医学可视化与可视分析

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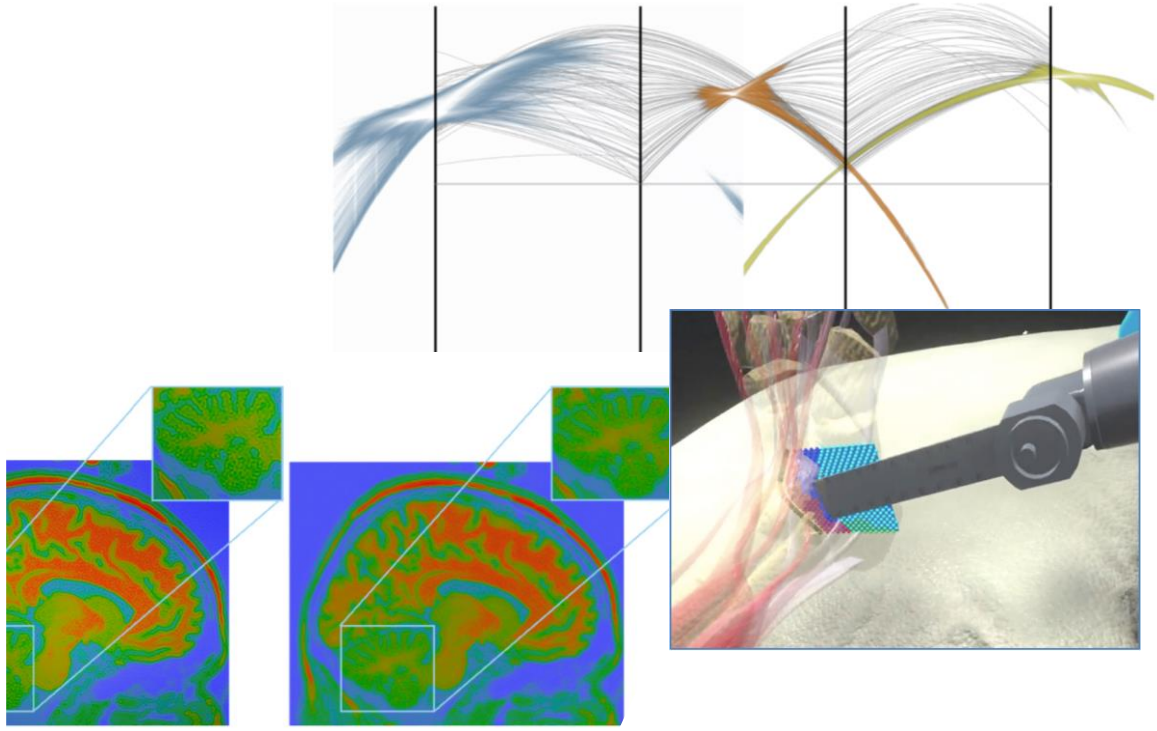
引言

- 医学需要可视化
  - 国自然项目查询显示2017-2021年医学科学部有4678条与可视化相关项目获批（所有学部里最多）
  - 同时期计算机科学领域只有297条
- 不同领域对可视化的理解差异很大
- 可视化就是画好看的图?

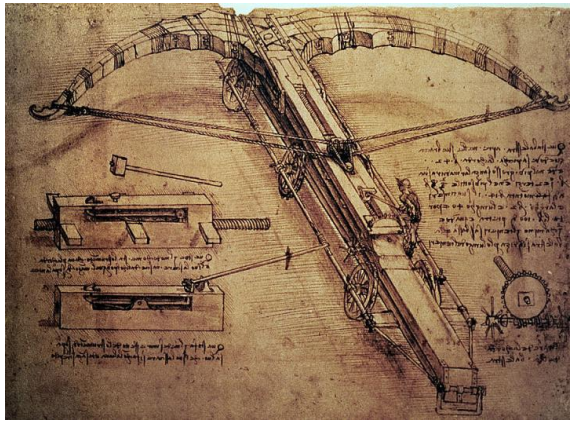


https://www.letpub.com.cn/

可视化 Visualization

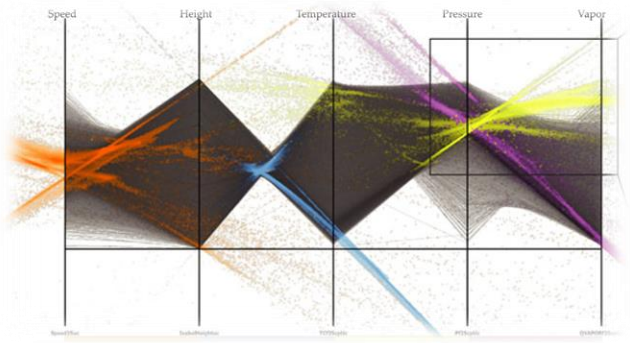
- 广泛意义上：构想，形成心理形象，使其可见

拉斯科洞穴壁画 约17000年前
https://upload.wikimedia.org/wikipedia/commons/thumb/2/27/Lascaux-IV_26.jpg/1280px-Lascaux-IV_26.jpg

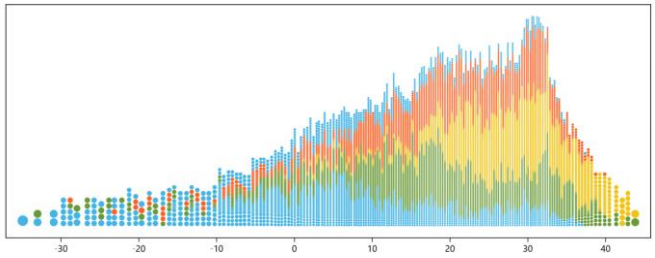


达芬奇 约15世纪
https://warriorgirl3.files.wordpress.com/2014/11/design-for-a-giant-crossbow-leonardo-da-vinci.jpg?w=720

- 数据科学：利用人类视觉感知和交互从数据驱动的图形图像中获取洞察——数据可视化



飓风模拟多维数据可视化
[Zhou & Weiskopf 2017, doi: 10.1109/TVCG.2017.2698041]

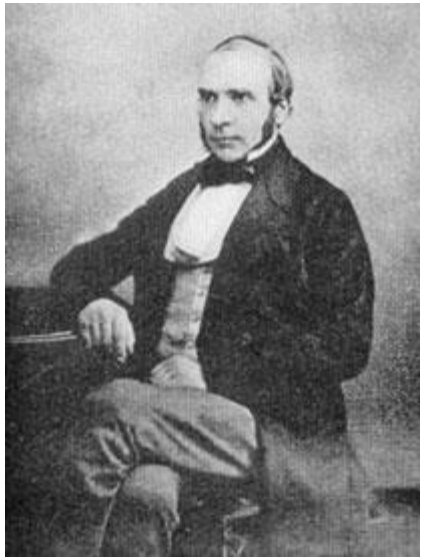


全球月均气温可视化
[Rodrigues & Weiskopf 2018, doi: 10.1109/TVCG.2017.2744018]

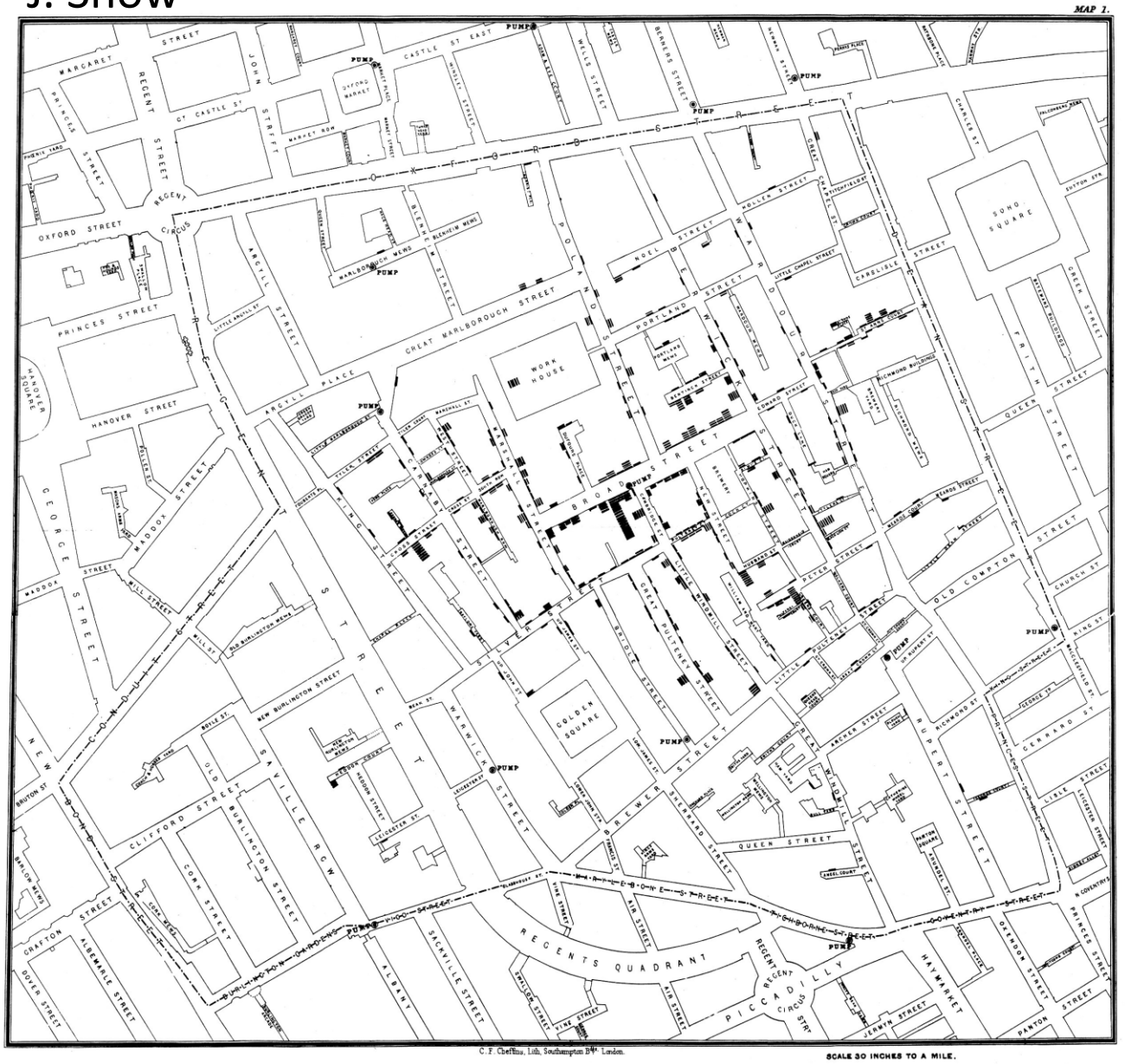
CT人体扫描可视化
[Martschinke, J. et al. 2019, doi:10.1111/cgf.13771]

历史上的医学可视化与可视分析

- Cholera map 1854 --- J. Snow
- 霍乱传染模式研究



[Originally from en.Wikipedia, Public Domain, https://commons.wikimedia.org/w/index.php?curid=403227]



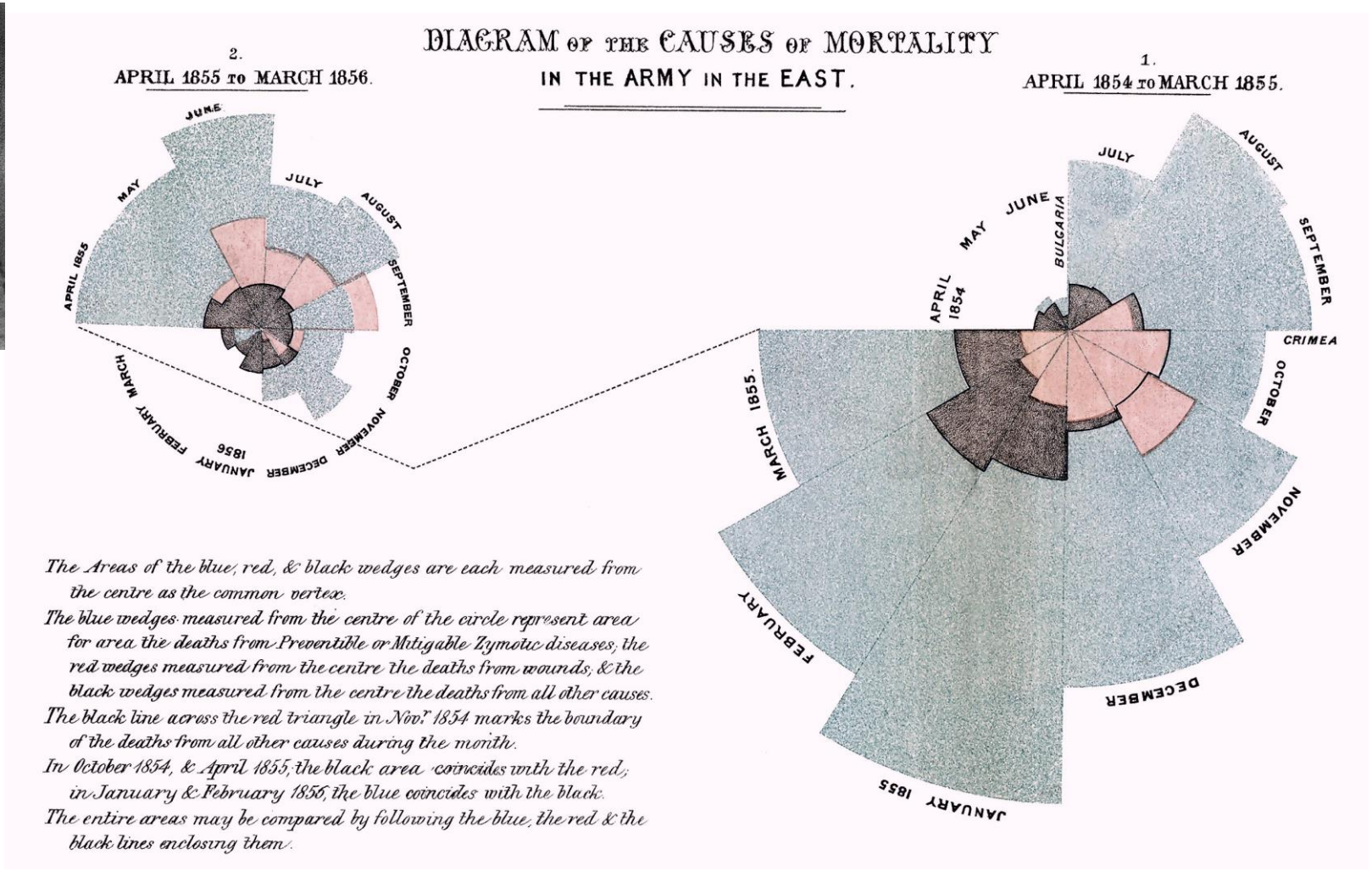
[By John Snow - Map of the book;On the Mode of Communication of Cholera; by John Snow, originally published in 1854. Digitally enhanced version found on the UCLA Department of Epidemiology website., Public Domain, https://commons.wikimedia.org/w/index.php?curid=2278605]

历史上的医学可视化与可视分析

- Rose chart 1859 --- F. Nightingale
- 克里米亚战争死亡原因分析

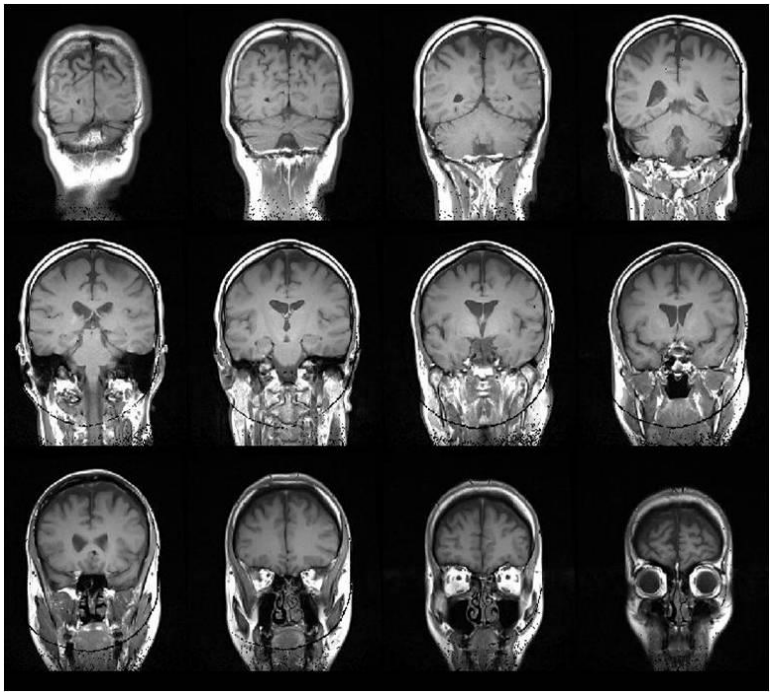
[By w:Florence Nightingale (1820–1910). - Public Domain, https://commons.wikimedia.org/w/index.php?curid=1474443]

[By Henry Hering (1814-1893) - National Portrait Gallery, London, Public Domain, https://commons.wikimedia.org/w/index.php?curid=61520366]



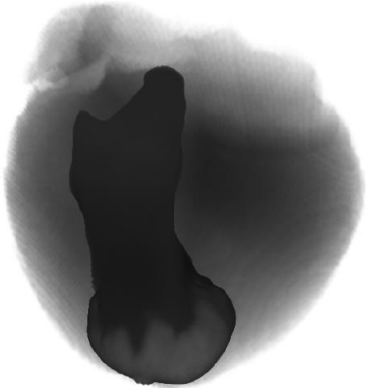
可视化与健康医疗

- 对健康医疗数据进行可视化、可视分析
  - 提高健康医疗数据分析能力；辅助健康医疗决策
- 辅助健康医疗过程
  - 提高健康医疗实践水平



脑部MRI数据

http://4.bp.blogspot.com/-BPNZ9LZfnX4/TqFoHX5dOSI/AAAAAAAAAFU/F316MyCLHZo/s1600/pre_nogad_montage34_edit.jpg



心肌缺血模拟数据体渲染
[Source: L. Zhou]

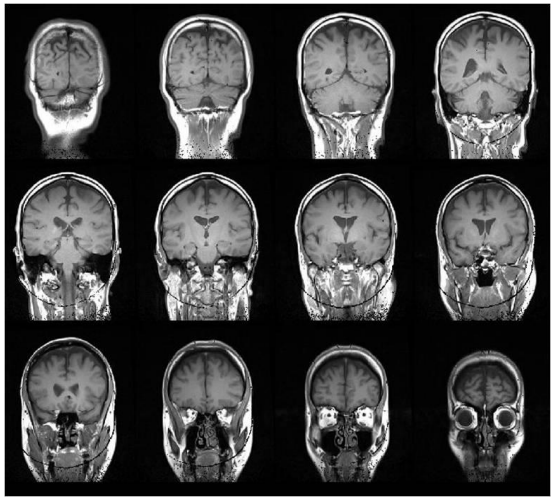
增强现实辅助手术

https://immersive-technology-healthcare.hcs-pharma.com/2019/03/01/augmented-reality-surgical-technology-unveiled-by-philips-and-microsoft/

可视化处理数据种类差异巨大

- 影像数据（二维，三维）
- 表格数据
- 层次结构数据
- 非结构数据
- ……

	Symbol	N11	N14	N1	N27	N3	N8	CDJIE	DHZ	JMY	LMENG	LSL	SGH	WHRU	WSY
2	A1BG	0.5645	0.1503	0.4451	0.1492	0.7234	0.1117	0.0645	0.3301	0.4823	0.0997	0.4797	0.4754	0.4303	0.3398
3	A2M	197.0306	93.9088	90.2652	360.0319	273.0878	80.8098	79.7098	166.174	101.5462	87.3495	104.0838	172.3037	140.6927	106.8786
4	A2ML1	26.9459	6.734	49.7505	13.1724	33.4317	43.8277	30.9469	4.6351	17.5137	24.9785	23.1412	6.1723	16.9964	11.1661
5	A2MP1	0.2883	0	0	0	0.031	0	0.4162	0.8802	0.4702	0.3145	0.748	1.1724	1.234	0.6909
6	A3GALT2	0	0	0.091	0	0	0	0.1263	0.2585	0.2518	0	0.1174	0.2482	0	0
7	A4GALT	26.5808	13.3641	12.6768	29.3892	39.2246	13.3254	21.2073	37.2913	11.0729	9.9988	18.2436	31.4095	17.3294	21.7379
8	AAAS	38.2259	37.178	29.1431	32.3595	37.8547	29.8753	21.0786	23.7101	16.8398	10.9726	15.3844	18.1043	16.6646	19.3478
9	AACS	45.2092	56.787	92.5636	31.6176	29.709	87.9038	21.6945	9.933	43.1694	42.0701	19.6508	34.2724	43.0972	19.8138
10	AACSP1	0.5753	0.2452	0.3629	0.1217	0.4537	0.4554	0.1529	2.8167	0.1905	0.2758	0.4975	0.864	0.4675	0.8786
11	AADAC	24.455	35.2528	25.404	17.9134	35.3256	71.6382	22.0789	22.9891	33.0504	28.2588	38.6698	8.5259	14.4697	36.2027
12	AADACL2	23.4643	27.757	22.7782	10.6707	15.9264	20.9236	23.9787	13.2983	20.4217	25.391	25.8656	9.1394	26.6872	25.5244
13	AADACL3	174.8368	94.125	569.6671	205.7836	144.6192	303.7702	390.8507	2.188	812.0157	453.1233	163.1581	423.6692	930.5285	409.5496
14	AADACP1	0	0.0897	0.3623	0.3563	0.1993	0.2	0	0	0.1921	0.2647	0.0597	0.1893	0.0714	0.0615
15	AADAT	4.3083	3.8759	4.5711	4.9101	6.2295	3.7892	5.6352	7.4075	2.4629	2.8587	2.8608	6.6022	2.5542	4.4001
16	AAGAB	30.1732	34.6211	44.2772	29.4888	29.3409	37.0318	31.892	22.3885	30.6468	34.3908	26.699	28.3897	32.6831	28.9904
17	AAK1	4.3885	3.1813	3.9969	5.488	7.4717	2.2428	2.2934	2.5484	1.9751	1.8612	1.9894	3.2594	2.0629	2.7466
18	AAMDC	57.6955	48.2837	29.2412	44.4559	46.0329	40.8307	16.5598	21.1644	12.3302	10.5534	27.2003	26.3361	15.3053	25.0923
19	AAMP	98.7465	101.9495	94.2585	86.2159	100.9133	105.7145	87.5731	80.8099	75.5185	69.417	70.6148	86.6586	83.9103	80.1564



2007年11月05日12:00:32
劳累后左侧腰酸腰痛，口腔溃疡好转，无咽喉疼痛，无左下肢麻木，无肢体浮肿，小便可，舌淡暗，苔薄白腻，脉沉弦。
11.05查尿常规示：PR03+,BLD1+。
处理：证候改善，效不更方。蛋白量增加，加用ARB。加用丹参活血。

金水宝胶囊[0.33g*63]	3粒/tid/14天/po	2瓶
昆明山海棠片[60片/盒]	2片/tid/14天/po	2盒
厄贝沙坦片(安博维)[0.15g*7s]	0.15g/qd/14天/po	2盒

中药处方：

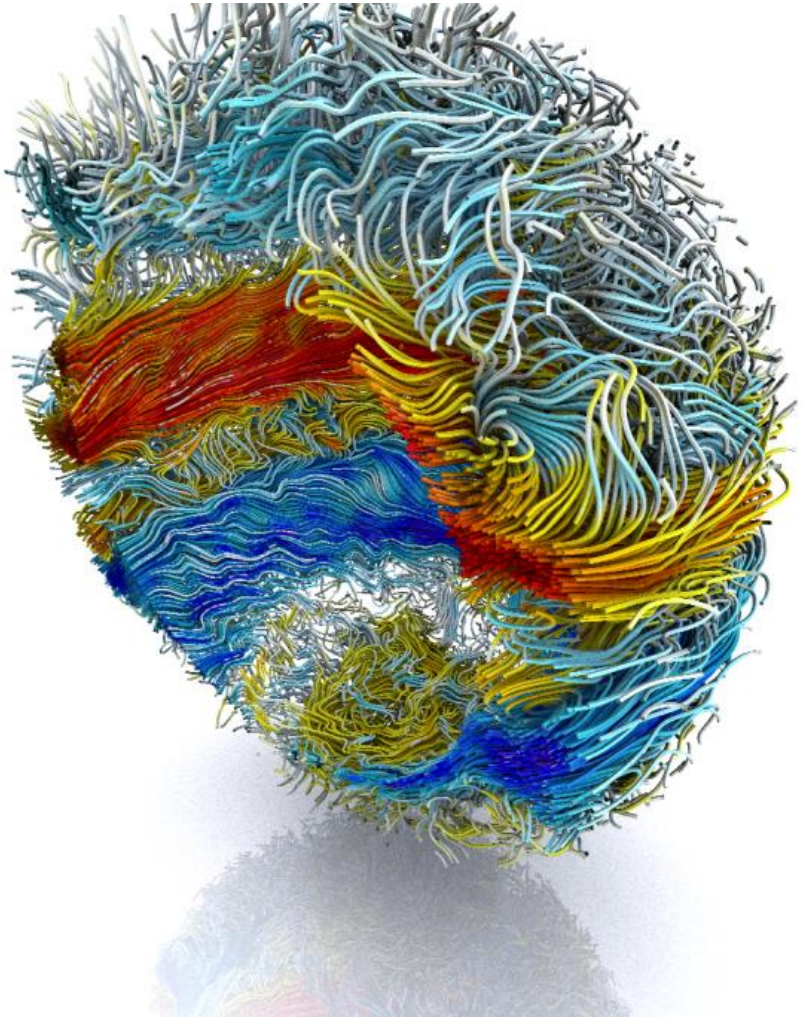
北芪(黄芪)30g	山萸肉(枣皮/制山萸肉)25g	泽泻(文且/泽且)15g
沙参25g	草决明(决明子)20g	生地(干地/地黄) 15g
茯苓皮(云苓皮)30g	杜仲(盐杜仲)20g	蒲公英20g
霍香(广霍香)15g	淮山(山药)15g	丹皮15g
吐丝子20g	甘草5g	丹参20g

煎服，共7剂

2009年06月24日12时
近1年半在其他肾病专科处就诊。
现无特殊不适，平素易感冒。目前口服强的松25mg qd一年。
处理：应用丁硼乳膏刷牙预防上呼吸道感染。加用具有类激素样作用的鹿角胶，加用具有抑制免疫炎症作用的苏木、七叶一枝花。
西药处方：

大纲

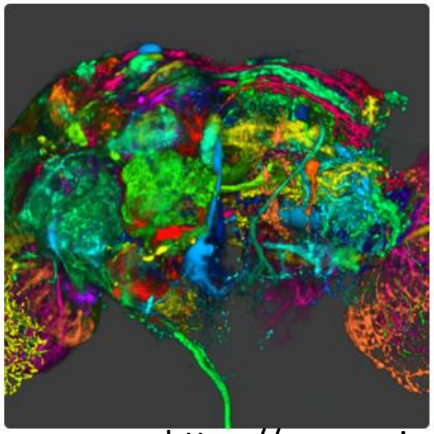
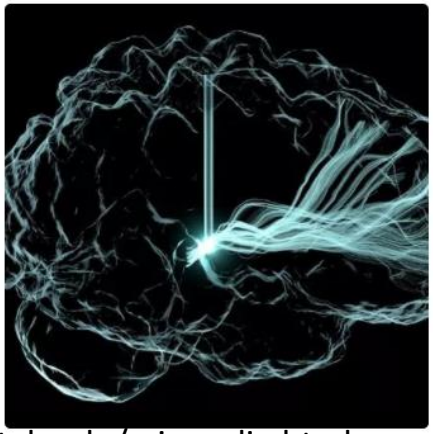
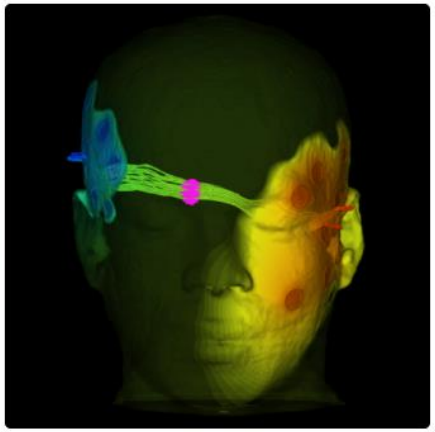
- 可视化
  - 科学可视化
    - 标量
    - 向量
    - 张量
  - 信息可视化
    - 表格
    - 图
    - 文本
    - 地理信息
- 可视分析
  - 交互
  - 可视分析举例
- 可视化和可视分析工程实现



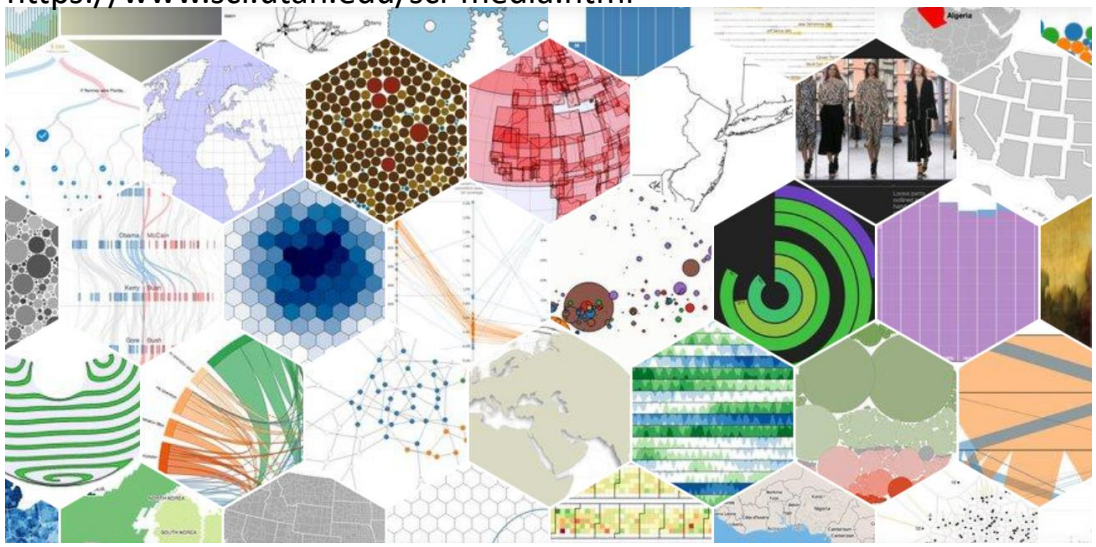
太阳磁场可视化
[Brownlee et al. 2015, 10.2312/EGPGV/EGPGV12/041-050]

可视化分类

- 科学可视化 Scientific visualization (SciVis)
- 信息可视化 Information visualization (InfoVis)
- 领域内正致力于融合各分支形成完整的学科体系

https://www.sci.utah.edu/sci-media.html



https://d3js.org/

Restructuring

The VIS Restructuring Committee (2016-2018)

The VIS Restructuring Committee was tasked in 2016 by the VEC (VIS Executive Committee) with considering alternative structures, such as a more unified conference, that may better enhance vibrancy and growth. It has generated the following documents:

- VIS Restructuring Recommendations, Fall 2018
- VIS Restructuring Workshop Executive Summary, Fall 2018
- VIS Restructuring Workshops Summary, Fall 2018
- VIS Restructuring Feedback, January 2018
- VIS Restructuring Report ("Phoenix Report"), Fall 2017

Committee Members: Hanspeter Pfister (chair), Hans Hagen, Daniel Keim, Tamara Munzner, Stephen North

The VIS Restructuring Committee has concluded its work and has spawned new committees with a more specific mandate in 2019.

The reVISe Committee (2019-ongoing)

The reVISe Committee was struck in February 2019 by the VEC (VIS Executive Committee), with the mandate of creating a concrete proposal for re-organizing the academic conferences (VAST, InfoVis, SciVis) under a single umbrella, including paper reviewing and governance. It meets weekly, and posts intermediate work products regularly including summarized meeting minutes and key findings. To contact the committee with feedback on any aspect of its work, please write to revise@ieeevis.org.

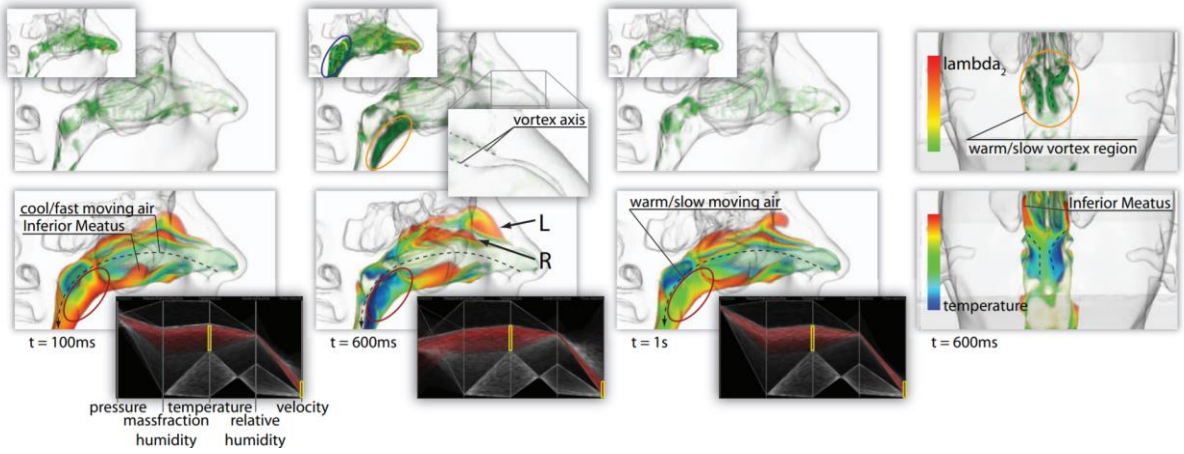
http://ieeevis.org/governance/restructuring

可视分析 Visual Analytics

- Visual analytics is the science of analytical reasoning supported by interactive visual interfaces.

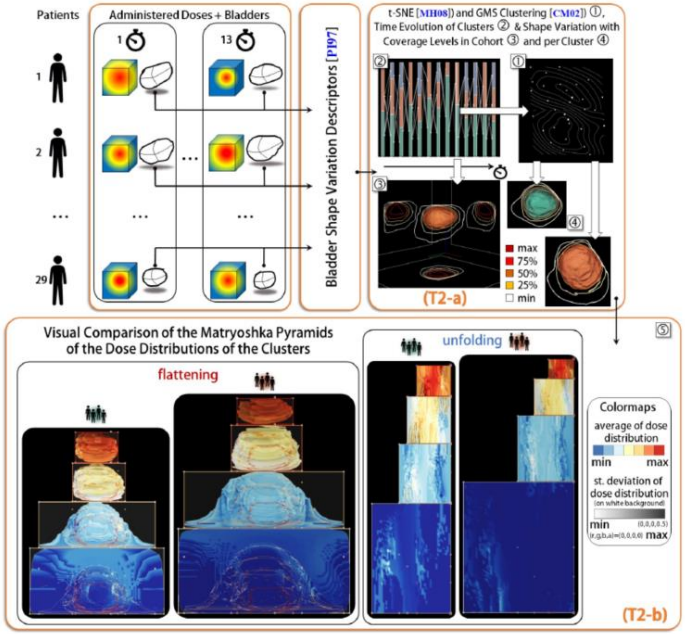
——[Keim D.A. et al. (2009) Visual Analytics. DOI: 10.1007/978-0-387-39940-9_1122]

- 可视化研究对一类数据进行绘制、展示、交互的方法
- 可视分析用集成多种可视化方法的交互可视界面解决具体问题



鼻腔气流分析

[S. Zachow et al., "Visual Exploration of Nasal Airflow," doi: 10.1109/TVCG.2009.198.]



放疗导致膀胱中毒分析

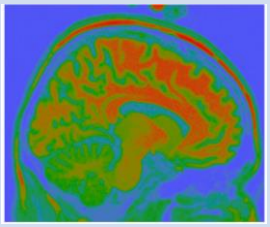
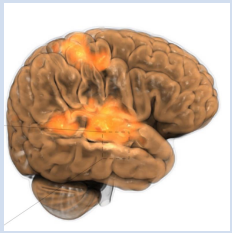
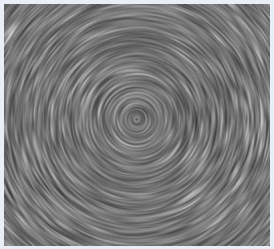
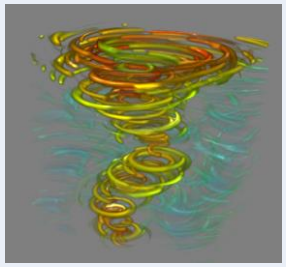
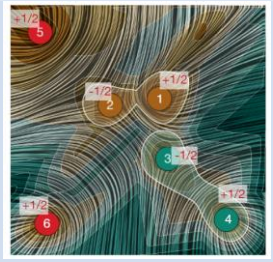
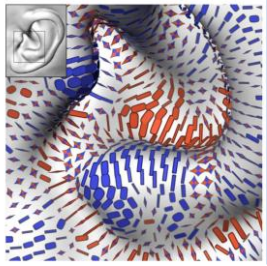
[R. Raidou et al. "Bladder Runner: Visual Analytics for the Exploration of RT-Induced Bladder Toxicity in a Cohort Study,". doi:10.1111/cgf.13413]

科学可视化

- 根据**一个数据变量**进行分类
- 假设数据在空间中是连续的——场

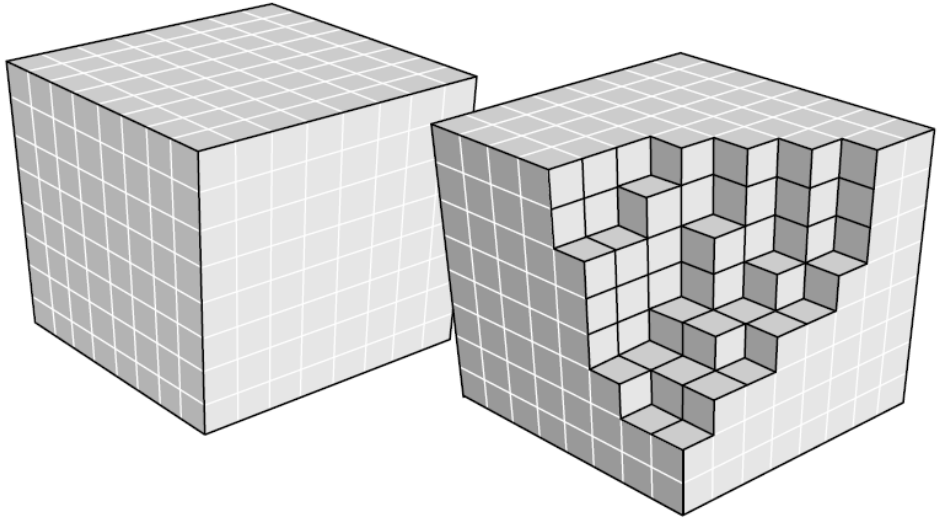
定义域 domain

值域 range

$\mathbb{R}^d$	$d = 2$	$d = 3$
$\mathbb{R}$ 标量 scalar 空间上任意一点的值是一个标量 0.5		 [D. Jönsson and A. Ynnerman (2017), Correlated Photon Mapping for Interactive Global Illumination of Time-Varying Volumetric Data. doi:10.1109/TVCG.2016.2598430.]
$\mathbb{R}^m, m = 2,3$ 向量 vector 空间上任意一点的值是一个向量 $[0.5, 0.5]$	 [Source: D. Weiskopf]	 [M. Falk, D. Weiskopf (2008): Output-Sensitive 3D Line Integral Convolution, doi:10.1109/TVCG.2008.25]
$\mathbb{R}^{m \times b}$ 张量 tensor 空间上任意一点的值是一个矩阵 $\begin{bmatrix} 0.5 & 0.1 \\ 0.1 & 0.2 \end{bmatrix}$	 [J. Jankowai et al. (2019), Robust Extraction and Simplification of 2D Symmetric Tensor Field Topology. doi:10.1111/cgf.13693]	 [T. Schultz and G. L. Kindlmann (2010), "Superquadric Glyphs for Symmetric Second-Order Tensors," doi: 10.1109/TVCG.2010.199.]

科学可视化的数据存储

- 实际中，将定义域（空间）离散化以网格(grids)或微粒(particles)方式存储数据
- 网格可分为规则网格(regular grids)和非规则网格(irregular grids)
- 简单来说，规则网格的元素(cell)之间有固定的连接方式，非规则网格需要显式定义每个元素和周围的连接方式
- 最常用的，立方体网格——均匀网格(uniform grid)
- 以像素pixel（二维）或体素voxel（三维）存储数据



体数据以体素存储在均一网格上

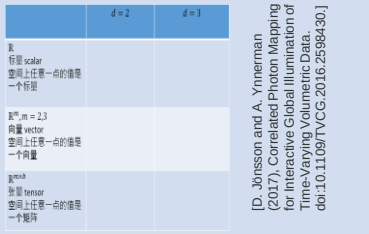
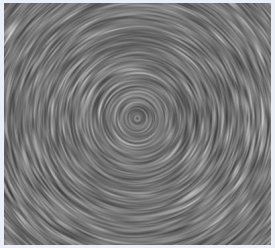
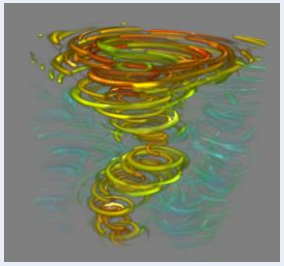
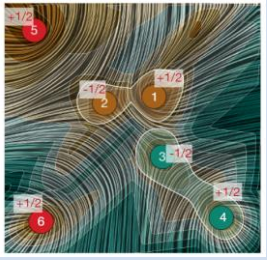
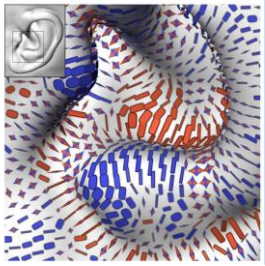
[K. Engel et al. (2004). Real-time volume graphics. DOI:10.1145/1103900.1103929]

标量可视化

- 空间上每个数据点代表一个标量

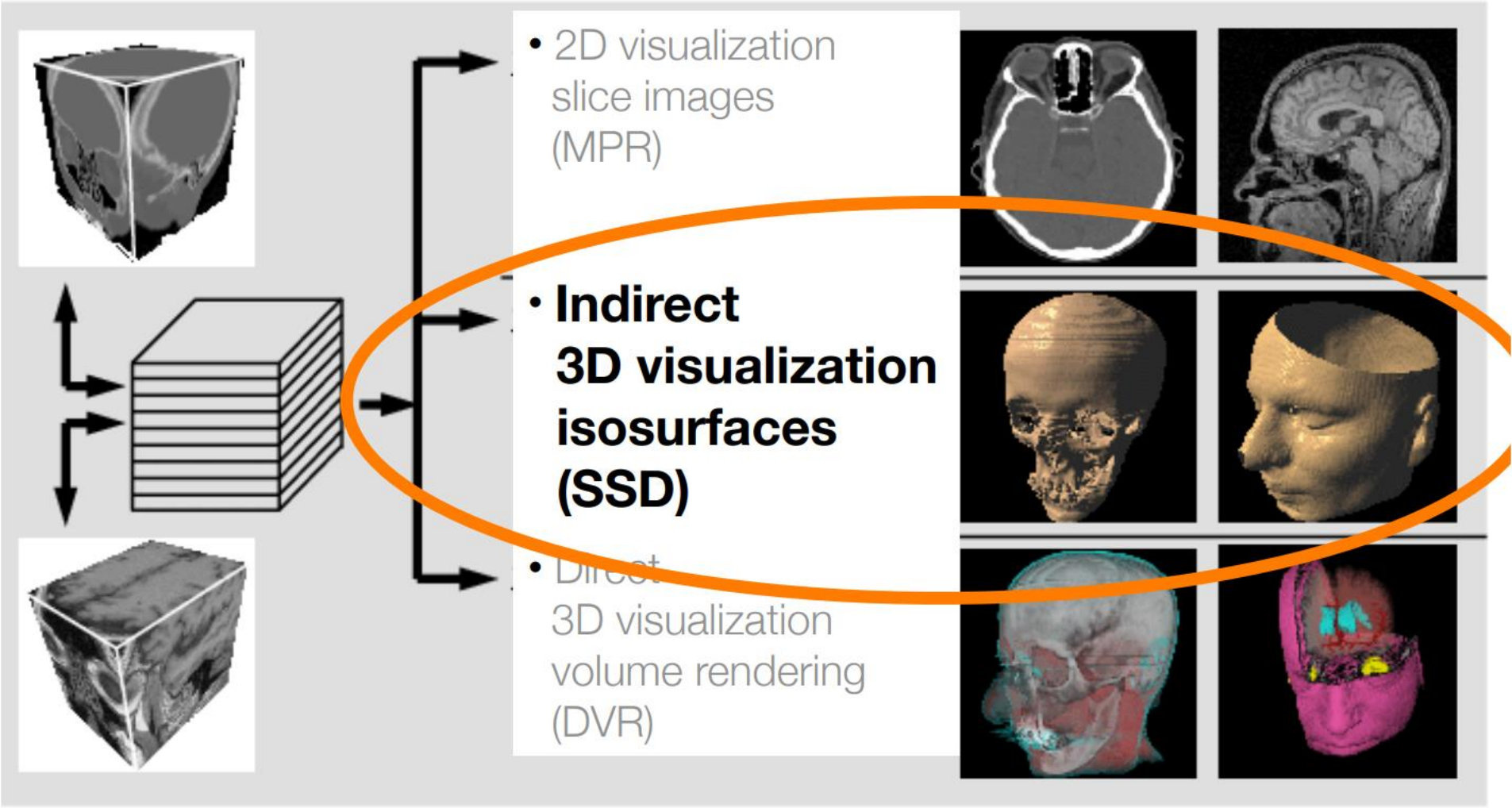
定义域 domain

值域 range

$\mathbb{R}^d$	$d = 2$	$d = 3$
$\mathbb{R}$ 标量 scalar 空间上任意一点的值是一个标量 0.5		 [D. Jönsson and A. Ynnerman (2017). Correlated Photon Mapping for Interactive Global Illumination of Time-Varying Volumetric Data. doi:10.1109/TVCG.2016.2598430.]
$\mathbb{R}^m, m = 2,3$ 向量 vector 空间上任意一点的值是一个向量 $[0.5, 0.5]$	 [Source: D. Weiskopf]	 [M. Falk, D. Weiskopf (2008): Output-Sensitive 3D Line Integral Convolution, doi:10.1109/TVCG.2008.25]
$\mathbb{R}^{m \times b}$ 张量 tensor 空间上任意一点的值是一个矩阵 $\begin{bmatrix} 0.5 & 0.1 \\ 0.1 & 0.2 \end{bmatrix}$	 [J. Jankowai et al. (2019), Robust Extraction and Simplification of 2D Symmetric Tensor Field Topology. doi:10.1111/cgf.13693]	 [T. Schultz and G. L. Kindlmann (2010), "Superquadric Glyphs for Symmetric Second-Order Tensors," doi: 10.1109/TVCG.2010.199.]

标量可视化——等值面绘制/提取 Isosurfacing

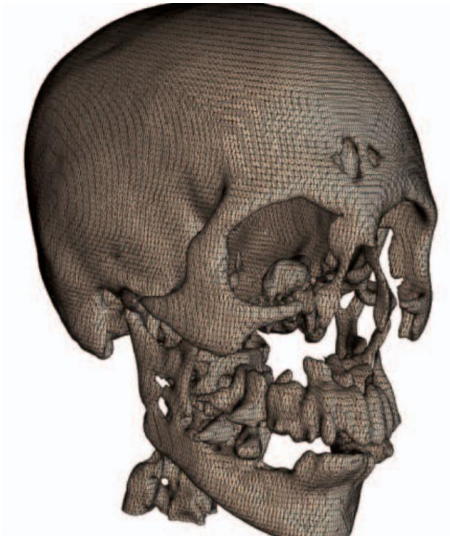
- 间接体渲染方法
- 提取某个数据值对应的等值面



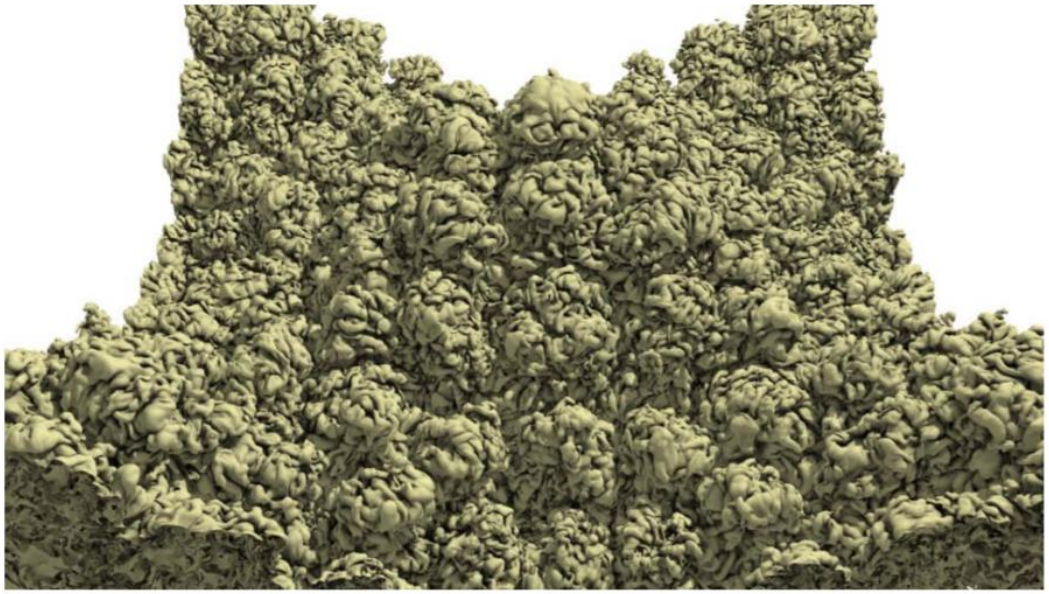
[Source: unknown. Taken from D. Weiskopf]

等值面绘制/提取

- 数据集 $f(x,y,z):\mathbb{R}^3\to\mathbb{R}$
- 数值 v 等值面的等值面 $S_v=\{(x,y,z)|f(x,y,z)=v\}$
  - 二维 isocontour
  - 三维 isosurface
- 在空间中查找所有数值为 v 的位置
- 如何找到这些位置？Marching cubes!



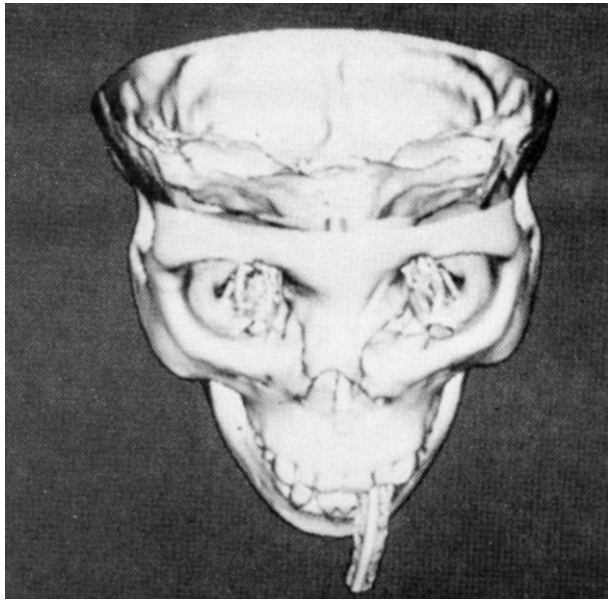
From [J. Schreiner, C. E. Scheidegger and C. T. Silva, "High-Quality Extraction of Isosurfaces from Regular and Irregular Grids," doi: 10.1109/TVCG.2006.149.]



[T. Ize et al. (2011). Real-Time Ray Tracer for Visualizing Massive Models on a Cluster. DOI:10.2312/EGPGV/EGPGV11/061-069]

Marching cubes

- 最常用的等值面绘制/提取方法
- 输出等值面的三角形网格



Computer Graphics, Volume 21, Number 4, July 1987

MARCHING CUBES: A HIGH RESOLUTION 3D SURFACE CONSTRUCTION ALGORITHM

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Abstract

We present a new algorithm, called *marching cubes*, that creates triangle models of constant density surfaces from 3D medical data. Using a divide-and-conquer approach to generate inter-slice connectivity, we create a case table that defines triangle topology. The algorithm processes the 3D medical data in scan-line order and calculates triangle vertices using linear interpolation. We find the gradient of the original data, normalize it, and use it as a basis for shading the models. The detail in images produced from the generated surface models is the result of maintaining the inter-slice connectivity, surface data, and gradient information present in the original 3D data. Results from computed tomography (CT), magnetic resonance (MR), and single-photon emission computed tomography (SPECT) illustrate the quality and functionality of *marching cubes*. We also discuss improvements that decrease processing time and add solid modeling capabilities.

CR Categories: 3.3, 3.5

Additional Keywords: computer graphics, medical imaging, surface reconstruction

1. INTRODUCTION.

Three-dimensional surfaces of the anatomy offer a valuable medical tool. Images of these surfaces, constructed from multiple 2D slices of computed tomography (CT), magnetic resonance (MR), and single-photon emission computed tomography (SPECT) illustrate the quality and functionality of marching cubes. We also discuss improvements that decrease processing time and add solid modeling capabilities.

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1. INTRODUCTION.

Three-dimensional surfaces of the anatomy offer a valuable medical tool. Images of these surfaces, constructed from multiple 2D slices of computed tomography (CT), magnetic resonance (MR), and single-photon emission computed tomography (SPECT) illustrate the quality and functionality of marching cubes. We also discuss improvements that decrease processing time and add solid modeling capabilities.

acetabular fractures [6], craniofacial abnormalities [17,18], and intracranial structure [13] illustrate 3D's potential for the study of complex bone structures. Applications in radiation therapy [27,11] and surgical planning [4,5,31] show interactive 3D techniques combined with 3D surface images. Cardiac applications include artery visualization [2,16] and non-graphic modeling applications to calculate surface area and volume [21].

Existing 3D algorithms lack detail and sometimes introduce artifacts. We present a new, high-resolution 3D surface construction algorithm that produces models with unprecedented detail. This new algorithm, called *marching cubes*, creates a polygonal representation of constant density surfaces from a 3D array of data. The resulting model can be displayed with conventional graphics-rendering algorithms implemented in software or hardware.

After describing the information flow for 3D medical applications, we describe related work and discuss the drawbacks of that work. Then we describe the algorithm as well as efficiency and functional enhancements, followed by case studies using three different medical imaging techniques to illustrate the new algorithm's capabilities.

2. INFORMATION FLOW FOR 3D MEDICAL ALGORITHMS.

Medical applications of 3D consist of four steps (Figure 1). Although one can combine the last three steps into one algorithm, we logically decompose the process as follows:

[W E. Lorensen and H E. Cline (1987). Marching cubes: A high resolution 3D surface construction algorithm. DOI:10.1145/37401.37422]

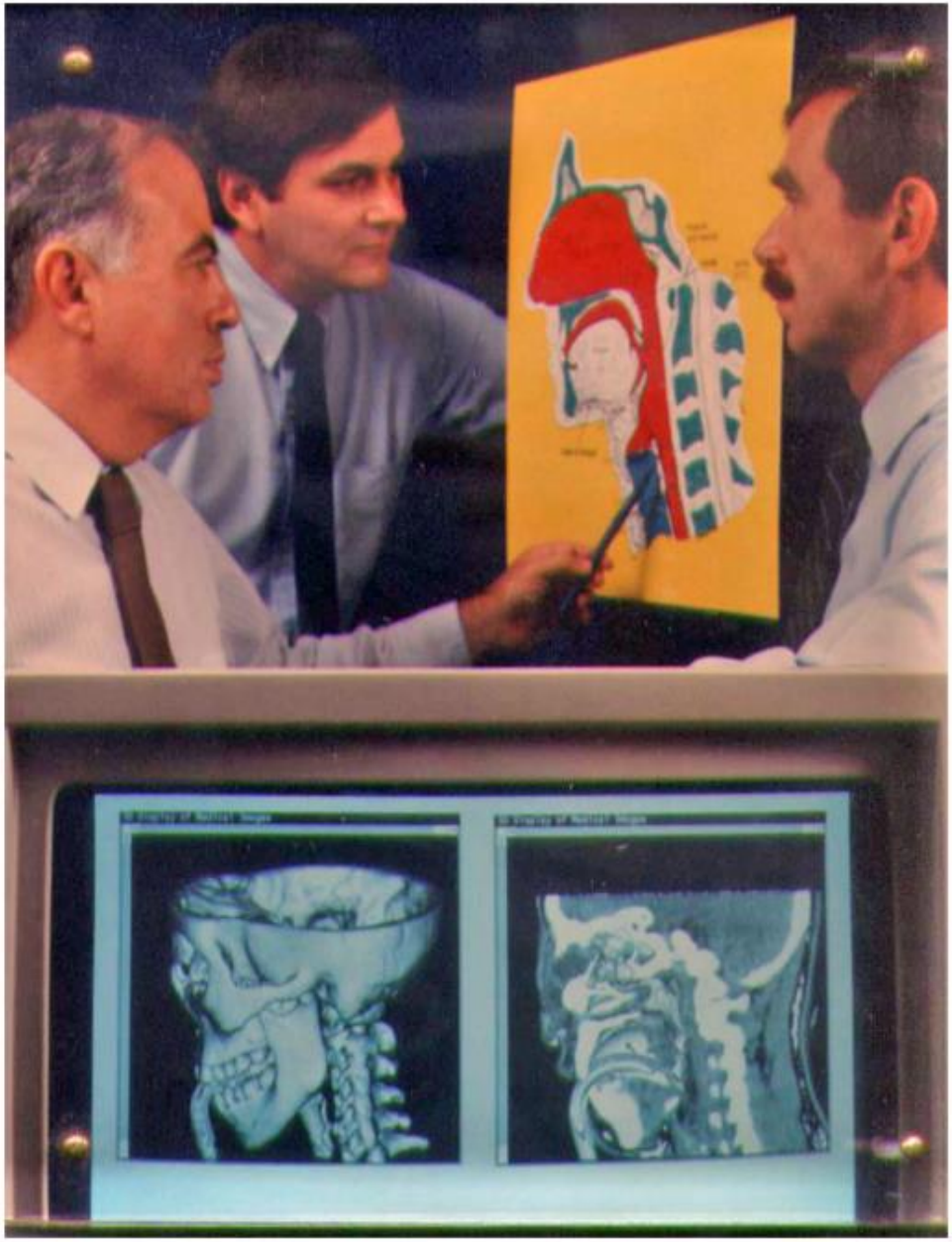
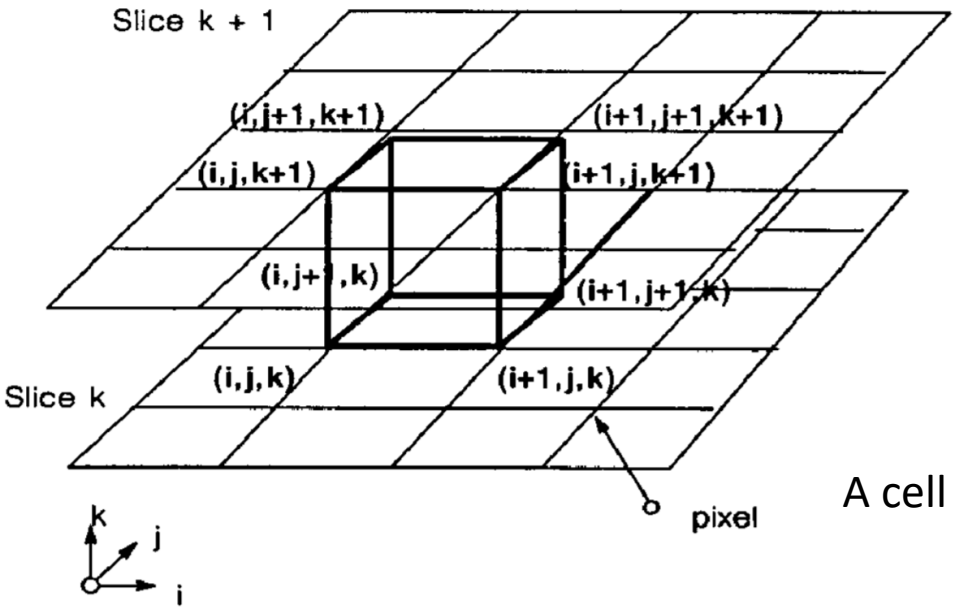


Figure 2. Early visualization using Marching Cubes. Harvey Cline (Left), Bill Lorensen (Middle), Sieg Ludke (Right), November 1988.

Marching cubes

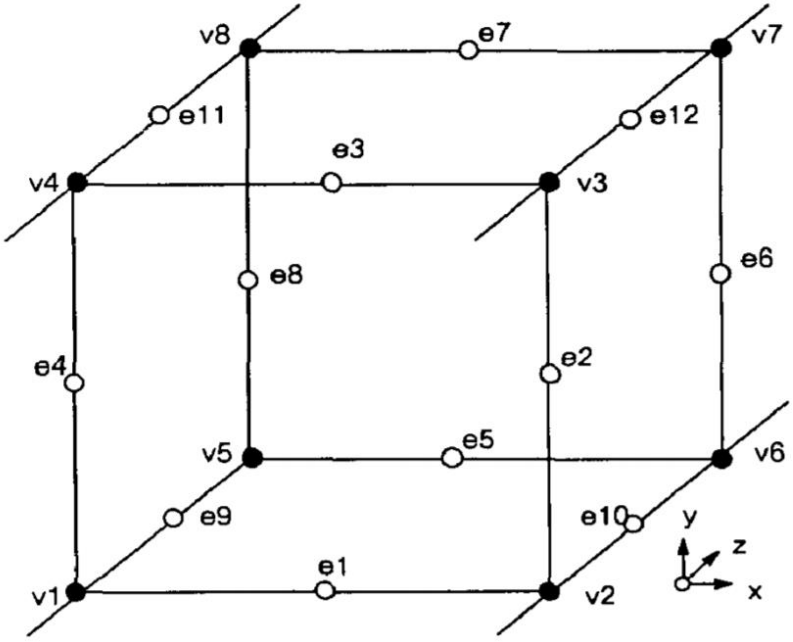
- 一种高效的近似方法；使用预先计算的表格
- 核心步骤
  - 考虑一个cell （8个顶点的立方体cube）
  - 判断每个顶点在等值面内部($f(x,y,z) <= v$)或外部($f(x,y,z) > v$)
  - 创建索引|index
  - 使用索引查询预计算表tbl[index]得到边列表
  - 插值计算边的位置
  - *计算梯度*
  - *处理有歧义的情况*
  - 移动到下一个cell (Marching)



From [W E. Lorensen and H E. Cline (1987).]

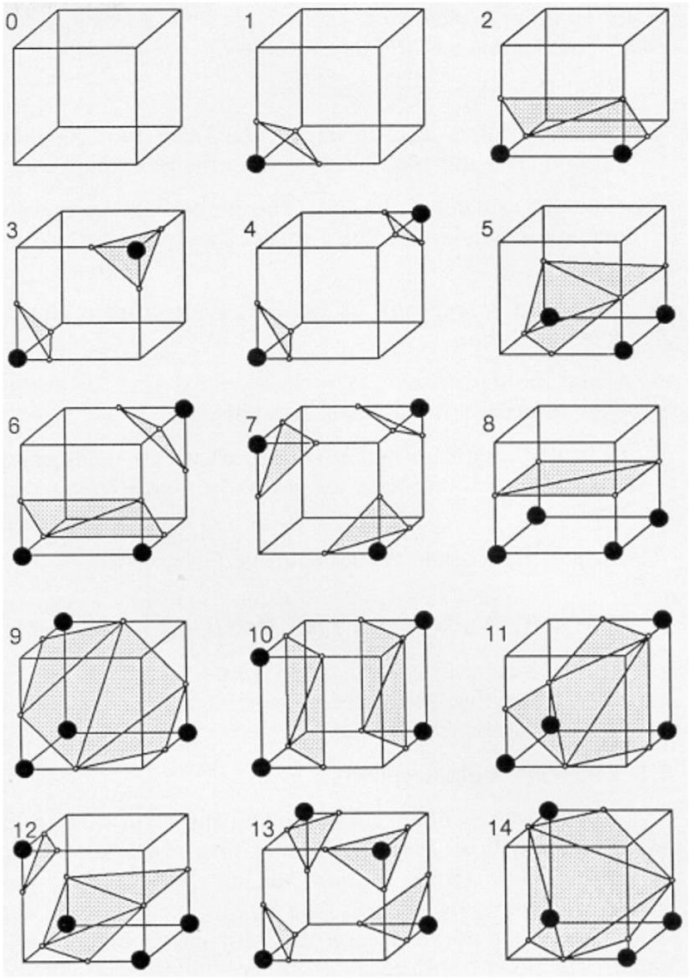
Marching cubes

- 对于一个cell三角形网格共有2^8=256 种情况，根据对称性，简化到15种独特的情况
- 从预计算表的边表tbl里根据index选择
- 根据顶点的数值，在各个方向插值确定边



index =	v8	v7	v6	v5	v4	v3	v2	v1

索引计算规则

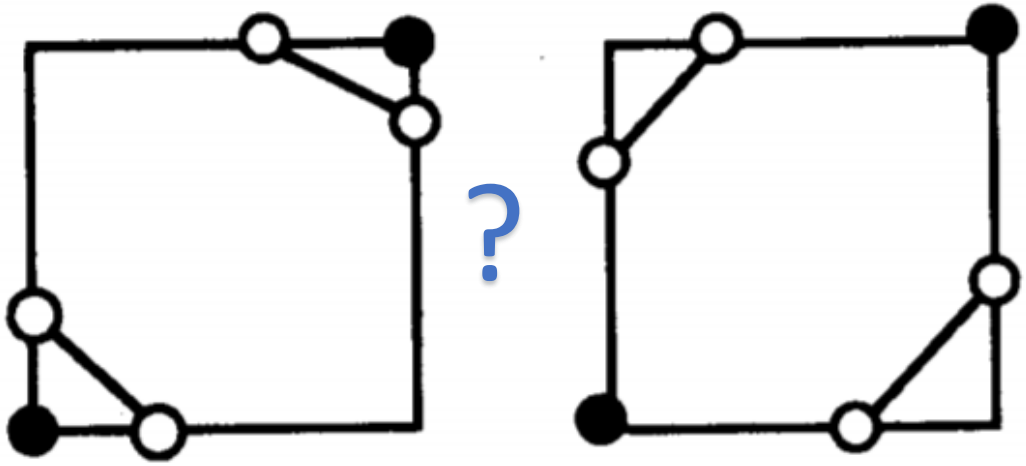


三角形网格等值面的15种情况

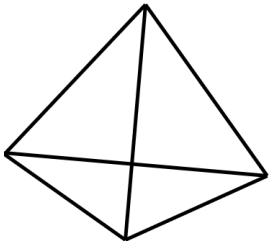
From [W E. Lorensen and H E. Cline (1987).]

