B UPDATING CENSUS URBAN AREA MAPS WITH LANDSAT DATA

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Background

Urbanized area (UA), maps have been produced as part of each decennial census since 1950 to provide a precise boundary between the urban and rural populations around large metropolitan areas. The UA boundary, a line enclosing the region of urban settlement, is primarily based on actual census population counts. Its location must be fixed immediately after the census to insure that statistics are published on schedule. The responsibility for locating and verifying the accuracy of the UA boundary rests with the Geography Division of the US Bureau of the Census.

An important precursor to updating an urbanized area boundary is the identification of a fringe of suburban territory to be considered for inclusion within the revised UA. The fringe zone must include all adjacent urbanized lands while minimizing the inclusion of large expanses of rural land. The outer line of this fringe is intially drawn prior to the census based on information other than population counts. When population counts become available, enumeration districts within the fringe zone are analyzed, and are included or excluded from the new UA. Finally, the outer line is modified to relfect these decisions, becoming the boundary of the newly revised urbanized area.

The preliminary mapping of the outer line is accomplished through a series of labor-intensive procedures involving manual analysis of many different source materials. The information must be assembled for preliminary work which begins at least two years prior to the census. Data are obtained in a variety of scales, sizes, formats and dates and include thematic maps, recent aerial photography, as well as political and statistical boundary information. Despite diverse origins, the information must be evaluated in such a manner that each UA is treated in a uniform and consistent manner. In an attempt to accelerate this mapping task, the Bureau of the Census is investigating ways to —

- Reduce the volume of source materials
- Obtain quick access to areas of interest
- Provide timely geographic coverage
- Insure that each UA is treated consistently.

The Census Bureau hopes that remote sensing technology, specifically the analysis of Landsat data, will fill this need.

The Census Bureau's experience with satellite imagery began in 1972 with an investigation into the utility of Landsat data for meeting the needs of developing countries for selected census and demographic purposes. With the success of this project and other work undertaken by the US Geological Survey, the Census Bureau became interested in using remote sensing for outer line delineation. Their initial investigation was based on analysis of Landsat photo-transparencies by means of a density slicer and additive viewer. Then, a follow-on study was formulated to determine if digital processing of Landsat data could be more useful for their purposes. Not being experienced in digital processing, the Geography Division entered into a relationship with NASA to develop an Application System Verification & Transfer (ASVT) project to evaluate potential contributions of Landsat to urbanized area work. Four research organizations cooperated in ASVT research: Goddard Space Flight Center (Borden & Williams, 1977 - Christenson et al, 1977), General Electric Company (1978A - 1978B), Computer Science Corporation (McKinney 1978, McKinney & Stauffer, 1978), and the Jet Propulsion Laboratory (JPL). Research activities conducted at JPL (Davis & Friedman, 1979, Friedman, 1980) are emphasized here.

Research Methodology

Three methodologies for analysis of urban areas were investigated. The simplest was the base level approach where color photographs and line printer maps were manually analyzed to locate the outer line. This approach emulated outer line mapping procedures currently in use at the Census Bureau. It was found that the enhancements alone were sufficient for mapping of geographic settings where abrupt transitions between urban and nonurban lands were present. In areas where suburbs intermingle with rural countryside, a land cover classification was also employed as source material. When these Landsat derived maps were compared to conventionally drawn outer line maps, it was found that the two boundary sets circumscribed the same general area. However, the Landsat products were analyzed in half the time required for mapping with the current technology.

A second approach was based on change detection. A simple image differencing routine was used to depict changes in reflectance values between the two anniversary Landsat scenes. This technique was tested for one urban region over several periods in time (McKinney & Stauffer, 1978). The results were similar to both the conventionally derived outer line and the boundary drawn with the base level approach.

From the base level and change detection research, it became apparent that Landsat offered both advantages and problems for the Geography Division. Positive features include —

- Timely & Expansive Coverage
- Adaptable Scale
- Variety of Formats
- Labor Saving Potential Noted

Evident limitations include —

- Lack of Resolution
- Need for Supporting Cartographic Information
- Possible Climatic Restraints

A wealth of information could be derived from the base-level and change detection approaches. However, these procedures required some amount of judgement on the part of the user in an attempt to standardize the products. It was hoped that with more intensive levels of computer processing, the analysis of Landsat data could require less human interpretation and results would be more consistent from urban area to area.

