— *Solution notes* —

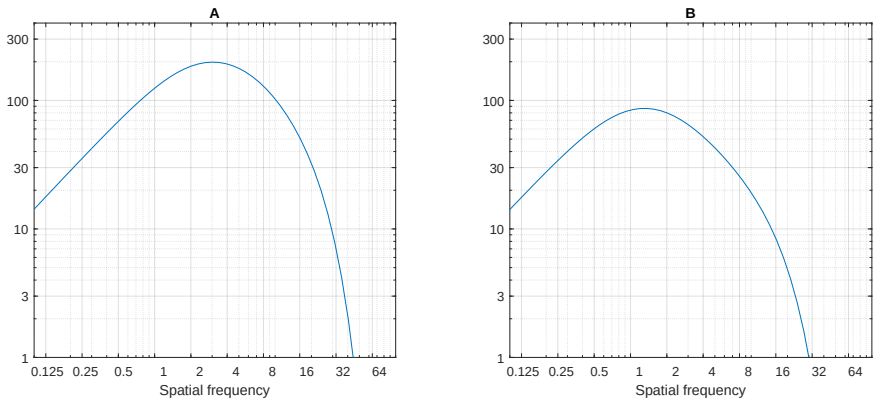
**COMPUTER SCIENCE TRIPOS Part II – 2019 – Paper 10**

## 1 Advanced Graphics and Image Processing (rkm38)

Answer TWO questions from three questions below, up to the total of 40 marks. The individual questions are marked (a), (b) and (c).

Models of visual perception

(*a*) The figure below shows two Contrast Sensitivity Functions




(*i*) What are the units on the X-axis? [2 marks]

(*ii*) What should be the label on the Y-axis? [4 marks]

(*iii*) Which of the plots (A or B) is for the luminance of $100\,\mathrm{cd/m^2}$ and which for $1\,\mathrm{cd/m^2}$? Justify your answer. [4 marks]

(*iv*) What is the minimum contrast that the eye can see for the plot in Figure A? [4 marks]

(*v*) A display has an angular resolution of 32 pixels per degree. If we are showing a pattern on that display of the maximum reproducible frequency (Nyquist frequency), what is the minimum contrast for the pattern to be just visible. Read the value from Figure A. [6 marks]

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*Answer:* (i) cycles per degree;
(ii) Sensitivity $[L/\Delta L]$;
(iii) Figure A shows the sensitivity for higher luminance ($100\,\mathrm{cd/m^2}$) because the sensitivities are higher;
(iv) The maximum sensitivity is 200 and the maximum contrast is the inverse of that value: $\Delta L/L = 0.005$.
(v) The Nyquist frequency of the display is half the sampling rate: 16 cycles per degree. The sensitivity at 16 cpd is 50 and the contrast is 0.02 or 2%.

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Latency and temporal vision

(*b*) Some display technologies suffer from an undesirable effect, known as a hold-type blur.

(*i*) Explain what is the cause of the hold-type blur. [4 marks]

(*ii*) What kind of eye motion is associated with the hold-type blur? [4 marks]

(*iii*) Explain how the hold-type blur is reduced in AR/VR headsets. [6 marks]

(*iv*) In what circumstances can the technique for reducing the hold-type blur introduce a visible flicker? [6 marks]

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*Answer:* (i) The hold-type blur is the results of the eyes smoothly following an object, while the image on the displays remains stationary for the duration of the frames. This causes the retinal images to be blurry;
(ii) The Smooth pursuit Eye Motion is associated with the hold-type blur;
(iii) The hold-type blur is reduced with low-persistence displays. Low-persistence displays shown an image for the fraction of the duration of a single frame (e.g. 1/5th) and remain blank for the remaining time. This introduces a stroboscopic effect and reduces the blur on the retina;
(iv) The flicker due to low-persistence display can become visible when the display refresh-rate is too low. The flicker is more visible for brighter displays and for parafoveal vision (the field of view outside the fovea).

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Tone mapping

(*c*) Tone-mapping is often performed on the luminance/grayscale channel alone and the colour is transferred from the original image.

(*i*) What are the reasons for performing tone-mapping on luminance/greyscale channel instead of separately on the red, green and blue channels? [4 marks]

(*ii*) Explain two techniques for transferring colours from the original image to its tone-mapped version. [10 marks]

(*iii*) Why do we often need to reduce saturation after performing colour transfer? [6 marks]

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*Answer:* (i) Tone-mapping is often performed on the luminance or greyscale channel alone because modifying each channel individually can cause hue shift. It is also done to reduce computation for expensive tone-mapping operators;
(ii) One technique transfers colour ratios as explained in slide 38 of the "High Dynamic Range and Tone-mapping" lecture. The second technique uses the colour space that separates luminance and chrominance channels, such as CIE Luv and CIE Lab. The technique is explained in slide 40.
(iii) A tone-mapping operator can make some colours much brighter and darker, moving them outside display's colour gamut. Reduced saturation can bring these colours back into the colour gamut.

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