Hardware-accelerated Rendering of Web-based 3D Scatter Plots with Projected Density Fields and Embedded Controls

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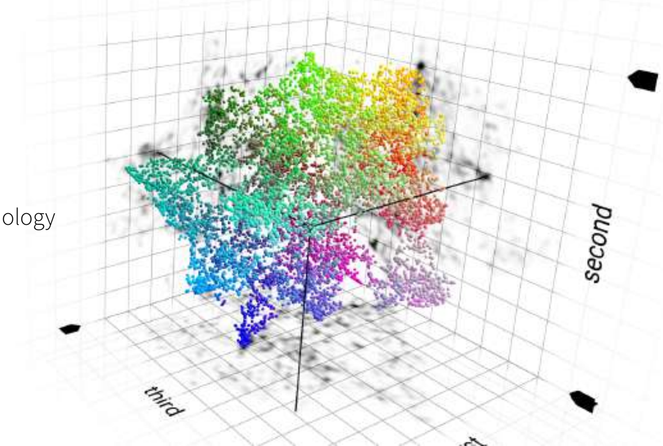
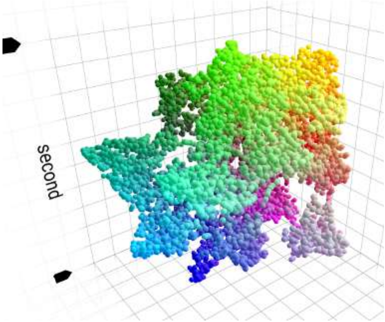


3D Scatter Plot Advantages

Comprehensible — Mapping of data points to 3D points is easily graspable, leveraging inherent human 3D understanding

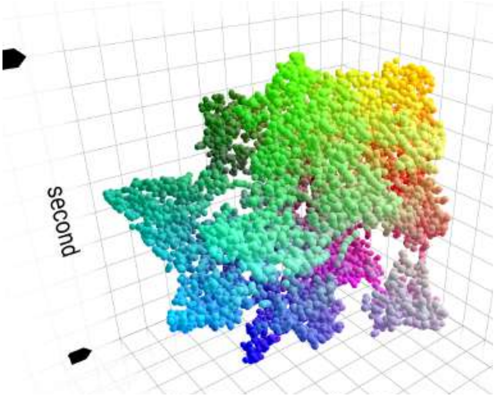
Versatile — Allow arbitrary mapping of data to visual variables

Performant — Hardware-accelerated rendering combined with instancing is fast



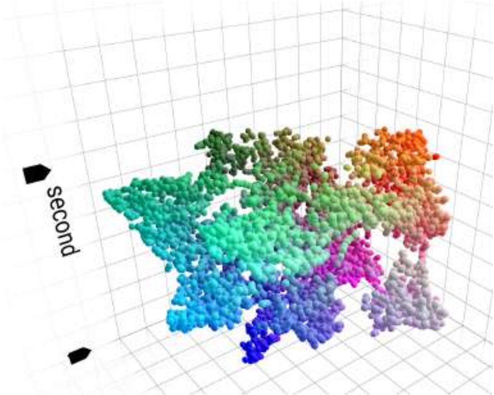
Main Issue: Occlusion

- Data points may be occluded by other data points based on view
- May even be surrounded on all sides, becoming inaccessible
- Well-known issue in 3D rendering



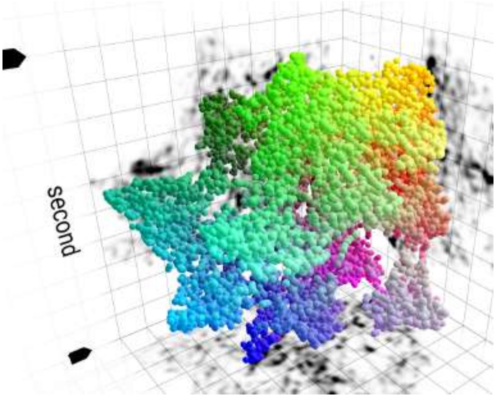
Trivial Solution: Hide Occluding Geometry

- Cutting planes allow filtering of visible data points
- Have to be placed manually

