SPACE STATION WILL HAVE REQUIREMENTS FOR CONDUCTING SUCH MANIPULATION/OBSERVATION ACTIVITIES AS CONSTRUCTION, MAINTENANCE, MANUFACTURING, EXPERIMENTS, RENDEZVOUS AND DOCKING, POINTING AND TRACKING, TARGET ACQUISITION/IDENTIFICATION, AND SOLAR SYSTEM OBSERVATIONS. INITIALLY, MOST OF THESE MANIPULATIONS/OBSERVATIONS WILL REQUIRE A MAN-IN-THE-LOOP WITH VIDEO DISPLAY, WHICH IN TURN WILL REQUIRE REAL-TIME PROCESSING OF DATA AND INFORMATION FOR VISUAL PRESENTATION WILL IMPROVE MAN’S OPERATIONAL CAPABILITIES. AS THE SPACE STATION MATURES, SOME OF THESE OPERATIONS WILL BECOME NEARLY AUTONOMOUS WITH MAN MONITORING, WHICH WILL CREATE AN ADDITIONAL NEED FOR REAL-TIME PROCESSING AT DATA RATES EXCEEDING 100 MBITS/SEC. PROCESSING AT SUCH HIGH RATES WILL MOST LIKELY BE ACCOMPLISHED BY SPECIAL PURPOSE COMPUTING IMPLEMENTING COMPUTATIONALLY SIMPLE ALGORITHMS. CURRENT TECHNOLOGY PROJECTIONS INDICATE THE LACK OF AVAILABILITY OF SUCH SPECIAL PURPOSE COMPUTING IN THE EARLY 1990S, AND NASA NEEDS TO ACCELERATE THIS TECHNOLOGY FOR APPLICATION TO SPACE STATION. POTENTIAL FUNCTIONS FOR VIDEO IMAGE SPECIAL PURPOSE PROCESSING ARE BEING INVESTIGATED, SUCH AS SMOOTHING, ENHANCEMENT, RESTORATION AND FILTERING, DATA COMPRESSION, FEATURE EXTRACTION, OBJECT DETECTION AND IDENTIFICATION, PIXEL INTERPOLATION/EXTRAPOLATION, SPECTRAL ESTIMATION AND FACTORIZATION, AND VISION SYNTHESIS. ALSO, ARCHITECTURAL APPROACHES ARE BEING IDENTIFIED AND A CONCEPTUAL DESIGN GENERATED. COMPUTATIONALLY SIMPLE ALGORITHMS WILL BE RESEARCHED AND THEIR IMAGE/VISION EFFECTIVENESS DETERMINED. SUITABLE ALGORITHMS WILL BE IMPLEMENTED INTO AN OVERALL ARCHITECTURAL APPROACH THAT WILL PROVIDE IMAGE/VISION PROCESSING AT VIDEO RATES THAT ARE FLEXIBLE, SELECTABLE, AND PROGRAMMABLE.
IMAGE/VISION PROCESSOR

- AUGMENT MAN'S REMOTE WORK CAPABILITIES
- REVIEW AND EDIT OBSERVATIONS
SPACE STATION EVOLUTION

~1990
BUILDUP
~2010
MATURE OPERATIONS

BUILDP OPERATIONS

MAN IN THE LOOP

NEAR AUTONOMOUS
MAN MONITORS

MANIPULATIONS
- CONSTRUCTION
- MAINTENANCE
- MANUFACTURING
- EXPERIMENTS
- RENDEZVOUS AND DOCKING

OBSERVATIONS
- EARTH/SOLAR SYSTEM/DEEP SPACE
- MANUFACTURING
- EXPERIMENTS
- POINTING AND TRACKING
- TARGET ACQUISITION/IDENTIFICATION
SPACE STATION ACTIVITIES NEEDING VIDEO

- CONSTRUCTION
- SATELLITE SERVICING
- RENDEZVOUS
- PROXIMITY OPERATIONS
- COMMUNICATION AND TRACKING
- INSPECTION
- MAINTENANCE
- PAYLOAD DELIVERY/RETRIEVAL
- EXPERIMENT MONITORING
- DATA MANAGEMENT
- TRAINING
EXAMPLE SPACE STATION APPLICATIONS
OF VIDEO IMAGE PROCESSING