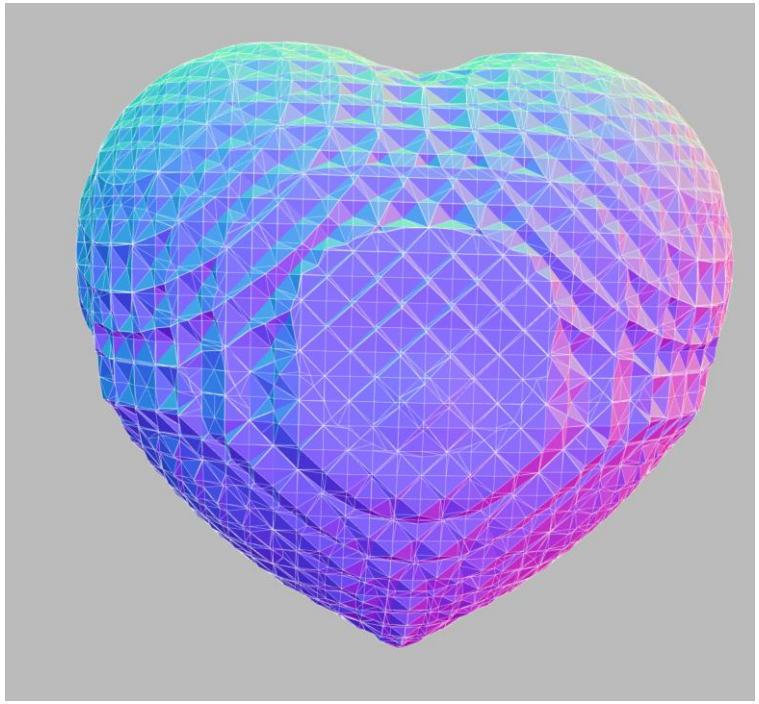
Marching cubes的问题

- 歧义情况判断（渐近线判断 asymptotic decider)
- 改善歧义情况和三角形形状——Marching tetrahedra



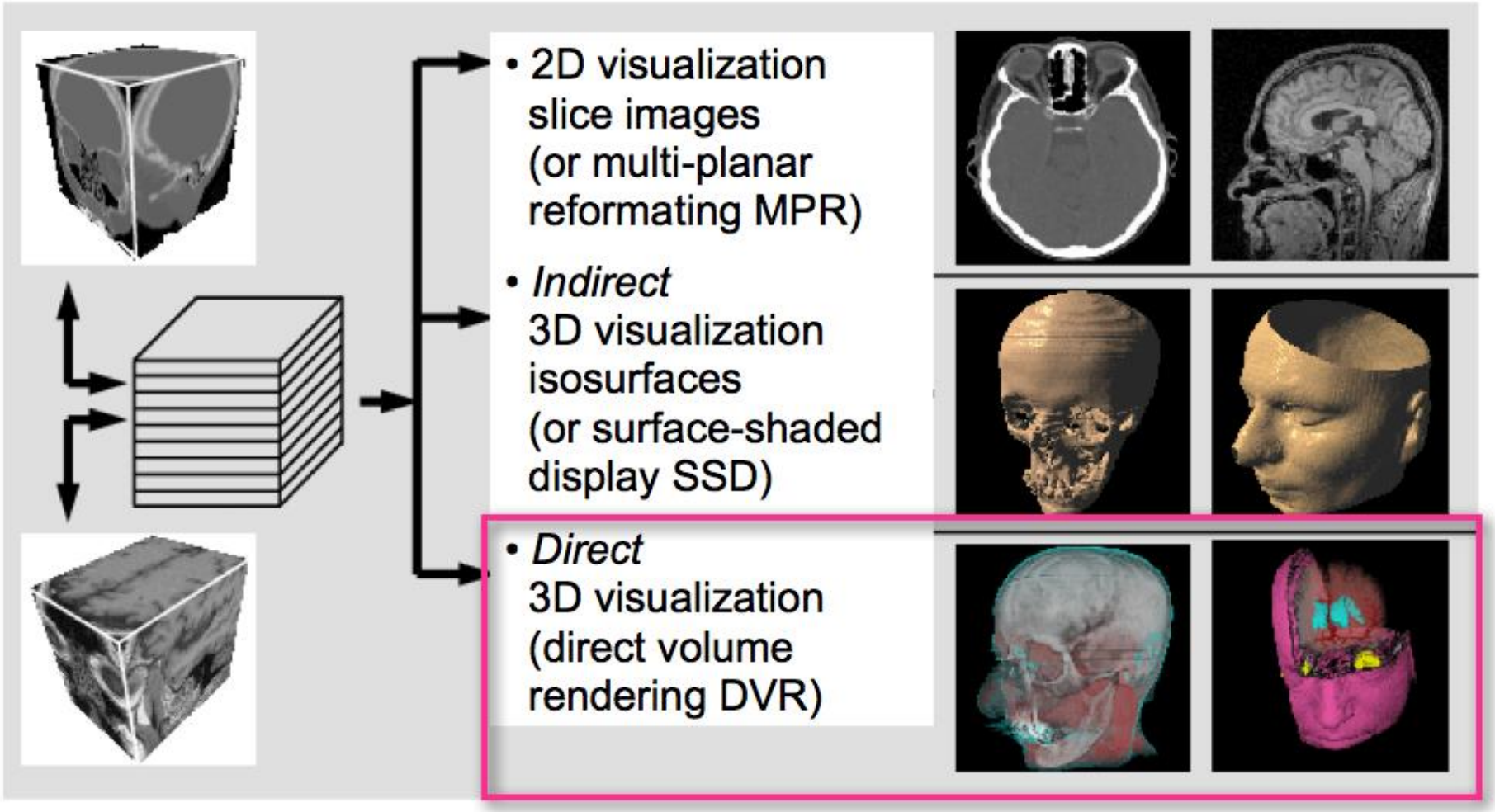
[G M. Nielson and B Hamann (1991). The asymptotic decider: resolving the ambiguity in marching cubes. doi: 10.5555/949607.949621]





https://d3x0r.github.io/MarchingTetrahedra/

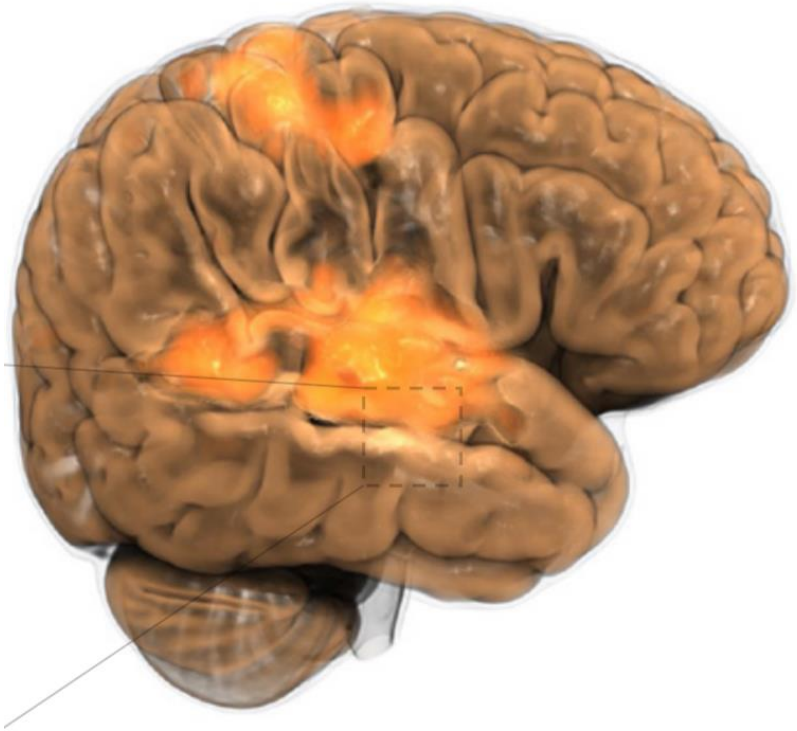
标量可视化——体渲染 Direct volume rendering



[Source: unknown. Taken from C. R. Johnson]

体渲染

- 等值面绘制只绘制了一个（或几个）数据值的等值面而不能绘制整个体数据→间接体渲染(indirect volume rendering)
- 体渲染或直接体渲染(direct volume rendering)将整个体数据进行绘制→简单来说，能看到体数据的内部



[D. Jönsson and A. Ynnerman (2017), Correlated Photon Mapping for Interactive Global Illumination of Time-Varying Volumetric Data. doi:10.1109/TVCG.2016.2598430.]

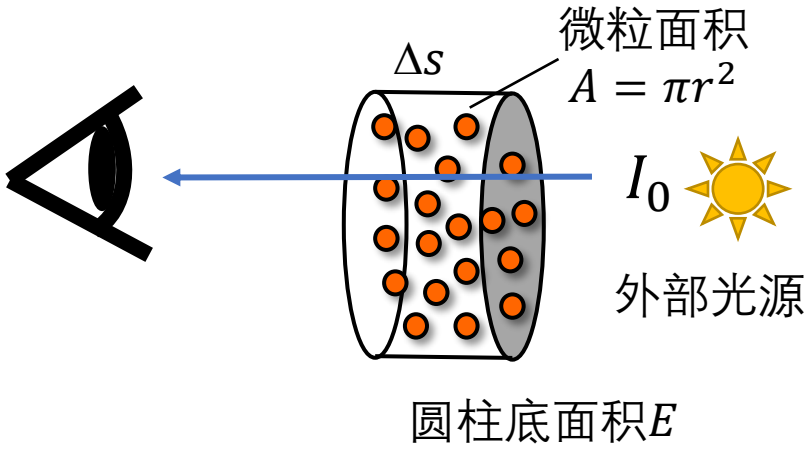
[Martschinke, J. et al.(2019), Adaptive Temporal Sampling for Volumetric Path Tracing of Medical Data. doi:10.1111/cgf.13771]

体渲染的物理基础

- 把数据建模成介质——光在介质中的传播
- 介质由可吸收和发射光的微粒构成——光学模型
- 微元法计算在空间微元ds上的光强变化dI
- $\frac{dI}{ds} = C(s)A\rho(s) - A\rho(s)I(s) = C(s)\tau(s) - \tau(s)I(s)$, 其中$\tau(s) = A\rho(s)$

发光强度 微粒密度 发射 吸收

消光系数
extinction coefficient



体渲染的物理基础

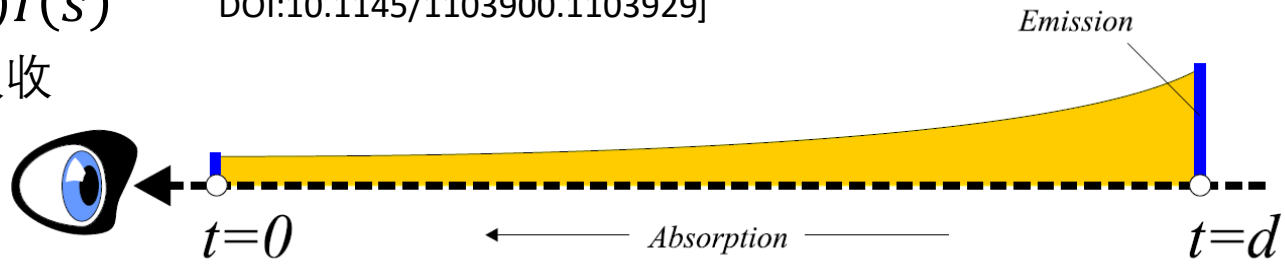
■体渲染积分公式

- $\frac{dI}{ds} = C(s)\tau(s) - \tau(s)I(s)$

  发射　　吸收

求解常微分方程

From [K. Engel et al. (2004). Real-time volume graphics. DOI:10.1145/1103900.1103929]



- $I(d) = \int_0^d g(s)\, e^{-\int_0^d \tau(t)dt} ds + I_0 e^{-\int_0^d \tau(t)dt}$

  发射　　吸收

体渲染积分公式

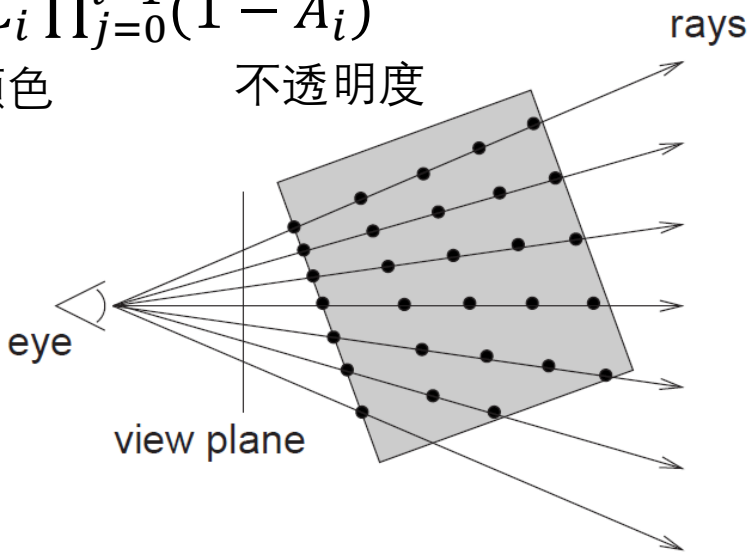
光线投射 Ray casting

- 当今最常用的体渲染技术
- 从视平面(view plane)发射光线，数值求解体渲染积分
- $I(d) = \int_0^d g(s)\, e^{-\int_0^d \tau(t)dt} ds + I_0 e^{-\int_0^d \tau(t)dt}$

近似+数值积分

- $\tilde{C} = \sum_{i=0}^{n} C_i \prod_{j=0}^{i-1}(1 - A_i)$

颜色　　不透明度



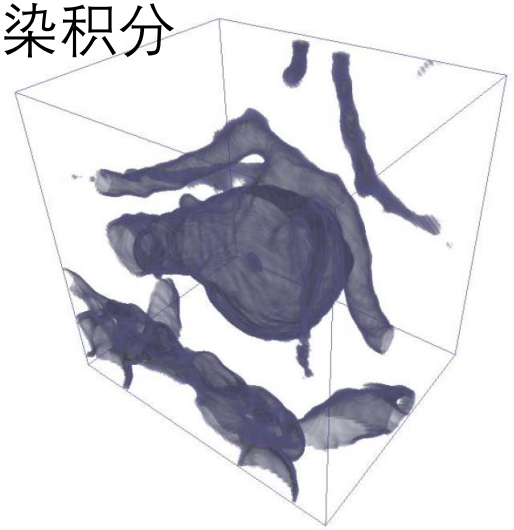


Figure 5.1: Volume rendering of an aneurysm data set.

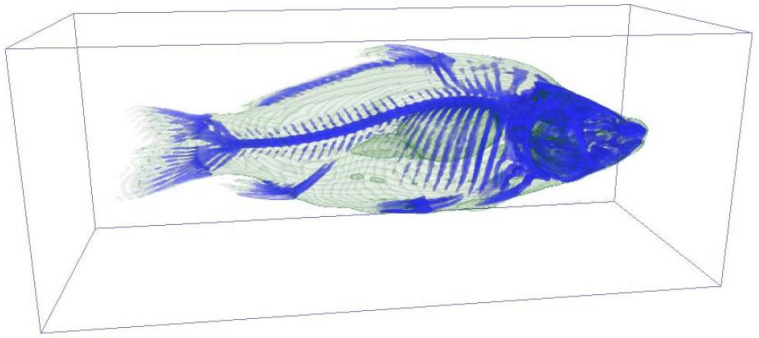
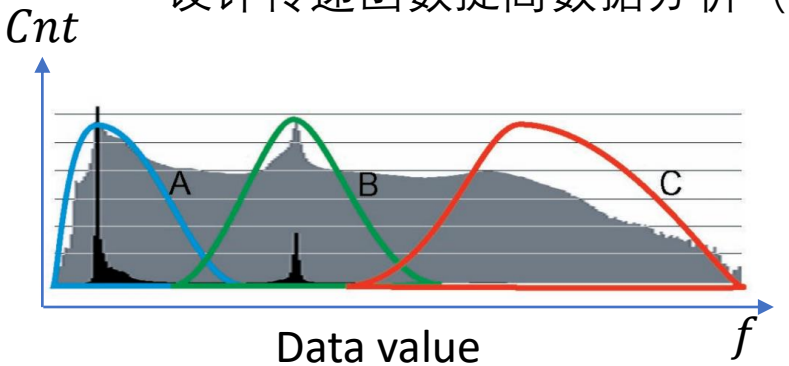


Figure 5.2: Volume rendering of the CT scan of a carp.

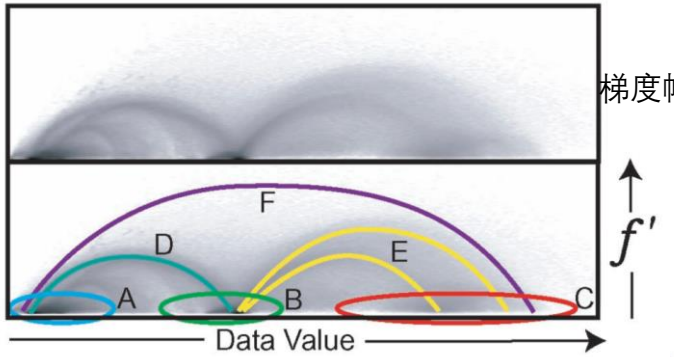
From [K. Engel et al. (2004). Real-time volume graphics. DOI:10.1145/1103900.1103929]

传递函数 Transfer function

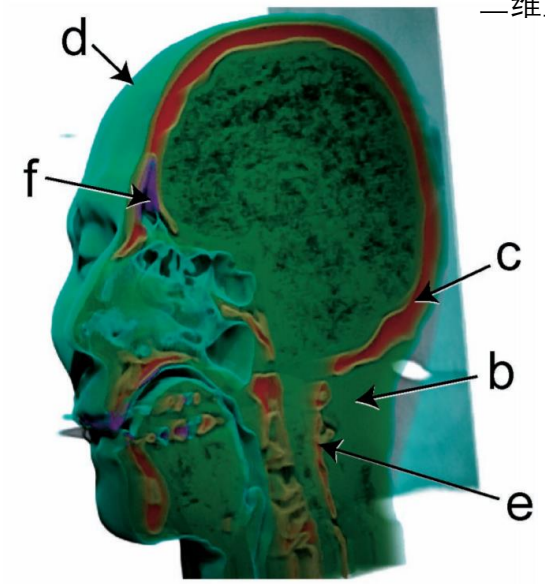
- 如何将数据值映射成光学属性(optical properties)：颜色和不透明度？
- 用传递函数在**值域**中定义颜色C和不透明度A
  - 从数据分析角度，传递函数提供了数据探索的工具
  - 设计传递函数提高数据分析（分类、分割）能力

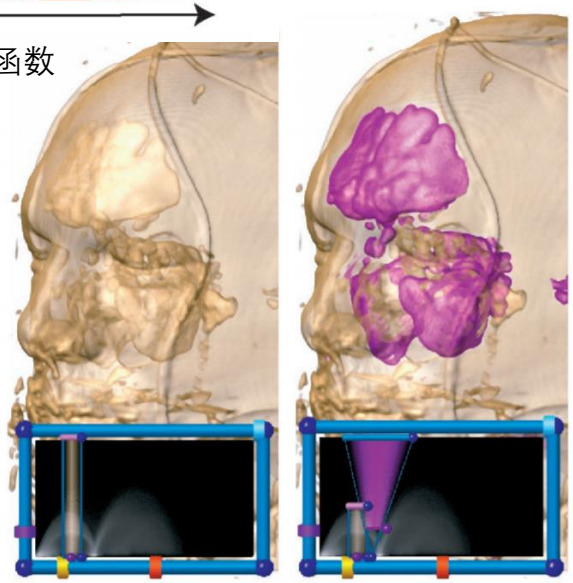


一维直方图和传递函数



二维直方图和传递函数

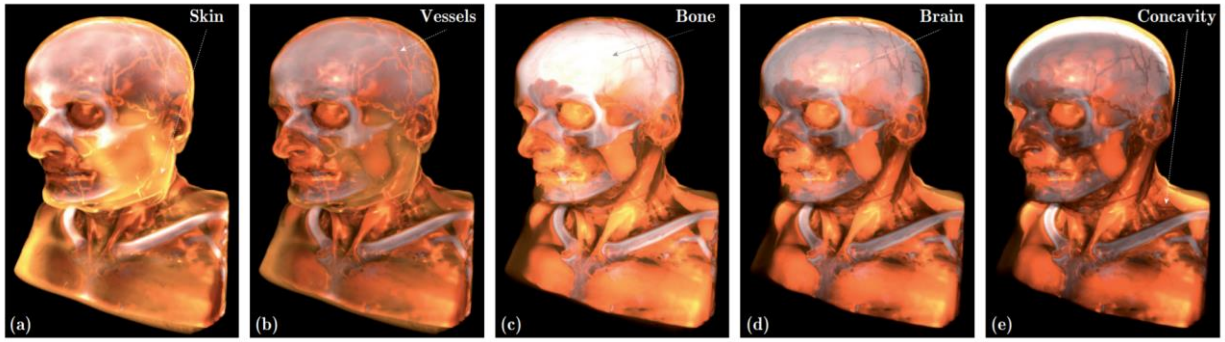


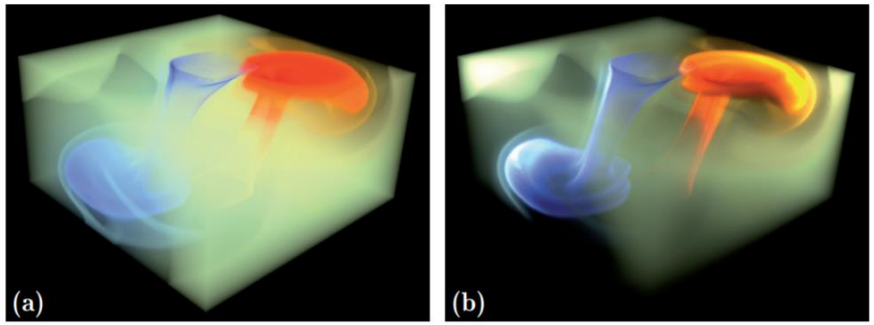

一维传递函数

[J. Kniss et al. (2002), "Multidimensional transfer functions for interactive volume rendering," doi: 10.1109/TVCG.2002.1021579.]

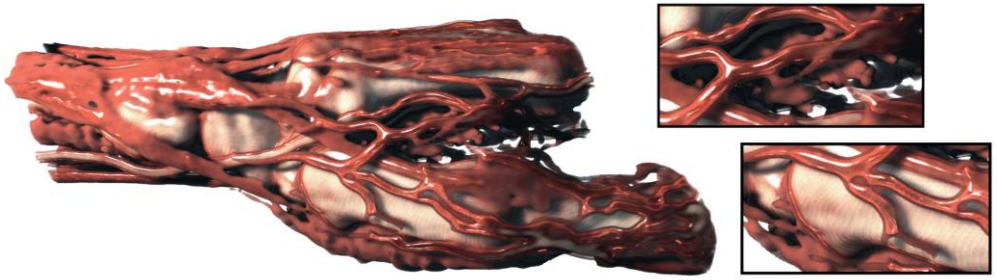
复杂光学模型/全局光照

- 吸收发射模型没有考虑散射(scattering) →局部光照(local illumination)
- 使用全局光照(global illumination)能大幅提高真实感，增强深度和形状感知
  - 阴影；半透明
- 全局光照计算复杂度高，需要各种高效率的近似算法实现交互绘制





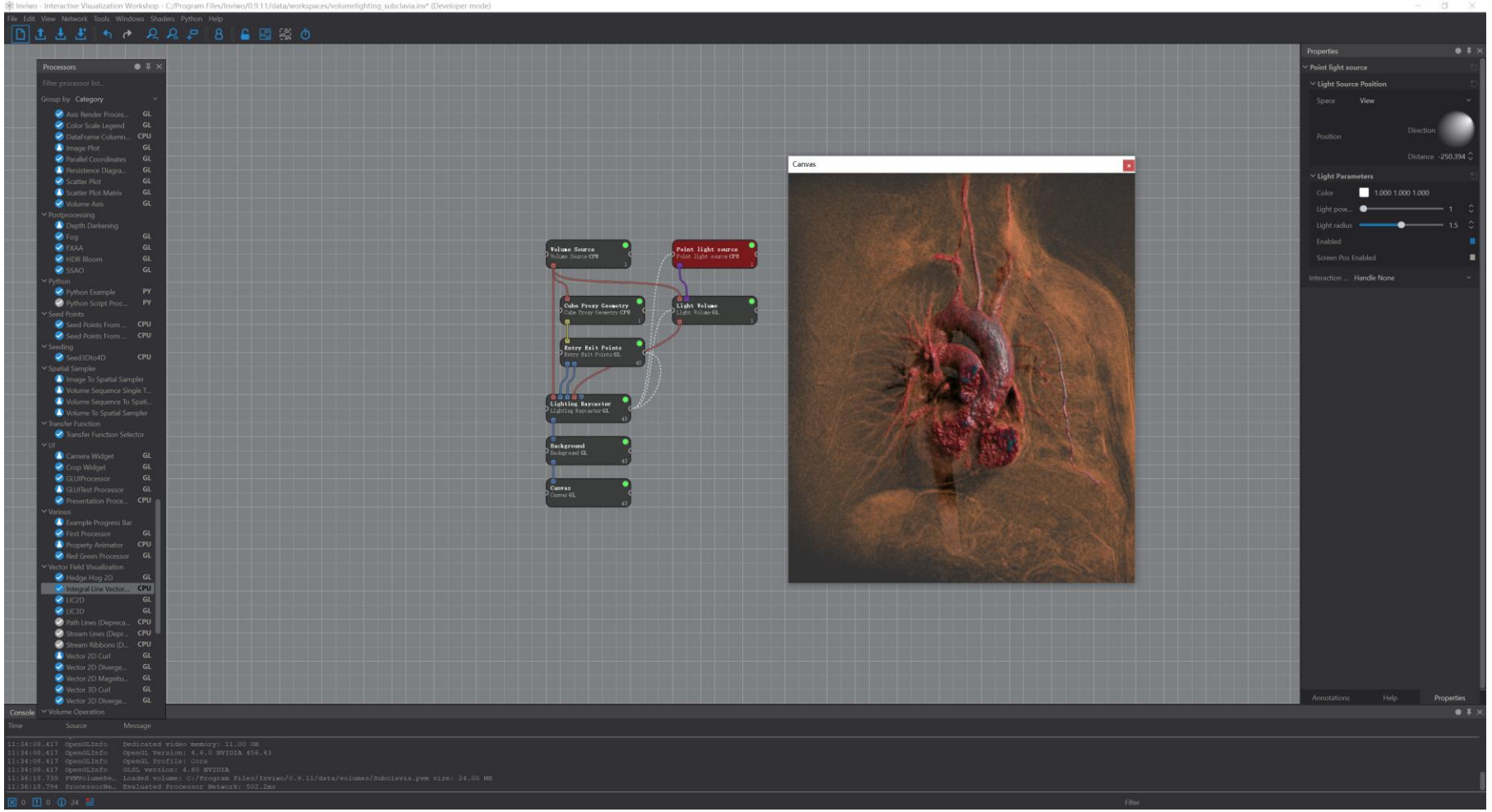
[M. Ament et al. (2013), "Ambient Volume Scattering," doi: 10.1109/TVCG.2013.129.]



[D. Jönsson et al. (2012), "Historygrams: Enabling Interactive Global Illumination in Direct Volume Rendering using Photon Mapping," doi: 10.1109/TVCG.2012.232.]

体渲染演示

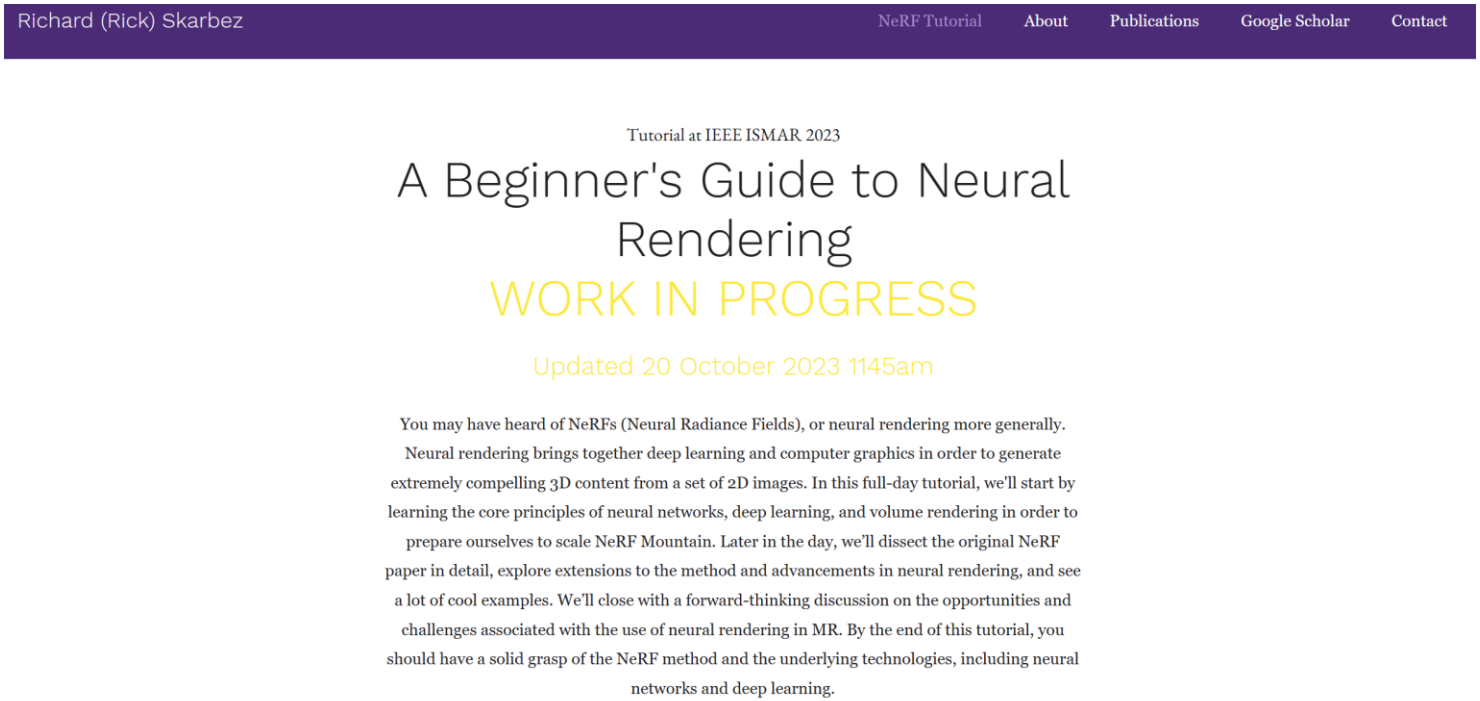
- 使用Inviwo
- 简易使用说明https://inviwo.org/media/inviwo-vcbm2019.pdf



https://inviwo.org

体绘制在其他领域的应用

- 计算机视觉和图形学领域最火的技术NeRF（Neural Radiance Fields）
- https://www.richardskarbez.com/nerf-tutorial



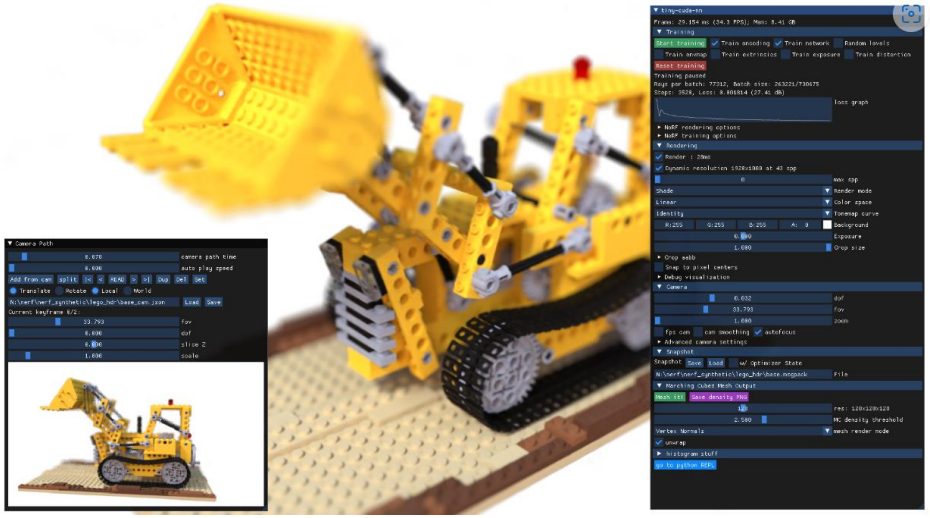
2020

NeRF: Representing Scenes as Neural Radiance Fields for View Synthesis

[paper] [demo site] [github]
[overview video] [100LoC video] [explainer video]
This is the paper that started the NeRF revolution.

NeRF 工具

- Nvidea instant-ngp
- https://github.com/NVlabs/instant-ngp



https://github.com/NVlabs/instant-ngp

README.md

Instant Neural Graphics Primitives

Ever wanted to train a NeRF model of a fox in under 5 seconds? Or fly around a scene captured from photos of a factory robot? Of course you have!

Here you will find an implementation of four **neural graphics primitives**, being neural radiance fields (NeRF), signed distance functions (SDFs), neural images, and neural volumes. In each case, we train and render a MLP with multiresolution hash input encoding using the tiny-cuda-nn framework.

> Instant Neural Graphics Primitives with a Multiresolution Hash Encoding
> Thomas Müller, Alex Evans, Christoph Schied, Alexander Keller
> *ACM Transactions on Graphics (**SIGGRAPH**), July 2022*
> Project page / Paper / Video / Presentation / Real-Time Live / BibTeX

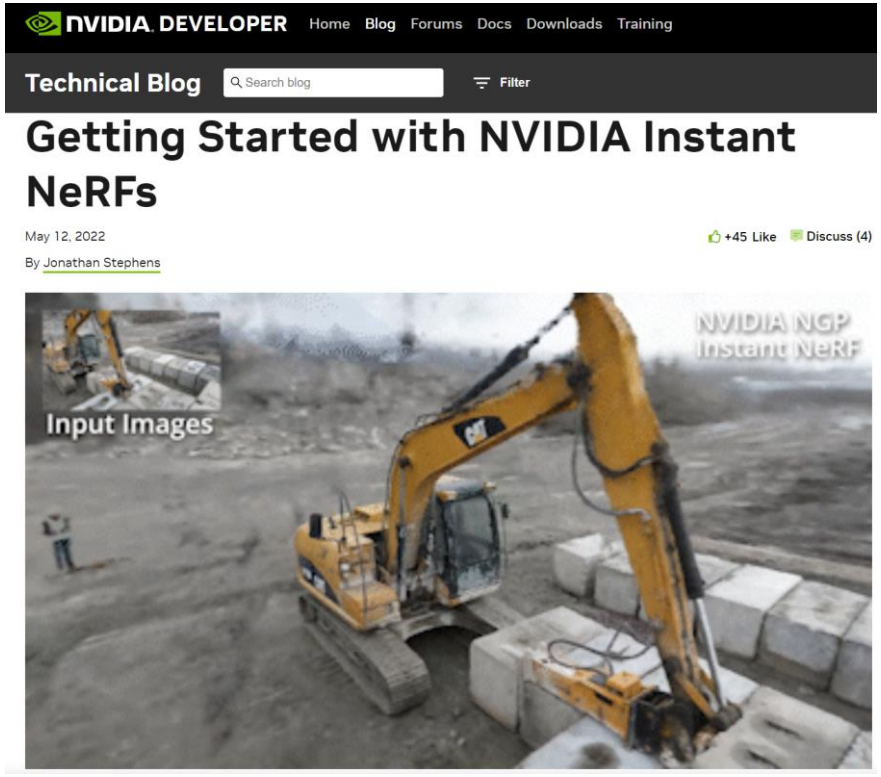
For business inquiries, please submit the NVIDIA research licensing form.

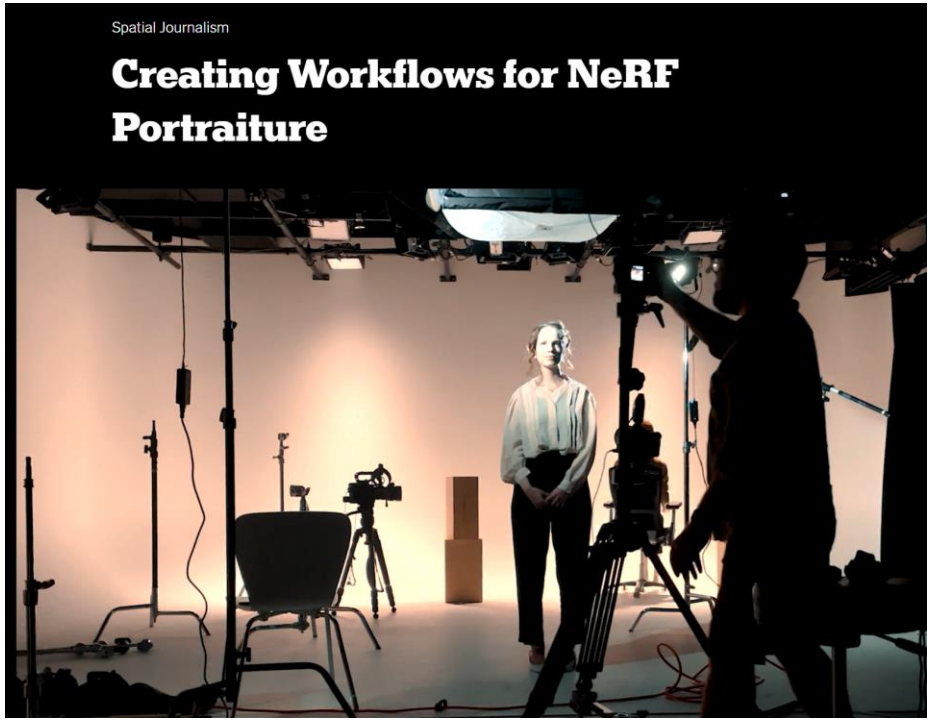
Installation

If you have Windows, download one of the following releases corresponding to your graphics card and extract it. Then, start `instant-ngp.exe`.

创建自己的NeRF

- https://developer.nvidia.com/blog/getting-started-with-nvidia-instant-nerfs/
- https://rd.nytimes.com/projects/creating-workflows-for-nerf-portraiture



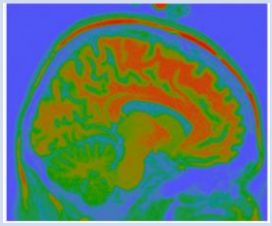
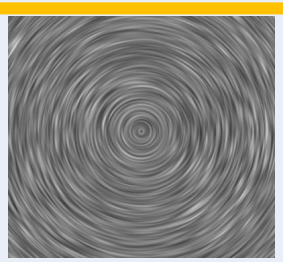
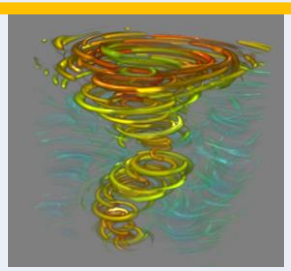
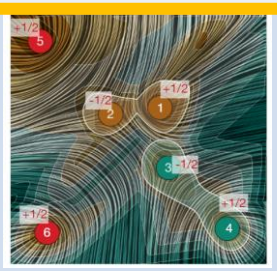
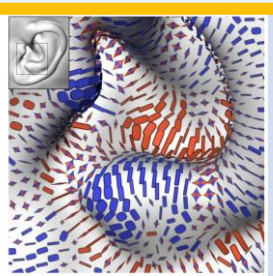


向量场可视化

- 空间上每个点的值是一个向量

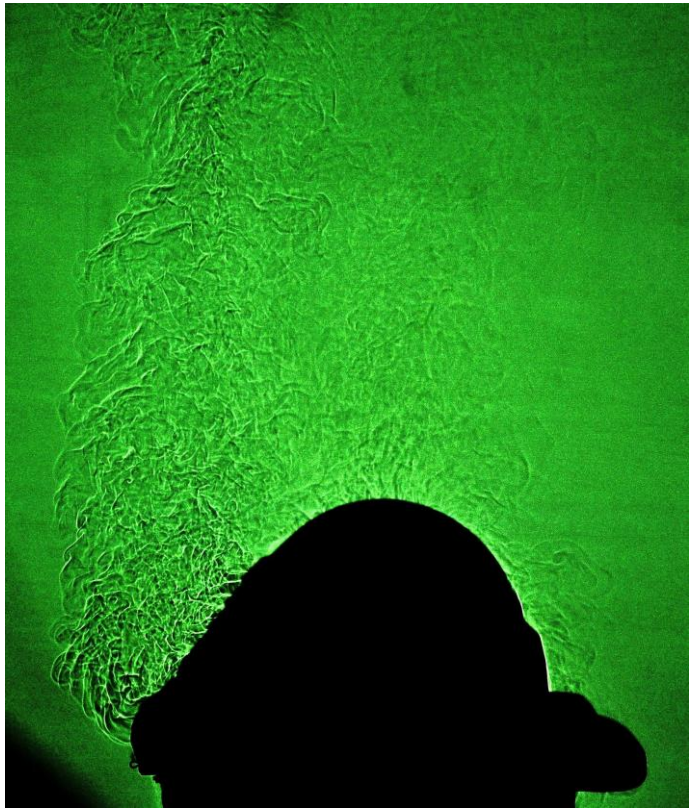
定义域 domain

值域 range

$\mathbb{R}^d$	$d = 2$	$d = 3$
$\mathbb{R}$ 标量 scalar 空间上任意一点的值是一个标量 scalar 0.5		 [D. Jönsson and A. Ynnerman (2017). Correlated Photon Mapping for Interactive Global Illumination of Time-Varying Volumetric Data. doi:10.1109/TVCG.2016.2598430.]
$\mathbb{R}^m, m = 2,3$ 向量 vector 空间上任意一点的值是一个向量 $[0.5, 0.5]$	 [Source: D. Weiskopf]	 [M. Falk, D. Weiskopf (2008): Output-Sensitive 3D Line Integral Convolution, doi:10.1109/TVCG.2008.25]
$\mathbb{R}^{m \times b}$ 张量 tensor 空间上任意一点的值是一个矩阵 $\begin{bmatrix} 0.5 & 0.1 \\ 0.1 & 0.2 \end{bmatrix}$	 [J. Jankowai et al. (2019), Robust Extraction and Simplification of 2D Symmetric Tensor Field Topology. doi:10.1111/cgf.13693]	 [T. Schultz and G. L. Kindlmann (2010), "Superquadric Glyphs for Symmetric Second-Order Tensors," doi: 10.1109/TVCG.2010.199.]

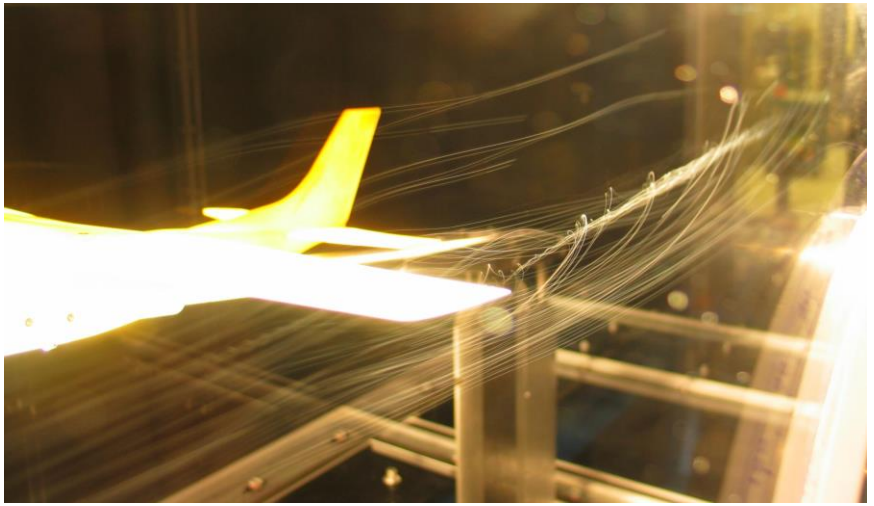
流场可视化Flow visualization——实验流体力学

- 向量可视化的主要形式是流场可视化
- 实验流体力学(fluid dynamics)中的流场可视化



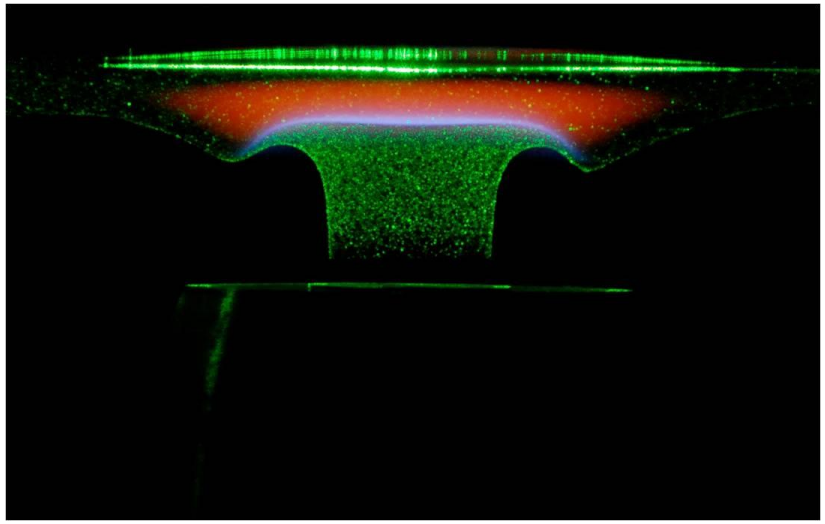
光学法

[By Gary S. Settles (Settles1) - Own work -- Photograph by Gary S. Settles using a commercial retro-reflective shadowgraph instrument manufactured by Floviz inc., CC BY 3.0, https://commons.wikimedia.org/w/index.php?curid=5254884]



表面流法

[By BenFrantzDale - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=2000680]

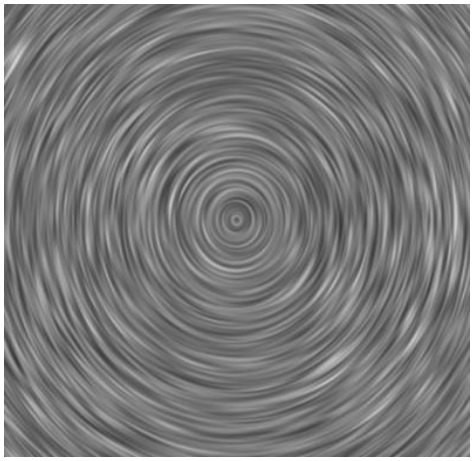


粒子跟踪法

[By AFLmcgill at English Wikipedia, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=21352301]

科学可视化中的流场可视化方法

- Texture-based (LIC, spot noise)
- Direct + geometry-based (hedehogs, glyphs)
- Direct + heuristic (magnitude, Laplacian, FTLE)
- Physically-based (Schlieren imaging, virtual rheoscopic fluids)

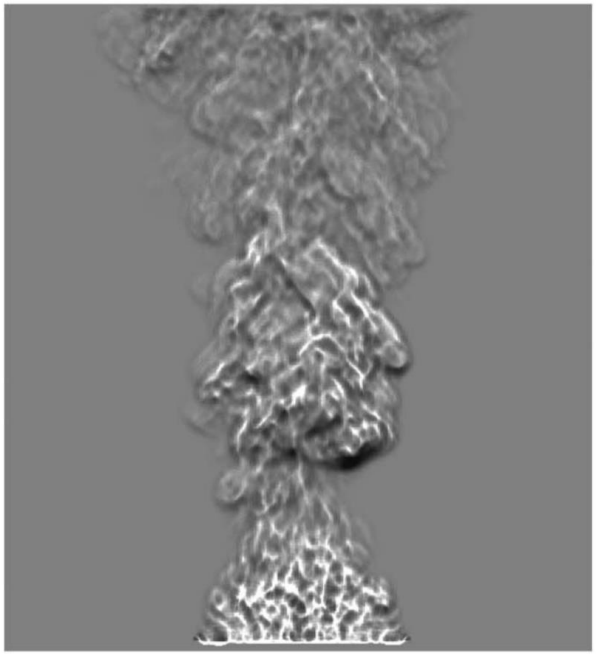


[Source: D. Weiskopf]

Line integral convolution (LIC)

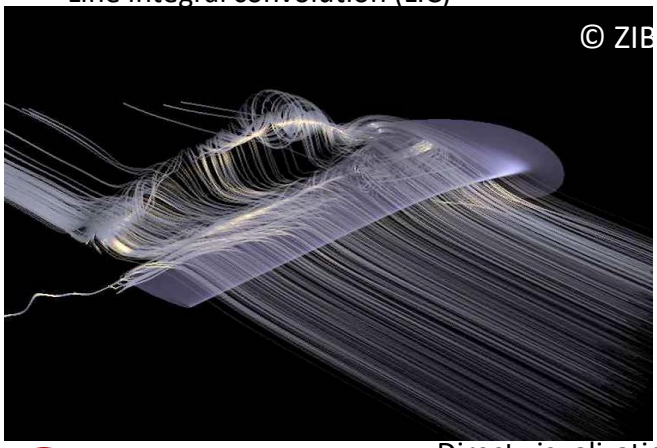
Glyphs

[R. van Pelt et al. (2014), Comparative Blood Flow Visualization for Cerebral Aneurysm Treatment Assessment. doi:10.1111/cgf.12369]



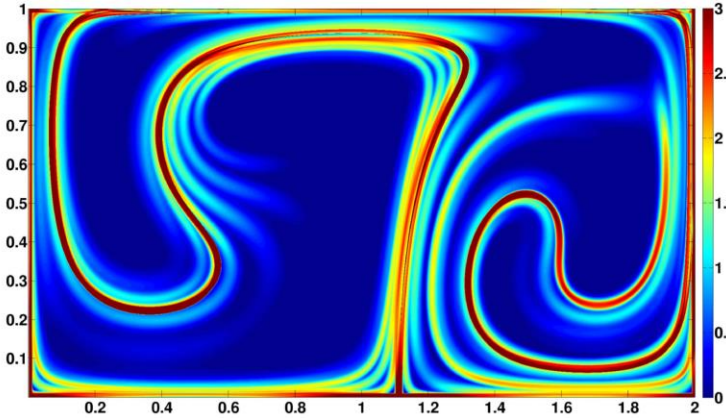
Schlieren imaging

[C. Brownlee et al. (2011), "Physically-Based Interactive Flow Visualization Based on Schlieren and Interferometry Experimental Techniques," doi: 10.1109/TVCG.2010.255.]



Direct visualization of streamlines

[Source: Zuse Institute Berlin]

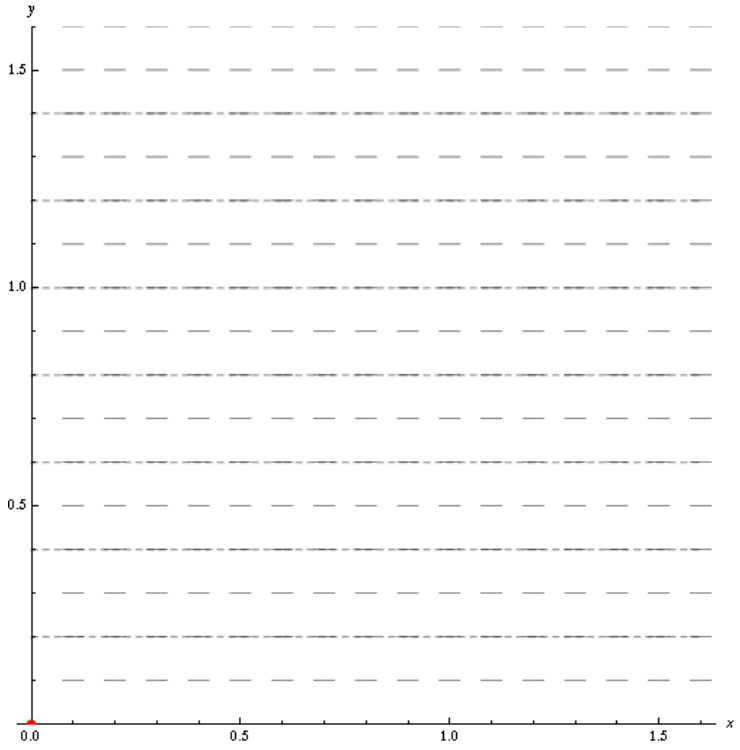


Finite-time Lyapunov exponents (FTLE)

[Pobitzer A. et al. (2012) Filtering of FTLE for Visualizing Spatial Separation in Unsteady 3D Flow. Doi: 10.1007/978-3-642-23175-9_16]

描述流场

- 稳定向量场(steady vector field)：向量场不随时间变化
- 不稳定向量场(unsteady vector field)：向量场随时间变化
- 如何描述流场？
  - Streamlines:描述某一时刻的向量场线
  - Pathlines:追踪一个粒子在一段时间形成的轨迹
  - Streaklines:描述从固定位置释放的染料经过一段时间形成的轨迹
  - 在稳定向量场里中这三种线是重合的



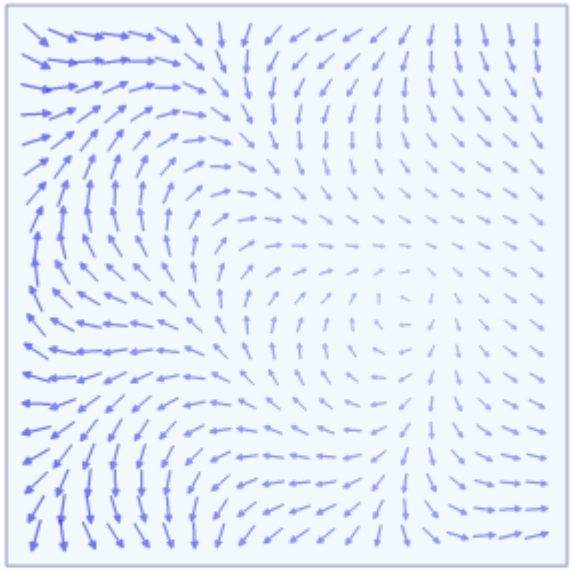
灰色虚线：steamlines
红色实线：pathlines
蓝色实线：streaklines

[By Fi1Kaiv8 - Own work. This diagram was created with Mathematica, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=5875279]

动图参见
slide28_Streaklines_and_pathlines_animation.gif

场线的计算

- 线积分
- 实际中使用数值积分
  - 欧拉法 Euler’s method
  - 龙格库塔法Runge-Kutta method
  - 可视化中标准使用四阶Runge-Kutta （精度较高）



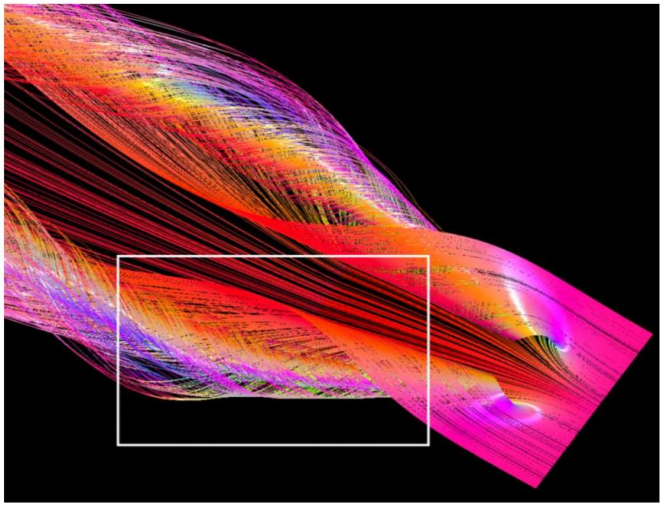
[By Lucas Vieira - Own work, Public Domain, https://commons.wikimedia.org/w/index.php?curid=20414448]
动图参见slide29_Line_integeral_of_vector_field.gif

向量场可视化渲染技术

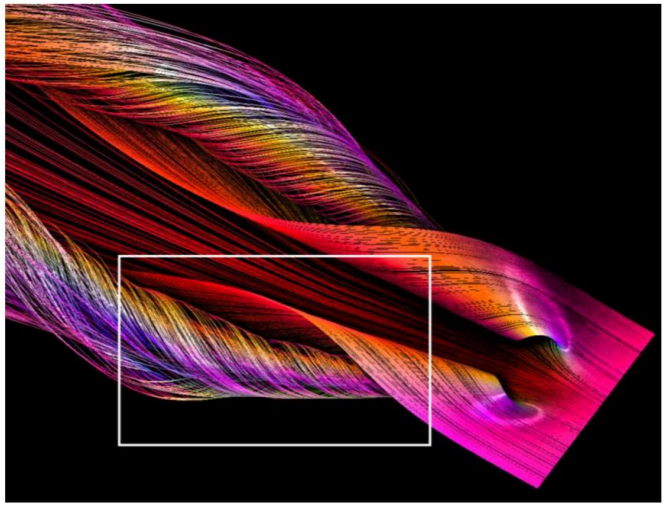
- 由于遮挡，正确地感知空间曲线曲面很困难
  - 局部光照
  - 阴影/环境光遮蔽 ambient occlusion
  - 非真实感绘制 illustrative rendering

非真实感绘制

[M. Hummel et al. (2010), "IRIS: Illustrative Rendering for Integral Surfaces," doi: 10.1109/TVCG.2010.173.]



局部光照

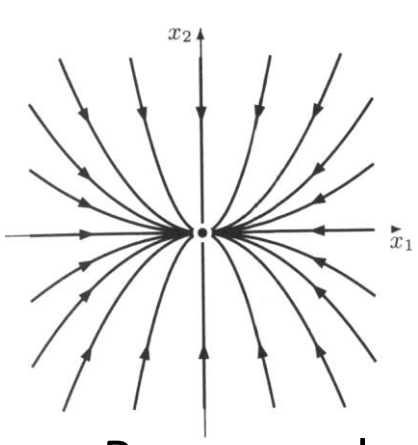


环境光遮蔽

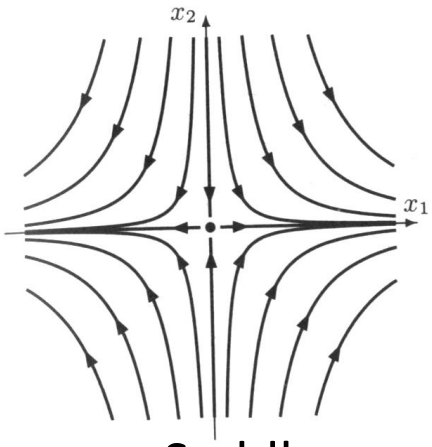
[S. Eichelbaum et al. (2013), "LineAO—Improved Three-Dimensional Line Rendering," doi: 10.1109/TVCG.2012.142.]

向量场拓扑

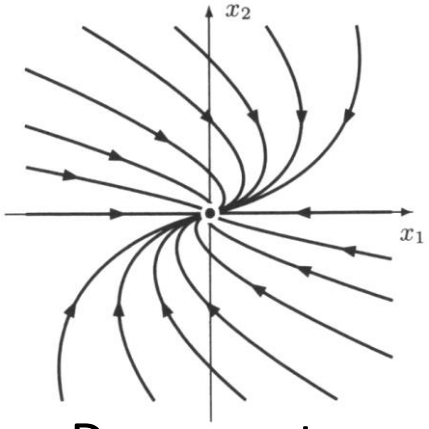
- 用拓扑分析向量场结构——理解不同流的行为
  - 找到驻点 critical points (fixed points)，环路 periodic orbits，分界线 separatices对向量场进行分割



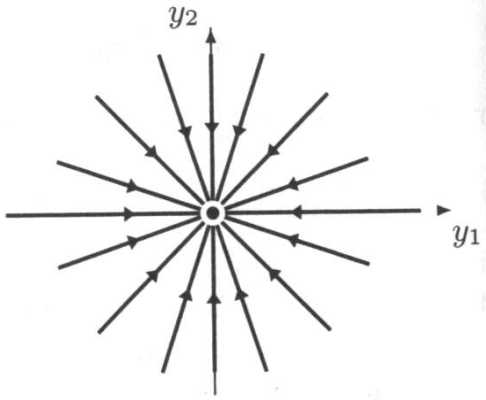
Proper node



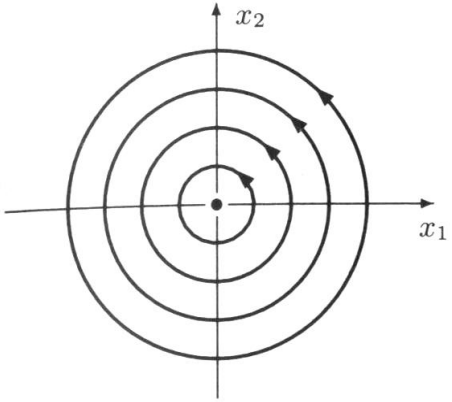
Saddle



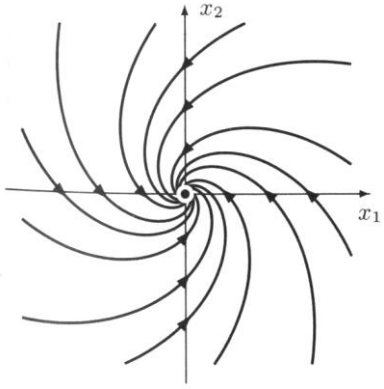
Degenerate node



Singular node



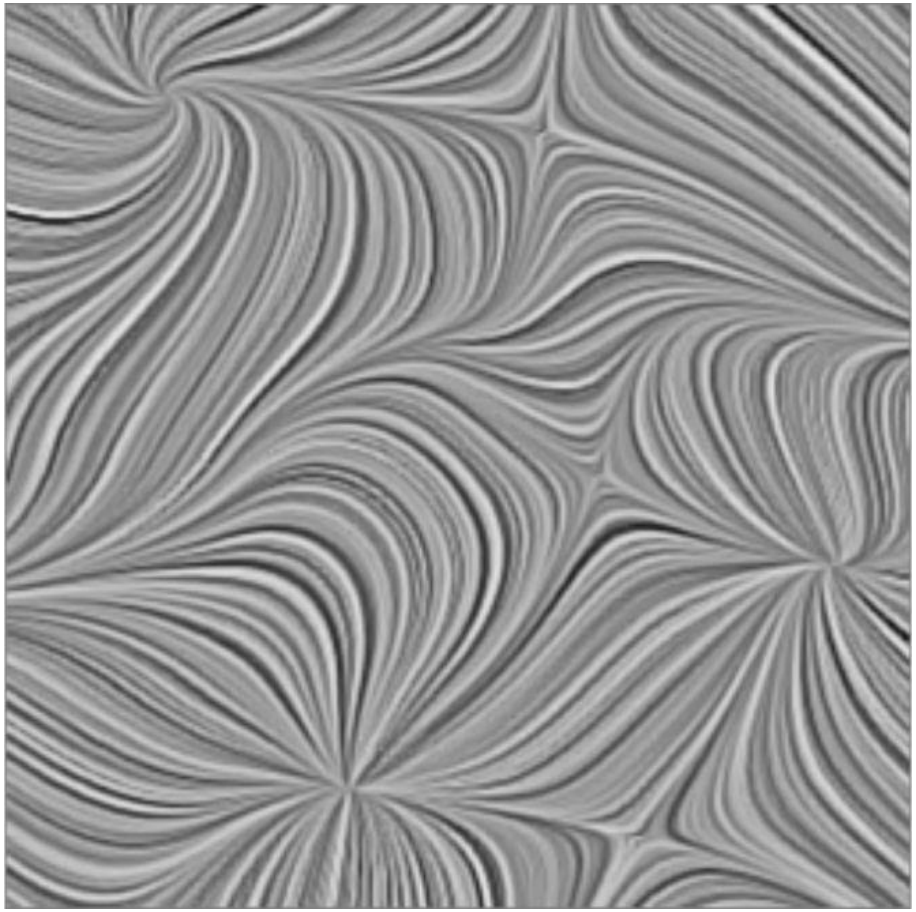
Center



Spiral or focus

[Source: D. Weiskopf]

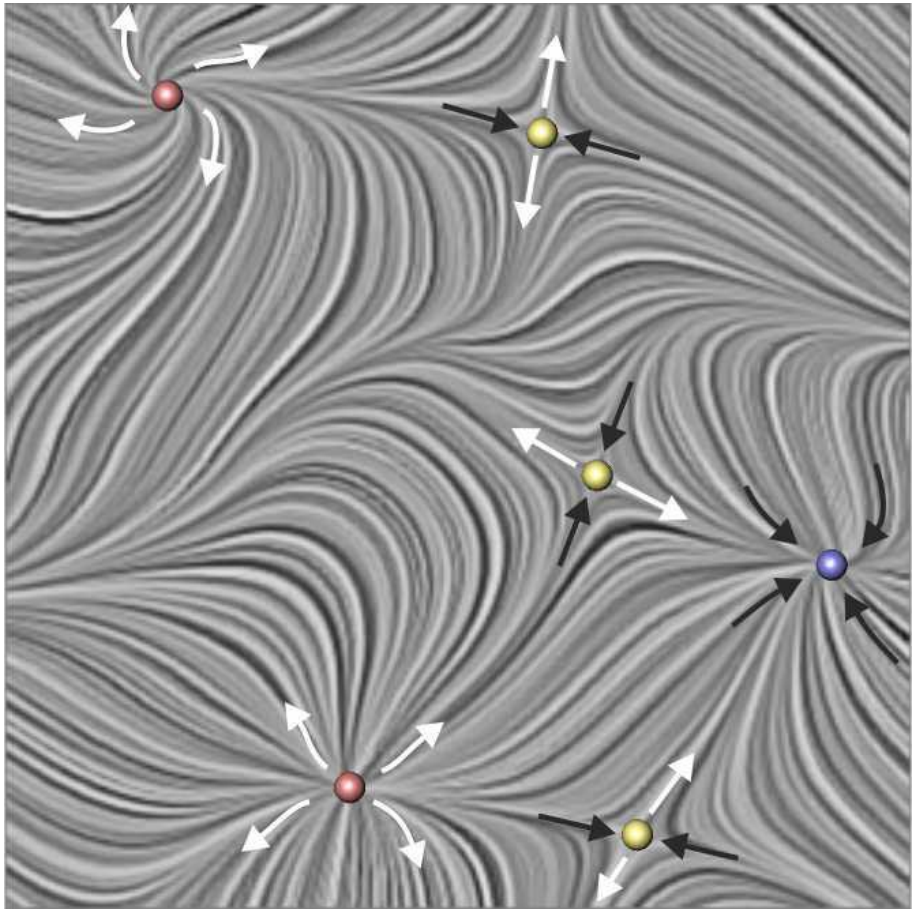
向量场拓扑分析步骤



[Weinkauf: Feature-Based Data Analysis, 2012, http://feature.mpi-inf.mpg.de/2012/feature-based-data-analysis]

Streamlines

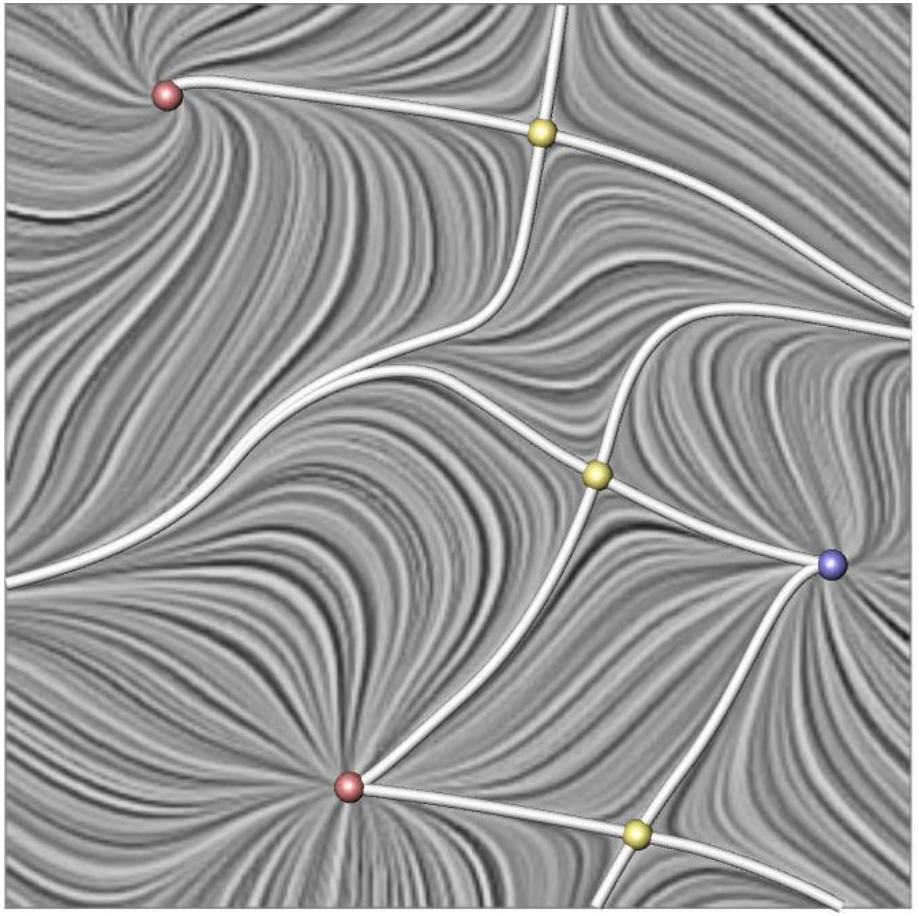
向量场拓扑分析步骤



[Weinkauf: Feature-Based Data Analysis, 2012, http://feature.mpi-inf.mpg.de/2012/feature-based-data-analysis]

Critical points

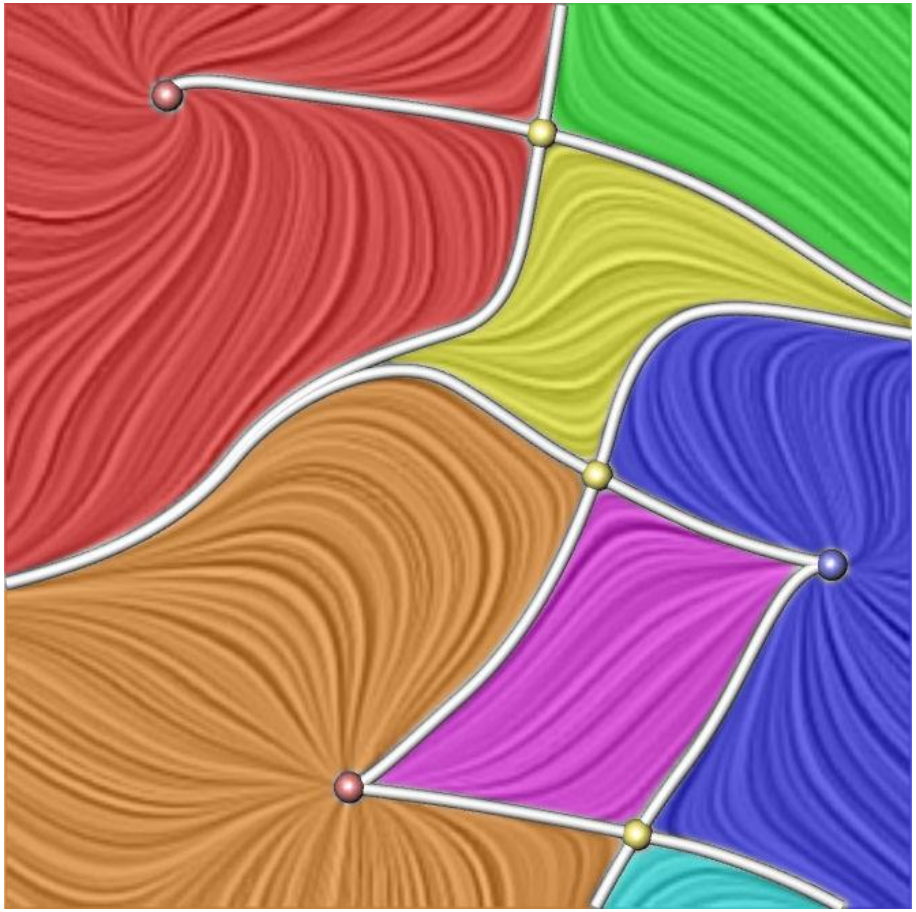
向量场拓扑分析步骤



[Weinkauf: Feature-Based Data Analysis, 2012, http://feature.mpi-inf.mpg.de/2012/feature-based-data-analysis]

Separation lines emanating from saddles

向量场拓扑分析步骤

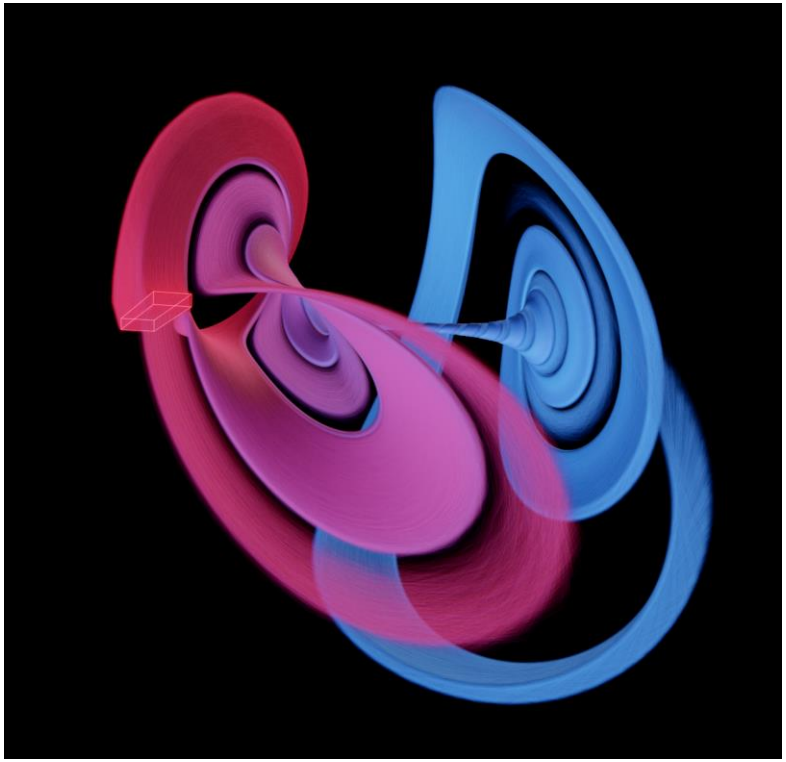


[Weinkauf: Feature-Based Data Analysis, 2012, http://feature.mpi-inf.mpg.de/2012/feature-based-data-analysis]

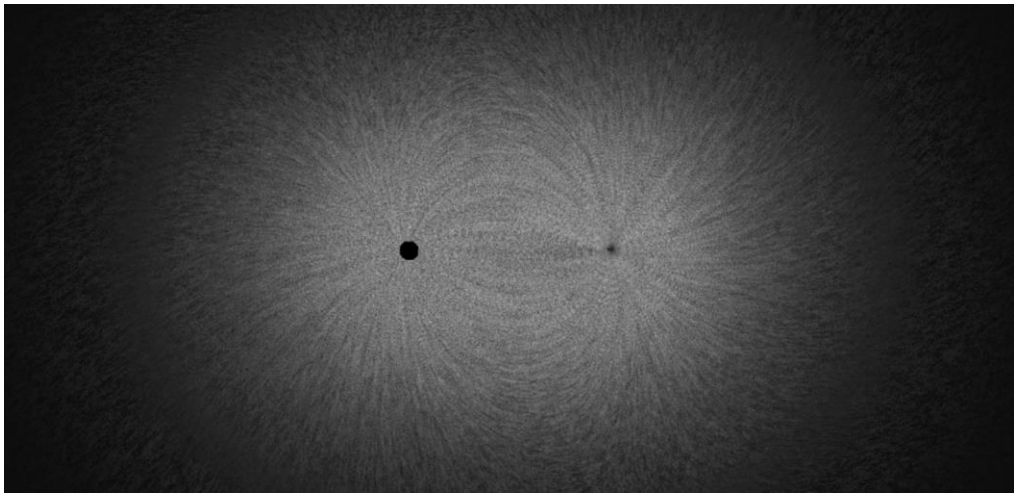
Sectors of different flow behavior

向量可视化演示

- 向量场直接可视化 https://portsmouth.github.io/fibre/
  https://philogb.github.io/page/wind/
- 线积分卷积LIC https://github.com/philogb/LIC/



https://portsmouth.github.io/fibre/



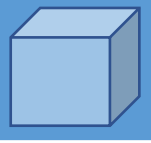
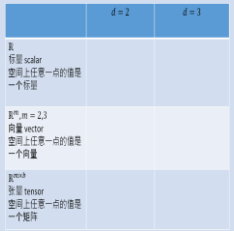
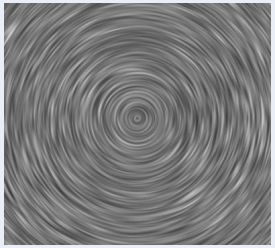
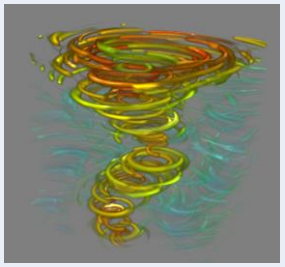
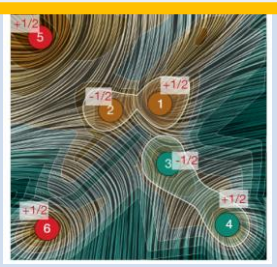
http://philogb.github.io/LIC/dipole.html

张量场可视化 Tensor visualization

- 空间上每个点的值是一个矩阵 $f: \mathbb{R}^d \rightarrow \mathbb{R}^{m \times b}$

定义域 domain

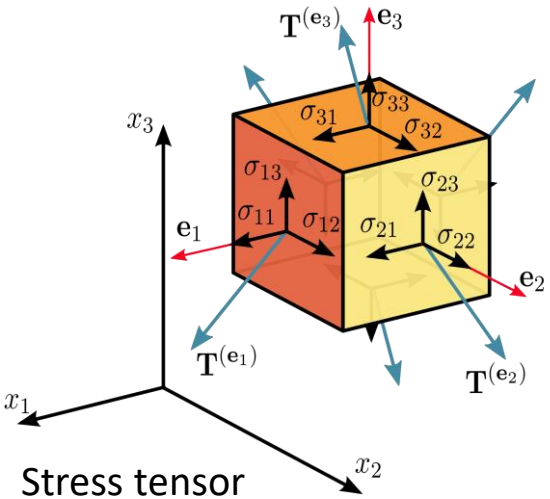
值域 range

$\mathbb{R}^d$	$d = 2$ 	$d = 3$ 
$\mathbb{R}$ 标量 scalar 空间上任意一点的值是一个标量 0.5		 [D. Jönsson and A. Ynnerman (2017). Correlated Photon Mapping for Interactive Global Illumination of Time-Varying Volumetric Data. doi:10.1109/TVCG.2016.2598430.]
$\mathbb{R}^m, m = 2,3$ 向量 vector 空间上任意一点的值是一个向量 $[0.5, 0.5]$	 [Source: D. Weiskopf]	 [M. Falk, D. Weiskopf (2008): Output-Sensitive 3D Line Integral Convolution, doi:10.1109/TVCG.2008.25]
$\mathbb{R}^{m \times b}$ 张量 tensor 空间上任意一点的值是一个矩阵 $\begin{bmatrix} 0.5 & 0.1 \\ 0.1 & 0.2 \end{bmatrix}$	 [J. Jankowai et al. (2019), Robust Extraction and Simplification of 2D Symmetric Tensor Field Topology. doi:10.1111/cgf.13693]	 [T. Schultz and G. L. Kindlmann (2010), "Superquadric Glyphs for Symmetric Second-Order Tensors," doi: 10.1109/TVCG.2010.199.]

