ELEC 421
Digital Signal and Image Processing

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Course Roadmap for DIP

Lecture	Title
Lecture 1	Digital Image Modalities and Processing
Lecture 2	The Human Visual System, Perception, and Color
Lecture 3	Image Acquisition and Sensing
Lecture 4	Histograms and Point Operations
Lecture 5	Geometric Operations
Lecture 6	Spatial Filters

Lecture 1:
Digital Image Modalities and Processing

Table of Contents

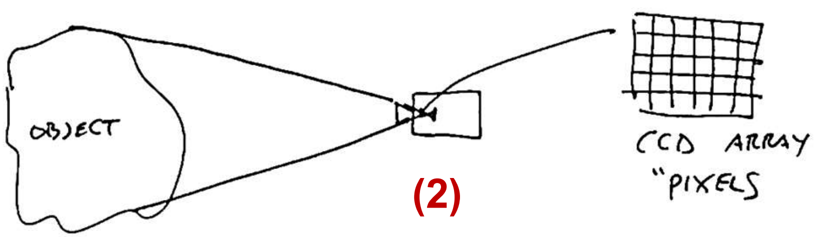
Where do digital images come from?

INTRODUCTION TO (DIGITAL) IMAGE PROCESSING

- WHERE DO DIGITAL IMAGES COME FROM?
- WHAT IS DIGITAL IMAGE PROCESSING?

DIGITAL CAMERAS

A



(1) **(2)** **(3)**

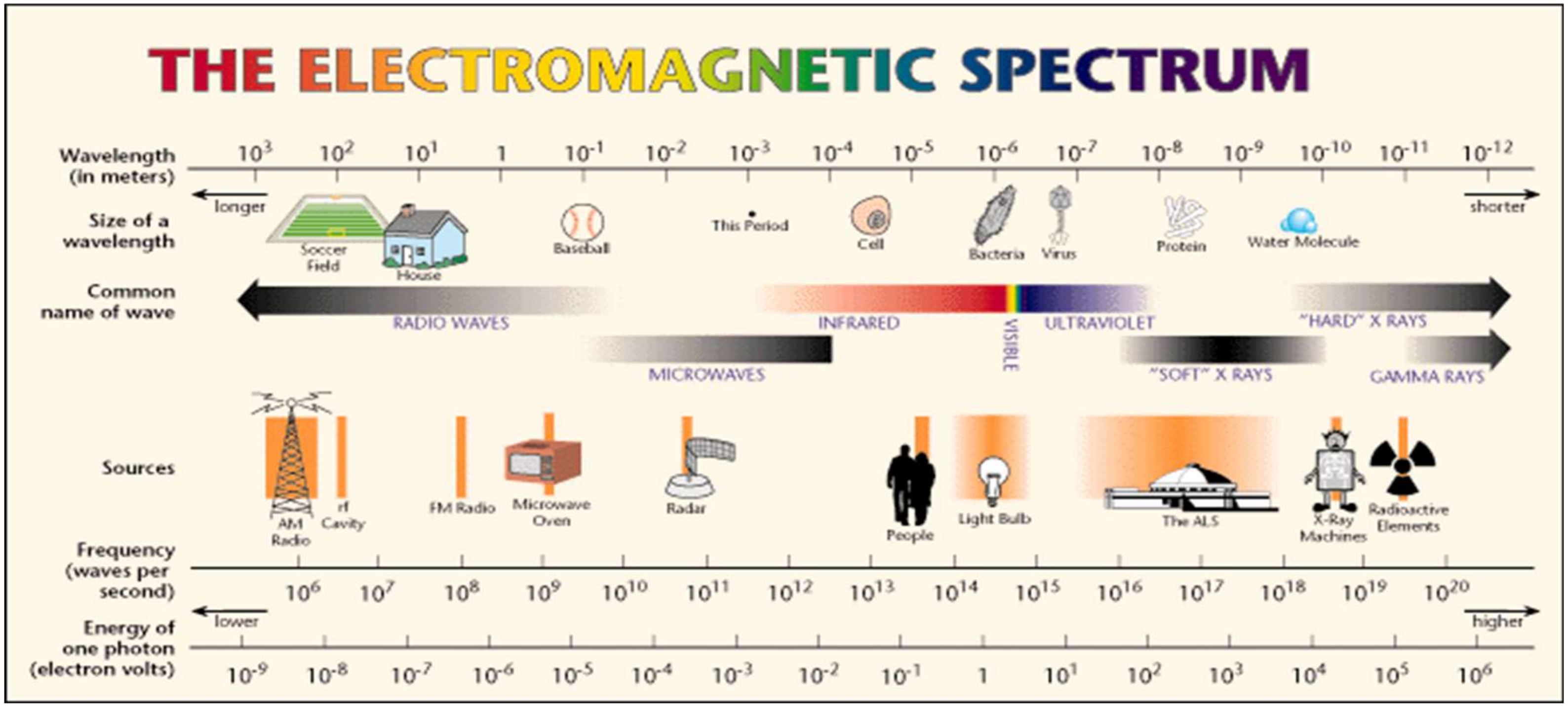
CCD: Charge-Coupled Device

- This is an introduction to **digital image processing** (**DIP**). It is called digital image processing because the vast majority of images that we are probably used to seeing on a daily basis are digital.
- In this lecture, we want to talk about two questions: **Where do digital images come from and what exactly is digital image processing?** The first question seems a bit obvious at first glance. The answer is that usually the digital images come from a **digital camera**. We take a picture and that is the end of story right! But, what we want to talk about is that, in reality, there are lots of ways to acquire images that either do not use a digital camera or do not even really use a system that we would think of as a camera at all. But they still form a 2D or 3D array of pixels that we can treat as digital image. So, there are lots of so-called **image modalities** that are other than the visible light camera on our smartphones.
- Using digital cameras, as shown in diagram **A**, we can see the underlying **image formation process**. Here, we have got some object, **(1)**, in the world, and then we have a digital camera, **(2)**, that looks at it and then inside the digital camera is an array of pixels, usually, a CCD array of pixels, **(3)**. In this process, somehow the object comes into the camera and it is imaged onto this tiny CCD array of pixels that are inside the camera. Later on, we are going to talk in detail about how exactly that image formation process works.

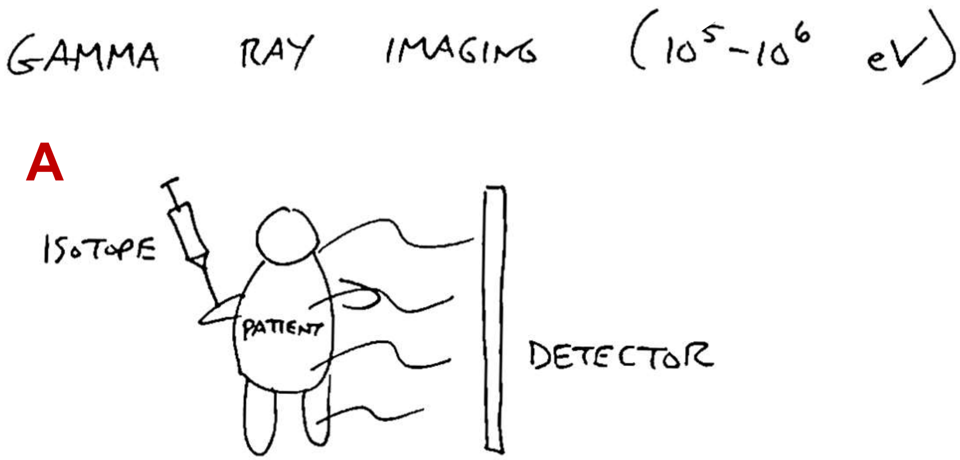
Digital imaging modalities

- There are a lot of other places where we can get images like **optics**, which we could just call digital images. They do not usually involve this notion of a physical object in 3D space that uses visible light to pass through lens onto a CCD array.
- There are lots of other ways to get images, and a lot of those things are ***outside of the visible spectrum***. All across the electromagnetic spectrum are ways we can acquire image like objects. And, so many of these are used for things like **medical diagnosis** and **treatment** or things like baggage and cargo screening. For instance, if one drives a truck through a checkpoint, we are not taking a picture of the truck with a digital camera, instead, these modalities take a picture with some sort of non-visible spectrum imaging. This is done to figure out what is inside the truck.
- Diagram **B** shows the electromagnetic spectrum.

B



Gamma-ray imaging

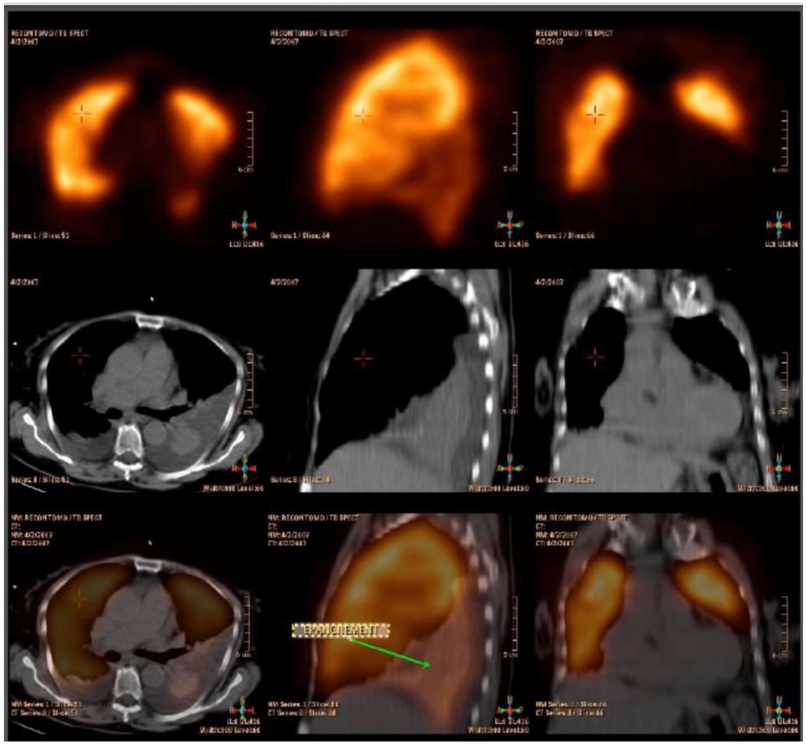


B

- We are going to go in ***decreasing energy*** along the electromagnetic spectrum. First, let us talk about high energy **gamma ray imaging**. In terms of energy, **electron volts** or **eV**, that is on the order of tens of thousands or millions of eV's. In the field of **medical imaging**, the most common place where we would see this is a patient or a subject that is injected with some sort of a radioactive dye, as shown in **A**.
- As seen in **A**, we have a patient who is getting injected with some sort of an ***isotope***. Right after the patient has been injected, they start to give off gamma rays and those gamma rays are received by a 1D or 2D **detector**. This type of imaging is used often for things like detecting infections or tumors, especially for things like bones.
- As an example of what those images look like, let us examine **B**. Here, we are seeing the gamma ray emission as kind of the pseudo-color red image from lungs.

