PC-2019/20 Course Project: Image Reader and 2D Pattern Recognition Asynchronous Execution

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Outline

Preview

- We will focus on multi threading and performance comparison between asynchronous and synchronous execution
- In the first part we will develop a simple Image Reader which reads all the images in a directory
- Later, with the aid of this Image Reader, we will apply the 2D Pattern Recognition algorithm on the read images.
- Such concatenation of operations has been conducted in synchronous and asynchronous manner for enabling a comparison between implementations

Technologies

- We have used the **C++17** which include *Filesystem* library that allows us to manage files without rely on external libraries
- For reading and writing on the images ha been used the **OpenCV** library
- We have used the **Boost thread library** which provides useful features such as: **thread pool** and **then** operation on future. (Not included in standard C++ library)
- For all the synchronous implementations **OpenMP** library has been used

Image Reader implementations

Algorithm 1: *Sync* ImageReader

Data: inputDir, numThreads Nt
Result: imagesVector

```
1 #pragma omp parallel for
    schedule(static)
    num_threads(numThreads)
2 for imageName in inputDir do
3 |   image =
  |     cv::imread(imageName)
4 |   #pragma omp critical
5 |   imagesVector.push_back(
  |     (image,imageName))
6 return imagesVector
```

Algorithm 2: *Async* ImageReader

Data: inputDir, ThreadPool Tp
Result: imagesVector

```
1 futImagesVector futIV = []
2 for imageName in inputDir do
3 |   lambdaImage =
  |     []{return cv::imread(imageName)}
4 |   futIV.pus_back(
  |     (boost::async(Tp,lambdImage),
  |     imageName))
5 for futImage in futIV do
6 |   imagesVector.push_back(
  |     (futImage[0].get(), futImage[1]))
7 return imagesVector
```

Pattern Recognition algorithm

Let's briefly recall the 2D Pattern Recognition algorithm

Algorithm 3: computeSAD

Data: queryMatrix Q, targetMatrix T, startRowIndex i, startColIndex j
Result: localSadValue

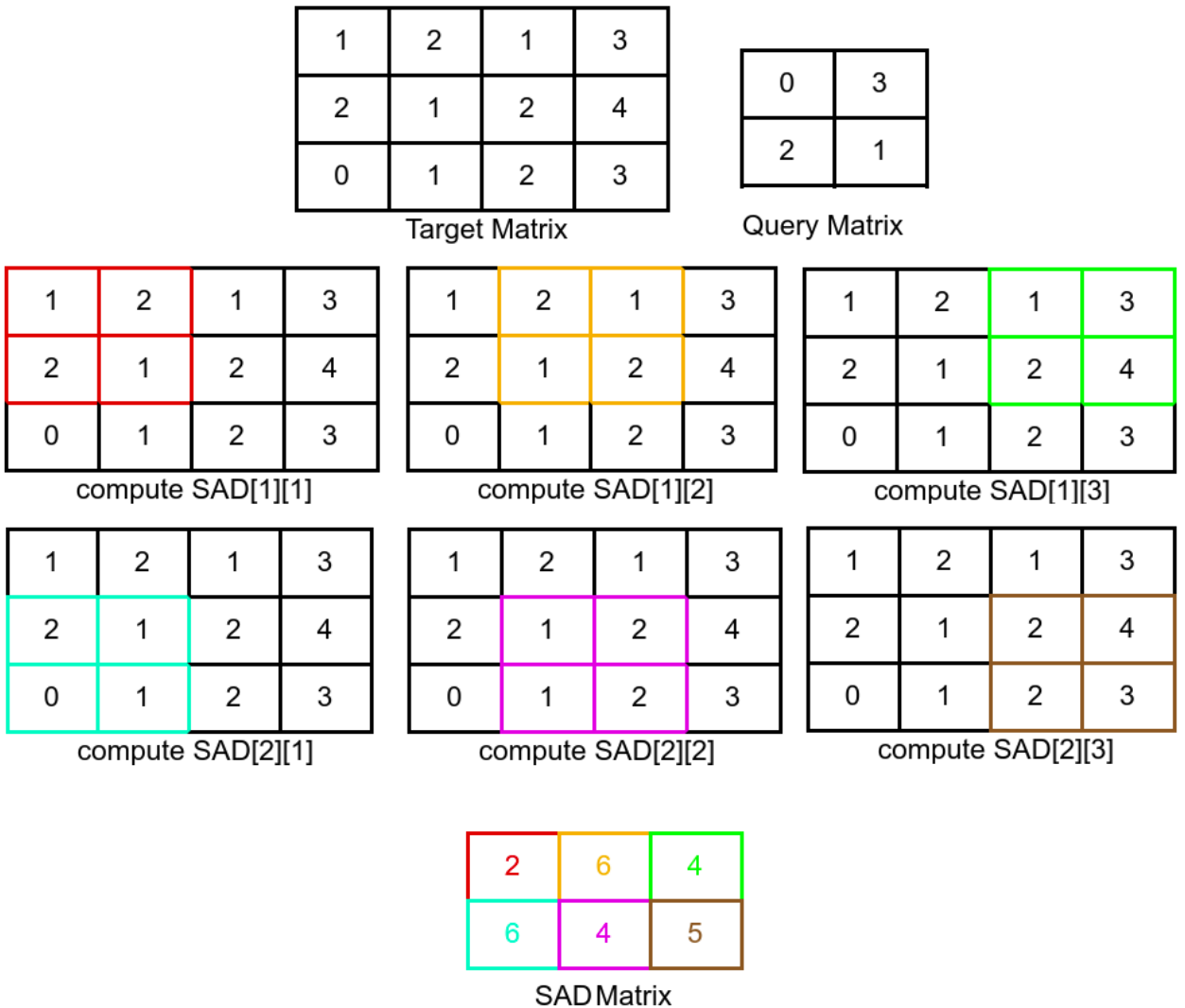
```
1 localSadValue = 0
2 for from k = 0 to Q.rows do
3 |   for from l = 0 to Q.cols do
4 |   |   targetV = T[i+k][j+l]
5 |   |   queryV = Q[k][l]
6 |   |   localSadValue +=
  |   |     | targetV - queryV |
7 return localSadValue
```