张量场

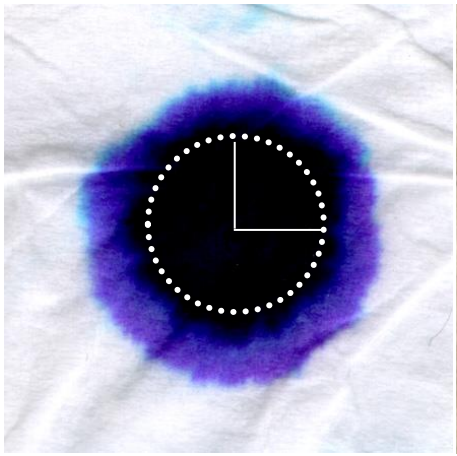
- 张量T是向量概念的推广，0阶张量即标量，1阶张量即向量，2阶张量为矩阵（可视化中所指的张量）
- 张量场 $f: \mathbb{R}^d \rightarrow \mathbb{R}^{m \times b}$
- 张量信息以矩阵描述，通常情况下
  - $m = b = d$，即在三维中是3×3矩阵
- 可视化中张量数据来源
  - 医学图像中：弥散张量 Diffusion tensor
  - 材料科学中：应力张量 Stress tensor,
    电导率张量 Conductivity tensor

$$T(x) = \begin{bmatrix} c_{11}(x) & c_{12}(x) & c_{13}(x) \\ c_{21}(x) & c_{22}(x) & c_{23}(x) \\ c_{31}(x) & c_{32}(x) & c_{33}(x) \end{bmatrix}, x \in \mathbb{R}^3$$

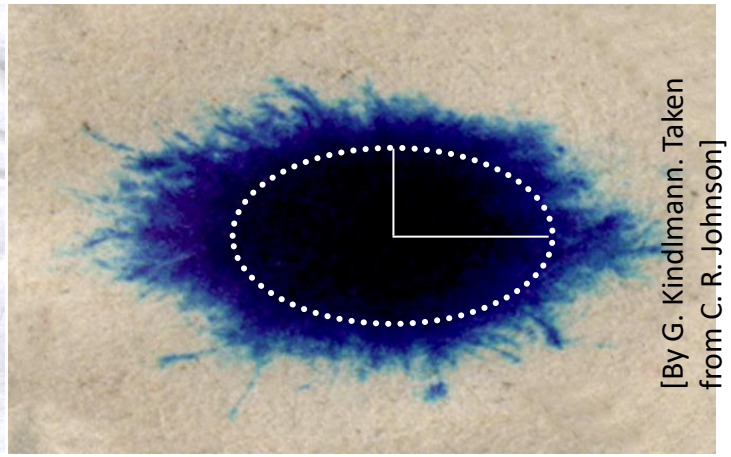


Stress tensor

[By Sanpaz - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=5668647]



面巾纸——各向同性isotropic



[By G. Kindlmann. Taken from C. R. Johnson]

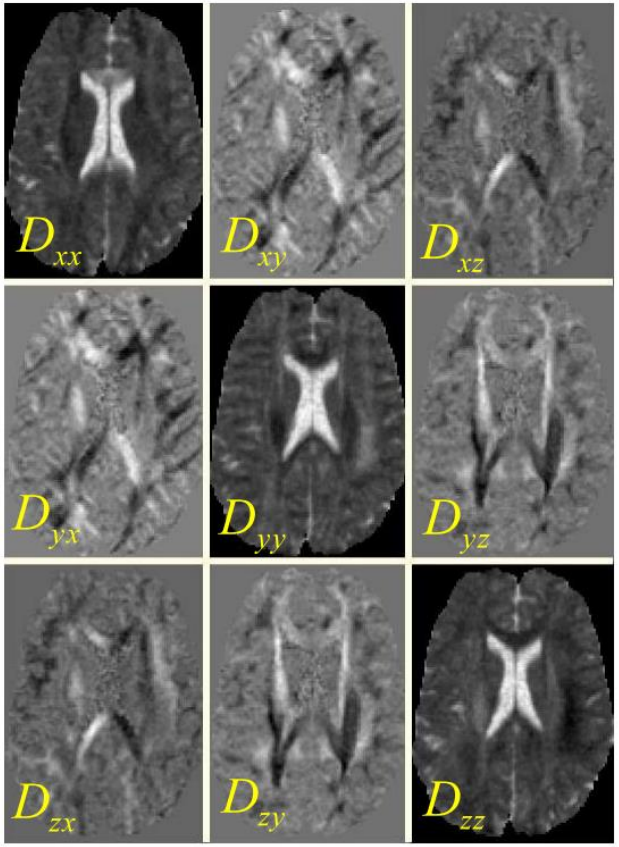
报纸——各向异性anisotropic

水在不同纸上的弥散

弥散张量和DTI

- 医学上，弥散张量描述水分子在组织中的各向异性扩散(anisotropic diffusion)
- 脑部含有方向性的纤维束(fiber tracks)
- 半正定，对称3 × 3方阵
- Diffusion tensor imaging (DTI)

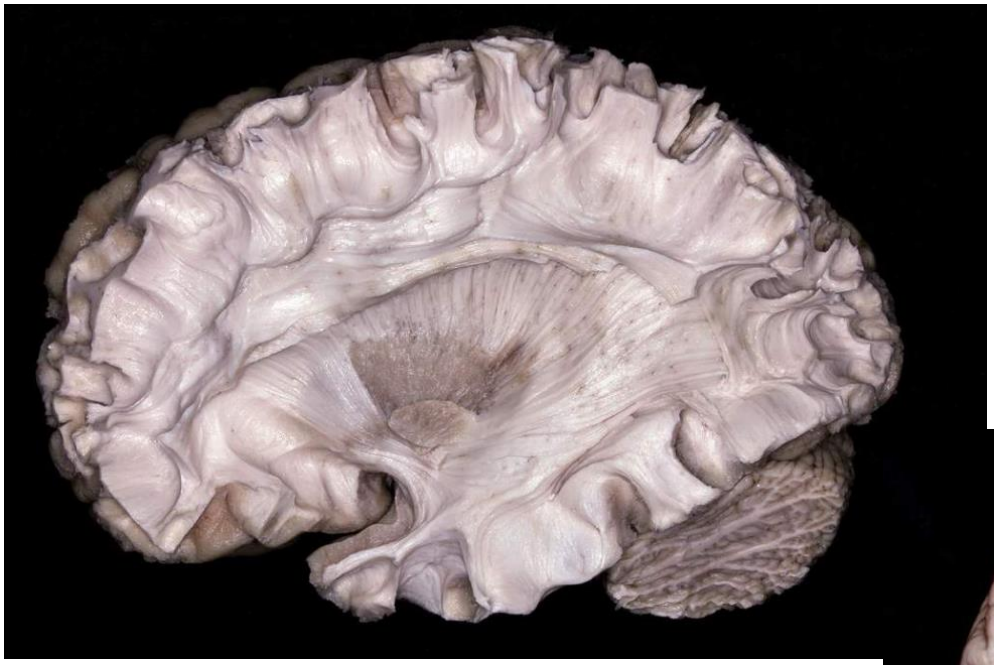
$$D = \begin{bmatrix} D_{xx} & D_{xy} & D_{xz} \\ D_{xy} & D_{yy} & D_{yz} \\ D_{xz} & D_{yz} & D_{zz} \end{bmatrix}$$



DTI
[http://tensorvis.org/uploads/Main/course_material_1b.pdf]

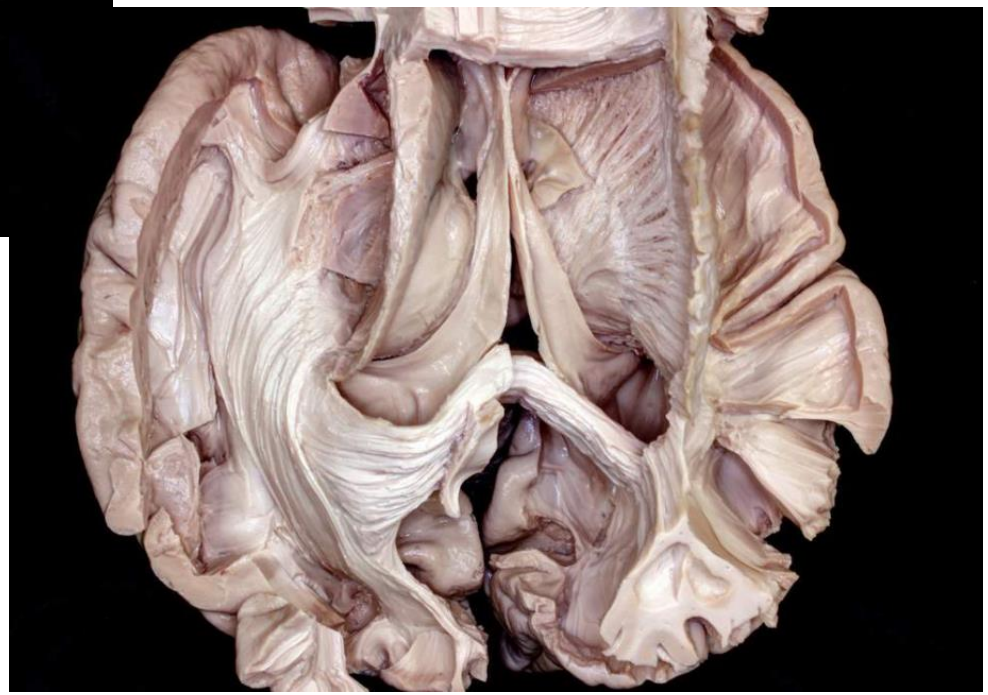
DTI的临床意义

- 脑白质中存在标量MR看不到的神经纤维束



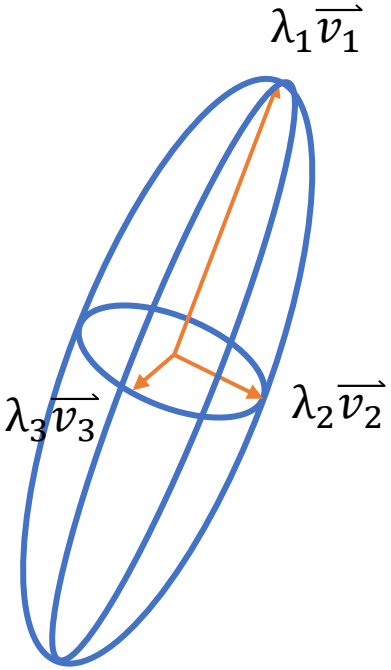
https://www.neurosurgicalatlas.com/neuroanatomy/major-white-matter-tracts-of-the-cerebral-hemisphere

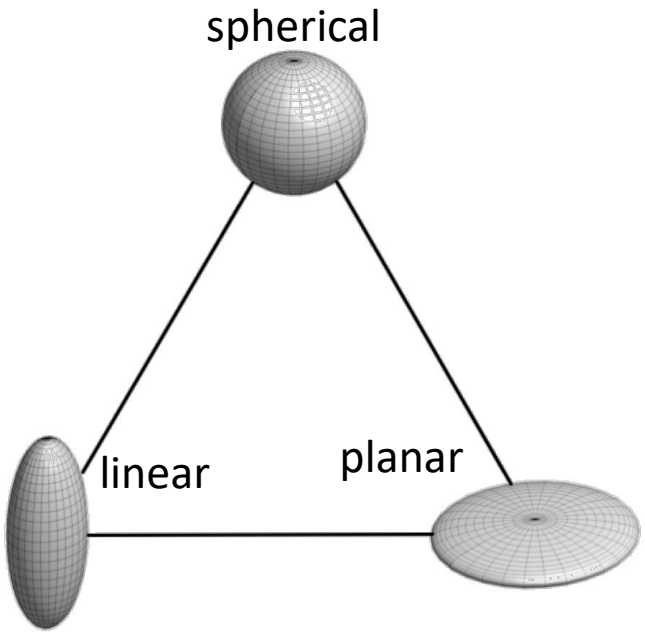
https://www.neurosurgicalatlas.com/neuroanatomy/white-matter-tracts-of-the-deep-cerebrum



特征分析

- 张量场分析工具：特征分析 Eigen analysis
  - Eigen是德语“自己的”
  - $\mathbf{D}\vec{v} = \lambda\vec{v} \rightarrow \det(\lambda\mathbf{I} - \mathbf{D}) = 0$, $\mathbf{I}$是单位矩阵
- 特征向量 Eigenvectors
  - $\overrightarrow{v_1}$, $\overrightarrow{v_2}$, $\overrightarrow{v_3}$
- 特征根 Eigenvalues:
  - $\lambda_1 \geq \lambda_2 \geq \lambda_3 \geq 0$

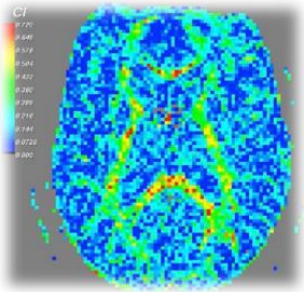




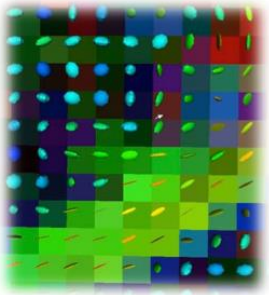
椭球表示不同的扩散样式
[http://tensorvis.org/uploads/Main/course_material_1a1.pdf]

张量场可视化方法

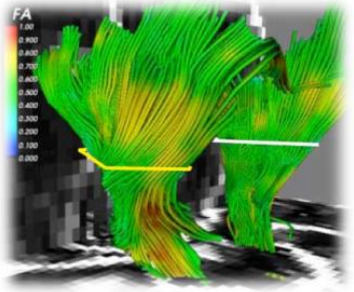
- Direct
  - Color-coding and Glyphs
  - Hue-Balls and Lit-Tensors
- Geometry-Based
  - Hyperstreamlines, and tensorlines
- Texture-Based
  - HyperLIC
- Feature-Based
  - Segmentation, Topological Features



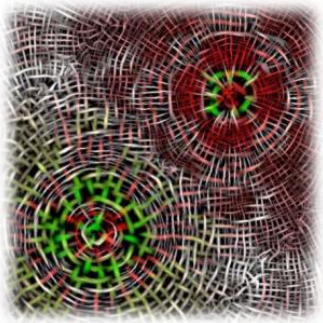
Scalar Fields



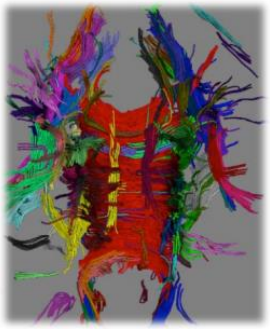
Glyphs



Tensor field lines

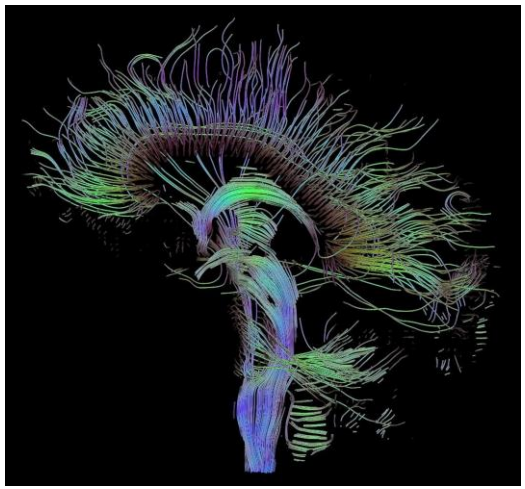


Texture



Segmentation

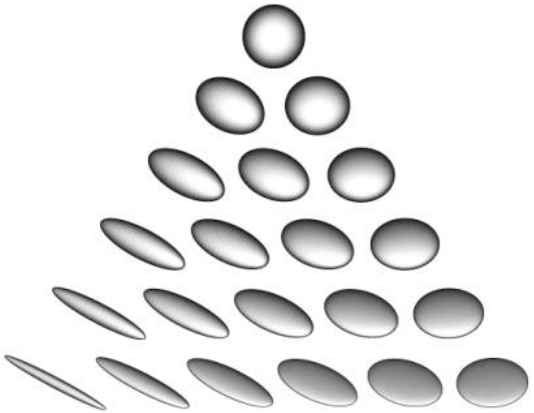
[http://tensorvis.org/uploads/Main/course_material_1b.pdf]



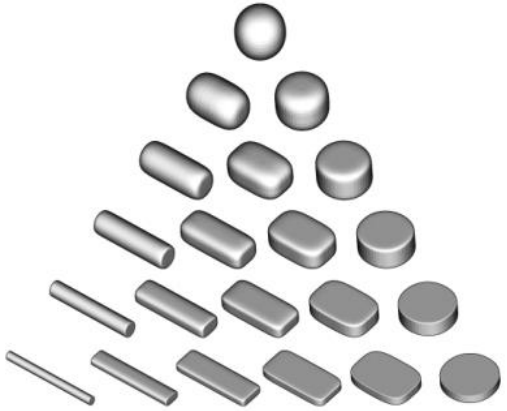
Tensor lines visualization of DT-MRI [From Thomas Schultz – Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=1201188]

张量场可视化绘制技术

- 同向量场一样，如何让人正确感知是张量场可视化的主要难题
- 图标(glyphs)在三维中感知有歧义——Superquadric glyphs
- 绘制张量线有遮挡——与向量场绘制技术通用
  - 阴影
  - 非真实感绘制

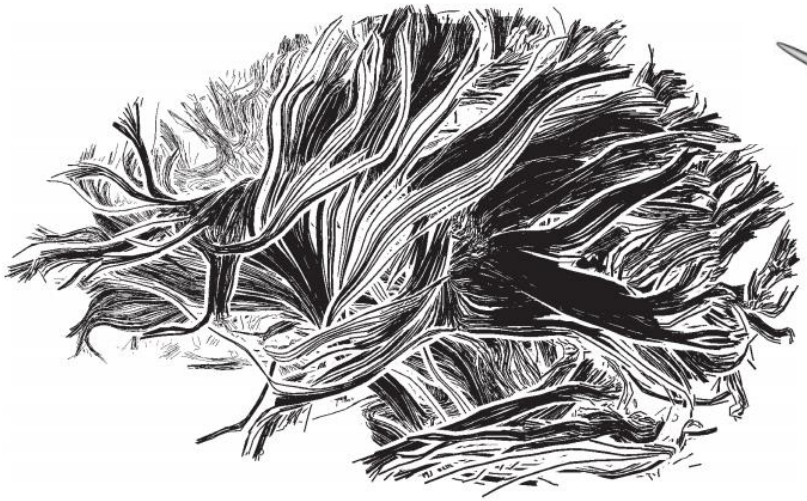


椭圆——有歧义



Superquadric——无歧义

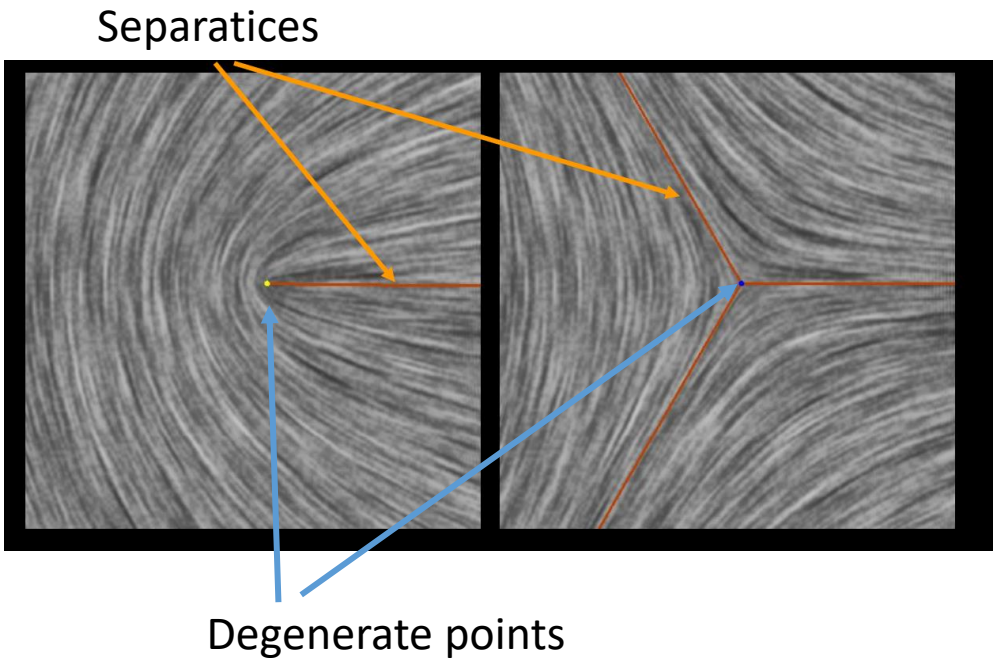
[G. Kindlmann. (2004), “Superquadric tensor glyphs," doi: 10.2312/VisSym/VisSym04/147-154.]

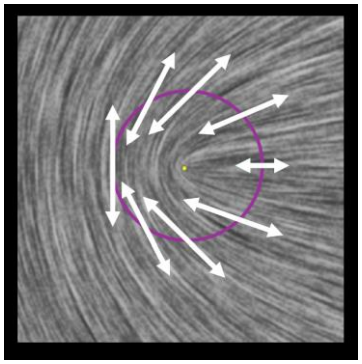


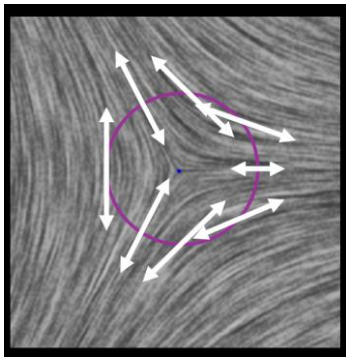
[M. H. Everts et al. (2009), "Depth-Dependent Halos: Illustrative Rendering of Dense Line Data," doi: 10.1109/TVCG.2009.138.]

张量场拓扑分析

- 描述张量场特性——理解不同区域张量的行为
- 方法与向量场拓扑分析类似
- 但，张量场线tensor field lines不是streamlines!
  - 向量场critical points→张量场degenerate points（各向同性的点）




Wedge


Trisector

[http://tensorvis.org/uploads/Main/course_material_2a.pdf]

健康医疗应用

- 标量场

Liang Zhou, Mengjie Fan, Charles Hansen, Chris R. Johnson, Daniel Weiskopf, "A Review of Three-Dimensional Medical Image Visualization", *Health Data Science*, vol. 2022, Article ID 9840519, 19 pages, 2022. https://doi.org/10.34133/2022/9840519

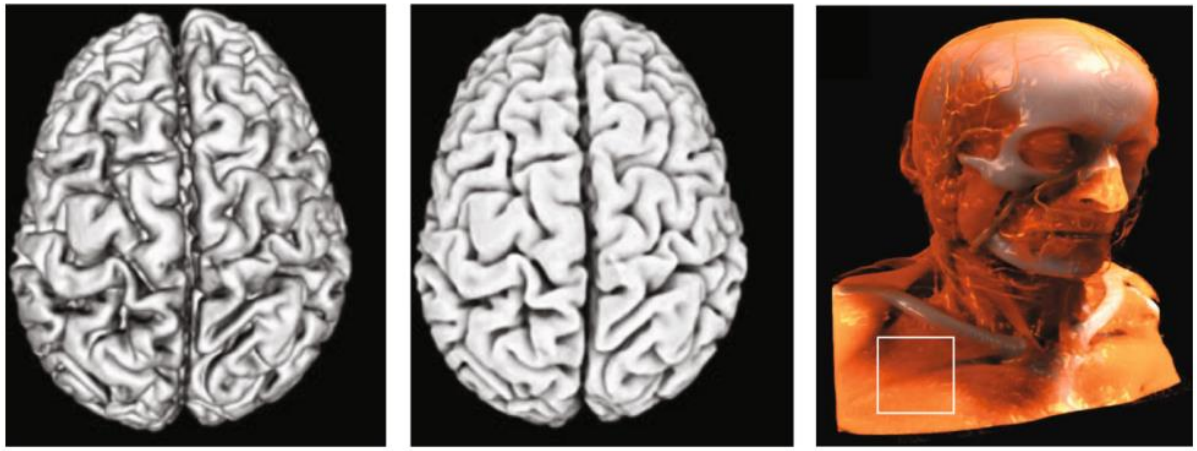
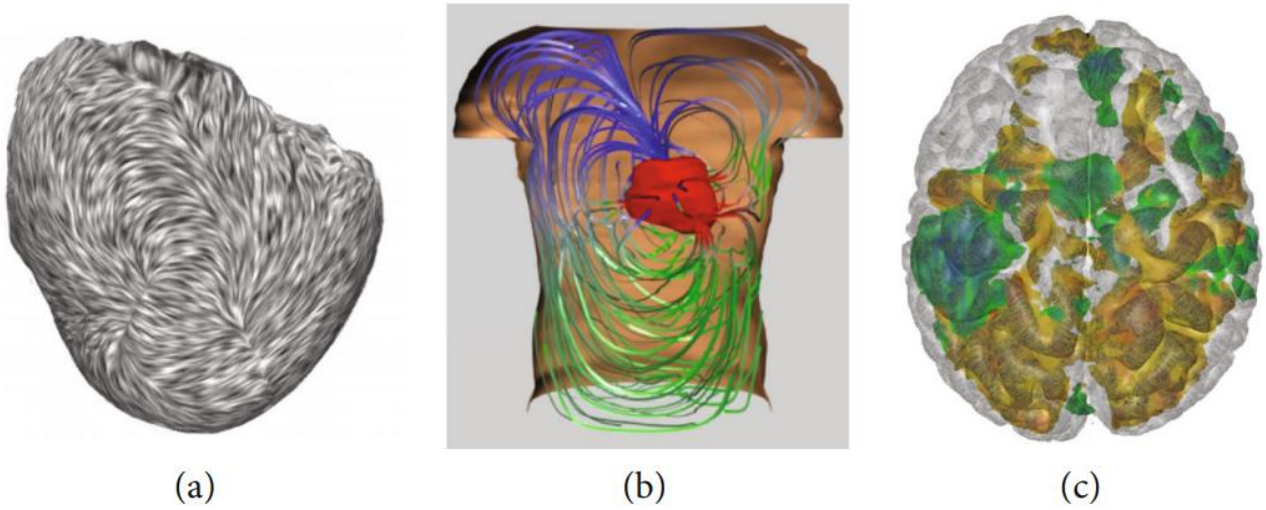


FIGURE 3: Direct volume rendering of a brain scan using (a) the traditional local illumination model and with (b) the directional occlusion shading [35] that approximates global illumination to enhance depth perception. ©2009 John Wiley & Sons, Inc. Reprinted, with permission, from Schott et al. [35]. A more advanced global illumination technique [36] generates the photorealistic rendering of a CT scan in (c). ©2014 IEEE. Reprinted, with permission, from Ament et al. [36].

健康医疗应用

- 向量场

Liang Zhou, Mengjie Fan, Charles Hansen, Chris R. Johnson, Daniel Weiskopf, "A Review of Three-Dimensional Medical Image Visualization", *Health Data Science*, vol. 2022, Article ID 9840519, 19 pages, 2022. https://doi.org/10.34133/2022/9840519



(a) (b) (c)

FIGURE 4: Vector field visualization of medical images. The LIC method is used to visualize (a) a simulation of the bioelectric field of the heart [41]. ©2008 IEEE. Reprinted, with permission, from Li et al. [41]. Streamlines are visualized as colored lines in bioelectric field simulations in (b) a torso (reprinted, with permission, from the SCI Institute). The visualization of a brain in (c) applies LIC with isosurfacing for an MRI scan along with volume rendering of a functional MRI (fMRI) [42]. ©2007 SPIE. Reprinted, with permission, from Schafhitzel et al. [42].

健康医疗应用

- 张量场

Liang Zhou, Mengjie Fan, Charles Hansen, Chris R. Johnson, Daniel Weiskopf, "A Review of Three-Dimensional Medical Image Visualization", *Health Data Science*, vol. 2022, Article ID 9840519, 19 pages, 2022. https://doi.org/10.34133/2022/9840519

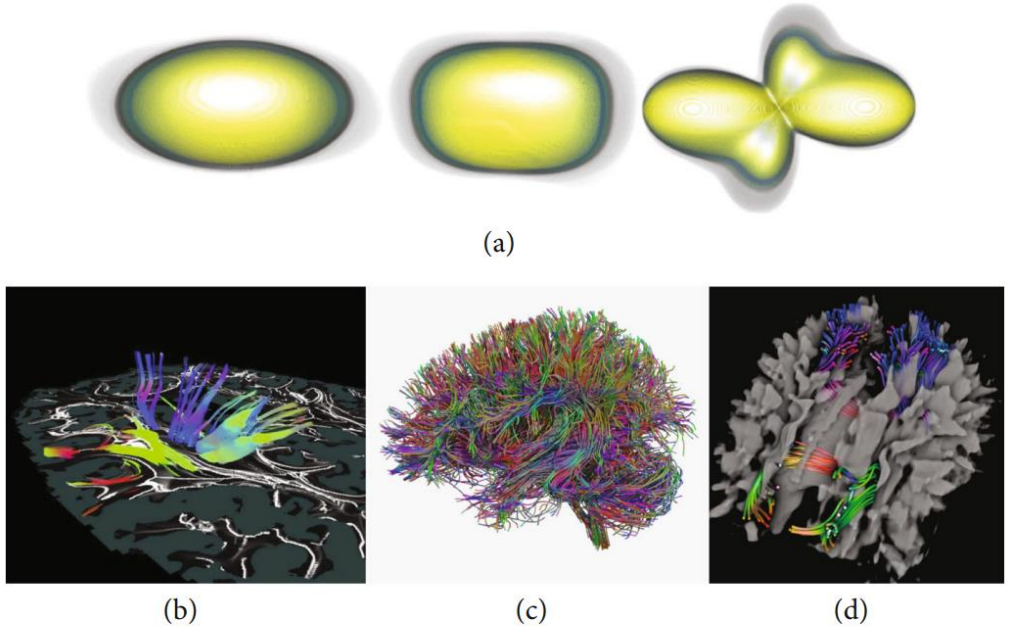


FIGURE 5: Visualizations of diffusion tensor medical images with (a) glyphs [63], (b) hybrid voxel-based and tractography method [64], and (c, d) tractography methods [61, 62]. Different uncertainty-aware glyph encodings are shown in (a), from left to right: ellipsoids, superquadrics, and fourth-order homogeneous polynomial [63]. A combined rendering of voxel-based visualization of characteristic curves along with extracted tractography is shown in (b) [64]. For tractography visualizations, extracted fiber tracts of the brain are visualized as tubes with shadows with (c) ray tracing [62] and are combined into the context of volume rendering of scalar MRI with unified volume and surface occlusion shading [61] (d). ©2012 IEEE. Reprinted, with permission, from Jiao et al. [63] (a). ©2011 IEEE. Reprinted, with permission from, Hlawatsch et al. [64] (b). ©2019 John Wiley & Son, Inc. Reprinted, with permission, from Han et al. [62] (c). ©2013 IEEE. Reprinted, with permission, from Schott et al. [61] (d).

健康医疗应用

- 诊断

Table 1: Summary of specialized medical image visualization techniques for diagnosis.

Reference	Data type	Scale	Location	Modalities
Lawonn et al. 2016 [87]	Scalar	Individual	Whole body	PET+CT
Jung et al. 2013 [88]	Scalar	Individual	Whole body	PET+CT
Wiemker et al. 2013 [89]	Scalar	Individual	Lymph nodes, lungs, breast, whole body	PET+CT+MR
Termeer et al. 2007 [90]	Scalar	Individual	Heart	Perfusion-MR+MR
Oeltze et al. 2006 [91]	Scalar	Individual	Heart	Perfusion-MR+CTA
Hennemuth et al. 2008 [92]	Scalar	Individual	Heart	MR
Kirisli et al. 2014 [93]	Scalar	Individual	Heart	CTA+SPECT
Meyer-Spradow et al. 2008 [94]	Scalar	Individual	Heart	SPECT
Williams et al. 2008 [95]	Scalar	Individual	Colon	CT
Mirhosseini et al. 2019 [96]	Scalar	Individual	Colon	CT
Song et al. 2017 [97]	Scalar	Individual	Chest, abdomen	CT
Viola et al. 2008 [98]	Scalar	Individual	Liver	US+CT
Zhou and Hansen 2014 [34]	Scalar	Individual	Brain	MR
Jösson et al. 2020 [99]	Scalar	Population	Brain	fMR+MR
Elbaz et al. 2014 [53]	Vector	Individual	Heart	PC-MR
Meuschke et al. 2016 [100]	Vector	Individual	Heart	PC-MR
Köhler et al. 2013 [52]	Vector	Individual	Heart	PC-MR
Born et al. 2013 [55]	Vector	Individual	Heart	PC-MR
van Pelt et al. 2010 [101]	Vector	Individual	Heart	PC-MR
van Pelt et al. 2011 [49]	Vector	Individual	Heart	PC-MR
Zhang et al. 2016 [102]	Tensor	Population	Brain	DT
Zhang et al. 2017 [103]	Tensor	Population	Brain	DT

Liang Zhou, Mengjie Fan, Charles Hansen, Chris R. Johnson, Daniel Weiskopf, "A Review of Three-Dimensional Medical Image Visualization", *Health Data Science*, vol. 2022, Article ID 9840519, 19 pages, 2022. https://doi.org/10.34133/2022/9840519

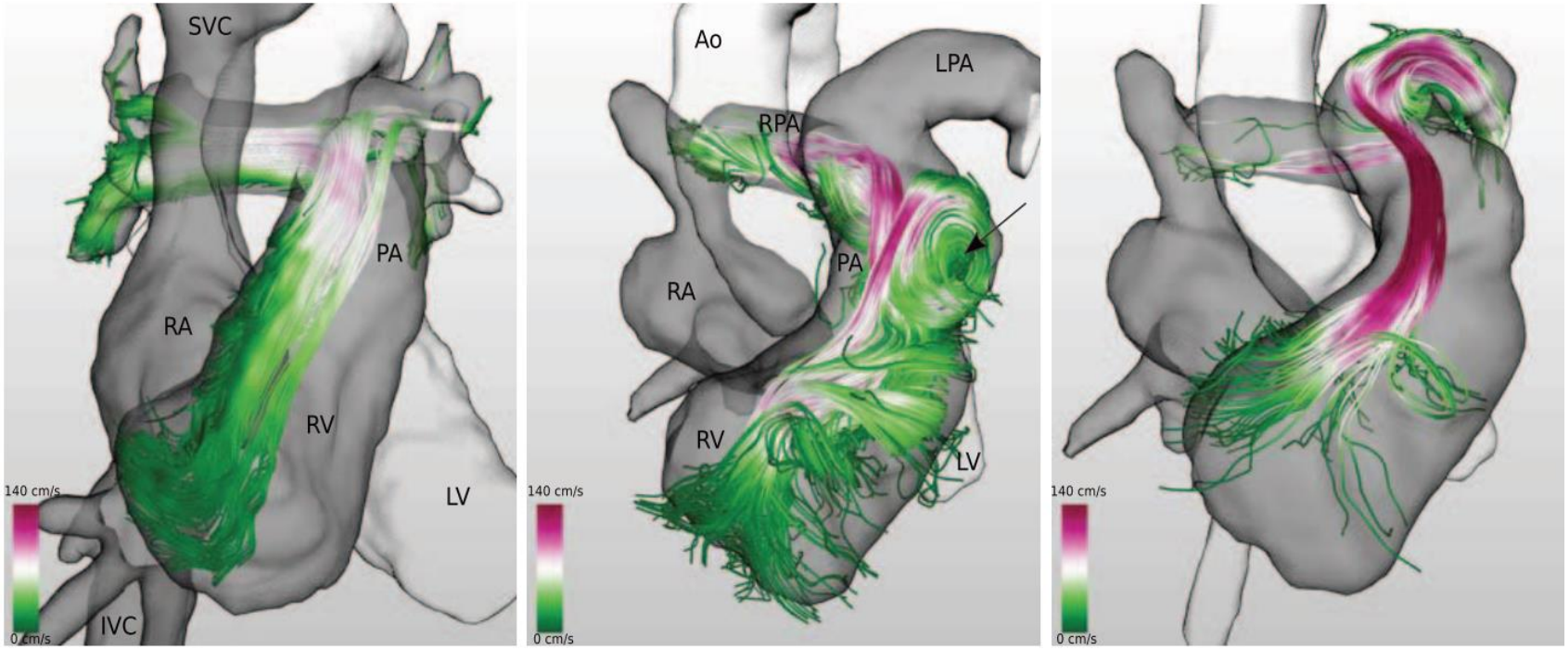


Fig. 4. Flow ratio into left and right lung during systole. Color-coding represents velocity. (a) Fastest streamlines in the pulmonary outflow tract of a healthy heart ($v_{max} > 90\ \frac{\text{cm}}{\text{s}}$). (b) Flow through upper detected vortex (arrow) directed at the RPA. (c) High-velocity jet ($v_{max} > 165\ \frac{\text{cm}}{\text{s}}$) directed at the LPA. Abbreviations: RA, right atrium; RV, right ventricle; LPA, left pulmonary artery; RPA, right pulmonary artery.

S. Born, M. Pfeie, M. Markl, M. Gutberlet, and G. Scheuermann, "Visual analysis of cardiac 4D MRI blood flow using line predicates," *IEEE Transactions on Visualization and Computer Graphics*

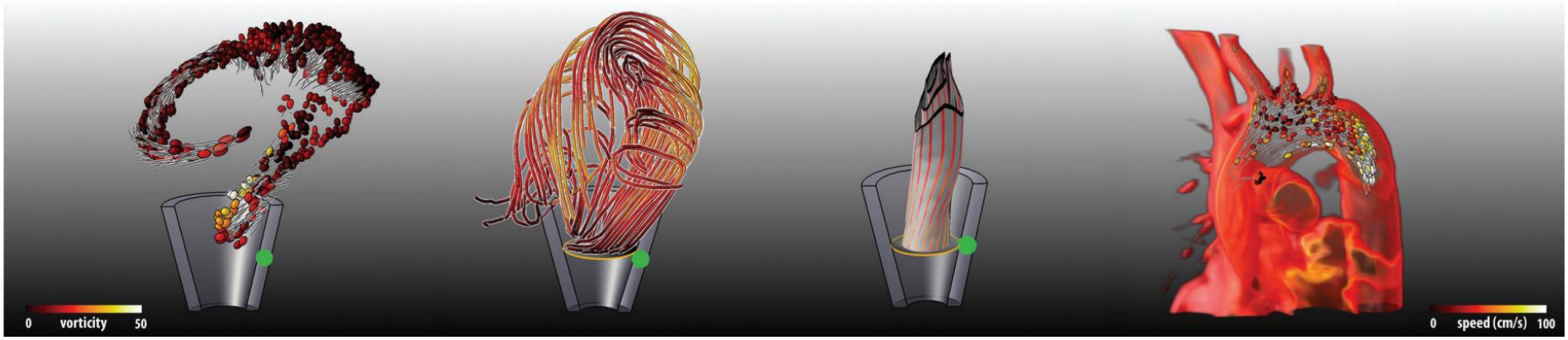
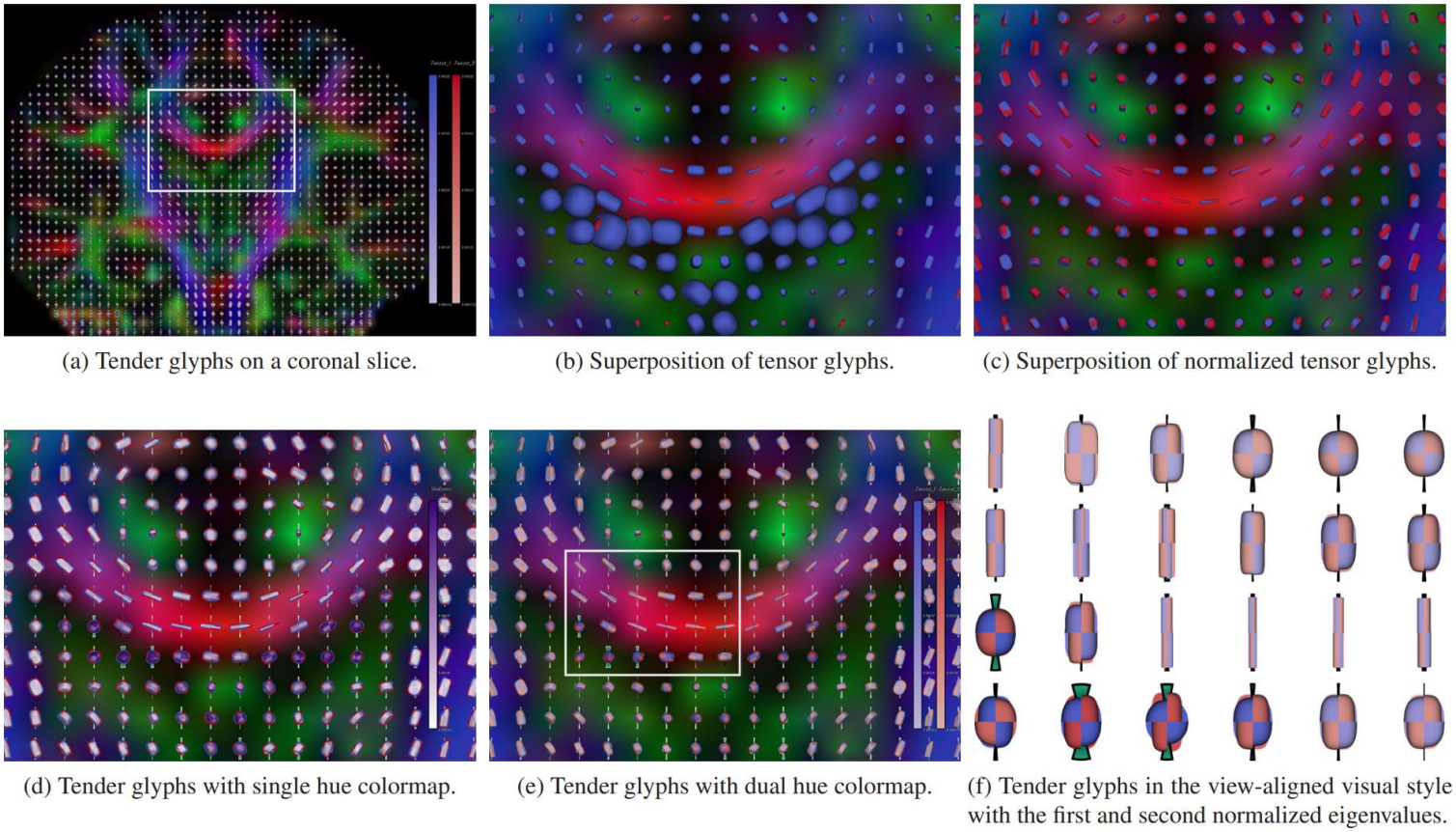


Fig. 1. Interactive virtual probe with flow visualization approaches, enabling exploration of cardiovascular 4D MRI blood-flow data. Color in the leftmost rendition encodes the blood-flow vorticity, while color in other renditions conveys the local blood-flow speed.

R. van Pelt, J. Olivan Bescos, M. Breeuwer et al., "Interactive virtual probing of 4D MRI blood-flow," *IEEE Transactions on Visualization and Computer Graphics*



(a) Tender glyphs on a coronal slice.

(b) Superposition of tensor glyphs.

(c) Superposition of normalized tensor glyphs.

(d) Tender glyphs with single hue colormap.

(e) Tender glyphs with dual hue colormap.

(f) Tender glyphs in the view-aligned visual style with the first and second normalized eigenvalues.

Fig. 11.The application of the Tender glyphs to compare two DTI datasets acquired with different b-values.

C. Zhang, T. Schultz, K. Lawonn, E. Eisemann, and A. Vilanova, "Glyph-based comparative visualization for diffusion tensor fields," *IEEE Transactions on Visualization and Computer Graphics*

健康医疗应用

- 治疗

Table 2: Summary of specialized medical image visualization techniques for treatment.

Reference	Data type	Scale	Location	Modalities
Rieder et al. 2008 [104]	Scalar	Individual	Brain	MR
Weiler et al. 2011 [105]	Scalar	Individual	Brain	MR
Khlebnikov et al. 2011 [106]	Scalar	Individual	Abdomen	CT
Beyer et al. 2007 [107]	Scalar	Individual	Brain	MR
Dick et al. 2011 [108]	Scalar	Individual	Bone	CT
Lundstrom et al. 2011 [109]	Scalar	Individual	Bone	CT
Smit et al. 2007 [110]	Scalar	Individual	Pelvic	MR
Butson et al. 2013 [111]	Scalar	Individual	Brain	MR
Vorwerk et al. 2020 [112]	Scalar	Individual	Brain	MR
Bock et al. 2013 [113]	Scalar	Individual	Brain	MR
Athwale et al. 2019 [114]	Scalar	Individual	Brain	MR
Blaas et al. 2007 [115]	Tensor	Individual	Brain	fMR+MR+DT
Born et al. 2009 [116]	Tensor	Individual	Brain	fMR+MR+DT
Diepenbrock et al. 2011 [117]	Tensor	Individual	Brain	fMR+MR+DT
Joshi et al. 2008 [118]	Tensor	Individual	Brain	fMR+MR+DT
Rieder et al. 2008 [119]	Tensor	Individual	Brain	fMR+MR+DT
Dick et al. 2009 [120]	Tensor	Individual	Bone	CT+sim

Note: sim: simulation.

Liang Zhou, Mengjie Fan, Charles Hansen, Chris R. Johnson, Daniel Weiskopf, "A Review of Three-Dimensional Medical Image Visualization", *Health Data Science*, vol. 2022, Article ID 9840519, 19 pages, 2022. https://doi.org/10.34133/2022/9840519

Teaser Figure: *Left: Brain, visualized using silhouettes, the lesion's spatial depth is displayed using a ring. Center: Combined rendering of brain tissue, skull and fiber tracts using a cutting plane. Right: The virtual path (cyan) from the entry point to the region of interest. The two crossed lines represent the diameter of the virtual cylinder.*

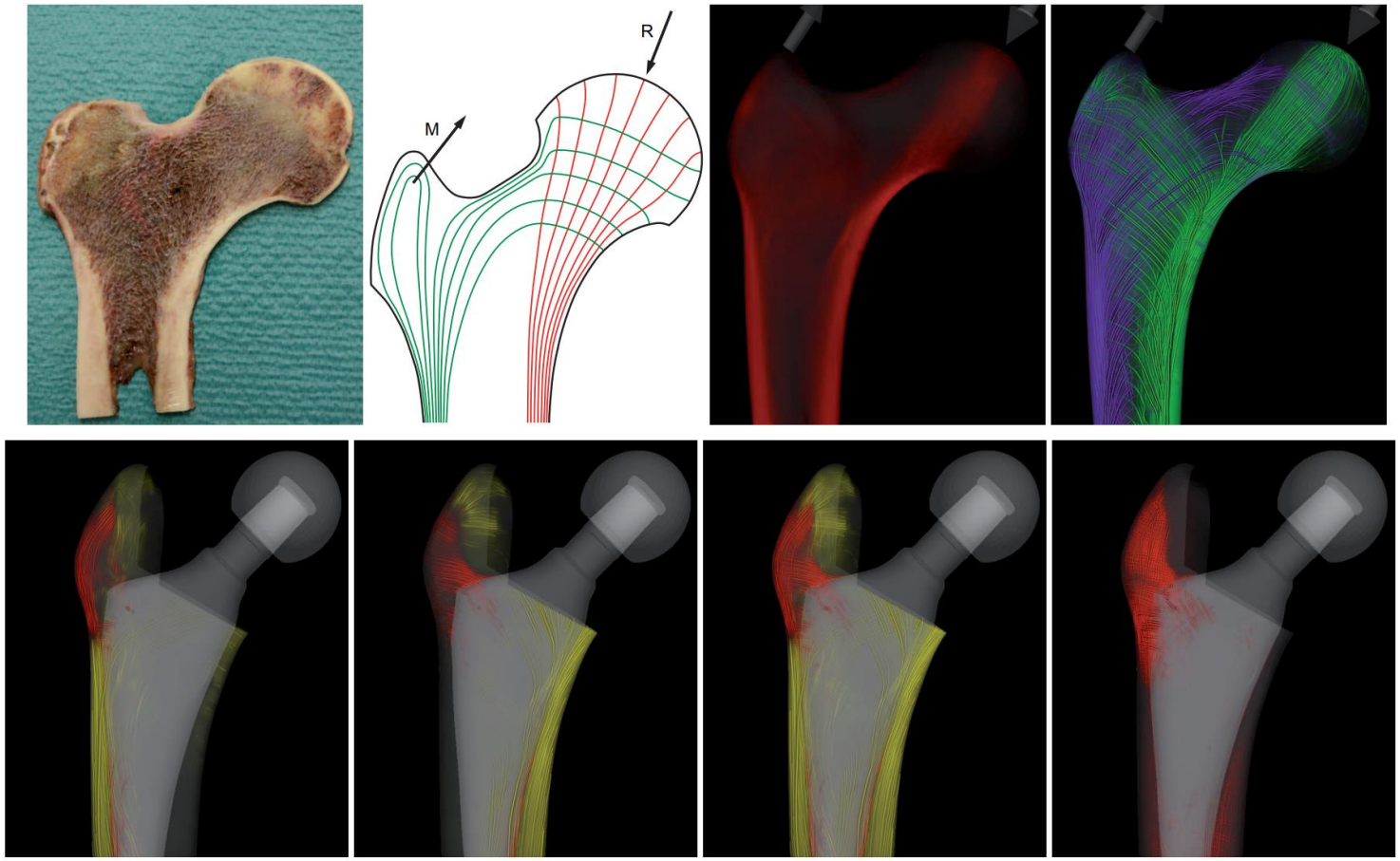


Fig. 3. Different options for the comparative visualization of the stress distribution after a simulated implant surgery and the physiological stress distribution (red = increase, yellow = decrease). Left: Change of normal stresses, tension only. Middle left: Change of normal stresses, compression only. Middle right: Change of normal stresses, both tension and compression. Right: Change of shear stresses.

C. Dick, J. Georgii, R. Burgkart, and R. Westermann, "Stress tensor field visualization for implant planning in orthopedics," *IEEE Transactions on Visualization and Computer Graphics*

健康医疗应用

- 预后

Table 3: Summary of specialized medical image visualization techniques for prognosis.

Reference	Data type	Scale	Location	Modalities
Raidou et al. 2016 [127]	Scalar	Population	Prostate	MR
Karall et al. 2018 [128]	Scalar	Population	Breast	MR
Raidou et al. 2018 [129]	Scalar	Population	Bladder	CT
Yamamoto et al. 2021 [130]	Scalar	Population	Prostate, bladder, rectum	CT

- 潜在应用

Table 4: Techniques with potential health science applications.

Reference	Scale	Location	Modalities	Features
Zachow et al. 2009 [131]	Individual	Nose	CT+sim	Fluid dynamics: speed, pressure, humidity, temperature
Gasteiger et al. 2012 [56]	Individual	Brain	CTA+sim	Fluid dynamics: inflow jet and impingement zone
Meuschke et al. 2019 [132]	Individual	Brain	CTA+sim	Fluid dynamics: vortex, blood flows
Rosen et al. 2016 [133]	Individual	Heart	MR+DT+sim	Bioelectric fields
Meuschke et al. 2017 [134]	Individual	Brain	Sim	Rupture risk of aneurysms, stress tensor
Zhou et al. 2021 [135]	Population	Brain, heart	MR+sim	Quantitative comparison of scalar medical images

Note: sim: simulation.

Liang Zhou, Mengjie Fan, Charles Hansen, Chris R. Johnson, Daniel Weiskopf, "A Review of Three-Dimensional Medical Image Visualization", *Health Data Science*, vol. 2022, Article ID 9840519, 19 pages, 2022. https://doi.org/10.34133/2022/9840519

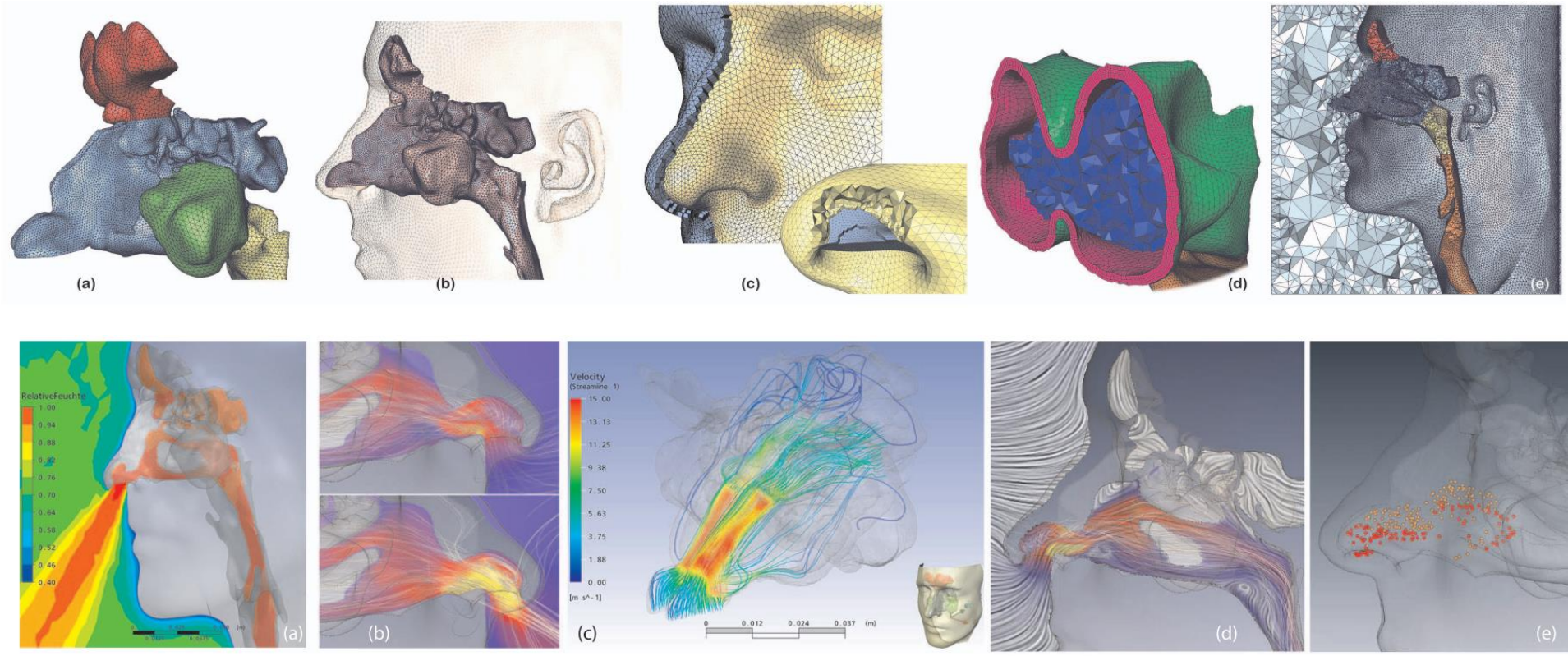


Fig. 5. Visualization of flow quantities: Relative humidity for an exhalation state (a), flow velocity within the nasal cavity (b) during inhalation (top) and exhalation (bottom), inspiratory flow velocity of up to 15 m/s with color coded stream lines (c), illuminated streamlines with color coded planar LIC visualization (d), and particle visualization along field lines with discrimination of left and right side (e).

S. Zachow, P. Muigg, T. Hildebrandt, H. Doleisch, and H.-C. Hege, "Visual exploration of nasal airflow," *IEEE Transactions on Visualization and Computer Graphics*

健康医疗应用

- 可视化软件

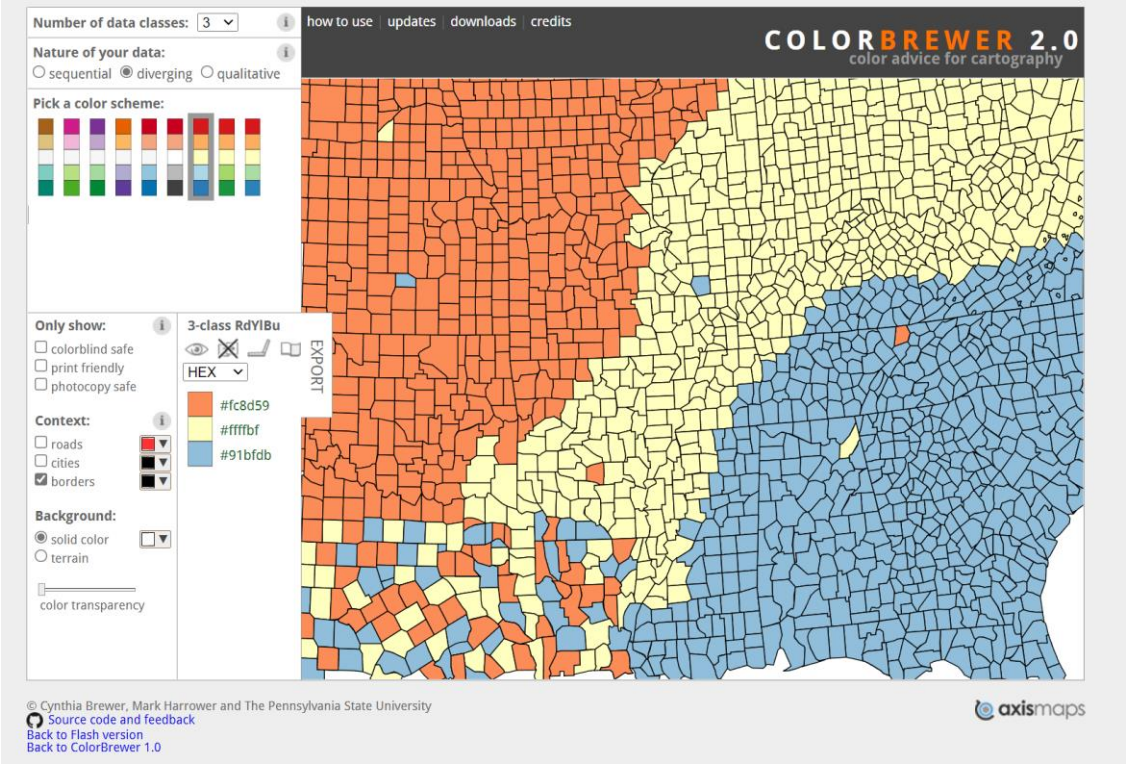
Table 5: Medical image visualization tools.

