ALGES
ADVANCED LABORATORY FOR GEOSTATISTICAL SUPERCOMPUTING

CUDA-Based Implementation of GSLIB: The Geostatistical Software Library

Daniel Baeza
dabaeza@alges.cl

Oscar Peredo
operedo@alges.cl

NVIDIA CUDA RESEARCH CENTER

amtc
ADVANCED MINING TECHNOLOGY CENTER


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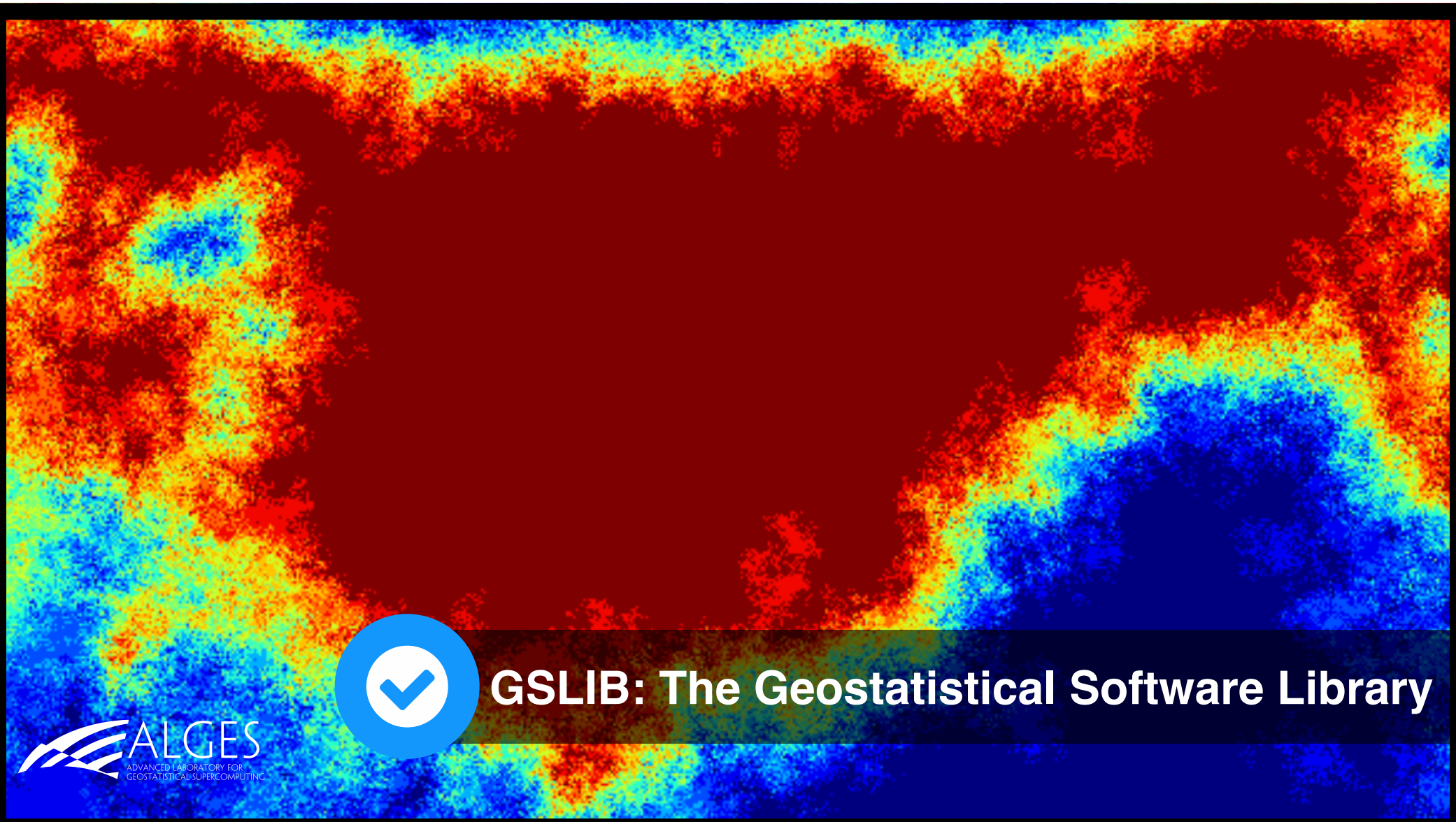
The Mining Process
Exploration
Evaluation
Planning
Operation


GSLIB: The Geostatistical Software Library
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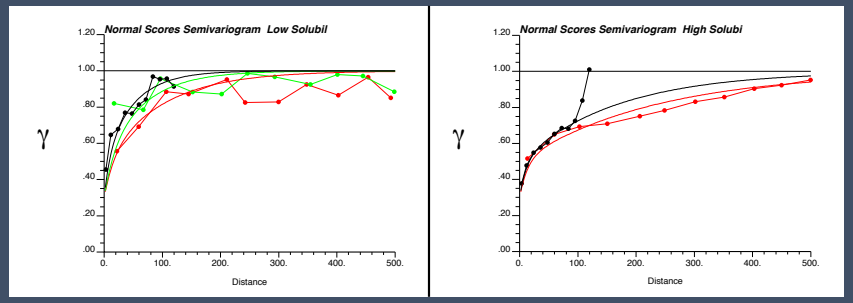
GSLIB: The Geostatistical Software Library

- GSLIB is a software package composed by a set of utilities and applications related with geostatistics
- Full implemented in Fortran 77/90
- Run in OSX, Linux and Windows
- Widely used for academics, researchers, engineers

GSLIB: Geostatistical Software Library and user's guide *(1998)*
Deutsch, Clayton V, Journel, André G

Variogram calculation with GSLIB

- **gamv** is the GSLIB variogram calculation method
- It's a fundamental tool in geostatistics
- Allow to quantify the spatial variability of a variable
- Used in geostatistical estimation and simulation
- High computational cost