Algorithm 4: PatternRecognition

Data: queryMatrix Q, targetMatrix T
Result: SADMatrix S

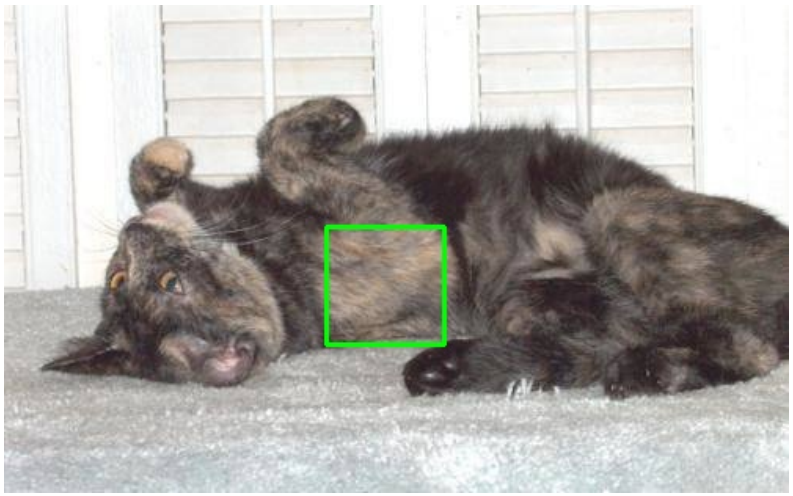
```
1 Define SADMatrix S
2 S.rows = T.rows - Q.rows + 1
3 S.cols = T.cols - Q.cols + 1
4 for from i = 0 to S.rows do
5 |   for from j = 0 to S.cols do
6 |   |   S[i][j] =
  |   |     computeSAD(P,Q,i,j)
7 cx, cy = argmin(S)
```

Trivial example



Full Execution

- We chain together the image reader and the 2D Pattern Recognition
- The image reader reads all the image from a known input directory
- The pattern recognition algorithm is applied to each image with a random query matrix and we draw a rectangle to identify the closest portion to that query



