PC-2019/20 Course Project: Parallel 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 to 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 includes *Filesystem* library that allows us to manage files without relying on external libraries
- For reading and writing on the images **OpenCV** library has been used
- 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

```
#pragma omp parallel for schedule(static) num_threads(numThreads)
for imageName in inputDir do
    image = cv::imread(imageName)
    #pragma omp critical
    imagesVector.push_back((image,imageName))
return imagesVector
```

Algorithm 2: *Async* ImageReader

Data: inputDir, ThreadPool Tp
Result: imagesVector

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

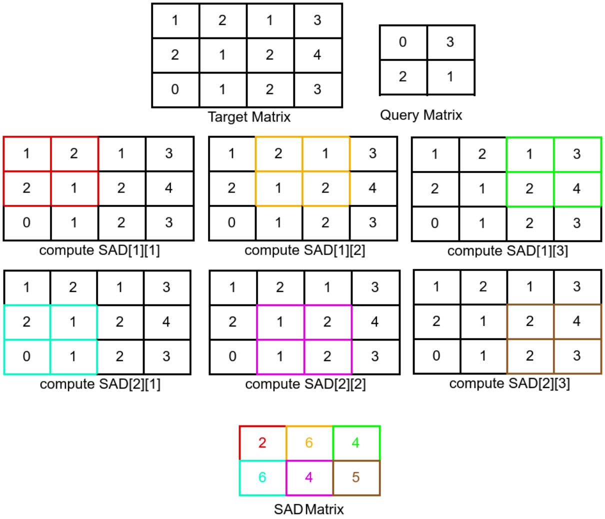
localSadValue = 0
for from k = 0 to Q.rows do
    for from l = 0 to Q.cols do
        targetV = T[i+k][j+l]
        queryV = Q[k][l]
        localSadValue +=
          | targetV - queryV |
return localSadValue
```

Algorithm 4: PatternRecognition

```
Data: queryMatrix Q,
      targetMatrix T
Result: SADMatrix S

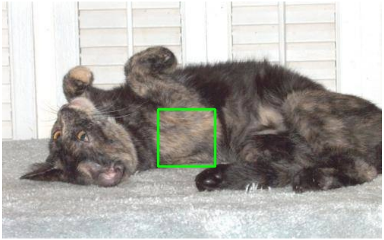
Define SADMatrix S
S.rows = T.rows - Q.rows + 1
S.cols = T.cols - Q.cols + 1
for from i = 0 to S.rows do
    for from j = 0 to S.cols do
        S[i][j] =
          computeSAD(P,Q,i,j)
cx, cy = argmin(S)
```

Trivial example



Full Execution

- We chain together the image reader and the 2D Pattern Recognition
- The image reader reads all the images 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

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

Algorithm 6: *Async* Full Execution

Data: inputDir, ThreadPool Tp, queryMatrix Q, outputDir

