Section A - Answer ALL questions

1. Leaving out compositing, list the remaining SIX main stages/processes of computer animation.

(3 marks)

Model Answer:

Modelling, Decoration, Animation, Lighting, Camera control, Rendering. (0.5 marks each)

2. Non-rigid deformation is used for complex animations such as facial expressions or articulated motion. Give a brief description of **direct vertex manipulation**.

(6 marks)

Model Answer:

Direct vertex manipulation is the simplest object deformation approach. It involves deforming the object through displacing each individual vertex (2 marks). To reduce the required input from the modeller, the displacement of each vertex can be propagated to nearby vertices while the magnitude of the displacement is attenuated (2 marks). The further away from the original displaced vertex, the smaller the displacement of the neighbouring vertex (2 marks).

3. Describe the **Angle+Axis** representation for rotations. State the theorem on which it is based. How do we interpolate orientation using this representation?

(5 marks)

Model Answer:

The Angle+axis representation uses a direction in space that is denoted by a 3d vector $(x, y, z)^T$ *(1 mark) and an angle* θ *by which the object is rotated around that axis (1 mark). Euler's theorem states that one can relate any 2 orientations by a single orientation about some axis (1 mark). To interpolate between two orientations each of which is represented by an axis and angle, we interpolate separately between the two axes and the two angles (2 marks).*

4. When rotating an object using the fixed angles representation, when does **gimbal lock** occur?

(4 marks)

Model Answer:

Gimbal lock occurs when two rotation axes coincide resulting in the loss of one degree of freedom. (In other words, changing the angles corresponding to each of those two axes gives the same rotation.)

5. How many parameters are needed to describe the configuration of a rigid object in 3d space? Explain your answer.

(3 marks)

Model Answer:

Six parameters. (1 mark) *Three of these are used to describe the position of the object in space (x-y-z)* (1 mark) *and three are used to describe orientation (yaw-pitch-roll).* (1 mark)

6. Which animation technique would you use to model each of the following:

   a) A flying airplane

   b) A forest

   c) A humanoid robot walking

   d) Smoke coming out of an explosion

   e) A bowling alley

   f) An egg splatting against the wall

   g) A fly-through a scene

(7 marks)

Model Answer:

a) Keyframing position & orientation

b) L-trees

c) Skeleton deformation

d) Particle systems

e) Simulation

f) Free Form Deformation or Vertex displacement

g) Keyframing camera position

7. Give a brief definition of **keyframing**, with FIVE examples of parameters it can be applied on.

(5 marks)

Model Answer:

Keyframing is an animation technique in which the state of the world is defined at certain time instances (keyframes) (2.5 marks). State can consist of any of the following: Position, orientation, speed, forces, colour, light, camera parameters etc. (0.5 mark each example)

8. Explain the steps involved in object deformation based on **FFD** (free-form deformation).

(5 marks)

Model Answer:

- *Object embedded in 3-d lattice/grid. (1 mark)*
- *Local co-ordinates of object vertices determined. (1 mark)*
- *Lattice distorted. (1 mark)*
- *Object vertex co-ordinates interpolated (usually Bezier or B-spline interpolation) (1 mark)*
- *Vertices mapped back to global space. (1 mark)*

9. Name the FIVE different spaces that form part of the **display pipeline**. (5 marks)

Model Answer:

Object space, World space, Eye space, Image space,Screen space (1 mark each)

10. Give definitions of **forward and inverse kinematics**. Which one is harder to achieve? Give an example of an animation task for which each technique is more suitable.

(7 marks)

Model Answer:

In forward kinematics we specify the configuration of joints over a time period and the animation system will calculate the resulting animation of the object (2 marks). In inverse kinematics we specify a joint tree and give the system the start and end positions. From this the animation system shall infer the configuration of the joints over time (and create the animation) (2 marks). Inverse kinematics is much harder to achieve (1 mark). FK is suitable for modelling simple curved motion (e.g. arms swinging during walk) (1 mark). IK is suitable for placing the end effector in a specific location (e.g. a character grabs an object, a robotic arm lifts a load, the character's feet must touch the ground while walking etc) (1 mark).

END OF SECTION A

Total: 50 marks

Section B - Answer any TWO of the following three questions

11. This question is about **physics simulation**.

a) Why is physics simulation used in computer animation? (2 marks)

Model Answer:

Physics simulation helps us to quickly create animations of lifeless objects that move and deform under the laws of physics (E.g. a billiard table or a football that is kicked). Instead of key-framing the motion or deformation we can just let the laws of physics determine how the object reacts to forces like gravity, friction, viscosity as well as how it interacts with other objects through collisions.

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b) Briefly explain what is meant by broad phase and narrow phase algorithms in the context of **collision detection**.