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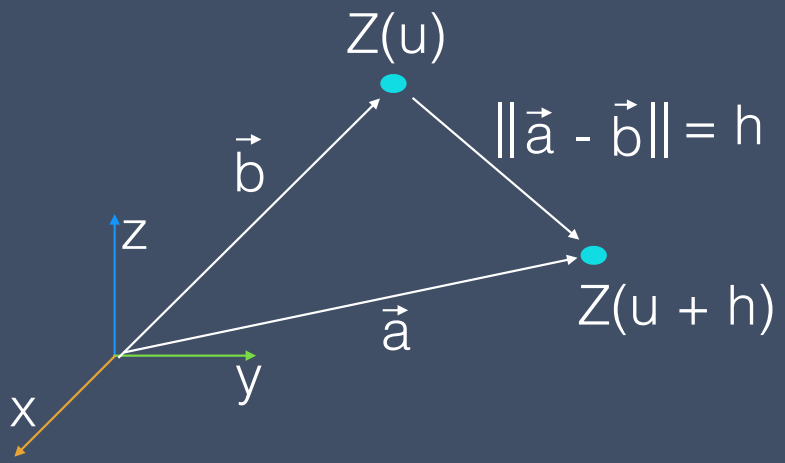
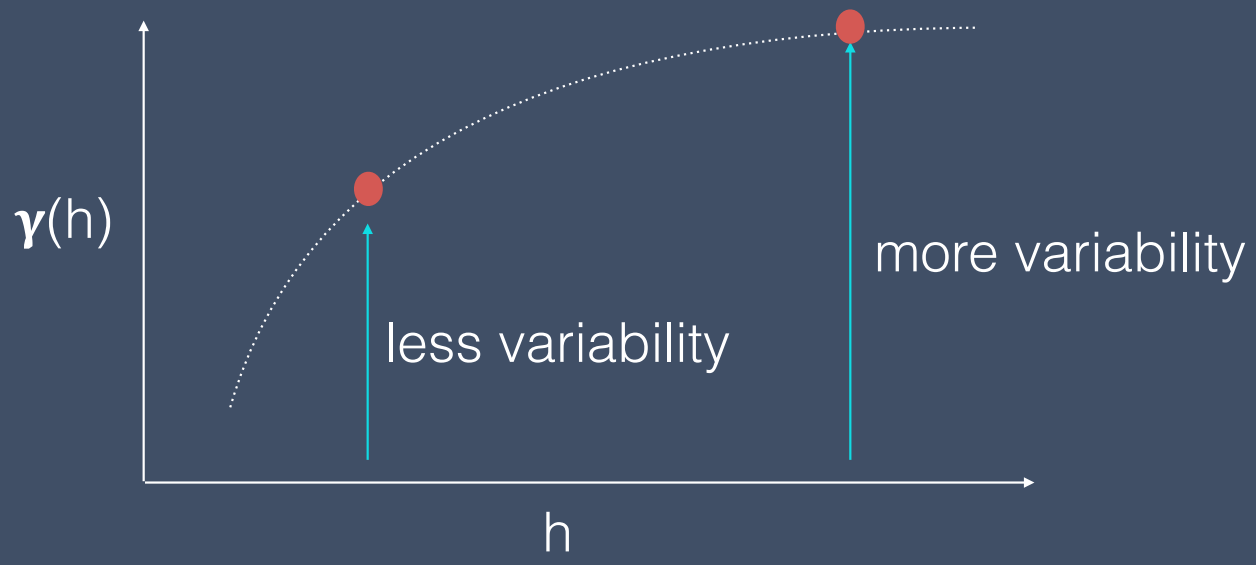
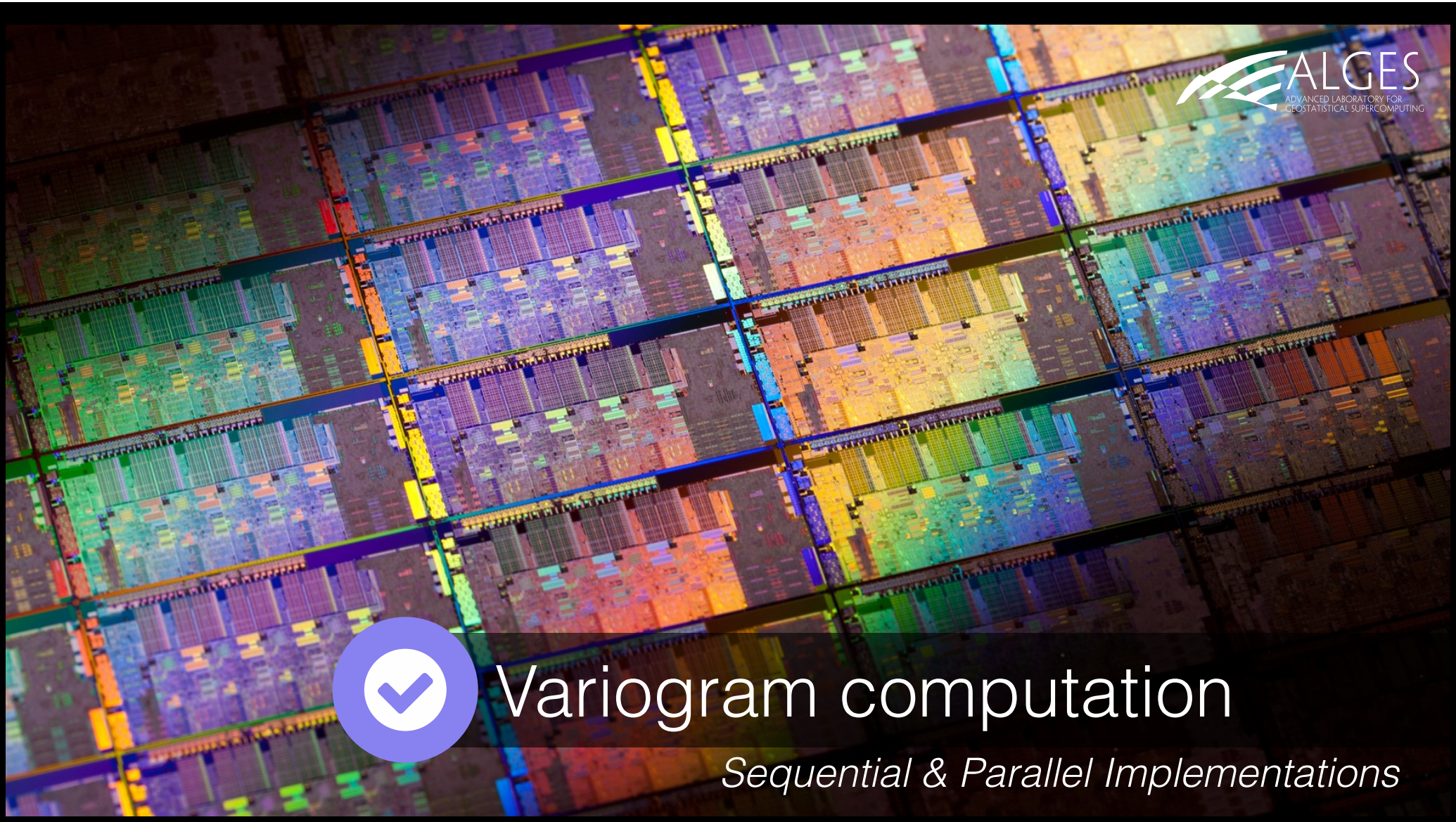
Variogram calculation



$$2\gamma(h) = \frac{1}{N(h)} \sum [z(u) - z(u + h)]^2$$





Variogram computation

Sequential & Parallel Implementations

Sequential implementation

Input:

- $(\mathbf{VR}, \Omega)$: sample data values $\mathbf{VR}$ (m columns) defined in a 3D domain of coordinates Ω
- $nvar$: number of variables ($nvar \leq m$)
- $nlag$: number of lags
- h: lag separation distance
- $ndir$: number of directions
- $\mathbf{h}_1, \ldots, \mathbf{h}_{ndir}$: directions
- $\tau_1, \ldots, \tau_{ndir}$: geometrical tolerance parameters
- $nvarg$: number of variograms
- $(ivtype_1, ivtail_1, ivhead_1), \ldots, (ivtype_{nvarg}, ivtail_{nvarg}, ivhead_{nvarg})$: variogram types

