SEARCH AND OPTIMIZATION ALGORITHMS FOR BINARY IMAGE COMPRESSION

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6th April 2018

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Outline

- Introduction
- Background
- Block Scan Pattern Search using Binary Particle Swarm Optimization (BPSO)
- Tree Based Search Algorithm
- Simulation Results
- Conclusion
- Future Scope

INTRODUCTION

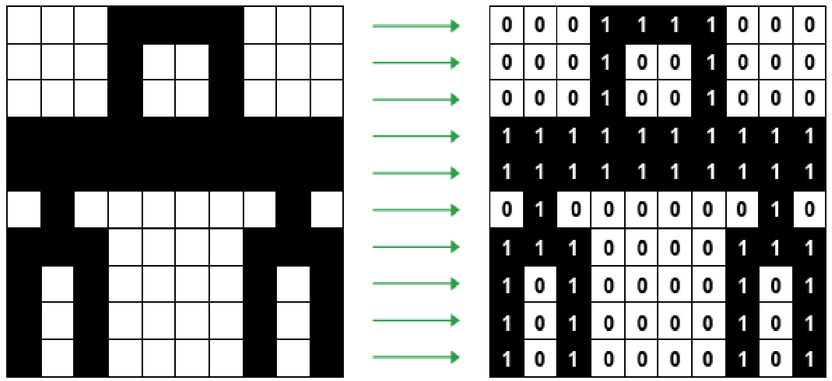
- Massive growth of image data.
- This work focuses on improving the efficiency of lossless compression of binary images.
- Main contribution of this work:

  We propose the use of two optimization algorithms.

  1. Binary particle swarm optimization (BPSO) algorithm which is shown to offer increasingly better compression with additional iterations.
  2. Tree-based search algorithm which searches for best grid structure for adaptively partitioning the image into blocks of varying sizes.

OVERVIEW OF THE PROBLEM

- Images contribute to huge part of data and information.
- Advanced high-resolution cameras capture images with all the intricate details leading to big overall file size.
- Storage and retrieval of data is challenging.
- Digital image compression is concerned with efficient reduction of size of digital images.
- We focus on **Lossless Compression of Binary Images.**
- Binary image: either “0” or “1”.



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APPROACHES

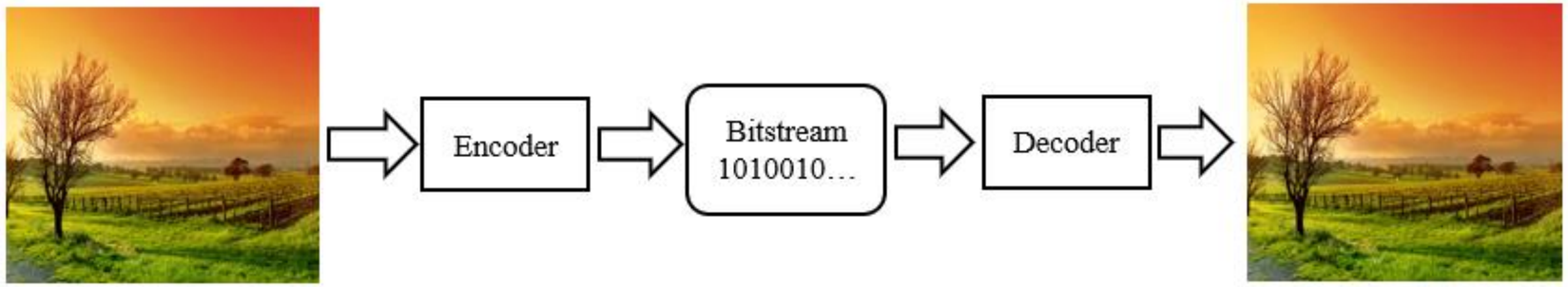
- Insufficient storage and demand for higher transmission rates.
- The images found on the web are compressed in some or other formats.
- The compression techniques used on these images can be classified as:

  Lossless Compression.

  Lossy Compression.
- A basic image compression algorithm:

  Stores the image into a compressed bit-stream, in a way as compact as possible.

  Decode the compressed bitstream to a reconstructed image as exact as possible to the original image.



REDUNDANCIES AND SCANNING PATTERNS

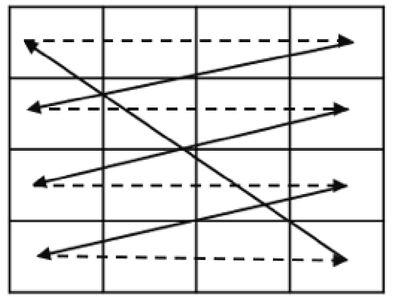
- In general three basic redundancies exist in digital images that follows:

  Inter-pixel redundancy

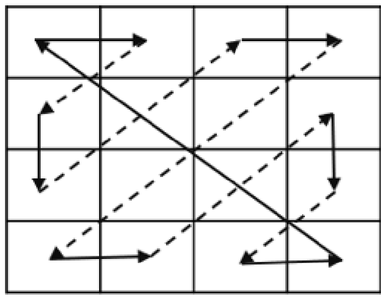
  Temporal redundancy

  Coding redundancy

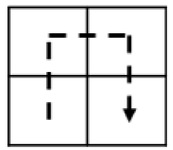
$$L_{avg} = \sum_{k=0}^{L-1} l(r_k)p(r_k)$$

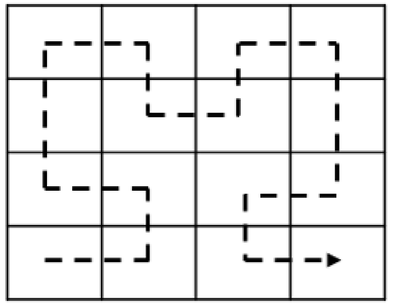


(a) Raster scan



(b) Zig-Zag scan



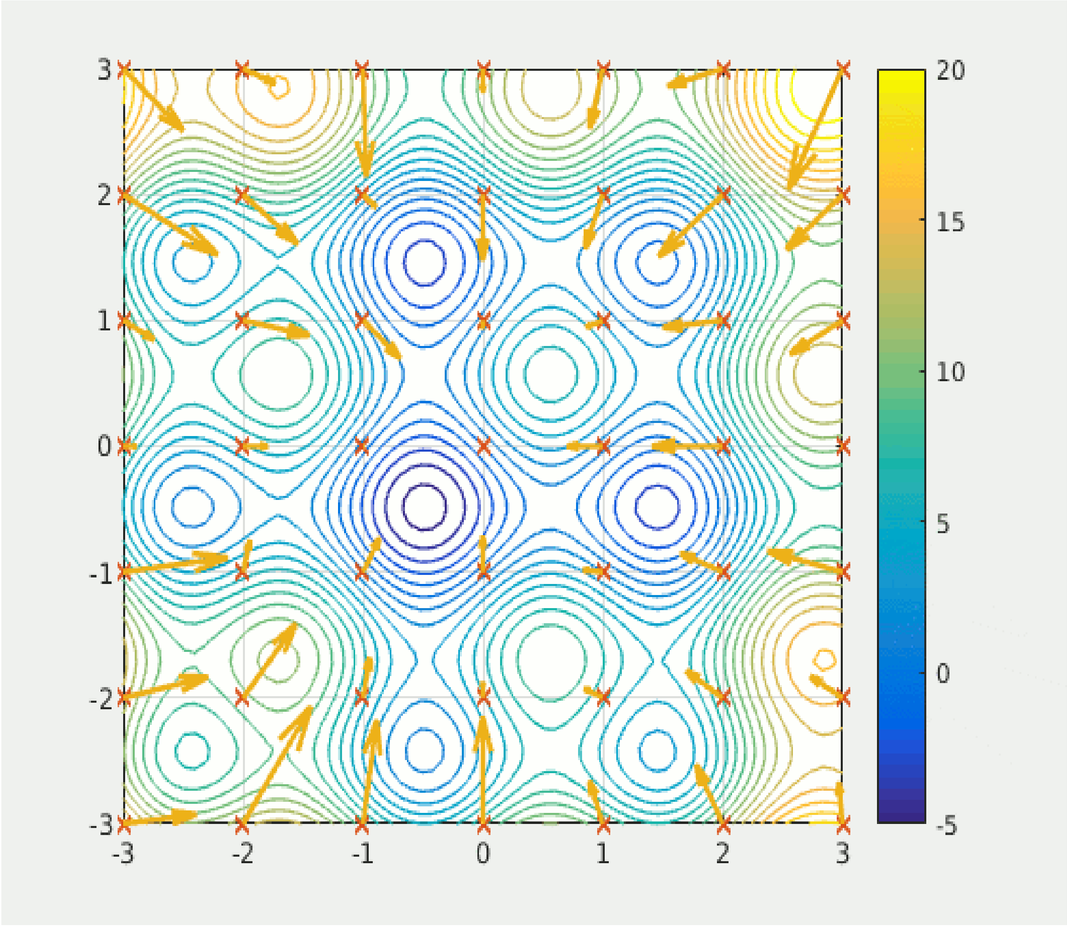


(c) Hilbert Scan

- Scanning patterns are used to traverse the pixels prior to coding.
- As the values of the pixels are non-homogenous in real images, different scanning patterns can lead to different inter-pixel redundancies.

OPTIMIZATION ALGORITHMS

- Particle Swarm Optimization (PSO) is a metaheuristics optimization algorithm.
- Simulates social behavior of the movement of an organism as a flock of birds or school of fish.



- Each member of the swarm is called a “particle”.
- Each particle represents a potential solution.
- Particles fly around the search space with certain velocity till an optimum solution is found.
- It is guided by:
  - Present location of the particle $\overrightarrow{x_i}(t)$.
  - Personal experience (P_{best}).
  - Overall experience (G_{best}).

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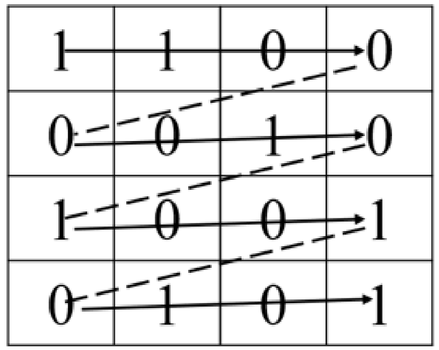
BLOCK SCAN PATTERN SEARCH USING BPSO

- BPSO: used to search for the best combination of scanning patterns used to traverse through the image blocks, generating interval sequences such that maximum compression is achieved.
- The following scanning patterns are used:

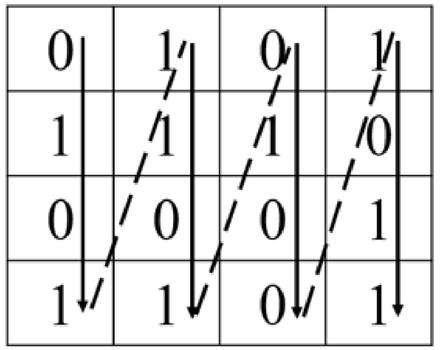
  Horizontal raster scan.

  Vertical raster scan.



Horizontal Scan

Interval sequence : [1 1 5 2 3 2 2].



Vertical Scan

Interval sequence : [2 2 1 1 2 2 3 2 1].

- Direction bit : “1” for horizontal.

  : “0” for vertical.

- Interval Generations:

  It calculates distance between the previous and next occurrence of the same binary symbol.

- Problem of coding the original image → Problem of coding the intervals.

