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SANTA BARBARA, CALIFORNIA 93106

GEOBASE INFORMATION SYSTEM IMPACTS ON SPACE IMAGE FORMATS

*Report of a Workshop at La Casa De Maria,
Santa Barbara, September 11-15, 1977*

**SANTA BARBARA REMOTE SENSING UNIT
SBRSU Technical Report 3**

**EDITED: D.S. Simonett, T.R. Smith, W. Tobler,
D.G. Marks, J.E. Frew, J.C. Dozier**

April, 1978

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EXECUTIVE SUMMARY

As Geobase Information Systems increase in number, size and complexity, the format compatability of satellite remote sensing data becomes increasingly more important. Because of the vast and continually increasing quantity of data available from remote sensing systems the utility of these data is increasingly dependent on the degree to which their formats facilitate, or hinder, their incorporation into Geobase Information Systems. To merge satellite data into a geobase system requires that they both have a compatible geographic referencing system. The cost of converting satellite data to a compatible format may be too large for many users. Greater acceptance of satellite data by the user community will be facilitated if the data are in a form which most readily corresponds to existing geobase data structures.

While most users agree that a common format is desirable the actual structure of that format is the subject of much debate. However, the following general points appear to represent a consensus of the user community:

- * A procedure for windowing and reformatting Landsat data so that it could directly overlay USGS map quadrangles would increase the utility of remote sensing data in geobase information systems. If this procedure is initiated it will result in the attraction of new users, reduced handling and processing time for all users, and an overall cost savings.
- * New geographic data bases designed to provide the public with information and serve the needs of federal and State agencies should be structured to offer maximum flexibility for conversion by external users. Both polygon and gridded approaches to a data base structure must continue to be evaluated. Both types may need to be supported by providers of image products.
- * A workshop bringing together representatives from local, county, regional, state and national levels of government is recommended. The workshop should examine both the recommendations given in this report, and the development of upwardly compatible geobase information systems between hierarchies of government.
- * At the state level a central agency should examine a common format philosophy in respect to its impact on the geographic information needs of the state. A formal procedure should be developed to support implementation of a common format at all agency levels.

The conference addressed a number of specific topics and made the following recommendations:

GENERAL FORMATS FOR FUTURE DIGITAL IMAGE PRODUCTS

Two distinct families of imagery should be available to users as standard products:

- * Uncorrected video data, either in completely unaltered, "raw" form, or radiometrically calibrated but not destriped, but with substantial header and annotation information.
- * Fully processed data, which has been radiometrically corrected, including destriping, and geometrically rectified to a UTM projection.

Also:

- * Processed data should be available in certain other projections and formats as "special-order" products, for which a somewhat longer order turnaround would be acceptable.

ANNOTATION

The best and most complete annotation should be made available to users of either raw or reformatted satellite data. All forms of annotation currently provided should continue to be provided. In addition, it is recommended that the following information be supplied with all digital image data:

- * Type of projection, if applicable.
- * Sampling interval in meters on the ground.
- * Up-to-date algorithms and coefficients for converting digital radiance numbers to actual space upwelling radiances.
- * Several ground control points identified in image and standard geo-reference coordinates.
- * More accurate geodetic grid ticks and nadir/format center coordinates (preferably designated in latitude and longitude).
- * More accurate spacecraft positional (altitude and attitude) information.
- * More spatially specific cloud coverage estimates.

RECTIFICATION

The rectified imagery should meet the following specifications:

- * The map projection employed should be conformal and the pixels should be aligned in an easting direction, amenable to Cartesian referencing. Universal Transverse Mercator was the projection preferred by users attending the conference.
- * Rectified imagery should be indexed to existing USGS 7-1/2 minute quadrangle topographic maps, whereon sample locations should be fixed.
- * Resampling should be done only once and should either preserve the nominal spatial resolution of the sensor, or, if confirmed by further study, transform to one of a series of standard resolutions, e.g. binary (16, 32, 64, 128 ... meters), or a sequence preferred by some users of 10, 25, 50, 100, 250 ... meters (10/25 series).
- * Projections other than the recommended UTM standard should be available upon request, but the transformations should be done from the raw data to avoid resampling data more than once.

In terms of assessing the effect of image rectification on image data accuracy the following is recommended:

- * Further investigations should be undertaken to determine the effects of various resampling algorithms, including double resampling, on radiometric and spatial fidelity, and classifier performance.
- * The rectification algorithms used should be provided with the data to the user community and algorithms for forward and inverse transforms between a variety of standard projections should be available for distribution to users.

SPATIAL RESOLUTION OF THE STANDARD PRODUCTS

- * "Raw" digital data should preserve the nominal spatial resolution of the imaging sensor.
- * The "corrected" digital data should be resampled at an interval selected from the binary series (i.e., 2^n meters) or the "10/25" series. For Landsat-D, a suggested resampling interval would be 25 or 32 meters.
- * Data compression techniques which irreversibly degrade spatial resolution should not be employed.
- * Precise evaluations of the effects on spatial resolution of any resampling algorithms employed, should be made available, either by broader dissemination of existing studies or the initiation of new ones.

RADIOMETRIC RESOLUTION

- * NASA should continue to improve their calibration procedures, and make all algorithms and constants available to the users through EDC (EROS Data Center).
- * Data in which striping is present must be available to the users in uncorrected form.
- * Pathwise calibration on an entire strip should be employed, to minimize scene-to-scene and along-track within-scene variations.
- * Future video data should be represented as 8-bit, unsigned binary integers in the range 0-255.
- * Further investigation (and/or broader dissemination of existing data) is needed regarding the effects of resampling on radiometric fidelity, and on the feasibility of applying atmospheric corrections at the system level.

SPECTRAL RESOLUTION OF SPACE SENSORS

- * Future operational sensor systems should (to the degree proven necessary) provide spectral continuity with multispectral bands already operational in the user community.

TEMPORAL RESOLUTION

- * NASA should provide for a more frequent overpass interval than the current 18 days, either by utilizing different orbital parameters or by the recent practice of staggering the orbits of 2 or more identical satellites.

- * Multiple coverage of path overlap areas should be retained.
- * Turnaround time on orders of image or digital products should be drastically reduced, to no more than 7 days from satellite overpass, with a preferred 2-day turnaround for time-critical uses.
- * Data archiving should permit preservation of good imagery of areas where cloud cover is a severe problem.

CCT FORMATS AND DATA STORAGE

- * Three logical structures, BIP (band interleaved by pixel), BIL (band interleaved by line) and BSQ (band sequential) should be available. The current structure, BIP2 (band interleaved by pixel pairs) is considered the least useful format.
- * The logical record structure of the image file should include substantial annotation for each record.
- * Physical blocking of data on a tape should allow for I/O buffer limitations of minicomputers.
- * Any data compression techniques employed should be reversible to the level of sensor noise.
- * An appropriate Federal agency, probably EDC, should distribute FORTRAN I/O subroutines for performing common manipulations of imagery in whatever formats are ultimately supplied.
- * 1600 bpi CCT's should continue to be the principal mode of data exchange until higher-density storage devices become more wide-spread.

DETERMINATION OF USER DEMAND, PRICING SCHEDULES AND ABSORPTION OF PREPROCESSING COSTS

- * Better estimates of the needs of the users of satellite data are required. The needs of State and local governments for several levels of processing of the data, and for various software implementations, seem poorly understood. NASA, or some other Federal agency, should undertake to provide more detailed estimates of these needs.
- * Both the demand and the pricing schedules should be jointly determined by analytical techniques such as Demand Revealing Processes. These determinations should be made for various product combinations and should be performed on a regularly scheduled basis.
- * A portion of the preprocessing costs should be absorbed by the Federal government, while the variable costs should be recovered from the aggregation of users. This federal investment will maximize the benefits obtained from the use of satellite data by overcoming the threshold necessary to initiate the diffusion of a technological innovation. In economic terms the federal subsidy should also be viewed as an investment aimed at maximizing the present value of the stream of net benefits obtained from the use of satellite data.
- * NASA, the EROS Data Center of the U.S. Department of the Interior, and such other federal agencies as should properly be involved, examine the division of responsibilities and costs between them, in order to implement the preceding recommendations.

SOFTWARE PORTABILITY

- * Where possible programs for general distribution should be written in FORTRAN. Departures from the ANSI X3.9 1966 standard should be isolated in subroutines and clearly documented. Especially, programs should isolate all input/output and bit manipulation portions. Implementation of this recommendation requires that programmers read and become familiar with the Standard. A new "Draft proposed ANSI FORTRAN" is in circulation, but it will probably be several years before compilers meeting it will be widely available.
- * It is recommended that NASA and EDC develop Image Processing and Analysis Software Standards to ensure that future software development is in as internally-consistent a form as possible, and to ensure that portability is enhanced.

LANDSAT-D

- * Data from the Thematic Mapper (TM) should be available in two formats:
 - uncorrected (radiometrically calibrated), and with extensive annotation
 - radiometrically corrected and geometrically rectified to a standard (UTM) map projection, scan line orientation, and pixel size
- * Since TM data will require some form of resampling, especially to coarser spatial resolutions employed by existing data bases, NASA should encourage the development and exchange of information on the effects of resampling.
- * Data compression for the TM is probably unavoidable, but should employ methods which are reversible at least to the level of rated sensor noise.
- * The logical structure of distributed TM data should be band-interleaved-by-line (BIL), with optional availability of band-sequential (BSQ), and band-interleaved-by pixel (BIP).
- * NASA should be aware of technological developments which when implemented by the user community, might affect the utilization of TM data such as increasing availability of high-density storage devices and array processors.

It was the conclusion of the conference that NASA, EROS Data Center, and other pertinent federal agencies, examine all of the preceding recommendations to determine their feasibility and implementation costs. This should be done to determine the benefits to the entire system of users, the division of responsibilities and costs between the agencies involved, and the contributions to be expected from users.

The following pages present background material on the problems of integrating remote sensing data into geobase information systems, as well as a brief discussion of existing remote sensing data and digital processing techniques. Following these are detailed discussions of each of the recommendations summarized above.

INTRODUCTION: A WORKSHOP TO EXAMINE GEOBASE INFORMATION SYSTEM

IMPACTS ON SPACE IMAGE FORMATS

PURPOSE OF THE WORKSHOP

A NASA-sponsored workshop to examine Geobase Information Systems Impacts on Space Image Formats was convened at LaCasa de Maria, Santa Barbara, on September 11-15, 1977. This workshop brought together some fifty NASA, other federal agency state, university, and private sector users and developers of Geobase Information Systems. These participants were asked to examine the potential impact of Geobase Information System formats and procedures on space image formats for Landsat-D and other future satellite systems.

The rationale behind the workshop was that Geobase Information Systems, would soon be so pervasive--if they were not already so -- as to markedly influence, or indeed potentially dictate, the formats of computer compatible tapes and other data products from space imaging systems. A thesis leading to the workshop was that if this indeed were the case, the acceptance of space remote sensing imaging from Landsat-D, and imaging radars in Space Shuttle, and other systems would be markedly conditioned by the degree to which the Computer Compatible Tape (CCT) format and other formats from these imaging systems facilitated, or hindered, their incorporation into Geobase Information Systems.

An underlying finding of the workshop was that the development of integrated resource monitoring systems characteristically required the parallel development of several technologies in addition to that of remote sensing. Acceptance of remote sensing by the user community thus may hinge on model development, low cost digital analysis, or some other parallel technology or conceptual development, or as in the case of this workshop upon the development of Geobase Information Systems, and their format compatibilities with space image products.

The Reformatting Problem

The front-end cost of adjusting Landsat 1 and 2 to a variety of formats when considered as a national aggregate is substantial. The possibility of endless reformatting of future space imaging CCT's--as a result of following the earlier Landsat 1 and 2 designs which are not readily compatible with user Geobase Systems--looms as a major burden on NASA space imaging systems. A number of authors have argued over the last several years that state and local agency remote sensing (amongst others) will not really mature until it is fully integrated into Geobase Information Systems and has been used routinely for a number of years (Simonett, 1976). In the

call for attendance at the workshop it was stressed that if these arguments are correct, it is important for NASA to examine these interface, compatibility, repetitive front-end and future re-formatting problems to find if cost effective satellite image formats can be provided by NASA and/or federal agencies, which facilitate or even advance the use of both satellite and Geobase data.

The members of the workshop were divided into five panels. Each panel addressed the same topics and concerns. At the end of the workshop the Chairmen of the respective panels met with the organizers and Mr. Frederic Billingsley of NASA headquarters to review the several panel reports and the discussion at the general meeting at the end of the conference, and to coordinate the recommendations. Much of the proceedings of individual panels were tape recorded and transcribed, in addition to the documentation given in the individual panel reports. Using these materials and further items prepared by the organizers, this report has been prepared. It documents for NASA and other federal and state agencies the necessity for developing standard format(s), the likely consequences of so doing, both for NASA and the other groups, and gives the underpinning technical and managerial questions, analysis, documentation and discussion.

Topics and Questions Considered at the Workshop

The topics and questions which were examined by each panel and the Review Panel were as follows:

Individual Contribution from all Attendees

Comments were requested from all attendees on the following topics:

1. Experience of problems in working with NASA CCT's; Summary of procedures in geobase systems with which NASA data was integrated.
2. Reactions to the suggestion(s) on NASA tape format(s) in each panel. Details on the impact on present systems, the costs of conversion, and the benefits, if any, from conversion and the use of a future standard format or formats.

Panel Recommendations to NASA/EROS Data Center on the Following Topics

1. Recommended format(s) for all future CCT products.
2. Questions for future working groups to address as a result of the above recommendation(s).
3. NASA/EDC positions on absorbing pre-processing and reformatting costs.
4. Future software development anticipated or needed and NASA/EDC roles in such development.

Panel Suggestions for Federal and State Agencies

1. Common formats for future data bases.

2. Pros and cons of common format philosophy.
3. Software transportability.

Supporting Documentation with Respect to:

1. The dimensions of the problem for:
Large federal data base developers/users
State agency users
University researchers
Private sector users.
2. Key references to published, unpublished reports, papers, memoranda.
3. Existing transportable software with brief notes on special attributes.

Special Technical Questions which were Examined

A considerable number of technical questions underpinned the workshop as follows:

1. Annotation required/desired:
 - a. Addressability of individual pixels
 - b. Scale factors
 - c. Ground Control Points
 - d. Tick marks
2. Considerations on reference systems and projections:
 - a. Requirements for latitude and longitude reference
 - b. Requirements for Space oblique Mercator, Universal Transverse Mercator, Lambert Conformal Conic, or other projections
 - c. Requirements for state plane coordinate grids
 - d. Requirements for new scales/grids for metrication
3. Pixel layout on the ground:
 - a. Cardinal directions, or in projection grid directions
 - b. Spacing considerations
4. Effects of sampling:
 - a. Double sampling
 - b. Nyquist sampling
 - c. Other sampling strategies
5. Questions on geobase systems:
 - a. Data storage considerations with respect to NASA and other formats
 - b. Optimal geocoding formats in relation to space images
 - c. Format family philosophies
 - d. Compatibility considerations for NASA digital image products with respect to census and other major national and state data bases

6. Effects of present and workshop-recommended format(s) on:
 - a. Radiometric and geometric accuracy
 - b. Temporal registration of data
 - c. Band to band registration
 - d. Precision desired/achievable with respect to latitude/longitude per pixel
 - e. Considerations on framing versus continuous image strips
7. Various present and future format cost implications:
 - a. To NASA
 - b. To Federal and State users
 - c. To individual users
 - d. To U.S. users in the aggregate
 - e. To foreign users and ground stations
8. Feasibility tests:
 - a. Recommendation for experiments with MSS re-sampling
 - b. Calibration
9. Software Portability:
 - a. Formats and word lengths for different types of computers and their different word lengths
 - b. Packing of information from more than one band into single words, and its effects on computers with different word lengths, and its adaptability to variable numbers of channels
 - c. Possibilities for program transportability, when words have to be unpacked, and potential for increased use of languages like PL/I or COBOL, which have bit or byte manipulation features as part of the standard language
10. Hardware Considerations:

Formats with respect to expected advances in linear processors, array processors, parallel processors, hard wired devices, graphics display and retrieval devices, computer architecture, mass storage devices, etc.

Questions on the LANDSAT-D Thematic Mapper

1. Should the data from the Thematic Mapper (LANDSAT-D) be:
 - a. Left alone; if so, what header information is desired?
 - b. Reprocessed for geometric improvements; if so, into what format(s), pixel spacing, and directions?
2. Contributions on re-sampling:
 - a. Does significant(!) degradation of radiometric quality occur as a result of re-sampling?
 - b. Do the advantages of re-sampling for many users outweigh losses of radiometric quality and, if so, why?
3. Data Compression of Thematic Mapper:

- Can we live with data compression from the Thematic Mapper?
(Some may be necessary because of the order of magnitude increase of the data streams over the Multispectral Scanner (M.S.S.).
What are the options and merits of each?
- a. Compression methods (on board)?
 - b. Sampled (alternate rows and columns)?
 - c. Other methods?
4. How should the data from the Thematic Mapper be structured, and why?
- a. Band sequential?
 - b. Band interleaved?
 - c. Fully sequential?
5. What options should be examined for the physical structure of tape delivered to users?
- a. CCT, 1600 or 6250 bits per inch?
 - b. CCT plus HDDT (High Density Digital Tape, greater than 6250 bpi)?
 - c. HDDT (High Density Digital Tape)?
 - d. Other?
6. Hardware Advances:
- What hardware advances are relevant in the next five years which impact on questions 3., 4., and 5., above?

In order to set the workshop recommendations in an appropriate context, the material of this report is organized in the following manner. First, some important characteristics of geographical information systems are presented, using a number of well-known systems employed in the U.S. Next, the incorporation of digital remote-sensing data into such systems is examined, along with the development of geo-base information systems which are an outgrowth of digital image processing systems.

Following this material on information systems the present situation with respect to existing digital remote sensing data is reviewed. Present products, data handling techniques, supplier processing and user processing are briefly described and discussed.

With both the preceding sections as background, the final section of the report gives the recommendations from the workshop, along with supporting discussions and analysis. The Executive Summary at the beginning of this report contains the essence of the three sections.

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GEOGRAPHICAL INFORMATION SYSTEMS

SOME IMPORTANT CHARACTERISTICS

A great deal of environmental data are currently available to decision makers. The increasing trend is to incorporate these data in a computerized geographically oriented information system. This is being done at the national level, at the state level, at the county level, at the municipal level, and by private firms. There are 50 states, nearly 3,200 counties, over 50,000 municipalities; and each of these contains many agencies and bureaus. The aggregate investment in these systems can thus be seen to be very large.

The components of a geographical information system include the conversion of the data to a machine readable form, structuring of the data in a manner capable of being processed, and the preparation of computer programs for retrieval, analysis, and/or display of the data. Each of these components is itself complex and extensive literature exists on each of these topics. Overviews are presented in Barraclough (1971), Calkins (1977), Gardner (1972), Hearle and Mason (1963), and Tomlinson (1973).

The locative aspects of the data--where the phenomena of concern are located on the earth--is the major part of any geographic information. Thus, a great deal of environmental data is converted to machine readable form by being copied from maps. Point phenomena are easily represented by geographical coordinates. These coordinates are names attached as labels to places on the earth's surface. Since the naming of places is easy, one single place may have several different names (or aliases) in different coordinate systems. Two well known systems are latitude/longitude, and Transverse Mercator coordinates. But a house, for example, also has an identification using a street name and number, at least in the European culture area. Conversion between these various aliases may be necessary. Early computerized urban transportation studies coded as many as sixteen geographical aliases for each location of interest. Technically the inter-conversions between the alternate names which may be given to a single place are relatively simple. Unfortunately, the user community is often not familiar with these technical details. Good reviews covering these topics include Clayton (1971), Gale (1969), Maling (1973), Moyer and Fisher (1973),

and Werner (1974).

A number of additional difficulties arise because of this problem of aliases. Although the conversions are generally simple conceptually, the actual computations may become quite extensive when the data volumes are large, as is typically the case in geographical information systems. Because the earth is round, and maps are flat, it is necessary to use map projections. Map projection coordinates are thus introduced as an additional family of aliases. These, also, are not technically difficult but are largely unfamiliar to the user community, and therefore cause a great deal of confusion. The Transverse Mercator system, for example, is used both for U.S.G.S. 1:250,000 maps and as a system of state plane coordinates, in slightly different variants. The Lambert Conformal Conic projection is used for a different set of maps (aeronautical charts) and also for state plane coordinates, also in slightly different variants. State plane coordinates have a legal status for property description in many states and are in one sense thus "official place names". The projection problem can only be avoided by using latitude and longitude coordinates, and these are generally the place names used for points in international affairs.¹

For local--municipal, county, and sometimes state--activities the latitude and longitude system is usually too awkward. But there is inevitably an area of interest which lies on, or overlaps, the border between two state plan coordinate systems, or two UTM zones. The natural tendency is to replace these two systems with one new system, and thus another alias is created. Where the problem really becomes vexing is when one obtains data from two different sources. These sources could be two different maps, or two different agencies. With distressing frequency the geographical names given to the same locations by these two sources will be different. The merging of geographical files thus becomes frustrating and troublesome if the relationship between the various aliases is not understood or not known, and expensive in any event. Many of the recommendations made in this report attempt to overcome some of these frustrations and expenses.

Geographical phenomena can also be structured in various ways, and this has important implications for the types of problems which are most efficiently attacked (Peucker and Chrisman (1975), Schmidt (1978)). The two important structures which have to date been associated with geographical information storage are known as the "topological" and the "grid" systems.

The topological structure is based on concepts from graph theory, and is most closely associated with the coding of bounded regions, called polygons, such as a soil patch, a census tract, a planning district, a watershed, etc. The most developed form of this scheme, known as Dual Independent Map Encoding (DIME), has been used by the census bureau to encode the entire street system for each of the 200 largest metropolitan areas in the U.S. In this scheme each street segment is treated as a directed line, with coordinates at the end points, and is associated with an area on the left and an area on the right hand side, and with a street name and with a range of house numbers. One advantage of this scheme is the quasi-automatic topological error checking which it permits. Most recently hierarchical methods and methods permitting nesting of areal phenomena have been described. The hierarchical schemes allow upward aggregation. The nested schemes recognize, for example, that a tree may be in a park in a city in.... These are probably the most realistic but are not yet widely implemented. All of these schemes describe areas as polygons with a finite number of vertices. They generally allow disjoint pieces and inclusions. They differ mainly in how they arrange the pointers between nodes, arcs, segments, edges, areas and adjacencies. Many workable schemes are now available, for example, to produce maps automatically using the two meters of magnetic tape required to store the 46,142 point latitude/longitude description of the U.S. counties. Point-in-polygon routines are commonplace for assigning point phenomena to regions; e.g., converting street address to census tract name. Polygon overlay programs are also available to convert land use polygons into areal counts by census tract polygons. The cost of this file merging procedure usually grows as the product of the number of polygons, and is also a function of their complexity. It is thus not an exponential problem but is sufficiently expensive to cause practical difficulties. Regional planning often consists of a concatenation of simple binary decisions which can be caricatured in the following manner: "If land slope is not steep and drainage is good and a road is nearby...then development is permitted." Here the logical intersection of three maps (sets of polygons) is required, and a practical problem might require several dozen such, often repeated as the criterion shift slightly in the process of political compromise. Thus polygon overlay is expensive in most present computer environments, although further development of algorithms and data structures promises to simplify polygon manipulation.

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In the grid schemes one replaces the polygons by a set of uniform regions, triangles or unit squares. This can be done in either of two ways, though the distinction is rarely noticed in practice. In the first instance one samples at a lattice of points; alternatively one aggregates data within the cells of a mesh. The advantage of a grid system is that the adjacency relation is constant, a form of spatial stationarity which makes analysis much easier. It also lends itself to representation in a computer. A disadvantage is that, for a given average resolution, the fit to the data is poorer. It is obviously an awkward way of storing a road pattern. The choice of an appropriate grid size is difficult, but bears a relation to storage requirements. Curiously, variable sized triangulations, the natural simplex in two dimensions, and much used in finite element analysis, have not been popular as cells for geographical data storage, probably because automatic scanners cannot easily capture the data in this form. Interconversion between grids using different lattice sizes requires knowledge of the limitations imposed by the sampling theorem, but otherwise causes no great difficulties.

Computer programs exist to convert between polygonal and grid data formats, subject to the same sampling limitations as above. As long as the internal geographical representation is "complete" one can convert from one structure to another. Thus, from one point of view, it does not matter which structure is used. The two difficulties are that (a) it is not entirely clear when a geographical data set is "complete", and (b) when the volume of observations is large it may be impractically expensive to convert from one organization to another. In merging data given in the two structures the relevant considerations are (a) which is less expensive to convert, and (b) which provides the greater flexibility for further processing given the aims of the agency. The availability of software for spatial data handling has recently been reviewed by Marble and others (1977).

In order to consider how digital remote-sensing data might be incorporated into existing geographical information systems we can draw on a detailed study prepared by the International Geographical Union Commission on Geographical Data Sensing and Processing (Tomlinson, 1976). This report reviews the San Diego Comprehensive Planning Organization system (CPO), the Minnesota Land Management Information System (MLMIS), the New York Land Use and Natural Resource Information System (LUNR), the Oak Ridge Regional Modelling Information System (ORRMIS) and a large system in Canada. The report, as published by UNESCO in 1976 does not, of course, reflect the

exact current status of each system.

The San Diego COP System records soil maps, land use maps, and traffic zone boundaries in polygon form using state plane coordinates. It has been used to report on land use by traffic zone as projected by an analytical urban growth model. Its use for a study of the impacts of a rapid transit system is proposed. The land use within noise contours of an airport and within similar contours of proposed airports, has been studied. A pilot study for flood control has been completed, using the intersection of land use and flood plain polygon data sets. Conversion to a 5,000 foot (1,524 meter) grid was used to convert traffic zone data for use in a pollutant dispersion model. The basic land use maps were in part developed from aerial photographs, and this was considered less expensive than having county agencies maintain an ongoing inventory from public construction records.

The Minnesota (MLMIS) system uses as its basic recording unit the 40 acre (16 ha) fractional section from the public land survey system. The land use, water orientation, and ownership status of the territory of each cell is recorded. The land use data were obtained primarily through the interpretation of aerial photographs. The variables are referenced by county, by minor civil division, by latitude and longitude, by section, township, range, and by government lot number. Provision is made to allow entry by 2, 5, or 10 acre units. At the minor civil division level the data are compatible with the Crop and Livestock Reporting Service data and U.S. Census Bureau population data. An application of an analytical model has resulted in the production of a map of the 40-acre average market value of buildings and land, and related maps and tables.

The New York (LUNR) system is the computerized record of an aerial survey of the state's land resources, supported by retrieval, analysis, and display computer programs. For each one kilometer (0.6 mile) square the system records 134 variable, about half of them numerical. Some 140,000 cells are required for the entire state, each indexed by rectangular coordinates, by county, by minor divisions, and by watershed. Some data are also recorded by 0.4 hectare (1 acre) cells for the entire state. Data can be retrieved from this system by arbitrary polygon (using coordinates) cell, or by county, or watershed. The system has been used for public planning and site evaluations.

The Oak Ridge National Laboratory (ORRMIS) system is coupled to a regional environmental systems model of socio-economic, land-use, ecological, and socio-political activities. Approximately 80% of the input data are in the form of maps. Geographically, a nested hierarchy of cells is used, the smallest cell being 3.75 seconds of latitude and longitude (circa 10 meters), and the largest is 7.5 minutes in the same coordinates. This grid is designed so that the modelling effort can be approached at the resolution appropriate to the need or data availability.

This brief review of four installations is hardly exhaustive of the thousands of such systems now in operation or under construction. Our conclusion, however, is that digital remote sensing data should be useable in all of these systems, but only if it is compatible with the diversity of these organizations. To this extent, we believe these to be representative descriptions.

INCORPORATION OF DIGITAL REMOTE SENSING DATA INTO GEOGRAPHICAL INFORMATION SYSTEMS

To merge remotely sensed data with one of these systems requires that they both reference the geography in the same way. The pixels of a digital image must somehow be made compatible with the remaining information in the data base. Each frame, as currently constituted, of a digital Landsat image contains a very large number of pixels, so large in fact that it may quickly overload the capability of the user agency. The cost of converting all of these pixels to fit the user's system may simply be too large. An intriguing notion is that it may be cheaper to convert all of the user's information to fit the image, leading to what has been referred to as an Image Based Information System (Bryant and Zobrist, 1976). That this is on occasion feasible is because a polygon file invariably contains fewer bits than does the image. The currently available County Boundary DIME File for the entire United States, for example, contains only slightly over 50,000 latitude/longitude pairs, that is, 10^5 numbers and this is considerably less than the number of pixels (3×10^7) in a single Landsat image. Psychologically, however, it may be difficult for the user to abandon his existing data structure just to make all his data fit a simple image. The user views the remotely sensed data as an addition to existing maps and geographically coded files. The pixel arrangement on subsequent satellite passes will of course also be slightly different geographically and will require another conversion. It would be misleading to argue that converting a geographically based information system to an image based system is always appropriate, or that it is always inappropriate. If several agencies use one image, then either each incoming image must be converted to fit each data base

or the several data bases must all be converted to fit each new image.

This emphasizes the utility of multitemporal imagery which has already been mutually registered by some central agency (such as EDC). The interconversions between image and other data structures would thus be standard for each data base system, rather than having to be rederived on an image-by-image basis. However, image overlay invariably requires resampling of the radiometric values, which is still a point of concern in the user community with regard to its effects on classification accuracy and intra-pixel mixture estimation.

For users willing to accept resampled imagery, the sheer volume of data contained in a single digital satellite image remains a problem. This will probably result in image reformatting being one of the single greatest data processing effort associated with any geobase system attempting to incorporate remote sensing data.

