三维重建

三维信息获取

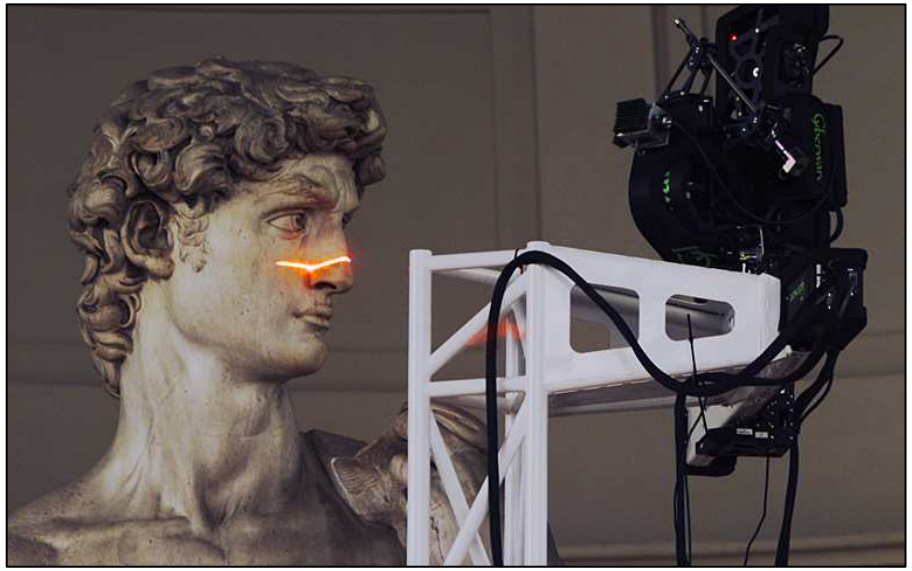
从散乱点集重建曲面

从几幅图像重建三维人脸

江南大学 董洪伟

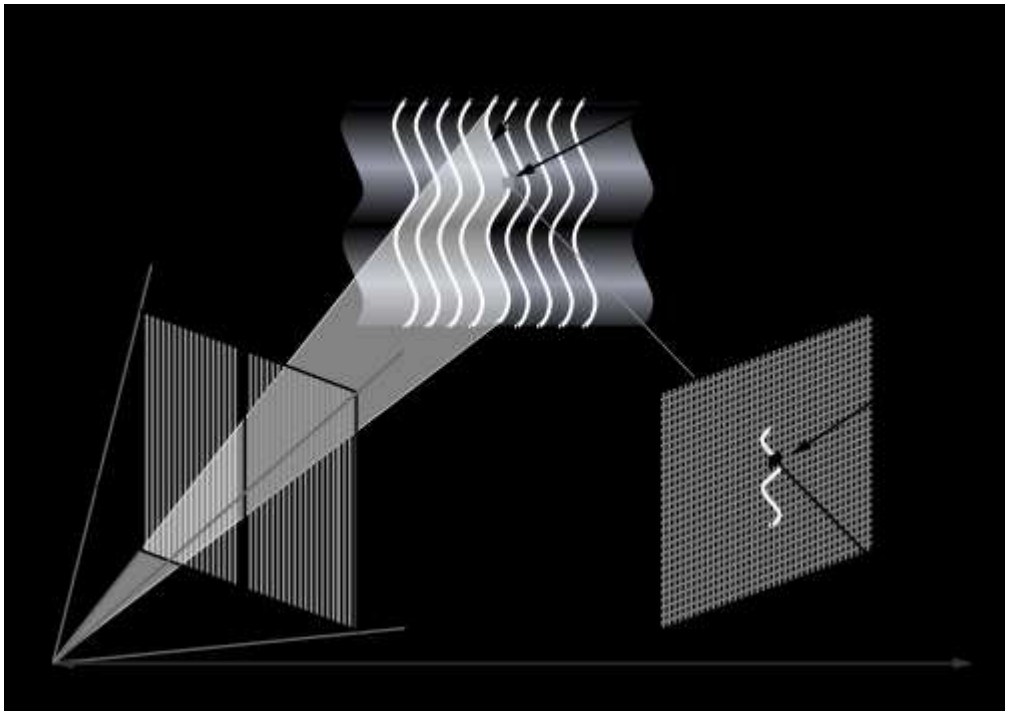
三维信息获取

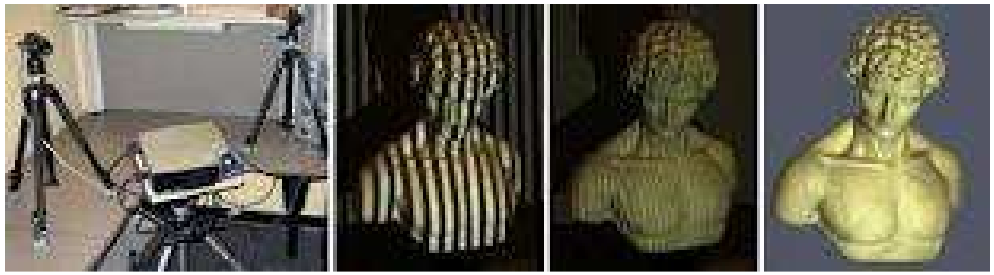
- 激光扫描：　基于三角原理



三维信息获取

- 结构光扫描：　基于三角原理





三维信息获取

- （立体匹配）多视几何：基于三角原理

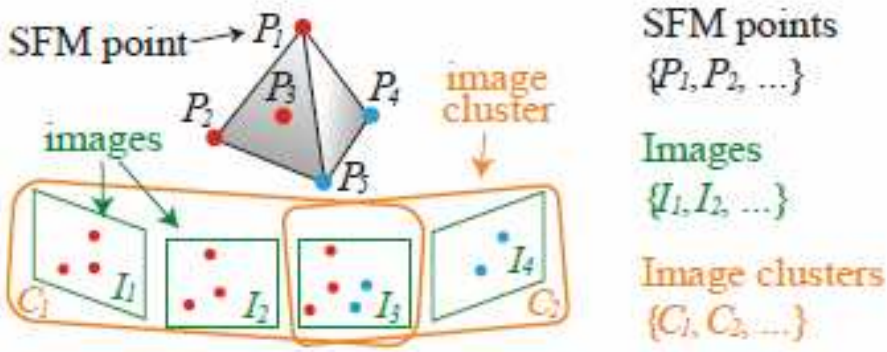


Figure 2. Our view clustering algorithm takes images $\{I_i\}$, SFM points $\{P_j\}$, and their associated visibility information $\{V_j\}$, then produces overlapping image clusters $\{C_k\}$.

三维信息获取

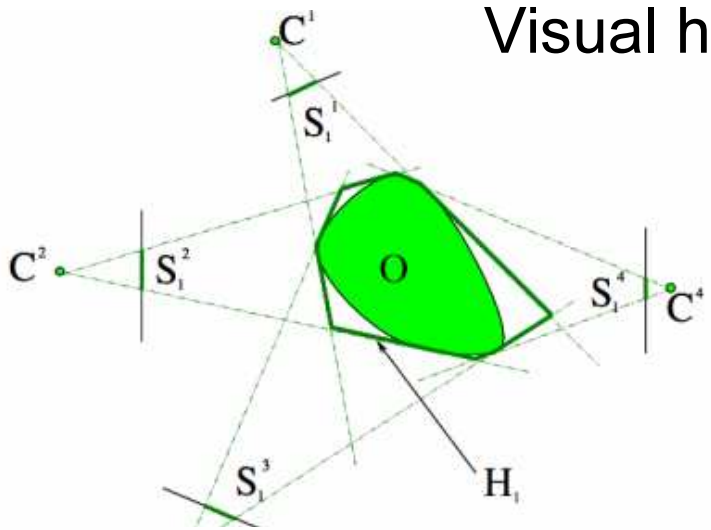
- （立体匹配）多视几何：基于三角原理

Figure 1. Our dense reconstruction of Piazza San Marco (Venice) from 13, 703 images with 27,707,825 reconstructed MVS points (further upsampled x9 for high quality point-based rendering).

三维信息获取

- Shape from X: ***silhouette***

Visual hull



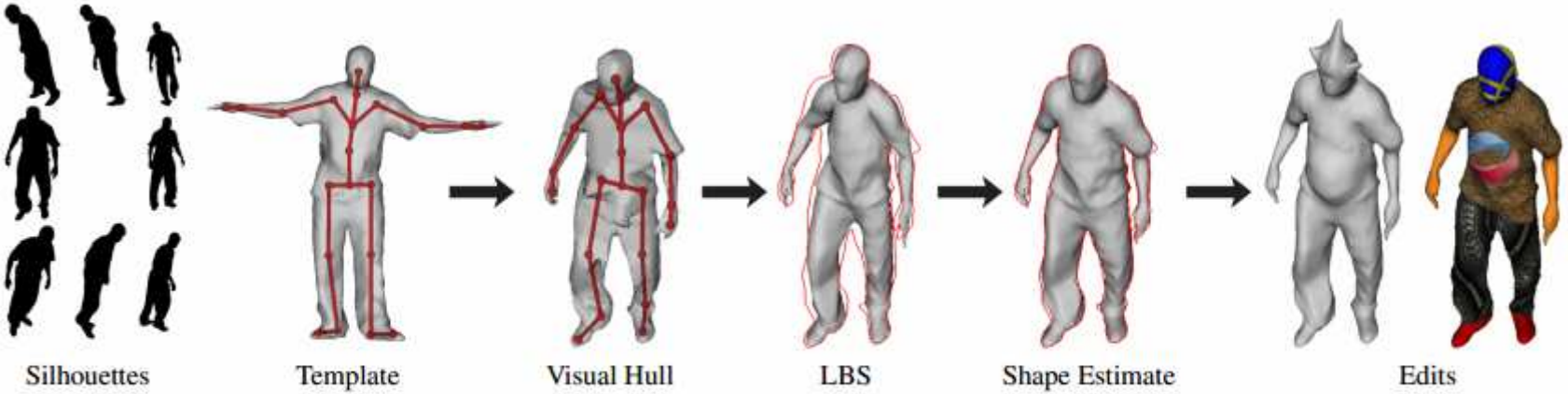


Figure 3: *From left to right, our system starts with a stream of silhouette videos and a rigged template mesh. At every frame, it fits the skeleton to the visual hull, deforms the template using linear blend skinning (LBS), and adjusts the deformed template to fit the silhouettes. The user can then easily edit the geometry or texture of the entire motion.*