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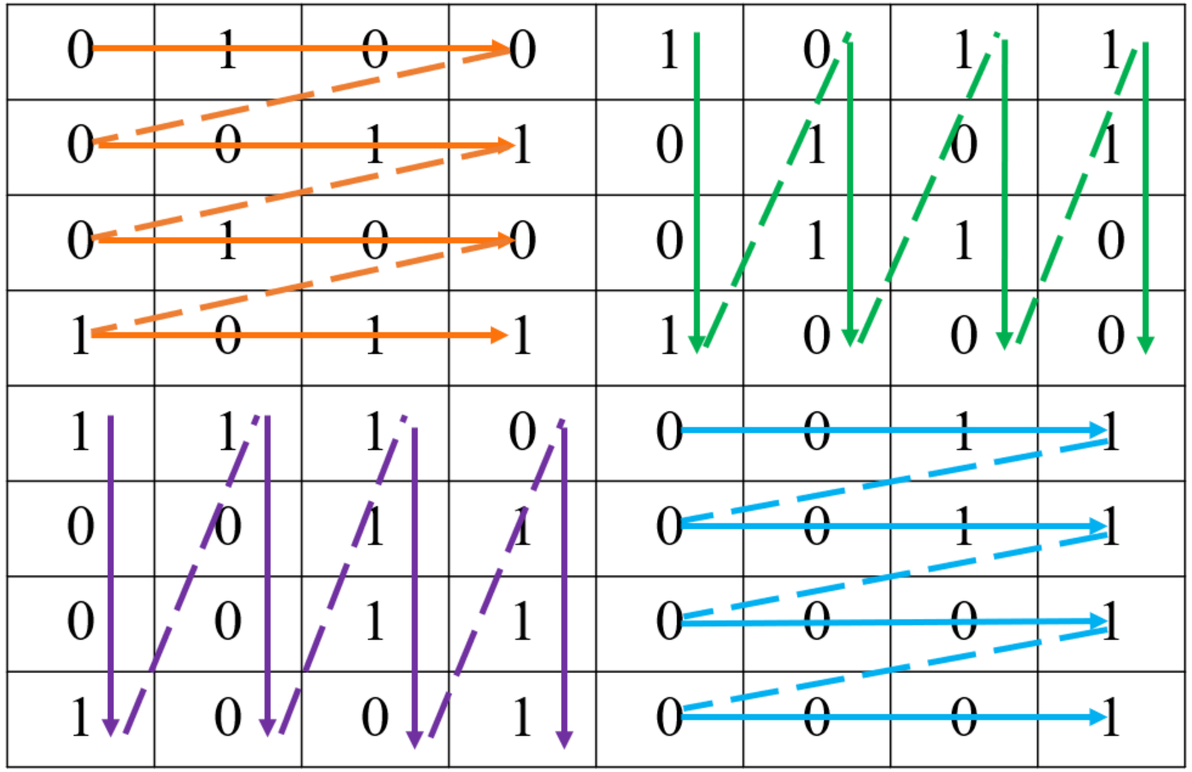
OVERVIEW



An 8X8 image.

Block 1: [2 5 1 2 3 2 1]	Block 2: [1 3 2 1 2 2 2 1]
Block 3: [1 3 1 4 1 1 3 1 1]	Block 4: [3 1 3 1 4 4]

(a) Interval sequences

1 Block 1	0 Block 2
0 Block 3	1 Block 4

(b) Direction Bits

(c) Bitmap

- The image is divided into uniform sized blocks.
- The scan paths for all the blocks are recorded as “Direction bits”.
- The interval sequences are generated following a scan path.

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ALGORITHM

- As the no. of blocks ↑, Search space ↑, Dimension ↑.
- Complexity increases with # of blocks.

$$No.of\ Blocks = \frac{Image\ Size}{Block\ Size}$$

$$r = \frac{M \times N}{p \times q}$$

Image = 256X256
Block size = 8X8
Blocks = 1024
Complexity = 2^{1024}

- Role of BPSO: Search for the best solution in the huge search space of combination of block scanning directions.

ALGORITHM

- Parameter initialization:
  - Particles are initialized with a vector.
  - Block are scanned in two directions → values in vector are discrete.
- Data structure of a particle:
  - Current position.
  - Best position so far.
  - Velocity of each particle.
  - Fitness value.

BPSO MODEL

- No of particles : N
- Dimension: D $(1 \leq d \leq D)$
- Representation of i^{th}particle :

$$x_i = (x_{i1}, x_{i2}, \ldots\ldots, x_{iD})$$

- Velocity : $v_i = (v_{i1}, v_{i2}, \ldots\ldots, v_{iD})$
- Personal best : $p_i = (p_{i1}, p_{i2}, \ldots\ldots, p_{iD})$
- Global best : $p_g = (p_{g1}, p_{g2}, \ldots\ldots, p_{gD})$
- Velocity update:

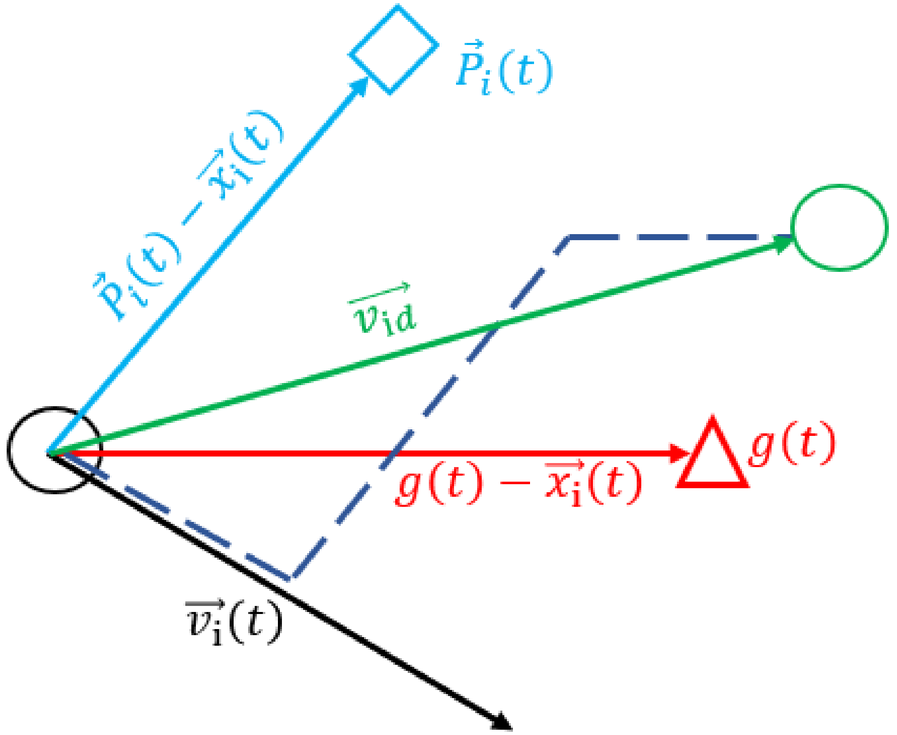
$$v_{id} = \omega v_{id} + c_1 r_1 (p_{id} - x_{id}) + c_2 r_2 (p_{gd} - x_{id})$$

- Position update: $if(rand() < S(v_{id}))$

$$then\ x_{id} = 1$$

$$else\ x_{id} = 0$$

where, $S(v_{id}) = \frac{1}{1+e^{-v_{id}}}$



BPSO search mechanism

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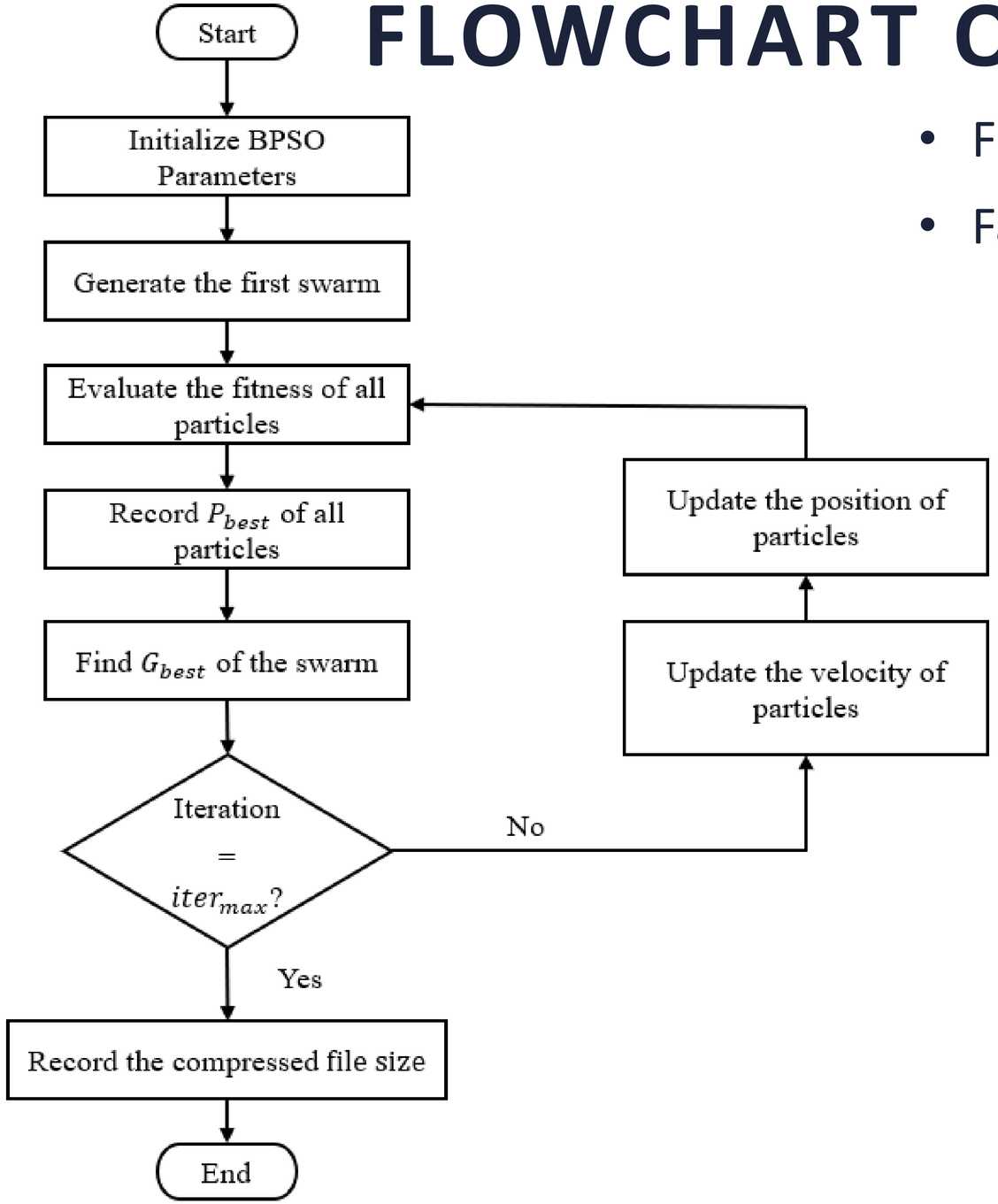
FLOWCHART OF THE BPSO ALGORITHM



- Fitness value: Compressed file size.
- Factors influencing the velocity:
  - Momentum term (ωv_{id})
    - Incorporates the effect of previous velocity on current velocity.
    - Larger value of ω: improves global search capability.
    - Smaller value of ω: improves the partial search capability.
  - Cognitive component ($c_1 r_1 (p_{id} - x_{id})$)
    - Distance from the personal best.
  - Social component ($c_2 r_2 (p_{gd} - x_{id})$)
    - Distance from the global best.

