浙江大学
ZHEJIANG UNIVERSITY

电子信息工程中的数学模型和方法

可视化建模（上）

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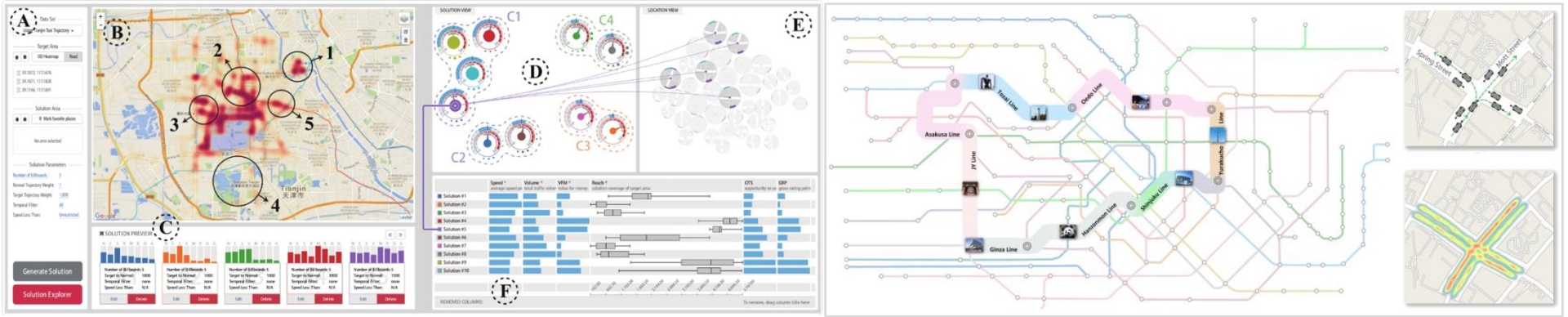


数据可视化与可视分析

什么是数据可视化？为什么我们要用数据可视化？

https://github.com/hongxin/vizmodeling

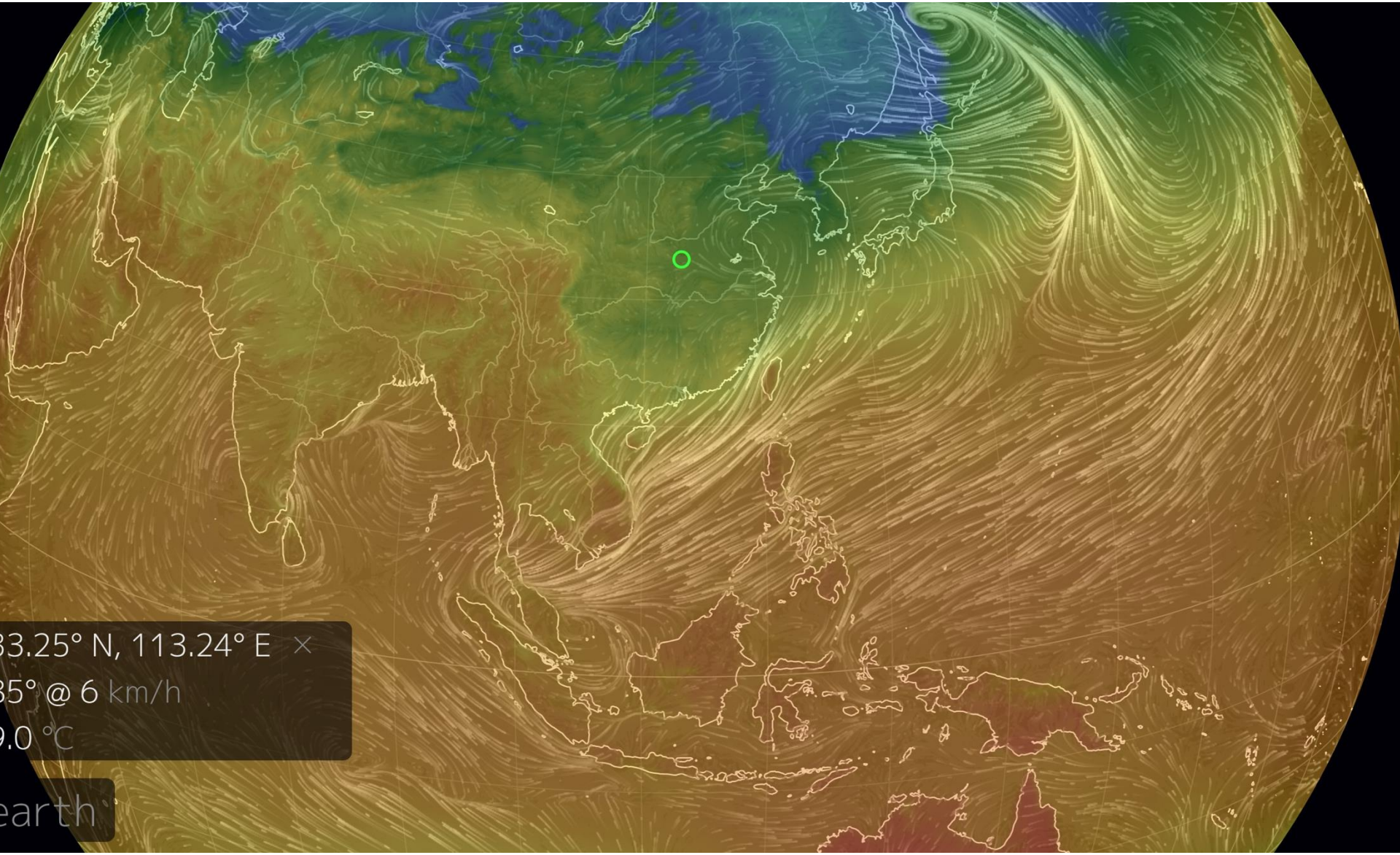
引子

2017 年双 11 的区域经济闪电图，将实时订单数据与物流干线结合展示

例子 – 飞行模式可视化

例子 – 全球气象可视化

https://earth.nullschool.net



例子 – 《本草纲目》可视化

药症方关联的中医药古籍交互可视分析方法

吴泓嘉, 张弛, 张宏鑫, 陈为, 夏佳志

ChinaVis 2023

ID 1239

本文提出了一种药症方关联的中医药古籍交互可视分析方法

吴泓嘉, 张弛, 张宏鑫, 陈为, 夏佳志. 药症方关联的中医药古籍交互可视分析方法[J]. 计算机辅助设计与图形学学报. DOI: 10.3724/SP.J.1089.2023-00623

什么是数据可视化？

数据可视化

- 创建并研究数据的**视觉表达（Visual Representation）**
  - 输入：数据（data）
  - 输出：视觉形式（visual form）
  - 目标：深入理解（insight）

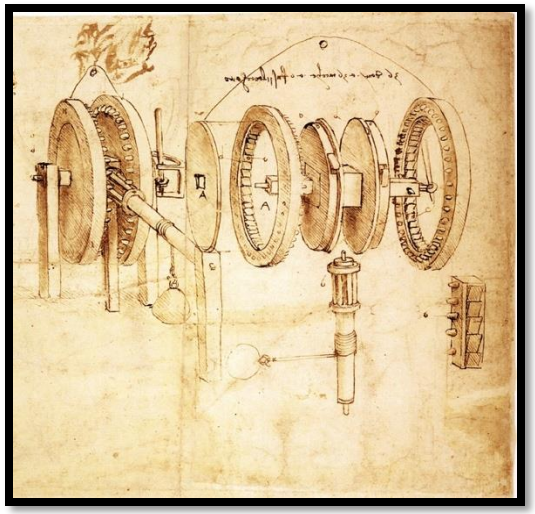
数据

视觉形式

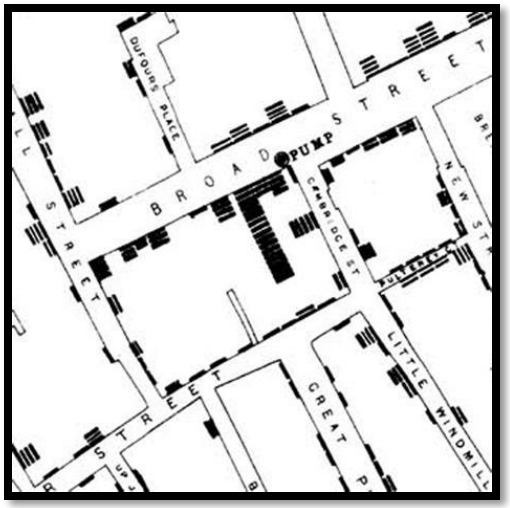
深入理解

数据可视化的主要任务

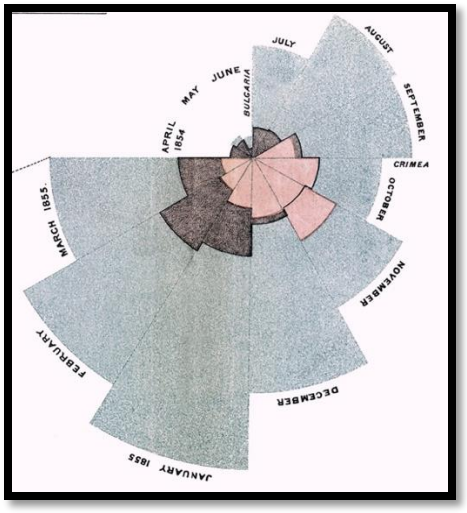
- 表示数据 – Represent
- 分析数据 – Analyze
- 交流数据 – Communicate



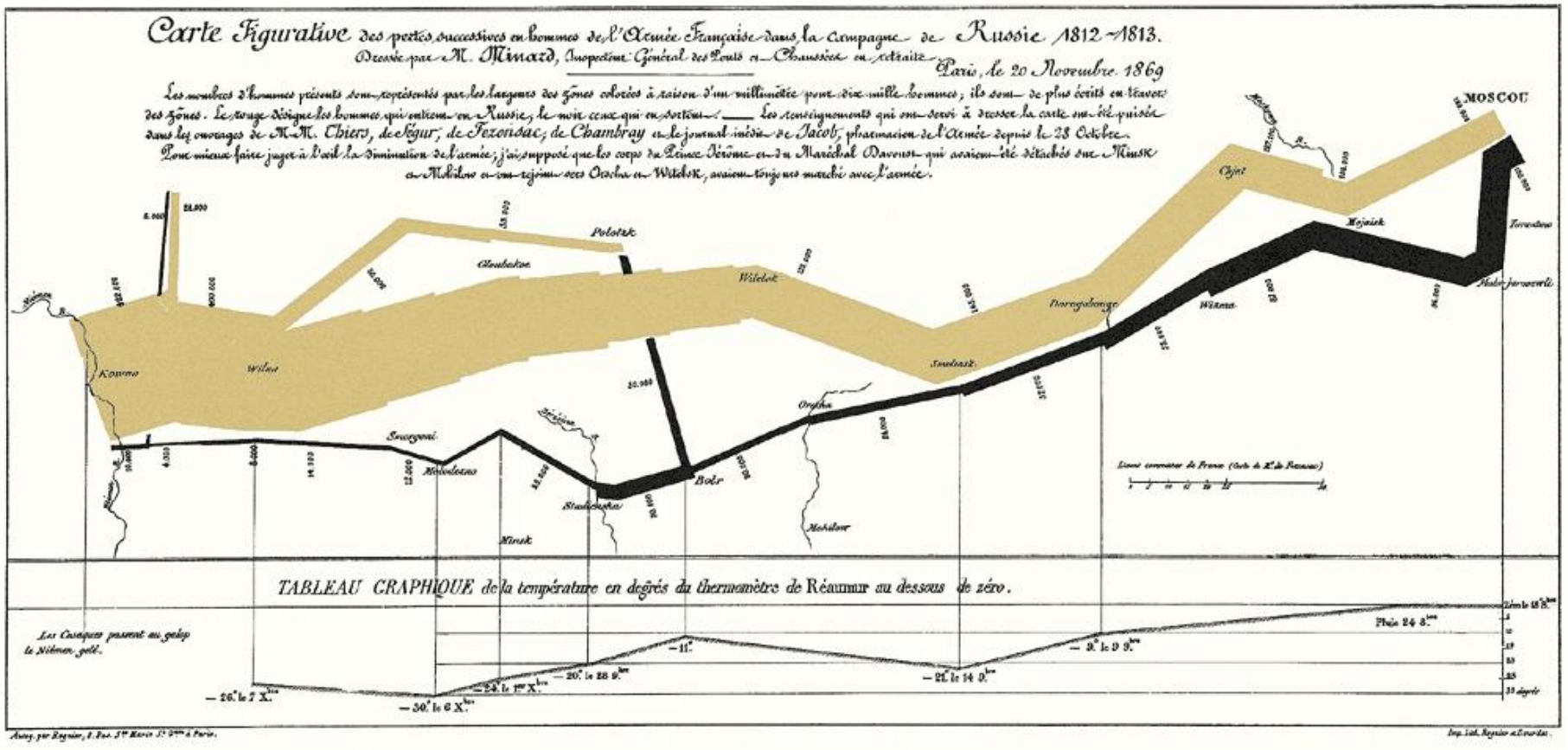
三维素描图



霍乱病例的分布

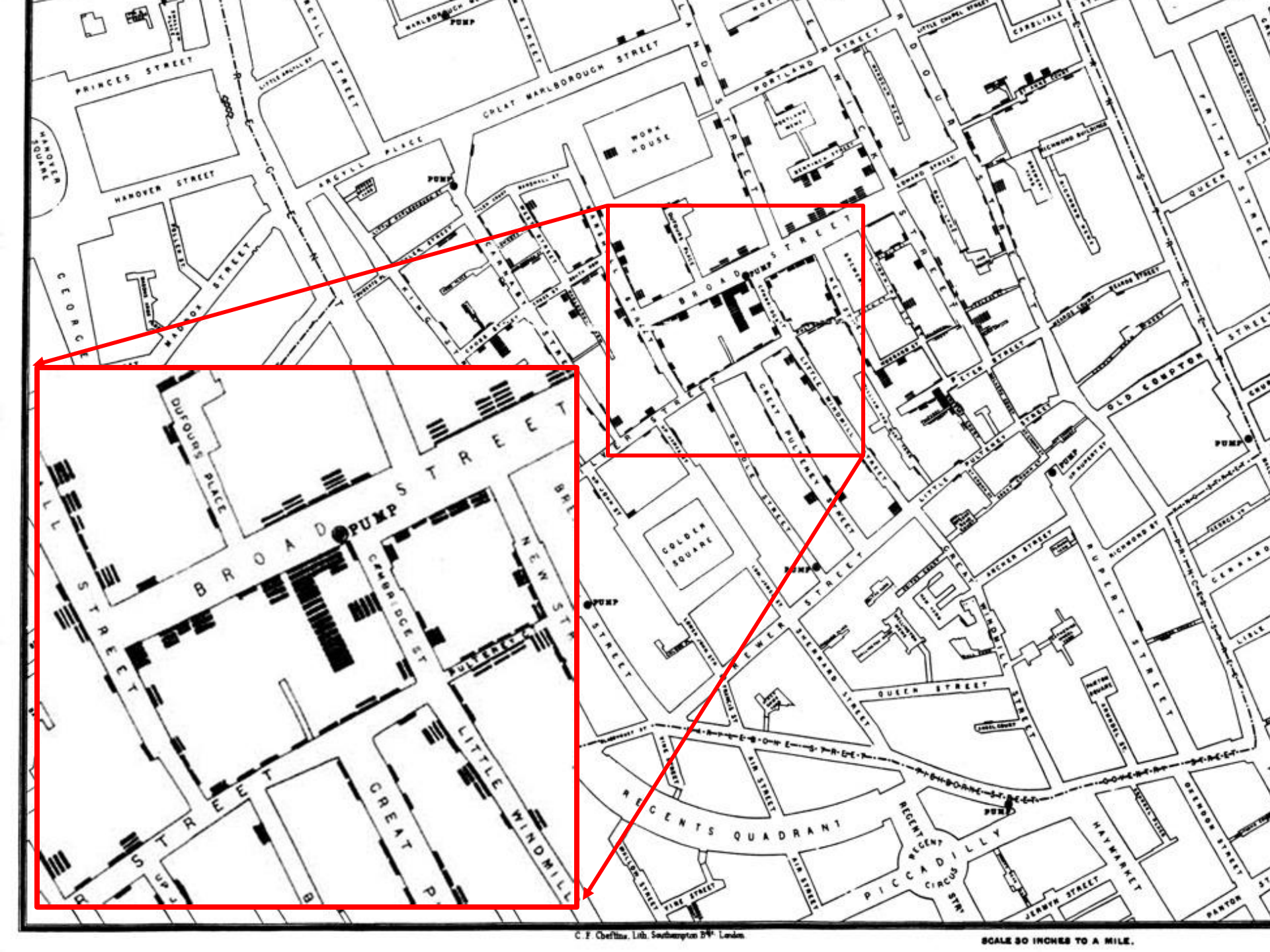


英国东征士兵死亡原因



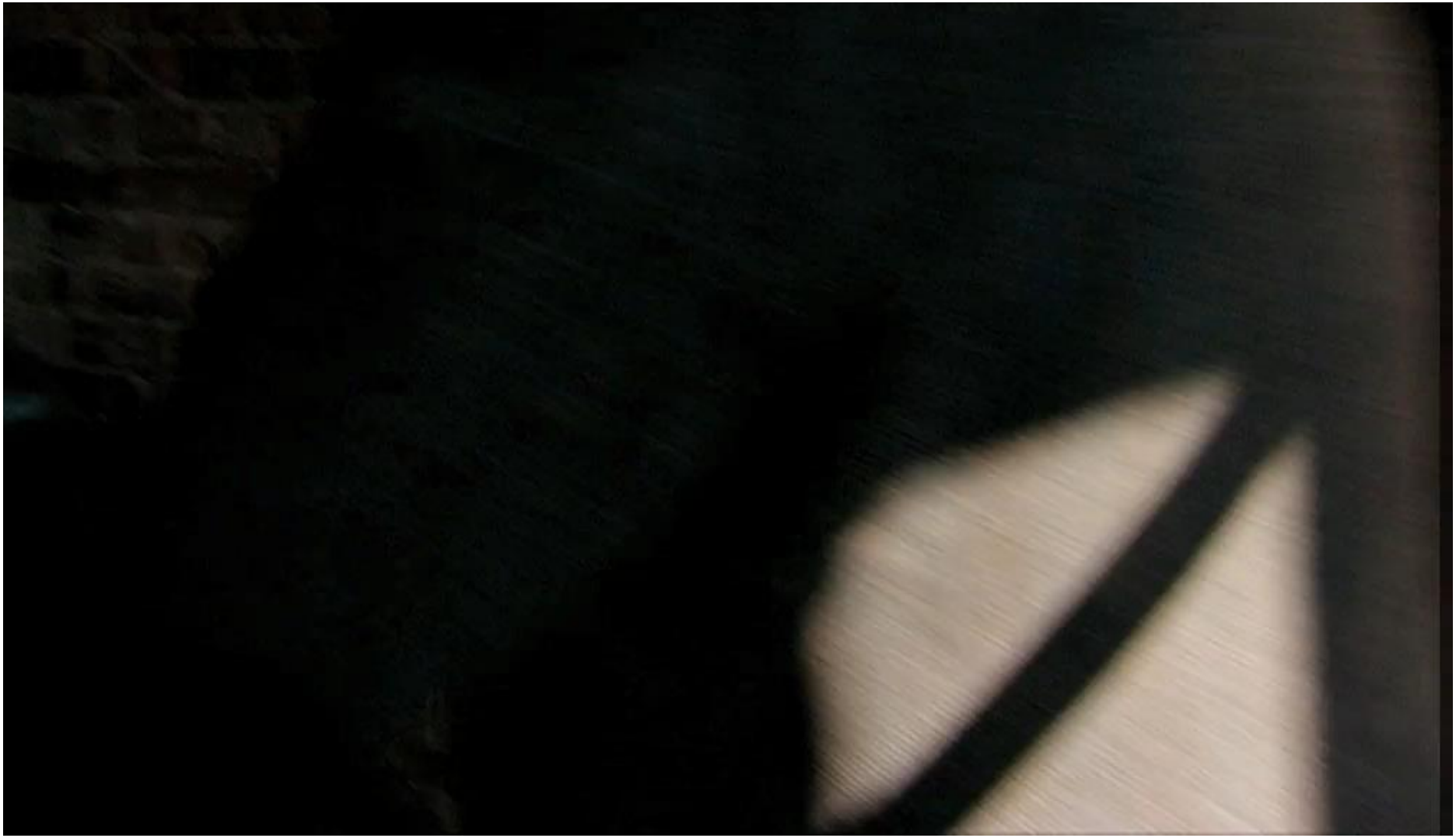
C. J. Minard, 1869

E. Tufte, Writings, Artworks, News



C. F. Cheffins, Lith. Southampton Bldgs. London.

Hans Rosling' TED talk



为什么要用数据可视化？

为什么要用数据可视化

- 人类认知存在天生的缺陷
  - Change blindness
- 统计数据存在盲区
  - Anscombe's Quartet

人类认知的缺陷

Daniel J. Simons and Daniel T. Levin,
Failure to detect changes to people during a real world interaction,1998

统计数据的盲区

Set A		Set B		Set C		Set D	
X	Y	X	Y	X	Y	X	Y
10	8.04	10	9.14	10	7.46	8	6.58
8	6.95	8	8.14	8	6.77	8	5.76
13	7.58	13	8.74	13	12.74	8	7.71
9	8.81	9	8.77	9	7.11	8	8.84
11	8.33	11	9.26	11	7.81	8	8.47
14	9.96	14	8.1	14	8.84	8	7.04
6	7.24	6	6.13	6	6.08	8	5.25
4	4.26	4	3.1	4	5.39	19	12.5
12	10.84	12	9.11	12	8.15	8	5.56
7	4.82	7	7.26	7	6.42	8	7.91
5	5.68	5	4.74	5	5.73	8	6.89

Summary Statistics

$u_X = 9.0$ $\sigma_X = 3.317$

$u_Y = 7.5$ $\sigma_Y = 2.03$

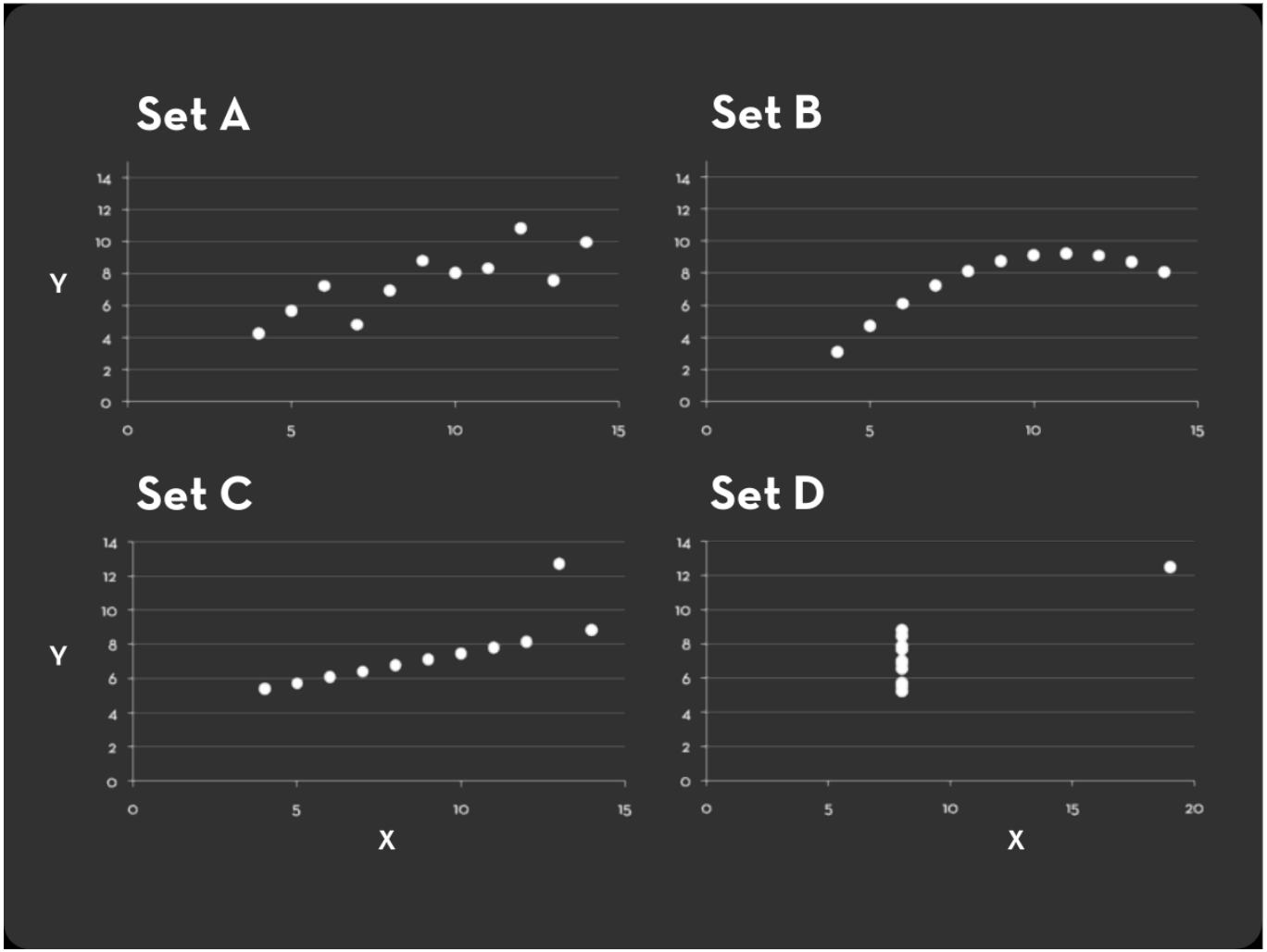
Linear Regression

$Y = 3 + 0.5\,X$

$R^2 = 0.67$

[Anscombe 73]