(4 marks)

Model Answer:

Testing for possible collisions of all object pairs is computationally expensive. Broad phase collision detection involves discarding those object pairs that definitely do not collide. (2 marks) In a subsequent phase which is known as narrow phase collision, the algorithm examines in more detail the remaining object pairs. (2 marks)

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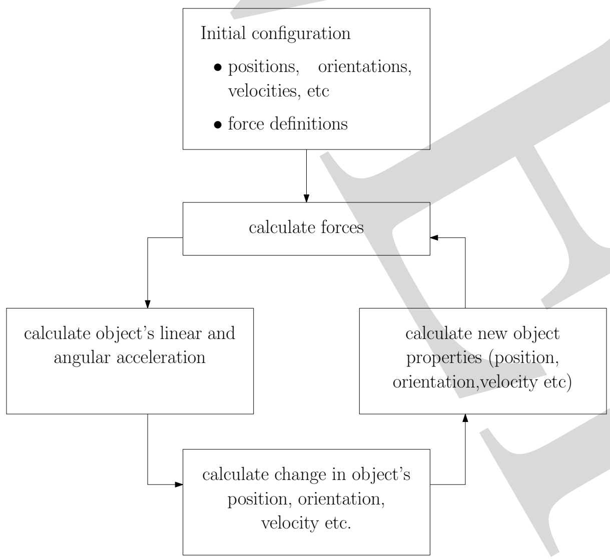
c) Describe the **simulation loop** employed in physics-based animation of rigid bodies.

(7 marks)

Model Answer:



(1 mark for each block + 2 for perfect explanation)

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d) We wish to simulate an object of mass $m = 2$ that moves along the x-axis under the influence of a constant force $F = -2$. Its velocity initially (at frame 0) is $v = 6$ and its position is at $x = 0$. Use Euler's algorithm to calculate the position of the object in frames 1 to 6.

(12 marks)

Model Answer:

Frame=0: $x = 0, v = 6.$

Frame=1:

$a := \frac{F}{m} = \frac{-2}{2} = -1$

$\Delta x := v * \Delta t = 6 * 1 = 6$

$\Delta v := a * \Delta t = -1 * 1 = -1$

$x := x + \Delta x = 0 + 6 = 6$

$v := v + \Delta v = 6 - 1 = 5$

Frame=2:

$a := \frac{F}{m} = \frac{-2}{2} = -1$

$\Delta x := v * \Delta t = 5 * 1 = 5$

$\Delta v := a * \Delta t = -1 * 1 = -1$

$x := x + \Delta x = 6 + 5 = 11$

$v := v + \Delta v = 5 - 1 = 4$

Frame=3:

$a := \frac{F}{m} = \frac{-2}{2} = -1$

$\Delta x := v * \Delta t = 4 * 1 = 4$

$\Delta v := a * \Delta t = -1 * 1 = -1$

$x := x + \Delta x = 11 + 4 = 15$

$v := v + \Delta v = 4 - 1 = 3$

Frame=4:

$a := \frac{F}{m} = \frac{-2}{2} = -1$

$\Delta x := v * \Delta t = 3 * 1 = 3$

$\Delta v := a * \Delta t = -1 * 1 = -1$

$x := x + \Delta x = 15 + 3 = 18$

$v := v + \Delta v = 3 - 1 = 2$

Frame=5:

$a := \frac{F}{m} = \frac{-2}{2} = -1$

$\Delta x := v * \Delta t = 2 * 1 = 2$

$\Delta v := a * \Delta t = -1 * 1 = -1$

$x := x + \Delta x = 18 + 2 = 20$

$v := v + \Delta v = 2 - 1 = 1$

Frame=6:

$a := \frac{F}{m} = \frac{-2}{2} = -1$

$\Delta x := v * \Delta t = 1 * 1 = 1$

$\Delta v := a * \Delta t = -1 * 1 = -1$

$x := x + \Delta x = 20 + 1 = 21$

$v := v + \Delta v = 1 - 1 = 0$

12. This question is about **homogeneous transformations**.

An animator wishes to move a three-dimensional object in a scene, that has its centre at $[1\ 3\ 2]^T$. The object needs to be rotated by 90 degrees about the x-axis followed by -90 degrees about the y-axis. It should then be scaled by a factor of 3 along the z axis and finally it needs to be translated by $[-1\ \ -1\ 5]^T$. The scaling and rotation are to be performed using the object centre as pivot point.

a) Write down (in homogeneous coordinate form) the transformations necessary to achieve the motion described above, stating clearly the order in which the transformations should be applied.