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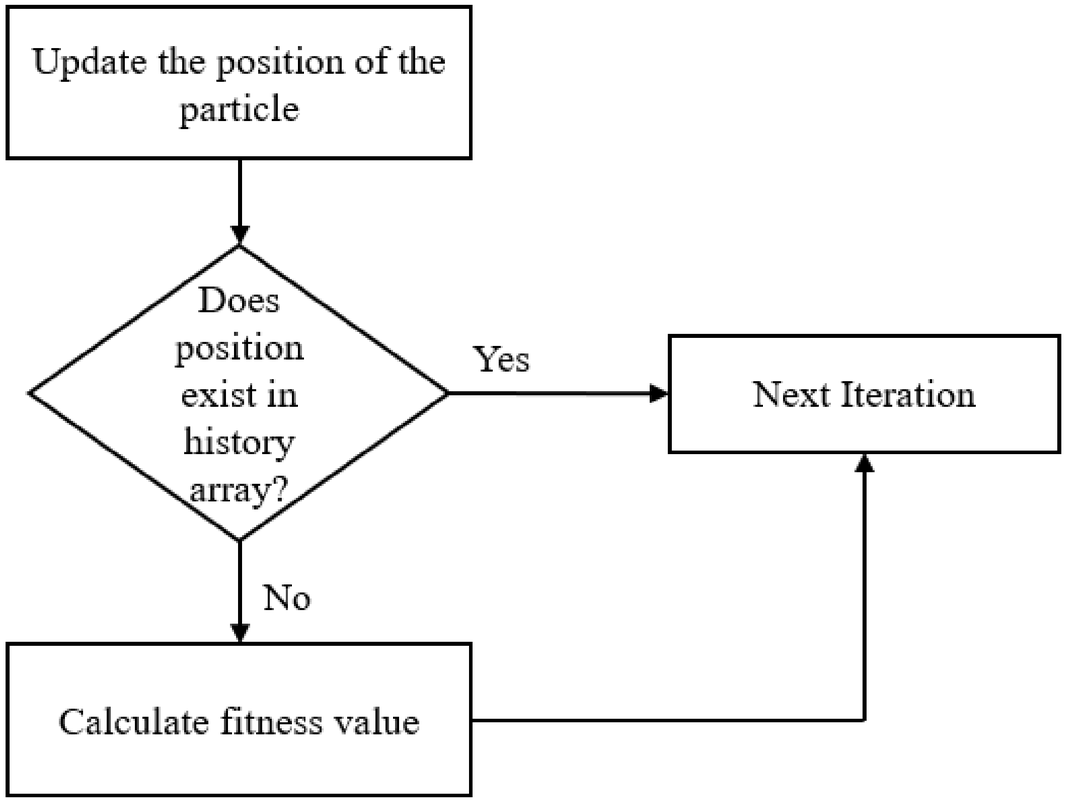
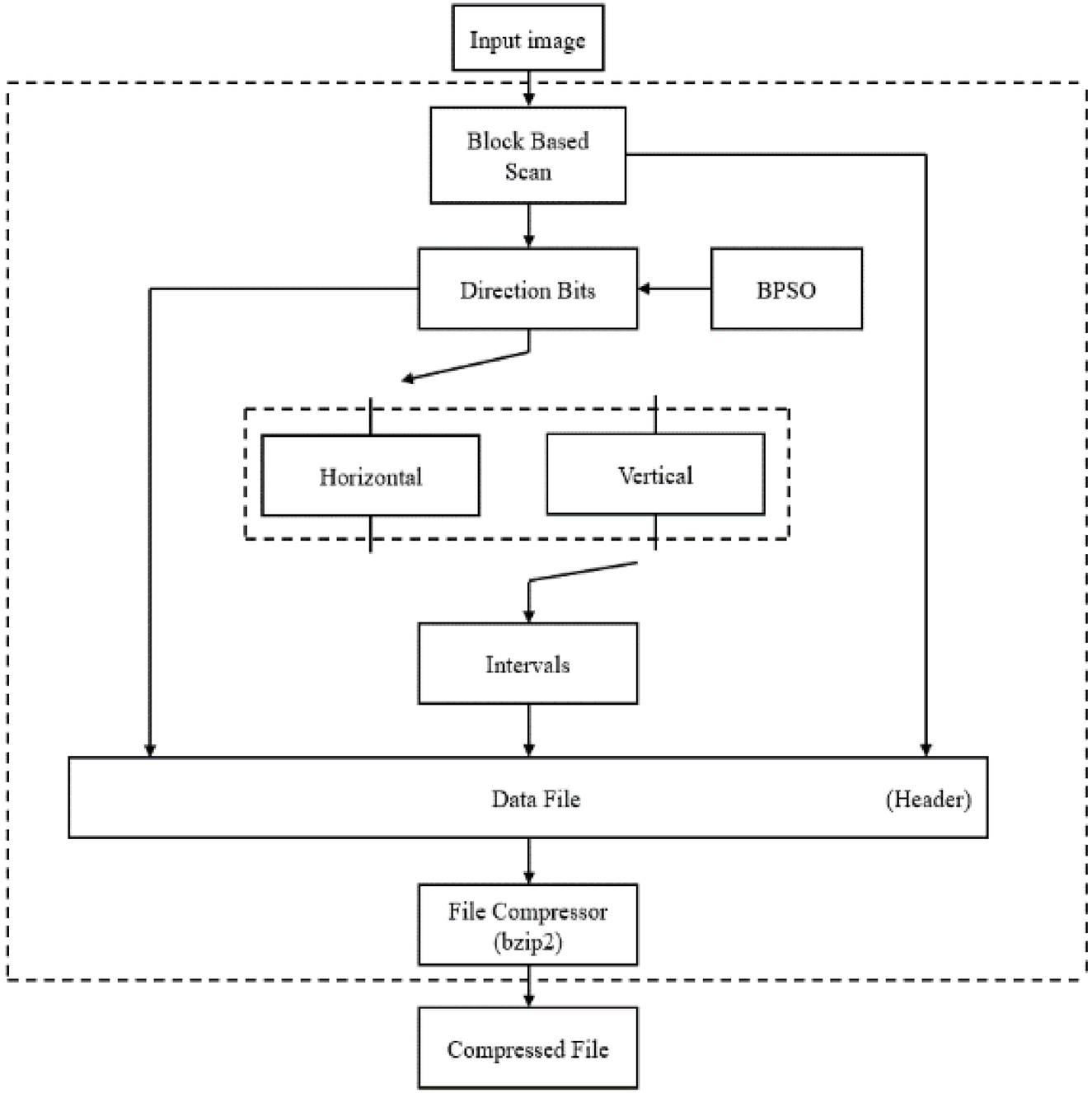
PARTICLE HISTORY PRESERVATION

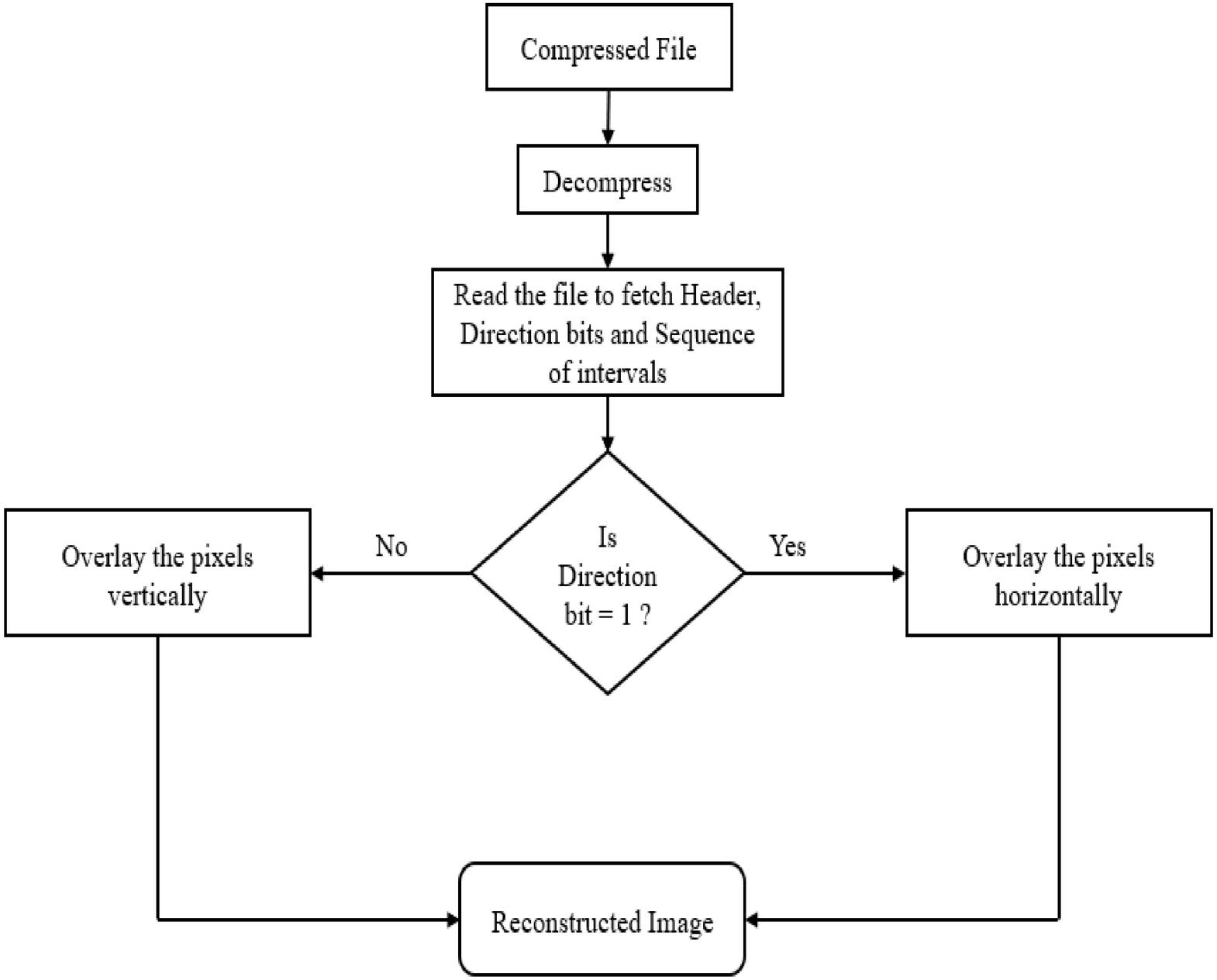


- Involvement of random numbers causes evaluation of same solution, which affects computational complexity and time consumption.
- Solution : Record history of all previously visited locations and its fitness values.
- Avoids redundant fitness calculations.



FITNESS FUNCTION

- Objective function : maps the search space to function space.
- Maxima and minima of objective function: not directly known.
- Different scanning path determines fitness value.
- Fitness value determines the optimality of the set of parameters.
- Data compression utility: bzip2
- With every iteration new direction bits are generated.
- Best fitness value : Global best.



DECODER

- Binary nature offers an advantage.
- Location of "0" and "1" completely determines the original binary image.
- Direction bits: helps to decode the intervals to convert back to location indices.
- If DB is "1" : overlay pixels horizontally
- If DB is "0" : overlay pixels vertically.
- Lossless check.

