Linear Pixel Shuffling

and

Pattern Recognition

Acknowledgments

- To Peter Anderson for developing LPS and coming up with the idea for this project

- To Keith Knox and Harvey Rhody for their help and suggestions

Definition

Linear Pixel Shuffling (LPS) is a method to get a semi-random ordering of pixels. Unlike other techniques, LPS creates a pixel ordering that is spread evenly across the image. It wraps around the image by use of modular arithmetic. A simple arithmetic progression is needed to determine the next pixel location.

Objective

The objective of this project is to compare Linear Pixel Shuffling (LPS) as a Pattern Recognition tool, against more traditional algorithms that are based on Space and Frequency Domain Correlation. The study will demonstrate the speed and efficiency of LPS as a potentially enhanced method for Pattern Recognition.

Outline

☞ • Introduction

- Procedure

- Results

- Conclusions

Experimental Rational

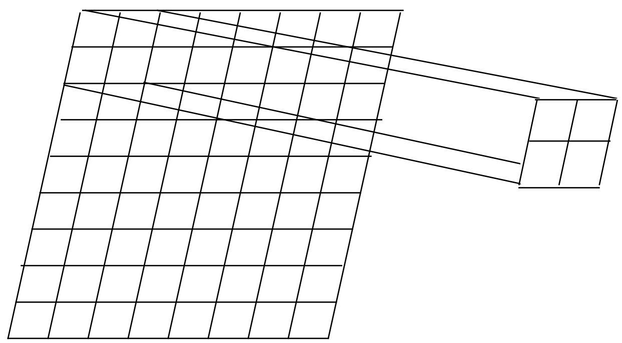
- Why compare LPS to Space Domain?
  - Traditional textbook algorithm
  - Same correlation equation
  - Used for large ratio problems

- Why compare LPS to Frequency Domain?
  - Used for small ratio problems

- Why compare LPS to Random Ordering?
  - Compare “pseudo-random” ordering of LPS against “true-random” ordering

Space Domain

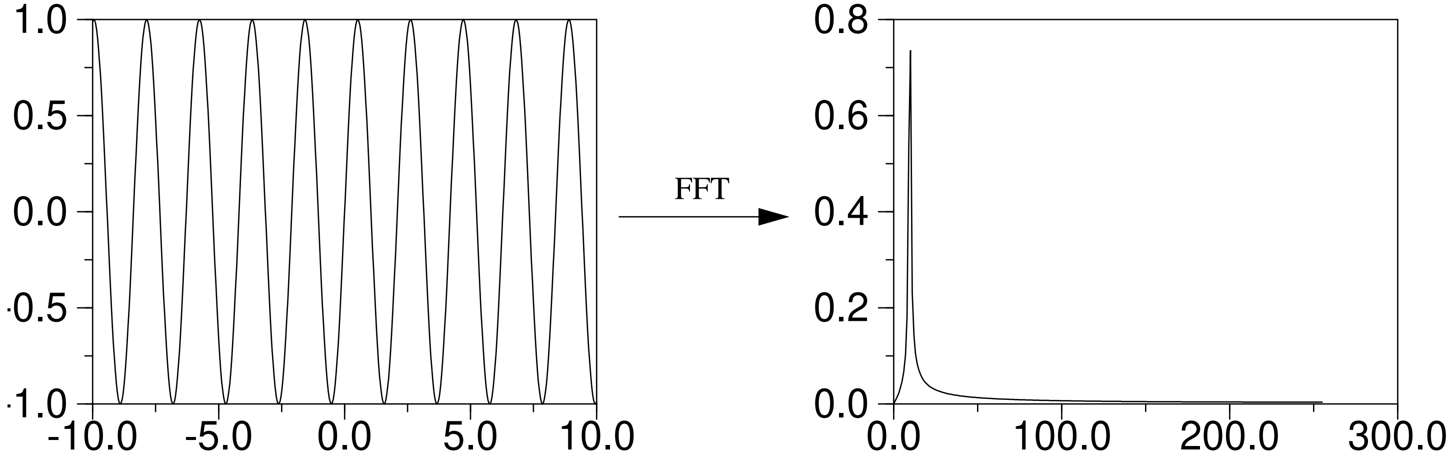
Method



Pixel Order

1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31	32	33	34	35
36	37	38	39	40	41	42
43	44	45	46	47	48	49

