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AN APPLICATION OF LARGE SCALE COMPUTING FACILITIES TO THE PROCESSING OF LANDSAT DIGITAL DATA IN AUSTRALIA

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I. ABSTRACT

An early issue in the Australian Wide Scale Wheat Monitoring Project, started in November, 1978, was whether to use area sampling, as in the LACIE, or to be innovative and attempt whole scene processing. The availability of a large computing system and acknowledgement of the trends in price and performance of computers influenced a decision towards whole scene processing.

The computing facilities used in this project are described.

An interactive facility supported by software called ER-MAN II is installed on an IBM 3033 which simultaneously supports several hundred other interactive users. The pros and cons of using such a shared facility for this type of work are explored.

The use of multi-temporal data has been the essence of the approach in this project. Reasons for its use, and its performance implications are discussed from the computing view point.

Results to date indicate that shared use of a large facility is feasible and effective. In addition, some calculations may not be possible on small CPU's

While the interactive processing of the combination of multi-temporal LANDSAT data and large areas is not common in Australia now, it is probable that its use will increase as the cost of computing equipment decreases.

II. HISTORY

A. PROJECT SETUP

IBM's aim in setting up its image processing facility in Sydney is to apply IBM Australia resource to research projects considered to be in the national interest.

The first, and major project undertaken is a three year joint research study of the estimation of the wheat crop in selected areas by the digital processing of LANDSAT data. The parties involved are IBM Australia Limited and NSW Department of Agriculture.

This project was initiated following the announcement of the Australian Government's decision in 1978 to install a LANDSAT receiving station at Alice Springs. Work commenced in October 1978 and is scheduled to continue until the end of 1981. The agricultural remote sensing aspects of this work are reported elsewhere at this symposium by Dawbin and Beach (1).

B. DECISIONS

One of the first IBM decisions following the signing of the research agreement with the NSW Department of Agriculture was whether to share the IBM Australia Compute Centre equipment

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* NSW (New South Wales) is the middle of the three Eastern states of Australia and lies between 29°S and 37°S latitude.

installed at Rosebery, a suburb of Sydney, or to install a special, stand-alone system elsewhere. A stand-alone machine would probably have been a nearly minimum configuration, ½ Mb (Million bytes, of main storage) 3145 and have little chance of upgrade over the life of the project. The author argued that it would be better to use the Compute Centre for the following reasons: (Also refer Table 1.)

1. The available CPU was already larger being a 4Mb 3158.

2. Upgrades were already planned for the Compute Centre.

3. Some technological advances which would be installed in the Centre for independent business reasons, could not be justified in a stand-alone environment e.g. 3800 printer rated at 20000 lines per minute.

4. All systems programming work would be done by an existing group, with no additional project resource being required.

5. All machine room functions e.g. operations, data control, malfunction correction and control would also require no extra manpower, or work for the project team.

6. Interactive programming via TSO (Time Sharing Option 2,3) would be available with no effort by the team and would not be installable on the alternative stand-alone machine.

That the decision was to use the Compute Centre is already known, but it is worth emphasising that the approach does assume:

1. The ER-MAN software was to be available anyway and would operate in the shared environment,

2. The software would run on the available CPU,

3. That there was spare capacity on the available CPU,

4. That the appropriate interactive terminal was to be purchased independent of this decision.

The computing facility consists of 3 major components:

Hardware: The Central Processor (CPU) has varied (refer Table 1):

Disk drives: One 200 Million byte (Mb) capacity IBM 3330-11 (4), has been used for application program and data residence throughout. A second drive has been used when required. (The total machine configuration includes multiple spindles of various types).

Tape drives: Usually only one used by this work at any time.

Special Display Terminal: A Ramtek 9300 Graphic Display (6) system is attached to a CPU channel via an IBM 2701 Data Adaptor Unit (7) with a special feature which assembles bytes coming from the channel into 16 bit words for the Ramtek. The terminal consists of a control unit, a colour TV monitor, black and white TV monitor keyboard and trackball (8).

Printer: An IBM 3800 printer was installed early in the project.

A variety of other devices associated principally with the IBM Australia data network is not described.