RENDEZVOUS
- TARGET IDENTIFICATION
- TARGET TRACKING FOR CROSS RANGE VELOCITY AND POSITION ESTIMATION
- POINT TARGET DETECTION

PROXIMITY OPERATIONS
- TARGET TRACKING FOR TARGET ORIENTATION, POSITION AND VELOCITY ESTIMATION

DATA MANAGEMENT
- BANDWIDTH COMPRESSION FOR DATA MOVEMENT AND ARCHIVING

INSPECTION
- MACHINE VISION TECHNIQUES FOR VERIFICATION OF SPACE STATION STRUCTURAL INTEGRITY AND DETECTION AND CLASSIFICATION OF DEFECTS

COMMUNICATION AND TRACKING
- BANDWIDTH COMPRESSION FOR DOWNLINK TRANSMISSION
- MULTI-TARGET TRACKING FOR AREA TRAFFIC CONTROL
- TARGET DETECTION AND IDENTIFICATION FOR AREA TRAFFIC CONTROL

CONSTRUCTION
- VERIFICATION OF CONSTRUCTION STEPS
VIDEO IMAGE PROCESSOR
506-58-13/N. D. MURRAY

OBJECTIVE

- Research and develop the real-time data and information processing of video image data for space station requirements.

APPROACH

- Investigate potential functions for video rate image/vision special purpose processing, identify architectural approach, and generate a conceptual design. Honeywell

- Research computationally simple algorithms and determine their image/vision effectiveness.

- Implement selected algorithms in special hardware designs and evaluate.

- Using results of proceeding efforts, implement an overall architectural design that will provide image/ vision processing at video rates that are flexible, selectable and programmable.
VIDEO SOURCES

• CAMERAS

INTERNAL

- MODULE CAMERAS
- EXPERIMENT MONITORING

EXTERNAL

- MRMS
- DOCKING PORTS
- LOCAL AREA TRAFFIC MONITORING
- SERVICING FACILITY
- ON MMUS
- OMV/OTV
- FREE FLIERS

• VIDEO STORAGE DEVICES

• UPLINK VIDEO
VIDEO IMAGE PROCESSING IN SPACE STATION

STORE/COMMUNICATION — CAMERAS — CONTROL

VIP — HUMAN INTERVENTION

DISPLAYS

- REAL TIME, 100 MBPS
ALGORITHMS

* PROCESSING
  REMOVAL OF NOISE
  HISTOGRAM
  THRESHOLDING

* ANALYSIS

  STRUCTURAL
  EDGES
  VERTICES
  REGIONS

  STATISTICAL
  DENSITY FUNCTION
  MOMENTS
  CO-OCCURRENCE
  MATRICES

* RECOGNITION
  OBJECTS
  TEXTURES

* UNDERSTANDING
  SCENE DESCRIPTION
  SPATIAL RELATIONSHIP
  MOTION PARAMETERS
NATURE OF PROCESSING

IMAGE:
ORDERED SETS OF NUMBERS

IMAGE FEATURES:
SYMBOLS ASSOCIATED WITH NUMERICAL VALUES
A : 37, 28
B : 20, 73

OBJECTS:
INTERRELATED SYMBOLS (GRAPH)

SCENE:
SEMANTIC NETS
FUNCTIONAL ANALYSIS

GOAL: FUNCTIONAL DECOMPOSITION OF SPACE STATION TASKS AND
DETERMINATION OF COMPUTATIONAL REQUIREMENTS

FEATURES:

- OPERATION THROUGHPUT
- DATA THROUGHPUT
- POTENTIAL PARALLELISM
- DATA DEPENDENT BEHAVIOR
- WORD SIZE REQUIREMENTS
- OPERATION DENSITY, (OPS/PIXEL OR OPS/FEATURE)
- IMPLICATIONS FOR
  - PROCESSING SUPPORT
  - COMMUNICATION REQUIREMENTS
  - CONTROL STRATEGIES
IMAGE ANALYSIS COMPUTATIONAL MODEL