Greater acceptance of the data by the user community will surely be enhanced if the data are available in a form which most nearly corresponds to existing data structures. Although geobase information systems are still in their infancy, and their existing data structures may be far from optimal, the fact remains that they represent a tremendous aggregate investment of time and effort, and must now participate in operational decision-making processes before they can further evolve. To the extent that remote sensing data requires either extensive pre-processing, or complete redesign of existing data structures, its incorporation into operational systems will be hindered. It thus behooves the suppliers of digital remote sensing data to determine which formats and levels of processing maximize the utility of their product to the greatest number of users by minimizing the "front-end" costs associated with data reformatting.

FOOTNOTE:

1. Even if the latitude/longitude system were used for the recording of imaged pixels a resampling would have to be done if the samples are to be evenly spaced, since there are fluctuations in the rate of travel of the scanning mirror, or else each pixel would have to have attached to it an individual latitude and longitude value.

- Aangeenbrug, R. (1976), ed., Auto-Carto II. Proc. Int. Conf. on Comp. Asst. Cartography. ACSM, Reston, VA.
- Amidon, E. and G. Aiken (1970) Algorithmic Selection of the Best Method for Compressing Map Data Strings, Comm. ACM. 14, 769-774.
- Bailey, H. (1956) Two Grid Systems that Divide the Entire Surface of the Earth into Quadrilaterals of Equal Area, Transactions. Am. Geophysical Union, XXXCII, 628-635.
- Barracough, R. (1971) Geographic Coding, Federal Statistics. Presidents Commission, Washington, D.C., Government Printing Office, 219-296.
- Baxter, R. (1976) Computer and Statistical Techniques for Planners. London, Methuen.
- Blum, H. (1976) Biological Shape and Visual Science, J. Theor. Bio., 38, 205-287.
- Bryant, N.A., and A.L. Zobrist (1976) IBIS: A Geographic Information System Based on Digital Image Processing and Image Raster Datatype. Symposium on Machine Processing of Remotely Sensed Data, Purdue University, June 29-July 1, pp. 1A 1-7. West Lafayette, Ind.
- Burton, W. (1977) Representations of Many-Sided Polygons and Polygonal Lines for Rapid Processing, Comm. ACM. 20, 166-171.
- Calkins, H. (1977) Information System Developments in North America, Proceedings. IGU Commission, Moscow, 1976, R. Tomlinson, ed., Ottawa, 93-114.
- Clayton, K. (1971) Geographical Reference Systems, The Geographical Journal. 137(1), 1-13.
- Connelly, D. (1968) The Coding and Storage of Terrain Height Data: An Introduction to Numerical Cartography. M.S. Thesis, Cornell Univ., Ithaca, N.Y.
- Ferguson, H. (1974) Point in Polygon Algorithms. Seattle, Urban Data Center.
- Freeman, H. (1961) On the Encoding of Arbitrary Geometric Configurations, IRE Trans. Elec. Comp. 10, 260-268.
- Freeman, H. (1974) Computer Processing of Line-Drawing Images, ACM Computing Surveys. 6(1), 57-97.
- Gale, L. (1969) Recommendations on the Type of Coordinate System for Correlating Files in a Data Bank System, The Canadian Surveyor. Vol. 23.
- Gardner, J. (1972) A Study of Environmental Monitoring and Information Systems. Iowa City, Institute of Urban and Regional Research.
- General Services Administration (1972) Worldwide Geographical Location Codes. Washington, D.C., Government Printing Office.

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OF POOR QUALITY

- Hearle, F. and R. Mason (1963) A Data Processing System for State and Local Governments. Englewood Cliffs, Prentice Hall.
- Jacobsen, J. (1968) Geometric Relationships for Retrieval of Geographic Information, IBM Systems Journal. Vol. 7, Nos. 3 and 4, 331-341.
- Maling, D. (1973) Coordinate Systems and Map Projections. London G. Philip.
- Marble, D., et al. (1977) Computer Software for Spatial Data Handling. IGU Commission, Buffalo, to appear.
- Mark, D. (1975) Computer Analysis of Topography: A Comparison of Terrain Storage Methods, Geografiska Annaler. 57(A), 3-4.
- Merrill, R. (1973) Representation of Contours and Regions for Efficient Computer Search, Comm. ACM. 16(2), 69-82.
- Morse, S. (1968) A Mathematical Model for the Analysis of Contouring Line Data, J.A.C.M. 15(2), 205-220.
- Moyer, D. and K. Fisher (1973) Land Parcel Identifiers for Information Systems. American Bar Foundation.
- Palmer, J. (1975) Computer Science Aspects of the Mapping Problem, Display and Analysis of Spatial Data. New York, J. Wiley, 155-172.
- Peucker, T. and N. Chrisman (1975) Cartographic Data Structures, The American Cartographer. 2(1), 55-69.
- Pfaltz, J. and A. Rosenfeld (1967) Computer Representation of Planar Regions by Their Skeletons, Comm. ACM. 10, 119-125.
- Shamos, M. (1977) Computational Geometry. New York, Springer.
- Switzer, P. (1975) Estimation of the Accuracy of Qualitative Maps, Display and Analysis of Spatial Data. New York, J. Wiley, 1-13.
- Switzer, P. (1971) Mapping a Geographically Correlated Environment, Statistical Ecology. Vol. 1, Univ. Park, Penn. State Univ. Press., 235-269.
- Tomlinson, R., ed. (1972) Geographic Data Handling. Vol. I and II, Ottawa, IGU Commission.
- Tomlinson, R., et al. (1976) Computer Handling of Geographic Data. Paris, UNESCO.
- U.S. Department of Commerce, Bureau of the Census, Documentation for the GBF/DIME file, GEO-202, Revised April 1976.
- Werner, P. (1974) National Geocoding, Annals. Assn. Am. Geographers, 64(2), 310-317.

EXISTING DIGITAL REMOTE SENSING DATA

PRESENT AND PROPOSED PRODUCTS

Currently a variety of satellite data products are available to users. The availability of these products is rapidly increasing as new and more sophisticated satellites become operational. Because of this users are many times unaware of the total scope and variety of satellite data products that are available now or will be in the near future. The following is a brief discussion of the availability of data products from some present and future environmental satellites. (For a more comprehensive survey on this topic see Hughes, C.L., and Campbell, D.C. (1977).)

Basically there are three types of environmental satellites: 1) earth resource satellites, 2) meteorological and oceanographic satellites, and 3) manned satellites. These operate in a variety of different orbit configurations. Meteorological and oceanographic satellites offer a high temporal resolution and low spatial resolution and correspondingly low data rates. Earth resource satellites generally offer low temporal resolution (Landsat repeat coverage is 18 days), high spatial resolution, and high data rates. Most satellites operate in sun-synchronous or geosynchronous orbits except for those whose sensors are primarily microwave (e.g., Seasat-A) because microwave does not require sunlight for operation. Several of the more applications-oriented satellites and their data products are described below.

LANDSAT

The most widely used earth resource satellite is Landsat. Landsat 1 was launched in 1972 and ceased operation in January 1978. Landsat 2, launched in January 1975 and Landsat 3, launched in March 1978, are currently operational. Together, the Landsats provide coverage at nine day intervals. The primary sensor on Landsat has been a MSS (Multispectral Scanner) with four bands in the visible and near infrared. Landsat 3 has a thermal channel as well which should become operational in May 1978.

Landsat D, to be launched in the early 1980's, will have an MSS similar to Landsat 1, 2, and 3, and will carry a Thematic Mapper (TM). The TM will have seven bands; four visible, two infrared, and one thermal. For a complete discussion of Landsat satellites see Landsat Data Users Handbook (1976), Doyle (1978) and Lynch (1976a, 1976b).

Landsat data is available through EROS (Earth Resources Observations System) Data Center (EDC) in Sioux Falls, South Dakota. EDC is operated by the U.S.

Geological Survey and works cooperatively with the National Cartographic Information Center (NCIC). Orders for data can be placed directly to EDC:

User Services
EROS Data Center
Sioux Falls, South Dakota 57198
Phone: (605) 594-6511 X151
FTS 784-7511

or by computer terminal link from the following regional field offices:

Topographic Office
U.S. Geological Survey
900 Pine Street
Rolla, MO 65401
Phone: (314) 364-3680
Hours: 7:45 - 4:15

Air Photo Sales
U.S. Geological Survey
Federal Center, Building #25
Denver, CO 80225
Phone: (303) 234-2326
Hours: 7:45 - 4:15

NCIC Information Unit
National Center - Stop 507
12201 Sunrise Valley Drive
Reston, VA 22092
Phone: (703) 860-6045
Hours: 7:45 - 4:15

Map and Air Photo Sales
U.S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025
Phone: (415) 323-2157
Hours: 7:45 - 8:15

There are several EROS Applications Assistance Facilities which maintain micro-film copies of data archived at the Center and provide computer terminal inquiry and order capability to the central computer complex at the EROS Data Center. Scientific personnel are available to assist in ordering.

The addresses are:

EROS Applications Branch
U.S. Geological Survey
Room 202, Building 3
345 Middlefield Road
Menlo Park, California 94025
Phone: (415) 323-8111
Hours: 8:00 - 4:15

EROS Applications Assistance
Facility
HQ Inter American Geodetic Survey
Headquarters Building
Drawer 934
Fort Clayton, Canal Zone
Phone: 83-3897
Hours: 7:00 - 3:45

EROS Applications Assistance
Facility
EROS Data Center
U.S. Geological Survey
Sioux Falls, South Dakota 57198
Phone: (605) 594-6511
Hours: 8:00 - 4:30

EROS Applications Assistance
Facility
U.S. Geological Survey
Suite 1880
Valley Bank Center
Phoenix, Arizona 85073
Phone: (602) 261-3188
Hours: 8:00 - 5:00

U.S. Geological Survey
Room 8-207-A, Building 1100
National Space Technology
Laboratories
Bay St. Louis, Mississippi 39520
Phone: (601) 688-3541
Hours: 8:00 - 4:30

EROS Applications Assistance
Facility
U.S. Geological Survey
1925 Newton Square East
Reston, Virginia 22090
Phone: (703) 860-7871
FTS: (900) 860-7871
Hours: 8:00 - 4:15

EROS Applications Assistance
Facility
University of Alaska
Geophysical Institute
College, Alaska 99701 (Fairbanks)
Phone: (907) 470-7558
Hours: 8:00 - 5:00

In addition, several EROS Data Reference Files have been established throughout the United States which maintain microfilm copies of data available from the EROS Data Center. However, they do not have personnel for consultation. The addresses, telephone numbers and hours of operation are as follows:

EROS Data Reference File
Public Inquiries Office
U.S. Geological Survey
108 Skyline Building
508 Second Avenue
Anchorage, Alaska 99501
Phone: (907) 277-0577
Hours: 9:00 - 5:30

EROS Data Reference File
Topographic Office
U.S. Geological Survey
900 Pine Street
Rolla, Missouri 65401
Phone: (314) 364-3680
Hours: 8:00 - 5:00

EROS Data Reference File
Public Inquiries Office
U.S. Geological Survey
Room 7638, Federal Building
300 North Los Angeles Street
Los Angeles, California 90012
Phone: (213) 688-2850
Hours: 9:30 - 4:00

EROS Data Reference File
Water Resources Division
U.S. Geological Survey
975 West Third Avenue
Columbus, Ohio 43212
Phone: (614) 469-5553
Hours: 8:00 - 4:30

EROS Data Reference File
Water Resources Division
U.S. Geological Survey
Room 343, Post Office and Court
House Building
Albany, New York 12201
Phone: (518) 474-3107 or 6042
Hours: 8:00 - 4:30

EROS Data Reference File
University of Hawaii
Department of Geography
Room 313C, Physical Science
Building
Honolulu, Hawaii 96825
Phone: (808) 9-4-8643
Hours: 8:00 - 4:00

EROS Data Reference File
Bureau of Land Management
729 NE Oregon Street
Portland, Oregon 97208
Phone: (503) 234-3361 X400
Hours: 8:00 - 4:00

EROS Data Reference File
Maps and Surveys Branch
Tennessee Valley Authority
20 Haney Building
311 Broad Street
Chattanooga, Tennessee 37401
Phone: (615) 755-2149
Hours: 8:00 - 4:00

In addition to the regular Landsat Facilities, the NOAA has 16 mm browse files of Landsat data. The reason for this service is that Landsat data is often used in conjunction with NOAA satellite data. There are 21 NOAA browse files; however these files will be terminated in October 1978.

University of Alaska
Arctic Environmental Information
and Data Center
142 East Third Avenue
Anchorage, Alaska 99501
Phone: (907) 279-4523

Lake Survey Center - CLx13
630 Federal Building & U.S. Court-
house
Detroit, Michigan 48226
Phone: (313) 226-6126

Inter-American Tropical Tuna
Commission
Scripps Institute of Oceanography
Post Office Box 109
LaJolla, California 92037
Phone: (714) 453-2820

National Weather Service, Central
Region
601 East 12th Street
Kansas City, Missouri 64106
Phone: (816) 374-5672

National Geophysical and Solar
Terrestrial Data Center
Solid Earth Data Service Branch
Boulder, Colorado 80302
Phone: (303) 499-1000 X 6915

National Weather Service, Eastern
Region
585 Stewart Avenue
Garden City, New York 11530
Phone: (516) 248-2105

National Oceanographic Data Center
Environmental Data Service
2001 Wisconsin Avenue
Washington, D.C. 20235
Phone: (202) 634-7510

National Climatic Center
Federal Building
Asheville, North Carolina 28801
Phone: (704) 258-2850 X620

Atlantic Oceanographic and
Meteorological Laboratories
15 Rickenbacker Causeway,
Virginia Key
Miami, Florida 33149
Phone: (305) 361-3361

National Severe Storms Lab
1313 Halley Circle
Normal, Oklahoma 73069
Phone: (405) 329-0388

National Weather Service, Pacific
Region
Bethel-Pauaha Building, WFP 3
1149 Bethel Street
Honolulu, Hawaii 96811
Phone: (808) 841-5028

Remote Sensing Center
Texas A & M University
College Station, Texas 77843
Phone: (713) 845-5422

National Ocean Survey - C3415
Building #1, Room 526
6001 Executive Boulevard
Rockville, Maryland 20852
Phone: (301) 496-8601

National Weather Service, Southern
Region
819 Taylor Street
Fort Worth, Texas 76102
Phone: (817) 334-2671

Atmospheric Sciences Library - D821
Gramax Building, Room 526
8060 - 13th Street
Silver Spring, Maryland 20910
Phone: (301) 427-7800

National Weather Service, Western
Region
125 South State Street
Salt Lake City, Utah 84111
Phone: (801) 524-5131

Service
Environmental Sciences Group
Suitland, Maryland 20233
Phone: (301) 673-5981

439 West York Street
Norfolk, Virginia 23510
Phone: (804) 441-6201

Northeast Fisheries Center
Post Office Box 6
Woods Hole, Massachusetts 02543
Phone: (617) 548-5123

Northwest Marine Fisheries Center
2725 Montlake Boulevard East
Seattle, Washington 98112
Phone: (206) 442-4760

University of Wisconsin
Office of Sea Grant
610 North Walnut Street
Madison, Wisconsin 53705
Phone: (608) 263-4836

National Climatic Center
Satellite Data Services Branch
Room 606, World Weather Building
Washington, D.C. 20233
Phone: (301) 763-8111

Digital data are available from EDC as CCT's (Computer Compatible Tapes) in the standard NASA format. This format is soon to change when EDC begins to implement the EROS Digital Image Processing System (EDIPS), which is discussed in depth in the next section on data handling techniques.

If raw data is required on a regular basis it may be obtained from:

IPF Support Services
Code 563
Building 23, Room E409
NASA Goddard Space Flight Center
Greenbelt, Maryland 20771
Phone: (301) 982-5406

NOAA Satellite Data

NOAA data is used primarily for meteorological and oceanographic studies and are of a much coarser spatial resolution than Landsat data. However, because these data have a higher radiometric resolution (8- or 10-bit vs. 6- or 7-bit quantization) they are of interest to earth resource monitors. Real time data products may be ordered and sent by mail or user's communication links by contacting:

National Environmental Satellite Service (NESS)
Director of Operations, FOB-4
Washington, D.C. 20233

Retrospective (archived) data products may be obtained from:

National Climatic Center (NCC)
Satellite Data Services Branch
Room 606, World Weather Building
Washington, D.C. 20233

Experimental Satellites

A number of other satellites are now or will be in the next few years providing digital data for experimental studies of the earth and its atmosphere. Many of these have poorly defined data output products and no mechanism estab-

ished for data dissemination. Users of these data may be required to have very sophisticated data processing facilities at their disposal. Some of these satellites are listed below and references are listed at the end of this section for further information on obtaining these data.

- * Seasat-A
 - Launch date: mid 1978
 - principal sensor: microwave
 - application: ocean monitoring
- * GEOS-3
 - launch date: April, 1975
 - principal sensor: radar altimeter
 - application: topographic mapping with extreme accuracy
- * AEM-A; (HCMM)
 - launch date: mid 1978
 - principal sensor: Heat Capacity Mapping Radiometer
 - application: continuous sensing of surface thermal characteristics
- * LAGEOS
 - launch date: May, 1976
 - principal sensor: none; passive laser reflection
 - applications: accurate determination of continental drift, plate tectonics, and distortions of the earth surface
- * SEOS-A
 - launch date: mid 1980's
 - principal sensor: LEST (Large Earth Survey Telescope)
 - application: high resolution continuous coverage of earth resources subjects
- * SHUTTLE (manned vehicle which can fly into satellite orbit)
 - launch date: 1979 or 1980
 - principal sensors: undetermined
 - applications: unlimited

References

- Doyle, F.J. (1978) The next decade of satellite remote sensing, Photogrammetric Engineering and Remote Sensing. 44 (2) 155-164.
- Hughes, C.L. and Campbell, C.E. (1977) The Status of Environmental Satellites and Availability of their Data Products. NASA-JSC and Lockheed Electric Co. LEC-10344 (Draft Copy)
- Lynch, T.J. (1976a) Data Compression Requirements for the Landsat Follow-on Mission. Greenbelt, MD. GSFC; X930-76-55.
- Lynch, T.J. (1976b) Ground Data Handling for Landsat-D. Greenbelt, MD. GSFC; X-930-76-264.
- NASA (1976) Landsat Data Users Handbook. NASA-GSFC Doc. No. 76SDS4258.

Selected Bibliography for Digital Image Data Products

AEM-A

Applications Explorer Missions (AEM) (1974) Mission Planners Handbook.
Goddard Space Flight Center, Greenbelt, Maryland.

Elson, B.M. (1976) Standard Satellites Under Development, Aviation Week
and Space Technology, 50-52.

User's Guide for Direct Readout Applications (1976) Applications Explorer
Mission-A, Heat Capacity Mapping Mission (HCMM). Goddard Space Flight
Center, Greenbelt, Maryland.

GEOS

Leitao, C.D., C.L. Purdy and R.L. Brooks (1975) Wallops Geos-C Altimeter
Preprocessing Report. NASA TMX-69357.

LAGEOS

Jaffe, L. Laser Geodynamic Satellite (LAGEOS), Mission Operation Report,
No. E, Office of Applications. Distributed by Executive Management
Services Division (AEM), NASA Headquarters.

Spencer, R.L. (to be published) The LAGEOS System. LAGEOS Program Manager,
Marshall Space Flight Center, NASA.

LANDSAT

Earth Resources Technology Satellite, ERTS-2, Reference Manual, General
Electric, Space Division, Valley Forge Space Center, Philadelphia,
PA.

Heaslip, G.B. (1976) Satellites Viewing Our World: The NASA LANDSAT and
the NOAA SMS/GOES, Environmental Management. 1(1), 15-29.

Horan, J.J. et al. (1975) In Orbit Calibration Performance of LANDSAT-2,
Applied Optics. 14(9) 2053-2054.

Lansing, J.C. Jr., and R.W. Cline (1975) Optical Engineering. 14(4) 312-322.

NASA (1976) LANDSAT Data Users Handbook. NASA Document #765DS4258.

Paulson, R.W. (1976) Use of Earth Satellites for Automation of Hydrological
Data Collection. U.S. Geological Survey, Reston, Virginia.

NOAA Satellites

- Brower, R.L. et al. (1976) Satellite Derived Sea Surface Temperatures from NOAA Spacecraft, National Environmental Satellite Service, NOAA, Technical Memorandum NESS 78.
- Corbell, R.P., C.J. Callahan, and W.J. Kotsch (1976) The GOES/SMS User's Guide. National Oceanic and Atmospheric Administration & National Aeronautics and Space Administration.
- Fordyce, D.V. and R.J. Wirth (1973) The Synchronous Meteorological Satellite (SMS) System. EASCON, Washington D.C., 52-59.
- Fortuna, J.J., and L.N. Hambrick (1974) The Operation of the NOAA Polar Satellite System, NOAA Technical Memorandum NESS 60, Office of System Integration, National Environmental Satellite Service, NOAA.
- Gedney, R.T. (1975) An Operational All-Weather Great Lakes Ice Information System, 3rd Canadian Symposium on Remote Sensing, Edmonton, Alberta, 73-82.
- Heath, D.N. et al. (1975) The Solar Backscatter and Total Ozone Mapping Spectrometer (SBUV/TOMS) for NIMBUS-G, Optical Engineering. 14(4) 323-331.
- Hoppe, R. and A. Ruiz (1975) Catalog of Operational Satellite Products, NOAA Technical Memorandum NESS 53, National Environmental Satellite Service, NOAA.
- Hussey, J.W. (1974) The Geostationary Environmental Satellite System. EASCON, 490-497.
- Johnson, J.C., F.C. Parmenter, and R. Anderson (1975) Environmental Satellites: Systems, Data Interpretation and Applications. National Oceanic and Atmospheric Administration, National Environmental Satellite Service, Washington D.C., 21-22.
- Lienesch J.H., B.P. Bauer and B.B. Goddard (1975) SMS Infrared Observation: Their Accuracy and Calibration, 10th International Symposium on Remote Sensing of the Environment. 27.
- McKowan, P.L. (1975) Data Processing Plan for Synchronous Meteorological and Geostationary Operational Environmental Satellites (SMS/GOES) X-565-75-276, Goddard Space Flight Center, Greenbelt, Maryland.
- McMillin, L.M. et al. (1973) Satellite Infrared Soundings from NOAA Spacecraft. National Environmental Satellite Service, NOAA, Government Printing Office.
- Oliver, V.J. and R.A. Scofield (1975) The Geostationary Meteorological Satellite (SMS): Its Advantages and Applications. 10th International Symposium on Remote Sensing of the Environment. 28.

Streaker, D.M. (1975) The Nimbus-G Sensor Systems: A Preliminary Description, Goddard Space Flight Center, Greenbelt, Maryland.

Tarpley, J.D. and B.A. Raymond (1975) Automated Measurements of Sea Surface Temperature From a Geostationary Environmental Satellite, 10th International Symposium on Remote Sensing of the Environment. 25-26.

The Nimbus-5 User's Guide (1972) Goddard Space Flight Center, Greenbelt, Maryland.

The Nimbus-6 User's Guide (1975) Goddard Space Flight Center, Greenbelt, Maryland.

SEASAT-A

Chism, S.B. (1977) Seasat-A Land Applications Data Processing Plan, LEC-9978.

SEOS

Lowe, D.S. (1974) Requirements for a Synchronous Earth Observatory Satellite (SEOS), Proceedings of the Society of Photo-Optical Instrumentation Engineers. 51, 115-123.

Walter, L.S. (1974) Synchronous Earth Observatory Satellite (SEOS), IEEE Electronics and Aerospace Systems Conference, Washington, D.C.

Young, P.J. (1975) Scanning System Tradeoffs for Remote Sensing from Geosynchronous Orbit. Optical Engineering. 14(4) 289-294.

SHUTTLE

OFT Payload Planning Status (1976). NASA, Shuttle Payload Integration and Development Office, Lyndon B. Johnson Space Center, Houston, Texas.

DATA HANDLING TECHNIQUES FOR EXISTING DIGITAL REMOTE SENSING

DATA

CURRENTLY AVAILABLE DATA

This discussion will be limited to Landsat data, which was the paramount concern of the conference. The basic references for this section are Thomas, 1975, and NASA, 1976.

A Landsat scene in digital form consists of 2340 scan lines. The nominal number of pixels per scan line is 3240, which, based on a scene size of 185 by 185 km, yields a nominal pixel size of 79 by 57 m (about 1.12 acres). In practice, the line length may vary from 3000 to 3450 pixels. The line length on the CCTs is adjusted to a multiple of 24 by systematically repeating selected pixels in lines which fall short of the adjusted line length (LLA).

The logical structure of the Landsat digital data is band interleaved by pixel pair. The fundamental unit of this structure is an eight-byte group, which consists of band 4 radiance numbers (RNs) for two adjacent pixels, followed by RN pairs for bands 5, 6, 7. All RNs are represented as eight-bit bytes, right-justified, with either 6 or 7 bit quantization.

Landsat data are stored on the CCT as four files, each file representing a quarter-width vertical strip of a single scene. In order to reconstruct scan line N in its entirety, one therefore must extract and concatenate record N + 2 from each of the four files. The '+ 2' allows for the I.D. and annotation record. These records are the first and second entries, respectively, in each strip file, and contain the following information:

ID record:	scene/frame ID
	file sequence number
	data record length
	data mode/correction code
	adjusted line length
annotation record:	Greenwich date of exposure
	format center lat/lon
	nadir lat/lon
	sun elevation and azimuth
	satellite heading
	orbit number
	data acquisition site

In addition, the last 56 bytes of each scan line contain sensor radiometric calibration coefficients and sample calibration levels.

The physical structure of the CCT may be specified as either 7 track, 800 bpi, or 9 track, 800 or 1600 bpi. At 1600 bpi density, all four files are placed on a

single 2400 foot tape. At 800 bpi, 2 tapes are required. On all tapes or tape sets there is a fifth file composed of data from the Special Image Annotation Tape (SIAT), containing information on spacecraft attitude and additional sensor performance data.

SUPPLIER PROCESSING OF LANDSAT DIGITAL DATA

Landsat MSS data enters the NASA Image Processing Facility (IPF) in the digital domain as wideband video tapes. The first operation performed on the data is reformatting to high-density digital tapes (HDDTs). These HDDTs are then input to a subsystem which performs radiometric calibration, decompression if bands 4, 5 and 6 have been compressed, and a second reformatting to the CCT distribution format. The system as currently configured (1977) applies geometric corrections only to photographic imagery, and these in only the most general sense.

The NASA IPF is currently being supplanted by the Master Data Processor (MDP) as the EROS Digital Image Processing System (EDIPS) nears completion. MSS video tapes entering the MDP will still be converted to HDDTs, but no photographic products will be generated. All subsequent processing will take place in the digital domain. The HDDTs will be radiometrically corrected and will have geometric correction coefficients written on the header. Corrected HDDTs will also be output which have been geometrically rectified to either a UTM, Polar Stereographic, or SOM projection. Resampling will be performed with either a cubic convolution or nearest neighbor algorithm.

NASA will retain only a limited "quick-look" capability for image generation or CCT production. Under the new system configuration, all Landsat data will leave NASA in HDDT form, for product generation by the EDIPS system at EDC. EDIPS is expected to become operational by mid-1978 (EROS Data Center, 1978), and will be the user community's primary source of Landsat digital data. EDIPS' primary digital product will be CCTs generated from fully corrected HDDTs, using the SOM (Space Oblique Mercator) projection and cubic convolution resampling. The logical structure will be either band-sequential or band-interleaved-by-line. Other projections (UTM, Polar Stereographic), resampling algorithms (nearest neighbor), and unprocessed ("archival") tapes will be available only on a special-order basis.

Various types of enhancement will be applied to digital data products in the EDIPS system (TRW, 1977). Default processing options include haze removal by subtraction of a scene-dependent haze bias, and contrast stretching according to a histogram equalization. In addition, users may request an RN histogram of each scene, and edge-enhancement by a Laplacian algorithm.

USER PROCESSING OF LANDSAT DIGITAL DATA

Currently, users are forced to perform most data corrections themselves. Examples follow of two systems which have been developed, at quite different scales, within the user community.

IBM has developed a large scale Image Processing Facility (IPF) for the manipulation of Landsat data (Bernstein and Ferneyhough, 1975). Input data is radiometrically calibrated using the NASA procedure, then subjected to 'supplemental' calibration which removes striping by statistically equalizing the detector output. Geometric correction of Landsat data is accomplished by selecting ground control points in the image and using these points to evaluate coefficients of spacecraft attitude functions. These functions are evaluated for a selected number of points in the image, yielding an 'interpolation grid' from which pixels for the rest of the corrected image may be located by bilinear interpolation. Once new pixel locations are established, their radiance numbers are assigned by one of several resampling algorithms. The rectification process is made more accurate by the a priori specification of systematic sensor errors, which are removed by direct modeling. These include distortions such as mirror velocity nonlinearity, line perspective, scan skew, and earth rotation.

A smaller-scale system with similar objectives has been implemented at the U.S. Army Engineer Waterways Experiment Station (Williamson, 1977). The constraint upon this system was a small (16K) computer. Data are corrected for pixel aspect ratio by repeating every third and twentieth scan line. Earth rotation distortions are compensated by offsetting every 12 scan lines one pixel westward. These systematic distortions are the most visible and are therefore the only ones explicitly corrected. The remainder of the geometric distortions are accounted for by translation, rotation, and affine "stretching" equations using coefficients derived from regression upon ground control points. These equations are evaluated for each point in the corrected image to yield an address on the original image, to the nearest whole pixel. This avoids radiometric interpolation but results in a loss in positional accuracy. The overall technique described is certainly less accurate than the IBM system, but is significantly less costly to implement and operate.

The two systems described above represent a cross-section of user responses to the Landsat data correction problem. Part of this problem will be alleviated by the implementation of EDIPS, but there are other difficulties to be overcome before the georeferenced use of Landsat data can become more widespread.

