On-Board Image Compression

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On-board image compression has seen limited use on NASA spacecraft. An example of successful on-board compression was the system designed at the Goddard Space Flight Center and flown on the Radio Astrononmy Explorer in lunar orbit (RAE-2) in 1973. In this case, the image compressed was that of the long flexible radio-astrononmy boom antennae that also provided gravity-gradient stabilization. The requirement for compression in this case came about because of the mismatch between the output data rate of the on-board camera system and the down-link communication channel. As data rates from future imaging sensors increase, the need for on-board compression will become a more common requirement.

An obvious first approach to on-board image compression is to find a compression algorithm that will provide the highest possible compression ratio. But the compression ratio cannot be increased beyond a certain point without introducing some distortion in the reconstructed, or decompressed, image. For a given image, this point is defined as the entropy, which is really the average information expressed in bits per pixel. From the statistics of the image, one can compute the entropy and from it obtain a prediction of the maximum compression ratio (for example, if the entropy is 4 bits/pixel and the uncompressed system would normally use 8 bits/pixel then the maximum compression ratio is 2:1). The utility of computing the entropy is that is tells one when to stop increasing the compression ratio if only little or no distortion is a system requirement. Because of the fact that the entropy represents a critical point, the maximum compression ratio, data compression schemes base been classified into two basic types: redundancy reduction (RR) and entropy reduction (ER). The former produce compression ratios below the theoretical maximum, and the latter, above it. In actual practice, there are also compression schemes which are combinations of RR and ER.

In selecting, designing and implementing an on-board compression scheme, a number of considerations and tradeoffs have to be investigated. As indicated above, the compression ratio must be traded of against the allowable residual distortion in the reconstructed image. The type and magnitude of this allowable distortion depends directly on the particular application of the imagery that is planned. An included question is the effect of this distortion on radiometric and geometric correction. The compression ratio also has to be traded off against the complexity of the on-board design. This includes such considerations as adaptive vs non-adaptive compression, the number of arithmetic operations per pixel, buffer storage and the need for error-control coding to protect the compressed data from communication channel errors.

ON-BOARD IMAGE COMPRESSION

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TOPICS

- BRIEF HISTORY OF ON-BOARD IMAGE COMPRESSION
- THE THEORETICAL MAXIMUM COMPRESSION RATIO
- CLASSES OF DATA COMPRESSION
- TRADEOFF ISSUES

WHAT IS DATA COMPRESSION?

DATA COMPRESSION IS THE REDUCTION OF:

- DATA VOLUME (SUCH AS IN A STORAGE MEDIUM)
- DATA TRANSMISSION TIME (SEC.)
- DATA TRANSMISSION RATE (BITS/SEC.)

  WHERE VOLUME = f(TIME X RATE)

DATA COMPRESSION IS ALSO CALLED:

- DATA COMPACTION
- SOURCE CODING

EXAMPLES:

- FACSIMILE - TIME REDUCTION
- VOICE - RATE (BANDWIDTH) REDUCTION

CLASSES OF DATA COMPRESSION

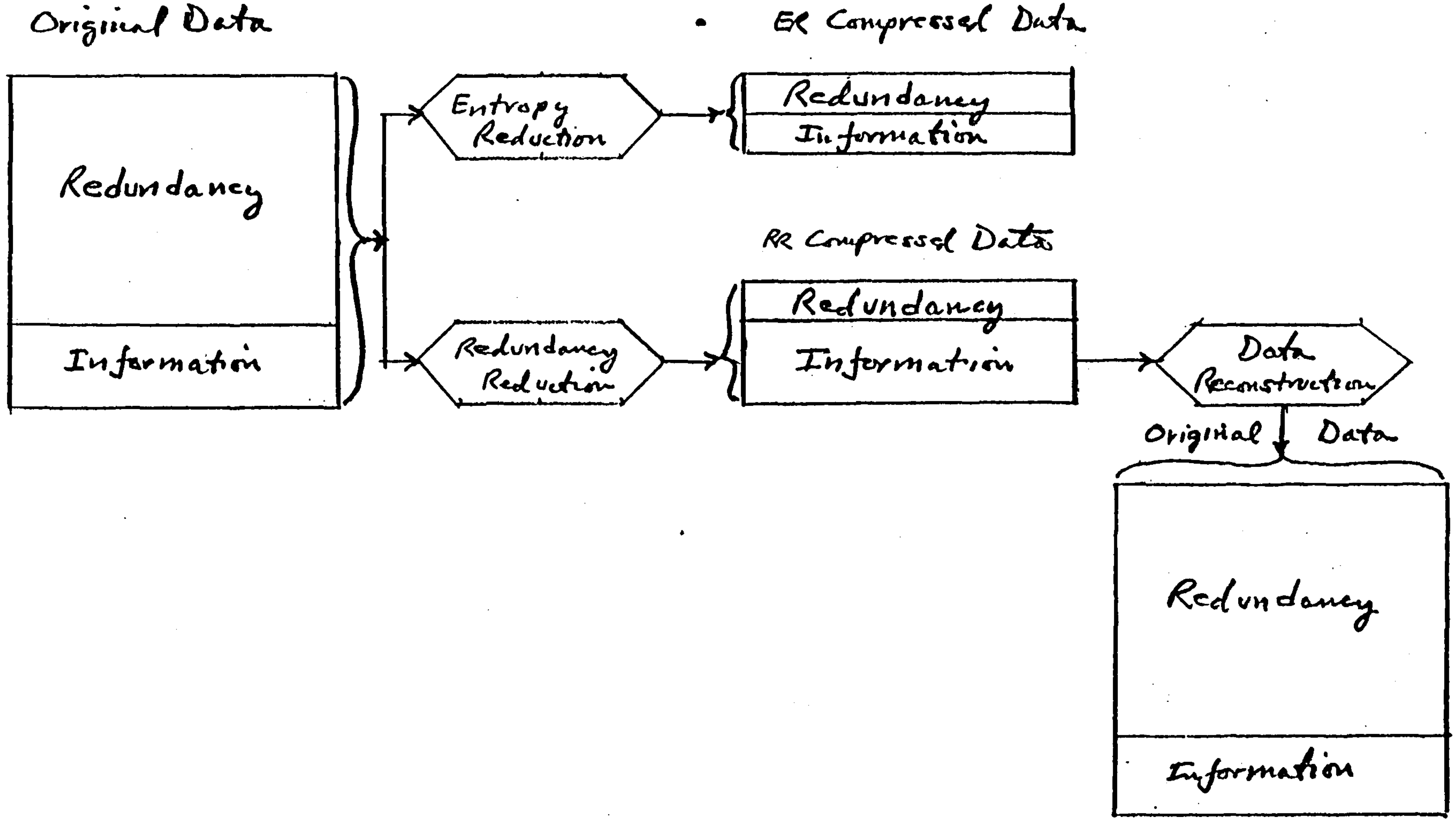
THERE ARE TWO CLASSES OF DATA COMPRESSION:

- ENTROPY REDUCTION
- REDUNDANCY REDUCTION

ENTROPY REDUCTION REDUCES THE AVERAGE INFORMATION IN THE DATA. THE INFORMATOIN THAT IS LOST CANNOT BE RECOVERED, SO THAT ENTROPY REDUCTION IS IRREVERSIBLE.

REDUNDANCY REDUCTION REDUCES OR REMOVES THE REDUNDANCY IN THE DATA IN SUCH A WAY THAT IT CAN BE PUT BACK AT A LATER TIME. IN THIS WAY, REDUNDANCY REDUCTION IS REVERSIBLE.