Gamma-ray imaging

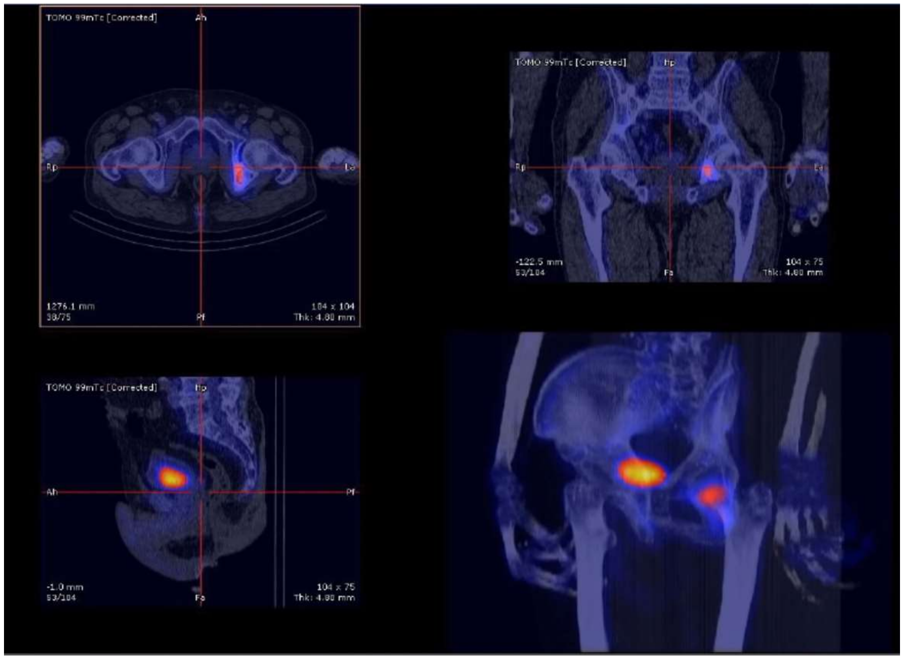
A
B
C



- In **B**, the middle row is a CAT scan (or CT-scan) and the bottom row is ***superimposing*** the image from the top, **A**, with the image in the middle. The combined image, **C**, has more information than either of **A** or **B** alone. Here, CAT stands for Computerized Axial Tomography, which is the same as CT-scan.
- Other imaging modalities are **SPECT** and **PET** imaging. SPECT stands for Single Photon Emission Computerized Tomography and PET stands for Positron Emission Tomography. These are all ***variants*** of gamma ray imaging.
- CT-scan uses X-ray and is more suitable for showing anatomy. That is, CT images can give us a sense of the structure of what is going on, but SPECT or PET are often used because they can give us a sense of behavior/function or physiology of what is going on inside the body.
- **Conclusion:** In **C**, we get both ***functional*** and ***structural*** details by superimposing CT and gamma-ray images (SPECT/PET images) onto each other.

Gamma-ray imaging

D



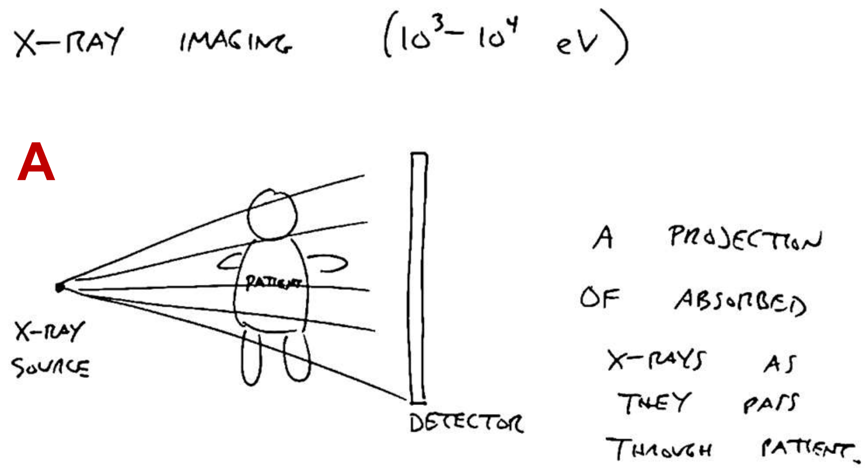
- Image **D** is another example where we have got this bluish image, which is a **CT-scan** along with the hot spots that are coming from some sort of **SPECT imaging**. This is telling us that there is something in the body at the red location, and that it is doing something abnormal. It is probably some sort of bone tumor, for example. Here, even though the bone may appear as white in the CT-scan, i.e., it looks the same as every other bone, the gamma ray imaging reveals, in this case, that there is something unusual about this particular bone.
- Gamma radiation is also used for astrophysical imaging, because these celestial bodies are always giving off radiation that can be detected with gamma rays scanners.

Gamma-ray imaging

A

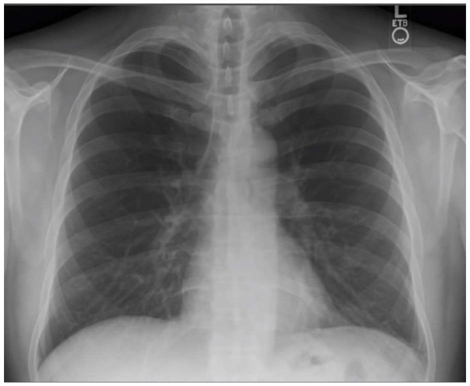
- Gamma ray imaging is also used for **cargo inspections**, as shown in **A**. Certainly, all sorts of ports or borders have these non-contact big imaging machines that trucks and cargo containers are driven through. They are used to detect any sort of radioactive material that is coming out of containers.
- At the same time, there are certainly lots of problems with false positives when using these scanning machines. For example, cat litter and bananas apparently admit background radiation that is enough to get these scanners confused! However, in general, if there are some sort of radioactive or fissile material in the trucks, these scanners will pick it up.
- **Conclusion:** These image scanners are one of the first lines of defense for all the cargo containers coming to any country. Here, all the cargos are scanned for radioactive possibilities.

X-ray imaging



- Next modality is **X-ray imaging**. This imaging modality is a little lower energy than gamma rays, i.e., 10^3 to 10^4 eV. We are probably more familiar with this modality than the other modalities. This is because almost everyone has probably gotten an X-ray, if not a full-body X-ray, at some point in their lives. At least, we have probably got a dental X-ray and used those **bitewings** that we have to put in our mouth while the dentists take the picture.
- Diagram **A** shows an example of X-ray in **medical imaging**. Here, we have got a patient in front of an X-ray source (an XRT or X-ray tube) and the X-rays coming from the source are blasted through the patient. Again, just like the gamma rays imaging, there is a detector that receives the X-rays. The number of X-rays received by the detector is reflective of how much of those X-rays have been absorbed by the patient.
- If there is no patient in the way, the X-rays pass through thin air since there is nothing in the way. Then they arrive in full strength at the detector. Instead, if they are passing through solid bone or something like that, then they are going to be blocked by the patient and they are going to have a lesser response on the detector. If the X-ray passes through our lung, for example, which has got a lot of air in it, the X-ray image is going to be a lot darker than something that passes through bone. This process is basically ***a projection of absorbed X-rays as they pass through the patient***.