GENERAL CONSIDERATIONS ON COMMON FORMATS FOR
GEOBASE INFORMATION SYSTEMS AND SATELLITE IMAGE PRODUCTS

There are currently a large number of geobase information systems in existence, and an even larger number under development or under consideration. The diverse purposes for which these are intended, and the incompatibilities between them in their original data, objectives, and analytical methods, seems to make it infeasible to find some common format philosophy or philosophies for geographic information systems. Within major federal agencies it is known that many data bases are being developed without knowledge of those already existing in the agency. Some 50 major geographically-based systems, all essentially independent, exist in the U.S. Geological Survey alone.

The inclusion of satellite data into these information systems further complicates the problem. How many of these should or could attempt to incorporate satellite image data is unknown. Despite these complexities, the search for standardization on some acceptable numbers of formats should proceed. This is both a general federal agency and state agency responsibility, since information systems development with geographically coded data is common to both parties. The complexity of this area is such that there are no easy solutions and no simple recommendations. The following discussion reflects both the difficulty of the problems and the diversity of opinions among those who attended the conference.

- * A procedure for windowing and reformatting Landsat so that it could directly overlay USGS map quadrangles would increase the utility of remote sensing data in geobase information systems. If this procedure is initiated it will result in the attraction of new users, reduced handling and processing time for all users, and an overall cost savings.
- * New geographic data bases designed to provide the public with information and serve the needs of federal and state agencies should be structured to offer maximum flexibility for conversion by external users. Both polygon and gridded approaches to a data base structure must continue to be evaluated. Both types may need to be supported by providers of image products.
- * A workshop bringing together representatives from local, county, regional state and national levels of government is recommended. The workshop should examine both the recommendations given in this report, and the development of upwardly compatible geobase information systems between hierarchies of government.
- * At the state level a central agency should examine a common format philosophy in respect to its impact on the geographic information needs of the state. A formal procedure should be developed to support implementation of a common format at all agency levels.

It is recognized that digital image products must serve the needs of two very different segments of the user and potential user community. The first is the very sophisticated research or industrial user; the second is the typical state, regional or county planning or resource group, which even collectively still lacks the resources to work with the raw digital image data. It was evident at the workshop that while these two types of users require different data products, that both would benefit from the availability of smaller, more specific image segments because:

1. Data storage, manipulation, processing, and subsequent information accessing would be simplified because the product would typically include far fewer pixels than the currently used "frame"
2. The potential of mini-computer use for digital image processing could be more fully realized because the size of the data sets to be manipulated would be reduced. This would serve to attract more potential users to both segments of the user community.

While the fully re-formatted products are aimed at the less sophisticated user, it was the confident expectation at the workshop that the merits of such products would soon bring all but a handful of researchers to prefer them, and to employ them routinely.

ATTRIBUTES

The advantages of the fully-reformatted products are as follows:

1. Resampled pixels would be consistent as to location, thereby facilitating (a) geobase file updating, (b) temporal comparisons of all types, (c) establishment of other file-manipulation procedures based on a standard location.
2. Arraying of square pixels in UTM (Universal Transverse Mercator) blocks is compatible with the raster formats of image-based geographical information systems.
3. Local users would be upwardly compatible with larger system users through development of data transfer based on a common format.
4. Significant economies of scale would be achieved through centralization of processing, with resultant overall system cost savings.
5. New users will be attracted.
6. There will be a notable reduction in the handling and processing time required of users themselves, to say nothing of the simplification of many software development problems.

The timeliness of delivery of such products is of continuing concern to users. It is important to ensure that these data products be delivered to users within 48 hours to 7 days depending on the urgency of the problem. Urgently-required materials may carry some premium pricing.

Present data delivery time is both slow and inconsistent. If an individual program manager is willing and able to use digital image data as an element in his decision-making process, it is most important that the data be delivered within a time frame which will allow ample time for analysis. The present system of data delivery gives the user no guarantee in terms of time of acquisition and delivery.

The decision making processes of federal and State agencies will not tolerate--or be willing to risk their decision alternatives on--a data source which is unreliable. The question of operational, and hence guaranteed, data delivery must soon be faced.

State Involvement in Federal Data Supply Decisions

Present steps for federal-state cooperation in technical criteria, cost policy and delivery need to be strengthened and improved. We know that they are already in place, but they are just not good enough.

Possible coordination between NASA-USGS-OMB-OSTP and National Council of State Legislators, the National Governors Association, and various State Planning Agencies should be explored.

Data Handling Responsibility within Government

Government agencies at all levels have a fundamental responsibility to be able to provide information systems which will offer the maximum public benefit over a long period of time. This is not a responsibility that can be shifted to the private sector for any extended period.

Data gathering agencies that provide data in a form that requires sophisticated technical manipulation before it is useful in the planning/decision making processes of government simply exacerbate the situation.

Federal agencies must provide basic data sets in a form that can be readily used by state and local government, with the staff, level of competency and availability of computational machinery that now exists in those governments.

This step will:

1. Encourage state and local governments to accept their responsibility to staff up for their own data handling operations.
2. Create a wider body of data users, that will in turn create an expanded market for special purpose products that can be supplied by the private sector.

Role of NASA as R & D Agency

The role of NASA as a research and development agency is not widely recognized or understood. Data in and of itself have no merit; they are either useful

or not useful. To be useful in the government context requires institutional change to adapt to the new data types and possibilities. All institutional change in local and state government requires upheaval, commitment and expenditure of sometimes scarce resources. These changes are taking place in response to the data provided by NASA. The changes are regarded locally as permanent - with NO understanding that NASA is acting in a research and development mode.

Regardless of whether the R & D nature of NASA activity has in fact been made clear to user governments, an institutional change in local and state governments is not an R & D venture.

The strategy of long-term data supply must be immediate concern to NASA if serious lack of confidence, misuse of funds and poor use of scarce technical resources is to be avoided.

Common Data Formats for Diverse Data Bases

On the matter of formats of data bases it is important that we define the term data base as interpreted in this discussion. Data bases can exist in both physical hard copy forms, e.g. maps film, statistical data, and in computerized forms containing representations of these data in digital form. For purpose of this discussion, a data base was defined as a computerized or automated assembly of data.

Automated data bases can be divided into three basic application types: internal, external and a combination of both. To further elaborate on these application types, internal data bases are those designed and containing data for internal federal or state agency applications. An example of this type of data base might be NOAA's National Weather Service data base of weather data which is used for weather forecasting purposes. An external data base is one designed to provide the public with information, such as the Department of Interior's Census Statistics data base. The third type of data base is one designed to satisfy both internal agency requirements and external user requirements. An example of this might be World Data Bank II, developed by the CIA to meet internal cartographic needs, but now available to external users through NTIS.

The design of new geographic data bases that will be of the external or combination types should be designed to offer maximum flexibility for conversion by external users. The workshop members were divided on to whether the point/polygon design structure offers this flexibility better as compared to the grided approach to a data base structure; and both approaches must continue to be evaluated, along with the development of efficient algorithms for conversion between them.

It is essential that a standard projection (preferably UTM) be integrated into the design structure. It was recognized that the standardization of the UTM projection represents a substantial cost to several federal agencies (NASA, DOI, EDC), but it was felt that this cost should be increased once by the federal agencies rather than a multitude of times by the many users. There would be an overall cost savings because federal agencies finance much of the user processing and because data processing for most users would be greatly simplified. Because the UTM projection is the standard for most of North America, digital image data preprocessed with UTM as the standard projection could be easily integrated or overlaid on geographic map data.

The preceding discussion applies to those data bases which may still be changeable or remain to be developed. However, most data base design and development activities preclude such changes once programming has begun.

Modification of existing national data bases is not likely. Federal data base development activities are dictated to a large degree by Federal Information Processing Standards (FIPS) and local agency standards and regulations which would in most instances limit an agency's ability to make changes, after the fact

With these considerations in mind, a principal concern expressed at the workshop was on the necessity for improved communication on such matters between agencies and levels of government to avoid freezing even more information systems in forms which are not easily compatible with digital image data.

The establishment of a new common data format for digital image data thus becomes important not merely because it appears most compatible with user needs, but also because it can in turn create an environment within which more geobase information systems will be designed to be compatible with such a data source.

RECOMMENDATIONS AND SUPPORTING DISCUSSION

GENERAL RECOMMENDATIONS FOR FUTURE DIGITAL IMAGE FORMATS

If satellite data is to attract a substantially larger user community in the future, it must satisfy the needs of applications-oriented users as well as those involved in research and development. NASA or EDC should be able to provide digital image products which are geared toward both types of users. It is with regard to this dichotomy in user demand that the following recommendations are made:

RECOMMENDATIONS

Two distinct families of imagery should be available to users on a standard product basis:

- * Uncorrected video data, either in completely unaltered 'raw' form, or radiometrically calibrated but not corrected, but with substantial header and annotation information.
- * Fully processed data, which has been radiometrically corrected (including destriping) and geometrically rectified to a UTM projection.

Both product families should include as annotation the geodetic coordinates of selected control pixels within the scene which could be/have been used to perform a rectification to a geobase reference system. Both product families should be accessible by segments corresponding roughly/exactly to 7 1/2 minute USGS topographic quadrangles. The fully processed data should exhibit east-west orientation of the scan lines. Also:

- * Processed data should be available in certain other projections and formats as 'special-order' products, for which a somewhat longer order turnaround would be acceptable.

DISCUSSION

Uncorrected data

The raw, uncorrected/calibrated data is needed by users who wish to perform local, precise radiometric measurements. These users generally have their own hardware and software for resampling and correcting the data. Annotation supplied with uncorrected tapes should contain information on sensor electronic and mechanical performance parameters, spacecraft attitude, etc., so that radiances can be derived from an "ideal" spacecraft in an ideal orbit. Dissemination of raw data will play a significant role in

determining the effect of resampling on classification and radiometric accuracy because it will allow the use of different resampling schemes.

Uncorrected data should be supplied with sufficient information to permit sophisticated users to rectify the imagery without themselves acquiring ground control information. This would probably consist of identifying a minimum number of pixels in the scene in terms of geodetic coordinates, and/or highly accurate spacecraft attitude information.

All users should be able to obtain only those portions of imagery relevant to their areas of inquiry. Users should not have to purchase and manipulate vast quantities of data which are of no use to them, in order to extract an important fraction thereof. To this end NASA should permit accession of all types of digital data by a latitude-longitude spatial window, subject to some minimum size constraint such as a USGS 7 1/2 minute topographic quadrangle. Virtually all conference participants agreed that standardization to 7 1/2 minute quads would be close to an optimum format.

Corrected data

To improve the dissemination of remote sensing data NASA should redefine its user community to include less sophisticated users. Improved data flow to experienced users may actually inhibit flow to first-time users. The fully corrected product recommended above should remedy this problem by providing, off-the-shelf, data which is in a standard projection, gridded in a manner that makes it easily compatible with other digital data bases.

One of the major difficulties in the use of Landsat data has been the high processing cost of geometrically correcting the data. This is a problem of both software and hardware that is caused by the mass of data (3×10^7 bytes) in one Landsat scene, and is compounded by the tilt of the spacecraft orbit. While rectification software is available, it is usually designed for larger computers and is time consuming to bring up even on these. The general feeling of the conference was that the majority of potential new users are smaller institutes or state agencies more interested in applications than in research and development. As such they have limited computer resources, usually consisting of mini-computer systems or access to small time-sharing systems. On such systems bulk I/O tends to be difficult or expensive. For the smaller user the computational cost of converting Landsat data to a usable data base format can become prohibitive. Moreover, the level of information

exchange within the user community is currently such that an institution which is primarily applications oriented may incur considerable costs developing a Landsat data-correction system, only to discover that much or all of an identical system has already been developed elsewhere. This duplication of R & D efforts, coupled with the limited portability of existing software packages, is a powerful limiting factor in the broader utilization of Landsat data.

For Landsat data to be useful it must be in a form compatible with other digital data bases. In addition to geometric rectification the data should be resampled to an east-west scan direction. This "rotation" is costly and difficult to perform on a small computer and should be done once by NASA. The recommendation to NASA that the projection be UTM is based on the need for a conformal projection which allows Cartesian (x,y) referencing with minimal distortion. From user comments the UTM alignment appears to be the most common alignment of user-community databases and other Government data structures such as the NCIC digital terrain tapes. Information lost in resampling to a new grid alignment was generally conceded to be insignificant compared to the difficulty of working with data structures which are not aligned. Some agencies will be using data referenced in state plane coordinates, and it would be useful to know by how much these differ from the UTM grid (it may be less than the Landsat sampling interval).

The corrected imagery should have a much more geographically specific accession structure than the uncorrected imagery. The most widely accepted proposal for a standard product was a direct overlay of the USGS 7 1/2 minute topographic quadrangle series, with fixed sample locations to facilitate multitemporal analysis.

Logical formatting of either uncorrected or corrected data should not be restrictive to users whose computer systems have limited I/O buffering or high I/O costs, nor should it discriminate with respect to users interested primarily in multispectral classification, image generation, or database augmentation. Since no single logical format seems to fulfill these requirements, it is recommended that the following three logical structures be available on request: band interleaved by pixel (BIP), band interleaved by line (BIL), and band interleaved by scene (band sequential or BSQ).

Special order products

The conference recognized the importance of specifying standard,

'pipeline' products for which NASA and EDC could configure their production system for high volume and maximum availability. However, there was a general agreement that the interests of users requiring specialized products should be protected, in that NASA or EDC should make a variety of processing options available on a retrospective basis. These might include:

- nonstandard quadrangles (e.g., to fit specific study areas)
- nonstandard projections (e.g., to fit numerous state plane systems)
- nonstandard sample spacings (e.g., to yield specific output scales on line printers, film writers, "grid" information systems, etc.)

The workshop members anticipated that the costs for these special products might well be more than for the standard products.

ANNOTATION

For digital data to be properly and efficiently processed, it must be associated with a thorough and accurate annotation record. The annotation must provide in a simple format the information required by the myriad users of data from Landsat-3, the thematic mapper on Landsat-D and other future space imaging systems. While the needs of these users will vary, the following recommendations and subsequent discussion are based upon the premise that the more annotation information provided to the user, the more universally usable Landsat and future Imaging Systems data will become.

RECOMMENDATIONS

Complete annotation should be made available to users of either raw or reformatted satellite data. All forms of annotation currently provided should continue to be provided. In addition, it is recommended that the following information be supplied with all digital image data:

- * Type of projection, if applicable.
- * Sampling interval in meters on the ground.
- * Up-to-date algorithms and coefficients for converting digital radiance numbers to actual space upwelling radiances.
- * Several ground control points identified in image and standard geo-reference coordinates.
- * More accurate geodetic grid ticks and nadir/format center coordinates (preferably designated in latitude and longitude).
- * More accurate spacecraft positional (altitude and attitude) information
- * More spatially specific cloud coverage estimates.

DISCUSSION

Utilization of existing digital image annotation varies greatly within the user community. Some users ignore it completely, although none were willing to suggest deletion of any existing annotation. On the other hand, some users make extensive operational use of annotation data; for example, the use of spacecraft heading to derive a systematic rotation correction. Recent deletion of this parameter from the annotation has caused some concern. Most users found the annotation data currently supplied to be deficient in some respect and recommended changes and additions. There was general agreement at the conference that NASA should supply all available annotation of CCT's.

If the image has been transformed to a specific map projection, the annotation should include a description of the projection, the specific parameters em-

ployed, and references to the relevant forward and inverse transformation algorithms.

Spatial sampling interval on the ground should be specified for each image (corrected for systematic distortions such as line perspective, scan nonlinearity, orbital parameters and earth curvature). This would be more accurate than the current practice of simply dividing the dimensions of the image matrix (e.g., 2340 lines by 3240 samples) into some standard frame size (e.g., 185 km on a side).

Conversion of digital radiance numbers (RNs) to actual space upwelling radiances ($\text{Wm}^{-2}\text{sr}^{-1}$) is usually accomplished by linearly mapping the quantization level onto the radiometric response (dynamic range) for each band. Since both the dynamic range (i.e., threshold and saturation values) and the order of the calibration equation may be subject to revision, it is essential that sufficient data be included with each CCT to permit rapid voltage-radiance conversions with the maximum accuracy achievable at the time the tape is generated.

Ground control points are necessary both for users of uncorrected tapes who wish to do their own rectification, and for users of corrected data who may wish to check the accuracy of the data for themselves. It is important that each image contain some reasonable minimum number of points (e.g., 10), which are identified in the annotation block in the image and geodetic coordinates, so that acceptable overlaying of image data to other image data, maps and information systems may be achieved. The RMS error of these control points in both image and geodetic space should be specified, so that some inferences may be made as to the accuracy of transformations based on these points. The geodetic system of reference should be latitude and longitude, on a specified ellipsoid, to be accessible to the largest number of users. There was general agreement among users attending the conference that latitude and longitude is the best coordinate system for location of ground control points.

Currently supplied corner and edge ticks, and nadir and format center coordinates, are too coarse to be useful for image rectification and location of pixels on the ground. These should be of the same order of accuracy as are those produced on the fully corrected image product, both for corrected and uncorrected data. If this requirement is met, it follows that these edge and center tick marks will also constitute additional control points.

Current (1978) spacecraft positional data is of insufficient accuracy to permit its use in scene correction. It is our understanding that, beginning with Landsat-3, improved spacecraft positional accuracy will be achieved. This new data should be supplied in more accurate form with both data modes, for users

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who wish to rectify full scenes on their own, and for those users who wish to find the positions of single pixels at a time. Concern was expressed by users interested in receiving and manipulating raw data that complete information be available in the CCT annotation record for image rectification.

Current cloud coverage estimates as supplied by the EDC are too vague to be useful to those users whose area of interest covers only a specific portion of a Landsat scene. It was suggested that cloud cover estimates include some comment on the spatial distribution of the cloud cover within the scene; e.g., by Cartesian quadrant, by CCT strip file, etc. There was discussion of the need for availability of quick-look, low quality imagery from EDC so that users could effectively evaluate imagery before ordering. This has been done successfully in Canada using photo-facsimile products 48 hours after satellite overpass. EDC's proposed image microfiche index will probably fill this need when it becomes operational.

RECTIFICATION

As recommended above, future Landsat imagery should be available both as raw data with improved header information, and also in a format which has been fully rectified to a standard projection, such that the tape may be accessed directly by a geodetic coordinate system. The following recommendations are made as to the specific nature of the fully corrected product.

RECOMMENDATIONS

The rectified imagery should meet the following specifications:

- * The map projection employed should be conformal and the pixels should be aligned east-west, amenable to Cartesian referencing. Universal Transverse Mercator was the projection preferred by users attending the conference.
- * Rectified imagery should be indexed to existing USGS 7-1/2 minute quadrangle topographic maps, and sample locations should be fixed.
- * Resampling should be done only once and should either preserve the nominal spatial resolution of the sensor, or, if confirmed by further study, transform to one of a series of standard resolutions; e.g., binary (16, 32, 64, 128... meters) or "10/25" preferred by some users (10, 25, 50, 100, 250... meters).
- * Projections other than the recommended UTM standard should be available upon request, but the transformations should be done from the raw data to avoid resampling data more than once.

In terms of assessing the effect of image rectification on image data accuracy the following is recommended:

- * Further investigations should be undertaken to determine the effects of various resampling algorithms, including double resampling, on radiometric and spatial fidelity and classifier performance.
- * The rectification algorithms used should be provided with the data to the user community and algorithms for forward and inverse transforms between a variety of standard projections should be available for distribution to users.

Rectification of imagery to a conformal projection assures that small shapes will be preserved and the general 'sense' of the image will be undisturbed. There was considerable discussion of exactly which projection should be used in light of the extremely varied needs of user agencies across the country. The consensus of this was:

1. If possible, given cost and processing constraints, users should be able to specify a variety of projections when ordering data.
2. If the standard product is to have only one standard projection,

then UTM is the most desirable because of its generally east-west orientation and widespread use (except at high latitudes where the Polar stereographic projection is more appropriate).

3. Most users find the Space Oblique Mercator (SOM) unacceptable, because it yields a grid rotated too radically for use with other geobase data systems, and which differs from spacecraft to spacecraft.

Some users prefer UTM outright because their other data bases and many USGS topographic sheets are already in this projection. Other users prefer the Lambert Conformal Conic (LCC) projection because it precisely matches the State Plane Coordinate System in many states. The difference between these projections at commonly used scales is mainly one of orientation; it is therefore not unreasonable to request both products. However at the scale of a 7-1/2 minute quadrangle, the differences are almost impossible to detect.

The problem with either UTM or LCC is in areas which occur across the boundaries of zones. Zone overlap is fairly easy to correct for; at the scale of a 7-1/2 minute quadrangle this would not be likely to occur. A study area spanning several zones would be a more difficult problem.

Space Oblique Mercator is unacceptable because no other geodetic data are oriented to SOM. Image data has been resampled by NASA to SOM and then must be resampled again by the user to be useful. One of the issues universally agreed upon at the conference was that any resampling should be done only once.

Current indexing techniques for Landsat data leave much to be desired. Indexing by frame does not correspond to any other geobase data format and thereby requires extensive modification to overlay Landsat data to other data bases. The main problems with indexing by frame are:

1. The size of the frame (roughly 185 km square or 7 1/2 million discrete spatial locations, or with 4 bands 30 million pixels) is much too large for most small users with limited computer resources.
2. The artificial frame boundaries are a memorialized holdover from the days of photo interpretation, and as such inhibit the use of Landsat data as a digital geobase data system. Providing mosaiking of multiple scenes and sub-scene segments to users is appropriate.

While some users may be interested in very large multiple frame segments of Landsat data, most smaller agency users desire smaller subimage segments. Satellite data is received as a continuous strip, hence boundaries and segment size could be user defined. This would present storage and processing problems for EDC. A standard indexing system should be employed which is manageable for EDC and correlates well with other digital data bases. There was good agreement at the conference that image data indexed by 7 1/2 minutes USGS quadrangles would satisfy these constraints:

1. The data segments would be smaller and more manageable for users

with limited computer resources.

2. Satellite data would be well referenced to the most common geodetic data base, e.g. topographic data or digital terrain tapes.
3. Problems of data discontinuity at path boundaries would be avoided because a 7 1/2 minute quad is small enough to be within the overlap between paths.

It was recognized that the system would be valid only in areas where 7 1/2 minute quads have been surveyed, but that includes most of the United States and Canada. A system adapted for other parts of the world requires separate analysis.

Image 'rotation' or resampling to scan lines along grid eastings is a computational problem requiring either very large quantities of main memory or a sophisticated (and usually slow) virtual memory system, both of which often exceed the capabilities of many users. Alignment of the scans so that the pixels run east-west in the selected projection, would be most cost-effective if done by NASA or EDC at the same time as the rectification.

The EDIPS system should be able to provide data in a variety of projections on a special order basis for users who have needs differing from the standard product. In addition, the algorithms for transformation of one projection into another should be made available to users. This will facilitate the use of Landsat data with other geobase data systems.

It was the general consensus of the conference that, although image resampling does not seem substantially to affect radiometric and classification accuracy, further investigation is needed into the effects of various resampling algorithms on radiometric fidelity, spatial resolution, and the performance of a variety of classifiers. In lieu of more definitive information on the effects of resampling, it is recommended that users have the option of requesting either nearest neighbor or cubic convolution resampling algorithms be used in producing their rectified tapes. (For further information on the effect of resampling, see the selected bibliography).

To provide maximum flexibility for users who 'personalize' their digital data, the algorithms and, more importantly, the ground control points and spacecraft positional data used in producing the rectified tape, should be made available for user inspection. The ground control and positional data should be included as part of the standard annotation, and the algorithms employed in the actual rectification should be subject to user modification and reversing, at their own installations.

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RESOLUTION REQUIREMENTS

SPATIAL RESOLUTION

Regarding spatial resolution, the conference attempted to strike a balance between scenarios which would provide the highest resolution achievable; and scenarios which would provide the maximum continuity with existing digital data base structures. The following recommendations are those which received general support. Other recommendations and some of the debate surrounding them are presented in the discussion.

RECOMMENDATIONS

- * "Raw" digital data should preserve the nominal spatial resolution of the imaging sensor.
- * The "corrected" digital data should be resampled at an interval selected from the binary series (i.e., 2^n meters), or the "10/25" series (10, 25, 50, 100, 250... meters). For Landsat-D, a suggested resampling interval would be 25 or 32 meters.
- * Data compression techniques which irreversibly degrade spatial resolution should not be employed.
- * Precise evaluations of the effects on spatial resolution of any resampling algorithms employed, should be made available, either by broader dissemination of existing studies or the initiation of new ones.

DISCUSSION

Appropriate spatial resolution for future sensor systems

It was the consensus of the conference that at least one of the available digital data products preserve the nominal spatial resolution of the sensor as well as the original radiometry without resampling. That is, raw CCT's should continue to be supplied as now. The rationale for this conclusion was that it would be pointless to implement a system with, say, 30 meter resolution, if the standard data product were constrained to 50 meter resolution. It is imperative that users who require high spatial resolution have access to the full capabilities of every sensor system.

Beyond agreement that maximum spatial resolution should be available on raw CCT's, there was considerable discussion as to the optimum spatial resolution for the standard, high-volume reformatted and resampled digital product as described earlier. Significant spatial resolution schemes which were proposed are listed below:

- Spatial resolution as a binary series: There was strong feeling that an optimum hierarchy of spatial resolutions could be obtained by scaling each resampled standard product pixel size to the nearest 2^n meters (e.g., 16, 32, 64, ...). Resampling following this scheme

would permit highly accurate upward aggregation, assuming the pixels were square (i.e., same sample interval in X and Y). No examples were given of existing data bases which follow this scaling hierarchy; it is anticipated that the pixel locations produced by resampling would be invariant as to geographic location to ensure direct overlay of multitemporal imagery. The principal advantage of the binary series is that all pixels nest in the next coarsest resolution, thus making for greater simplicity in pixel aggregation and manipulation.

- Spatial resolution in a "10/25" series: A number of users at the conference, and a wide group of Canadian users after the conference, expressed interest in a sequence of resolutions, here specified as the "10/25" series, as follows: 10, 25, 50, 100, 250, 500, 1000...meters. Only the step from 10 to 25 and 100 to 250 meters fails to nest and users felt this was worth the simplicity of the resolution steps suggested. Fixed pixel locations were also desired.
- Spatial resolution as multiples of current resolutions: It was noted that some existing data bases have adopted the current Landsat sample interval as the determinant of their fundamental grid cell. For the sake of continuity, many users felt that future digital data should be supplied in the current 57 x 79 meter cells or some integer multiple/fraction thereof. Other users argued that this would be too restrictive of future improvements in resolution, and that the current cell size is resampled to overlay existing data bases, or to produce constant-scale output on specific display devices (film writer, line printer, etc.), at least as frequently as it is used 'as is'.
- Nominal sensor resolution as the standard resolution: Many users felt that the nominal sensor resolution was actually the most appropriate resolution to offer as a standard product. They reasoned that the uses to which Landsat data are put are sufficiently diverse that to endorse a particular 'synthetic' resolution might tend to discriminate in favor of some users and against others. These users also felt that, rather than providing a range of spatial resolutions, NASA should devote its energies to other processing options.

Something of a consensus emerged that the most significant group currently interested in a fixed resolution were those users relying on the spatial resolution of current Landsat data. It was proposed that future Landsats, therefore, either carry an MSS similar to the present ones, in addition to any higher-resolution devices, or else that NASA make the data from future high resolution sensors available at current Landsat resolutions as one optional product. This met with some acceptance. Finally, many argued that data aggregation was a relatively simple enough task to be left to the user, and should not be ascribed such importance as to impede future progress in sensor technology.

The users who pushed most vigorously for either the binary series or the "10/25" series of pixel resolutions, and fixed pixel locations, aligned on eastings, argued strongly that such products would greatly expand the usefulness of all NASA digital image products, and lead to their much more widespread use. There is no doubt that by so doing, multitemporal comparisons, and nesting of NASA or NOAA products will be transformed from being very burdensome to simple operations. The merits of such standardization warrant careful scrutiny by NASA and EDC.

RADIOMETRIC RESOLUTION

The principal radiometric problems addressed by the conference were calibration, striping, and quantization. Users were concerned that radiometric corrections be transparent to the unsophisticated user, yet amendable to modification by the sophisticated user.

RECOMMENDATIONS

- * NASA should continue to improve their calibration procedures, and make all algorithms and constants available to the users through EDC.
- * Data in which striping is present must be available to the users in uncorrected form.
- * Pathwise calibration on an entire strip should be employed, to minimize scene-to-scene and along-track within-scene variations.
- * Future video data should be represented as 8-bit, unsigned binary integers in the range 0-255.
- * Further investigation (and/or broader dissemination of existing data) is needed regarding the effects of resampling on radiometric fidelity, and on the feasibility of applying atmospheric corrections at the system level.

DISCUSSION

Calibration improvements

Current radiometric calibration procedures were generally felt to be inadequate, in that most imagery still exhibits varying degrees of interdetector striping. It was pointed out that this is a hardware as well as software problem, that the tolerances of the sensors and film recorders need to be quite precise before striping subsides to a level that is undetectable to the human eye. If a software calibration procedure other than the current filtered-regression is devised, it should be at least as thoroughly documented as at present, with raw calibration levels, gains, and offsets continuing to be supplied on at least the uncorrected CCT's.

User striping corrections

If system calibration fails to eliminate striping, most users would seem to prefer to remove it themselves by having access to uncorrected data. It was noted that users to whom striping is most offensive have already devised means of statistically normalizing interdetector gain variations, and it was not unreasonable to expect them to continue to use their specific algorithms. In

addition, some users desired access to uncorrected striped data in order to obtain radiometric levels that have not been subject to statistical 'blurring'. It was especially felt that users to whom actual radiometric values, in terms of space upwelling radiance, are important, should be able to process new CCT's themselves. Other users would very likely want destriping applied by EDC to the corrected, standard product imagery.

