Design of Digital Image Processing Systems

James L. Mannos
Chairman/Editor

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DESIGN OF DIGITAL IMAGE PROCESSING SYSTEMS

Volume 301

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INTRODUCTION

Within the last several years, digital image processing technology has been expanding rapidly into many new application areas. This growth has been spurred in large part by the development of more powerful and cost-effective architectures for digital image processing systems, which in turn have resulted from the dramatic advances in digital electronics.

The intent of this Proceedings is to provide a clearer insight into the state of the art in digital image processing system design by bringing together typical user requirements, descriptions of hardware components such as display/processors, and descriptions of existing or under development digital image processing systems. The papers comprising this Proceedings were selected to cover a broad range of topics and to provide a sufficient level of detail to support both beginning users, who are interested in integrating off-the-shelf components for a basic image processing system capability, and more experienced users who are interested in the latest system architectures to achieve high performance.

The Proceedings are divided into four sections. The first section is focused on a diverse but representative set of applications including, among others: cartographic, legal, geological, and educational topics. The emphasis in this section is placed on the requirements which each application puts on the system design.

The second section is concerned with the specialized hardware components, or building blocks, of which image processing systems are constructed. This includes a description of the hardware components, the types of problems they were designed to solve, and the opportunity that they offer for improved system performance. The widespread use of auxiliary high speed processors such as array processors, special purpose chips, and video rate display/processors is particularly evident.

The final two sections describe the overall hardware/software architectures of a large number of existing or under development image processing systems. These systems range from small individual microprocessor-based systems to large interactive, multi-user systems to support tens of users. Applications supported range from general image processing to specialized areas such as remote sensing, medical imagery, image interpretation, video-bandwidth compression, and automatic fabric defect detection.

It should be noted that there are other image processing system designs that could not be included in this Proceedings because of size constraints (e.g., some of the interesting parallel processing systems being developed in the research community). We have, however, tried to select a sufficiently representative group of systems in current use to act as a catalyst for those interested in designing image processing systems or components. The number and diversity of these systems is a testimony to the interest and growth in this area.

James L. Mannos
ESL, Incorporated

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Session 1

Applications and Their Requirements on Digital Image Processing Systems

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Image processor design requirements in land-use planning

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Introduction: Computer-Aided Landuse Planning

Computer-aided landuse planning can be broken into two important phases. These two phases, which I will refer to as Data Collection and Modeling, make separate demands on the architecture of the image processor. The first phase involves the creation of large geographic databases containing a wide variety of geographic variables. Figure 1 (2) shows an example of such a database, created to model growth and impacts on a suburban region south of Boston, Massachusetts. Each entry on the list refers to a data "element", a complete map of the distribution of that variable. Some data elements are continuously varying numeric values (e.g., topographic elevation); other elements contain purely nominal values (e.g., vegetation type) where each value refers to a specific type. The major feature that each element in the database has in common with the others is that they all are registered in space or contain the information necessary to effect such registration quickly. The sources for each data element vary. Some are digitally produced and therefore available in digital form; others are compiled by hand and drawn manually or with a digital plotter. Many have to be laboriously digitized. Continuous variables are often digitized in a gridded form, while discrete, homogeneous variables are typically digitized in some sort of polygon form where only the boundaries between regions are stored. This second type of digitization and storage method appeals to cartographers and substantial research(1) is being devoted to the processing of such data, but this paper will only address it when it must be converted to gridded form for processing.

Such a database requires continual updating and maintenance, but it can prove to be very useful as an end in itself. Since it contains such varied data in a spatially registered form, a landuse planner can quickly grasp all of the relevant details regarding a given area and evaluate the suitability of a given project on that site. Planning commissions can track the changes in their community, and pass ordinances to direct those changes to a desired area. And researchers can simulate the growth of a region over a number of years or decades and evaluate the success of experimental control measures.

