18 these give a simple curve–of–growth analysis from
25	Error in flux	
26	Core 3 flux	peak pixel, $1/2\times$ rcore, rcore, $\sqrt{2}\times$ rcore, $2\times$ rcore, $2\sqrt{2}\times$ rcore,
27	Error in flux	$4\times$ rcore, $4\sqrt{2}\times$ rcore, $8\times$ rcore, $8\sqrt{2}\times$ rcore, $16\times$ rcore,
28	Core 4 flux	$16\sqrt{2}\times$ rcore, $32\times$ rcore
29	Error in flux	
30	Core 5 flux	$4\times$ basic core, ensures $\sim 99\%$ of PSF flux

31	Error in flux	
32	Core 6 flux	Extras for generalised galaxy photometry further spaced
33	Error in flux	
34	Core 7 flux	by $\sqrt{2}$ in radius to ensure correct sampling out to
35	Error in flux	
36	Core 8 flux	reasonable range of aperture sizes
37	Error in flux	
38	Core 9 flux	Note these are all corrected for pixels from overlapping neighbouring images
39	Error in flux	
40	Core 10 flux	
41	Error in flux	
42	Core 12 flux	Biggest would be 32$\times$ rcore ie. $\approx$30 arcsec diameter
43	Error in flux	
44	Petrosian radius	r_p as defined in Yasuda et al. 2001 AJ 112 1104
45	Kron radius	r_k as defined in Bertin and Arnouts A&A Supp 117 393
46	FWHM radius	r_{fhwm} average image radius at half PeakHeight
47	Petrosian flux	Flux within circular aperture to $k \times r_p$
48	Error in flux	
49	Kron flux	Flux within circular aperture to $k \times r_k$
50	Error in flux	
51	FWHM flux	Flux within circular aperture to $k \times r_{fwhm}$ – simple alternative
52	Error in flux	
53	Error bit flag	Bit pattern listing various processing error flags
54	Sky level	Local interpolated sky level from background tracker
55	Sky variance	Local estimate of variation in sky level around image
56	Child/parent	Flag for parent or part of deblended deconstruct
		The following are accreted directly after standard catalog generation
57	RA	RA and Dec explicitly put in columns for overlay programs that cannot, in
58	Dec	general, understand astrometric solution coefficients. Derived exactly from
		WCS in header and XY in parameters 5 & 6
59	Classification	Flag indicating probable classification: eg. -1 stellar, $+1$ non–stellar, 0 noise
60	Statistic	An equivalent N(0,1) measure of how stellar–like an image is, used in
		deriving parameter 59 in a 'necessary but not sufficient' sense
		From the further processing pipeline after deriving a suitable PSF
61	PSF flux	Fitted flux from PSF
62	Error in flux	
63	X coord	Updated PSF-fitted X centroid
64	Error in coord	
65	Y coord	Updated PSF-fitted Y centroid
66	Error in coord	