OLLSCOIL NA GAILLIMHE
UNIVERSITY OF GALWAY

Semester 1 Examinations 2022-2023 MARKING SCHEME

Course Instance Code(s)	4BCT, 4BS, 4BMS
Exam(s)	B.Sc. (CS&IT) B.Sc. B.Sc. (Biomedical Sc.)
Module Code(s)	CT404, CT336
Module(s)	Graphics and Image Processing
Paper No.	1

External Examiner(s)	Dr. R. Trestian
Internal Examiner(s)	Prof. M. Madden *Dr. S. Redfern

Instructions: Answer any three questions.
All questions carry equal marks.

Duration	2 hours
No. of Pages	7
Discipline(s)	Computer Science
Course Co-ordinator(s)	Dr. C. O'Riordan

Requirements:

Release in Exam Venue	Yes [x]	No [ ]
MCQ Answersheet	Yes [ ]	No [x]
Handout	None	
Statistical/ Log Tables	None	
Cambridge Tables	None	
Graph Paper	None	
Log Graph Paper	None	
Other Materials	None	
Graphic material in colour	Yes [x] No [ ]	

PTO

Q.1. (Graphics)

(i) Provide short sections of code illustrating **translation**, **rotation**, and **scaling** in either Canvas2D or Threejs. *Note that the final page of this exam paper lists some commonly used functions in Canvas2D and Threejs.* [8]

If using Canvas2D:

Use of context.translate(x,y).	[2]
Display of some graphics in this transformed coordinate system	[1]
Use of context.rotate(angle)	[2]
Display of some graphics in this transformed coordinate system	[1]
Use of context.scale(x,y).	[1]
Display of some graphics in this transformed coordinate system.	[1]

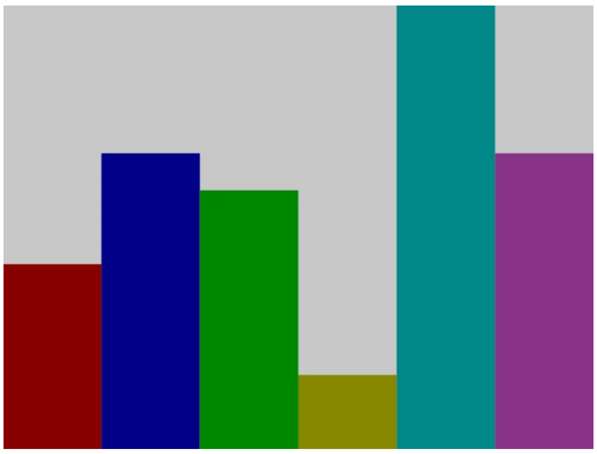
or

If using Threejs:

Instantiation of a mesh object (or properly explained assumption that it exists)	[2]
object.position.set(x,y,z) or direct assignment of values to object.position.x etc.	[2]
object.rotation.set(x,y,z) or direct assignment of values to object.rotation.x etc., or use of object.rotateOnAxis(axis, angle).	[2]
object.scale.set(x,y,z) or direct assignment of values to object.scale.x etc.	[2]

(ii) Using the code below as a starting point, write Javascript/Canvas2D code for use in the **draw()** function which will draw a bar chart from the data contained in the **data[]** array. Note that each entry in the **data[]** array is an object containing both a value and a colour. The chart should apply appropriate scales on the *x* and *y* axes, bearing in mind that the number of entries in **data[]** as well as their values may change, i.e. you should not hard-code the scales. There is no requirement to label the axes. [12]

Grey background ctx.fillRect( )	1
Calculation of highest bar	2
Correct iteration	1
Correct bar widths	1
Correct bar heights	2
Flip the y axis	1
ctx.fillStyle( ) for each bar colour	2
Correct ctx.fillRect( ) for each bar	2