Name	Data types	Features
ParaView	Scalar, vector, tensor	Analysis, large datasets, parallel/super computing
Voreen	Scalar, vector	Rapid prototype
Inviwo	Scalar, vector	Rapid prototype
MegaMol	Scalar, vector	Particles, rapid prototype
SCIRun	Scalar, vector, tensor	Modeling, simulation, analysis
3D Slicer	Scalar	AI, segmentation
Seg3D	Scalar	Segmentation
ImageVis3D	Scalar	Large datasets
FluoRenderer	Scalar	Confocal microscopy data

Liang Zhou, Mengjie Fan, Charles Hansen, Chris R. Johnson, Daniel Weiskopf, "A Review of Three-Dimensional Medical Image Visualization", *Health Data Science*, vol. 2022, Article ID 9840519, 19 pages, 2022. https://doi.org/10.34133/2022/9840519

可视化各领域的通用问题：如何选择颜色？

- 简单答案：使用预定义的，广泛认可的色标（color maps）
- 当前使用最广泛的，不会出错的选择——Colorbrewer



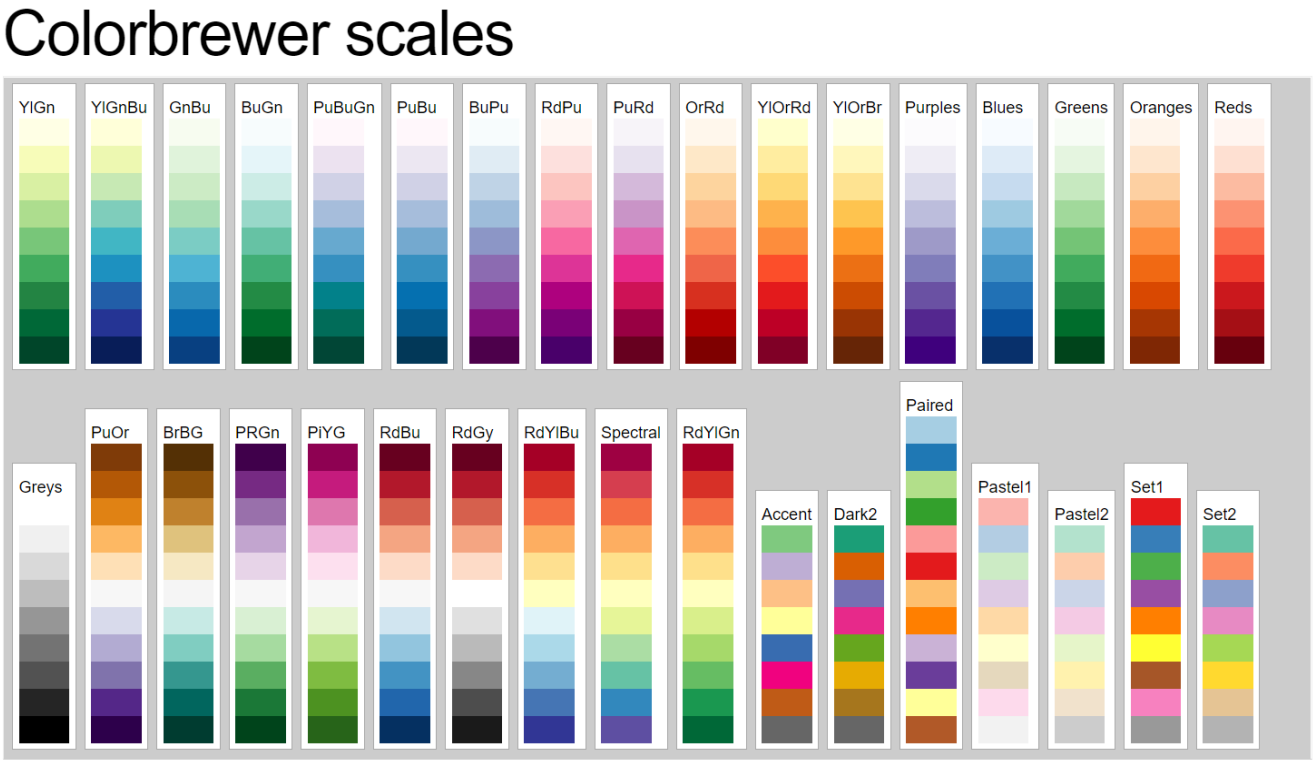
https://colorbrewer2.org/

Colorbrewer色标

- 当前最流行，公认符合可视化领域要求的色标
- 三大类
  - Sequential
  - Diverging
  - Qualitative
- 在符合视觉感知的颜色空间中进行颜色计算和选取
- 在流行的语言中都有做好的库：JavaScript，R，Python，Matlab……
- 通过网站方便选取：colorbrewer2.org

Colorbrewer色标

- 下列色标如何分类成Sequential，diverging，qualitative?
- 它们分别适合哪些数据?



http://bl.ocks.org/mhkeller/10504471

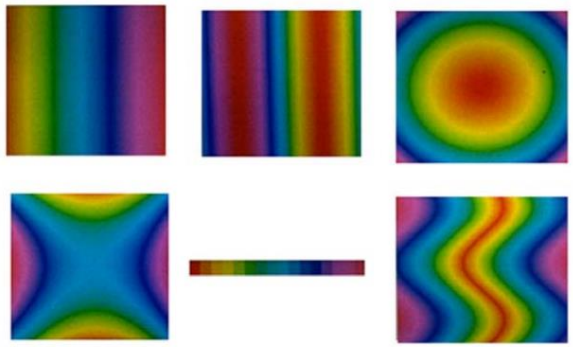
可视化中颜色设计的要求

- 需要满足几方面（有冲突）的需求

Color Sequences for Univariate Maps: Theory, Experiments, and Principles

Colin Ware
University of New Brunswick

经典文章，值得阅读

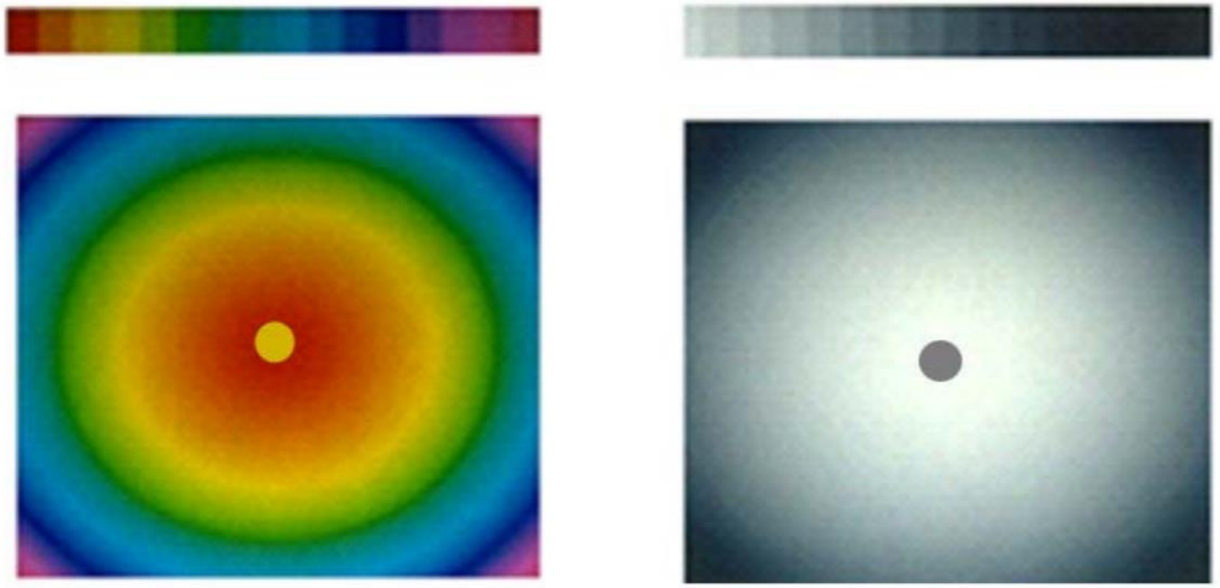


http://ccom.unh.edu/sites/default/files/publications/Ware_1988_CGA_Color_sequences_univariate_maps.pdf

[C. Ware, "Color sequences for univariate maps: theory, experiments and principles,", doi: 10.1109/38.7760.]

可视化中颜色设计的要求

- 色标需要完成的数据任务
  - 颜色信息表示数值(metric)
  - 亮度信息表示形态(form)



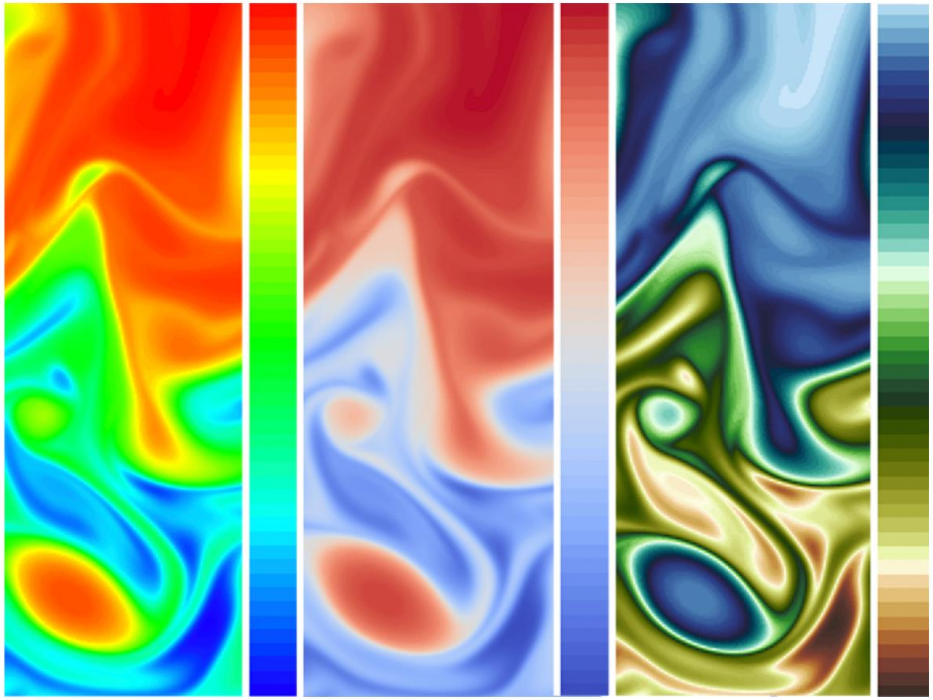
Metric comprehension

Form comprehension

[C. Ware, "Color sequences for univariate maps: theory, experiments and principles,", doi: 10.1109/38.7760.]

更多好用的色标设计工具

- Visualizing Science: How Color Determines What We See

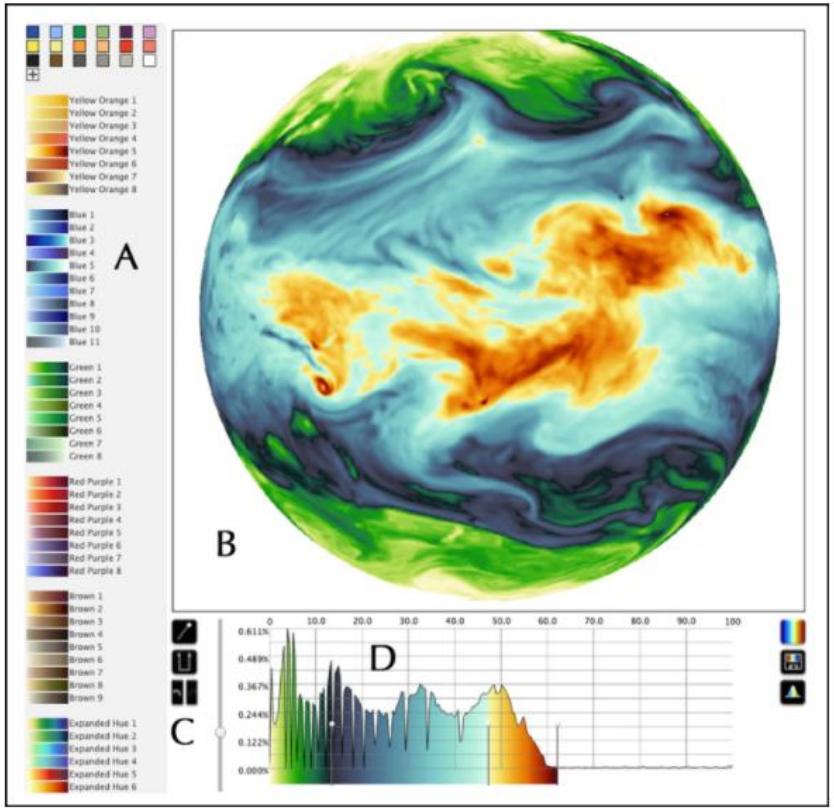


Scientists use data visualization to quantify, interpret, evaluate, and communicate information. Recent research into the ways that people see and interpret colors is improving tools to convey visual data clearly and accurately. This image shows a comparison of the same data set displayed using the traditional rainbow colormap (left), a cool–warm colormap (middle), and a "wave" colormap, illustrating how visible detail can change when data are portrayed with different color gradients. Credit: Graphic created by Francesca Samsel with data processed and provided by M. Petersen, Los Alamos National Laboratory (LANL), using MPAS-Ocean

[https://eos.org/features/visualizing-science-how-color-determines-what-we-see]

更多的色标设计工具

- 连续色标设计 ColorMoves



[F. Samsel, S. Klaassen and D. H. Rogers, "ColorMoves: Real-time Interactive Colormap Construction for Scientific Visualization,", doi: 10.1109/MCG.2018.011461525.]

更多的色标设计工具

- 分类色标设计 Colorgorical

http://vrl.cs.brown.edu/color

可视化中颜色设计的要求

- 详细的方法综述和实用的具体数据色标选择方针

A Survey of Colormaps in Visualization

Liang Zhou and Charles D. Hansen, *Fellow, IEEE*

Abstract—Colormaps are a vital method for users to gain insights into data in a visualization. With a good choice of colormaps, users are able to acquire information in the data more effectively and efficiently. In this survey, we attempt to provide readers with a comprehensive review of colormap generation techniques and provide readers a taxonomy which is helpful for finding appropriate techniques to use for their data and applications. Specifically, we first briefly introduce the basics of color spaces including color appearance models. In the core of our paper, we survey colormap generation techniques, including the latest advances in the field by grouping these techniques into four classes: procedural methods, user-study based methods, rule-based methods, and data-driven methods; we also include a section on methods that are beyond pure data comprehension purposes. We then classify colormapping techniques into a taxonomy for readers to quickly identify the appropriate techniques they might use. Furthermore, a representative set of visualization techniques that explicitly discuss the use of colormaps is reviewed and classified based on the nature of the data in these applications. Our paper is also intended to be a reference of colormap choices for readers when they are faced with similar data and/or tasks.

Index Terms—Color, colormap, visualization, perception, survey

1 INTRODUCTION

Color vision is an important and fast channel for humans to acquire information. A colormap is a mapping from data values to colors that generates visual structures for the data [27]. Colormaps are commonly used in many domains in computer sciences, e.g., computer graphics, visualization, computer vision and image processing. In this paper, we focus on colormap generation techniques and applications in the visualization domain.

Colormaps play an important role in visualization as they are able to improve the efficiency and ef-

the topic of colormapping in visualization, in which they briefly review colormap papers and provide guidelines for using those techniques. An extended survey [90] from Silva et al. is more comprehensive. They summarize factors to be considered in colormapping, e.g., data types, tasks, spatial frequency, and audience, and survey techniques indicating different design guidelines. Furthermore, they introduce existing colormapping tools that help the design of colormaps. Reviews of colormapping techniques can also be found in the book by Ware [109], in which color theories, perception issues are discussed, and col-

[L. Zhou and C. D. Hansen, "A Survey of Colormaps in Visualization,", doi: 10.1109/TVCG.2015.2489649.]

可视化中颜色设计的要求

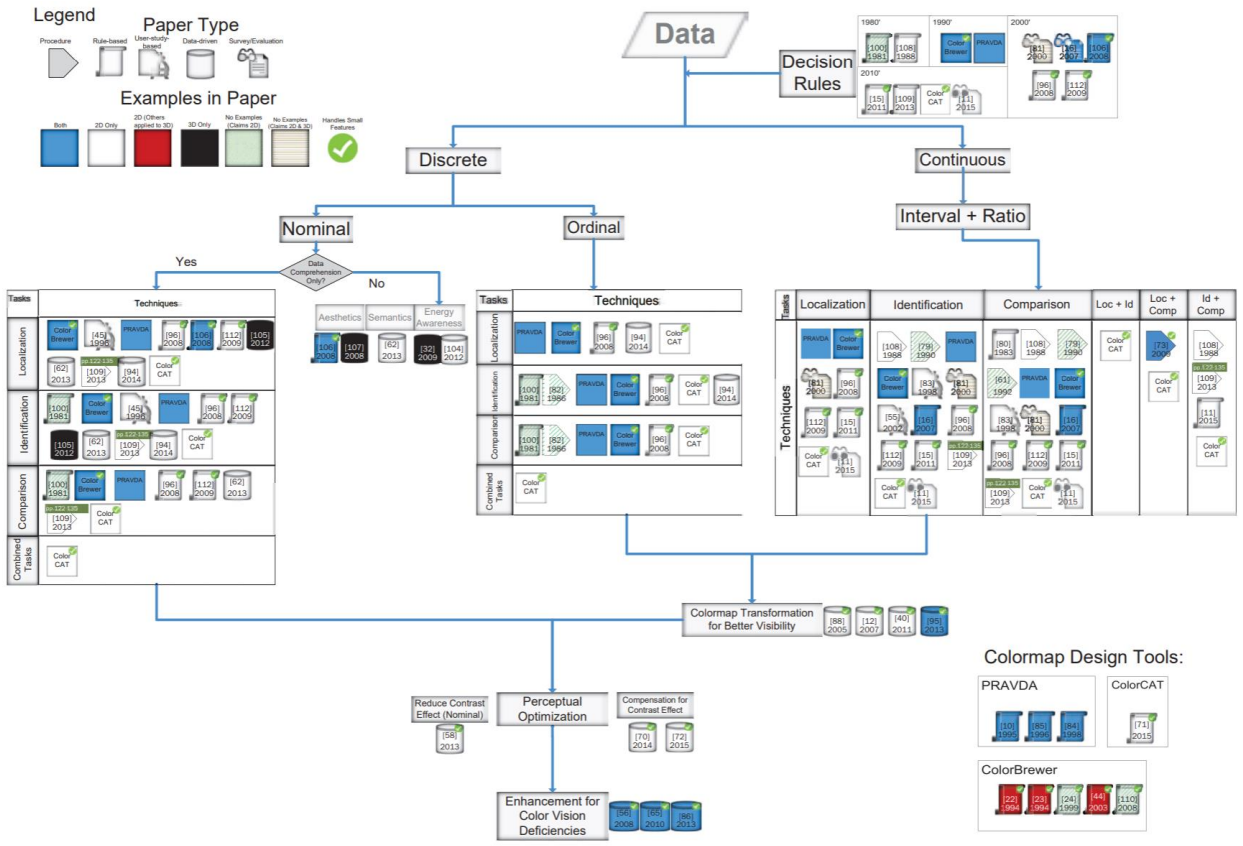


Fig. 9. A taxonomy of colormap generation papers.

[L. Zhou and C. D. Hansen, "A Survey of Colormaps in Visualization,", doi: 10.1109/TVCG.2015.2489649.]

色标的评价理论框架

The Good, the Bad, and the Ugly: A Theoretical Framework for the Assessment of Continuous Colormaps

Roxana Bujack* Los Alamos National Laboratory

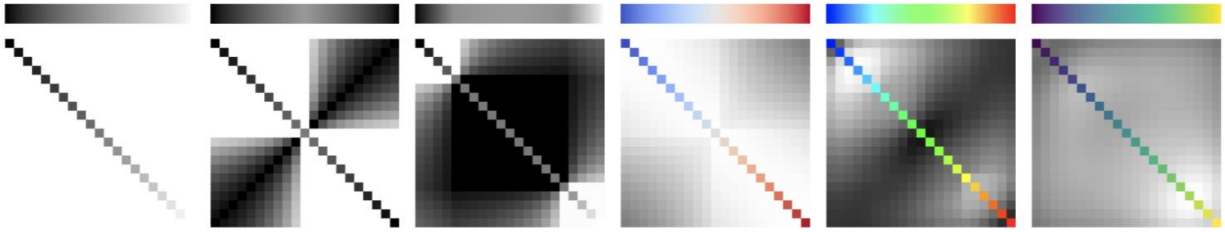
Terece L. Turton† University of Texas at Austin

Francesca Samsel‡ University of Texas at Austin

Colin Ware§ University of New Hampshire

David H. Rogers¶ Los Alamos National Laboratory

James Ahrens‖ Los Alamos National Laboratory



(a) Greyscale. Constant speed between each pair of points.

(b) Half greyscale. Const. speed in each half, drops to zero across the halves.

(c) Flat greyscale. Constant grey in $[0.2, 0.8]$ results in a speed of zero.

(d) Cool/warm divergent. Const. speed in each half, but not across halves.

(e) Rainbow. High speed around blue, low around green.

(f) Viridis. Low variations in speed result in its uniform appearance.

[R. Bujack, T. L. Turton, F. Samsel, C. Ware, D. H. Rogers and J. Ahrens, "The Good, the Bad, and the Ugly: A Theoretical Framework for the Assessment of Continuous Colormaps,", doi: 10.1109/TVCG.2017.2743978.]

彩虹色标争论

- Rainbow Color Map (still) considered harmful.

- Rainbow Colormaps Are Not All Bad

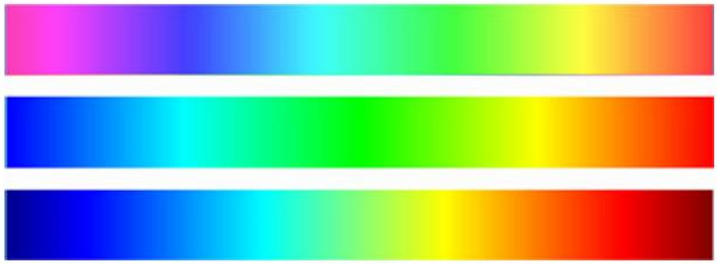
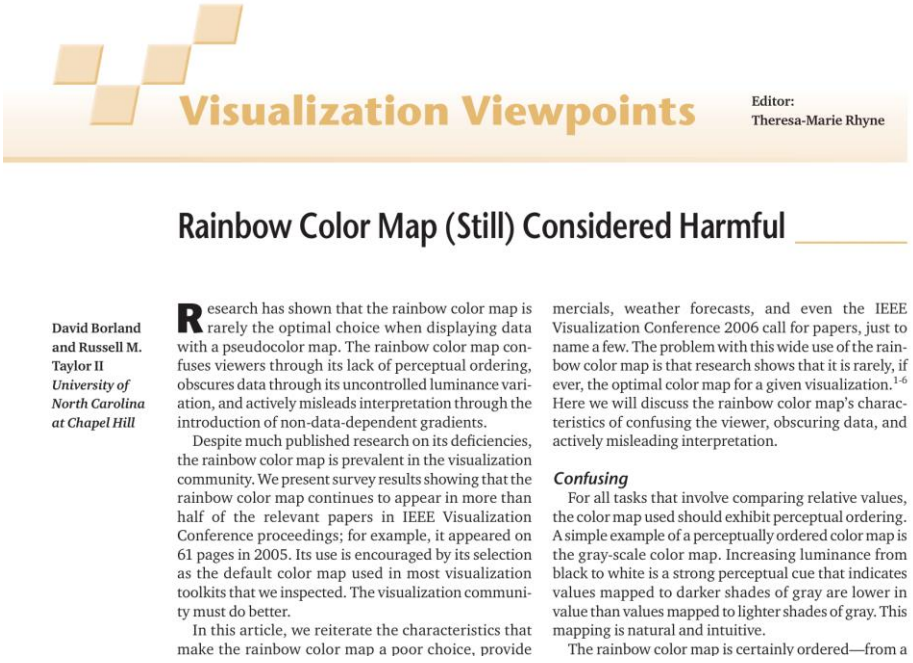


FIGURE 2. Three popular rainbow colormaps. Top: The classic HSV Rainbow. Middle: The Paraview Blue-Red Rainbow has no magenta. Bottom: Jet adds dark ends.



Visualization Viewpoints

Editor:
Theresa-Marie Rhyne

Rainbow Color Map (Still) Considered Harmful

David Borland and Russell M. Taylor II
University of North Carolina at Chapel Hill

Research has shown that the rainbow color map is rarely the optimal choice when displaying data with a pseudocolor map. The rainbow color map confuses viewers through its lack of perceptual ordering, obscures data through its uncontrolled luminance variation, and actively misleads interpretation through the introduction of non-data-dependent gradients.

Despite much published research on its deficiencies, the rainbow color map is prevalent in the visualization community. We present survey results showing that the rainbow color map continues to appear in more than half of the relevant papers in IEEE Visualization Conference proceedings; for example, it appeared on 61 pages in 2005. Its use is encouraged by its selection as the default color map used in most visualization toolkits that we inspected. The visualization community must do better.

In this article, we reiterate the characteristics that make the rainbow color map a poor choice, provide

mercials, weather forecasts, and even the IEEE Visualization Conference 2006 call for papers, just to name a few. The problem with this wide use of the rainbow color map is that research shows that it is rarely, if ever, the optimal color map for a given visualization.[1-6] Here we will discuss the rainbow color map's characteristics of confusing the viewer, obscuring data, and actively misleading interpretation.

Confusing

For all tasks that involve comparing relative values, the color map used should exhibit perceptual ordering. A simple example of a perceptually ordered color map is the gray-scale color map. Increasing luminance from black to white is a strong perceptual cue that indicates values mapped to darker shades of gray are lower in value than values mapped to lighter shades of gray. This mapping is natural and intuitive.

The rainbow color map is certainly ordered—from a

EDITOR: Theresa-Marie Rhyne, theresamarierhyne@gmail.com

DEPARTMENT: VISUALIZATION VIEWPOINTS

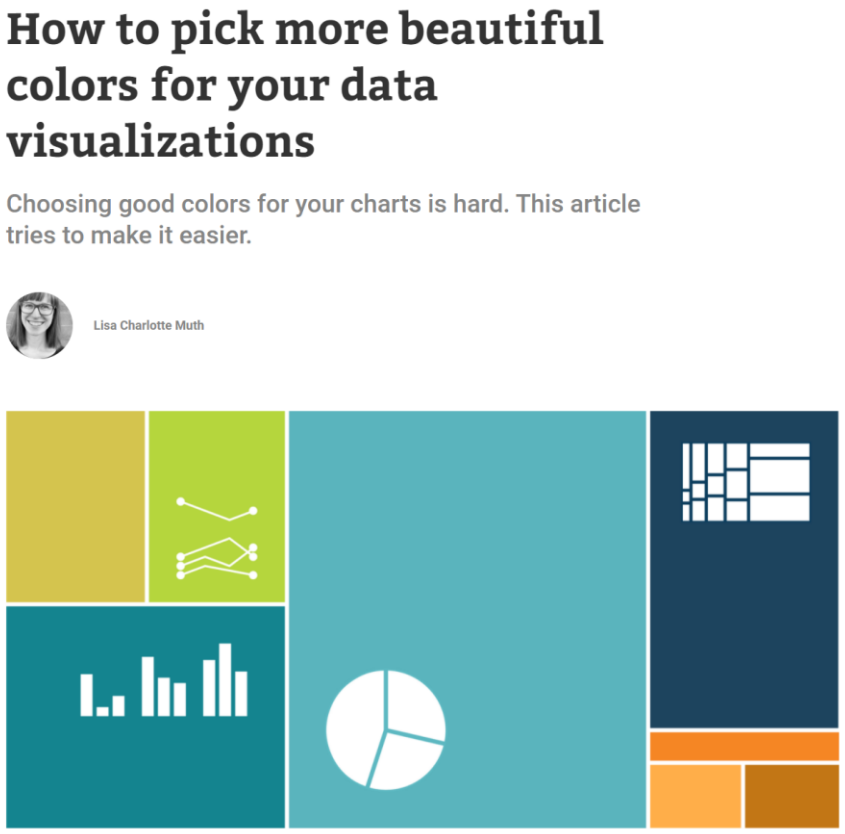
Rainbow Colormaps Are Not All Bad

Colin Ware, *University of New Hampshire, Durham, NH, 03824, USA*
Maureen Stone, *Tableau Research, Seattle, WA, 98103, USA*
Danielle Albers Szafir, *University of North Carolina at Chapel Hill, Chapel Hill, NC, 27599, USA*

Some 15 years ago, Visualization Viewpoints published an influential article titled Rainbow Color Map (Still) Considered Harmful *(Borland and Taylor, 2007). The paper argued that the "rainbow colormap's characteristics of confusing the viewer, obscuring the data and actively misleading interpretation make it a poor choice for visualization." Subsequent articles often repeat and extend these arguments, so much so that avoiding rainbow colormaps, along with their derivatives, has become dogma in the visualization community. Despite this loud and persistent recommendation, scientists continue to use rainbow colormaps. Have we failed to communicate our message, or do rainbow colormaps offer advantages that have not been fully appreciated? We argue that rainbow colormaps have properties that are underappreciated by existing design conventions. We explore key critiques of the rainbow in the context of recent research to understand where and how rainbows might be misunderstood. Choosing a colormap is a complex task, and rainbow colormaps can be useful for selected applications.*

可视化各领域的通用问题：如何选择颜色？

- 复杂答案：手动选择，适合信息可视化
- https://blog.datawrapper.de/beautifulcolors/



如何选择颜色？

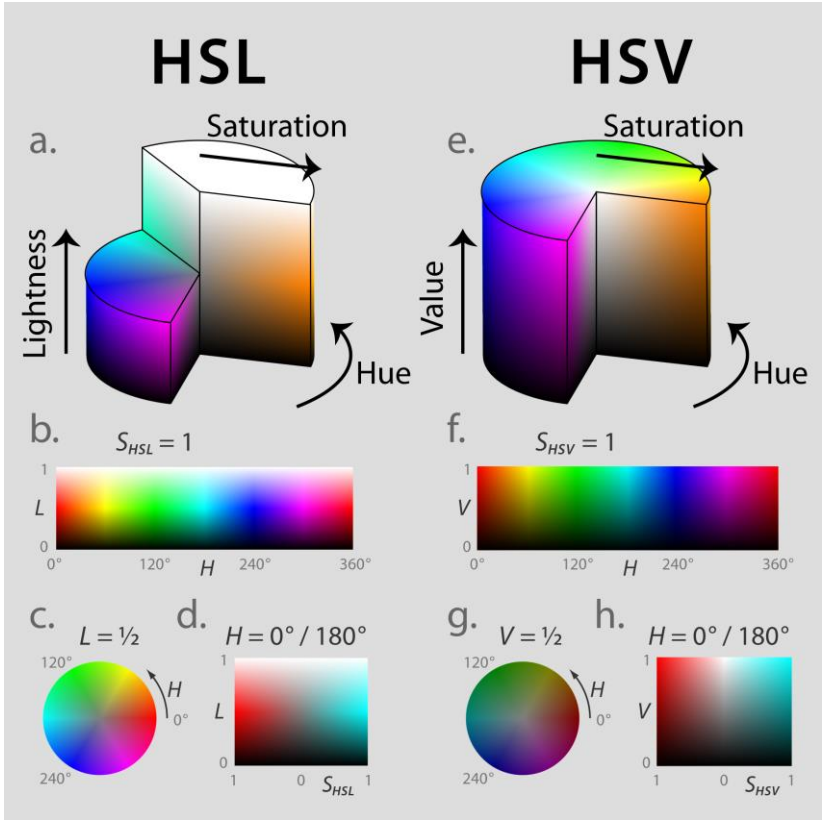
- 颜色空间
  - RGB 显示设备用
  - HSV 设计者用
  - CIELab 试图描述人类感知
  - CIEXYZ 试图描述人类感知
  - CMYK 打印设备用
  - YUV 区分亮度Y和其他颜色通道
  - YCbCr 区分亮度Y和其他颜色通道
  - ……
- 颜色空间之间的转换

如何选择颜色？

- HSV颜色空间
  - Hue 色相
  - Saturation 饱和度
  - Value/Brightness 亮度

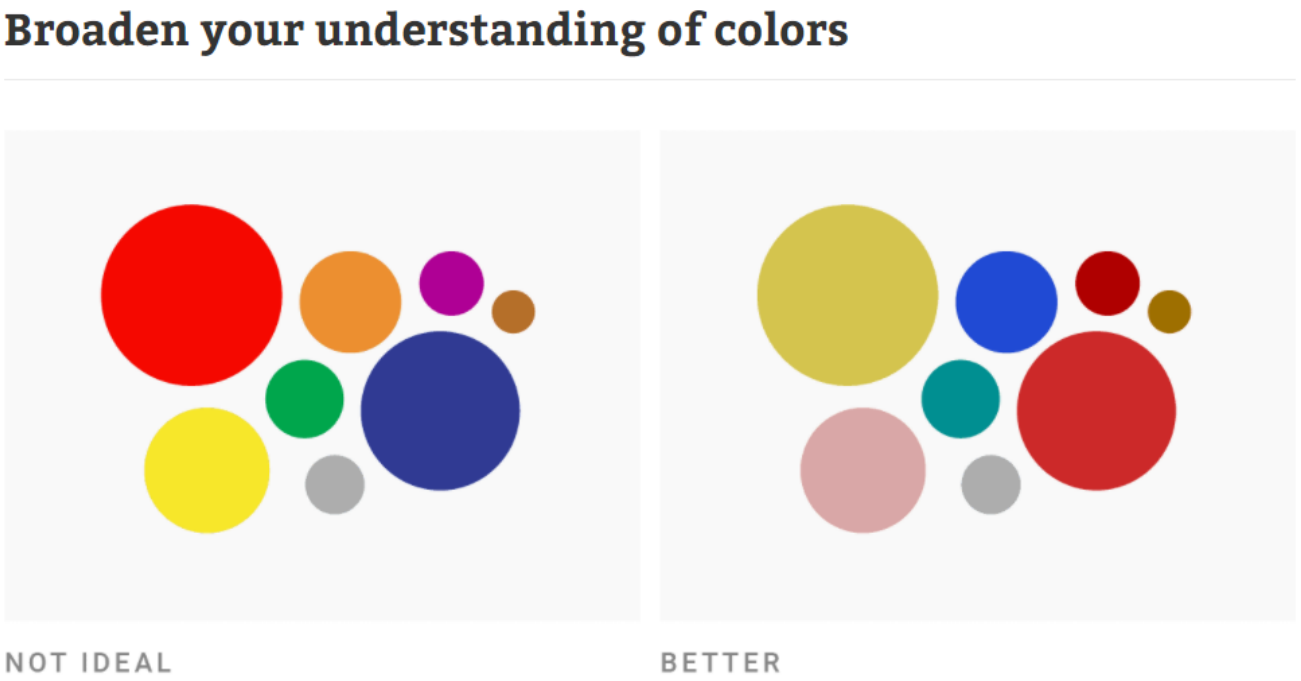
- **Hue** ranges from 0° to 360°...that's your typical color wheel: 
- **Saturation** ranges from 0% (grey) to 100% (super duper colorful!!):
- **Brightness/Value** ranges from 0% (black) to 100% (the actual color): 

HSL/HSV 颜色空间



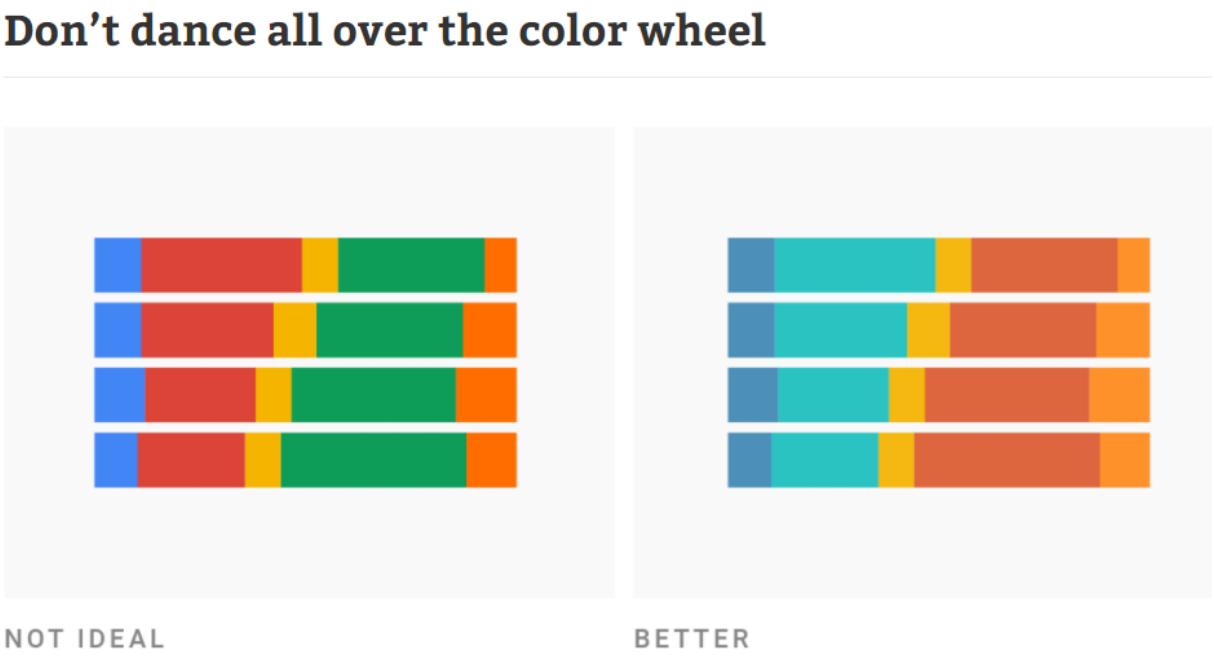
[By Jacob Rus - Own work, CC BY-SA 3.0,
https://commons.wikimedia.org/w/index.php?curid=9445469]

拓展对颜色的理解



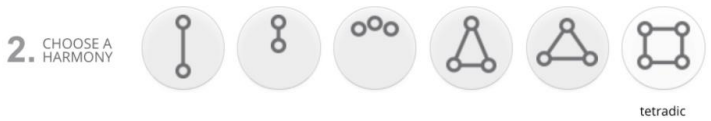
https://blog.datawrapper.de/beautifulcolors/

没必要用太多色相



https://blog.datawrapper.de/beautifulcolors/

使用互补色



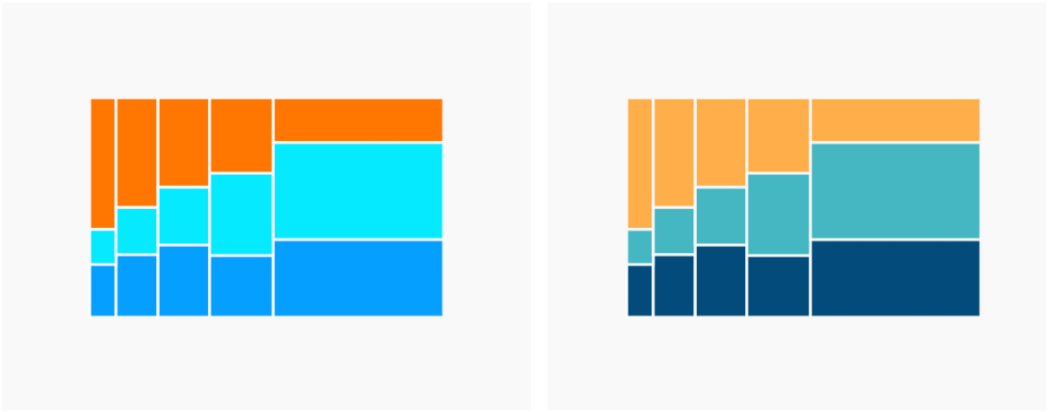
Lots of these tools let you choose different harmonies. One of them is called “square” or “tetradic”. **Don’t use it.** It will result in too many hues – and we’re on a mission to avoid that.

If the distance becomes small enough, you’re basically using **complementary** colors. And that’s a great choice! Lots of complementary color pairs work fantastic together. **If in doubt, use complementary colors and their neighbors.**

https://blog.datawrapper.de/beautifulcolors/

调整饱和度、亮度，使色相达到预期效果

Use saturation and lightness to make your hues work



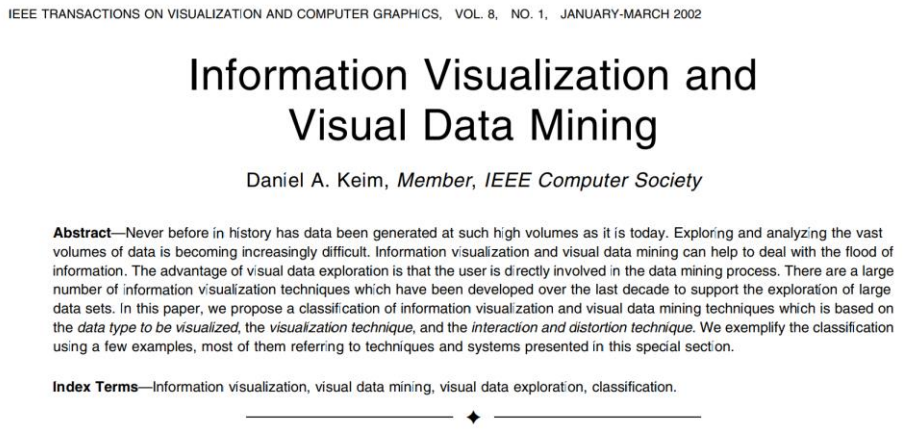
NOT IDEAL BETTER

Saturation and brightness are as important as hue. In fact, you can create new colors when you just change the saturation and brightness. Here are two color pairs with the same hue, just different saturation and lightness: ●● / ●●. (If you change the hue just a tiny bit, you'll achieve even better results: ●● / ●●.)

https://blog.datawrapper.de/beautifulcolors/

信息可视化

- 可视化不包含固有空间信息的数据 Information visualization focuses on data sets lacking inherent 2D or 3D semantics and therefore also lacking a standard mapping of the abstract data onto the physical screen space. -- D. Keim
- 数据集分类
  - 表格数据
  - 树和图
  - 集合
  - 文本
  - 地理数据
  - ……


IEEE TRANSACTIONS ON VISUALIZATION AND COMPUTER GRAPHICS, VOL. 8, NO. 1, JANUARY-MARCH 2002 1

Information Visualization and Visual Data Mining

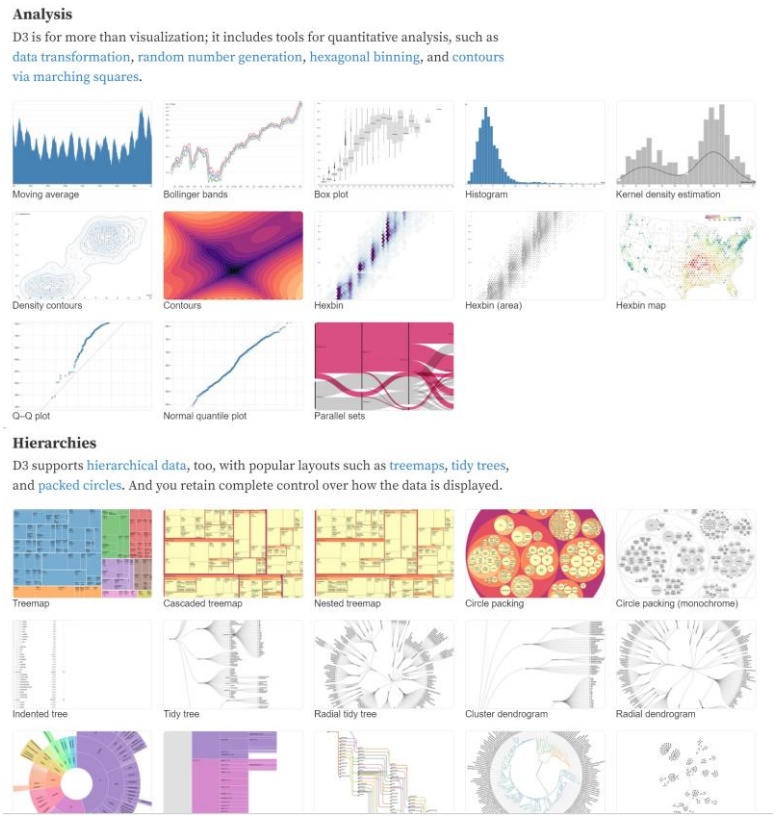
Daniel A. Keim, *Member*, *IEEE Computer Society*

Abstract—Never before in history has data been generated at such high volumes as it is today. Exploring and analyzing the vast volumes of data is becoming increasingly difficult. Information visualization and visual data mining can help to deal with the flood of information. The advantage of visual data exploration is that the user is directly involved in the data mining process. There are a large number of information visualization techniques which have been developed over the last decade to support the exploration of large data sets. In this paper, we propose a classification of information visualization and visual data mining techniques which is based on the *data type to be visualized*, the *visualization technique*, and the *interaction and distortion technique*. We exemplify the classification using a few examples, most of them referring to techniques and systems presented in this special section.

Index Terms—Information visualization, visual data mining, visual data exploration, classification.

[D. A. Keim, (2002), "Information visualization and visual data mining," doi: 10.1109/2945.981847.]

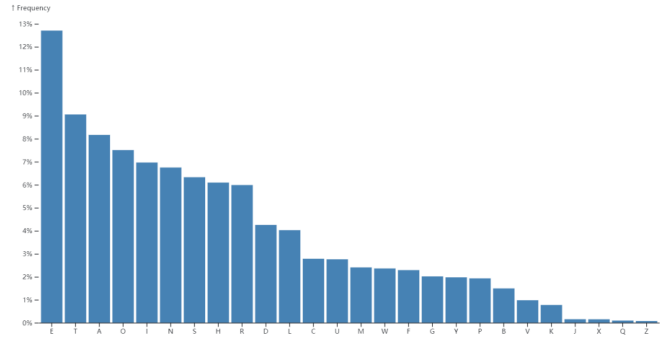
https://observablehq.com/@d3/gallery



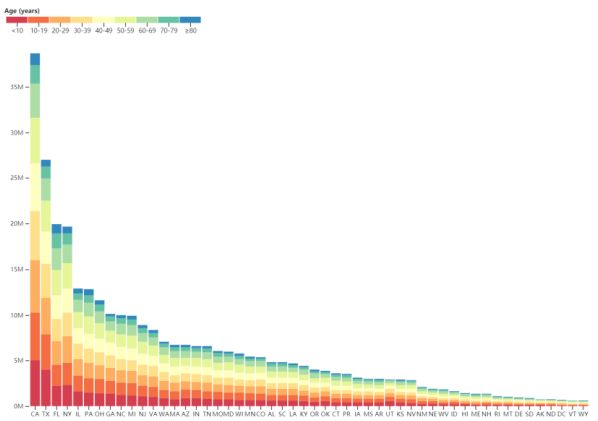
[J. Heer et al. (2010). A Tour through the Visualization Zoo: A survey of powerful visualization techniques, from the obvious to the obscure. DOI: 10.1145/1794514.1805128]

表格数据可视化
——单变量数据

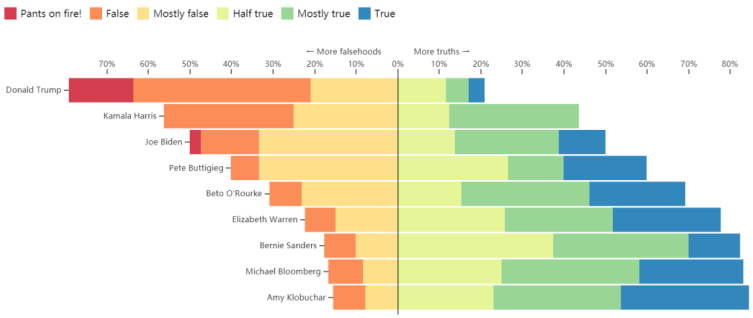
柱状图 Bar chart



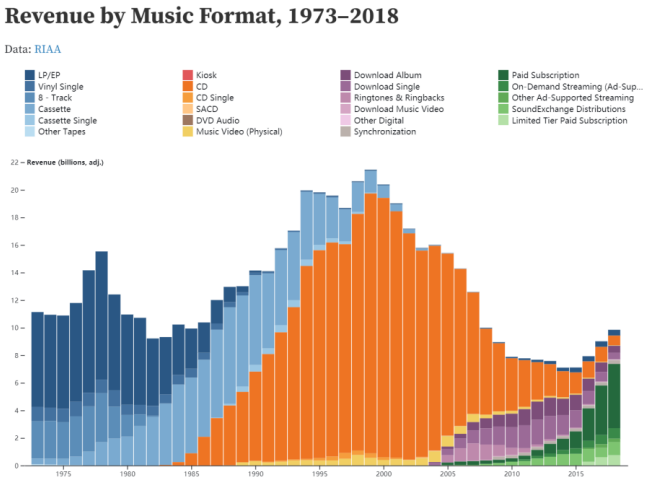
https://observablehq.com/@d3/bar-chart



https://observablehq.com/@d3/stacked-bar-chart



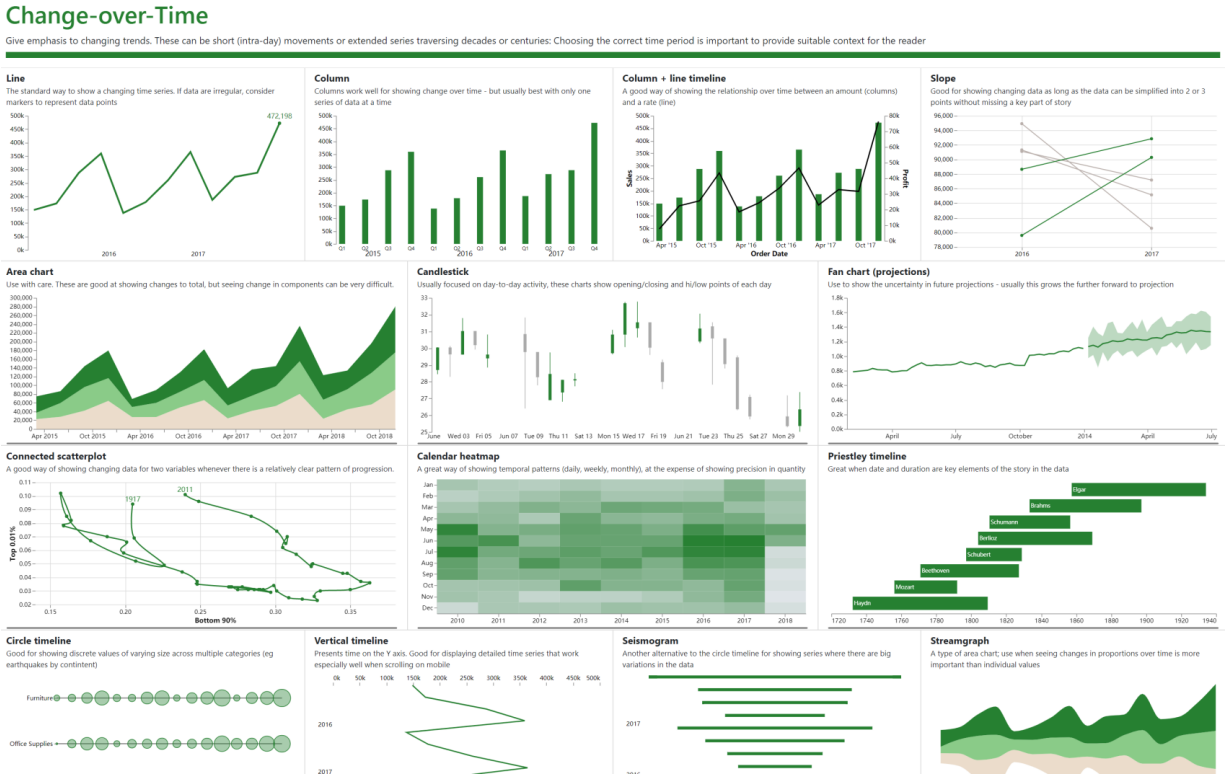
https://observablehq.com/@d3/diverging-stacked-bar-chart



[By M. Bostock]

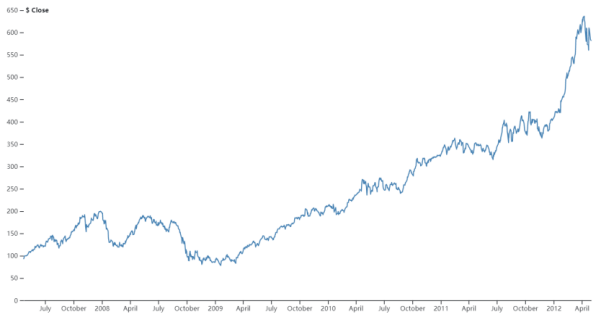
https://observablehq.com/@mbostock/revenue-by-music-format-1973-2018

随时间变化的表格数据



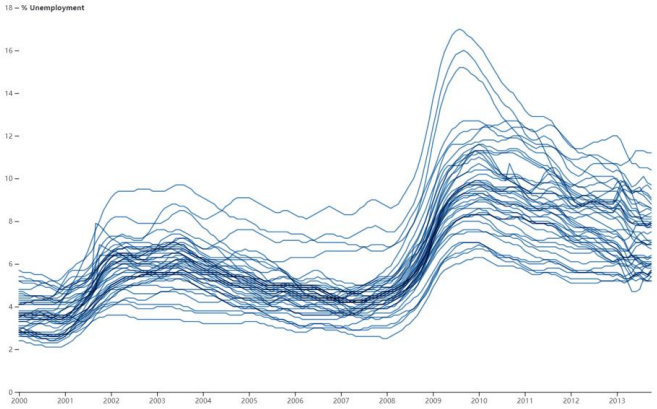
[By Pratap Vardhan, https://gramener.github.io/visual-vocabulary-vega/]

线图 Line chart

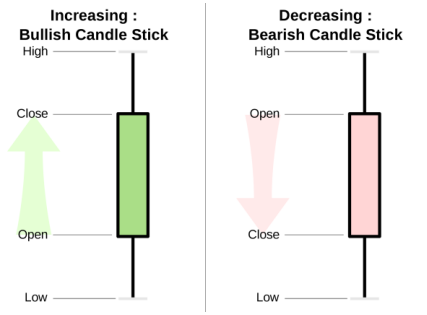


https://observablehq.com/@d3/line-chart

https://observablehq.com/@d3/candlestick-chart



https://observablehq.com/@d3/multi-line-chart



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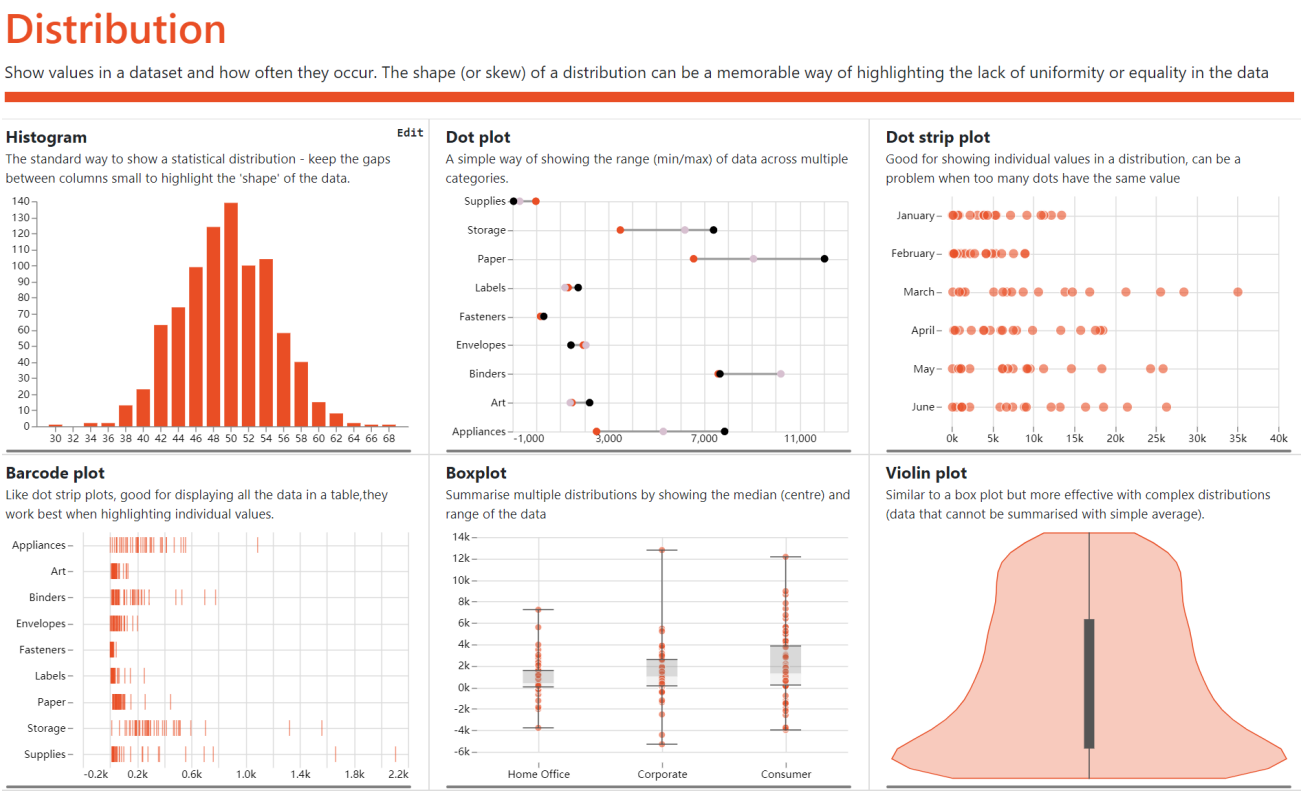
[By M. Bostock]

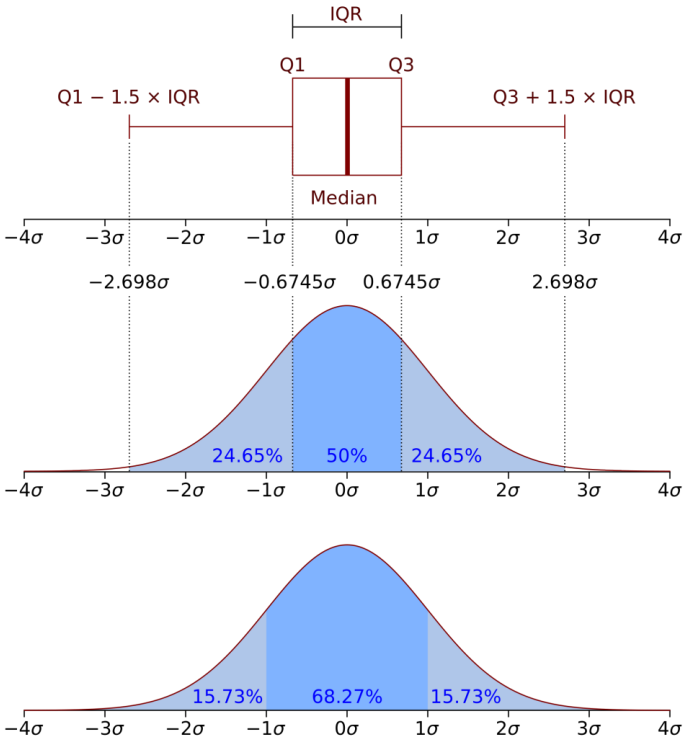
统计分布可视化



[By Pratap Vardhan, https://gramener.github.io/visual-vocabulary-vega/]

箱形图 Boxplot

- Box-and-Whisker plot



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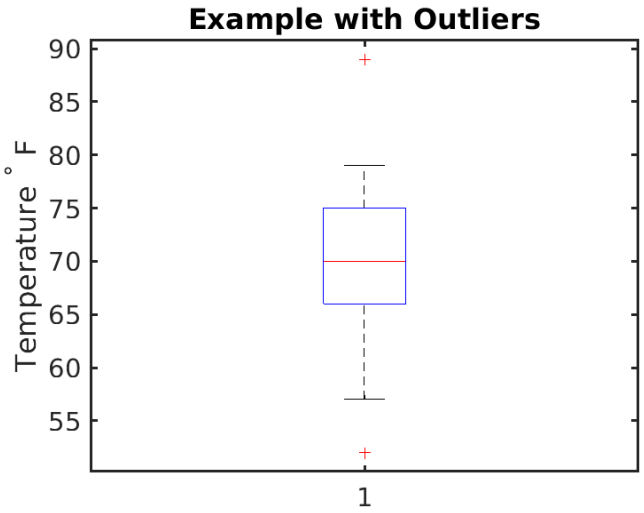
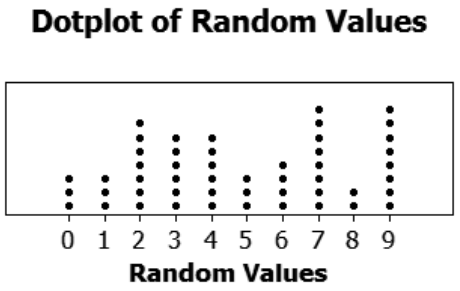


[By Ever.chae - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=84823719]

点图 Dot plot

- 用点代表数值（例如次数）



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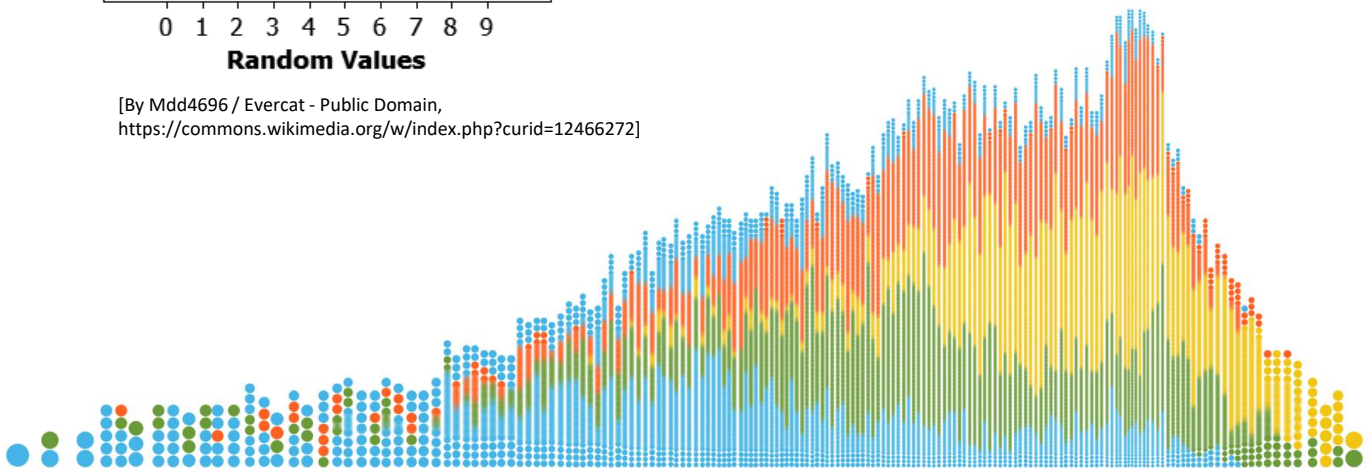
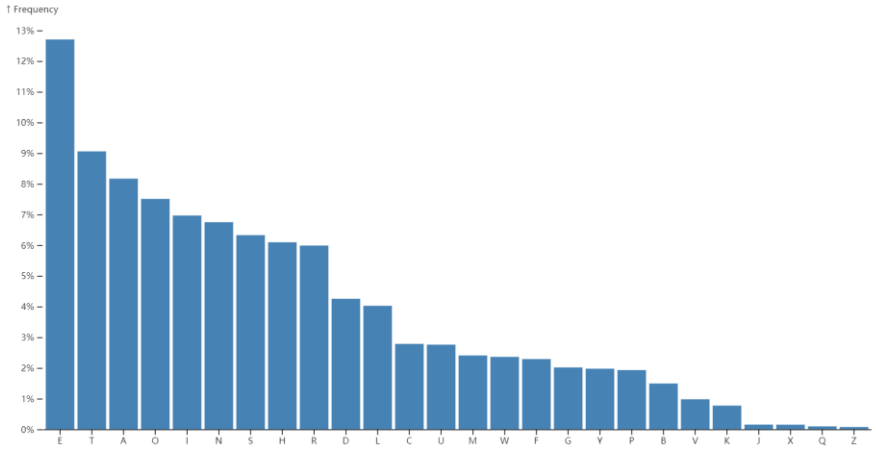


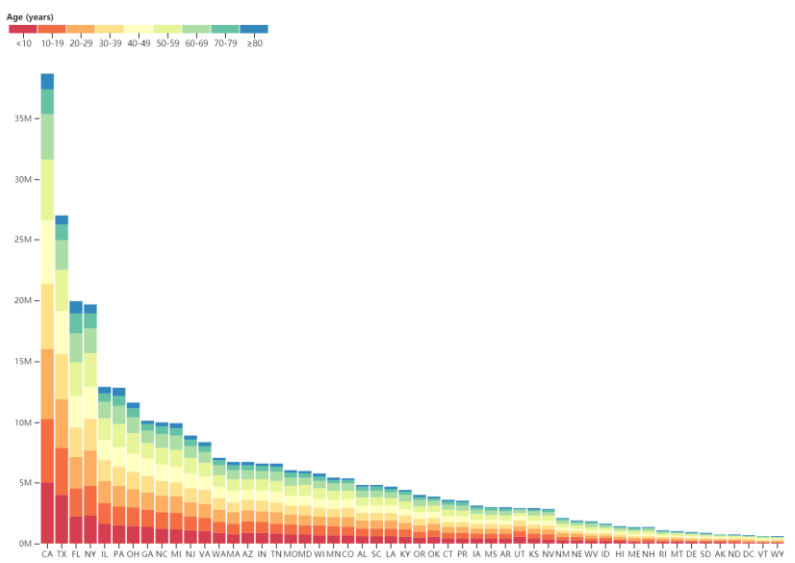
非线性点图

[N. Rodrigues and D. Weiskopf (2018), "Nonlinear Dot Plots," doi: 10.1109/TVCG.2017.2744018.]

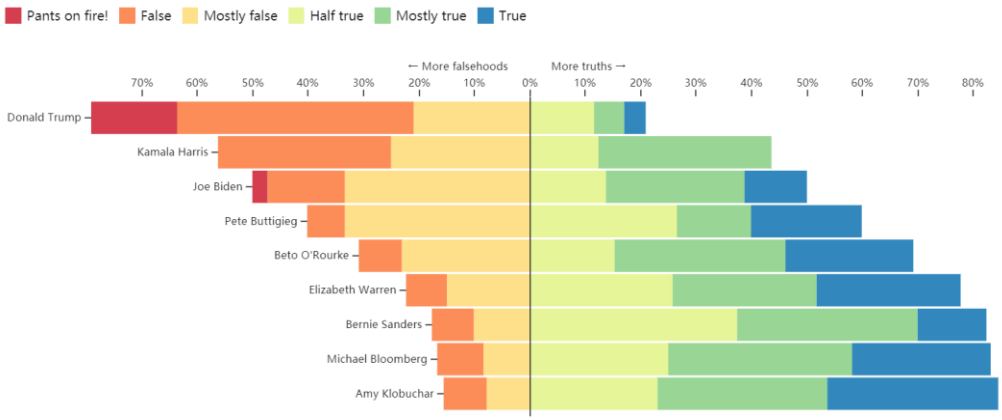
柱状图 Bar chart



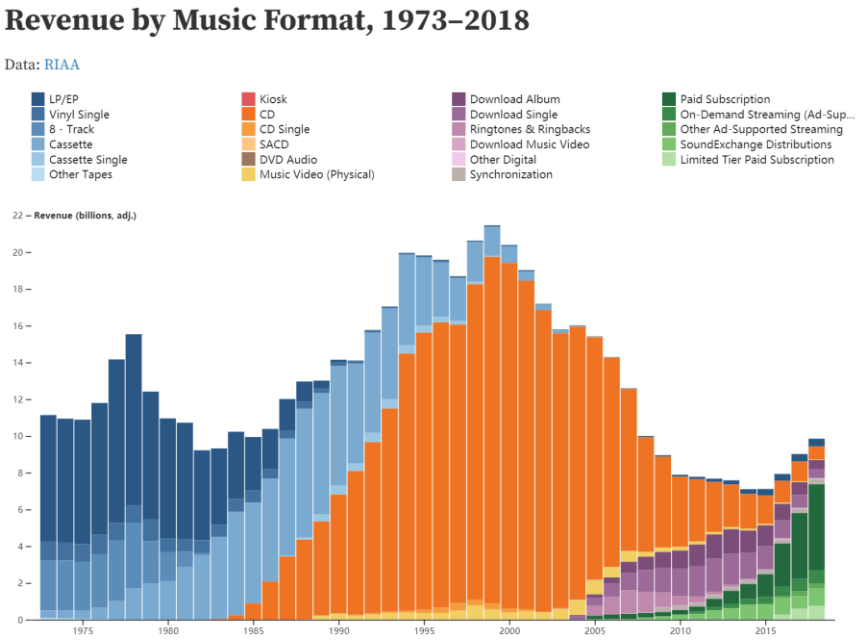
https://observablehq.com/@d3/bar-chart



https://observablehq.com/@d3/stacked-bar-chart



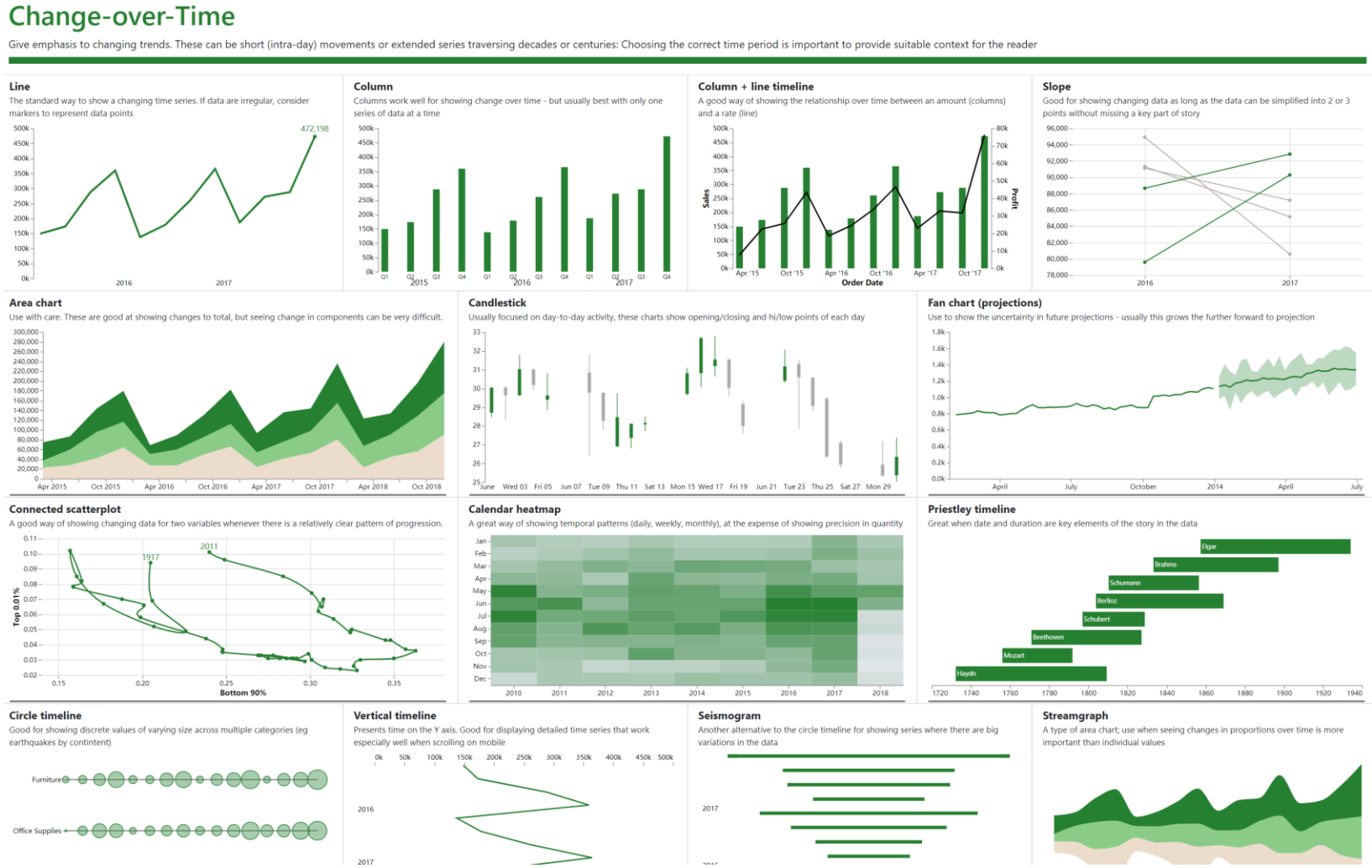
https://observablehq.com/@d3/diverging-stacked-bar-chart



[By M. Bostock]

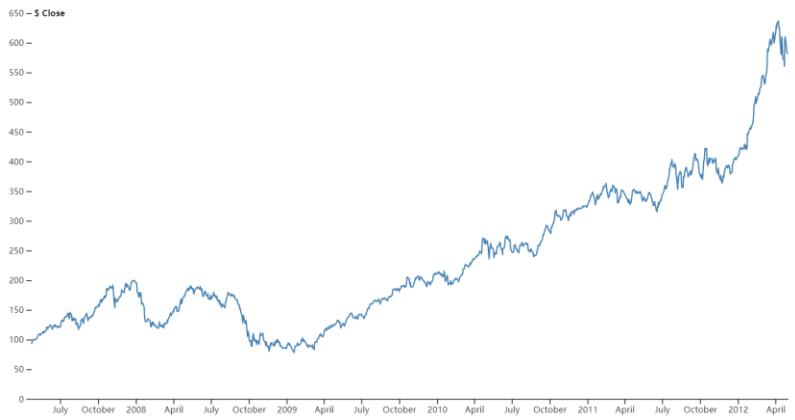
https://observablehq.com/@mbostock/revenue-by-music-format-1973-2018

随时间变化的表格数据



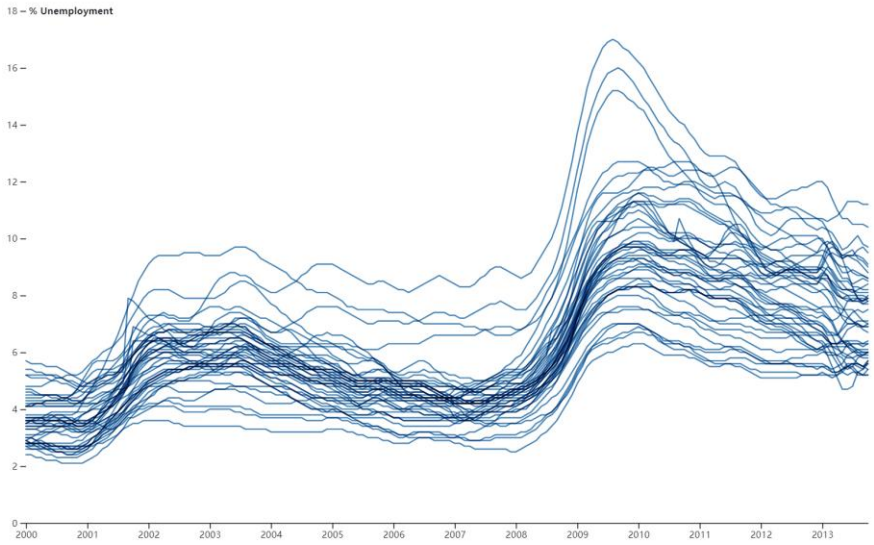
[By Pratap Vardhan, https://gramener.github.io/visual-vocabulary-vega/]

线图 Line chart

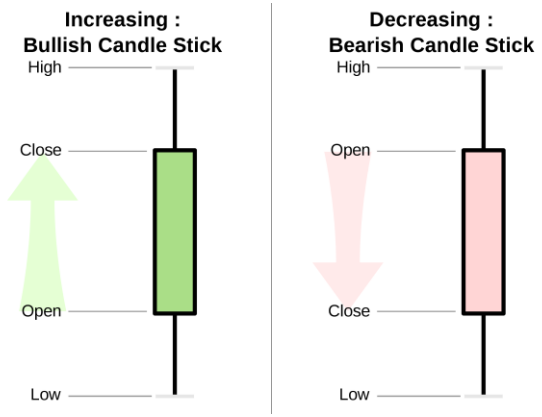


https://observablehq.com/@d3/line-chart

https://observablehq.com/@d3/candlestick-chart



https://observablehq.com/@d3/multi-line-chart



[By Probe-meteo.com - Probe-meteo.com, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=26048221]

[By M. Bostock]

统计分布可视化

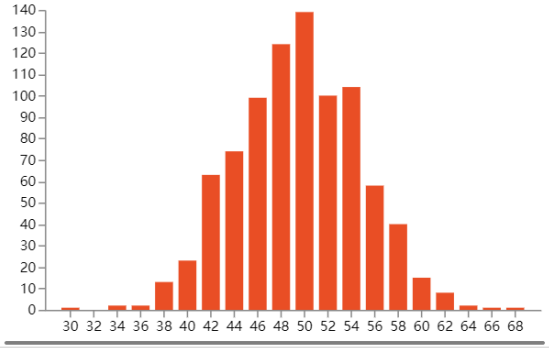
Distribution

Show values in a dataset and how often they occur. The shape (or skew) of a distribution can be a memorable way of highlighting the lack of uniformity or equality in the data

Histogram

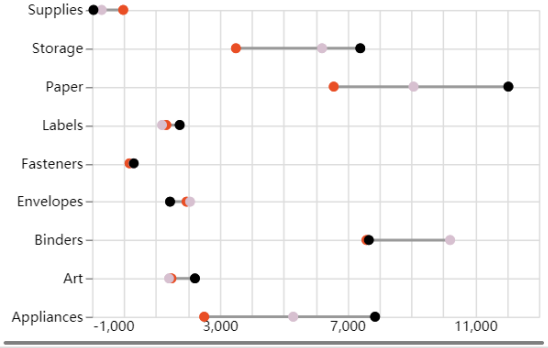
Edit

The standard way to show a statistical distribution - keep the gaps between columns small to highlight the 'shape' of the data.