三维信息获取

- Shape from X:
  photometric

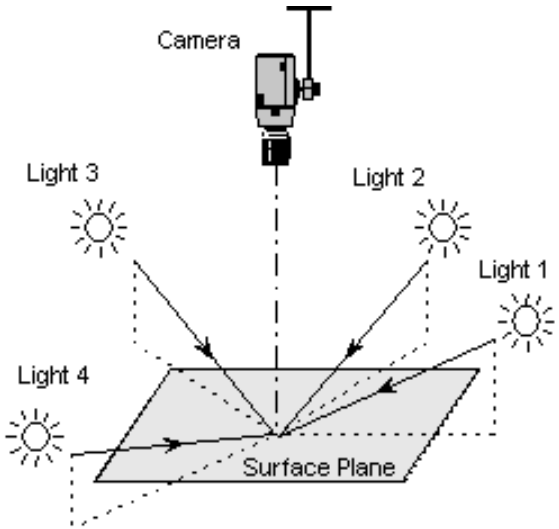
Woodham假设：

Lambertian reflectance,

known point-like distant light sources,

const albedo

$$I = \rho L \bullet n$$



Woodham 1980

三维信息获取

- Shape from X:
  shading

Woodham假设：
Lambertian reflectance,

known point-like
distant light sources,

const albedo

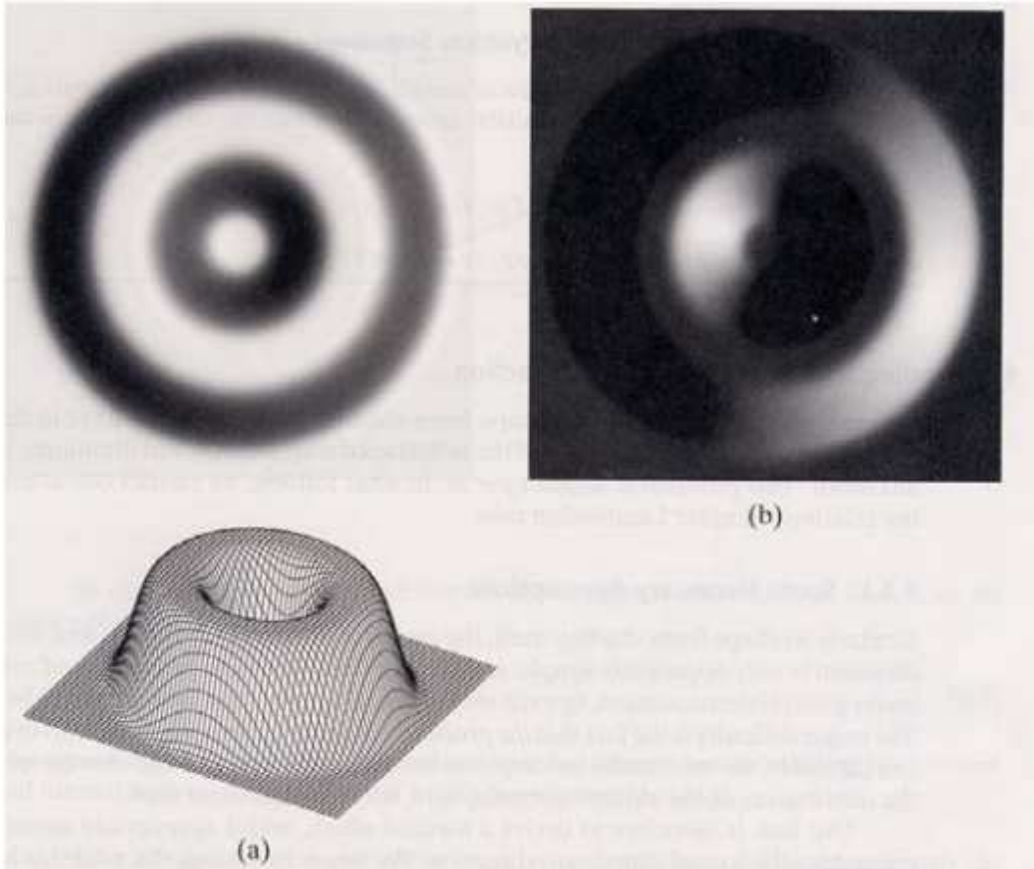
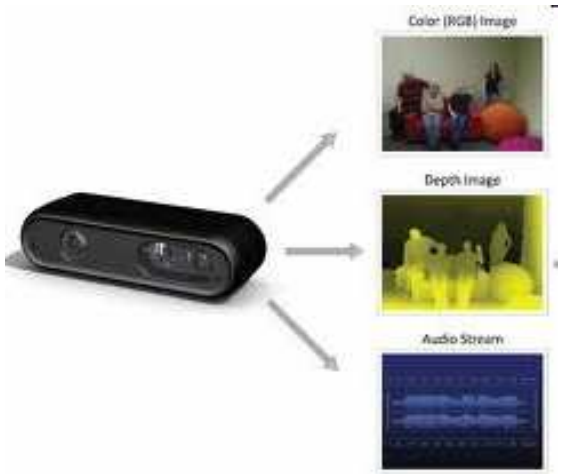


Figure 9.2 Two images of the same Lambertian surface seen from above but illuminated from different directions and 3-D rendering of the surface. Practically all the points in the top left image receive direct illumination ($\mathbf{l} = [0.20, 0, 0.98]^\top$); some regions of the top right image are in the dark due to self-shadowing effects ($\mathbf{l} = [0.94, 0.31, 0.16]^\top$).

三维信息获取

- 深度相机： 立体视觉、Time-of-Flight(TOF)



PrimeSense **Depth Camera**

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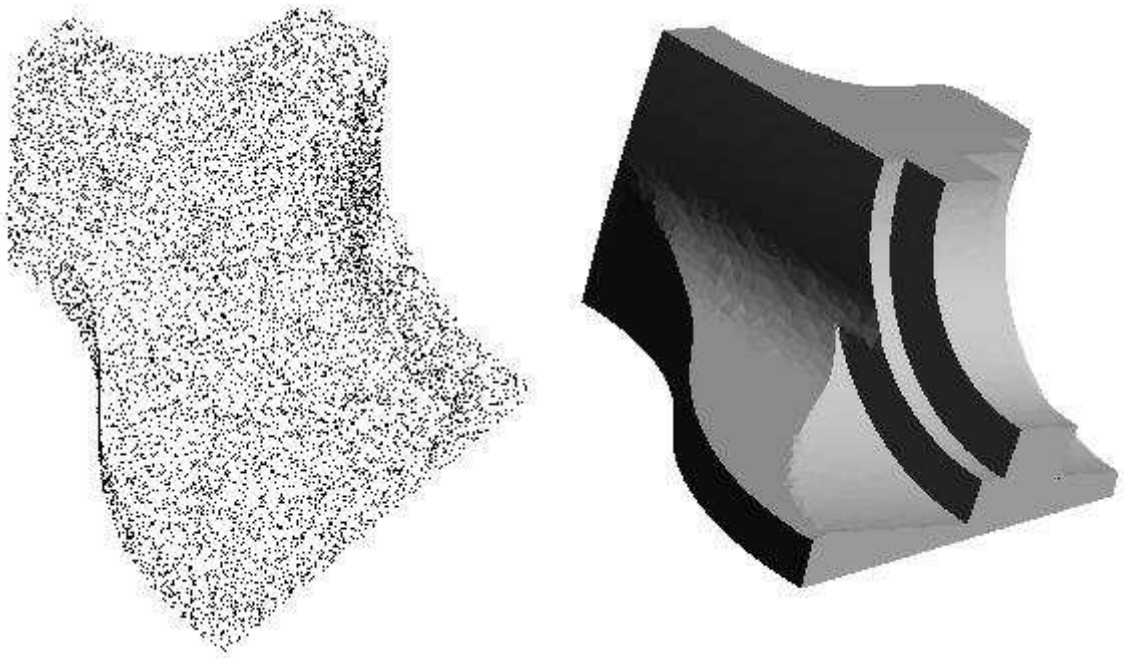
从散乱点集重建曲面

- 从三维获取方法得到的点云构造3D网格曲面-逆向工程
  - •表面物性分析
  - •数控加工
  - •参数化
  - •绘制
  - •碰撞检测



从散乱点集重建曲面

- 隐函数(implicit function): Hoppe[HDD97]、Possion[KBH06] 、MLS[ABCO01]

- 计算几何(Computational Geometry)：Dalaunay[dey2007]、Voronio[Amenta1998]

- 波前法/增量式扩展(Advancing front)[HM02,LTW04]

从散乱点集重建曲面

主要参考文献

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- M. Kazhdan, M. Bolitho, and H. Hoppe. Poisson Surface Reconstruction.2006
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- JU, T., LOSASSO, F., SCHAEFER, S., AND WARREN, J. 2002.Dual contouring of hermite data. 2002

从散乱点集重建曲面

- Shachar Fleishman, Daniel Cohen-Or, Cl´audio T. Silva.Robust Moving Least-squares Fitting with Sharp Features.2005
- Huang J, Menq CH. Combinatorial manifold mesh reconstruction and optimization from unorganized points with arbitrary topology. 2002
- Hong-Wei Lin, Chiew-Lan Tai, Guo-Jin Wang. A mesh reconstruction algorithm driven by anintrinsic property of a point cloud. 2004
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- Nina Amenta , Marshall Bern , Manolis Kamvysselis . A New Voronoi-Based Surface Reconstruction Algorithm. 1998

从散乱点集重建曲面

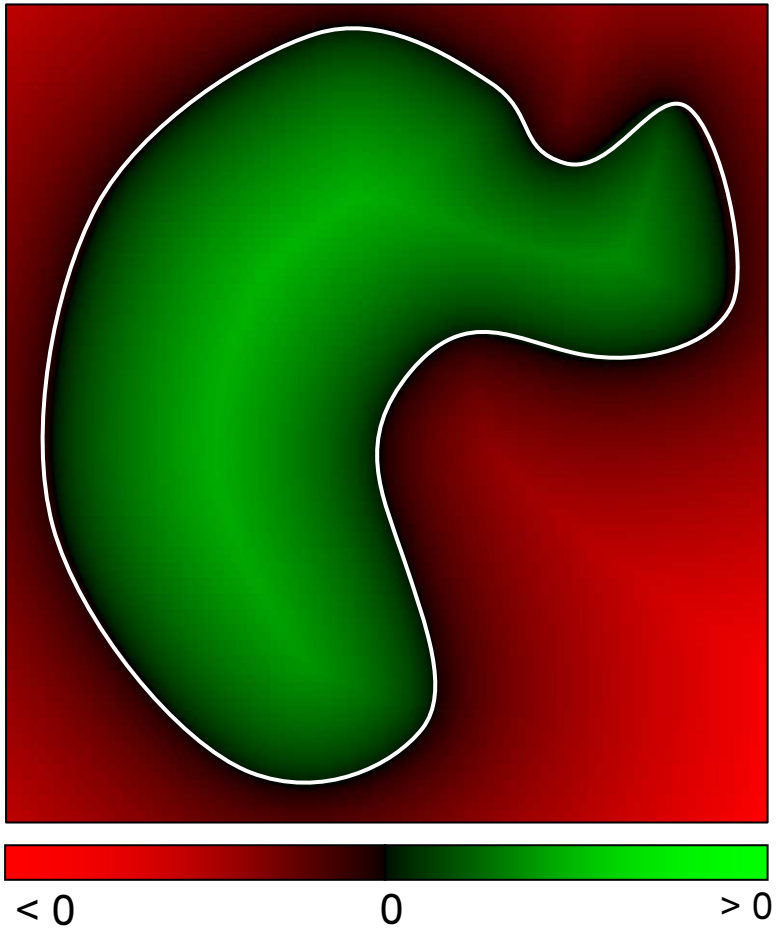
- 大多数算法都假设：
  潜在曲面的光滑性
  前两种方法一般还假设曲面是封闭的
  许多算法虽有理论保证，但要求充分稠密的采样
- 仅少数算法能重建特征敏感的曲面.
- 在Advancing front方法中，只有和隐函数MLS方法结合的拟合曲面重建算法[FCOS05]可以恢复尖锐特征

Implicit function

- Define a function with value less than zero outside the model and greater than zero inside

- Extract the zero-set

Mrching Cube



Michael Kazhdan 06

MLS

$H = \{x | \langle n, x \rangle - D = 0, x \in \mathbb{R}^3\}, n \in \mathbb{R}^3, \|n\| = 1$