Frequency Domain

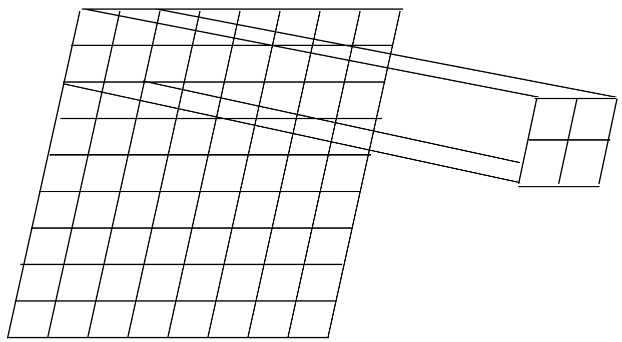


Pixel Order

1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31	32	33	34	35
36	37	38	39	40	41	42
43	44	45	46	47	48	49

Random Ordering

Method

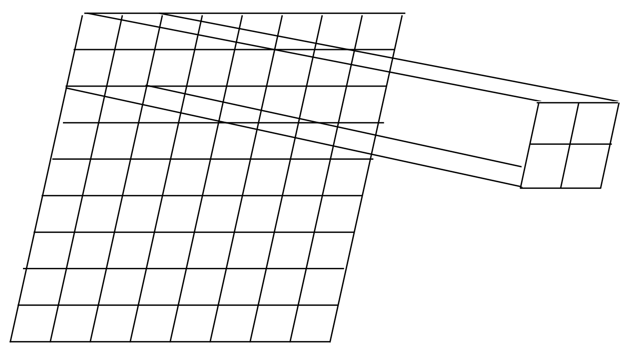


Pixel Order

31	14	11	15	21	23	12
39	19	10	28	3	36	41
20	25	4	32	1	40	9
30	22	46	8	33	6	47
24	38	26	13	49	34	44
29	42	38	17	43	2	18
16	35	48	7	45	37	5

Linear Pixel Shuffling

Method



Pixel Order

1	15	30	46	11	27	42
24	38	5	20	34	2	16
47	12	28	43	8	25	39
21	35	3	17	31	48	13
44	9	26	40	6	22	36
18	32	49	14	29	45	10
41	7	23	37	4	19	33

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Algorithm Implementation

Space Domain

Space Domain isn't implemented in the traditional way. Instead, this algorithm sums the absolute value of the difference between corresponding pixels.

Advantages to this method are:

- Subtraction of average not necessary
- Perform calculations with integer rather than floating point data

The algorithm steps are:

1. At [row = 0, col = 0], find the difference
2. Check difference value for minimum
3. Move to the next pixel location until every pixel in the image is sampled

Algorithm Implementation (cont.)

Frequency Domain

- In order to save time, no *beercanning* or *checkerboarding* is done. The FFT routine assumes the 0 point to be in the middle, and the software uses this point as the first element in the array. Consequently, the inverse FFT will show the highest correlation in the upper left corner of the pattern.
- The software needs a black (pixel value 0) background with a non-black pattern. Autorecognition is used to determine if pattern and/or image must be inverted.

Algorithm Implementation (cont.)

The steps for this algorithm are as follows:

1. Determine 2^N size equal to or greater than the largest dimension of the pattern and image
2. Zero pad pattern and image to the size determined in (1)
3. Calculate Fourier Transform of image and pattern
4. Multiply the FFT of the image and pattern on a pixel-by-pixel basis
5. Take the inverse Fourier Transform of multiplication
6. Search for a maximum in the inverted transform results

Algorithm Implementation (cont.)

Random Ordering

- Same steps as Space Domain except that the selection of the next pixel is totally random.

Algorithm Implementation (cont.)

Linear Pixel Shuffling

Instead of a sequential pixel ordering, change in position is calculated by:

$$\text{New X} = (\text{Old X} + \text{X increment}) \ \% \ \text{xmax}$$
$$\text{New Y} = (\text{Old Y} + \text{Y increment}) \ \% \ \text{ymax}$$

- % indicates modulus operation
- X increment, Y increment, xmax, and ymax are parameters affecting the pixel ordering.
- The parameters used in this project came from a list of prime numbers.
- Same steps as Space Domain with the exception being the selection of the next pixel.

Software Implementation

Sherlock

Sherlock is an Open Look™ application that can read in an image and pattern and run the 4 algorithms.

