Course Content Questions (课程内容问题)

Question 1: Mesh Data Structures

EN: Compare face-based and halfedge data structures for triangle meshes. Why is the halfedge structure advantageous for many geometry processing operations?

CN: 比较三角网格的面基础结构和半边数据结构。为什么半边结构在许多几何处理操作中具有优势?

Answer Keywords:

- **Face-based structure** (面基础结构): **simple** implementation, **memory-efficient**, **limited adjacency** information
- **Halfedge structure** (半边结构): splits each edge into **directed halfedges**, stores **origin vertex**, **face**, **next halfedge**, and **opposite halfedge**
- **Advantages** (优势): **efficient traversal** (one-ring neighborhood), **complete adjacency** information, **convenient for mesh operations** (edge flips, vertex splits)
- **Applications** (应用): essential for operations requiring **neighborhood information**, like **remeshing** and **subdivision**

Question 2: Differential Geometry of Surfaces

EN: What is the first fundamental form in differential geometry and why is it important for geometry processing?

CN: 微分几何中的第一基本形式是什么，为什么它对几何处理很重要?

Answer Keywords:

- **First fundamental form** (第一基本形式): **quadratic form** that measures **surface metric**
- **Coefficients** (系数): **E, F, G** that capture parameterization distortion
- **Mathematical expression** (数学表达): $ds^2 = Edu^2 + 2Fdudv + Gdv^2$
- **Enables** (实现): computing **lengths**, **angles**, and **areas** on the surface
- **Represents** (表示): the **intrinsic geometry** (independent of embedding)
- **Applications** (应用): **texture mapping**, **parameterization**, **isometric mappings**

Question 3: Laplace-Beltrami Operator

EN: Describe how the spectral analysis of the Laplace-Beltrami operator can be used for shape processing.

CN: 描述Laplace-Beltrami算子的谱分析如何用于形状处理。

Answer Keywords:

- **Spectral analysis** (谱分析): similar to **Fourier analysis** for signals
- **Eigendecomposition** (特征分解): produces **eigenfunctions** and **eigenvalues**
- **Frequency interpretation** (频率解释): **low eigenvalues** capture **global shape**, **high eigenvalues** capture **details**
- **Applications** (应用): **shape filtering**, **comparison**, **segmentation**, **compression**
- **Multi-scale** (多尺度): provides resolution hierarchy of shape representation

- **Shape-dependent** (形状依赖): each shape has unique basis functions

Question 4: Surface Curvature

EN: Describe a shape that has positive Gaussian curvature but negative mean curvature. How is this possible geometrically?

CN: 描述一个具有正高斯曲率但负平均曲率的形状。从几何上这是如何可能的?

Answer Keywords:

- **Gaussian curvature** (高斯曲率): $K = \kappa_1\kappa_2$ (product of principal curvatures)
- **Mean curvature** (平均曲率): $H = (\kappa_1+\kappa_2)/2$ (average of principal curvatures)
- **Possible when** (可能情况): both principal curvatures are **negative**
- **Example** (例子): **inner surface of a sphere**, where curvatures bend away from normal
- **Geometric meaning** (几何意义): locally **elliptic** but curving in the **opposite direction** of the normal
- **Visual description** (视觉描述): surface that is **concave** while maintaining **elliptical behavior**

Question 5: Marching Cubes Algorithm

EN: Explain how the Marching Cubes algorithm works to extract a mesh from an implicit function. What are its strengths and weaknesses?

CN: 解释Marching Cubes算法如何从隐式函数中提取网格。它有哪些优势和弱点?

Answer Keywords:

- **Purpose** (目的): extract **triangular mesh** from **implicit function**
- **Steps** (步骤): **discretize** space, **evaluate** at vertices, determine **inside/outside** configuration, calculate **intersection points**, create **triangles** using lookup table
- **Strengths** (优势): **robust**, **simple** to implement, creates **watertight meshes**, **parallelizable**
- **Weaknesses** (弱点): **loses sharp features**, produces **poor triangle quality**, **uniform sampling** inefficiency
- **Improvements** (改进): Extended Marching Cubes, Dual Contouring

Question 6: Surface Parameterization

EN: Compare and contrast different types of surface parameterization methods and their application scenarios.