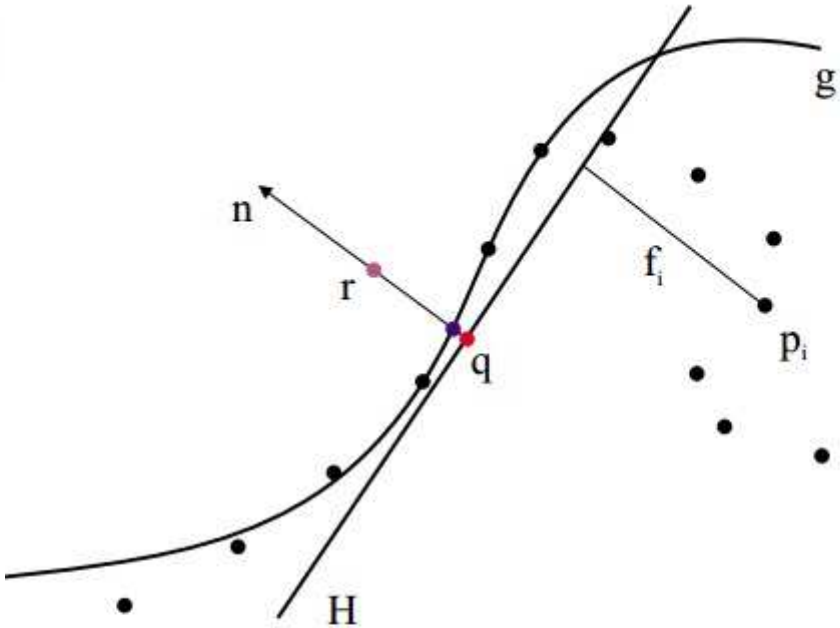
H is found by minimizing

$$\sum_{i=1}^{N} (\langle n, p_i \rangle - D)^2 \, \theta(\|p_i - q\|)$$

a polynomial approximation g is found by minimizing

$$\sum_{i=1}^{N} (g(x_i, y_i) - f_i)^2 \, \theta(\|p_i - q\|)$$

f_i the height of p_i over H, i.e $f_i = n \cdot (p_i - q)$



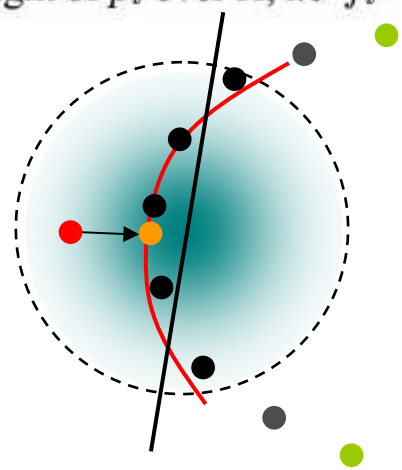
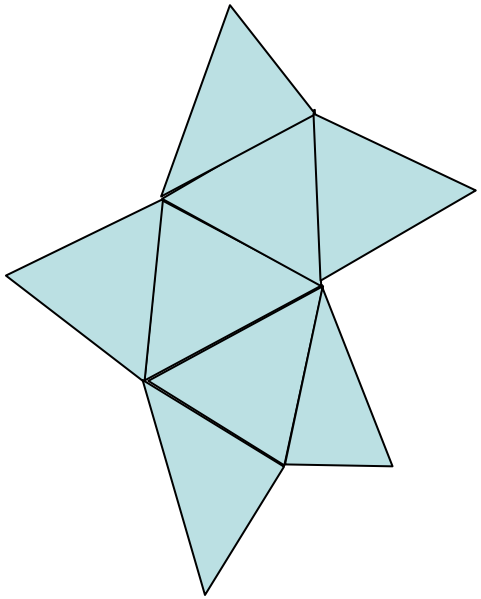


Figure 3: The MLS projection procedure: First, a local reference domain H for the purple point r is generated. The projection of r onto H defines its origin q (the red point). Then, a local polynomial approximation g to the heights f_i of points p_i over H is computed. In both cases, the weight for each of the p_i is a function of the distance to q (the red point). The projection of r onto g (the blue point) is the result of the MLS projection procedure.