```
futImagesVector =
  AsyncImageReader(inputDir,Tp)
futuresTask = []
for futImage, imageName in futImagesVector do
    futuresTask.push_back(
      futImage.then(Tp,[Q](futImage){
        image = futImage.get()
        cx,cy = PatternRecognition(Q,image)
        topLeftPoint tlp = (cx, cy)
        bottomRightPoint brp =
              (cx + Q.cols, cy + Q.rows)
        cv::rectangle(image, tlp, brp, green)
        return image, ImageName}
        ).then(Tp,[outputDir](futOutput){
              image = futOutput.get()
              cv::imwrite(outputDir +
                    imageName, image) }))
for futTask in futuresTask do
    futTask.wait();
```

Full Execution algorithms

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        ).then(Tp,[outputDir](futOutput){
              image = futOutput.get()
              cv::imwrite(outputDir +
                    imageName, image) }))
for futTask in futuresTask do
    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

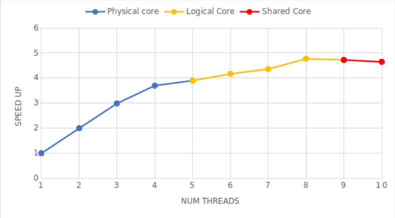
- The tests have been conducted on an Ubuntu 18.04 LTS machine equipped with:
  - Intel Core i7-4790 3.6GHz with Turbo Boost up to 4Ghz, 4 core/8 thread processor
  - RAM 16 GB DDR4
  - Western Digital Blue 1TB Hard Disk 7200rpm
- The metrics used are execution time and SpeedUp S_P, it is calculated as
$$S_P = \frac{t_s}{t_p}$$
- The high precision C++11 library *chrono* has been used for measuring the execution time.

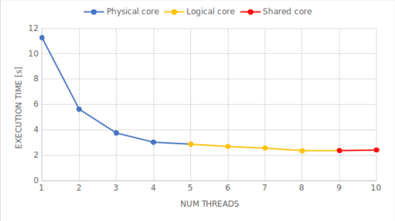
Tests

- Each time has been measured running each test 5 times and taking the average as a result
- All the images come 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 a subset of 25K images (the original training set) has been used
- For testing the Full Execution a subset of 5K images taken from the original test set has been used . 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

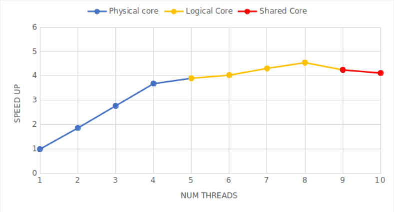


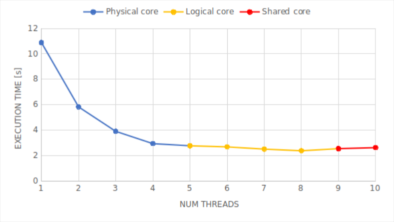


Sync Image Reader		
Num threads	Execution time	SpeedUp
1	11,26s	1,00x
2	5,64s	2,00x
3	3,77s	2,99x
4	3,04s	3,70x
5	2,89s	3,90x
6	2,70s	4,17x
7	2,58s	4,36x
8	**2,36s**	**4,77x**
9	2,38s	4,73x
10	2,42s	4,65x

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

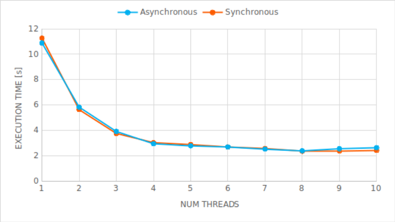
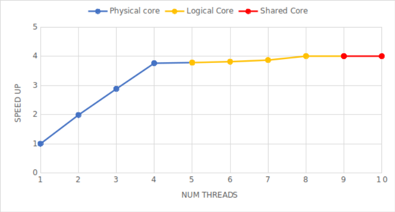
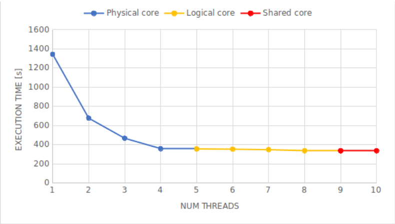


Image Reader Comparison		
Num threads	Asynchronous	Synchronous
1	10,88s	11,26s
2	5,84s	5,64s
3	3,92s	3,77s
4	2,95s	3,04s
5	2,79s	2,89s
6	2,70s	2,70s
7	2,53s	2,58s
8	2,39s	**2,36s**
9	2,56s	2,38s
10	2,64s	2,42s

Synchronous Full Execution results

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

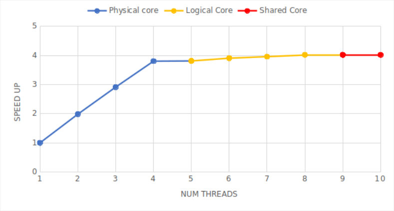


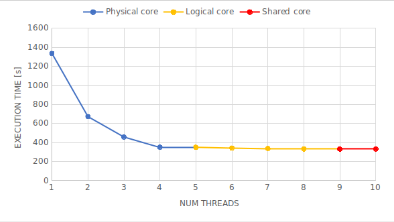


Sync Full Execution		
Num threads	Execution time	SpeedUp
1	1343,88s	1,00x
2	676,92s	1,99x
3	466,57s	2,88x
4	357,43s	3,76x
5	355,48s	3,78x
6	352,65s	3,81x
7	347,69s	3,87x
8	**335,72s**	**4,00x**
9	336,096s	4,00x
10	336,166s	4,00x

Asynchronous Full Execution results

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

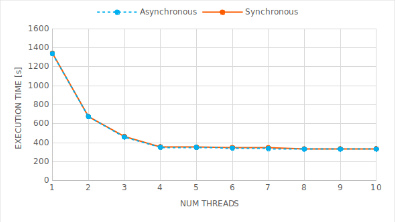




Async Full Execution		
Num threads	Execution time	SpeedUp
1	1336,63s	1,00x
2	672,91s	1,99x
3	458,49s	2,92x
4	351,09s	3,81x
5	350,43s	3,81x
6	341,90s	3,91x
7	337,35s	3,96x
8	**332,10s**	**4,02x**
9	332,15s	4,02x
10	332,267s	4,02x

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