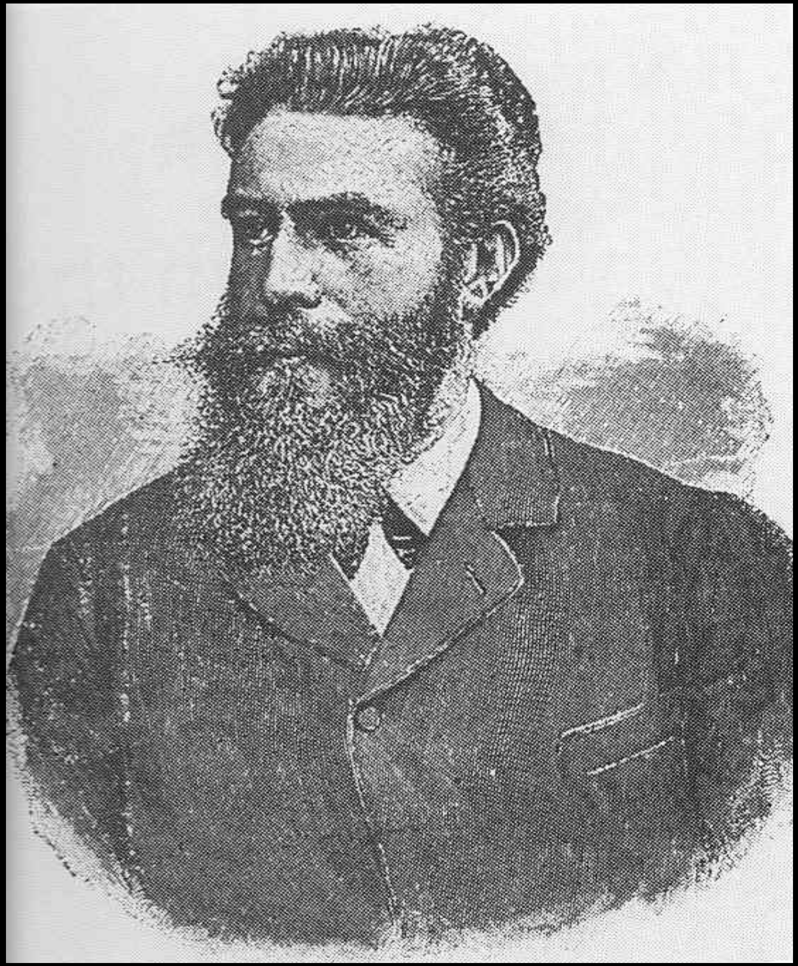
Imaging Physics - Xray



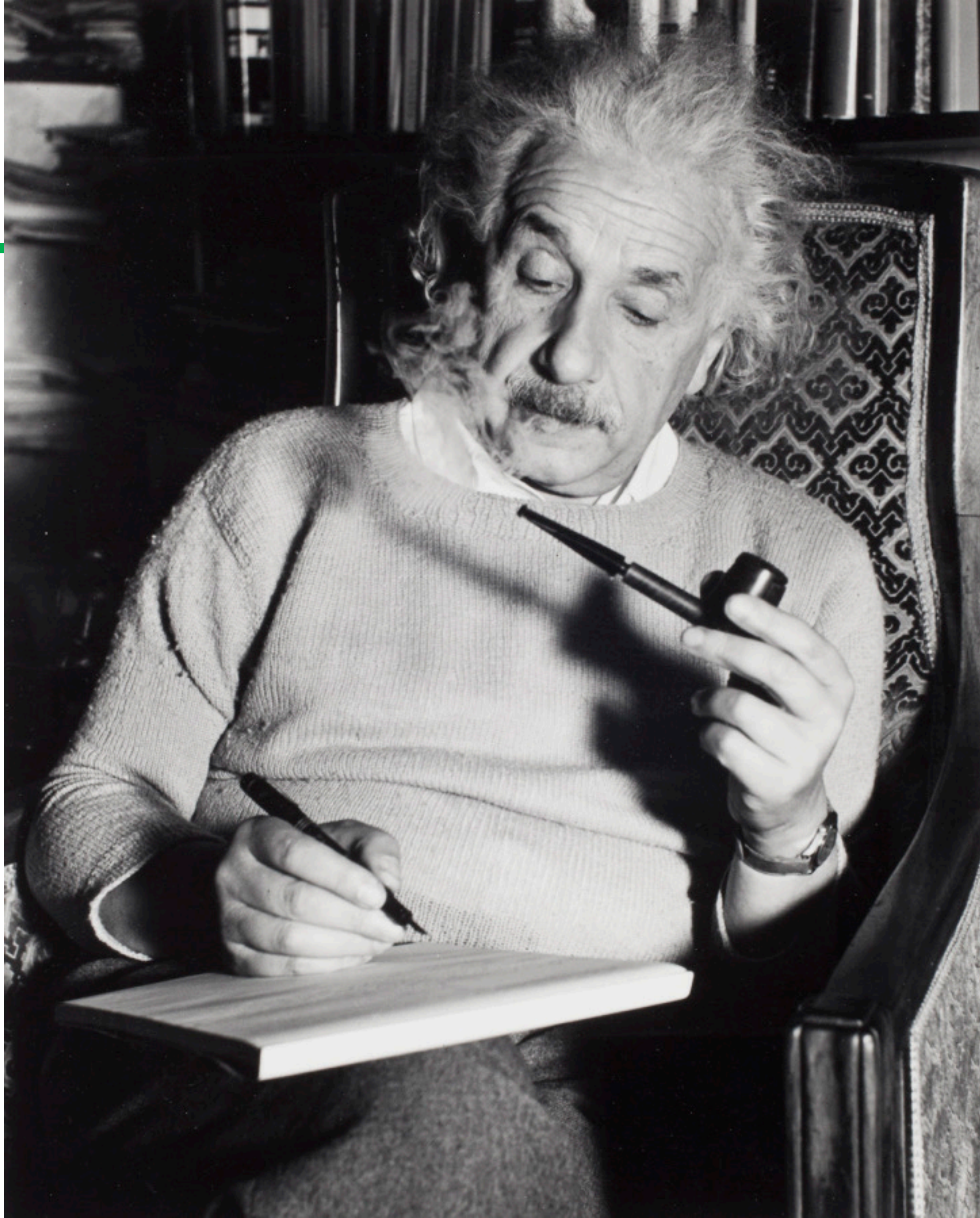
German scientist Wilhelm Röntgen, discovered it in 1895. He named it *X-radiation* to signify an unknown type of radiation. Before their discovery, X-rays were just a type of unidentified radiation

Ayelet Akselrod-Ballin, PhD

02| Imaging Physics – X-ray

X-ray

- 01 | Introduction - Why? What? How?
- 02 | Basic physics - Xray Tube, Bremsstrahlung Radiation
- 03 | Other: Nanox tube, PACS and DICOM



Applications: Fractures