Full Execution algorithms

Algorithm 5: *Sync* Full Execution

```
Data: inputDir, numThreads Nt, queryMatrix
      Q, outputDir
1  imagesVector =
     SyncImageReader(inputDir,Nt)
2  #pragma omp parallel for schedule(static)
     num_threads(numThreads)
3  for image, imageName in imagesVector do
4  |     cx, cy = PatternRecognition(Q, image)
5  |     topLeftPoint tlp = (cx,cy)
6  |     bottomRightPoint brp =
   |       (cx + Q.cols, cy + Q.rows)
7  |     cv::rectangle(image, tlp, brp, green)
8  |     cv::imwrite(outputDir + imageName,
   |       image)
```

Algorithm 6: *Async* Full Execution

```
Data: inputDir, ThreadPool Tp, queryMatrix Q,
      outputDir
1  futImagesVector =
     AsyncImageReader(inputDir,Tp)
2  futuresTask = []
3  for futImage, imageName in futImagesVector do
4  |     futuresTask.push_back(
   |       futImage.then(Tp,[Q](futImage){
5  |         image = futImage.get()
6  |         cx,cy = PatternRecognition(Q,image)
7  |         topLeftPoint tlp = (cx, cy)
8  |         bottomRightPoint brp =
9  |               (cx + Q.cols, cy + Q.rows)
10 |         cv::rectangle(image, tlp, brp, green)
11 |         return image, ImageName}
12 |         ).then(Tp,[outputDir](futOutput){
13 |               image = futOutput.get()
14 |               cv::imwrite(outputDir +
15 |                     imageName, image) }))
16 for futTask in futuresTask do
17 |     futTask.wait();
```

Full Execution algorithms

Algorithm 7: *Sync* Full Execution

```
Data: inputDir, numThreads Nt, queryMatrix
      Q, outputDir
1  imagesVector =
     SyncImageReader(inputDir,Nt)
2  #pragma omp parallel for schedule(static)
     num_threads(numThreads)
3  for image, imageName in imagesVector do
4  |     cx, cy = PatternRecognition(Q, image)
5  |     topLeftPoint tlp = (cx,cy)
6  |     bottomRightPoint brp =
   |       (cx + Q.cols, cy + Q.rows)
7  |     cv::rectangle(image, tlp, brp, green)
8  |     cv::imwrite(outputDir + imageName,
   |       image)
```

Algorithm 8: *Async* Full Execution

```
Data: inputDir, ThreadPool Tp, queryMatrix Q,
      outputDir
1  futImagesVector =
     AsyncImageReader(inputDir,Tp)
2  futuresTask = []
3  for futImage, imageName in futImagesVector do
4  |     futuresTask.push_back(
   |       futImage.then(Tp,[Q](futImage){
5  |         image = futImage.get()
6  |         cx,cy = PatternRecognition(Q,image)
7  |         topLeftPoint tlp = (cx, cy)
8  |         bottomRightPoint brp =
9  |               (cx + Q.cols, cy + Q.rows)
10 |         cv::rectangle(image, tlp, brp, green)
11 |         return image, ImageName}
12 |         ).then(Tp,[outputDir](futOutput){
13 |               image = futOutput.get()
14 |               cv::imwrite(outputDir +
15 |                     imageName, image) }))
16 for futTask in futuresTask do
17 |     futTask.wait();
```

Full Execution algorithms

Algorithm 9: *Sync* Full Execution

```
Data: inputDir, numThreads Nt, queryMatrix
      Q, outputDir
1  imagesVector =
     SyncImageReader(inputDir,Nt)
2  #pragma omp parallel for schedule(static)
     num_threads(numThreads)
3  for image, imageName in imagesVector do
4      cx, cy = PatternRecognition(Q, image)
5      topLeftPoint tlp = (cx,cy)
6      bottomRightPoint brp =
         (cx + Q.cols, cy + Q.rows)
7      cv::rectangle(image, tlp, brp, green)
8      cv::imwrite(outputDir + imageName,
         image)
```