Geographic Information System Approach to UA Analysis

The use of an information system for Urbanized Area analysts provide the analyst with additional data for making qualified decisions needed for identifying areas of urban land cover and the position of the outer line. Although Landsat imagery alone is useful in mapping urban land, the use of additional data allows the delineation of outer line to be made more efficiently and accurately. For the Urbanized Area ASVT, the Image Based Information System (IBIS), was utilized to integrate Landsat data and other source materials. (IBIS is a subset of the Video Image Communication & Retrieval (VICAR), digital image processing system developed by JPL).

IBIS is a fully automated raster based information system (Bryant & Zobrist, 1977), comprised of a group of general purpose programs which can be organized logically into processing steps to handle complex spatial problems. With IBIS, raster, tabular and graphical data types can be integrated for the analysis of spatial phenomina (Figure 1). Image data, such as Landsat imagery or scanned aerial photographs, in addition to graphical data, such as maps, are utilized as IBIS data sets. Additionally, tabular forms of data, such as population counts, can be entered into IBIS via a table-structured input.

Digital image processing techniques are utilized to perform most data base storage, retrieval and analysis operations. Spatial registration of image data planes and the removal of distortions related to differing map projections or other spatial aberations are performed by automated rubber sheeting procedures. Consequently, several image planes may be registered to a common plaimetric base for the analysis of geographic phenomina. When combined, these data planes are referred to as the IBIS data base.

Special purpose algorithms have been developed for the overlay, aggregation, and cross-tabulation of data from one image with data from other image planes. These analysis capabilities are further extended by algorithms designed to perform mathematical and logical arithmetric functions. Output products are commonly derived from image data planes and non-image data files. Both pictorial products and tabular listings may be obtained directly from any image data plane, a combination of image data planes, or from a combination of image and non-image data.

The Orlando/Florida Case Study

The population of the Orlando, Florida Standard Metropolitan Statistical Area (SMSA), increased significantly between 1970 and 1975. Consequently, it was expected that a substantial amount of urban area expansion would occur. To determine if any distinguishable features could be detected for locating the optimal position of the outer line, three types of data were integrated —

- Census Tract Boundary Information
- Census Population Statistics
- Thematic Data From Landsat

The derivation or urban expansion information required for this decision involved the completion of 4 processing steps —

- Preparation
- Identification
- Classification
- Data Set Integration (Figure 2)

In the data preparation phase, raw data was read and transformed into a standardized format, and all geometric transformations were effected. As a result, all image data planes were in common registry and could be overlaid during subsequent processing steps. For Landsat data, Computer Compatible Tapes (CCTs) were converted to a standard VICAR image data set format and a study area was extracted and saved for later processing.

To prepare the census data plane, a digitized census tract boundary file was transformed into image space after completion of a spatial rectification routine to insure a precise planimetric fit to the data base.

The identification of urbanized areas from Landsat and the census data required the extraction of particular signature information from the source materials. Spectral signatures for urban and nonurban land were derived from histogram analysis of the Landsat data (Friedman & Angelici, 1979). For census data, the identification of an urbanized area signature involved more complex processing. First, census tracts* within the Orlando SMSA were identified and measurements for each tract were determined. Then, census population data for 1970 were added enabling the derivation of population density levels through the use of a statistical package in IBIS. Finally, decisions were made, categorizing whether each tract had urban status or not based on a population density cutoff of at least 1,000 people per square mile.

After identification of urban signature characteristics, the data planes were classified. For the Landsat data plane, a thematic map depicting urban and non-urban land was produced through a thematic classification of the data based on the spectral signature information derived previously. The census data plane was processed in a similar manner yielding a map of urbanized census tracts based on computed 1980 population density levels.

The determination of urban expansion between 1970 and 1975 required the integration of the census based (1970), and Landsat based (1975) data planes. The process simply involved the addition of the two thematic data planes and an additional census tract boundary data plane for georeference (Figure 3). The resultant thematic map and a tabular listing (Figure 4), reporting urban expansion proved to be quite useful to the Geography Division.