(10 marks)

Model Answer:

1. Translation of obj centre to origin $T_1 = \begin{bmatrix} 1 & 0 & 0 & -1 \\ 0 & 1 & 0 & -3 \\ 0 & 0 & 1 & -2 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

2. An x-rotation $R_1 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

3. A y-rotation $R_2 = \begin{bmatrix} 0 & 0 & -1 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

4. A z-scaling $S = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 3 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

5. Translation of origin to obj centre $T_2 = \begin{bmatrix} 1 & 0 & 0 & 1 \\ 0 & 1 & 0 & 3 \\ 0 & 0 & 1 & 2 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

6. Translation $T_3 = \begin{bmatrix} 1 & 0 & 0 & -1 \\ 0 & 1 & 0 & -1 \\ 0 & 0 & 1 & 5 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

b) Explain how the transformations from (a) can be combined into one single transformation and perform the necessary calculations to arrive at this composite transformation.

(8 marks)

Model Answer:

They should be combined into a single composite transformation M defined by $M = T_3 T_2 S R_2 R_1 T_1$

$$M = \begin{bmatrix} 0 & -1 & 0 & 3 \\ 0 & 0 & -1 & 4 \\ 3 & 0 & 0 & 4 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

c) Before this motion is applied a vertex on the object has global coordinates $[1\ 5\ 3]^T$. Use the transform computed in (b) to calculate the new global coordinates of the vertex. By considering how one would transform a million vertices, illustrate the computational efficiency of homogeneous coordinates.

(4 marks)

Model Answer:

$$M\begin{pmatrix}1\\5\\3\\1\end{pmatrix}=\begin{pmatrix}-2\\1\\7\\1\end{pmatrix}$$

Transforming a million vertices costs 1 million matrix-vector multiplications plus the almost-negligible cost of computing M. Without homogeneous coordinates we would need 6 matrix-vector multiplications per vertex, i.e. 6 times as much computational cost.

d) Without performing the calculation, describe how you would efficiently undo the motion.

(1 mark)

Model Answer:

We can obtain the opposite transformation by calculating the matrix inverse of M and multiplying all vertices with that matrix.

e) Explain why storing a 3d orientation in matrix form is wasteful in terms of memory.

(2 marks)

Model Answer:

We need 3DOF to describe an orientation while a matrix uses 9 DOF (non-homogeneous) or 16DOF (homogeneous). Either of those cases suffices as an explanation.

As an aid the 3 rotational transformation matrices are listed below together with common sine and cosine values so you can perform the calculations without a calculator:

$$\begin{bmatrix}1&0&0&0\\0&\cos\theta&-\sin\theta&0\\0&\sin\theta&\cos\theta&0\\0&0&0&1\end{bmatrix}\begin{bmatrix}\cos\theta&0&\sin\theta&0\\0&1&0&0\\-\sin\theta&0&\cos\theta&0\\0&0&0&1\end{bmatrix}\begin{bmatrix}\cos\theta&-\sin\theta&0&0\\\sin\theta&\cos\theta&0&0\\0&0&1&0\\0&0&0&1\end{bmatrix}$$

$\cos 0^\circ = 1,\ \sin 0^\circ = 0,\ \cos 90^\circ = 0,\ \sin 90^\circ = 1,\ \cos(-90^\circ) = 0,\ \sin(-90^\circ) = -1$

13. Two widely used methods for generating and animating natural objects and phenomena are **L-systems** and **particle systems**.

a) Explain what L-systems are and how they are used to generate models of natural objects

(8 marks)

Model Answer:

L-systems are compact, iterative systems designed to generate fractal (self-similar) graphics (2 marks). They use a string representation with small vocabulary where string symbols are mapped to graphics commands (2 marks). An L-system consists of an axiom (starting configuration) (1 mark) and one or more production rules that are applied in an iterative manner (1 mark). The string characters correspond to turtle graphics commands that, when executed, produce a graphical rendering of the L-system (1 mark). L-systems can be used to model natural objects (e.g. trees) that exhibit a high degree of self-similarity (1 mark).

b) Give the output of the initial state and the first TWO iterations of the following L-system:

```
Axiom F
F→F[+F]F angle = 60°
```

both in string representation and in graphical form. (9 marks)

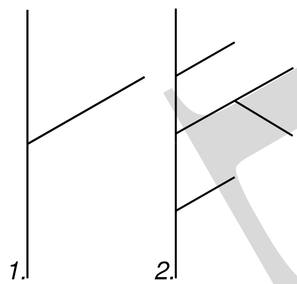
Model Answer:

String:

```
1.  F[+F]F
2.  F[+F]F[+F[+F]F]F[+F]F
```

(2 marks each)

Graphical:



(2.5 marks each)

c) Describe what particle systems are and how they are used to create animated effects. Name two examples of phenomena that can be modelled by particle systems.

(8 marks)

Model Answer:

Particles systems are procedural systems (1 mark) that can be used to model amorphous, dynamic and fluid objects/phenomena (1 mark) like clouds, smoke, water, explosions, fire, etc (2 marks, 1 for each example). The object is represented as a cloud of small primitives (particles) that define its volume (2 marks) and that can change their individual position or other attributes with time (2 marks).

END OF EXAMINATION PAPER

Total: 125 marks