统计数据的盲区



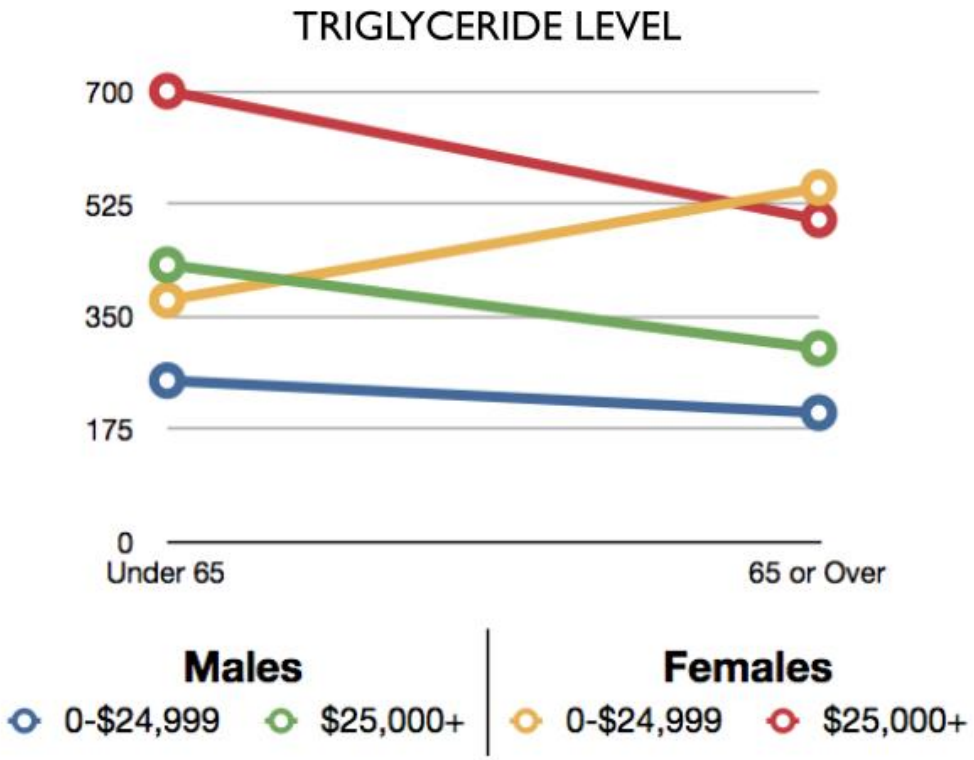
小测试

三酸甘油脂水平在**哪个年龄段和收入水平的人群**中随年龄增长表现出不同的趋势？

	男性		女性	
收入水平	65岁以下	65岁及以上	65岁以下	65岁及以上
0-$24,999	250	200	375	550
$25,000+	430	300	700	500

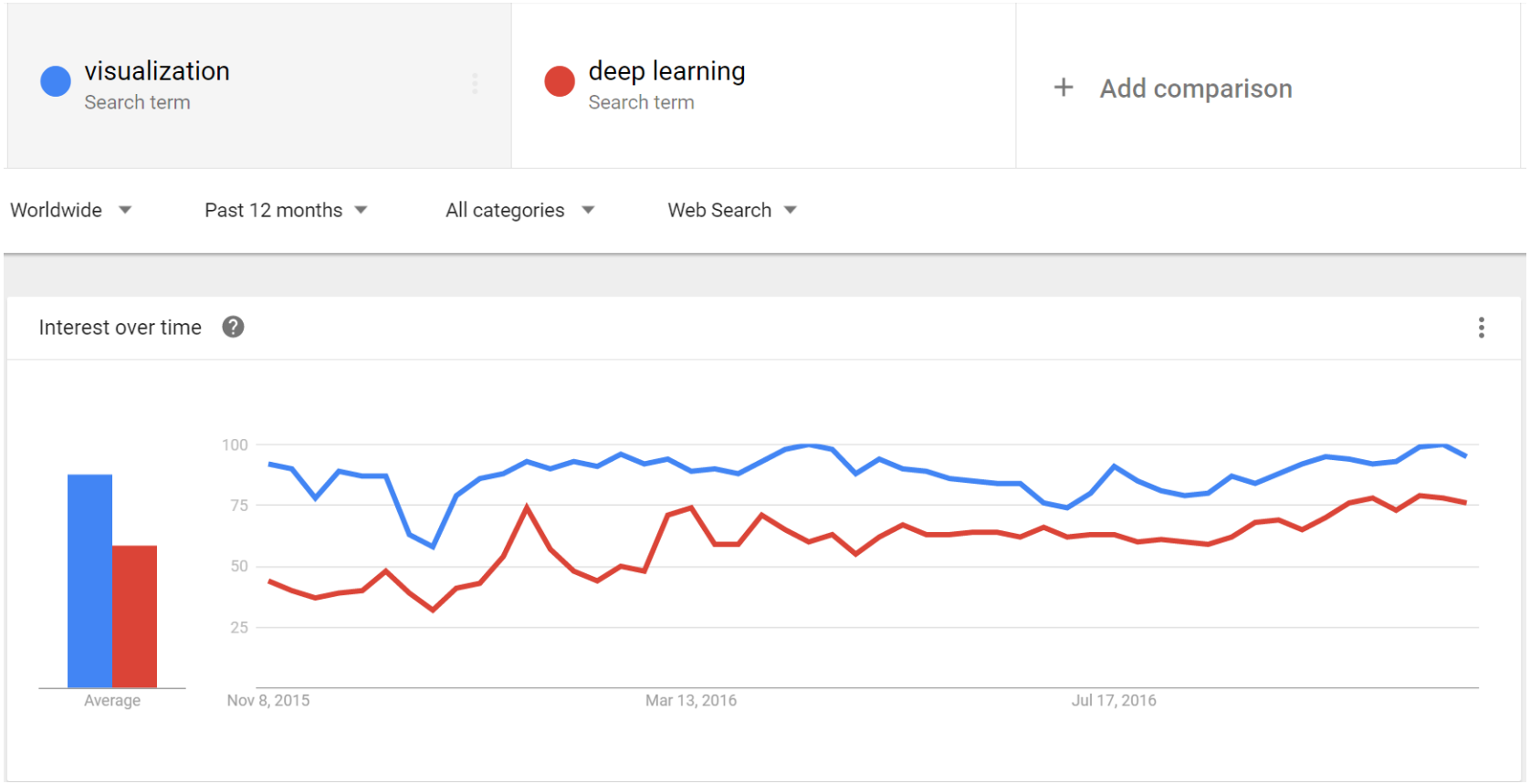
数据可视化的力量

三酸甘油脂水平在**哪个年龄段和收入水平的人群**中随年龄增长表现出不同的趋势？



可视化热度

可视化与深度学习



可视化是一个跨学科领域

可视化与图形学

图形学

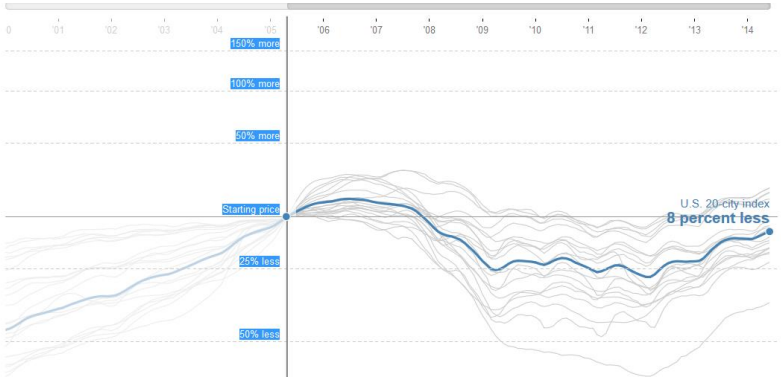
- 照片真实感
- 模拟
- 现实世界
- 视觉媒介

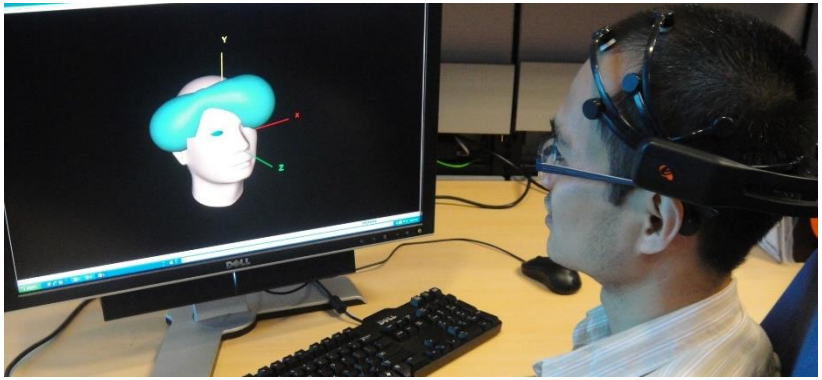
可视化

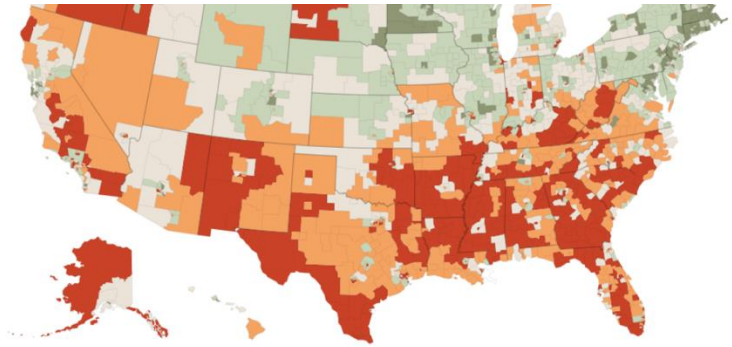
- 描述性
- 增强理解
- 传达信息

可视化与人机交互

- 可视化主要处理**数据**
- 人机交互主要关注**人与机器之间的交互行为**





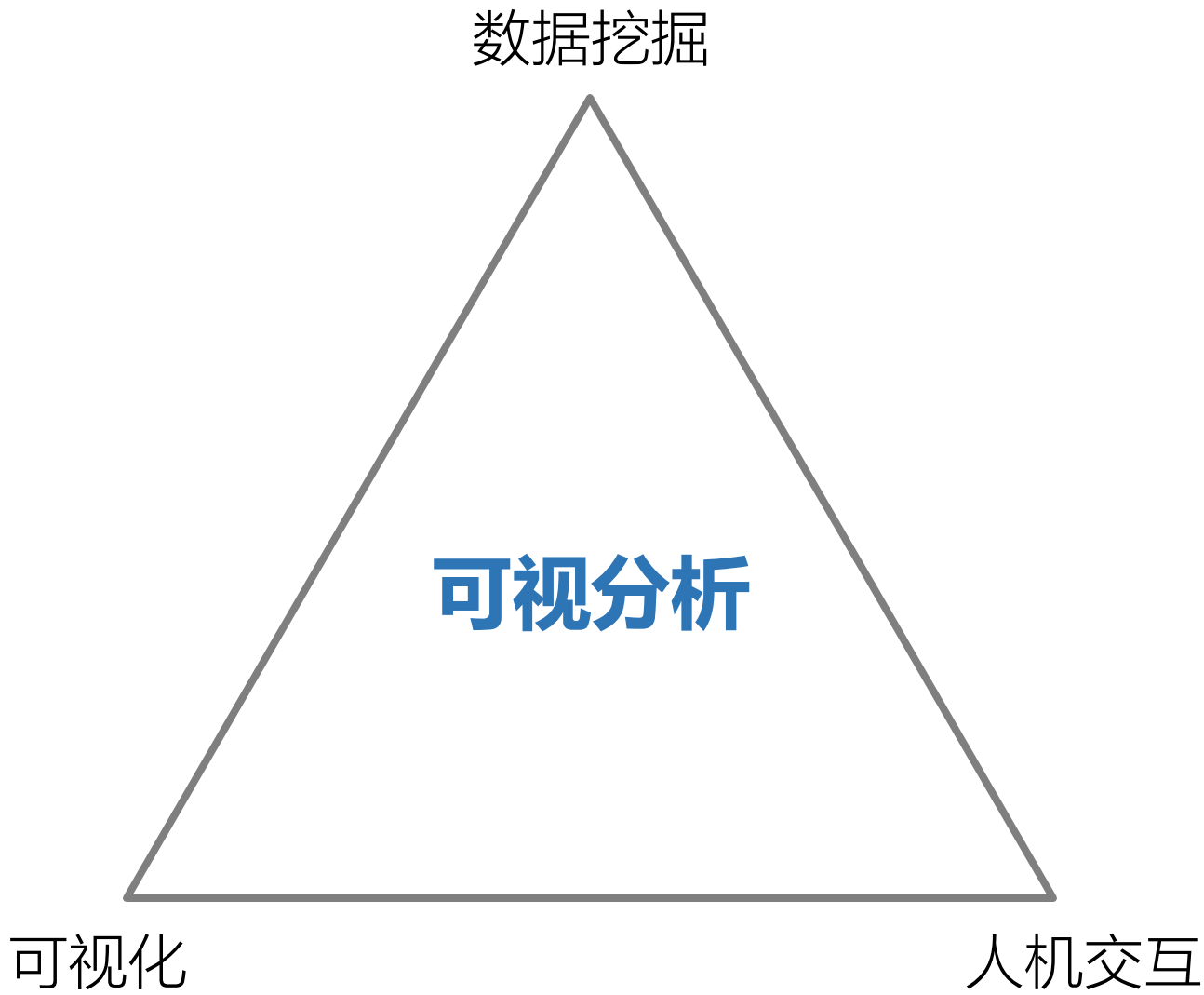


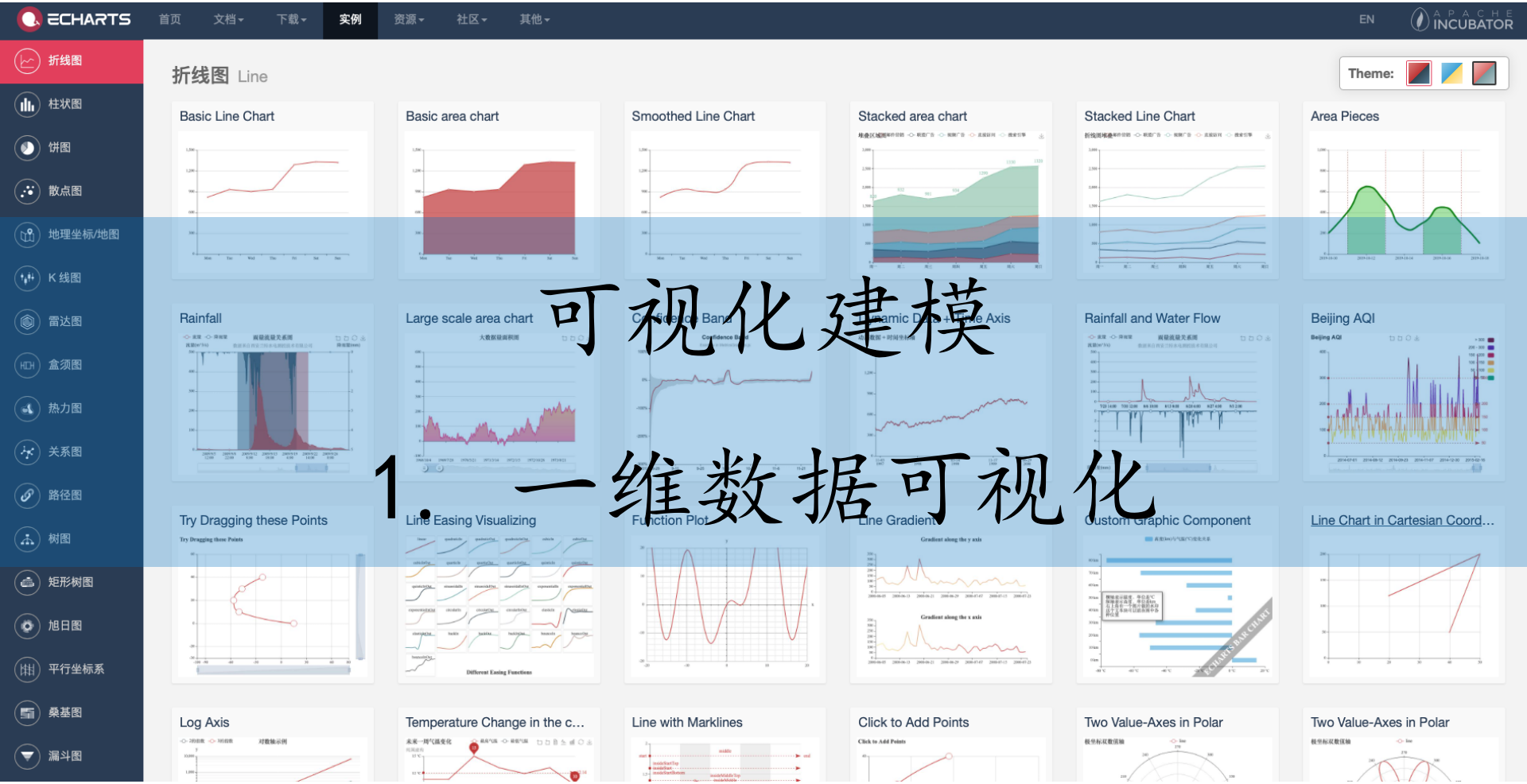
可视化与数据挖掘

- 数据挖掘（Data Mining）更关注**自动化**的算法
- 可视化通过让人类参与其中实现**交互式的数据分析**

（港科大）屈华民教授对可视化与数据挖掘的观点

可视分析



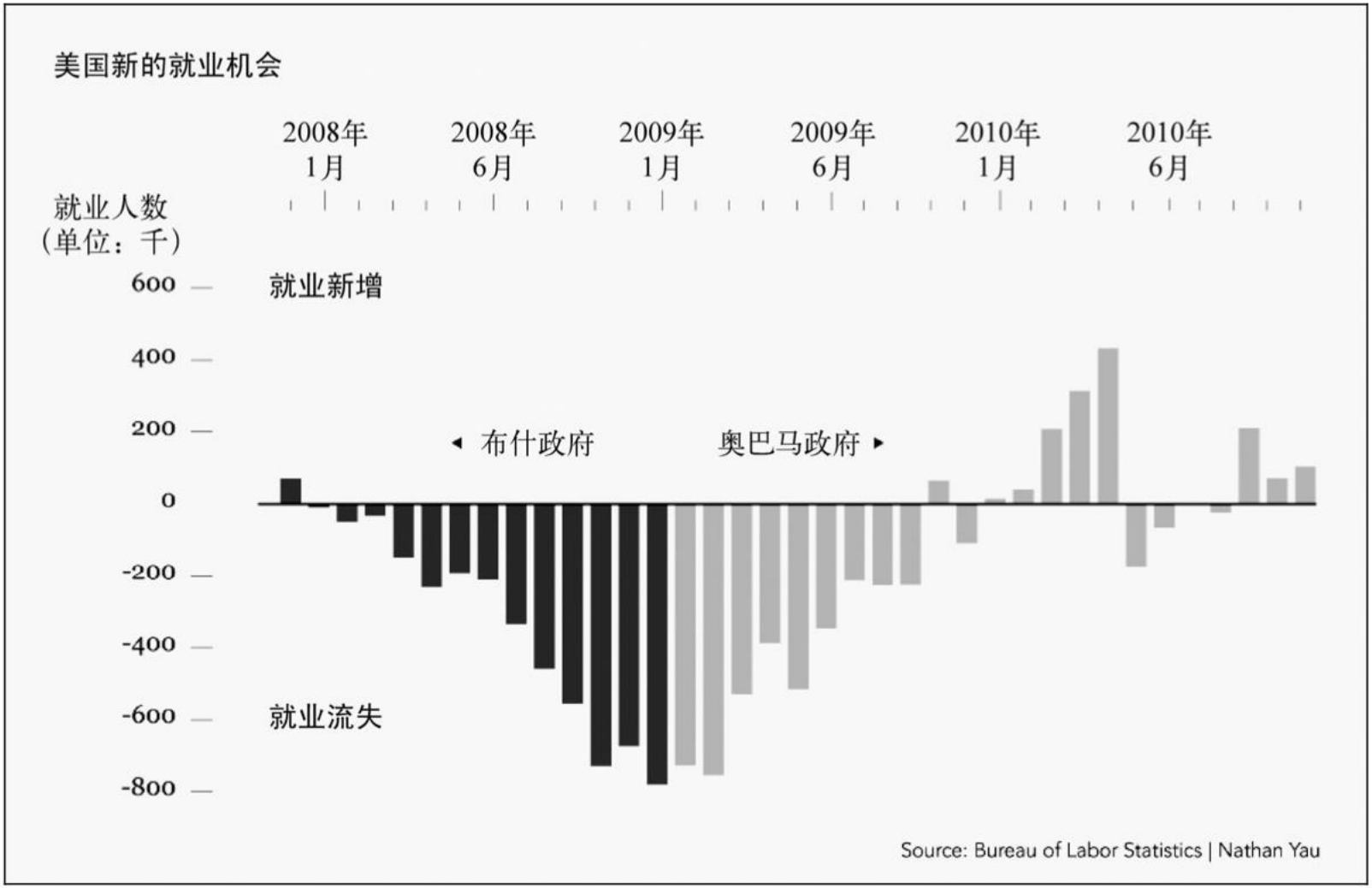


可视化建模

1. 一维数据可视化

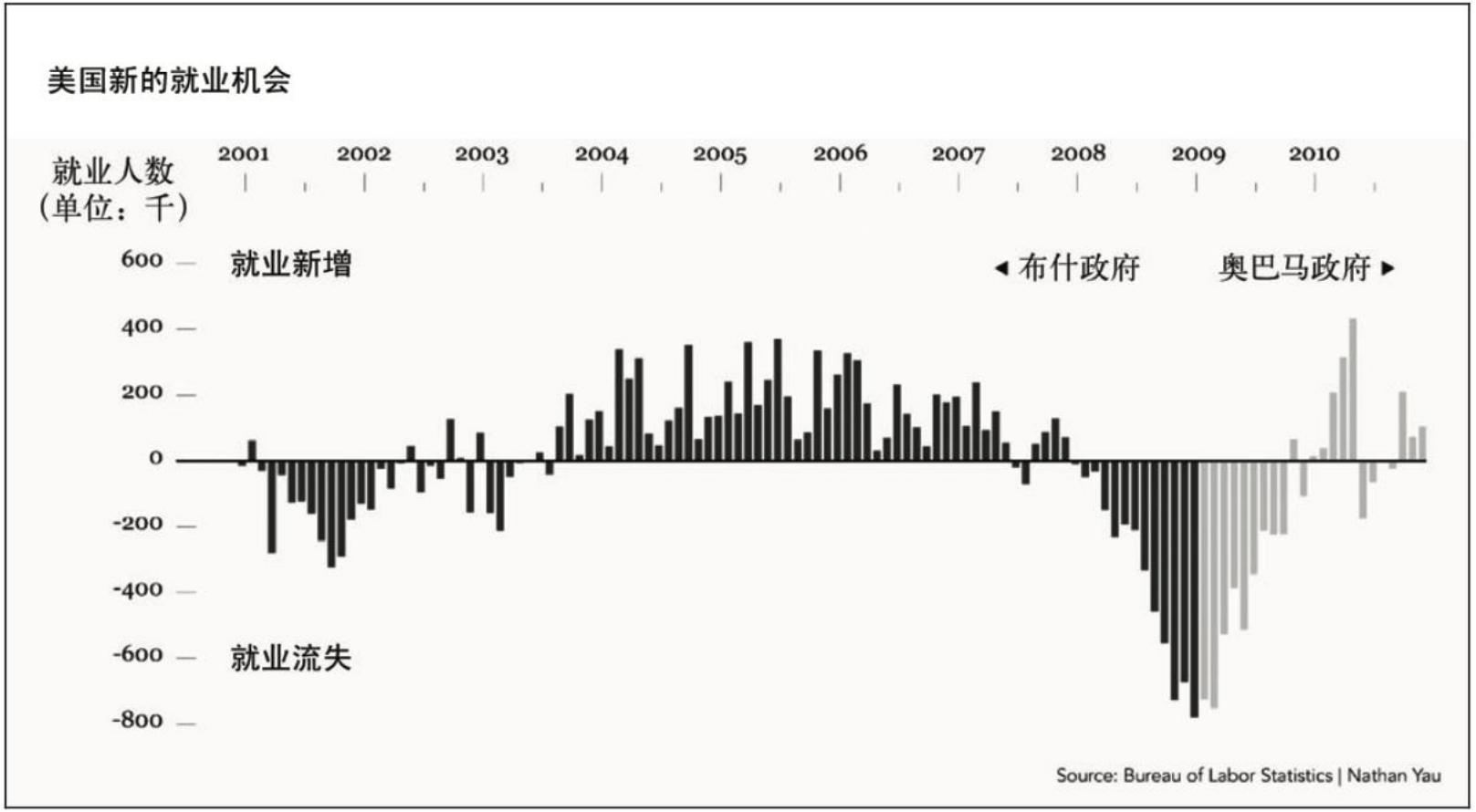
以Echarts为例 https://echarts.apache.org/zh/index.html