- Written in C on a Sun 4/40
- Uses the XView toolkit
- Fast Fourier Transform routine originally written in Fortran by Norman Brenner in 1968. Code translated to C by Keith Knox of Xerox Webster Research Center, September 1990
- Timing macros written by George V. Neville-Neil, Universiteit Twente
- Implements Space Domain, Frequency Domain, Random Ordering, and LPS

Software Implementation (cont.)

After an algorithm has run, information about it is presented. In Batch Mode, it is written to the screen. In UI Mode, a window pops up with the information. Both cases provide the following:

Test	-	Name of algorithm
Ratio	-	ratio between image and pattern (image:pattern)
Time	-	algorithm runtime (h:m:s)
Pos	-	Location of a match
Image	-	filename of the image
Pattern	-	filename of the pattern (or *from image* if cropped)

Software Implementation (cont.)

Tools used:

- CodeCenter (programming environment by CenterLine Software, Inc.)
- FrameMaker (publishing tool by Frame Technology Corporation)
- Lotus (spreadsheet by Lotus Development Corporation)
- Ace/gr (free 2D graphing program for exploratory data analysis written by Paul Turner; xvgr is the xview version)
- Xerox in-house software

Common Experimental Elements

- 4 algorithms were used
- Euclidean distance values were obtained every 2 seconds.
- Euclidean distances were compared.
- Correlation values were plotted.

Experiments

Experiment 1

Objective

- Ascertain if LPS had any speed advantage.

Experimental Conditions

- Keep the center of the pattern constant while the size is changed.
- Five pattern sizes were: 3x3, 5x5, 11x11, 41x41, and 81x81. The image is 500x500.

Experiments (cont.)