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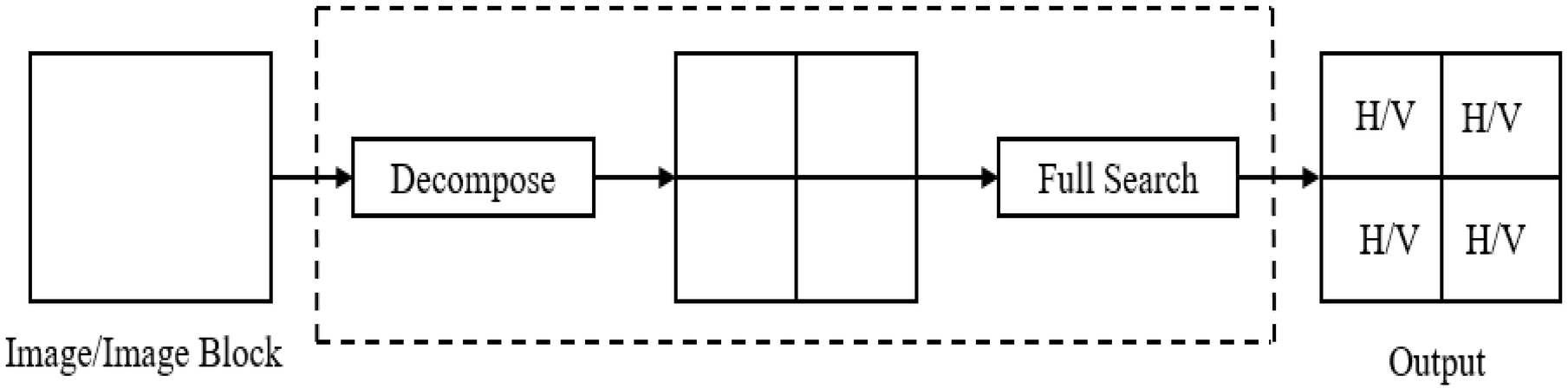
TREE BASED SEARCH ALGORITHM

- BPSO based search method is limited by the fixed block size.
- Several regions of an image are less compressible than other regions.
- Changing statistics of an image.
- Exploiting the smoothness in portion of an image by splitting it into variable length segments.
- Portions dominated by change : retained as smaller blocks.
- Smooth segments : chosen not to be divided further.
- Tree based algorithm steps:

    a. Full search of image sub-blocks.
    b. Optimal tree structure.
    c. Two-level splitting of the original image.

FULL SEARCH OF IMAGE SUB-BLOCK

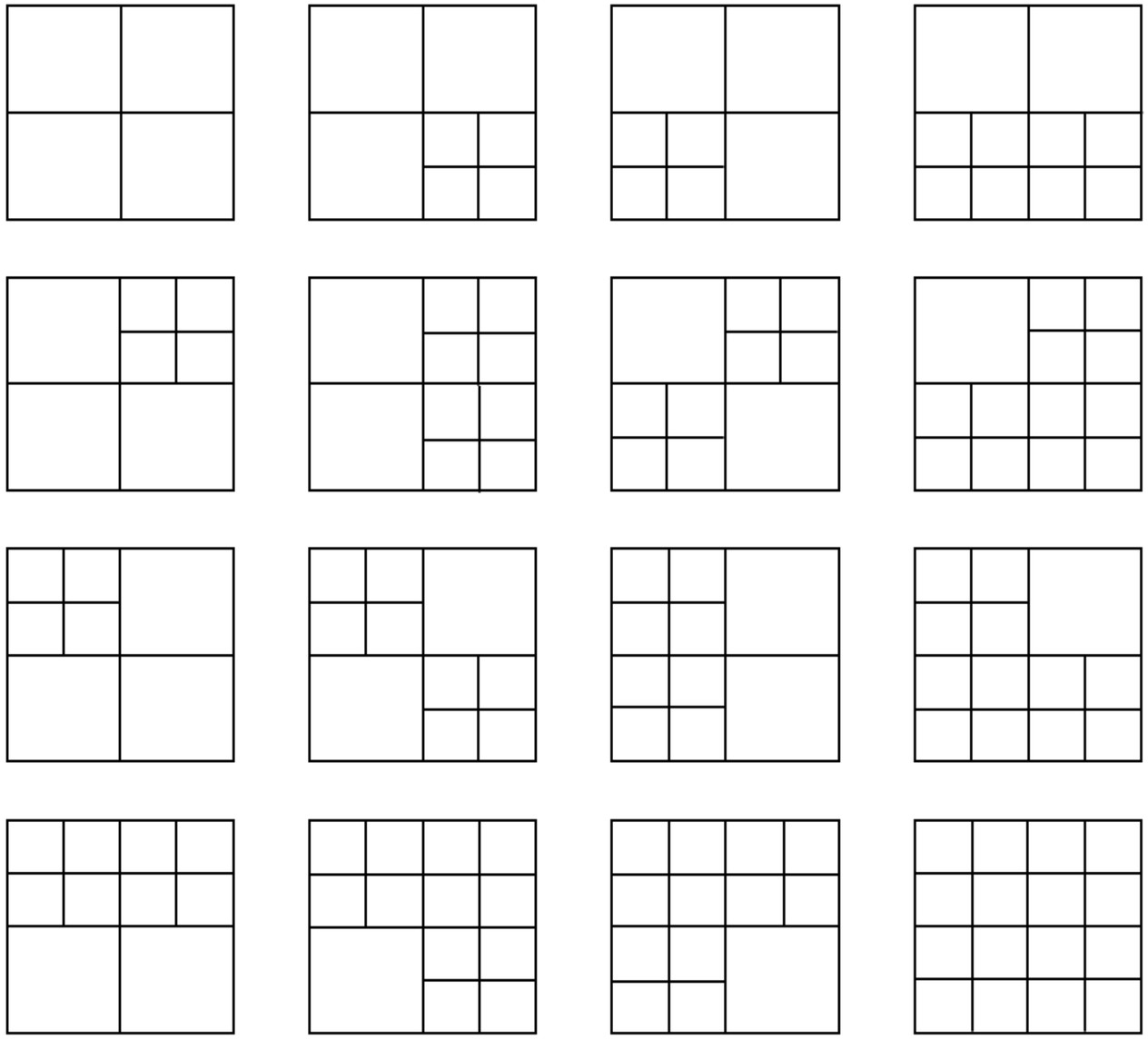


- Full search : To examine the change in the amount of compression achieved.
- Advantages : guarantees to explore all the search paths to solve a given problem.
- High computational complexity ⟶ difficult for real time implementation.
- Operations:

  Divide the image into 4 equally sized blocks

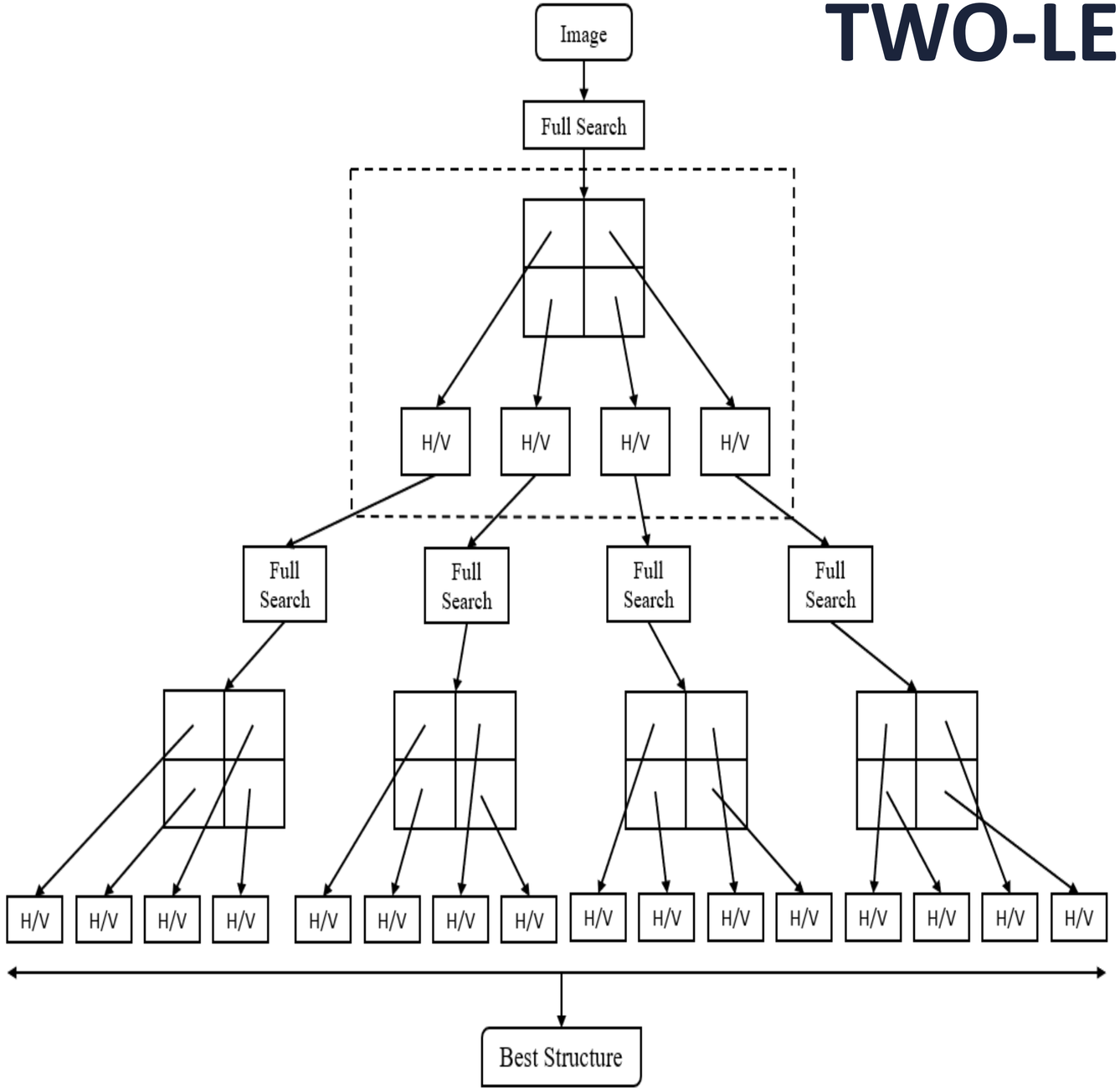
  Find the best combination of scanning patterns.

ADAPTIVE GRID STRUCTURE



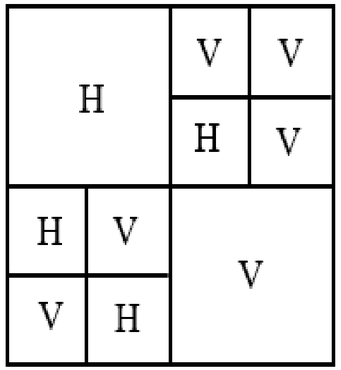
- Content of an image → regions contained in the image.
- larger blocks for smooth regions
- Smaller blocks for regions with largely varying content.
- Binary decisions : full search performed on the sub-blocks.
- Non-uniform areas: isolated from the remaining parts of the image.
- There are total of 16 structures.