We introduce MURA, a large dataset of musculoskeletal radiographs containing 40,561 images from 14,863 studies, where each study is manually labeled by radiologists as either normal or abnormal. 7 Categories: Shoulder, humerus, elbow, forearm, wrist, hand, and finger

https://arxiv.org/pdf/1712.06957.pdf

Rajpurkar, MURA: Large Dataset for Abnormality Detection in Musculoskeletal Radiographs,2018

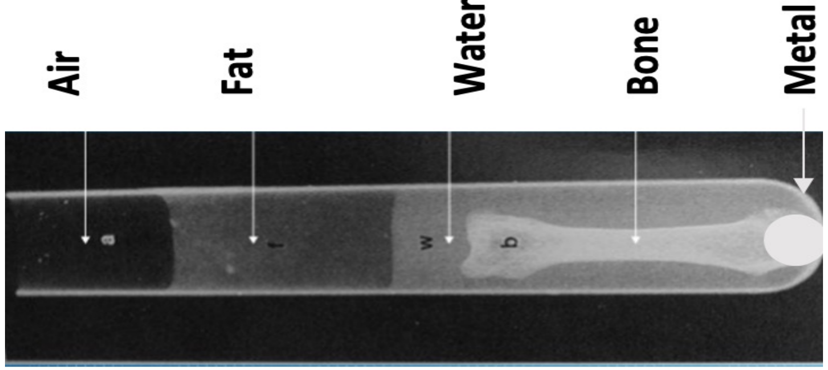
Applications: Chest X-ray


https://en.wikipedia.org/wiki/Chest_radioraph

Factors Determining the X-ray brightness

- **Density** :
  - radiolucent and radiopaque (x-ray relatively less exposed)