Extended Applications

Data processing should not be limited to the steps outlined previously, for data may be obtained in many diverse formats, and several types of output products may be desired. In another phase of the study, potential areas of urban expansion were mapped for the Seattle/Everett SMSA. The processing steps were similar to those previously outlined, with the exception that 1975 data was obtained from a land cover classification of Landsat data provided by the US Geological Survey (Gaydos & Newland, 1978). The Census Bureau hopes to minimize their data processing load by utilizing all sources of classified Landsat data. As in the Orlando case study, the final maps depicting urban expansion between 1970 & 1975 appeared to be quite useful for locating the position of a new outer line.

The utilization of population density values as measured by census tract can only provide a rough approximation of the urbanized area boundary. The Geography Division must consider other more detailed geographic parameters when determining the urban fringe. In a final application covering the urban megalopolis surrounding Boston, Massachusetts, the actual 1970 urbanized area boundary for 7 individual SMSAs were digitized and converted into image format. This data plane was integrated with Landsat and other census data to indicate areas where urban expansion might have occurred since 1970.

Conclusion

The urban expansion maps and tabular listings generated through the implementation of IBIS are considered to be a significant advancement for UA analysis when compared to products generated from Landsat imagery alone. A geographic reference can be displayed in conjunction with land cover information. In most cases, data obtained from several diverse sources will not need to be analyzed independently as previously required for UA outer line delineation procedures. Furthermore, the outer line update process is now based on a set of procedures which can be repeated for any geographic region, permitting the evaluation of all urban fringe zones in a unified and consistent manner.

Another advantage of the system is the ability to build the data base over a period of time. New data planes obtained from various sources can always be added. Consequently, the development of a dynamic data base is possible. Urban expansion over several periods of time can be monitored, and urban expansion predictions may even become possible in the future.

The Bureau of Census' response to the IBIS methodology for mapping the outer line was favorable —

> "The Geography Division considers a geographic information system where the data sources can be integrated by means of graphic screen displays and tabular listings to be a useful addition to their analysis capabilities. Possible system inputs are either land cover or change classification maps overlaid with choroplethic displays of population density. The information system provides a method to synthesize Landsat and other data in an optimum format to enable the user to make quick, reliable decisions with a minimum of interpretation" (Davis & Friedman, 1979)

Continued development of the methodology for mapping the outer line may lead towards implementation of an operational system at the Census Bureau.

* In this example, census tracts are used as units to display rural and urban area. Under actual working conditions, the geographic components of the urban fringe zone would be smaller units such as enumeration districts, block groups and blocks.

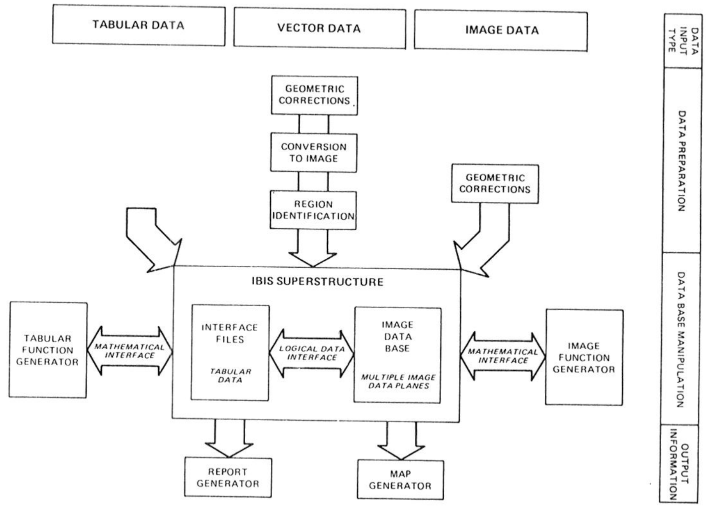

Figure 1 A configuration diagram of Image Based Information System. Major features of IBIS, including data input, data preparation, data base manipulation and data output are depicted.

