Mean shift clustering algorithm

comparison between sequential, openMP and CUDA implementations

Parallel Computing (9 CFU)

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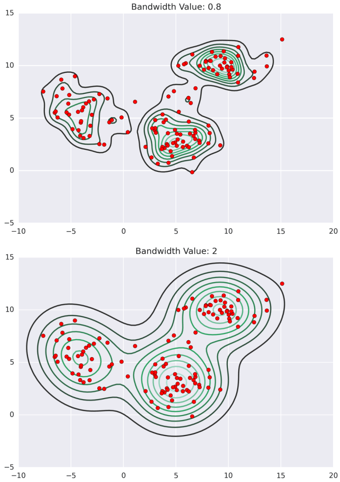
Contents overview

Introduction

Mean Shift

- Non-parametric **clustering** procedure
- Computational Complexity: $\mathcal{O}(n^2)$.
- **Embarrassingly parallel** structure



Mean Shift

- It builds upon the concept of **kernel density estimation** (KDE).
- At each step of the procedure a kernel function is applied to each point that causes the points to shift in the direction of the nearest peak of the KDE surface:

$$K(x) = e^{-\frac{x^2}{2\sigma^2}} \tag{1}$$

where x: distance, σ : *bandwidth*.

Implementation

Sequential Version

Algorithm 1 Mean shift algorithm

procedure $\textsc{MeanShift}(\textit{original\_points})$

  $\textit{shifted\_points} \leftarrow \textit{original\_points}$

  while $\textit{iteration} < \textit{N\_ITERATIONS}$ **do**

    for $\textit{point}$ **in** $\textit{shifted\_points}$ **do**

      $\textit{point} \leftarrow \textsc{ShiftPoint}(\textit{point}, \textit{original\_points})$

Implemented in C++

Sequential Version

Algorithm 2 Mean shift subroutine

procedure $\textsc{ShiftPoint}(\mathit{point}, \mathit{original\_points})$

$\quad \mathit{num} \leftarrow 0$

$\quad \mathit{den} \leftarrow 0$

$\quad$ **for** op **in** $\mathit{original\_points}$ **do**

$\qquad \mathit{dist} \leftarrow \textsc{ComputeDistance}(\mathit{point}, \mathit{op})$

$\qquad w \leftarrow \textsc{Kernel}(\mathit{dist}, \mathit{BANDWIDTH})$

$\qquad \mathit{num} \leftarrow \mathit{num} + \mathit{op} * w$

$\qquad \mathit{den} \leftarrow \mathit{den} + w$

$\quad$ **return** $\mathit{num}/\mathit{den}$

Parallel Version: OpenMP

- OpenMP (Open Multiprocessing) is an API for shared-memory parallel programming.
- It follows the the **fork-join** programming model.
- It does not require program restructuring, but only the addition of **compiler directives**

Parallel Version: OpenMP

Algorithm 3 Mean shift openMP algorithm

procedure OMPMEANSHIFT(*original_points*)
  shifted_points ← *original_points*
  while *iteration* < *N_ITERATIONS* **do**
    #pragma omp parallel for schedule(static)
    for *point* **in** *shifted_points* **do**
      point ← SHIFTPOINT(*point*, *original_points*)

Parallel Version: CUDA naive

- Each Point to be shifted assigned to a thread.
- **Coalesced access** to global memory: points are stored as *Structure of Arrays* $[x_1, ..., x_n, y_1, ...y_n, z_1, ..., z_n]$.
- Access to the array is done: *BlockDim.x * BlockIdx.x* + *threadIdx.x*.