fluid and soft tissue



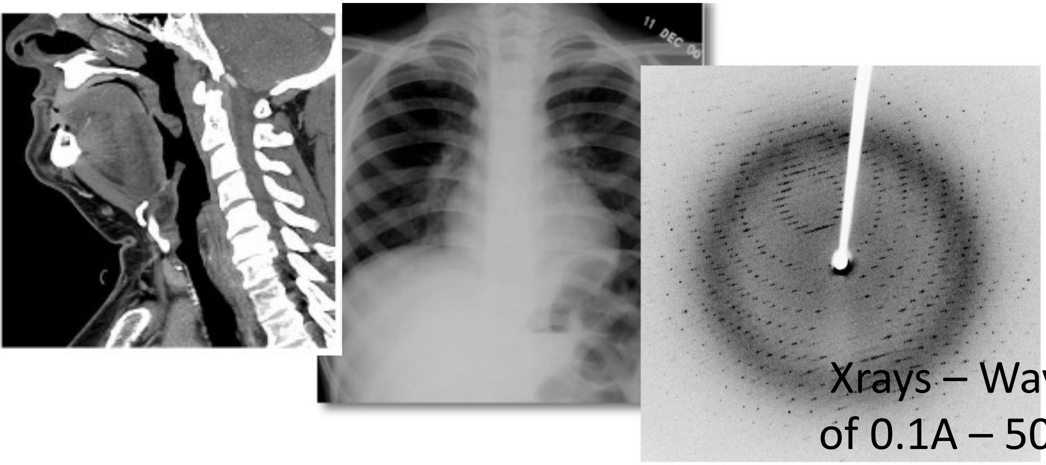
- **Thickness**:
  - The thicker the brighter
- **Exposure duration**:
  - Short/Long exposer too bright/dark (time for more X-ray's to pass)

Any part of the film where xray struck is black, white where no xray struck unexposed.