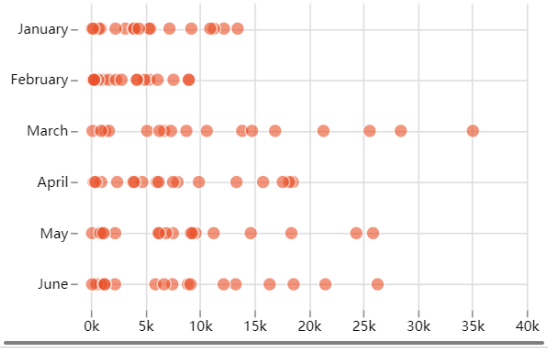
Dot plot

A simple way of showing the range (min/max) of data across multiple categories.



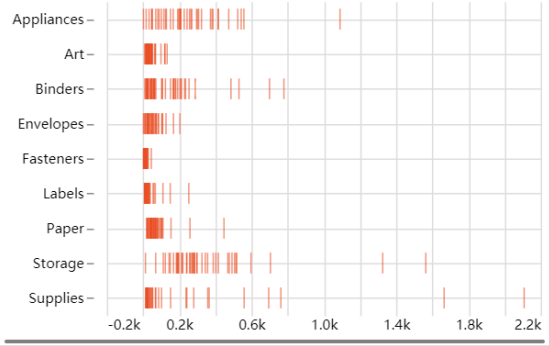
Dot strip plot

Good for showing individual values in a distribution, can be a problem when too many dots have the same value



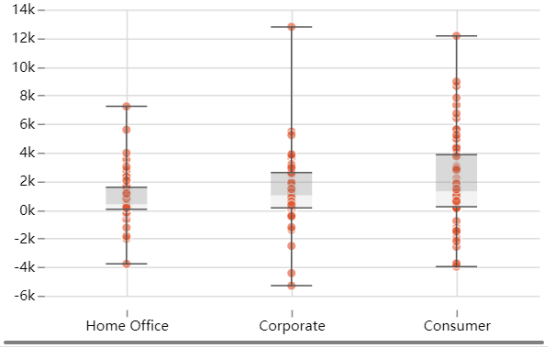
Barcode plot

Like dot strip plots, good for displaying all the data in a table,they work best when highlighting individual values.



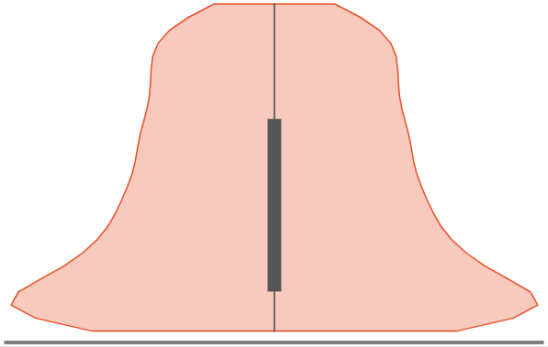
Boxplot

Summarise multiple distributions by showing the median (centre) and range of the data



Violin plot

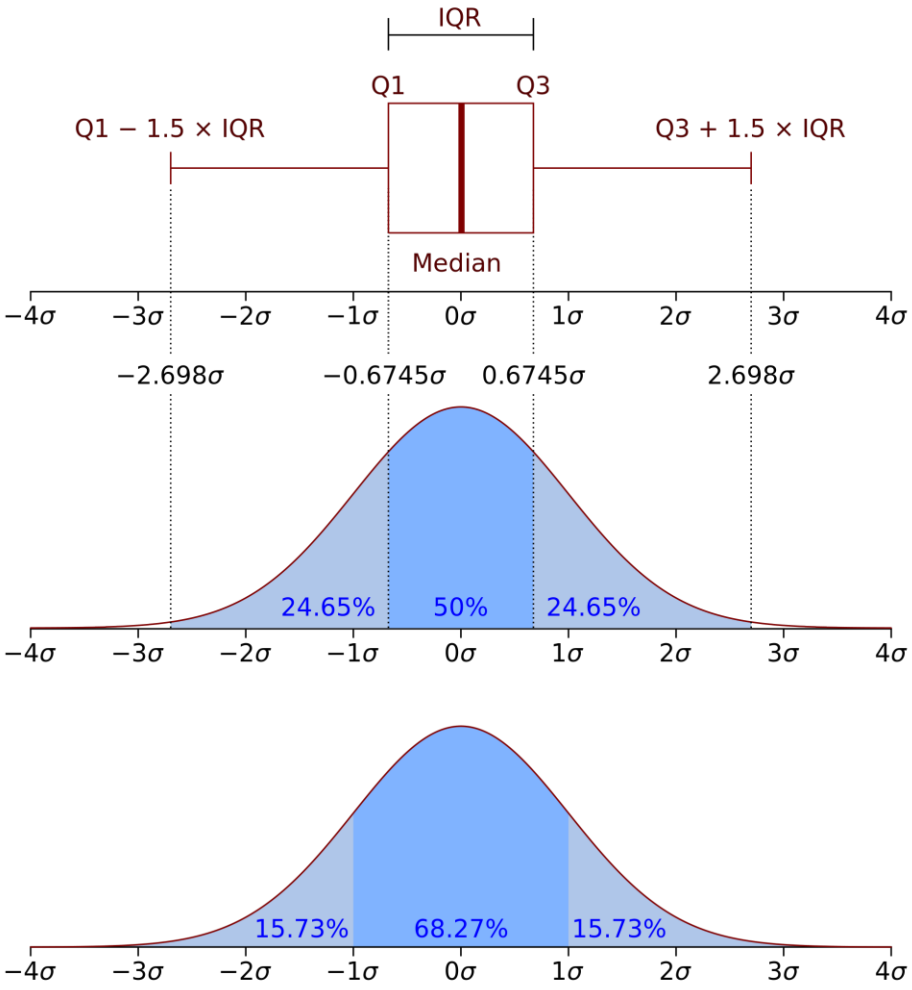
Similar to a box plot but more effective with complex distributions (data that cannot be summarised with simple average).



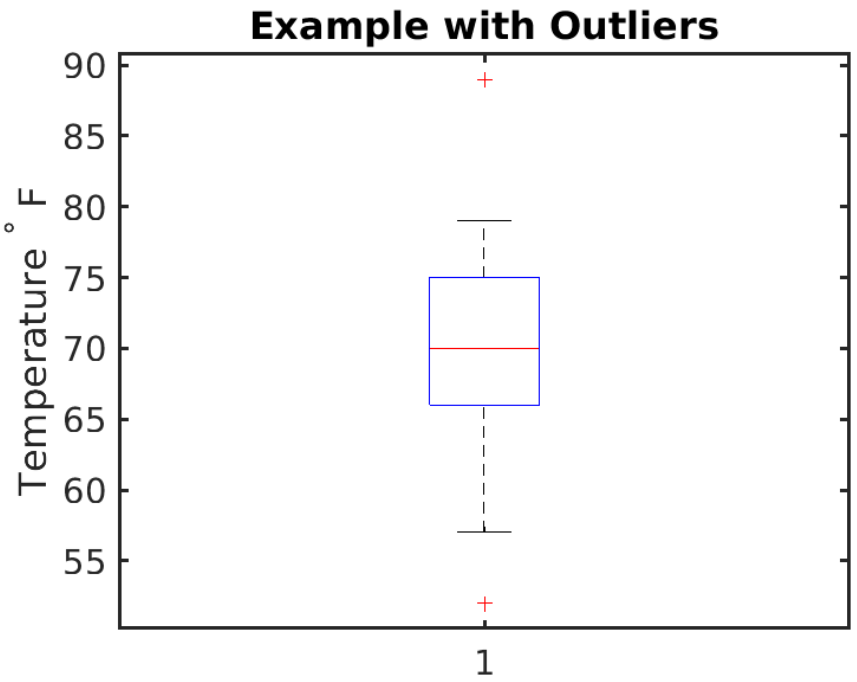
[By Pratap Vardhan, https://gramener.github.io/visual-vocabulary-vega/]

箱形图 Boxplot

- Box-and-Whisker plot



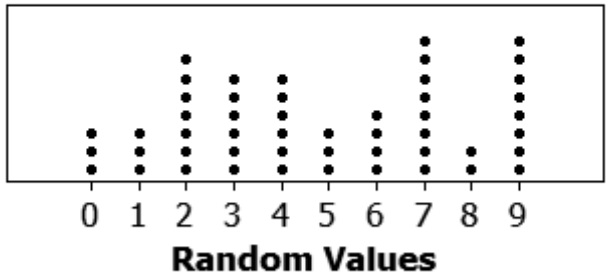
[By Jhguch at en.wikipedia, CC BY-SA 2.5, https://commons.wikimedia.org/w/index.php?curid=14524285]



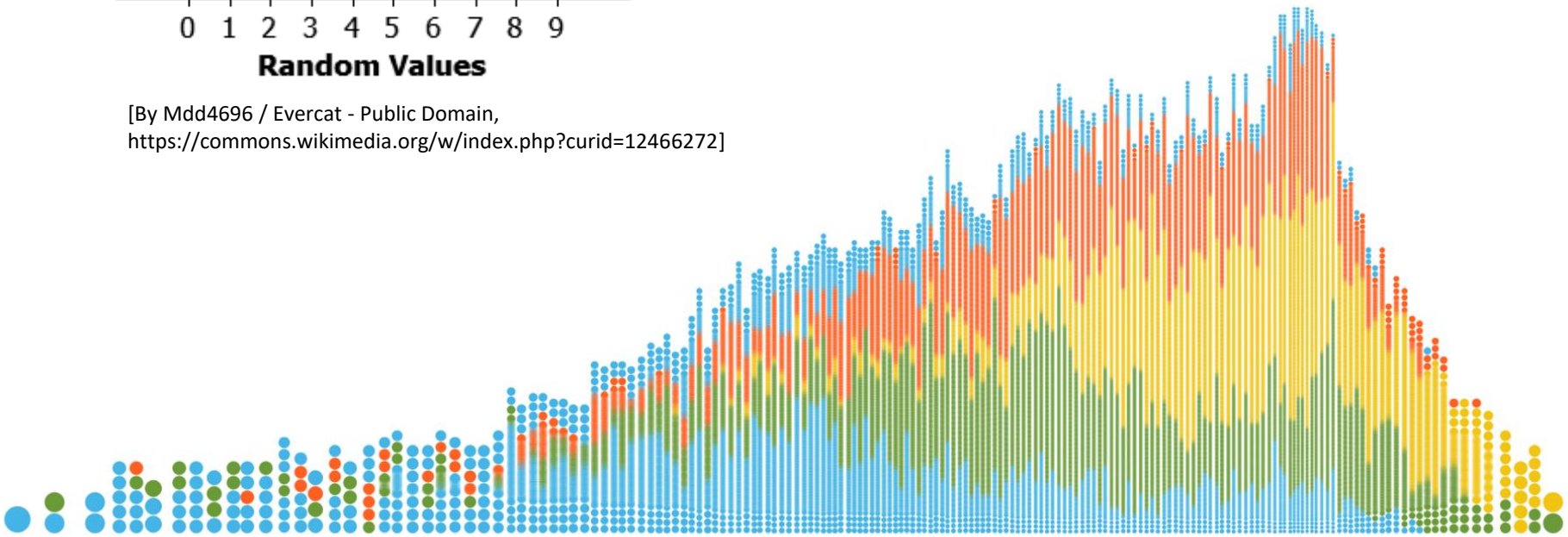
[By Ever.chae - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=84823719]

点图 Dot plot

- 用点代表数值（例如次数）



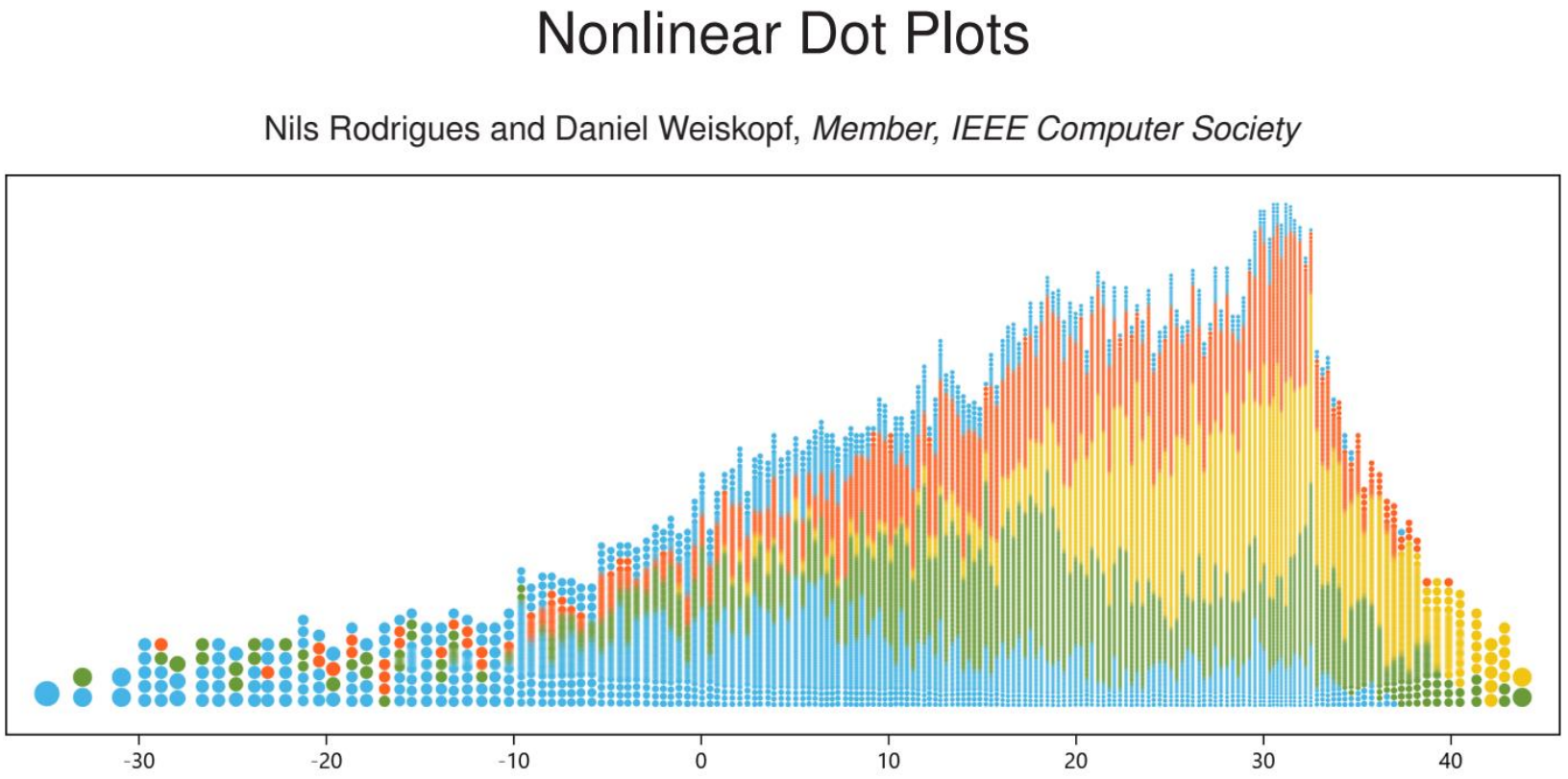
[By Mdd4696 / Evercat - Public Domain, https://commons.wikimedia.org/w/index.php?curid=12466272]



非线性点图

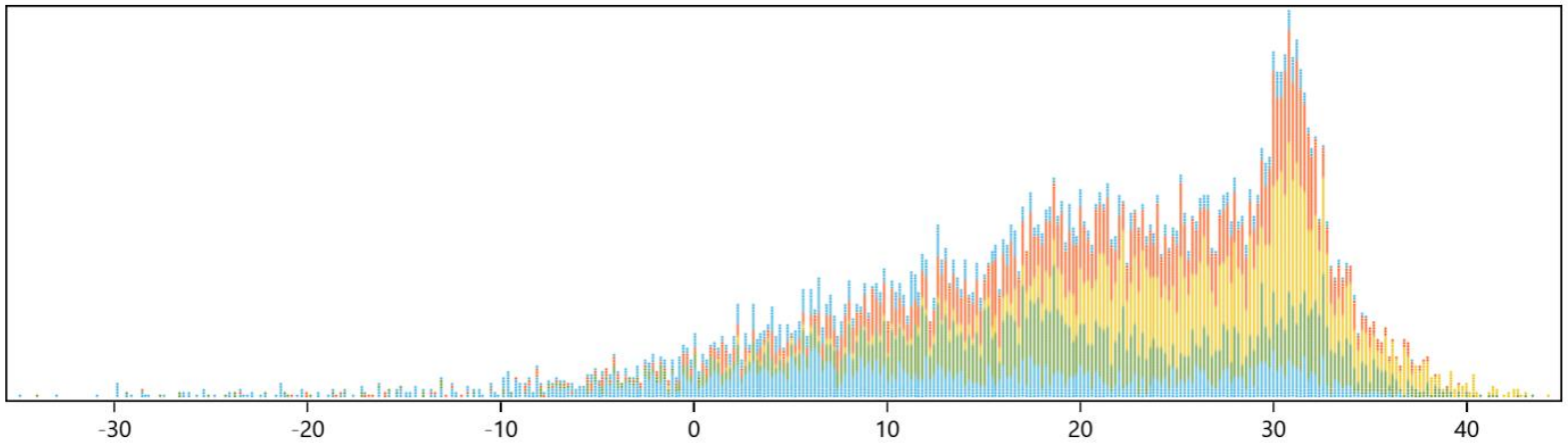
[N. Rodrigues and D. Weiskopf (2018), "Nonlinear Dot Plots," doi: 10.1109/TVCG.2017.2744018.]

点图的扩展研究



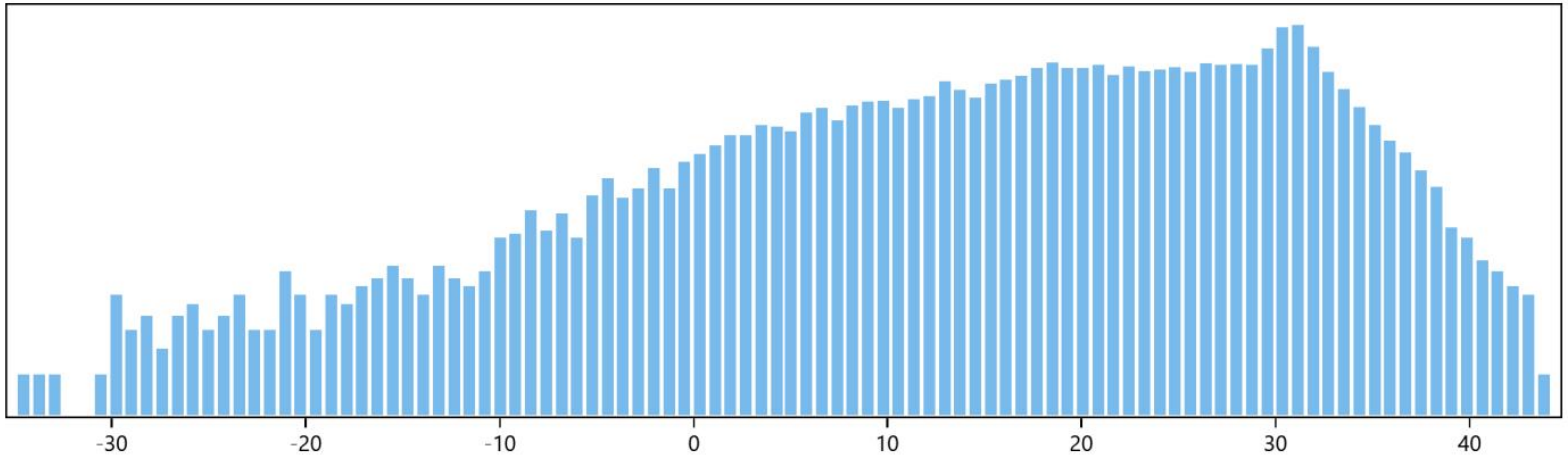
[N. Rodrigues and D. Weiskopf, "Nonlinear Dot Plots," in IEEE Transactions on Visualization and Computer Graphics, doi: 10.1109/TVCG.2017.2744018.]

传统方法的局限



(a) Linear dot plot

(b) Strip dot plot (root plot with $s = 1$)

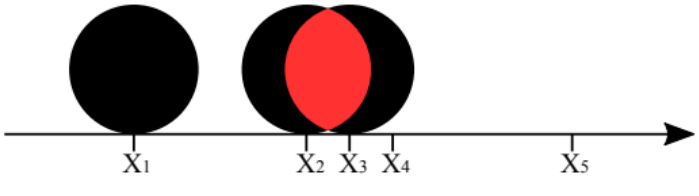


(c) Logarithmic histogram

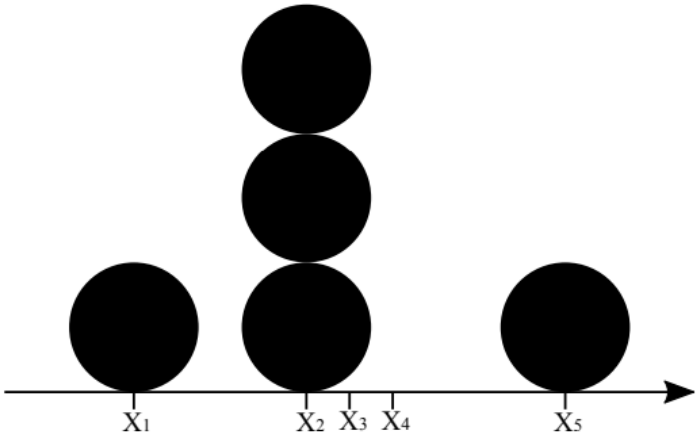
[N. Rodrigues and D. Weiskopf, "Nonlinear Dot Plots," in IEEE Transactions on Visualization and Computer Graphics, doi: 10.1109/TVCG.2017.2744018.]

非线性点图

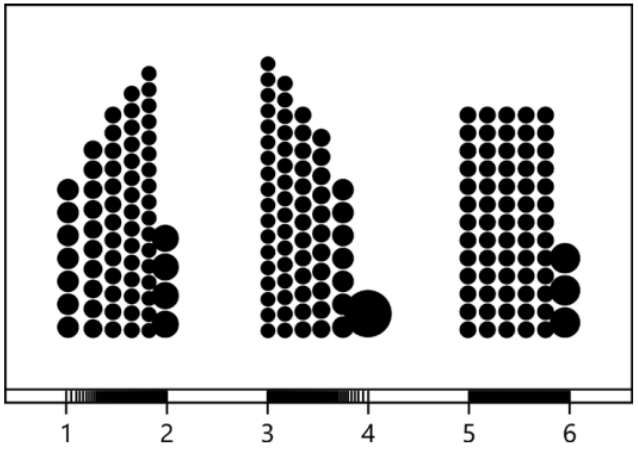
- 点的放置位置，点的大小设置



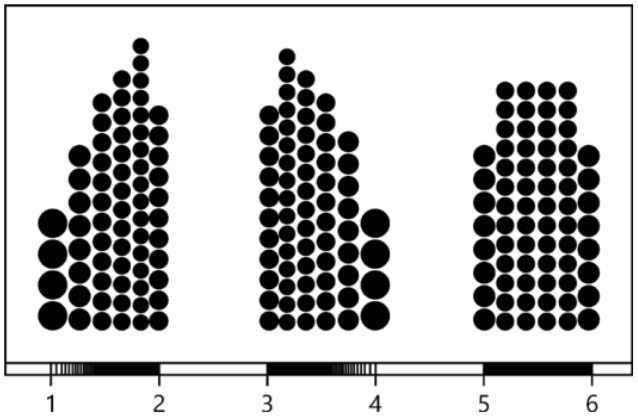
(a)



(b)



(a) Single left-to-right pass

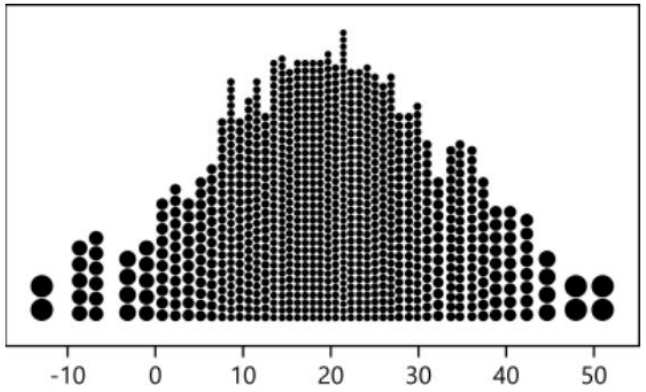


(b) Two opposed passes combined

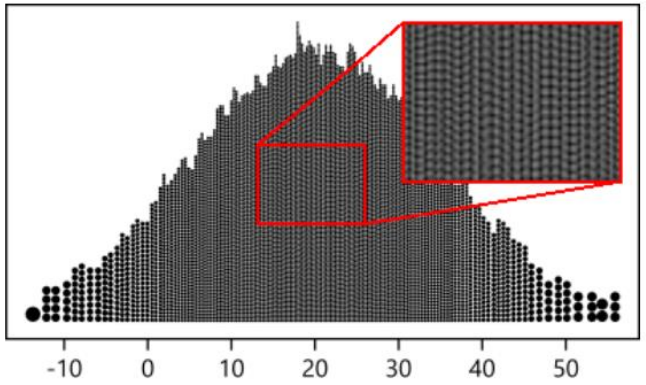
[N. Rodrigues and D. Weiskopf, "Nonlinear Dot Plots," in IEEE Transactions on Visualization and Computer Graphics, doi: 10.1109/TVCG.2017.2744018.]

非线性点图

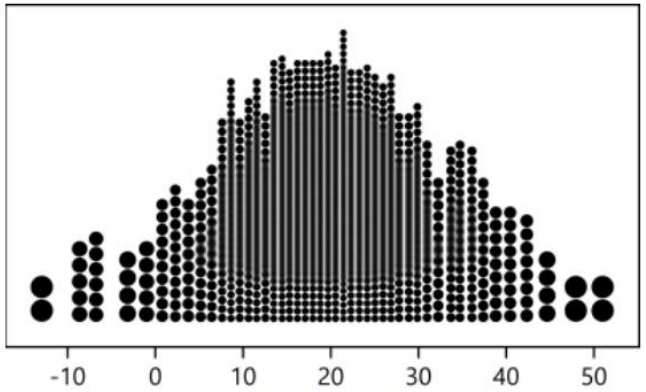
- 绘制



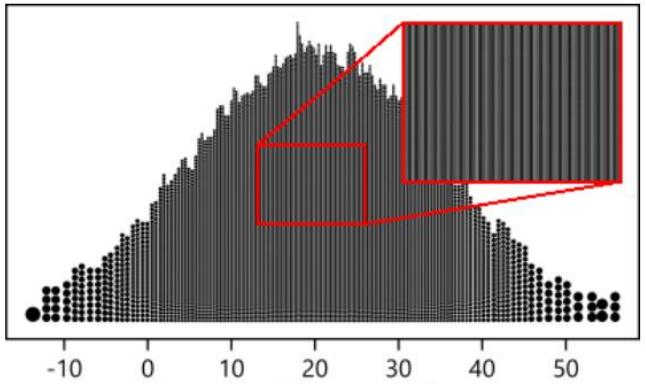
(a) 1,000 dots without blur



(b) 10,000 dots without blur



(c) 1,000 dots with blur



(d) 10,000 dots with blur

[N. Rodrigues and D. Weiskopf, "Nonlinear Dot Plots," in IEEE Transactions on Visualization and Computer Graphics, doi: 10.1109/TVCG.2017.2744018.]

非线性点图的改进

- 非线性点图按照固定的列显示；存在严重moire´ 效应

Relaxed Dot Plots: Faithful Visualization of Samples and Their Distribution

Nils Rodrigues, Christoph Schulz, Sören Döring, Daniel Baumgartner, Tim Krake, and Daniel Weiskopf

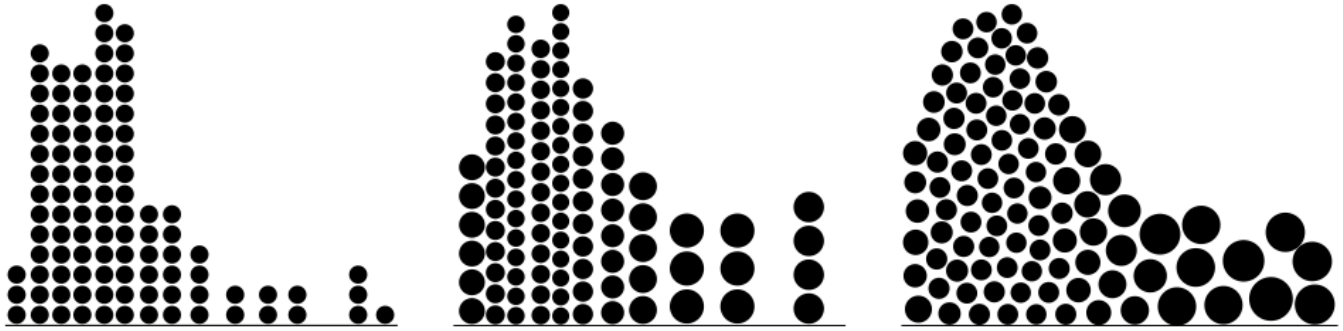
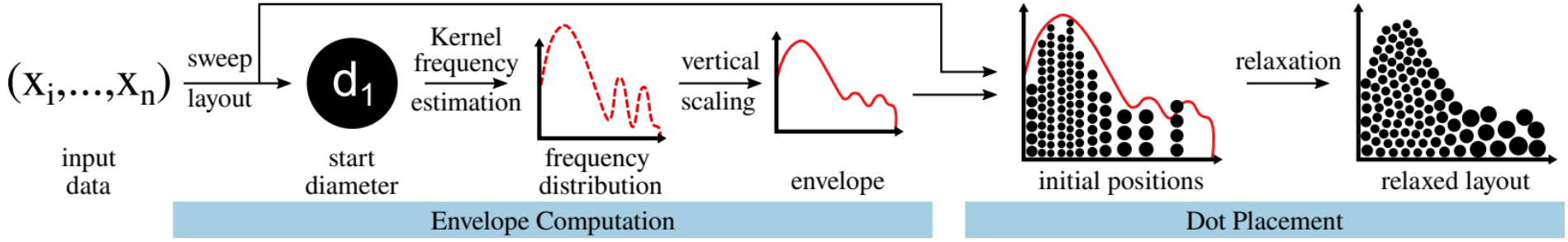
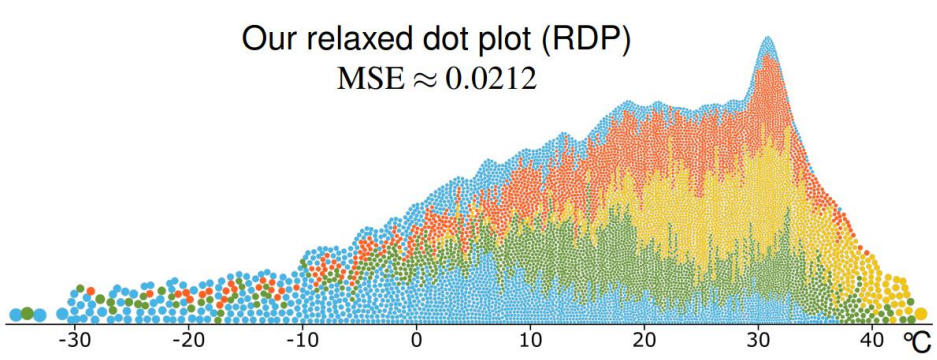
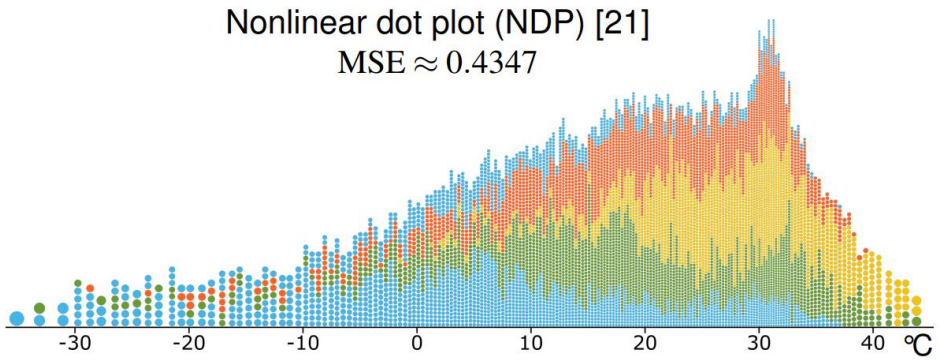


Fig. 2: A column-based linear layout (left), a nonlinear layout (middle), and our relaxed layout, constrained to a more faithful envelope with locally equidistant dot spacing (right).

[N. Rodrigues, C. Schulz, S. Doring, D. Baumgartner, T. Krake and D. Weiskopf, "Relaxed Dot Plots: Faithful Visualization of Samples and Their Distribution," in IEEE Transactions on Visualization and Computer Graphics, 1912, doi: 10.1109/TVCG.2022.3209429.]





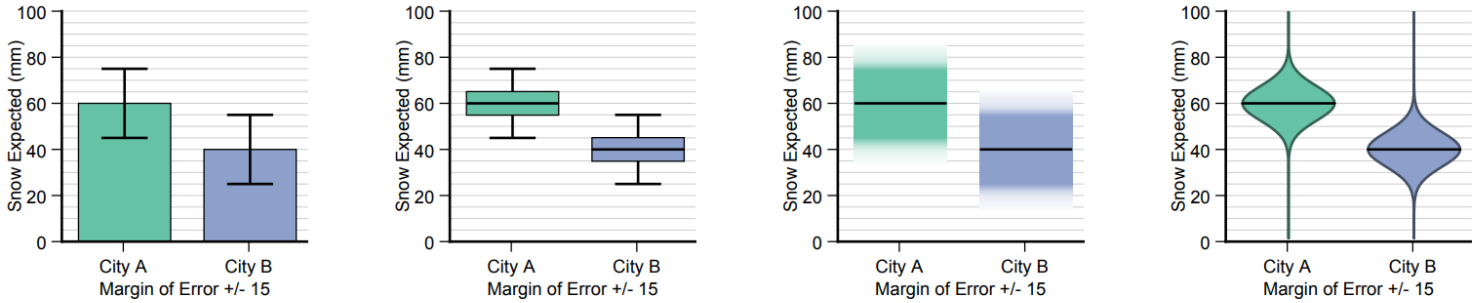


[N. Rodrigues, C. Schulz, S. Doring, D. Baumgartner, T. Krake and D. Weiskopf, "Relaxed Dot Plots: Faithful Visualization of Samples and Their Distribution," in IEEE Transactions on Visualization and Computer Graphics, 1912, doi: 10.1109/TVCG.2022.3209429.]

传统方法表示数据分布的问题

Error Bars Considered Harmful: Exploring Alternate Encodings for Mean and Error

Michael Correll *Student Member, IEEE*, and Michael Gleicher *Member, IEEE*



(a) **Bar chart** with error bars: the height of the bars encodes the sample mean, and the whiskers encode a 95% t-confidence interval.

(b) **Modified box plot**: The whiskers are the 95% t-confidence interval, the box is a 50% t-confidence interval.

(c) **Gradient plot**: the transparency of the colored region corresponds to the cumulative density function of a t-distribution.

(d) **Violin plot**: the width of the colored region corresponds to the probability density function of a t-distribution.

Fig. 1. Four encodings for mean and error evaluated in this work. Each prioritizes a different aspect of mean and uncertainty, and results in different patterns of judgment and comprehension for tasks requiring statistical inferences.

[M. Correll and M. Gleicher, "Error Bars Considered Harmful: Exploring Alternate Encodings for Mean and Error," in IEEE Transactions on Visualization and Computer Graphics, doi: 10.1109/TVCG.2014.2346298.]

Looks Good To Me: Visualizations As Sanity Checks

Michael Correll, Mingwei Li, Gordon Kindlmann, and Carlos Scheidegger

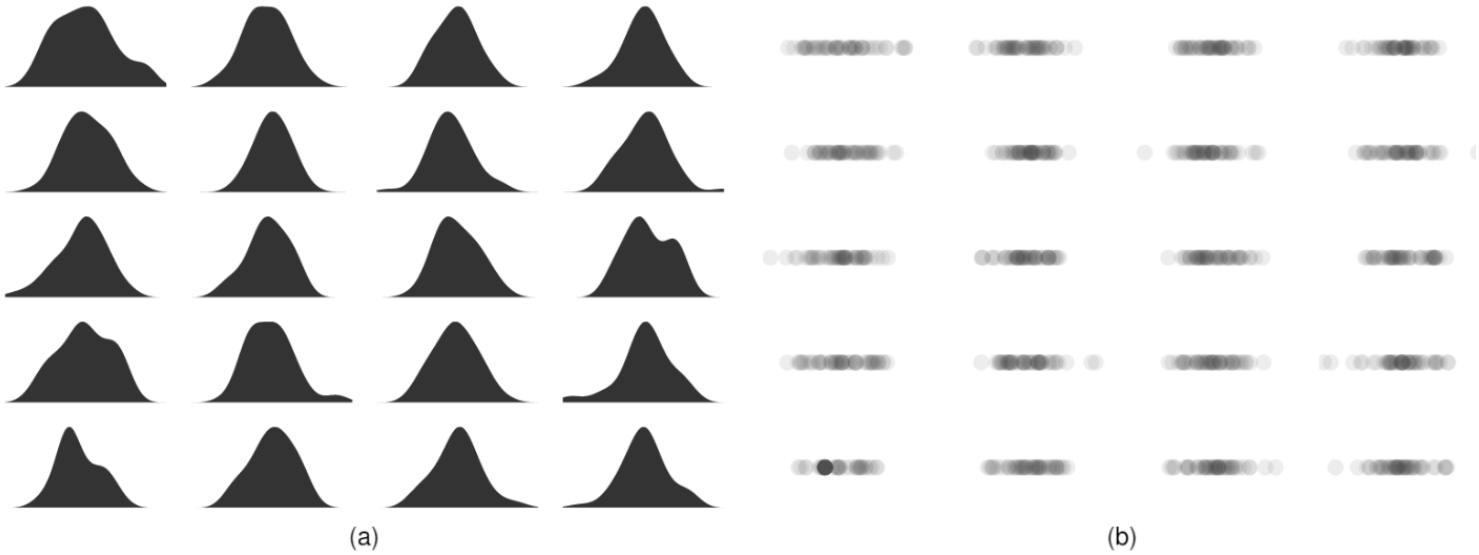


Fig. 1: Example lineups from our evaluation. Both Fig. 1a and 1b show the same univariate datasets. 19 of these charts are "innocent" random samples from a Gaussian. One "guilty" chart is mostly random draws, but 20% of samples have an identical value (an extraneous mode). The oversmoothed density plot makes this abnormality difficult to see (participants were only 35% accurate at picking out the correct density plot). Low opacity dot plots, however, make the dark black dot of the mode easier to detect (85% accuracy). See §5.1 for the right answer.

[M. Correll, M. Li, G. Kindlmann and C. Scheidegger, "Looks Good To Me: Visualizations As Sanity Checks," in IEEE Transactions on Visualization and Computer Graphics, doi: 10.1109/TVCG.2018.2864907.]

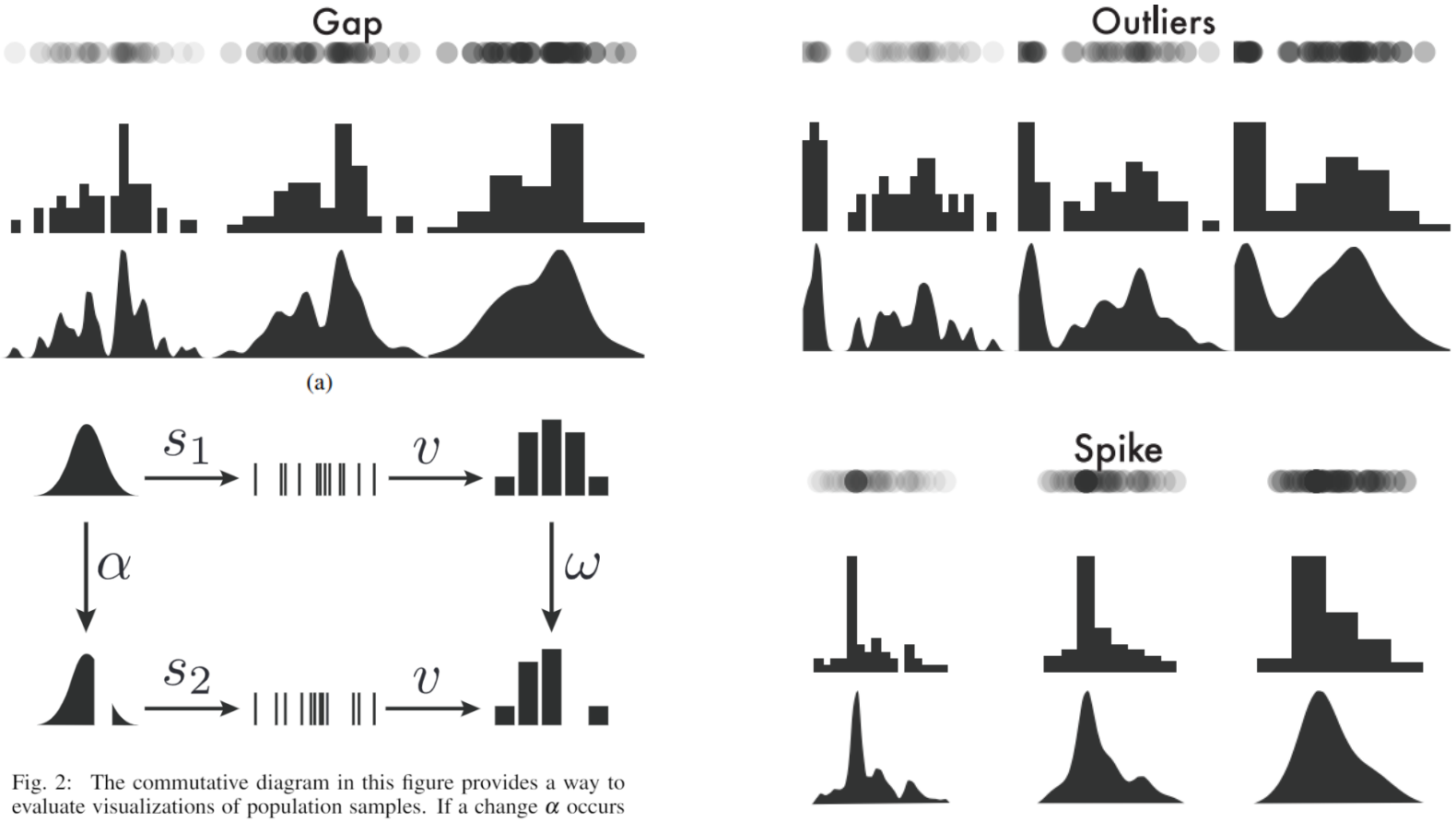
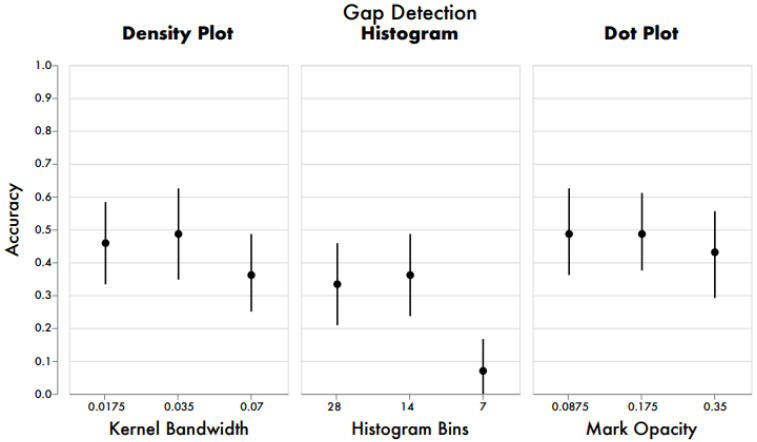
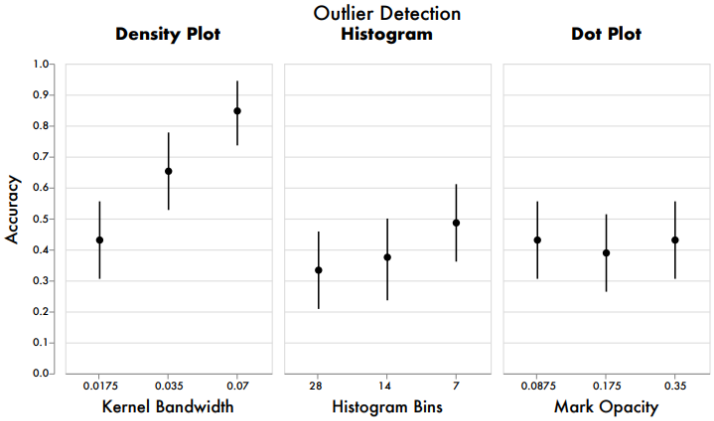


Fig. 2: The commutative diagram in this figure provides a way to evaluate visualizations of population samples. If a change α occurs in the population distribution (for instance, the introduction of a flaw such as a region of missing values), we expect to see a proportionally large change in the visualization ω. However, the data to be encoded is often a sample of this unknown distribution: this sampling s can also introduce visual changes in the resulting mapping from data to visualization v.

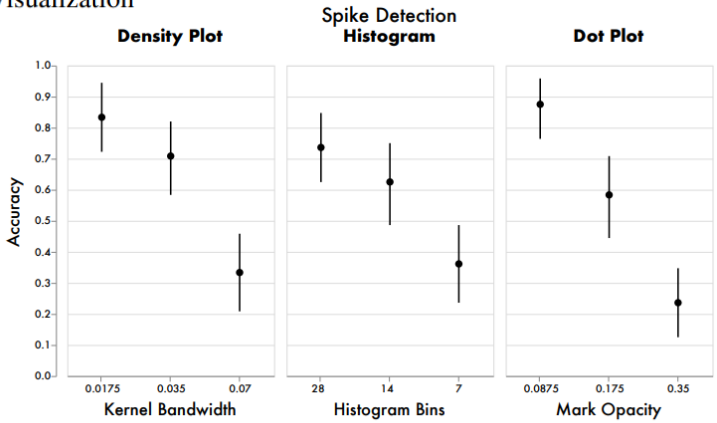
[M. Correll, M. Li, G. Kindlmann and C. Scheidegger, "Looks Good To Me: Visualizations As Sanity Checks," in IEEE Transactions on Visualization and Computer Graphics, doi: 10.1109/TVCG.2018.2864907.]



(a) Gap Detection by Visualization



(b) Outlier Detection by Visualization



(c) Spike Detection by Visualization

[M. Correll, M. Li, G. Kindlmann and C. Scheidegger, "Looks Good To Me: Visualizations As Sanity Checks," in IEEE Transactions on Visualization and Computer Graphics, doi: 10.1109/TVCG.2018.2864907.]

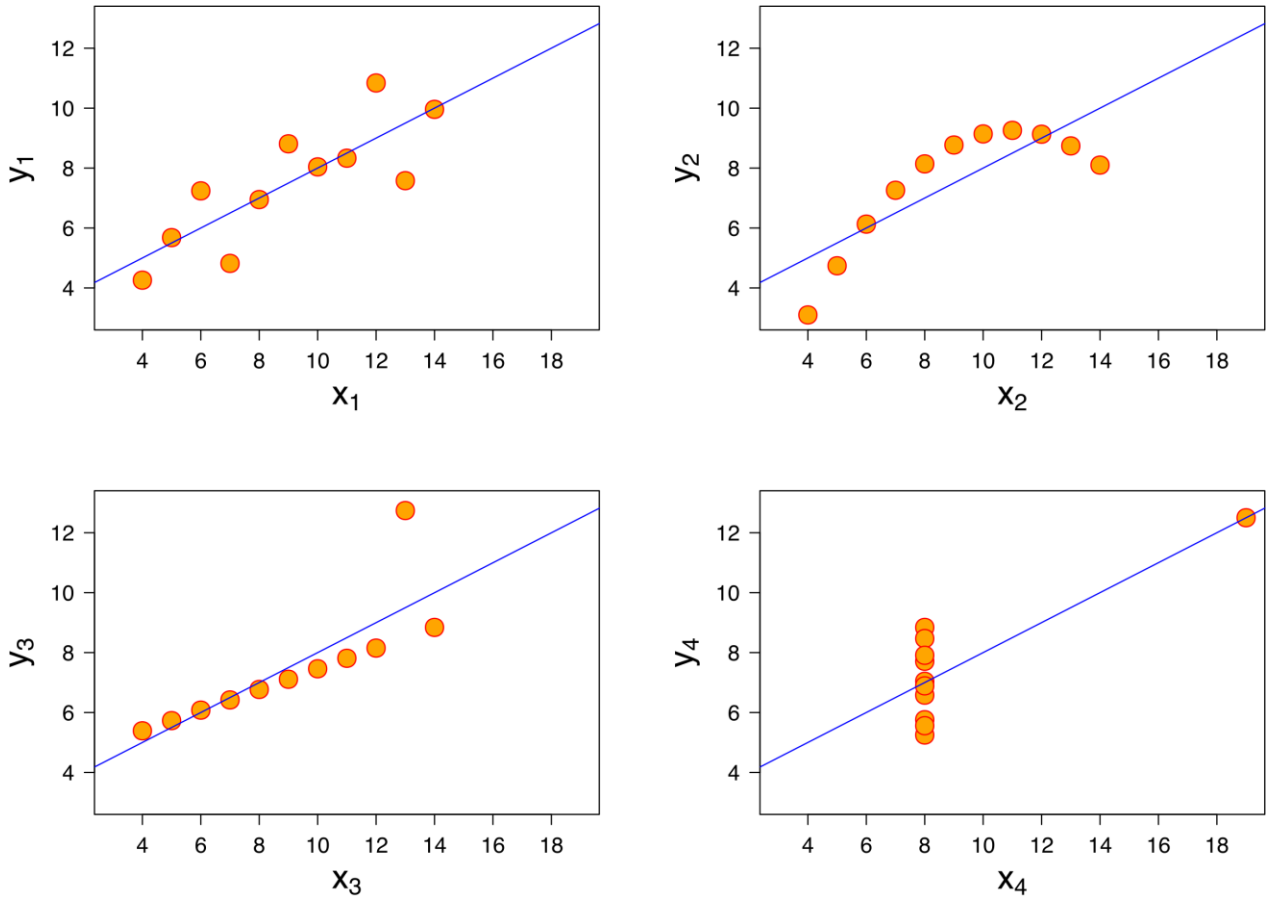
多维度表格数据可视化

- 散点图，散点图矩阵
- 平行坐标系
- 降维可视化
- ……

fixed acidity	volatile acidity	citric acid	residual sugar	chlorides	free sulfur dioxide	total sulfur dioxide	density	pH	sulphates	alcohol	quality
7.4	0.7	0	1.9	0.076	11	34	0.9978	3.51	0.56	9.4	5
7.8	0.88	0	2.6	0.098	25	67	0.9968	3.2	0.68	9.8	5
7.8	0.76	0.04	2.3	0.092	15	54	0.997	3.26	0.65	9.8	5
11.2	0.28	0.56	1.9	0.075	17	60	0.998	3.16	0.58	9.8	6
7.4	0.7	0	1.9	0.076	11	34	0.9978	3.51	0.56	9.4	5
7.4	0.66	0	1.8	0.075	13	40	0.9978	3.51	0.56	9.4	5
7.9	0.6	0.06	1.6	0.069	15	59	0.9964	3.3	0.46	9.4	5
7.3	0.65	0	1.2	0.065	15	21	0.9946	3.39	0.47	10	7
7.8	0.58	0.02	2	0.073	9	18	0.9968	3.36	0.57	9.5	7
7.5	0.5	0.36	6.1	0.071	17	102	0.9978	3.35	0.8	10.5	5
6.7	0.58	0.08	1.8	0.097	15	65	0.9959	3.28	0.54	9.2	5
7.5	0.5	0.36	6.1	0.071	17	102	0.9978	3.35	0.8	10.5	5
5.6	0.615	0	1.6	0.089	16	59	0.9943	3.58	0.52	9.9	5
7.8	0.61	0.29	1.6	0.114	9	29	0.9974	3.26	1.56	9.1	5
8.9	0.62	0.18	3.8	0.176	52	145	0.9986	3.16	0.88	9.2	5
8.9	0.62	0.19	3.9	0.17	51	148	0.9986	3.17	0.93	9.2	5
8.5	0.28	0.56	1.8	0.092	35	103	0.9969	3.3	0.75	10.5	7
8.1	0.56	0.28	1.7	0.368	16	56	0.9968	3.11	1.28	9.3	5
7.4	0.59	0.08	4.4	0.086	6	29	0.9974	3.38	0.5	9	4
7.9	0.32	0.51	1.8	0.341	17	56	0.9969	3.04	1.08	9.2	6
8.9	0.22	0.48	1.8	0.077	29	60	0.9968	3.39	0.53	9.4	6
7.6	0.39	0.31	2.3	0.082	23	71	0.9982	3.52	0.65	9.7	5
7.9	0.43	0.21	1.6	0.106	10	37	0.9966	3.17	0.91	9.5	5
8.5	0.49	0.11	2.3	0.084	9	67	0.9968	3.17	0.53	9.4	5
6.9	0.4	0.14	2.4	0.085	21	40	0.9968	3.43	0.63	9.7	6
6.3	0.39	0.16	1.4	0.08	11	23	0.9955	3.34	0.56	9.3	5
7.6	0.41	0.24	1.8	0.08	4	11	0.9962	3.28	0.59	9.5	5
7.9	0.43	0.21	1.6	0.106	10	37	0.9966	3.17	0.91	9.5	5
7.1	0.71	0	1.9	0.08	14	35	0.9972	3.47	0.55	9.4	5
7.8	0.645	0	2	0.082	8	16	0.9964	3.38	0.59	9.8	6
6.7	0.675	0.07	2.4	0.089	17	82	0.9958	3.35	0.54	10.1	5

散点图 Scatterplot

- 将数据的两个维度分量的位置在笛卡尔坐标系中
- 经典例子：Anscombe’s quartet



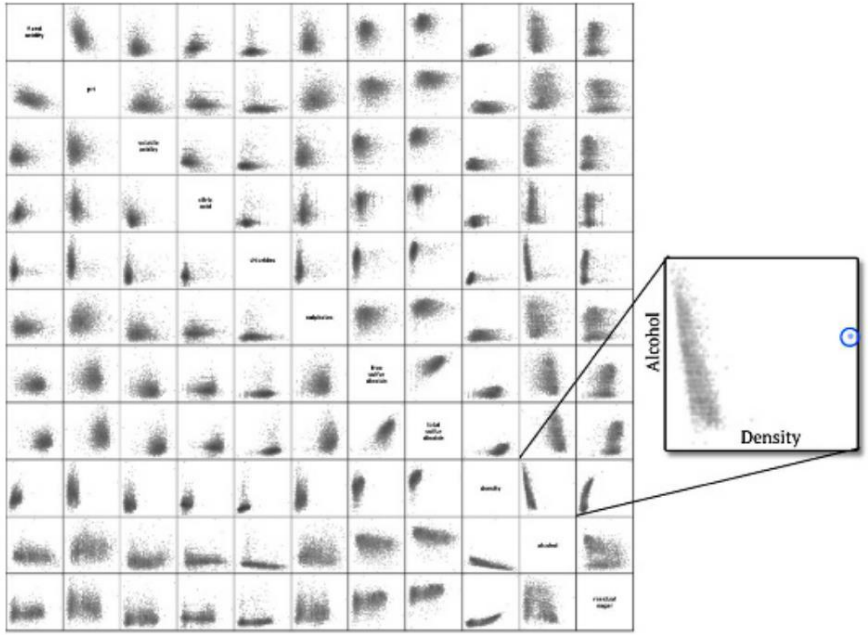
Anscombe’s quartet：四个分布不同的数据集有完全相同的线性拟合结果

[By Anscombe.svg: Schutz(label using subscripts): Avenue - Anscombe.svg, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=9838454]

散点图矩阵 Scatterplot matrix (SPLOM)

- 将散点图按照所有变量/维度两两组合成矩阵（每一行/列是一个维度）
- 可扩展性问题

[https://observablehq.com/@d3/scatterplot-matrix]

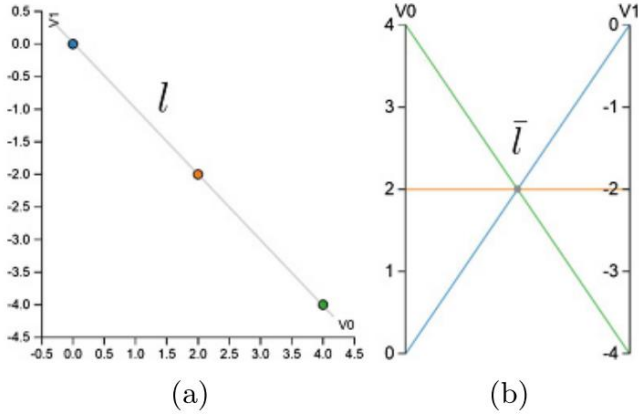


葡萄酒化学成分数据可视化 *注意离群点

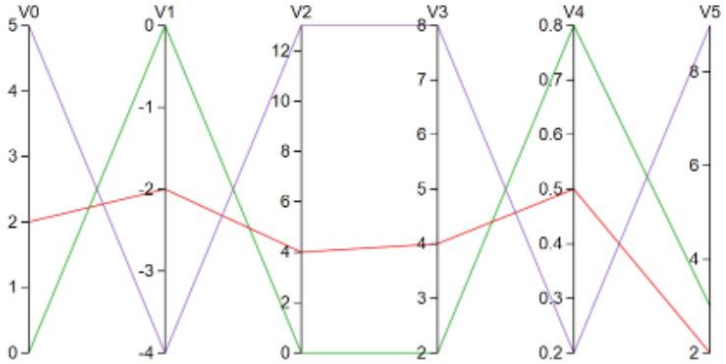
[Source: L. Zhou]

平行坐标系 Parallel coordinates

- 平行放置坐标轴，以折线可视化数据
- 维度扩展性好；离群点

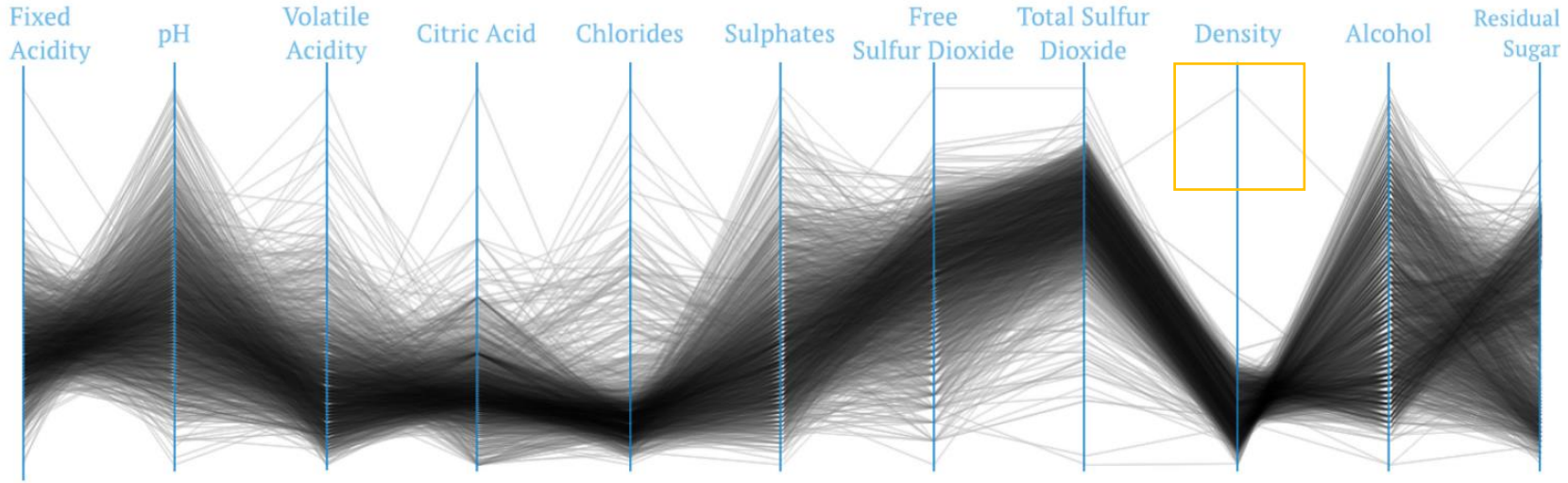


(a) 笛卡尔坐标系　(b) 平行坐标系



V0	V1	V2	V3	V4	V5
0	0	0	2	0.8	3
2	-2	4	4	0.5	2
5	-4	13	8	0.2	9

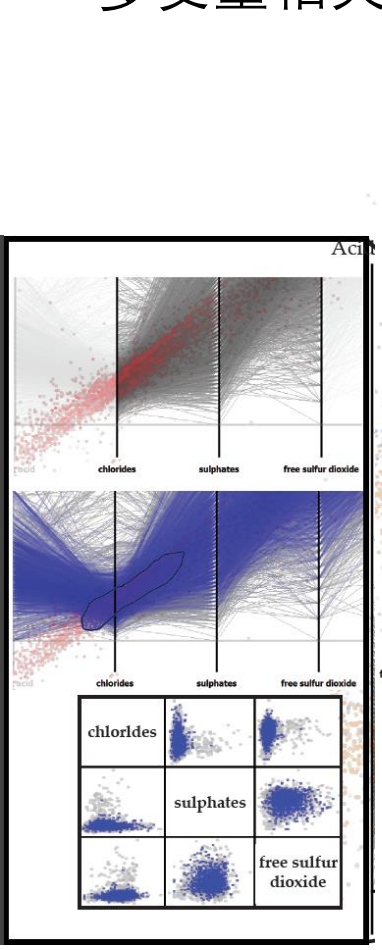
[Source: L. Zhou]

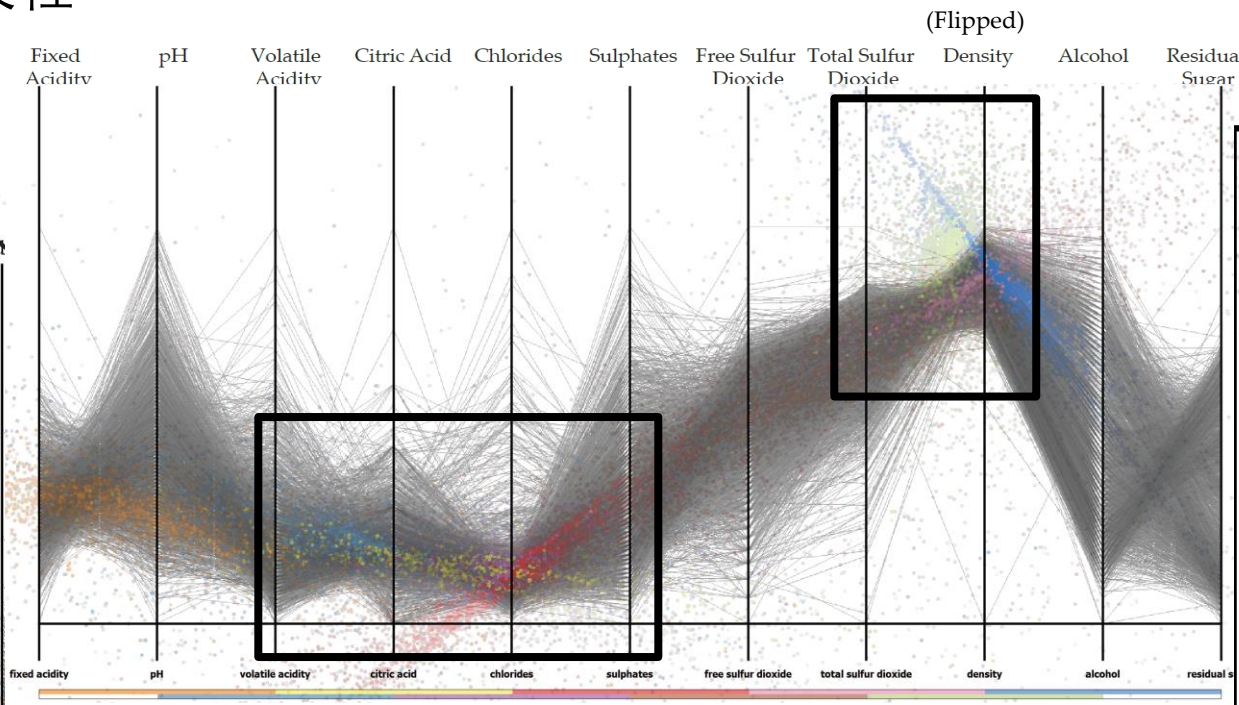


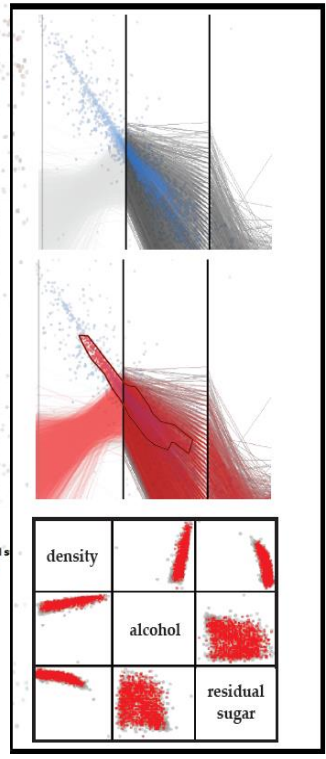
葡萄酒化学成分数据可视化 *对比散点图矩阵中的离群点

平行坐标系 Parallel coordinates

- 问题：遮挡；相关性；聚类……
- 多变量相关性



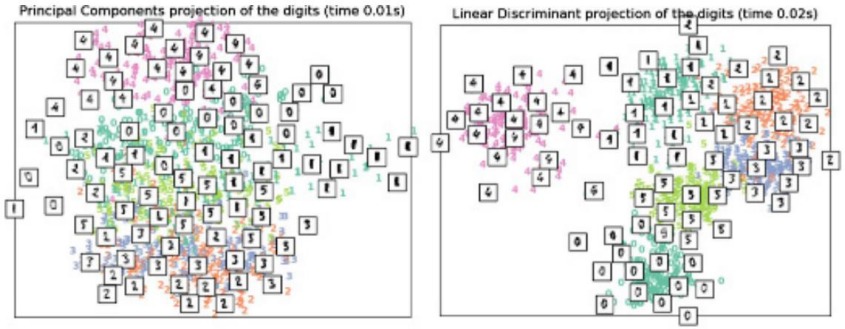




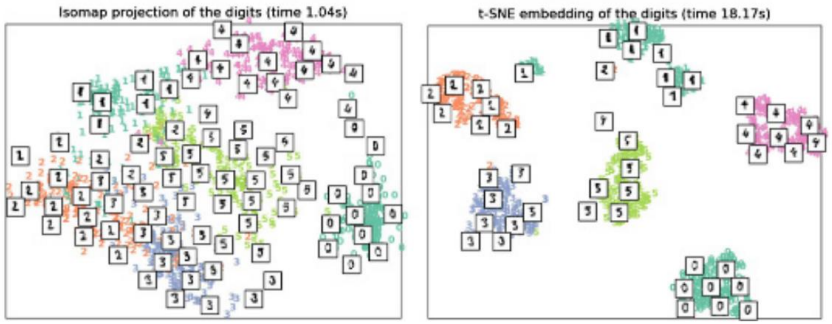
[L. Zhou and D. Weiskopf (2017), "Indexed-Points Parallel Coordinates Visualization of Multivariate Correlations," doi: 10.1109/TVCG.2017.2698041.]