一维数据可视化



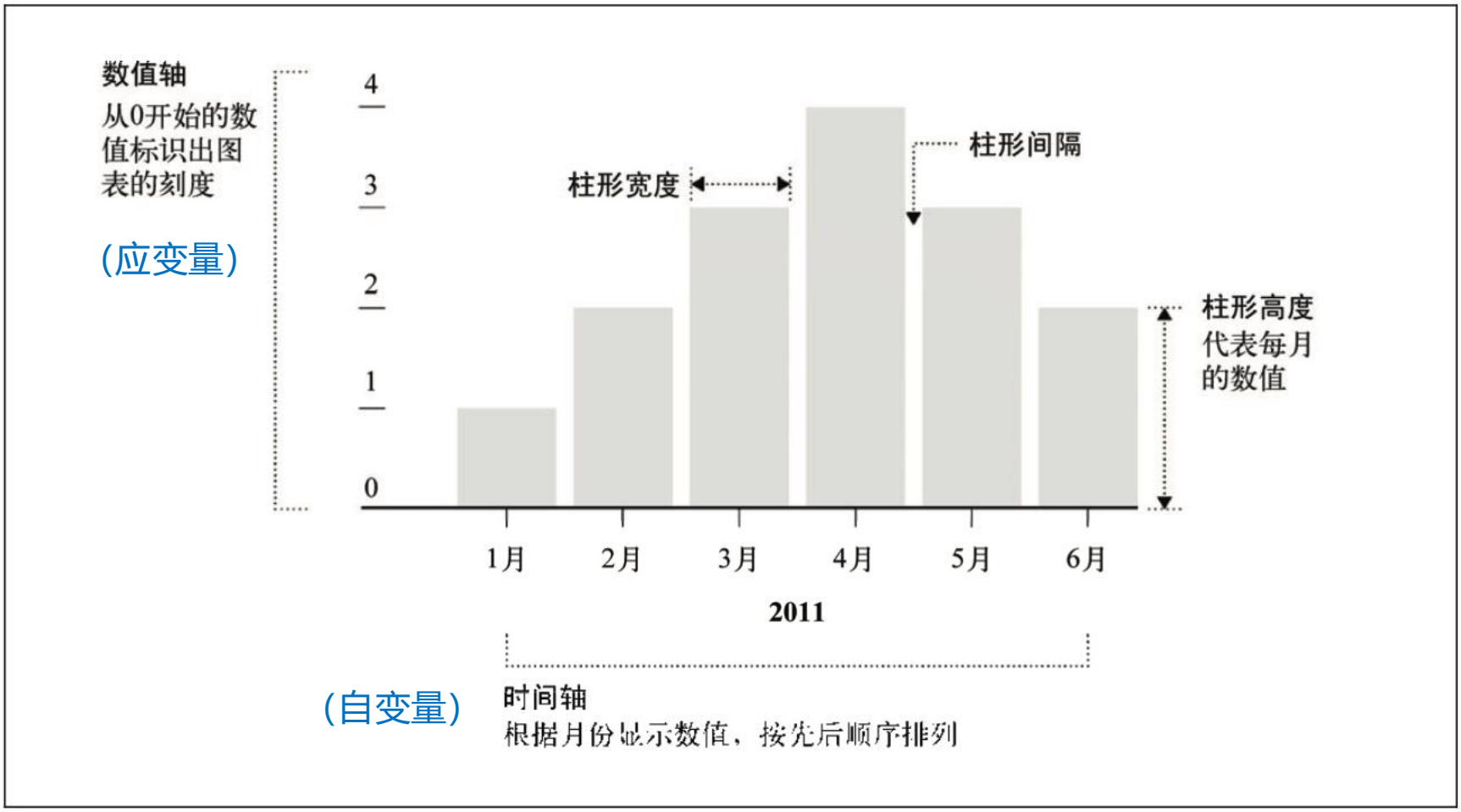
巴拉克·奥巴马执政后失业的变化

一维数据可视化



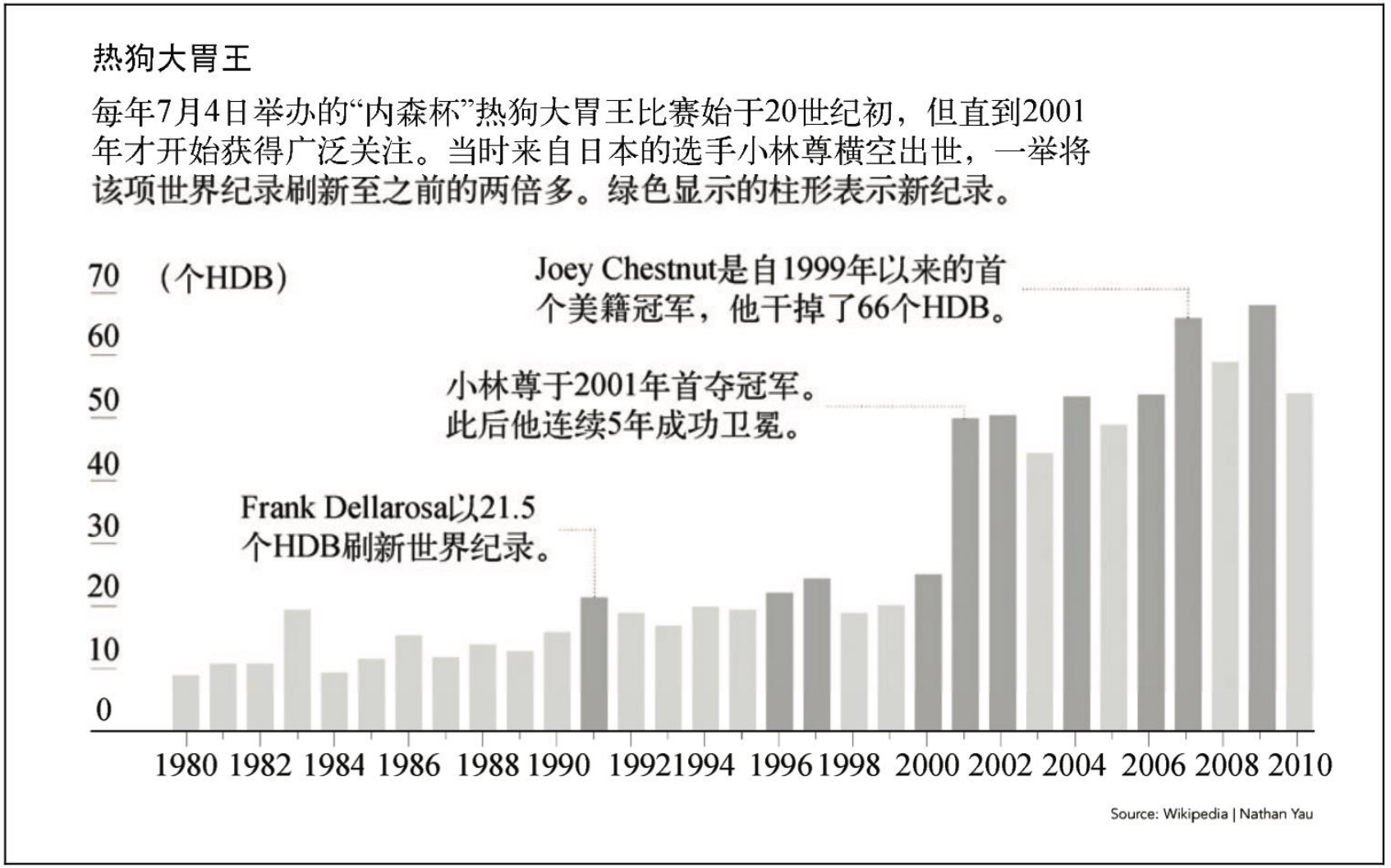
2001—2010年的美国失业变化

一维数据可视化 - 柱形图



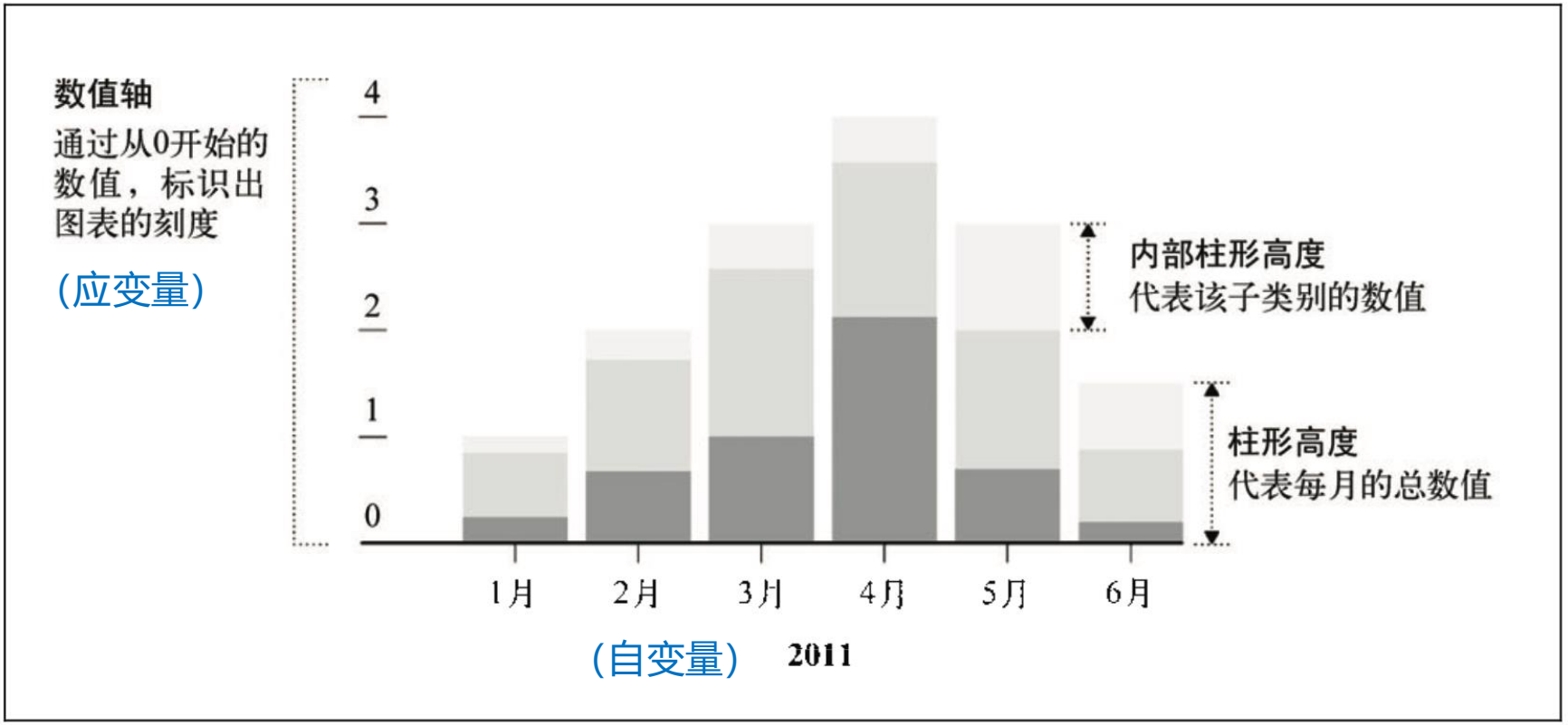
柱形图的基本框架

一维数据可视化 - 柱形图例



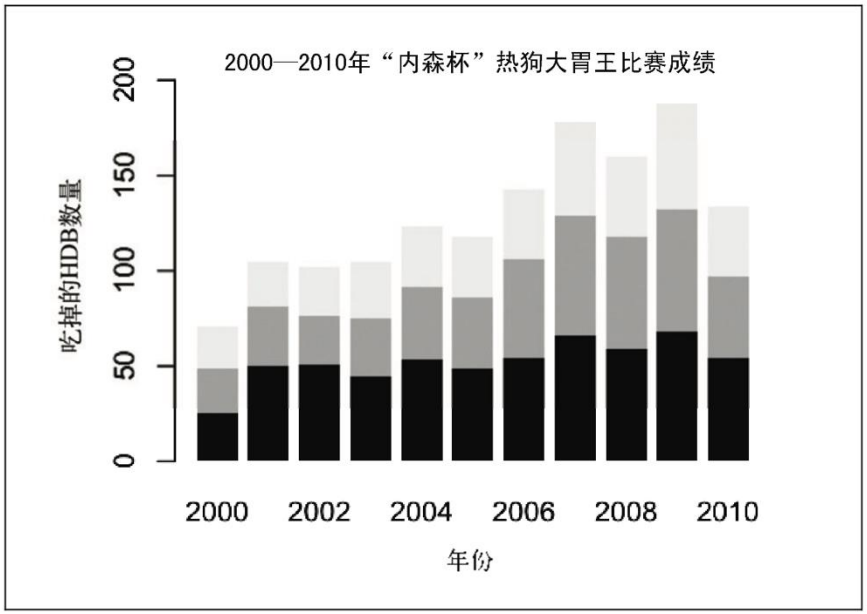
“内森杯”热狗大胃王比赛成绩的柱形图

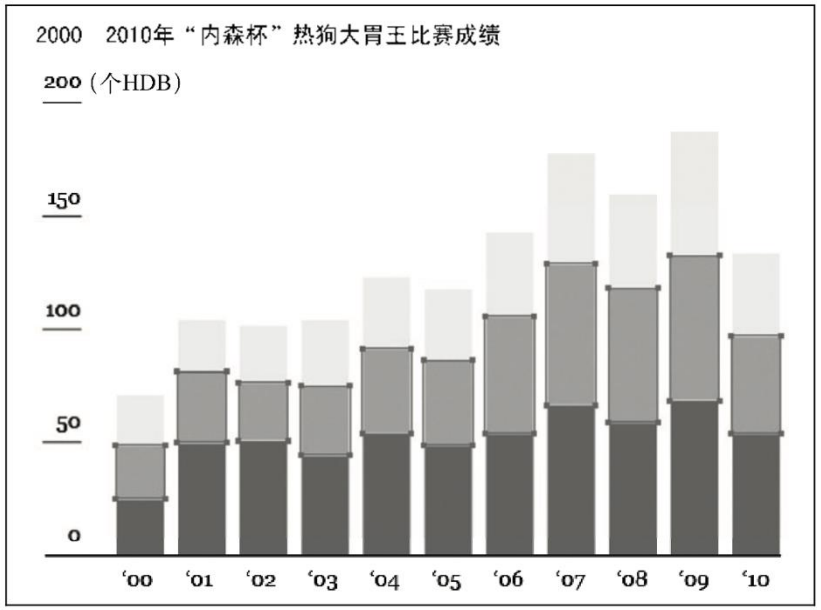
一维数据可视化 – 堆叠柱形图



堆叠柱形图的基本框架

一维数据可视化 - 堆叠柱形图例

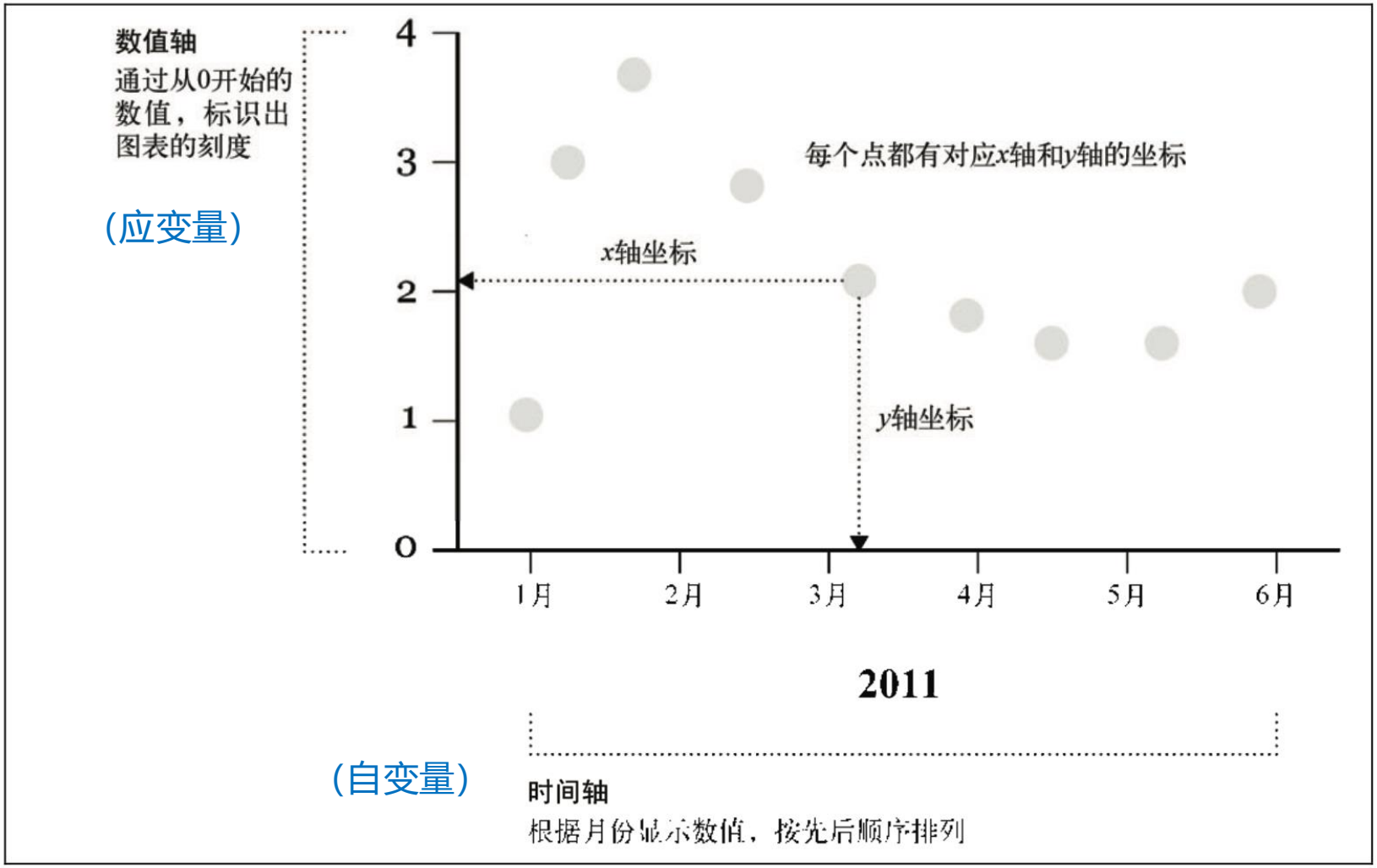




R语言创建的堆叠柱形图
(提示：调用barplot函数)

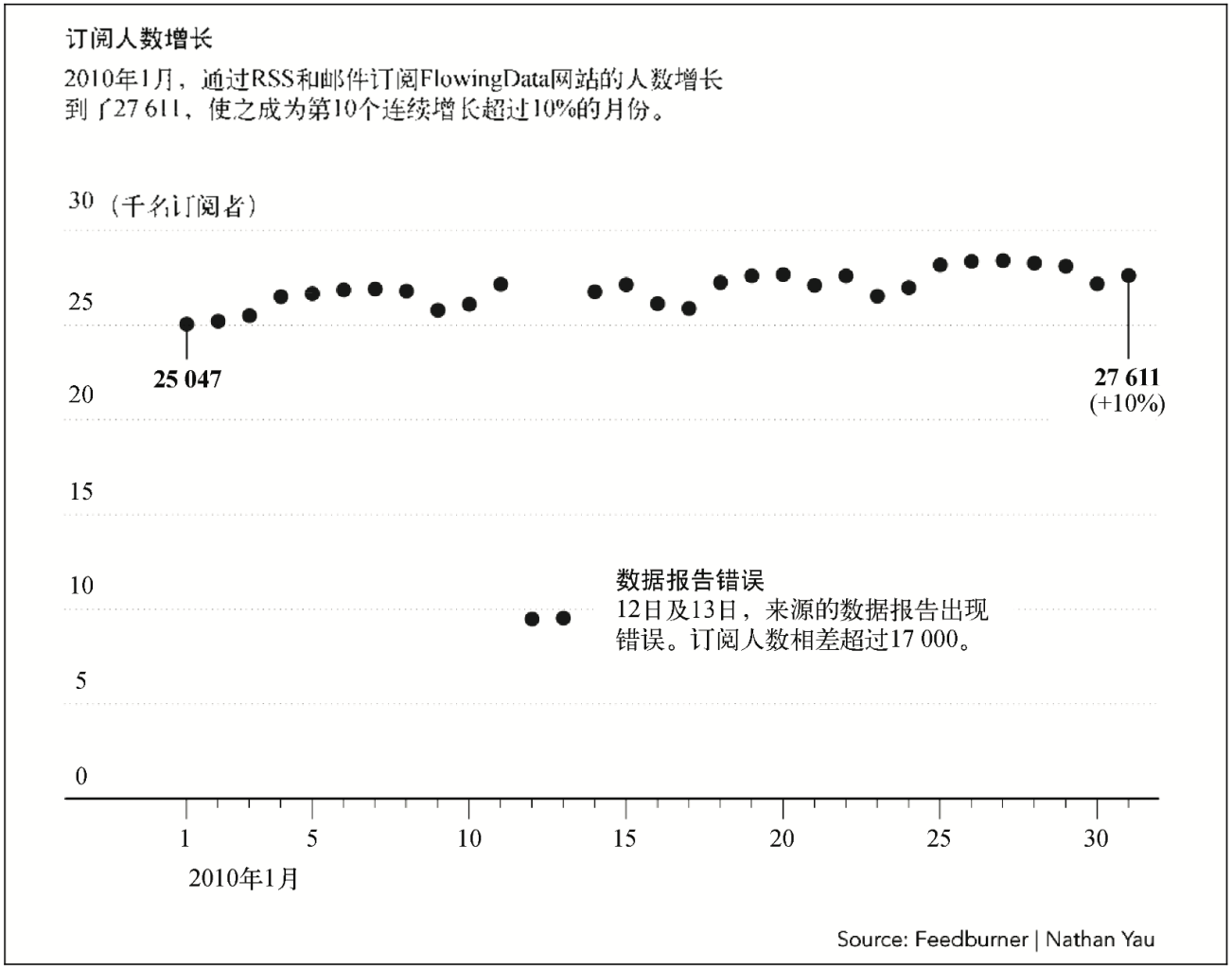
美化后的堆叠柱形图
(提示：使用illustrator)

