Overview
The goal of this project is to investigate the mechanisms by which emission tomographic
detections associated with a given two-dimensional distribution of radioactive tracer are
converted into a diagnostically-useful image.

You are given a two-dimensional source distribution of radionuclide within a single slice of a
hypothetical subject, who is to undergo PET imaging. This image corresponds to a 512 x 512
grid of locations, to be interpreted as representing a lateral and vertical extent of 100cm,
centered at the origin of the PET scanner detector ring.

You are expected to achieve two tasks as a part of this project. First, you will generate
detections in the ring over a variety of integration windows. Second, you will use these
detections to identify coincident events, and subsequently apply your projection tomography
reconstruction code from Project #2 to reconstruct the PET tracer distribution image.

The Assignment
Part I: (Ideal) Forward Simulation

Your first goal is to develop a simulator that is capable of generating a list of detections
associated with the positron emissions from the given 2D radionuclide spatial distribution
(patient512.tif), and an assumed half-life (see below). Given a particular half-life, your
program should be capable of taking the input radionuclide distribution matrix to produce a list
of arrival times, over a given integration time, for each of the detectors in the ring. Note that
you will need to develop equations to identify the detectors at which the two emitted photons
arrive at the inner surface of the detector ring. To achieve accurate timing, you must consider
the distance the photons must travel and the effect this will have on the times of arrival for the
two photons at their respective detectors. This will also require that you select an appropriate
time interval on which your simulation operates; you should consider basing this value on the
time required for a photon to reach the detectors.

You are to develop this simulation for a ring detector system having a radius of 0.75m, and
a total of 360 or 1080 detectors. You should consider the given radionuclide having a half-life
of either 120s (e.g., $^{15}$O) or 20min (e.g., $^{13}$C). Assume that the intensity values in the
patient512.tif image represent voxel-wise concentrations at the nanoCurie (nCi) level.
To correctly account for the possibility that photons are not successfully detected due to
absorption by the body (recall that your body absorbs 99% of incident x-ray radiation),
incorporate a means to input a probability of absorption to be applied to each emitted photon.

Report Content: In the written report, please address the following:
1. For each total number of detectors, provide equations that identify the detectors at which
   the two photons arising from a single annihilation event arrive.
2. Indicate and justify the temporal mechanism by which your simulation works.
3. For each of 360 and 1080 detectors, and the tracer in the patient having a half-life of 120s,
   provide the output of the arrival times between $t = 0.50$ and $0.51$ s, for detectors located
   between 50-59 degrees, and for 230-239 degrees. Provide counts of total arrivals for these
   same detectors for a 10s integration time. Repeat for a half-life of 20min using a 40s
   integration time.
**Part II: Coincidence Detection**

Develop an algorithm that identifies coincidence events and converts these events into lines of response that may be used for image reconstruction. This will require, at minimum, selection of a coincidence window, and may require that you develop a heuristic algorithm to limit erroneous coincidence detections.

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<tr>
<th>Report Content:</th>
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<tbody>
<tr>
<td>1.</td>
<td>Provide and justify your coincidence detection window.</td>
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<td>2.</td>
<td>Describe and discuss any additional constraints you may have placed on coincidence detection.</td>
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<tr>
<td>3.</td>
<td>For the simulation you conducted in I.3., attempt to quantify the number of erroneous detections you have obtained, considering at least two (one good, one poor) values of coincidence window AND the probability of photon absorption in the set {0, 0.05, 0.5}.</td>
</tr>
<tr>
<td>4.</td>
<td>For the simulation you conducted in I.3., and for your best coincidence detection algorithm, provide the values associated with all lines of response between the detectors at angles 50-54 degrees and those at 230-234 degrees. Provide for both 360 and 1080 detectors.</td>
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**Part III: Image Reconstruction**

Now use the lines of response computed in II. to reconstruct the spatial distribution of the tracer, as a \(128 \times 128\) pixel image, centered at the origin. This implies that the resulting pixels are \(\sim 1\) cm per side, and possible locations, in pixels, extend (for both axes) from -64 to +64.

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<td>1.</td>
<td>Provide and justify the algorithm you have chosen to effect image reconstruction.</td>
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<td>2.</td>
<td>Create your own (512 \times 512) image with a single location of radionuclide and directly quantify the point-spread function. Regardless of mechanism you have used, evaluate how this blur (i.e., the point-spread function!) changes with (a) number of detectors, (b) duration of coincidence window, and (c) variation in the probability of photon absorption.</td>
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<td>3.</td>
<td>In the case of the patient, compare your reconstructed images from II.3. with the original images, for each of the probabilities of photon absorption. How does the accuracy of your reconstruction change with (a) number of detectors, (b) duration of coincidence window, and (c) variation in the probability of photon absorption?</td>
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**What You Submit**

**Written Report:** You must provide a PDF report describing what you did that includes figures, graphs, images, and references. Since this course involves images, you are strongly advised to put images in your report.

**Paper Formatting:** The report should be limited to 15 pages or less, so please be prudent in your selection of included images. You must use 12 point type with 1.5 spaces between lines. In addition to the textual and image content, please indicate (in the captions or in an Appendix) the particular electronic file (see below) that corresponds to each included image.

**Submission:** Please submit your project by e-mail to thomas_8923@sendtodropbox.com by the specified due date and time. Your submission should use “ECE 620 Project #3” as the Subject line, and you should attach (1) your PDF report and (2) a ZIP file containing \(a\) your reconstruction programs and \(b\) all final images you have generated for this project. Please store all images in the TIF format! If there are intermediate images of particular interest (or that have been incorporated into your report), please include them.