Systems Software: The operating system used is IBM OS/VS2 (MVS) (9). The execution time resource manager of MVS has enabled the work described here to be given a despatching priority which gets the work done without impacting other users. (But also see section IV.)

Application program: ER-MAN II (10, 11, 12), based on NASA's ERIPS (10, 17) provides the functions used in the joint research projects at Rosebery. The only new function added to ER-MAN in Australia permits the LOADING of 2 new formats of data, in particular that supplied by the Australian LANDSAT Station (ALS) in Canberra.

The principle function used in all projects is the maximum likelihood classification technique. The mathematics of this are well described elsewhere.

Table 1. History.

1972 -
LANDSAT launched ERIPS/NASA

1975 - - OS/VS1
ER-MAN available (2314 disks @ 29Mb)

1978 - - MVS
ER-MAN version from Oslo (3330-11 disks @ 200Mb) RAMTEK 9300

1979 RAMTEK 9300 installed in Sydney.

	Sydney CPU for ERMAN		Relative * Performance of CPU (5)	Operating System
1979	3158 U	4Mb	850	MVS
1979	3158 MP	6Mb	950	MVS
1979	3033	8Mb	4400	MVS
1980	3033	12Mb	4400	MVS
1981	3033	16Mb	4400	MVS
cf:	3145	.5Mb	350	VS1

* Hypothetical standard processor assumed rated at 1000. These figures, while derived for a different operating environment, are provided as a guide.

C. REQUIREMENTS

In anticipation of the need to demonstrate useful results to potential users, it was decided to aim to produce wheat estimates on a shire basis so that comparison with official figures would be possible.

The largest wheat growing shire in NSW is centred on the town of Narrabri. The bounding rectangle to include this shire is approximately 2/3 of a LANDSAT scene. This implies a requirement to handle over 20Mb per acquisition if registration was to be done once only per acquisition, as was hoped. Since ER-MAN had an explicit limitation of 10Mb for its largest image, at least some modification was essential. The subsequent decision to increase the ER-MAN limitation to 100Mb appeared to give sufficient capability for the multi-temporal work envisaged.

Table 2. Pros/Cons Compute Centre (CC) from Project Viewpoint

	Cost	Benefit
1. Large Machine	0	Greater processing capacity to do large classifications.
2. Upgrades planned/installed 3158MP 3033	IDAM perform. problem. 3 man monts work & some project delays.	Some upgrades had no impact - others great and positive. Capability to do larger classifications. Reduced researcher time per function.
3. Technological Advances		
TSO Updates	-	None
MVS Updates	1 bug caused 2 day's	Improved performance options.
3800 Printer installed		Quicker output - fewer delays Improved character map.
4. Systems Programming by CC	Occasional problem when project not allowed for in implementing change. (Est-cost - 2 man days max.) Negotiation time for non-used operation.	No installation work by project team. Skilled assistance available. All base software at latest level. (Est. savings 2½ man years.)
5. Machine room run by CC	Some delays e.g. Tape Some errors - and some forced program changes. (Est cost - 4 man weeks.) Special demos for CC	All normal operations handled. All access problems handled. All machine problems fixed. (Est. savings 2½ man years.) High level of co-operation.
6. TSO Availability	One 3270 terminal.	Rapid diagnosis of problems. Ease of program change and job submission. (Est. savings 1 man year.)
7. Access to VNET	Use of remote (rather than local) attached 3270.	Rapid access to IBM workers in Pans/Oslo. Assistance with problems. Transmission of fixes between centres. (Est. savings 3 man months.)
Totals	5 man months.	75 man months.

VNET - A telecommunications network connecting IBM machines in various locations and worldwide.

The need for processing of multi-temporal data is based on the fact that wheat looks (spectrally) like other ground covers at various individual stages of its growth: e.g. like ploughed ground immediately before/after sowing, like other green vegetation after emergence. However, a classification based on combination of LANDSAT data from a number of these stages produces good results. In computing terms, this requires the combination of a number (n) of acquisitions, for a given scene, spread over time and so produces an image of 4n bands for the area. An example of such a multitemporal image is shown in fig. 1.