TWO TYPES OF DATA COMPRESSION



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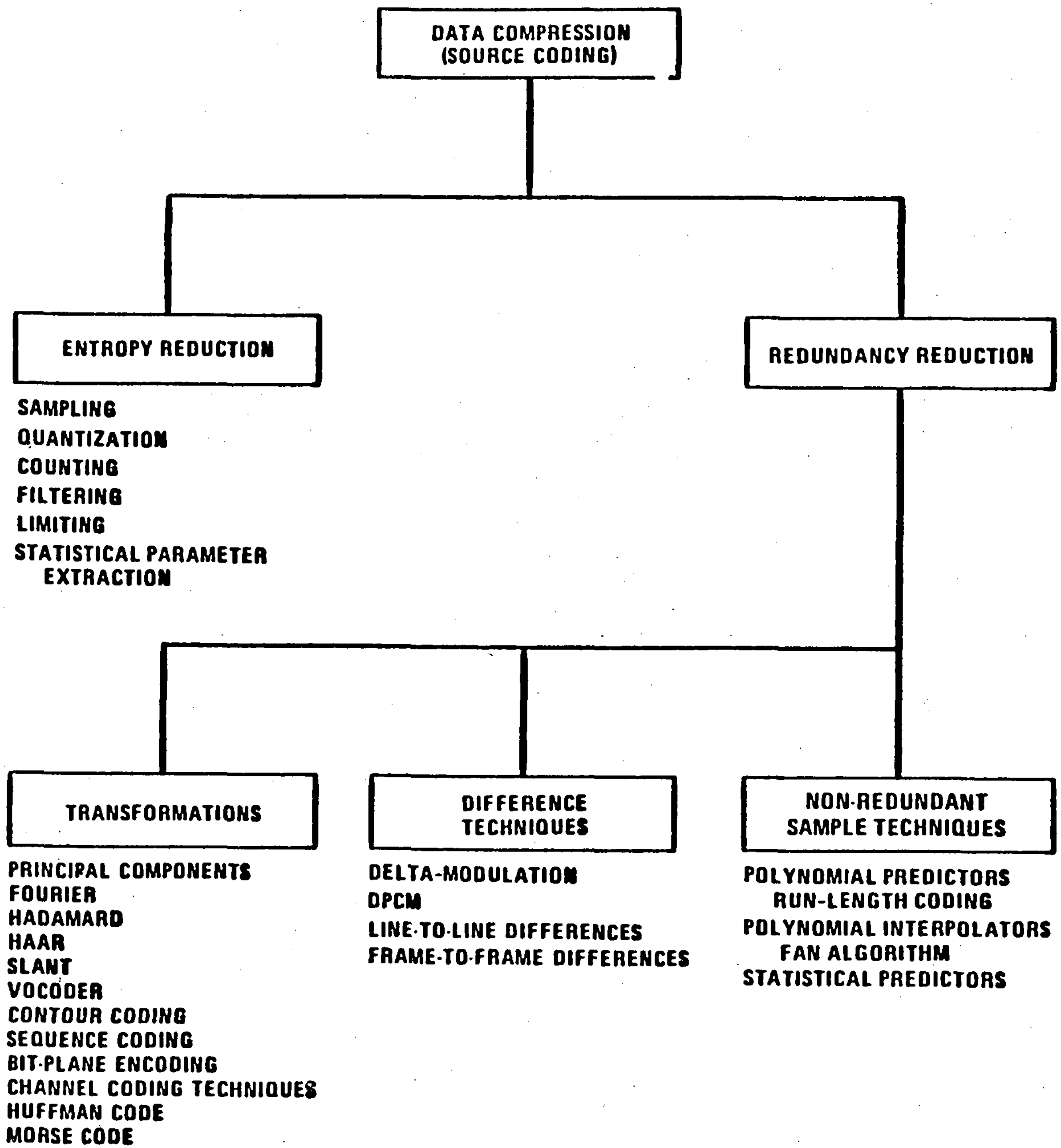


Classes of Data Compression

THE RADIO ASTRONOMY EXPLORER -2 ON-BOARD COMPRESSION

- ON RAE-2 IN LUNAR ORBIT - 1973
- COMPRESSED PANORAMIC CAMERA IMAGE OF ANTENNA BOOMS AND MOON*
- REQUIRED COMPRESSION RATIO: 32:1
  (CAMERA OUTPUT: 20,000 BPS; DOWNLINK: 625 BPS)
- USED A COMBINATION OF:
  ENTROPY REDUCTION: SKIP 3 OUT OF 4 SCAN LINES (4:1)
  REDUNDANCY REDUCTION: ADAPTIVE RUN-LENGTH CODING OF SAVED LINE (8:1)
- CONVOLUTIONALLY ENCODED FOR CHANNEL ERROR PROTECTION
- VOLUME: 1000 CM^3; POWER: 0.4W; CMOS TECHNOLOGY

*"ON-BOARD IMAGE COMPRESSION FOR THE RAE LUNAR MISSION," W. H. MILLER, T. J. LYNCH, IEEE TRANS. ON AEROSPACE AND ELECTRONIC SYS., VOL. AES-12, NO. 3, MAY 1976, PP 327-335

ENTROPY

INFORMATION IS DEFINED IN TERMS OF THE LOGARITHM OF THE PROBABILITY OF A GIVEN OUTPUT FROM A DATA SOURCE.