Algorithm 10: *Async* Full Execution

```
Data: inputDir, ThreadPool Tp, queryMatrix Q,
      outputDir
1  futImagesVector =
     AsyncImageReader(inputDir,Tp)
2  futuresTask = []
3  for futImage, imageName in futImagesVector do
4      futuresTask.push_back(
         futImage.then(Tp,[Q](futImage){
5          image = futImage.get()
6          cx,cy = PatternRecognition(Q,image)
7          topLeftPoint tlp = (cx, cy)
8          bottomRightPoint brp =
9              (cx + Q.cols, cy + Q.rows)
10         cv::rectangle(image, tlp, brp, green)
11         return image, ImageName}
12         ).then(Tp,[outputDir](futOutput){
13             image = futOutput.get()
14             cv::imwrite(outputDir +
15                 imageName, image) }))
16 for futTask in futuresTask do
17     futTask.wait();
```

Full Execution algorithms

Algorithm 11: *Sync* Full Execution

Data: inputDir, numThreads Nt, queryMatrix Q, outputDir

```
1  imagesVector =
     SyncImageReader(inputDir,Nt)
2  #pragma omp parallel for schedule(static)
     num_threads(numThreads)
3  for image, imageName in imagesVector do
4      cx, cy = PatternRecognition(Q, image)
5      topLeftPoint tlp = (cx,cy)
6      bottomRightPoint brp =
         (cx + Q.cols, cy + Q.rows)
7      cv::rectangle(image, tlp, brp, green)
8      cv::imwrite(outputDir + imageName,
         image)
```

Algorithm 12: *Async* Full Execution

Data: inputDir, ThreadPool Tp, queryMatrix Q, outputDir

```
1  futImagesVector =
     AsyncImageReader(inputDir,Tp)
2  futuresTask = []
3  for futImage, imageName in futImagesVector do
4      futuresTask.push_back(
         futImage.then(Tp,[Q](futImage){
5          image = futImage.get()
6          cx,cy = PatternRecognition(Q,image)
7          topLeftPoint tlp = (cx, cy)
8          bottomRightPoint brp =
9              (cx + Q.cols, cy + Q.rows)
10         cv::rectangle(image, tlp, brp, green)
11         return image, ImageName}
12         ).then(Tp,[outputDir](futOutput){
13             image = futOutput.get()
14             cv::imwrite(outputDir +
15                 imageName, image) }))
16 for futTask in futuresTask do
17     futTask.wait();
```

Full Execution algorithms

Algorithm 13: *Sync* Full Execution

Data: inputDir, numThreads Nt, queryMatrix Q, outputDir

```
1  imagesVector = SyncImageReader(inputDir,Nt)
2  #pragma omp parallel for schedule(static) num_threads(numThreads)
3  for image, imageName in imagesVector do
4      cx, cy = PatternRecognition(Q, image)
5      topLeftPoint tlp = (cx,cy)
6      bottomRightPoint brp = (cx + Q.cols, cy + Q.rows)
7      cv::rectangle(image, tlp, brp, green)
8      cv::imwrite(outputDir + imageName, image)
```

Algorithm 14: *Async* Full Execution

Data: inputDir, ThreadPool Tp, queryMatrix Q, outputDir

```
1  futImagesVector = AsyncImageReader(inputDir,Tp)
2  futuresTask = []
3  for futImage, imageName in futImagesVector do
4      futuresTask.push_back(
         futImage.then(Tp,[Q](futImage){
5          image = futImage.get()
6          cx,cy = PatternRecognition(Q,image)
7          topLeftPoint tlp = (cx, cy)
8          bottomRightPoint brp =
9                (cx + Q.cols, cy + Q.rows)
10         cv::rectangle(image, tlp, brp, green)
11         return image, ImageName}
12         ).then(Tp,[outputDir](futOutput){
13         image = futOutput.get()
14         cv::imwrite(outputDir +
15               imageName, image) }))
16 for futTask in futuresTask do
17     futTask.wait();
```

Points of interest

- Synchronous execution uses OpenMP for enabling parallelism
- In Asynchronous execution we can highlight:
  - We need the *futuresTask* vector since at the end of the algorithm we need to wait that all images have been processed
  - Thanks to **then** function in line 4 and 12 we can fully decouple the task **I/O** bound from the task **CPU** bound.
  - The function **get** applied to the futures in line 5 and in line 13 is not blocking.