X-ray imaging



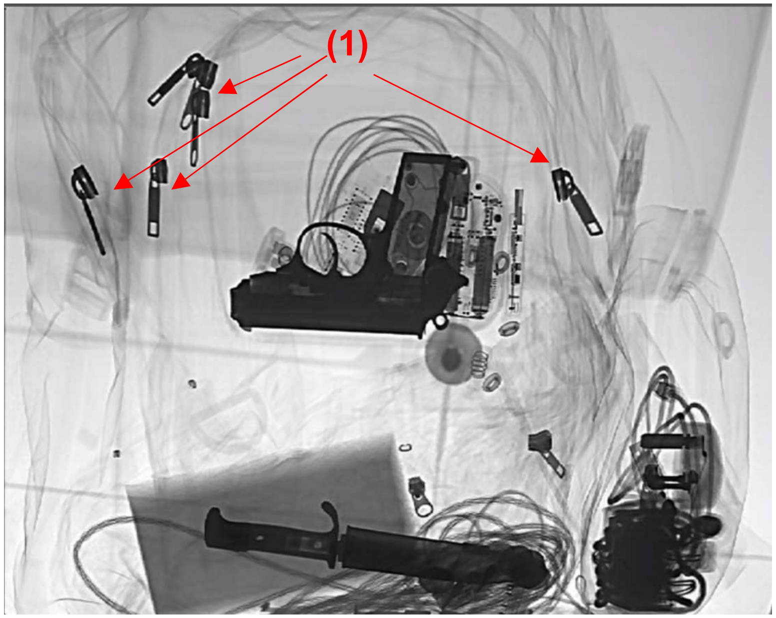
A

B

C

- Picture **A** is a ***radiograph*** of a standard chest X-ray. Here, the spinal cord, the bones, and the arms (and similar organs), are soaking up more X-rays. So, they appeared lighter and then the ones where there is a lot of air, look to be darker. The **advantage** of this is that if there is some big tumor inside the lung, an X-ray may be able to pick it up as some sort of big mass that is visible in this projection. The **downside** is that, here, all we get is this two-dimensional projection of what is fundamentally a 3D object, i.e., our body.
- What we really like to get is more like a 3D image of the patient, instead of just one 2D projection. That is why when we get an X-ray, we may get it for ***multiple angles*** to see if they can nail down what they are actually seeing.
- Picture **B** shows a hand X-ray which is usually used for seeing if we have got broken bones. Picture **C** is an example for dental X-rays. This is not a standard bitewing image. Here, instead, we see the ***panoramic X-ray*** around the head. Basically, we put our head into a specialized X-ray machine, we rest our chin on a support, and this X-ray machine goes around our head and makes this whole picture.

X-ray imaging

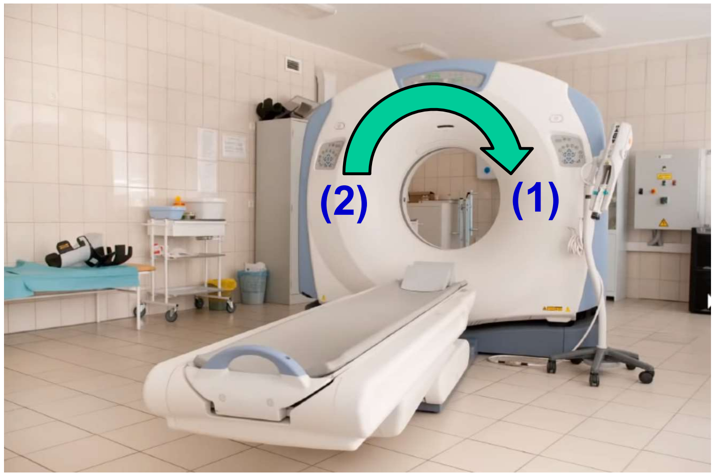


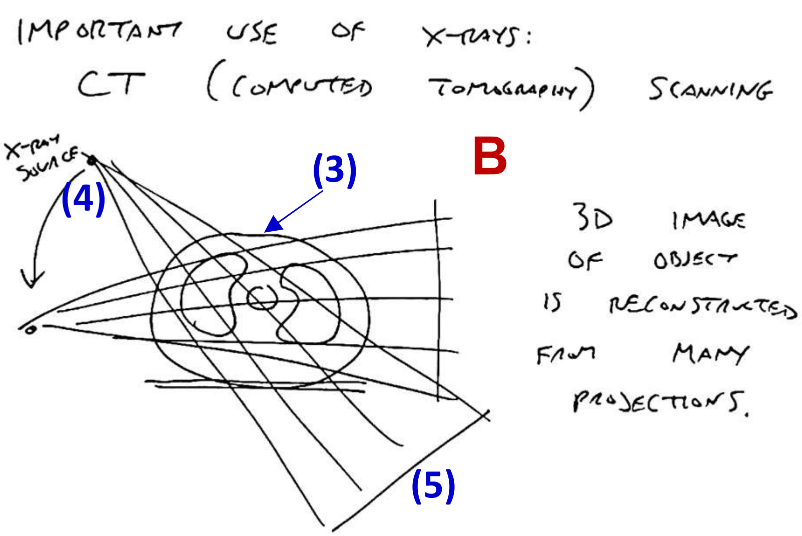
A

- Picture **A** shows another kind of machine which is available in the airports for **baggage screening**. These also use X-rays. In some airports, when we put our bag on the conveyor belt and as we go through security, they most likely use these types of X-ray machine.
- We know since metal absorbs X-rays at much different rate than clothing/cloth, we can see things standing out in X-ray machine. In this picture, we are looking at a backpack. Here, we can see that the objects that really stand out are: the zippers of the backpack, **(1)**, the gun, the circuit board, and the knife, along with other metallic objects. On the other hand, things like the clothing/cloth is invisible to the X-ray. This is definitely another big reason why X-rays are used in real life.

CT (computed tomography) imaging

A

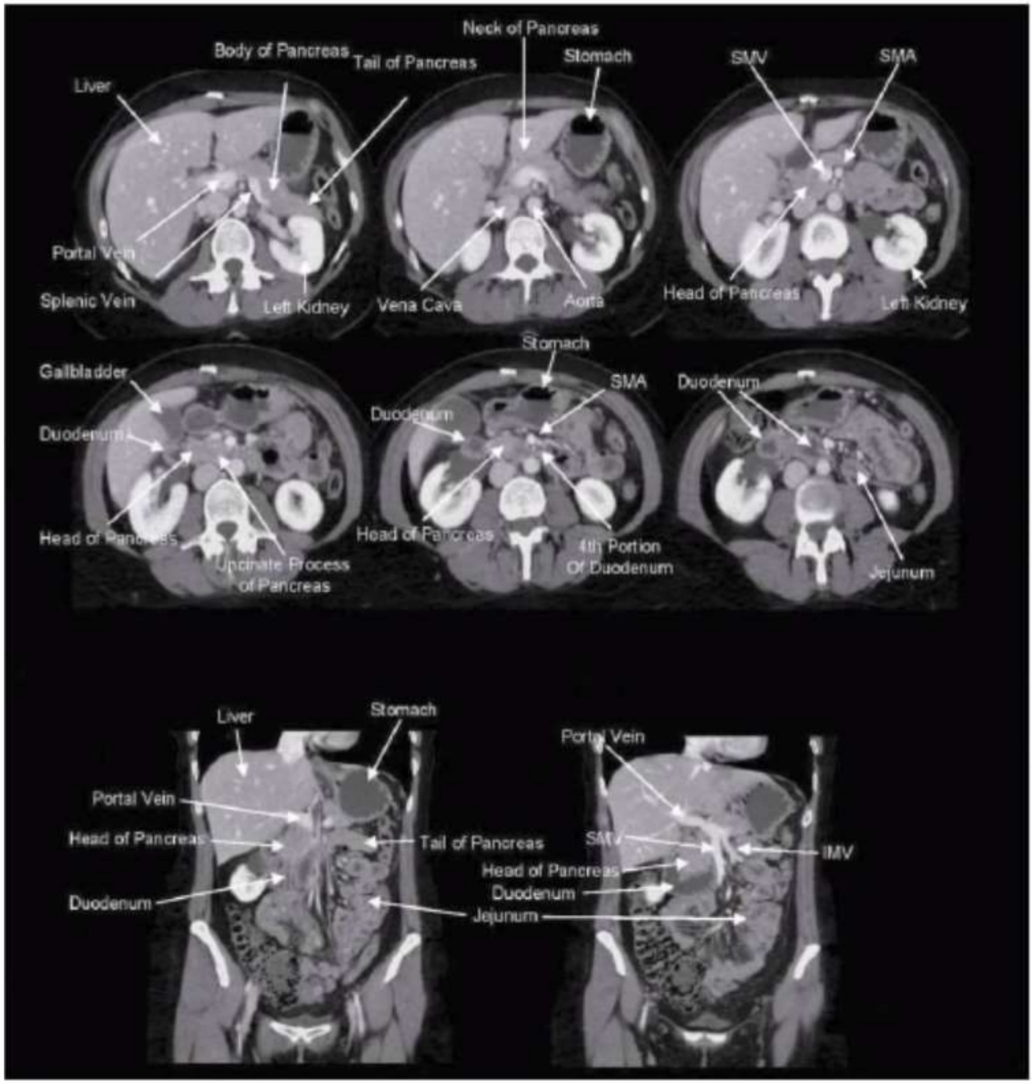




- Now, let us talk about CT-scan. That is a variant of X-rays. It is still using X-rays but it is using lots of X-rays that are sent through the patient at ***different angles***. So, instead of just patient standing and getting a single X-ray from one angle, we go into this machine, **A**. The CT-scanner has a rotating **X-ray emitter**, which is inside the gantry, shown by **(1)**, along with a parallel aligned **detector**, shown by **(2)**. These two pieces of hardware rotate together and simultaneously around the patient. The machine acquires lots of projections and those projections are then reconstructed to form the inside of the patient.
- As shown in **B** schematically, an important use of X-rays is CT or computed tomography scanning, also called CAT scans. The way it works is to imagine that **(3)** represents the cross-section of the patient. The structures shown inside the patient could be their lungs or their heart. The patient is lying on this couch or moving table and then there is an X-ray source (XRT), shown by **(4)** that is sending projections through the patient. And then, the XRT is rotating around, acquiring many different projections. The detector is shown by **(5)**.
- **Conclusion:** It turns out that we can actually reconstruct a three-dimensional structure. This case is like a 2D diagram, but in general, we can reconstruct the 3D structure of what is inside the patient from looking at a whole bunch of these projections. So, basically, the 3D image of the object is reconstructed for many projections.