Advancing fronts

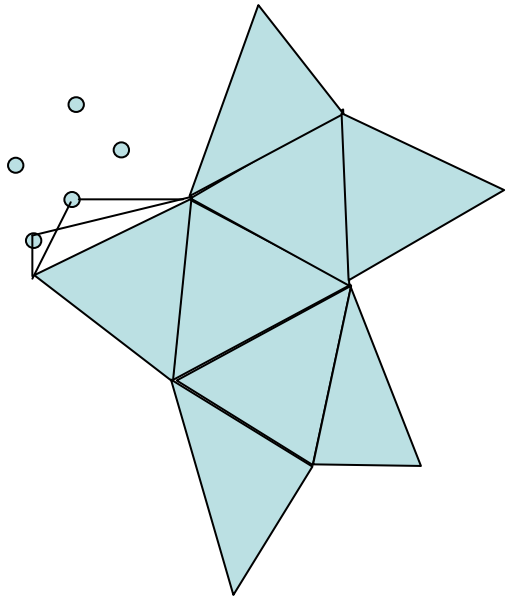
- 从一个种子点或一个种子三角形出发增量地扩展



Advancing fronts

- 关键：

1）为待扩展边界确定最佳的扩展点



最大夹角

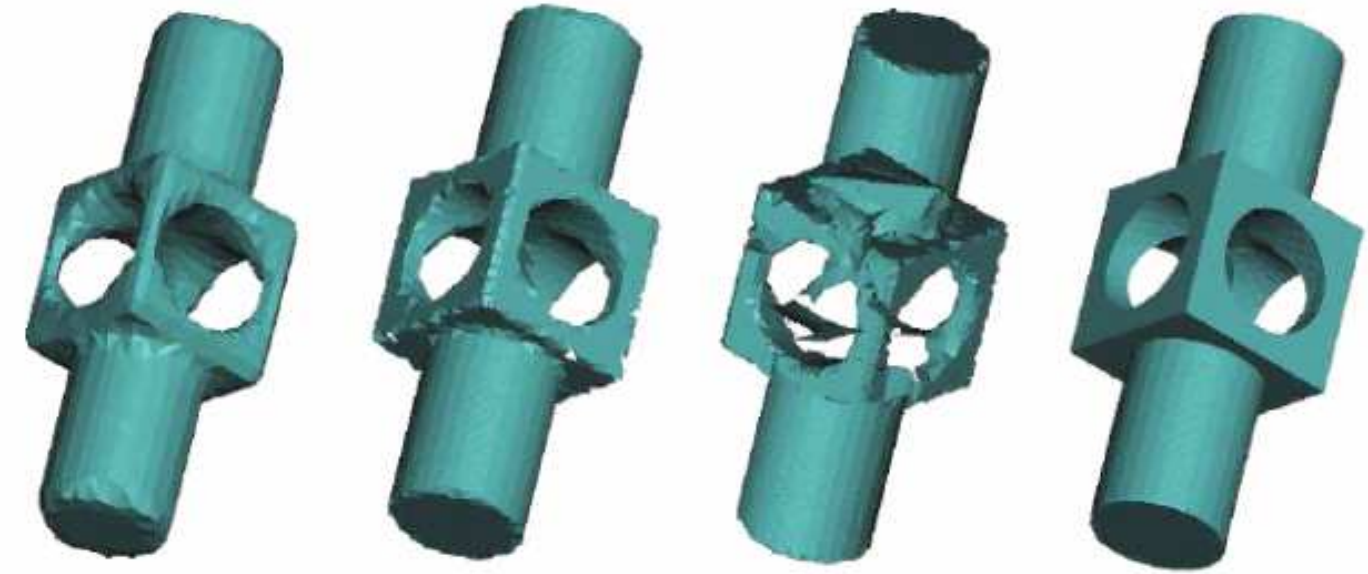
最短距离

最小面积

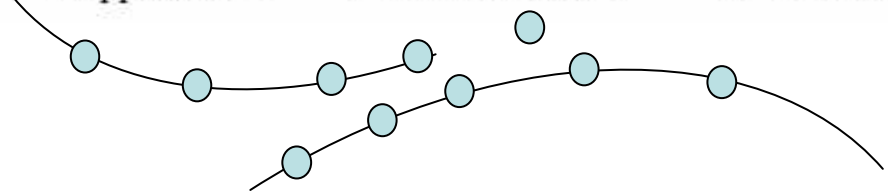
2）保证拓扑完整性

Advancing fronts

- 问题：不光滑的特征（尖锐特征磨光），邻接的曲面片



a Hoppe算法[4]　b Cocone算法[1]　c IPD算法[13]　d 本文算法



分片驱动的特征敏感的曲面重建

- 创新点：

分片驱动：重建每个光滑区域，而不是将整个曲面看成一个光滑曲面

特征敏感：在分片相遇处进行特征检测和求交，恢复尖锐特征。

两者的组合使用使算法更健壮，可以处理带尖锐特征的或不均匀采样的曲面

分片驱动的特征敏感的曲面重建

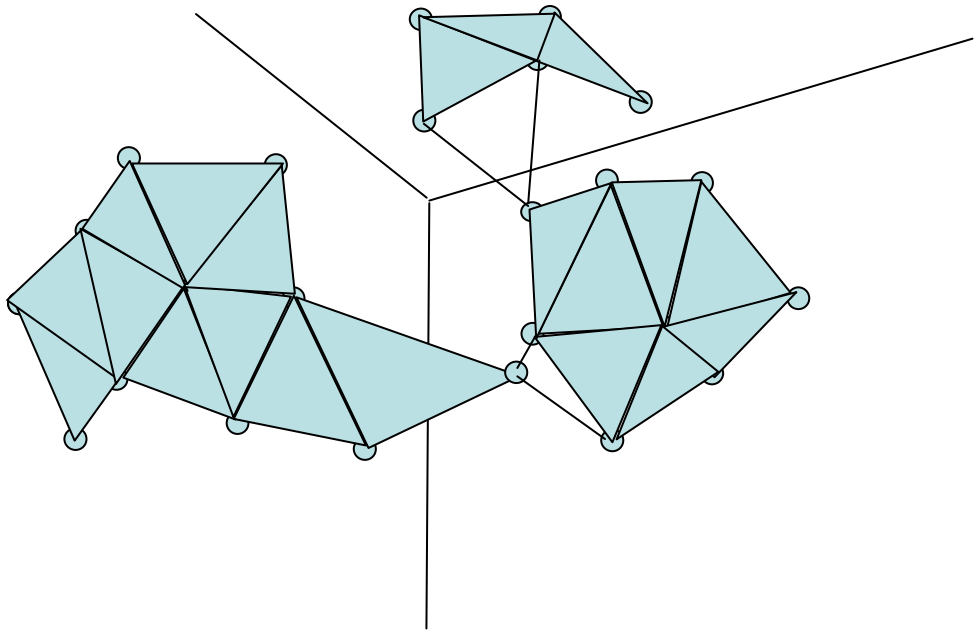
- 分片驱动：

  从光滑的种子出发，扩展边界，不破坏光滑性。该过程不管重复直到找不到可以扩展的光滑区域

  传统的Advancing front只从一个种子出发，我们则从多个种子出发。

a.二面角超过阀值

b. 接触到其他分片，且接触处不光滑

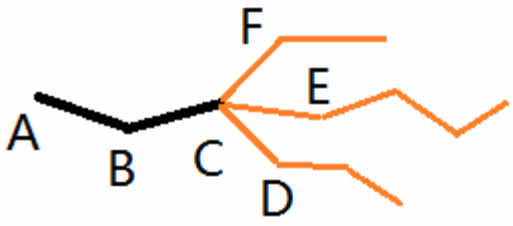


分片驱动的特征敏感的曲面重建

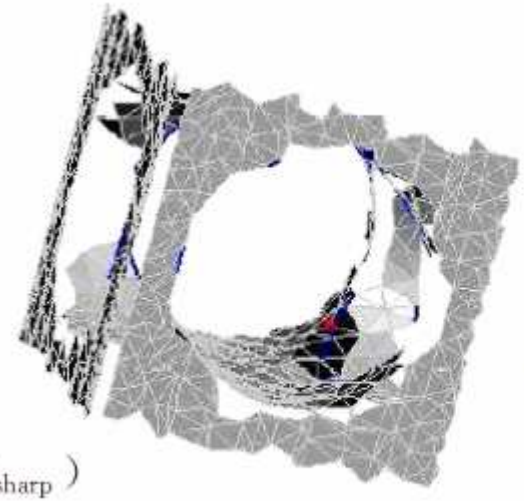
- 特征敏感：

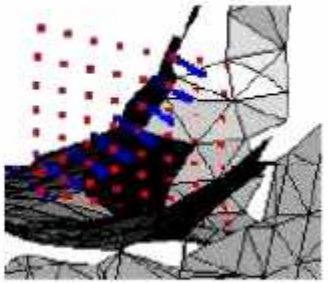
  在多个分片接触处进行特征求交，将顶点重定位到特征线上或插入新特征点。

  a) 特征跟踪和检测[LPR*02] b) 特征求交



2 个光滑阈值 $\theta_{feature}$ 和 θ_{sharp}（$\theta_{feature} > \theta_{sharp}$）





某特征点的局部拟合曲面的离散采样

分片驱动的特征敏感的曲面重建

- 元素分类、特征跟踪和检测

1）检测不光滑内边（二面角>2*分片的平均二面角

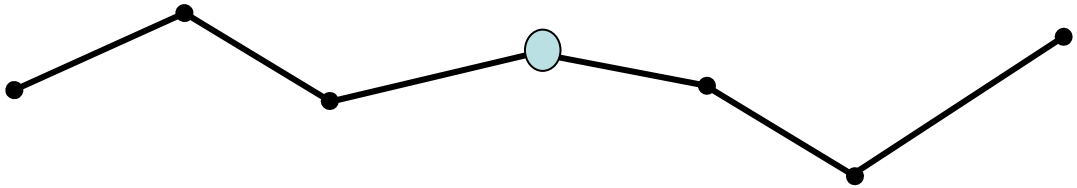
2）网格元素的分类（光滑或非光滑）和 特征跟踪

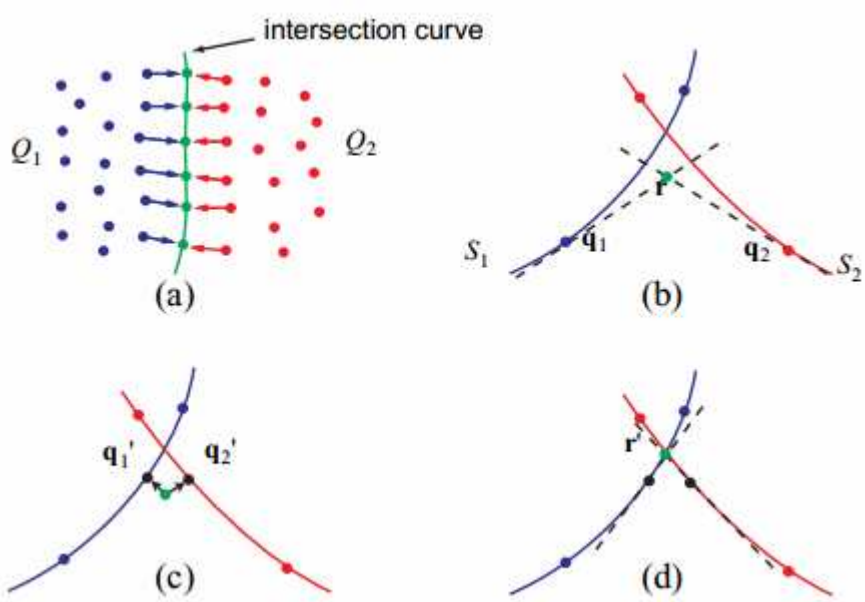
$\alpha_{feature} > \alpha_{sharp}$

分片驱动的特征敏感的曲面重建

- 特征求交

  从特征跟踪线中间开始特征求交





PKK*02

分片驱动的特征敏感的曲面重建

- 算法过程

while(存在光滑种子点){

种子三角化；

光滑分片扩展segment smooth advancing front

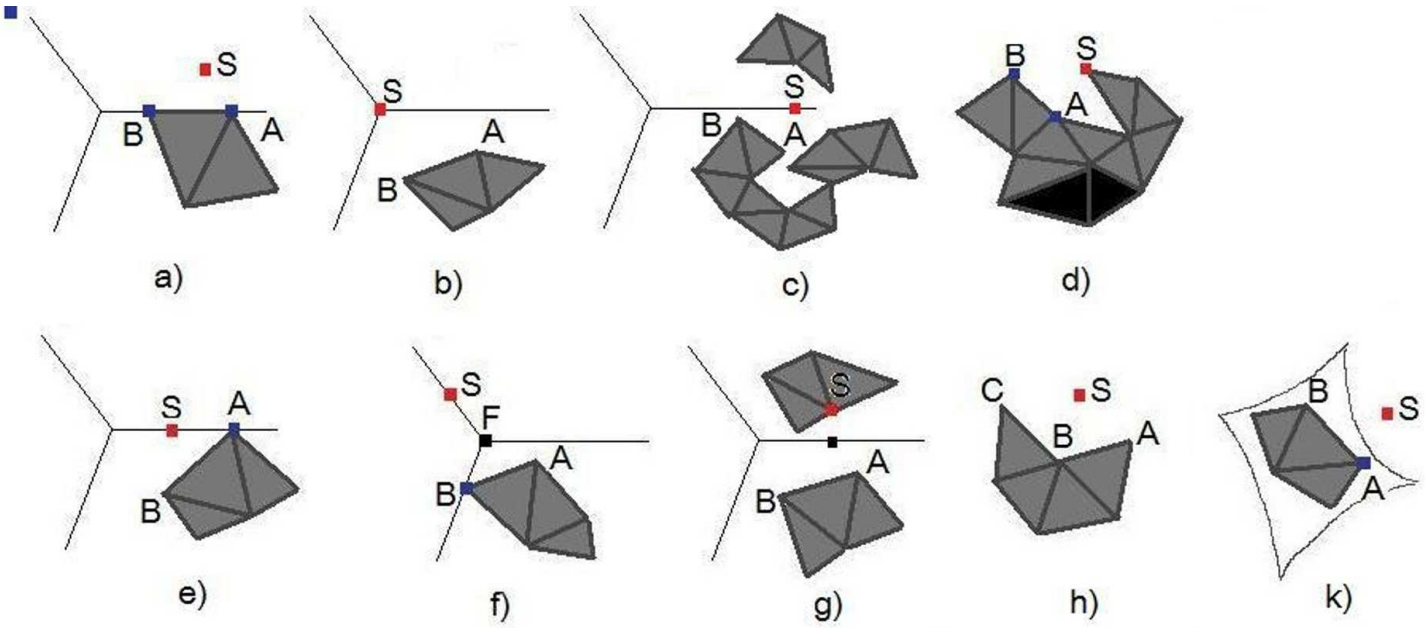
特征敏感分片扩展 segment feature sensitive advancing front