Experiment 2

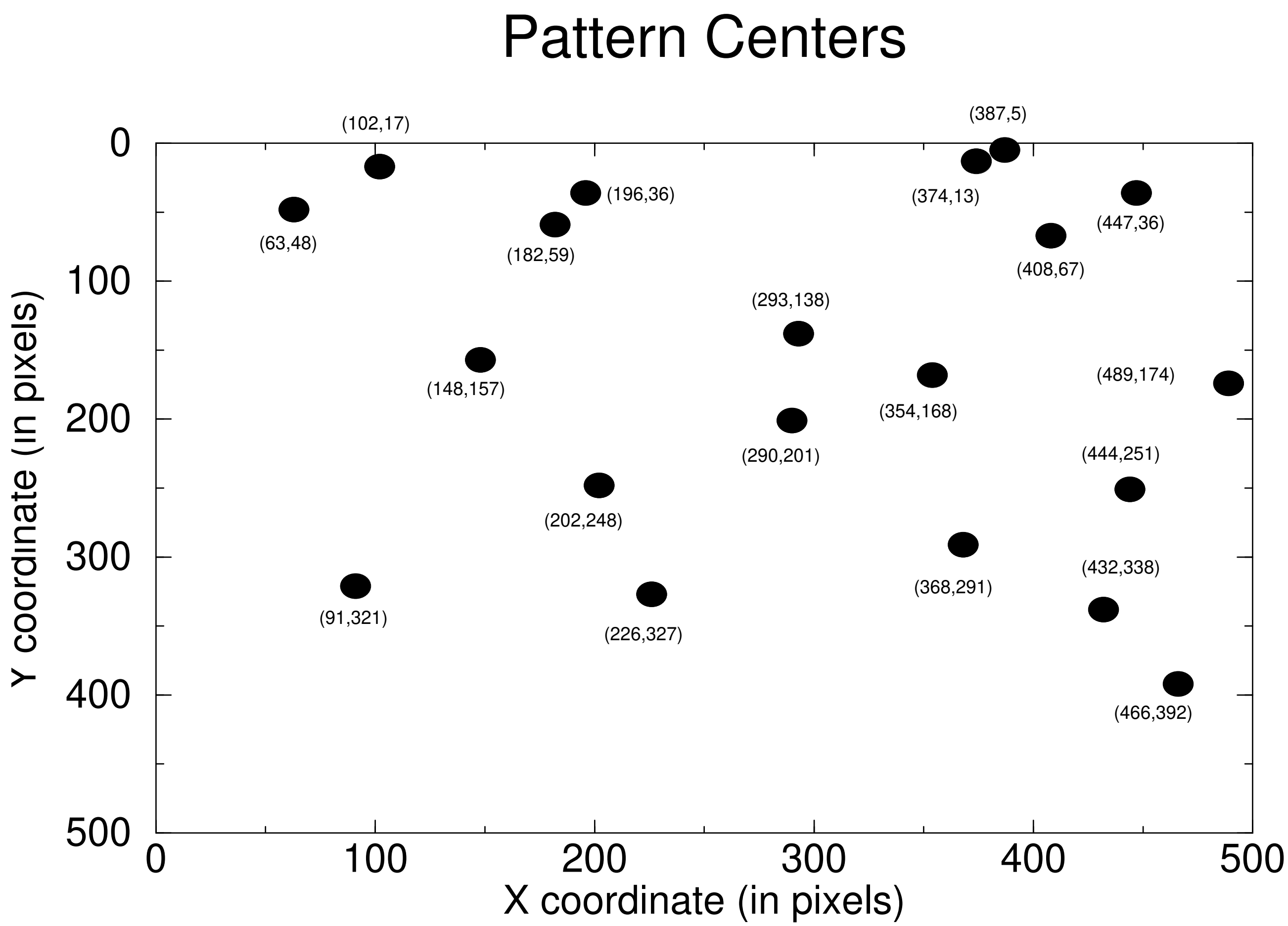
Objective

- Establish shift invariance of LPS.

Experimental Conditions

- Keep the pattern size the same and move the pattern around the image.
- Pattern size is 11x11. The image size is 500x500.
- Experiment 2 had 20 cases.

Experiments (cont.)



Experiments (cont.)

Experiment 3

Objective

- Determine the influence of image/pattern noise on LPS[1].

Experimental Conditions

- Image consists of a scanned-in page of text. The pattern is a circle created by a rubber stamp.
- Image size is 612x792. The pattern size is 94x95.

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1. This experiment was performed to demonstrate the use of LPS with typical images. It is not intended to demonstrate the effect of image noise. A detailed study of LPS and noise is beyond the scope of this project