Spatial scale of calibration algorithm

The current calibration algorithm is reinitialized for each HDDT entering the NASA IPF system. By serially filtering the detector gain and offset, there often results noticeable along-track gain variations within a scene, which may become substantial over the portion of the path which the HDDT covers. Many users would prefer a type of calibration whereby the filtered gain and offset resulting at the end of each HDDT is applied uniformly throughout the HDDT. This would seem to eliminate some intra- and interscene gain variations for which users must presently compensate themselves.

Quantization and Representation

Some users expressed dissatisfaction with the limited dynamic range imposed on present Landsat data by a six-bit quantization, especially those users who require imagery over snow-covered areas, where Landsat often saturates. It was felt that this problem could be alleviated by adopting an eight-bit quantization for future Landsat data. It was also suggested that all video data, regardless of its quantization level at the sensor, be expanded to fill the range 0-255. This would be accomplished by zero-fill of the least significant bit (i.e., multiplication by $2^{(8-n)}$, where n is the quantization level at the sensor); or, where appropriate, by nonlinear decompression. A standard quantization would simplify comparison of radiometric levels from different sensors (e.g., saturation would always be level 255), and would reduce the number of rescaling procedures necessary when displaying the data on devices with other than 256 gray levels (e.g., lineprinters, storage tubes, etc.)

Further investigations

Participants required more information on the radiometric effects of re-sampling. Especially concerned were those users who convert digital to analog radiances. It was felt that further elucidation is needed of the effects of standard resampling algorithms relative to these subsequent data conversions. It was acknowledged that most users are not concerned with the analog behavior of the data, and that in regard to resampling in general, sufficient information may already exist and may simply require wider distribution.

A number of users expressed an interest in including atmospheric corrections as a standard processing option. Users already familiar with employing these corrections in their own work cautioned that a universally applicable atmospheric correction might not be feasible, and it was recommended that further study be done on a possible system-wide atmospheric correction.

SPECTRAL RESOLUTION

The conference was concerned with spectral resolution to the extent that future sensor systems provide continuity with existing spectral classification schemes.

RECOMMENDATIONS

- * Future operational sensor systems should (to the degree proven necessary), provide spectral continuity with multispectral bands already operational in the user community.

DISCUSSION

Users were less concerned with evaluating the utility of the current Landsat MSS bands than they were that future operational satellites might render current operational applications of MSS data obsolete. It was especially feared that the great amount of effort which some users have invested in developing classifiers based on the current MSS division of the spectrum would be for naught if data in these bands does not continue to be available. Users expressed concern that the data from Landsat-D would require expensive "re-education" of currently operational multispectral classifiers; many were not aware of NASA's tentative plans to incorporate an MSS aboard Landsat-D in addition to the TM (Lynch, 1976a). It appears that such an interim measure would be effective until the parameters for an operational series of Landsat follow-on craft can be finalized (see Colvocoresses, 1977).

This should not be construed as intending to limit further development of multispectral scanning systems; rather, that future spectral coverage assignments should consider the operational use being made of existing spectral bands.

Beyond the concern for data continuity, the conference did not address such questions as optimum spectral partitionings, etc.

References

- Colvocoresses, A.P. (1977) Proposed Parameters for an Operational LANDSAT. Photogrammetric Engineering and Remote Sensing. 43 1139-1145
- Lynch, T.J. (1976a) Data Compression Requirements for the LANDSAT Follow-on Mission. Greenbelt, Maryland: Goddard Space Flight Center X-930-76-55.

TEMPORAL RESOLUTION

The conference discussed temporal resolution both in terms of the overpass interval of the satellite, and in the broader contexts of timeliness of data delivery, and temporal breadth of the archival data base.

RECOMMENDATIONS

- * NASA should provide for a more frequent overpass interval than the current 18 days, either by utilizing different orbital parameters or by the recent practice of staggering the orbits of 2 or more identical satellites.
- * Multiple coverage of path overlap areas should be retained.
- * Turnaround time on orders of digital products should be drastically reduced, certainly to no more than 7 days from satellite passage and preferably within 48 hours.
- * Data archiving should permit preservation of good imagery of areas where cloud cover is a severe problem.

DISCUSSION

More frequent overpasses

Many users found the current overpass interval of 18 days too infrequent for a variety of disciplines, either for events which have a higher temporal frequency (e.d., meteorology), or for low-frequency events of acute intense magnitudes (e.g., hydrology: floods, snowfall). To some users it seemed that the most appropriate solution to this problem would be several Landsat type satellites whose intervals were staggered to provide a higher coverage frequency. There were no suggestions as to how to deal with the correspondingly higher data volume and subsequent archiving problems, nor any agreement on what might be an optimum overpass interval. This appears to be a problem which needs more input from a greater spectrum of the user community.

Coverage in path overlap areas

Some users expressed concern that a system which permits image accession by specification of the relevant USGS quadrangle, or by some other geodetic reference, could lead to the arbitrary assignment of a geographical location to a single overpass. For areas which lie in the zone of overlap this might lead to half or more of the data for that location being discarded. Users, especially those at high latitudes who have come to rely on multiple coverage due to overlap, recommended that any accession system allow the specification of one or any combination of overlap imagery for a specific location.

Turnaround time

Almost all users felt that the temporal resolution of the data in terms of overpass interval was irrelevant when compared to the time spent waiting for an imagery order to be filled. Waits of 3 months or more for a CCT order were not uncommon. It was generally felt that standard products should be available to the degree that time spent in transit would be the single greatest factor between an order's being received by EDC and its delivery to the user. On retrospective order, it was conceded that a longer wait was justifiable; however, delays on the order of months were judged extreme by anybody's standards. The comment was made that current users would "sacrifice anything for timeliness"; however, others countered, from experience in providing their own rapid turnaround, that there was a point at which users would prefer to wait if the overall quality of the image would be impaired. A specific recommendation which arose in connection with this problem, and received moderate support, is that EDC should establish a priority system regarding availability of imagery immediately following an overpass; this recommendation received support from users who felt that the current speed with which an order is filled has no discernible relation to the urgency of the user's need.

Archiving

There were some users who operated in areas where factors such as frequent cloud cover, or dependence upon the satellite's limited on-board storage capability, prohibit the obtaining of acceptable imagery with any degree of regularity. These users were concerned that, should data volume considerations result in a shorter overall archival period, imagery which was old but still useful by virtue of its relative rarity would be discarded. It was urged that such problem areas be identified, and that the archival period of acceptable imagery of these areas be suitably adjusted.

The structure of the data on a CCT is of particular importance to all users. The tape format is especially critical for I/O considerations and related computational costs to users processing Landsat data. In addition, various techniques used by NASA for the data stream and for more efficient data storage have an impact on users in the areas of data reliability and software and hardware development. In light of this, the following recommendations were made.

RECOMMENDATIONS

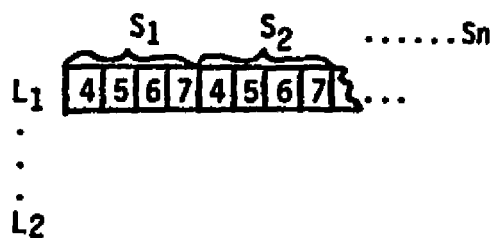
- * Three logical structures, BIP (band interleaved by pixel), BIL (band interleaved by line) and BSQ (band sequential) should be available. The current structure, BIP2 (band interleaved by pixel pairs) is considered the least useful format.
- * The logical record structure of the image file should include substantial annotation for each record.
- * Physical blocking of data on a tape should provide for I/O buffer limitations of minicomputers.
- * Any data compression techniques employed should be reversible to the level of sensor noise.
- * An appropriate Federal agency, probably EDC, should distribute Fortran I/O subroutines for performing common manipulations of imagery in whatever formats are ultimately supplied.
- * 1600 BPI CCT's should continue to be the principal mode of data exchange until higher-density storage devices become more widespread.

DISCUSSION

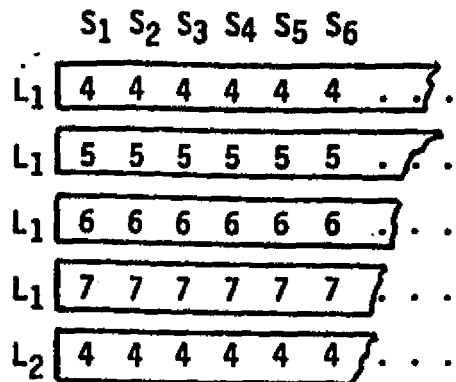
Users at the conference were divided as to the optimum interleaving format for the image matrix. There was, however, good agreement that the currently used system of band interleaved by pixel pairs (BIP2) was the least convenient possible format. Listed below are the four possible formats for a CCT:

	S_1	S_2	S_1	S_2	S_1	S_2	S_1	S_2	S_3	S_4	S_3	S_4	S_3	S_4	S_3	S_4	S_5	S_6	S_5		S_n
L_1	4	4	5	5	6	6	7	7	4	4	5	5	6	6	7	7	4	4	5	}	
.																					
.																					
.																					
L_n																					

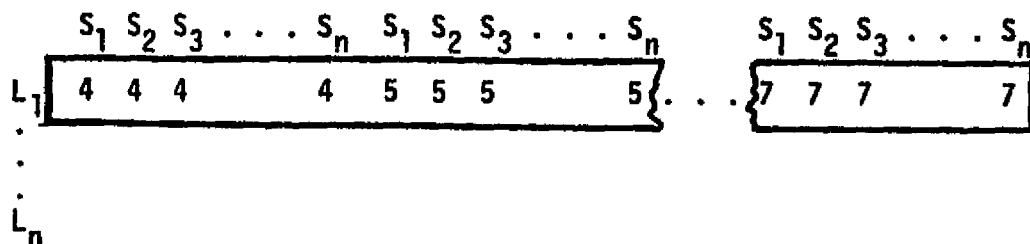
2. BIP (e.g., DIRS format)



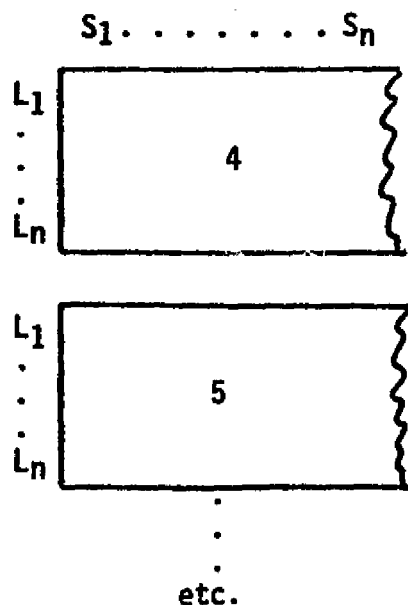
3. BIL (e.g., LARS format)



4. Packed BIL (e.g., LARS format)



5. BSQ (e.g., VICAR format)



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Band interleaved by pixel (BIP) is the ideal format for classifications. Minimal bit manipulation is required and reformatting is not usually required. Band sequential (BSQ) is ideal for single band analysis and most image generation devices. It is fairly complex to reformat from BIP to BSQ, but the band interleaved by line (BIL) format is the intermediate format. From BIL it is fairly easy to reformat to either BIP or BSQ and is therefore an adequate format for either classification, single band analysis, or image construction. The BIL format allows unformatted reads and requires only a modest amount of core for reformatting.

Of the four formats illustrated BIP2 is the least flexible. Regardless of the application, data formatted in BIP2 must be reformatted. BIL is the most flexible and if one format is to be selected as the standard, users felt that it should be BIL. The consensus of the conference was, however, that it should be possible to get data in each of the three previously mentioned formats (BIP, BIL and BSQ).

While a truly "universal" tape format was acknowledged to be an unrealistic expectation, it was suggested that whatever format is ultimately adopted would be considerably more flexible if it incorporated annotation for each data record. Using this scheme, video data could be interspersed with character data (e.g., image and descriptive text); raster and polygon formats could be included in the same file; and image scenes could be of arbitrary dimensions. This "record-comprehensive" annotation would also be amenable to the construction of scene and tape directories so that users could directly access only those portions of a tape that were of immediate interest.

Many users expressed concern that digital data is often placed on tape in the largest possible physical blocks. Whether the motive is to reduce I/O's or to squeeze more files onto a single tape, this practice often results in a tape which is unreadable to users of "mini" computers, where large I/O buffers consume an inordinate amount of main memory. It was recommended that users at least have the option of specifying block sizes as small as 4K (4096 (8-bit) bytes) without cost penalty. Smaller block sizes should also be available, even though this would require a single scan line to span several blocks. As the user community increases in size the reliance on mini-computer systems for image data analysis will also increase. On the other hand, memory for mini-computers is likely to become increasingly less expensive.

Concern was expressed that increasing data volume would result in the application of data-compression techniques that were not fully reversible. It was argued that deployment of sensors whose data rates required irreversible compression would tend to negate any resolution gains such sensor systems might exhibit. It was agreed that any data compression techniques employed by NASA be subject to user scrutiny, and their effect on the nominal quality of the data be fully documented.

Along with the agreement that a single optimum tape format for video data probably did not exist, there was agreement that one of the single highest costs to digital image users is that of reformatting the data until it is digestible to their particular computer system, regardless of whether the data has been rectified, how it is framed, etc. This is basically an I/O-intensive programming problem, which to be solved efficiently often requires a level of programming skill which the typical user does not possess. Recognizing Fortran as the standard calling language, it was recommended that NASA, EDC, or some other appropriate Federal agency, make available a basic set of I/O subroutines which have been tailored to whatever image formats are ultimately adopted, as well as to formats (CCT's, Digital Terrain Tapes) which are already in widespread use.

While users expressed interest in high density modes of data transfer (e.g., 6250 bpi digital tape, optical discs, etc.) it was generally agreed that the widespread application of this technology at the end-user level is still a few years distant. Some concern was expressed for the significance of bit errors associated with current HDDT's (high density digital tapes); it was recommended that these be evaluated statistically to the user community's satisfaction before high-density devices become a significant mode of exchange. Most users prefer the current 800 and 1600 bpi tapes for end-user distribution, while acknowledging that much higher data densities will be required at the archival and interagency bulk-transfer levels.

DETERMINATION OF USER DEMAND, PRICING SCHEDULES AND ABSORPTION OF PREPROCESSING COSTS

Assuming that both data and software are to be provided as suggested in earlier sections of this report, it is necessary to determine the level of user demand, the pricing structure for these products and the degree to which NASA and/or other federal agencies will absorb preprocessing costs. This section addresses these complex questions. The recommendations are followed by a discussion of the points which have led to their adoption.

RECOMMENDATIONS

- * Better estimates of the needs of the users of satellite data are required. The needs of state and local governments for several levels of processing of the data, and for various software implementations, seem poorly understood. NASA, or some other federal agency, should undertake to provide more detailed estimates of these needs.
- * Both the demand and the pricing schedules should be determined by an analytical technique such as the demand revealing processes (discussed below). These determinations should be made for various product combinations and should be performed on a regularly scheduled basis.
- * A portion of the preprocessing costs should be absorbed by the federal government, while the variable costs should be recovered from the aggregation of users. This federal investment will maximize the benefits obtained from the use of satellite data by overcoming the threshold necessary to initiate the diffusion of a technological innovation. In economic terms the federal subsidy should be viewed as an investment aimed at maximizing the present value of the stream of net benefits obtained from the use of satellite data.
- * NASA, the EROS Data Center of the U.S. Department of the Interior, and such other federal agencies as should properly be involved, examine the division of responsibilities and costs between them, in order to implement the preceding recommendations.

DISCUSSION

A variety of beliefs and opinions concerning user demands, pricing structures and preprocessing costs were expressed at the Workshop. However, a firm consensus was apparent among the participants. In the following discussion, the main categories of concern are isolated and the diversity

of opinions is represented. Following this, the consensus is summarized, and finally a solution to the problem of determining user demands and pricing structures is presented. The solution is an attempt to incorporate the consensus into a sound economic structure. An extended discussion of the solution may be found in Appendix C.

Ranges of Belief Concerning User Demands, Pricing Structures, and Pre-processing Costs.

On the Identity of the Users of Concern:

1. The users of concern are agencies of state and local governments.
2. The users of concern are those of 1. above and private sector users.
3. The users of concern may be viewed as a pyramid, with decreasing technical sophistication towards the base.
4. Many potential users are not presently actual users of satellite data.

On the Costs to Present Users of Satellite Data:

1. Many users, especially agencies of state and local governments, face a number of significant costs in using satellite data. Among these are the direct costs of obtaining the data, the costs of personnel training, the costs of software development, the opportunity costs resulting from duplication of effort, the costs of data processing, the costs of delay in obtaining the required information from the data, and the costs of uncertainty, particularly concerning the continuity of the data products.
2. The direct costs of obtaining the data are (at present) reasonable.
3. All costs apart from the direct costs of 2. are very high, and inhibit a significant number of potential users from employing satellite data.
4. A small number of users are not deterred from using satellite data by the costs of 3.

On the Benefits From Use of Satellite Data:

1. There are potential net benefits, not currently accruing, to be had from the use of satellite data by users of concern.
2. Multiplier effects for the economy exist with respect to the adoption of satellite data processing by the users of concern.

3. Net system benefits are not maximized by the current provision of data.

On the Demands of Users:

1. The demands of most classes of users are insufficiently well known and should be investigated.
2. Knowledge concerning user demands should be continually monitored.
3. A full cost/benefit analysis of user demands would be extremely difficult and costly to implement. Alternative methods of assessment of demand should be used.
4. There should be sensitivity to local variation in user demands.

On Federal Government Alternatives Concerning Demand and Supply:

1. NASA should not be involved in the question of both determining and satisfying user demands.
2. NASA should be involved in the question of both determining and satisfying user demands.
3. Some agency of the federal government should be involved in the question of both determining and satisfying user demands.
4. Regional centers should be set up both to determine and to satisfy user demands.
5. Centralized processing and distribution of data and software would maximize economies of scale.
6. Regional centers would be more responsive to the local needs of users.
7. Both training centers and information dissemination offices should be set up by the federal government.

On the Federal Government Alternatives Concerning Pricing Structures and Cost Absorption:

1. The federal government should act to maximize system net benefits.
2. The agency concerned with supplying data and software should use full cost recovery.
3. The agency concerned with supplying data and software should recover the front-end costs of setting up the processing and distribution system.
4. Direct grants should be made to users to encourage their use of satellite data.

5. In determining the pricing structure of products, the agency concerned with distribution should take account of the public goods characteristics of data and software.
6. The price structure of products should be uniform for all users.
7. The price structure of products should not necessarily be uniform for all users.
8. The federal government subsidy should be viewed as an investment to optimize the present value of the stream of net benefits from satellite data use.

The Consensus of Beliefs Concerning User Demands, Pricing Structures and Preprocessing Costs:

There was a high degree of agreement among participants concerning the user demands, pricing structure and preprocessing costs. The consensus of beliefs is now summarized.

1. A significant set of users are the agencies of state and local governments.
2. These users of present satellite data products incur severe costs in processing the products.
3. System net benefits are being lost due to lack of adoption of satellite data products.
4. The demands of users should be investigated and monitored.
5. Centralized processing and supply of data products and software should be implemented in order to take full advantage of economies of scale.
6. At least part of the front-end costs of setting up a system of data and software supply should be borne by the federal government agency.
7. Variable costs of data and software supply should be borne by the users.
8. Some users should be subsidized in their use of data and software products relative to other users.
9. The overall aim of the federal government should be to provide data and software with a pricing structure that would maximize system net benefits over a period of years.

A Proposed Solution to the Problem of Determining User Demands and Pricing Structures

It is proposed that Demand Revealing Processes be applied to provide

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a solution to the problem of determining user demands and price structures for various combinations of data and software supplied by a federal government agency to other Federal government and state and local government users. The theory and application of the Processes is presented in detail in Appendix C.

As applied to the present problem, Demand Revealing Processes are a simple and elegant device whereby federal, state, and local government agencies are induced to reveal their "true" preferences, in terms of willingness to pay, for various combinations of data and software products. Given a required degree of cost recovery for the central agency providing the products, the Demand Revealing Processes indicate the mix of products to be supplied. The pricing structures take account of differential willingness to pay among users, while changing preferences may be taken into account by continual application of the Processes. The combination of Demand Revealing Processes and the supply of data and software may be viewed as an optimal investment strategy regarding the application of satellite imagery by the agencies of state and local governments.

SUMMARY

NASA, or some central government agency, should apply Demand Revealing Processes in order to determine the true demands of state and local governments for satellite data and software products in a continually updated manner. Such processes would allow varying degrees of cost recovery in relation to supplying various mixes of data and software, while users would face charges directly related to their "true" willingness to pay, despite the public goods nature of such satellite products.

While a portion of the preprocessing costs should be absorbed by the federal government agency, the application of the Demand Revealing Processes and the provision of various combinations of data and software should be viewed as an optimal investment decision, whereby the present-value of the net benefits of satellite data use is maximized.

SOFTWARE PORTABILITY

In the preceding sections recommendations were made on development of standard format(s) for digital image products, and on absorption of most of these front end costs by federal agencies as part of a "seeding" program to facilitate their use. Recommendations were also made on the development of software--to fully use these data--as part of geographical information systems. The software developed for these purposes should be as fully portable as possible, for a variety of computers. The present section addresses existing problems of lack of portability, and the resulting immense burden on users, because of the idiosyncratic development of software without agreed-upon standards. Some preliminary recommendations for standard procedures are given and discussed. The establishment of Image Processing and Analysis Software Standard Procedures is recommended for NASA and EDC consideration.

RECOMMENDATIONS

- * Where possible, programs for general distribution should be written in FORTRAN. Departures from the ANSI X3.9 1966 Standard should be isolated in subroutines and clearly documented. Especially, programs should isolate all input/output and bit manipulation portions. Implementation of this recommendation requires that programmers read and become familiar with the standard. A new "Draft Proposed ANS FORTRAN" is in circulation, but it will probably be several years before compilers meeting it will be widely available.
- * It is recommended that NASA and EDC develop Image Processing and Analysis Software Standards to ensure that future software development is in as internally-consistent a form as possible, and to ensure that portability is enhanced.

DISCUSSION

Like many other present-day scientific endeavors, use of digital satellite data requires a large expenditure of time on the development, conversion, debugging, maintenance, and operation of computer programs designed to manipulate these data. Moreover, many of these programs are available for transport to other users, often at nominal cost. The reason for this is that many of the programs are in the public domain, having been developed by state or federal agencies, or by University researchers funded by state or federal grants. Those in the private sector are also concerned with program portability, and this concern will increase in the future, along with the growth in numbers of commercial purveyors of image processing software. The latter are expected to engage in practices similar to present software houses (which sell programs for mathemati-

cal and statistical analysis) and also sell their image processing and analysis software.

At present the costs associated with software conversion are enormous, and they are frustrating because they are commonly under-budgeted. In the Geography Department at the University of California, Santa Barbara, it is currently estimated that 80 percent of staff programming effort is expended in converting and debugging programs which at one time were running on other systems. It is clearly to everyone's advantage if these conversion costs can be decreased, and this section discusses ways in which software portability might be enhanced. (Brown, 1976; Aird et al., 1977).

The FORTRAN Language

For a variety of reasons, this document considers the portability problem in the context of using FORTRAN as the major computing language. This is perhaps unfortunate, as FORTRAN is by today's standards an inelegant and cumbersome language with some severe disadvantages, which are examined in the following pages. However, a preponderance of the existing code used to manipulate digital satellite data is in FORTRAN, and this is likely to be true of most such software developed in the next decade. Moreover, if any language is to replace FORTRAN, it must certainly be able to incorporate FORTRAN subprograms with a minimum of conversion effort.

FORTRAN does have many advantages. It is widely used and widely taught and many subroutines for mathematical and statistical analysis exist. Compilers are available for almost every type of computer. Because of the minimal requirements for information about a subprogram required by a linkage editor or loader, it is usually easy to incorporate machine code subprograms into a FORTRAN program, and it is also usually feasible to incorporate FORTRAN subprograms into programs written in other languages.

Because of its wide use on a variety of machines, some agreement about what constitutes FORTRAN is necessary. To this end the American Standards Association (ASA) began to define a standard language in the early 1960's, completing the work in 1966 after the organization had changed its name to United States of America Standards Institute (UASAI). The name has since been changed to American National Standards Institute (ANSI), and the standard language is now called ANSI X3.0 1966 FORTRAN (ANSI, 1966). Most major compilers accept any program conforming to the standard, but many include additional features. At present a draft of a new standard FORTRAN is in circulation (ACM, 1976) and will probably be approved as the new standard, with modifications. It will probably be several years, however, before most compilers conform to the new standard.

Problems with FORTRAN and its Portability

There are many reasons why FORTRAN would perhaps not be the language of choice for manipulation and analysis of digital satellite data, were it not for the large corpus of pre-existing programs and programmers familiar with the language. Most compilers for the language are poor (Good & Moon, 1973; Hazel, et al., 1973). Rarely do they provide adequate compile-and run-time diagnostics, including subscript checking, and allow for creation of optimized, efficient load modules. The language is cumbersome, requiring use of many statement labels, and structured programming is difficult to accomplish. Moreover, ANSI FORTRAN contains a number of limitations which make satellite data analysis difficult or impossible, as well as imposing hardships on other types of programming.

For these reasons most compilers support lots of extensions to the Standard, and many users write their own machine language code to perform certain other operations. These "extras" typically encourage machine and machine company dependence. Students learning FORTRAN at a given university learn the version implemented on the local machine. As they move elsewhere and become programmers, they pick up new features available on other machines. The end result is that many experienced and competent programmers do not know what isolates the Standard and what does not, and may be quite surprised when they find one of their programs will not run under a different version of FORTRAN. Compounding this problem is the fact that very few compilers flag their allowed departures from ANSI Standard, and therefore there is no reason or mechanism available to get programmers to conform to the standard (Pyster & Dutta, 1978). In fact the same program may compile successfully on two separate systems, produce no warning or diagnostic messages on either, and produce different results.

Some desirable and widely used capabilities which do not conform to ANSI FORTRAN are listed below (some of these are adapted from Larmouth, 1973a, 1973b). All of these capabilities are available on some compilers, and many of them exist in the draft proposed ANSI FORTRAN (1976).

- 1) ANSI FORTRAN has no provision for direct access input/output (available in the new draft).
- 2) There are no bit manipulation routines or logical masking functions.
This is a serious obstacle, because satellite data are composed of lots of small numbers, which are generally packed in groups into a whole computer word. Moreover, the fact that a byte is of different lengths in different machines may cause problems.
- 3) There is no specific provision for string or character handling.
(The new draft includes the CHARACTER*length specification, but the collating sequence is not fixed; Sabin, 1976).
- 4) There are no data structures.

- 5) Recursive subprograms are not permitted.
- 6) There is no provision for dynamic space allocation. (Larmouth, 1973b, describes a way to accomplish this using COMMON.)
- 7) Mixed mode expressions are prohibited (e.a. $A = A + I$ is illegal).
- 8) An array may contain no more than 3 subscripts (7 in the new draft).
- 9) Subscript expressions can be no more complicated than constant * variable $\pm$ constant (relaxed in new draft, but dimensioned variables and function references are still prohibited).
- 10) There is no IMPLICIT or NAMELIST declaration (IMPLICIT is in the new draft).
- 11) Implied loops in DATA statements are not supported; if X is dimensioned at 3, DATA X / 3*0.0/ is illegal (relaxed in new draft).
- 12) A real variable cannot be assigned to a complex one.
- 13) There is no REAL*8, INTEGER*2, or LOGICAL*1 declaration.
- 14) There are no end-of-file or error traps (there are in the new draft).
- 15) Names longer than 6 characters are not supported.
- 16) Do loops crossing zero or going in negative direction are illegal (relaxed in new draft).
- 17) Expressions or array references may not appear in DO or computed-GOTO statements.
- 18) There is no provision for use of quotes in Hollerith strings (relaxed in new draft).
- 19) There is no list-directed input/output (but available in new draft).

In addition, there are desirable features available in other languages which would be useful in FORTRAN. PL/I allows the variable declaration statements to specify precisely what precision (number of bits) is needed, while ANSI FORTRAN allows only REAL or DOUBLE PRECISION for floating point numbers and only INTEGER for integers. The number of bits assigned to integers varies from 16 to 60 on various machines, and the number assigned to single precision floating point numbers varies from 32 to 60. The relative error magnitude caused by a reduction from 60 to 32 bits is estimated at 10^9 (Good and Moon, 1973). Therefore, a numerical routine which runs perfectly well on a CDC 6400 machine may be swamped with error on an IBM 360. Converting the routine to double precision for the IBM is very tedious, unless provision is made in the original source code for this possibility (Aird et al., 1977).

ANSI FORTRAN allows the compiler to use either static or automatic storage allocation in subroutines. Most compilers use static allocation, and many of us have taken advantage of this fact by storing values in internal variables in subroutines between calls. Such subroutines may well introduce errors if run on a system where storage allocations are automatic. For example, according to ANSI FORTRAN and to the new draft, a variable whose value is initialized by a

DATA statement on the first call to a subroutine, and whose value is modified by the subroutine, is undefined on a second call to the subroutine:

```
SUBROUTINE XYZ (A,B)
  DATA L/O/
  L = L +1
  .
  .
  .
  RETURN
  END
```

The value of L at the second call to XYZ is probably 1, but may not be.

ANSI FORTRAN does not specify the mechanisms by which parameters are passed to subroutines, and Waite (1976) has identified five major variations. The Standard prohibits redefinition of a dummy argument that is associated with another dummy argument by the CALL statement. It also prohibits redefinition of a dummy argument that becomes associated with a variable in COMMON between the calling routine and the subroutine. However, many compilers will detect neither error, and there are a number of variations in the possible answers. Two examples follow; the values for N at the execution of the WRITE statement are unpredictable.

.	.
.	.
.	.
N = 1	COMMON N
CALL XYZ (N,N)	CALL XYZ (N,N+3)
Write (6,---) N	Write (6,---) N
STOP	STOP
END	END
SUBROUTINE XYZ (I,J)	SUBROUTINE XYZ (I,J)
I = I + 1	COMMON L
J = 2 * I + 2	I = I + 1
RETURN	L = L + J
END	I = J * L
	RETURN
	END

Procedures to Enhance Portability

It is not reasonable to expect all programmers to adhere to ANSI FORTRAN. In some cases the non-standard features available are merely frills, and these should be eschewed completely. Some features, however, such as direct-access input/output, bit manipulation, end-of-file traps, etc., may be very useful,

even essential, to efficient programming.