CT (computed tomography) imaging

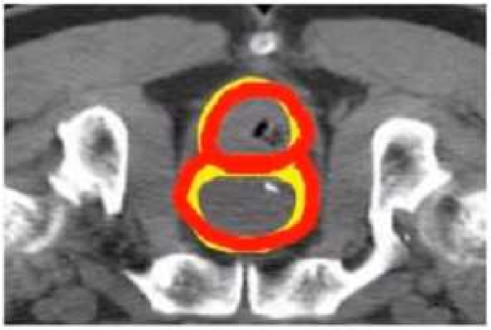
A



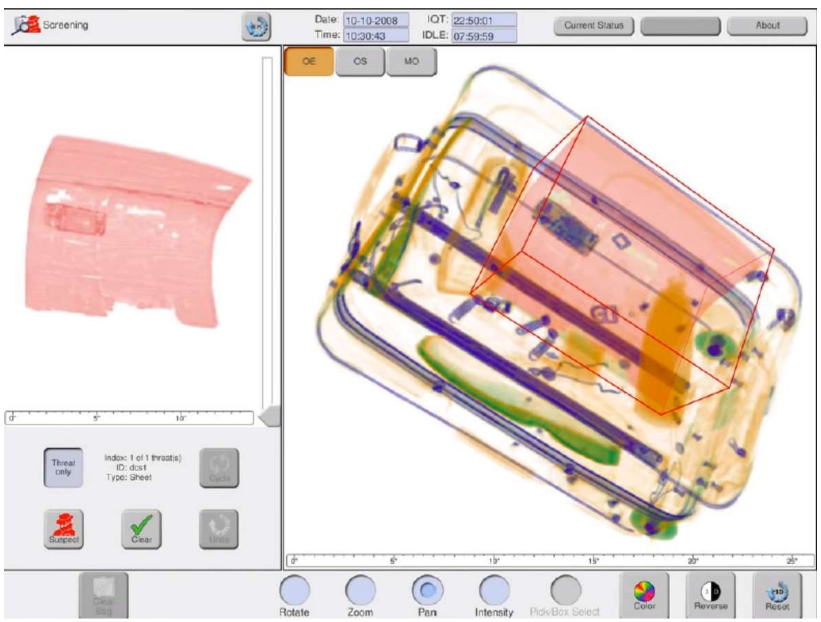
- The intuition is if we saw enough projections, there should be more than enough information there to get at what is inside the body. Images in **A** are an abdominal CT where we see many slices of the patient. Slices in **A** are what we get by doing it with the CT machine. We can pick out all sorts of structures using this imaging modality.
- A long time ago, there was a project called the **Visible Human Project** where they literally took very thin slices of a person and scan them. The NLM (the National Library of Medicine) Visible Human Project has created publicly-available complete, anatomically detailed, 3D representations of a human male body and a human female body. Specifically, they provide a public-domain library of cross-sectional cryosection, CT, and MRI images obtained from one male cadaver and one female cadaver.

CT (computed tomography) imaging

A



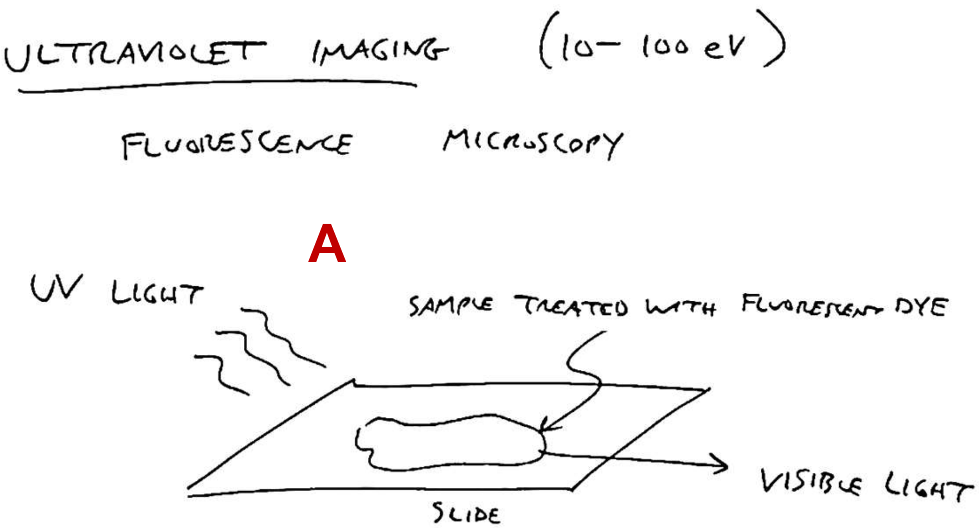
B



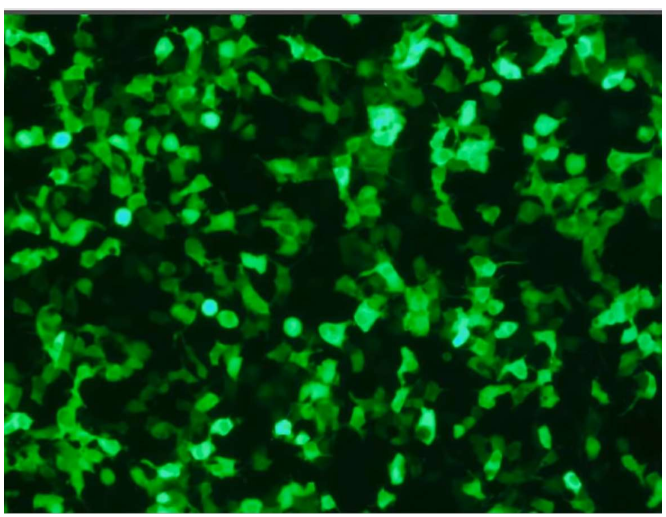
- There is a lot of ongoing research on prostate cancer detection that uses digital image processing techniques. As an example, the CT-scan shown in **A** depicts how we can analyze CT-scans slices and then try to automatically segment organs. For prostate cancer, the yellow outlines are what the doctor outlined in the CT-scan and the red outlines are what we can get by using an ***automatic algorithm***. The idea here being that we want to interpret what is going on in the CT-scan by ***automatically*** detect the cancerous tissues.
- CT-scanning is also beginning to be more used for baggage screening. So, it is probably still true that if we go to our typical airport, they are using just a **standard X-ray scanning**. But, in the back room of the airports or certainly at bigger airports, they are starting to do CT-scanning of the baggage. As shown in **B**, the advantage of this is that we can rotate the bag in 3D and look at it from all angles and see this kind of **pseudo-color image** of what is inside.
- **Conclusion:** We can imagine that CT-scanning, for both medical and non-medical applications, is a lot more reliable for screening than if we are just seeing in one X-ray projection of it.

Ultraviolet imaging

A

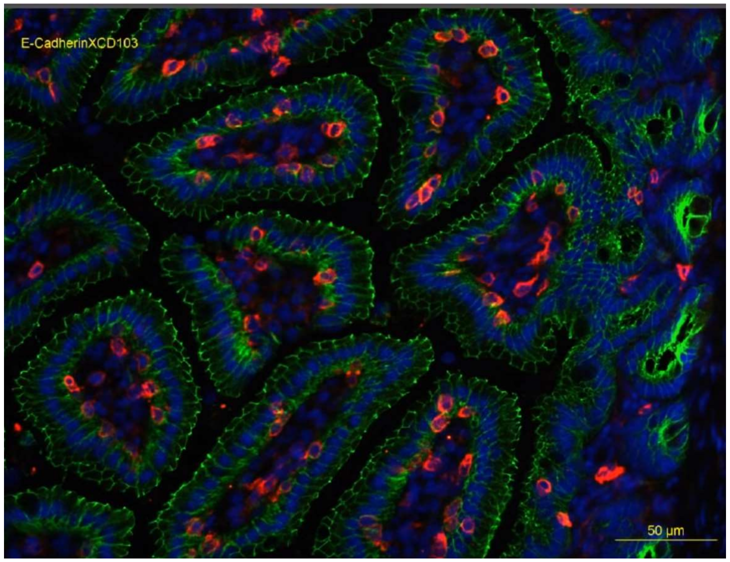


B

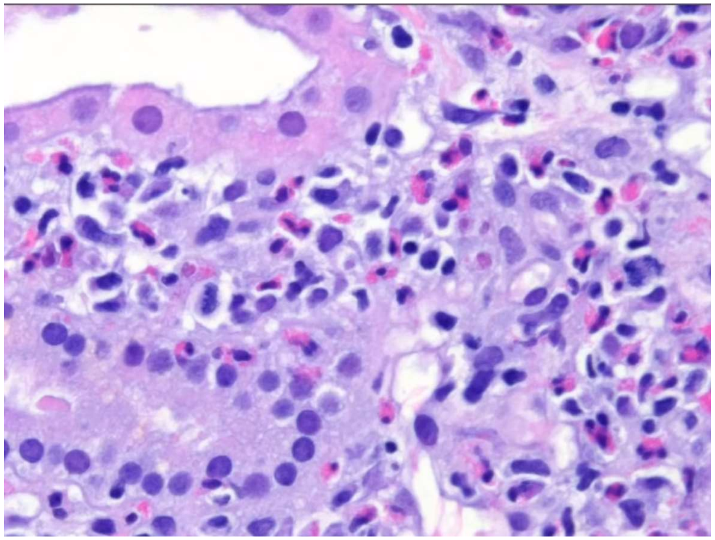


- Next is **ultraviolet imaging**. This is often used in different kinds of microscopy, especially, **fluorescence microscopy**. What that means is that we have a sample on a slide, shown in **A**, and this sample has got some sort of fluorescent dye, for example, **green** fluorescent protein, which is a very common dye. Then we shine UV (ultraviolet) light onto the sample, and what comes off is visible light. That is what fluorescence is, i.e., lower energy photons. We are going from UV down to the visible spectrum. This is very common in terms of ***imaging of biological cells***.
- For example, as shown in **B**, we inject our sample with a protein that glows green and different components of the cell will pick up that green at different densities. This image is what we get from a fluorescence microscopy, where each of these green blobs is a cell nucleus.

