THE UNIVERSITY OF NEW SOUTH WALES

SCHOOL OF PHYSICS

Computational & experimental physics PHYS3112

Example questions for the final exam

Friday 09$^{\text{th}}$ June 2017

Each question is worth the same mark
Duration: 2 hours

Please hand this exam paper in with your solution booklet

NAME:

STUDENT NUMBER:

Part A—please use a separate examination book for each part

Question 1

Here are three formulae for calculating the variance of an array of numbers x_i:

$$\text{var} = \frac{1}{n-1}\sum_{i=0}^{n-1}(x_i - \bar{x})^2$$

$$\text{var} = \frac{1}{n-1}\left\{\left(\sum_{i=0}^{n-1} x_i^2\right) - n\bar{x}^2\right\}$$

$$\text{var} = \frac{1}{n-1}\left\{\sum_{i=0}^{n-1}(x_i - \bar{x})^2 - \frac{1}{n}\left(\sum_{i=0}^{n-1}(x_i - \bar{x})\right)^2\right\}$$

- Suppose that you were using a small microcontroller that had no way of storing more than a hundred numbers. The microcontroller also has an ADC that is producing a 16-bit integer every millisecond. The microcontroller has access to each number as it is produced, but can't store them. Explain how you would calculate the variance of 1000 of these measurements.
- Explain the reason for the difference between the first and last of the equations above.

Question 2

Consider the following differential equation for a system:

$$\alpha^3\ddot{x} + \sqrt{\beta}\dot{x} + \gamma = \sin\omega t$$

where the Greek letters are all constants.

- Is this an *ordinary* differential equation?
- Is this a *linear* differential equation?
- Is this a *homogenous* differential equation?
- Is this a *first, second, or third order* differential equation?
- Write the equation in state-variable (normal) form suitable for writing a function to pass to `scipy.integrate.odeint`.

Question 3

Compare and contrast the Euler, leapfrog, and 4th order Runge Kutta techniques for numerical integration. There is no need to write down equations.

Question 4

What does it means to say that an ADC is "guaranteed monotonic"?

Why is the guarantee important for servo-systems?

What is a bit-error, an offset error, a gain error, a quantisation error?

Question 5

A physicist wanted to use the file "/dev/random/" on a Linux computer to supply random numbers, but was surprised that the file only produced about 100 bytes when first read. And reading the file again immediately after the first attempt produced no bytes. What is going on here?

Question 6

Consider the following sources of "random" numbers: a linear conguential generator, the Mersenne Twister, /dev/random, /dev/urandom.

Explain, giving reasons, which of these would be a good choice for the following usage cases:

- Creating a cryptographically secure communication channel.
- A Monte-Carlo physics simulation.
- A non-critical application for an 8-bit microcontroller.

Question 7

Discuss the calculation of the fourier transform in the following cases.

- You have billions of fourier transforms to calculate on a slow computer. Your data arrays are all of length 131.
- As above, but with length 511.
- You are trying to distinguish two frequencies that are close together, and one has a much larger amplitude than the other.

Question 8

How is the power spectrum related to the real and imaginary parts of the FFT?

In the Higher Year Lab our experiment produce real numbers. Can we therefore just keep the real component of the complex FFT and ignore the imaginary component?

Question 9

Consider an experiment where you are measuring the voltage across a resistor that is cooled to 10K and has an extremely small current flowing through it.

The noise in your voltage measurement will have contributions from shot noise, Johnson noise, and $1/f$ noise. Describe the physical reason for these three different sources of noise. Which is these are examples of white noise?

Question 10

Sketch the time response of a servo-system to a Heaviside forcing function at $t = t_0$, showing examples of under-damping, over-damping, and critical damping.

Question 11

In studying the behaviour of servo-systems governed by linear ODEs, how can we change the problem from one requiring the solution of diffential equations, to one involving algebraic equations?

Can this technique be generalised to work for non-linear ODEs?

Question 12

Suppose that you have a servo-system controlled by a PID controller. Further suppose that the integral and differential coefficients were set to zero.

- At long times after a disturbance, after an equilibrium is reached, how would the output compare to the set-point?
- How would you change the PID coefficients to improve the equilibrium performance?
- How would you change the PID coefficients to reduce the time required for equilibrium to be reached?

Question 13

Consider a weak quantum measurement of a quantum system.

In a weak measurement both the system being measured and the measurement device are quantum systems. The three steps in a weak quantum measurement are

1. The quantum measurement device is prepared in some known state.
2. We weakly couple the quantum measurement device to the quantum system.
3. After this we perform a strong quantum measurement on the measurement device.

Describe qualitatively what happens to our knowledge of the state of the quantum system as the strength of the measurement is increased. And what happens to state of the quantum system *after* the measurement has been made?

Question 14

Consider the Stern-Gerlach experiment described in the 2nd lecture on quantum measurements. With atoms prepared with 100% polarisation in the x direction, how would the spots appear on the screen in the z direction? How would this change, if at all, if the magnets were rotated about the y axis by 90 degrees?

Question 15

In modelling the climate system, give as many examples as you can of required inputs to the calculations that are difficult to predict (hint: an example would be a future volcanic eruption).

Question 16

How might you use a climate model to determine the degree to which human factors have affected the climate?

Simulations have shown that it is likely that humans are responsible for more than 100% of the observed change in the climate? How is it possible for the human contribution to exceed 100%?