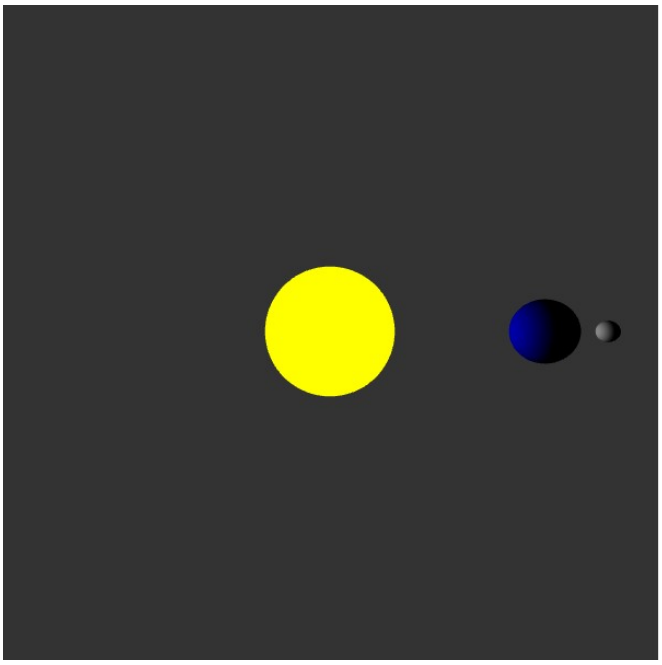
```
<html>
 <head>
  <script>
  function draw() {
     var canvas = document.getElementById("canvas");
     var ctx = canvas.getContext("2d");
     var data = [
       {val:5, color:"#880000"}, {val:8, color:"#000088"},
       {val:7, color:"#008800"}, {val:2, color:"#888800"},
       {val:12, color:"#008888"}, {val:8, color:"#883388"},
     ];
     // to do: write code here to draw a bar chart using Canvas2D


  }
  </script>
 </head>

<body onload='draw();'>
 <canvas id="canvas" width="600" height="450"></canvas>
</body>
</html>
```

Q.2. (Graphics)

Examine the **Javascript/Threejs** code provided below (and on the next page), which sets up a display of a sun, planet, and moon as in the picture below.



(i) In order for the program to provide an animation whereby the blue planet rotates around the yellow sun, while at the same time the grey moon rotates around the blue planet, it will be necessary to **nest their coordinate systems using pivots**. Explain what this means and why it is necessary. [7]

- Rotation is on local coordinate system 2
- Local coordinate system specifies difference from parent coord system 2
- So to effect rotation around a point away from an object's centre, we nest in a pivot 2
- Planet pivot nests in sun; moon pivot nests in planet 1

(ii) Provide the code changes that are needed in the **draw( )** function to establish this nesting. *Note that the final page of this exam paper lists some commonly used functions in Threejs.* [7]

- Instantiate planetPivot as empty Three.Object3D( ) 1
- Make planet as a child of planetPivot, and planetPivot as child of the scene (or of the sun) 2
- Instantiate moonPivot 1
- Make moon as a child of moonPivot, and moonPivot as a child of planet 1
- Adjust local coordinate of moon to (3, 0, 0) 2

(iii) Write suitable code for the **animate( )** function to apply a small amount of rotation per frame, to the planet pivot so that the planet orbits the sun, and to the moon pivot so that the moon orbits the planet. [6]

- New global vars for pivots and current rotation angles 3
- Update rotation angles a little each frame 1
- Set the rotation of each pivot on each frame e.g. planetPivot.rotation.set(0,planetRot,0) 2

```
<html>
 <head>

  <script src="three.js"></script>
  <script>
   'use strict'

   var renderer, scene, camera;
   var sun, planet, moon;

   function draw() {
    // create renderer attached to HTML Canvas object
    var c = document.getElementById("canvas");
    renderer = new THREE.WebGLRenderer({ canvas: c, antialias: true });

    // create the scenegraph
    scene = new THREE.Scene();
    scene.background = new THREE.Color( 0x333333 );

    // create a camera
    var fov = 75;
    var aspect = 600/600;
    var near = 0.1;
    var far = 1000;
    camera = new THREE.PerspectiveCamera( fov, aspect, near, far );
    camera.position.set(0, 0, 20);
    camera.lookAt(new THREE.Vector3(0,0,0));

    // add a light to the scene (at the location of the sun)
    var light = new THREE.PointLight(0xFFFFFF);
    light.position.set(0, 0, 0);
    scene.add(light);

    // create the sun, planet, and moon
    sun = new THREE.Mesh(
     new THREE.SphereBufferGeometry(3,60,60),
     new THREE.MeshBasicMaterial({color: 0xffff00}) );
    sun.position.set(0, 0, 0);
    scene.add(sun);

    planet = new THREE.Mesh(
     new THREE.SphereBufferGeometry(1.5,60,60),
     new THREE.MeshLambertMaterial({color: 0x0000AA}) );
```

```
      planet.position.set(10, 0, 0);
      scene.add(planet);

      moon = new THREE.Mesh(
        new THREE.SphereBufferGeometry(0.5,60,60),
        new THREE.MeshLambertMaterial({color: 0x888888}) );
      moon.position.set(13, 0, 0);
      scene.add(moon);

      animate();
    }

    function animate() {
      setTimeout(animate, 20);

      renderer.render(scene, camera);
    }
   </script>
  </head>

  <body onload="draw();">
    <canvas id="canvas" width="600" height="600"></canvas>
  </body>
</html>
```