一维数据可视化 – 散点图



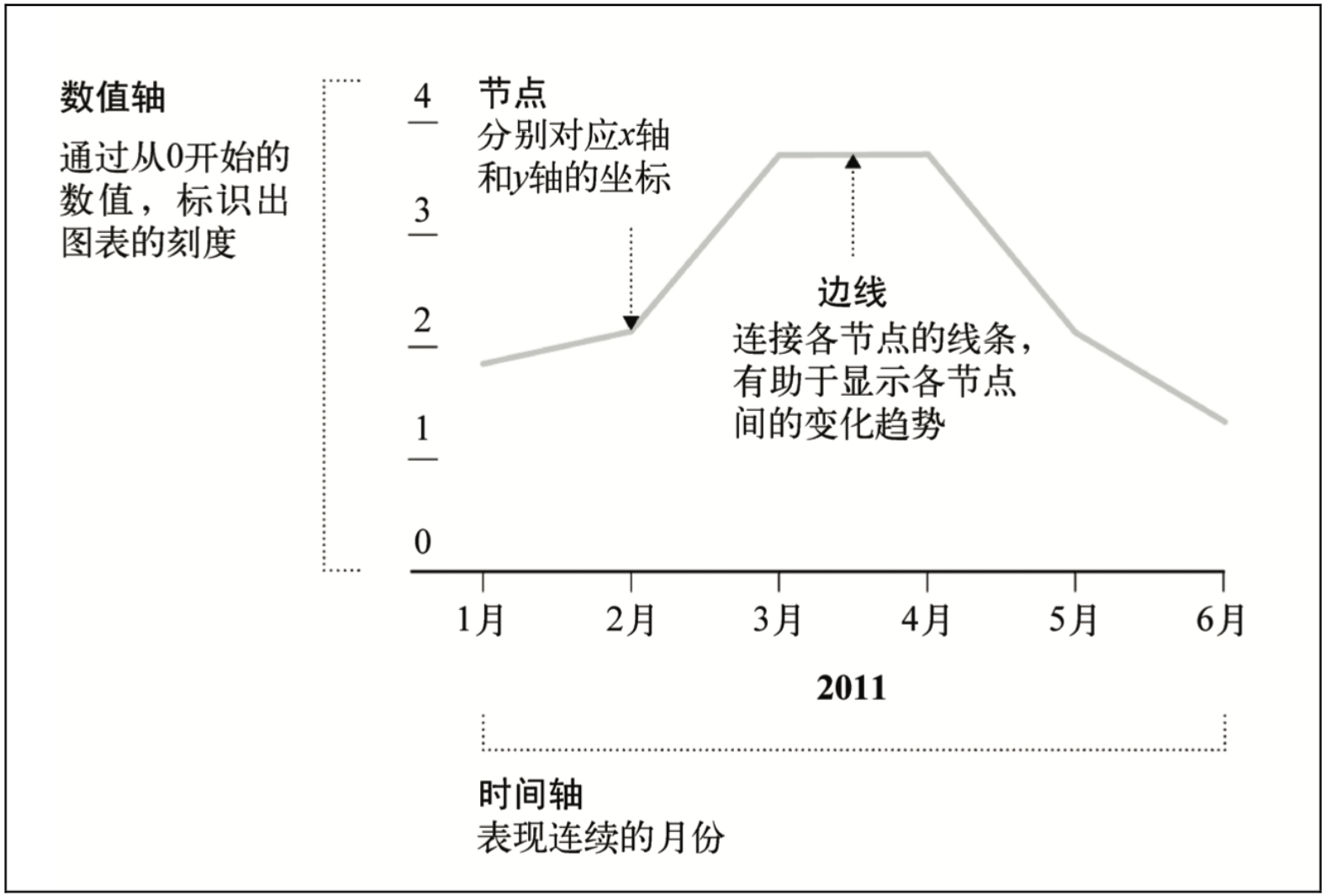
散点图的基本框架

一维数据可视化 - 散点图例



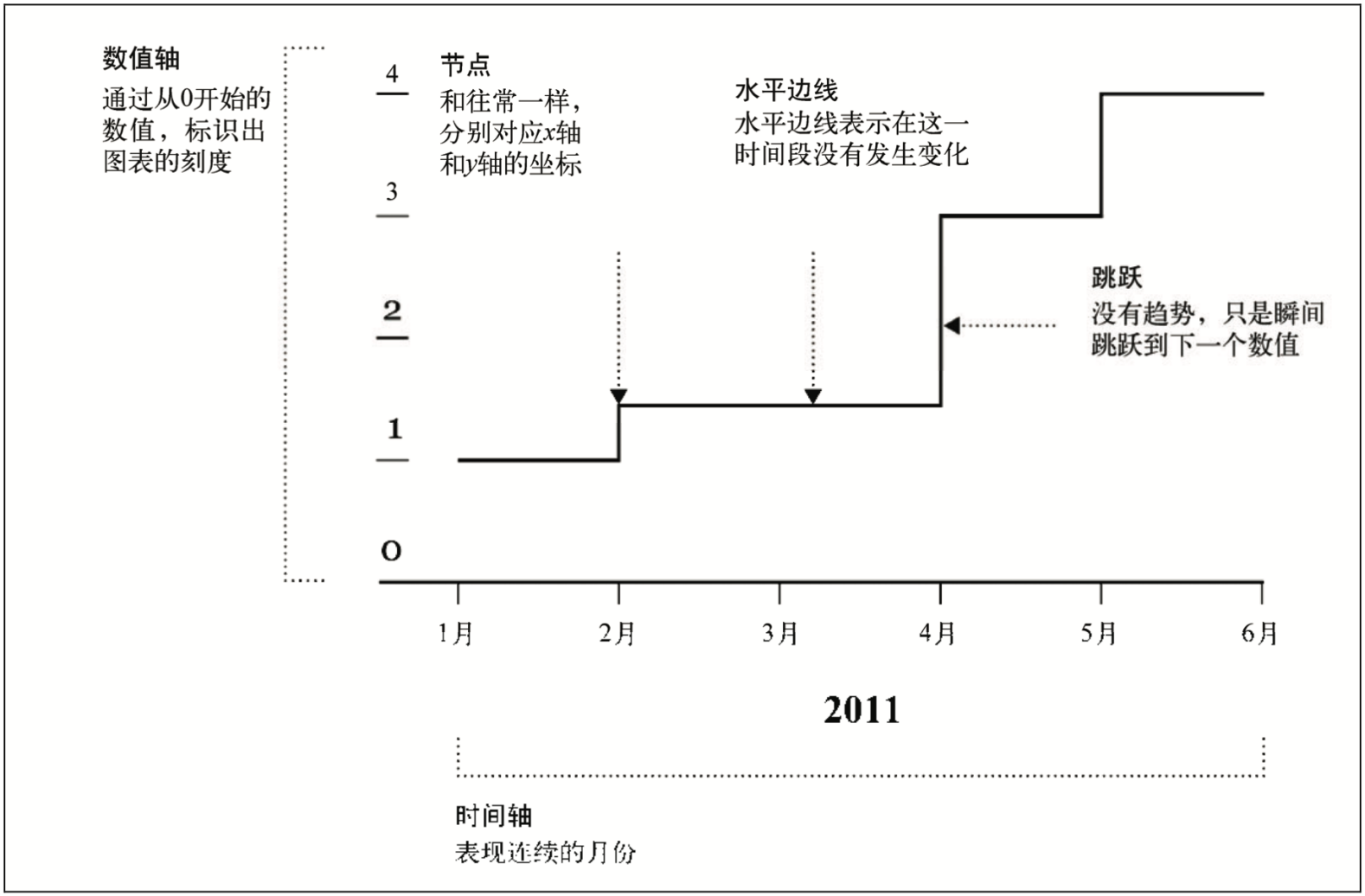
在R中创建并在Illustrator中设计得到的散点图

一维数据可视化 - 折线图



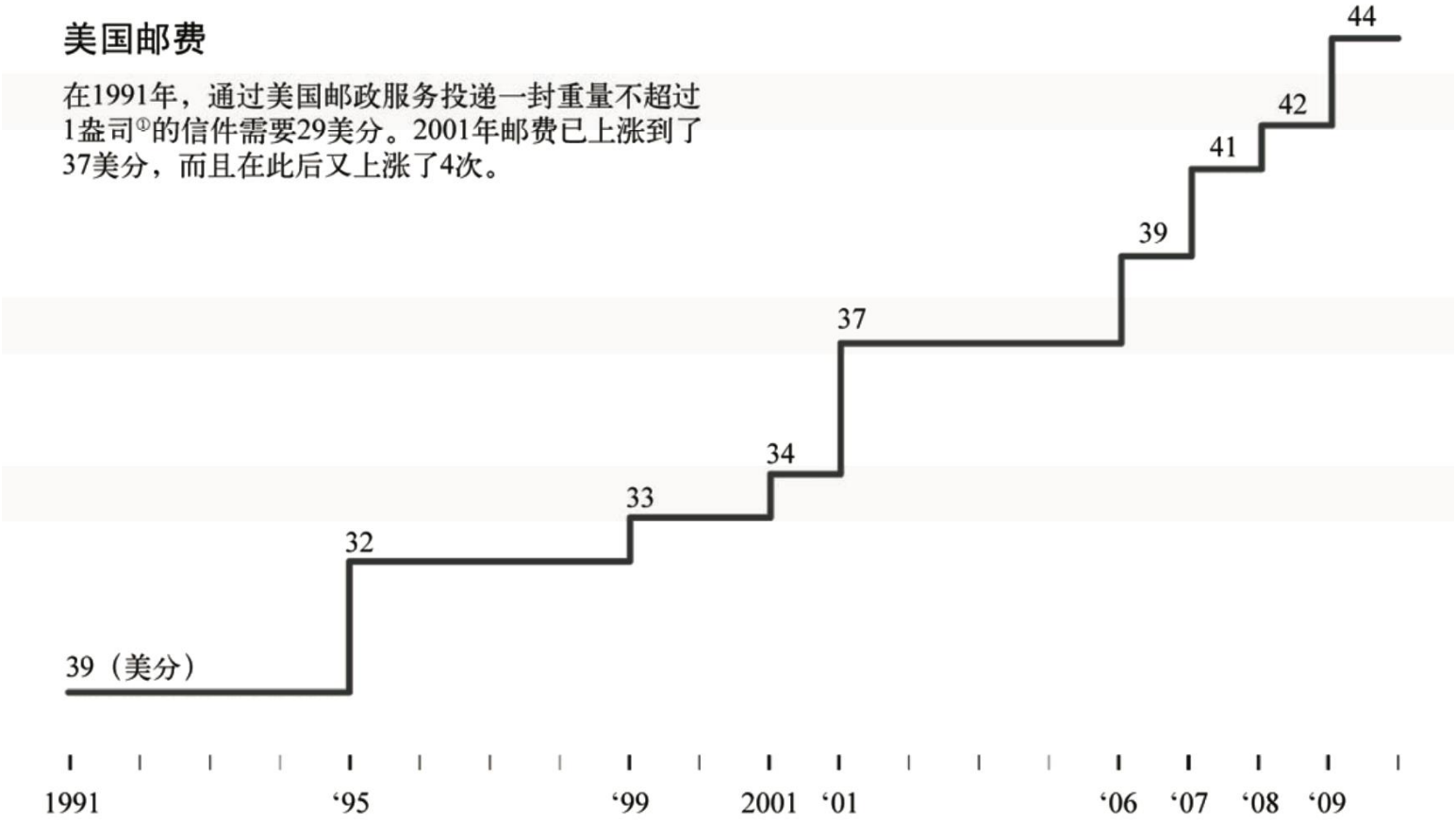
思考：延续型和离散型表达的异同点

一维数据可视化 - 阶梯图



思考：延续型和离散型表达的异同点

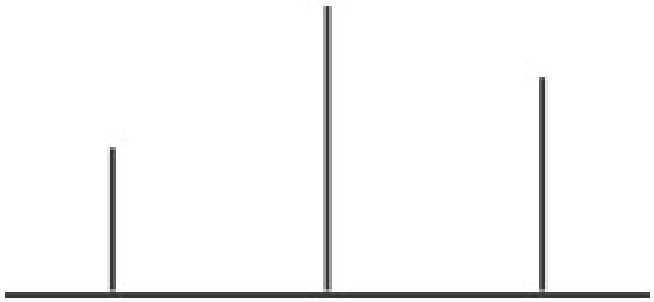
一维数据可视化 – 阶梯图例



显示美国邮费变化的阶梯图

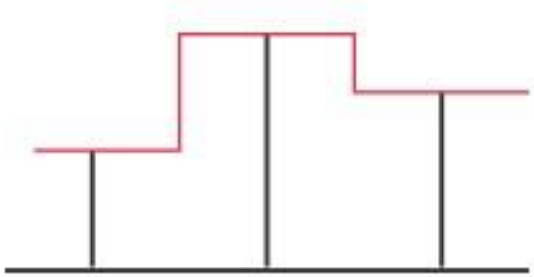
一维数据可视化 – 插值

Goal: Interpolate Values



一维数据可视化 – 插值

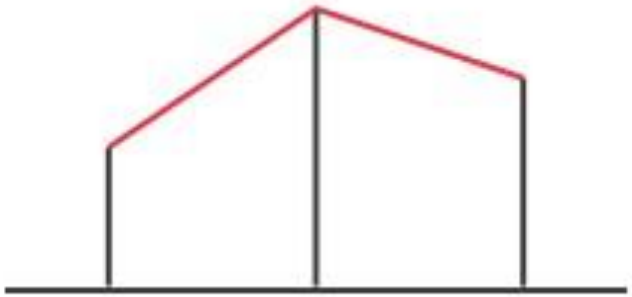
Nearest Neighbor Interpolation



Problem: values not continuous

一维数据可视化 – 插值

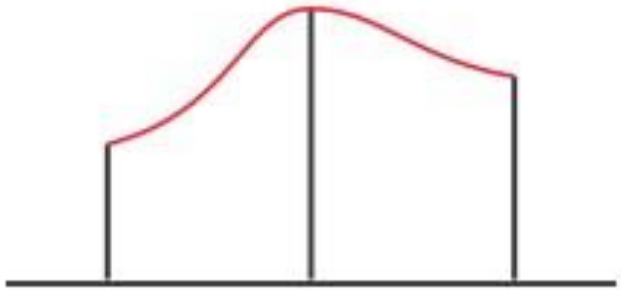
Linear Interpolation



Problem: derivatives not continuous

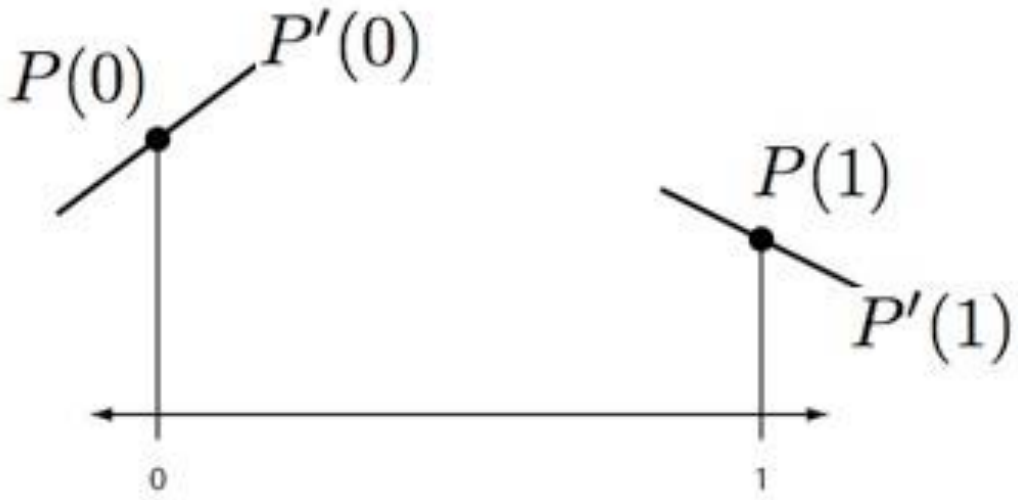
一维数据可视化 – 插值

Smooth Interpolation?



一维数据可视化 – 插值

Cubic Hermite Interpolation



Given: values and derivatives at 2 points

一维数据可视化 – 插值

Cubic Polynomial Interpolation

Assume cubic polynomial

$$P(t) = a\,t^3 + b\,t^2 + c\,t + d$$

Why? 4 constraints => need 4 degrees of freedom

一维数据可视化 – 插值

Cubic Hermite Interpolation

Assume cubic polynomial

$$P(t) = a\,t^3 + b\,t^2 + c\,t + d$$

$$P'(t) = 3a\,t^2 + 2b\,t + c$$

Solve for coefficients:

$$P(0) = h_0 = d$$

$$P(1) = h_1 = a + b + c + d$$

$$P'(0) = h_2 = c$$

$$P'(1) = h_3 = 3a + 2b + c$$

一维数据可视化 – 插值

Matrix Representation

$$
\begin{aligned}
h_0 &= d \\
h_1 &= a + b + c + d \\
h_2 &= c \\
h_3 &= 3a + 2b + c
\end{aligned}
$$

$$
\begin{bmatrix} h_0 \\ h_1 \\ h_2 \\ h_3 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 1 \\ 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 0 \\ 3 & 2 & 1 & 0 \end{bmatrix} \begin{bmatrix} a \\ b \\ c \\ d \end{bmatrix}
$$

一维数据可视化 – 插值

Matrix Representation of Polynomials

$$P(t) = \begin{bmatrix} a & b & c & d \end{bmatrix} \begin{bmatrix} t^3 \\ t^2 \\ t \\ 1 \end{bmatrix}$$

Hermite Basis Functions

$$\begin{bmatrix} a & b & c & d \end{bmatrix} \begin{bmatrix} t^3 \\ t^2 \\ t \\ 1 \end{bmatrix} = \begin{bmatrix} h_0 & h_1 & h_2 & h_3 \end{bmatrix} \begin{bmatrix} H_0(t) \\ H_1(t) \\ H_2(t) \\ H_3(t) \end{bmatrix}$$

$$P(t) = \sum_{i=0}^{3} h_i \, H_i(t)$$

Matrix Representation

$$\begin{bmatrix} h_0 \\ h_1 \\ h_2 \\ h_3 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 1 \\ 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 0 \\ 3 & 2 & 1 & 0 \end{bmatrix} \begin{bmatrix} a \\ b \\ c \\ d \end{bmatrix}$$

Solve for a, b, c, d

$$\begin{bmatrix} a \\ b \\ c \\ d \end{bmatrix} = \begin{bmatrix} 2 & -2 & 1 & 1 \\ -3 & 3 & -2 & -1 \\ 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} h_0 \\ h_1 \\ h_2 \\ h_3 \end{bmatrix}$$

Inverse Matrix

一维数据可视化 – 插值

Matrix Inverse

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 1 \\ 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 0 \\ 3 & 2 & 1 & 0 \end{bmatrix} \begin{bmatrix} 2 & -2 & 1 & 1 \\ -3 & 3 & -2 & -1 \\ 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix}$$

Change Basis

$$\underbrace{\begin{bmatrix} a & b & c & d \end{bmatrix} \begin{bmatrix} 0 & 1 & 0 & 3 \\ 0 & 1 & 0 & 2 \\ 0 & 1 & 1 & 1 \\ 1 & 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} 2 & -3 & 0 & 1 \\ -2 & 3 & 0 & 0 \\ 1 & -2 & 1 & 0 \\ 1 & -1 & 0 & 0 \end{bmatrix}}_{\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}} \begin{bmatrix} t^3 \\ t^2 \\ t \\ 1 \end{bmatrix}$$

Change Basis

$$\underbrace{\begin{bmatrix} a & b & c & d \end{bmatrix} \begin{bmatrix} 0 & 1 & 0 & 3 \\ 0 & 1 & 0 & 2 \\ 0 & 1 & 1 & 1 \\ 1 & 1 & 0 & 0 \end{bmatrix}}_{\begin{bmatrix} h_0 & h_1 & h_2 & h_3 \end{bmatrix}} \begin{bmatrix} 2 & -3 & 0 & 1 \\ -2 & 3 & 0 & 0 \\ 1 & -2 & 1 & 0 \\ 1 & -1 & 0 & 0 \end{bmatrix} \begin{bmatrix} t^3 \\ t^2 \\ t \\ 1 \end{bmatrix}$$

一维数据可视化 – 插值

Change Basis

$$\underbrace{\begin{bmatrix} a & b & c & d \end{bmatrix} \begin{bmatrix} 0 & 1 & 0 & 3 \\ 0 & 1 & 0 & 2 \\ 0 & 1 & 1 & 1 \\ 1 & 1 & 0 & 0 \end{bmatrix}}_{\begin{bmatrix} h_0 & h_1 & h_2 & h_3 \end{bmatrix}} \underbrace{\begin{bmatrix} 2 & -3 & 0 & 1 \\ -2 & 3 & 0 & 0 \\ 1 & -2 & 1 & 0 \\ 1 & -1 & 0 & 0 \end{bmatrix} \begin{bmatrix} t^3 \\ t^2 \\ t \\ 1 \end{bmatrix}}_{\begin{bmatrix} H_0(t) \\ H_1(t) \\ H_2(t) \\ H_3(t) \end{bmatrix}}$$

一维数据可视化 – 插值

Hermite Basis Functions

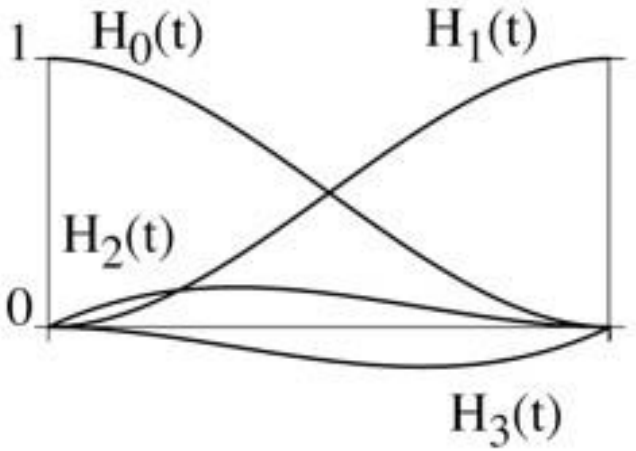
$$\begin{bmatrix} H_0(t) \\ H_1(t) \\ H_2(t) \\ H_3(t) \end{bmatrix} = \begin{bmatrix} 2 & -3 & 0 & 1 \\ -2 & 3 & 0 & 0 \\ 1 & -2 & 1 & 0 \\ 1 & -1 & 0 & 0 \end{bmatrix} \begin{bmatrix} t^3 \\ t^2 \\ t \\ 1 \end{bmatrix}$$

$$H_0(t) = 2t^3 - 3t^2 + 1$$

$$H_1(t) = -2t^3 + 3t^2$$

$$H_2(t) = t^3 - 2t^2 + t$$

$$H_3(t) = t^3 - t^2$$

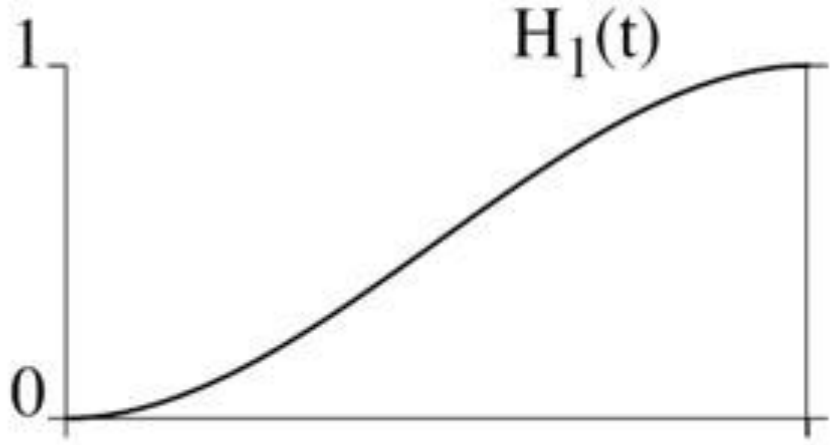


一维数据可视化 – 插值

Ease

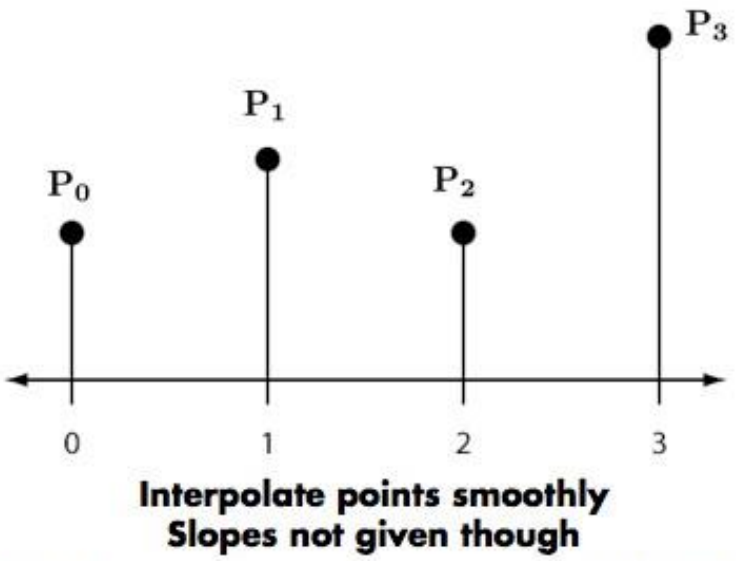
A very useful function

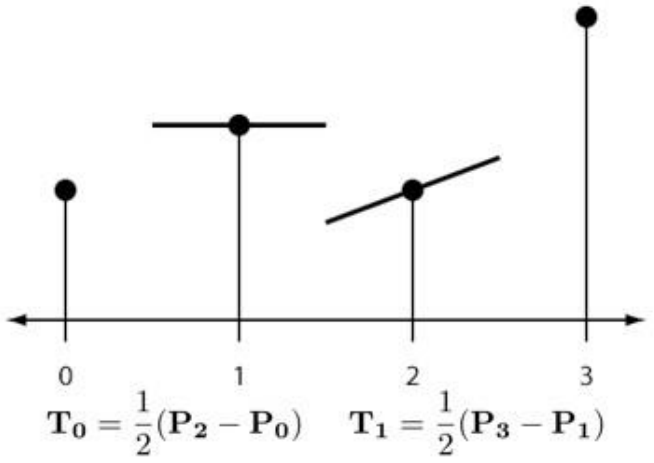
In animation, start and stop slowly (zero velocity)