https://www.youtube.com/watch?v=PDaRNPUNc10

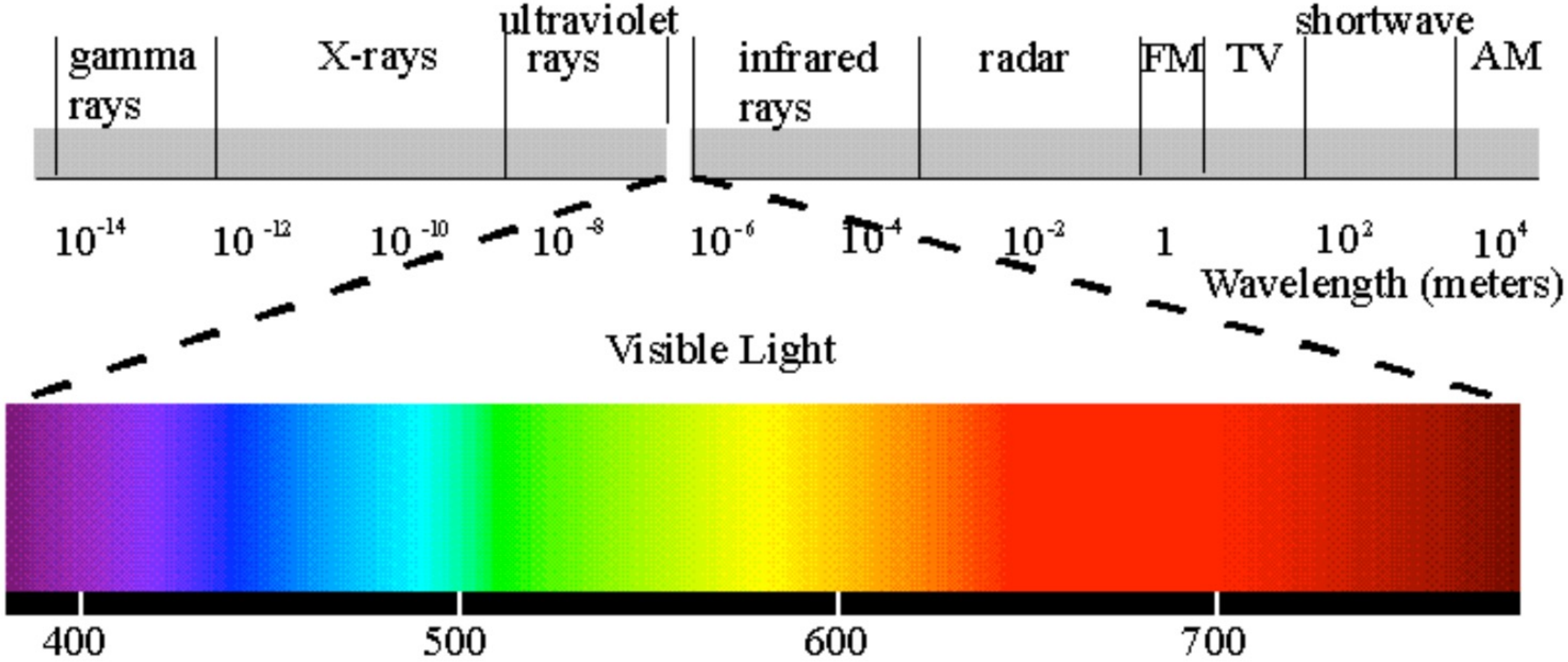
Type of Electormagnetic radiations

Medical CT



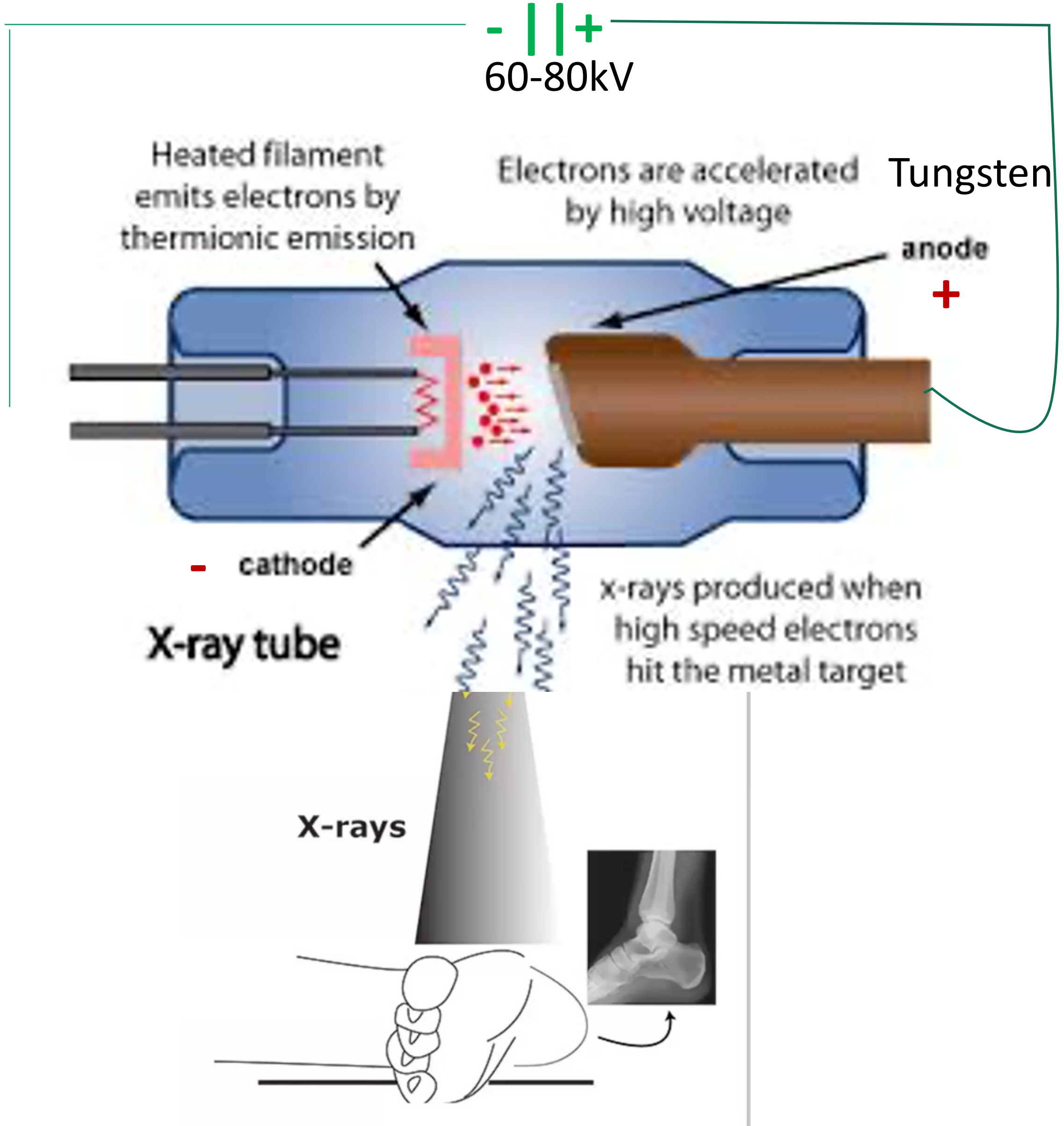
Xrays – Waves of 0.1A – 50A

Cosmic10^9;



X-ray Tubes

- A vacume tube that uses high voltage to accelerate the electrons, released by a hot cathode, at a very high speed to the anode.
- Due to the large potential difference by the time the electron reach the anode they have energy of (60-80kv)