}

Global feature sensitive advancing front

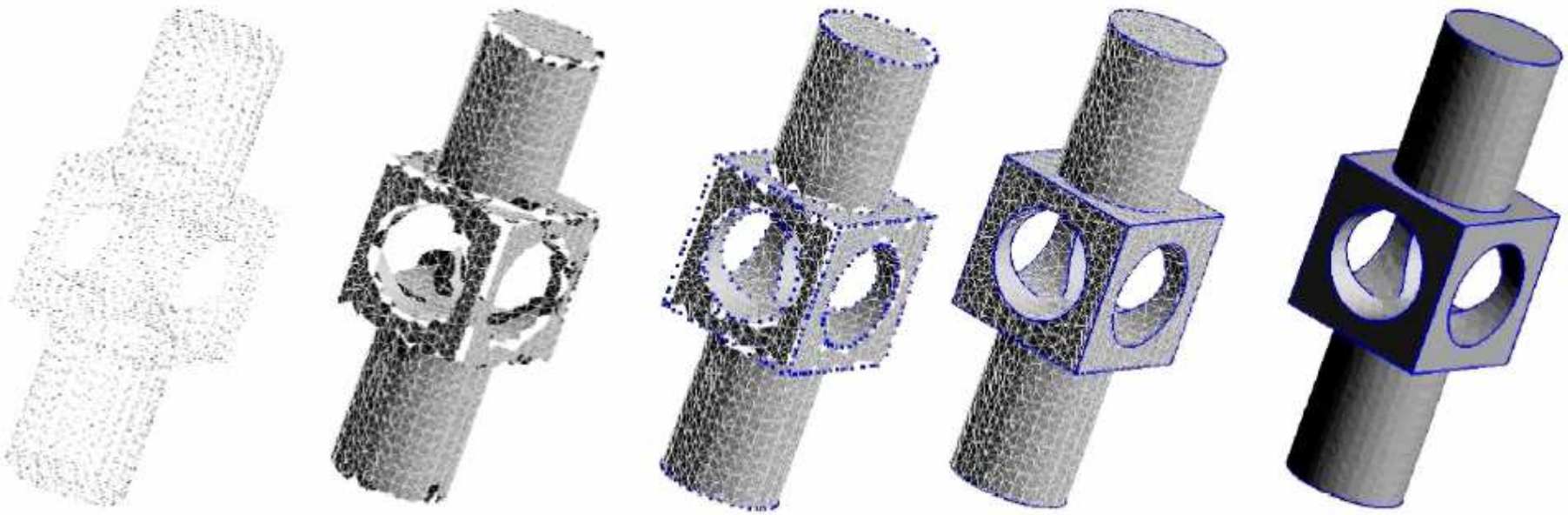
分片驱动的特征敏感的曲面重建

- 光滑分片扩展:二面角阀值控制，张角最大优先
- 特征分片扩展：分片误差控制，多种不同优先情形



分片驱动的特征敏感的曲面重建

- 示例

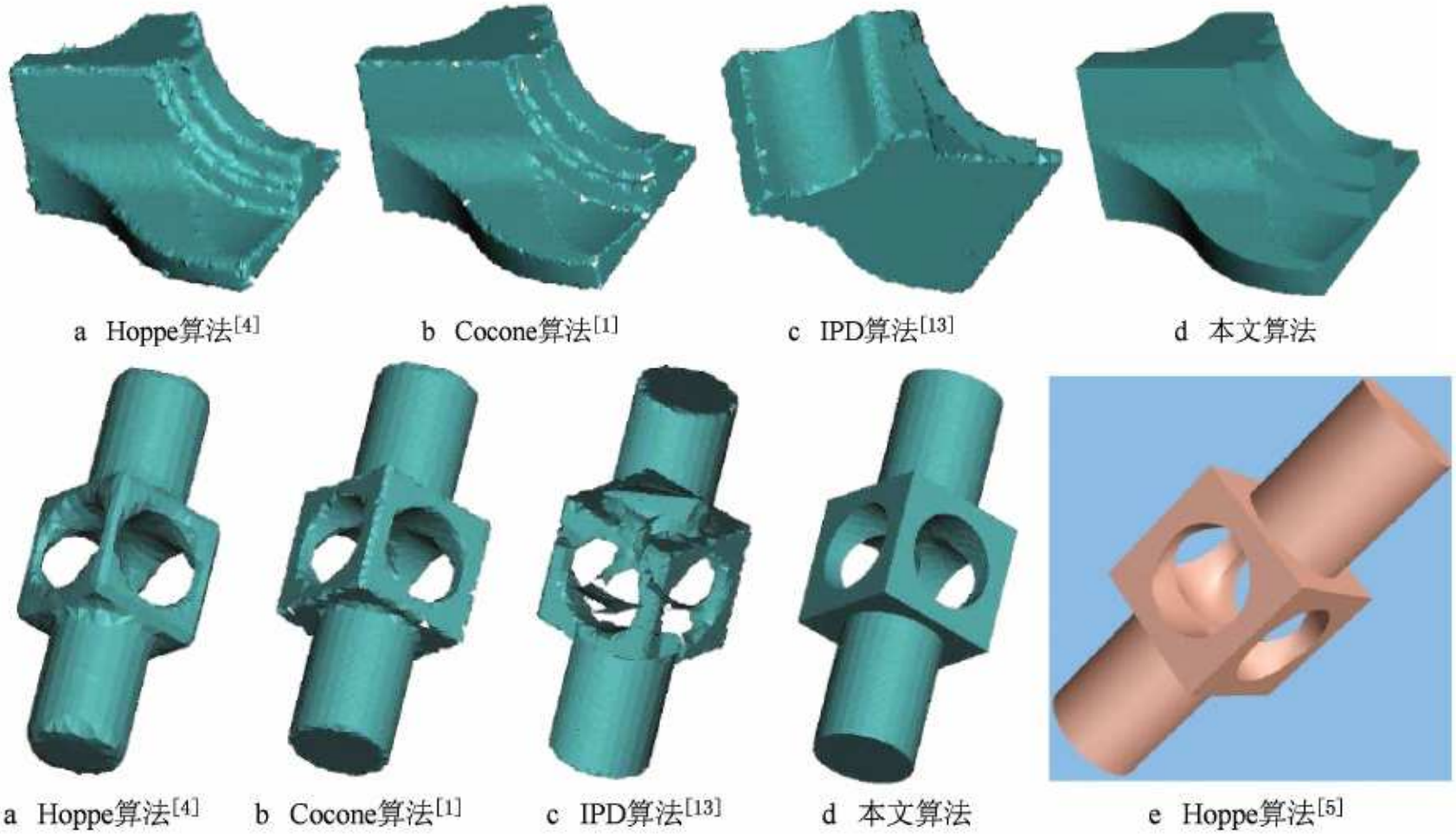


a 点集模型　　b 未边界光顺和特征求交的分片结果　　c 完整的分片重建结果　　d 最后的重建结果

图 5　Mechaprt 模型的曲面重建

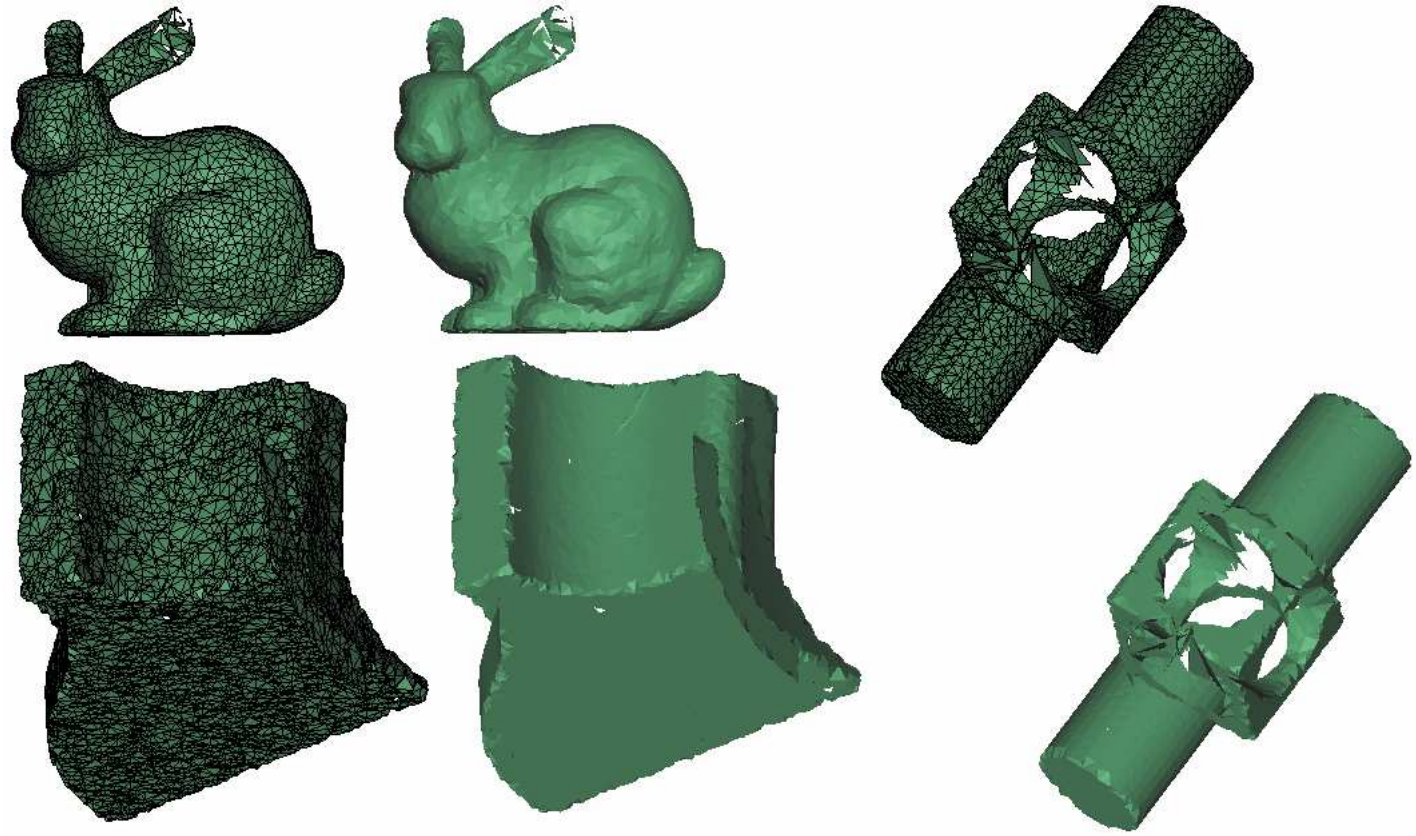
分片驱动的特征敏感的曲面重建

- 比较



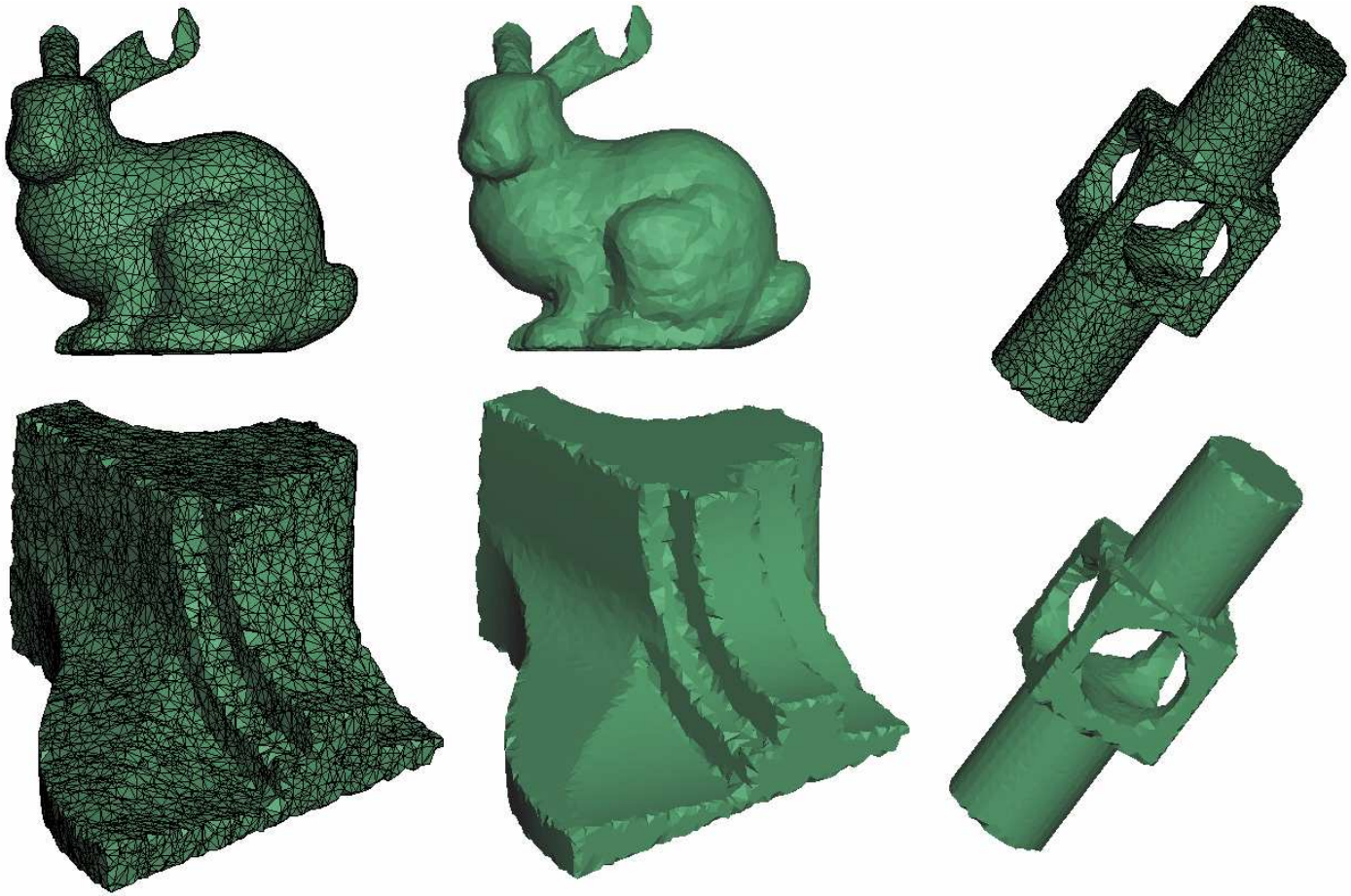
分片驱动的特征敏感的曲面重建

- 比较: IPD



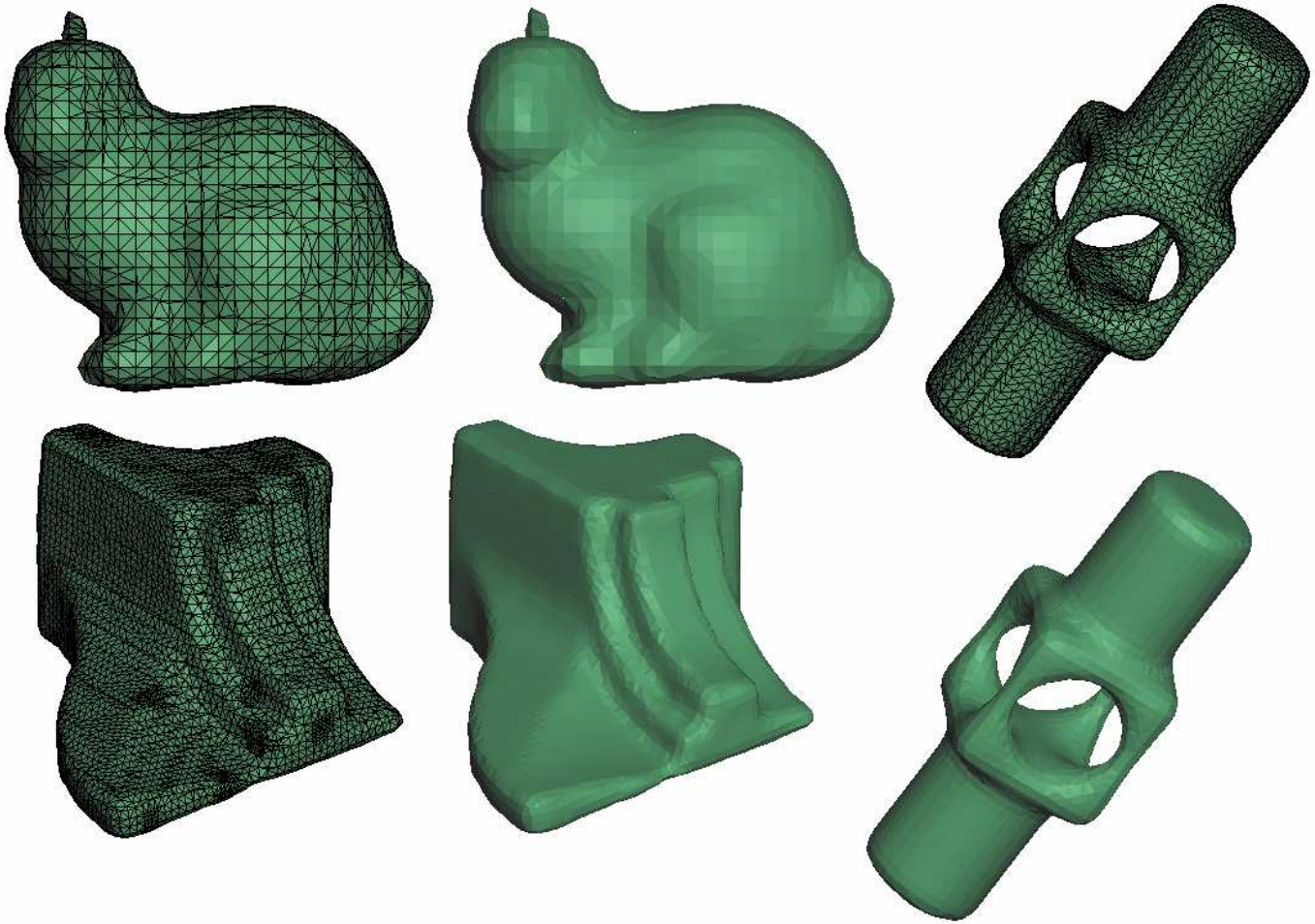
分片驱动的特征敏感的曲面重建

- 比较: levelpeeling



分片驱动的特征敏感的曲面重建

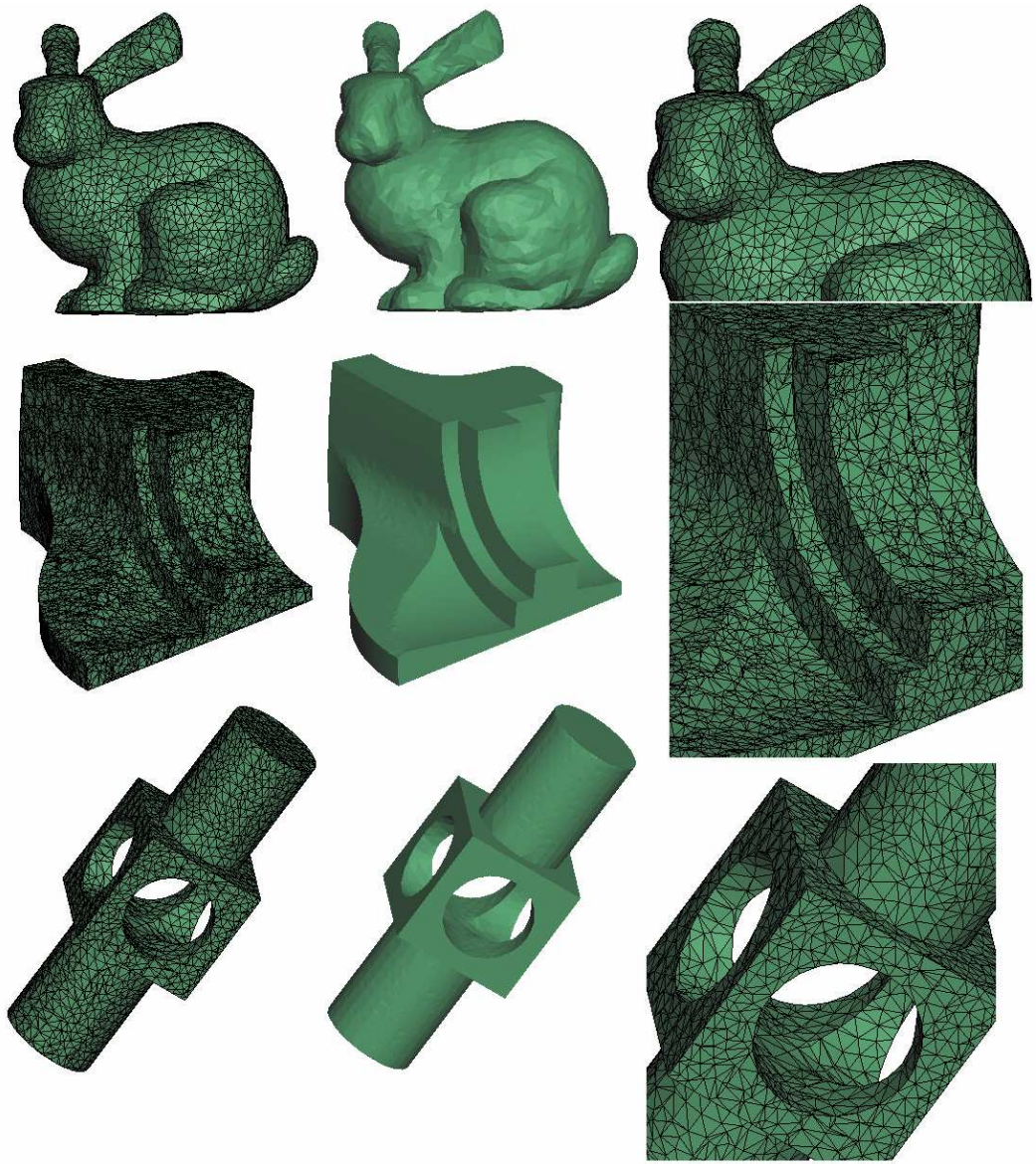
- 比较: poisson



分片驱动的特征敏感的曲面重建

- 比较:

ours



分片驱动的特征敏感的曲面重建

- 分片扩展：因为针对是光滑区域，所以无需进行拓扑完整性检查。速度快
- 特征求交：需要进行曲面拟合、MLS投影等，稍微费时。好在数量少。

表 1　本文算法对测试模型的运行结果

点云模型	点数	分片数	顶点数	特征点数	三角形数	分片重建时间/s	缝合重建时间/s
Mechpart	4 102	13	4 300	573	8 619	0.176 608	0.324 223
Fandisk	10 000	12	10 230	834	20 445	0.467 8	0.483 614