Setup parameters & Load data

```
Read input parameter file;
Read sample data values file;
β ← zeros(nvar × nlag × ndir × nvarg);
for i ∈ {1, ..., |Ω|} do
    for j ∈ {i, ..., |Ω|} do
        for id ∈ {1, ..., ndir} do
            for iv ∈ {1, ..., nvarg} do
                for il ∈ {1, ..., nlag} do
                    p_i = (x_i, y_i, z_i) ∈ Ω;
                    p_j = (x_j, y_j, z_j) ∈ Ω;
                    if (p_i, p_j) satisfy tolerances τ_id and ||p_i − p_j|| ≈ h_id × il × h then
                        Save (VR_{i,ivhead_iv} or VR_{i,ivtail_iv}) and (VR_{j,ivhead_iv} or VR_{j,ivtail_iv}) according to variogram ivtype_iv into β;
γ ← build variogram using statistics β Write γ in the output file
```

Main computation: Loop over pairs of points

Read computation results

Output: Output file with γ values

Sequential implementation

```
4  for i ∈ {1, ..., |Ω|} do
5      for j ∈ {i, ..., |Ω|} do
6          for id ∈ {1, ..., ndir} do
7              for iv ∈ {1, ..., nvarg} do
8                  for il ∈ {1, ..., nlag} do
9                      p_i = (x_i, y_i, z_i) ∈ Ω;
10                     p_j = (x_j, y_j, z_j) ∈ Ω;
11                     if (p_i, p_j) satisfy tolerances τ_id and ||p_i − p_j|| ≈ h_id × il × h then
12                         Save (VR_{i,ivhead_iv} or VR_{i,ivtail_iv}) and (VR_{j,ivhead_iv} or VR_{j,ivtail_iv}) according to variogram ivtype_iv into β;
```

Sequential implementation

```
4  for i ∈ {1, ..., |Ω|} do
5      for j ∈ {i, ..., |Ω|} do
6          for id ∈ {1, ..., ndir} do
7              for iv ∈ {1, ..., nvarg} do
8                  for il ∈ {1, ..., nlag} do
9                      p_i = (x_i, y_i, z_i) ∈ Ω;
10                     p_j = (x_j, y_j, z_j) ∈ Ω;
11                     if (p_i, p_j) satisfy tolerances τ_id and ||p_i − p_j|| ≈ h_id × il × h then
12                         Save (VR_{i,ivhead_iv} or VR_{i,ivtail_iv}) and (VR_{j,ivhead_iv} or VR_{j,ivtail_iv}) according to variogram ivtype_iv into β;
```

Sequential implementation

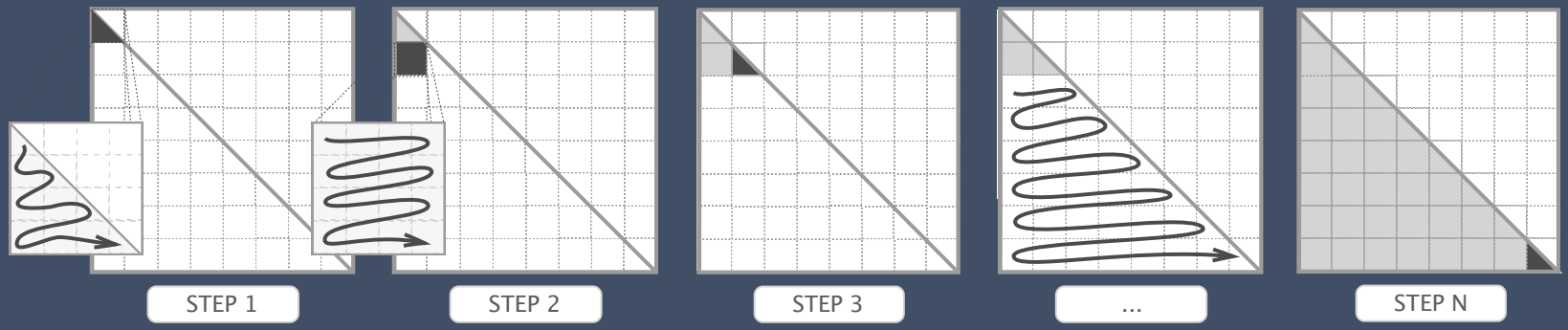
```
4  for i ∈ {1, ..., |Ω|} do
5      for j ∈ {i, ..., |Ω|} do
6          for id ∈ {1, ..., ndir} do
7              for iv ∈ {1, ..., nvarg} do
8                  for il ∈ {1, ..., nlag} do
9                      p_i = (x_i, y_i, z_i) ∈ Ω;
10                     p_j = (x_j, y_j, z_j) ∈ Ω;
11                     if (p_i, p_j) satisfy tolerances τ_id and ||p_i − p_j|| ≈ h_id × il × h then
12                         Save (VR_{i,ivhead_iv} or VR_{i,ivtail_iv}) and (VR_{j,ivhead_iv} or VR_{j,ivtail_iv}) according to variogram ivtype_iv into β;
```

COMPUTE_STATISTICS(p_i, p_j)

Sequential implementation

```
4  for i ∈ {1, ..., |Ω|} do
5      for j ∈ {i, ..., |Ω|} do
6          for id ∈ {1, ..., ndir} do
7              for iv ∈ {1, ..., nvarg} do
8                  for il ∈ {1, ..., nlag} do
9                      p_i = (x_i, y_i, z_i) ∈ Ω;
10                     p_j = (x_j, y_j, z_j) ∈ Ω;
11                     if (p_i, p_j) satisfy tolerances τ_id and ||p_i − p_j|| ≈ h_id × il × h then
12                         Save (VR_{i,ivhead_iv} or VR_{i,ivtail_iv}) and (VR_{j,ivhead_iv} or VR_{j,ivtail_iv}) according to variogram ivtype_iv into β;
```

COMPUTE_STATISTICS(p_i, p_j)



Parallel implementation

GPU Kernel

```
1  id_x = blockId.x*blockDim.x + threadId.x                /* x threads coord in the GPU grid */
2  id_y = blockId.y*blockDim.y + threadId.y                /* y threads coord in the GPU grid */
3  Set and Initialize shared memory in the block
4  __syncthreads()
5  iter_x = id_x
6  iter_y = id_y
7  while (iter_x & iter_y ∈ ChunkPoints)                   /* Chunk points belongs thread (x,y) */
8  do
9      j = iter_x + |Ω|/2
10     i = iter_y
11     COMPUTE_STATISTICS(p_i, p_j)  <--
12     store result in shared memory via atomic functions
13     if (iter_x > iter_y) then
14         i = iter_y
15         j = iter_x
16         COMPUTE_STATISTICS(p_i, p_j)  <--
17         store result in shared memory via atomic functions
18     else
19         if (iter_x == iter_y) then
20             i = iter_y
21             j = iter_y
22             COMPUTE_STATISTICS(p_i, p_j)  <--
23             store result in shared memory via atomic functions
24         i = iter_x + |Ω|/2
25         j = iter_y + |Ω|/2
26         COMPUTE_STATISTICS(p_i, p_j)  <--
27         store result in shared memory via atomic functions
28     UP_DATE(iter_x, iter_y)
29 __syncthreads()
30 save Statistics values that are in shared memory into globa memory via atomic functions
   Output: Array β
```