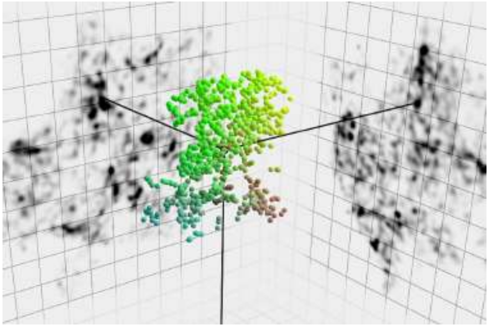


A View Inside: Density Maps

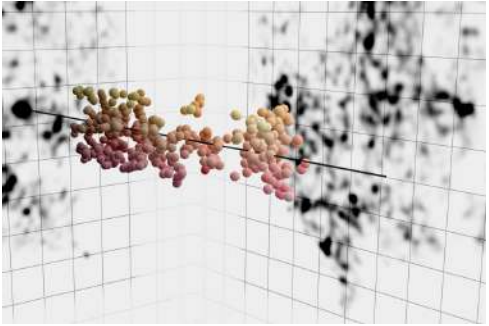
- X-ray-like 2D view
- Projected onto grid planes to provide reference



References Between 3D and 2D Plots



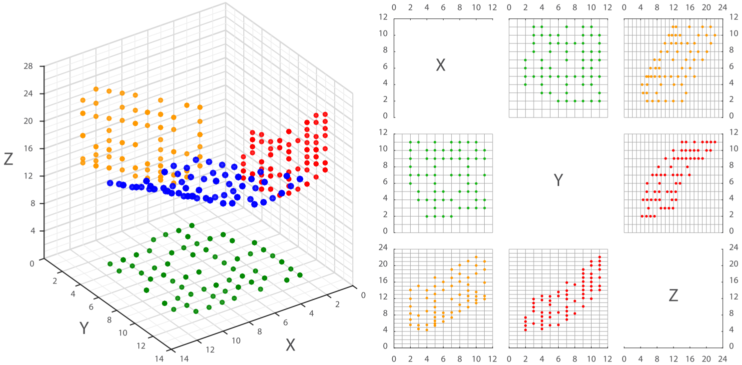
References lines from point to grids facilitate orientation



References lines placed perpendicular on grids allow analyzing clusters

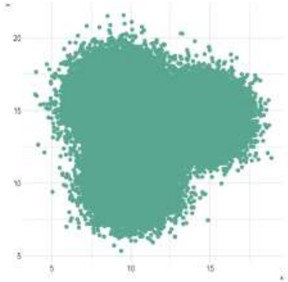
Demo

Building on Scatter Plot Matrices

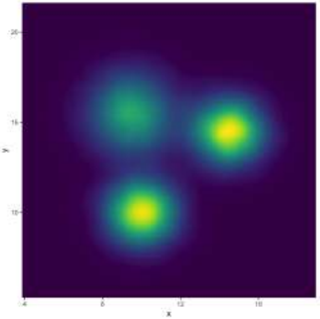


Graphic by RIDC NeuroMat, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=60578568

2D Projection Introduces Overplotting



Overplotting: Data points overlap, becoming indistinguishable

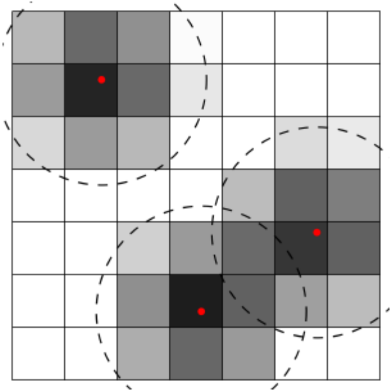


Solution: Visualize density

Graphics by Yan Holtz, data-to-viz.com, https://www.data-to-viz.com/caveat/overplotting.html

Rendering the Density Maps

- Project points to 2D
- Calculate distance to point center per output bin
  - Choose adequate distance function (e.g. linear)
- Add up distance per bin to calculate density



Storing the Density Maps

- Count using the stencil buffer
  - Only 8 bit precision in WebGL 2[1]
- Add up using integer textures
  - No blending of integer textures (not even additive) in WebGL 2[2]
- Add up using floating point textures
  - No filtering of 32-bit floating point textures in WebGL 2[3]
  - Greatly reduced precision due to 16-bit textures' 10-bit mantissa

[1] OpenGL ES 3 specification, table 3.14
[2] OpenGL ES 3 specification, chapter 4.1.7
[3] OpenGL ES 3 specification, table 3.13

On Density Map Precision

- IEEE 754 half floats (16 bit) store 1 sign bit, 5 exponent bits and 10 mantissa bits
- 11 effective bits of precision (due to implicit leading 1)
- Only $2^{11} = 2048$ distinct values
- Example: Assuming normal distribution, 0.04 % of points affect the center bin [4]
- Target precision of 0.1 allows for 500 thousand points in plot