Bunny	2 503	6	2 527	280	5 050	0.099 304 3	0.124 142
Smooth-feature	1 433	6	1 608	204	3 212	0.053 231 8	0.103 343
Mannequin	11 703	2	11 695	264	23 371	0.429 751	0.141 42
Dino	56 307	1	56 302	0	112 599	2.595 22	0.087 209 9

分片驱动的特征敏感的曲面重建

- 有待改进：

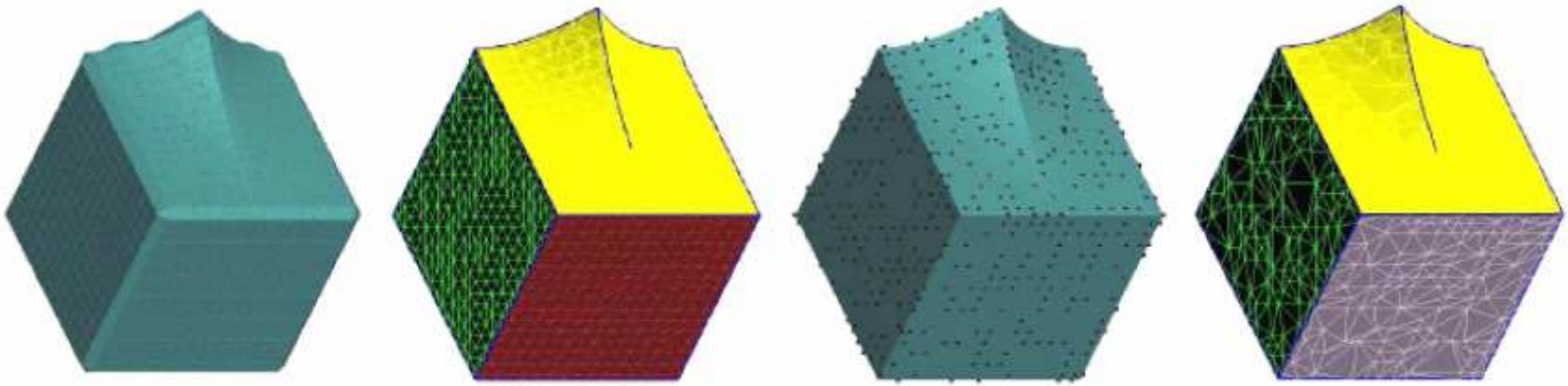
  1）小分片的特征检测与求交

  2）特征曲线的光滑性

分片驱动的特征敏感的曲面重建

- 有待改进：
  1）小分片的特征检测与求交
  2）特征曲线的光滑性

光滑的工程倒角反而被尖锐掉了！



a 原始模型　b 从a中点集的重建结果　c 对b模型随机采样点集　d 对c点集重建结果

三维重建

三维信息获取

从散乱点集重建曲面

从几幅图像重建三维人脸

江南大学 董洪伟

从多幅图像的三维人脸重建

- 基于立体视觉（多视几何）原理,主要有两类：

  1. 散乱数据插值变形重建：用SFM恢复稀疏语义点对模板人脸

  2. 基于稠密立体匹配：如基于窗口的立体匹配、Graph Cut 。立体相机已经普遍了。
- 参数化模型拟合：Morphable Model
- 基于光度立体

从多幅图像的三维人脸重建

Synthesizing Realistic Facial Expressions from Photographs, 1998

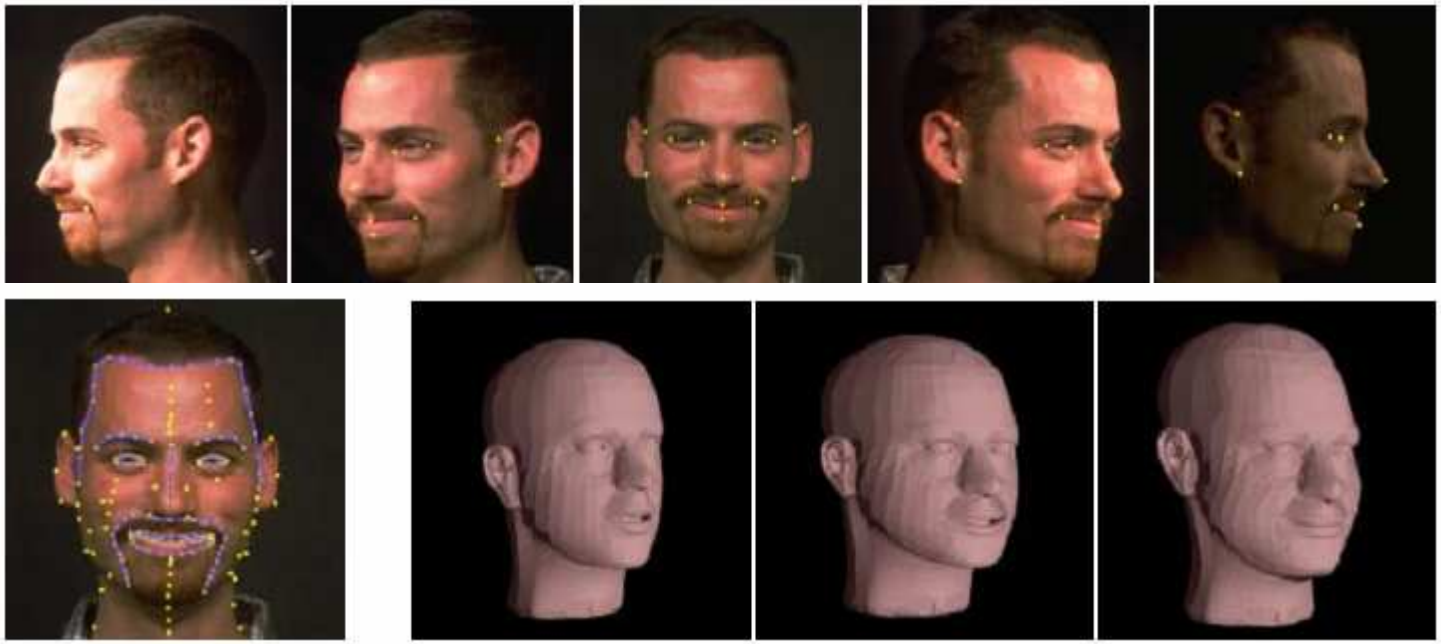
F. Pighin, J. Hecker, D. Lischinski, R. Szeliski, and D. Salesin