Each thread compute
only a couple of correlation values

Parallel implementation

```
1  id_x = blockId.x*blockDim.x + threadId.x                    /* x threads coord in the GPU grid */
2  id_y = blockId.y*blockDim.y + threadId.y                    /* y threads coord in the GPU grid */
3  Set and Initialize shared memory in the block
4  __syncthreads()
5  iter_x = id_x
6  iter_y = id_y
7  while (iter_x & iter_y ∈ ChunkPoints)                       /* Chunk points belongs thread (x,y) */
8  do
9      j = iter_x + |Ω|/2
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11     COMPUTE_STATISTICS(p_i, p_j)
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13     if (iter_x > iter_y) then
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17         store result in shared memory via atomic functions
18     else
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22             COMPUTE_STATISTICS(p_i, p_j)
23             store result in shared memory via atomic functions
24         i = iter_x + |Ω|/2
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26         COMPUTE_STATISTICS(p_i, p_j)
27         store result in shared memory via atomic functions
28     UP_DATE(iter_x, iter_y)
29 __syncthreads()
30 save Statistics values that are in shared memory into globa memory via atomic functions
```

Output: Array β

Parallel implementation

```
1  id_x = blockId.x*blockDim.x + threadId.x                    /* x threads coord in the GPU grid */
2  id_y = blockId.y*blockDim.y + threadId.y                    /* y threads coord in the GPU grid */
3  Set and Initialize shared memory in the block
4  __syncthreads()
5  iter_x = id_x
6  iter_y = id_y
7  while (iter_x & iter_y ∈ ChunkPoints)                       /* Chunk points belongs thread (x,y) */
8  do
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29 __syncthreads()
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```
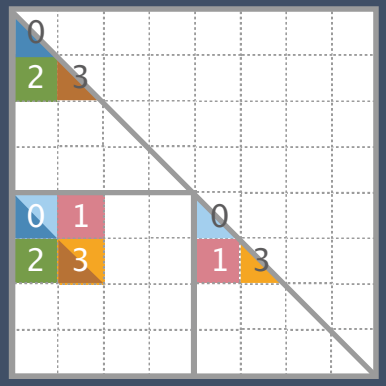

Output: Array β



STEP 1

Parallel implementation

```
1  id_x = blockId.x*blockDim.x + threadId.x                    /* x threads coord in the GPU grid */
2  id_y = blockId.y*blockDim.y + threadId.y                    /* y threads coord in the GPU grid */
3  Set and Initialize shared memory in the block
4  __syncthreads()
5  iter_x = id_x
6  iter_y = id_y
7  while (iter_x & iter_y ∈ ChunkPoints)                       /* Chunk points belongs thread (x,y) */
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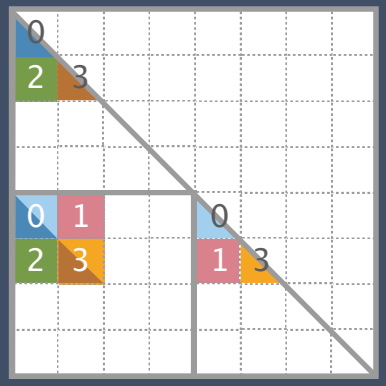
Output: Array β



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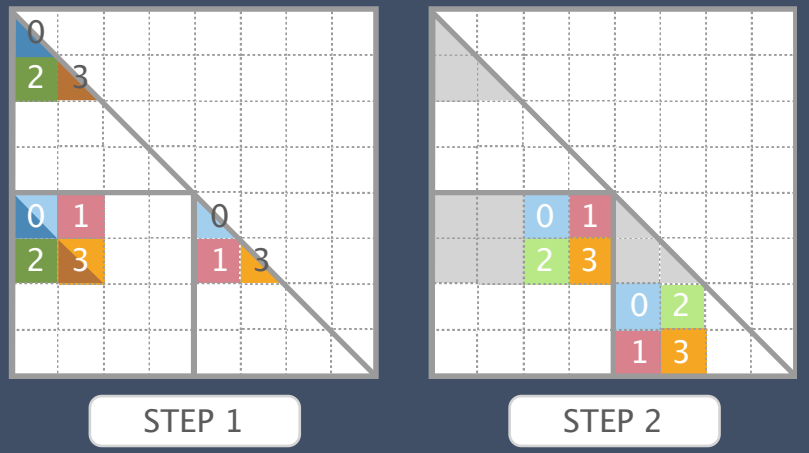
Output: Array β



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```

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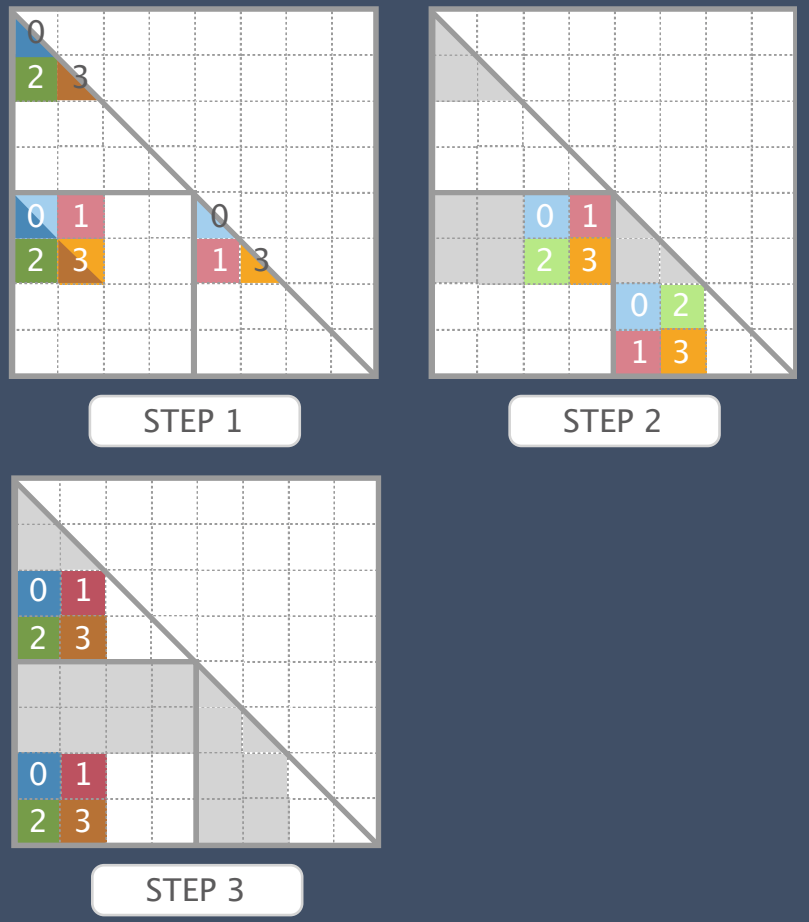