CLASS 1 (ENHANCEMENT) → IMAGES → COMMANDS

CLASS 2 (EXTRACTION) → IMAGES → (FEATURES) DATA STRUCTURES

CLASS 3 (EVALUATION) → RESULTS

DATA STRUCTURES

LOW-LEVEL IMAGE PROCESSING

HIGH-LEVEL IMAGE UNDERSTANDING
PARALLEL TASKS MAY BE FORMULATED BY EXPLOITING PARALLELISM IN THE TRANSFORMATIONS OR DATA STRUCTURES

TRANSFORMATIONS MAY BE CLASSIFIED AS

- IMAGE TO IMAGE (PREPROCESSING)
- IMAGE TO DATA STRUCTURE (DATA REDUCTION)
- DATA STRUCTURE TO DATA STRUCTURE (HIGH LEVEL)
# Image-to-Image Functions

<table>
<thead>
<tr>
<th>Example</th>
<th>MOPS</th>
<th>Data Access Pattern</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detector Compensation</td>
<td>8-9</td>
<td>Fixed, Highly Parallel</td>
</tr>
<tr>
<td>Thresholding</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Filtering</td>
<td>400</td>
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<tr>
<td>Correlation</td>
<td>400</td>
<td></td>
</tr>
<tr>
<td>Edge Detection</td>
<td>400-800</td>
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<tr>
<td>Enhancement</td>
<td>100</td>
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<tr>
<td>Change Detection</td>
<td>8</td>
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<tr>
<td><strong>IMAGE-TO-IMAGE FUNCTIONS (CONTINUED)</strong></td>
<td></td>
<td></td>
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<tr>
<td>------------------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- DATA DEPENDENCIES</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- VERY LOW</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- WORD SIZE REQUIREMENTS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- PIXEL RESOLUTION</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- OPERATION DENSITY</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- 10-10(^2) OPS/PIXEL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- PROCESSING SUPPORT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- SIMPLE ARITHMETIC OPERATIONS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- COMMUNICATION</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- FIXED, PREDETERMINED</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- CONTROL STRATEGIES</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- SYNCHRONOUS, SIMD</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### IMAGE-TO-DATA STRUCTURE FUNCTIONS

<table>
<thead>
<tr>
<th>EXAMPLES</th>
<th>MOPS</th>
<th>DATA ACCESS PATTERN</th>
</tr>
</thead>
<tbody>
<tr>
<td>REGION GROWING</td>
<td>20-30</td>
<td>CONSTRAINED</td>
</tr>
<tr>
<td>LINE AND SHAPE DETECTION (HOUGH TRANSFORM)</td>
<td>200-300</td>
<td>FIXED</td>
</tr>
<tr>
<td>ENCODING VIA</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>- QUAD TREES</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>- RECTANGLE CODES</td>
<td>30</td>
<td>PREDETERMINED</td>
</tr>
<tr>
<td>STATISTICS</td>
<td></td>
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</tbody>
</table>
**IMAGE-TO-DATA STRUCTURE FUNCTIONS**
(Continued)

<table>
<thead>
<tr>
<th>Category</th>
<th>Details</th>
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<tbody>
<tr>
<td>DATA DEPENDENCIES</td>
<td>TENDS TO BE HIGH</td>
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<tr>
<td>WORD SIZE REQUIREMENTS</td>
<td>16 BITS</td>
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<tr>
<td>OPERATION DENSITY</td>
<td>$10^{-3}$ OPS/FEATURE</td>
</tr>
<tr>
<td>PROCESSING SUPPORT</td>
<td>ARITHMETIC, SOME LOGICAL, LIMITED FLOATING POINT</td>
</tr>
<tr>
<td>COMMUNICATION</td>
<td>CAN BE STRUCTURED IN A MANNER THAT CAN BE PREDETERMINED</td>
</tr>
<tr>
<td>CONTROL STRATEGIES</td>
<td>INCLINED TOWARD MIMD</td>
</tr>
</tbody>
</table>
## DATA STRUCTURE-TO-DATA STRUCTURE FUNCTIONS