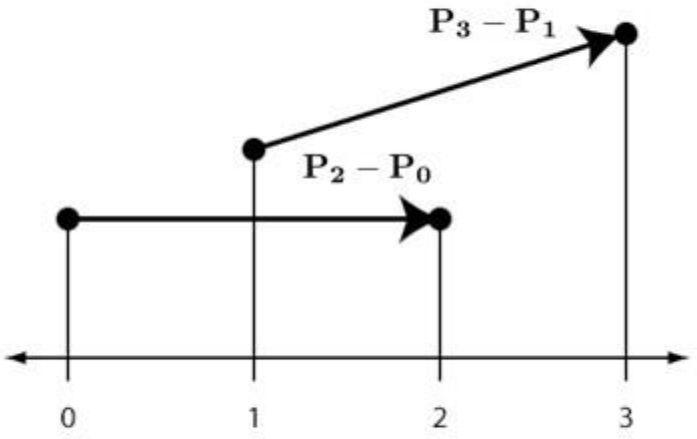


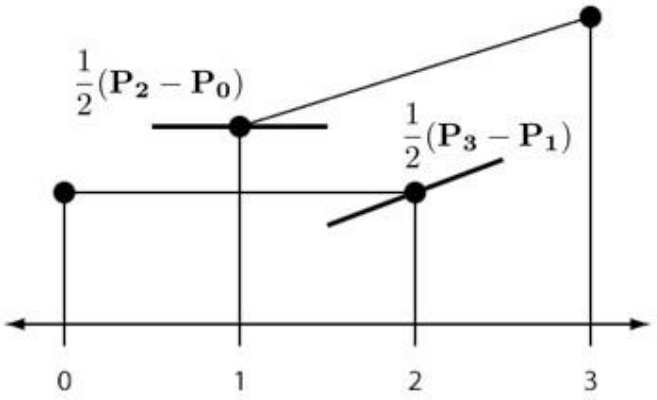
$$H_1(t) = -2t^3 + 3t^2 = t^2(3 - 2t)$$

一维数据可视化 – Catmull-Rom插值



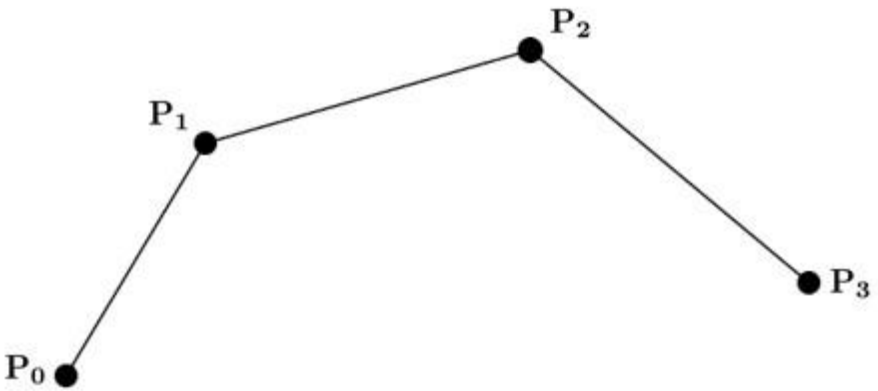




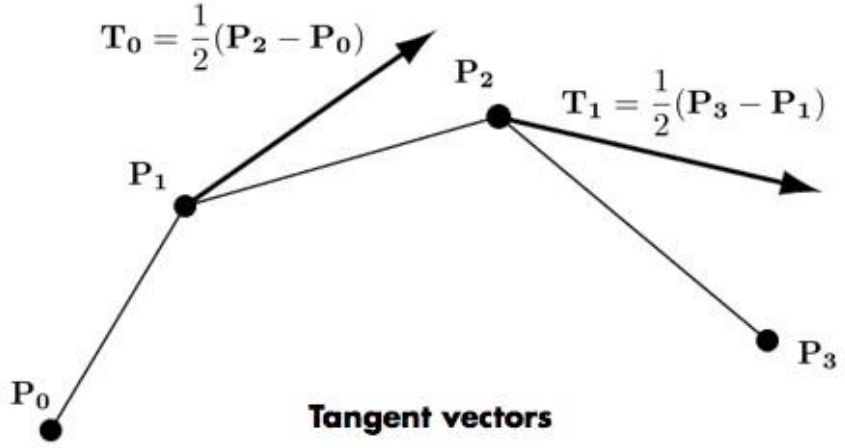


一维数据可视化 – Catmull-Rom插值

Catmull-Rom Interpolation



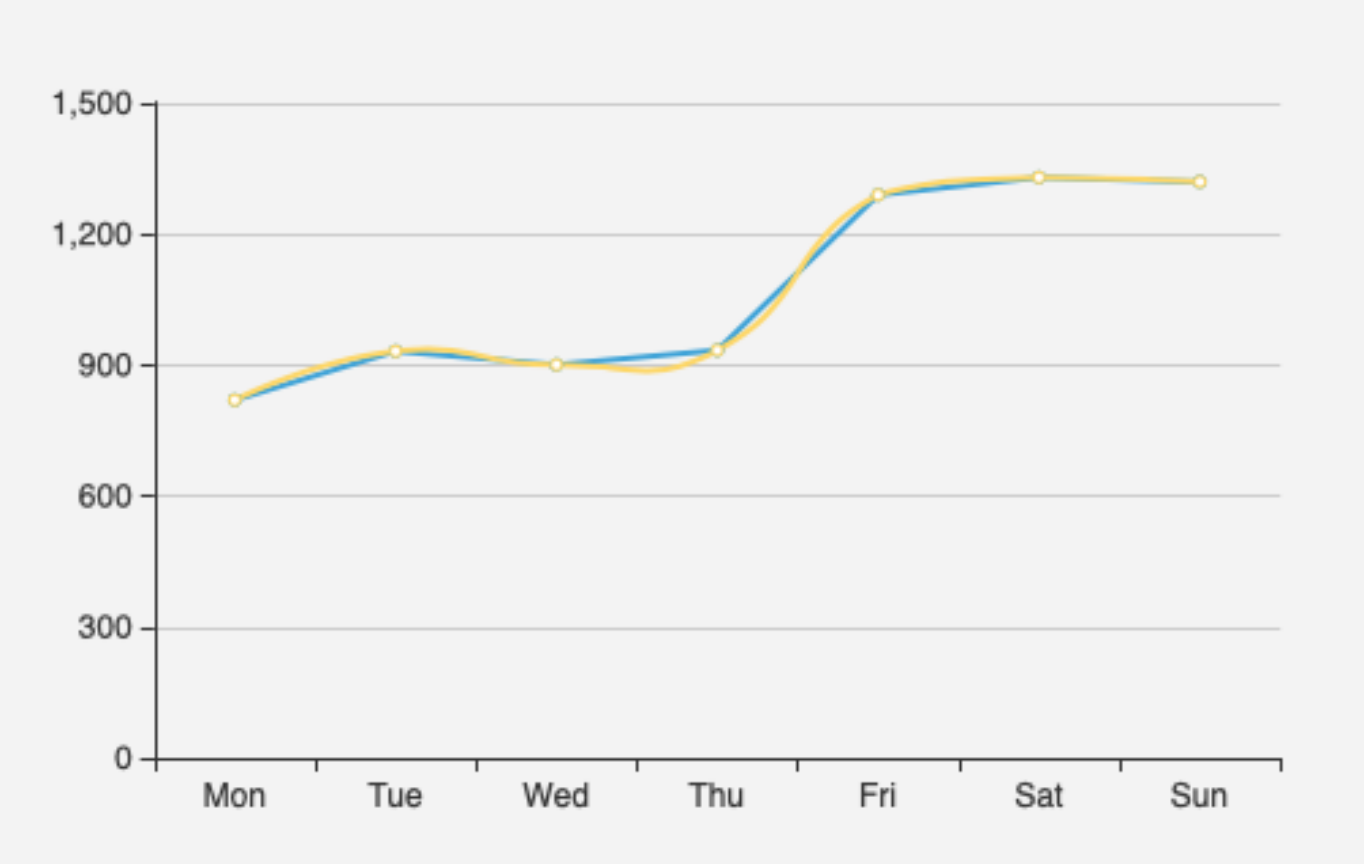
We can interpolate points as easily as values



Tangent vectors

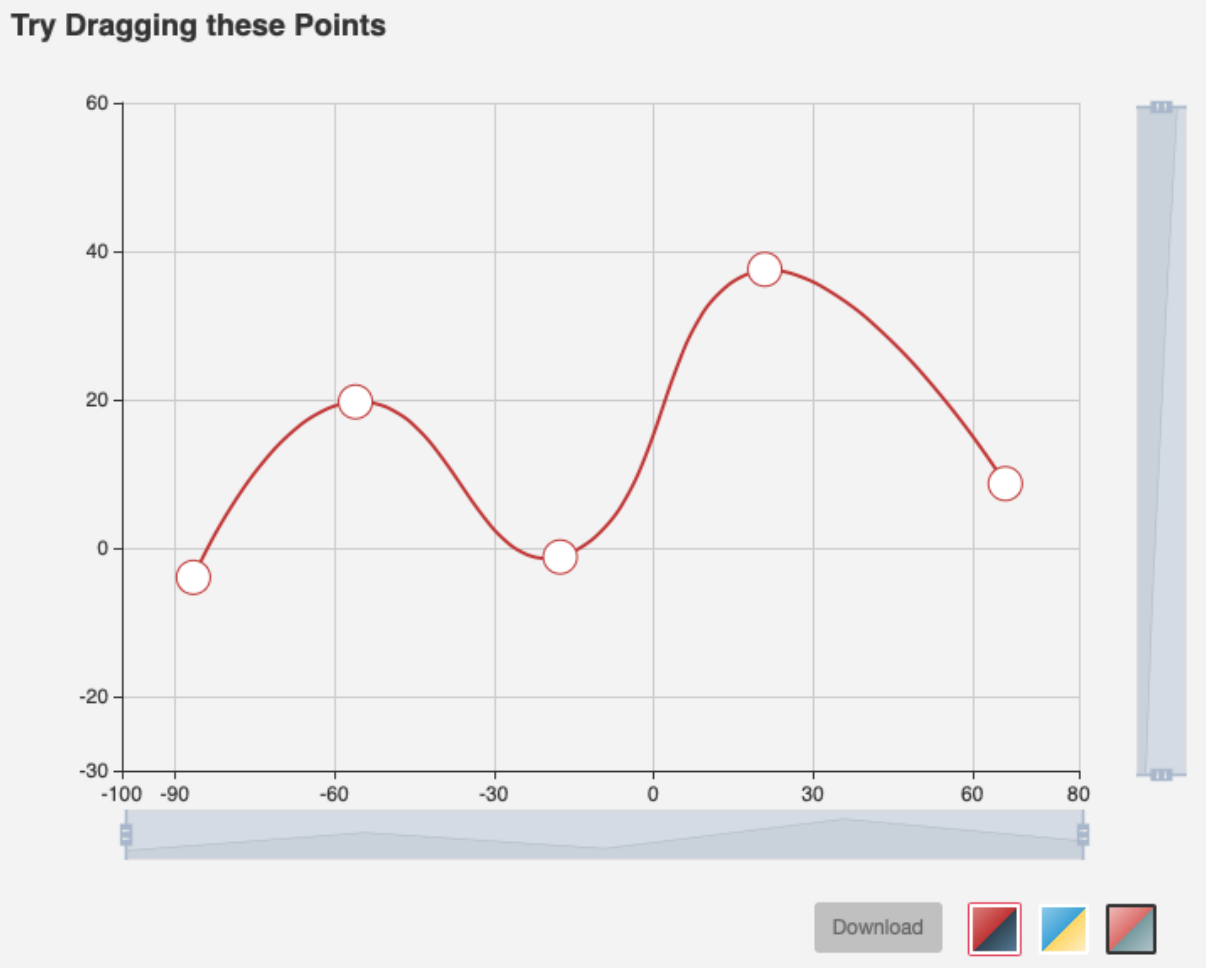
$$\boldsymbol{p}(t) = (2t^3 - 3t^2 + 1)\boldsymbol{p}_0 + (t^3 - 2t^2 + t)\boldsymbol{m}_0 + (-2t^3 + 3t^2)\boldsymbol{p}_1 + (t^3 - t^2)\boldsymbol{m}_1$$

一维数据可视化 – Catmull-Rom插值例



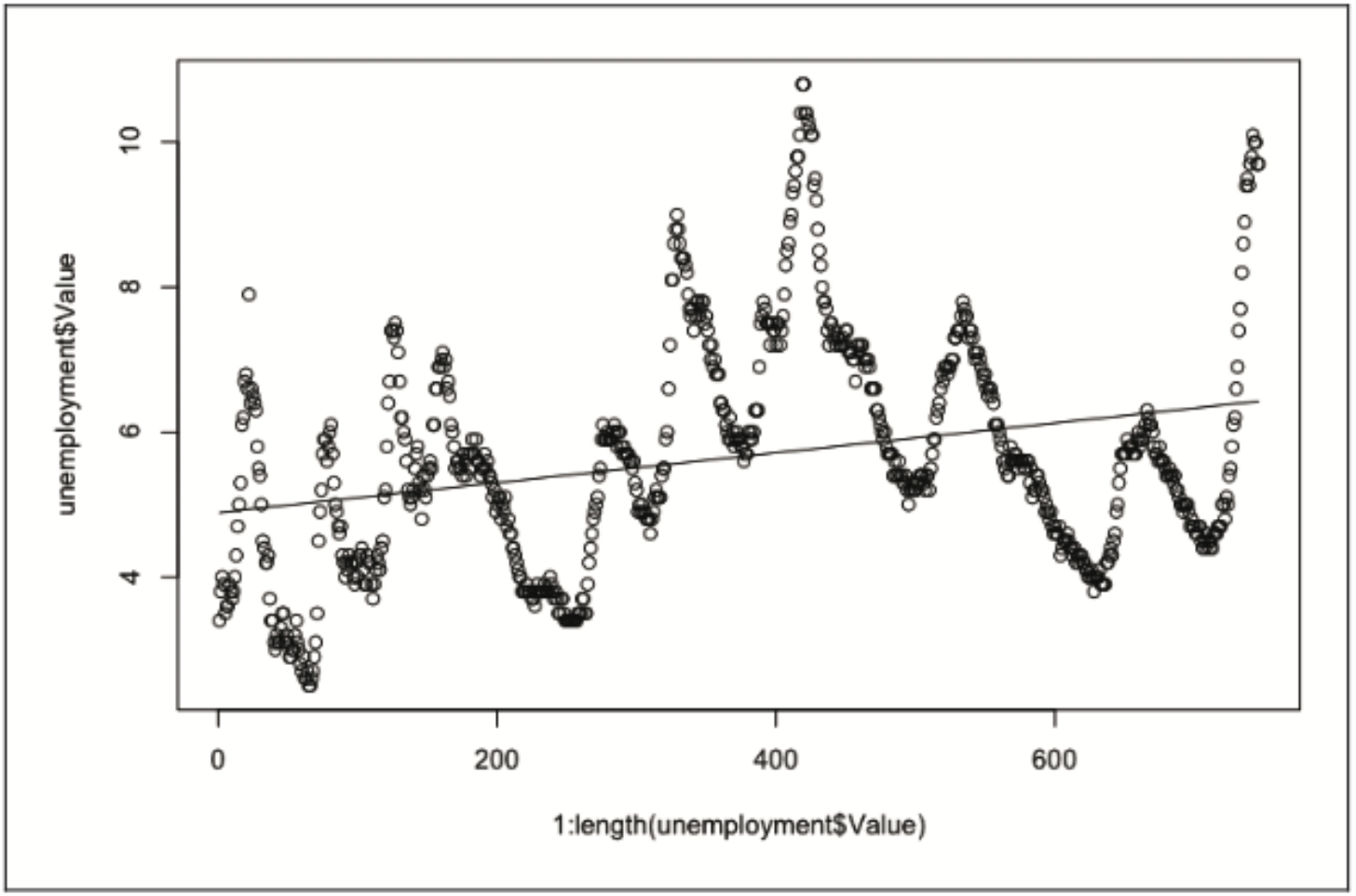
Echarts中的例子

一维数据可视化 – Catmull-Rom插值例



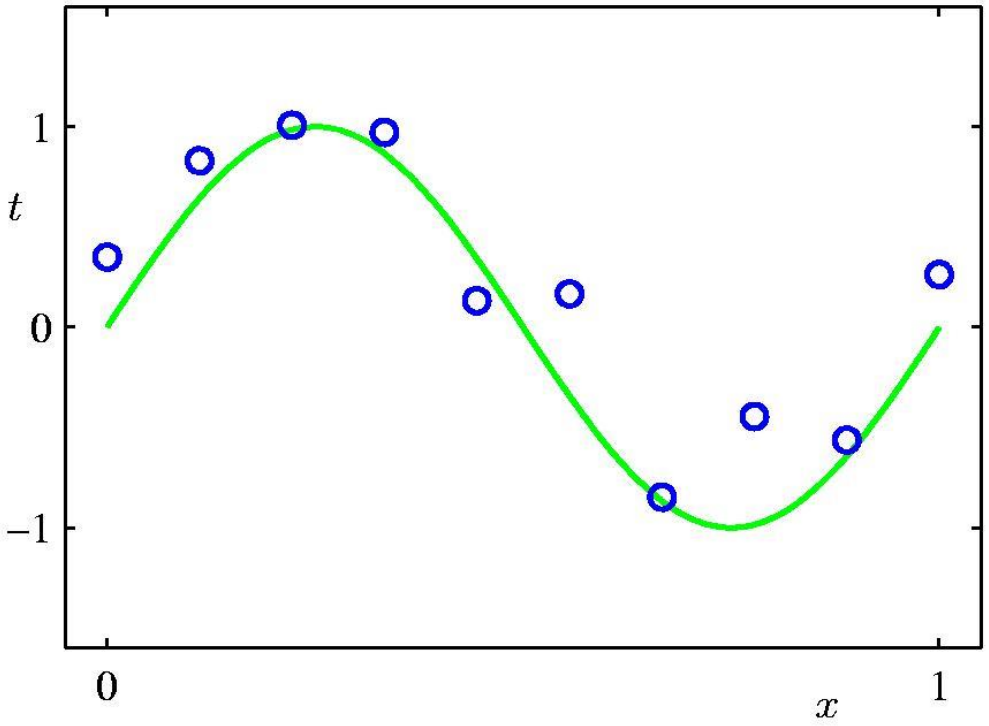
Echarts中的例子
https://echarts.apache.org/zh/index.html

一维数据可视化 – 拟合



失业率数据的散点图与直线拟合

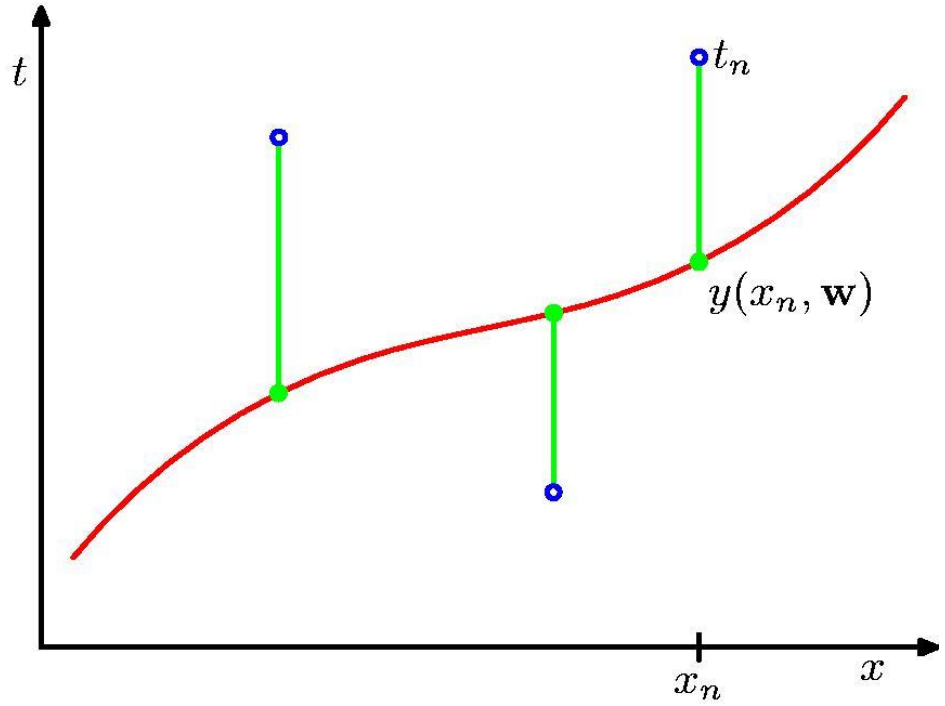
一维数据可视化 - 多项式拟合



$$y(x, \mathbf{w}) = w_0 + w_1 x + w_2 x^2 + \ldots + w_M x^M = \sum_{j=0}^{M} w_j x^j$$

多项式函数与多项式基

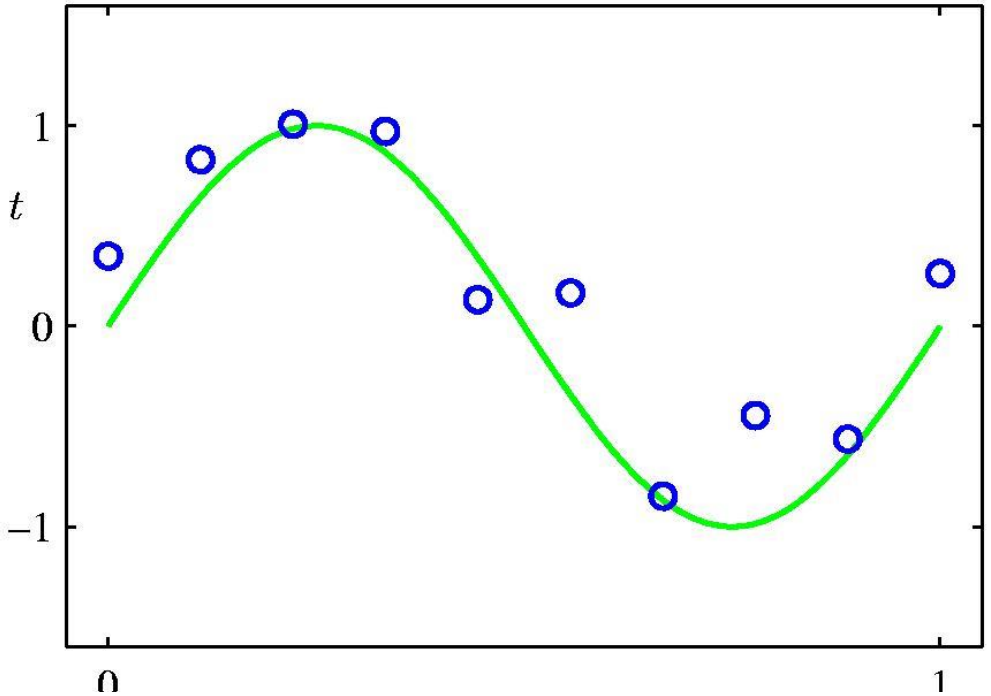
一维数据可视化 - 多项式拟合



$$E(\mathbf{w}) = \frac{1}{2}\sum_{n=1}^{N}\{y(x_n, \mathbf{w}) - t_n\}^2$$

平方和误差函数

一维数据可视化 – 多项式拟合



$$\boldsymbol{p}(x) = \begin{pmatrix} x^0 \\ x^1 \\ \vdots \\ x^M \end{pmatrix}$$

$$\mathrm{w} = \begin{pmatrix} w^0 \\ w^1 \\ \vdots \\ w^M \end{pmatrix} \qquad \mathrm{y} = \begin{pmatrix} y^0 \\ y^1 \\ \vdots \\ y^N \end{pmatrix}$$

$$y_j = \mathbf{p}(x_j) \cdot \mathbf{w}$$

$$y(x, \mathbf{w}) = w_0 + w_1 x + w_2 x^2 + \ldots + w_M x^M = \sum_{j=0}^{M} w_j x^j$$

$$\mathbf{y} = \mathbf{P}(\mathbf{x}) \cdot \mathbf{w}$$

Matrix form

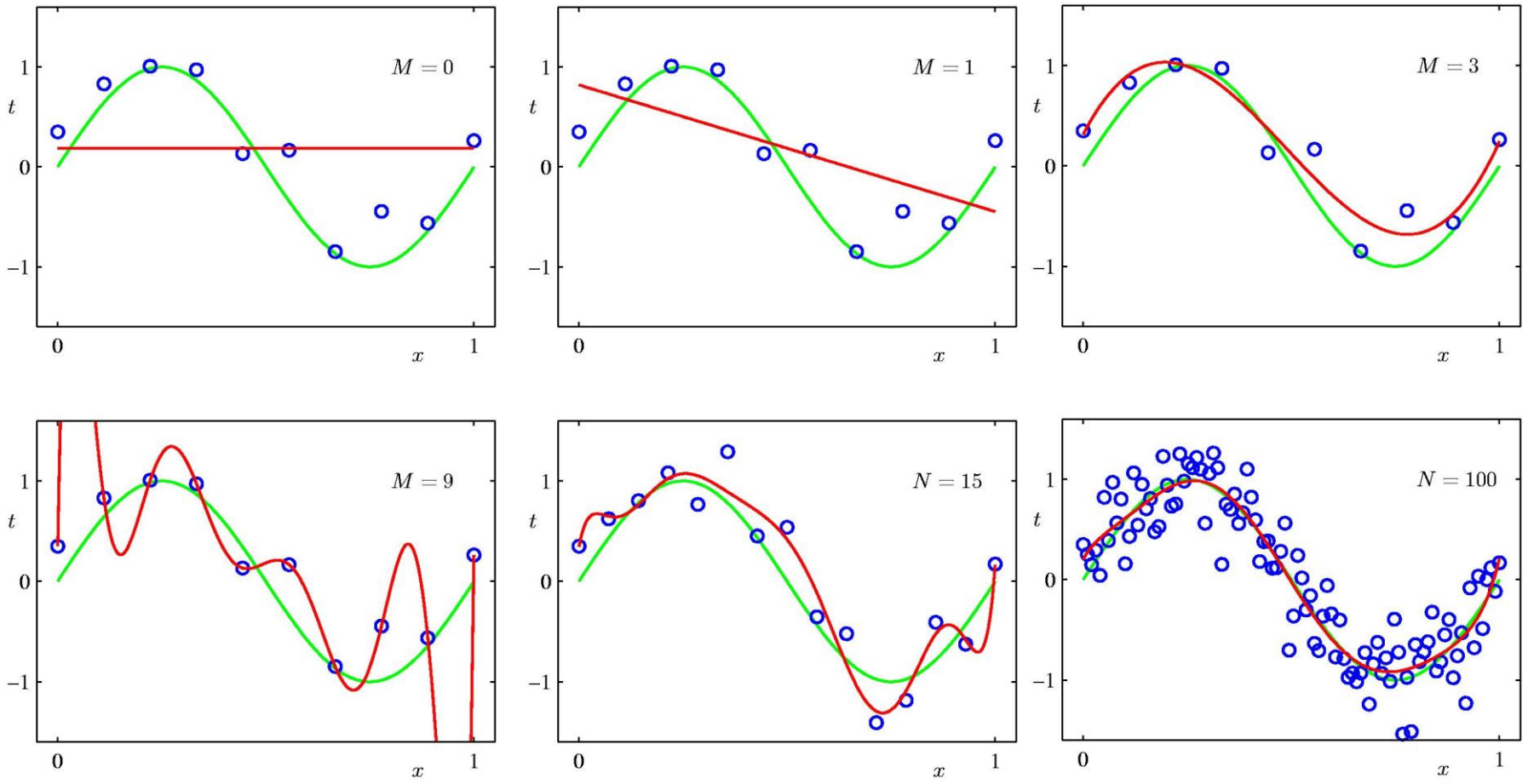
$$\arg\min_{\mathbf{w}} \left\| \mathbf{y} - \mathbf{P}(\mathbf{x}) \cdot \mathbf{w} \right\|^2$$