降维可视化

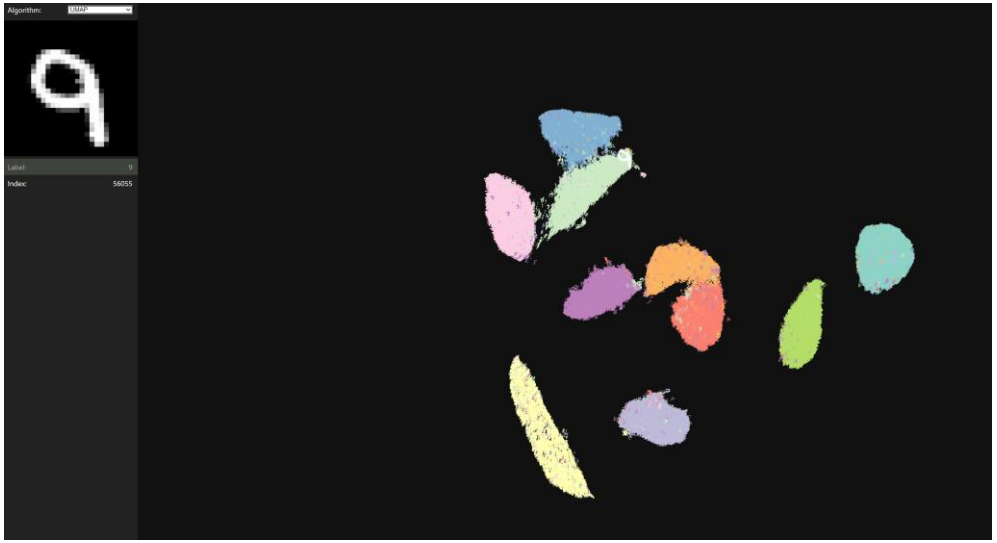
- 使用降维(dimensionality reduction)算法将多维度数据降成低维(一般是二维)
- 选择合适的降维算法
  - 线性降维 PCA, 线性版本MDS
  - 非线性降维 MDS, LLE, Isomap, tSNE, Umap……



(a) PCA (b) LDA



(c) Isomap (d) tSNE



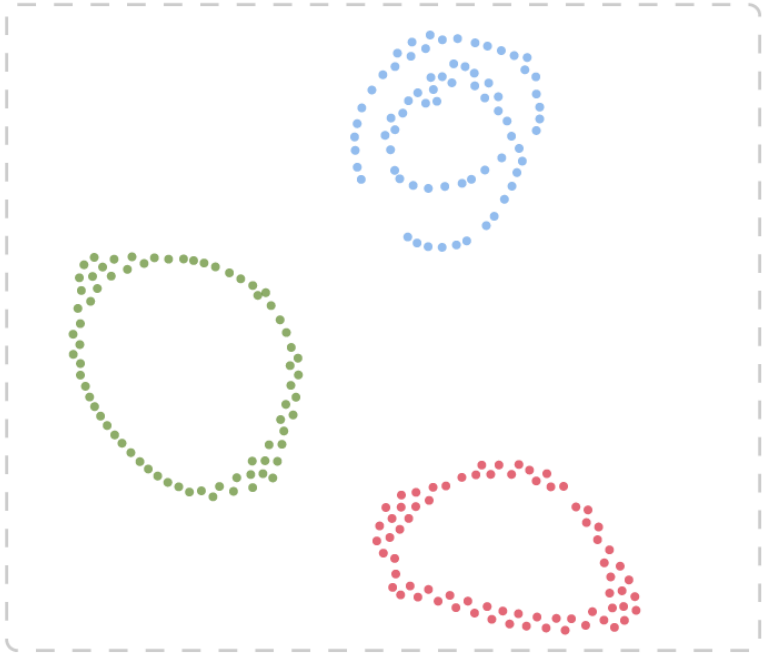
https://grantcuster.github.io/umap-explorer/

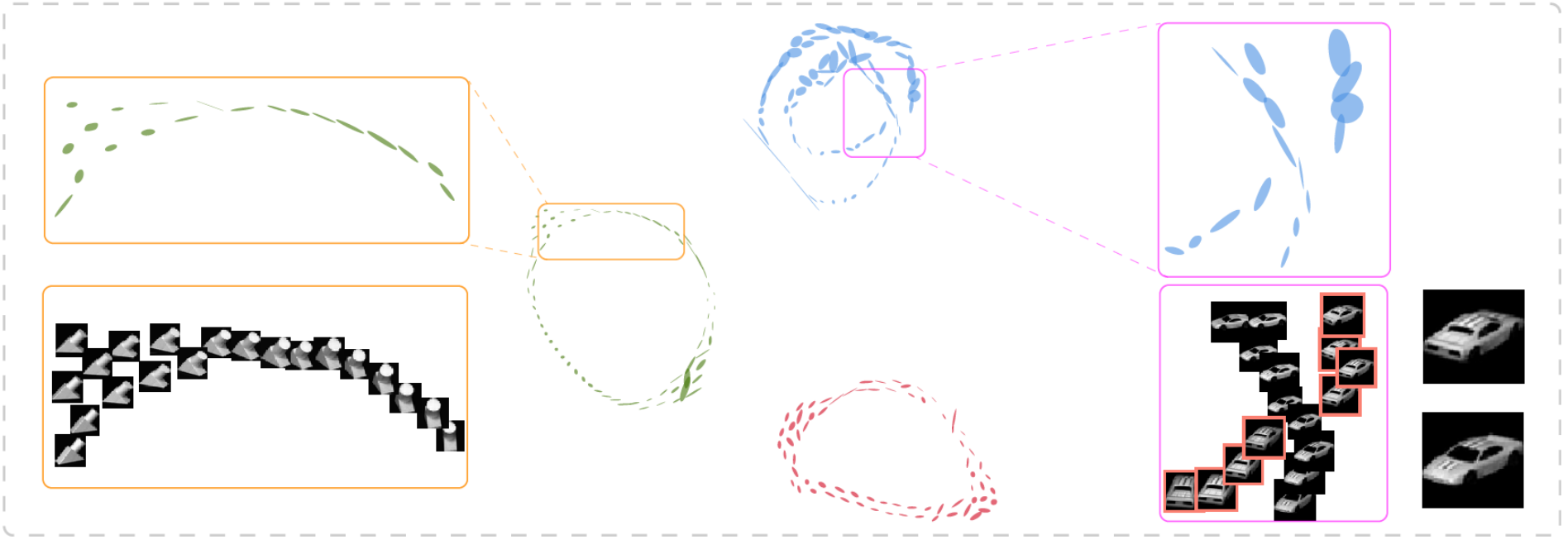
[source: L. Zhou, DR methods from http://scikit-learn.org/stable/]

降维可视化

- 可视化数据在原始维度的邻域信息在低维的投影

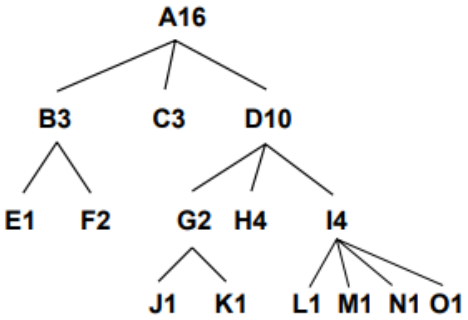
[R. Bian et al., “Implicit Multidimensional Projection of Local Subspaces," doi: 10.1109/TVCG.2020.3030368.]



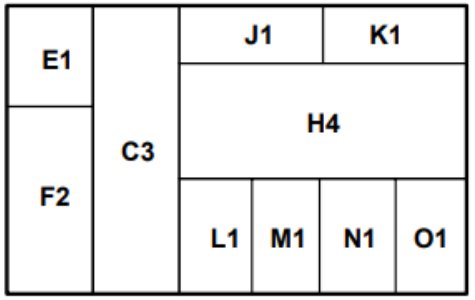


树可视化

- 层次结构 hierarchical structures
- 节点连接图 node-link diagram



Node and link diagram



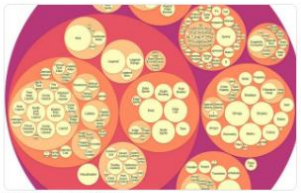
Treemap

[from J. van Wijk]


Treemap

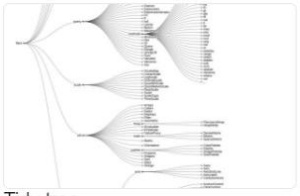

Cascaded treemap

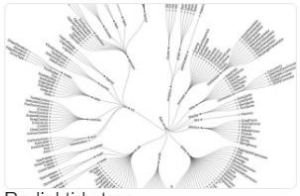

Nested treemap

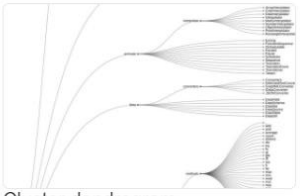

Circle packing

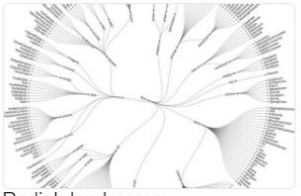

Circle packing (monochrome)

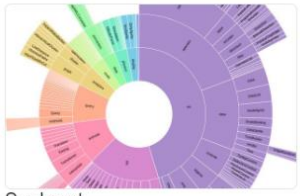

Indented tree


Tidy tree

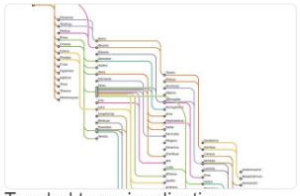

Radial tidy tree

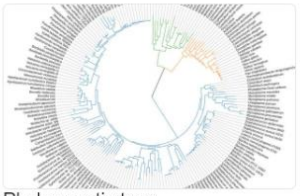

Cluster dendrogram

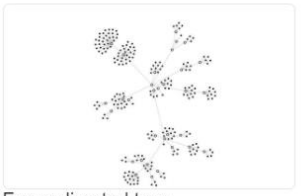

Radial dendrogram


Sunburst


Icicle


Tangled tree visualization


Phylogenetic tree

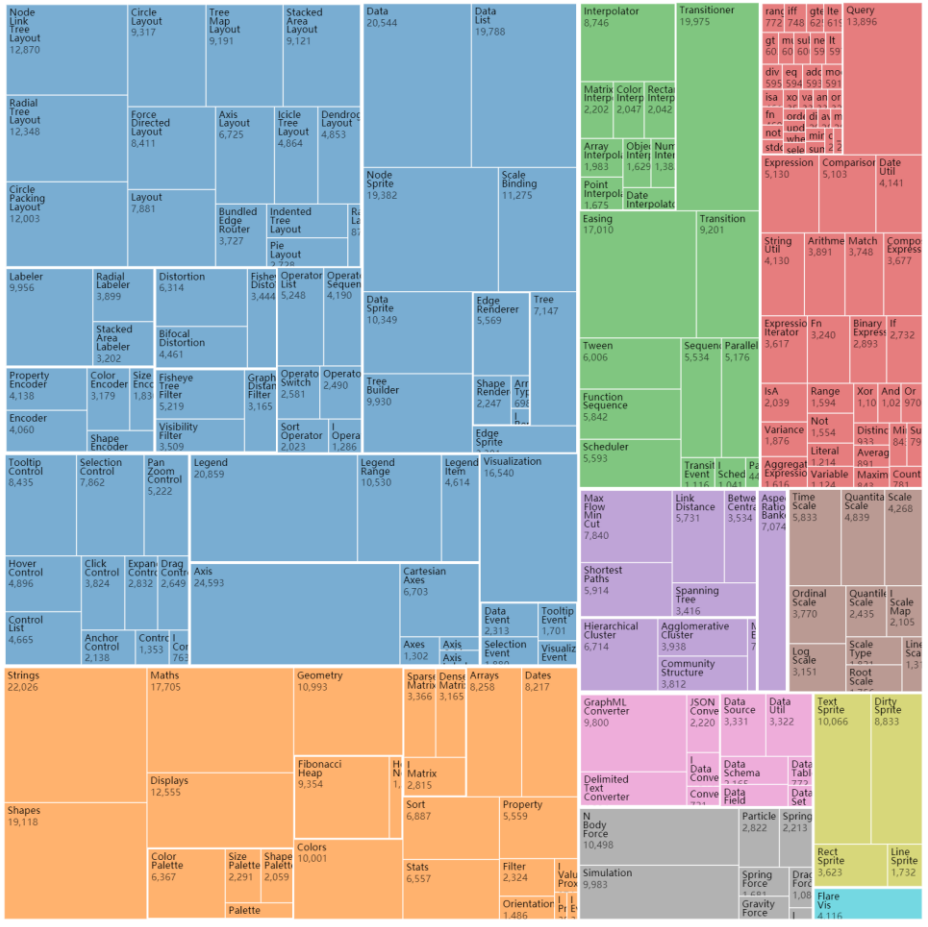

Force-directed tree

https://observablehq.com/@d3/gallery

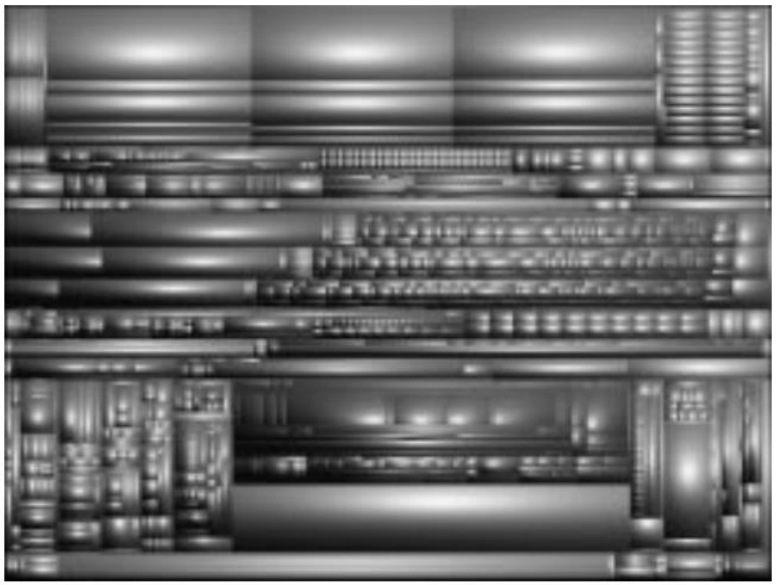
方形树图 Treemaps

- 紧凑，空间填充，递归显示层次结构
- 用方形表示结点，方形大小表示结点的数值，用方形的组织、颜色、光照等表示层次

https://eagereyes.org/techniques/treemaps



https://observablehq.com/@d3/treemap [By M. Bostock]



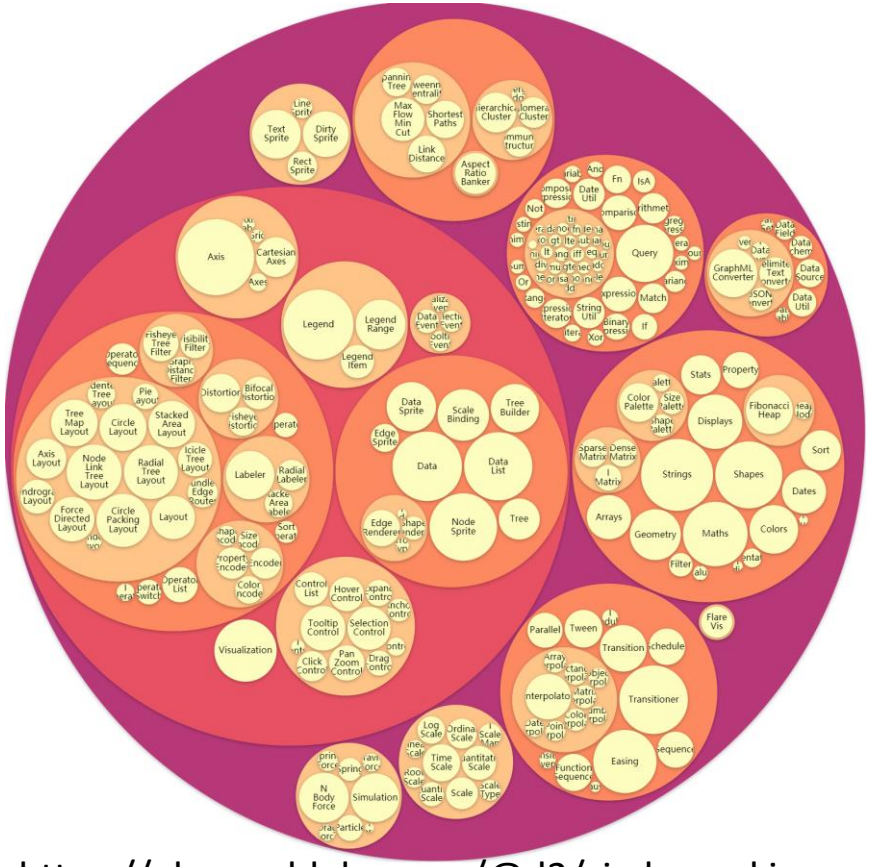
Cushion treemaps

[J. J. Van Wijk and H. Van de Wetering (1999), "Cushion treemaps: visualization of hierarchical information," doi: 10.1109/INFVIS.1999.801860.]

不必画线区分节点，更有效利用空间

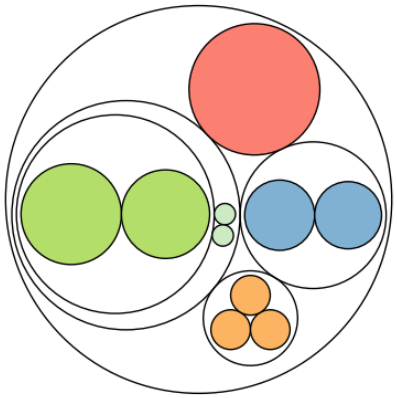
圆形树图 Circular/bubble treemaps

- 比方形树图松散，展示层次结构更清晰，方便添加额外信息和交互

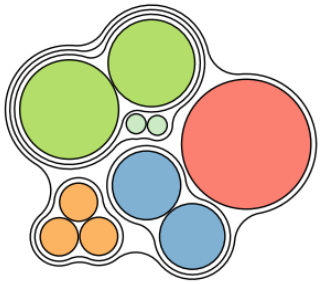


https://observablehq.com/@d3/circle-packing

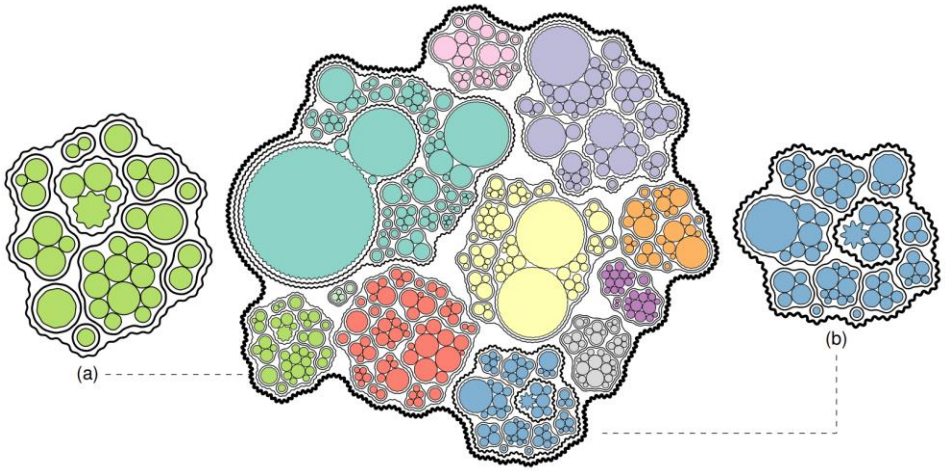
[By M. Bostock]



(a) Circular Treemap



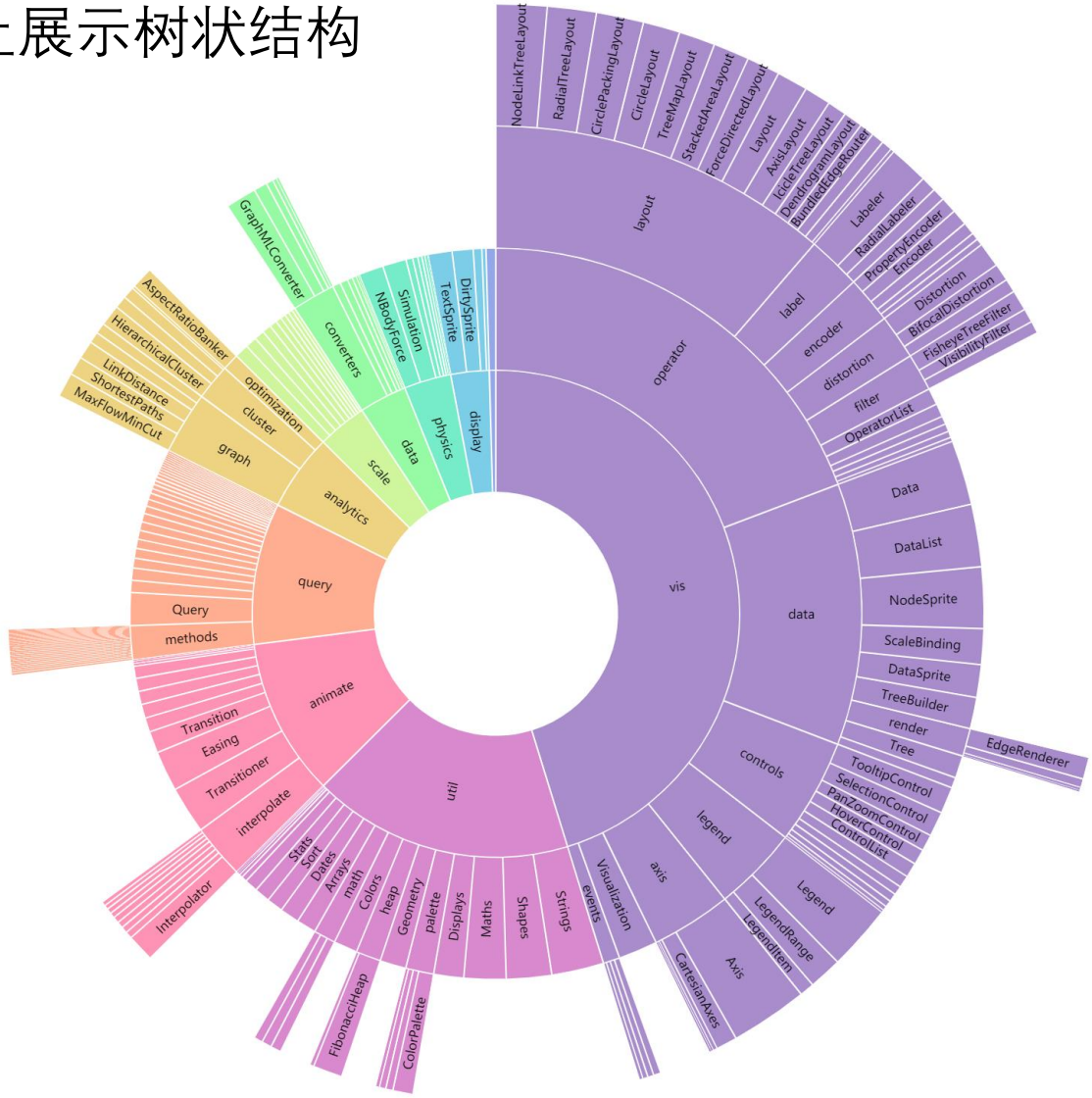
(b) Bubble Treemap



[J. Görtler et al. (2018), "Bubble Treemaps for Uncertainty Visualization," doi: 10.1109/TVCG.2017.2743959.]

Sunburst graph

- 在圆形布局上展示树状结构

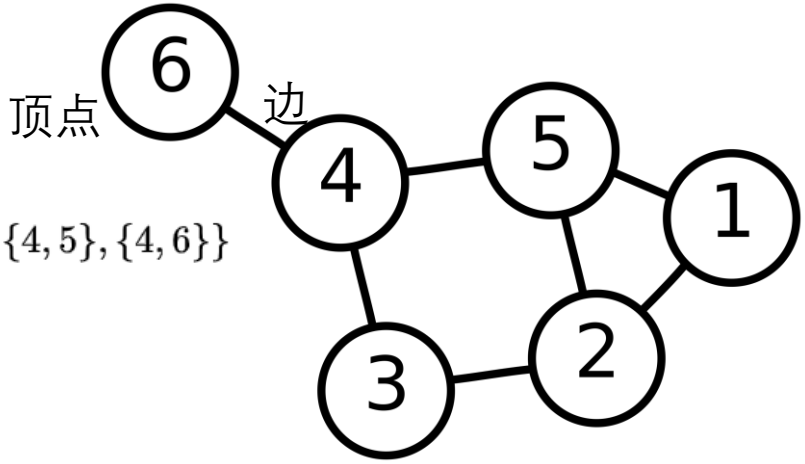


[By M. Bostock]

https://observablehq.com/@d3/sunburst

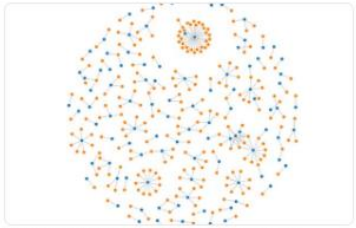
图可视化 Graph visualization

- 图
  - 顶点 vertex $V = \{1, 2, 3, 4, 5, 6\}$
  - 边 edge $E = \{\{1, 2\}, \{1, 5\}, \{2, 3\}, \{2, 5\}, \{3, 4\}, \{4, 5\}, \{4, 6\}\}$
  - 无向图 undirected graph
  - 有向图 directed graph
- 图绘制 graph drawing

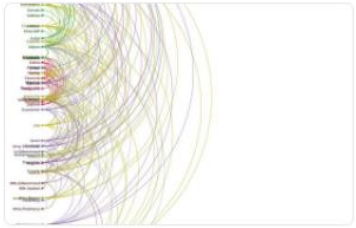


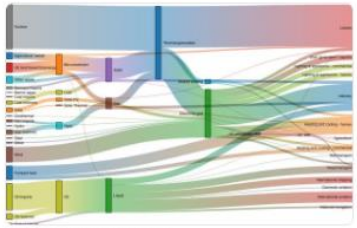
[By User:AzaToth - Image:6n-graf.png simlar input data, Public Domain, https://commons.wikimedia.org/w/index.php?curid=820489]

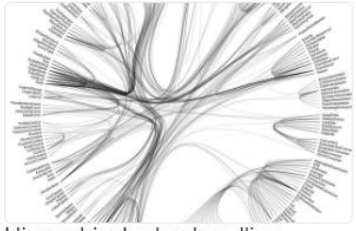

Force-directed graph

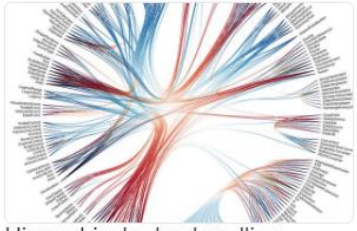

Disjoint force-directed graph

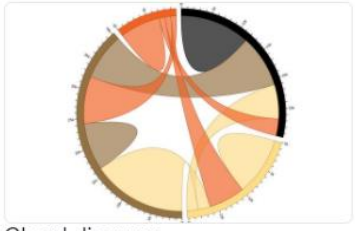

Mobile patent suits

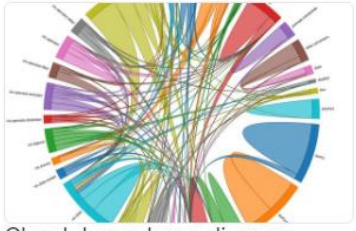

Arc diagram


Sankey diagram


Hierarchical edge bundling


Hierarchical edge bundling


Chord diagram

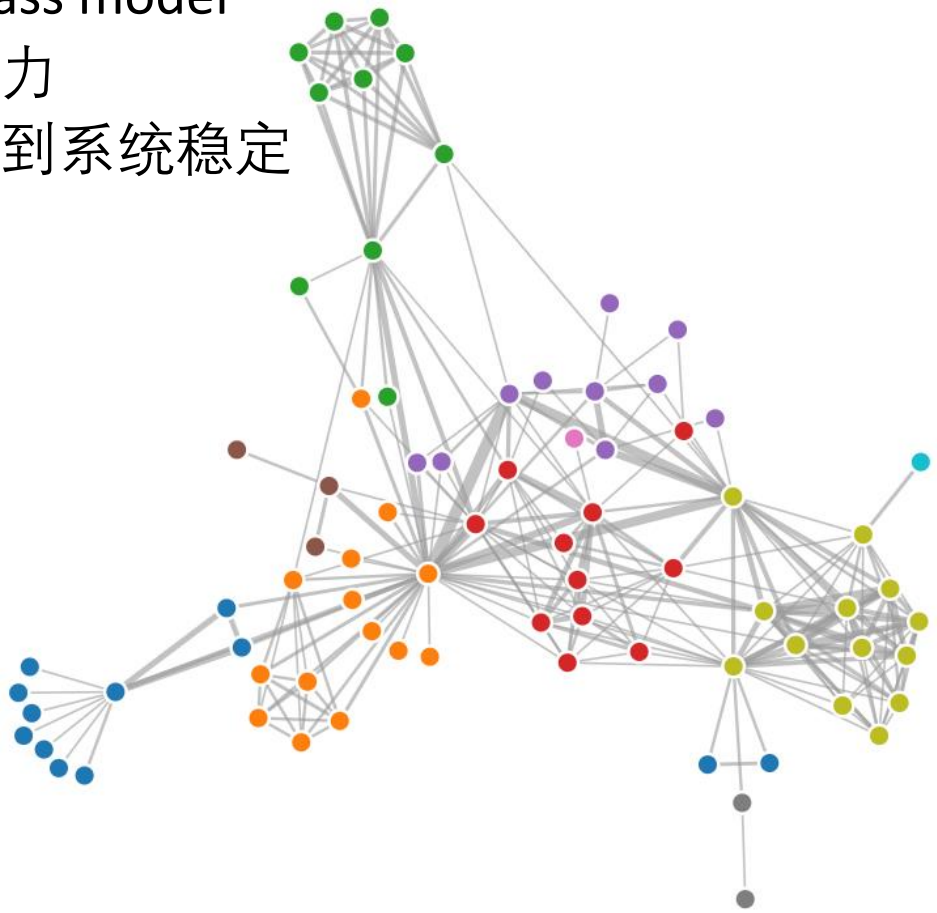

Chord dependency diagram

[By M. Bostock]

https://observablehq.com/@d3/gallery

图布局 Graph layout

- 节点连接图中如何合理布局
- 力导向布局
  - 弹簧质点模型 spring-mass model
  - 相连顶点间有引力和斥力
  - 从初始状态不断迭代直到系统稳定



[By M. Bostock] https://observablehq.com/@d3/force-directed-graph

边捆绑 Edge bundling

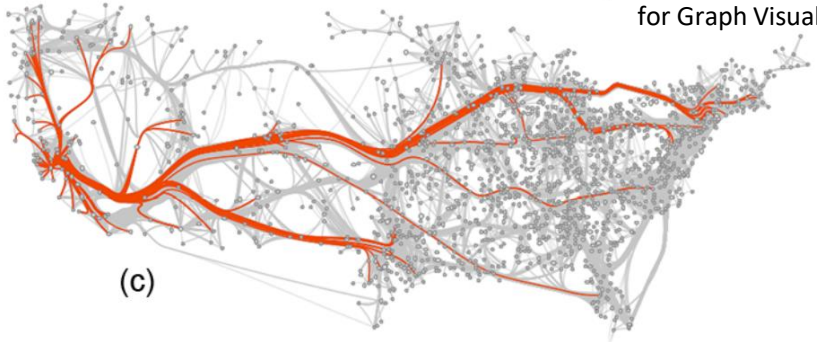
- 图的边较多时会使可视化杂乱(cluttered)，影响获取信息
- 将可视化中临近的边进行捆绑，降低杂乱程度

Figures from [D. Holten and J. J. van Wijk (2009), "Force-Directed Edge Bundling for Graph Visualization," doi: 10.1111/j.1467-8659.2009.01450.x.]

No bundling

Force-based edge bundling

[D. Holten and J. J. van Wijk (2009), "Force-Directed Edge Bundling for Graph Visualization," doi: 10.1111/j.1467-8659.2009.01450.x.]



Geometry-based edge clustering

[W. Cui et al. (2008), "Geometry-Based Edge Clustering for Graph Visualization," doi: 10.1109/TVCG.2008.135.]

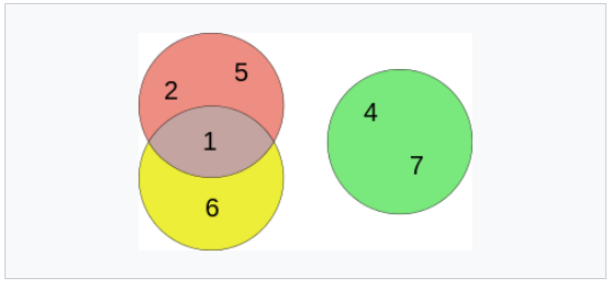
集合

- 欧拉图 Euler diagram ——不包括空集的集合间逻辑组合
- 文氏图 Venn diagram ——集合之间的所有逻辑组合（包括空集）
- 基于面积的方法

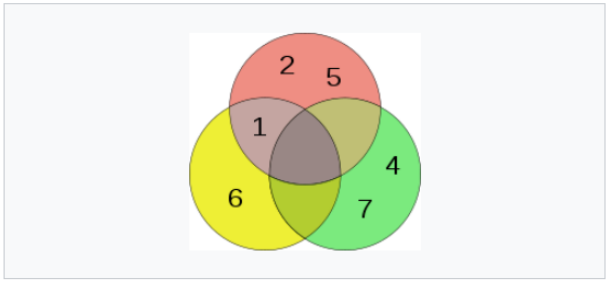
[C. Collins et al., "Bubble Sets: Revealing Set Relations with Isocontours over Existing Visualizations," doi: 10.1109/TVCG.2009.122.]

- $A = \{1, 2, 5\}$
- $B = \{1, 6\}$
- $C = \{4, 7\}$

The Euler and the Venn diagram of those sets are:



Euler diagram

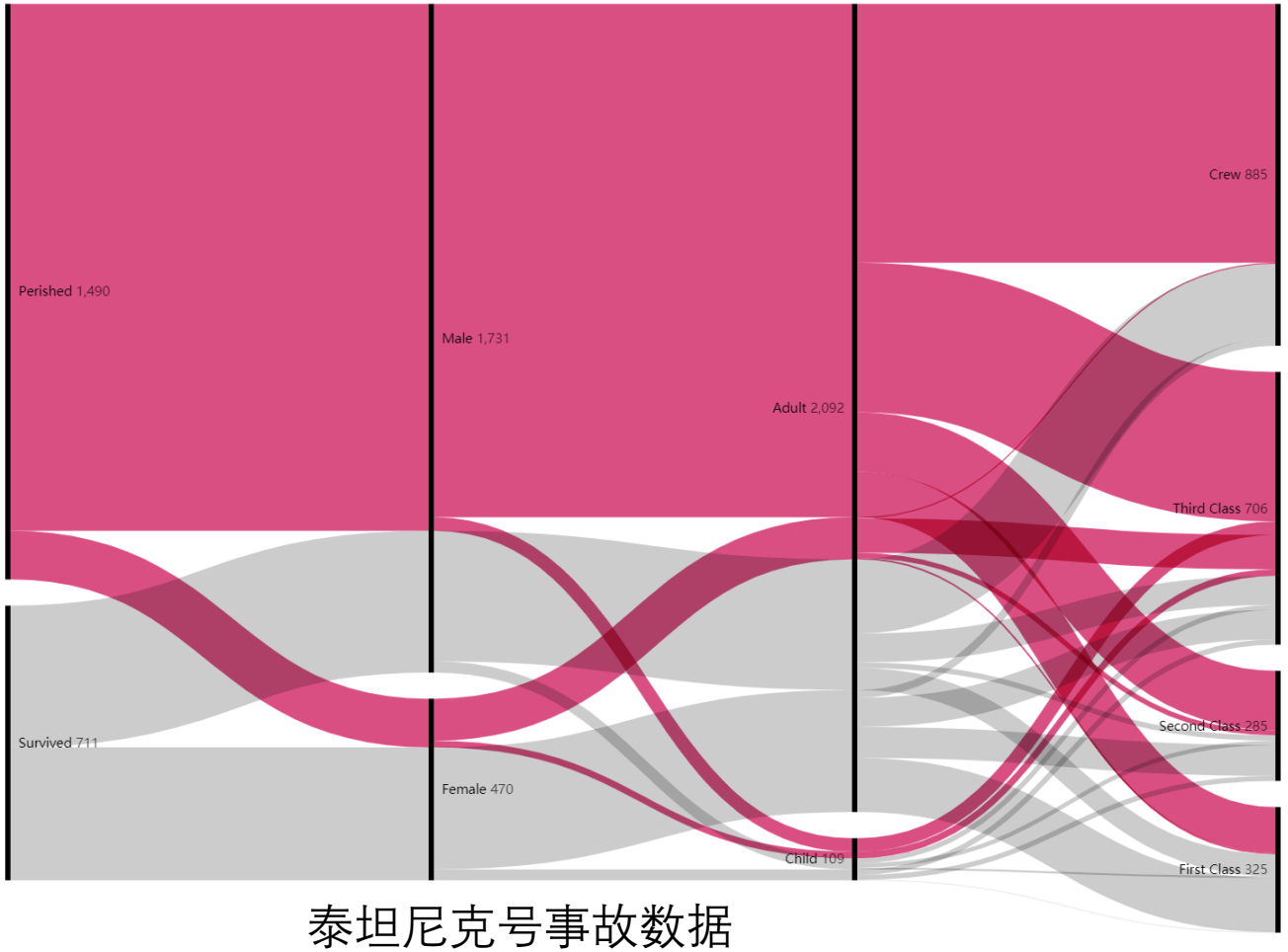


Venn diagram

[https://en.wikipedia.org/wiki/Venn_diagram]

平行集 Parallel sets

- 基于聚合的方法
- 类似于平行坐标系，但可视化分类数据



泰坦尼克号事故数据

https://observablehq.com/@d3/parallel-sets

[By M. Bostock]

文本可视化 text visualization

- 结构化的数据之外存在大量非结构化的文本
- 需要可视方式更加直观高效地理解文本

https://textvis.lnu.se/

词云 Word clouds (Wordle)

- 提供文本的简单概览：用词频控制词的大小
- 使用适当的颜色、字体、布局提升美观度

Wordle

http://www.edwordle.net/

ShapeWordle

[Y. Wang *et al*. (2020), "ShapeWordle: Tailoring Wordles using Shape-aware Archimedean Spirals," doi: 10.1109/TVCG.2019.2934783.]

词树 Word tree

- 可视化关键词和其上下文

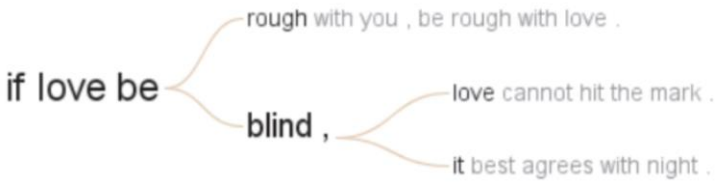
Text

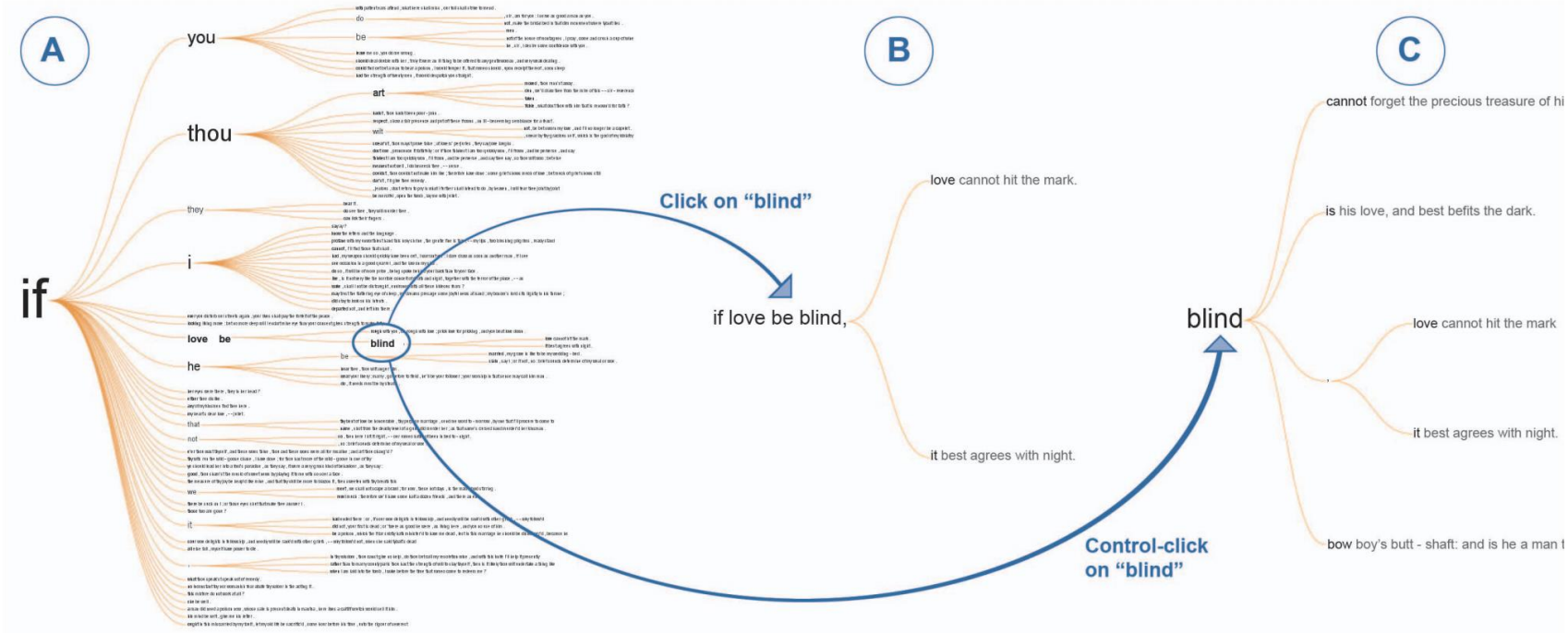
if love be rough with you , be rough with love .

if love be blind , love cannot hit the mark .

if love be blind , it best agrees with night .

WordTree

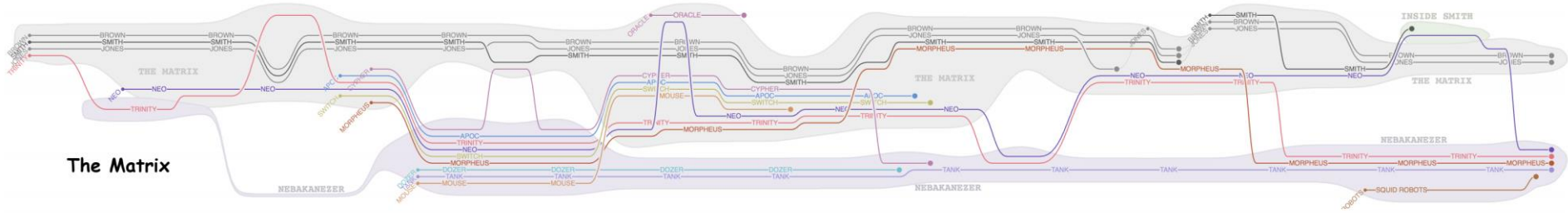




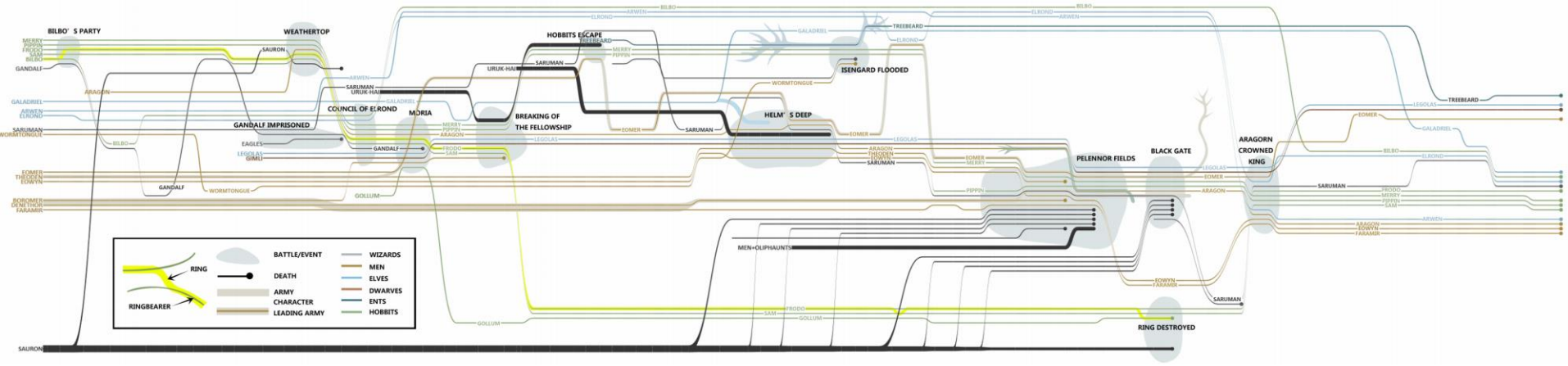
[M. Wattenberg and F. B. Viégas, (2008), "The Word Tree, an Interactive Visual Concordance," doi: 10.1109/TVCG.2008.172.]

可视化文本中的故事

- 可视化故事的发展



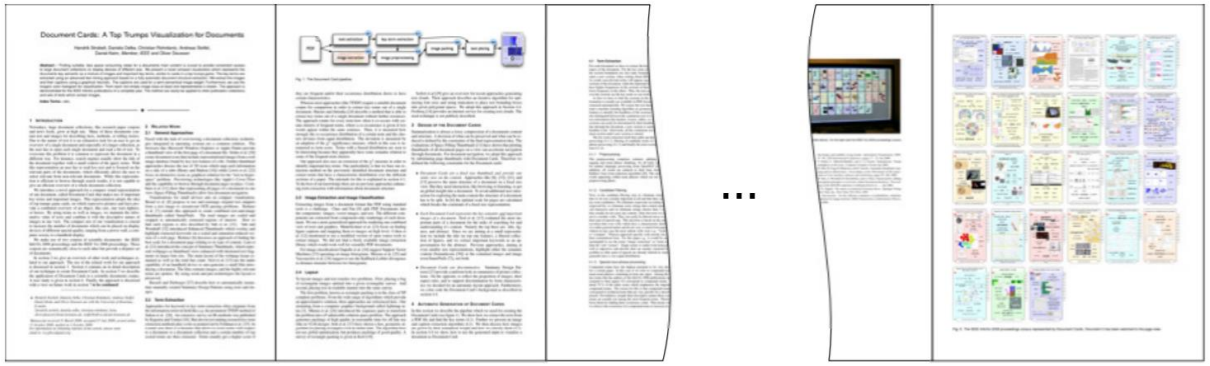
[Y. Tanahashi and K. Ma (2012), "Design Considerations for Optimizing Storyline Visualizations," doi: 10.1109/TVCG.2012.212.]

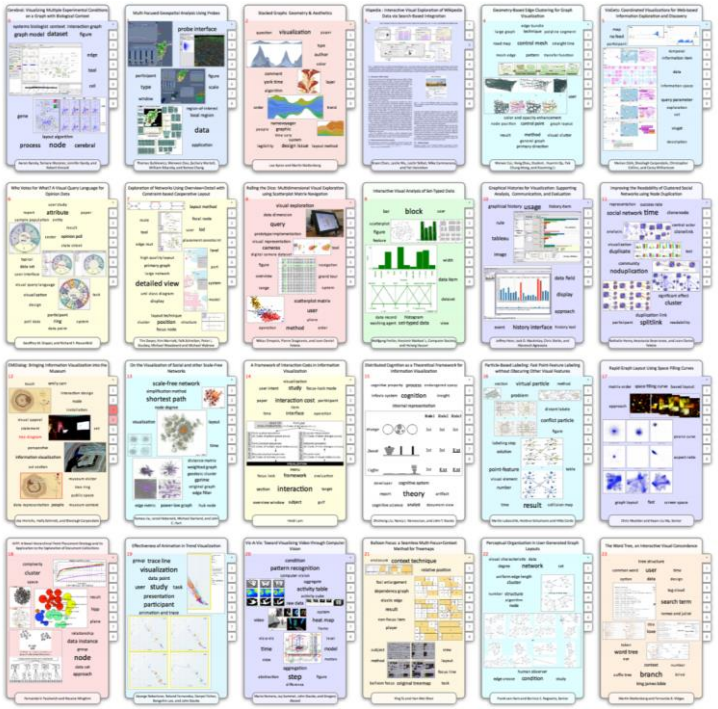


[S. Liu et al. (2013), "StoryFlow: Tracking the Evolution of Stories," doi: 10.1109/TVCG.2013.196.]

多文本可视化

- 总结科学文本重要信息和图

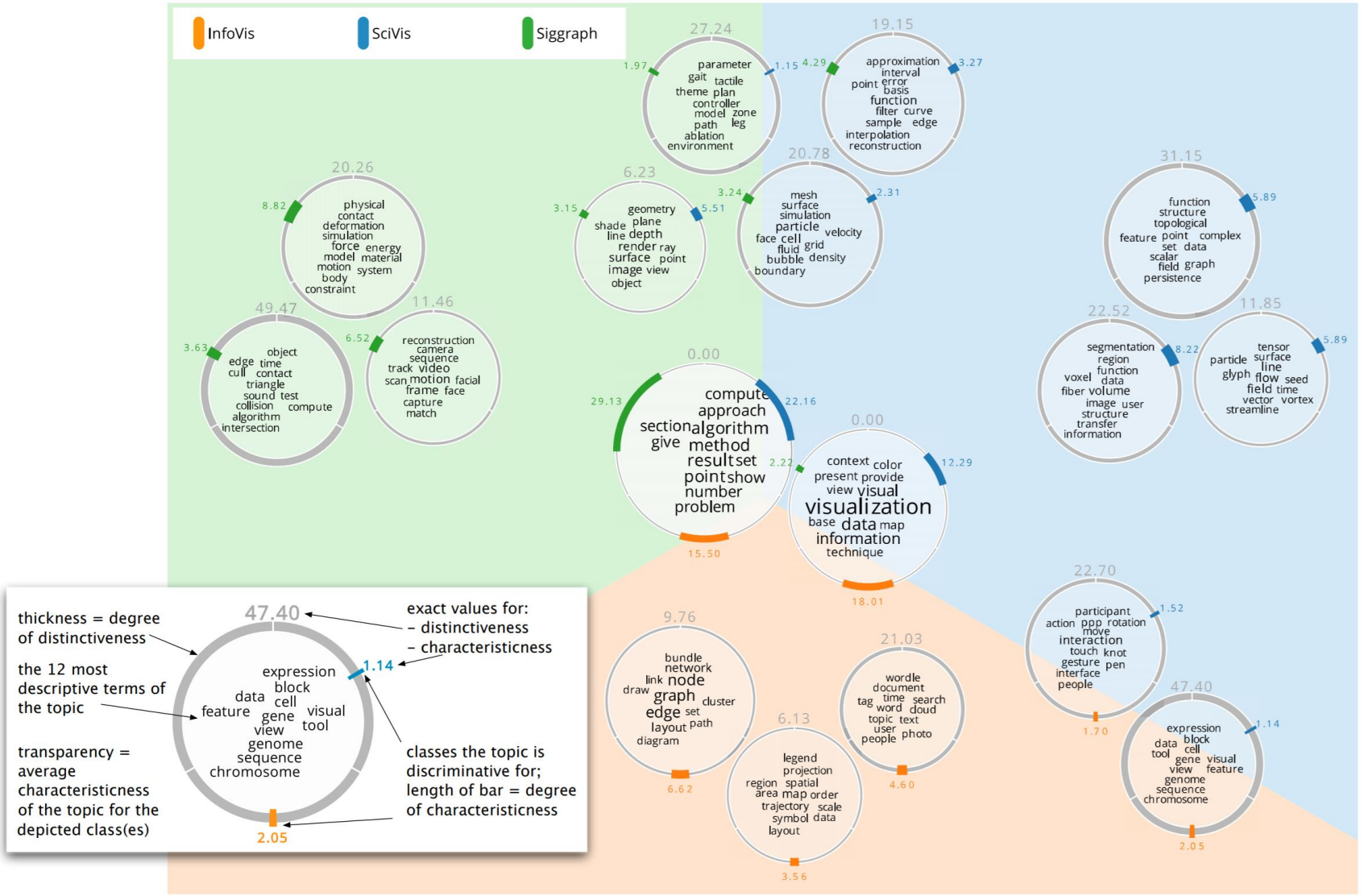




[H. Strobelt et al. (2009), "Document Cards: A Top Trumps Visualization for Documents," doi: 10.1109/TVCG.2009.139.]

文本集合比较

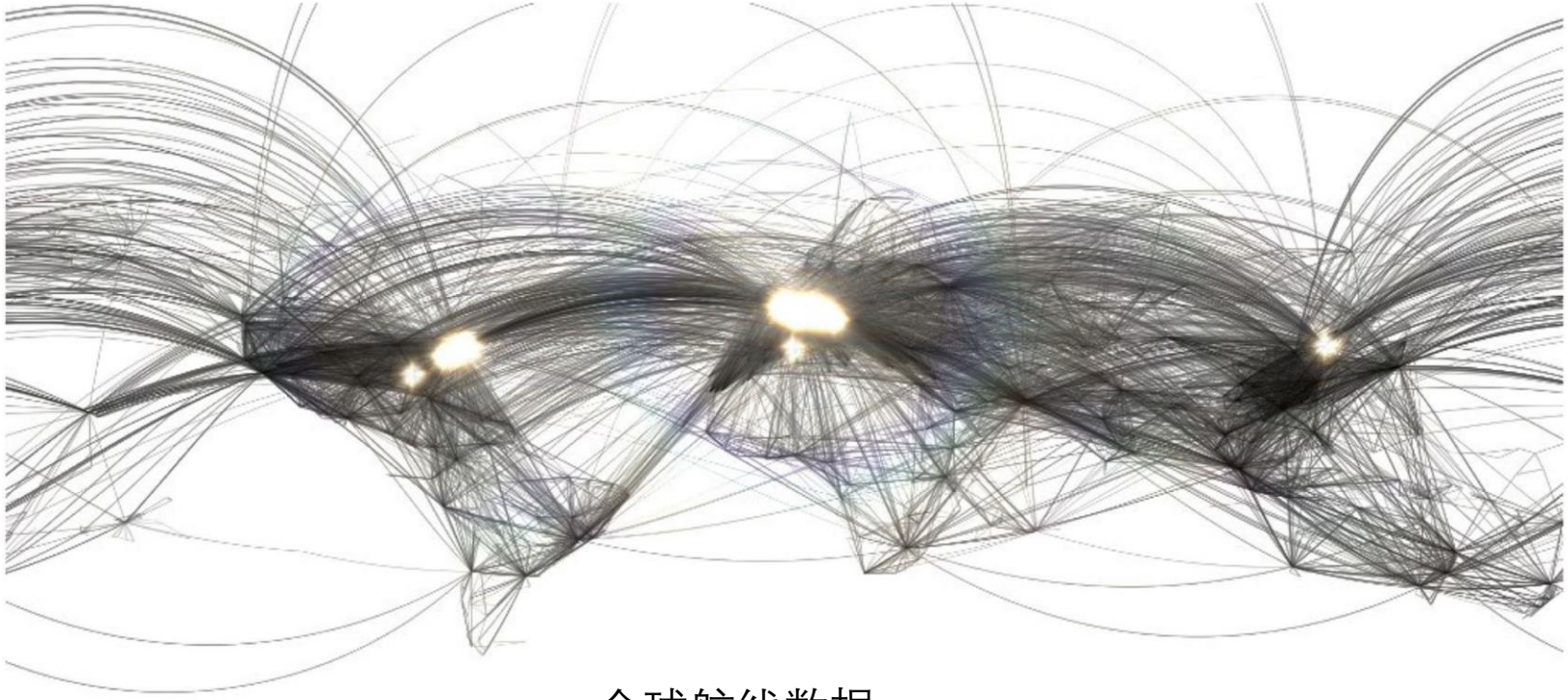
- 关键词比较



[D. Oelke et al. (2014): Comparative Exploration of Document Collections : a Visual Analytics Approach, doi: 10.1111/cgf.12376]

地理数据

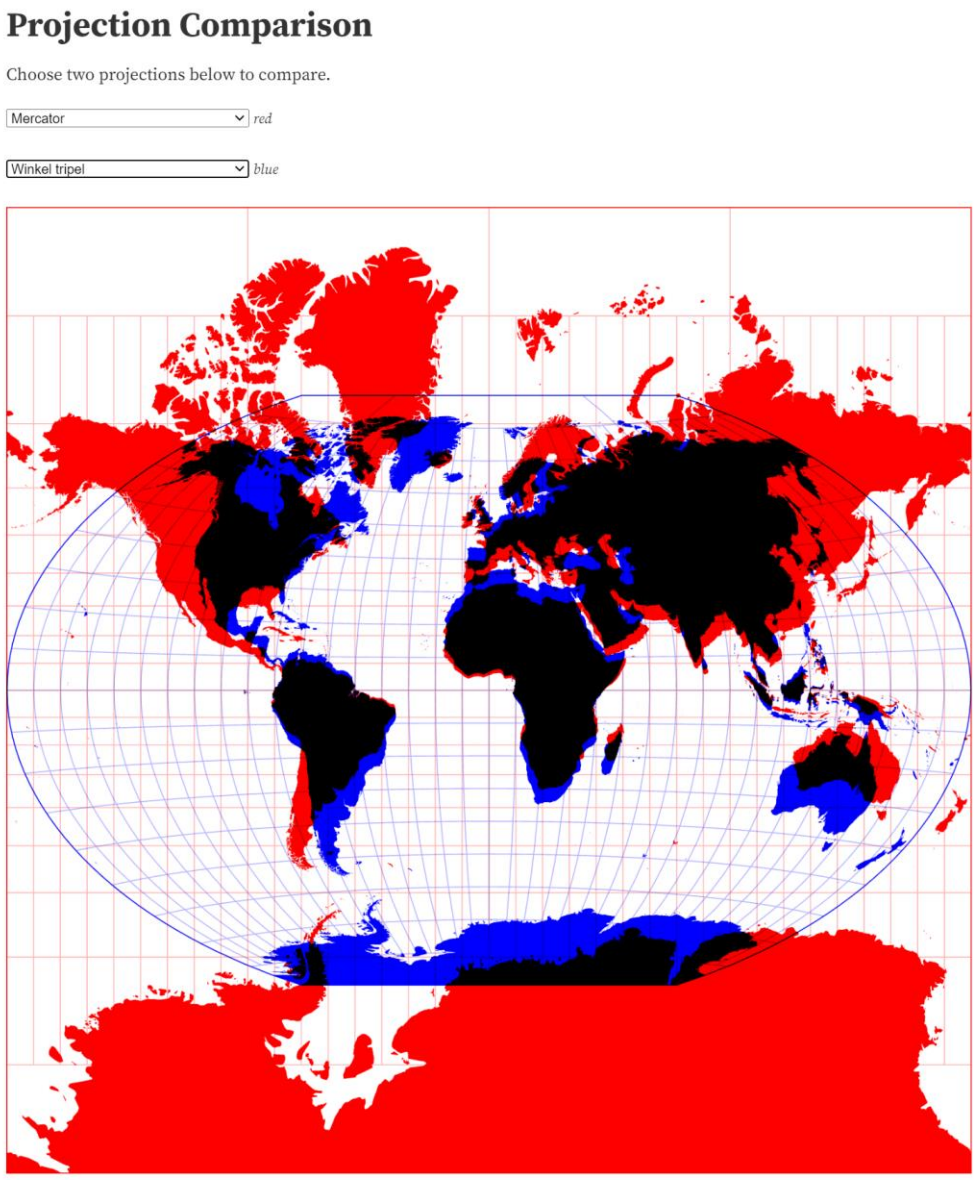
- 地图投影
- 直接可视化
- 分级统计图 choropleth map
- 轨迹可视化 trajectory visualization



全球航线数据 [L. Zhou et al. (2020), "Photographic High-Dynamic-Range Scalar Visualization," DOI: 10.1109/TVCG.2020.2970522]

地图投影

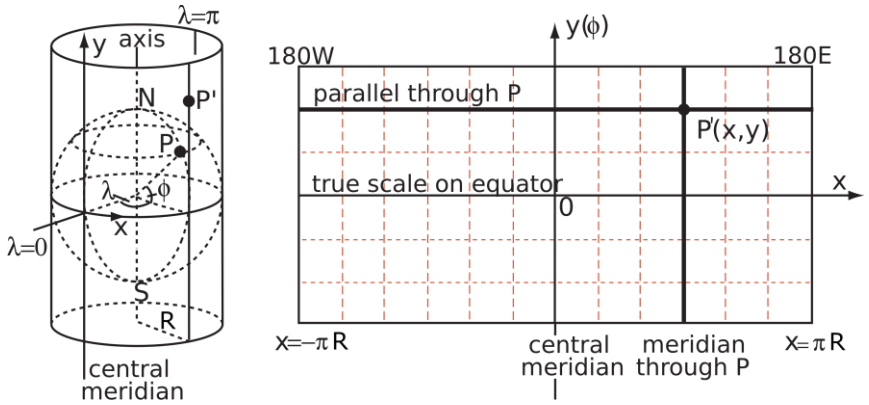
- 球面→平面
- 投影的性质：等面积？等角？南北极？
- 投影需要考虑各种畸变：面积，方向，距离
- Mercator投影
- Winkel tripel 投影



https://observablehq.com/@d3/projection-comparison

Mercator投影

- Gerardus Mercator，1569年
- 方便导航
- 投影到圆柱；远离赤道畸变很大

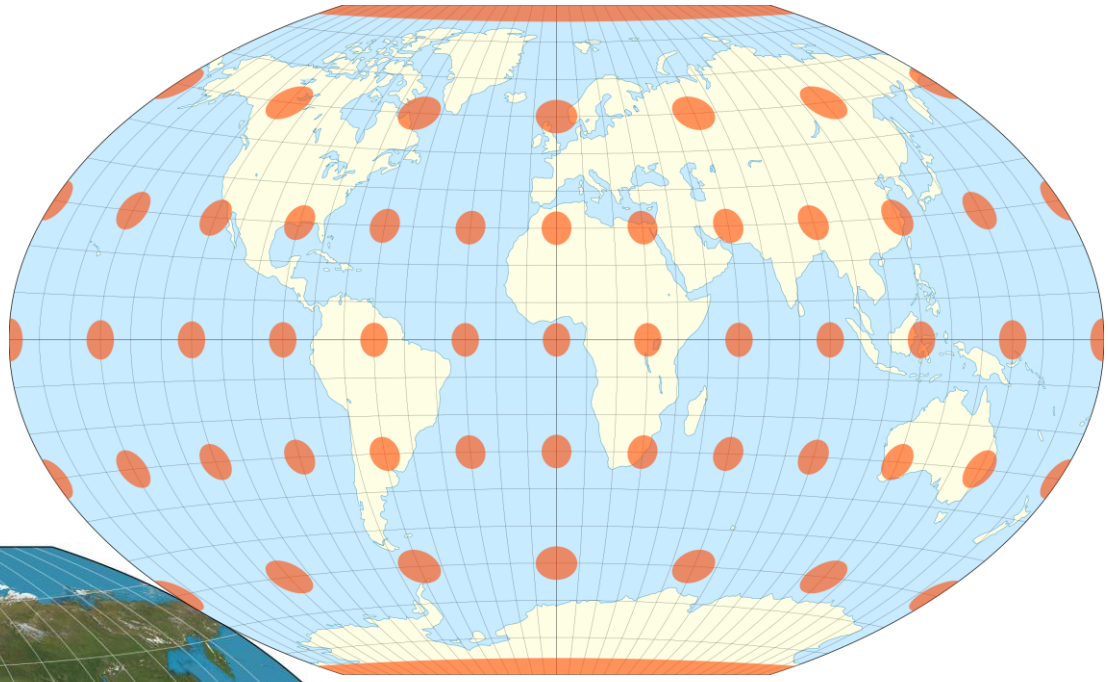


[By Peter Mercator - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=20168429]

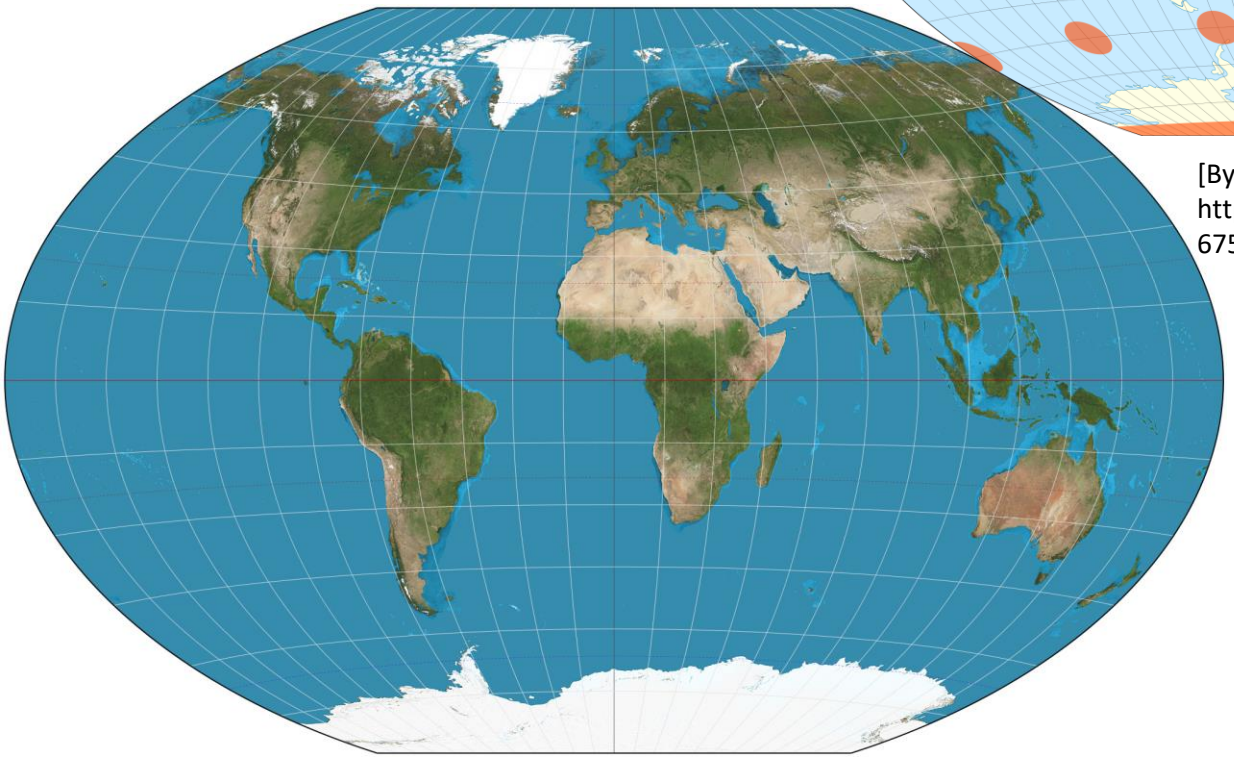
[By Jakub Nowosad - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=73955926]