Equipment,metrics and profiling

- The tests have been conducted on a Ubuntu 18.04 LTS machine equipped with:
  - Intel Core i7-4790 3.6GHz with Turbo Boost up to 4Ghz, 4 core/8 thread processor
  - RAM 16 GB DDR4
  - Western Digital Blue 1TB Hard Disk 7200rpm
- The metrics used are execution time and SpeedUp S_P, it is calculated as

$$S_P = \frac{t_s}{t_p}$$

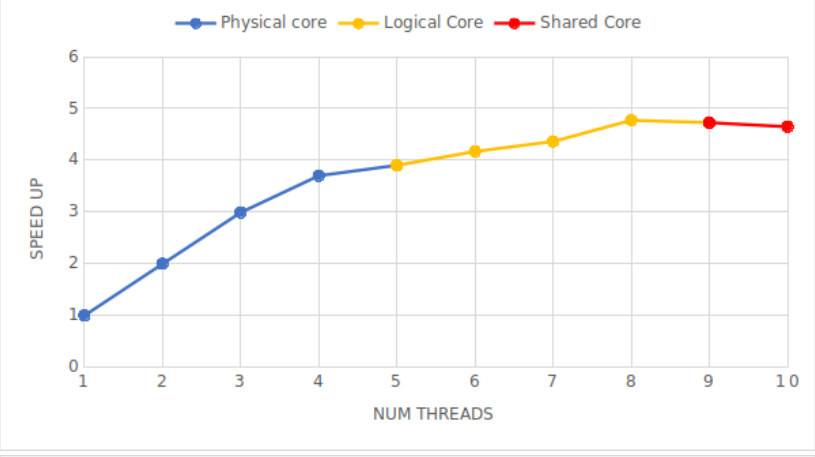
- The high precision C++11 library *chrono* has been used for measuring the execution time.

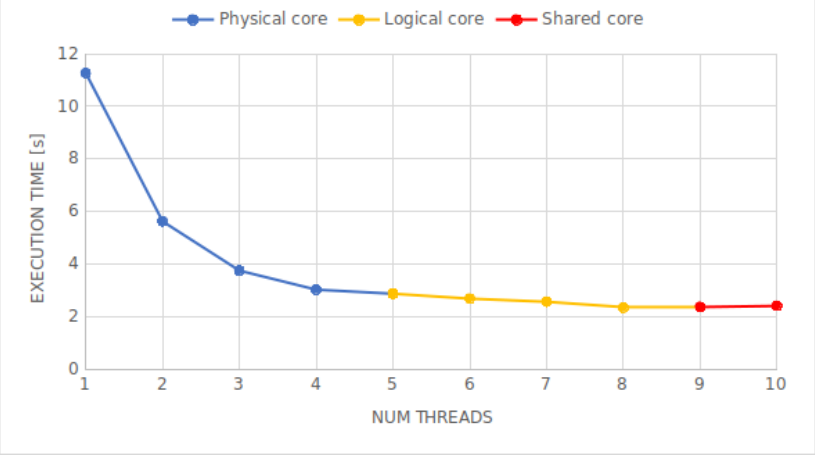
Tests

- Each time has been measured running each test 5 times and taking the average as a result
- All the images taken from dogs vs cat Kaggle competition, which includes 37.5K (cats and dogs) images and has a size of 850MB
- For testing the image reader has been used a subset of 25K images (the original training set)
- For testing the Full Execution has been used a subset of 5K images taken from the original test set. The query matrix used has dimensions dimension 50×50 pixels.