Results
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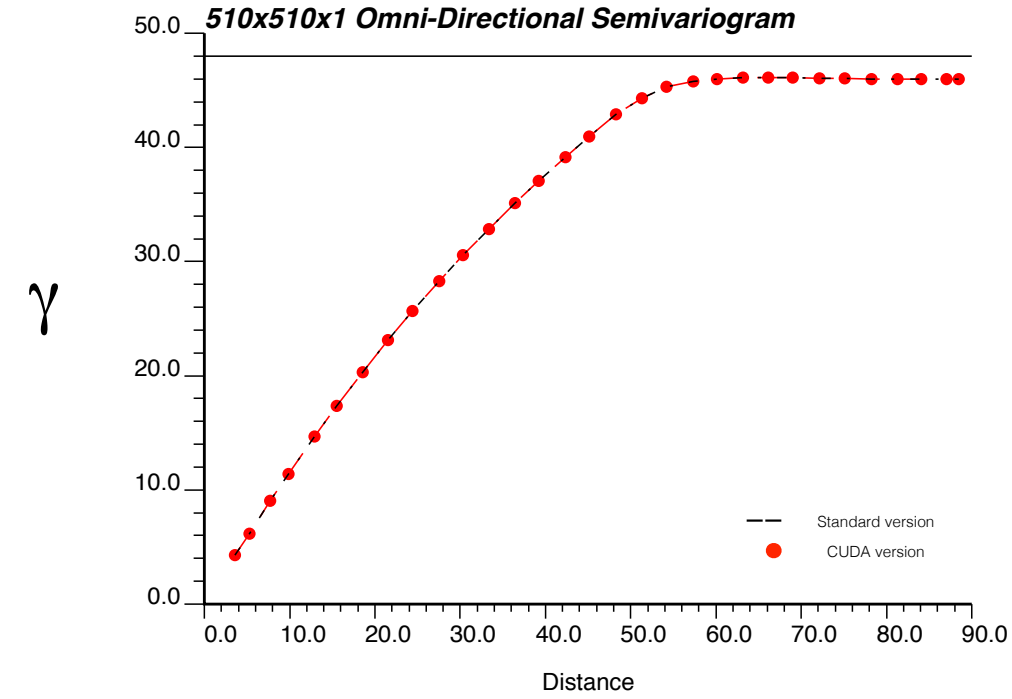
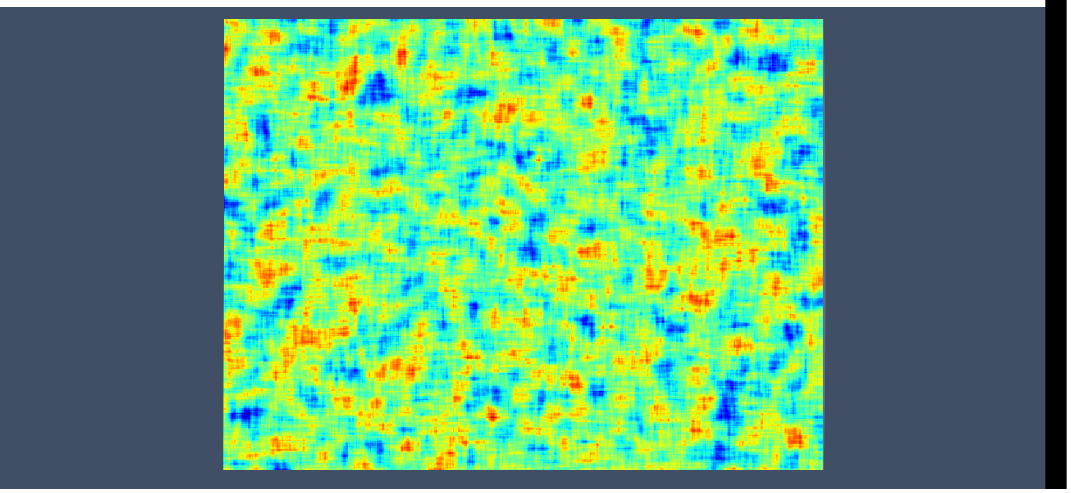
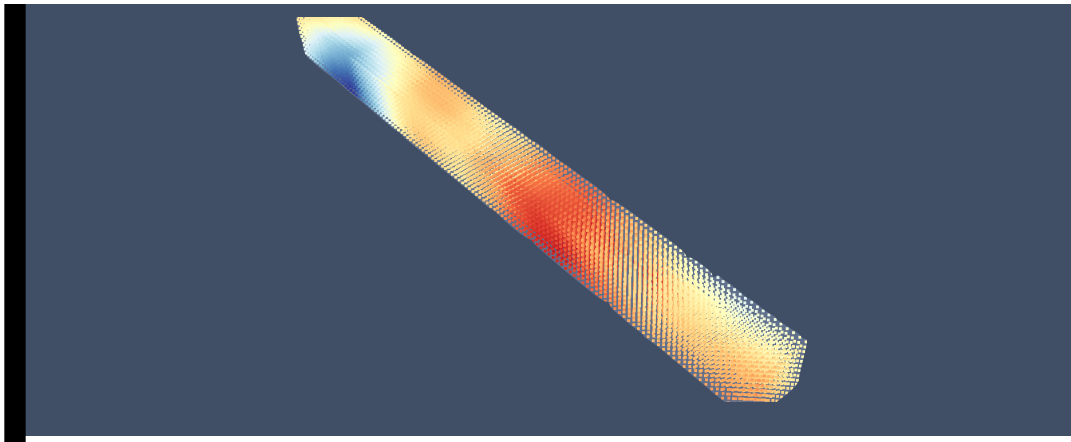
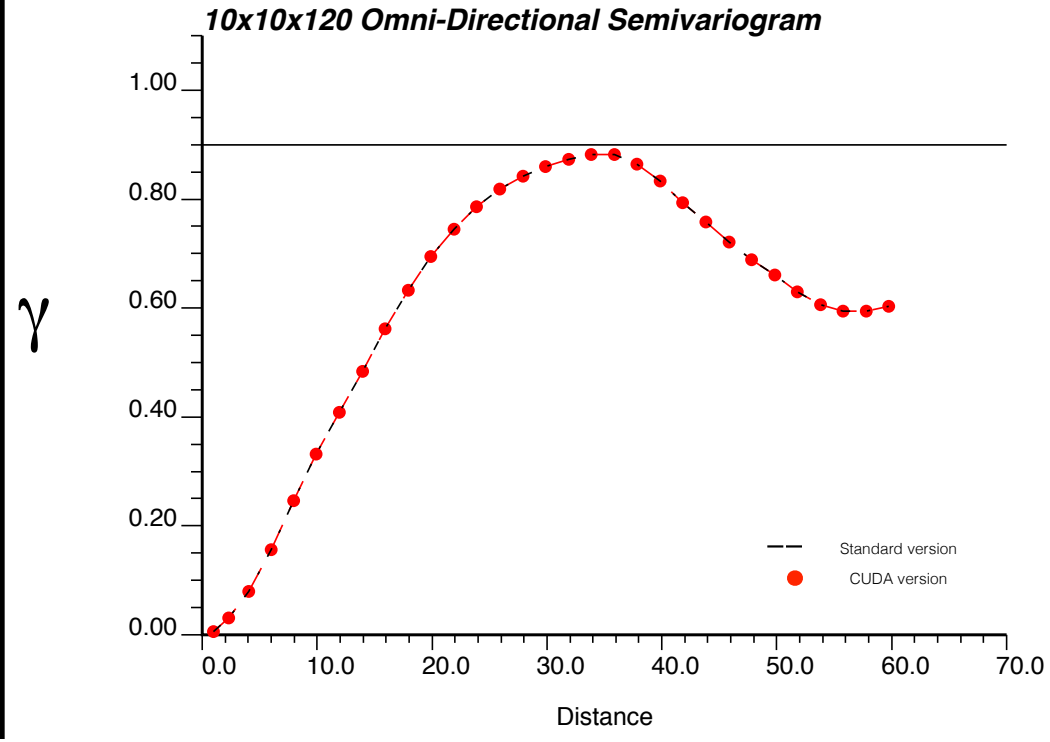