- The frequency of the x-rays and the wavelength will depend on the type of metal. In medical X-ray tubes the target is usually tungsten, or molybdenum for softer X-rays such as in mammography.



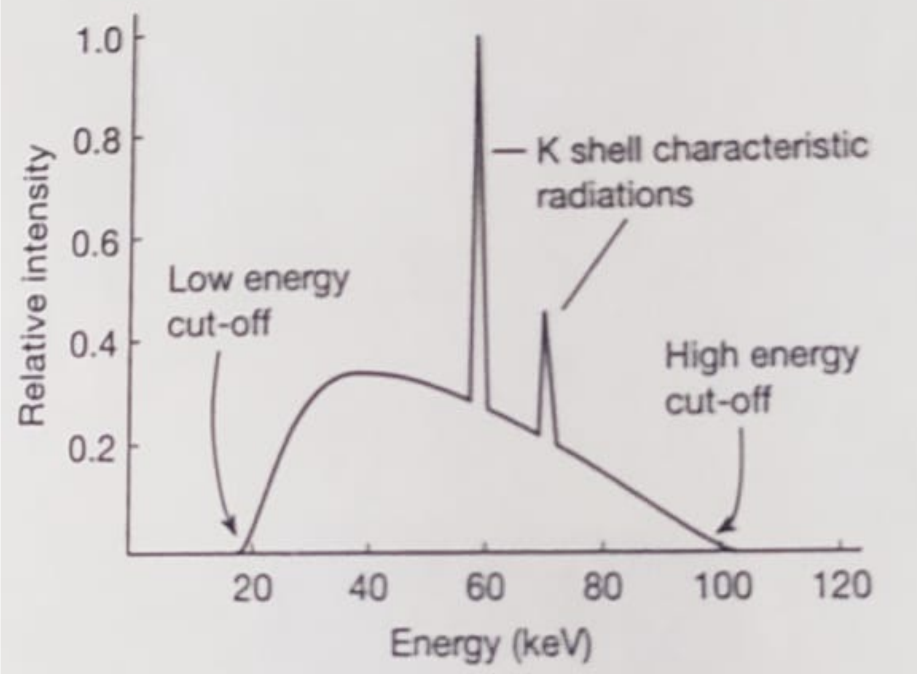
Bremsstrahlung Radiation

(1) Bremsstrahlung (braking radiation) - produced when energetic electrons are interact with the nuclei, slowdown, lose energy ⇢ energy is radiated in the form low intensity xray's radiation independent of the anode material