	Data Element Name	Data Range		Data Element Name	Data Range
1	Topographic Elevation	0-500 ft.	22	Commercial Landuse Type	8 categories
2	Topographic Slope	8 categories	23	Industry Landuse Type	17 categories
3	Topographic Orientation	10 categories	24	Public Facilities	12 categories
4	Watersheds	290 categories	25	Recreation Landuse Type	10 categories
5	Ridgelines	2 categories	26	Percent Impervious Cover	6 categories
6	Water Feature Type	11 categories	27	Historical Features	8 categories
7	Surface Water Quality	5 categories	28	Air/Rail Transportation	9 categories
8	Ground Water Yield	5 categories	29	Highway Transportation	10 categories
9	Soil Units	97 categories	30	Proposed Highways	7 categories
10	Landcover 1952	16 categories	31	Travel Time from pt x	0-30 minutes
11	Landcover 1970	16 categories	32	Travel Time from pt y	0-30 minutes
12	Vegetation Type	10 categories	33	Travel Time from pt z	0-30 minutes
13	Forest Type	12 categories	34	Sewer Service Capacity	10 categories
14	Forest Density	5 categories	35	Water Service Capacity	12 categories
15	Forest Height	6 categories	36	Elec., Gas, Telephone	8 categories
16	Wetland Type	10 categories	37	Ownership	7 categories
17	Habitat Edge Interfaces	20 categories	38	Parcel Size	10 categories
18	Agriculture Type	10 categories	39	Zoning	11 categories
19	Housing Type	15 categories	40	Neighborhoods	8 categories
20	Housing Density	0-255 units/cell	41	Town	5 categories
21	Housing Age	4 categories			

Figure 1. A Sample Geographic Database.

In addition, the database can be seen as a necessary input to the second phase process, i.e., landuse and environmental impact modeling. A planner will create a mathematical model to evaluate the comparative suitability of different areas for a given landuse, or to predict the magnitude of impacts associated with such a landuse in a sensitive area. Models can be made to equitably handle the tradeoffs between competing interests as well as simulate and predict secondary effects from a suggested course of action. While the data collection phase has utilized image processing in the last decade, landuse modeling is still very experimental. So while the design considerations that result from data collection are fairly well known, the features that might suit a modeling application are still somewhat speculative. Modeling is a largely theoretical field at this time, but image processing advances suggest the capability for dramatically increasing the power of modeling in landuse planning. The image processor can be considered more generally as a spatial data processor that is already well suited to handling the major problems associated with large scale landuse modeling. If we consider this modeling application, how will it affect future processor architectures. In the next sections, I will examine each phase in greater detail and discuss the design considerations that each imposes on the image processor, effectively transforming it into a "spatial data processor".

Data Collection Phase

Landuse Planning obviously depends heavily on the availability and accuracy of landuse maps. The technology of remote sensing has been applied to the production of these maps. With the advent of the LANDSAT program, digital image processing has been introduced to this process, and the image processing industry is now heavily dependent on LANDSAT users. Classification techniques are applied to multispectral and multitemporal imagery, resulting in landcover and predicted landuse maps. The present limitations of resolution and classification accuracy are significant, but they are offset by the lowered cost of data production and the repetitive coverage of large areas. In some remote areas LANDSAT provides the only data available. In any case, this is the predominant interface between image processing and landuse planners, and it has been well documented during the last ten years.

Landuse planning often involves the use of data sources other than those produced through remote sensing and image processing. One important data source is topographic elevation and its secondary products (e.g., slope and orientation). Traditionally, topographic data has been produced using conventional airphotos and stereo plotters. The output has been the familiar contour map "quads" and, occasionally, digital contour files or gridded data bases. Digital image processors can take these digital products and merge them with satellite images or landuse-landcover maps. In addition, the topographic data can be further processed to produce the secondary data mentioned above. Slope and orientation maps can be generated in the image processor hardware by using neighborhood operators. Hillshadings can be produced in real time, where the appearance of the study area is simulated for a given solar position. This can be used to improve classification accuracy in the production of landuse-landcover maps. Some research has even been directed to the automatic production of topographic data by image processing techniques(3). In this application the image processor is programmed to perform the same functions as the stereo plotter, either under supervision or automatically.