Ultraviolet imaging



A



B

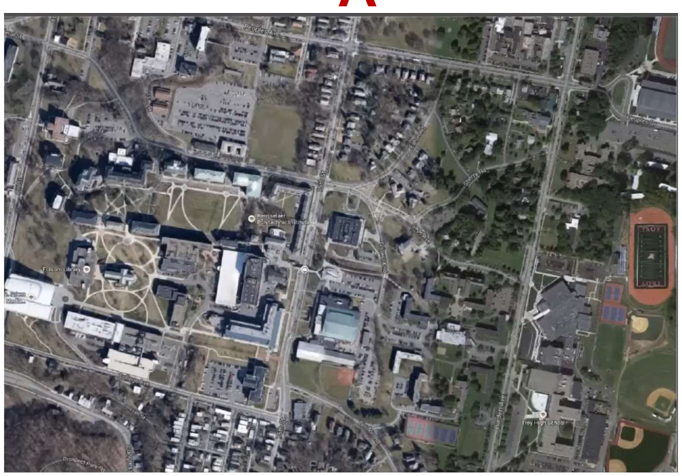
- It is even possible to ***tag*** multiple different fluorescence dyes onto different kinds of cells. As shown in **A**, we could have something that fluoresces **green**, something that fluoresces **red** or **blue** or **amber**, etc., all at the same time. So, it is a ***multi-dimensional fluorescence image***.
- An active research area in biological image processing is that after having these great images of all these different UV fluorescence proteins with different colors, we try to use DIP (Digital Image Processing) to figure out how we can automatically recognize the cells, and the things that are connecting the cells, and so on.
- In contrast, photo **B** is like a ***visible microscopy image***. That is also what we deal with in our every day life, i.e., **visible-band imaging**. Here, visible-band imaging means capturing images using light within the visible spectrum.

Visible-spectrum imaging

VISIBLE-BAND IMAGING (1 eV)

- SMARTPHONES
- CONSUMER DIGITAL IMAGING
- LIGHT MICROSCOPE
- REMOTE SENSING (SATELLITE) (ALSO INFRARED)
- MANUFACTURING / INSPECTION
- SPACECRAFT IMAGING
- LICENSE PLATE RECOGNITION
- BIOMETRICS

A



- **Visible-Band Imaging (1 eV):** Certainly, we know our **smartphones** or basically any sort of **consumer digital imaging devices** belong to this category. The image we just had on the biological imaging, the one from a **light microscope**, also belongs to this category. In light microscopy, we stained a sample with a dye and noticed that the sample takes up dye at different rates depending on what the properties of the sample is. Then we shone a light through it to see what was going on in the sample. Another example is **remote sensing**, like satellite imagery. This is definitely a big topic and also includes ***infrared***. Here, infrared is just out of the visible spectrum, but it gives us information about how hot something is. Satellite images are, e.g., what comes from Google Maps. Image **A** is from a satellite very high up. We may also be able to ***superimpose*** onto this satellite image, our infrared images. The superimposed image can give us some sense of what kind of terrain we are looking at, because different terrains give off different information in infrared.
- There is also lots of visible-band imaging in **manufacturing** or **industrial inspection**. For example, we have conveyor belts with cameras that are making sure the components that are going under them are appropriate. That happens constantly in many industrial inspections. Here, we can also mention other examples, such as what the engineers do in the automation technologies (***Systems and Control***), and how they use ***machine vision*** in the context of monitoring various industrial processes.

Visible-spectrum imaging

VISIBLE-BAND IMAGING (1 ev)

- SMARTPHONES
- CONSUMER DIGITAL IMAGING
- LIGHT MICROSCOPE
- REMOTE SENSING (SATELLITE) (ALSO INFRARED)
- MANUFACTURING / INSPECTION
- SPACECRAFT IMAGING
- LICENSE PLATE RECOGNITION
- BIOMETRICS

A

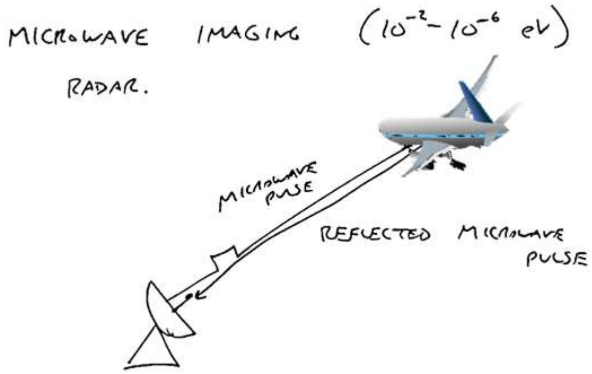
- Another example for visible-band imaging is **spacecraft imaging**. These spacecrafts look down at the earth using visible imaging.
- Also, things like **license plate recognition** or **biometrics** use visible-band imaging.
- In biometrics, shown in **A**, we are trying to extract some information about a person. Things such as their hand shape, retinal pattern, iris pattern, or fingerprint. Even, the shape of the ears can be very discriminative. Another example in biometrics is how a person walks, i.e., gait recognition (also more commonly known as gait analysis). All that information is inferred from visible images.
- In this class, we are going to motivate almost everything that we do with visible images, because they are easier to take and also easier to analyze. Later on, we can treat those other kinds of modalities just like they ***were*** visible images.

Millimeter-wave imaging

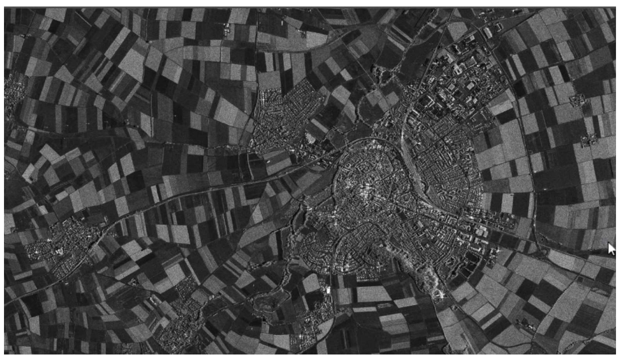
mm-WAVE (THz) IMAGING – $10^{-1} - 10^{-2}$ eV

- We can go beyond the visible spectrum the other way. So far, we started out at gamma rays and went down to X-rays, and then down to what we could see, the visible band. Now, we can actually go beyond what we can see, in the other direction to what we call **millimeter-wave** (**MMW**) **imaging** or **terahertz imaging** (or **THz imaging**). These two are slightly different from one another, but for the purpose of this course, we are treating them the same.
- MMW imaging, **30** GHz to **300** GHz (wavelengths from **1** to **10** millimeters) or THz imaging, **0.1** THz to **10** THz (wavelengths from **30** micrometers to **3** millimeters), are non-destructive imaging technique that lie on the electromagnetic spectrum between microwaves and infrared radiation. They have relatively good penetration depth, and hence, allow MMW/THz waves to see deeper into some materials, like clothing or packaging.
- They have applications in **Security Screening** at airports or border crossings to detect hidden weapons or contraband. Also, they are explored in **Non-Destructive Testing (NDT)** that are used to inspect materials for defects or hidden structures without damaging the object. It also has applications in **Medical Imaging**, where it is being used for applications, such as cancer detection or wound healing monitoring. They are also used in **Environmental Monitoring** to detect air pollution or identify specific chemicals in the environment.

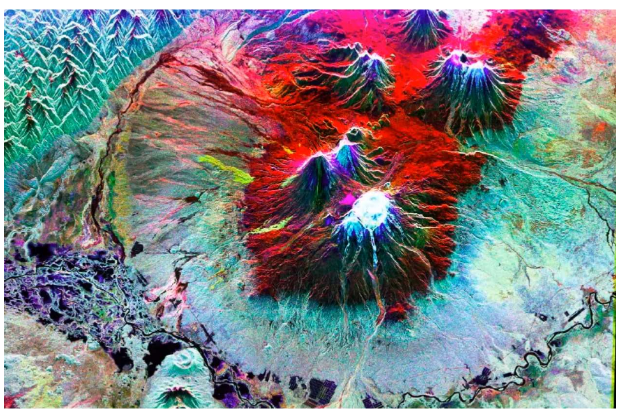
Microwave imaging



A



B



C

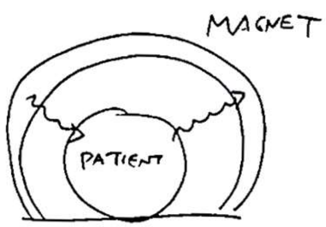
- Below millimeter wave level, we have **microwave imaging**. Here, we go from millimeter to micro and that is where we get into imaging using **radars**. In A, we have a case where it is not really so much of an image per se. What we are doing is we have some sort of an ***emitter*** that is sending out a ***microwave pulse*** and there is an object like an airplane hit by it. Now, based on whether something returns at the time of delay of the return, we can infer what is out there in the sky. Here, using radar systems, we cannot only tell what is out there in the sky, but also what is on the ground. Radar is used both standing on the ground and looking up. That is more in line of military application and sometimes we will even see planes that has a big cylinder on top, i.e., they have got a radar inside of them. These planes are probably trying to do radar imaging in the sky to other aircraft. But certainly we can point a radar imaging system down and get **terrain models**, as shown in B. Terrain models created using radar data are basically the digital representations of the Earth's surface topography.
- Using these methods, such as **synthetic aperture radar** (**SAR**), we can get these very nice detailed terrain models. We can also get a pseudo-color image of a radar image looking at the ground, as shown in C.