CN: 比较和对比不同类型的曲面参数化方法及其应用场景。

Answer Keywords:

- **Conformal** (保角): preserves **angles**, applications in **texture mapping**
- **Equiareal** (等面积): preserves **areas**, useful for **uniform sampling**
- **Isometric** (等距): preserves **distances**, only possible for **developable surfaces**
- **Boundary methods** (边界方法): **fixed boundary** vs **free boundary**
- **Optimization approaches** (优化方法): **energy minimization** vs **direct feature optimization**

- **Selection factors** (选择因素): model **complexity**, **distortion tolerance**, **computational resources**

Question 7: Mesh Deformation

EN: Compare surface-based deformation and space-based deformation methods. What are their respective advantages and limitations?

CN: 比较基于表面的变形和基于空间的变形方法。它们各自的优势和局限性是什么?

Answer Keywords:

- **Surface-based** (基于表面): works directly on **mesh vertices**
- **Space-based** (基于空间): deforms the **embedding space**
- **Surface advantages** (表面优势): **precise local control**, better **detail preservation**
- **Space advantages** (空间优势): **independent of mesh complexity**, can deform **multiple objects**
- **Surface limitations** (表面局限): complexity scales with **mesh size**, potential for **unintuitive results**
- **Space limitations** (空间局限): less **precise control**, potential for **unwanted distortion**

Assignment-Related Questions (作业相关问题)

Question 8: ICP Algorithm (CW1)

EN: Explain the ICP (Iterative Closest Point) algorithm for point cloud registration. What are its main steps and limitations?

CN: 解释用于点云配准的ICP（迭代最近点）算法。它的主要步骤和限制是什么?

Answer Keywords:

- **Purpose** (目的): **align two point clouds** (source to target)
- **Main steps** (主要步骤): **point selection**, **finding correspondences**, **rejecting bad pairs**, **computing transformation** (using SVD), **iterative refinement**
- **Limitations** (限制): requires **good initial alignment**, can get stuck in **local minima**, struggles with **partial overlaps**, **sensitive to outliers**
- **Variants** (变体): **point-to-point** vs **point-to-plane** ICP, **weighted** approaches

Question 9: Point Cloud Registration Implementation (CW1)

EN: In CW1, how did you implement point cloud registration? Discuss your method choices and main challenges.

CN: 在CW1中，你如何实现点云配准？讨论你的方法选择和主要挑战。

Answer Keywords:

- **Preprocessing** (预处理): **normal estimation**, **voxel downsampling**, **feature computation**
- **Initial alignment** (初始对齐): **feature matching** or **manual alignment**
- **Fine registration** (精细配准): **point-to-point** and **point-to-plane** variants, **k-d tree** for search
- **Refinement** (优化): **correspondence filtering**, **iterative weighting**, **termination criteria**

- **Challenges** (挑战): **partial overlap**, **local minima**, **computational efficiency**, **parameter tuning**

Question 10: Normal Estimation (CW1)

EN: Describe the method you used for point cloud normal estimation in CW1. What parameters did you choose and why?

CN: 描述你在CW1中用于点云法线估计的方法。你选择了哪些参数，为什么？

Answer Keywords:

- **Method** (方法): **PCA-based** normal estimation
- **Neighborhood** (邻域): **k-nearest neighbors** or **fixed radius** search
- **Parameter selection** (参数选择): balancing **noise robustness** vs **detail preservation**
- **Orientation** (方向): ensuring **consistent orientation** using **viewpoint** or **propagation**
- **Challenges** (挑战): handling **sparse regions**, dealing with **sharp features**, managing **boundary effects**

Question 11: Discrete Curvature Computation (CW2)

EN: Explain how you calculated discrete Gaussian and mean curvature on meshes in CW2. What are the key differences between uniform and cotangent weighting schemes?