FOR A MEMORYLESS SOURCE (ALL OUTPUTS ARE INDEPENDENT):

$$I_i = -\log_2 P_i$$

WHERE I_i IS THE INFORMATION OF THE i^{TH} OUTPUT, P_i IS THE PROBABILITY OF THE i^{TH} OUTPUT

ENTROPY IS THE AVERAGE INFORMATION

FOR A MEMORYLESS SOURCE:

$$H_I = -\sum_{i=1}^{M} P_i \log_2 P_i$$

WHERE H_I IS THE ENTROPY OF THE SOURCE, M IS THE NUMBER OF POSSIBLE OUTPUTS

FOR A SOURCE WITH MEMORY, ASSUMING A FIRST ORDER MARKOV MODEL:

$$H_{(Y/X)} = -\sum_{i=1}^{M} \sum_{j=1}^{M} P(i,j) \log_2 P(j/i)$$

WHERE $P(i,j) = P(i)\, P(j/i)$

MAXIMUM COMPRESSION RATIO

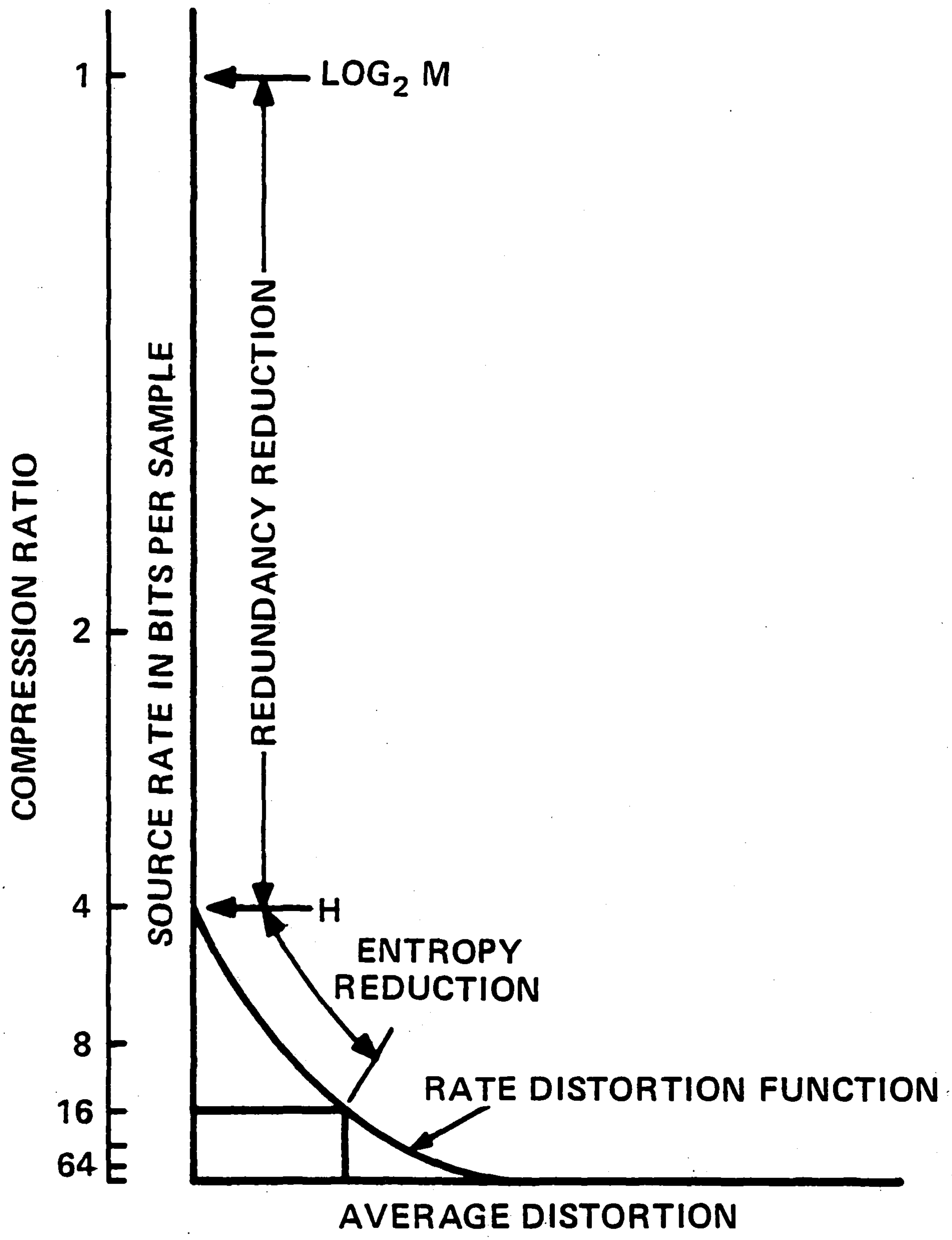
$$\text{ACTUAL BIT COMPRESSION RATIO} = \frac{\text{NUMBER OF UNCOMPRESSED BITS IN A BLOCK}}{\text{NUMBER OF COMPRESSED BITS IN SAME BLOCK}}$$