Landuse planners must often merge non-digital data sources with digitally produced data in a geographic database. Image processing can profitably be applied to such map digitization. For example, a hand-compiled geologic map can be digitized as an image, and manually or automatically "classified" into a digital representation of the map contents. This opens up a huge vista of conventional data sources that once had to be manually digitized. And with this step the image processor has become the central element in creating a comprehensive geographic database. This is a natural step in that image processing has had to master the techniques for handling large, spatial databases efficiently. Digital image processors are, in many ways, simply boxes of RAM memory organized to store and display data in a two-dimensional manner. They allow the user to think in terms of arrays that are 512 x 512 x n, which few host computers are prepared to handle.

Finally, there is often a need for secondary products made by processing the database. Principal among these is the need for proximity maps where each cell is evaluated according to how close it is to the given feature(s) in a base map. This kind of factor can affect the attractiveness of a given area for development, as in proximity to a smelly landfill; or it can reflect an important legal feature of an area, as in mandatory building setbacks and rights-of-way. Proximity maps are an essential part of a geographic database but they are rarely stored. Since there are a huge number of different features that a proximity analysis might use, they are usually recalculated and then discarded. However, since they are computationally expensive to produce, their use is limited at the present time.

Design Considerations For Data Collection

The present generation of image processors are well suited for many of the required data collection tasks such as LANDSAT classification. This application is their predominant market. In addition, many of the available image processors provide the high-speed spatial operators that are necessary for converting topographic data to slope and orientation maps. A 3 x 3 convolver is adequate for this task. Larger spatial operators are required for the production of proximity maps and some of the available image processors provide this capability at near real-time. Finally, most of these image processors have the ability to input data from an external video port. This can allow the digitization of existing maps and their merging with other data in a geographic database.

One weakness of existing image processors concerns their ability to geometrically register the various data types in a geographic database. In the past, this task has been performed in host computer software, occasionally using the image processor's memory for storage before and after the transformation. Use of the image processor's memory has increased the speed of the operation because image transfer rates generally exceed disk transfer rates and do not suffer from rotational latency problems. Nevertheless, geometric correction is still far from real-time when it relies on the host computer. In the past year, a few manufacturers have announced "warpers" integrated with the image processor hardware but improvement in speed that these new devices will provide is still unclear. This task is generally only performed at the time the database is created, and the improvement in execution speed that hardware implementations allow may not justify the cost, particularly when the task is only performed rarely.

Landuse Modeling Phase

In parallel with the development of remote sensing and digital image processing technology, land use planners have been experimenting with more quantitative approaches to processing their data and arriving at decisions. Landuse Modeling techniques have been used for the production of "capability" or "suitability" maps. In this application, what is being "modeled" is the general public's decision and evaluation process as it surveys its economic needs and its environment. These models generally are simple arithmetic combinations of five to ten data variables and they are performed on a cell-by-cell basis. Some of the earlier attempts were performed graphically. Each map input was produced as colored areas on a sheet of clear film. The model results were simply the overlay of all the necessary sheets on a light table. Models of this type have been used for the last fifty years(4). Combination is limited to addition and the number of inputs is limited by the clarity of the clear film and the brightness of your light table! However, the results are presentable and the methodology was easily understood by laymen.

ELEMENT	WEIGHT	DESCRIPTION
Slope	1	Level slopes received higher values, while steep slopes were considered restrictive and given lower values.
Foundation Soils	1	Based on Unified Soils Classifications, soils with stable foundation conditions in the greater than 30" soil layer were given higher values.
Vegetation	1	Areas with forest cover were given higher values because of the amenity value provided.
Highway Proximity	2	Areas within 3000' of primary and secondary arterials were given higher values to avoid extensive road building and to provide good truck access.
Water Service Proximity	2	Areas within 3000' of existing municipal water service were given higher values to avoid the need for constructing new water service lines.
Sewer Proximity	2	Areas within 3000' of existing sanitary sewer service were given higher values to avoid the need for constructing new sewer lines.
Rail Proximity	4	Areas within 6000' of existing rail lines were given higher values to avoid construction of rail spurs.
Travel Time	4	Areas within the shortest travel time contours of the I-95 interchanges were given the highest values to provide good truck access.
Wetland Avoidance	4	Areas which were outside of wetlands were given high values to avoid construction difficulties and legal problems.
Existing Use Avoidance	4	Areas with no existing uses were given higher values. Existing development and public use areas were give lower values.