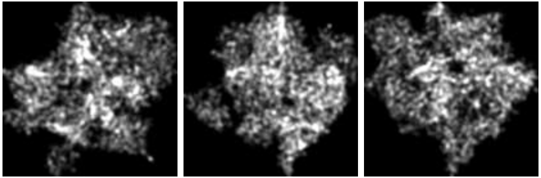
[4] Resolution 512 px, 5 px point size. Using $\mu = 255,5$ and $\sigma = 100$, approximately 2 % of points fall into $[253, 258]$, affecting the center pixel. Extending this to 2D results in 0.04 % of points. See onlinestatbook.com/2/calculators/normal_dist.html

Improving Density Map Precision

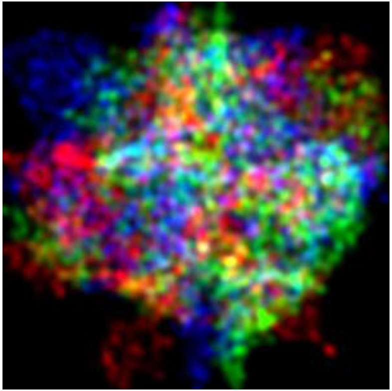
- Use 32-bit floating point textures, allowing for 4 billion points to be handled [5]
- Distribute points onto multiple buffers, which are combined during an additional post-processing pass

[5] 23 bit mantissa, 24 bit precision, $2^{24} = 16{,}777{,}216$ distinct values. Assuming max. 0.04 % of points affecting a single bin and target precision of 0.1, $2^{24} * 0.1/0.02^2 = 4{,}194{,}304{,}000$ points can be handled.

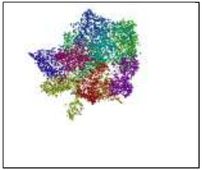
Storing the Density Maps



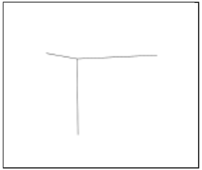
- Stored in RGB texture
- One density map per channel

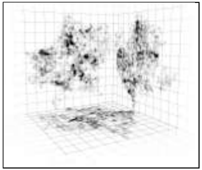


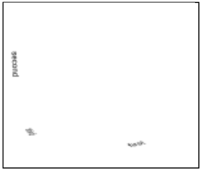
Assembling the Scene

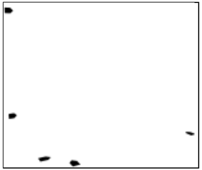

Data Points

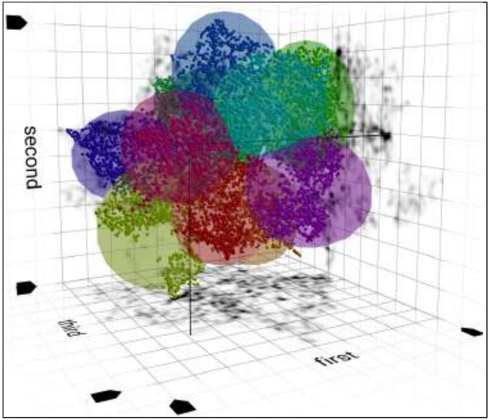

Clusters


Reference lines


Grids with density maps


Labels


Cutting plane handles



Performace Impact of This Technique

- Decreased rendering resolution compared to main rendering pass (e.g., 256×256 instead of 1920×1080, factor 31.6)
- Simpler shaders compared to main rendering pass
- Density maps can be cached as long as data remains unchanged
- In total: no significant impact on rendering performance

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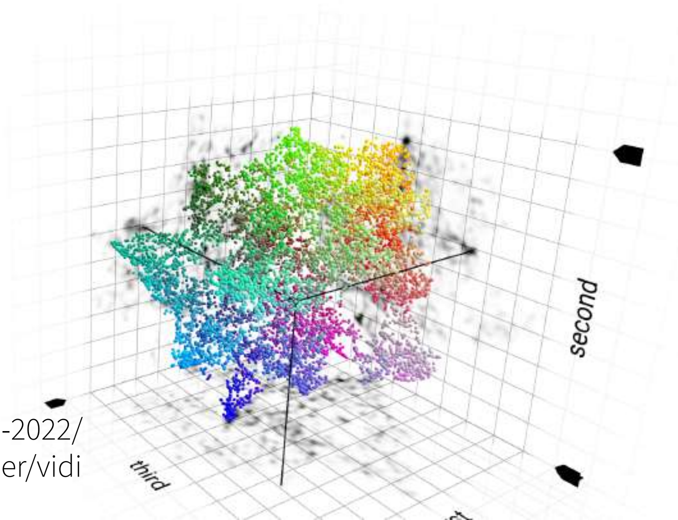

Try it out: demo.varg.dev/vidi/web3d-2022/
Source Code: github.com/lukaswagner/vidi