TWO-LEVEL RECURSIVE SPLITTING

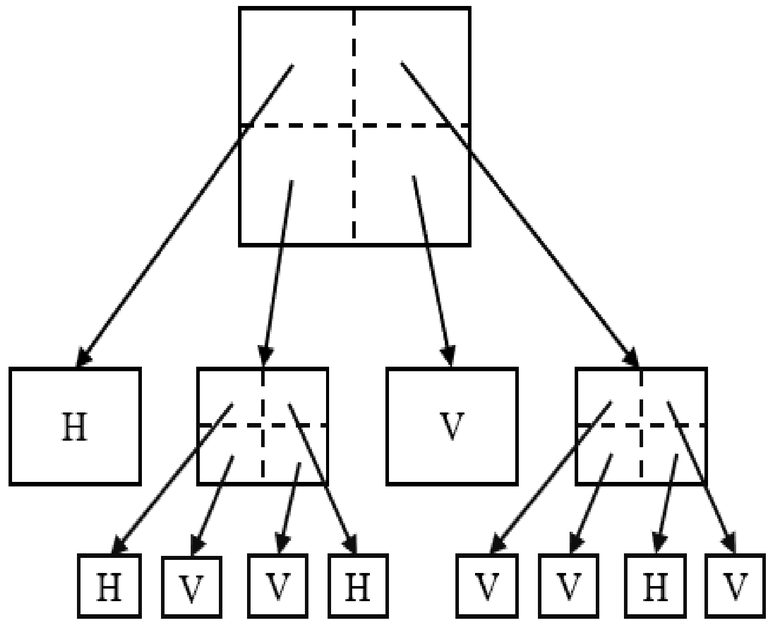


- Computationally simple and very effective.
- Image : “original tree” (root node).
- Image can be represented by a tree structure.
- Segmentation:
  - Performed iteratively.
  - Controlled at each step.
- Split parent block ⟶ child node.
- Tree structure is designated by series of bits that indicate termination.

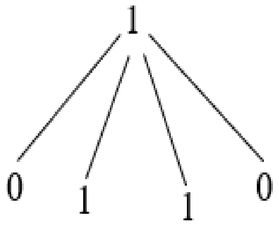
FINAL STRUCTURE



(a) Optimal Tree Structure



(b) Optimal Tree Path



(c) Decision Bits

- Direction bits : represents division.
- Each node has either no offspring or four offsprings.
- If the block is divided :
  - Binary decision for selection of scanning direction.
- The procedure terminates after two-level recursive splitting.
- Data file : Tree structure and sequence of intervals, header.
- Final step: Data compression utility.
- Lossless check.

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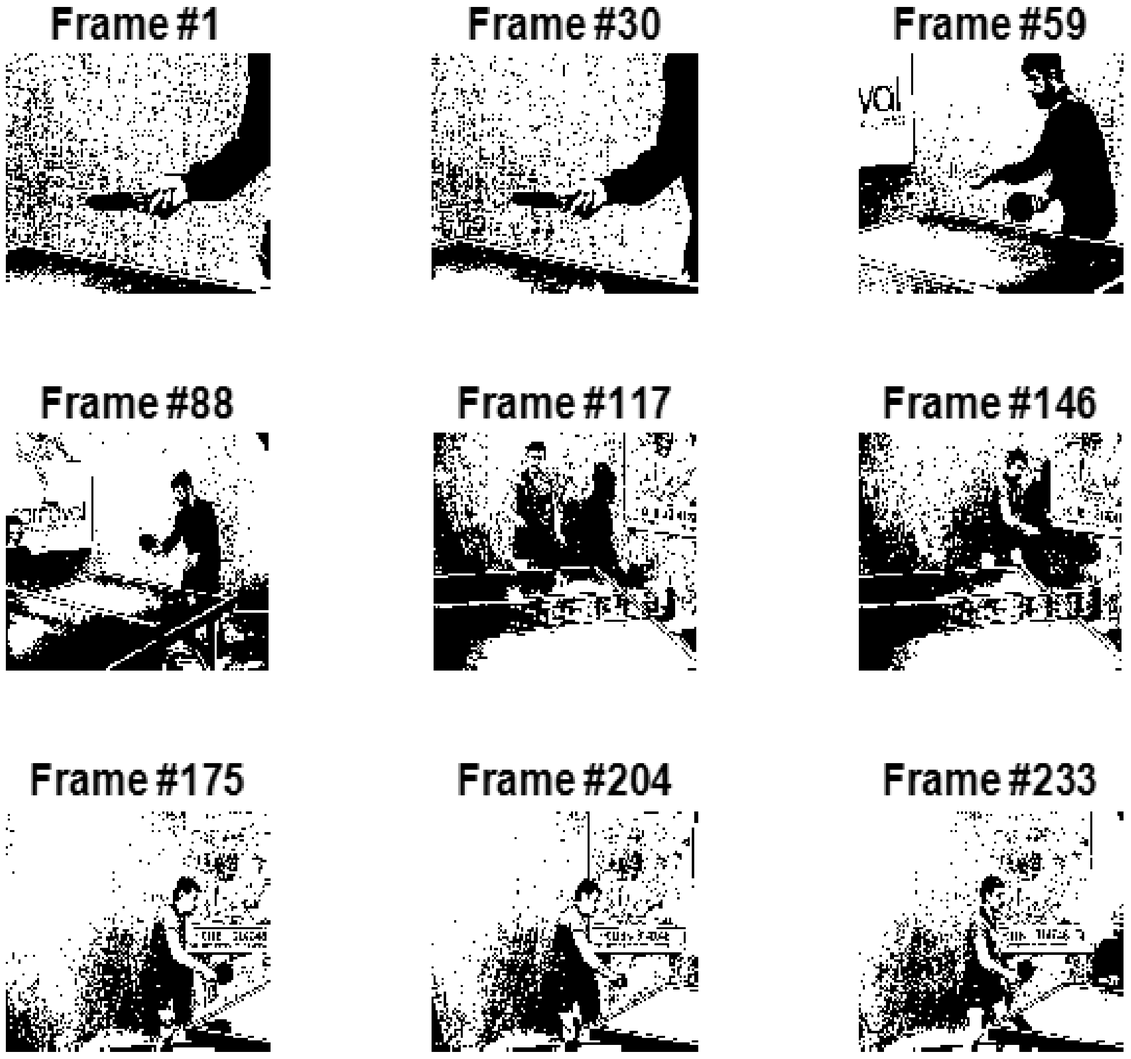
SIMULATION RESULTS



Binary images obtained by thresholding greyscale images from a video sequence

- Binary images were generated using thresholding from greyscale images.
- Proposed algorithms were tested on several images datasets and compared with the following lossless compression schemes:
  - CCITT
  - FAX3
  - FAX4
  - JPEG 2000
  - JBIG2
- Proposed method:
  - BSPO.
  - Tree-based search method.

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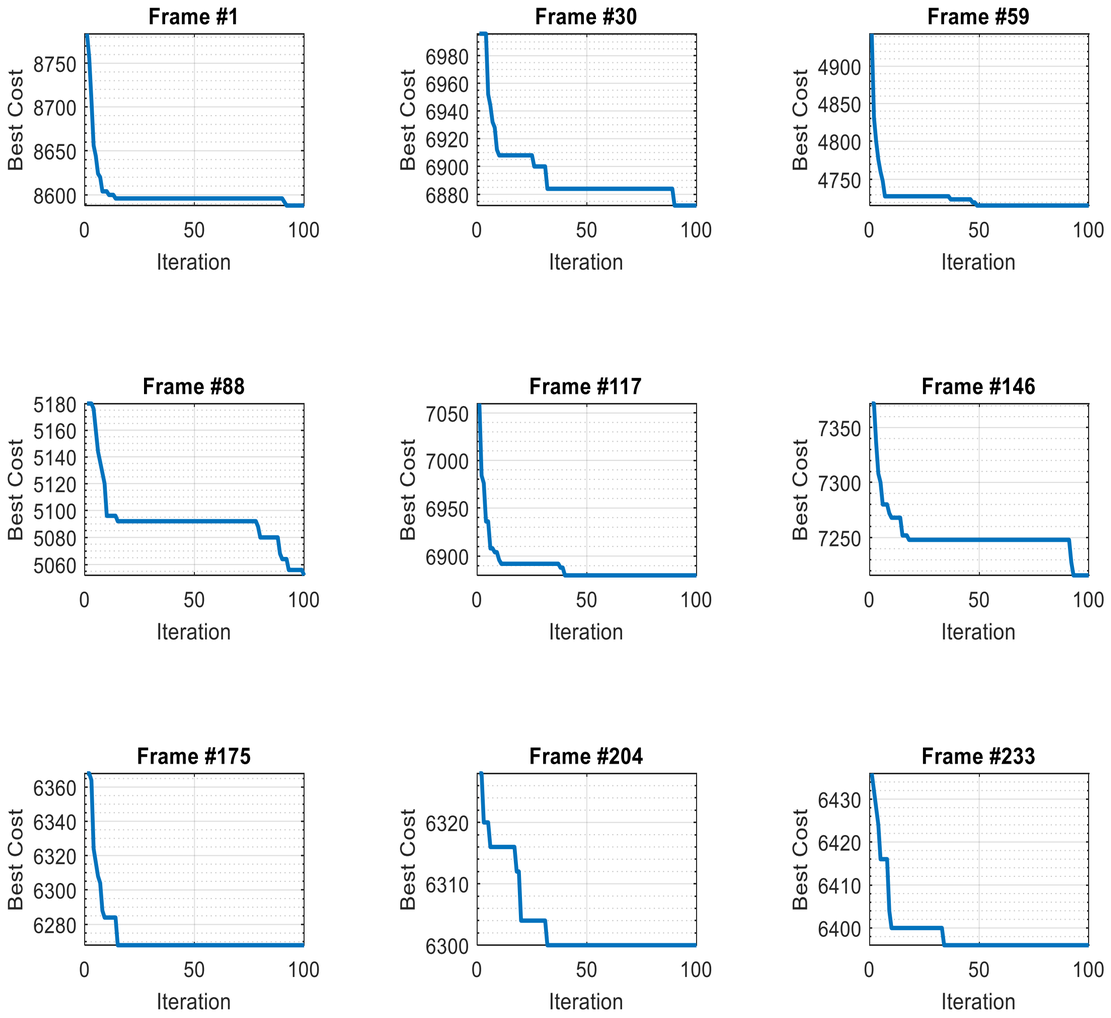
SIMULATION RESULTS



The cost function value with each iteration

- The cost function value (the compressed file size) changes with each iteration.
- No of iterations: 100 (for BPSO)
- Reduction in compressed file size.
- Unique (optimal) scan path at 100^{th} iteration.
- Bitmap: for viewing the scan directions of the blocks within an image.
- “1”, i.e., white for horizontal scan and “0” for vertical scan.
- Similar frames gives similar bitmaps:
  - Frame 204
  - Frame 233