Narrabri 1980 LANDSAT Acquisition	MSS Band	ER-MAN Band
1. June 11	4	1
	5	2
	6	3
	7	4
2. August 31	4	5
	5	6
	6	7
	7	8
3. September 18	4	9
	5	10
	6	11
	7	12
4. October 6	4	13
	5	14
	6	15
	7	16
5. August 13	4	17
	5	18
	6	19
	7	20

Figure 1. Composition of ER-MAN image used in the study of the 1980 wheat crop. Each data plane consists of 1737 lines x 2002 pixels resulting in a total image size of 69.5 million bytes.

D. FULL SCENE?

The question of whether to use a segmentation technique as in the LACIE (14), or attempt full scene processing was discussed at length by the authors. The decision to attempt full scene processing was mutually agreed on the basis of our estimation of our workloads in either approach.

Part of the argument was based on the fact that our team was to be 2 people over most of the project. It appeared from comments at the LACIE Symposium in October 1978, that the accurate registration of acquisitions would be a concern, and that it, with the tools available in Sydney, would require nearly the same effort to obtain suitably registered segments, as it would for large areas.

In addition, in Australia we did not have access to GSFC (16) to produce our registered images.

This contrasts with the conclusion reached at the start of the LACIE (15), but reflects the difference in emphasis of Australians looking at the Australian crop with 1979/80 technology against LACIE looking at foreign crops with 1974 technology.

Then came the gambles:

1. That it was possible for the ER-MAN II software to be successfully modified (mechanically) within available resource/time constraints.

2. That the internal algorithms would not need change just to handle large areas (Registration in particular).

3. That the software, which has some intricate linkages into MVS, would not create problems in a machine environment which was, and is, used to support IBM's Australia-wide operation.

III ACHIEVEMENTS

The gambles paid off. The version of ER-MAN II installed in Australia was obtained from the IBM Scientific Centre in Oslo, Norway and includes their modifications to provide support for the MVS operating system, the RAMTEK 9300 Display System and IBM 3330-11 disk drives (200 Mb capacity).

1. The "LOAD" and "IMAGE CREATION" functions were modified and operational within weeks of first installation. Only 1 constant needed change in each. (10 million changed to 100 million).

2. The "Pattern Recognition" application took longer as internal work data sets had implicit limitations e.g. size of data records.

3. Full scenes have been input to "REGISTRATION" and large areas output from it with acceptable accuracy.

4. In "PATTERN RECOGNITION", the largest area processed so far is of 1.1 million hectares which is included in an image of 1737 lines x 2002 pixels, 80 metre square pixels, and the biggest single classificaton was 60 Mbytes (1700 lines x 1700 pixels x 20 channels with

29 classes) using the maximum likelihood classifier.

5. The intricate operating system interfaces did not cause any trouble, but the image access method (IDAM) (17) did. For several months processing was severely curtailed while the problem was defined and interim techniques developed. A fix was finally implemented (in June, 1980) using a new access method made availabe by E. Froyland of IBM Norway.

IV PERFORMANCE

A. RESULTS

This section provides some elapsed time figures and comments on CPU utilisation which were obtained in Sydney and were used in part in verifying the prediction formulae presented later.

There is no claim implicit here that these times are exactly reproducible on an identical machine configuration. Any accuracy implied in the quoted times is of the measurement of the event itself at the particular time of its occurrence. That there are orders of magnitude difference between the upper and lower bounds of the values however, is significant. The types of issue which prompted the recording of these times ranged
from: "Shall we sit and wait for it to finish";
through: "Have we time for a cup of coffee?";
and: "Let's have lunch while we run this.";
to: "Does the budget let us do this one?";
and: "Can we do this at all?".

At this level of accuracy we have not attempted to specifically include initialisation/termination times in our formulae, but recommend that the starting point for extrapolation be a short, but not trivial, use of the function to be projected. This assumes that intialisation/termination time is negligible in a function which runs for say 5-10 minutes on this sized equipment.

When most of these times were recorded, the normal peak CPU utilisation, with ER-MAN dormant, was approximately 30%.

B. REGISTRATION

The Registration function of ER-MAN uses Ground Control Points (GCP's) to rectify raw MSS data to Universal Transverse Mercator (UTM) co-ordinates. The output subset is defined by most North, South, East and West Latitude and Longitude values nominated by the user. Output pixel size is also nominated by the user, and an 80 metre (square) pixel is usually requested. (One project has used 40 metres, producing 4 times the output data volume.)