510x510x1 Omni-Directional Semivariogram
γ
50.0
40.0
30.0
20.0
10.0
0.0
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
Distance
Standard version
CUDA version

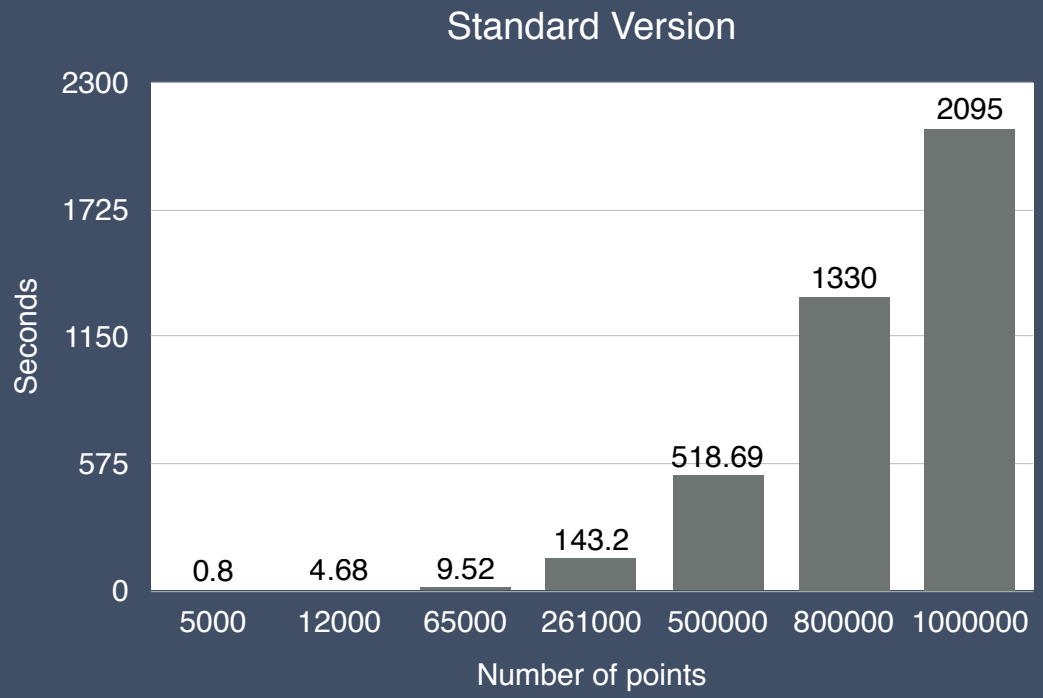





10x10x120 Omni-Directional Semivariogram
γ
1.00
0.80
0.60
0.40
0.20
0.00
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
Distance
Standard version
CUDA version

Dell Precision T7600

- Intel Xeon E5
- 3.3 GHz CPU Frequency
- 10 MB cache
- 16GB RAM (1,6 MHz)
- 1 TB HDD
- Linux



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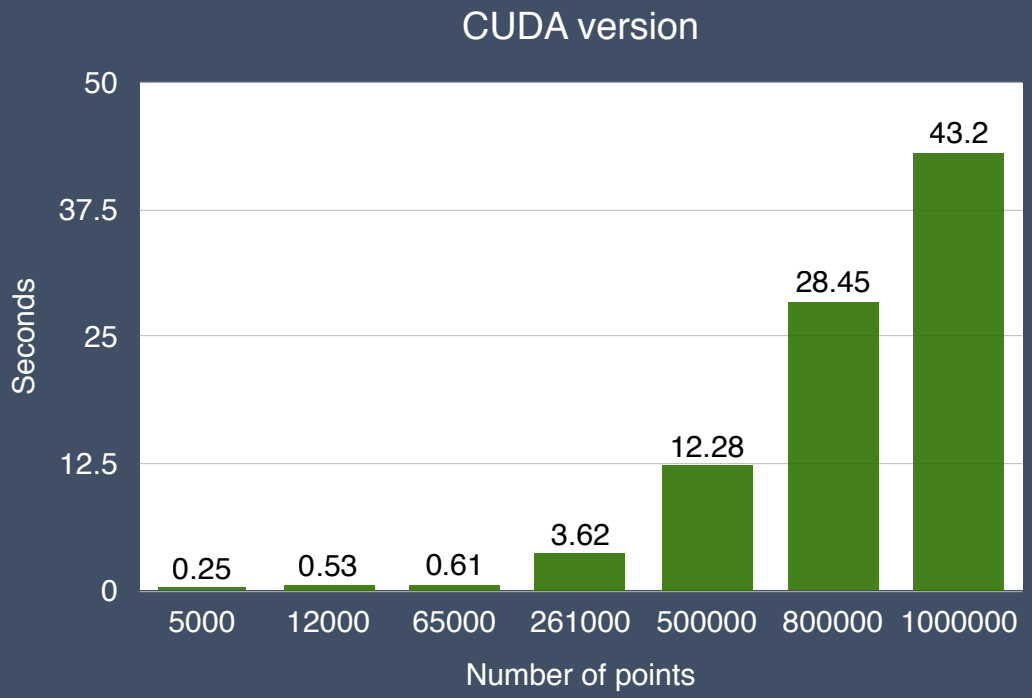
Tesla c2075

- 448 CUDA cores
- 1.15 GHz Frequency of CUDA cores
- 6GB RAM
- 114 GB/sec Memory bandwidth