Least squares

$$\mathbf{w} = (\mathbf{P}^{\mathrm{T}}\mathbf{P})^{-1}\mathbf{P}^{\mathrm{T}}\mathbf{y}$$

Normal equation

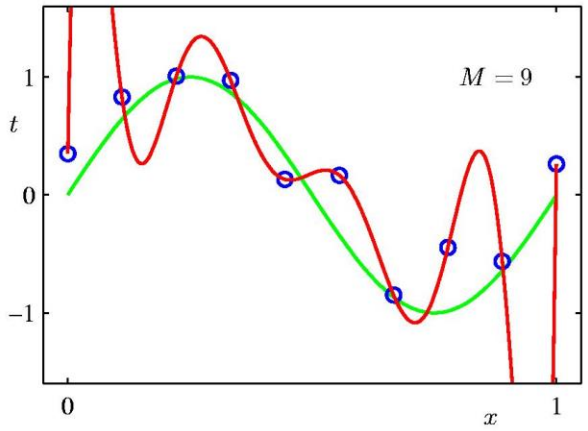
一维数据可视化 - 多项式拟合



$$E(\mathbf{w}) = \frac{1}{2}\sum_{n=1}^{N}\{y(x_n, \mathbf{w}) - t_n\}^2$$

平方和误差函数

一维数据可视化 - 过拟合现象

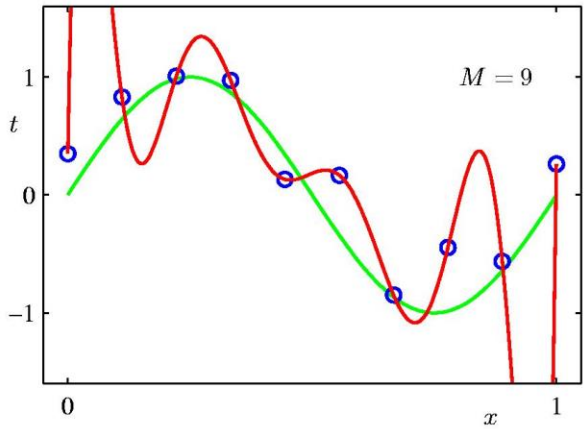


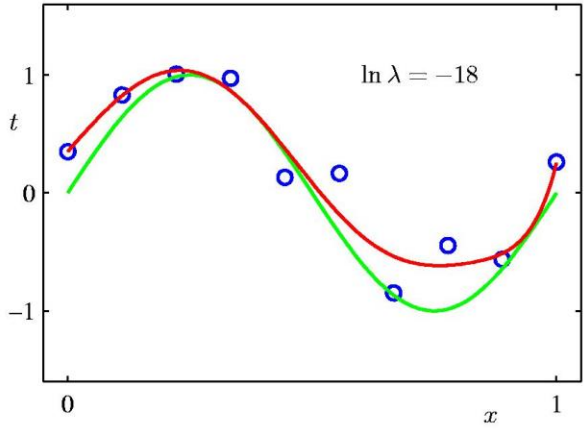
$$E(\mathbf{w}) = \frac{1}{2}\sum_{n=1}^{N}\{y(x_n, \mathbf{w}) - t_n\}^2$$

平方和误差函数

	$M=0$	$M=1$	$M=3$	$M=9$
$w_0^\star$	0.19	0.82	0.31	0.35
$w_1^\star$		-1.27	7.99	232.37
$w_2^\star$			-25.43	-5321.83
$w_3^\star$			17.37	48568.31
$w_4^\star$				-231639.30
$w_5^\star$				640042.26
$w_6^\star$				-1061800.52
$w_7^\star$				1042400.18
$w_8^\star$				-557682.99
$w_9^\star$				125201.43

一维数据可视化 - 过拟合现象及其解法





$$E(\mathbf{w}) = \frac{1}{2}\sum_{n=1}^{N}\{y(x_n,\mathbf{w}) - t_n\}^2$$

平方和误差函数

$$\widetilde{E}(\mathbf{w}) = \frac{1}{2}\sum_{n=1}^{N}\{y(x_n,\mathbf{w}) - t_n\}^2 + \frac{\lambda}{2}\|\mathbf{w}\|^2$$

正则函数校正

一维数据可视化 - LOESS拟合

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Volume 74, 1979 - Issue 368

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Theory and Method

Robust Locally Weighted Regression and Smoothing Scatterplots

William S. Cleveland

Pages 829-836 | Received 01 Mar 1978, Published online: 05 Apr 2012

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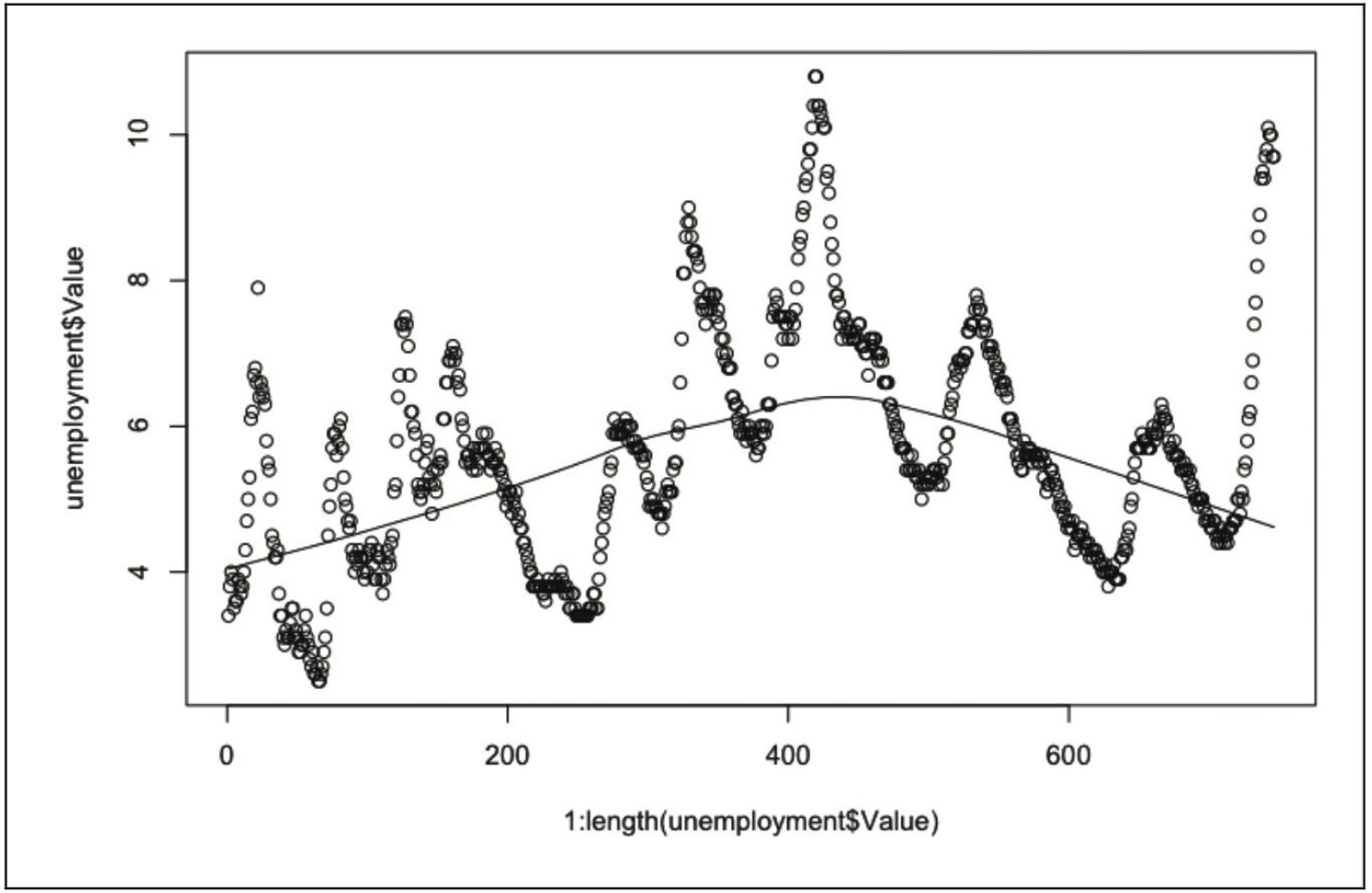
Abstract

The visual information on a scatterplot can be greatly enhanced, with little additional cost, by computing and plotting smoothed points. Robust locally weighted regression is a method for smoothing a scatterplot, (x_i, y_i), $i = 1, \ldots, n$, in which the fitted value at z_k is the value of a polynomial fit to the data using weighted least squares, where the weight for (x_i, y_i) is large if x_i is close to x_k and small if it is not. A robust fitting procedure is used that guards against deviant points distorting the smoothed points. Visual, computational, and statistical issues of robust locally weighted regression are discussed. Several examples, including data on lead intoxication, are used to illustrate the methodology.

Key Words: Graphics, Scatterplots, Nonparametric regression, Smoothing, Robust estimation

William Cleveland
Robust Locally Weighted Regression and Smoothing Scatterplots
Journal of the American statistical association 74.368 (1979): 829-836.

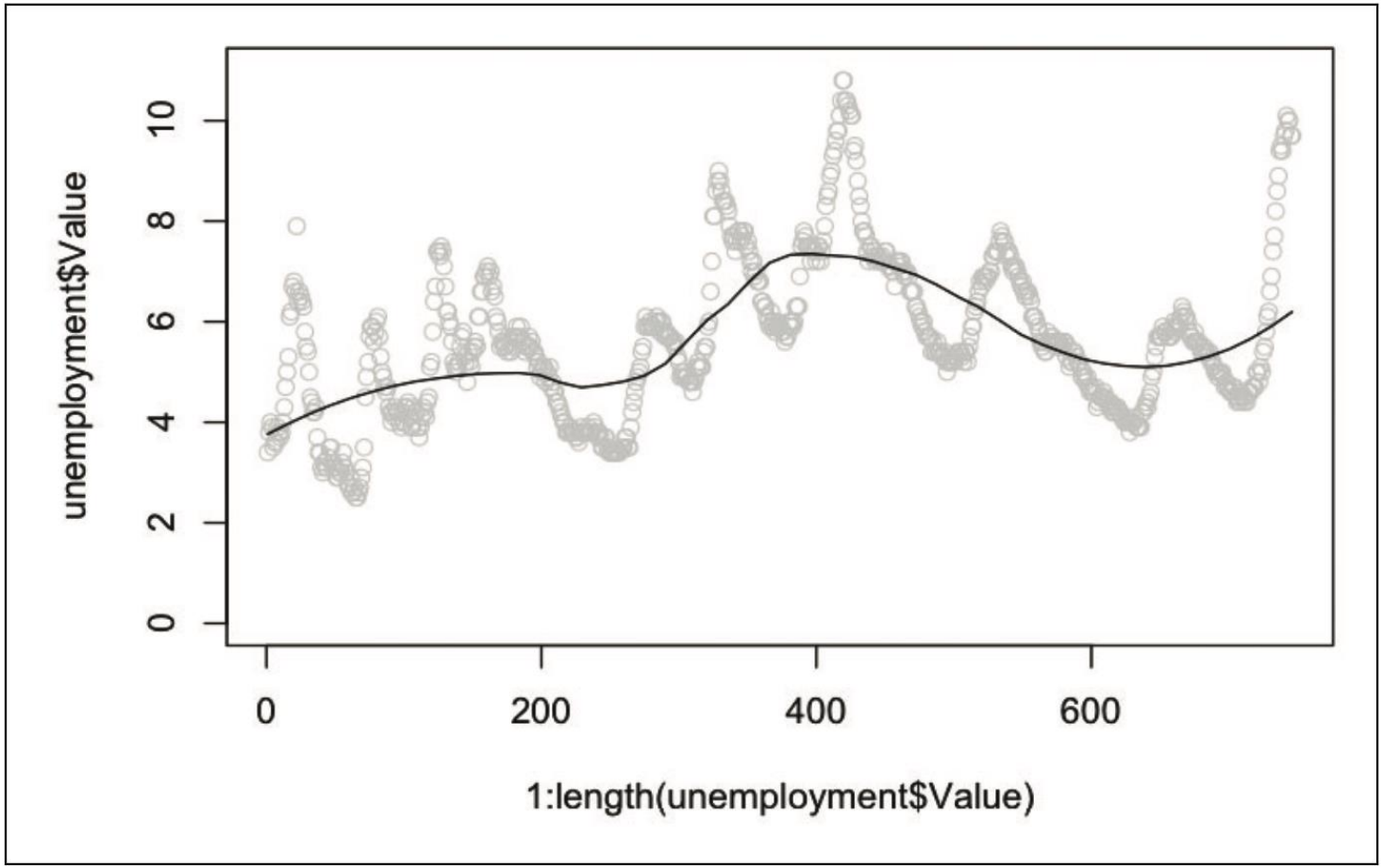
一维数据可视化 - LOESS拟合例



R语言实现：

```
scatter.smooth(x=1:length(data$Value), y=data$Value)
```

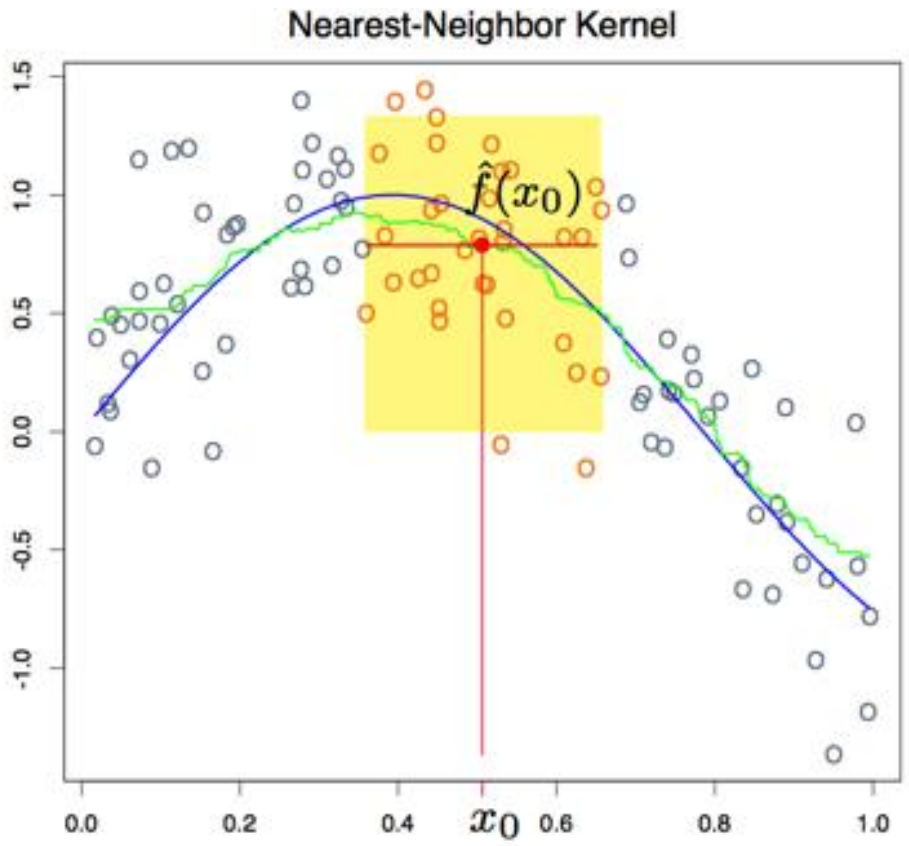
一维数据可视化 - LOESS拟合例



R语言实现（更多参数调整）：

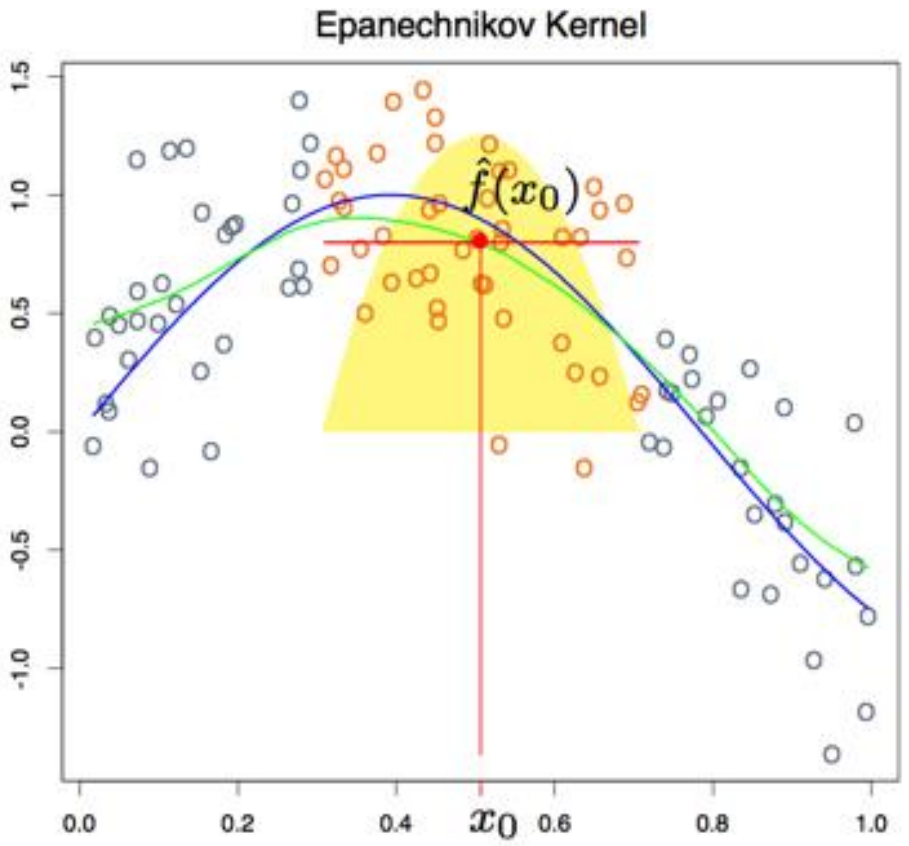
```
scatter.smooth(x=1:length(data$Value), y=data$Value,
degree=2, span=0.5)
```

一维数据可视化 - LOESS拟合



K-NN平均回归造成结果不连续

$$\hat{f}(x) = Ave(y_i | x_i \in N_k(x))$$



Kernel方法带来了连续光滑的结果

$$\hat{f}(x_0) = \frac{\sum_{i=1}^{N} K_\lambda(x_0, x_i) y_i}{\sum_{i=1}^{N} K_\lambda(x_0, x_i)}$$

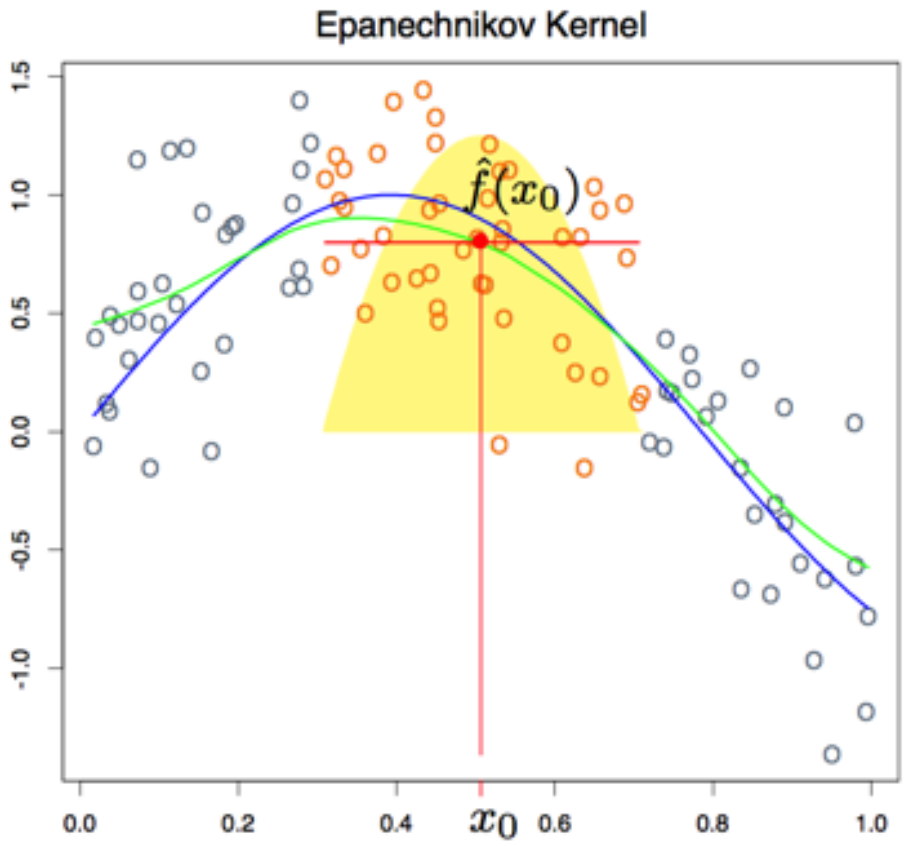
一维数据可视化 - LOESS拟合

$$\hat{f}(x_0) = \frac{\sum_{i=1}^{N} K_\lambda(x_0, x_i) y_i}{\sum_{i=1}^{N} K_\lambda(x_0, x_i)}$$

$$K_\lambda(x_0, x_i) = D\left(\frac{|x_0 - x_i|}{\lambda}\right)$$

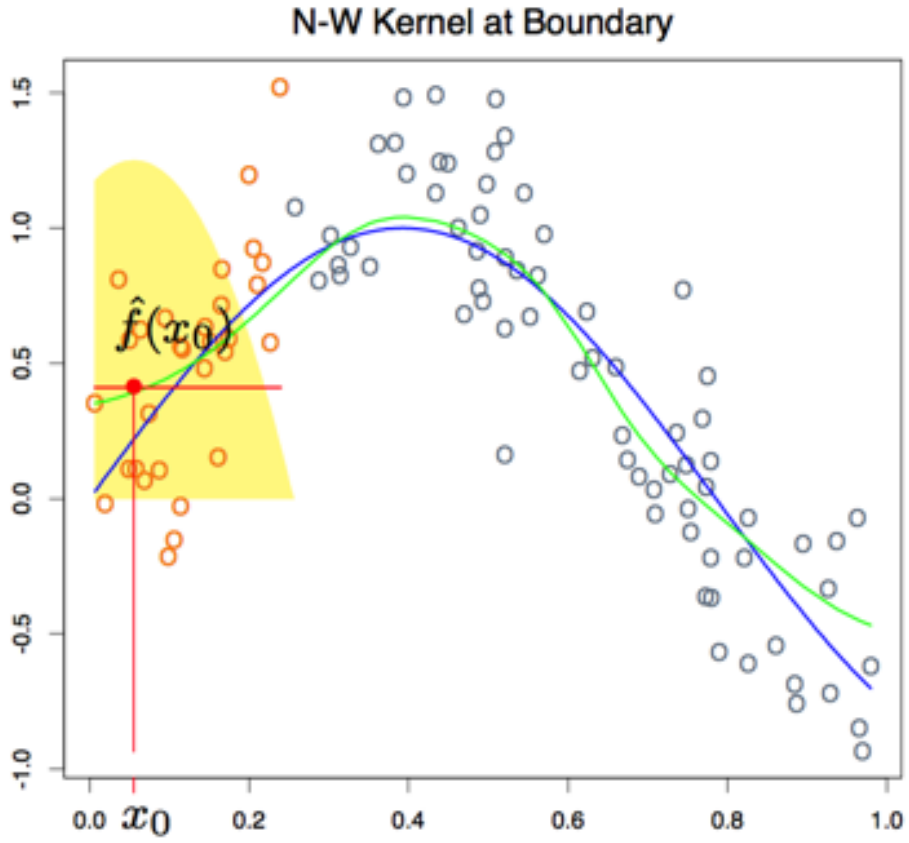
$$D(t) = \begin{cases} \frac{3}{4}(1 - t^2) & for|t| < 1 \\ 0 & otherwise \end{cases}$$