$$\text{MAXIMUM COMPRESSION RATIO} = \frac{\text{NUMBER OF UNCOMPRESSED BITS/SAMPLE}}{\text{MINIMUM NUMBER OF BITS/SAMPLE}}$$

$$\text{MAX CR} = \frac{\log_2 M}{H}$$

WHERE M IS THE NUMBER OF LEVELS

H IS THE ENTROPY


COMPRESSION RATIO
SOURCE RATE IN BITS PER SAMPLE
1
2
4
8
16
64
LOG_2 M
REDUNDANCY REDUCTION
H
ENTROPY REDUCTION
RATE DISTORTION FUNCTION
AVERAGE DISTORTION

RECENT MEASUREMENTS OF ENTROPY

ENTROPY MEASUREMENTS MADE FOR 2 IMAGES ORIGINALLY AT 3 METER RESOLUTION*

NATURAL (GEOLOGICAL) IMAGE

CULTURAL (URBAN) IMAGE

		3M	9M	30M
GEOLOGIC	H_I	5.078	5.059	4.888
	H_M	2.506	3.051	2.853
URBAN	H_I	5.336	5.312	5.128
	H_M	2.725	3.283	2.834

*ENTROPY MEASUREMENTS AND MAXIMUM COMPRESSION RATIO WITH NO DISTORTION, W. H. MILLER, T. J. LYNCH, C. R. KILGORE, GSFC MAY 1982

TRADE-OFF ISSUES

- COMPRESSION RATIO vs DISTORTION
- COMPRESSION RATIO vs COMPLEXITY
- COMPRESSION SCHEME vs TECHNOLOGY SPEED LIMITATION

COMPRESSION vs DISTORTION

- o EFFECT ON SPATIAL RESOLUTION
  - E.G. EDGE BLUR
- o EFFECT ON RADIOMETRIC RESOLUTION/ACCURACY
  - E.G. AMPLITUDE OFFSET DUE TO:
    - UNCORRECTED CHANNEL ERRORS
- o POSSIBLE ARTIFACTS IN RECONSTRUCTED IMAGE DUE TO ATMOSPHERIC EFFECTS

COMPRESSION vs COMPLEXITY

- ADAPTIVE vs NON-ADAPTIVE
- NUMBER OF OPERATIONS PER PIXEL
- BUFFER STORAGE
- ERROR CONTROL

Modular Data Transport System (MDTS)

COMPARISON GaAs/Si MULTIPLIER (8 x 8)

	Si(TTL)	Si(ECL)	GaAs
MULTIPLY TIME (TWO 8 BIT NO.)	45ns	19ns	6ns
POWER	0.9w	4.4w	0.3w
MANUFACTURER	MMI	MOTOROLA	ROCKWELL

USGS REMOTE IMAGE PROCESSING SYSTEM (RIPS)

- o RIPS PROCESSORS BASED ON CROMEMCO Z80 MICROCOMPUTERS WILL PROVIDE IMAGE ANALYSIS CAPABILITIES AT USGS CENTERS

- o RIPS PROCESSORS COMMUNICATE WITH ONE ANOTHER AND THE HP3000 BASED IDIMS SYSTEM AT EROS DATA CENTER VIA A PROTOCOL THAT HAS PROVISIONS FOR DATA COMPRESSION AND ERROR CORRECTION