Figure 2. A Simple Industrial Suitability Model.

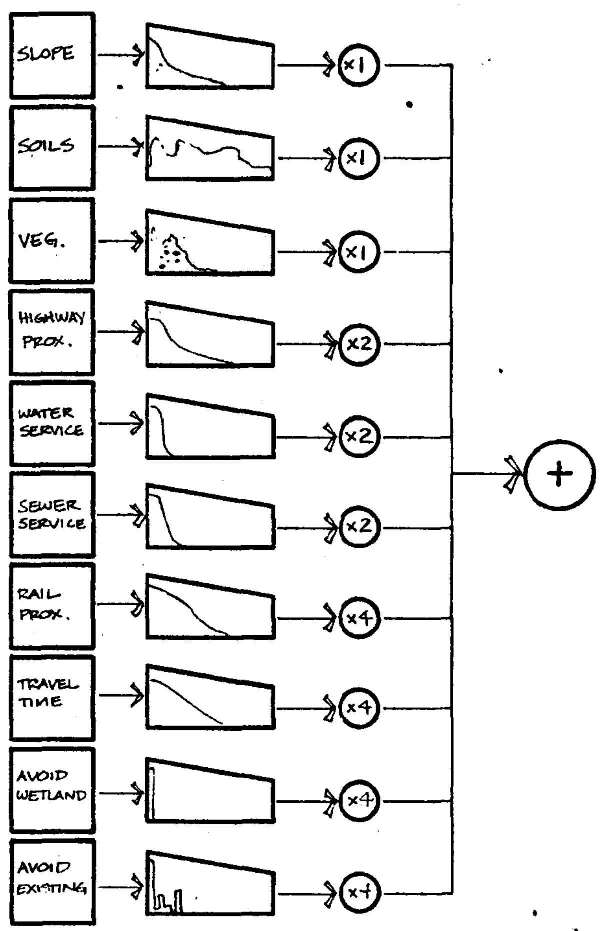

Figure 3. Model Diagram.

During the late sixties, computers were proposed to perform this modeling(5,6). Because of limitations in computing technology and availability of data, these first models were only slightly more complex than their clear film ancestors. Figure 2(2) shows a simple suitability model for the location of an industrial facility and figure 3 shows it in diagram form. This model attempts to explicitly mimic the site evaluation behavior of an industrial developer as he surveys the area represented by the database. It has a variety of data element inputs, each with a different content and range of values, which are input to utility functions and transformed to individual suitability maps. These are summed with weights that reflect the relative importance of each input to the final result. The weighting can be accomplished in the transforms by scaling. In practice, the weights require calibration and fine tuning and this necessitates multiple runs of the model which are both costly and time-consuming. When complete, this model will produce an output suitability map where high values correspond to good prospective sites and low values correspond to bad sites.

At present the use of such techniques is limited by weak theoretical foundations and cumbersome technology. The technical problems can be seen as holding back the theoretical development by preventing experimentation and presentation of the results. When the run of a simple model takes hours, the database is limited to a small area or large cells, and the results are smudged lineprinter listings with poorly-adjusted overstrikes, the theory will not advance rapidly. Largely for this reason, the theory behind such models is largely intuitive. Planners have been unable to apply even simple statistical techniques like regression or sensitivity analysis to their models because of the sheer size of the database and the difficulty in manipulating it. Models have proved to be cumbersome to calibrate and modify. Consequently, researchers have tended to construct simple models because the theory and technology would not support complex formulations.

Figure 3 shows a remarkable similarity to the architecture of many of the available image processors. The utility function is conceptually equivalent to a lookup table loading while the summation stage is analogous to the arithmetic combination logic in the image processor pipeline. This is largely coincidental but demonstrates the applicability of image processors to more general spatial processing applications. The next section will discuss how image processor architecture can be refined and tailored to further satisfy modeling needs.