- 散乱数据插值变形重建

1）在从不同角度拍摄图像上手工指定足够多的语义点

2）SFM确定相机参数和稀疏点三维坐标

3）模板的插值变形



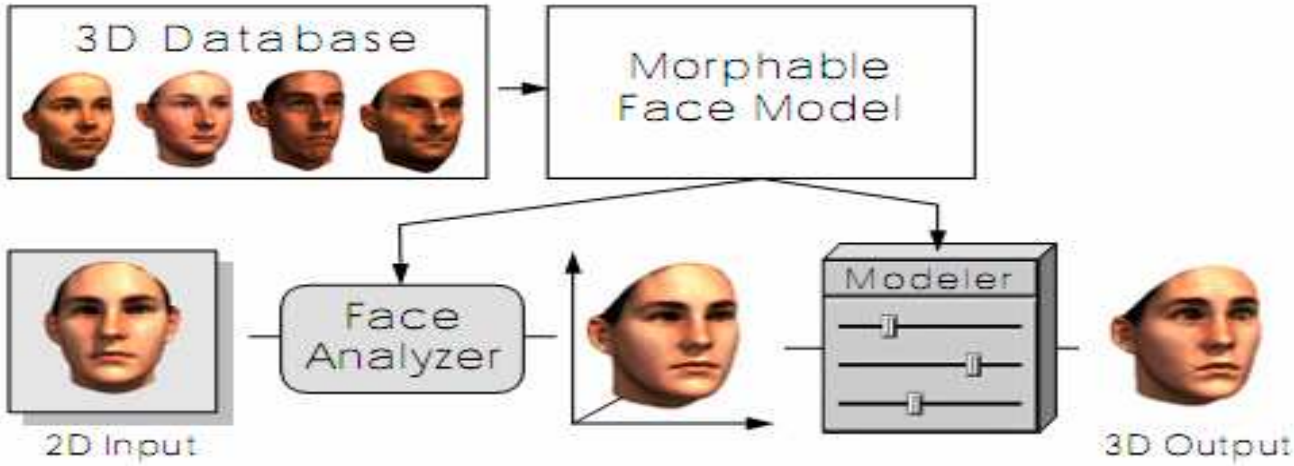
从多幅图像的三维人脸重建

A Morphable Model For The Synthesis Of 3D Faces, 1999 V. Blanz and T. Vetter

- Morphable face Model

1）从配准好的数据库学习一个Morphable Model

2）将参数化人脸投影拟合到输入的一幅（或多幅）图像上，得到模型参数。



2010. 刘利刚等采用类似方法：参数化人体模型拟合图像轮廓，对人体图像进行变形

从多幅图像的三维人脸重建

High Resolution Passive Facial Performance Capture.2010. Bradley D., Heidrich W., Popa T., et al.

- 立体匹配

  1）14个相机两两配对构成7个双目立体对, 9个LED发光板装置（每个发光板由192个LED组成）形成均匀光照

  2）双目立体匹配计算深度数据。

Figure 1: *High resolution passive facial performance capture. From left to right: Acquisition setup; one reference frame; the reconstructed geometry (1 million polygons); final textured result; and two different frames.*

从多幅图像的三维人脸重建

High-Quality Single-Shot Capture of Facial Geometry.2010. T. Beeler, B. Bickel, P. Beardsley, R. Sumner, M. Gross.

- 立体匹配
  1）立体匹配
  2）超分辨率分析superResolution

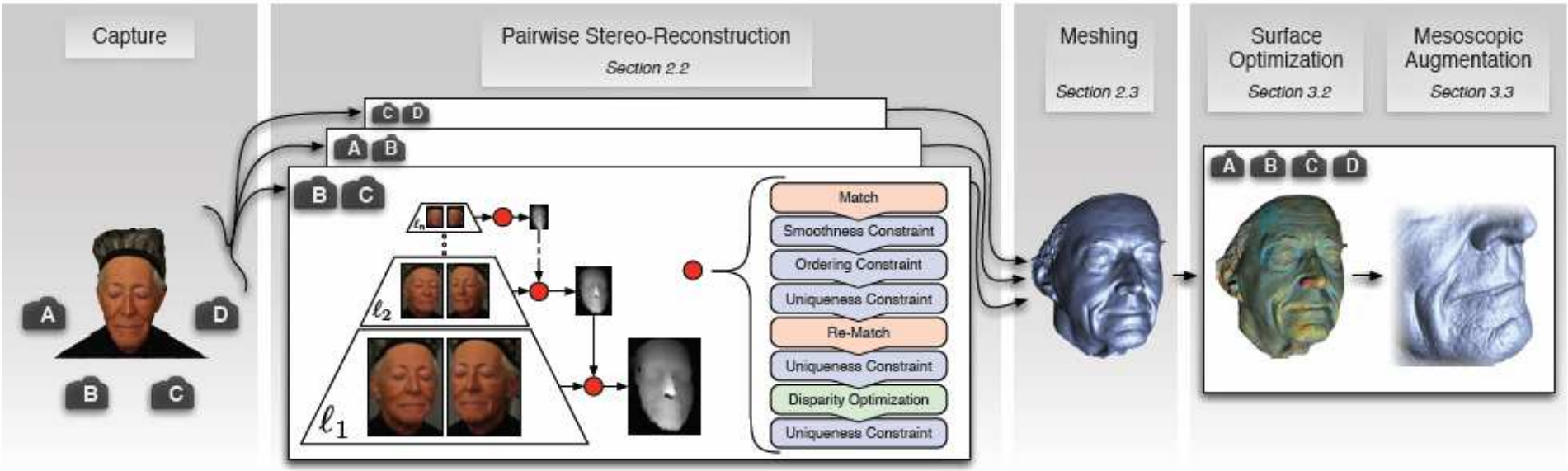
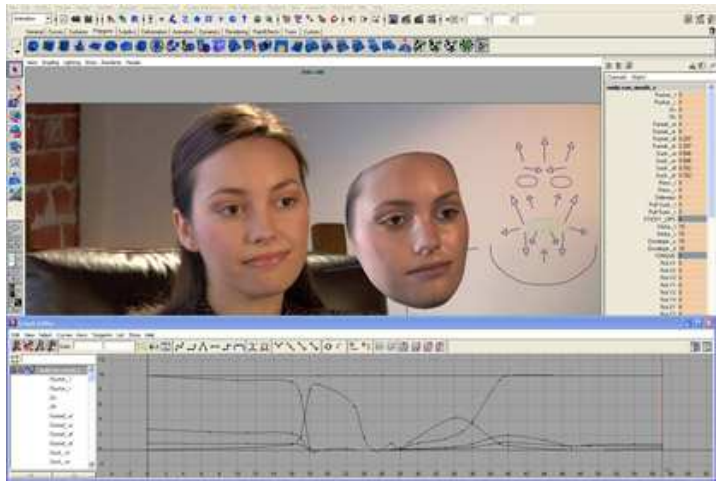


Figure 2: The proposed system - *The subject is captured with multiple cameras. This figure shows a four-camera setup, but the system can incorporate an arbitrary number of cameras.*

从多幅图像的三维人脸重建

The Digital Emily Project: Achieving a Photorealistic Digital Actor.2010. O. Alexander, M. Rogers, W. Lambeth, M. Chiang, W. Ma, C. Wang, P. Debevec.

- 光度立体：Digital Emily



从多幅图像的三维人脸重建

- 立体匹配的能量：

  $E = E_d + E_s$

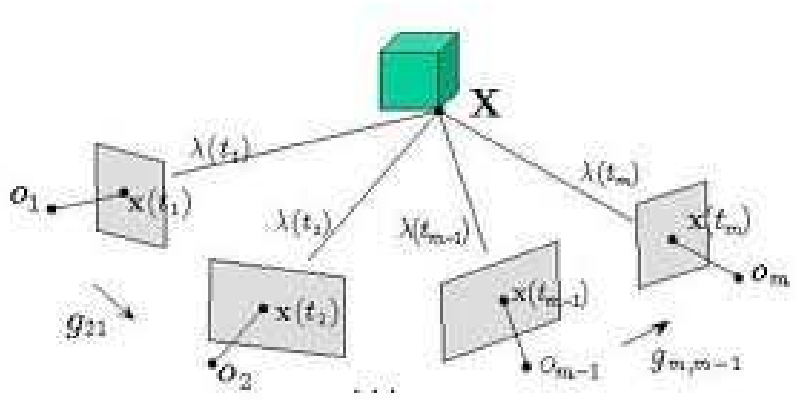
- 求解：普遍采用离散优化方法

从多幅图像的三维人脸重建

- 我们采用基于网格变形方法的连续优化技术求解下述类似能量：

$$\{\boldsymbol{x}_i\},\theta = argmin_{\{\boldsymbol{x}_i\},\theta}\sum_k\sum_{x\in M}\rho(I(\boldsymbol{g}_k(\boldsymbol{p}(\boldsymbol{x}),\theta))-I(\boldsymbol{g}_{C(k)}(\boldsymbol{p}(\boldsymbol{x}),\theta)))$$

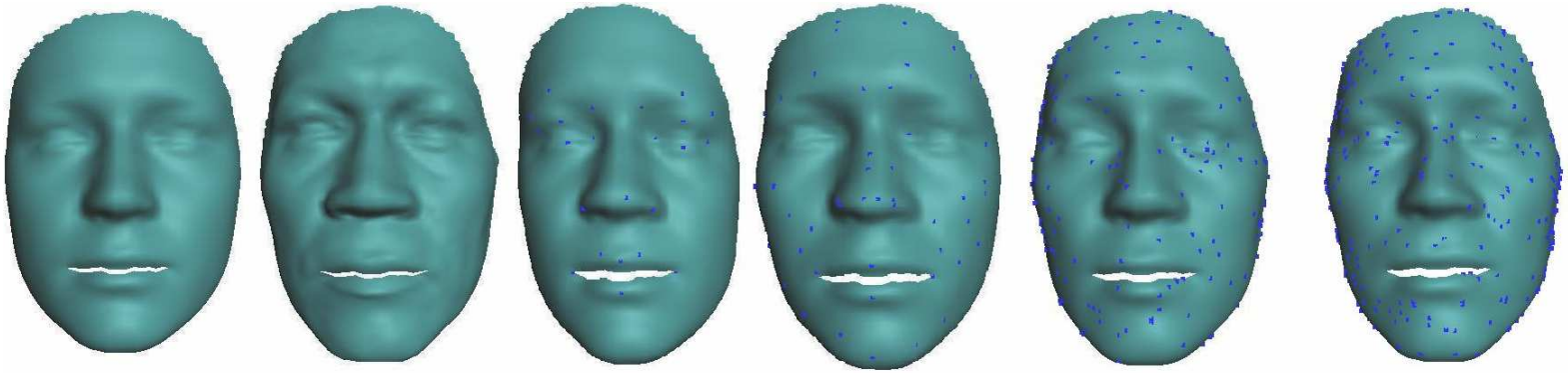
$$+\alpha\sum_{i=1}^{m}\left\|L(\boldsymbol{x}_i)-L(\boldsymbol{x}_i')\right\|^2$$