- o EROS DATA CENTER WILL PROVIDE PORTIONS OF LANDSAT SCENES (256x240x4 BANDS) ON 8" FLOPPY DISKS

- DISPLAY RESOLUTION

  96x140x6 - 512x512x16,000,000

- MICROPROCESSORS

  6502 1Mz - 68000 8Mz

- MEMORY SIZE

  64K - 2000 K

- SOFTWARE

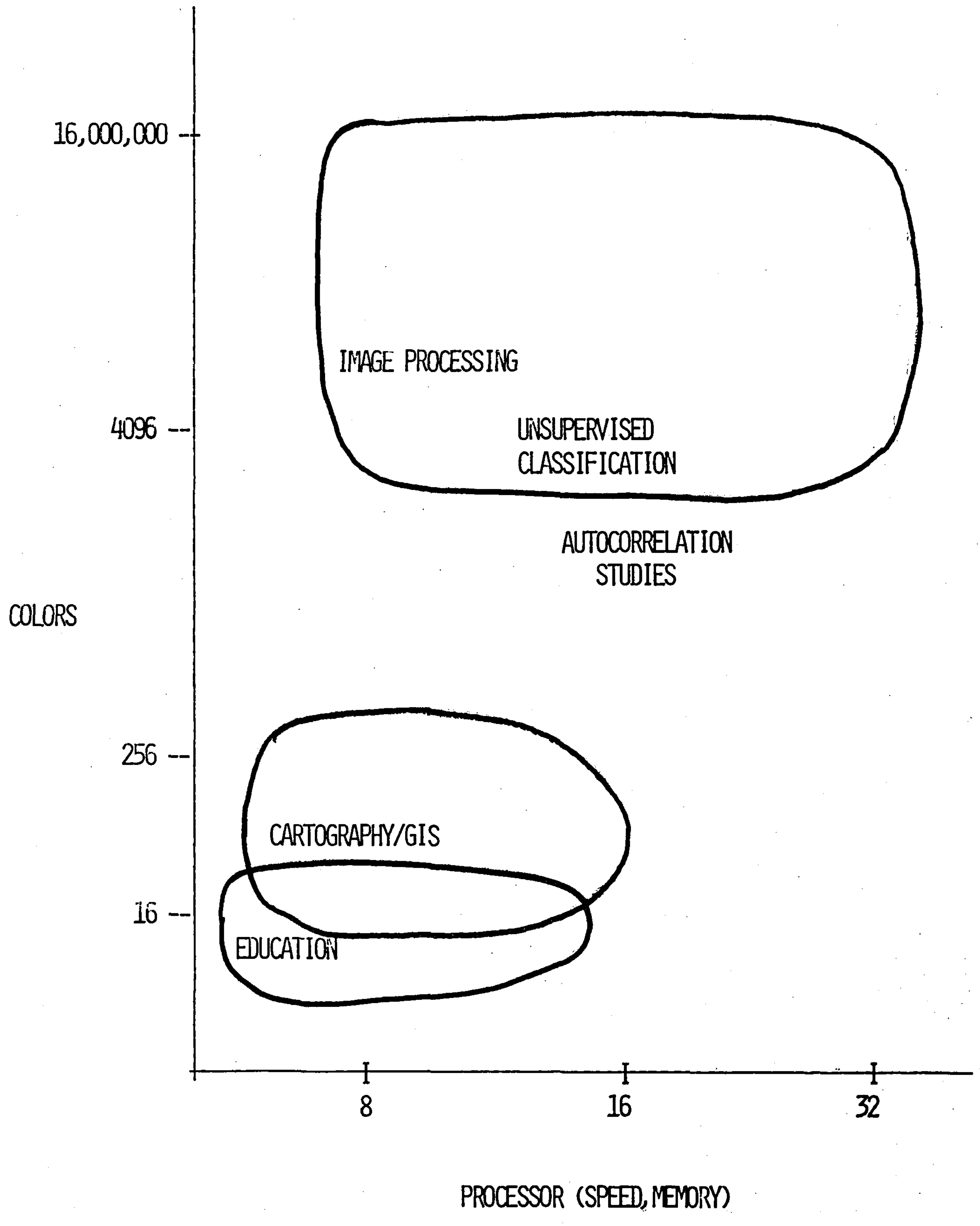
  IMAGE ANALYSIS - GEOGRAPHIC INFORMATION SYSTEMS
  ASSEMBLY LANGUAGE - FORTRAN

- PERIPHERALS

  9 TRACK TAPE DRIVE
  HARD DISK 5-300 MBYTES
  FLOPPY DISK 80-1MBYTE

- COST

  $4000-$45,000


16,000,000
4096
256
16
COLORS
IMAGE PROCESSING
UNSUPERVISED
CLASSIFICATION
AUTOCORRELATION
STUDIES
CARTOGRAPHY/GIS
EDUCATION
8
16
32
PROCESSOR (SPEED, MEMORY)