Synchronous Image Reader results

Test executed on 25K images with a total size of 582MB

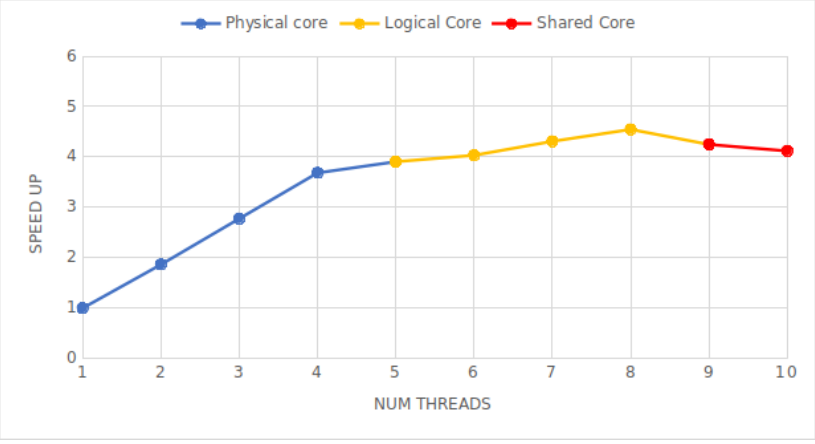


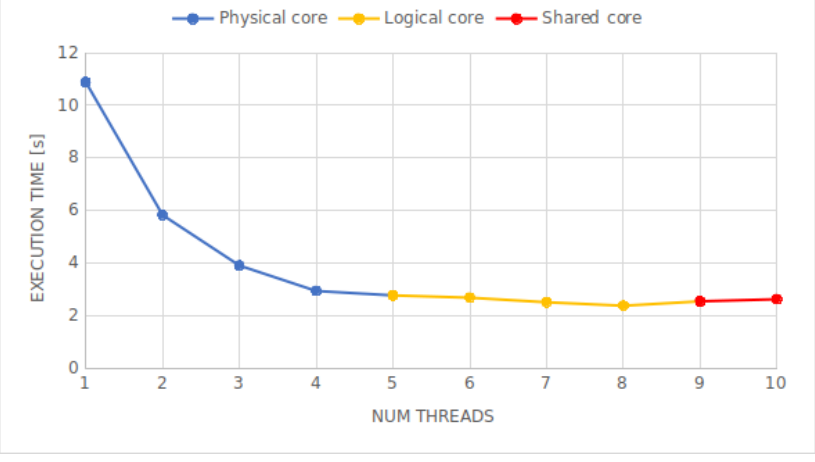


Sync Image Reader		
Num threads	Execution time	SpeedUp
1	11,26s	1,00x
2	5,64s	2,00x
3	3,77s	2,99x
4	3,04s	3,70x
5	2,89s	3,90x
6	2,70s	4,17x
7	2,58s	4,36x
8	**2,36s**	**4,77x**
9	2,38s	4,73x
10	2,42s	4,65x

Asynchronous Image Reader results

Test executed on 25K images with a total size of 582MB





Async Image Reader		
Num threads	Execution time	SpeedUp
1	10,88s	1,00x
2	5,84s	1,86x
3	3,92s	2,78x
4	2,95s	3,68x
5	2,79s	3,91x
6	2,70s	4,03x
7	2,53s	4,31x
8	**2,39s**	**4,55x**
9	2,56s	4,25x
10	2,64s	4,12x