Q.3. (Graphics)

(i) Many of the techniques used in real-time 3D graphics programming attempt to maximise the realism of the rendered scene while processing a minimal number of polygons. With specific reference to the so-called 'polygon budget', and using diagrams where appropriate, discuss each of the following techniques: [12]

a) Frustum Culling

- Explanation of viewing frustum, with field of view and near/far clipping planes 2
- Helping the polygon budget by only rendering if inside viewing frustum 1

b) Back Face Culling

- Do not render polygons that face away from the camera 1
- Applicable to Convex objects 0.5
- Method of calculation via vector dot product. 0.5
- Helping the polygon budget by only rendering those that can be seen. 1

c) Portal Culling

- Indoor scenes are best 0.5
- Definition of sectors and portals 1
- View between sectors is considered occluded unless passing through portal 1
- Helps the polygon budget by culling geometry assigned to a sector 0.5

d) Levels-of-Detail (LODs)

- Reduced polygon-count versions of a mesh. 1
- Selected at runtime according to size of object on screen 1
- Helps the polygon budget by using less polygons for distant objects 1

(ii) Real time graphics algorithms are categorised as operating in either **world space** or in **image space**. Explain the meaning of world space algorithms and image space algorithms from the point of view of the rendering pipeline. List one algorithm which could operate in world space (and explain why world space is appropriate to it) and list one algorithm which could operate in image space (and explain why image space is appropriate to it). [8]

- World space: operates on vertices prior to projecting them onto the camera plane 2
- Image space: operates on pixels after they have been projected and drawn into the pixel buffer 2
- Example world space alg. – must benefit from accuracy of world space, or use the data which is lost following projection, e.g. individual surfaces 2

- Example image space alg. – must benefit from the efficiency of image space, or of the data which doesn't exist prior, e.g. colour/brightness 2

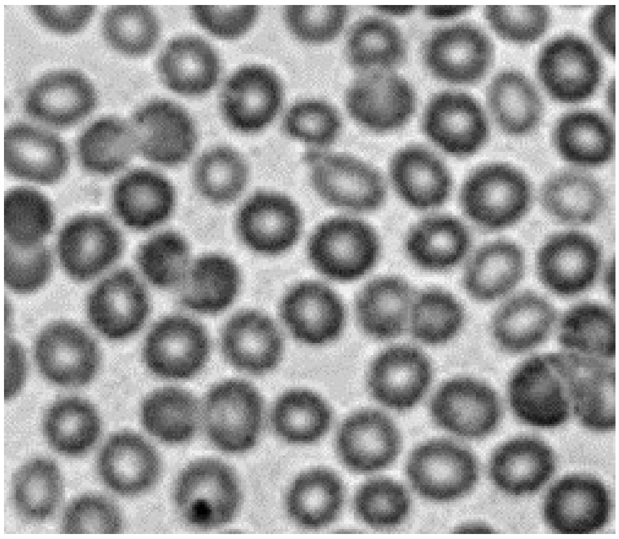
Q.4. (Image Processing)

(i) With respect to morphological image processing, outline the following operations: **erosion**, **dilation**, **opening**, and **closing**, as applied to binary images. What are these operations useful for? [10]