Epanechnikov 二次kernel函数

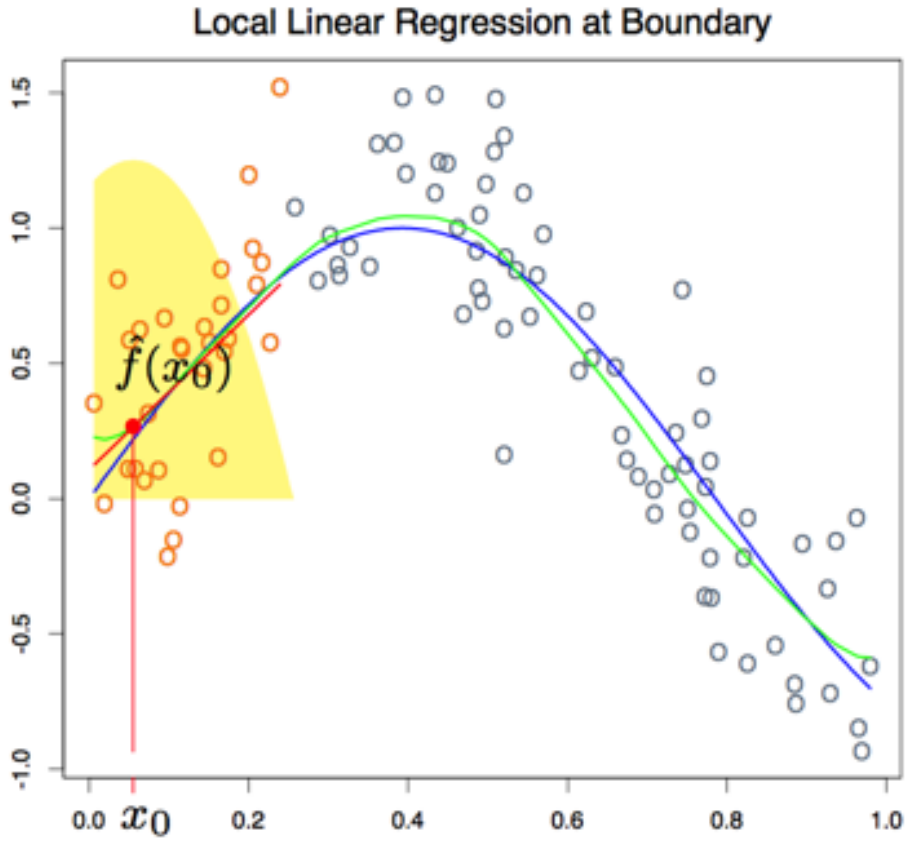


kernel方法带来了连续光滑的结果

一维数据可视化 - LOESS拟合



Kernel方法存在边界问题
开始与结束区段的点
其左右邻域是不对称的
导致了平滑后的值偏大或偏小



需要对权值做再修正

一维数据可视化 - LOESS拟合

$$\min_{\beta} \sum_{i=1}^{N} K_\lambda(x_0, x_i)[y_i - \sum_{j=0}^{d} \beta_j x_i^j]^2$$

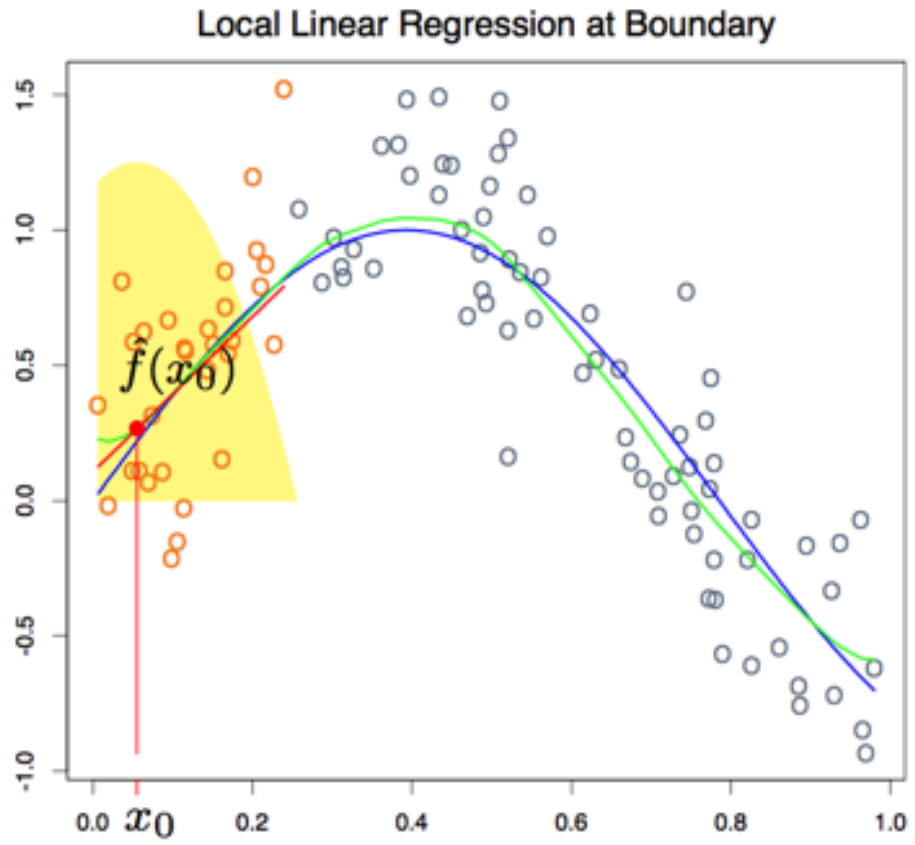
$$B = \begin{pmatrix} 1 & x_1 & \cdots & x_1^d \\ 1 & x_2 & \cdots & x_2^d \\ \vdots & \vdots & \ddots & \vdots \\ 1 & x_N & \cdots & x_N^d \end{pmatrix}$$

$$W_{x_0} = \begin{pmatrix} K_\lambda(x_0, x_1) & 0 & \cdots & 0 \\ 0 & K_\lambda(x_0, x_2) & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & K_\lambda(x_0, x_N) \end{pmatrix}$$

$$\Delta = \left(\beta_0, \beta_1, \cdots, \beta_d \right)^T$$

$$Y = \left(y_1, y_2, \cdots, y_N \right)^T$$

$$\min_{\Delta} (Y - B\Delta)^T W_{x_0} (Y - B\Delta)$$



需要对权值做再修正

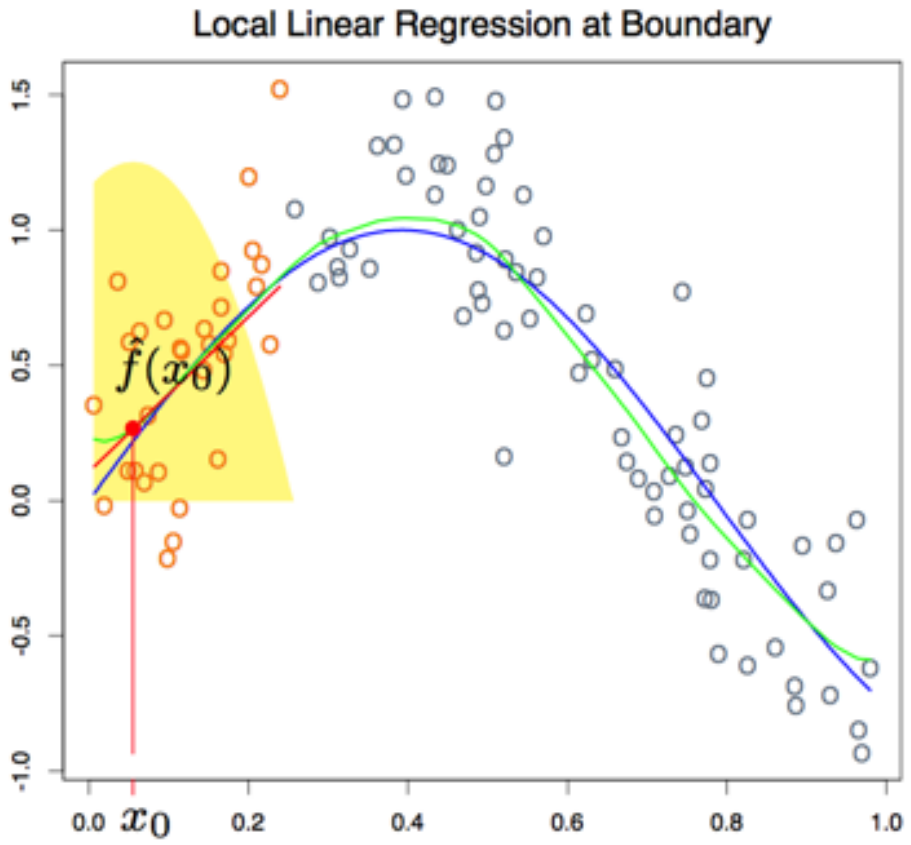
$$\hat{f(x_0)} = \sum_{j=0}^{d} \beta_j x_0^j$$

一维数据可视化 - LOESS拟合

$$\Delta = (B^T W_{x_0} B)^{-1}(B^T W_{x_0} Y)$$

$$e(x_0) = \left(1, x_0, \cdots, x_0^d\right)$$

$$\hat{f}(x_0) = e(x_0)(B^T W_{x_0} B)^{-1}(B^T W_{x_0} Y)$$
$$= \sum_i w_i(x_0) y_i$$



需要对权值做再修正

$$\min_{\Delta}(Y - B\Delta)^T W_{x_0}(Y - B\Delta)$$

$$\hat{f}(x_0) = \sum_{j=0}^{d} \beta_j x_0^j$$

一维数据可视化 - Robust LOESS拟合

计算残差

$$e_i = y_i - f(\hat{x}_i)$$

根据残差计算Robust Weight

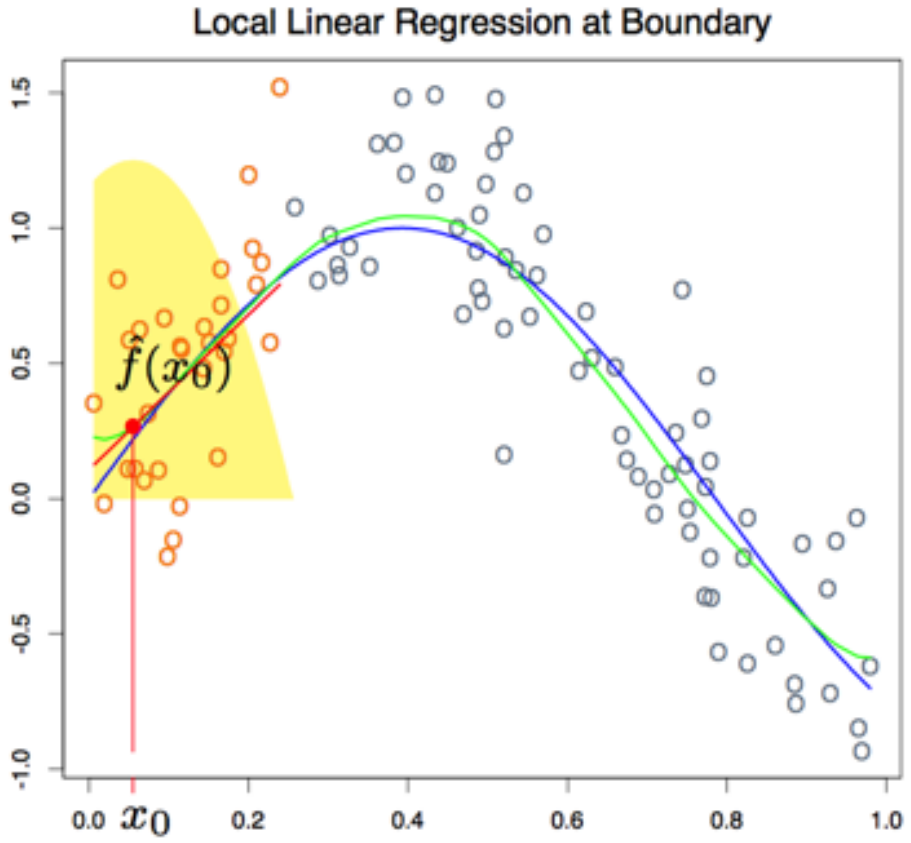
$$\delta_i = B(e_i/6s)$$

其中
s为残差绝对值序列$|e_i|$的中位数

B函数为bisquare函数

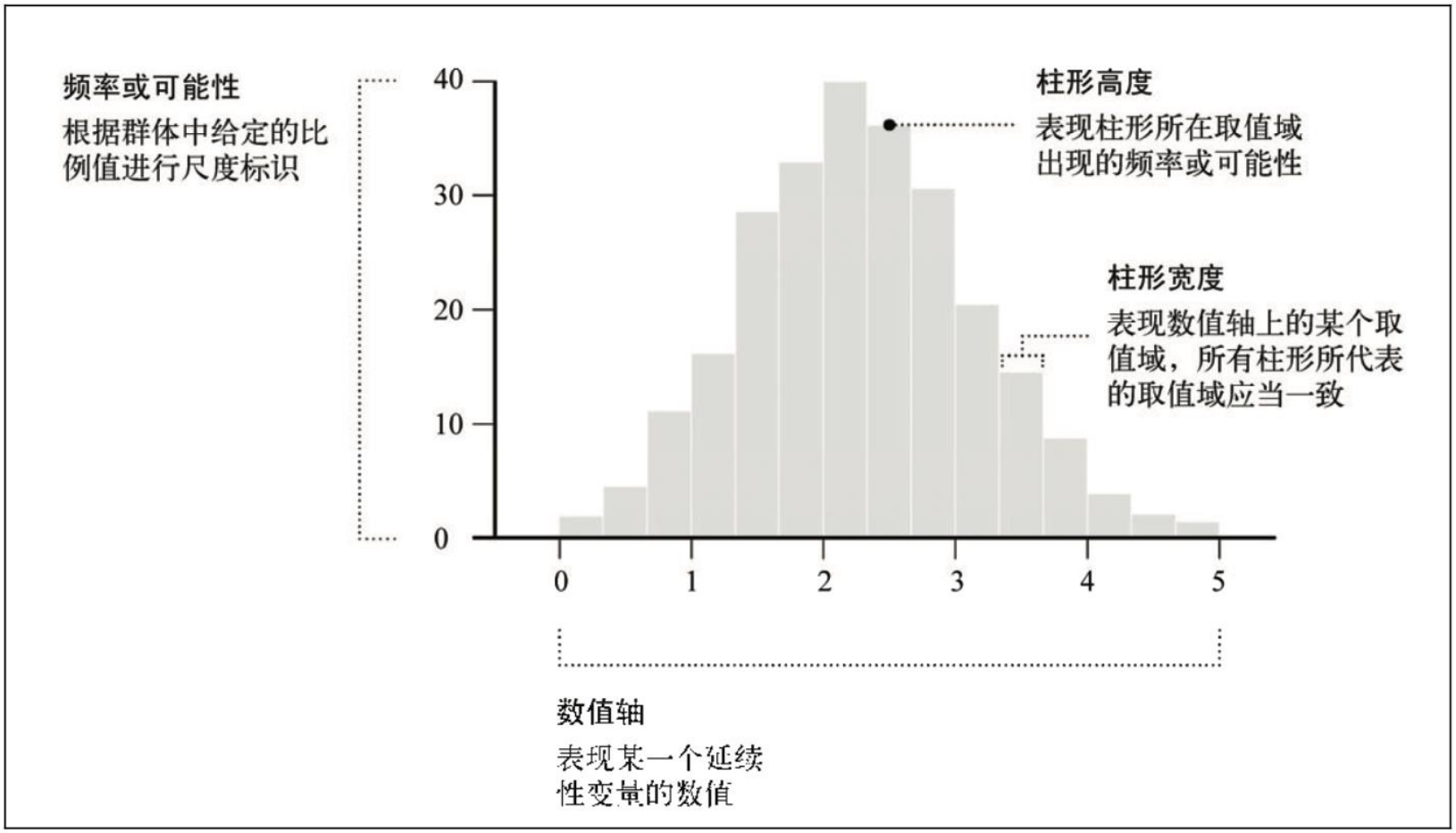
$$B(u) = \begin{cases} (1-u^2)^2 & for \quad 0 \le u < 1 \\ 0 & for \quad u \ge 1 \end{cases}$$