Image Reader comparison

Test executed on 25K images with a total size of 582MB

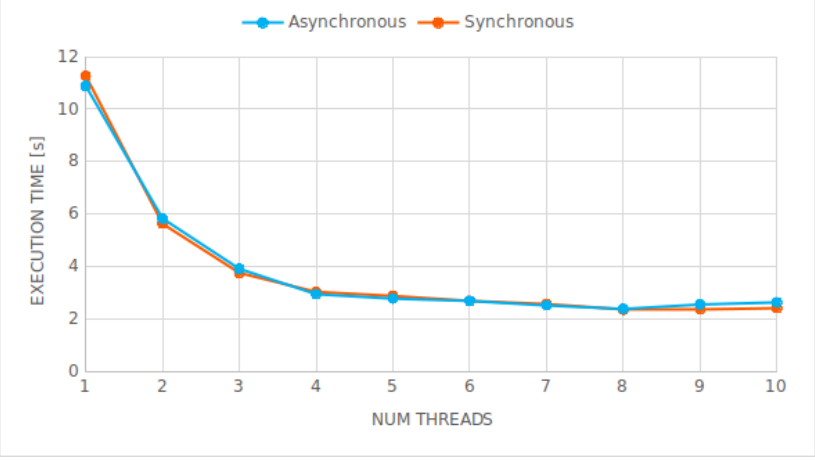
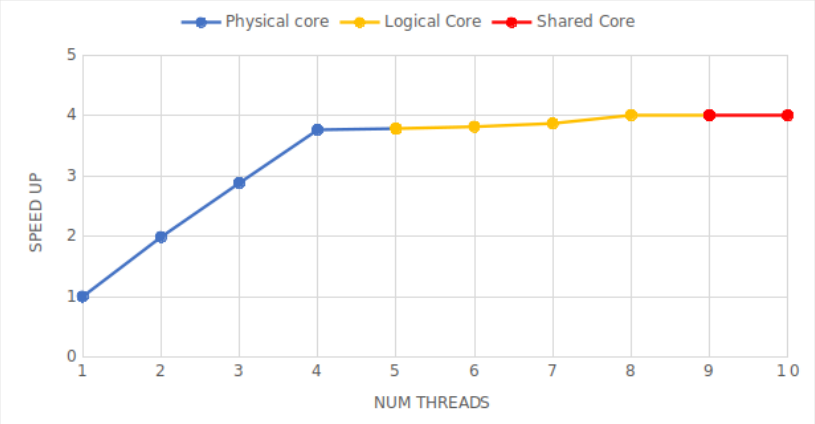
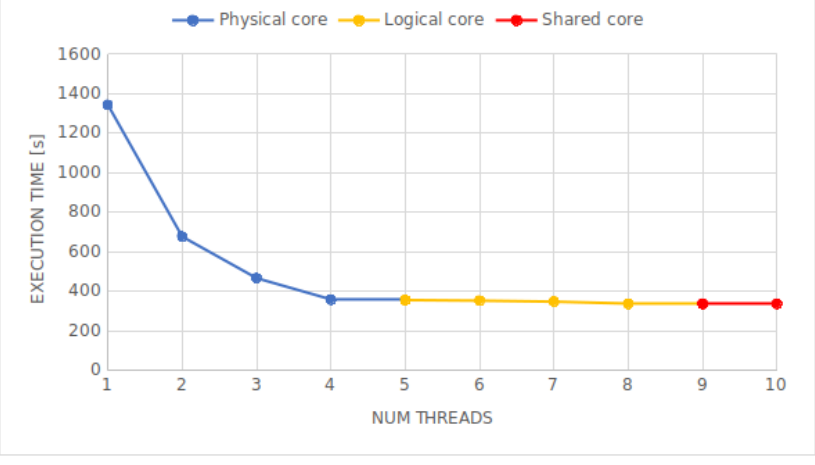


Image Reader Comparison		
Num threads	Asynchronous	Synchronous
1	10,88s	11,26s
2	5,84s	5,64s
3	3,92s	3,77s
4	2,95s	3,04s
5	2,79s	2,89s
6	2,70s	2,70s
7	2,53s	2,58s
8	2,39s	**2,36s**
9	2,56s	2,38s
10	2,64s	2,42s