Radio-band imaging

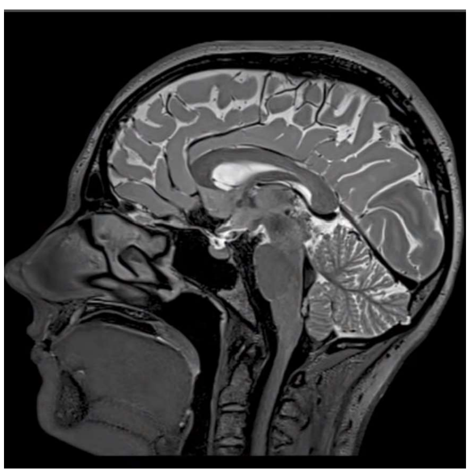
RADIO-BAND IMAGING (10^{-6} - 10^{-9} eV)

MRI (MAGNETIC RESONANCE IMAGING)

A

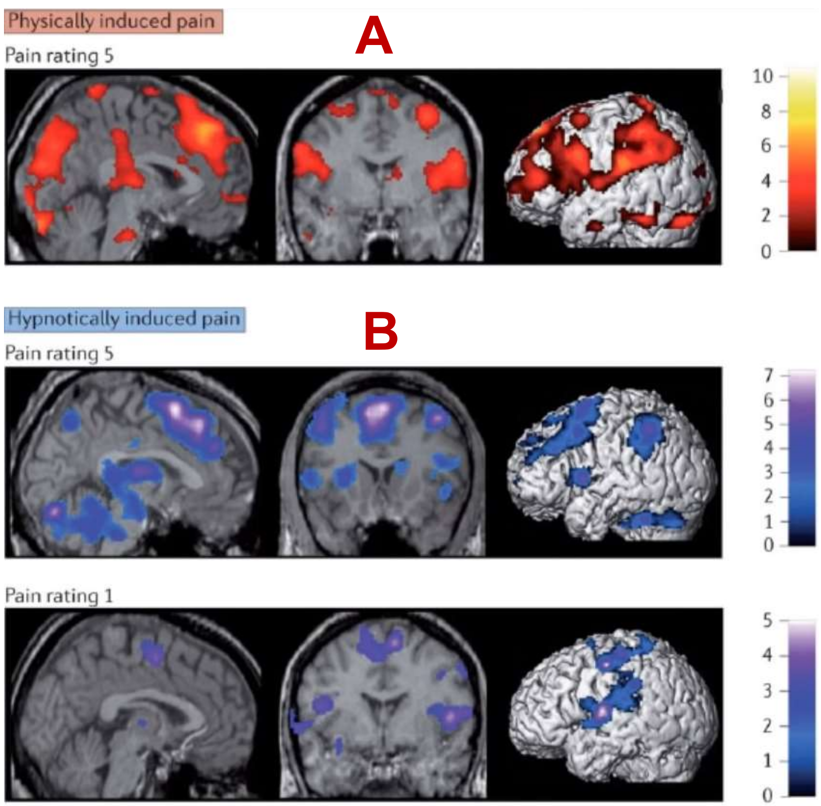


B



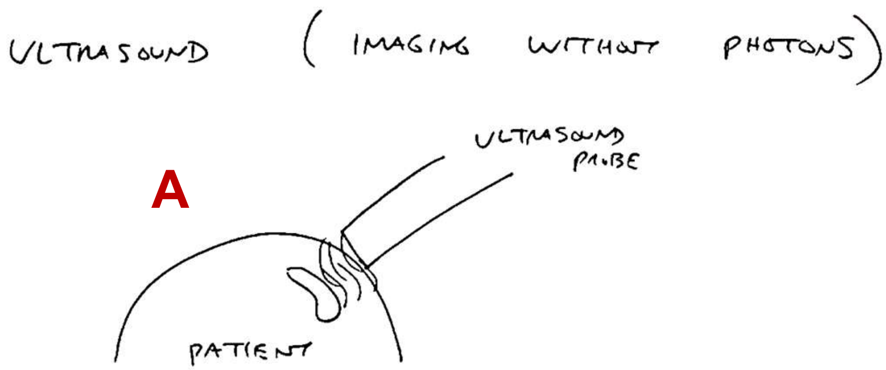
- Next we come to **radio-band imaging** and that is where we have things like the **MRI**, which stands for **magnetic resonance imaging**. In this case, as shown in **A**, we have a patient lying on a couch/table, and then they are surrounded by a huge magnet. This magnet is pulsing ***radio waves*** into the patient and those waves are being reflected and detected.
- By knowing the way the radio waves are reflected and the strength by which they are reflected we can generate a detailed 3D model of what is going on inside of the body, as shown in **B**.
- In MRI, we get images that are very detailed. One very nice characteristic of MRI is that it uses ***non-ionizing radiation***. That is, it is not like we are pumping X-ray radiation into the patient, which can potentially lead to cell mutation, or sometimes even cancer.

Radio-band imaging



- Regular MRI also has an extension or a variant that is called **functional MRI** or **fMRI**, shown in **A** and **B**. It turns out that oxygen take up in blood changes the MR images of the brain. So, the images are different for oxygenated blood versus less oxygenated blood.
- When we overlay fMRI image on top of the regular MRI image we get images like **A** or **B**. If we ask someone in this MRI tube to do some sort of a task, we can see what parts of their brain light up. Also, we can see that depending on ***how*** pain is being induced, i.e., physically or hypnotically, we will see two different sets of fMRI, **A** or **B**. Additionally, depending on the **Pain Rating** (from **1** to **5**), we get different images.
- **Conclusion:** This particular study is trying to tell us that there is a difference between the way that our brain reacts (or ***functions***) to real pain versus the pain that is not actually occurring to us, but it is being induced in us by hypnotism. In MRI systems, we can get this kind of 3D image with the ***functional part*** superimposed on the ***regular part***.

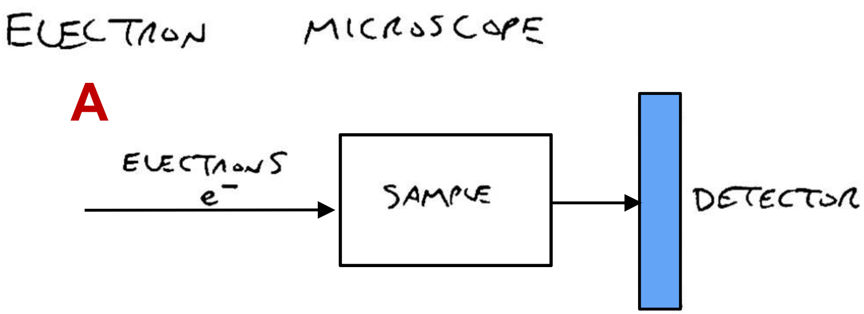
Ultrasound imaging



B

- Next, we will discuss **ultrasound imaging** modality. Ultrasound is a modality that is not technically inside the electromagnetic spectrum. There is no electromagnetic energy wave, instead, that is a ***pressure wave*** that is created from sound. As presented in **A**, what is happening with ultrasound is ***imaging without photons at all***. For all the modalities we talked about so far, there is some sort of a photon with some sort of energy involved and we use that to create an image. However, here, there is no photons at all.
- In medical ultrasound imaging, we have a patient, and an ultrasound probe and this probe is pulsing sound waves inside the patient, which we cannot hear. The structures inside the patient are bouncing back the sound waves to the detector. The images produced are usually a lot less of a high quality image than a CT-scan or an MRI-scan. But it is ***much quicker than MRI-scan***, and ***much safer*** than X-ray. We can basically do it on the fly.
- In **B**, we see an image of a pregnant woman getting the real-time image of what is going on with the fetus. So, in some sense, it is like a nice quick and dirty imaging. We could do some sort of ***automated understanding*** of what is going on in these images too, but they are a lot grainier than the images we get with ionizing radiation (X-ray or CT) or other non-ionizing radiation, such as MRI.

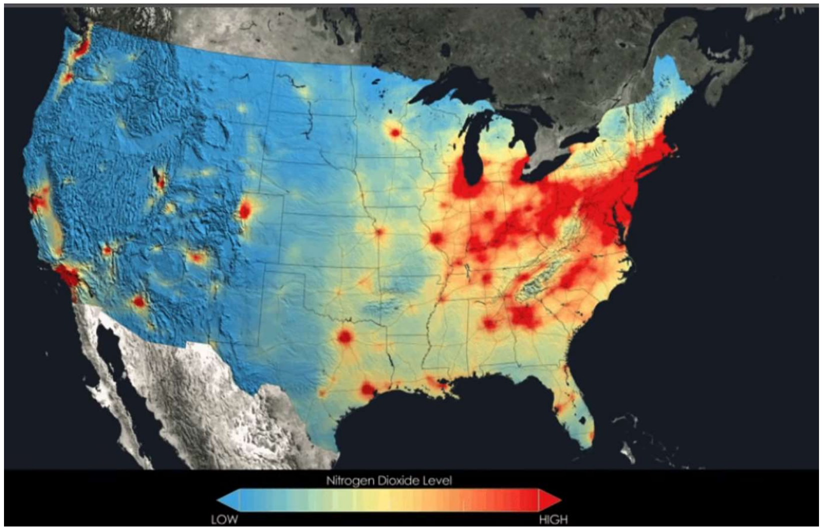
Electron microscopy



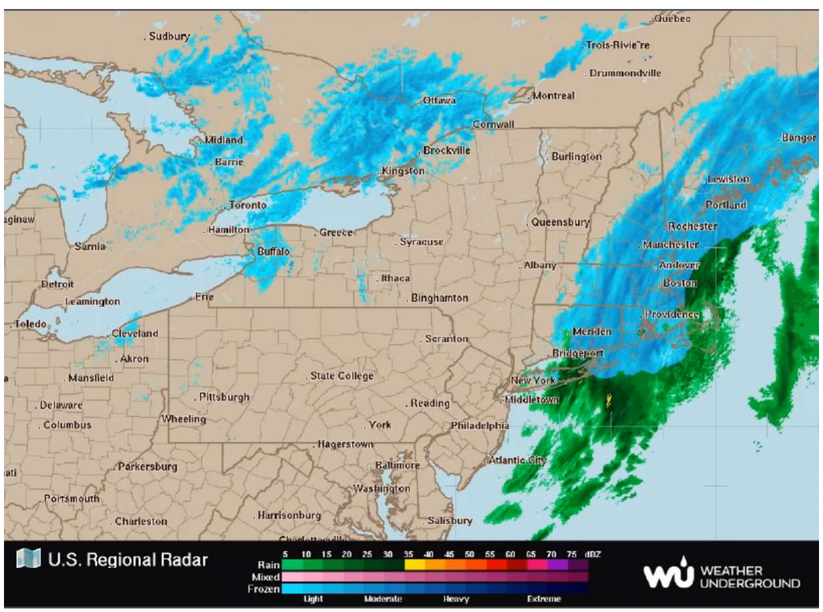
- Another non-photon-related imaging modality is **electron microscopy** imaging. Let us see how a scanning electron microscope actually works.
- As shown in **A**, we have a sample and we are throwing ***electron beams*** at it and the sample is soaking up or diffracting the electrons. On the other side, we have a detector that is going to detect the electrons leaving the samples, and hence, will create the image. So, this modality is actually very similar to X-rays, but with electrons instead of with X-rays photons.