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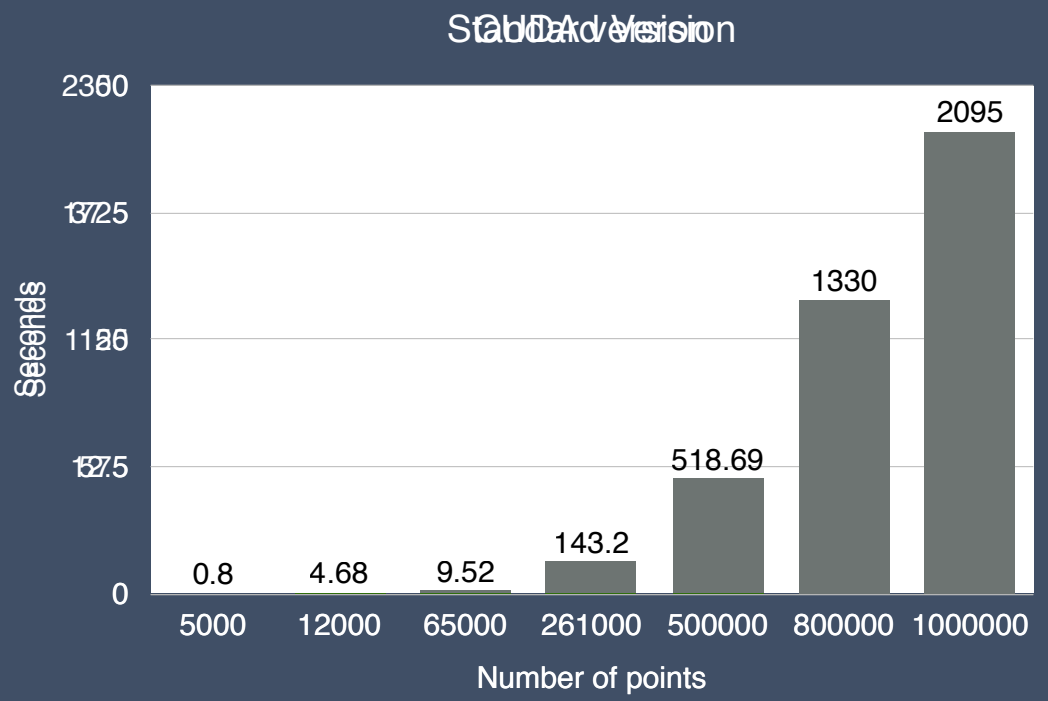