A workable solution to the resulting portability problems is to follow good modular programming practices, and to isolate and clearly document the portions of the program which depart from the Standard. In particular, programs whose input/output and bit manipulation statements lie in separate subprograms from the rest of the program are much easier to convert. Even if very meager documentation is supplied with programs (as is usually the case) the documentation should clearly specify where the program departs from the Standard, what routines perform input and output, and the sequence of input variables. Subroutines which perform bit or character manipulation should include good descriptions of any local routines which are used, so that the recipient can substitute his own. Implementation of these practices depends on programmers being familiar with the Standard, and there is no substitute for a careful reading of the appropriate documents (see Chrisman and White, 1978).

The esthetic deficiencies in the FORTRAN language can be overcome through use of a preprocessor (such as ALTRAN, RATFOR, or STAGE2) which converts the source code of the program into ANSI FORTRAN, which is compiled for execution, or which may be transported to a facility which lacks a preprocessor.

References

- Aird, T.J., E.L. Battiste, and W.C. Gregory (1977) Portability of mathematical software coded in FORTRAN. ACM Transactions on Mathematical Software. 3, 113-127.
- ANSI X 3.9 (1966) American National Standard FORTRAN. New York: American National Standards Institute.
- ANSI BSR X3.9 (1976) Draft proposed ANS FORTRAN. ACM SIGPLAN Notices, 11(3)
- Brown, P.J. ed. (1976) Software Portability: An Advanced Course. Cambridge: Cambridge University Press.
- Chrisman, N., White, D. (1978) Programming for Transportability: A Guide to Machine Independent FORTRAN. Laboratory for Computer Graphics, Harvard University, Cambridge, Mass.
- Good, J. and B.A.M. Moon (1973) FORTRAN -- as provided by some major machines manufacturers in 1970. Software - Practice and Experience. 3, 9-14.
- Hazel, P., J. Larmouth and A. Stonely (1973) Some comments on FORTRAN systems. Software - Practice and Experience. 3, 185-187.
- Larmouth, J. (1973a) Serious FORTRAN. Software - Practice and Experience. 3, 87-107.
- Larmouth, J. (1973b) Serious FORTRAN - Part 2. Software - Practice and Experience. 3, 197-225.
- Pyster, A. and A. Dutta (1978) Error-checking compilers and portability. Software - Practice and Experience, (in press).
- Sabin, M. (1976) Portability -- some experiences with FORTRAN. Software - Practice and Experience. 6, 393-396.
- Waite, W.M. (1976) Theory, P.J. Brown, ed. Software Portability: An Advanced Course. Cambridge University Press. 7-19.

SELECTED BIBLIOGRAPHY

The following selected list of bibliographic references, though terse, contains many of the important recent articles on the topics covered in this report and should be a useful guide to readers unfamiliar with the area.

The references are listed under the following subheadings:

Geobase Information Systems

Multispectral Sensing and Analysis

Resolution

Digital Image Processing

Sampling

State Agency and Selected International Applications

GEOBASE INFORMATION SYSTEMS

- Angelici, G.L., Bryant, N.A. (1976) Techniques for the creation of land use maps and tabulations from Landsat imagery. Paper presented at the Second Annual William T. Pecora Memorial Symposium, Sioux Falls, South Dakota, Oct. 25-29.
- Beatty, W.H. and Tragni, F. (1977) A rectangular coordinate system for geometrically corrected Landsat MSS images. 11th International Symposium on Remote Sensing of Environment, Apr. 26.
- Billingsley, F.C., Bryant, N.A. (1975) Design criteria for a multiple input land use system, Proc. NASA Earth Resources Symposium, Houston, Tex, June, NASA TM X-58168, Vol I-B, 1389.
- Billingsley, F.C. (1976) Quo vadis, remote sensing? AIAA/AAS Bicentennial Symposium, Oct. 8.
- Bryant, N.A., Zobrist, A.L. (1976) IBIS: A geographic information system based on digital image processing and image raster datatype, Proc. Symposium on Machine Processing of Remotely Sensed Data, Purdue University, W. Lafayette, Ind., June.
- Bryant, N.A., Zobrist, A.L. (1976) Integration of socioeconomic data and remotely sensed imagery for land use applications. Paper presented at Second Annual William T. Pecora Memorial Symposium, Sioux Falls, South Dakota, Oct. 25-29.
- Bryant, N.A., George, A.J., Hegdahl, R. (1977) Tabular data base construction and analysis from thematic classified Landsat imagery of Portland, Oregon. Proceedings of the Fourth Purdue: LARS Symposium on Machine Processing of Remotely Sensed Data. W. Lafayette, Ind., June 21-22, 313-318.
- Bryant, N.A., Zobrist, A.L. (1977) An image based information system: Architecture for correlating satellite and topological data bases. Paper to be presented at the Advanced Study Symposium on Topological Data Structures for Geographic Information Systems, Harvard University, Cambridge, Mass., Oct.
- Calkins, H.W., Marble, D.F., Peuquet, D.J. (1977) Information system support of regional environment analysis, Workshop on Regional Environmental Systems Studies, RANN/NSF, Seattle, Wash., June 20-24.
- Calkins, H.W., Tomlinson, R.F. (1977) Geographic Information Systems, Methods, and Equipment for Land Use Planning, 1977. International Geographical Union Commission on Geographical Data Sensing and Procession, Ottawa, Canada.
- Chrisman, N. (1974) The impact of data structure on geographic information processing. Presented at Auto-Carto I, Internal Report 74-4, Laboratory of Computer Graphics, Harvard University, Cambridge, Mass.
- Chrisman, N. (1975) Topological geographic representation, Proceedings, Urban and Regional Information Systems Association (URISA), Vol 1, Aug. 194-202.

Geobase Information Systems
(Continued)

- Chrisman, N.R. (1975) Topological information systems for geographical representation. 2nd International Symposium on Computer Assisted Cartography, Reston, Virg., Sept.
- Cicone, R.C. (1973) Remote sensing and geographically based information systems. Proceedings of the 11th International Symposium on Remote Sensing of Environment, Ann Arbor, Mich., July.
- Colvocoresses, A.P. (1975) Evaluation of the cartographic application of ERTS-1 imagery. The American Cartographer, Vol 2, No 1, 5-18.
- Colvocoresses, A.P. (1977) Map projection options for Landsat. U.S. Geological Survey Memorandum EC-50-Landsat, Apr. 12.
- Cooke, D.F., Maxfield, W.H. (1967) The development of a geographic base file and its uses in mapping. Proc. URISA, Garden City, LI, Sept.
- Corbett, J.P. (1975) Topological principles in cartography, 2nd International Symposium on Computer Assisted Cartography, Reston, Virg.
- Craib, K.B., Watkins, T.H. (eds.) (1977) Proceedings of the First Conference on the Economics of Remote Sensing Information Systems. Dept. of Economics, San Jose State University, San Jose, Calif., Jan. 19-21.
- Defense Intelligence Agency (1973) Geopolitical Data Elements and Related Features. USDIA Manual 65-18A, Washington, D.C.
- Department of the Army (1958) Universal Transverse Mercator Grid. Dept. of the Army Tech. Manual TM 5-241-8.
- Doyle, F.J. (1975) Cartographic presentation of remote sensor data. In Manual of Remote Sensing, Vol II - Interpretations and Applications. American Society of Photogrammetry. Falls Church, Virg., 1077-1106.
- Dueker, K.J. (1972) A framework for encoding spatial data. Geographic Analysis, 4:98-105.
- Dueker, K.J. (1974) Urban geocoding. Annals of Assoc. of American Geographers. 64, 318-325.
- Dueker, K.J. (1975) Geographic data encoding issues. Technical Report #43, The Institute of Urban and Regional Research, University of Iowa, Iowa City, Iowa, Apr.
- Dueker, K.J., Noynaert, E. (1977) Interactive digitizing, editing and mapping: data structure considerations. Prepared for Advanced Study Symposium on Topological Data Structures for Geographic Information Systems, The Laboratory for Computer Graphics and Spatial Analysis, Harvard University, Oct. 16-21.

Geobase Information Systems
(Continued)

- Durfee, R.C. (1974) ORRMIS: Oak Ridge Regional Modeling Information System, Part I. ORNL-NSF-EP-73, Oak Ridge National Laboratory, Oak Ridge, Tenn.
- Dyer, H.L., et al (1975) Information System for Resource Management and Related Applications. Argonne National Laboratory, for the Office of Land Use and Water Planning (2 Vols).
- Edson, D. (1975) Digital cartographic data base preliminary description. 2nd International Symposium on Computer Assisted Cartography, Reston, Virg.
- Ericksen, R.H. (1976) Digic Series User's Manual. Department of Geography, University of Iowa, Iowa City, Iowa. Sept.
- Federation of Rocky Mountain States, Inc. (1977) A Geographic Information System for Environmental Planning. Project Briefing Paper, Jan.
- Higham, A.D. (ed.) (1972-73) Multispectral Scanning Systems and their Potential Application to Earth Resource Surveys (6 Vols), Plessey Radar Research Centre, Havant, Hampshire, England.
- Hyde, R.F., Killpack, C.L. (1976) Project ASTI: Adapting satellite data to IMGRID. Holcomb Research Institute, Regional and Environmental Assessment Program Bulletin No. 12-8-76.
- Hyde, R.F., Killpack, C.L. (1977) A new method for classifying and applying Landsat data to land use planning and analysis in a geographic information system. Paper presented at the 1977 American Association of Geographers, April 22, 1977, Salt Lake City, Utah. Holcomb Research Institute, Regional and Environmental Assessment Program Bulletin No. 4-22-77.
- Jalbert, J.S., et al (1977) ORNL/NUREG: A Cell Based Land Use Screening Procedures for Regional Siting Analysis.
- Land Use Analysis Laboratory (1974) Status report of the Land Use Analysis Laboratory. Iowa Agricultural and Home Economics Station, Iowa State University of Science and Technology, Nov. 73 through Nov. 74, 1-3, 56-76.
- Land Use Analysis Laboratory (1977) Research considerations - a land information system support program. Iowa Agricultural and Home Economics Station, Iowa State University of Science and Technology, Ames, Iowa, 1-4, 92-102.
- Langrebe, D., Phillips, T., White, T., Kenny, G. (eds.) (1975) Information Systems and Services. NASA Earth Resources Symposium, Vol I-B: 1087-1483.
- Malila, W.A., Hieber, R.H., McCleer, A.P. (1973) Correlation of ERTS MSS data and earth coordinate systems. Conference on Machine Processing of Remote Sensing Data, LARS, Oct., Purdue University, W. Lafayette, Ind.

Geobase Information Systems
(Continued)

- Miller, W.R. (1975) A Survey of Geographical Based Inform. Systems in Calif. Intergovernmental Board on Electronic Data Processing, State of Calif., May.
- Mitchell, W.B., Guptil, S.C., Anderson, E., Fegeas, R.G., Hallam, C.A. (1977) GIRAS: A Geographic Information System for Handling Land Use and Land Cover Data. U.S. Geological Survey Professional Paper 1059, Washington, D.C.
- Moldoff, B., Roberts, J.R., Spitzer, J.F. (1978) Serving the Earth Resources Community: A Plan for Data Management and Data Sharing, MTR-4711, The MITRE Corporation, Houston, Texas, Feb.
- Power, M.A. (1975) A Computerized Geographic Information System: An Assessment of Important Factors in their Design, Operation and Success. Center for Developmental Technology, Washington University, St. Louis, Mo., December.
- Rowland, J.B. (1977) The Hotine Oblique Mercator Projection applied to Landsat mapping. U.S. Geological Survey Memorandum EC-50-Landsat, Apr. 12.
- Schlosser, E.H., Brown, M.L. (1976) Detection and Mapping Package Vol 1-3, NASA contract NAS9-12200.
- Schmidt, A. (ed.) (1977) Proceedings of the 1st International Symposium on Topological Data Structures for Geographical Information Systems, Harvard Laboratory for Computer Graphics, Dedham, Mass.
- Scinton, D. (1977) User's Manual for IMGRID Geographic Data Base Program, Harvard Graduate School of Design, Harvard University, Boston, Mass.
- Switzer, W.A. (1977) Overview, Canadian Geodata Information Systems. Lands Directorate, Environment Canada, Unpublished, Feb.
- Tobler, W. (1969) Geographic filters and their inverses. Geographical Analysis, Vol 1.
- Tomlinson, R.F., et al (1973) Computer handling of geographic data, Natural Resource Research XIII, 81.
- U.S. Army Corps of Engineers (1977) Proceedings of a Seminar on Variable Grid Resolution - Issues and Requirements. Hydrologic Engineering Center, U.S. Army Corps of Engineers, Davis, Calif. .
- U.S. Bureau of the Census (1970) Census Use Study: The DIME Geocoding System, Report No. 4, Washington, D.C.
- USDI (1975) Office of Land Use and Water Planning (draft) Information Systems: A Technical Description of Software and Hardware.

**Geobase Information Systems
(Continued)**

- Warner, P.A. (1974) National geocoding. *Annals of Assoc. of American Geographers*. 64, 310-317.
- Zobrist, A.L., Bryant, N.A., Landini, A.J. (1976) IBIS, A geographic information system that can use satellite data for urban analysis. Paper presented at the 14th Annual Conference of the Urban and Regional Information Systems Association, Aug. 29, Sept. 2, Atlanta, Georgia.
- Zobrist, A.L. (1976) Elements of an image based information system. *Proceedings of the Caltech/JPL Conference on Image Processing*, Pasadena, Calif., Nov. 3-5, 3-1/3-5.
- Zobrist, A.L. (1977) Elements of an image based information system. Paper presented at the IEEE Workshop on Picture Data Description and Management, Chicago, Ill., Apr.
- Zobrist, A.L. (to appear) Elements of an image based information system, *IEEE Transactions on Software Engineering*.

MULTISPECTRAL SENSING AND ANALYSIS

- Addington, J.D. (1975) A hybrid classifier using the parallelepiped and bayesian techniques. Proc. American Soc. Photogrammetry 41st Annual Meeting, March.
- Andrews, H.C. (1972) Introduction to Mathematical Techniques in Pattern Recognition. Wiley-Interscience, New York.
- Angelici, G.L., Bryant, N.A., Friedman, S.Z. (1977) Techniques for land use change detection using Landsat imagery. Proceedings, Fall, ASP-ACSM Convention, Little Rock, Ark., Oct. 18-21.
- Bizzell, R.M., Fernison, A.H., Hall, F.G., Bauer, M.E., Davis, B.J., Malila, W.A., Rice, D.P. (1975) Crop Identification Technology Assessment for Remote Sensing (CITARS), (10 Vols), Johnson Space Center, Houston, Texas, Report JSC-09393, Dec.
- Bongard, N. (1970) Pattern Recognition. Spartan-MacMillan, New York.
- Cato, G.A. (1972) Basic principles of earth resources sensing. Remote Sensing of Earth Resources, Vol. 1, University of Tennessee, 64.
- Cheng, et al (1968) Pictorial Pattern Recognition. Thompson Book Co., Washington, D.C.
- Cicone, R.C., Malila, W.A., Crist, E.P. (1977) Investigation of Techniques for Inventorying Forested Regions, Volume II: Forestry Information System Requirements and Joint Use of Remotely Sensed and Ancillary Data, ERIM 122700-35-F₂, Ann Arbor, Mich. Nov.
- Colvocoresses, A.P. (1970) ERTS-A satellite imagery. Photogrammetric Eng. 36(6), 555-560.
- Colvocoresses, A.P. (1977) Proposed parameters for an operational Landsat. Photogrammetric Eng. 43(9), 1139-1145.
- Doyle, F.J. (1978) The next decade of satellite remote sensing. Photogrammetric Eng. 44(2), 155-164.
- Duda, R., Hart, P. (1972) Pattern Classification Scene Analysis. Wiley-Interscience, New York.
- Fu, K.S. (1968) Sequential Methods in Pattern Recognition and Machine Learning. Academic Press, New York.
- Fukunaga, K. (1972) Introduction to Statistical Pattern Recognition. Academic Press.
- Goldberg, I.L. (1969) Design considerations for a multispectral scanner for ERTS. Proc. of Symposium on Inform. Processing. Purdue University, W. Lafayette, Ind.

Multispectral Sensing and Analysis
(continued)

- Grebowsky, G.J. (1975) Characteristics of Digital Multispectral Scanner Data. NASA/GSFC X-563-75-169.
- Holmes, R.A. (1971) Data requirements and data processing: earth resources surveys. S.P.I.E. Journal. 9, 52-56.
- Holter, M.R., Wolfe, W.L. (1959) Optical-mechanical scanning techniques. Proc. IRE. 47.
- Holter, M.R., Polcyn, F.C. (1964) Comparative Multispectral Sensing. Report No. 2900-484-S, University of Michigan. Infrared and Optics Lab.
- Hyde, R.F., Goward, S.N., Mausel, P.W. (1977) ISURSL levels classification: A low cost approach to multispectral data analysis. Symposium Proceedings, Machine Processing of Remotely Sensed Data, Laboratory for Applications of Remote Sensing, Purdue University, W. Lafayette, Ind., June, 322-332, IEEE Catalog No. 77CH 1218-7 MPRSD.
- Kanal, L.N. (1968) Pattern Recognition. Thompson Book Co., Washington, D.C.
- Kauth, R.J., Richardson, W. (1977) Procedure B: A Multisegment Training Selection and Proportion Estimation Procedure for Processing Landsat Agricultural Data, ERIM 122700-31-F, Environmental Research Institute of Michigan, Ann Arbor, Mich., Nov.
- Kolers, P.A., Eden, M. (1968) Recognizing Patterns: Studies in Living and Automatic Systems. MIT Press, Cambridge, Mass.
- Landgrebe, D.A. (ed.) (1974) A Study of the Utilization of ERTS-1 Data From the Wabash River Basin: Final Report. LARS Information Note 052375, Laboratory for Applications of Remote Sensing, Purdue University. W. Lafayette, Ind.
- Lintz, J. Jr., Simonett, D.S. (eds.) (1976) Remote Sensing of Environment. Addison-Wesley, Reading, Mass.
- Lowe, D.S., Braithwaite, J.G., Larowe, V.L. (1966) An Investigative Study of a Spectrum-Matching Imaging System. University of Michigan, Willow Run Lab., No. 8201-1-F.
- Lynch, T.J. (1976a) Data Compression Requirements for the Landsat Follow-On Mission. NASA/GSFC X-930-76-55.
- Lynch, T.J. (1976b) Ground Data Handling for Landsat-D. NASA/GSFC X-930-76-264.
- MacDonald, R.B., Erb, R.B., Hall, F.G. (1977) LACIE: a look into the future. Proceedings of The Eleventh International Symposium on Remote Sensing of Environment, ERIM and University of Michigan, Ann Arbor, Mich., Nov.

Multispectral Sensing and Analysis
(continued)

- Malila, W.A., Cicone, R.C., Sadowski, F.G., Crist, E.P. (1977) Investigation of Techniques for Inventorying Forested Regions, (2 Vols), ERIM 122700-35-F, Environmental Research Institute of Michigan, Ann Arbor, Mich. Nov.
- Meisel, W.S. (1972) Computer-Oriented Approaches to Pattern Recognition. Academic Press, New York.
- Mendel, J.M., Fu, K.S. (1970) Adaptive Learning and Pattern Recognition Systems: Theory and Applications. Academic Press, New York.
- Minsky, M., Papers, S. (1968) Perceptrons. MIT Press, Cambridge, Mass.
- Nalepka, R.F., Colwell, J.E., Rice, D.P. (1977) Forecasts of Winter Wheat Yield and Production Using Landsat Data, ERIM 114800-38-F, Environmental Research Institute of Michigan, Dec.
- NASA (1976) Landsat Data Users Handbook, NASA Document 76SDS4258, Goddard Space Flight Center. Replaces earlier ERTS Data Users Handbook, Doc. 715D4249.
- NOAA (1977) NOAA Program Development Plan for Seasat-A Research and Applications, Washington, D.C.
- Norwood, V.T. (1969) Optimization of a multispectral scanner for ERTS. in Proc. 6th International Symposium on Remote Sensing, University of Michigan.
- Otterman, J., Fraser, R.S. (1976) Earth-atmosphere system and surface reflectivities in arid regions from Landsat MSS data. Remote Sensing of Env. 5(4), 247-266.
- Palgen, J.J. (1970) International Bibliography of Pictorial Pattern Recognition. Allied Research Associates, Inc., Concord, Mass., Apr.
- Patrick, E. (1972) Statistical Pattern Recognition. Prentice Hall.
- Proc. of the 38th Annual Meeting of the American Society of Photogrammetry (1972). Washington, D.C. (Also subsequent meetings).
- Reeves, R.G., Anson, A., Landon, D. (eds.) (1975) Manual of Remote Sensing (2 Vols). American Soc. of Photogrammetry. Falls Church, Virg.
- Robinove, C.J. (1977) A radiometric interpretive legend for Landsat digital thematic maps. Photogrammetric Engineering and Remote Sensing. 43(5), 593-594.
- Sebestyen, G.S. (1962) Decision Making Processes in Pattern Recognition. MacMillan, New York.

**Multispectral Sensing and Analysis
(continued)**

- Shahrocki, F. (1972) Remote Sensing of Earth Resources. Vol. 1. University of Tennessee, Tallahoma, Tenn. (Also subsequent symposia).
- Steiner, D., Salerno, A. (eds.) (1975) Manual of Remote Sensing: Remote Sensing Data Systems, Processing and Management, Chapter 12, Vol. 1.
- Uhr, L., (1966) Pattern Recognition. Wiley, New York.
- Watanabe, S. (1969) Methodologies of Pattern Recognition. Academic Press, New York.
- Woo, W.G., Donelan, E.G. (1970) A Multispectral Point Scan Camera for Earth Resources Technology Satellite. AIAA Paper No. 70-319.
- Wyatt, A.W., Ellis, M.L., Bell, A.E. (1975) The application of remote sensing technology to the inventory of playa lakes in the high plains of Texas. NASA Earth Resources Survey Symposium. P. W-18.
- Zaitzeff, E.M., Wilson, C.L., Ebert, D.H. (1970) MSDS - An Experimental 24-Channel Multispectral Scanner System. Bendix Technical Journal.

**ORIGINAL PAGE IS
OF POOR QUALITY**

RESOLUTION

- Ahern, F.J., Goodenough, D.G., Jain, S.C., Rao, V.R., Rochon, G. (1977a) Use of clear lakes as standard reflectors for atmospheric measurements. Proceedings of the 11th International Symposium of Environment, Ann Arbor, Mich. Apr., 731-755.
- Ahern, F.J., Murphy, J. (1978) Radiometric Calibration of CCRS Landsat Products. Canada Centre for Remote Sensing, Ottawa, Canada, Report in Preparation.
- Altman, J.H. (1967) Image quality criteria for data recording and storage. Jour. SMPTE. 76(7) July, 629-634.
- Barnard, T.W. (1972) Image evaluation by means of target recognition. Photogr. Sci. and Eng. 16(2), March/April, 144-150.
- Barstow, J.M., Christopher, H.N. (1961) The measurement of random video interference to monochrome and color television pictures. AIEE Pacific General Meeting, Salt Lake City, Utah, Aug. 23-25, AIEE Paper 61-1004.
- Billingsley, F.C. (1971) Image processing for electron microscopy: II. A.) digital systems. A chapter in Advances in Optical Electron Microscopy, Barer and Coslett (eds.) Academic Press.
- Billingsley, F.C. (1975) Noise considerations in digital image processing hardware. A chapter in Topics in Applied Physics, T. Huang (ed.) Springer-Verlag.
- Born, M., Wold, E. (1959) Principles of Optics-Electromagnetic Theory of Propagation, Interference and Diffraction of Light. Pergamon Press.
- Charman, W.N. (1964) Spatial frequency spectra and other properties of conventional resolution targets. PS&E. 8.
- Coltman, J.W. (1954) The specification of imaging properties by response to a sine wave input. Journal of the Optical Society of America. 44(6), June.
- Colvocoresses, A.P. (1977) Landsat resolution--empirical analysis of Landsat picture element (pixel) response. U.S. Geological Survey Memorandum EC-58-Landsat, Dec. 15.
- Colvocoresses, A.P. (1977) Overall Evaluation of Landsat (ERTS) Follow-On Imagery for Cartographic Application. NASA/GSFC ID. No. 23960, Greenbelt, Md.
- Colvocoresses, A.P. (1978) Geometric corrections routinely applied to Landsat MSS imagery. U.S. Geological Survey Memorandum EC-61-Landsat, Mar. 3.
- Eberhardt, E.H. (1966) Signal-to-Noise Ratio of Image Dissector. ITT Industrial Laboratories, Fort Wayne, Ind., Technical Note No. 101, Nov.

Resolution
(continued)

- Fry, G.A. (1961) Relation of blur functions to resolving power. Journal of the Optical Society of America. 51(5) May, 560-563.
- Fultz, G.L. (1965) The Effect of Source Noise on Quantization Accuracy and on PE Statistics. JPL Tech. Memo 3341-65-5.
- General Electric Space Division (1976) Landsat-D. Position Determination and Attitude Correction Study Final Report. GE Document No. 76SDS4277, Valley Forge Space Center, Philadelphia, Penn.
- Goodman, J.W. (1968) Introduction to Fourier Optics. McGraw-Hill Book Co.
- Grabau, W.E. (1976) Pixel Problems. U.S. Army Engr. Waterways Exp. Sta. Misc. Paper M-76-9, Vicksburg, Ms.
- Hacking, K. (1962) The relative visibility of random noise over the grey scale. Jour. Brit. IRE. Apr., 307-310.
- Hammill, H.B., Holladay, T.M. (1970) The effects of certain approximations in image quality evaluation from edge traces. SPIE Journal. Sept.
- Horwitz, H., Nalepka, R.F., Morgenstern, J. (1971) Estimating the proportions within a single resolution element of a multispectral scanner. Proc. of 7th International Symposium on Remote Sensing of Environ. Ann Arbor, Mich.
- Huck, F.O., Katzberg, S.J., Kelly, W.L. IV (1972) The facsimile camera - its potential as a planetary lander imaging system. Optical Eng. 11(4,5), July-Oct.
- Jenness, J.R. Jr., Eliot, W.A., Ake, J.A. (1967) Intensity Ripple in a raster generated by a gaussian scanning spot. Journal of the SMPTE. June.
- Jensen, N. (1968) Optical and Photographic Reconnaissance Systems. John Wiley and Sons, Inc.
- Jet Propulsion Lab. (1970) Tech. Brief 67-10005 and 67-10630. Technical Support Package on Image Processing System. JPL, Calif. Instit. of Tech., Pasadena.
- Johnson, C.B. (1972) Modulation transfer functions: a simplified approach. Electro-Optical Systems Design, Nov.
- Johnston, D.M. (1968) Target recognition on TV as a function of horizontal resolution and shades of gray. Human Factors. 10(3), June.
- Jones, R.A. (1965) Image evaluation by edge gradient analysis. Society of Photo-Optical Instrumentation Engineers, 11th Annual Tech. Symposium. Aug. 22-26.
- Jones, R.A. (1967) An automated technique for deriving MTF's from edge traces. Photogr. Sci. and Eng. 11(2), March/Apr.

Resolution
(continued)

- Jones, R.C. (1958) On the point and line spread functions of photographic images. *Journal of the Optical Society of America*. 48(12), Dec.
- Kaneko, T. (1976) Evaluation of Landsat image registration accuracy. *Photogrammetric Engineering and Remote Sensing* 42(10), 1285-1299.
- Katzberg, S.J., Huck, F.O., Wall, S.D. (1973) Photosensor aperture shaping to reduce aliasing in optical-mechanical line-scan imaging systems. *Applied Optics*. 12(5), May.
- Kelly, D.H. (1965) Spatial Frequency, bandwidth, and resolution. *Applied Optics* 4(4), Apr.
- Knudson, D.R., Teicher, S.N., Reintjes, J.F., Gronemann, U.F. (1968) Experimental evaluation of the resolution capabilities of image-transmission systems. *Information Display*, Sept.-Oct.
- Kratky, V. (1974) Cartographic Accuracy of ERTS. *Photogrammetric Eng.* 40(2), 203-212.
- Lamberts, R.L. (1958) Relationship between the sine-wave response and the distribution of energy in the optical image of a line. *Journal of the Optical Soc. of America*. 48(7), July.
- Lamberts, R.L. (1962) Application of sine-wave techniques to image-forming systems. *Journal of the Optical Soc. of Motion Picture and Television Engineers*. 71(9), Sept.
- Lewis, N.W., Hauser, T.V. (1962) Microcontrast and blur in imaging systems. *The Journal of Photog. Science*. 10.
- Marchand, E.W. (1964) Derivation of the point spread function from the line spread function. *Journal of the Optical Soc. of America*. 54(7), July.
- Marchand, E.W. (1965) From line to point spread function: The general case. *Journal of the Optical Soc. of America*. 55(4), Apr.
- Morgenstern, J.P., Nalepka, R.F., Kent, E.R., Erickson, J.R. (1976) Investigation of Landsat Follow-on Thematic Mapper Spatial, Radiometric and Spectral Resolution, ERIM 119300-10-F, Ann Arbor, Mich., June.
- O'Neill, E.L. (1963) Introduction to Statistical Optics. Addison Wesley.
- Oppenheim, A.V., Schafer, R.W., Stockham, T.G. (1968) Nonlinear filtering of multiplied and convolved signals. *Proc. IEEE* 56(8), Aug., 1264-1291.
- Perkin-Elmer Corporation (1963) The Practical Application of Modulation Transfer Functions. A symposium held at Perkin-Elmer, Mar. 6.

