Lesson 12 Handling massive terrains

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Raster pyramids == simple & easy & used

original grid

Figure 12.1: (a) The pyramid for a given raster file. **(b)** One 4×4 raster downsampled twice with average-method.

(a)





9	8.5
5	4.8

12	12	12	8
7	5	6	8
8	5	4	9
7	2	2	6

(b)

Raster pyramids == simple & easy & used



How does it work in practice?

For certain GIS formats, eg GeoTIFF, the lower-resolutions rasters can be stored directly in the same file as the original raster, and this is standardised.

For other formats, if the GDAL library is used (the *de facto* open-source library for GIS images and grids), the pyramids can be stored in an auxiliary file with the extension .ovr, which is actually a TIFF format.

The GDAL utility gdaladdo C can create automatically the pyramids for a few formats, and the downsampling method can be chosen. In QGIS, one can use gdaladdo, or there is also a built-in mechanism, as can be seen in Figure 12.2

Figure 12.2: QGIS has the option to create the pyramids automatically.



Spatially indexing points (aka find nearest neighbourgs)





Spatially indexing points (aka find nearest neighbourgs)





Spatially indexing points (aka find nearest neighbourgs)



Question: startinpy has a closest_point() function and yet it builds the DT: how does that work?





 $\leftarrow \rightarrow$ C \bigcirc https://hugoledoux.github.io/startin_wasm/

startin O	
# vertices	18
# triangles	16
🗹 draw Del	aunay triangulation
🗹 draw Vor	onoi diagram
insert	
O delete	
insert rando	om points
1000	\sim
reset	



Triangulation of billions of points? Why should you care?

- (raw points not always the best: too many, noise, doesn't fit in memory, etc)
- We want to extract iso-contours
- We want to create a grid of the area (TIN-based interpolation methods; kriging will not work...)
- Noise project of RIVM: one and only one "base terrain" of NL (to replicate all computations)
- One way to obtain a good simplification of an area is to create the TIN in the first place

Partitioning the area into sub-tiles and triangulate each? Easy in theory...





What I describe today is basically this paper



Figure 1: Streaming computation of Delaunay triangulations in 2D (Neuse River) and 3D. Blue quadrants or octants are unfinalized space where future points will arrive. Purple triangles and tetrahedra are in memory. Black points and their triangles and tetrahedra have already been written to disk or piped to the next application.

Abstract

We show how to greatly accelerate algorithms that compute Delaunay triangulations of huge, well-distributed point sets in 2D and 3D by exploiting the natural spatial coherence in a stream of points. We achieve large performance gains by introducing *spatial finalization* into point streams: we partition space into regions, and augment a stream of input points with finalization tags that indicate when a point is the last in its region. By extending an incremental algorithm for Delaunay triangulation to use finalization tags and produce streaming mesh output, we compute a billion-triangle terrain representation for the Neuse River system from 11.2 GB of LIDAR

Delaunay triangulator, by Agarwal, Arge, and Yi [2005]; see Section 6. We also construct a nine-billion-triangle, 152 GB triangulation in under seven hours using 166 MB of main memory.

A streaming computation makes a small number of sequential passes over a data file (ideally, one pass), and processes the data using a memory buffer whose size is a fraction of the stream length. We have implemented two- and three-dimensional triangulators that read streams of points as input, and produce Delaunay triangulations in streaming mesh formats. The memory footprint of the 2D triangulator is typically less than 0.5% of the output mesh size (sometimes much less). The memory footprint of the 3D triangu-

Streaming datasets: conveyor belt idea for unlimited data

"A stream is a sequence of potentially **unlimited data** elements made available over time"



"Normal functions [designed for batch data] cannot operate on streams"

"items on a conveyor belt being processed one at a time rather than in large batches"











Streaming datasets: conveyor belt idea for unlimited data





Examples:

- 1. calculate volume
- 2. convert to gITF
- 3. repair geometry
- 4. add/remove attributes
- 5. filter with bbox





Insertion deletes all the triangles whose circumcircle contains ρ







Unix pipes for streaming

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Streaming is realised with Unix pipes

The key to implementing streaming of geometries is to use Unix pipes (also called *pipelines*).

Pipelines were designed by Douglas McIlroy at Bell Labs during the development of Unix, and they allow to chain several processes together. The output of a process becomes the input of the next one, and so on (the data flowing through the process is the *stream*). Given 2 processes, the 2nd one can usually start before the 1st one has finished processing all the data.

In Unix, the pipe operator is the vertical line "|", and several commands can be chained with it: "cmd1 | cmd2 | cmd3". A simple example would be "ls -l | grep json | wc -l" which would:

- 1. list all the files in the current directory (one file name per line);
- send this to the operator grep which would discard all lines not having the keyword "json";
- send this to the operator "wc -l" which counts the number of line.