Winkel tripel 投影

- Winkel 1921
- 目标：最小化三种(tripel)畸变：
  - 面积；方向；距离
- 国家地理学会National Geographic Society使用的标准投影



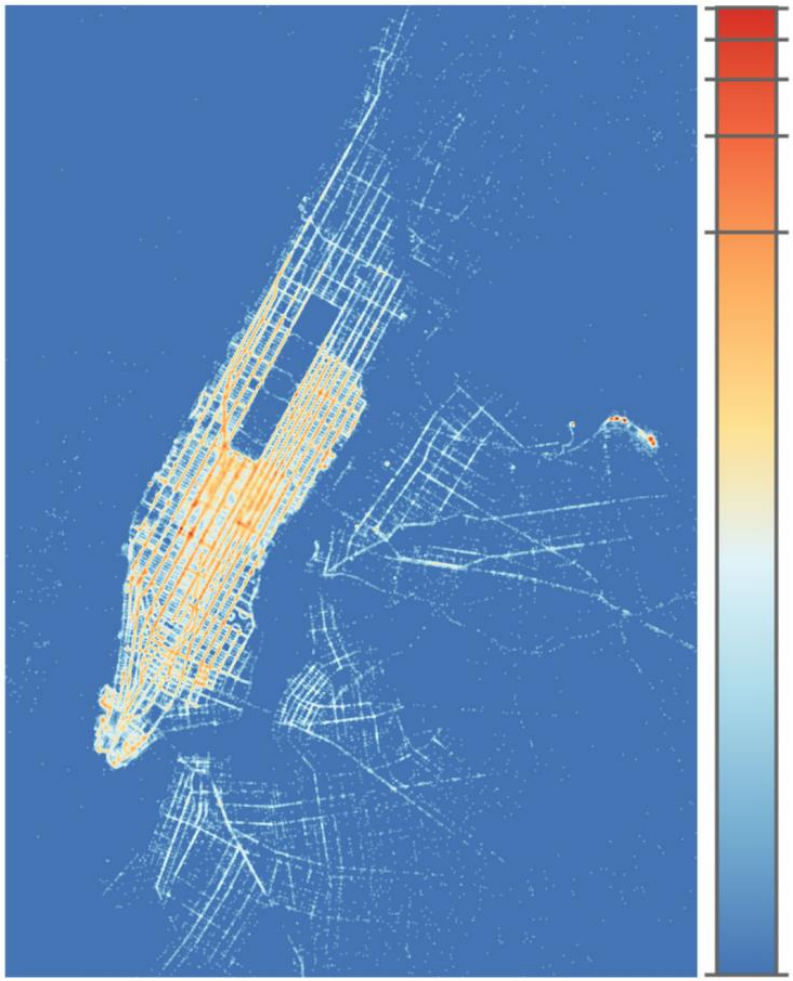
[By Justin Kunimune - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=66467590]

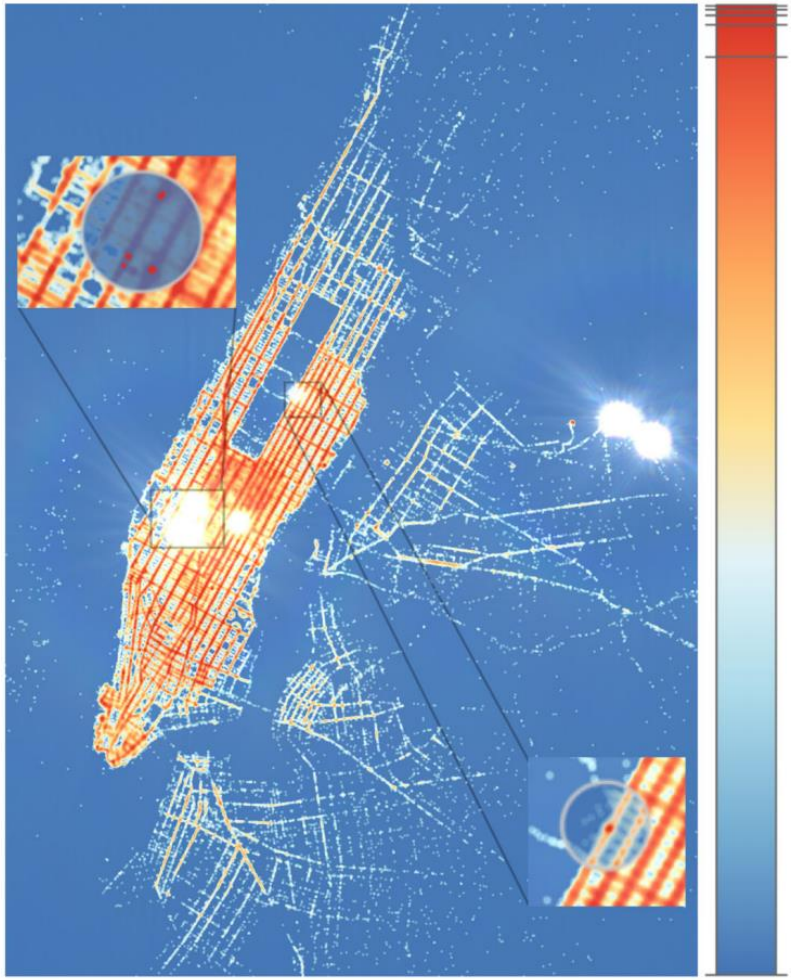


[By Strebe - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=16115375]

地理数据直接可视化

- 在地图相应位置（经纬度）绘制数据点
- 感知问题



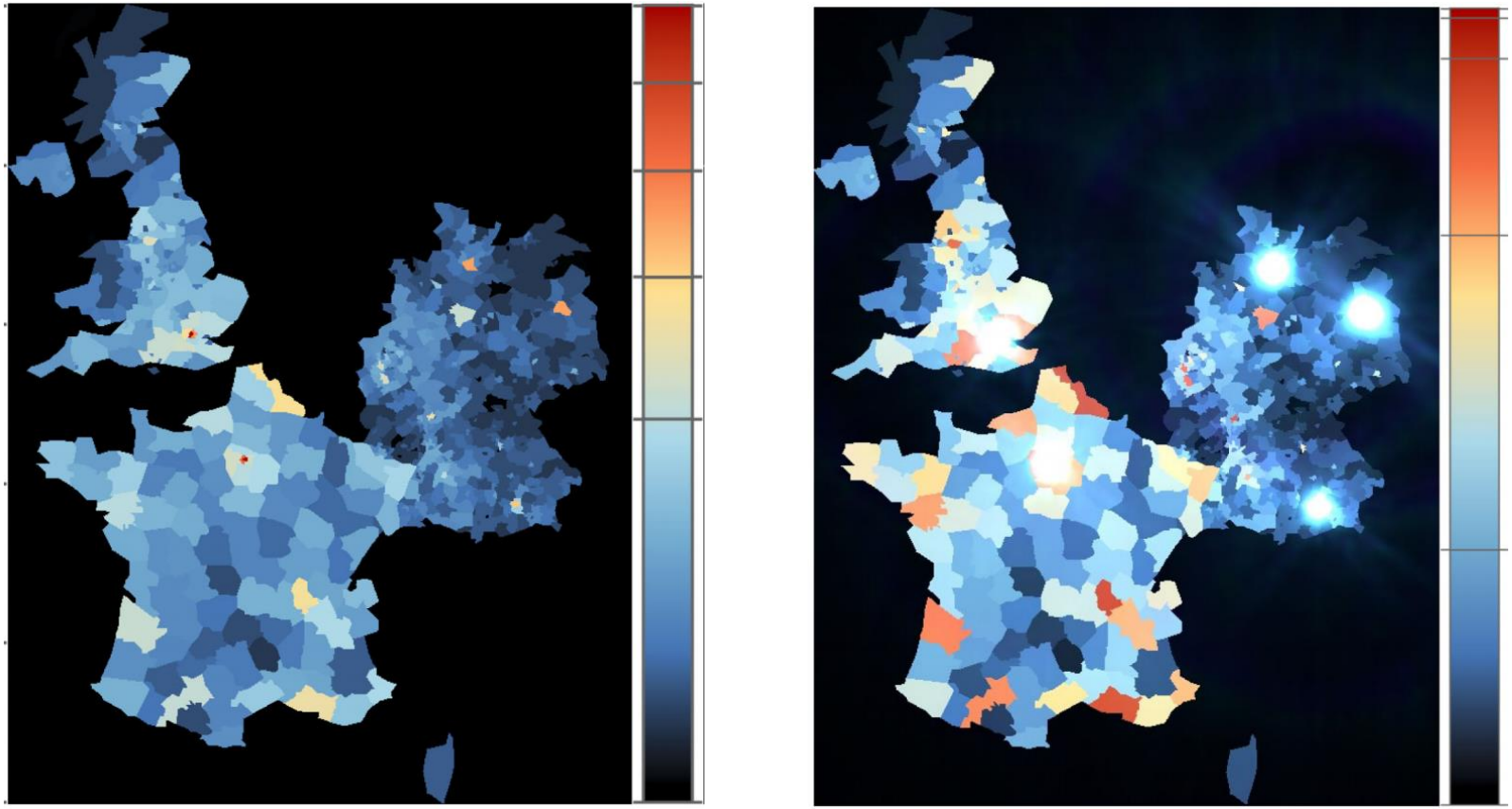


纽约市出租车接客位置数据

[L. Zhou et al. (2020), "Photographic High-Dynamic-Range Scalar Visualization," DOI: 10.1109/TVCG.2020.2970522]

分级统计图 Choropleth map

- Baron Pierre Charles Dupin, 1826, “cartes teintées” (coloured map)
- 在区划单元内用颜色表示数值

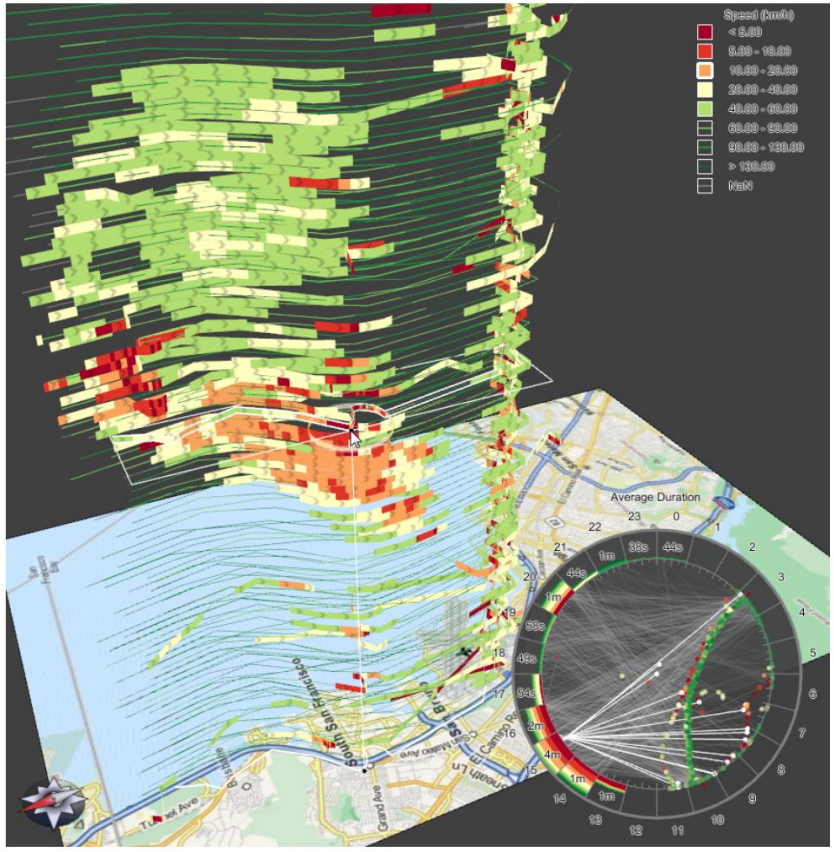


英法德三国人均GDP数据

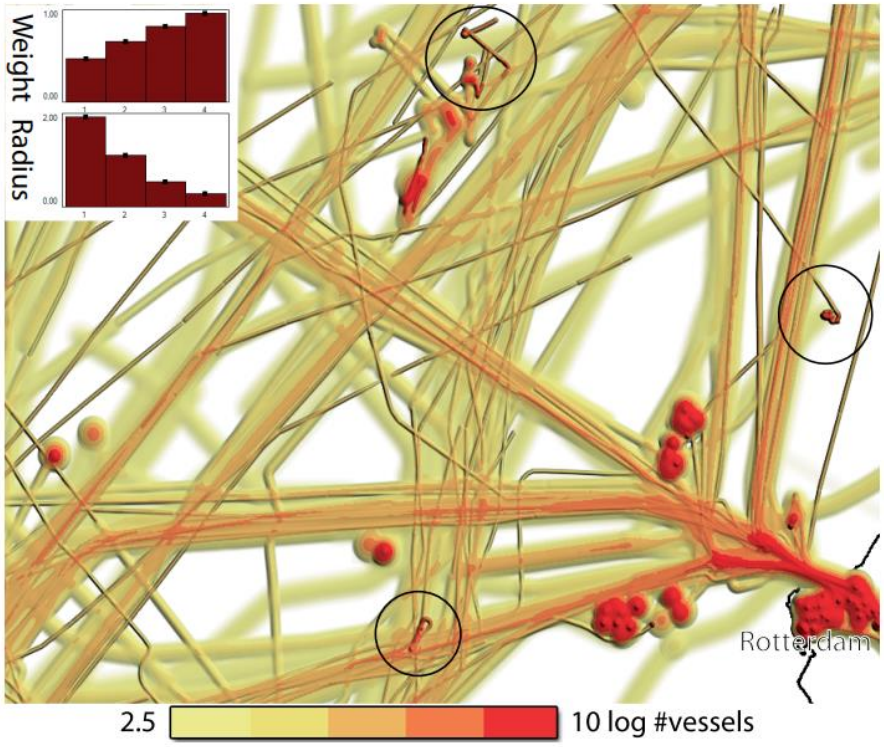
[L. Zhou et al. (2020), "Photographic High-Dynamic-Range Scalar Visualization,“ DOI: 10.1109/TVCG.2020.2970522]

轨迹可视化 Trajectory visualization

- 各种移动互联网应用采集了大量交通轨迹信息
- 空间时间spatio-temporal信息

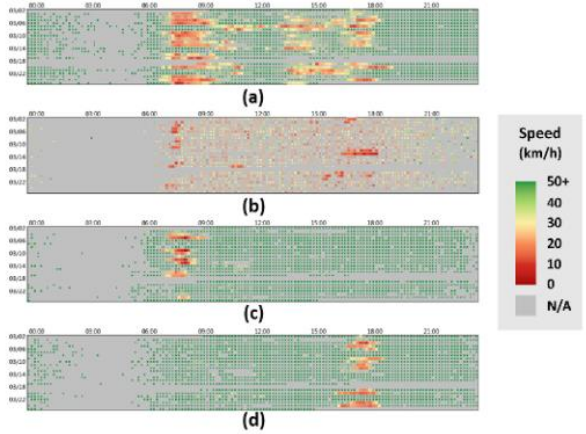


[C. Tominski et al. (2012), "Stacking-Based Visualization of Trajectory Attribute Data," doi: 10.1109/TVCG.2012.265.]



[R. Scheepens et al. (2011), "Interactive visualization of multivariate trajectory data with density maps," doi: 10.1109/PACIFICVIS.2011.5742384.]

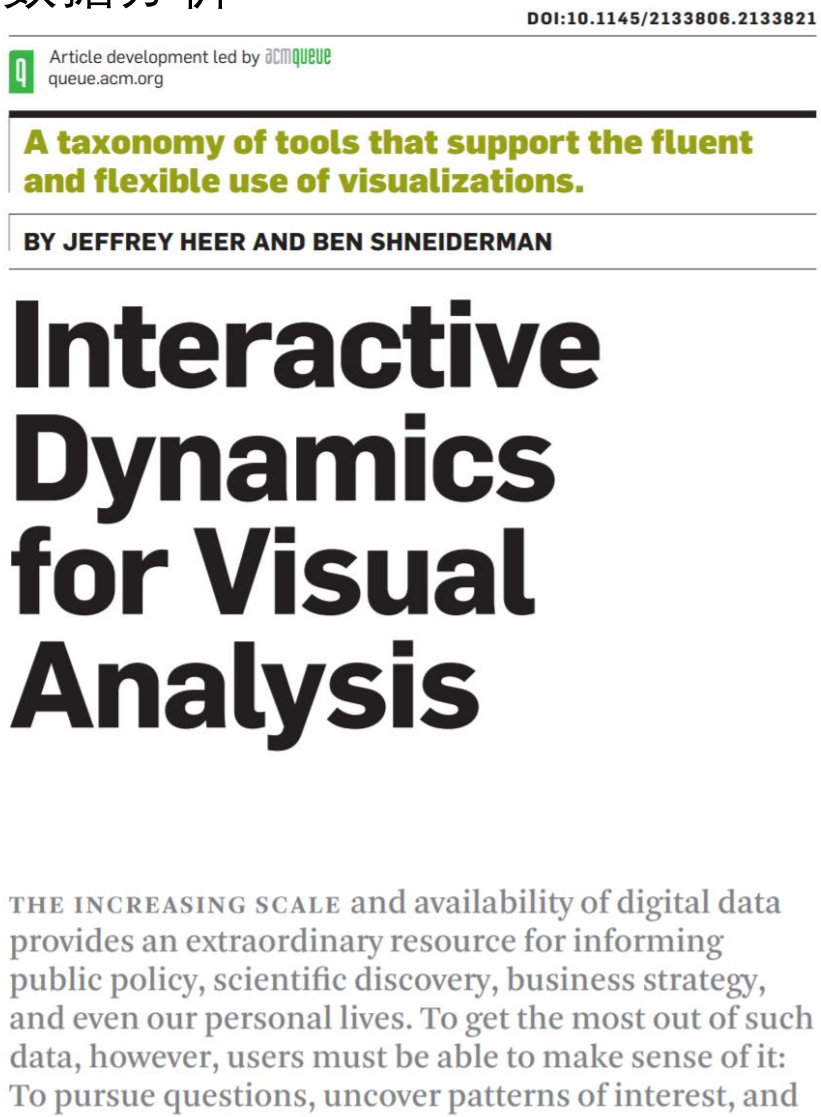
轨迹可视化



[http://vis.pku.edu.cn/trajectoryvis/en/index.html]

可视分析

- 有机结合各种可视化，交互地进行数据分析
- User Interaction 用户交互
- Brushing and linking 关联更新
- Linked views 关联视图
- Focus + context 聚焦加上下文技术



DOI:10.1145/2133806.2133821

Article development led by acmqueue
queue.acm.org

A taxonomy of tools that support the fluent and flexible use of visualizations.

BY JEFFREY HEER AND BEN SHNEIDERMAN

Interactive Dynamics for Visual Analysis

THE INCREASING SCALE and availability of digital data provides an extraordinary resource for informing public policy, scientific discovery, business strategy, and even our personal lives. To get the most out of such data, however, users must be able to make sense of it: To pursue questions, uncover patterns of interest, and

[Jeffrey Heer and Ben Shneiderman. 2012. Interactive dynamics for visual analysis. Commun. ACM 55, 4 (April 2012), 45–54. DOI:10.1145/2133806.2133821]

可视分析交互分类法

Taxonomy of interactive dynamics for visual analysis.

Data and View Specification 数据和视图定制	**Visualize** data by choosing visual encodings.
	Filter out data to focus on relevant items.
	Sort items to expose patterns.
	Derive values or models from source data.
View Manipulation 视图操纵	**Select** items to highlight, filter, or manipulate them.
	Navigate to examine high-level patterns and low-level detail.
	Coordinate views for linked, multidimensional exploration.
	Organize multiple windows and workspaces.
Process and Provenance 处理和记录	**Record** analysis histories for revisitation, review, and sharing.
	Annotate patterns to document findings.
	Share views and annotations to enable collaboration.
	Guide users through analysis tasks or stories.

[Jeffrey Heer and Ben Shneiderman. 2012. Interactive dynamics for visual analysis. Commun. ACM 55, 4 (April 2012), 45–54. DOI:10.1145/2133806.2133821]

可视分析交互举例

Taxonomy of interactive dynamics for visual analysis.

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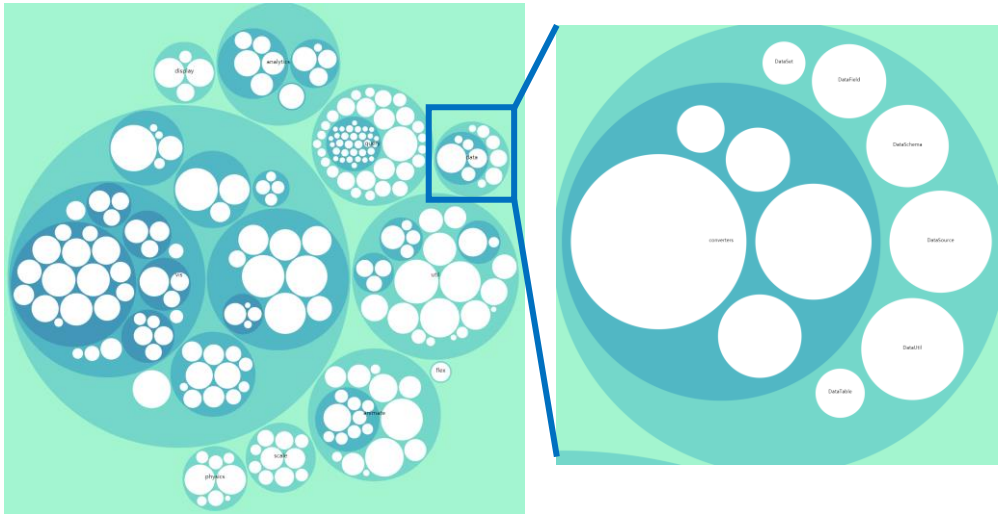
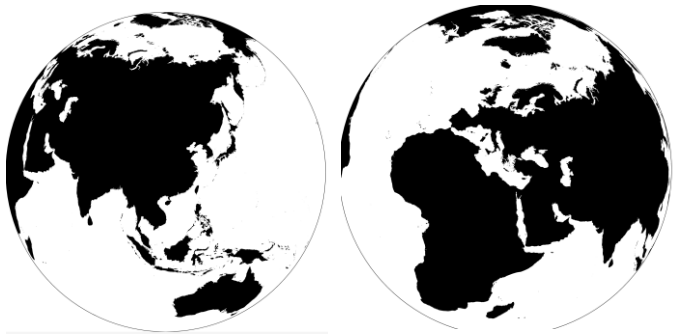
[Jeffrey Heer and Ben Shneiderman. 2012. Interactive dynamics for visual analysis. Commun. ACM 55, 4 (April 2012), 45–54. DOI:10.1145/2133806.2133821]



气泡树图缩放

https://observablehq.com/@d3/zoomable-circle-packing

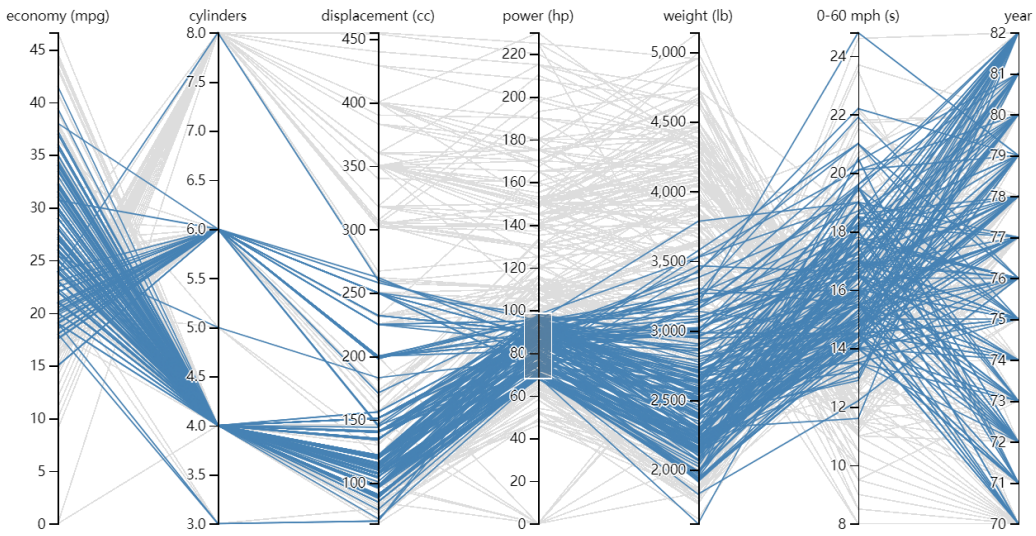


地球旋转

https://observablehq.com/@d3/versor-dragging

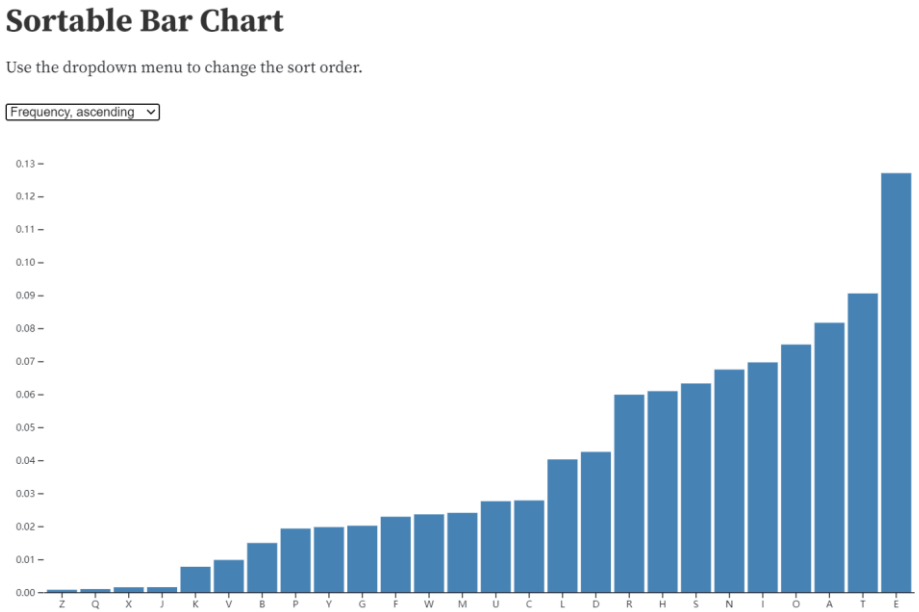
可视分析交互举例

- 过滤filter；排序sort



https://observablehq.com/@jerdak/parallel-coordinates-d3-v4

平行坐标系查询 query



https://observablehq.com/@d3/sortable-bar-chart

Brushing and Linking 关联更新

- 在一个视图中对数据进行选择(brushing)，在其他视图中显示更新(linking)

Figure 9. Brushing and linking of baseball statistics in GGobi.

Source: [Jeffrey Heer and Ben Shneiderman. 2012. Interactive dynamics for visual analysis. Commun. ACM 55, 4 (April 2012), 45–54. DOI:10.1145/2133806.2133821]

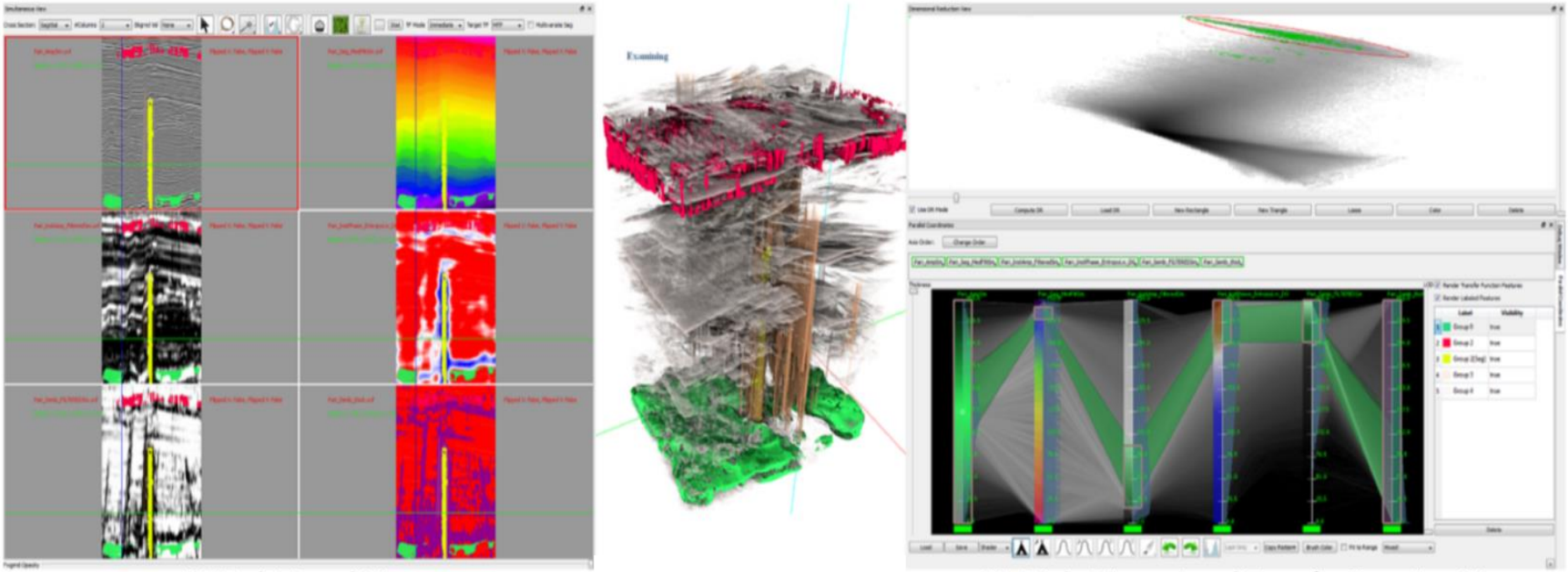
Linked Views 关联视图

- 多个能同时显示并互相关联的视图，即在一个视图中的操作会影响其他视图

[L. Zhou and C. Hansen (2013), "Transfer function design based on user selected samples for intuitive multivariate volume exploration,", doi: 10.1109/PacificVis.2013.6596130.]

(2) Volume Rendering View

(3) Projection View

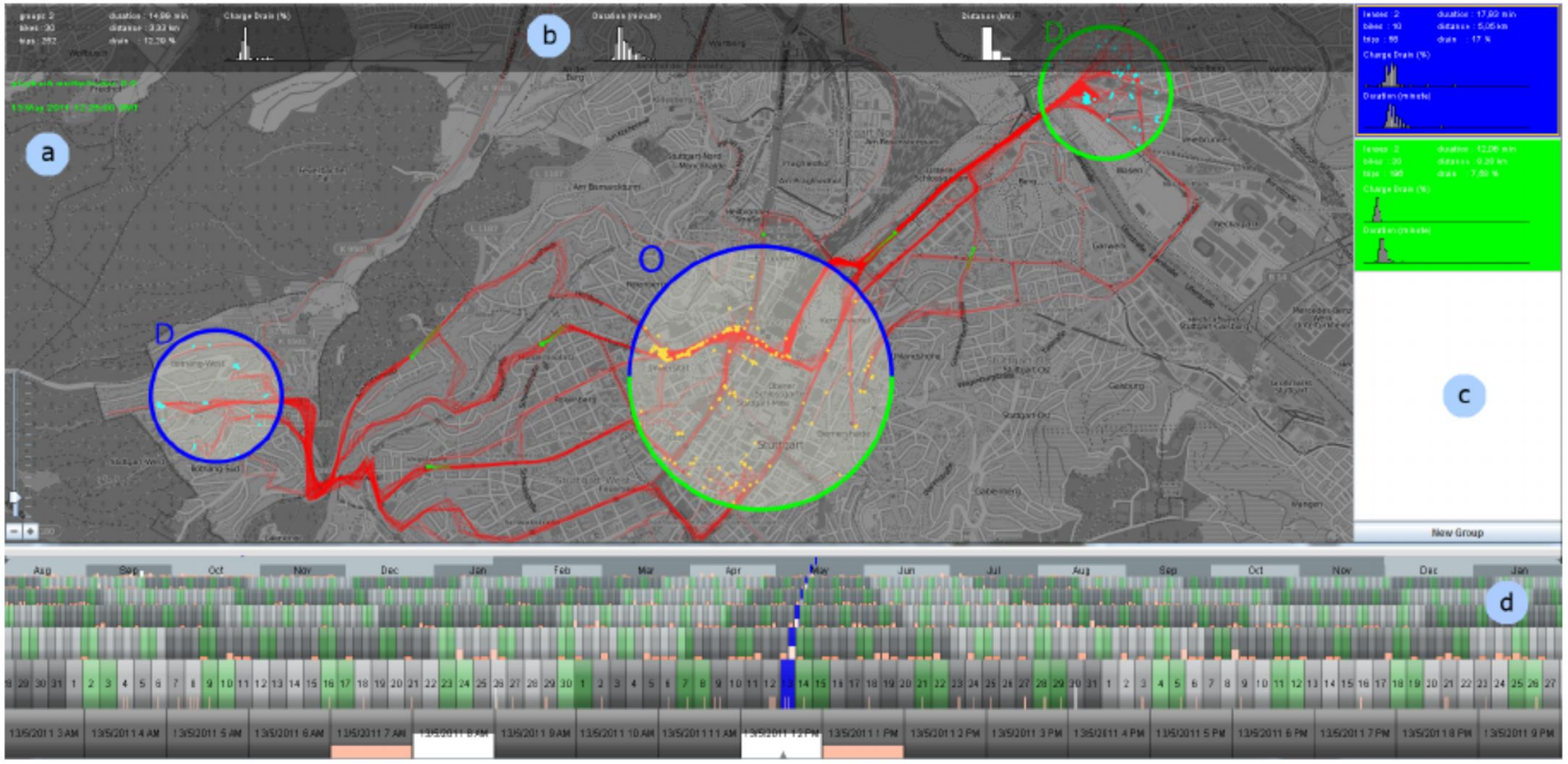


(1) Multi-Panel View

(4) High-Dimensional Transfer Function View

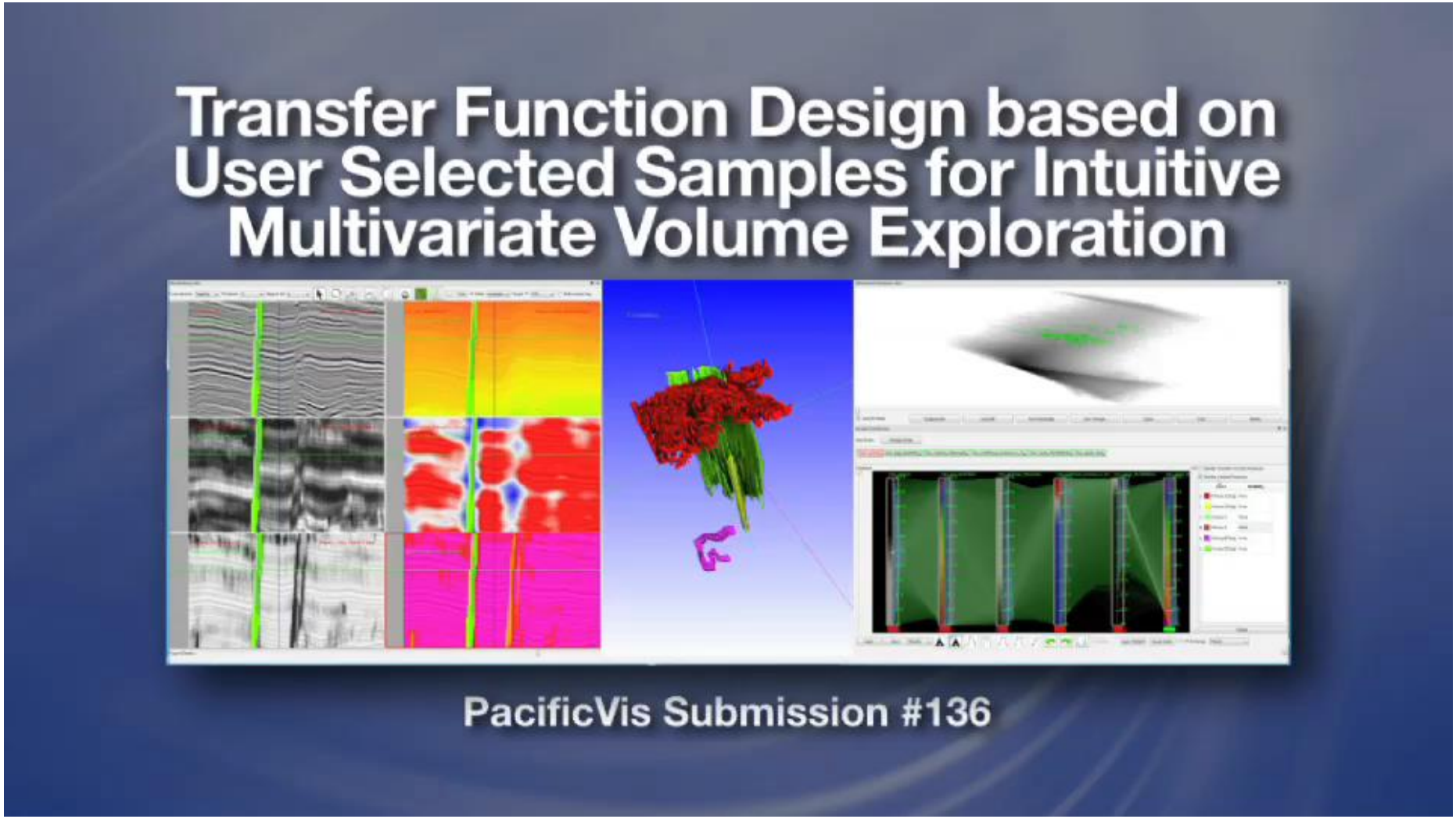
多变量体数据探索系统

Linked Views 关联视图



[R. Krüger et al. (2013), TrajectoryLenses – A Set-based Filtering and Exploration Technique for Long-term Trajectory Data. doi:10.1111/cgf.12132]

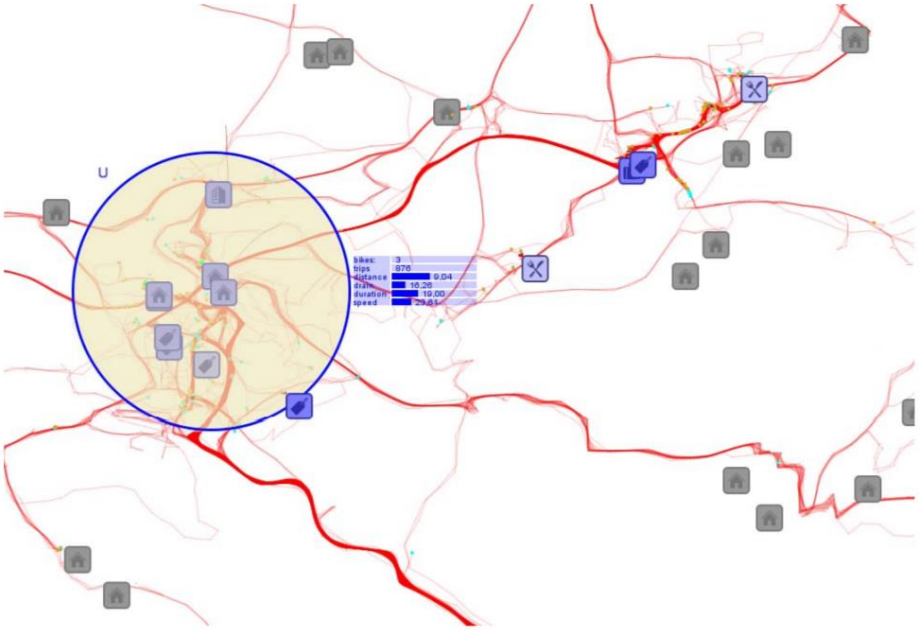
Linked Views 关联视图



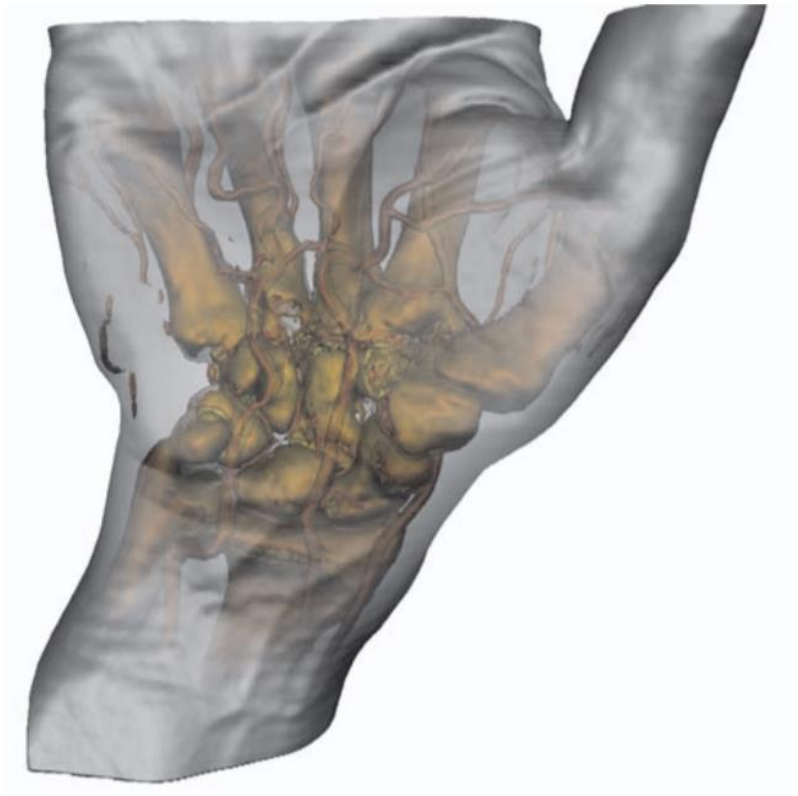
[L. Zhou and C. Hansen (2013), "Transfer function design based on user selected samples for intuitive multivariate volume exploration,", doi: 10.1109/PacificVis.2013.6596130.]

Focus + Context 聚焦和上下文技术

- 展示兴趣区域(focus)，提示未展示部分(context)



[R. Krueger et al. (2014), "Visual Analysis of Movement Behavior Using Web Data for Context Enrichment," doi: 10.1109/PacificVis.2014.57.]



[J. Kruger et al. (2006), "ClearView: An Interactive Context Preserving Hotspot Visualization Technique," doi: 10.1109/TVCG.2006.124.]

可视分析举例：轨迹可视化

- 分析交通、经济、社会生活等多方面信息

IEEE VAST 2013

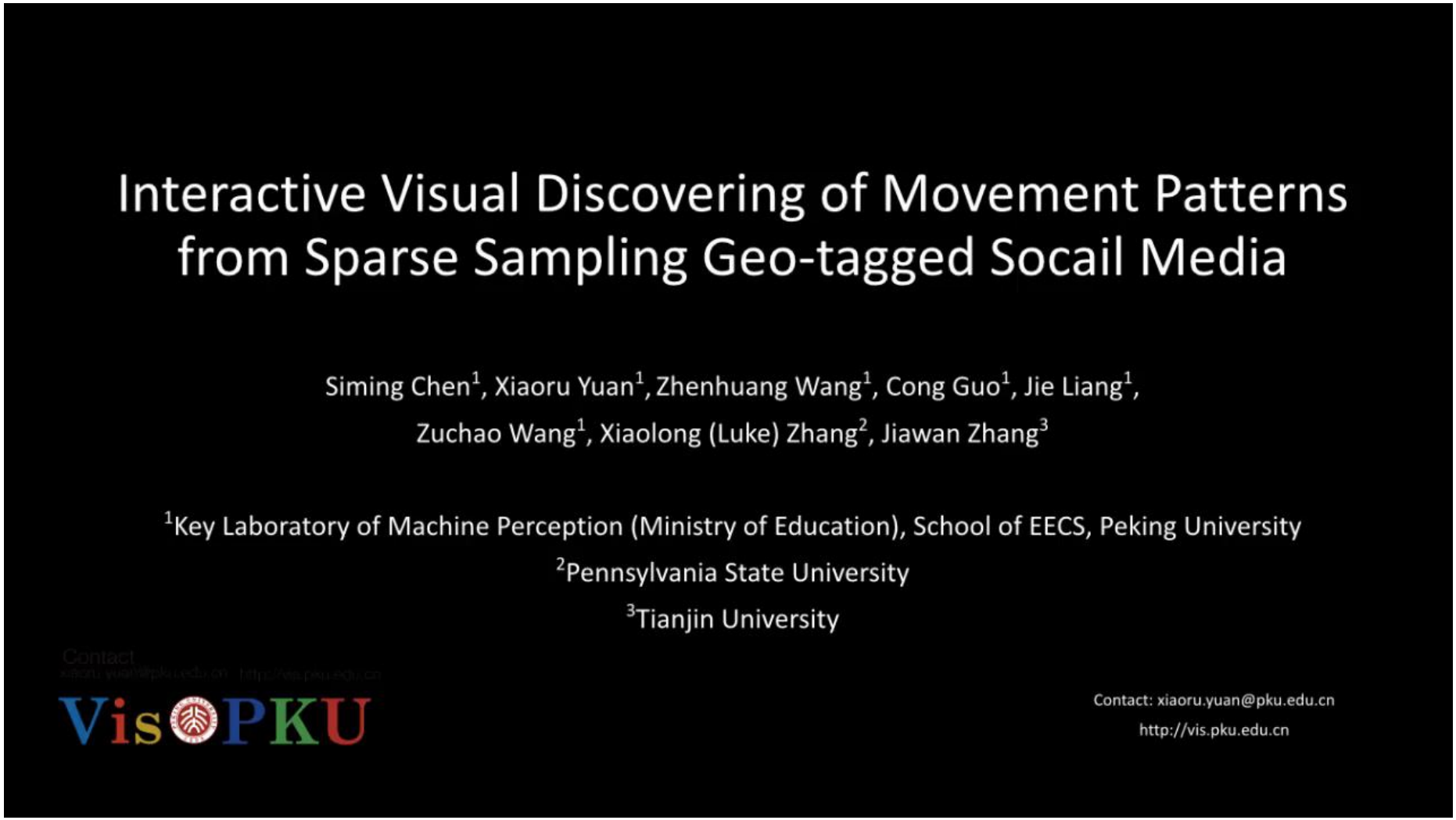
Visual Traffic Jam Analysis based on Trajectory Data

Zuchao Wang[1], Min Lu[1,2], Xiaoru Yuan[1,2], Junping Zhang[3], Huub van de Wetering[4]

1) Key Laboratory of Machine Perception (Ministry of Education), School of EECS, Peking University
2) Center for Computational Science and Engineering, Peking University
3) Shanghai Key Laboratory of Intelligent Information Processing, and School of Computer Science, Fudan University
4) Department of Mathematics and Computer Science, Technische Universiteit Eindhoven

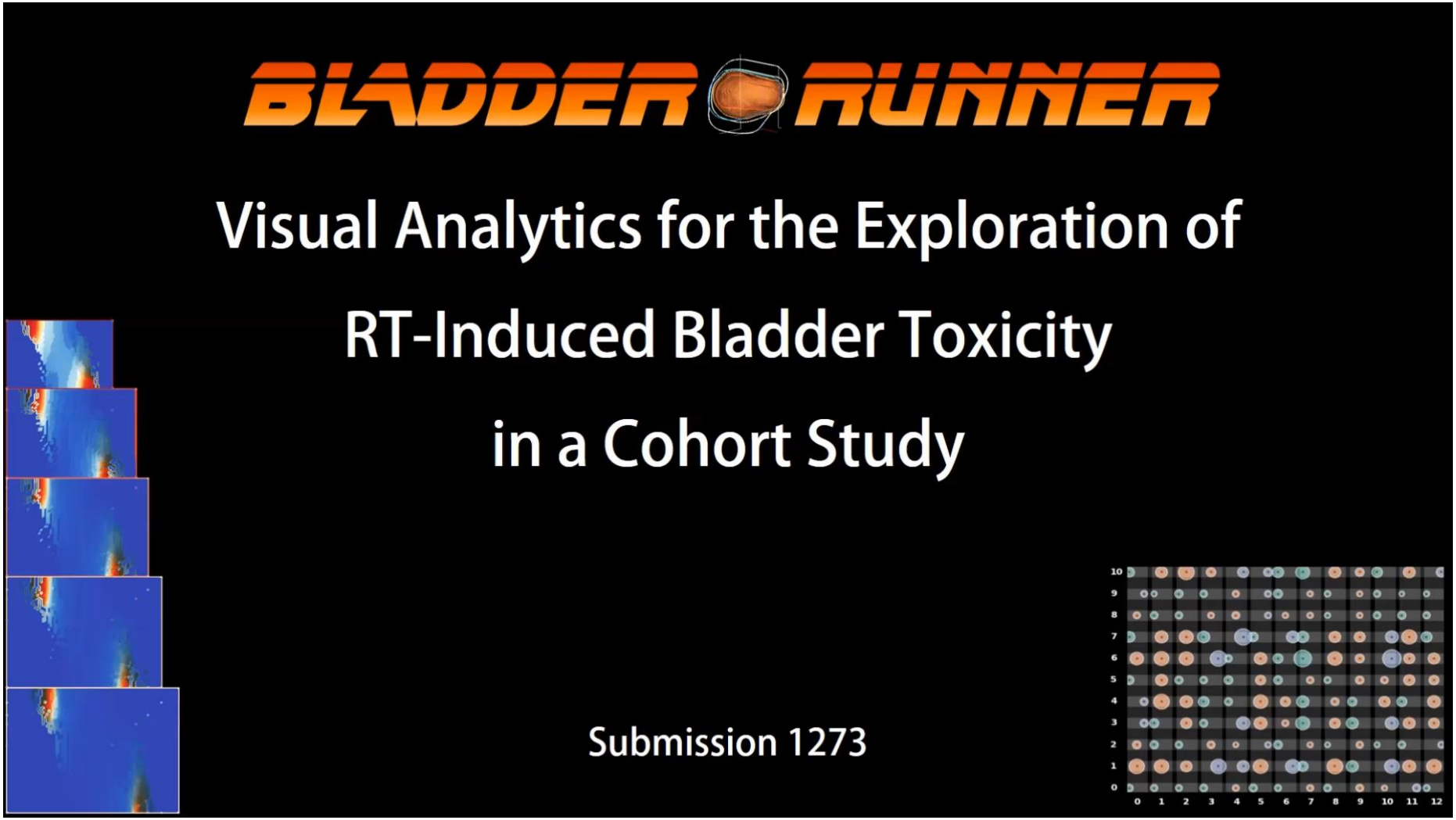
[Z. Wang et al. (2013), "Visual Traffic Jam Analysis Based on Trajectory Data," doi: 10.1109/TVCG.2013.228.]

可视分析举例：轨迹可视化



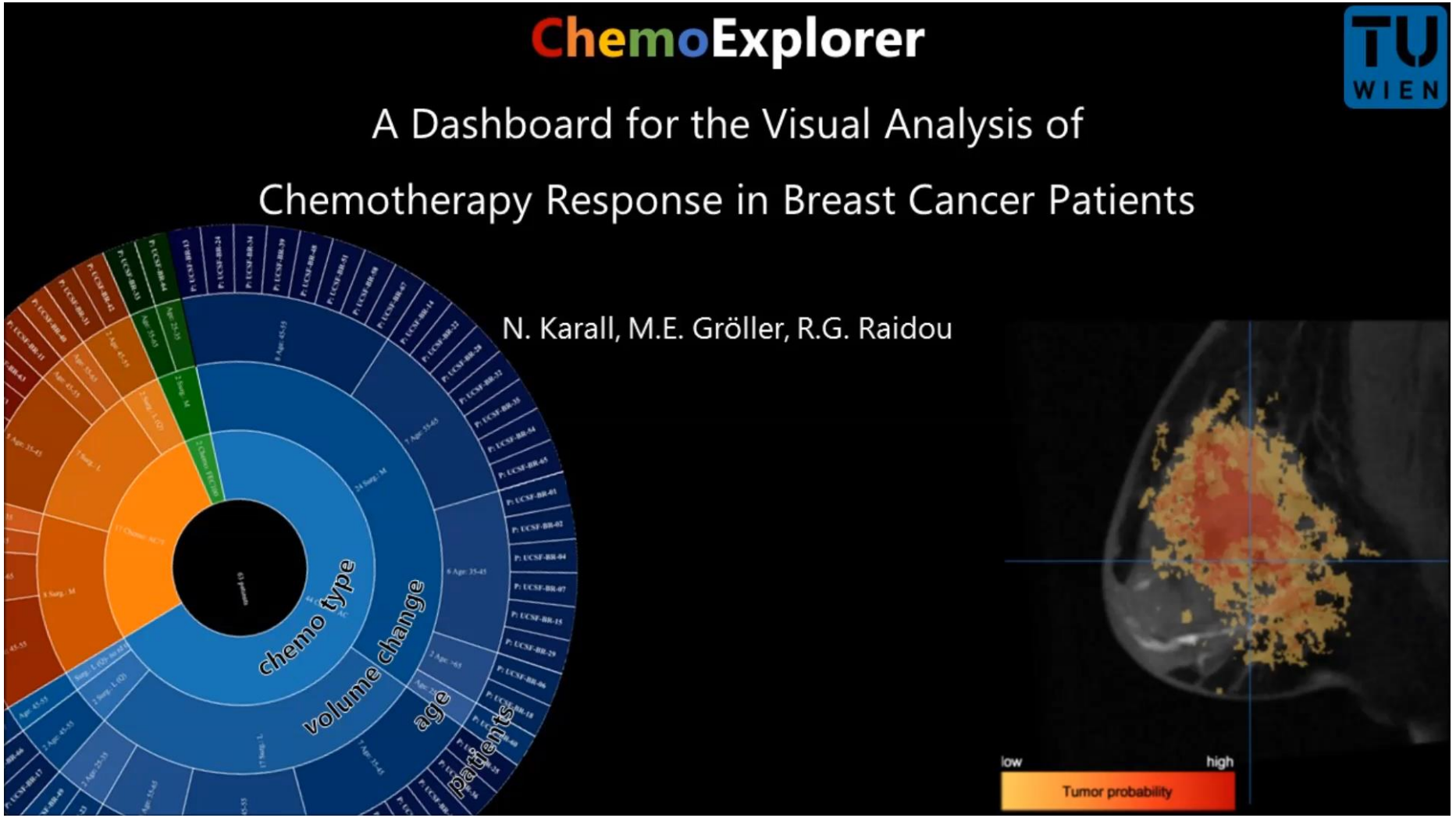
[S. Chen et al. (2016), "Interactive Visual Discovering of Movement Patterns from Sparsely Sampled Geo-tagged Social Media Data," doi: 10.1109/TVCG.2015.2467619.]

可视分析举例：健康医疗



[R. Raidou et al. "Bladder Runner: Visual Analytics for the Exploration of RT-Induced Bladder Toxicity in a Cohort Study,". doi:10.1111/cgf.13413]

可视分析举例：健康医疗



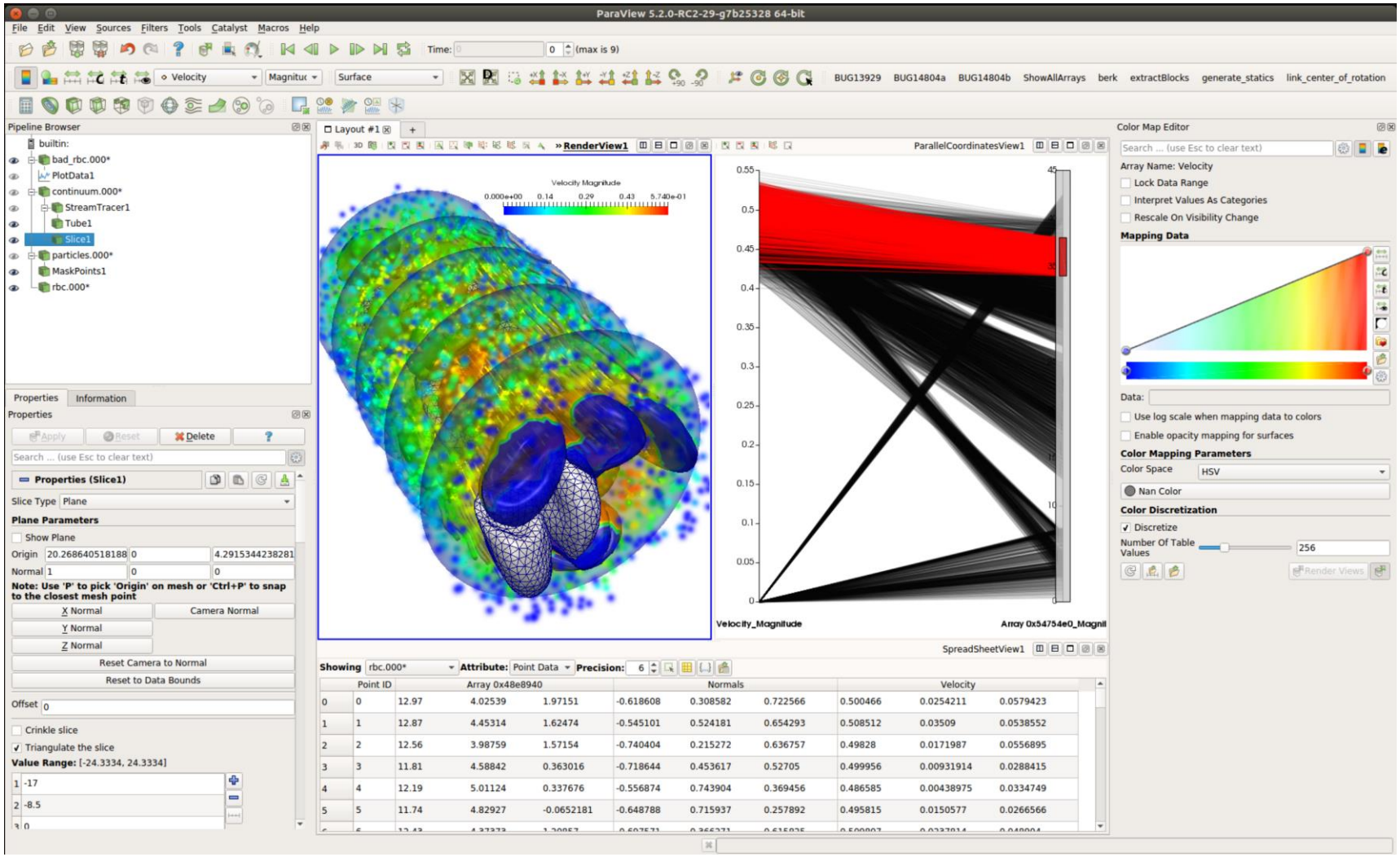
[N. Karall, et al. "ChemoExplorer: A Dashboard for the Visual Analysis of Chemotherapy Response in Breast Cancer Patients,". doi:10.2312/eurovisshort.20181077]

可视化和可视分析工程实现

- 可视化和可视分析工具
  - 科学可视化：
    - ParaView https://www.paraview.org/
    - SCI Institute的各种工具 https://www.sci.utah.edu/sci-software/visualization.html
    - Inviwo https://inviwo.org/
    - Voreen https://www.uni-muenster.de/Voreen/index.html
    - ……
  - 信息可视化，可视分析：
    - Tableau https://www.tableau.com/
    - Power BI https://powerbi.microsoft.com/
    - ……
- 可视化软件库
    - VTK https://vtk.org/
    - D3 https://d3js.org/
- 编码实现可视化可视分析
  - 编程语言：
    - C++, JavaScript, Python, R……
  - 技能：
    - 交互界面（UI） 编程——Qt, Vue.js……
    - 图形编程——OpenGL, WebGL
    - 图形处理器（GPU） 编程——Shaders, CUDA

Paraview

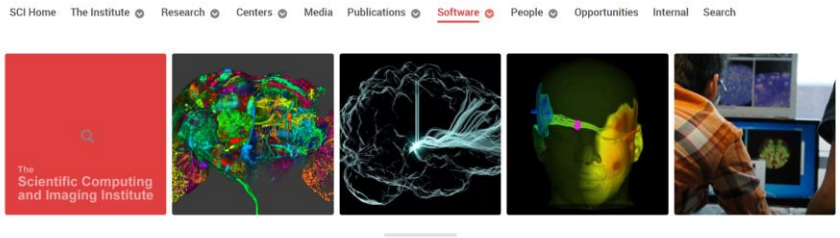
- 科学可视化、可视分析，数据处理
- 开源软件；使用VTK库；支持大规模数据



https://www.paraview.org/

SCI Institute的各种工具

- 科学可视化的各种开源工具
- 包括集成式问题解决、图像分析、几何形状建模、模拟、可视化



SCI Software

Scientific Software Environments

Software at the SCI Institute is developed in close collaboration with application users to satisfy real needs within their research communities. We use a robust, yet agile software process that is fully open-source to produce software environments that integrate leading-edge algorithms in image processing, scientific visualization, and scientific computing. Software products developed at the SCI Institute can be categorized in the following ways: Problem Solving Environments (Integrated Modeling, Simulation, and Visualization), Image Analysis, Geometric and Shape Modeling, Simulation, and Visualization.

