Activity 3: What is Computed Tomography (CT)?

Computed Tomography (CT) uses math to form an image that shows a single “slice” of the head by combining data from X-rays taken at multiple angles. This process is called back projection and is often used to image the brain. The photo below shows a patient receiving a CT scan.

Comparing CT Images with Standard X-rays

1. **Standard X-ray image** – human head

By Hellerhoff [CC-BY-SA-3.0], via Wikimedia Commons
How does back projection work?

Back projection is a method of combining data from multiple beams of X-rays to create a picture of the inside of the body. In the example below we are looking (from the top) at a layer of the head with X-rays being sent through from the back and right sides. The intensity of the X-rays exiting the front and left sides of the head are represented in the data with arbitrary numerical values (and will be represented by playing cards in the activity below).
In this example, each beam passes through four points in the head. If we want to know the density of one of those points, we must combine data from both of the beams that pass through the point. This is shown below by adding the values of the two beams at each intersecting point.

Above, we used a simplified version of back projection to calculate the density of each of the points in the example head. These densities are then printed on a screen as an image of that layer of the head. In an actual CT scan, back projection is much more complex because it combines beams from many other angles.
To visualize the image, the numbers are colored in using the key provided below. This allows you to see an image similar to what a doctor would see when looking at a CT scan. In this case, a computer algorithm would assign a color or shade of gray to each value in the cross section to produce an image.

<table>
<thead>
<tr>
<th>Number on Image</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-3</td>
<td>Red</td>
</tr>
<tr>
<td>4-6</td>
<td>Orange</td>
</tr>
<tr>
<td>7-9</td>
<td>Yellow</td>
</tr>
<tr>
<td>10-12</td>
<td>Green</td>
</tr>
<tr>
<td>13-15</td>
<td>Blue</td>
</tr>
<tr>
<td>16-20</td>
<td>Purple</td>
</tr>
</tbody>
</table>

Tumors are often more dense than healthy tissue. Can you locate which point is most likely to be a tumor in the image above? It’s the section that blocks the most X-rays from both sides of the head, showing that it’s the most dense.

Now you will do a simple back projection of your own based on the previous example using playing cards to represent the X-ray data collected.
**Procedure**

1. First, remove the kings, queens, and jacks from the deck, and use the ace to represent the number one.

2. Place four cards horizontally and four cards vertically around a 4-by-4 grid. These cards represent the X-ray data from a CT scan. Each one is the measured X-ray intensity for a single beam.

3. For each square in the grid, add the number from the card at the top of the column to the number of the card in the row to the left.

4. Write the answer in its corresponding space in the grid provided below.

5. Now color in the boxes using markers and the provided color code. You’ve just used back projection to create a CT image from X-ray data!

<table>
<thead>
<tr>
<th>X-ray data</th>
<th>Card 1</th>
<th>Card 2</th>
<th>Card 3</th>
<th>Card 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-ray data</td>
<td>Card 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X-ray data</td>
<td>Card 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X-ray data</td>
<td>Card 3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X-ray data</td>
<td>Card 4</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

X-ray beams

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Activity 4: Ultrasound and Submarines

When a submarine wants to find an object, it transmits a sound wave and then listens with a special device to see if the sound wave is reflected back. By calculating how long it takes for the wave to return, the people on the submarine can determine the distance to the underwater object.

The concept of sonar is based on the formula distance equals speed (or rate) multiplied by time. Remember: the sound waves have to reach the object, reflect off its surface, and travel back the same distance to be received by the sensor. Therefore, the distance to the object from the submarine will be half of the total distance traveled by the sound. For example, if Submarine A transmits a pulse moving at 1,450 meters per second and receives the echo 1 second later, then Submarine B is 725 meters away, or written in equation form:

\[
\text{total distance} = \text{speed} \times \text{time} \\
\text{distance between subs} = \frac{(1450 \text{ m/sec}) \times (1 \text{ sec})}{2} = 725 \text{ m}
\]

Now suppose that a submarine at the surface wanted to survey an underwater area that is 100 meters across. Because the submarine uses the sonar in bursts, we need to figure out the smallest interval between bursts that will still give a fairly accurate reading. In this activity, you will help the submarine identify all objects below it that are at least 5 meters long.
**Procedure**

1. Using the image below and starting from the left, draw vertical lines every 10 meters from the top of the water where submarine A is located to the ocean floor. How many submarines did your sonar hit (intersect)? How many did it miss? Note: if the survey line does not clearly pass through the object, it doesn’t count as a hit. Record your answers in the chart provided below.

2. Repeat step 1 with an interval of 5 meters.

3. Repeat step 1 with an interval of 2.5 meters.

<table>
<thead>
<tr>
<th></th>
<th>Hit</th>
<th>Miss</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 meters</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 meters</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.5 meters</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

According to your data, how far apart must your survey lines be in order to detect all the submarines in the field? ______________
Activity 5: Imaging with Sound

“3D Ultrasound” of 29-week-old baby by Kickstart70
[Public domain], via Wikimedia Commons

Medical ultrasound devices work much like the submarine surveying the field. But unlike our submarine, which moves along the surface of the water and scans every few meters, the ultrasound device uses a sensor that consists of many little “drums” in a line. Each drum can send and receive sound pulses. This allows the ultrasound device to survey a wide area at once. It is as if 50 submarines are lined up at the surface, imaging the depths of the ocean at the same time.

You are going to design your own echolocation system. You will need to survey a field of objects (designed by your classmates) and determine where all the objects are.

Materials List

Each group needs:

- Box or other small box with lid
- Pair of wooden chopsticks
- Ruler
- Graph paper
- Corrugated cardboard
- Objects for bottom of “sea floor”

To share with entire class:

- Markers
- Masking tape
- Glue stick
- Pipe cleaners
- Wooden craft sticks
- Scissors
**Procedure**

1. First, you must make a locator (aka your ultrasound device) to take depth readings at specified positions. Remember, you should be able to tell precisely where your locator is in relation to the edges of the box and how deep the locator goes when taking your reading. Also keep in mind the size of the objects.

2. Draw a map of the terrain you plan to use. Before you receive supplies, you must show the instructor your locator and design.

3. Next, build the 3D terrain to test another team’s locator device. Tape the graph paper onto a piece of cardboard. Then tape various objects on the paper to make your terrain. See examples below.

   Your terrain may include anything that will fit inside the box. It can look like a landscape. It can include random objects. It could also be something specific. For example, you could design something that looks like the face of a baby inside a mother’s womb. The key is that your subjects be three-dimensional (ultrasound would not be able to detect a picture drawn on the paper).

4. Now exchange maps. Put your map into another group’s locator box making sure the other group’s members are not looking when you do it.

5. Challenge the other group to find all of the objects that make up your terrain.

6. While they’re mapping your design, create a map on graph paper of the other team’s design using your own locator.