Table 3. Registration: Elapsed times on 3033.

Input			
Lines	1100	2340	2340
Pixels	1200	3240	3240
Bands	4	4	4
Output			
Lines	463	1737	1737
Pixels	585	2002	2002
Bands	4	4	4
Time	2 min	1hr 40min	65min
Notes	1,2	1,2	1,3

Note: 1. 1st order polynomial used.
2. Input and Output on same disk.
3. Input and Output on separate disk drives, same channel.

This function is I/O bound on the 3033/3330-11 configuration.

C. CLASSIFICATION

The classification technique available within ER-MAN and used in all our joint projects is the maximum likelihood. Here, for each pixel in the study or "test" area, the probability that the pixel belongs to each class is calculated and the pixel is assigned to the class to which it has the highest probability of belonging. This calculation is described in reference 13, which also contains a warning for workers planning to use many bands: the number of pixels in a training class must be at least n+1 for mathematical validity, and should be between 10n and

100n for statistical validity, where "n" is the number of bands to be used for classification.

Failure to observe the "n+1" independent pixel limitation has caused program failures during attempts to invert a co-variance matrix. For successful classifications a selection of times have been recorded in table 4.

Table 4. Classification elapsed times on 3033.

	I	II	III	IV	V
Lines	512	512	989	1780	1700
Pixels	512	512	978	1700	1700
Classes	16	15	19	4	29
Bands	4	12	11	4	15
Time	3m27s	10m	34m	16m41s	5h 23m

Monitoring (18) the execution of a number of classifications shows ER-MAN averaging about 60% of CPU time.

C. DIVERGENCE

When the calculation, specified in the first column of Table 5, was invoked, no prior calculation of the expected time had been done. The fact, that this single calculation exceeded the entire budget for the project of which it was a minor part, was the reason for commencing a more detailed performance monitoring and projection effort. (The question as to the value of this calculation in Remote Sensing terms is not addressed by these authors.)

Table 5. Divergence: Elapsed times on 3033.

	I	II	III	IV	V	VI
Input Bands	20	20	14	15	20	20
Output Bands	8	2	6	8	4	8
Classes	10	29	15	14	29	2
Elapsed Time	2h*	27s	4m	7m	8m57s	13m20s

* This used 1.5 hours CPU time.

D. OTHER FUNCTIONS

Of the other functions used in Sydney none uses a significant amount of systems resource and has the variability of the above. As a result no times have been recorded for them.

The image access method (IDAM) referred to above (section III), and two other minor, but frequently used modules, have been modified for performance reasons. IDAM modifications were implemented to stop ER-MAN from locking out other users of the system. A function, the Field Overlay processor, which writes training field boundaries on to the colour monitor was modified to reduce the time to display those fields. In addition, the time to execute the Class Summary Report program is excessive and work is progressing on reducing that.

E. PREDICTION

Most of the work in this area has been done in conjunction with New Zealand projects (19) in various visits to use the ER-MAN facility in Sydney.

It should be emphasised that these estimators are deliberately gross, their purpose being to obtain a rapid approximation to the order of magnitude of a task being considered.

The following items have been specifically excluded:

1. Initialisation and termination overheads with ER-MAN;

2. Effects of paging activity in the CPU;

3. Effects of other, higher priority, high CPU useage jobs in the system;

4. Effects of exclusion of channel sets during processing of divergence.

The basic proposition in the following formulae is that it is both practical and easy to predict elapsed time to sufficient accuracy if you can start from an actual time from the same environment for the function you wish to predict. This produces the simple equation

$$T2 = F21.\ T1 \qquad -1$$

Where:

T2 is the required time estimate for task Task 2.

T1 is a result from the same machine environment for the same function, but for Task 1, and: F21 =

$$\frac{\text{Computation time for Task 2}}{\text{Computation time for Task 1}} \qquad -2$$

At first sight, the definition of F21 as the ratio of the amounts of computation time to achieve the two tasks, appears to beg the question.