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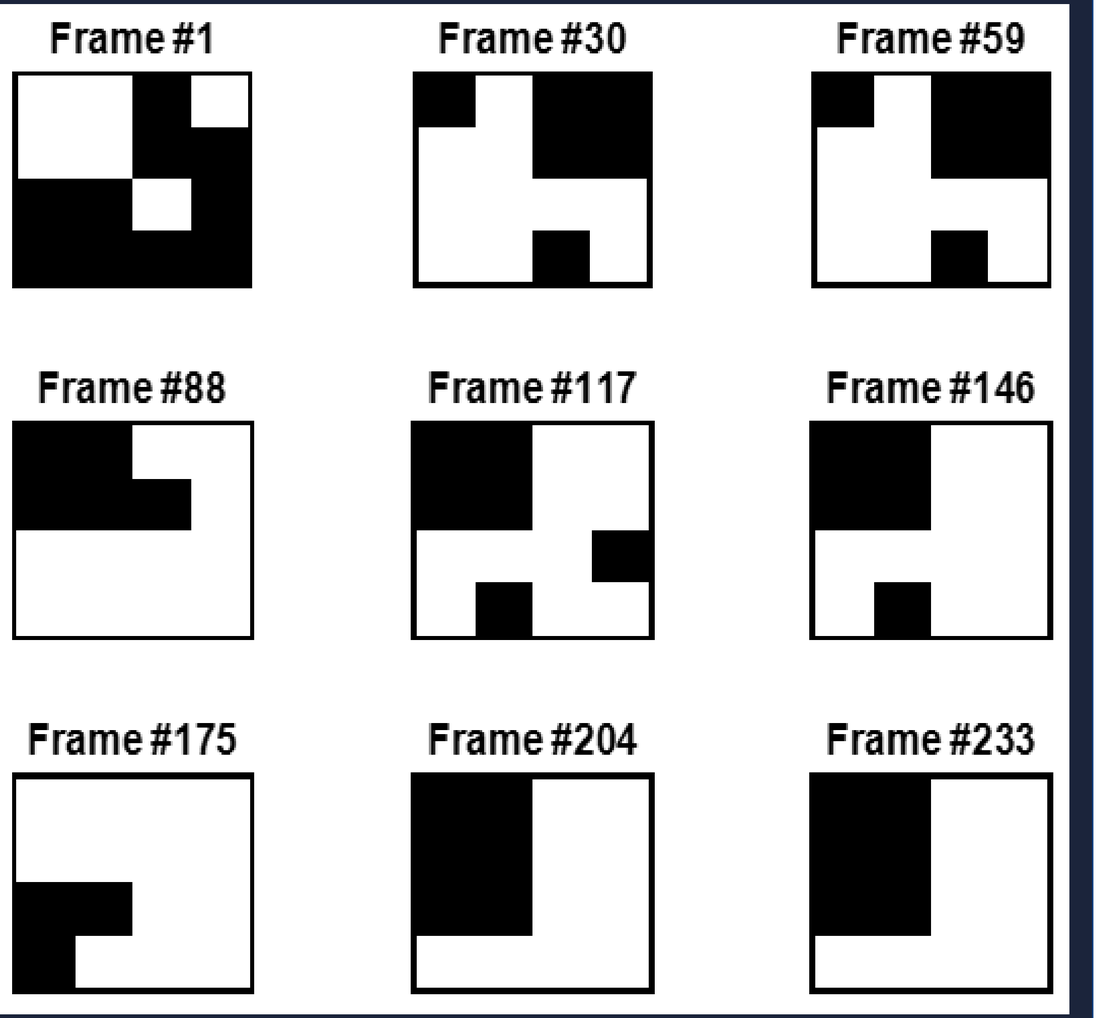
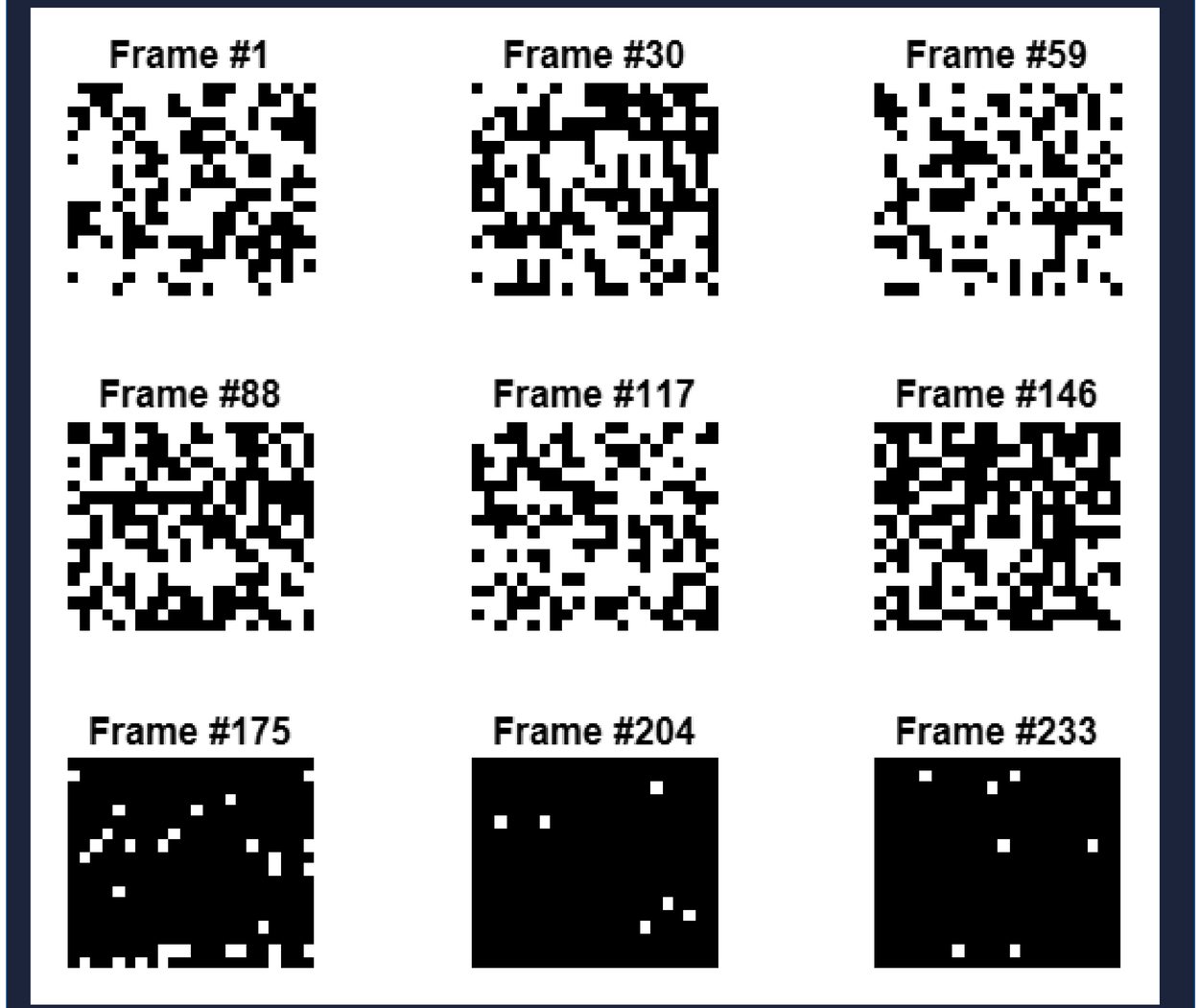
BITMAPS

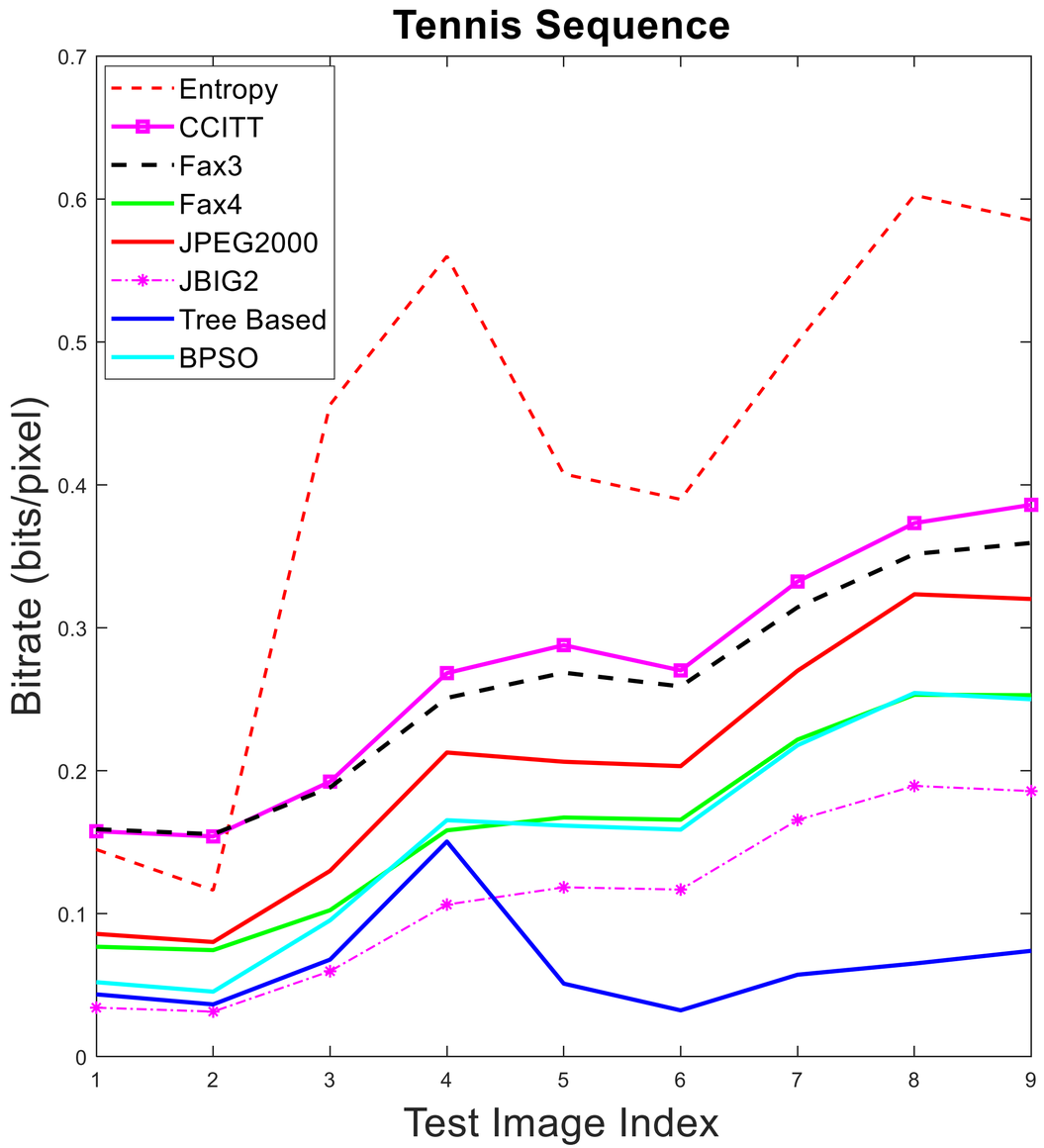


Bitmaps using Tree-based algorithm



Bitmaps using BPSO

COMPARISON OF PROPOSED ALGORITHMS WITH OTHER TECHNIQUES



Compression results for the "Tennis" sequence

- Test image index 1, 2, 3, 4, 5, 6, 7, 8, and 9 refers to frame 1, 30, 59, 88, 117, 146, 175, 204, 233 in sequence, respectively.
- BPSO provides significantly higher compression than other methods.
- BPSO method has lower compression than JBIG2 standard method on average.
- Tree-based search algorithm achieves highest compression for frame 5 to 9.