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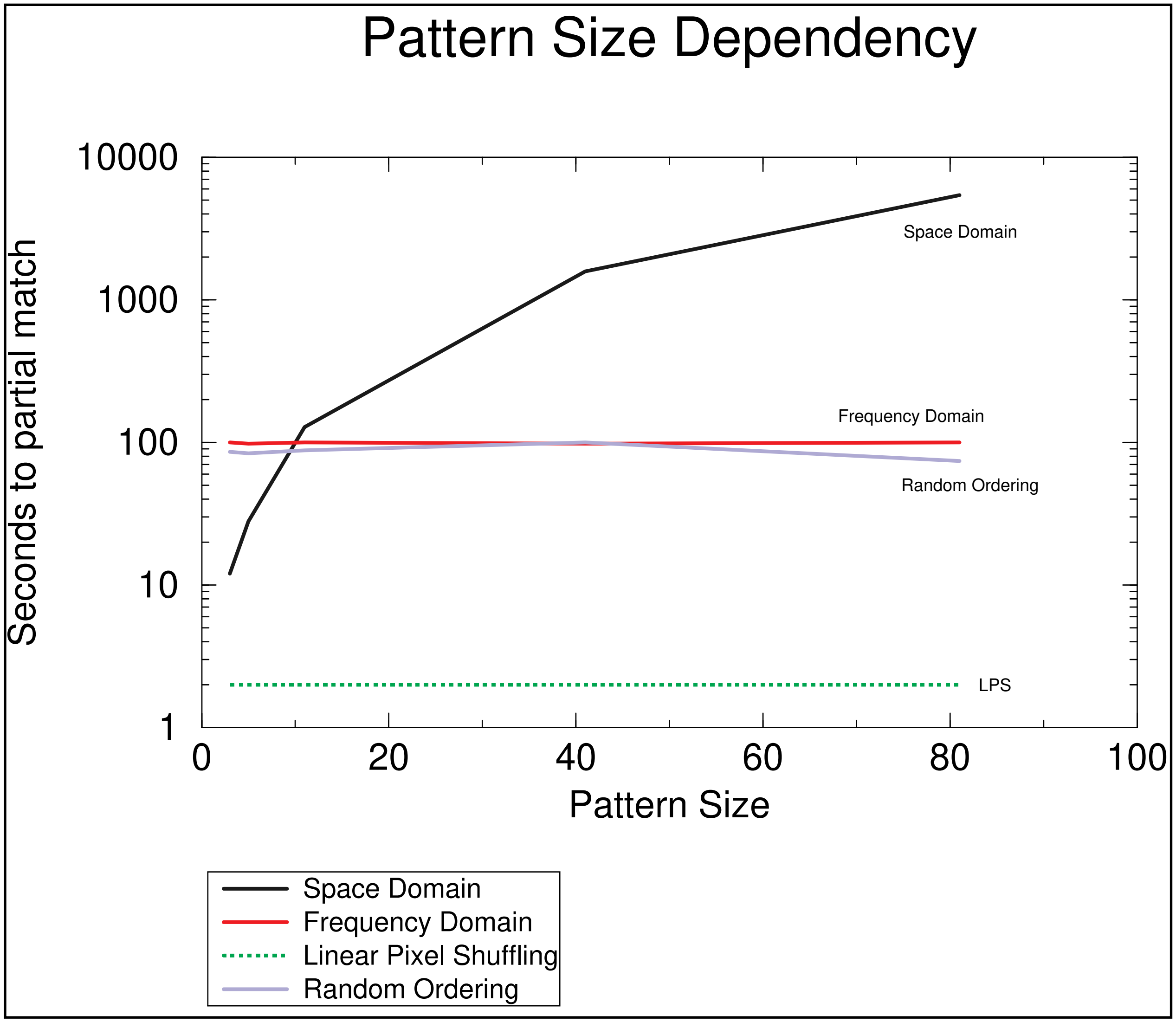
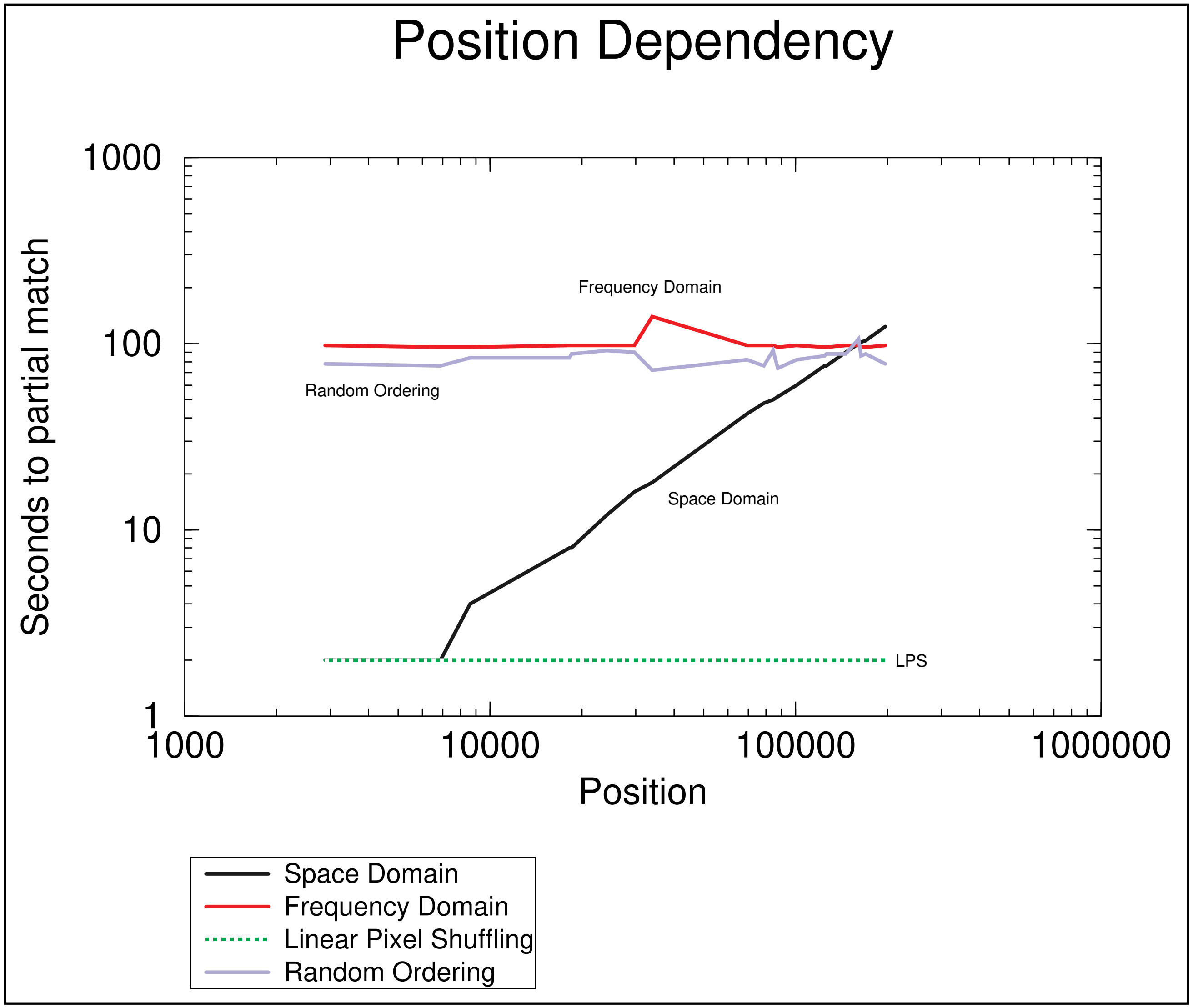