从多幅图像的三维人脸重建

- 基于位置约束的Lalancian变形

$$\{\boldsymbol{x}_i\} = argmin_{\boldsymbol{x}_i} \sum_{i=1}^{N} \left\| L(\boldsymbol{x}_i) - \boldsymbol{\delta}_i' \right\|^2 + \lambda \sum_{i=1}^{m} \left\| \boldsymbol{x}_i - \boldsymbol{p}_i \right\|^2$$



a 模板人脸　b 目标人脸　c 23个位置约束　d 46个位置约束　e 150个位置约束　f 250个位置约束

基于位置约束的Lapalcian网格变形

从多幅图像的三维人脸重建

- 图像一致性约束可以提供足够多的方程

$$D(\boldsymbol{p},\theta)=\sum_{k}\sum_{p\in M}\left\|I(\boldsymbol{g}_{k}(\boldsymbol{p}(\boldsymbol{x}),\theta))-I(\boldsymbol{g}_{C(k)}(\boldsymbol{p}(\boldsymbol{x}),\theta))\right\|^{2}$$

从多幅图像的三维人脸重建

- 算法

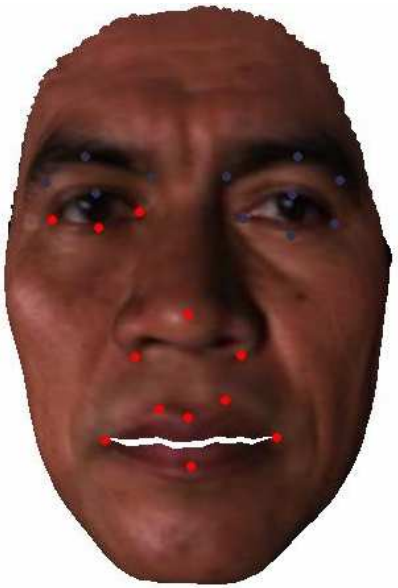
```
int IterN = 0;   //目标函数求解次数
计算人脸模板的Lapalcian坐标
while(IterN <3){
    计算变形人脸模型上三角形的可见性；
    旋转Lapalcian坐标；
    do{
        固定全局变换，应用Levenberg-Marquardt算法求解顶点坐标；
        固定顶点坐标，应用Levenberg-Marquardt算法求解全局变换参数；
    }while(未收敛或达到最大迭代数)；
    应用Levenberg-Marquardt算法同时求解顶点坐标和全局参数；
    IterN++;
}
```

从多幅图像的三维人脸重建

- 相机外部参数

  手工指定或基于AAM检测语义点

  用SFM（ structure fro motion ）方法求解语义点的三维坐标和相机外部参数：基于模板的SFM更可靠



根据正面图像特征点选择合适的人脸模板

迭代求解{

1) 求相机参数

2）求语义点

}

从多幅图像的三维人脸重建

- 计算变形人脸模型上三角形的可见性

  将当前的人脸模板投影到每幅图像的投影平面上确定可见区域

- 迭代更新模型顶点和相机参数直到收敛或达到最大指定迭代数

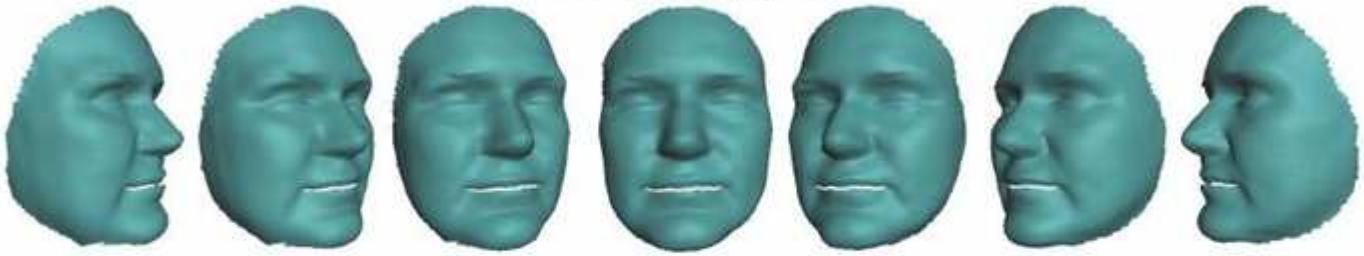
  3-4次外部迭代，内部迭代10-15次基本收敛-共30-60次

  总时间10秒左右。

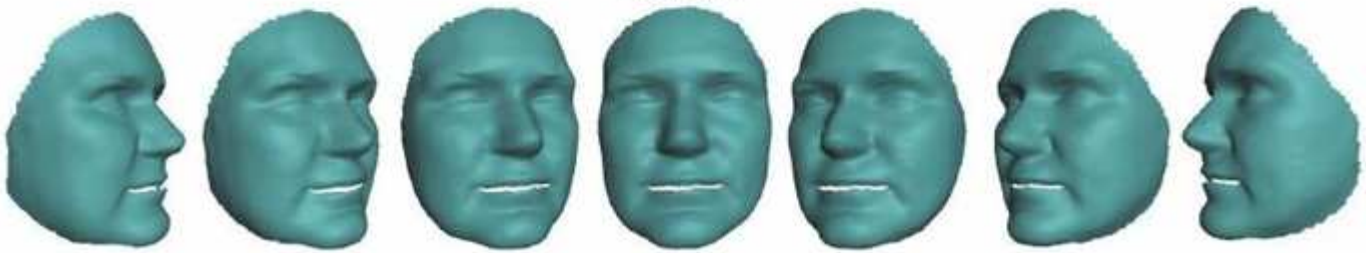
从多幅图像的三维人脸重建

- 基于模板人脸的网格变形优化重建

a 7个不同角度输入图像



b 真正模型



c 重建结果

从多幅图像的三维人脸重建

- 基于模板人脸的网格变形优化重建

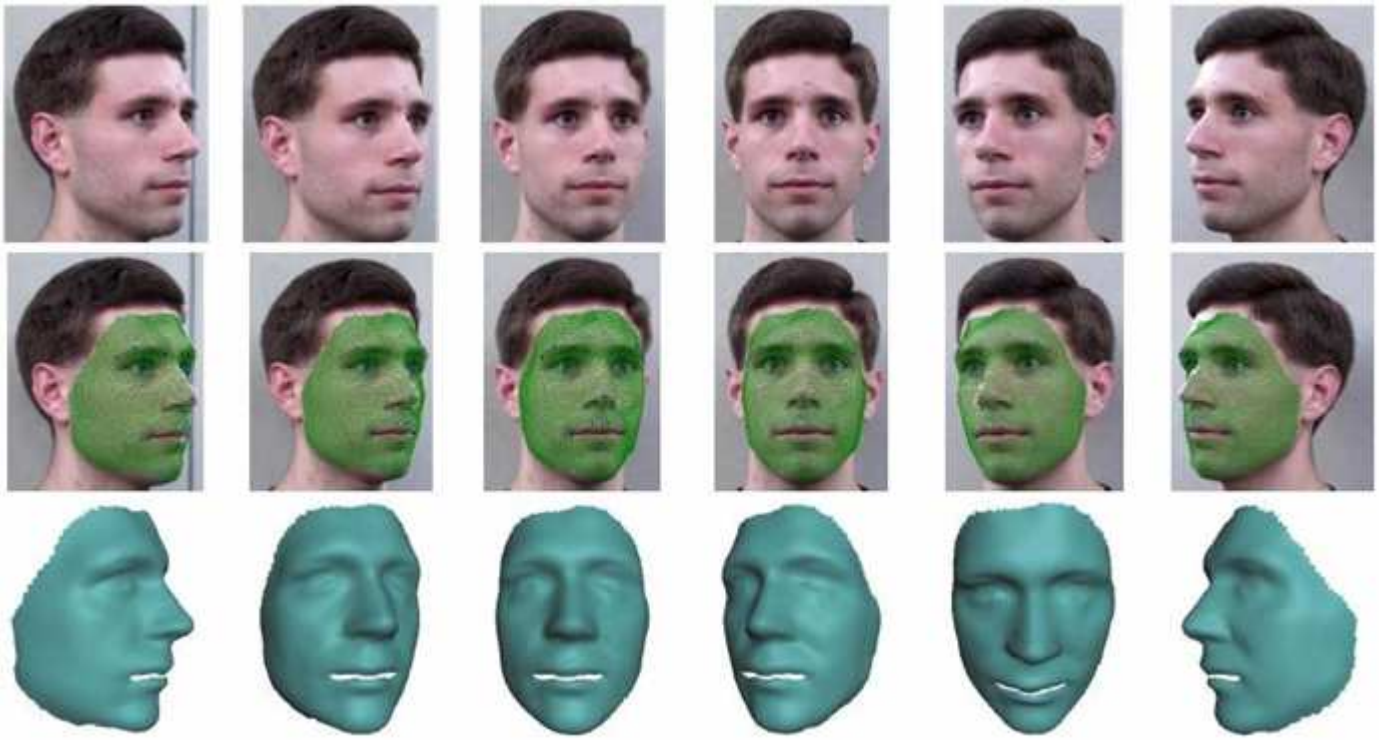
d 7个不同角度输入图像

e 真正模型

f 重建结果

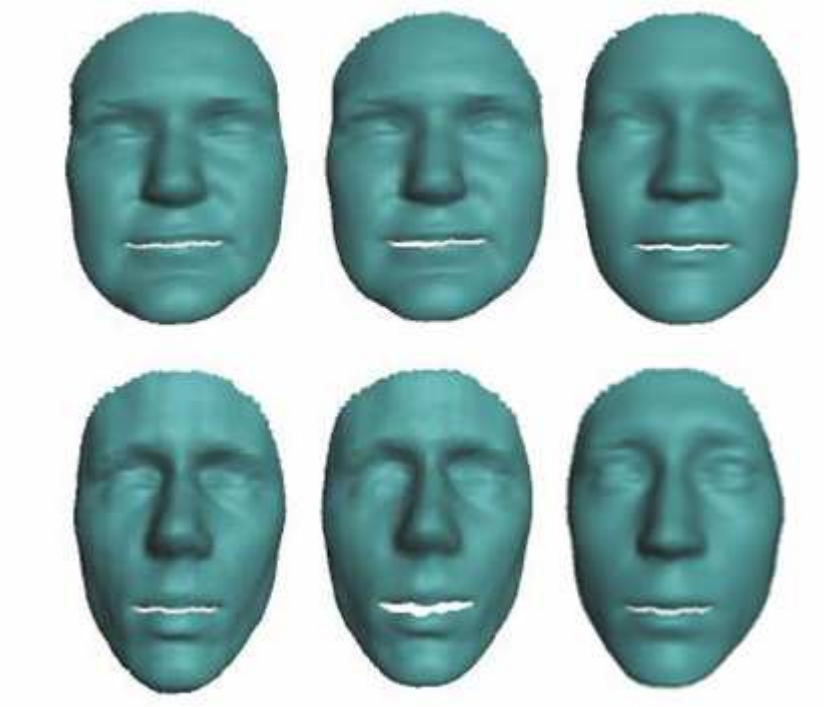
从多幅图像的三维人脸重建

- 真实照片



从多幅图像的三维人脸重建

- 与Morphable model（PCA）方法的比较



a 真正的模型　b 本文算法　c 可形变算法

中性人脸模型的两个内眼角的距离为91.4488，可形变重建方法对于其中的女性和男性模型的重建平均绝对误差分别为1.58563和0.986905；

本文方法对于其中的女性和男性模型的重建平均绝对误差分别为0.10653和0.165893

从多幅图像的三维人脸重建

- 特点：

  1) 不需要进行立体匹配，因此不需要对图像Rectif

  2) 基于模板的变形

  3 连续优化，不同于立体匹配或图割

- 缺点：需要模板，但不需要基于数据库的参数化模板

从多幅图像的三维人脸重建

- 更准确的相机参数估计？
- 宽基线图像角度过大，角度小一些结果是否更好？
- 结合其他约束(constrains)如:特征点、轮廓等，甚至统计模型Proir？

Will be better

Future work

- 三维(获取)重建的自动、并行与实时[KinectFussion]、带外
- 从大规模网络相片的三维重建[Photo Tourism]、树木花草的重建[深圳先进技术研究院] …
- 三维人脸：捕获、重建、合成、动画、编辑、传输…
- 三维人脸的难点：高精度细节、眼睛、嘴
- …