SYSTEM	APPLEPIPS	AIPE	MIPS	IMPAC
DISPLAY RESOLUTION	96x140 PIXELX x 6 COLORS	40x40x16	80x160x16	128x120x16
IMAGE SIZE	192x280 PIXELS x 4 BANDS	40x40x4	80x160x4	128x128x16
COMPUTER	APPLE II	APPLE II	ATARI 800	VECTOR MZ
MEMORY	64 K	64 K	64 K	64 K
DISK STORAGE	124 K	124 K	80 K	630 K
LANGUAGE	BASIC, ASSEMBLY	BASIC	BASIC, ASSEMBLY	FORTRAN
SOURCE CODE	BASIC ONLY	BASIC	BASIC, ASSEMBLY	NOT AVAILABLE
COST (HARDWARE, SOFTWARE)	$3,650	$3,150	$2,600	$13,000
CONTACT	TELESYS GROUP	FRED GUNTHER	E.J. MASUOKA	EGBERT SCIENTIFIC SOFTWARE

	APPLEPIPS	MIPS	IMPAC
DENSITY SLICE	1	1	1
IMAGE ALGEBRA	1	1	1
HISTOGRAM	1	1	
FILTERING	2		
HARDCOPY GRAPHICS	2	1	1
COMMUNICATIONS ROUTINES	1	1	2
CLASSIFIERS:			
PARALLELPIPED	1	1	1
MINIMUM DISTANCE	2		
MAXIMUM LIKELIHOOD	2		2
UNSUPERVISED CLUTTERING	2		2
PRINICPAL COMPONENTS			2

1 = STANDARD SYSTEM

2 = OPTIONAL AND/OR UNDER-DEVELOPMENT

SYSTEM	ERIM	RIPS	ERDAS
DISPLAY RESOLUTION	240x256 PIXELS 256 COLORS	256x242x4096	256x240x32,000 w/1 GRAPHICS PLANE 512x480x16
IMAGE SIZE	LIMITED BY DISK STORAGE	256x240x4 BANDS	LIMITED BY DISK STORAGE
COMPUTER	CROMEMCO Z80	CROMEMCO Z80	CROMEMCO Z80
MEMORY	64 K	64 K	64 K
FLOPPY DISK STORAGE	780 K	780 K	780 K
HARD DISK STORAGE	10 M	--	16 M, 80 M
9 TRACK TAPE DRIVE	YES	--	YES
FLOATING POINT PROCESSOR	--	--	YES
LANGUAGES	FORTRAN, ASSEMBLY	FORTRAN, ASSEMBLY	FORTRAN, ASSEMBLY
SOURCE CODE	NOT AVAILABLE	YES	APPLICATIONS PROGRAM ONLY
COST	$25,000	$21,000	$45,000-$65,000
CONTACT	ERIM	EROS DATA CENTER	ERDAS

	RIPS	ERIM	ERDAS
FALSE COLOR DISPLAY	X	X	X
COLOR SLICED DISPLAY	X	X	X
GRAY LEVEL MAPS	X	X	X
HISTOGRAMS	X	X	X
RATIOS	X	X	X
CONTRAST ENHANCEMENT	X	X	X
FILTERING	X		X
SMOOTHING	X		X
IMAGE RECTIFICATION			X
CLASSIFICATION:			
MAXIMUM LIKELIHOOD		X	X
MINIMUM DISTANCE			X
SUITS WAGNER ALGORITHM	X		
UNSUPERVISED CLUSTERING			X
G.I.S. FUNCTIONS	NONE	UNDER DEVELOPMENT	IMGRID

SYSTEM	GAS	MIDAS
DISPLAY RESOLUTION	256x242x4096	512x512x16,000,000
MICROPROCESSORS	8086/8087,Z80	68000/8087
MEMORY	2.5 MBYTES	2 MBYTES
FLOPPY DISK	1 M	
HARD DISK	160 M	160 M
TAPE DRIVE	9 TRACK 25 IPS	
LANGUAGE	FORTRAN	FORTRAN
USERS	3	1
COST	$31,000	$36,600
CONTACT	E.J. MASUOKA/GSFC	WALT DONOVAN, INFORMATICS, INC. LARRY HOFFMAN, NASA/AMES