Pattern Size Dependency
Seconds to partial match
10000
1000
100
10
1
0
20
40
60
80
100
Pattern Size
Space Domain
Frequency Domain
Random Ordering
LPS
Space Domain
Frequency Domain
Linear Pixel Shuffling
Random Ordering


Position Dependency
1000
100
10
1
1000
10000
100000
1000000
Seconds to partial match
Position
Frequency Domain
Random Ordering
Space Domain
LPS
Space Domain
Frequency Domain
Linear Pixel Shuffling
Random Ordering

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Conclusions

- LPS was the most efficient Pattern Recognition algorithm. Compared to other methods, LPS was:
  - 5 - 2700x faster for pattern size dependence
  - 24 - 41x faster for pattern position dependence
  - 5 - 103x faster for a real test case

- Results show that LPS is independent of position and pattern size

Limitations

- This project did not investigate the effects of image/pattern noise. However, results from the single real test case suggest that LPS may calculate erroneous correlations in the presence of noise.
- LPS algorithm used is insufficient to deal with an unknown number of patterns
- Due to the 1 second time resolution, the inherent ef ficiency of LPS may be greater than values determined in this project

Future Research

- Add intelligent processing to:
  - handle an unknown number of patterns
  - find a pattern center quicker by concentrating on areas with high correlations
- Expand the study to include the effects of noise
- Expand the study of other techniques for obtaining LPS parameters to evaluate their efficiency

Numerical Results

Experiment 1

TABLE 1. first partial match found

Case	Space	Freq	Random	LPS
3x3	12	100	86	2
5x5	28	98	84	2
11x11	128	100	88	2
41x41	1,584	98	100	2
81x81	5,424	100	74	2

TABLE 2. found pattern center

Case	Space	Freq	Random	LPS
3x3	12	100	96	8
5x5	28	100	116	14
11x11	130	100	194	62
41x41	1,768	100	1,920	812
81x81	6,866	100	5,376	3,136

Numerical Results (cont.)

Experiment 2

TABLE 3. first partial match found (in seconds)

Case	Space	Freq	Random	LPS
(102,17)	4	96	84	2
(148,157)	48	98	76	2
(182,59)	16	98	90	2
(196,36)	8	98	84	2
(202,248)	76	96	86	2
(226,327)	102	96	86	2
(290,201)	60	98	82	2
(293,138)	42	98	82	2
(354,168)	50	98	92	2
(368,291)	90	98	88	2
(374,13)	2	96	76	2
(387,5)	2	98	78	2
(408,67)	18	140	72	2
(432,338)	104	96	88	2
(444,251)	76	96	88	2
(447,36)	8	98	88	2
(466,392)	124	98	78	2
(489,174)	52	96	74	2
(63,48)	12	98	92	2
(91,321)	100	98	106	2

Numerical Results (cont.)

TABLE 4. found pattern center (in seconds)

Case	Space	Freq	LPS	Random
(102,17)	6	96	44	146
(148,157)	50	98	22	126
(182,59)	20	98	158	148
(196,36)	12	98	112	210
(202,248)	78	96	86	200
(226,327)	106	98	168	88
(290,201)	64	98	62	196
(293,138)	44	98	44	140
(354,168)	54	98	92	216
(368,291)	92	98	98	178
(374,13)	4	96	156	104
(387,5)	2	98	38	234
(408,67)	22	140	28	164
(432,338)	108	98	68	120
(444,251)	80	98	100	106
(447,36)	12	98	8	160
(466,392)	128	98	106	210
(489,174)	56	96	154	192
(63,48)	16	98	62	176
(91,321)	104	98	104	124

Numerical Results (cont.)