(2) Characteristic Xrays – when electrons interact with the atomic electrons in the target material. Electrons which transition between the shells emit photons whose energy is the particcular difference between the binding of the two shells

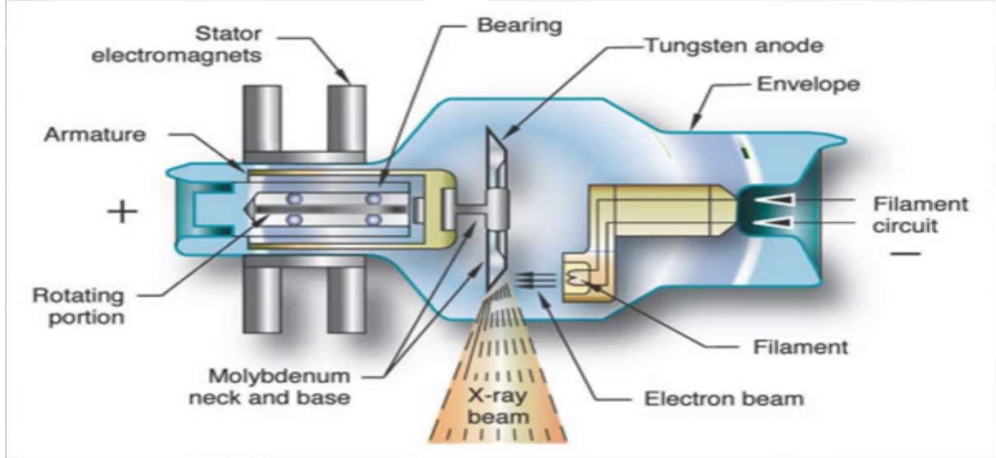
(3) For low dose x-ray - energy differences are not as high ⇢ less damaging to the body.

Spectrum radiatioin incident on a patient for an X-ray tube operatiing at 100kVp usinig tungsten target and 2.5 mm aluminium filtration



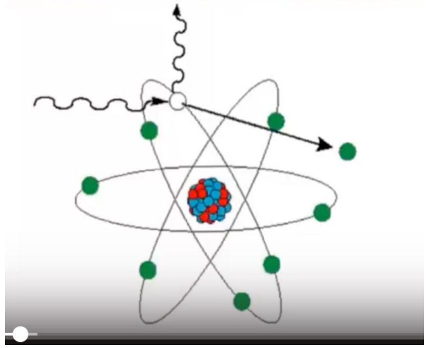
	Z	keV	keV
W	74	**59.3**	67.2
Mo	42	17.5	19.6

Thermionic emission (TE)



- TE - The process by which a Cathode emits the free electrons when it is heated.
- In thermionic Cathodes, the filament heats up by passing filament current , so it emits free electrons from the metal surface. The number of free electrons emitted by the Cathode depends on two factors: the amount of heat applied and the work function. The higher level of heat is applied, the more electrons are emitted.
- The melting point (3300C) of tunsget is very high compared to other metals.
- The anode is connected by a stem, which allows its shaft to rotate freely inside the tube. The anode shaft is surrounded inside the x-ray tube by a rotor.
- The rotation allows the anode surface being bombarded by electrons to be constantly refreshed with cooler tungsten.
- The building up of the heat is a major engineering problem.

Radiation



- For diagnostic medical X-rays imaging the x-ray energies incident upon patients runs from a low of 10keV to 150 keV
- Ionizing radiation: X-ray photons carry energy to ionize atoms and disrupt molcular bonds.
- The mean radiation dose to an adult from a chest radiograph is ~ 0.02 mSv (front view)

Exposure to cosmic rays during a roundtrip airplane flight from New York to Los Angeles 3 mrem 0.03 mSv
One dental x-ray 5 mrem 0.05 mSv
One chest x-ray 10 mrem 0.1 mSv
One mammogram 70 mrem 0.7 mSv
One year of exposure to natural radiation (from soil, cosmic rays, etc.) 300 mrem 3 mSv

https://www.cdc.gov/nceh/radiation/emergencies/measurement.htm

Xray

הטלה של אובייקט תלת -
מימדי על מישור דו-מימדי.
חיסרון:
נקודה על צילום רנטגן רגיל מתקבלת
מסכום הפוטונים העוברים דרך כל
הרקמות, על הקו המחבר בין המנורה
לבין לוח הצילום.
p
s
$I_{(p)} = I_0 \, exp(-\int_s^p \mu(s) ds)$