CN: 解释你在CW2中如何计算网格上的离散高斯曲率和平均曲率。均匀权重和余切权重方案有什么主要区别？

Answer Keywords:

- **Gaussian curvature** (高斯曲率): **angle deficit** formula (2π - sum of adjacent angles)/area
- **Mean curvature** (平均曲率): magnitude of **Laplace-Beltrami** operator applied to vertex positions
- **Uniform weights** (均匀权重): depend only on **connectivity**, simpler but less accurate
- **Cotangent weights** (余切权重): account for **mesh geometry**, more accurate but sensitive to **mesh quality**
- **Area normalization** (面积归一化): using **Voronoi**, **barycentric**, or **mixed** area schemes

Question 12: Laplacian Smoothing (CW2)

EN: Compare explicit and implicit Laplacian smoothing methods you implemented in CW2. What are their relative strengths and when would you choose one over the other?

CN: 比较你在CW2中实现的显式和隐式Laplacian平滑方法。它们各自的优势是什么，什么情况下你会选择其中一种而非另一种？

Answer Keywords:

- **Explicit smoothing** (显式平滑): $x' = x + \lambda\Delta x$, **simple** implementation, **local** updates
- **Implicit smoothing** (隐式平滑): $(I-\lambda\Delta)x' = x$, requires solving a **linear system**
- **Explicit advantages** (显式优势): **computational efficiency**, **easier implementation**
- **Implicit advantages** (隐式优势): **unconditional stability**, better **feature preservation**
- **Parameter effects** (参数效果): **step size** λ, number of **iterations**

- **Volume shrinkage** (体积收缩): both methods cause shrinkage, more pronounced in **explicit method**

Question 13: Spectral Mesh Analysis (CW2)

EN: Describe how you used spectral analysis of the Laplace-Beltrami operator in CW2. How does the number of eigenvectors affect reconstruction quality?

CN: 描述你在CW2中如何使用Laplace-Beltrami算子的谱分析。特征向量的数量如何影响重建质量?

Answer Keywords:

- **Implementation** (实现): computing **eigendecomposition** of the **discrete Laplacian** matrix
- **Reconstruction** (重建): representing coordinates as **linear combinations** of eigenvectors
- **Basis functions** (基函数): from **low frequency** (global shape) to **high frequency** (details)
- **Approximation quality** (近似质量): improves with **more eigenvectors** but with **diminishing returns**
- **Filtering effects** (过滤效果): using subset of eigenvectors performs implicit **smoothing**
- **Applications** (应用): **shape analysis**, **compression**, **feature detection**

Additional Important Topics (补充重要主题)

Here are a few more important topics that might be worth preparing for:

Remeshing Techniques

EN: Explain different approaches to remeshing and how you would choose between them for different applications.

CN: 解释重网格化的不同方法，以及你如何为不同应用选择它们。

Answer Keywords:

- **Parameterization-based** (基于参数化): works in **2D domain**, good for **global structure**
- **Direct 3D methods** (直接3D方法): works on **surface**, better for **high resolution**
- **Isotropic** (各向同性): uniform elements, useful for **simulation**
- **Anisotropic** (各向异性): elements follow **curvature directions**, efficient representation
- **Feature preservation** (特征保留): techniques to maintain **sharp features**
- **Application factors** (应用因素): numerical **stability** vs **accuracy** vs **efficiency**

Implicit vs. Explicit Surface Representations

EN: Compare implicit and explicit surface representations. What are their respective strengths and typical applications?

CN: 比较隐式和显式表面表示。它们各自的优势和典型应用是什么?

Answer Keywords:

- **Explicit** (显式): directly represents **surface points** (e.g., mesh, NURBS)
- **Implicit** (隐式): represents surface as **level set** of a function (e.g., SDF)
- **Explicit strengths** (显式优势): easy **point sampling**, direct **rendering**, easy **local editing**

- **Implicit strengths** (隐式优势): simple **inside/outside** tests, easy **boolean operations**, handles **topology changes**
- **Conversions** (转换): using **marching cubes** (implicit→explicit) or **distance functions** (explicit→implicit)
- **Applications** (应用): CAD (**explicit**), physical simulation (**implicit**), medical imaging (**implicit**)