- At least one example of a morphological template 1
- Explanation of how a template is applied to each pixel in the input image, to produce an output image 2
- Detailed explanation of the template's effect on binary images 1
- Dilation as the inverse of erosion 1
- Opening as a concatenation of erosion+dilation 1
- Opening effect on binary images 1
- Closing as a concatenation of dilation+erosion, 1
- Uses: low-level cleaning up, low level topological analysis 2

(ii) The image below is of blood cells, and it is required that a fully automated system is developed to accurately count the number of cells in images such as this. Present a suitable and robust set of image processing algorithms for this task. Explain why each step you have chosen is appropriate. [10]

- Dealing with noise: why and how 3
- Isolation using (edge detection, thresholding, Hough Transform: why and how) or using (morphology approaches: why and how – to include shine in centres) 4
- Final counting 3



Q.5. (Image Processing)

(i) Many automatic image analysis algorithms begin by **smoothing** an image, and then applying an **edge detection** filter in order to ascertain the evidence for the edges of objects in the image.

a) Discuss the use of smoothing and edge detection for these purposes. [5]

- Edge detection: what is it? 2
- Effect of noise 1
- Smoothing: dampens high frequency noise with little damage to larger objects 2

b) Discuss two approaches that might be used to deal with problems such as fragmentary edges and occluded edges. [5]

- Explanation of a template matching technique e.g. Hough Transform 2
- Explanation of a line linking technique e.g. relaxation 1
- Why they're robust 1
- How they move us towards successful segmentation 1

(ii)

a) Discuss the image processing technique called **active contours**. In your answer, explain in simple terms the algorithmic concept of **optimisation**. [5]

- Snaxels 2
- Forming a closed loop / perimeter 1
- Constraints and concept of 'minimum energy' 1
- Optimisation: problem space search: local, global, random, directed 1

b) Describe a suitable set of optimisation constraints (sometimes called energy factors) for accurately tracing the outline of a hand in an image such as the one shown below, using active contours. What purpose does each constraint have? [5]

- These seem like good candidates; others may be acceptable..
    - Edge strength + purpose 1
    - Centroid + purpose 1
    - Angular continuity + purpose 1
    - Brightness + purpose 1
    - Distance continuity + purpose 1

Some useful methods/properties of the Canvas 2D Context object:

Method/Property	Arguments/Values	Notes
fillRect	(Left, Top, Width, Height)	Draw a filled rectangle
beginPath	None	Start a stroked path
moveTo	(X, Y)	Move the graphics cursor
lineTo	(X, Y)	Draw a line from graphics cursor
stroke	None	End a stroked path
fillStyle	="rgb(R,G,B)"	Set fill colour
strokeStyle	="rgb(R,G,B)"	Set line colour
save	None	Save the current coordinate system
restore	None	Restore the last saved coord system
translate	(X,Y)	Translate the coordinate system
rotate	(angle)	Rotate the coordinate system clockwise, with angle in radians
scale	(X,Y)	Scale the coordinate system independently on the X and Y axes

Some useful objects/methods from the Threejs library:

Object/Method	Notes
new THREE.WebGLRenderer({canvas:c})	Constructs a renderer, attached to the Canvas object c
new THREE.PerspectiveCamera(fov,aspect,near,far)	Constructs a camera, with the specified field-of-view, aspect ratio, near clipping distance, far clipping distance
new THREE.Scene();	Constructs a scene
new THREE.PointLight(0xffffff);	Constructs a white point light
object.position.set(x,y,z)	Sets an object's x,y,z position relative to its parent
object.rotation.set(x,y,z)	Sets an object's x,y,z rotation (using Euler angles) relative to its parent
object.rotateOnAxis(new THREE.Vector3(0,1,0), 0.1)	Rotates object by 0.1 radians on the y axis
object1.add(object2)	Sets object2 as a child of object1
object.parent	Obtains a reference to the parent of object
camera.lookAt(new THREE.Vector3(0,0,0));	Turns a camera object to face the world coordinate 0,0,0
new THREE.BoxGeometry(20, 20, 20)	Constructs Box geometry, with specified width, height, depth
new THREE.MeshLambertMaterial({color: 0xfd59d7})	Constructs a Lambert (Phong) material of the specified colour
new THREE.Mesh(geometry, material)	Constructs a mesh using the specified geometry and material
renderer.render(scene, camera)	Uses a renderer to draw a scene as seen by a camera, onto the renderer's Canvas