Resolution
(continued)

- Perrin, F.H. (1960) Methods of appraising photographic systems, Part II-manipulation and significance of the sine-wave response function. Journal of the Soc. of Motion Picture and Television Engineers. 69(4), Apr.
- Puccinelli, E.F. (1976) Ground location of satellite scanner data. Photogrammetric Eng. 42(4), 537-543.
- Rosenau, M.D. Jr. (1966) Image evaluation by edge gradient analysis. Soc. of Photo-Optical Instrumentation Engineers. 11th Annual Tech. Symposium, Aug. 22-26.
- Schoonmaker, J.W. Jr. (1974) Geometric evaluation of MSS images from ERTS-1. Proc. of 40th Annual Meeting, ASP. 582-587.
- Scott, R., Scott, R.M., Shack, R.V. (1963) The use of edge gradients in determining modulation-transfer functions. Photogr. Sci. and Eng. 7(6).
- Shelton, C.R. (1966) Spatial frequency response of flying-spot-scanner systems. A paper from the 11th SPIE Tech. Symposium, Aug. 22.
- Shelton, C.F., Herd, H.H., Leybourne, J.J. (1967) Grey-level resolution of flying spot scanner systems. SPIE Photo Optical Systems Seminar, May, Rochester, New York.
- Tatian, B. (1965) Method for obtaining the transfer function from the edge response function. Journal of the Optical Soc. of America. 55(8).
- Thomas, C.E., Kahn, A., Tisdale, G., Spink, T. (1972) Detection of TV imagery by humans vs machines. Applied Optics. 11(5), 19-7-1056.
- Walli, C.R. (1964) Quantizing and sampling errors in hybrid computation. Proc. Fall Joint Computer Conference. 545-558.
- Welch, R. (1971) Modulation transfer functions. Photogrammetric Eng., 37(3), 247-260.
- Zimmerman, J. (1965) A practical approach toward the determination of resolution requirements. Society of Photo-Optical Instrumental Engineers, 10th Tech. Symposium, Aug. 16-20.

DIGITAL IMAGE PROCESSING

- Aldred, B.K. (1972) Points in Polygon Algorithms. U.K. Scientific Centre/Peterlee. (IBM, United Kingdom, Ltd) Rep. UKSC-0025 61 pp.
- Andrews, H.C. (1976) Outer product expansions and their uses in digital image processing. IEEE Trans. on Computers, C-25(2), Feb.
- Anuta, P.E. (1973) Geometric Correction of ERTS-1 Digital Multispectral Scanner Data. LARS Information note 103073, Laboratory for Applications of Remote Sensing, Purdue University, W. Lafayette, Ind.
- Anuta, P.E. (1977) Computer-assisted analysis techniques for remote sensing data interpretation. Geophysics, 42(3), 468-481.
- Anuta, P.E. (1977) Digital Registration of Topographic Data and Satellite MSS Data for Augmented Spectral Analysis. LARS Information note 011277, Laboratory for Applications of Remote Sensing, Purdue University, W. Lafayette, Ind.
- Arcelli, C., Levialdi, S. (1971) Picture processing and overlapping blobs. IEEE Transactions on Computers, Vol. C-20(9), Sept., 1111-1115.
- Bendix Corp. (1972) Image data processing. Bendix Tech. Journal, 5(1), Spring.
- Bernstein, R., Ferneyhough, D.G. Jr. (1975) Digital image processing. Photogrammetric Eng. 41(12), Dec., 1465-1476.
- Bernstein, R., Schoene, L.P. Jr. (1976) Advances in digital image processing of earth observation sensor data. Paper presented at 13th Space Congress, Coco Beach, Fla., Apr. 7-9, FFC 760069.
- Billingsley, F.C., Goetz, A.F.H., Lindsley, J.N. (1970) Color differentiation by computer image processing. Photogr. Sci. and Eng. 14, 28.
- Billingsley, F.C. (1972) Computer-generated color image display of lunar spectral reflectance ratios. Photogr. Sci. and Eng. 16, 51.
- Billingsley, F.C. (1973) Digital image processing for information extraction. Int. Jour. Man-Machine Studies. 5, 203-214.
- Billingsley, F.C., Goetz, A.F.H. (1973) Computer techniques used for some enhancements of ERTS images. Symposium on Significant Results obtained from ERTS-1, NASA SP-327.
- Billingsley, F.C. (1973) Some digital techniques for enhancing ERTS imagery. Proc. ASP Remote Sensing Symposium, Sioux Falls, S.D., Oct.
- Blackwell, R.J. (1970) Fingerprint image enhancement by computer methods. 1970 Carnahan Conference on Electronic Crime Countermeasures, Apr. 17, Lexington, Ky.

Digital Image Processing
(continued)

- Brestenreiner, F., Greis, U., Helmberger, J., Stadler, K. (1976) Visibility and correction of periodic interference structures in line-by-line recorded images. Journ. Appl. Photo. Eng. 2(2), Spring, 86-92.
- Carter, V.P., Billingsley, F., Lamar, J. (1977) Summary Tables for Selected Digital Image Processing Systems. U.S. Geological Survey Open-File Report 77-414.
- Dragg, J.L., Naugle, N.W. (1971) Photometric reduction of lunar orbiter video tapes. SPIE Journal. July 9, 159-165.
- Ekstrom, M.P. (1973) On the numerical feasibility of digital image restoration. Proc. of the IEEE, Aug., 1155-1156.
- Ellefson, R., Swain, P.H., Wray, J.R. (1973) Urban Land-Use Mapping by Machine Processing of ERTS-1 Multispectral Data: A San Francisco Bay Area Example. LARS Information Note 101573, Purdue University, W. Lafayette, Ind.
- Eppler, W.G. (1974) An improved version of the table look-up algorithm for pattern recognition, 9th International Symposium on Remote Sensing of the Environment, Ann Arbor, Mich.
- Gaven, J.V. Jr., Tavitian, J., Hollanda, P.A. (1971) Relative effects of gaussian and poisson noise on subjective image quality. Applied Optics. 10(9), Sept., 2171-2178.
- Goetz, A.F.H., Billingsley, F.C., Yost, E., McCord, T.B. (1971) Apollo 12 multispectral photography experiment. Proc. of the Second Lunar Science Conference, Suppl. 2. Geochim. Cosmochim. Acta. Vol. 3, MIT Press, 2301.
- Goodenough, D.G. (1976) Image 100 Classification Methods for ERTS Scanner Data. Canadian Journal of Remote Sensing 2(1), 18-29.
- Green, W.B., et al (1975) Removal of instrument signatures from Mariner 9 television images of Mars. Applied Optics. 14, 105, Jan.
- Huang, T.S., Schreiber, W.F., Tretiak, O.J. (1971) Image processing, Proc. of the IEEE, Vol. 59(11), Nov., 1586-1609.
- Hunt, B.R. (1975) Digital image processing (survey). Proc. IEEE. 63, 693-708.
- Janssen, T.J., Kozlowski, G.C., Luther, A. (1968) Real-time digital subtraction and enhancement of video pictures. SPIE Journal. Apr. 6 - May, 120-124.
- Jayroe, R.R. (1976) Nearest Neighbors, Bilinear Interpolation, and Bicubic Interpolation Geographic Correction Effects on Landsat Imagery. NASA TM X-73348, Marshall Space Flight Center.

Digital Image Processing
(continued)

- Jones, C. (1974) Implementation of an advanced table look-up classifies for large area land use classification. 9th International Symposium on Remote Sensing of the Environment, Ann Arbor, Mich.
- Julesz, B. (1966) Computers, patterns, and depth perception. Bell Laboratories Record, Sept., 261-266.
- Kapany, N.S., Burke, J.J. (1962) Various image assessment parameters. Journal of the Optical Soc. of America. 52(12), 1351-1361.
- Kohler, R.J., Howell, H.K. (1963) Photographic image enhancement by superimposition of multiple images. Photogr. Sci. and Eng. 7(4), 241-245.
- Kratky, V., (1972). Photogrammetric solution for precision processing of ERTS images. XII International Congress of Photogrammetry, Ottawa, Canada, July.
- Kriegler, F.J., Gordon, M.F., McLaughlin, R. H., Marshall, R.E. (1975) The MIDAS processor. Proceedings of the Tenth International Symposium on Remote Sensing of Environment, Ann Arbor, Mich., Oct.
- Lamar, J.V., Merrifield, P.M. (1973) Pseudocolor transformation of ERTS imagery. Proc. Symposium on Significant Results obtained from ERTS-1, NASA SP-327, 1187.
- Lambeck, P.F. (1977) Signature Extension Preprocessing for Landsat MSS Data. ERIM 122700-32-F, Environmental Research Institute of Michigan, Ann Arbor, Mich., Nov.
- Landgrebe, D.A. (1971) Systems Approach to the Use of Remote Sensing. LARS Information Note 041571. Laboratory for the Application of Remote Sensing, Purdue University, W. Lafayette, Ind.
- Levine, M.D, O'Handley, D.A., Yagi, G.M. (1973) Computer determination of depth maps. Computer Graphics and Image Processing, Vol. 2(2).
- Lipkin, B.S., Rosenfeld, A. (eds.) (1970) Picture Processing and Psychopictorics. Academic Press, New York.
- Loomis, R.G. (1965) Boundary networks. In Communications of the ACM, Vol. 8, no. 1, Jan., 44-48.
- Malila, W.A., Crane, R.B., Turner, R.E. (1972) Information Extraction Techniques for Multispectral Scanner Data. Report No. 31650-74-T, Willow Run Laboratories, Ann Arbor, Mich.
- Marble, D.F., Peuquet, D.J. (1977) Computer Software for Spatial Data Handling: Current Status and Future Developmental Needs. Geographic Information Systems Laboratory Research Report No. R-77/8. SUNY, Buffalo.

Digital Image Processing
(continued)

- McMillan, C.W., Billingsley, F.C., Frazer, R.E. (1974) Fast scan EM with digital image processing as applied to dynamic experiments. *Wood Science*. 6(3), 272-277.
- Minter, R.T., Gardner, C.T., Wills, B.E., Corbett, B.W. (1974) Earth Observation Division's Version of the Laboratory for Applications of Remote Sensing System. NASA contract NAS9-12200.
- Narendra, P.M., Goldberg, M. (1977) A graph theoretic approach to image segmentation. *Proceedings of IEEE Conference on Image Processing*, Troy, New York, June.
- Nathan, R. (1971) Image Processing for Electron Microscopy: I. Enhancement Procedures. *Advances in Optical and Elec. Microscopy*. Vol. 4. Academic Press, New York, 85-125.
- Ornstein, S.M., et al (1972) The terminal IMP for the ARPA computer network. *AFIPS Conference Proceedings*, Vol. 40, SJCC.
- Ozga, M., Donovan, W.E. (1977) An interactive system for agricultural acreage estimates using Landsat data. *Fourth Symposium on Machine Processing of Remotely Sensed Data*, Purdue University, W. Lafayette, Ind., June.
- Perkin-Elmer (1971) A Symposium on Sampled Images. The Perkin-Elmer Corp., Optical Group, Norwalk, Conn. (Completed Issue).
- Peuquet, D.J. (1977) Raster Data Handling in Geographic Information Systems. Geographic Inf. Systems Laboratory Research, Report R-77/7, SUNY, Buffalo.
- Phillips, R.L. (1974) Computer graphics in urban and environmental systems. In *Proceedings of the IEEE*, 62(4), Apr., 437-452.
- Preston, K. Jr., Norgren, P.E. (1972) Interactive image processor speeds pattern recognition by computer. *Electronics*, Oct. 23, 89-98.
- Proceedings of the IEEE* (1972) Digital Picture Processing. 60(7), July.
- Ray, R.M., Ozga, M., Donovan, W.E., Thomas, J.D., Graham, M.L., (1975) EDITOR, An Interactive Interface to ILLIAC IV - ARPA Network Multispectral Image Processing Systems. Center for Advanced Computation. University of Illinois at Champaign-Urbana, Urbana, Ill. Document no. 114, June.
- Rifman, S.F., et al (1976) Experimental Study of Digital Image Processing Techniques for Landsat Data: Final Report. NAS5-20085, NASA/GSFC.
- Rindfleisch, T.C. (1966) Photometric method for lunar topography. *Photogrammetric Eng.* 32, March, 262-276.

Digital Image Processing
(continued)

- Roberts, L.G., et al (1970) Computer network development to achieve resource sharing. AFIPS Proceedings, SJCC. Vol. 36.
- Rosenfeld, A. (1973) Progress in picture processing: 1969-71 (a bibliography), Computing Surveys. 5(2), 581-108.
- Rosenfeld, A., Kak, A.C. (1976) Digital Picture Processing. Academic Press, New York.
- Schoonmaker, J.W. Jr. (1974) Geometric evaluation of MSS images from ERTS-1. Proc. of ASP 40th Annual Meeting, St. Louis, Mo., 582-587.
- Seidman, J.B. (1972) Some practical applications of digital filtering in image processing. In Proceedings of the Symposium on Computer Image Processing and Recognition. University of Missouri-Columbia, Aug. 24-26.
- Selzer, R.H. (1968) The use of computers to improve biomedical image quality. Fall Joint Computer Conference, 817-834.
- Shlien, S., Smith, A.M. (1975) A rapid method to generate spectral theme classification of Landsat imagery. Remote Sensing of Environment 4, pp. 67-77.
- Starbuck, R.R. (1977) Overview and Examples of the EDITOR System for Processing Landsat Data. New Techniques Section, Research and Development Branch, USDA/SRS, Washington, D.C., March.
- Strome, W.M., Vishnubhatla, S.S., Guertin, F.E. (1975) Format Specification for Canadian Landsat MSS System Corrected Computer Compatible Tape. Ottawa, Canada Centre for Remote Sensing, Report 75-3.
- Svedlow, M., McGillem, C.D., Anuta, P.E. (1976) Experimental examination of similarity measures and preprocessing methods used for image registration. Symposium on Machine Processing of Rem. Sensing Data. LARS, W. Lafayette, Ind., June.
- Taber, J.E. (1973) Evaluation of digitally corrected ERTS images. 3rd ERTS-1 Symposium, Vol. 1-5, 1837-1842.
- Taylor, M.M. (1973) Principal components colour display of ERTS imagery. Proceedings of 3rd ERTS Symposium, Washington, D.C., Vol. 1, Sect. 3 pp. 1877-1897.
- Thomas, V.L. (1975) Generation and Physical Characteristics of the Landsat-1 and 2 MSS Computer Compatible Tapes. NASA/GSFC X-563-75-233.
- TNRIS (1978) Support Activities Report: Forest Land Mapping by Computer-Assisted Analysis of Landsat Data. available thru TNRIS, Austin, Texas.

Digital Image Processing
(continued)

- TRW (1977) EROS Digital Image Processing System: An Overview. TRW Defense and Space Systems Group, Redondo Beach, Calif.
- Turinetti, J.D., Mintzer, O.W. (1973) Computer analysis of imagery. Photogrammetric Eng. 39(5), 501-505.
- Williamson, A.N. (1977) Corrected Landsat images using a small digital computer. Photogrammetric Eng. 43(9), 1153-1159.
- Wong, K.W. (1975) Geometric and cartographic accuracy of ERTS-1 imagery. Photogrammetric Eng. 41(5), 621-635.
- Wood, D.C. (1975) Packet-Switching Networks: An International Survey, MTP-403. The MITRE Corporation, Washington, D.C., Aug.
- Wylie, A.D., et al (1974), Users Guide and Software Documentation for the Algorithm Simulation Test and Evaluation Program (ASTEP), Revision 1. NASA/JSC Internal Note No. 73-FM-71.
- Yakimovsky, Y. (1974) Boundary and Object Detection in Real World Images. Tech. Memo. 33-709. Jet Propulsion Laboratory. Pasadena, Ca., Nov.
- Yakimovsky, Y. (1976) On the Problem of Embedding Picture Elements in Regions. Tech. Memo. 33-774. Jet Propulsion Laboratory. Pasadena, Ca., June.

SAMPLING

- Andrews, H.A., Patterson, C.L. (1976) Digital interpolation of discrete images. IEEE Trans. on Computers, C-25(2), Feb.
- Balakrishnan, A.V. (1962) On the problem of time jitter in sampling. Inst. Rad. Eng. Trans. Infor. Theory, 226-236.
- Berger, T. (1967) On detection of sparsely sampled data. Proc. of the IEEE, May, 700-701.
- Brown, W.M., Palermo, C.J. (1969) Effects of phase errors on resolution IEEE Trans. on Mil. Electronics, Jan., 4-9.
- Carliolaro, G.L. (1968) Dependence on Sampling Frequency of Amplitude Statistical Parameters of Signals. Alta Frequenza. XXXVII(11).
- Choa, S.C. (1966) Flutter and time errors in magnetic data recorders. IEEE Trans. Aerospace Elect. Systm. Redwood City, Ca., March, 214.
- Chu, N., McGilliam, C., Anuta, P. (in publication) Effects of Interpolation and Enhancement on Classification of Landsat MSS Data. Lab. for App. of Remote Sensing Technical Report, Purdue University, W. Lafayette, Ind.
- Crochiere, R.E., Rabiner, L.R. (1976) Further considerations in the design of decimators and interpolators. Trans. ASSP 24(4), 296-311.
- Dunbridge, B. (1966) Analysis of analog-to-digital converter time aperture error. Presented at the National Telemetry Conf., Boston, Mass. Telemetry Journal, August/September, 32-36.
- Ferneyhough, D.G. Jr., Neblack, C.W. (1977) Resampling Study: IBM Final Report. NAS5-21865, NASA/GSFC.
- Gaarder, N.T. (1972) A note on the multidimensional sampling theorem. Proc. of the IEEE, Feb., 247-248.
- Gardenhire, L.W. (1963) The use of digital data systems. Presented at National Telemetry Conf., Albuquerque, N.M., May.
- Gaven, J.V. Jr., Tavitian, J. (1979) The informative value of sampled images as a function of the number of gray levels used in encoding the images. Photogr. Sci. and Eng. 14(1), 16-20.
- Gibbs, A.J. (1966) Simulation of a low-pass transmission system for sampled data. Proc. of the IEEE, 443-444.
- Goetz, A.F.H., Billingsley, F.C. (1973) Digital image enhancement techniques used in some ERTS application problems. 3rd ERTS-1 Symposium. Vol. 1-B, 1971-1972.

Sampling
(continued)

- Goodman, L.M. (1966) Optimum sampling and quantizing rates. Proc. of the IEEE, Jan., 90-92.
- Harger, R.O. (1965) An analysis of recorder motion errors in optical processing. Appl. Optics 4(4), 383-386.
- Hollanda, P.A., Scott, F. (1970) The informative value of sampled images as a function of the number of scans per scene object and the signal-to-noise ratio. Photogr. Sci. and Eng. 14(6), 407-412.
- Hou, H.S. (1976) Least Squares Image Restoration Using Spline Interpolation. University of Southern California, Report USCIP-650, Feb.
- Jayroe, R.R. (1976) Nearest Neighbor, Bilinear Bicubic Interpolation Geographic Correction Effects on Landsat Imagery. NASA TMS-73398, NASA/MSFC.
- Kennedy, J.G., Williamson, A.N. (1976) A Technique for Achieving Geometric Accordance of Landsat Digital Data. U.S. Army Eng. Waterways Exp. Sta. Misc. Paper M-76-16, Vicksburg, Ms.
- Liu, B., Stanley, T.P. (1965) Error bounds for jittered sampling. IEEE Trans. on Automatic Control. AC-10(4), Oct.
- Lohmann, A.W., Paris, D.P. (1965) Influence of longitudinal vibrations on image quality. Appl. Optics. 4(4), Apr., 393-397.
- Oetken, G., Parks, T.W., Schussler, H.W. (1975) New results in the design of digital interpolators. IEEE Trans. on Acoustics, Speech and Signal Processing, ASSP-23(3), June.
- Oppenheim, A.V., Johnson, D.H. (1972) Discrete representation of signals. Proc. of IEEE. 60(6), June, 681-691.
- Peyrovian, M.J. (1976) Image Restoration by Spline Functions. University of Southern California, Report USCIP-680, Aug.
- Robiner, L.R., Crochiere, R.E. (1976) On the design of all-pass signals with peak amplitude constraints. BSTJ. 55(4), Apr., 395-407.
- Ratz, A.G. (1964) The effect of tape transport flutter on spectrum and correlation analysis. IEEE Trans. on Space Electronics and Telemetry, Dec.
- Reimer, R., McGillem, C. (1973) Constrained Optimization of Image Restoration Filters. LARS Information 022573.

ORIGINAL PAGE IS
OF POOR QUALITY

Sampling
(continued)

- Rifman, S.S., McKinnon, D.W. (1974) Evaluation of Digital Correction Techniques for ERTS Images. TRW Corporation, Final Report No. 20634-6003-TU-00, for NASA Goddard Space Flight Center, Greenbelt, Md., March. Also related Report No. 26232-6004-TU-01.
- Scott, F., Hollanda, P.A. (1970) The informative value of sampled images as a function of the number of scans per scene object. *Photogr. Sci and Eng.* 14(1), 21-27.
- Scott, R.M. (1959) Contrast rendition as a design tool. *Photogr. Sci. and Eng.* 3(4), 201-209.
- Shlien, S. (1978) Geometric correction, registration and resampling of Landsat imagery. *Canadian Journal of Remote Sensing*, In Press.
- Van Vlecks, E. (1976) A TRW Study on Resampling for Data Compression and its Effects on Classification Accuracy.
- Waggener, W.N. (1967) Digital TV and the sampling theorem. *Electronic Communicator*, March/April.

STATE AGENCY AND SELECTED INTERNATIONAL APPLICATIONS

- Battelle (1975) North Dakota Regional Environmental Assessment Program. Battelle Columbus Laboratories, 113 p.
- Canadian Land Inventories (1976) Land Capabilities in Agriculture, Preliminary Report. Lands Directorate, Environment Canada, Apr.
- Canadian Land Inventories (1977) Agricultural Land, Urban Centres, Fisheries and Environment. Canada. Lands Directorate, July.
- Conitz, Merrill (1978) A development assistance program in remote sensing. Photogrammetric Eng. 44(2), 1977-182.
- Dobson, J.E. (1976) ORNL/NUREG, The Maryland Power Plant Siting Project: An Application of the ORNL Land Use Screening Procedures.
- Faust, N.L., Spann, G.W. (1977) Landsat Information For State Planning. Georgia Tech Engineering Experiment Station Final Technical Report, NASA Contract Report NAS8-30653.
- Fredland, D., et al (1977) Council of State Governments, 1(2), 1-13, Students of State Planning Information System.
- Harwood, P., et al (1977) Development and Application of Operational Techniques for the Inventory and Monitoring of Resources and Uses for the Texas Coastal Zone. General Land Office of Texas, Austin, Texas, NASA Contract No. NAS5-20986.
- IBM (1975) North Dakota REAP System Requirements and Conceptual Design. International Business Machines, Federal Systems Division, Gaithersburg, Md. 175 p.
- IBM (1976a) North Dakota REAP System Analysis Details Report. International Business Machines, Federal Systems Division, Gaithersburg, Md. 2750 p.
- IBM (1976b) North Dakota REAP System Analysis and Plan Report. International Business Machines, Federal Systems Division, Gaithersburg, Md. 164 p.
- Maryland Department of State Planning (1973) Maryland Automated Geographic Information System Technical Analysis Series.
- McKeon, J.B. (1977) Land Cover Analysis of North Dakota REAP Report No. 77-5. North Dakota Regional Environmental Assessment Program, Bismark, N.D., 28 p.
- Neece, R.N., Ellis, M.L., Wells, J. (1974) An overview of remote sensing activities in Texas. 9th International Symposium on Remote Sensing of the Environment, Ann Arbor, Mich.
- Palmer, C. (1977) Landsat in Texas state agencies. National Conference of State Legislatures Legislative Workshop on State Uses of Satellite Remote Sensing #4, North Lake Tahoe, Nev. 61.

State Agency and Selected International Applications
(Continued)

- REAP (1975) Technical Task Force Reports. North Dakota Regional Environmental Assessment Program, Bismarck, N.D. 196 p.
- REAP (1978) REAP System Conceptual Design. North Dakota Regional Environmental Assessment Program, Bismarck, N.D. (draft).
- Reid, J.R., Brown, P.J. (1977) Land Cover Maps of North Dakota. North Dakota Regional Environmental Assessment Program, Bismarck, N.D. 8 p.
- Strome, W.M., Shaw, E. (1972) Canada Centre for Remote Sensing ERTS Program. 8th International Symposium on Remote Sensing of the Environment, Ann Arbor, Mich., Oct.
- USDI (1976) State Resource Management Programs - A Primer.
- USGS (1975) Information/Data Handling: A Guidebook for Development of State Programs. U.S. Geological Survey, for U.S. Dept. of the Interior, July.

APPENDIX A

A CONFERENCE TO EXAMINE GEOBASE INFORMATION SYSTEM

IMPACTS ON SPACE IMAGE FORMATS

Location: LA CASA DE MARIA RETREAT HOUSE
8000 El Bosque Road
Santa Barbara, California
Sept. 11-15, 1977

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APPENDIX B

SPECIFIC RECOMMENDATIONS REGARDING LANDSAT-D

The conference did not specifically address Landsat-D related questions, but it arrived at recommendations which are applicable to Landsat-D specifically as well as NASA-produced data in general. These general recommendations, placed in the context of Landsat-D, are summarized below.

RECOMMENDATIONS

- * Data from the Thematic Mapper (TM) should be available in two formats:
 - uncorrected (radiometrically calibrated) and with extensive annotation
 - radiometrically corrected and geometrically rectified to a standard map projection, scan line orientation, and pixel size
- * Since TM data will require some form of resampling, especially to coarser spatial resolutions employed by existing databases, NASA should encourage the development and exchange of information on the effects of resampling.
- * Data compression for the TM is probably unavoidable, but should employ methods which are reversible at least to the level of rated sensor noise.
- * The logical structure of distributed TM data should be band-interleaved-by-line (BIL), with optional availability of band-sequential (BSQ), and band-interleaved-by pixel (BIP).
- * The physical structure of TM data tapes should be primarily 9-track 1600 bpi, with optional availability of 6250 bpi tapes as high-density tape drives come into wider usage.
- * NASA should be aware of technological developments which, when implemented by the user community, might affect the utilization of TM data, such as increasing availability of high-density storage devices and array processors.

APPENDIX C

A SOLUTION TO THE PROBLEM OF DETERMINING USER DEMANDS AND PRICING STRUCTURES

By Robert Deacon, Terence R. Smith & David Simonett

NOTE: This paper was prepared after the Conference as part of a contribution to the Proceedings of the Second Conference on the Economics of Remote Sensing Information Systems, San Jose State University, January 1978.

ABSTRACT

While local government agencies are important potential users of satellite data, the rate of adoption of this technology by such users has been relatively low. This fact is partly due to the high costs associated with processing the currently available satellite data. It is proposed that a central agency supply a mix of products involving both data in varying stages of processing and software for manipulating the various classes of data. Since both the data and software may be characterized as public goods, it is further proposed that the demands of this class of users, as well as the pricing structure of the products, be determined by use of Demand Revealing Processes (DRPs), which encourage users to reveal their true demands. The combination of DRPs and the provision of data and software may be viewed as a "seeding" of the adoption process, whereby the net present value of the stream of benefits accruing from local government use of satellite data are maximized

A SOLUTION TO THE PROBLEM OF DETERMINING USER DEMANDS AND PRICING STRUCTURES

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The consensus of beliefs essentially imposes certain conditions on the federal government that should be met in relation to supplying satellite related products. Any solution to the problem of determining both user demands and pricing structures should incorporate these constraints. The following section contains a proposed solution to the problem that incorporates the major constraints, as well as taking into account the economic nature of the products that should be supplied. The basic ideas are that Demand Revealing Processes, as described below, should be used to determine jointly both user demands over various optional outputs and a pricing structure that would be sensitive to individual user demands. Such processes not only make provision of data products sensitive to user demands and allow any required degree of cost recovery, but may also be incorporated into a central processing system that would take full advantage of economies of scale. Moreover, the implementation of such a process could be viewed as an investment decision designed to optimize the present value of the stream of net benefits from the use of satellite data.

The following discussion of the proposed solution is structured as follows. First, the characteristics of the large numbers of potential users lying toward the base of the pyramid of users is examined. Second, some problems relating to cost benefit studies concerning the use of satellite data are discussed, and in particular, the problem that data and software are essentially public goods. Third, a description of Demand Revealing Processes is given, relating to the determination of both user demand and pricing structures. Fourth, these ideas are applied to satellite data products and attendant problems as noted. Finally, the application of Demand Revealing Processes and the provision of data products and software is interpreted in terms of an investment decision.

Users Near the Base of the Pyramid of Users: Characteristics and Problems.

Actual and potential users of satellite data may be thought of as being a pyramid of users, with the horizontal axis representing numbers of users and the vertical axis increasing sophistication. At the top of the pyramid there are a few extremely sophisticated users such as the large oil companies, who have the capability, for example, of taking the original computer compatible tapes (CCTs) containing Landsat image data, and processing the data entirely with their own resources. Included in this group of sophisticated users are also major research universities, federal laboratories with a research emphasis and the major national facilities maintained by NASA. Towards the base of the pyramid we may con-

CCTs in their original format. Rather than try to analyze the composition of the whole pyramid, however, we concentrate on a stratum that appears to be of high importance, namely the agencies of state and local governments with which we were concerned in this Workshop. This group is not of the highest sophistication, yet it is capable of using computer data in formats which do not pose the very large front-end investment costs of working with the raw computer compatible tapes. This group of users is also sufficiently large to greatly expand the user community if they can be brought, at modest investment to themselves, into a position where they may use NASA products. The potential importance of satellite data to this class of users was clearly spelled out in a recent study by Eastwood et al. (1976) (addressing the needs of government agencies in five states). A diagrammatic presentation of this user pyramid is given in Figure 1 in which the relationships between types, numbers and sophistication of users are presented.