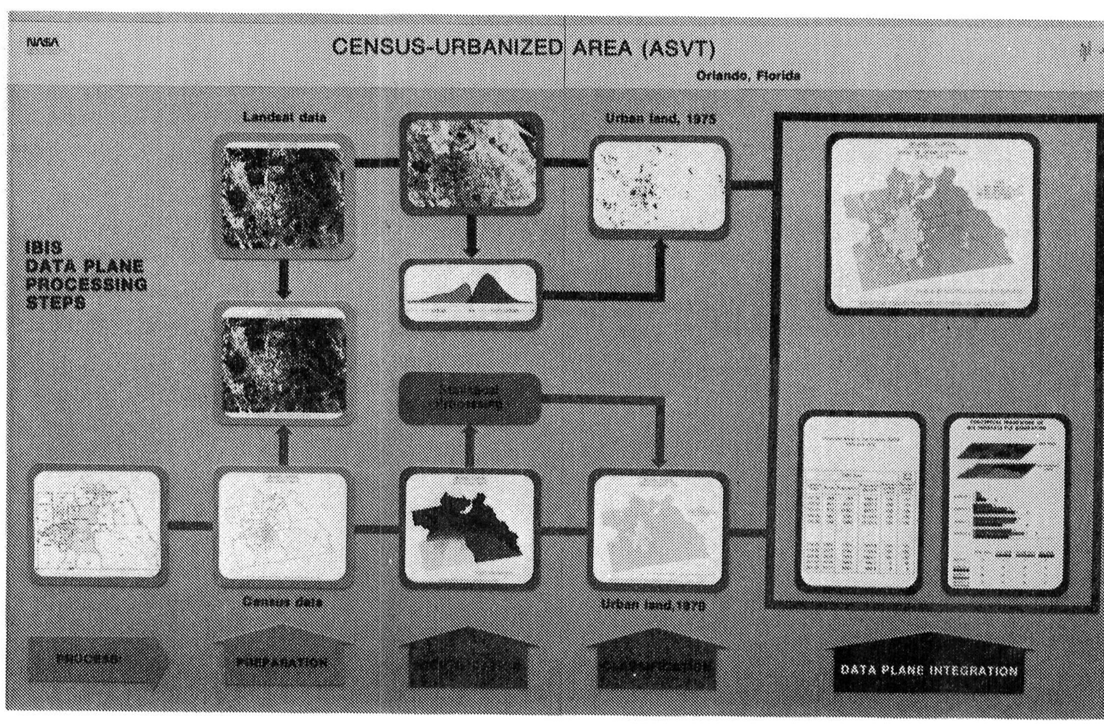

Figure 2 Overview of data processing for the Orlando case study

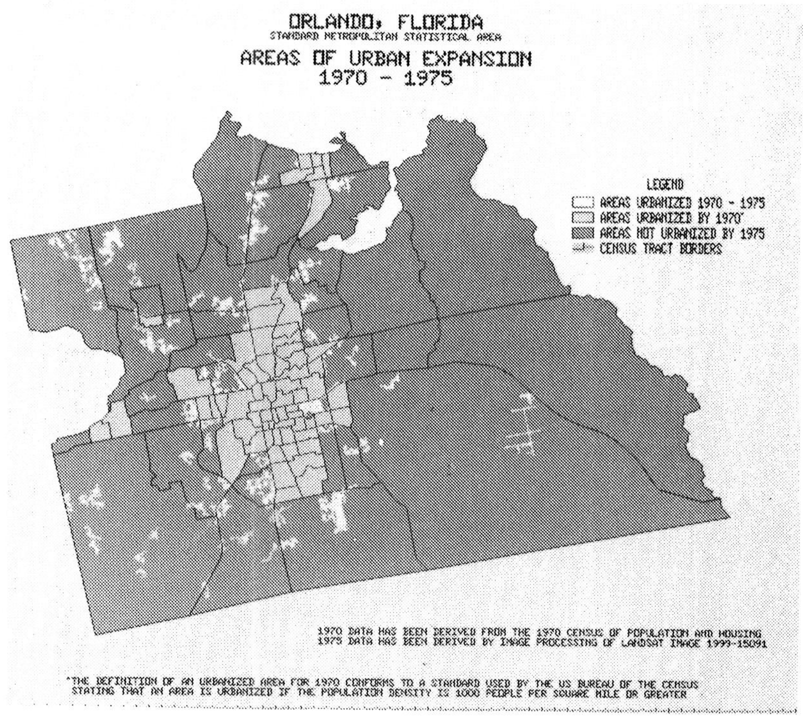

Figure 3 Integration of 1970 & 1975 data plane results in the depiction of urban area expansion between 1970–1975

URBANIZED LAND COVER STATISTICS FOR THE ORLANDO SMSA
ORLANDO, FLORIDA
1970 AND 1975

1970 STATISTICS BASED ON THE 1970 CENSUS OF POPULATION AND HOUSING
1975 STATISTICS BASED ON URBAN CHANGE DETECTION FROM LANDSAT IMAGERY