Problem Solving Environments | Image Analysis | Geometric and Shape Modeling | Simulation | Visualization

Problem Solving Environments (Integrated Modeling, Simulation, and Visualization)

FEBio

FEBio is a nonlinear finite element solver that is specifically designed for biomechanical applications. It offers modeling scenarios, constitutive models and boundary conditions that are relevant to many research areas in biomechanics. All features can be used together seamlessly, giving the user a powerful tool for solving 3D problems in computational biomechanics. The software is open-source, and pre-compiled executables for Windows, Mac OS X and Linux platforms are available.
More information and links to downloads

PreView

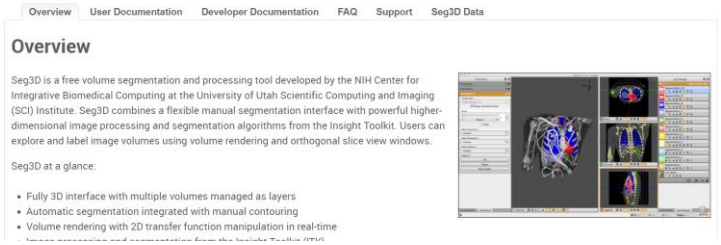
PreView is a Finite Element (FE) preprocessor that has been designed specifically to set up FE problems for FEBio. It allows the user to specify the boundary conditions and material properties in a user-friendly graphical environment.
More information and links to downloads

PostView

Postview is a finite element post-processor that is designed to visualize and analyze results from an FE analysis. It can import the FEBio extendible plot file format (XPLT), as well as several other data formats (e.g. LSDYNA Keyword, LSDYNA binary database, VTK). It also offers a way to add additional data to an already loaded model.
More information and links to downloads

https://www.sci.utah.edu/sci-software/visualization.html

Seg3D



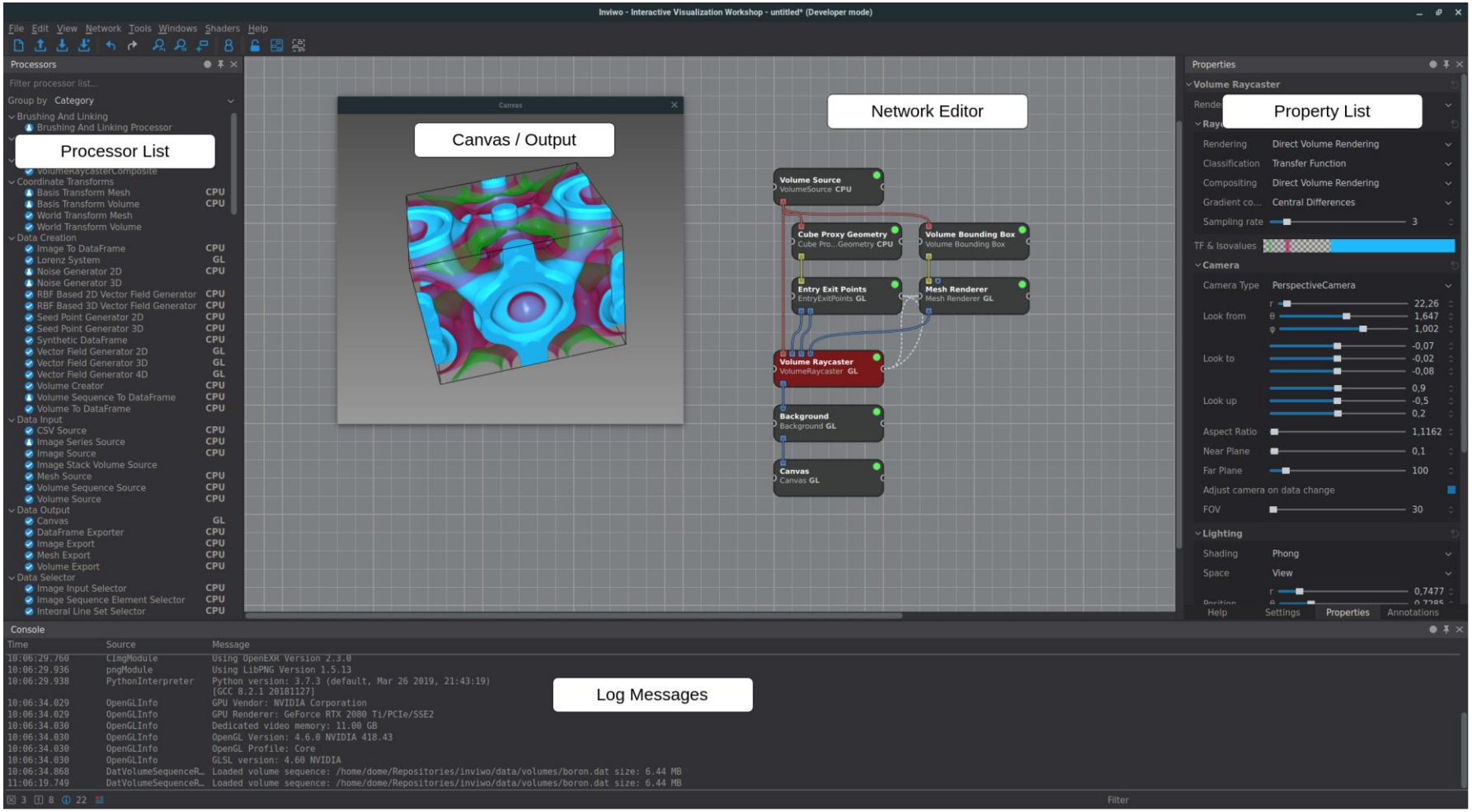
https://www.sci.utah.edu/software/seg3d.html

ImageVis3D

https://www.sci.utah.edu/software/imagevis3d.html

Inviwo

- 科学可视化
- 开源软件；模块化搭建可视化；高质量渲染



https://inviwo.org

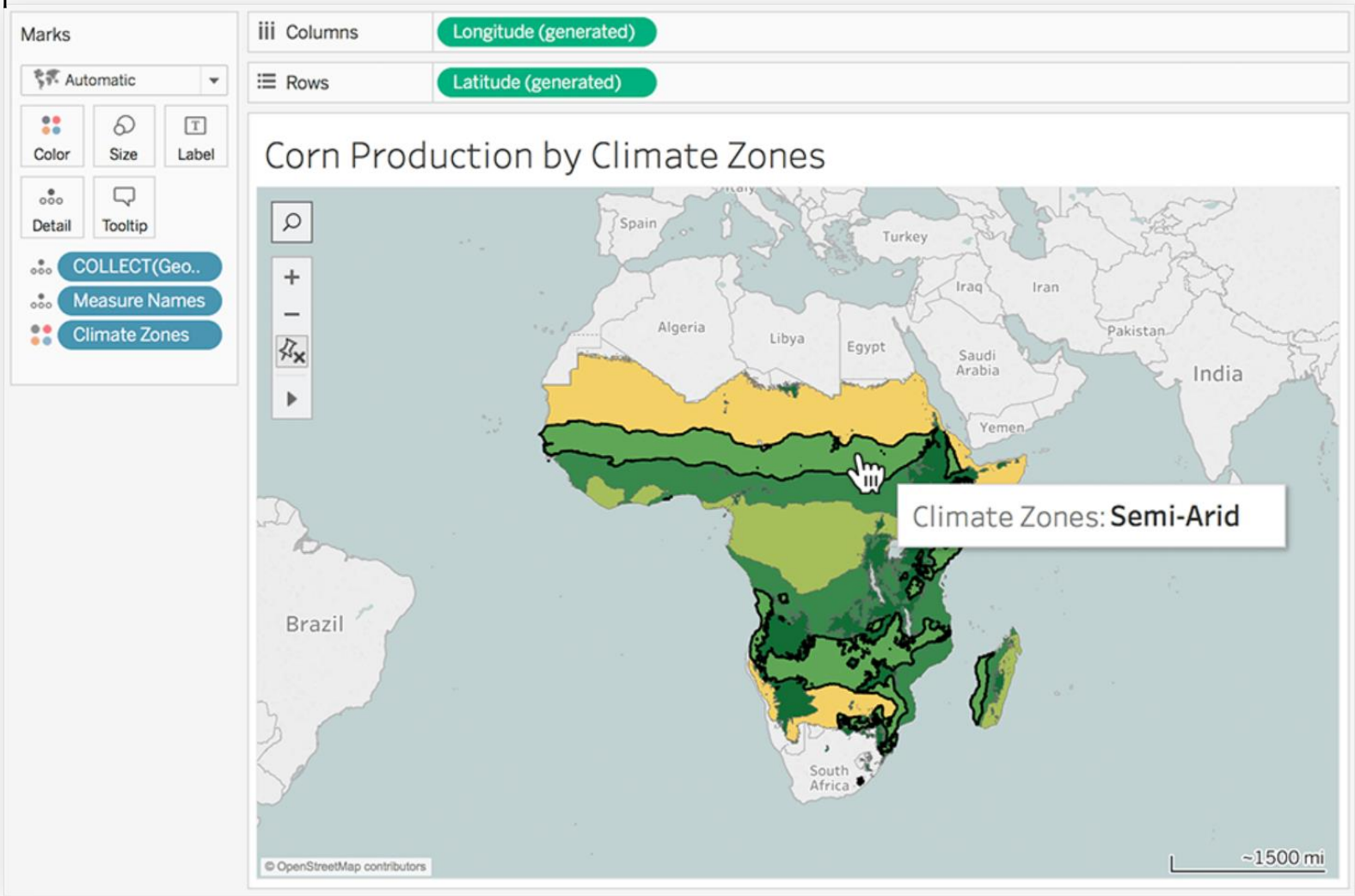
Voreen

- 科学可视化
- 开源软件；模块化搭建可视化；高质量渲染

https://www.uni-muenster.de/Voreen/index.html

Tableau

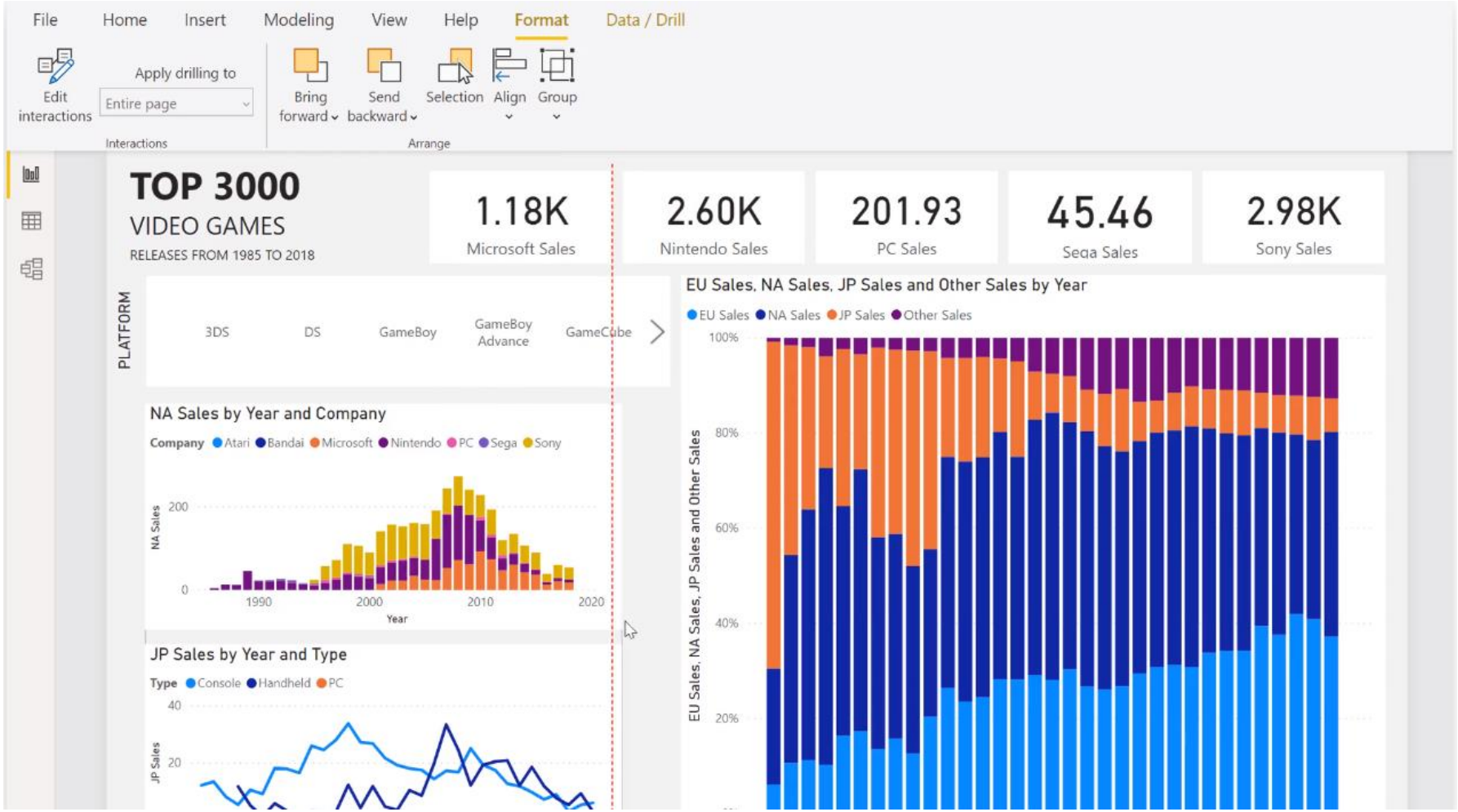
- 信息可视化、可视分析
- 商业软件



https://www.tableau.com

Power BI

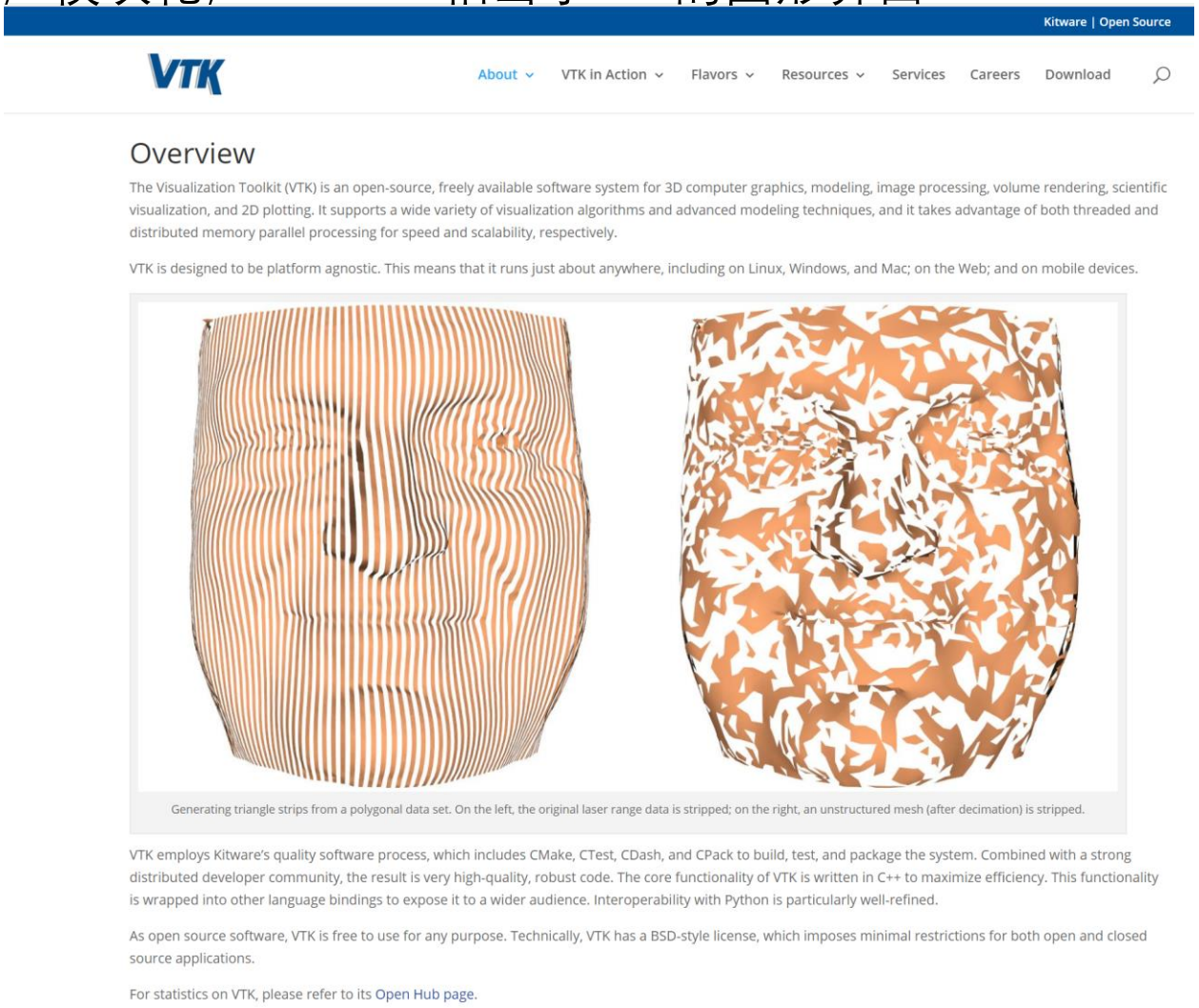
- 信息可视化、可视分析
- 商业软件



https://powerbi.microsoft.com/

VTK——The Visualization Toolkit

- 科学可视化，图像处理
- 开源软件；模块化；Paraview相当于VTK的图形界面

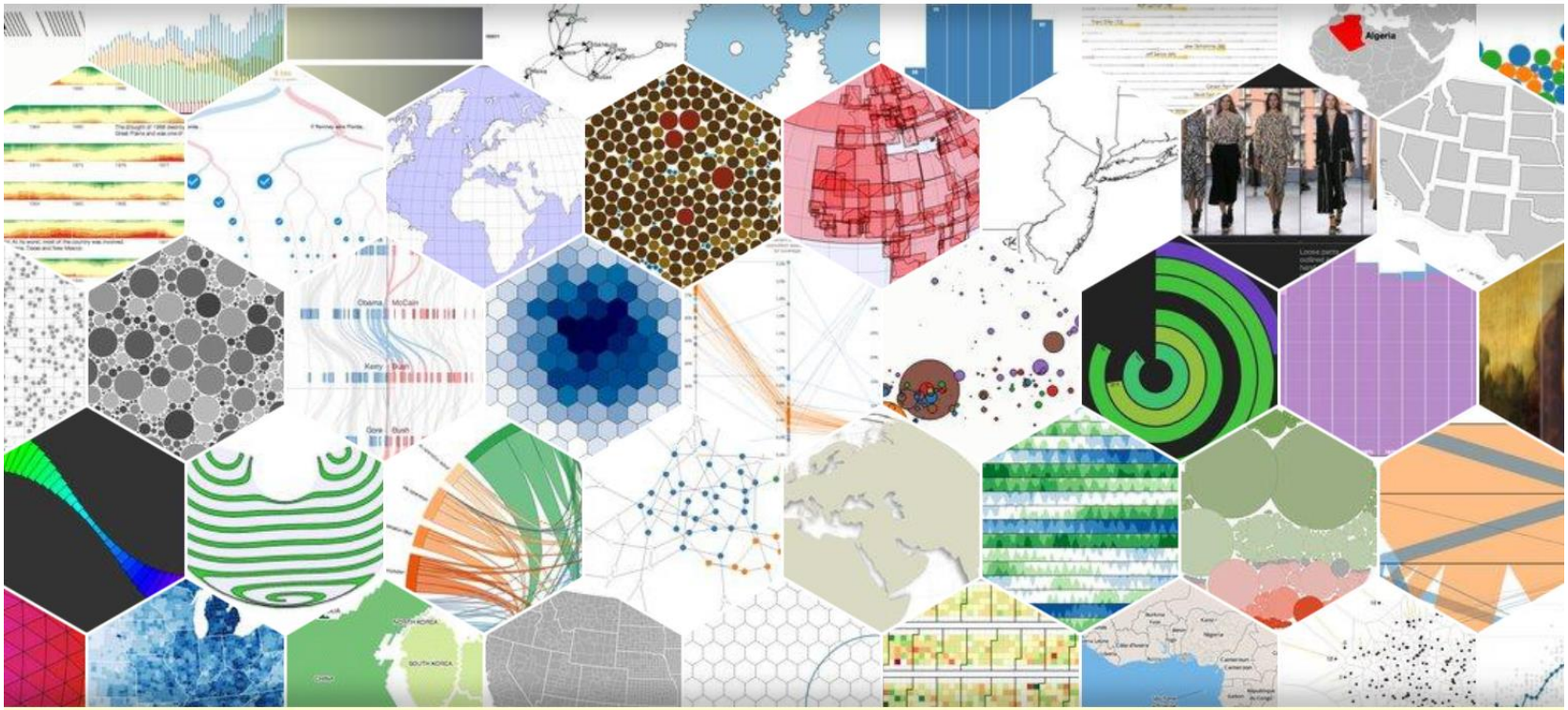


https://vtk.org/

D3—Data-Driven Documents

- JavaScript库
- 开源（一个.js文件）；方便操纵网页DOM；包含大量例子

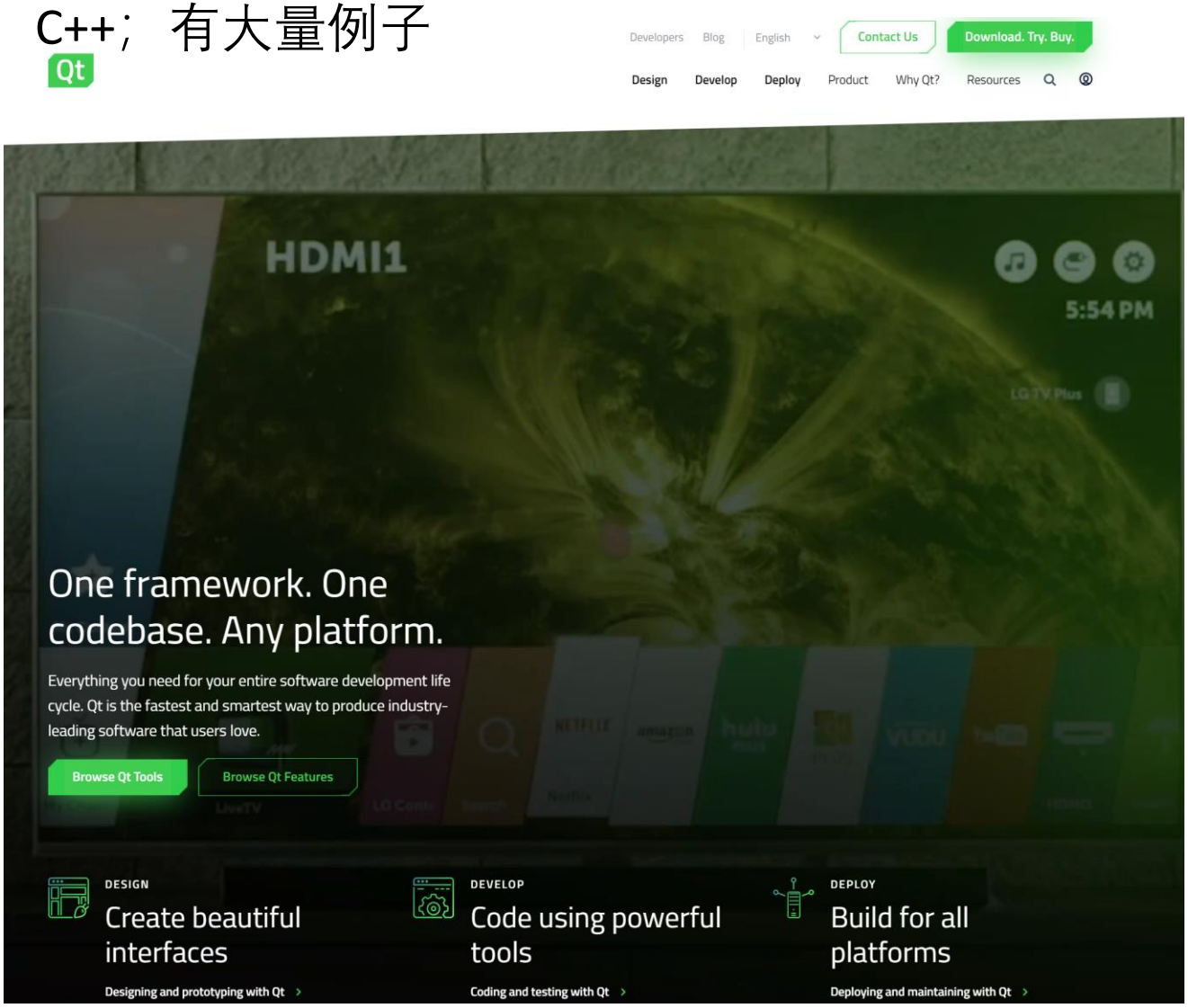
Data-Driven Documents



https://d3js.org/

Qt

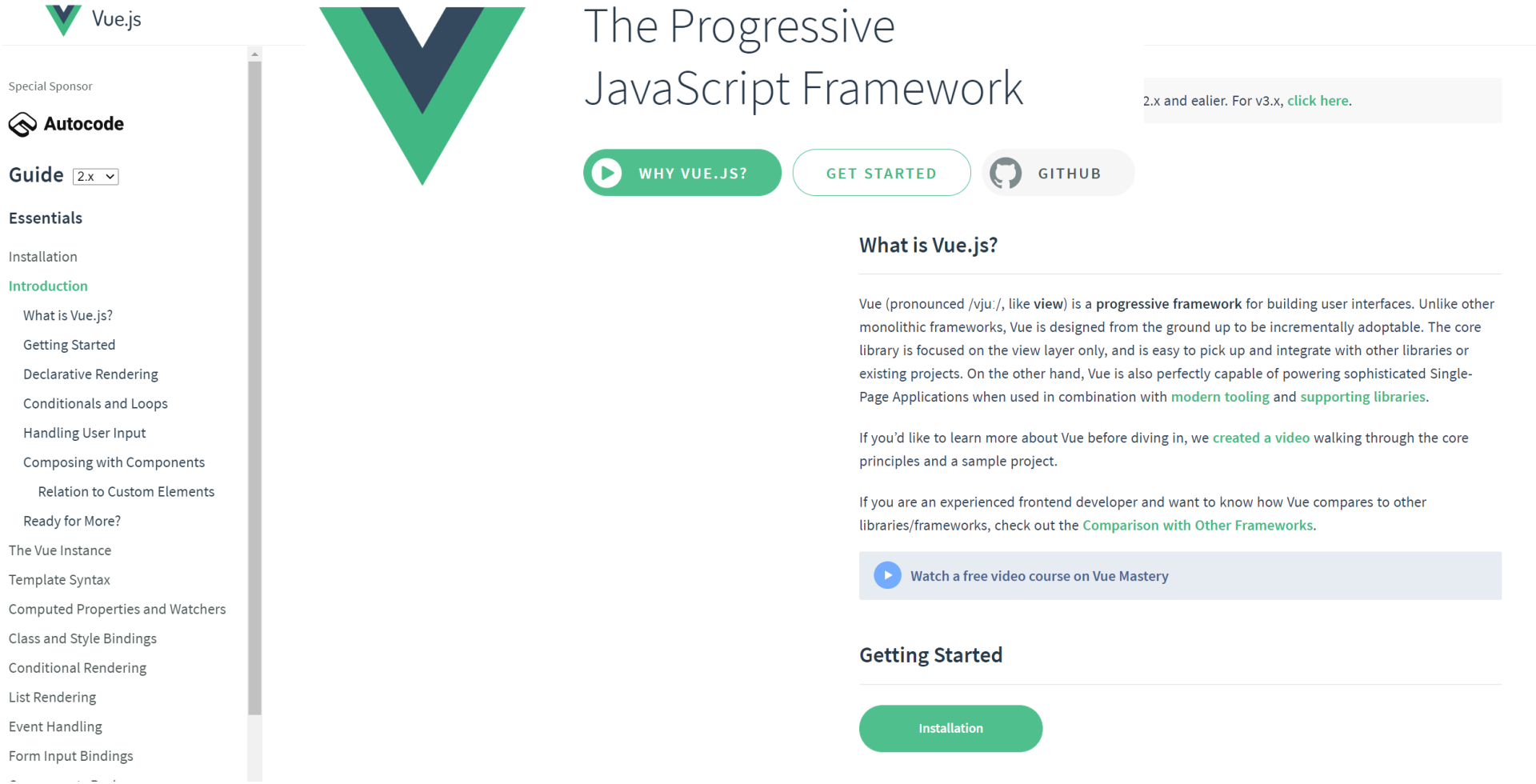
- 跨平台图形界面库——适合科学可视化可视分析应用
- 有开源版本；C++；有大量例子



https://www.qt.io/

Vue.js

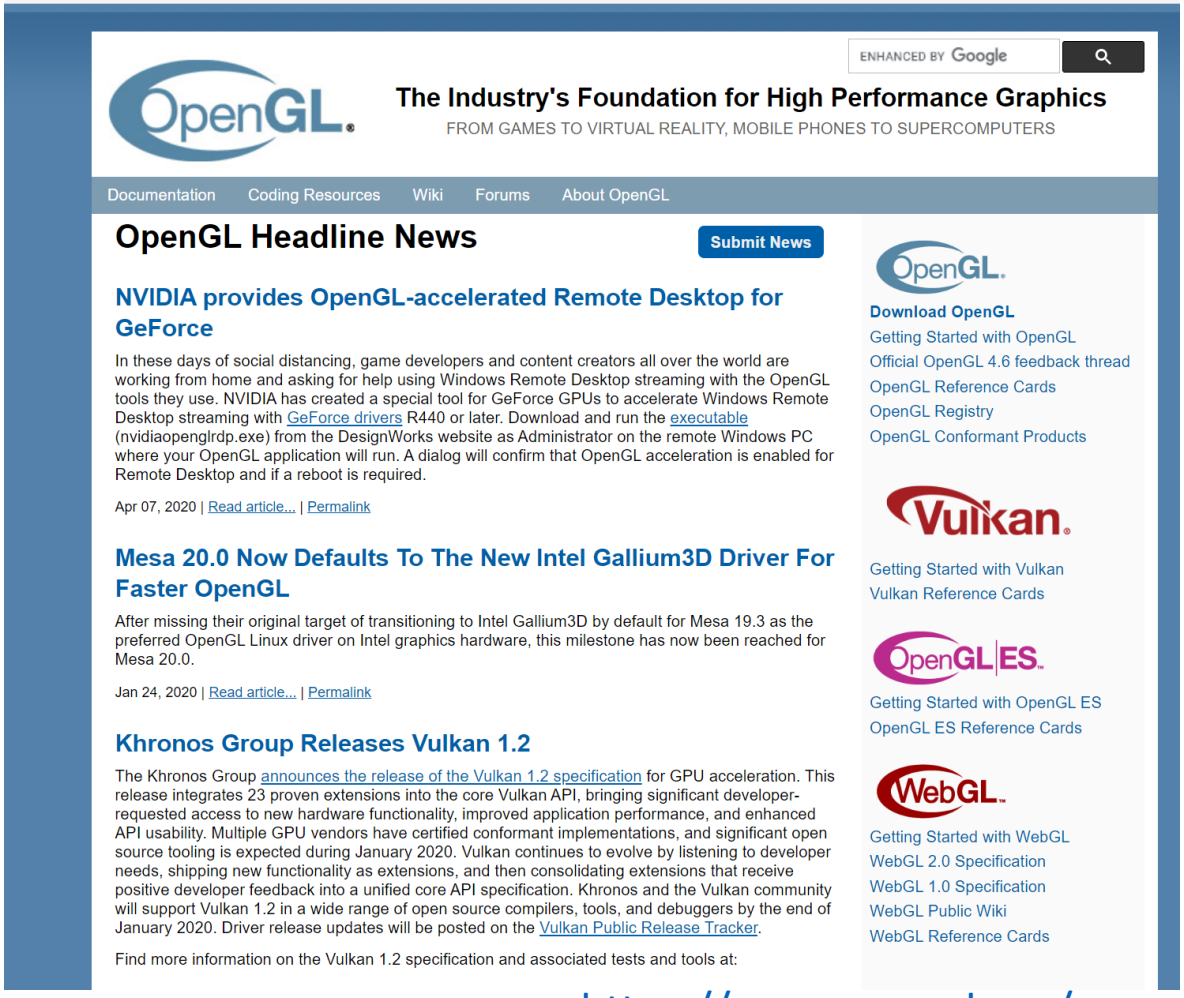
- JavaScript图形界面库——适合信息可视化可视分析应用
- 开源；有大量例子



https://vuejs.org/

图形编程——OpenGL，WebGL

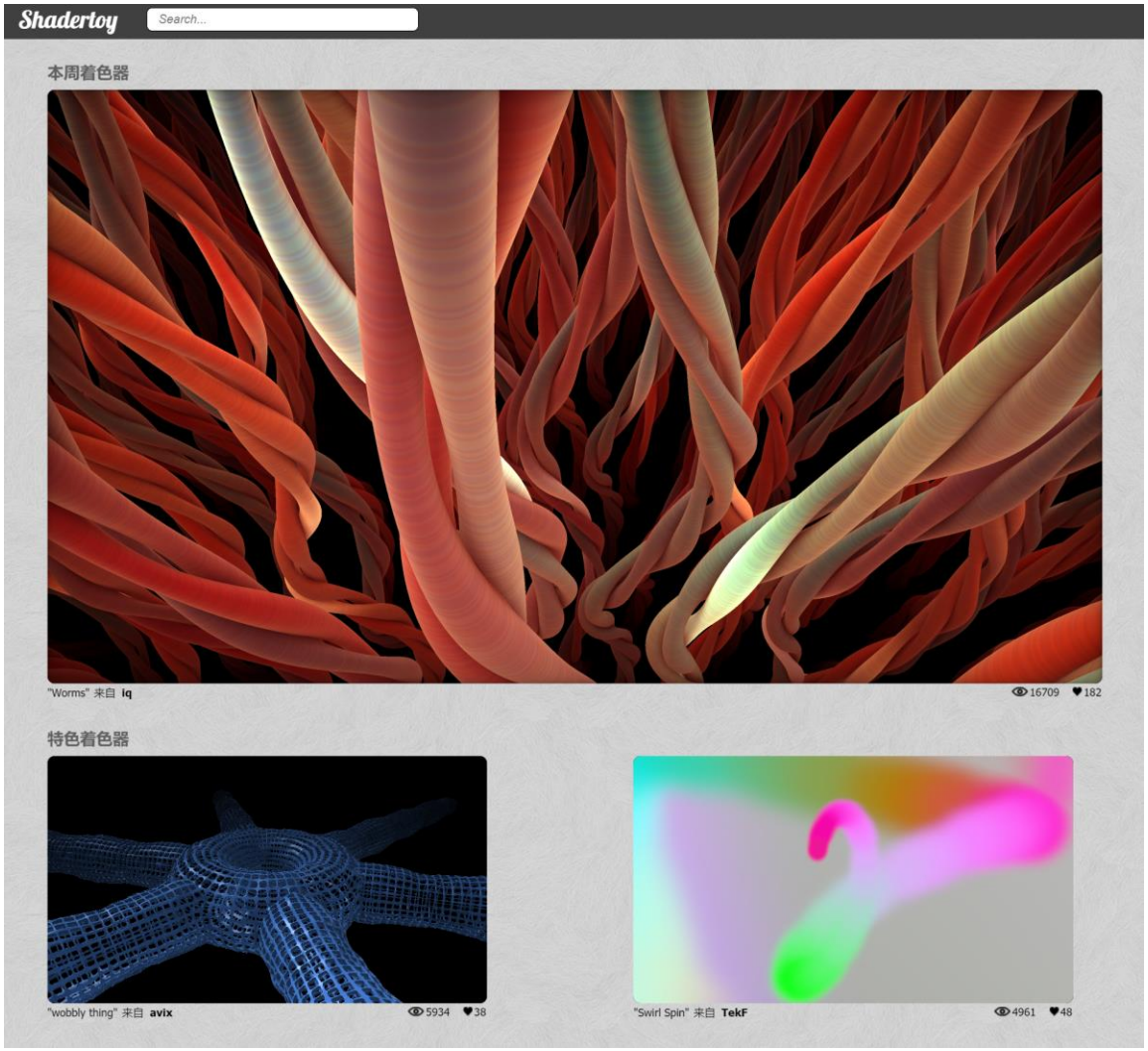
- 跨平台硬件加速图形接口
- OpenGL：单机应用；WebGL：网络应用
- 需熟悉现代图形流水线CPU+GPU；代码量较大；要仔细考虑计算效率



https://www.opengl.org/

图形处理器（GPU）编程——着色器（shaders）

- 在GPU上运行的并行程序编程，主要负责绘制
- GLSL（OpenGL着色器）； WebGL



WebGL着色器编程分享平台（有大量例子）：
https://www.shadertoy.com/

图形处理器（GPU）编程——CUDA

- CUDA (Compute Unified Device Architecture)：nVidia公司的GPU加速的并行高性能计算平台和接口
- 大规模计算；需深刻理解硬件和并行计算原理；各种科学计算；深度学习

CUDA Toolkit

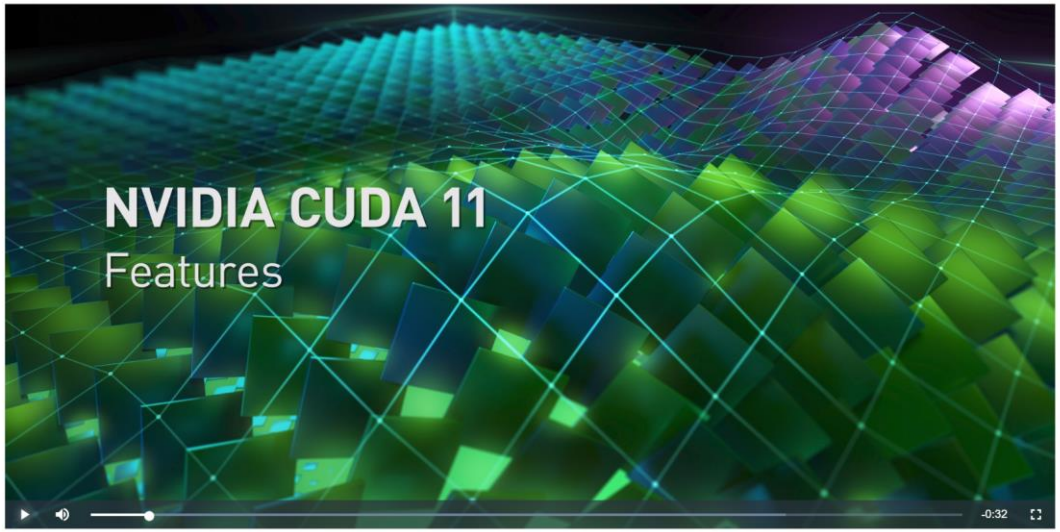
Develop, Optimize and Deploy GPU-Accelerated Apps

The NVIDIA® CUDA® Toolkit provides a development environment for creating high performance GPU-accelerated applications. With the CUDA Toolkit, you can develop, optimize, and deploy your applications on GPU-accelerated embedded systems, desktop workstations, enterprise data centers, cloud-based platforms and HPC supercomputers. The toolkit includes GPU-accelerated libraries, debugging and optimization tools, a C/C++ compiler, and a runtime library to build and deploy your application on major architectures including x86, Arm and POWER.

Using built-in capabilities for distributing computations across multi-GPU configurations, scientists and researchers can develop applications that scale from single GPU workstations to cloud installations with thousands of GPUs.

Download Now

CUDA 11 Features



CUDA 11 introduces support for the NVIDIA Ampere architecture, Arm server processors, performance-optimized libraries, and new developer tool capabilities.

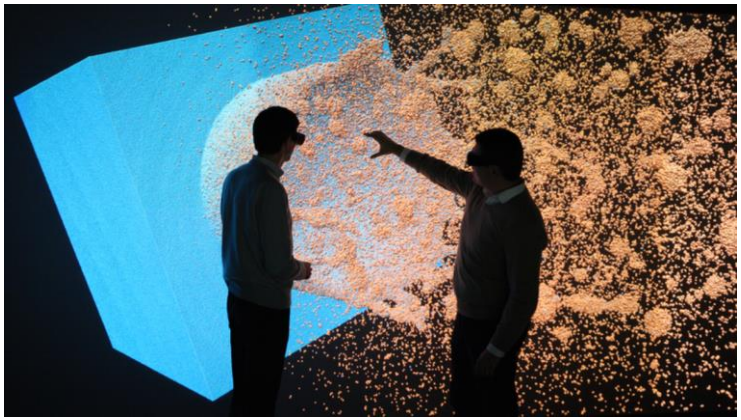
Support for the NVIDIA Ampere architecture includes next generation Tensor Cores, mixed precision modes, Multi-Instance GPU (MIG), advanced memory management, and standard C++/Fortran parallel language constructs.

https://developer.nvidia.com/cuda-toolkit

研究展望：健康医疗与可视计算互动

- 可视计算：所有和图形图像相关的计算机领域的统称（包括可视化，图形学，图像处理，虚拟/增强现实，等等）
- 可视计算能为健康医疗做什么？
  - 对健康医疗数据进行可视化、可视分析
    - 面向专家；面向大众
  - 辅助健康医疗过程，提高健康医疗实践水平
- 健康医疗能为可视计算做什么？
  - 为可视化可视分析设计感知实验，用户实验
  - 利用生理学、心理物理学中的模型提出新的可视计算方法

可视计算



健康医疗

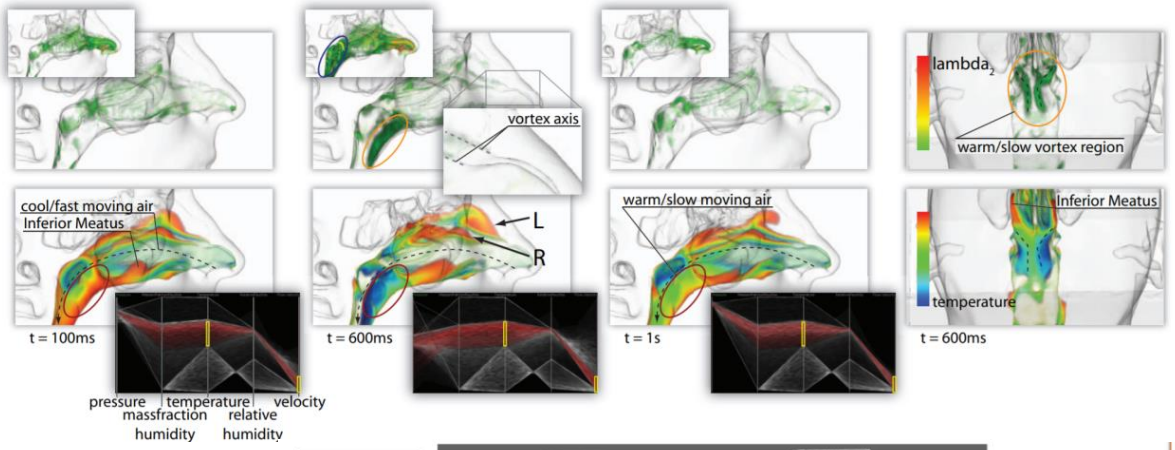
https://www.visus.uni-stuttgart.de/img/presse_und_medien/multimedia/galerie_visualisierungen/visualisierungslabor_und_powerwall/6453514365.png?__scale=w:1200,h:675,cx:0,cy:42,cw:800,ch:450

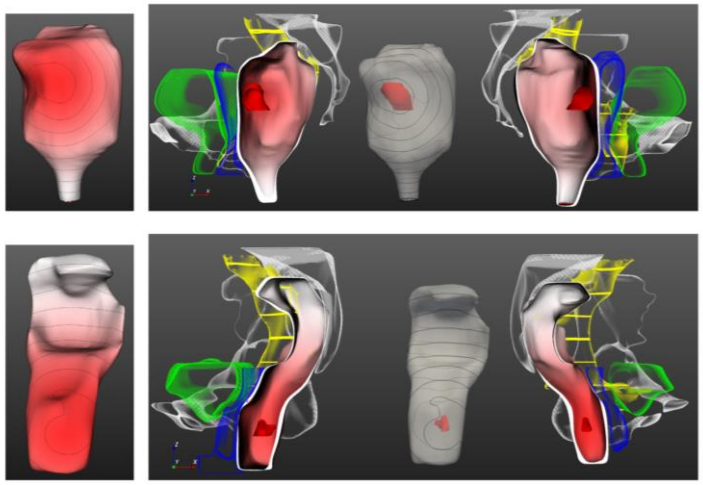
https://blog.csdn.net/hacker_long/article/details/84723368许可证: CC BY-SA

面向专家的健康医疗可视分析

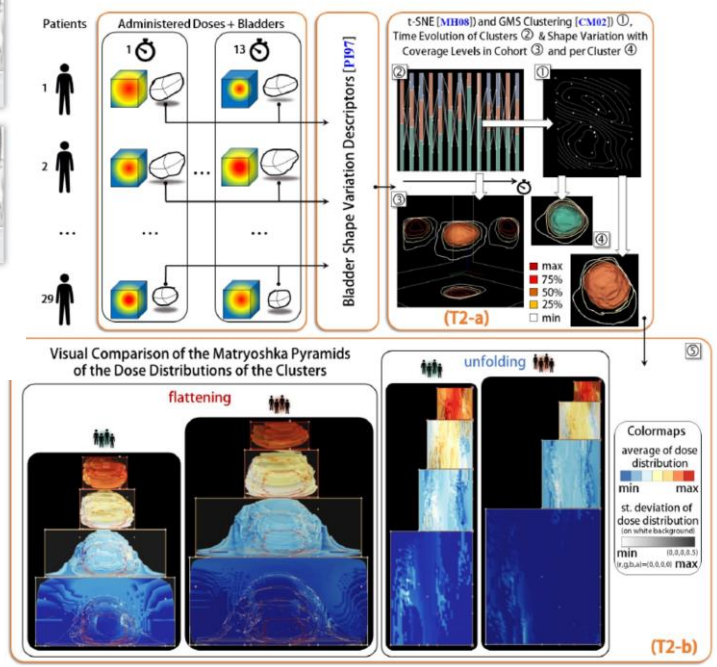
- 解决临床和实验中的具体问题

鼻腔气流分析 [S. Zachow et al., "Visual Exploration of Nasal Airflow," doi: 10.1109/TVCG.2009.198.]





骨盆肿瘤手术规划 [N. Smit et al., "PelVis: Atlas-based Surgical Planning for Oncological Pelvic Surgery," doi: 10.1109/TVCG.2016.2598826.]



放疗导致膀胱中毒分析[R. Raidou et al. "*Bladder Runner*: Visual Analytics for the Exploration of RT-Induced Bladder Toxicity in a Cohort Study,". doi:10.1111/cgf.13413]

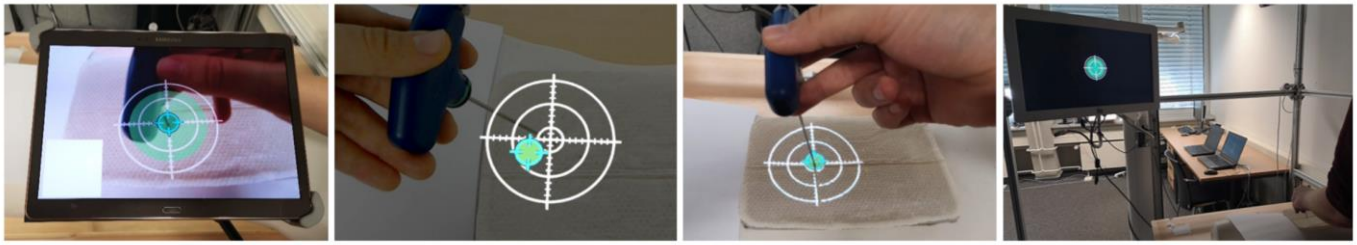
面向大众的健康医疗可视化

- 医疗参与者信息不对称亟待解决
- 如何让普通人看懂病历，化验结果，处方？
- 如何向普通人更好地解释手术方案，建立合理预期？
- 医学科普

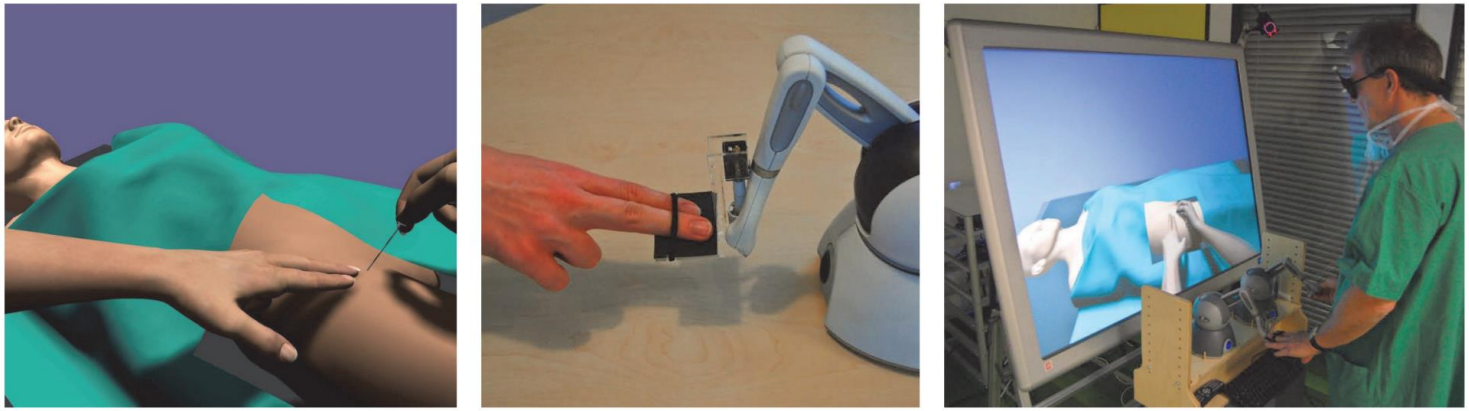
https://betterhealthwhileaging.net/wp-content/uploads/2017/09/Depositphotos133833238m-2015-compressor.jpg, license: creative commons

可视计算辅助健康医疗过程

- 增强/虚拟现实进行临床训练
- 增强/虚拟现实辅助、提高临床实践



增强现实辅助进针
[F. Heinrich et al., "Comparison of Augmented Reality Display Techniques to Support Medical Needle Insertion," doi: 10.1109/TVCG.2020.3023637.]



虚拟环境触诊训练
[S. Ullrich and T. Kuhlen, "Haptic Palpation for Medical Simulation in Virtual Environments," doi: 10.1109/TVCG.2012.46.]

可视计算辅助健康医疗过程

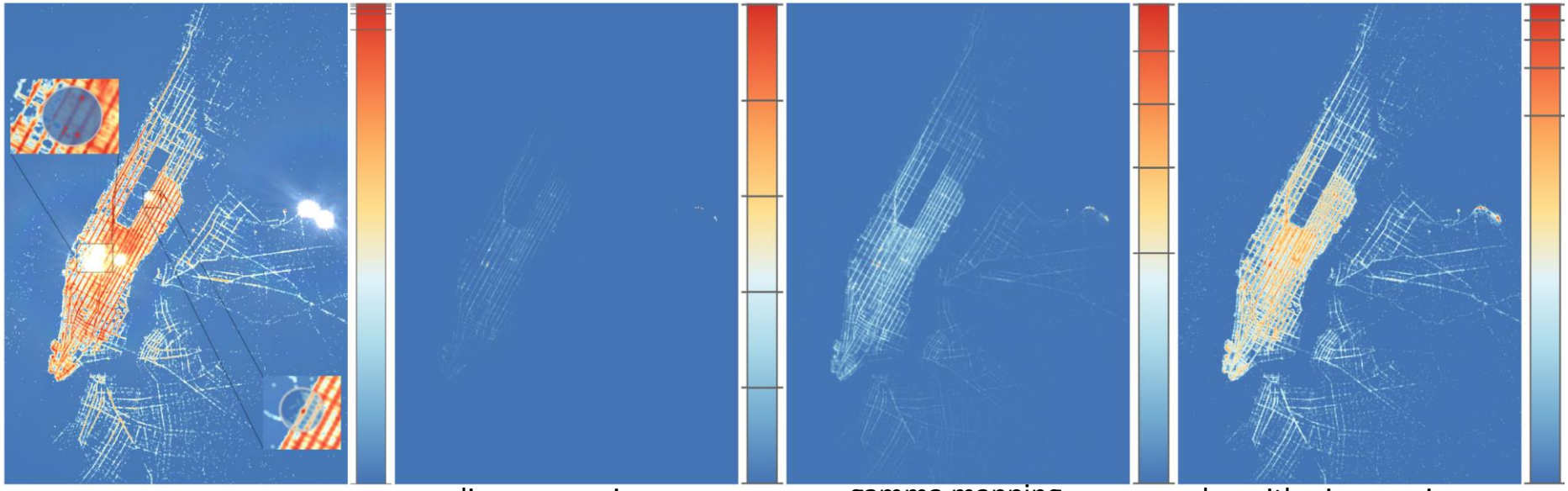
- 更广泛意义上的健康：体育运动中的动作引导

混合现实动作引导

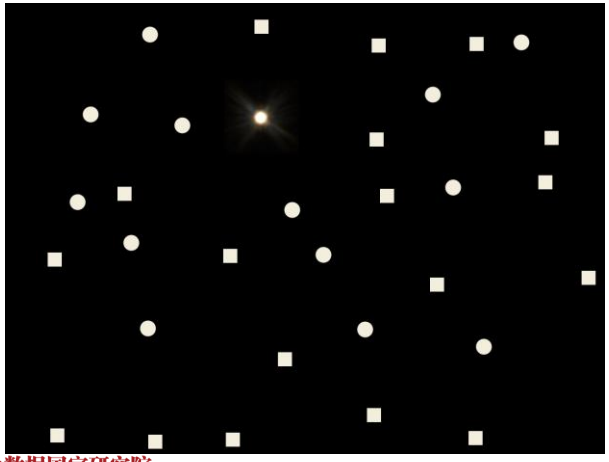
[X. Yu et al., “Perspective Matters: Design Implications for Motion Guidance in Mixed Reality,” (ISMAR 20’), to appear.]

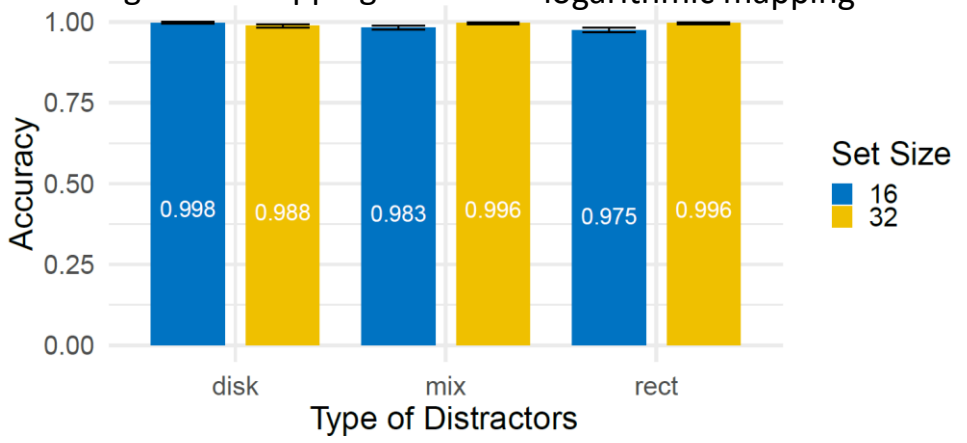
感知实验设计

- 通过感知实验得知眩光是前注意（preattentive）视觉元素



ours　　linear mapping　　gamma mapping　　logarithmic mapping

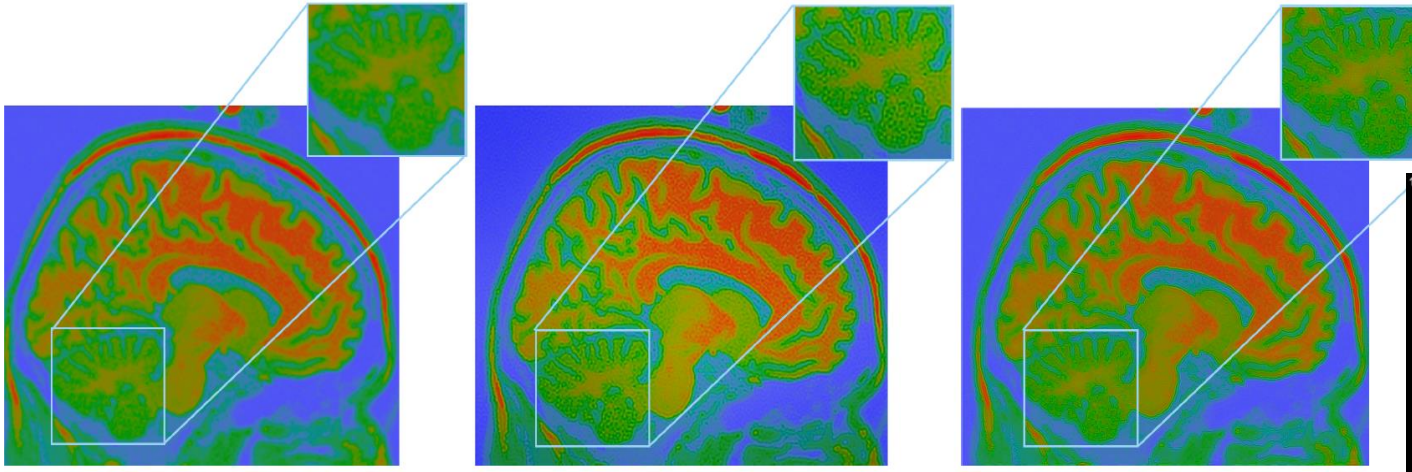


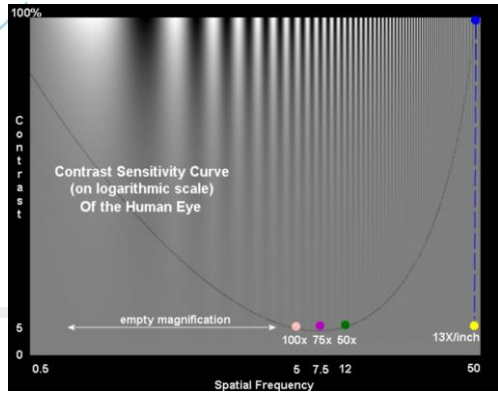


[L. Zhou, M. Rivinius, C. R. Johnson, and D. Weiskopf, "Photographic High-Dynamic-Range Scalar Visualization," doi: 10.1109/TVCG.2020.3030473]

基于阈值空间视觉的感知增强

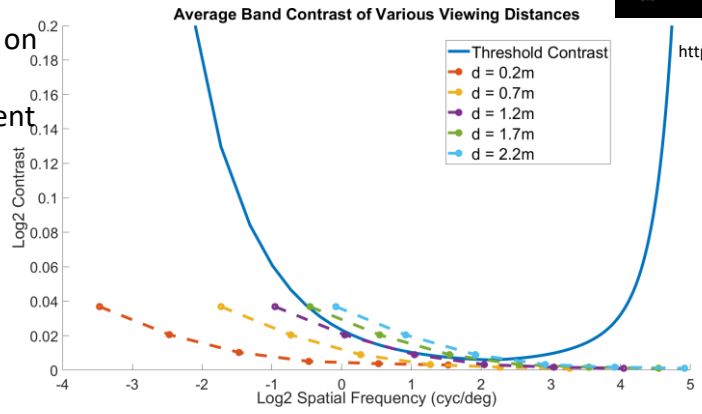
- 对比敏感度函数（Contrast Sensitivity Function)---Daly's CSF
- 计算不同图像不同频段的对比度
- 利用虚拟观测距离调节对比度增强幅度





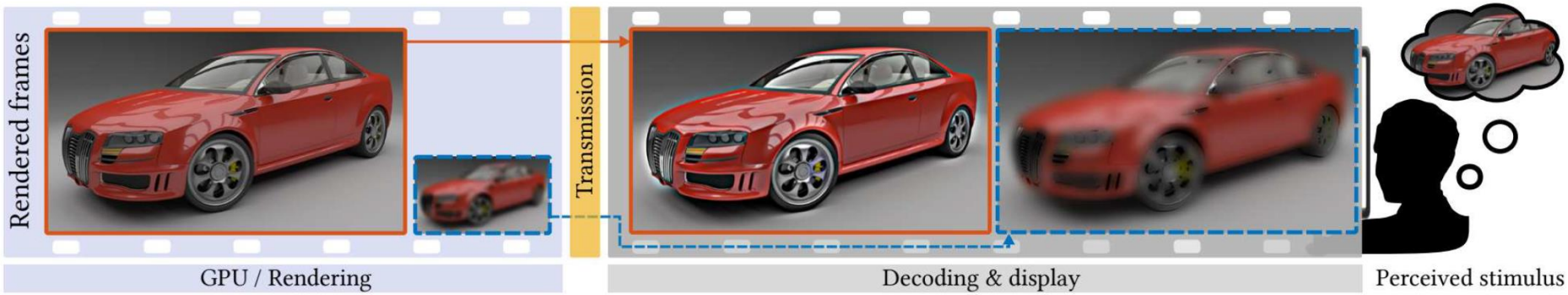
http://www.cityastronomy.com/rez-mag-contrast.htm

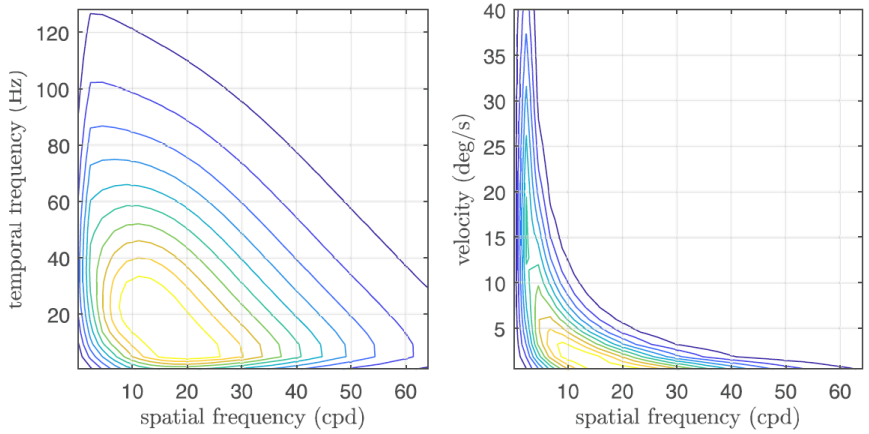
[L. Zhou and D. Weiskopf (2018). Contrast Enhancement based on Viewing Distance, doi: 10.1145/3231622.3231628]
[L. Zhou et al. (2019). Perceptually Guided Contrast Enhancement Based on Viewing Distance, doi: 10.1016/j.cola.2019.100911]



基于感知模型提出高效的可视计算方法

- 利用其它感知现象、感知模型提出高效的可视计算方法





基于空间时间视觉模型提高虚拟现实绘制效率

[G. Denes et al. "Temporal Resolution Multiplexing: Exploiting the limitations of spatio-temporal vision for more efficient VR rendering," doi: 10.1109/TVCG.2019.2898741.]

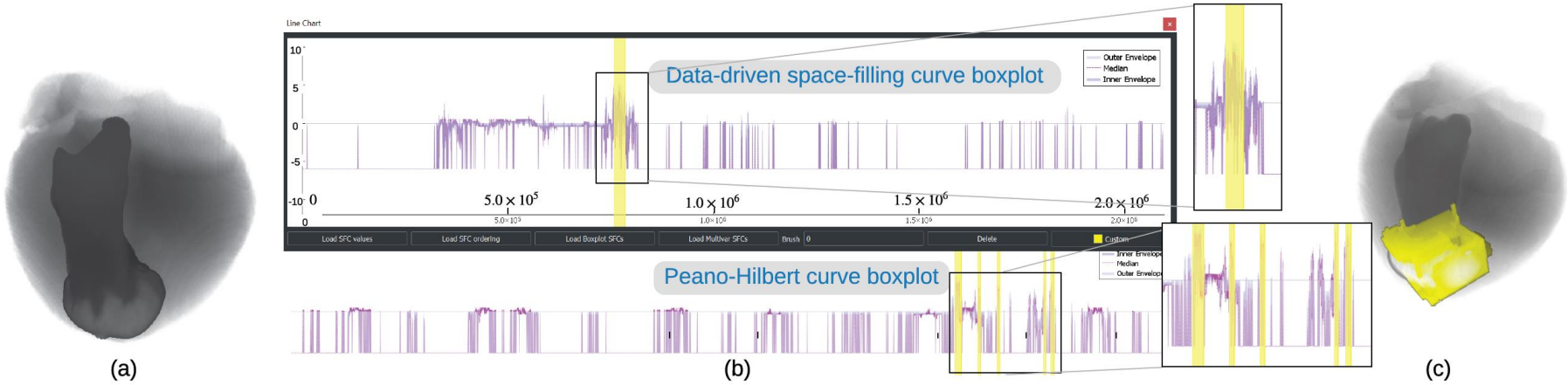
用健康医疗中的模型为虚拟环境建模

- 健康医疗为虚拟环境建模
  - 身体指标、性别、年龄、疾病等等

虚拟环境中的体型体重感知 [Anne Thaler et al. 2019. The Influence of Visual Perspective on Body Size Estimation in Immersive Virtual Reality. DOI:https://doi.org/10.1145/3343036.3343134]

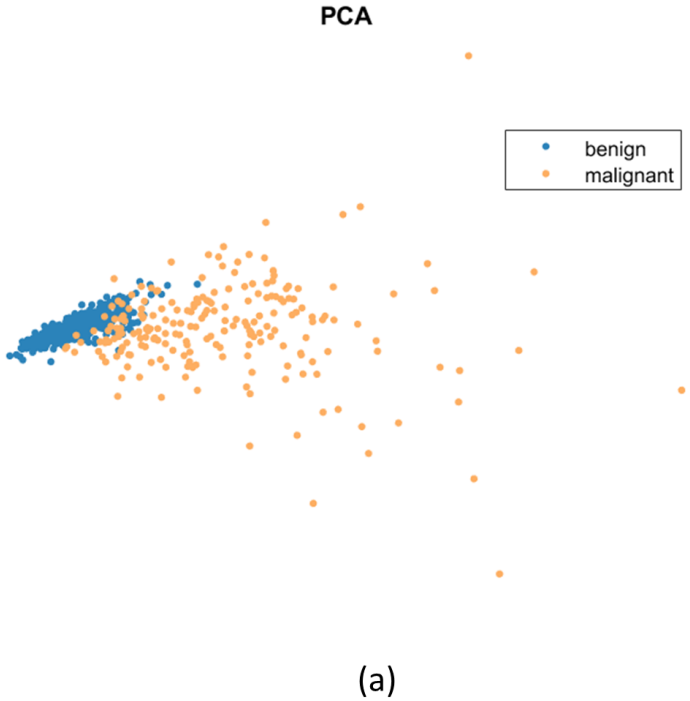
总结

- 可视化领域分类
- 科学可视化
- 信息可视化
- 可视分析
- 可视化和可视分析工程实现
- 健康医疗与可视计算研究展望

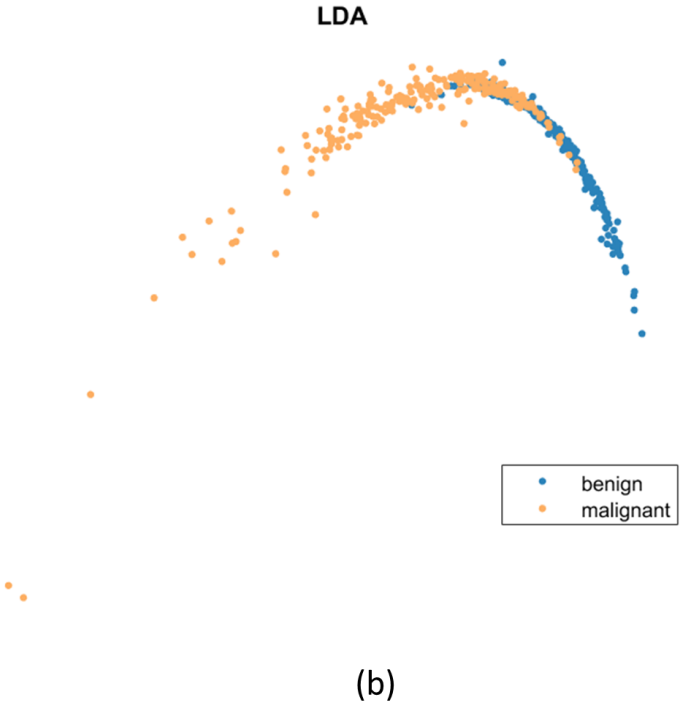


心肌缺血模拟数据集合可视化

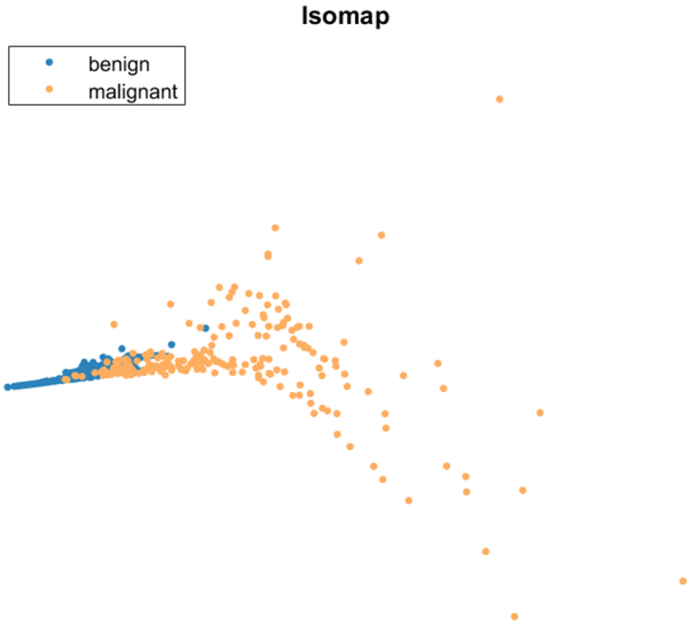
[L. Zhou et al. (2020). Data-Driven Space-Filling Curves. doi: 10.1109/TVCG.2020.3030473.]


PCA
benign
malignant

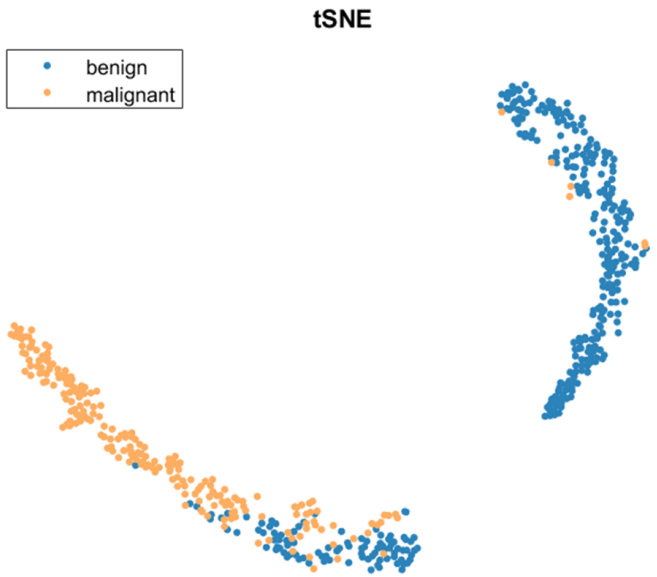
(a)


LDA
benign
malignant

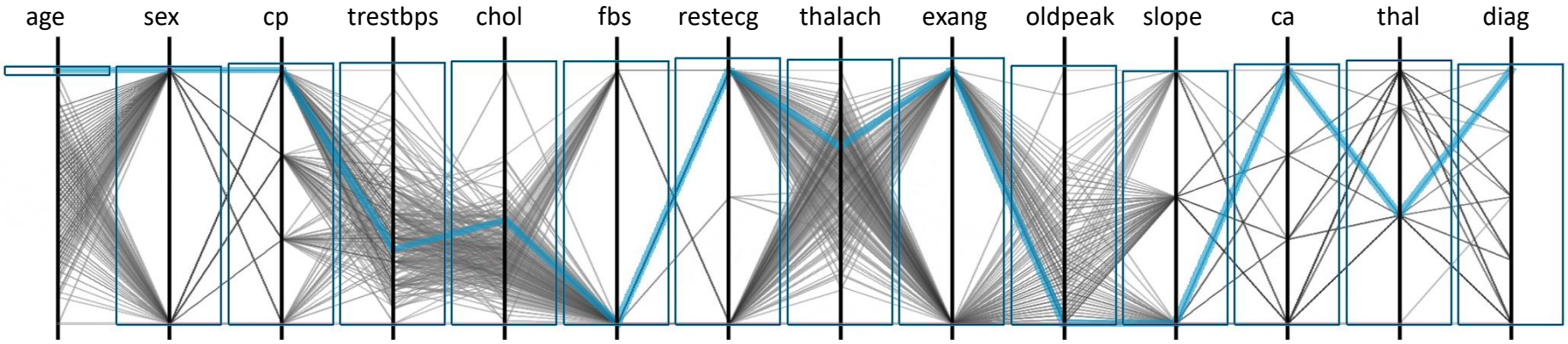
(b)

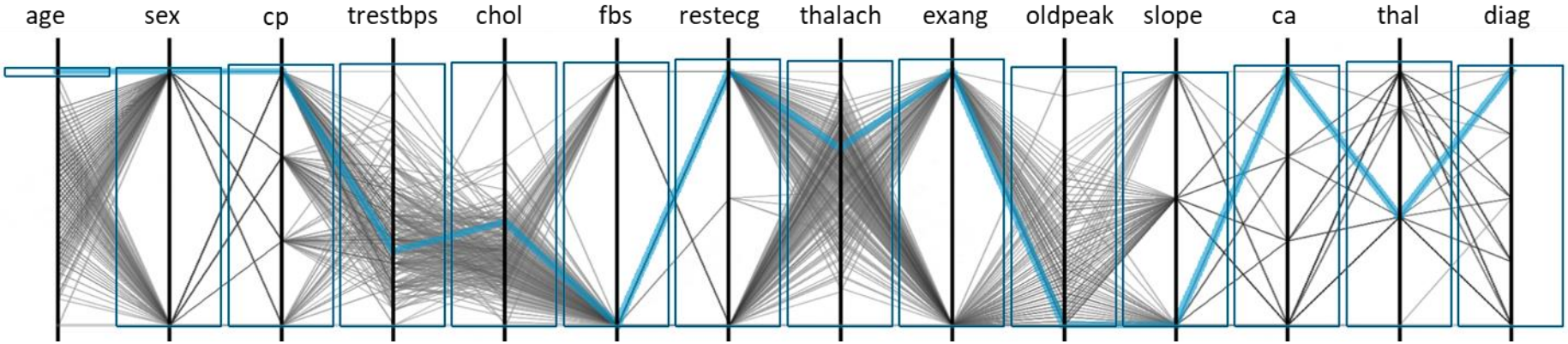

Isomap
benign
malignant

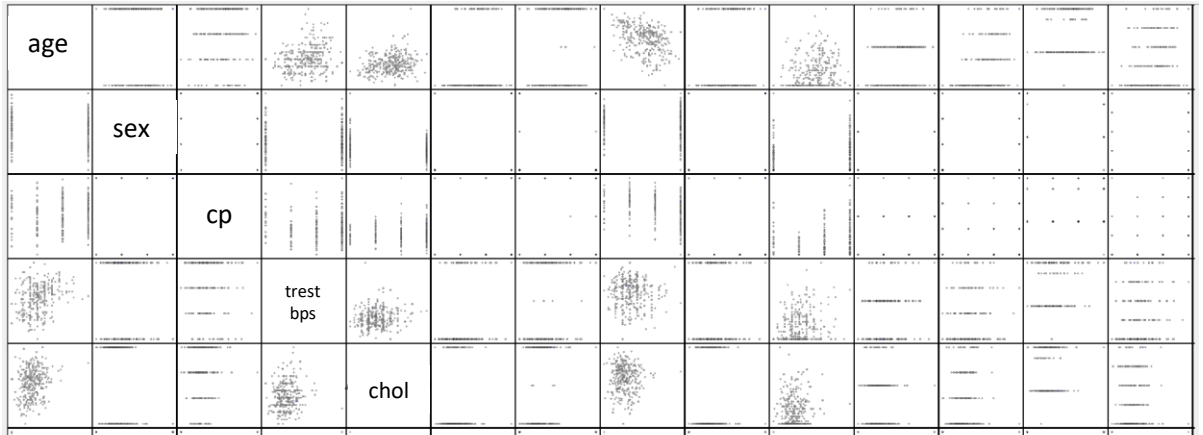
(c)


tSNE
benign
malignant

(d)



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