Synchronous Full Execution results

Test executed on 5K images with a query matrix 50×50 pixels

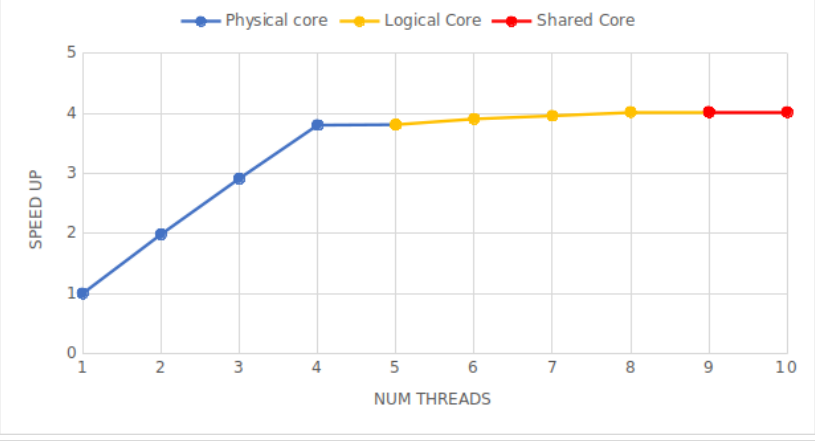


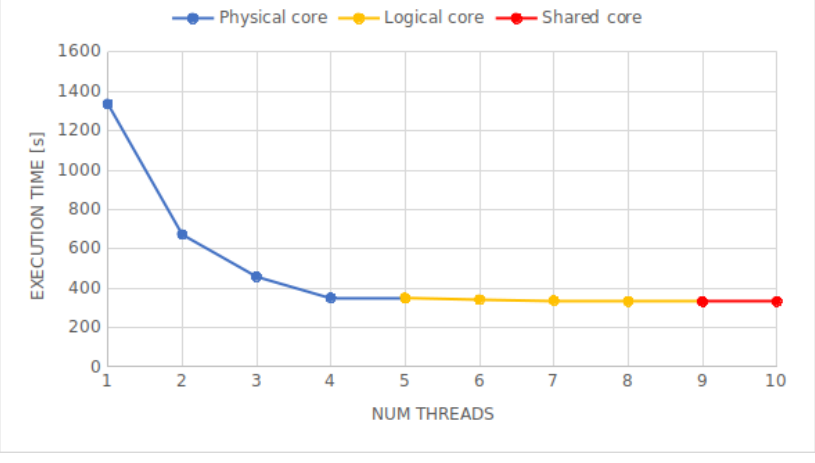


Sync Full Execution		
Num threads	Execution time	SpeedUp
1	1343,88s	1,00x
2	676,92s	1,99x
3	466,57s	2,88x
4	357,43s	3,76x
5	355,48s	3,78x
6	352,65s	3,81x
7	347,69s	3,87x
8	**335,72s**	**4,00x**
9	336,096s	4,00x
10	336,166s	4,00x

Asynchronous Full Execution results

Test executed on 5K images with a query matrix 50×50 pixels

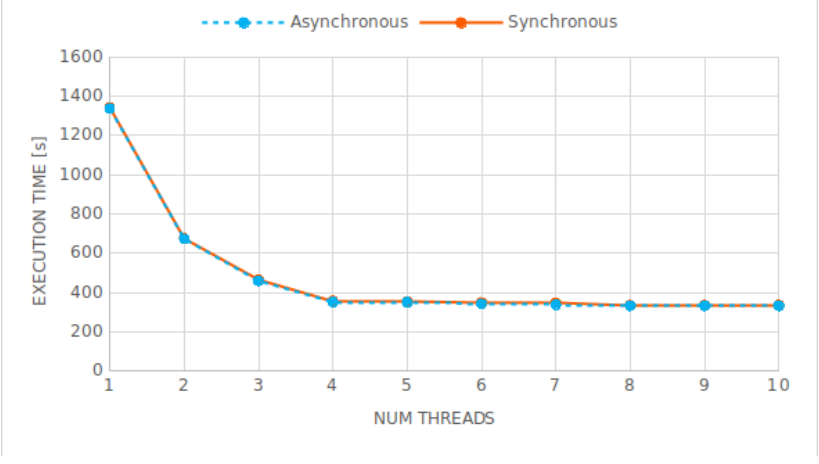




Async Full Execution		
Num threads	Execution time	SpeedUp
1	1336,63s	1,00x
2	672,91s	1,99x
3	458,49s	2,92x
4	351,09s	3,81x
5	350,43s	3,81x
6	341,90s	3,91x
7	337,35s	3,96x
8	**332,10s**	**4,02**
9	332,15s	4,02x
10	332,267s	4,02x

Full Execution comparison

Test executed on 5K images with a query matrix 50×50 pixels



Full Execution Comparison		
Num threads	Asynchronous	Synchronous
1	1336,63s	1343,88s
2	672,91s	676,92s
3	458,49s	466,57
4	351,09s	357,43s
5	350,43s	355,48s
6	341,90s	352,65s
7	337,35s	347,69s
8	**332,10s**	335,72s
9	332,15s	336,09s
10	332,26s	336,16s

Conclusions

- Both implementations of the Image Reader achieve very similar execution time
- We have a **4.5x** SpeedUp in asynchronous implementation and a **4,7x** SpeedUp in the synchronous one
- Due to the CPU bound nature of the problem also in the Full Execution both implementations achieve very similar results, actually we have a little improvement in the asynchronous implementation
- Thanks to the parallel structure, in the Full Execution we have achieved a **4x** SpeedUp