<table>
<thead>
<tr>
<th>EXAMPLES</th>
<th>MOPS</th>
<th>DATE ACCESS PATTERN</th>
</tr>
</thead>
<tbody>
<tr>
<td>• MATCHING DESCRIPTIONS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- GRAPHS</td>
<td>1-3</td>
<td>PREDETERMINED</td>
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<tr>
<td>- CONTOURS</td>
<td>20-30</td>
<td>PREDETERMINED</td>
</tr>
<tr>
<td>• MATCHING FEATURE VECTORS</td>
<td>1-2</td>
<td>FIXED</td>
</tr>
<tr>
<td>• 3-D STRUCTURE</td>
<td>?</td>
<td>UNKNOWN</td>
</tr>
<tr>
<td>• INFERENCE RULE EVALUATION</td>
<td>?</td>
<td>UNKNOWN</td>
</tr>
<tr>
<td>• POSITION ESTIMATION, TRACKING</td>
<td>?</td>
<td>UNKNOWN</td>
</tr>
</tbody>
</table>
DATA STRUCTURE-TO-DATA STRUCTURE
FUNCTIONS (CONTINUED)

- DATA DEPENDENCIES - VERY HIGH
- WORD SIZE REQUIREMENTS - 32-64 BITS
- OPERATION DENSITY - $10^4$-$10^6$ OPS/FEATURE
- PROCESSING SUPPORT - SYMBOLIC OPERATIONS, DATA
  MANIPULATION, NON-NUMERIC OPERATIONS
- COMMUNICATION - DYNAMIC, VARIABLE
- CONTROL STRATEGIES - MIMD
**FUNCTIONAL ANALYSIS SUMMARY**

<table>
<thead>
<tr>
<th>IMAGE TO IMAGE</th>
<th>IMAGE TO DATA STRUCTURE</th>
<th>DATA STRUCTURE TO DATA STRUCTURE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DATA DEPENDENCIES</strong></td>
<td>LOW</td>
<td>MEDIUM</td>
</tr>
<tr>
<td><strong>ACCURACY</strong></td>
<td>PIXEL RESOLUTION</td>
<td>16 BITS</td>
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<tr>
<td><strong>OPERATION DENSITY</strong></td>
<td>10-10^2 OPS/PIXEL</td>
<td>10-10^3 OPS/FEATURE</td>
</tr>
<tr>
<td><strong>DATA THROUGHPUT</strong></td>
<td>8-500 MOPS</td>
<td>10-300 MOPS</td>
</tr>
<tr>
<td><strong>PROCESSING REQUIRED</strong></td>
<td>ARITHMETIC, SIMPLE</td>
<td>ARITHMETIC, LOGICAL</td>
</tr>
<tr>
<td><strong>CONTROL</strong></td>
<td>SYNCHRONOUS (SIMD)</td>
<td>TOWARD MIMD</td>
</tr>
<tr>
<td><strong>COMMUNICATION</strong></td>
<td>FIXED</td>
<td>CAN BE STRUCTURED AND PREDETERMINED</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2-108
FUNCTIONAL ANALYSIS SUMMARY
(CONTINUED)

- MIX OF COMPUTATIONS AND CONTROL STRATEGIES

- INCREASING NON-DETERMINISTIC BEHAVIOR

- SHIFT IN POTENTIAL PARALLELISM FROM DATA TO ALGORITHMS

- PERHAPS CONFLICTING ARCHITECTURAL SOLUTIONS?

- ROLE OF COLOR NEEDS TO BE DETERMINED

- IMPACT OF DYNAMIC AND STATIC NATURE OF DATA STRUCTURES TO BE EVALUATED
Computational Characteristics

10^8 - 10^9 BITS/SEC.
- Enhancement
- Filtering
- Edge Detection
- Histogram
- Vertices
- Statistics

10^3 - 10^5 BITS/SEC.
- Objects
- Matching
- Understanding

10^4 - 10^6 OPS/FEATURE
- Inference
- Searching
- Matching
- Constructing
- Descriptions

Operation Density
- 10 - 10^2 OPS/PIXEL

10^3 - 10^4 FEATURES/SEC.
CONCURRENT PROCESSING ARCHITECTURES

- SPECIAL-PURPOSE PROCESSORS
- WORD-SEQUENTIAL PROCESSORS
- ASSOCIATIVE PROCESSORS
- ARRAY PROCESSORS
- PIPELINE PROCESSORS
- RECONFIGURABLE PROCESSORS
- MULTIPROCESSORS
- DATA FLOW PROCESSORS
- OBJECT-ORIENTED PROCESSORS
- INFERENCE PROCESSORS