$\,\mathrm{W}\,$ Wavefront .obj file - Wikipedia $\,\, imes\,$ +https://en.wikipedia.org/wiki/Wavefront_.obj \mathbf{C} **⊡** \rightarrow Ω Article Talk 維

Wavefront .obj file

From Wikipedia, the free encyclopedia

For other uses, see Obj (disambiguation).

OBJ (or .OBJ) is a geometry definition file format first developed by Wavefront Technologies for its Advanced Visualizer animation package. The file format is open and has been adopted by other 3D graphics application vendors.

The OBJ file format is a simple data-format that represents 3D geometry alone — namely, the position of each vertex, the UV position of each texture coordinate vertex, vertex normals, and the faces that make each polygon defined as a list of vertices, and texture vertices. Vertices are stored in a counter-clockwise order by default, making explicit declaration of face normals unnecessary. OBJ coordinates have no units, but OBJ files can contain scale information in a human readable comment line.

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OBJ geometry format

Filename extension	.obj
Internet media type	model/obj ^[1]
Developed by	Wavefront Technologies
Type of format	3D model format

Streaming DT architecture



Finaliser based on quadtree



9 points and a "normal" stream



9 points and a stream with finalisation tags









Yellow tr = in memory

White tr = written to stream



of geometric entities and the proximity of their representations in [the file]"

"a correlation between the proximity in space

Spatial coherence







position in file/stream



last point position



first point position

low spatial coherence



high spatial coherence

Spatial coherence



position in file/stream



last point position

low spatial coherence



high spatial coherence

Spatial coherence



(a) 6 million point Baisman Run dataset in Broadmoor, Maryland

Figure 2.4: Spatial coherence as inherent property of real-world datasets. Adapted from Isenburg et al. [2006b, p. 3].





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2023-01-10T16:24:16Z WARN sstdt2::triangulator walk.4 2023-01-10T16:24:16Z INFO sstdt2::triangulator Cell 4379 finalised (1294 vertices) 2023-01-10T16:24:16Z INFO sstdt2::triangulator Cell qtc[1, 2, 0, 3, 1, 3] finalised 2023-01-10T16:24:16Z INFO sstdt2::triangulator Cell qtc[1, 2, 0, 3, 1] finalised 2023-01-10T16:24:16Z INFO sstdt2::triangulator Cell qtc[1, 2, 0, 3] finalised 2023-01-10T16:24:16Z INFO sstdt2::triangulator Cell qtc[1, 2, 0, 3] finalised	2023-01-10T16:24:16Z WARN	sstdt2::triangulator walk.3
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2023-01-10T16:24:16Z INFO sstdt2::triangulator Cell qtc[1, 2, 0] finalised	2023-01-10T16:24:16Z INFO	sstdt2::triangulator Cell gtc[1, 2, 0, 3] finalised
	2023-01-10T16:24:16Z INF0	sstdt2::triangulator Cell gtc[1, 2, 0] finalised
2023-01-10T16:24:16Z INFO sstdt2::triangulator Cell gtc[1, 2] finalised	2023-01-10T16:24:16Z INF0	sstdt2::triangulator Cell gtc[1, 2] finalised
2023-01-10T16:24:16Z INFO sstdt2::triangulator Cell gtc[1] finalised	2023-01-10T16:24:16Z INF0	sstdt2::triangulator Cell gtc[1] finalised
2023-01-10T16:24:16Z INFO sstdt2::triangulator Cell gtc[] finalised	2023-01-10T16:24:16Z INF0	sstdt2::triangulator Cell gtc[] finalised
2023-01-10T16:24:17Z INFO sstdt2::triangulator Finalise the guadtree root cell	2023-01-10T16:24:17Z INF0	sstdt2::triangulator Finalise the guadtree root cell
2023-01-10T16:24:17Z INFO sstdt2 dt.number of vertices() = 0	2023-01-10T16:24:17Z INFO	<pre>sstdt2 dt.number_of_vertices() = 0</pre>
2023-01-10T16:24:17Z INFO sstdt2 max # points in DT during process: 242733	2023-01-10T16:24:17Z INFO	sstdt2 max # points in DT during process: 242733
2023-01-10T16:24:17Z INFO sstdt2 max # triangles in DT during process: 300567	2023-01-10T16:24:17Z INFO	sstdt2 max # triangles in DT during process: 300567
2023-01-10T16:24:17Z INFO sstdt2 🗸	2023-01-10T16:24:17Z INFO	sstdt2 🗸

Maarten de Jong MSc Geomatics thesis on the topic

MSc thesis in Geomatics

Simplification of Massive TINs with the Streaming Geometries Paradigm

Maarten de Jong 2021



- How to create a 50cm grid with TIN linear interpolation for 1B points?
- If we want to use Laplace interpolation, is it possible?