Information overlays/human-generated imagery

A



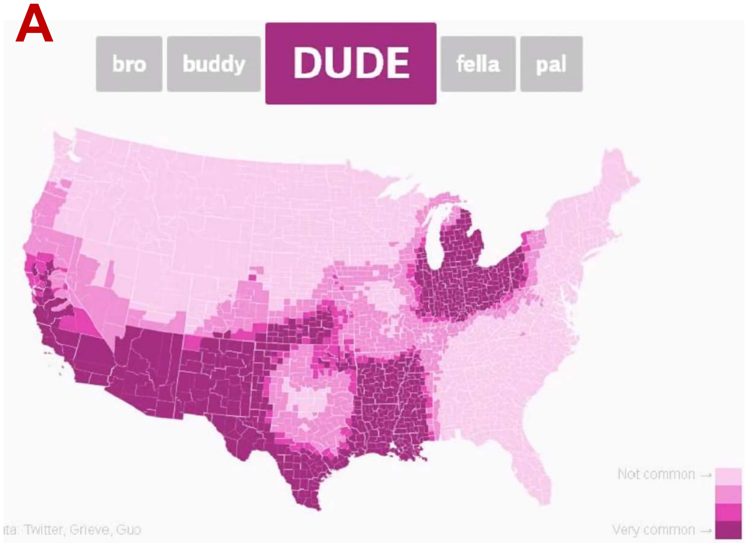
B



- There are lots of images that ***we can create on our own*** that do not come from emitter, detectors or sensors, but ***images that we synthesize as humans.*** For example, a very common thing is something like the map in **A**. This map shows the **nitrogen dioxide level** in the United States. This is like a **pollution map** over the US. This data, the nitrogen dioxide concentration level, is ***superimposed on a map***. Now, we can use image analysis techniques to understand where the hot spots of this pollution are.
- Another example is the **weather maps** (such as rainfall), shown in **B**. Here, we have got returns from radar (i.e., our data) that are superimposed on a map. Now, we could process this image jointly with color.

Information overlays/human-generated imagery

A



B

- The images we generate could be ***entirely data-driven*** like the **census data** shown in **A**. Here, we want to know where people use the word **bro**, **buddy**, **dude**, **fella** or **pal**! By looking at this image, for example, we could find the ***dude concentration***.
- Another example is shown in **B**. This image is about how we pronounce or call certain words in different parts of a country, such as in the US. In this case, people are asked about what they call the thing that they go to in order to get a drink from in the school hall. Some people call it a **water fountain** and others call it **drinking fountain** or even a **bubbler**.
- **Conclusion:** All the superimposed maps are still images, but they are not taken with any camera or scanner. But still, they are all images that we could analyze and understand what is going on.

Image processing topics; Low-, mid-, and high-level image processing

DIGITAL IMAGE PROCESSING

LOW-LEVEL : PREPROCESSING TO REMOVE NOISE, SHARPEN, OR ENHANCE AN IMAGE

IMAGE $\longrightarrow$ IMAGE

A

B

- Let us now talk about various **levels of digital image processing**. There are different levels to the problem of DIP. First, we are going to talk about **low-level image processing**.
- This is basically like ***pre-processing*** the image to ***remove noise from it***, ***sharpen it***, or ***enhance it***. So, generally, this means if the input is an image, the output is also an image.
- For example, let us look at **A** and **B**. This is a low-level image processing problem. In **A**, we have got a blurry image and we want to apply some image processing technique, e.g., we want to sharpen this image up.
- If we have blurred up an image, we have lost the high-frequency information or the high detail information, and we will probably not be able to get back this great image (shown in **B**). However, if we know how the image was blurred, we can do pretty well and recover the sharpness. This is called a low-level task in the sense that if we start with that ***blurry image***, we get a ***resulting image***.
- The same thing would apply, for example, if this image had noise in it or if it was tilted and we needed to rotate it. Or, even if we had poor contrast and we wanted to make the colors pop better. All these things are considered to be low level image processing tasks. *By no means, this terminology implies that these techniques are not important. It is just saying that we are **processing pixels to produce other pixels**.*

Image processing topics; Low-, mid-, and high-level image processing

DIGITAL IMAGE PROCESSING

LOW-LEVEL : PREPROCESSING TO REMOVE NOISE, SHARPEN, OR ENHANCE AN IMAGE

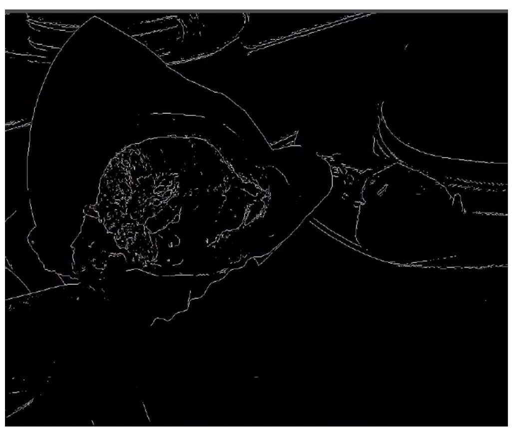
IMAGE → IMAGE

MID-LEVEL : SEGMENTING AN IMAGE INTO REGIONS /OBJECTS; DESCRIBING AN IMAGE CONCISELY

IMAGE → ATTRIBUTES (EDGES, LINES, REGIONS)

A

B



- Next are the mid-level image processing problems, things like **segmenting an image** into regions or objects, and **describing an image** concisely. Here, we start with the image and what we come out with is **attributes**, for example, edges, lines, or various little regions.
- In the context of image **A**, mid-level DIP would be like saying we take this image and we try and find the edges of that image, and we eventually end up with a **binary image** that looks like **B**. We can see that, for example, since the border between the white paper and the black or dark table is a big difference between white and black, we can really pick out that edge automatically. Whereas, when looking at the edges inside of the strawberry, there is lots of different colors inside it and when we try and do edge detection, we get more of a mess!

Image processing topics; Low-, mid-, and high-level image processing

DIGITAL IMAGE PROCESSING

LOW-LEVEL : PREPROCESSING TO REMOVE NOISE, SHARPEN, OR ENHANCE AN IMAGE

IMAGE → IMAGE

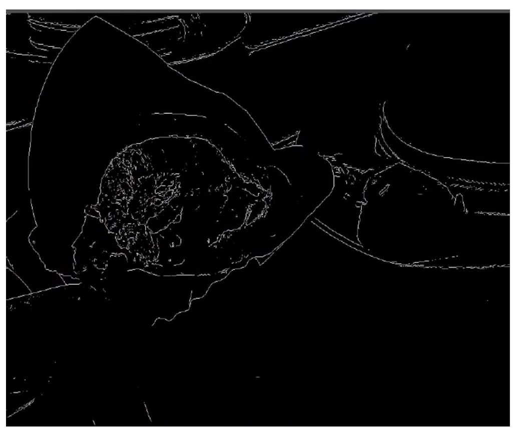
MID-LEVEL : SEGMENTING AN IMAGE INTO REGIONS / OBJECTS; DESCRIBING AN IMAGE CONCISELY

IMAGE → ATTRIBUTES (EDGES, LINES, REGIONS)

A

(*)

B



- **Detecting edges or similar attributes** is the first building block to trying to understand what is going on in the image. If we had cells on a microscope slide, maybe we could find the edges of cells, i.e., their boundaries. That would be the first step in understanding what is going on in the image.
- In summary, what we have done here is that we have taken the image we had initially, and we produced a ***description of the image*** that it is not just pixels, but is more like primitive objects. Here, we are talking about edges.
- On another note, let us suppose we were trying to find the ***orientation*** of the picnic table in **A** and ***where*** this image is taken. We could try and detect the long straight lines shown by **(*)** and superimpose those on the image. As another example, for understanding an urban scene, we might want to find the edges of buildings and windows in order to determine the vanishing points of where the camera is looking.

