RECOVERED IMAGES

Emmanuel Candès – I find medical imaging to be a wonderful discipline… Before World War I, to understand anatomy, one had to perform dissections… We could not see inside the human body. One had to open it up to see what's going on inside. The world of medical diagnostic completely changed with the discovery of X-rays by Wilhelm Roentgen, which gave birth a little later to radiography. The limitation of X-rays is that they only provide a two-dimensional impression of structures inside the human body. We cannot really distinguish between what is far and what is close, what's in front and what's behind. So it is not really possible to recover this three-dimensional universe. We only see its shadow. This is the reason why I believe the medicine has been completely disrupted by two major revolutions: the invention of the CT scan and that of the magnetic resonance (MR) scan. Magnetic resonance imaging (MRI) is an exquisite and non-invasive technique, which uses the quantum properties of matter to image biological tissues. Now I will use a metaphor: in a scan, you excite the nucleus of atoms by means of a magnetic field. These nuclei will respond to this excitation, they will sing if you will, and in all respects this is this music that gets recorded. The question is this: how do we go from the music of these atoms to an image? This is where mathematics come into play. There is a precise mathematical model which relates the data recorded by the scanner to the image we wish to form. By inverting the model, we get an image… What's really remarkable is that the transformation which produces observed data from an image is well known: this is the famous Fourier transform, named after Fourier, a French mathematician who lived in the 19th century. Fourier introduced this transformation to understand heat propagation! And we unexpectedly find it in medical imaging…

A few years ago, we were lucky to be contacted by radiologists who were trying to speedup the acquisition times of MR scans, which can be very long. Long acquisition times can be problematic because we all know that patients move at least a little bit after a while, and so everything gets blurred. This is a big problem for pediatrics. Children have difficulties staying still so that images are always blurred and this is why MRI is not used as much. Going faster, means collecting fewer samples, fewer data points. Now in math, everybody knows that if you have one hundred thousand unknowns, well we would need at least one hundred thousand equations. We had twenty times fewer equations than this absolute minimum. Yet, we had an algorithm that reconstructed images those images our colleagues from radiology were sending us without any error, even when 95% of the information was missing. This algorithm was calculating something very simple: there are many possible solutions because of all the missing data and all the algorithm does is to seek the simplest solution, the sparsest solution, that which looks the least as noise in a sense. And we realized is that this nearly simple minded algorithm perfectly recovered all those images. With my colleague Terence Tao from UCLA, we developed a theory explaining when one can expect quasi miraculous reconstructions and when we cannot. Now I am going to tell you a real story. This happened a few years ago at Stanford's hospital. There was a two-year old boy who had received a liver transplant. His latest medical tests were truly alarming and his life was at risk. Doctors needed a high-resolution scan to know whether ducts were obstructed. The problem as we have seen is that a high-resolution image takes two minutes, two minutes during which this boy would not be able to take a single breath. So doctors used this rapid acquisition technique we talked about. After 15 seconds instead of 2 minutes, they got a high-resolution image. They saw obstructed ducts and performed surgery. Today, this boy is doing quite well. Now to return to mathematics, the fast acquisition techniques I am speaking of are applied in microscopy, in astronomy, in electronics and in many other fields. This is the power of math. And what's really good is this: when everything becomes numbers as in our digital age, well you can imagine that people like me are not short on finding good problems to solve.

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