Experiment 3

TABLE 5. first partial match found (in seconds)

Case	Space	Freq	Random	LPS
text	10,186	550	844	98

TABLE 6. found pattern center (in seconds)

Case	Space	Freq	Random	LPS
text	14,506	550	7,676	7,162

Numerical Analysis of Results

Experiment 1

TABLE 7. timing for Experiment 1 cases

Case	# pixels	Seconds/ Pixel	Pixels/ Second	# of pixels til 1st partial match	Seconds
3x3	200,400	5.9880E-05	16,700.0000	570	3.4132E-02
5x5	200,400	1.3972E-04	7,157.1429	570	7.9641E-02
11x11	200,400	6.4870E-04	1,541.5385	570	3.6976E-01
41x41	200,400	8.8224E-03	113.3484	5	4.4112E-02
81x81	200,400	3.4261E-02	29.1873	5	1.7131E-01

Numerical Analysis of Results (cont.)

Experiment 2

TABLE 8. timing for Experiment 2 cases

Case	# pixels	Seconds/ Pixel	Pixels/ Second	# of pixels til 1st partial match	Seconds
(102,17)	8,602	6.9751E-04	1433.6667	98	6.3374E-02
(148,157)	78,648	6.3574E-04	1572.9600	583	3.7701E-01
(182,59)	29,682	6.7381E-04	1484.1000	160	1.0347E-01
(196,36)	18,196	6.5949E-04	1516.3333	4	2.5867E-03
(202,248)	124,202	6.2801E-04	1592.3333	555	3.5891E-01
(226,327)	163,726	6.4742E-04	1544.5849	412	2.6643E-01
(290,201)	100,790	6.3498E-04	1574.8438	191	1.2352E-01
(293,138)	69,293	6.3498E-04	1574.8409	525	3.3951E-01
(354,168)	84,354	6.4016E-04	1562.1111	151	9.7648E-02
(368,291)	145,868	6.3071E-04	1585.5217	279	1.8042E-01
(374,13)	6,874	5.8190E-04	1718.5000	60	3.8801E-02
(387,5)	2,887	6.9276E-04	1443.5000	416	2.6902E-01
(408,67)	33,908	6.4881E-04	1541.2727	442	2.8583E-01
(432,338)	169,432	6.3742E-04	1568.8148	338	2.1858E-01
(444,251)	125,944	6.3520E-04	1574.3000	159	1.0282E-01
(447,36)	18,447	6.5051E-04	1537.2500	43	2.7807E-02
(466,392)	196,466	6.5151E-04	1534.8906	362	2.3410E-01
(489,174)	87,489	6.4008E-04	1562.3036	604	3.9059E-01
(63,48)	24,063	6.6492E-04	1503.9375	63	4.0741E-02
(91,321)	160,591	6.4761E-04	1544.1442	638	4.1258E-01

Numerical Analysis of Results (cont.)

The results for Frequency Domain in the 408x67 case obviously don't seem to belong. This anomaly is explained by background processes running at the same time. Repeat trials of this case show the results to be similar to other case results.

TABLE 9. results for 5 retrials of case 408x67 for partial match

Case	Space	Freq	Random	LPS
retrial 1	20	99	42	2
retrial 2	18	99	39	2
retrial 3	18	98	114	2
retrial 4	18	98	82	2
retrial 5	20	99	80	2
means	18.8	98.6	71.4	2

TABLE 10. results for 5 retrials of case 408x67 for pattern center

Case	Space	Freq	Random	LPS
retrial 1	24	99	120	28
retrial 2	22	99	158	28
retrial 3	22	98	268	26
retrial 4	22	98	176	26
retrial 5	22	99	100	28
means	22.4	98.6	164.4	27.2

The same approximate values resulted for Space Domain, LPS, and Random Order as in the original test case. Rerunning this particular case shows that the 140 seconds from the original experiment is not correct. The mean values for Frequency Domain are close to other case results, as expected.

Numerical Analysis of Results (cont.)

Experiment 3

TABLE 11. timing for Experiment 3 case

Case	# pixels	Seconds/ Pixel	Pixels/ Second	# of pixels til 1st partial match	Seconds
text	314,061	4.6188E-02	21.6504	2089	9.6488E+01