Design Considerations For Landuse Modeling

After the data collection process is complete, we have created a large geographic database. As discussed above this database can include dozens of data elements. The processing stage involves combining these elements into landuse models. Such a model might require the arithmetic combination of as many as sixteen of these data elements to produce an overall suitability map. The image processors presently available are generally limited to around sixteen inputs which they can store and combine; an entire database is too large. Since one landuse model may be only part of an overall study that includes other models, and each model may require different elements of the database, it would be ideal to have the whole geographic database resident in memory at once. Then a given model would involve selectively enabling only those database elements that contribute to it by modifying a channel-enable list and loading the necessary transforms in lookup tables. Also since some of the available image processors allow multiple combining "pipelines", having the whole database resident in memory would permit multiple models to be executed simultaneously with each result displayed as a different color.

Expanding existing image processor architecture to allow as many as sixty-four channels is not the major factor holding back this development. Memory cost is the major limiting factor. However, as shown in figure 1, many of the data elements do not require 8-bit precision. In fact, most require only 4-bit memories. The output of the utility function (LUTs) should be 8 bits but the memory precision can often be less. One option is to compress multiple data elements into a single channel of memory, but this will complicate the construction and dynamic modification of the transforms necessary during modeling. A conceptually simpler solution (though not necessarily easier to implement in hardware) is to allow dynamic redefinition of memory channel precision. In this scheme memory channels would become logical entities that were mapped onto segments of physical memory. Each data element would only be allocated as much precision as it required and unused (wasted) bits of memory would be eliminated. Such an architecture would then require less memory to hold a geographic database; in fact, the amount of memory that presently exists in a large LANDSAT application image processor might also suffice for storing the modeling database if precision was redefinable.

Programmatic memory depth is a difficult concept to implement in existing hardware, and increasing RAM densities will probably only make the situation worse. Consequently, a compromise may have to be reached, namely a module of memory depth that is smaller than 8 bits but not quite 1 bit. Some of the available image processors are presently offering memory in 4 bit deep modules and this may solve most of the problems associated with wasted memory. Four bits or sixteen distinct levels, is sufficient for many data elements in a geographic database, particularly where the encoded values in a data element are nominal (e.g., refer to landuse or vegetation types). The remaining elements in a database would be allocated an 8 bit memory. A few elements might require more (e.g., topographic elevation), but in most cases this kind of data can be quantized to 8 bits after slope and orientation have been calculated in the data collection phase.

Once we have configured the image processor memory so that it contains the entire database, we then load the required LUT transformations and enable the proper channels to initiate the model. The user can then be expected to tailor the transformations so as to modify the displayed results. This fine tuning process would require fairly sophisticated host computer software to acquire, modify and restore user selected transforms. As mentioned above, in many cases, models are not used in isolation. Rather it is useful to be able to have multiple models running simultaneously, perhaps displayed in different colors. This capability would permit the user to examine the competitive nature of some landuses, such as commercial and light industry, for the same parcel of land. These two landuses would each be modeled and then run in parallel. A given area might turn out to be very suitable for light industrial growth but have a higher suitability for commercial growth. Simultaneous high suitability for two landuses might then have feedback effects, such as inflated market value, that might tip the balance in an unexpected manner.

Parallelism in the image processor architecture can thus be seen as an advantage when modeling landuse competition. Some of the available image processors provide three parallel "pipelines", one devoted to each of the three primary colors. Ideally, a landuse application would like to see this parallelism extended to some user-selectable value. This has numerous repercussions on the rest of image processor architecture but it also provides some interesting new features. For example, many-pipeline architectures simplify the provision for multi-user, multi-display capability in an image processor. However, as the number of pipelines increases, the multiplexing of data lines becomes extremely difficult and, again, compromises may be required. An architecture which makes use of a frame buffer or memory pool devoted only to refreshing the display is one possibility. It could be continually updated by one fast pipeline and permit near-simultaneous model calculation followed by simultaneous display of the results.