However, for Classification:

$$F21 = \frac{L2.P2.M2(M2+1).K2}{L1.P1.M1(M1+1).K1} \qquad -3$$

and for Divergence, for a given number of classes:

$$F21 = \frac{{}^{M2}C_{B2}}{{}^{M1}C_{B1}} \qquad -4$$

are estimators we have used with some success:

Where:

Ln = Number of Lines used,
Pn = Number of Pixels used,
Mn = Number of Bands used as input,
Bn = Number of Bands used as output,
Kn = Number of classes considered.

We have found that our need for prediction for an anticipated large computation is in fact preceded by a number of related, but smaller calculations. For example it is usual to run a test classification on a small area before attempting the large one, so that the factor F21 simplifies in that case to

$$F21 = \frac{L2.P2}{L1.P1}$$

since the number of bands and classes remain constant.

The following example illustrates the technique for divergence, using the result in Column II of Table 5 to predict the result in Column V.

$$T2 = \frac{{}^{20}C_4}{{}^{20}C_2} \times 27 \text{ seconds}$$

$$= \frac{20 \times 19 \times 18 \times 17}{4 \times 3 \times 2 \times 1} \times \frac{2 \times 1}{20 \times 19} \times 27 \text{ secs}$$

$$T2 = \frac{18 \times 17}{4 \times 3} \times 27 \text{ seconds}$$

$$= 688.5 \text{ seconds}$$

$$= 11 \text{ mins } 28 \text{ seconds.}$$

cf actual time of 8 mins 57 seconds.

The estimate was used to support the decision to proceed with the calculation, and no quantitative work has been done to investigate the detail difference between it and the actual time.

F. CAPABILITY

The emphasis in this section lies in the difference between using a 370-145 in a stand-alone location and the shared use of the 3033. The relative performance capability 3033:3145 of 4400:350 (5) or about 12.5:1 is a major part of the story, but does not include the increased main storage, additional I/O channels and devices and better operating system available on the larger machine.

In Table 4, all the classifications, even V, were done interactively. In our normal work, trial classifications lasting up to 10 minutes are frequent even during a single session. These often lead to a refinement in the set of training classes needed for a final, large area classification. The ability to do these has led to major advances in short spaces of time, as measured in elapsed days of the research worker's effort.

Extrapolating back to the 3145, with the assumptions;

1. that on the 3033 the classification used 60% CPU, and

2. that on a dedicated 3145, it could use 80% CPU, and

3. that the figures from Table 1 are valid for this extrapolation:

$$\text{Time (3145)} = \frac{10 \times .6 \times 4400}{.8 \times 350} \text{ minutes}$$
$$= 94 \text{ mins approx}$$

i.e. Time (3145) = 1.5 hours (say). In this time continuity of thought is lost, as is the possibility of exploring several different approaches in available researcher time.

On the same basis, the column V result would have taken over 50 hours.

These time estimates for the 3145 should be taken as being minimum possible times, as it is probable that other system constraints would not permit the ER-MAN function to obtain the full 80% CPU utilisation assumed. Thus the reduced main storage availability, implicit in the machine, would probably introduce a paging (9) load which could increase the estimate considerably - an order of magnitude is not impossible.

Such elapsed times resulted in workers not using those functions often, if at all and it is the authors' contention that a lot of the research in the use of classification techniques (in particular) in Australia has been restricted by the amount of computing power available to the researchers.

V. PROJECT INTERACTIONS

Table 6 summarises the projects which have used the Rosebery facility.

In the context of this paper, the major importance of the set of projects was on their interactions from both the computing and remote sensing viewpoints.

The anticipated major modification to ER-MAN was the set of individually-minor changes related to permitting processing of large areas and several acquisitions for use by New South Wales Department of Agriculture in the wheat study. The New Zealand work used these large area capabilities and raised questions on the statistical, and mathematical validity of some calculations.

The New Zealand team also introduced to us the text book "Remote Sensing, The Quantitative Approach" edited by Swain and Davis (13), which has assisted many of us in our work and our understanding of it.

While some of the projects study only small areas, <u>all</u> in fact at some stage directly used at least some of the full-scene features.

In addition knowledge of the system gleaned by work on one project was passed on to the others.

For example: The classification of training fields was found to be very useful for checking homogeneity of classes, and also often indicated the need to define new training classes.

<u>Table 7.</u> Joint projects undertaken.