Parallel Versione: CUDA naive

Algorithm 4 CUDA naive kernel

procedure $\textsc{NaiveKernel}(shifted\_pts, orig\_pts)$

$idx \leftarrow threadIdx.x + blockIdx.x * blockDim.x$

if $idx < |orig\_pts|$ **then**

$sp \leftarrow shifted\_pts[idx]$

$tot\_weight \leftarrow 0$

$new\_spt \leftarrow 0$

for op **in** $orig\_pts$ **do**

$dist \leftarrow \textsc{ComputeDistance}(op, sp)$

$weight \leftarrow \textsc{Kernel}(dist, BW)$

$new\_spt \leftarrow new\_spt + op * weight$

$tot\_weight \leftarrow tot\_weight + weight$

$shifted\_pts[idx] \leftarrow new\_spt / tot\_weight$

Parallel Version: CUDA Tiling

- Limit global memory access making use of shared memory

Algorithm 5 CUDA kernel tiling - data loading

$tile \leftarrow shared\_mem\_array[TILE\_WIDTH]$

$n\_tiles \leftarrow (|orig\_pts| - 1)/(TILE\_WIDTH + 1)$

for $tile\_i$ **in** n_tiles **do**

   $tile\_idx \leftarrow tile\_i * TILE\_WIDTH + threadIdx.x$

   if $tile\_idx < |orig\_pts|$ **then**

      $tile[tx] \leftarrow orig\_pts[tile\_idx]$

   else

      $tile[tx] \leftarrow null\_pt$

   $\_\_syncthreads()$

Experiments

Dataset

- We generated sets of 3d points using *sklearn.dataset.make_blobs()*.
- It generates **gaussian distribution** with 3 centers and 1.5 standard deviation.
- Datasets dimensions: 100, 1.000, 10.000, 100.000, 500.000, 1.000.000.

Experiments setting

All the tests have been performed on a machine equipped with:

- CPU: Intel Core i7-860 @ 2.80GHz, with 4 cores/ 8 threads
- GPU: NVidia GeForce GTX 980, 4 GB (with CUDA 10.1)
- Average over 15 runs

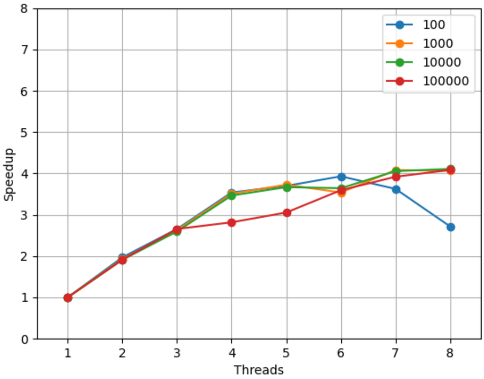
Speedup

To compare the performance of a sequential respect to a parallel implementation: **speedup** metric.

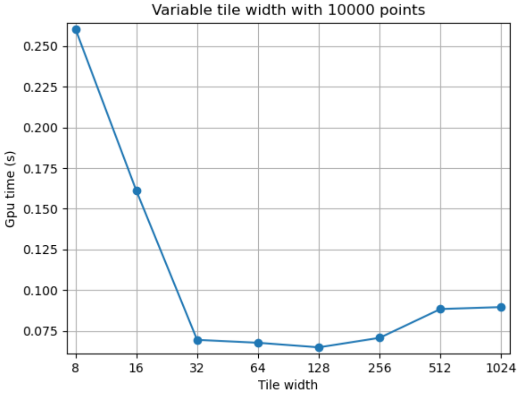
$$S = \frac{t_S}{t_P}$$

where t_s: sequential time execution, t_p: parallel time execution.

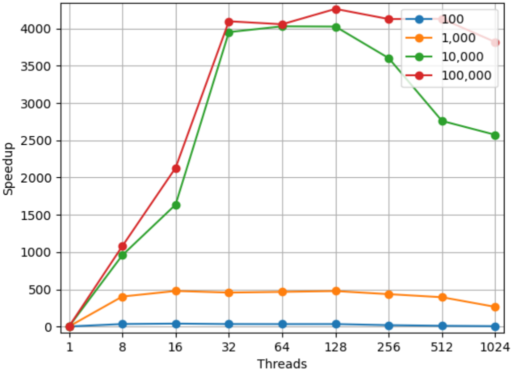
Speedup: Sequential over OpenMP



GPU Time varying tile width



Speedup: Sequential over CUDA



Conclusions

Conclusions

- Mean shift $\mathcal{O}(n^2)$, but **embarrassingly parallel** structure

OpenMP

- Implementation difficulty: very low
- Speedup: sub-linear

CUDA

- Implementation difficulty: higher
- Speedup: up to 4400x time faster.

Thanks for the attention