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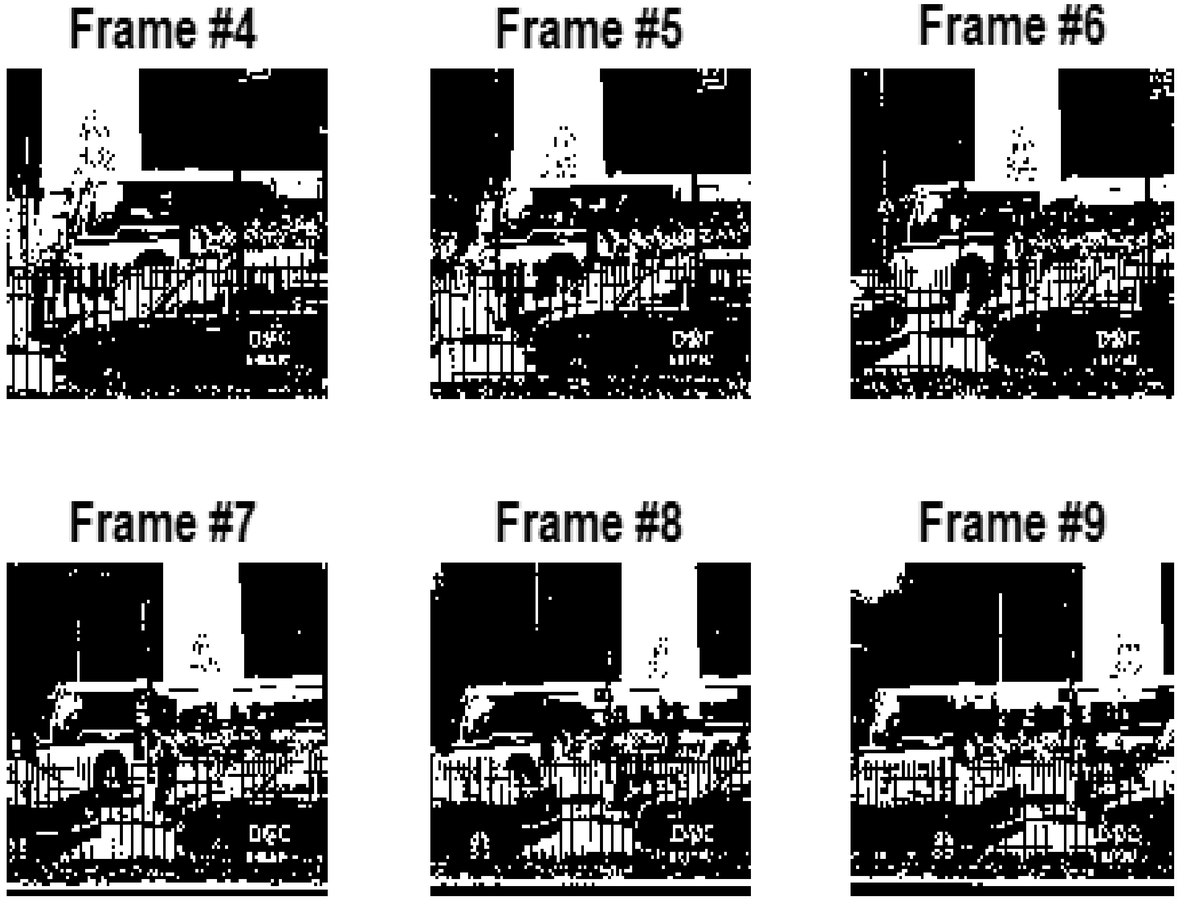
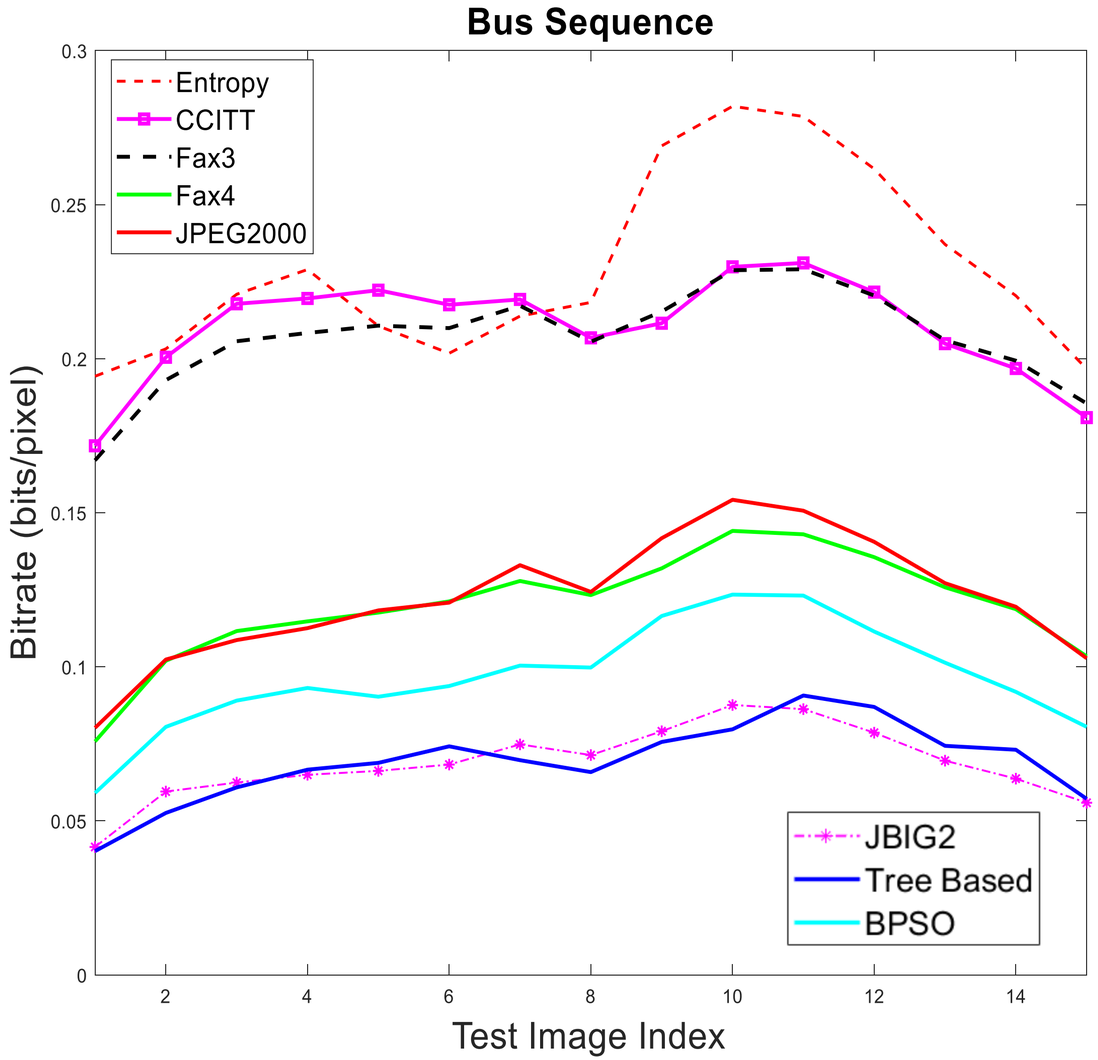
"BUS" SEQUENCE



Binary images obtained from the "Bus" sequence.



Compression results for the "Bus" sequence.

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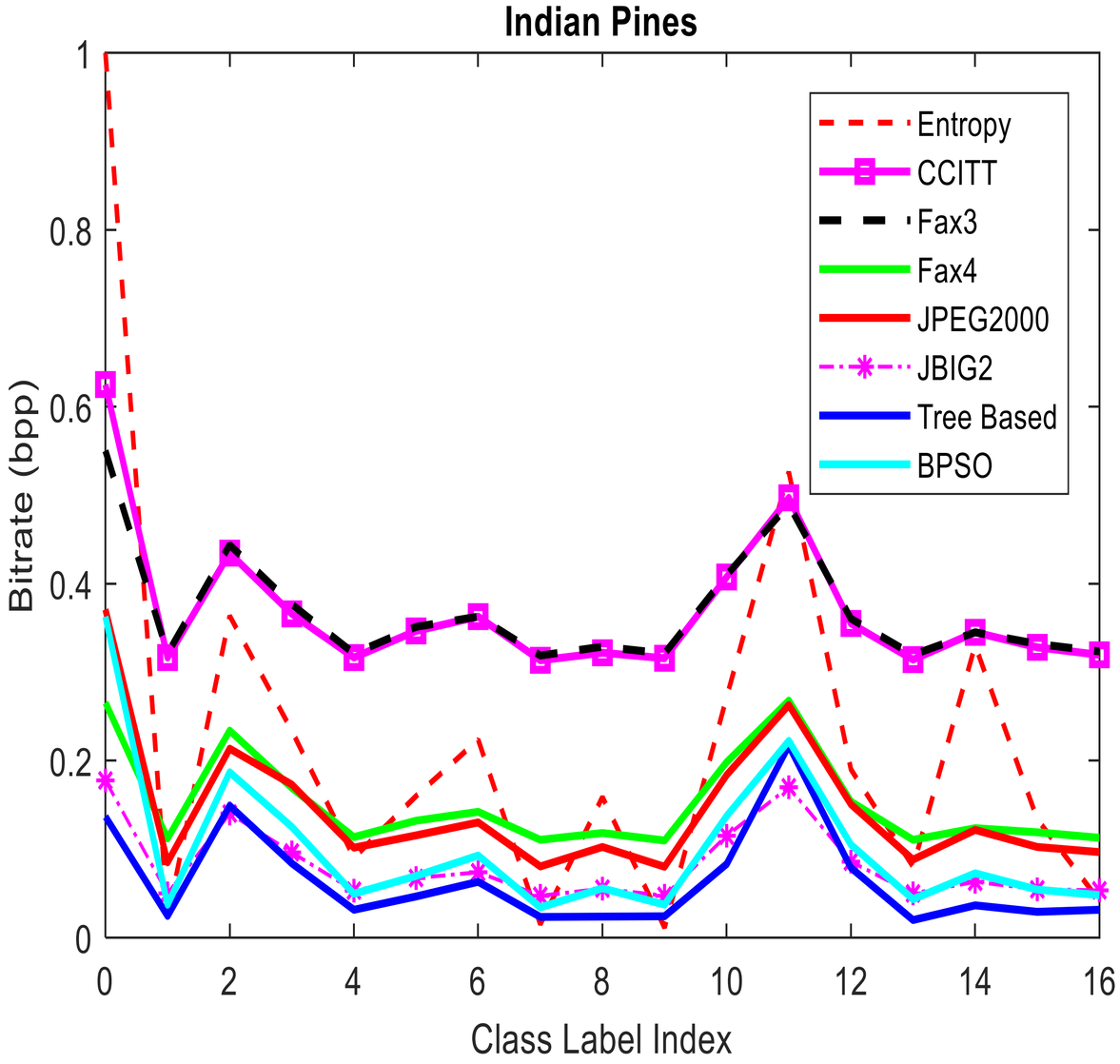
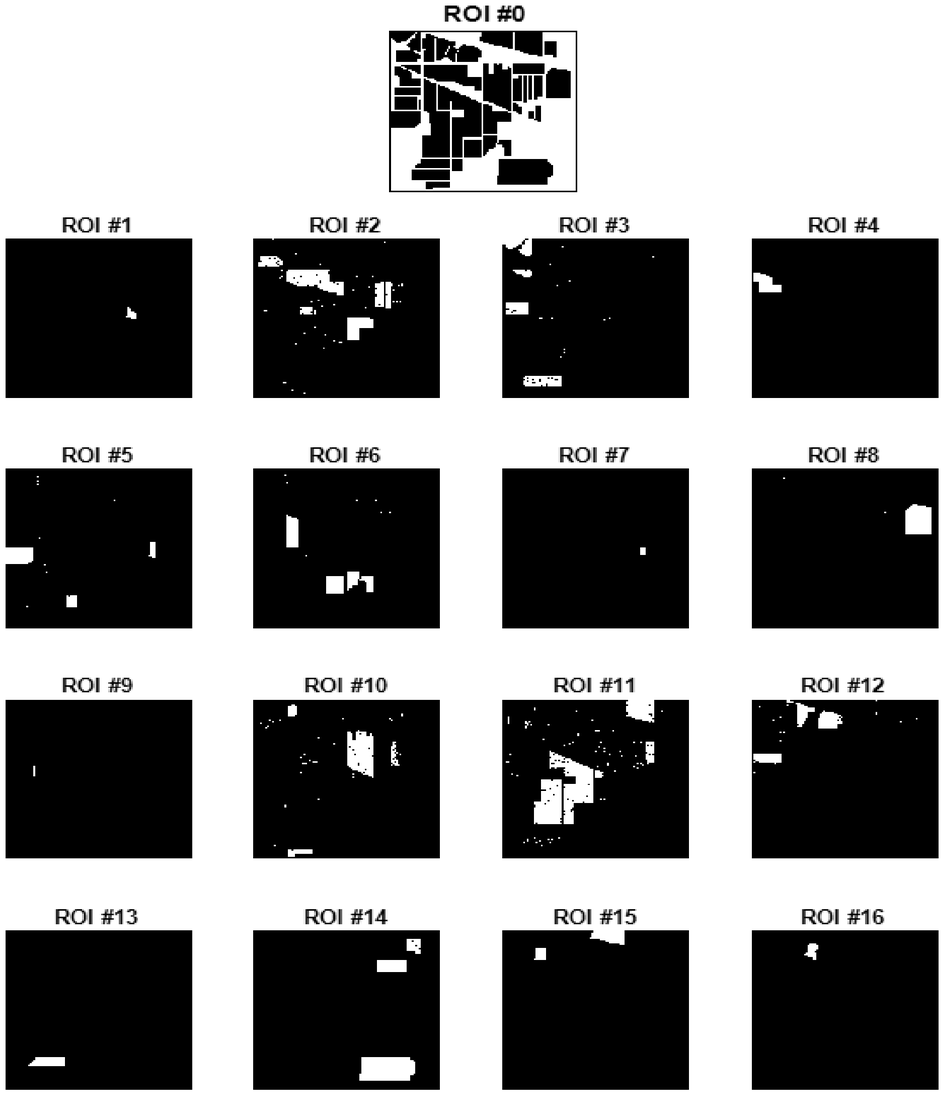
HYPERSPECTRAL DATASET