A second graphical presentation of users is shown in Figure 2 in relation to types of data supplied by NASA and the likelihood of these users to engage in research and development, or only in operational use of satellite data. Federal agencies are largely responsible for much of the present research either in-house or through funding of universities and consulting companies. Large corporations also take a modest share of the research with their own internal research funds. It is noticeable that little state funding is given to research in this area (see Simonett, 1976) and that virtually no local government research funding is available. However, some development has to be carried out in some measure by all users except to the degree that the federal government acts in loco parentis for the smaller and less sophisticated users. What is important in the diagram is that operational use of fully processed satellite data greatly expands the number of users other than the federal agencies. The latter may constitute less than 25 percent of total users. Also summarized in this diagram is the requirement for fully processed data to facilitate the move to operational use of satellites for all users.

In the Eastwood et al. study (1976) on state agency uses of remote sensing they found that for the most part the data demanded by these users is easily mappable onto common base maps, such as the 1:24,000 U.S. Geological Survey quadrangles. Second, they found that the Landsat CCTs presently available required a degree of analysis and research beyond the capabilities and means of most of the agencies. Third, net benefits would result were the agencies able to obtain satellite data in a preprocessed form from NASA or other federal agencies.

Problems of Cost-Benefit Studies. Since 1965, considerable research and funding has been devoted to the National Aeronautics and Space Administration,

FIGURE 1

THE PYRAMID OF USERS

NUMBERS VS. SOPHISTICATION

SPECIALIZED FEDERAL,
UNIVERSITY AND LARGE
CORPORATION RESEARCH
LABORATORIES

Few Users

MOST

UNIVERSITY
TEACHING

MEDIUM
SIZE CORPORATION

USER SOPHISTICATION

FEDERAL OPERATIONAL AGENCIES
WITH MANDATED PROGRAMS

STATE GOVERNMENT
AGENCIES

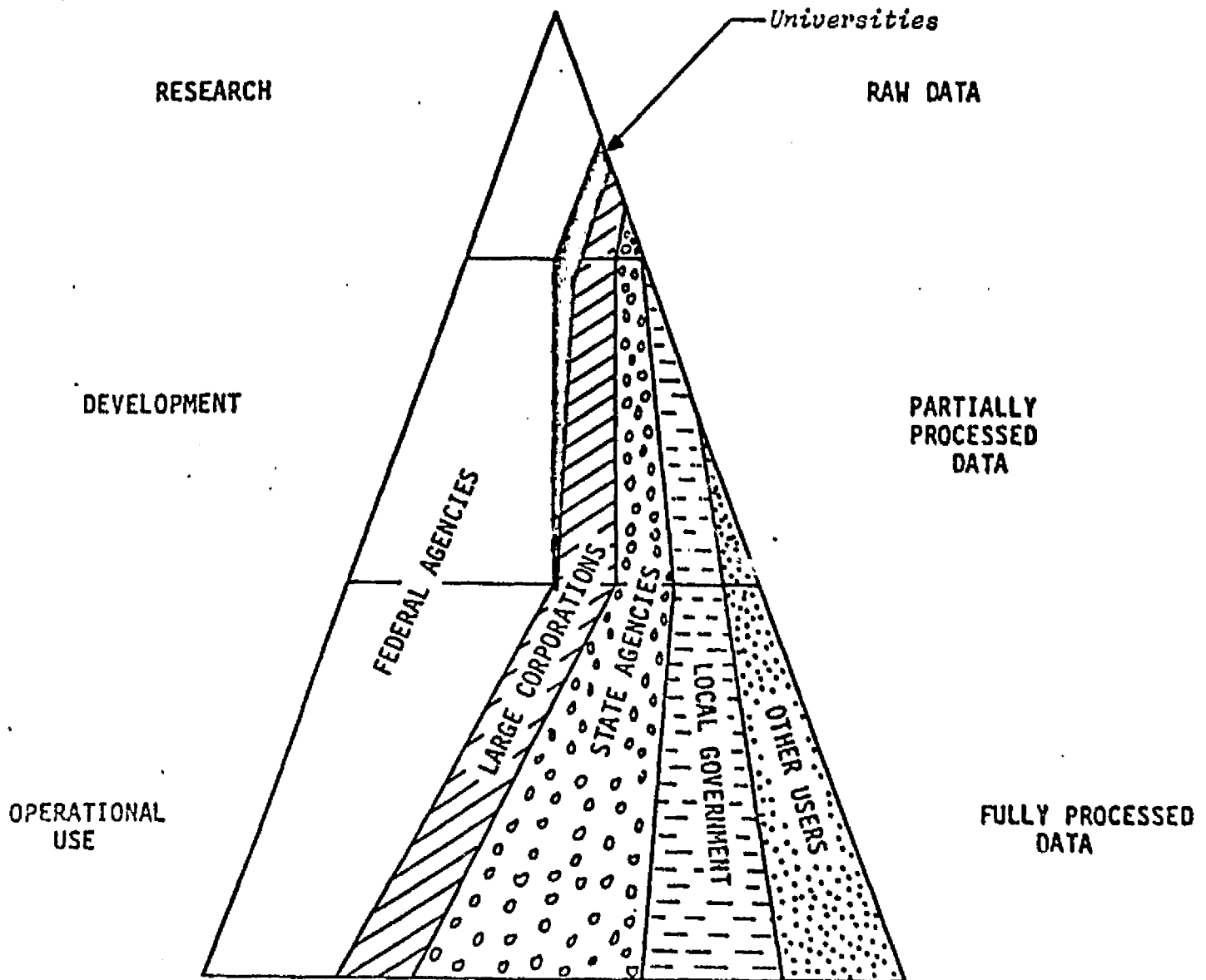
COUNTY AGENCIES
SMALL BUSINESS
SECONDARY EDUCATION

Many Users

LEAST

FIGURE 2

THE PYRAMID OF USERS
in Relation to Types of
Data Supplied by NASA



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OF POOR QUALITY

he Department of the Interior and other agencies, to estimating the costs and benefits of various earth resource survey systems.¹ Some of these cost-benefit studies have examined a number of applications, such as land use planning, flood warning, and mineral exploration, while others have focused upon a single function such as improved crop forecasting. A few studies have attempted to compare the economic merits of alternative data collection modes, e.g., aircraft vs. satellite based observation platforms, but most have concentrated attention only on satellite systems.² Despite considerable ingenuity and effort, many observers have expressed misgivings over the figures, particularly on benefits, obtained in these studies.³ That these misgivings are well founded is demonstrated by the very wide range of benefit estimates found in various studies for similar categories of use,⁴ and the resort to cost-effectiveness studies--as in the case of a 1974 study for the Department of the Interior--because of the hesitation in forecasting future uses of imperfectly defined future products. Moreover, with few exceptions, these studies have not directly addressed the question of how satellite data and information should be processed and transmitted in usable form to final users.

Space Image Data, Cost-Benefit Studies and Public Goods. In large measure, these problems concerning the outcome of cost-benefit studies can be directly traced to the nature of the product studied, which is the data (or information) that various final users employ in their decision-making processes. Benefits that individual users obtain from the data produced are typically viewed in terms of derived demands for information as an input to planning and decision-making activities. Thus, the value of the input is derived from the value of the final product or service produced by the user. Krzyckowski, et al. (1971) provide a three-way classification that is useful in analyzing the nature of benefits of various types of information. According to their scheme, data obtained from remote sensing will either "yield (1) the same information as now exists, (2) better information than now exists, or (3) new information."⁵ For information in the first category, the task of estimating benefits is simplified since it is reasonable to assume that the value of such data exceeds current cost; thus, the potential benefit attributable to a new data source is fully reflected in a reduction in the cost of obtaining it. The latter two categories of information are more problematic. Logically, one must describe the nature of the "better" or "new" data, hypothesize the way in which it will alter decisions, and then attribute benefits to the gains accruing from better-informed decision-making.⁶ This sequence of logical steps is spelled out clearly in Zissis, et al. (1972, p. 82), in Krzyckowski, et al. (1971, p. 33), and in Earth Satellite Corporation-Booz-Allen (1974, Vol. 5, pp. 13-17).

The last two steps in this chain of reasoning are conceptually the most difficult. The second requires a well developed model of the decision process and its underlying goals. The third is greatly simplified if the decision-making activity pertains to a product exchanged in ordinary markets, where prices can be directly observed. Given this, it is not surprising that the best developed methodology for estimating such benefits lies in the area of improved crop forecasts. Since the farmers, processors, speculators, etc., involved in agriculture are private entrepreneurs, the profit motive provides a natural goal and characterization of decision-making. The existence of well organized markets for agricultural products implies a ready source of data on relevant market values. As Stoney (1977, pp. 7-8) points out, however, this is the only area where formal economic models have been systematically employed. Moreover, he notes that benefits to the resource exploration industry, and contributions to state and local government may be "doomed to be ignored because their needs have yet to be expressed in precise mathematical terms."⁷ In general, when applied analysts have confronted the question of benefits derived from actions of public agencies, or from better management of non-market resources, they have been forced either to rely on educated guesses or to term such benefits unquantifiable.

All applications of benefit cost analysis characterize benefits as willingness to pay for the services delivered. Underlying the benefit-cost criterion is the well known compensation principle; if benefits exceed costs, then the stream of receipts could potentially be distributed among individuals so that no person is made worse off, and at least some gain as a result of the project. The presumed reason for relying upon government provision rather than simply selling such items to final consumers at prices that cover cost is that the commodities in question exhibit public good attributes which present difficulties for any market-like distribution system based upon voluntary exchange.

The variety of public information gathering services in the U.S., including the collection and processing of data obtained from aircraft or satellite platforms, are natural examples of public goods. In what is probably the most important of such activities, the federal government collects a wealth of socio-economic information through various censuses; once collected, the use of this information by one party does not make it less available for others. Much the same is true of data or information collected by remote sensing techniques. True, the physical documents in which this information is transmitted (e.g., images, data tapes, etc.) are private goods, in that one person's use at least partially precludes use by others. But, the information contained in these documents is not subject to this sort of rivalness in consumption. These same remarks apply, perhaps with even more force, to the software that may be used to analyze the data.

Public goods in particular, and items generating consumption externalities in general, are capable of yielding benefits that may be simultaneously enjoyed by several users. Efficient provision of such commodities requires knowledge of the demands of all consumers simultaneously. If efficient provision is to arise from competitive behavior, then different agents must face different prices for such items (see Groves and Loeb, 1975, pp. 211-212). An "incentive problem" arises because these individualized prices are directly dependent upon the preferences and valuations of individual agents, and these agents are not generally motivated to reveal them accurately.

Demand Revealing Processes. Until recently, it was widely agreed that any attempt to base provision levels and payment shares upon reported demands for public goods will automatically create incentives to misrepresent preferences. In the last decade, however, a class of pricing mechanisms has been identified which simultaneously identifies the efficient level of public good provision and solves the problem of extracting payments from users in order to cover costs. All of the mechanisms discovered to date are isomorphic up to a system of fixed charges levied upon individuals (fixed in the sense that one agent's charge does not depend on the behavior he pursues). Each mechanism is characterized by a transfer, to each individual, of the full reported net benefits obtained by all other users of the public good.⁸ Intuitively, the latter feature induces each party to take into account the benefit obtained by other consumers when reporting his valuation of the service.

To illustrate, let $i=1...N$ be an index of users of the public good, and let Q be the set of possible public consumption levels. Efficient provision of the public good occurs at q^* , which solves

$$\max_{q \in Q} \sum_{i=1}^N B_i(q) - C(q) \quad (1)$$

where $B_i(q)$ is a function relating individual i 's true benefit to the level of the public good provided (q), and $C(q)$ is a total cost function. The set of alternatives may either be continuous or discrete, though in the present context a discrete set of choices seems more realistic. To introduce the proposed pricing mechanism, consider the following allocation and cost distribution rule. Each individual will report, to a central agency, a total benefit function (or, alternatively, a demand function) for the service in question. In the case of a discrete set of alternatives, this would merely be a schedule of the individual's maximum willingness to pay for each of the alternatives under consideration. The "center" will process these messages and produce the level of service that max-

imizes the total of reported net benefits. In addition, it will transfer to individual j the following amount:

$$\sum_{i \neq j} \hat{B}_i(q) - C(q) - A_j. \quad (2)$$

$B_i(q)$ is the reported benefit function of individual i , A_j is j 's lump sum charge, and both of these are assumed to be independent of the function that j reveals. From (2) it is clear that the transfer may be positive or negative (i.e., a charge) depending upon the magnitude of A_j . In most specifications, the fixed charges (A_j) are sufficiently large to make the transfer negative for most consumers.

Individual j 's total reward consists of his personal benefit, $B_j(q)$, plus the transfer in (2). Since the center selects q to maximize total reported net benefits, j 's total reward will be maximized only if he reports his true benefit function to the center. To induce honest reporting of benefits by all parties, the same type of transfer offered to j is made available to all individuals in the group.

Two features of this general class of Demand Revealing Processes are noteworthy⁹. First, even though a particular user's public good consumption level and cost share depend upon the benefits reported by all agents, the individual's best strategy is to reveal his true benefit function regardless of the behavior of others. This dominance property is stronger than that which exists in an ordinary Nash equilibrium, where honest reporting is the best strategy only if all others report honestly as well. Further, given the structure of incentives, the center can quite naturally assume that all individuals are reporting true benefit schedules; it has no particular reason to attempt to estimate benefits itself. Individual mistakes and inaccuracies may of course arise, but unless there is some compelling reason to believe that the center can avoid these more efficiently than the individual user can, the center is justified in taking the reported benefit schedule as datum.

In the absence of lump sum charges, any central agency using this pricing scheme would obviously encounter a deficit. It is to solve this apparent problem that systems of fixed charges have been proposed; actually, these charges are not an integral part of the incentive structure embodied in the pricing mechanism. Among the charge systems proposed by various authors, the one developed by Groves and Loeb (1975) has two attractive features. First, it guarantees that the center will not run a deficit; i.e., in sum, the "transfers" made to individuals will be negative and sufficient to defray the cost of provision. Second, even though payments by individuals fully cover costs, each party is assured some non-negative benefit from the outcome; no individual will be made worse off as a result of the allocation process described here.

The Groves-Loeb system of fixed charges is parameterized by two N dimensional vectors $q_1, \dots, q_N$ which represents the amount of the good each party would have provided in the absence of coordination, and $t_1, \dots, t_N$, a set of signed "cost shares" that sum to unity. To ease exposition, assume that the per unit cost of the item is a constant, c . Given these definitions, the Groves-Loeb fixed charge for individual j is

$$A_j = c\bar{q}_j - t_j c\bar{q} + \max_{q \in Q} \left[\sum_{i \neq j} \hat{B}_i(q) - (1 - t_j)cq \right] \quad (3)$$

where $q = q_1$, the aggregate amount of the item provided in the absence of coordination. It is straightforward to show that such a system of charges yields a surplus (or, possibly, budget balance) for the center. Combining (2) and (3), the transfer to party j is

$$T_j = \left[\sum_{i \neq j} \hat{B}_i(q^*) - (1 - t_j)cq^* \right] - \max_{q \in Q} \left[\sum_{i \neq j} \hat{B}_i(q) - (1 - t_j)cq \right] + t_j(c\bar{q} - c\bar{q}^*) - c\bar{q}_j, \quad (4)$$

where q^* is the level of provision chosen by the center. In (4), the sum of the two terms in brackets is clearly non-positive, for $j=1 \dots N$. Summing the remaining terms over all individuals, to characterize the total transfer (T), yields

$$T \leq \sum_{j=1}^N t_j(c\bar{q} - cq^*) - \sum_{j=1}^N c\bar{q}_j \quad (5)$$

$$\text{or } T \leq -cq^*, \text{ since } \sum_{j=1}^N t_j = 1 \text{ and } \sum_{j=1}^N c\bar{q}_j = c\bar{q}.$$

It is somewhat more difficult to demonstrate that a suitable set of positive cost shares exists to satisfy the second claim, that all individuals gain from the system as compared with decentralized voluntary provision of service. Though existence can be shown, general formulae for computing such cost shares have not yet been developed. However, Groves and Loeb (1975, pp. 224-225) discuss how the problem might be approached in practice.

In the context of choice among a finite number of alternatives, the system of charges is less complex than it might appear from (4). As the number of agents involved in the pricing scheme (N) increases, the probability diminishes that a given

individual's reported benefit will alter the center's choice among alternatives. Thus, it is likely that for most agents the two terms in brackets in (4) will be equal (i.e., their dollar votes won't alter the outcome) in which case their charge would be correspondingly simplified. The system of charges can be further simplified if one is willing to forego either of the two features possessed by the Groves-Loeb scheme. The lump sum fee system proposed by Clarke (1971) drops the first two terms in (3) so that the transfer in (4) merely becomes the two terms in brackets minus $t_j c_j^*$. It is obvious that this system insures a non-negative surplus for the center, but it can no longer be guaranteed that all parties will gain when the system is introduced. The latter feature may well be important if membership in the bidding group is voluntary.¹⁰

The Application of Demand Revealing Processes to Satellite Data and Software Products. In the general field of earth resource survey systems, there appear to be a number of specific areas in which these pricing mechanisms could be employed. One obvious application is where the items supplied to users include software routines (for further data processing) which possess public good attributes. Likewise, if a number of users desire information on a particular area, the processing activity itself yields joint consumption benefits. In both cases, a major portion of the cost of producing the final product is largely independent of the number of final users employing it. Consider, for example, the development of software and suppose that three alternative levels of processing designated X, Y, Z, which perhaps represent increasing refinement of the raw data, are to be examined. If it is known, beforehand, that only one level of processing will be undertaken, the list of choices presented to potential users may simply be X, Y, Z. Of course, one of these options may involve no processing at all, i.e., the raw data. To allow participants in the process to form accurate valuations, it would be necessary to describe the general characteristics of the data obtained under various alternatives. Once they have gained familiarity with the nature of the choices, each would be asked to submit a list of bids representing their agency's maximum willingness to pay for each alternative, with the understanding that the choice would be made and cost shares assigned in the manner described earlier. Typically, one would not expect the group of potential users to be homogeneous; it may be a mixture of private firms and representatives of local government agencies. Likewise, the users to which they put the data may vary, but this is of no consequence.

If the possibility exists that more than one type of processing will be adopted, (e.g., X and Y) then the list of alternatives must be extended. This is essentially due to the fact that Demand Revealing Processes, as presently designed, select only a single alternative from the list. If all possible combinations are allowed, the set

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of choices must include XY, (X and Y), XZ, YZ and XYZ; i.e., a set of mutually exclusive options that collectively exhaust the range of choices under consideration. If a given user finds that two of the simple options, say X and Y, are complementary or substitutable for one another, then his reported benefit for the combination (XY) would differ from the sum of reported benefits for the two simple options.

Conceptually, the type of process described here could be applied to other decisions involved in providing data to final users. For example, it might find use in deciding whether or not to add an extra item of hardware to a proposed aircraft or satellite based platform. More generally, one can conceive of its use in selecting the overall configuration of instruments on future platforms. The reason for centering the preceding discussion around the question of processing and the final form data will take is that this is an area where very little information exists on benefits. Received benefit cost studies have largely neglected these questions; implicitly, it has been assumed that final consumers will find that the data fits their needs.

To the extent that local agencies will be among the set of demanders (e.g., for land use planning, watershed management, traffic system design, etc.) the benefits they report will, in all likelihood, be voiced through political representatives, and benefit figures will be colored by the political process. Although representative democracy is only an imperfect device for registering the preferences of the citizenry, decision making by elected officials is an integral part of the traditional political structure. Further, "representative reporting" seems clearly preferable to the current practice of denoting benefits from such non-market uses as "unquantifiable", or of ignoring benefits entirely and falling back to cost effectiveness studies, a course which many cost/benefit studies have in fact followed. If confronted with such a decision making algorithm, local public agencies may well find it in their interest to conduct their own benefit-cost analyses for projects under consideration. In this case, the benefit figures reported would be measured in terms of the actual decision and action the agency would take as a result of the new information, and would not reflect some hypothetical optimum course of action postulated by an independent benefit cost analysis.

Problems in Applying Demand Revealing Processes. One could expect to encounter a variety of practical problems in any attempt to apply the allocation mechanisms described here. In particular, the formulae for computing individual payments appear complex. Actually, this difficulty may be more apparent than real. Attempts to implement Demand Revealing Processes in experimental situations (Babb and Scherr, 1975, and Smith, 1976) have found the subject quite capable of making choices, once the mechanics of the pricing system were explained. Perhaps the only non-experimental

attempt to employ a pricing system for allocating public goods was the Public Broadcasting System's Station Program Cooperative (SPC) (Ferejohn and Noll, 1976). The product involved is similar to that provided by remote sensing information systems in that the total cost of producing and transmitting a particular television program is only slightly dependent upon the number of stations at which it is received and broadcasted. In the SPC case, program descriptions or pilots were distributed to individual stations for evaluation. The stations were then assigned prices (which differed by station) for various programs, and were asked to indicate which programs they desired to purchase at assigned prices. The central coordinator then raised prices up or down, depending upon initial responses, in order to cover total costs. The process was repeated, iteratively, on the basis of updated prices. Unlike the Demand Revealing Process, the SPC mechanism was not carefully designed to promote an efficient structure of incentives; in fact, there was no guarantee that it would even converge to an equilibrium, although it did when implemented. The important point, however, is that individuals involved in the process were able to reach decisions and register choices when confronted with a rather complex allocation algorithm.

An important conceptual difficulty surrounds the composition of the group involved in the pricing process. Within the static context of models developed to date, it is assumed that the membership of the group of potential users is known beforehand. Thus, questions of entry and exit by individuals has not been addressed. By quaranteeing some non-negative benefit to each member, the Groves-Loeb system partially avoids the problem of exit. However, the question of how to proceed if agents, initially omitted from the group, wish to join after the allocation decision has been made deserves further study. This may be particularly important if the item produced is "non-exclusive," in which case incentives to dissemble over desires to join the group may arise. A full treatment of these issues would require a dynamic treatment of these processes.

Given these and other potential difficulties,¹¹ together with the novelty of the approach, it would be premature to suggest that Demand Revealing Processes should supplant existing decision making institutions in the area of remote sensing information system. It seems appropriate, however, to recommend continued study, and perhaps trial experiments, in remote sensing applications.

An Investment Devision. The application of Demand Revealing Processes (DRP's) in the case of local and state government users appears to possess several useful attributes. First, the centralized provision of data and software should offer the maximal returns to scale available, yet the use of DRP's implies a high degree of flexibility with respect to meeting user demands. Second, such a system could be implemented within the present government structure, and might be viewed as an inter-

mediate step towards establishing the type of distribution envisaged by Eastwood, et al. (1976). Third, and in relation to the prior point, it may be viewed as a "seeding" mechanism whereby more and more potential users come to adopt the use of satellite data. This last point is now analyzed in somewhat more detail.

Two of the cost-benefit studies (The Seasat Study by Econ, and the Earth Resource Survey Cost Benefit Study by Earth Satellite Corporation--Booz-Allen Applied Research) both mention the adoption process by which a new technology diffuses throughout a society, although both stop short of any analytical treatments. A common analytical approach to the problem of technology transfer is by use of the logistic equation (see Montroll, 1974)

$$\frac{dp}{dt} = \alpha p (P-p) \quad (6)$$

where p is the proportion of potential users who have adopted the innovation at time t , α is a rate constant and P is the total number of potential users. While this equation has been found to be an adequate model of many diverse systems, one of its main points of interest for the current problem is that the logistic equation has three parameters that have useful interpretations in terms of policy decisions. The three parameters are the initial level of adoption p_0 , the rate constant α and the saturation level P . The initial level of adoption parameter may in fact be viewed as a seeding parameter, and gives rise to the following important implication. If one assumes that α and P are fixed in value, the higher the initial level of seeding, p_0 , the sooner a fixed percentage of the potential adopters come to adopt the new technology and the earlier the aggregate system comes to enjoy the benefits of the technology. Hence, one may consider the problem of finding an optimum level of seeding.

In order to solve this problem, it is first necessary to define the net present value (NPV) of the stream of benefits arising from the seeded adoption process. If $E(p_0)$ is the cost of seeding at an initial level p_0 , and $R(p(t))$ is the instantaneous rate of flow of benefits from having a level of adoption $p_0 \leq p(t) \leq P$ at any time t , then

$$NPV = \int_0^{\infty} R(p(t)) e^{-it} dt - E(p_0) \quad (7)$$

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where i is the relevant discount rate.

Evidently, the level of seeding p_0 that maximizes the net present value of benefits is either zero (a "corner" solution) or some value $0 < p_0 \leq P$. In the lat-

ter case, the optimal degree of seeding may be found by taking the derivative of NPV with respect to p_0 , setting the result equal to zero, and solving

$$\frac{dE}{dp_0} = \int_0^{\infty} e^{-i\tau} \frac{dR}{dp_0} (p(\tau)) d\tau \quad (8)$$

for p_0 . Some insight into the solution to this problem may be obtained by assuming that the adoption process is described by the logistic equation (6). Hence, the number of adopters $p(t)$ at any time $t \geq 0$ is given by

$$p(t) = \frac{P}{1 + \frac{1}{\kappa} e^{-\alpha P t}} \quad (9)$$

where $\kappa = p_0/(P-p_0)$ depends on the initial conditions. One may then substitute (9) into (8). However, it is not difficult to show that

$$\frac{dR}{dp_0} = \frac{1}{\alpha P} \frac{d \ln \kappa}{dp_0} \cdot \frac{dR}{dt} \quad (10)$$

and it follows upon integrating (8) by parts that

$$1/i \frac{dE}{dp_0} = \frac{1}{\alpha P} \cdot \frac{d \ln \kappa}{dp_0} \int_0^{\infty} [R(p(\tau)) - R(p_0)] e^{-i\tau} d\tau \quad (11)$$

But since

$$\frac{1}{\alpha P} \frac{d \ln \kappa}{dp_0} = \frac{1}{\alpha p_0 (P-p_0)} \quad (12)$$

one may write the result as

$$1/i \cdot \frac{dE}{dp_0} \frac{dp}{dt} \Big|_{\substack{t=0 \\ p=p_0}} = \int_0^{\infty} [R(p(\tau)) - R(p_0)] e^{-i\tau} d\tau \quad (13)$$

For the present case, this equation determining the optimal level of seeding p_0 has the following useful interpretation. The right hand side of (13) may be viewed

as the present value of the stream of benefits from the adoption process that are additional to those benefits if the level of adoption were held at the seeding level p_0 . The left hand side of (13) may be interpreted as the present value of a perpetual stream of marginal costs, where the marginal cost relates to the additional cost per unit time initially incurred by using a seeding level p_0 . Therefore, when the level of seeding p_0 is chosen in an optimal manner, the two expressions are equal.

The importance of these results for the present study follows from two facts. First, it has been shown that the optimal stream of net benefits from the adoption of satellite data use by local government agencies is sensitive to the "initial" number of adopters. If this initial number is small relative to P and if the marginal costs of seeding are sufficiently small, then the system is losing net benefits and it would pay to encourage more users by means of investing in a seeding program. Second, one may interpret the provision of satellite data and software by a centralized agency as a seeding process. As such, there should be an optimal level of provision that would result in a maximal present value of net benefits. Furthermore, the provision of data and software, rather than direct subsidies to users to encourage use as previously suggested by Simonett (1976), should prevent local duplication of effort. The importance of the DRP's in such a process is that not only could they be used to obtain information on user demand, and hence on possible pricing structures, but they could also provide information on benefits arising from the use of satellite data that would indicate an optimal level of seeding. Hence, one may view the overall process involving DRP's and the associated provision of data and software as a process whereby optimal system benefits are obtained.

While it is not suggested that the process of adoption of satellite data processing by local government agencies will necessarily follow the logistic law, nor that the task of calibrating an approximate model in terms of p_0 , α and P is easy, it is maintained that there are benefits to be had from thinking in terms of such a model. A further point of interest is that the ultimate saturation level may even be positively related to the initial level of seeding ($P = P(p_0)$, $P' > 0$) in which case the argument for seeding becomes even stronger.

It seems clear that NASA could take a central role in exploring the possibilities of seeding the system by using Demand Revealing Processes to implement a centralized system of data and software provision. Such a role could be temporary (since seeding is a "temporary" process), until a system, such as that envisaged by Eastwood, et al. (1976) were implemented. Alternatively it could persist in parallel to some degree with such a system.

SUMMARY

NASA, or some central government agency, should apply the use of Demand Revealing Processes in order to determine the true demands of state and local governments for satellite data and software products in a continually updated manner. Such processes would allow varying degrees of cost recovery in relation to supplying various mixes of data and software, while users would face charges directly related to their "true" willingness to pay, despite the public goods nature of such satellite products.

While a portion of the preprocessing costs should be absorbed by the federal government agency, the application of the Demand Revealing Processes and the provision of various combinations of data and software should be viewed as an optimal investment decision, whereby the present-value of the net benefits of satellite data use is maximized.

Footnotes

1. Several of these studies are surveyed in Krzyckowski, et al. (1971) and in Craib and Watkins (1977).
2. An example of comparative analysis is Craib (1977).
3. See the discussion by Hart (1977, pp. 357,358).
4. Recent estimates of the benefits due to improved crop inventory figures range between \$.7 million to \$174 million per year; see Ray and Keith (1977).
5. Krzyckowski, et al. (1971, p. 14).
6. At the same time, these two categories may be the most important for applications of remote sensing technology. In their review of past benefit cost studies, Krzyckowski, et al. estimate that about 83% of "valid benefit estimates for the U.S." are attributable to better information and 13% accrue to new information. Only about 4% are represented by information available now.
7. William E. Stoney, (1977, pp. 8-9).
8. The class of mechanisms discussed below was independently put forth by Vickery (1961), Clark (1971), and Groves (1973). Relationships between individual pricing schemes are discussed in Loeb (1977).
9. For elaboration on these and other related points, see Groves and Loeb (1976, p. 216).
10. A number of technical shortcomings of these mechanisms have been pointed out (Groves and Ledyard, 1977). If individual benefit functions contain income effects, the assumption that one individual's benefit function is independent of the schedules reported by others is violated. Further, as with other collective choice institutions, Demand Revealing Processes are not immune to manipulation by coalitions. Though little empirical evidence has been presented, Tideman and Tullock (1976) argue persuasively that such problems are likely to be of small practical importance. However, in a large number of situations there is little likelihood that one individual's response will alter the outcome; correspondingly it may not "pay" the individual to expend the resources or introspective effort required to report an accurate benefit function.
11. Under existing practices, a number of federal agencies provide information to the general public without charge (except possibly for distribution). Thus, potential users have no unsatisfied demand for the types of information available and attempts to obtain demand schedules for such data would be fruitless unless the present system were changed. In the absence of change, utilization of Demand Revealing Processes would appear to be confined to categories of information not currently provided.