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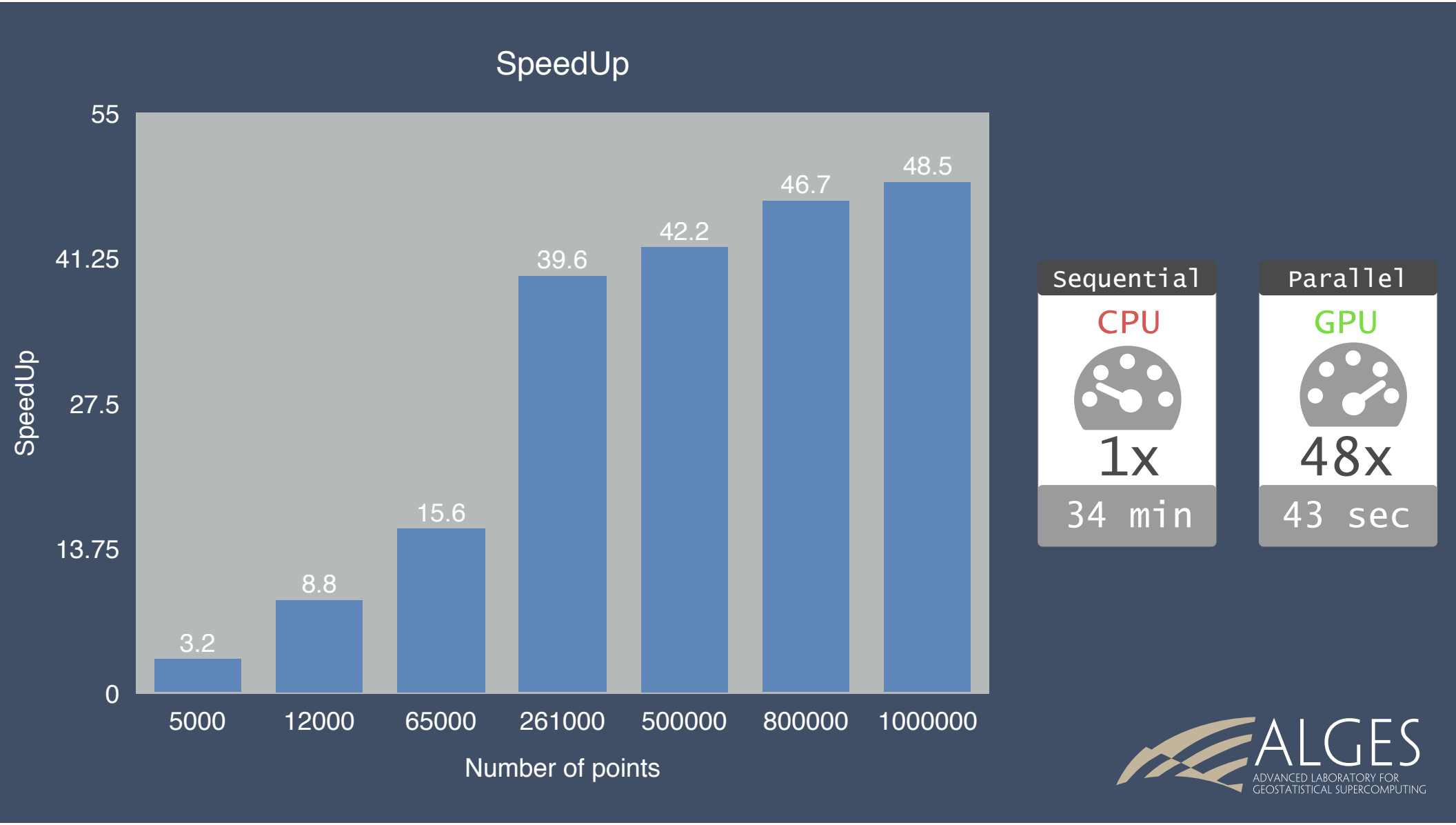
SpeedUp
55
41.25
27.5
13.75
0
SpeedUp
3.2
8.8
15.6
39.6
42.2
46.7
48.5
5000
12000
65000
261000
500000
800000
1000000
Number of points
Sequential
CPU
1x
34 min
Parallel
GPU
48x
43 sec
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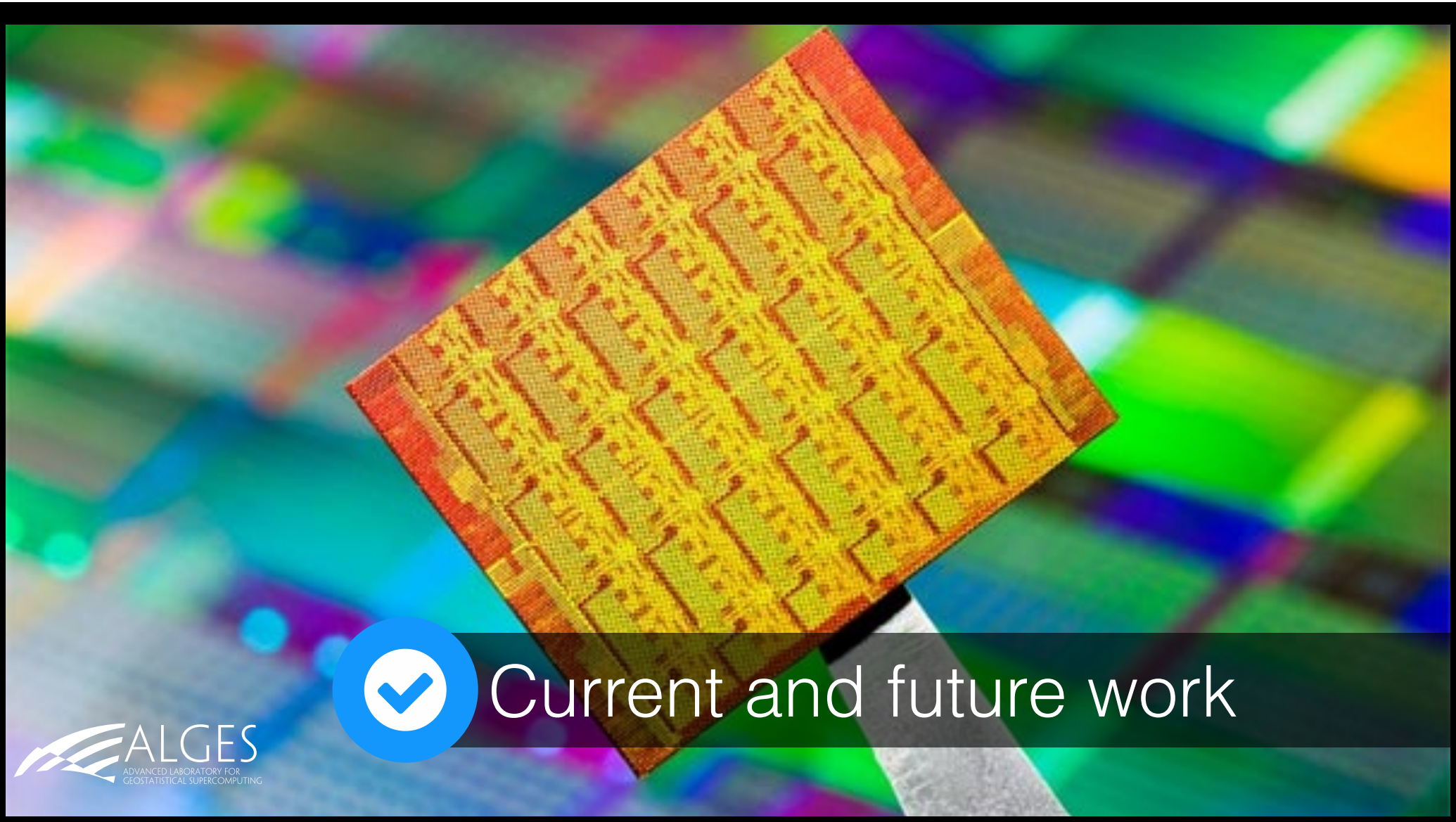
Current and future work
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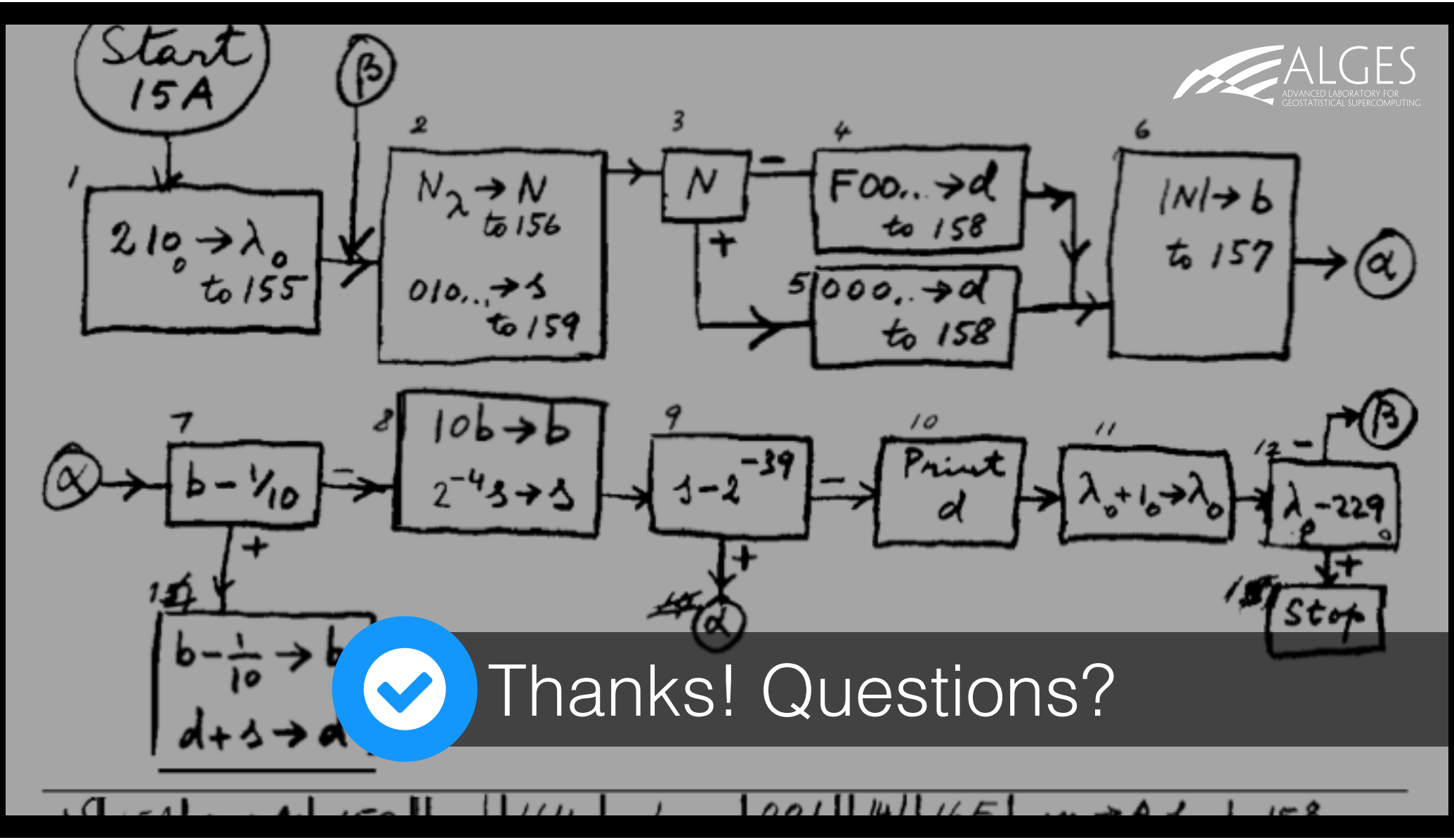
- Finish the CUDA version of indicator simulation and gaussian simulation of GSLIB
- Release the first GSLIB-CUDA version with these three methods


Start
15A
β
1
2
3
4
5
6
α
7
8
9
10
11
12
13
14
15
Stop
Thanks! Questions?