用robustness weight乘以
kernel weight作为新的weight



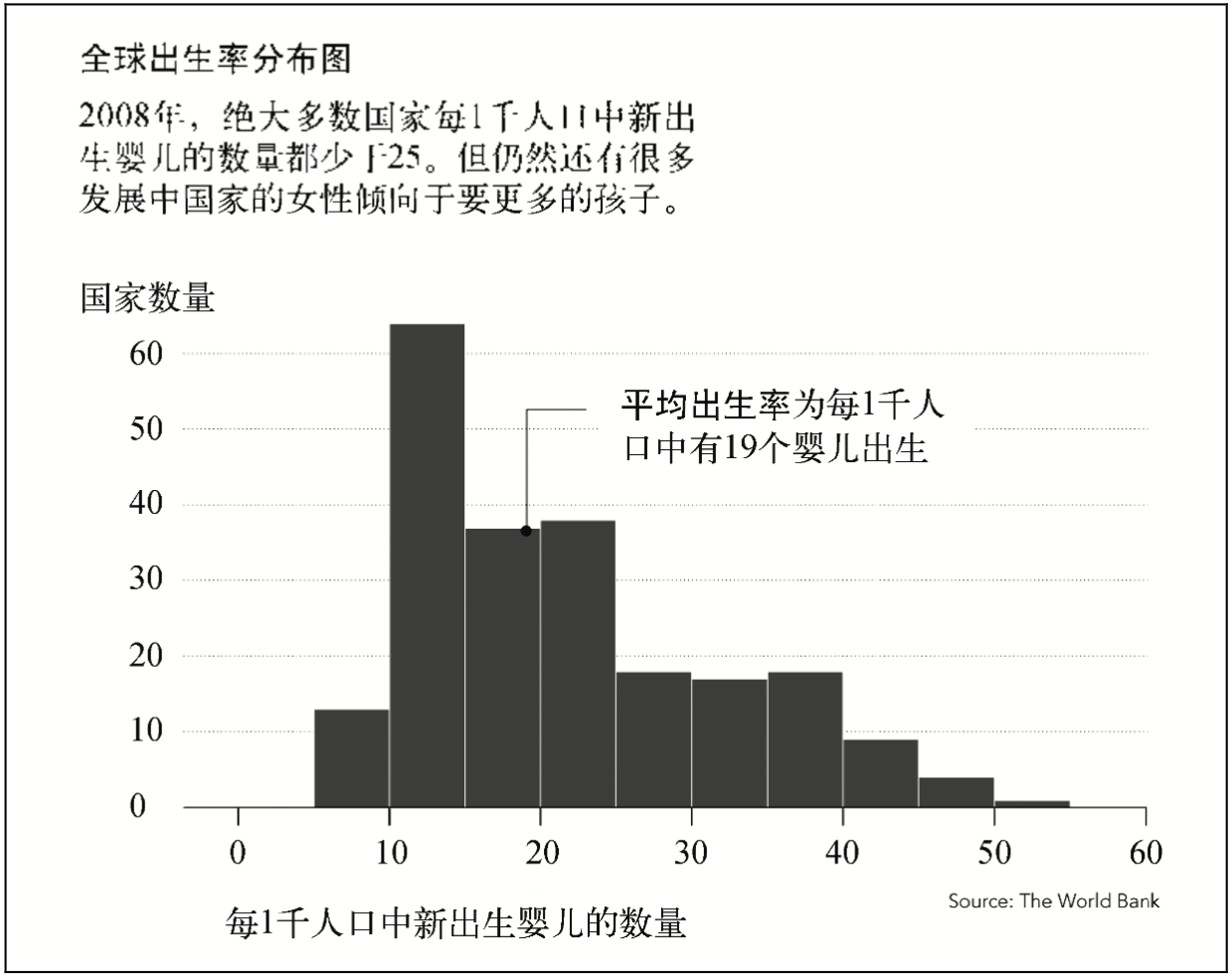
剔除残差较大的异常点
对于回归的影响

一维数据可视化 - 直方图



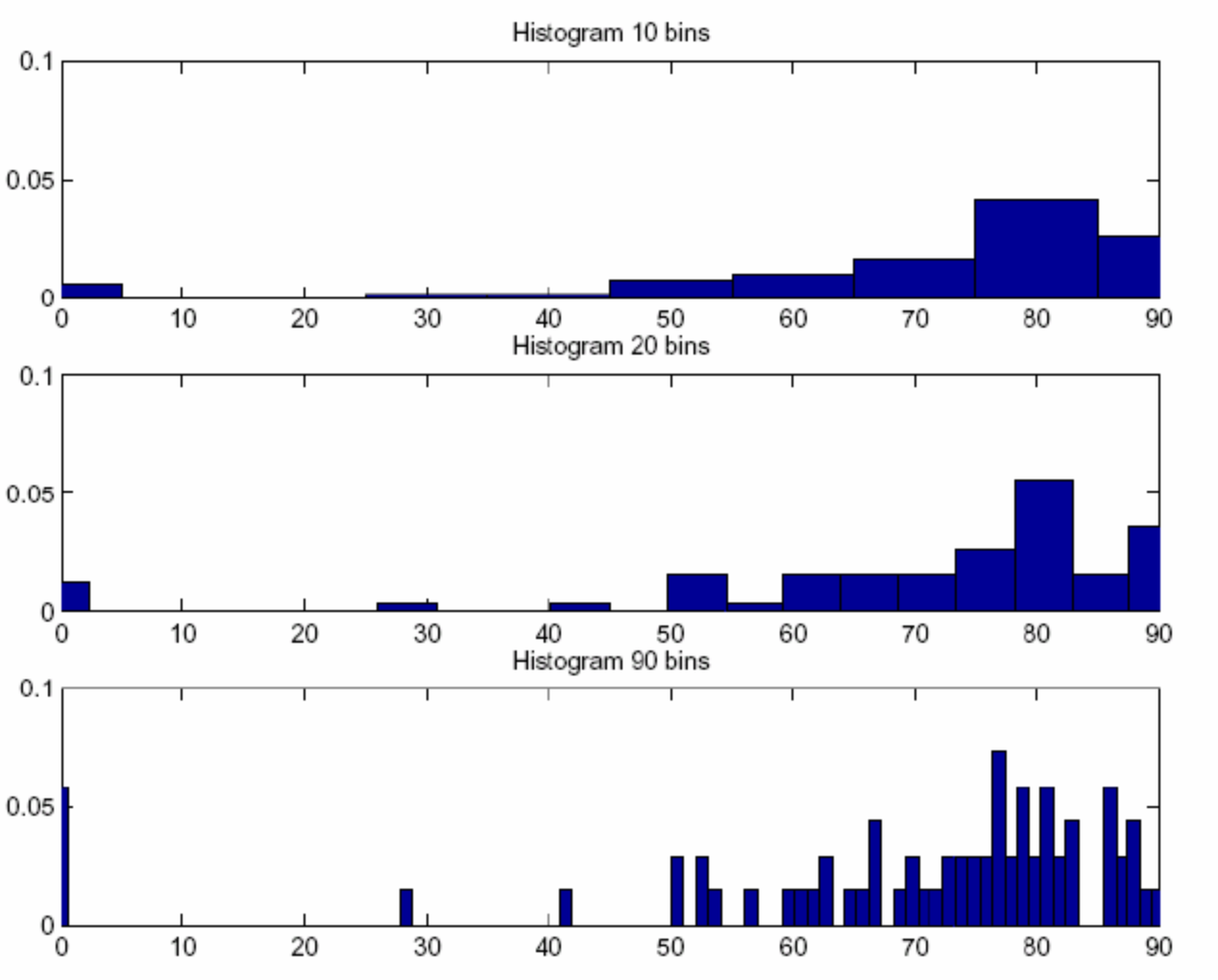
直方图的基本框架

一维数据可视化 - 直方图例



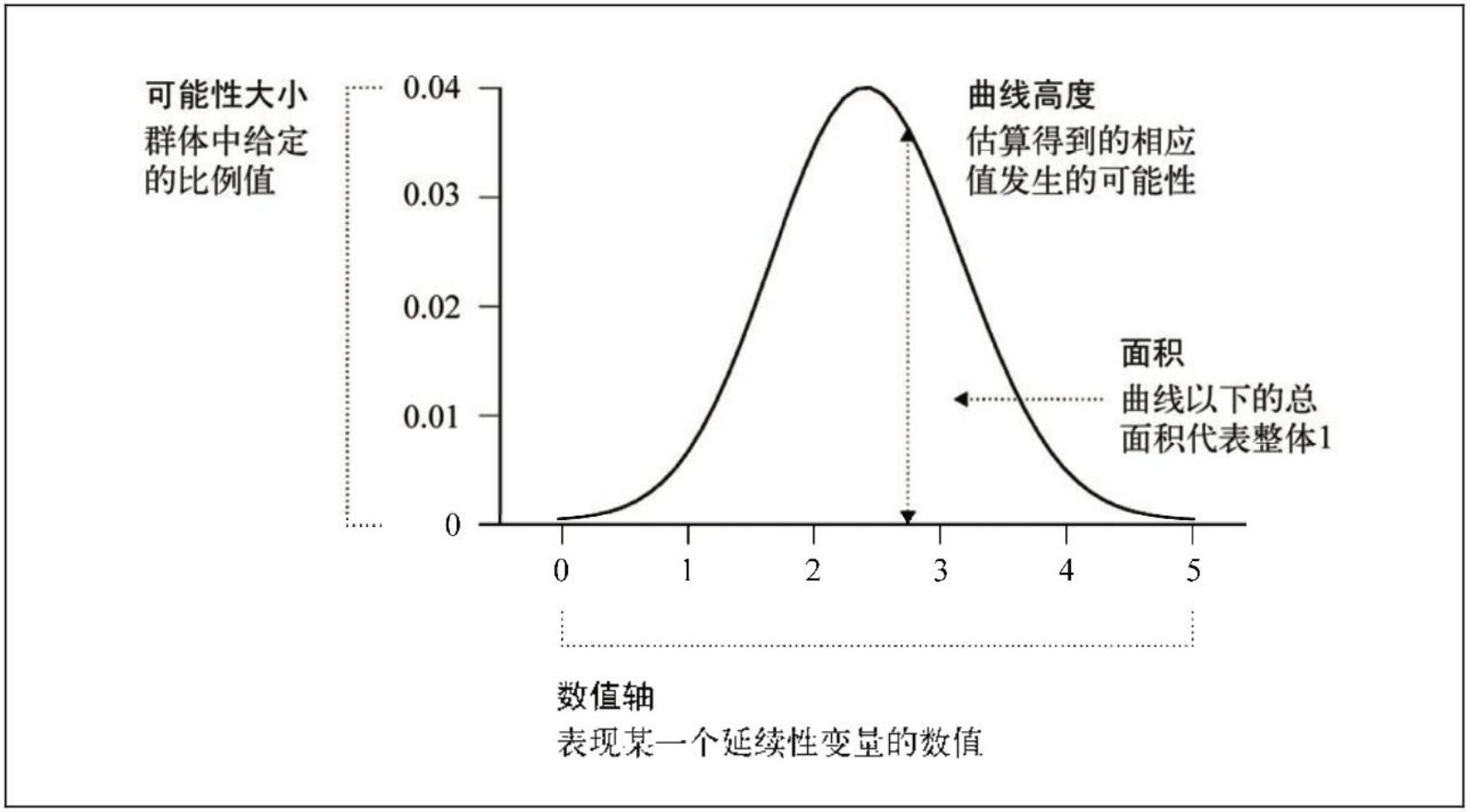
全球出生率分布图

一维数据可视化 – 直方图的缺点



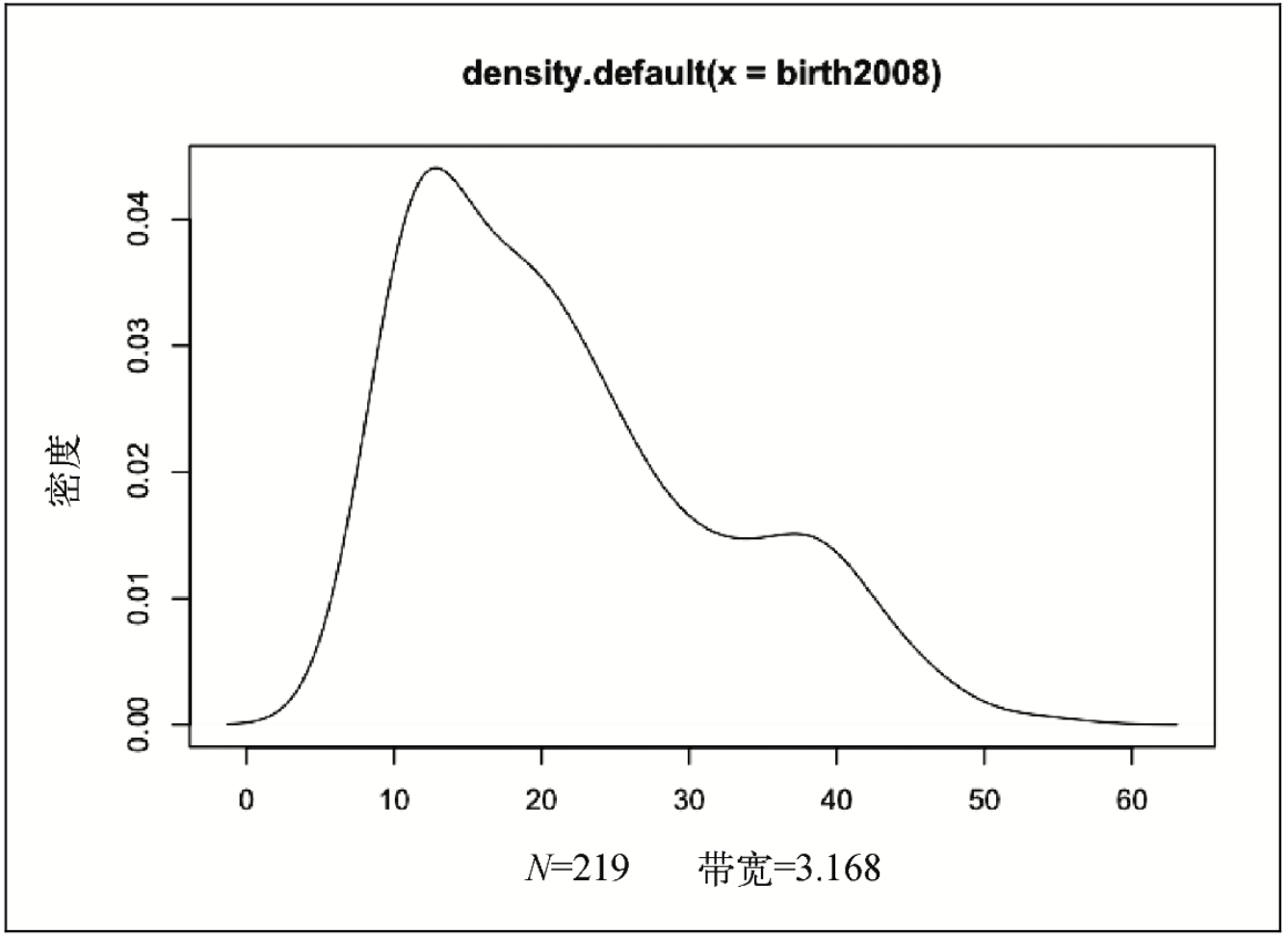
不同采样率下的直方图

一维数据可视化 – 密度图



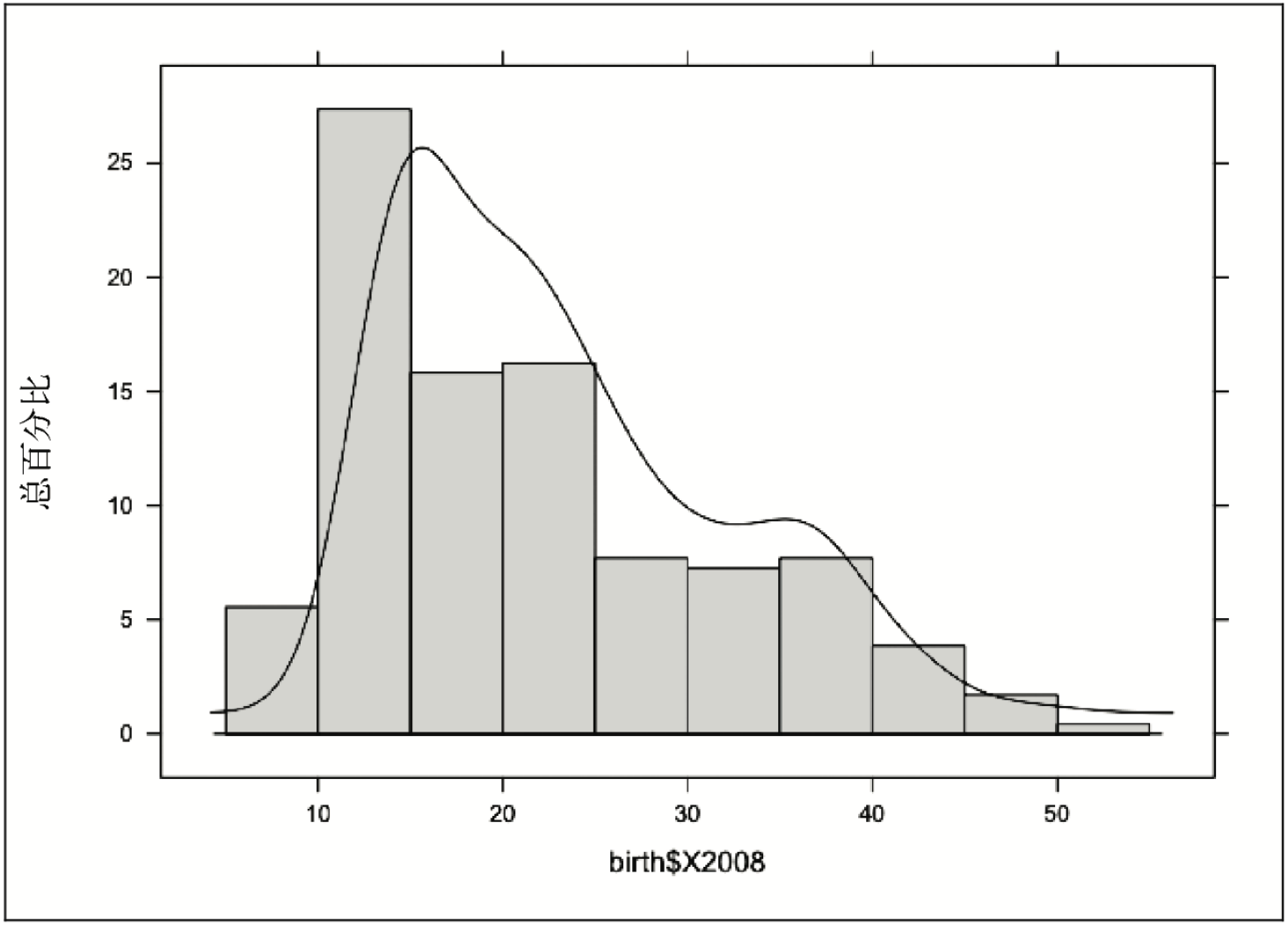
密度图的基本框架

一维数据可视化 – 密度图例



全球出生率的密度图

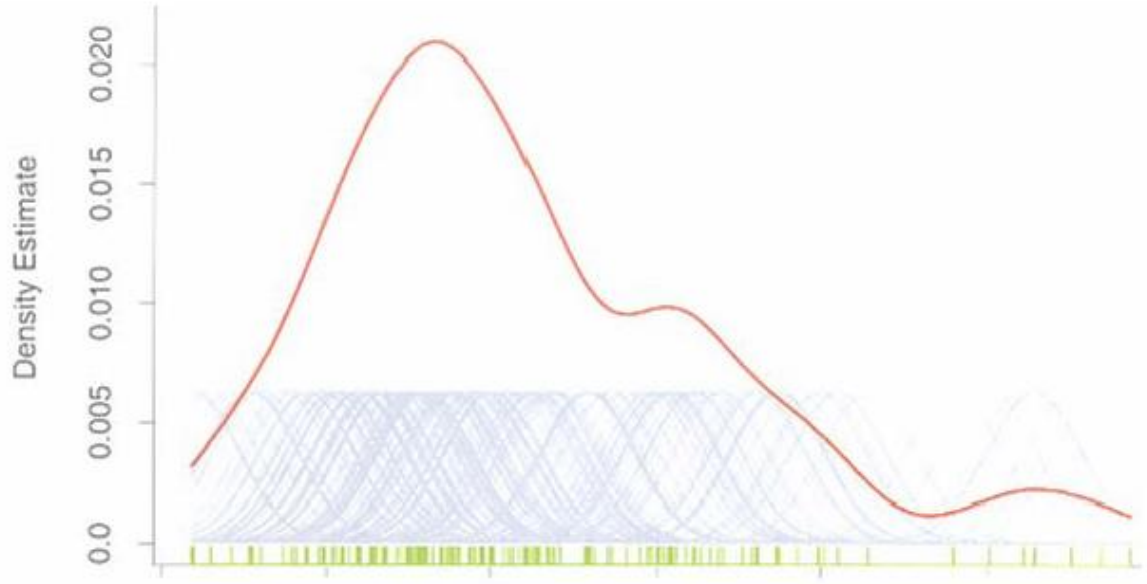
一维数据可视化 - 图例



全球出生率的直方图与密度图混合

一维数据可视化 – 密度图原理

Parzen example



from Hastie *et al.*

密度图与非参数估计

一维数据可视化 - 核密度估计

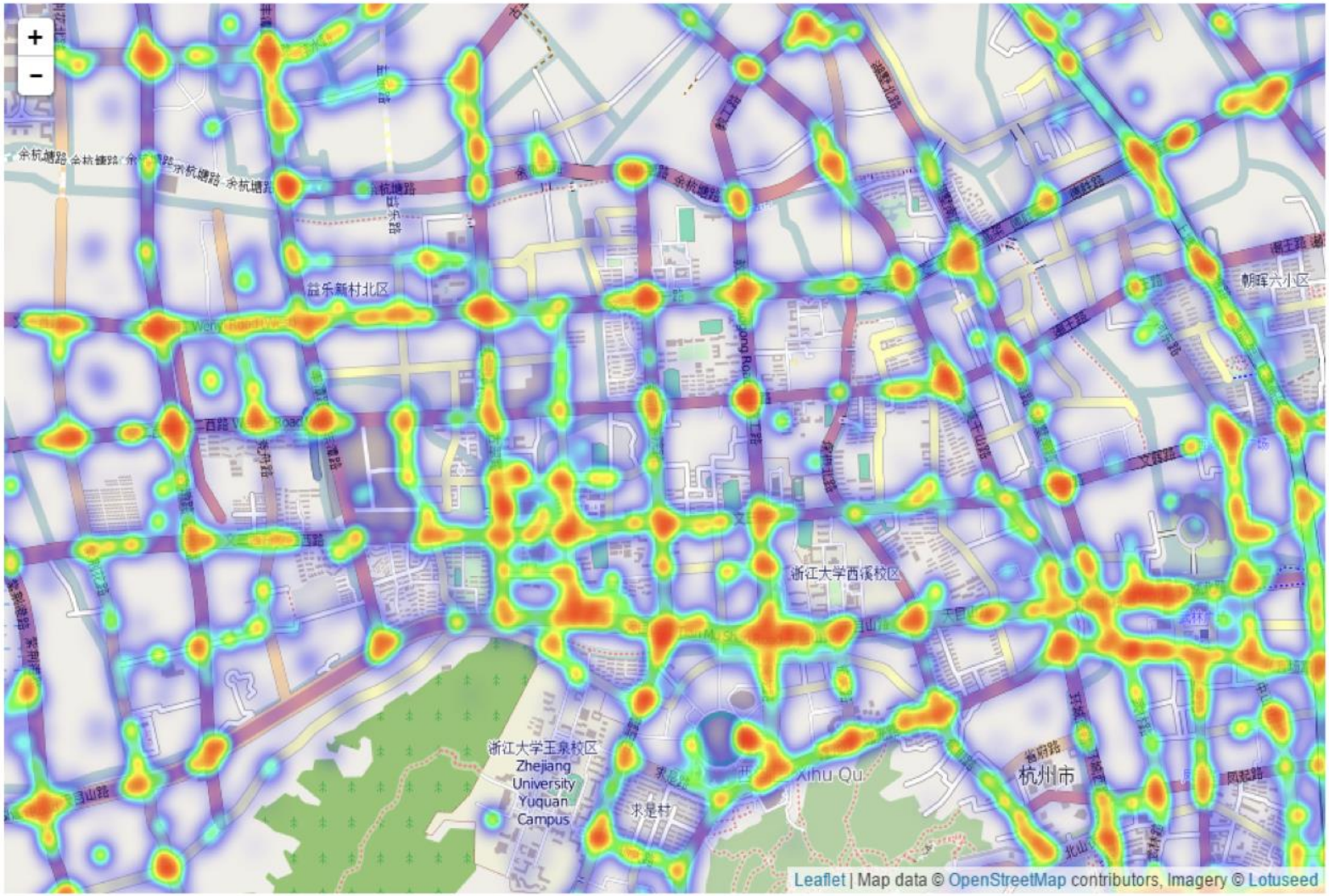
- Multivariate kernel density estimation

$$f(x) = \frac{1}{nh^d} \sum_{i=1}^{n} \frac{1}{h} K(\frac{x - x_i}{h})$$

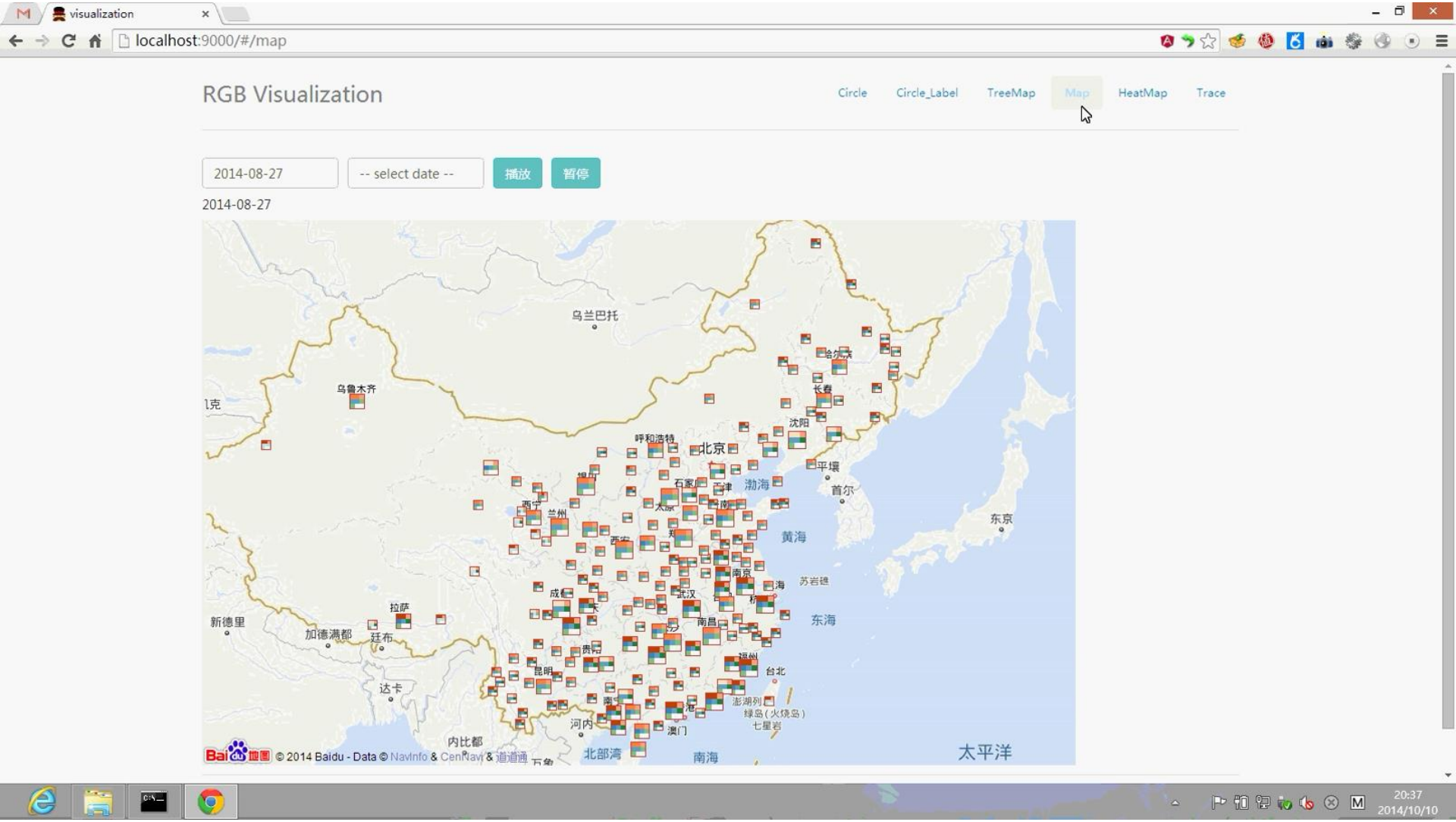
- Kernels
  - Gaussian $K_N = (2\pi)^{-d/2} \exp(-\frac{1}{2}\|\mathbf{x}\|^2)$
  - Epanechnikov

$$K_E = \begin{cases} 1/2c_d^{-1}(d+2)(1-\|\mathbf{x}\|^2) & \text{if } \|\mathbf{x}\| < 1 \\ 0 & \text{otherwise} \end{cases}$$

手机日志数据分析 - 热力图



手机日志数据分析 - 热力图



浙江大学
ZHEJIANG UNIVERSITY

主要参考资料
《大数据可视化建模》

陈为

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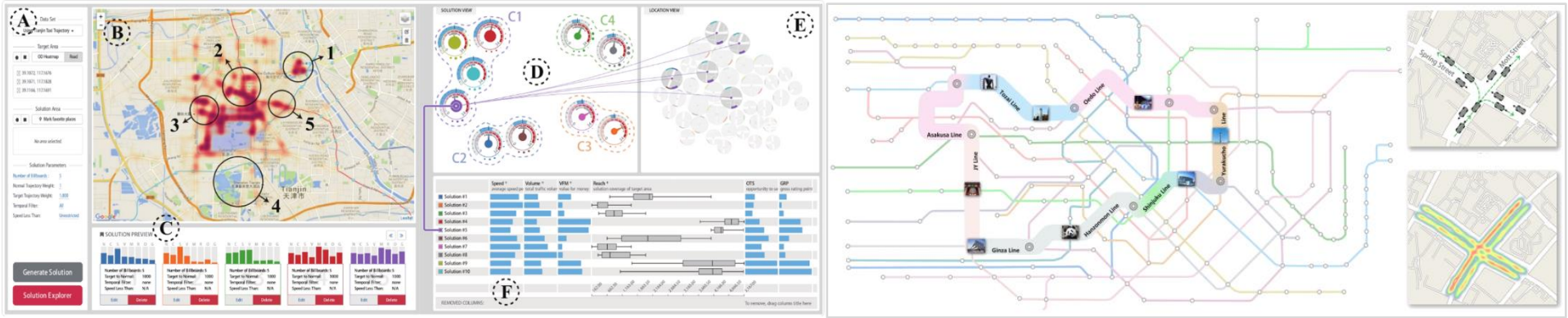
http://www.cad.zju.edu.cn/home/chenwei



谢谢

Thank You

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