References

- Babb, E.M. and B.A. Scherr (1975) Pricing Public Goods: An Experiment with Two Proposed Pricing Systems, Public Choice. 23, 35-48.
- Clarke, E.H. (1971) Multipart Pricing of Public Goods, Public Choice. 17-33.
- Craib, K.B. (1977) The Cost-Effectiveness of Operational Remote Sensing Technology: A Comparative Analysis, Proceedings of the First Conference on the Economics of Remote Sensing Information Systems. San Jose State University. 229-244.
- Craib, K.B. and T.H. Watkins, eds. (1977) Proceedings of the First Conference on the Economics of Remote Sensing Information Systems. San Jose State University.
- Earth Satellite Corporation and Booz-Allen Applied Research Corporation (1974) Earth Resources Survey Benefit-Cost Study. Vol. 1, 2, 5. U.S. Geological Survey.
- Eastwood, L.F. (1976) Program on Earth Observation Data Management Systems: Final Report. Center for Development Technology, Washington University, St. Louis, Missouri.
- Econ (1976) SEASAT Economic Assessment, for National Aeronautics and Space Administration, Contract NASW-2558. Vols. 1-10. Econ Inc., Princeton, New Jersey.
- Ferejohn, J.A. and R.G. Noll (1976) An Experimental Market for Public Goods: The PBS Station Program Cooperative, American Economic Review. 66(1), 267-274.
- Groves, T. (1973) Incentives in Teams, Econometrica. 41, 617-631.
- Groves, T. and J. Ledyard (1977) Some Limitations of the Demand Revealing Process, Public Choice. 29(2), 107-124.
- Groves, T. and M. Loeb (1976) Incentives and Public Inputs, Journal of Public Economics. 5, 353-359.
- Hart, G. (1977) Panel Discussion on the Economics of Remote Sensing, Proceedings of the First Conference on the Economics of Remote Sensing Information Systems. San Jose State University. 357-358.
- Kryczkowski, R., D.N. Powell, and E.S. Putnam (1971) Review and Appraisal: Cost-Benefit Analysis of Earth Resources Survey Satellite Systems. N.A.S.A.
- Loeb, M. (1977) Alternative Versions of the Demand-Revealing Process, Public Choice. 29(2), 15-27.

References: Costs

- Ballard, R.J. and L.F. Eastwood (1977) Estimating Costs of Machine Processing of Remotely Sensed Data. Proc. LARS Symp. on Machine Proc. of Remotely Sensed Data, Purdue University, W. Lafayette, Ind.
- Eastwood L.F. Jr., T.R. Hays and G.G. Ornkovich (1978) Comparison of Photointerpretive and Digital Production Methods for Four Key Remote Sensing Based Information Products. Second Conference on the Economics of Remote Sensing Information Systems, San Jose, California, January 19-21, 1978.
- Eastwood, L.F. (1976) Program on Earth Observation Data Management Systems: Final Report. Center for Development Technology, Washington University, St. Louis, Missouri.
- Fitzpatrick, A. (1975) Cost, Accuracy and Consistency Comparisons of Land Use Maps from High Altitude Aircraft Photography and ERTS Imagery, Final Report - Volume 6 Central Atlantic Regional Ecological Test Site (CARETS) Project. NASA Goddard Space Flight Center and US Geological Survey, Reston, Virginia.
- Lyon, R.J.P., Prelat, A. (1978) Cost and analysis of merging geophysical, geological, and Landsat data for mining exploration. Second Conference on the Economics of Remote Sensing Information Systems, San Jose, California, January 19-21, 1978.
- Montroll, E.W. and W. Badger (1974) Quantitative Aspects of Social Phenomena. Gordon and Breach, New York.
- Power, N.A. (1975) Computerized Geographic Information Systems: An Assessment of Important Factors in their Design, Operation and Success, M.S. Thesis, Program in Technology and Human Affairs, Washington University, Report No. CDTDM-R(T)-75/3. 176 pp.
- Ray, D.E. and K. Keith (1977) Crop Forecasting Benefits of Landsat: Review of Three Recent Studies, Proceedings of the First Conference on the Economics of Remote Sensing Information Systems. San Jose State University. 128-149.
- Simonett, D.S. (1976) Remote Sensing by State Agencies; Remote Sensing for Land and Resource Management in the South and Southwest, Proceedings, Centennial Academic Assemblies. Texas A&M University. 32-48.
- Smith, V.L. (1976) The Principle of Unanimity and Voluntary Consent in Social Choice (mimeo). University of Arizona.
- Stoney, W.E. (1977) Remarks to the First Conference on the Economics of Remote Sensing Information Systems, Proceedings of the First Conference on the Economics of Remote Sensing Information Systems. San Jose State University. 4-12.

References: Costs
(continued)

- Systems Control, Inc., and Aeronutronic Ford (1976) User Data Dissemination Concepts for Earth Resources: Final Report. Prepared for NASA Ames Research Center, Sunnyvale, California.
- Tideman, T.N. and G. Tullock (1976) A New and Superior Process for Making Social Choices, Journal of Political Economy. 84, 1145-1159.
- Vickery, W. (1961) Counterspectulation, Auctions and Competitive Sealed Tenders, Journal of Finance. 16, 8-37.
- Zisses, G.J., K.P. Heiss, and R.A. Summers (1972) Design of a Study to Evaluate Benefits and Cost of Data From the First Earth Resources Technology Satellite (ERTS-A). Willow Run Laboratories, University of Michigan, Ann Arbor, Michigan.

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APPENDIX D

DATA COMMUNICATIONS SYSTEM

(Modified from material provided by John R. Roberts after the conference)

In order to achieve the goal of full sharing and management of earth resources data for users throughout the country, the role of data communications must not be overlooked. The attributes, functions, implementations, and future considerations of a potential Data Communications System are discussed below. It is recognized that this capability already exists for federal agencies, but it should be expanded to include all users.

Attributes

The following are key attributes of the Data Communications System which would enhance the utility of earth resources data for users:

1. **Accessibility.** Using a terminal, the customer would dial government-provided inward WATS (area code 800) lines to access integrated data base indexes. It may be necessary that a terminal be government-furnished to qualified users.
2. **Versatility.** The customers may scan for data availability at their own pace, choose among established formats for their desired products, and select standard preprocessing options.
3. **Response Time Reduced.** Orders could be placed from the terminal during the same session, rather than mailed, if suitable security measures are included. If not, orders could be placed by phone to EDC.
4. **Timeliness.** If the earth resources data source agency (e.g., Eros Data Center) could update the data base index, the user could learn the availability of the latest data faster than presently.
5. **Correctness.** Manual handling of the order prior to entry into a computer system is reduced.

Data Management Functions

The Data Communication System would enable the users to search the data base (index), place orders for retrieval of data (products), and would advise him of billing and accounting matters. A properly designed, user-oriented system could provide at least the three data management functions, described below, in an easy-to-use, efficient manner:

1. **Search Data Base Index.** The customer inputs or indicates

established search parameters, such as:

- a. location by latitude/longitude of center point or corners or by place name (or UTM?);
- b. quality, cloud cover percentage;
- c. time of year or season;
- d. spectral bands; and
- e. cartographic overlays.

The system would provide responses in terms of product availability (images or CCTs or HDDT's and supporting software as applicable), costs of services, and delivery times. Also, other options, such as established format selection (for tapes), or preprocessing could be set forth. Further, standing queries could be established and activated by a simple call procedure.

2. Order for Retrieval. The customer may then request products which he feels suit his needs, using the same parameters as above, or additional options, such as scale, projections, alternative formats and preprocessing. Products are sent by mail.
3. Billing and Accounting. Established users would have their own accounts, and could query their status and request billing.

Implementation

There are a few implementation courses to be considered. For instance, a central system, with redundant host computers, multi-access central data base, and communications (front-end) processors could be a viable solution. However, there may be better ways to serve the user community, particularly if possible overloading of such a facility were a concern. Another approach would be to provide regional centers to handle the data base index queries, order processing, and accounting. There would still be a central data base of remotely sensed data, with which each of the regional centers would have a high speed communications link for order placement. Reformatting and preprocessing, if required could still be done centrally. A further refinement of this approach would be to provide capability at each regional center to store that region's most recently acquired data which would be turned over to the archival data base after passage of a set amount of time to make room for more recent data. Such capabilities as those above are within the state of the art.

Whatever approach is taken, a prime consideration must be that all matters which relate to the interface presented to the user must be standardized and remain consistent in their growth. Such matters would include data formats, communications protocols, media formats, data structures,

user-oriented procedures, and data management services. Reference 1 is a plan for an earth resources data management and data sharing approach, which involves the use of the ARPANET and inward WATS lines. This plan, if implemented, would make available earth resources services, not only from five NASA Centers and the EROS Data Center, but from any such resource connected to the ARPANET. This plan also addresses the problem of data formats and structures standardization and presents cost and schedule estimates.

Future Considerations

So far, the transfer of actual image data over communications lines has not been proposed here. For most present users, the use of the mail is fast enough. However, given the ever-increasing local capabilities of image processing terminals and the lower costs of larger memory subsystems, coupled with unforeseen future urgencies (earthquake prediction?), such capabilities should be considered for future applications. This may be accomplished by means of satellite communications systems, judicious use of change data approaches, clever data compression techniques or combinations thereof. Useful image segments could be transmitted over 50 Kbps lines in less than one minute. Within localized complexes (buildings) of large organizations a shared, video bus technique is quite promising for rapid transfer of high volumes of data.

Another consideration is that as the Data Communications System approach described above matures, other geographical data bases could be incorporated with conversion to standard formats, to better serve the user and start the process toward fully integrated data bases in this field. The user could experiment with their usage of this data, leading to a refinement of their requirements for the national data base.

APPENDIX E

Background Material Presented to Conference Attendees

(The following two essays were prepared before the conference by F.C. Billingsley and distributed to the attendees upon arrival. While they do not necessarily represent the conclusions of the workshop, they were instrumental in providing an initial focus to the problems later addressed by the conference.)

T U F T E A U F*

by F. C. Billingsley

THE PROBLEM

The number of "universal" tape formats are in existence. None of these have all of the required data for completely understanding the tape contents to the extent of being able to read the tapes and find all of the data. Most of these have most of the required information, but none has all. None is completely satisfactory as proposed. In addition, most have a mixture of information in the headers relating both to the format and to the data itself. The latter makes the headers unduly complex and long. The headers are different for each application and cannot be brought under format control without being extremely complex (to cover everything needed).

What is considered here is a format philosophy which is aimed at accomplishing the following:

- * Provide a (video tape) data interchange format which will allow the local user to read the tapes to determine such factors as the basic logical structure of the data on the tape
- * Provide a structure which is expandable, to allow the inclusion of all necessary ancillary data, without requiring extensive unused space
- * Provide a structure which will handle, in the same logical format, either cellular data (integer, real, or complex, or logical), numerical lists (such as geographical polygon lists), and alphameric lists (such as nominal data files). Inclusion of the list data causes no additional problems, since a list may be considered to be a line of data. These lists are of crucial importance within geographical data systems, as much external data is in this form

* The Universal Format to End All Universal Formats

- * Provide a structure which is useable within a local data system as well as for interchange, thus possibly minimizing reformatting problems for the users.

SO WHAT?

A format philosophy can be defined to hold all of the above data types. A polygon or nominal data list is logically equivalent to an image line. All of the data types require the same types of ancillary data for use: geographical location, scale, identifiers, date of generation, source, specific annotations, etc. All may be interleaved in the same ways: several spectral bands or polygon lists may be interleaved, or N or 1/N lines may be packed per logical record, etc.

Polygon data may be converted to cellular form for use, to allow it to be used with continuum cellular data such as imagery or continuum altitude data. Therefore commonality of the ancillary data format is important. (Conversion of continuum data to be polygon form is usually not convenient, as that requires converting the continuum to a series of steps, outlining of the various homographic areas, and converting to polygon lists.)

Since one or more data sets may be closely related (e.g., multiple spectral bands, or stereo pairs) it is desirable to be able to reference them together under one directory.

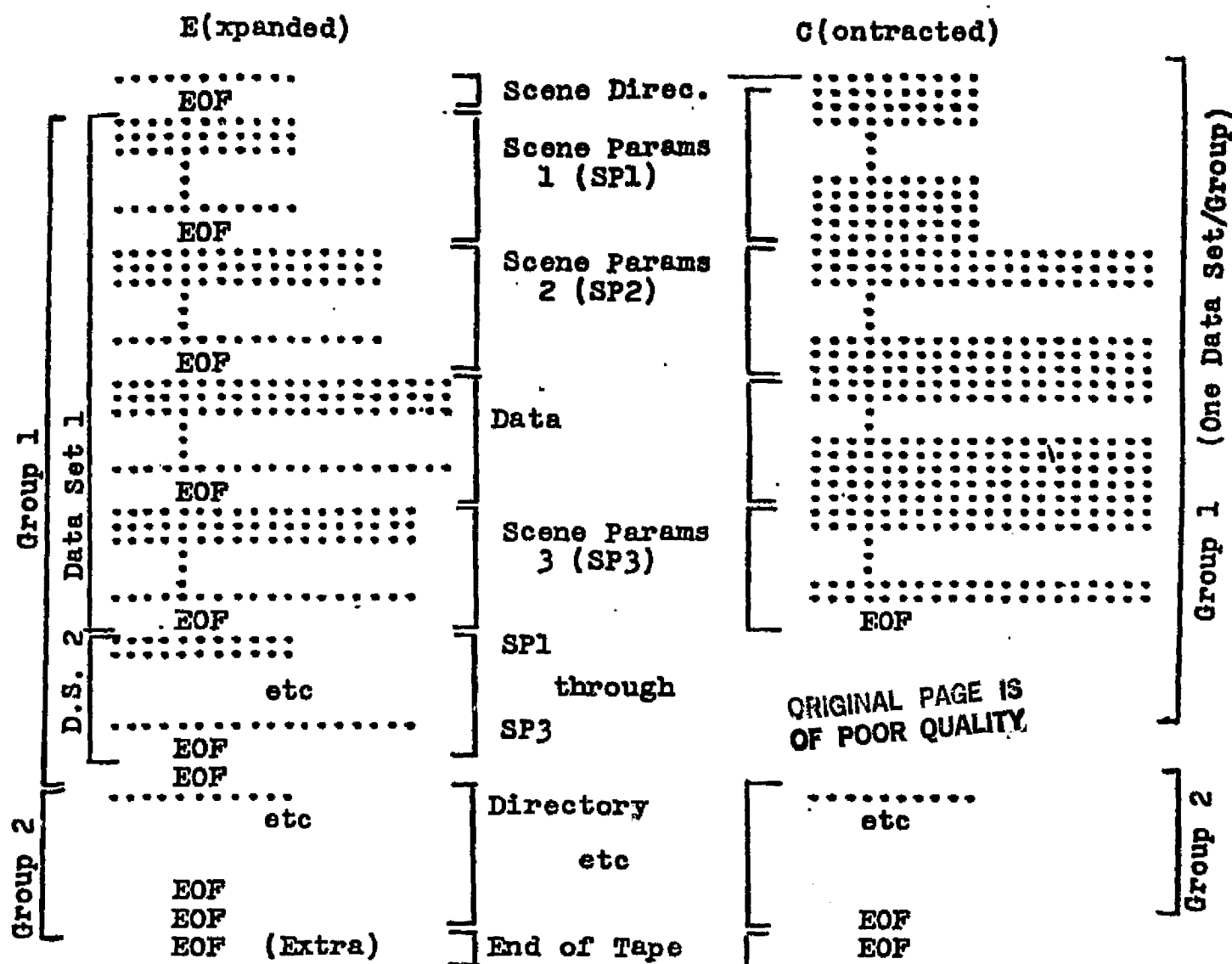
Some of the ancillary data may refer to the entire data set, and other may vary line-by-line. Both Types are needed. Both types may shrink to zero; the quantity of each must be stated.

Information required to read the scene must be in a fixed format scene directory. (Format number and revision, number and size of lines/logical record, number of data sets in the group, bytes/data unit (e.g., pixel), data packing plan (e.g., spectral interleaving), data type, etc.). The scene directory is the only record required to be present.

Data set specific data may be in ancillary records. These have been found useful to be either the size of the directory record or the size of the data records. Both should be possible.

Some projects may define that a given type of record (e.g., a fixed header as the first parameter record) will always be present. This is within the above structure, and is part of the project-specific format definition.

Two basic data structures have been used. Both have advantages and disadvantages. Either should be possible.



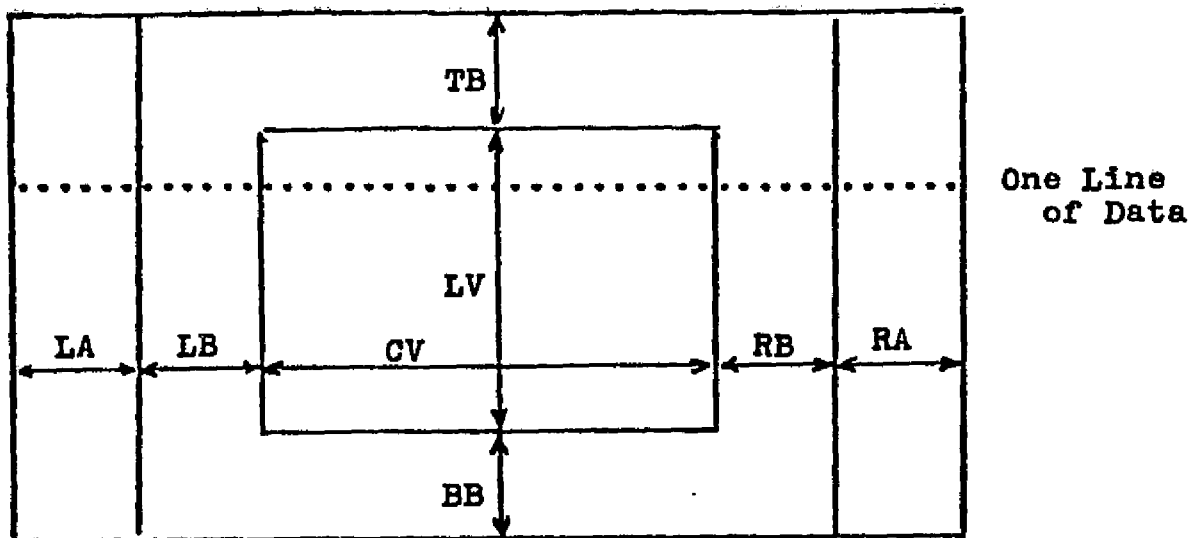
During operation, the system reads the Directory to ascertain data structure following, and refers to the operating instructions (the execute command) for further instructions.

The quantity of all types of records (except the directory) may be changed during operation, and the length and number of SPs and data may be altered. Directory entries are modified and updated to match.

The entire assembly may be preceeded by a Tape Directory (TD) if desired.

The first 6 bytes are to be reserved for record ID and line count.

For a (Cellular) data it has been found desirable to allow the cellular data itself to be surrounded by a border (containing, for instance, tic marks, grey scales, human-readable annotations, in cellular form) which would be treated by a film recorder as part of the image, and having each line preceeded by a left annotation (LA) group of bytes and followed by a right annotation (RA) group of bytes. LA and RA provide locations for line-specific data,



such as image line number. It has also been found desirable to count cells by number of cell lines (LV) and number of cells/line (CV), even though each cell may contain multi-byte data. For consistency, LB and RB are also to be counted by cells, with the expectation that the number of bytes/cells is the same as for CV. LA and RA are normally alpha-meric, and are counted in bytes.

It has also been found desirable to be able to pack P lines of data per logical record or allow I/P lines/record.

Because of external considerations and to allow sufficient room for additional entries to be defined, it is suggested that the TD directory be 360 bytes long. For the same reason, it is suggested that the scene directory SD also be 360 bytes.

NASA data transfer standard is ASCII. This should be adhered to for all alphabetic and numerical annotation unless specifically coded. Binary should be used for video data and (perhaps) record number.

With these definitions, it is possible to define a Tape Directory (TD) and a Scene Directory (SD).

TAPE DIRECTORY (TD) INFORMATION TO READ THE TAPE

An isolated file consisting (normally) of one record. Since the tape set may contain more than one image, from several sources, no specific image data to be included except (optional) a set of image names. TD applies to a set of tapes, each having a volume number. It is logically possible to have more than one logical tape per physical tape. TD is fixed length (360 bytes) with fixed field locations.

LANDSAT ICD

Byte loc	Field Length	Field Definition
1 - 4	4	Record # (starts at 1 after EOF)
5,6	2	Record Type Code (0118 for TD record)
	4	Record Length, this record (0360 for TD)
	20	TD Format Control # and Revision #
	1	Tape Volume #
	1	Number of Volumes in set
	8	Tape ID at User Location
	8	Generation Location, this Tape
	12	Generation Date, This Tape YYMMDDHHMMSS

Suggested:

-180		Reserved for Future Format Control
181-360	180	Permanently Uncontrolled - For Local Use
	b (blank)	Not defined or not yet filled
	0 (zero)	A number. Do not use zero fill for fields which later are to contain numerical data.

SCENE DIRECTORY (SD)

INFORMATION TO READ THE SCENE

Applies to a set of logical scenes (LS) following and their parameter records. Each scene in the set must have the same structure. Each LS may have several interleaved/concatenated individual images. The true video data may be surrounded by borders. SD is fixed length (360 bytes) with fixed field locations. SD is normally one record, but may logically contain several records, all of the same length.

SUGGESTED FIELD LENGTHS AND GROUPINGS ARE AS FOLLOWS:

FORMAT DEFINITION	LENGTH Bytes	LOCATION
Record # (starts at 1 after EOF)	6	
Record Type Code (0228 for SD Record)	2	
SD Format Control # and Revision #	20	
Format Control # and Revision # for bytes 257-360 of SD and for SPs and video	20	
First Byte of Uncontrolled Field (FBU)	4	
SCENE IDENTIFICATION		
Scene ID	20	
Location generating this scene	8	
Date of Generating this Scene YYMMDDHHMMSS	12	
Date of Last Processing this Scene YYMMDDHHMMSS	12	

DATA LOCATION INFORMATION

Code for Expanded (with EOF) or Contracted (w/o EOF)	1
Number of Logical Scenes for this SD (NLS)	1
Line Packing Factor - Number of lines per Logical Record (P)	2
Record Length, this record (0360 for SD)	4
Number of SD records (normally = 1) (SD)	4
Record length of SPI, Bytes (NSI)	8
Number of SPI Records (SPI)	4
Record Length of SP2, Bytes (NS2)	8
Number of SP2 Records (SP2)	4
Record Length of SP3, Bytes (NS3)	8
Number of SP3 Records (SP3)	4
Number of lines, Top Border (TB)	4
Number of lines, Video Data (LV)	8
Number of lines, Bottom Border (BB)	4
Number of Bytes, Left Annotation (LA)	4
Number of Bytes, Right Annotation (RA)	4
Number of Cells, Left Border (LB)	4
Number of Cells, Right Border (RB)	4
Number of Cells, Video Data (CV)	8
Bytes per Cell, Border Left and Right (NB)	2
Bytes per Cell, Video (NV)	2
Total Length of a	
"Line": $LL = LA + NB * (LB + RB) + NV * CV + RA$	8
A Packed Logical Record contains $P * LL + 6$ bytes (PLR)	

DATA TYPE INFORMATION	LENGTH BYTES	LOCATION
Date Type: Cellular (), Logical (), Alphameric ()	1	
For Cellular Data: Real (), Integer (), Complex (), Non-complex ()	1	
For Integer, non-complex, cellular: Number of significant bits Left () or Right () Justification		
For Real: Number of bytes, mantissa Number of bytes, exponent		
For Complex: Number of bytes, real part Number of bytes, imaginary part, etc.	2	

MULTI-CHANNEL INFO FOR VIDEO CELL INTERLEAVE

Number of Channels Interleaved	2	
Interleaving Code: Line Interleaved (),		
BIPN Cell int N at a time (N),		
Band Sequential BSQ ()	2	
Reserved for future format control		-(FBU-1)
Permanently Uncontrolled - for Local Use.		
(LANDSAT may define some of these -		
other users look out!)		FBU-End

FOOD FOR THOUGHT ON MAKING LANDSAT DATA OF MORE USE

by F.C. Billingsley

With the advent of digital corrections being used for LANDSAT C and the changes in parameters for LANDSAT D, the present definitions and concepts of standard scenes will be changed. In addition, the large size, in pixels, of each scene causes problems in CCT formats and film recorders.

Discussed below are a number of ideas which may be considered in order to make the data more usable to the digital user. It is realized that some are controversial; they are presented to provide stimulation and discussion.

GEOGRAPHICAL PIXEL LAYOUT

Almost all of the discussions to date have assumed that, of course, the images will be projected to some sort of map form. There is certainly a great utility in data for this form. But with the increasing usefulness of digital data analysis, the finesse involved in the digital analysis becomes the controlling factor.

Defining such sensor records in terms of ϕ and λ has nothing to do with map projections as long as the values are simply expressed in digital form. Therefore, we must answer the two questions: (1) do we really intend to facilitate digital analysis and digital data base symptoms? (2) if so, which users, digital or mappers, should have to do any subsequent remapping?

It is proposed here that because of the digital data processing finesse required and possible, either raw data or first-generation interpolated data be supplied to the digital user and that his format be given preference.

The considerations for the digital user are to minimize all of the reasonably local mosaicing problems both along track and across track and to allow call-up of a given area with very simple extraction mathematics. The format should be one adapt-

able to spacecraft at various altitudes, spacecraft such as SEASAT and HCMM, which have widely differing orbits, and to two-dimensional data derived from other sources.

Because of the large number of map projections and scales in use, no one map projection will be universally acceptable. Thus, for map making, there is an implicit acceptance of the need for secondary projection. Does secondary interpolation hurt? IBM is doing a study for GSFC to investigate secondary interpolations and have come to the preliminary conclusion that a second interpolation makes only about 1 percent difference in multispectral classification (well within the classification accuracy noise) and only 1 to 2 digital number difference at edges. Thus, even for digital user, secondary interpolation produces only a minor effect. For the map maker, it should not be visible at all. Therefore, it is entirely rational to suggest that the map maker accept a set of digital data which has been optimized for the digital user and do whatever projection he needs from that.

But what ground layout should be used? One school of thought holds that for the digital user the optimum form of data is latitude/longitude--that is, the pixel lines should be aligned along latitude lines with pixel spacing equal along the earth surface. An alternate to this would be east-west pixel lines, with pixels spaced equally in longitude. Since lat/long is still the most universal transfer reference format, this may turn out to be the most versatile for all users, as the projection equations from this to all of the map projections are readily available.

Then, if map makers want some projection such as SOM, HOM, polyconic, or whatever, they could reinterpolate from the first order interpolated data provided to digital users. The additional interpolation will be invisible to them. This reinterpolation will also be simplified if the initial interpolation is into east-west pixel lines; from these it is easy to produce maps whose edges are east-west-north-south, thus corresponding to the available maps anyway.

PIXEL SIZE

For digital processing, pixel size determines that amount of data to be handled. However, most users will eventually make pictures from the data. With incoming pixels in the 30 m IFOV range, operating with pixels larger than this will reduce the data resolution for both the analysis and film recording. Also, very few film recorders have other than "round number" pixel spacing (typically 25, 50, 75, 100) available.

Producing maps at standard scales is desirable, although map projections will still be a problem; keeping pixels small will minimize further data loss in the required interpolations.

CALIBRATION

With the inherent slow change of instrument parameters and the much better attitude control of the spacecraft on LANDSAT D, and even better opportunity than now will exist for precise calibrations over entire swaths. The ability to use long term averages should minimize the intersensor striping caused by calibration noise and should produce a better model of spacecraft motion, allowing better geometric corrections. Thus, consideration should be given to calibrating an entire swath before breaking into scenes. This should appreciably simplify the calibration procedures, which now start over each frame, and produce more frame-to-frame consistency. Then, if this is done, there is not reason to break the bulk data into frames for archiving, thus further simplifying the NASA processing. Some framing capability will still be needed for local film production and quality control.

ARCHIVE RETRIEVAL

If full geometric and radiometric calibration can be done by swath, the archive need only to locate a segment of data for reproduction and dissemination. This allows much more freedom in choosing the segment: e.g., to output a specific county or tract, on request, as well as standard frames. In the coming days of digital data bases and digital operations, the best data compression for the users will be data avoidance--the archive can be a tremendous help in this by sending the users only the requested areas, which may be less than the standard frames, or may cross standard frame boundaries. Thus, the swath storage. Eventual switch to video disc will speed the retrieval, as access will be much more rapid than running down an HDT to find a segment.

Continued conversations with various users strengthens the belief that most data requests within a digital data system will continue to be by lat/long or UTM coordinates. The archive can expect to receive requests by blocks bounded by geographical coordinates, and the users at their consoles will address the data in the same way. Therefore, digital data for use in such systems should be in such a format as to enable easy data manipulation in these desired reference system. This, also, is facilitated by swath storage. There is enough overlap in the orbit tracks to allow the extraction of contiguous sets of square frames aligned with lat/long or UTM--the archive should consider these as possible standard products.