Another consideration when evaluating image processors for a landuse planning application would involve easing the long term database storage problem. Since geographic databases typically exhibit a high degree of spatial correlation, particularly when the cell size is small, simple data compression has often been used. Run-length encoding is common and some research has been devoted to the use of more sophisticated techniques like quadtree encoding and polygon encoding. An important feature for an ideal image processor would be the capability to decode compressed data at high speed as it is transferred from the host computer. At present, a few of the available image processors will transform data on input or place it in a specified window location within a larger image, but high speed decompression is not available. This is because images typically exhibit less spatial homogeneity and image compression usually employs different, more complex algorithms. This capability could offset the requirement for a completely resident database, in that very high speed data input of compressed files might still permit near real-time modeling of different landuses. The minimum requirement would be run-length encoding decompression. Hardware polygon plotting and filling would also greatly simplify storage problems and permit planners to use some commercially available data "off the shelf". In recent years, the landuse planning profession has broken into two camps with some advocating polygon or chain databases to eliminate the need for large grids and enormous storage requirements. Some data elements are most easily encoded in a polygon format and government agencies are distributing data in this form. In the foreseeable future, polygon based data sources will be widely available. An image processor based system which attempts to handle all geographic data in a landuse planning environment must be prepared to accommodate all data sources, among them polygon sources.

Data Collection:

- o Typical LANDSAT processing capabilities.
- o 3 x 3 spatial operator for topographic processing.
- o n x n spatial operator for proximity map creation.
- o High speed image digitization for map encoding.
- o Geometric registration capabilities.

Modeling:

- o Provision for large numbers of channels.
- o Dynamic definition of individual channel precision.
  - o Dynamic definition of spatial size.
  - o User selectable number of independent pipelines.

    OR
  - o Fast single pipeline distinct from multiple display frame buffers.
- o Data compression/decompression on input/output

Figure 4. Summary of Possible Design Features.

Conclusion

The above discussion concerns the extension of image processor systems further into the landuse planning process. They are already fairly well suited to such an application, but this suitability has been largely accidental. Figure 4 gives a summary of the major points made in this paper regarding landuse planning and image processor architecture. But it is important to note that existing architectures already exhibit the necessary overall structure. The enhancements and features discussed here would tend to generalize image processor architecture to a form of "spatial data processor". As we consider new designs and new features for coming generations of image processors, we must consider also the evolving use of these devices in a wider range of applications. Landuse planners are presently using these devices as data collection tools but as they grow familiar with the technology there will likely be a synergistic development of new methods in landuse modeling. These new methods will demand new features from the image processor market suited to their specific problems. An awareness of the new features may allow the image processor industry to seed these new developments, accelerating the technological advances of landuse planning as well as opening a broader market.

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Geology and image processing

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Abstract

The design of digital image processing systems for geological applications will be driven by the nature and complexity of the intended use, by the types and quantities of data, and by systems considerations. Image processing will be integrated with geographic information systems (GIS) and data base management systems (DBMS). Dense multiband data sets from radar and multispectral scanners (MSS) will tax memory, bus, and processor architectures. Array processors and dedicated-function chips (VLSI/VHSIC) will allow the routine use of FFT and classification algorithms. As this geoprocessing capability becomes available to a larger segment of the geological community, user friendliness and smooth interaction will become a major concern.

Introduction

The geological applications of digital image processing are affected by three considerations:

1) The nature and complexity of the problem
2) Types and quantities of data
3) Processing tools available, including displays

Any attempt to predict requirements for future image processing systems should address all three of these strongly interacting factors.

In addition, the role of image processing is somewhat different among the various user groups:

1) Research-oriented groups pursue advanced methods including sensors and information extraction techniques. System flexibility is at a premium since the research commonly involves extensive software development.
2) Operations-oriented groups, especially in the energy and minerals industry, have focussed on providing interpretation of enhanced digital images. Mature, modularized software and high-fidelity playback capabilities are especially desirable in this environment. Since enhancement is a rather subjective process, smoothly interactive software and displays having onboard processing are also used extensively.
3) Production-oriented groups seek to optimize throughput of a fairly restricted set of algorithms, commonly on large data sets. This segment of the community has led the shift from software to hardware processors.