Compression results of bi-level IP ROI maps.



“Indian Pine (IP)” hyperspectral image dataset

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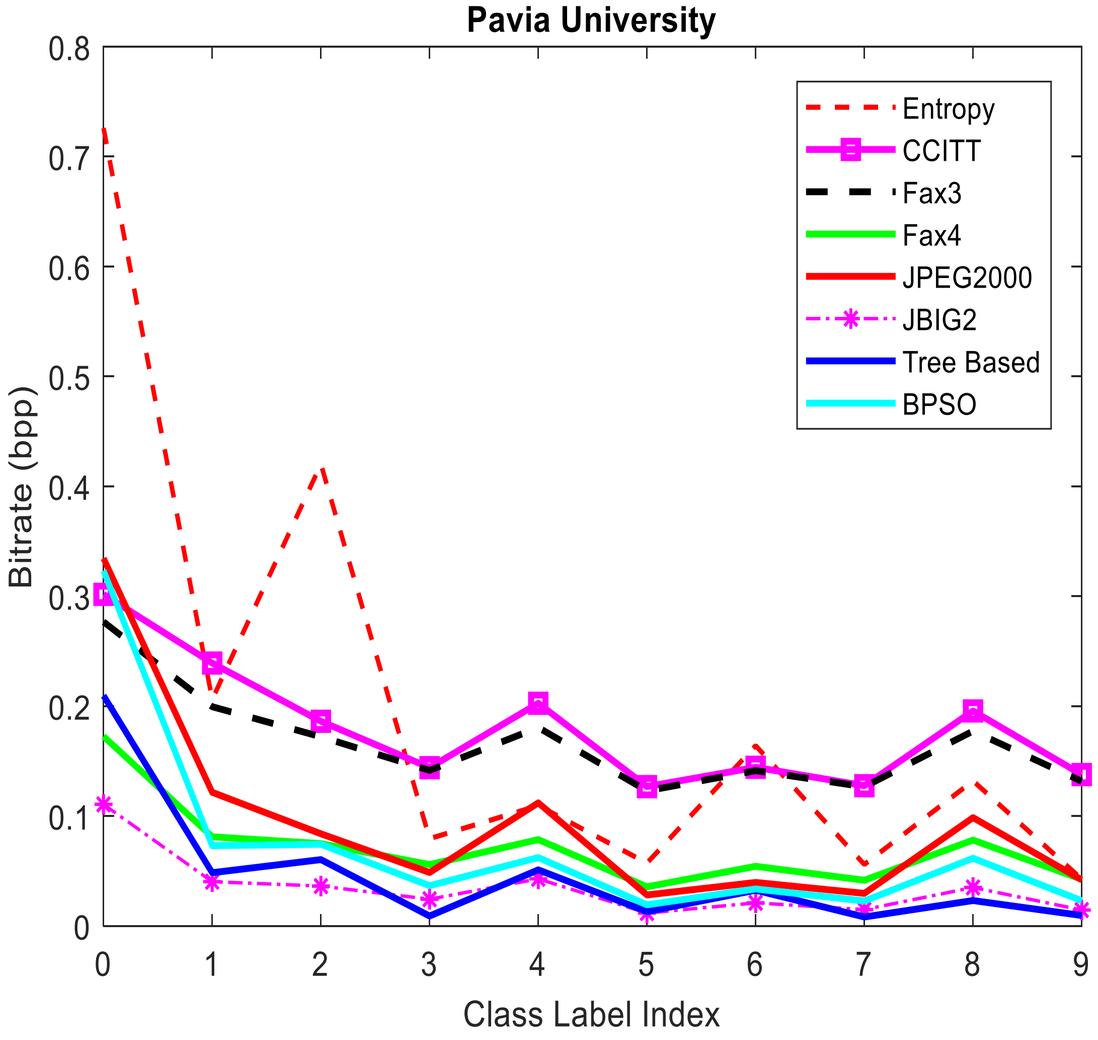
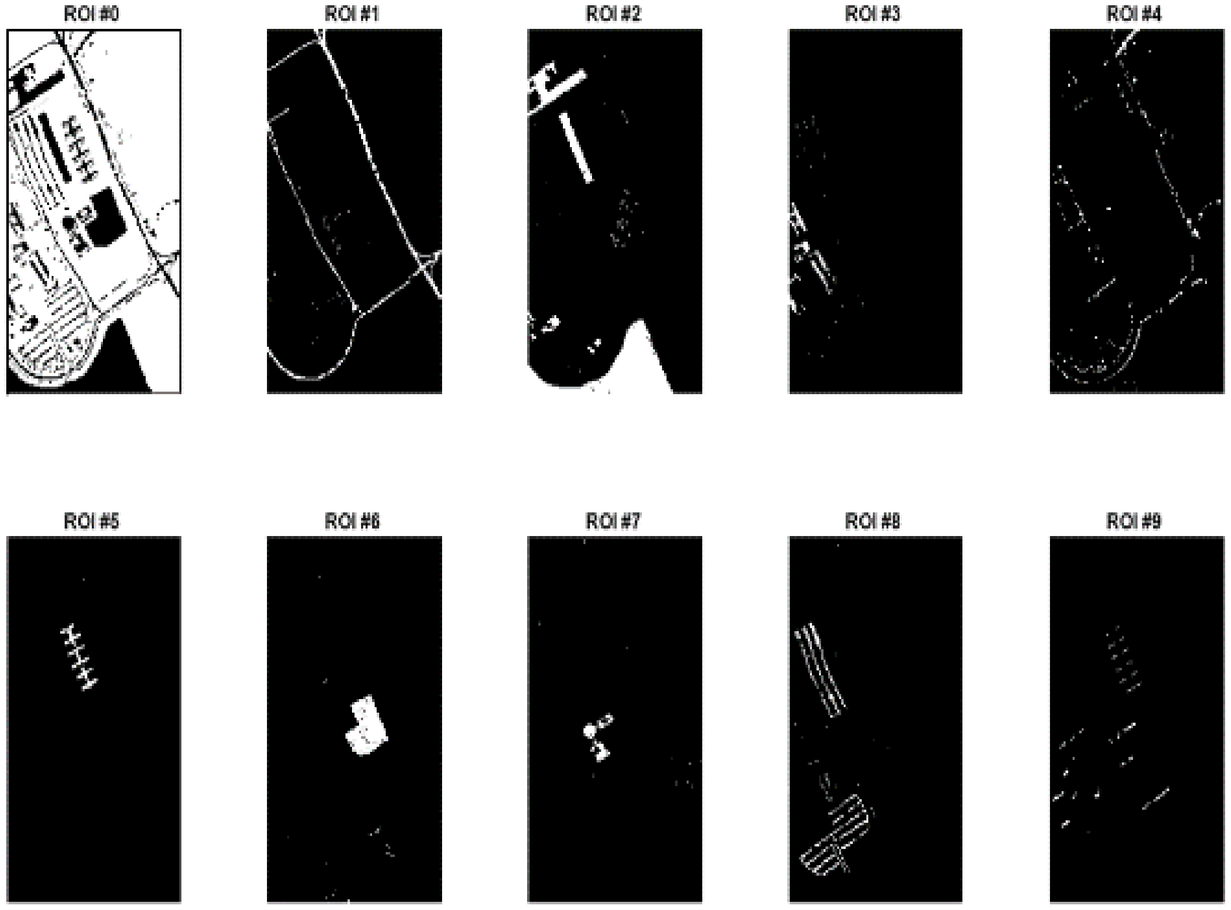
“PAVIA UNIVERSITY” DATASET



Compression results of bi-level PU ROI maps.



“Pavia University (PU)” hyperspectral image dataset

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CONCLUSION

- We proposed two optimization and search methods for lossless compression of binary images.
- BPSO is shown to offer increasingly better image compression with additional iterations.
- The algorithm explores different search paths to reach the most optimal one.
- We observed reduction in file size with every iteration resulting in improvement of compression.
- Tree based search algorithm searches for best grid structure employing blocks of varying sizes.
- Non-uniform block size exploits different regions of the image based on its intrinsic nature.
- Extensive simulations showed that we can achieve higher compression on average.

FUTURE EXPANSION

- The proposed methods used two scan paths, hence operating in low-dimension space.
- A general extension to this work could be to increase the number of scan paths to choose from, which will result in generating different interval sequences.
- Alternatively, we can explore search paths using more advanced BPSO models.
- In addition, the tree-based search scheme has only two levels which limits the scope of this research.
- The two-level tree-based scheme can be extended to more levels, with the goal of increasing the compression significantly.

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Thank You!

Any questions?