			1970 POPULATION STATISTICS		1970 URBANIZED LAND COVER STATISTICS		1975 URBANIZED LAND COVER STATISTICS		URBANIZED LAND COVER CHANGE BETWEEN 1970 AND 1975		
---	CENSUS TRACT NUMBER	TOTAL ACRES PER TRACT	NUMBERS OF PEOPLE	DENSITY PER MILE SQUARED	ACRES	PCT	ACRES	PCT	ACRES	PCT	MAJOR
102	NO TRACT	1161155	0	0.0	0	0.0	0	0.0	0	0.0	
66	166.00	89141	2224	16.1	0	0.0	6	0.0	6	100.0	
91	212.00	64934	2131	21.0	0	0.0	0	0.0	0	0.0	
67	167.00	157858	7379	29.9	0	0.0	1483	0.9	1483	100.0	
71	171.00	76679	3817	31.9	0	0.0	2406	3.1	2406	100.0	
96	207.00	21553	1637	48.6	0	0.0	671	3.1	671	100.0	
89	210.00	11803	943	51.1	0	0.0	684	5.8	684	100.0	
79	179.00	30373	3533	74.4	0	0.0	2026	6.7	2026	100.0	
70	170.00	24780	3345	86.4	0	0.0	1351	5.5	1351	100.0	
92	213.00	26394	3620	87.8	0	0.0	0	0.0	0	0.0	
78	178.00	30054	4600	98.0	0	0.0	1694	5.6	1694	100.0	
69	168.00	41116	5369	99.1	0	0.0	2864	7.0	2864	100.0	
48	146.00	15705	3373	137.5	0	0.0	1278	8.1	1278	100.0	
93	214.00	6035	1650	175.0	0	0.0	636	10.5	636	100.0	YES
95	216.00	11830	3519	190.4	0	0.0	1253	10.6	1253	100.0	YES
97	208.00	12496	3889	199.2	0	0.0	1383	11.1	1383	100.0	YES
35	135.00	5125	1717	214.4	0	0.0	442	8.6	442	100.0	
85	206.00	4349	1461	215.0	0	0.0	294	6.8	294	100.0	
75	175.00	14725	5823	253.1	0	0.0	1327	9.0	1327	100.0	
65	165.00	9319	4067	279.3	0	0.0	0	0.0	0	0.0	
64	164.00	7420	3959	341.5	0	0.0	687	9.3	687	100.0	
49	149.00	5100	2908	364.9	0	0.0	739	14.5	739	100.0	YES
72	172.00	1749	1007	368.5	0	0.0	0	0.0	0	0.0	
24	124.00	3575	2610	467.3	0	0.0	1260	35.3	1260	100.0	YES
90	211.00	3545	2345	513.6	0	0.0	0	0.0	0	0.0	
31	131.00	1503	1259	535.9	0	0.0	1048	69.7	1048	100.0	YES
100	221.00	4526	3865	546.5	0	0.0	726	16.0	726	100.0	YES
47	147.00	3437	3031	564.3	0	0.0	662	19.2	662	100.0	YES
50	150.00	5014	4558	581.8	0	0.0	146	2.9	146	100.0	
94	215.00	5227	4940	604.9	0	0.0	285	5.4	285	100.0	
101	222.00	5517	5693	660.4	0	0.0	480	8.7	480	100.0	
77	177.00	2795	3197	732.1	0	0.0	72	2.6	72	100.0	
96	217.00	4735	5620	764.5	0	0.0	489	10.4	489	100.0	YES
51	151.00	5075	6331	798.4	0	0.0	130	2.6	130	100.0	
45	145.00	1702	2127	800.0	0	0.0	403	23.7	403	100.0	YES
69	169.00	3943	5371	871.9	0	0.0	1374	34.9	1374	100.0	YES
36	136.00	4247	5801	874.1	0	0.0	301	7.1	301	100.0	
41	141.00	2484	4045	1042.2	2484	100.0	2484	100.0	0	0.0	
23	123.00	3629	6458	1140.5	3629	100.0	3629	100.0	0	0.0	

Figure 4 Portion of Tabular Report containing indicators of potential urban land area expansion for Orlando SMSA