Image processing topics; Low-, mid-, and high-level image processing

DIGITAL IMAGE PROCESSING

LOW-LEVEL: PREPROCESSING TO REMOVE NOISE, SHARPEN, OR ENHANCE AN IMAGE

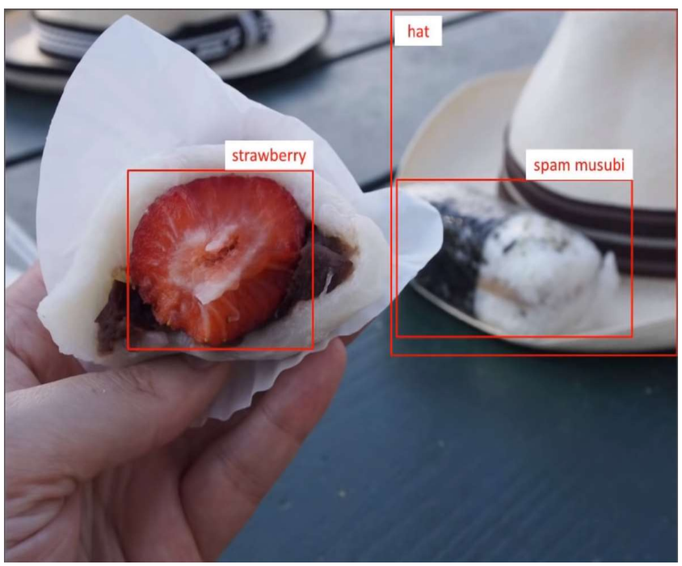
IMAGE → IMAGE

MID-LEVEL: SEGMENTING AN IMAGE INTO REGIONS/OBJECTS; DESCRIBING AN IMAGE CONCISELY

IMAGE → ATTRIBUTES (EDGES, LINES, REGIONS)

HIGH-LEVEL: MAKING SENSE OF AN IMAGE
IMAGE UNDERSTANDING, COMPUTER VISION

A



- Next is **high-level image processing**. In general, we would call this "***making sense of an image***", "image understanding", and "computer vision". For example, a computer vision problem would be something like taking our image **A**, and understanding that "this is a strawberry" or " this is a hat", etc.
- Another example (in the field of computer vision) is that we could apply a face detector to take an image of a room with people in it, and then automatically assign which pixels in the image correspond to faces. However, something like a **face recognition** process would be even higher level. Here, instead of just trying to pinpoint faces, i.e., things like "this is a face", we are also trying to actually ***recognize*** and perhaps ***name those persons***.
- Just a quick reminder that **Computer Vision** is a field of artificial intelligence (AI) that aims to train computers to interpret and understand the visual world. In simpler terms, it is about enabling computers to "see" and make sense of digital images and videos.

Major topics in image processing

MAJOR CATEGORIES FOR DIGITAL IMAGE PROCESSING

- IMAGE ACQUISITION

- Let us just drill down a little bit into the major topics in DIP.
- **Image Acquisition:** This is about how the human visual system works. That is, it is about how we, as humans, understand and perceive represented things like color, intensity, brightness, and so on. We are going to talk about how our eye and our brain work together to actually make the images that we see in our head. So, we need to talk about the biology and the perception of that a little bit. Then we are going to talk about how digital cameras actually gather light from the world, put it onto a CCD, and produce the pixel values. This is mainly about what the actual process of producing an image is when we go from the camera to the image in, let us say, Photoshop. Also, other related topics are how things like CAT-scanners work. For example, how do we actually model the process of projection of rays passing through a body in the X-rays and in the CAT-scanning?

Major topics in image processing

MAJOR CATEGORIES FOR DIGITAL IMAGE PROCESSING

- IMAGE ACQUISITION
- IMAGE MANIPULATION AND ENHANCEMENT
  (SUBJECTIVE)

- **Image Manipulation and Enhancement:** This is the kind of thing that we would do as an amateur in Photoshop, and perhaps later on, as a professional biomedical engineer in dealing with medical images. We take a picture, and we say we do not really like this picture so much. We might say things like: we wish that was more contrasty, we wish it was brighter, or we wish it was rotated a little bit so the horizon line was parallel to the ground as opposed to tilted like this, and so on. So, this is basically the process of tweaking an image, in a way that we would tweak it in Photoshop. This is mostly a ***subjective process***. This is mainly about how we make the image looks better ***to us*** by doing things like geometric operations, grayscale operations or color operations.

Major topics in image processing

MAJOR CATEGORIES FOR DIGITAL IMAGE PROCESSING

- IMAGE ACQUISITION
- IMAGE MANIPULATION AND ENHANCEMENT (SUBJECTIVE)
- IMAGE RESTORATION (OBJECTIVE)

- **Image Restoration:** This operation is a little bit more specific and a little bit more ***objective process*** than just enhancing the image. For example, if we know that the image has been blurred and if we have an estimate for how the image was blurred, then we can do some image restoration. An example is when we are taking an image of a street scene and our hands are shaking. Or, as another example, when we take a picture at night, and we cannot get a lot of light into the camera. So, here, what we get is a shaky image because maybe the lamppost is like a jaggedy line instead of being a straight line. That jaggedy line (a non-smooth line) gives us a clue for how we moved the camera. If we know what was the blur applied to the image, we can try and undo that blur to get a sharper image. And that is the case where ***there is an objectively right answer***. So, if we know how a signal has been degraded, we can use what we learned in DSP and select the best possible filter to apply in order to get a desired signal, i.e., an unblurred image.

Major topics in image processing

MAJOR CATEGORIES FOR DIGITAL IMAGE PROCESSING

- IMAGE ACQUISITION
- IMAGE MANIPULATION AND ENHANCEMENT (SUBJECTIVE)
- IMAGE RESTORATION (OBJECTIVE)
- IMAGE RECONSTRUCTION FROM PROJECTIONS

- **Image Reconstruction from Projections:** This deals with how images are generated in CT-scans. CT (Computed Tomography) imaging relies on a technique called image reconstruction from projections to create the detailed cross-sectional images of our body.
- Here is a simplified breakdown:
  - **X-ray Projections:** During a CT-scan, an X-ray source rotates around us, sending X-rays through our body at different angles. These X-rays are not directly captured as images, but rather the intensity of the X-rays that pass through our body is measured by detectors on the opposite side. This creates a series of 2D projection images containing information about the X-ray attenuation (absorption) along each path.
  - **Mathematical Transformation:** Each projection image represents a one-dimensional view of the X-ray attenuation within our body at a specific angle. The magic happens with a mathematical process called **filtered backprojection (FBP)**. This algorithm essentially takes all these projection images and mathematically backprojects the information they contain to reconstruct a 3D image of the X-ray attenuation within our body.
  - **Image Formation:** The reconstructed 3D image shows different tissue types based on their varying X-ray attenuation properties. Denser tissues, like bones, attenuate the X-rays more, appearing brighter in the final image. Conversely, less dense tissues, like soft tissues or air, attenuate less, appearing darker.

Major topics in image processing

MAJOR CATEGORIES FOR DIGITAL IMAGE PROCESSING

- IMAGE ACQUISITION
- IMAGE MANIPULATION AND ENHANCEMENT (SUBJECTIVE)
- IMAGE RESTORATION (OBJECTIVE)
- IMAGE RECONSTRUCTION FROM PROJECTIONS
- IMAGE COMPRESSION

- **Image Compression:** On the web, there are all sorts of file formats, JPEG, PNG, bitmap, etc. We know that some of those images have bigger file sizes or better **image fidelity** than others. Here, image fidelity refers to the accuracy with which a process renders an image, minimizing visible distortion or information loss. Image compression drills down into how these image compression standards work. Some of these standards are **lossless**, meaning that we can compress the image and be sure that we got exactly the same pixels that we started with. On the other hand, some of them are **lossy**, which means that we are changing the pixel values a little bit, but we are doing so at the benefit of getting much better compression ratios. Here, the image looks almost the same! For example, a JPEG image ***is*** a lossy compressed image, but it looks pretty good compared to the huge bitmap or raw file that we would get from a Google camera.

Major topics in image processing

MAJOR CATEGORIES FOR DIGITAL IMAGE PROCESSING

- IMAGE ACQUISITION
- IMAGE MANIPULATION AND ENHANCEMENT (SUBJECTIVE)
- IMAGE RESTORATION (OBJECTIVE)
- IMAGE RECONSTRUCTION FROM PROJECTIONS
- IMAGE COMPRESSION
- IMAGE SEGMENTATION (EDGES, LINES, OBJECTS)
- IMAGE UNDERSTANDING / COMPUTER VISION

- **Image Segmentation (Edges, Line, Objects):** Image segmentation is along the lines of what we were talking about when we were looking, for example, at edges, lines, objects, etc. How do we actually find these primitives in the image? That is the first step up the ladder towards the mid-level image processing. Here, we usually deal with things like detecting long straight lines in images. Or, for example, detecting things like blobs in images that come from cells in microscope slide.

- **Image Understanding/Computer Vision:** As we go a little bit further, we will need to discuss image understanding and computer vision. Some of these topics are: How various algorithms work when we take a picture or medically scan a patient and we say “this is a person”, “this is a car”, “this is a street”, “this is a tumor”, “this is the healthy tissue or organ”, and so on.

Major topics in image processing

MAJOR CATEGORIES FOR DIGITAL IMAGE PROCESSING

- IMAGE ACQUISITION
- IMAGE MANIPULATION AND ENHANCEMENT (SUBJECTIVE)
- IMAGE RESTORATION (OBJECTIVE)
- IMAGE RECONSTRUCTION FROM PROJECTIONS
- IMAGE COMPRESSION
- IMAGE SEGMENTATION (EDGES, LINES, OBJECTS)
- IMAGE UNDERSTANDING / COMPUTER VISION
- ADVANCED TOPICS (e.g., VISUAL EFFECTS)

- **Advanced Topics:** For example, how do we ***compose*** images? Any single frame of a movie is a composite of many elements. Examples are: Actors who have been shot/filmed on a green screen computer graphic, backgrounds, real props, artificial smoke, and other elements like that. These are all topics that are covered under the umbrella category of **Visual Effects** in movies. Note that in the context of computer vision and movies, the term "real props" refers to physical objects used in a scene rather than **C**omputer-**G**enerated **I**magery (**CGI**).
- How do we take all these separate elements and composite them into the same image to make that image look realistic? How do we hide the seams when the image has been manipulated and we pushed two images against each other?
- Some of the other topics are: image blending, combining images, reshaping images, resizing images, and watermarking images. For example, in newspaper printing, how do we manipulate the dots in the image, in both grayscale and color, to be able to make it look like it has all the shades of gray or shades of color.

End of Lecture 1