1. Wheat-major project	- 3 years	to 1981
2. Ground Salinity	- 6 months	1980
3. Wetland Monitoring	- 6 months	1980
4. Grassland Curing	- 1.5 years	to 1982
5. IBM NZ & DSIR-various	-1 year	to 1980
6. University support	- 3-4 months	each

VI. PROBLEMS

The problems we have experienced are outlined below and the first four are ranked in priority order.

A. REGISTRATION ACCURACY

The initial problem in our major project was the production of a multi-temporal image, and this was followed by issues of accuracy of overlaying successive acquisitions.

This continues to be a problem to us in working on new areas. The definition of Latitude and Longitude to sufficient accuracy for Ground Control Points (GCP's) reliably indentifiable in the imagery has been time consuming and prone to error. The authors have worked to produce a multi-temporal image which is good enough to permit the agricultural study to proceed; but have assumed that other workers are addressing the issue and that a better solution will be found independent of this study. As a result no research into new algorithms or programming has been done.

In particular, GCP's were located where possible in accordance with the recommendations of Orti (20), and Bernstein (21) i.e. GCP's in multiples of eight down the east and west edges of the required subset.

One major source of delay was that some GCP's calculated from one map sheet were inconsistent with others in different map series. This was particularly true when the use of large areas forced the use of map sheets at different scales.

We have used a first order polynomial in all our registrations to date, except for one trial of a second order polynomial which appears to indicate an increased need for GCP's to be as recommended here.

Best overlaying results, acquisition to acquisition, were obtained when the same set of GCP's in each acquisition were used.

B. DEFINITION OF SET OF CLASSES

The definition of the set of ground cover classes necessary and sufficient to cover both the geographical area and the spectral range remains an issue, and is considered more fully by Dawbin and Beach (1).

C. PERFORMANCE IMPACT

As mentioned earlier, our processing at one stage did have a significant affect on other users of the system.

This was caused by the excessive channel utilisation by the image access method, which effectively locked out the MVS system's access to its page data sets. The fix supplied by E. Froyland of IBM Oslo basically introduced a "Set Sector" command into the disk command chain (4). Since its introduction the lock-out has not recurred.

D. PROGRAM ERRORS

Program errors came in three major groups:

1. Those introduced as a result of earlier "largeness" related modifications.

For example, when a work data set, e.g. Classification Output, required an increased record size to allow for additional pixels/line, we did not immediately identify the subsequent programs which used the data set and execution time errors occurred.

2. Some, related to the previous set, were the result of the increased data security implemented within MVS (fetch protect); and

The Fetch Protect (22) errors were particularly difficult to trace and fix as their occurrence was frequently intermittent, but were usually the result of the inadvertant moving of more than enough data into a receiving field when the (shorter) sending field terminated on a page boundary.

3. Performance.

Some functions were found which appeared to take too long to do what appeared to be a simple function. Where the function was either rarely used at all, or at most once per day the issue has not been pursued. However, in two functions "Field Overlay" and "Class Summary Report" the times were sufficiently long for some workers to refrain from using them when their use may have proved useful. In these cases corrective action has been taken and both functions are now faster, although the second still needs more work. (In fact these problems really only become apparent with a larger number of training classes, and so could be considered size-related.)

E. LEARNING CURVE AND ISOLATION

While the availability of VNET (Table 2) provided rapid access to some IBM workers overseas some of the questions we needed to ask should have been addressed to people without access to VNET. e.g. IBM Mexico Scientific Centre, where the authors were trained in the functions and use of ER-MAN, is not attached to VNET. Conversational access to appropriate workers in LARS, LACIE and GSFC would have helped in resolution of a number of problems.

VII. CONCLUSION

The availability of a large, fast computing system has been a great advantage to the major research projects undertaken in Sydney. The processing of both large areas and multiple acquisitions of LANDSAT data is thought to be innovative in Australia.

While the historical trends of decreasing cost and increasing capability of computing systems continue, as is expected, the ability to cost effectively process LANDSAT data will increase as will the ability to handle the increasing data volumes from planned future satellites.

Australia is in a position to capitalise on these trends as it has large areas of low value land, being two-thirds semi-arid or drier, and the alternative techniques for repetitive monitoring appear to be excessively expensive, with little chance of their costs decreasing.

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