You must answer all questions. For full credit, an answer must be both correct and well-presented (clear and concise). If you feel a question is ambiguous, state any assumptions that you need to make. Also, several of the questions are "essay" questions. For these, there are many correct answers. It is more important that you provide a good argument for the answers you give, than that you give the "most correct" answer. Sometimes, we are particularly looking for your ability to make a clear and concise argument based on things you are aware of, rather than to see if you can find the best possible answer, or have seen all possible research on the topic.

Question 1: The modern paper

You were asked to read the paper

"Structure-Aware Shape Processing",
by N. Mitra, M. Wand, H. Zhang, D. Cohen-Or, V. Kim and Q. Huang
(Eurographics 2013 State-of-the-art Reports, also in SIGGRAPH 2014 Courses)

Based on your analysis of this paper and any of its citations you have reviewed, but also using your general knowledge of the graphics principles in your reading list, answer the following questions:

1. There are several factors that inspired researchers to venture into this type of work. For example, there is the possibility of using structure-aware synthesis to facilitate object recognition; if we have a generative model for a large family of furniture, maybe we can use it as a component of a computer vision system that identifies furniture in 3D scans of indoor environments.

   Describe **three** other motivations for structure-aware shape processing, apart from this object recognition application.

2. Structure-aware shape processing is generally split into an "analysis" stage and a "processing" stage. One of the traits that has been strongly emphasized in the literature as very important for the analysis stage is the detection and characterization of **symmetries**. For example, symmetries often receive much greater attention than geometrical features such as curvature, the color texture of model parts, or the local smoothness of surfaces.

   Why do symmetries have such an important role in structure-aware shape processing?

3. Skinning can be interpreted as a special case of structure-aware deformation task; in this case, "structure" is encoded by means of an articulated skeleton. Give an example of a structure-aware deformation concept (or specific technique) that goes beyond skinning - explain the difference and state why "conventional" skinning would be inadequate in reproducing the same effect.

Question 2: Representations of 3D Rotations

The following 4 representations are commonly used to represent 3D rotations in computer graphics:

a. 3x3 rotation matrices
b. Unit quaternions
c. "Euler Angles" (rotation around 3 fixed axes, such as roll, pitch, yaw or XYZ)
d. Rotation vectors (i.e. the normalized axis of rotation, scaled by an angle-dependent factor)

1. For each of these 4 representations, describe a situation where it is the most appropriate representation. Be sure to explain why the other 3 representations are less than ideal for this application.

2. Imagine a keyframe animation for animating the motion of a rigid body that flies through space. The system allows the user to set poses (specific orientations) that the system will interpolate. For each of the 4 representations, describe a drawback of using that representation for such a system.

3. Consider a densely sampled discrete rotation signal. For example, the result of capturing the orientation of a rigid object moving through space, captured 30 times per second. Consider applying a low-pass filter to this signal. It's a simple low-pass filter – convolution with a kernel like [¼ ½ ¼] . Applying a traditional filter (as a convolution) to a rotation signal is challenging. *[There is a "right way" to do it – but we took that paper off the qual reading list a few years ago. It involves converting to a different representation. We're not asking for that solution here.]*

   For each of the first 3 rotation representations (3x3 matrices, unit quaternions, Euler Angles): describe how you might work out a "hack" to make this filtering work (at a minimum, the result of the filter should be a valid sequence of rotations). Explain what can go wrong, and when it will be a good approximation to the right answer. Avoid the solution of converting each frame to a different representation, filtering that alternate representation, and converting back. But if this is the best you can come up with, be sure to give details (like how you apply a convolution to that new representation).

Question 3: Rendering Systems

Consider the following types of rendering systems:

a. A system using polygon rasterization and fragment shaders, including multiple-pass rendering and texture read-backs (basically, the modern OpenGL model as realized on an up-to-date graphics card).
b. A "from-the-eye" (sometimes called a "backwards") distribution ray-tracer.
c. A bi-directional ray tracer (which shoots some from-the-light-source rays, gathers the light into a caching structure, and then uses a backwards ray-tracer).
d. A radiosity renderer

For **each** of these 4 cases:

- Describe a scene that it can render well, that would be challenging to render using each of the other approaches.
- Pick one of the other approaches (that are not so appropriate for this task) and explain why it would be hard to use it in this scenario.

Question 4: Representations of three-dimensional models

Several representations are used, in varied contexts, to encode 3D models of solid objects, including:

a. Explicit surface mesh representations, such as triangle or quadrilateral meshes - If the object in question is volumetric, this would be a representation of its boundary surface.
b. Explicit volumetric meshes, such as tetrahedral or hexahedral meshes.
c. Implicit surfaces (a.k.a. level sets)
d. Point clouds
e. Subdivision surfaces
f. Constructive Solid Geometry representations, using either analytic primitives, or components from one of the aforementioned categories.

For each of these representations, describe one task or application where its use would be particularly convenient or beneficial, **and** one task for which using this description would be particularly problematic.

Question 5: Mesh-based deformers

A recent approach to character animation is to enclose the geometry of the character (typically a polygonal mesh) within a simpler polyhedron, called a cage. As the cage is manipulated, the geometry is deformed accordingly.

1. What are the advantages and disadvantages of having animators manipulate the character using the cage rather than the surface mesh itself? (Hint: there are good and bad traits in both approaches).

2. Harmonic coordinates are one popular technique used to create the generalized barycentric coordinates for skinning. What nice properties of Harmonic coordinates make them particularly useful for skinning?

3. One way to implement the cage-based deformations is to divide the control polyhedron into tetrahedra, and use barycentric interpolation to position each vertex of the mesh within the tetrahedron that contains it. A second way to implement cage-based deformations is to use some form of generalized Barycentric coordinates to define a single coordinate system over the entire control polyhedron. Discuss the advantages and disadvantages of each approach. (Hint: there are good and bad traits in both approaches).

4. Common skinning techniques use an internal skeleton, and perform a weighted average of the different coordinate systems (associated with individual bones) for each vertex. What are the pros and cons of cage-based control compared to this more common skeletal-based skinning?

   [Note: Often skeletal skinning uses linear blending (or weighted averaging), which causes bad artifacts. If you list these kinds of visual artifacts as a con (and therefore a pro of cage-based skinning), you must explain why it is easier to address these issues in a cage-based approach than a skeleton-driven approach. Remember that many of the artifacts have been addressed by more recent skeleton-driven approaches such as Dual Quaternion skinning.]