The distinctions among these groups are blurring as the impact of computer technologies diffuses through the community and as the operations groups apply incresingly sophisticated processing to multispectral data. This sophistication results, in part, from increased computer effectiveness, either a brute-force reduction in machine cycle time or a more surgical use of specialized architectures, e.g. feedback-loop processors.

The following sections expand upon these considerations and attempt to recognize some trends for the 1980's.

The problems

The fundamental goal in the use of computer-processed imagery is the generation of better geologic maps. The level of complexity of these maps ranges from automatically-classified rock-stratigraphic maps to more restrictive thematic maps displaying lineaments or alteration zones. It is sometimes convenient to distinguish between lithologic mapping, which concentrates on spectral properties of surfaces, and lineament mapping, which utilizes spatial relationships to identify linear features. In practice, distinct spectral units (marker beds) can provide valuable clues concerning folding and faulting.

From an analyst/interpreter viewpoint one can distinguish two types of lithologic mapping:

1) Identification of different rock-stratigraphic units by rigorous utilization of spectral properties and knowledge of the stratigraphic colunn.

2) Discrimination of units, a more empirical approach exploiting the human capabilities of incorporating hue, intensity, texture, and context into an interpretation. Units are discriminated as being different, rather than by rock name.

With the development of computer texture mapping and other pattern recognition techniques, as well as appropriate stratigraphic models, it may be possible to merge the rigor of the former with the power of the latter. It is worth noting that the two types of mapping have rough parallels in image processing terms, namely, classification and enhancement, respectively.

The trend in processing is toward the use of color ratio composites and principal-component images generated from narrow-band sensors. These high-resolution instruments have been optimized for detection of oxidation, hydration, and chlorophyll-related spectral features based upon laboratory and field studies. Additional processing includes geometric rectification to map base. This step commonly follows spectral processing because resampling may degrade spectral differences.

Attempts to improve the discrimination of lithologies will also utilize combined spatial and spectral processing. In orbital radar images the power spectrum of the scene is dominated by two components: low-frequency surface properties and high-frequency topographic effects (Figure 1). A technique involving a combination of hue encoded low frequencies and intensity encoded high frequencies appears particularly effective is enhancing lithologic and structural informaion.

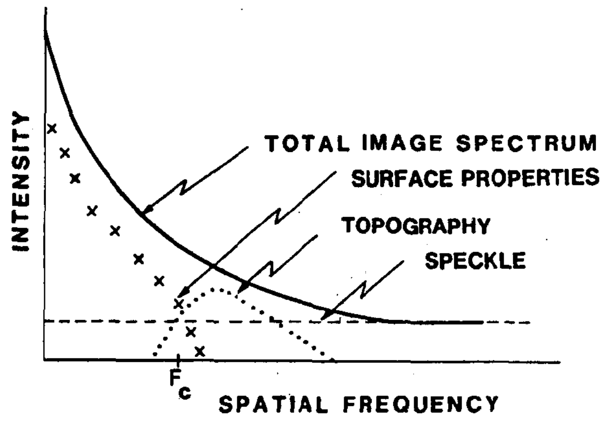

Figure 1. Radar image spectrum

Lineament mapping, by contrast, has not been as amenable to direct computer recognition methods. This is because tonal boundaries associated with ridge lines, valleys and other entities of little geological significance are commonly more heavily modulated than are the subtle manifestations of faulting. It appears likely that lineament mapping will continue to utilize high-pass filters (tailored to avoid artifacts), commonly in an interactive environment with video-rate updating. An additional mapping technique for subtle topographic features involves the use of image simulations.

Digital elevation models (DEM) are a valuable image-like data set. As tools for geographical analysis, the analyst may compute and display elevation, slope, aspect, and higher-order power spectral measures for terrain analysis. By modelling solar or radar illumination geometry, it is possible to simulate imagery having any arbitrary viewing geometry. Figure 2 shows a simulated radar image of part of the Pine Mountain Thrust in Tennessee. Such simulations are being used to assess the detection and orientation of structures and to provide stereo coverage at regional scale. In the future, it is likely that analysts will routinely merge this stereo information with image data to enhance interpretation. The addition of topographic data may also improve the capability of automatic classifiers.