Nanox's cold Cathode

- Using Micro-Electrical-Mechanical-Systems (MEMS) techniques, the Nanox chip contains millions of nanoscale gates in a single chip, about 1 square cm.
- A very high electric field is induced at the nanoscale gap between the cone emitters and the hole right above them (called the "gate hole"). The high electric field is highly effective at extracting electrons from the cone emitters. These electrons make up the electron beam between the Cathode and the Anode.
- Nanox's chip: From a metal filament heated to 2,000° Celsius limiting the X-ray switching speed & stability , requiring special cooling and rotation mechanics to a field of 100-million nano-cones on a silicon chip emitting digitally controlled electron streams enabled by a low voltage.
- ⇢more control of the voltage level, the # of electrons released, expected to lengthen the tube lifetime and improve cost-effectiveness of the tube.

https://www.nanox.vision/

PACS and DICOM

- **PACS - picture archiving and communications system** which electronically stores images and reports. Method for distributing, retrieving and managing medical images. Components:
  - Secure network to the database for the image to be uploaded and transferred
  - Workstation for allowing radiologists and doctors to view and study the image
  - Secure archives for storage: image and its supporting documents can be available for the people who are permitted to view it.
- **RIS - radiological information system** is the core system for the electronic management of imaging departments. The major functions of the RIS can include patient scheduling, resource management, examination performance tracking, reporting, results distribution, and procedure billing.
  - RIS complements HIS (hospital information systems) and PACS (picture archiving and communication system), and is critical to efficient workflow to radiology practices. EMR electronic medical record , EHR = electronic health record.

https://www.adsc.com/blog/what-are-the-differences-between-pacs-ris-cis-and-dicom
https://en.wikipedia.org/wiki/Radiological_information_system

DICOM

DICOM
Digital Imaging and Communications in Medicine

- DICOM is a software integration standard that is used in Medical Imaging.
- The core of DICOM is a **file format** and a **networking protocol**.
  DICOM File Format – All Medical Images are saved in DICOM format. Medical Imaging Equipment creates DICOM files. Doctors use DICOM Viewers, computer software applications that can display DICOM images, to diagnose the findings in the images. DICOM files contain more than just images. Every DICOM file holds patient information (name, ID, sex and birth date), important acquisition data (e.g., type of equipment used and its settings), and context of the imaging study that is used to link the image to the medical treatment it was part of.
- **DICOM Network Protocol** – All medical imaging applications that are connected to the hospital network use the DICOM protocol to exchange information, mainly DICOM images but also patient and procedure information. The DICOM network protocol is used to search for imaging studies in the archive and restore imaging studies to the workstation in order to display it. There are also more advanced network commands that are used to control and follow the treatment, schedule procedures, report statuses and share the workload between doctors and imaging devices.

http://dicomiseasy.blogspot.com/2011/10/introduction-to-dicom-chapter-1.html

X-ray References

- https://www.youtube.com/watch?v=os_TPISKhiE
- https://www.youtube.com/watch?v=nSivTK6Icu4
- Medical Imaging Physics: W. Hendee, E. Ritenour, 2002
- Medical Imaging – vol 1, J. Beutel, H.Lundel, R.L. Van Metter, SPIE press , 2000
- Use the pydicom in order to write scripts that open and manipulate the dicom files.

Statistics(https://en.wikipedia.org/wiki/Receiver_operating_characteristic)

		True condition				
	Total population	Condition positive	Condition negative	Prevalence $= \frac{\Sigma \text{ Condition positive}}{\Sigma \text{ Total population}}$	Accuracy (ACC) $= \frac{\Sigma \text{ True positive} + \Sigma \text{ True negative}}{\Sigma \text{ Total population}}$	
Predicted condition	Predicted condition positive	**True positive**	**False positive,** Type I error	Positive predictive value (PPV), Precision $= \frac{\Sigma \text{ True positive}}{\Sigma \text{ Predicted condition positive}}$	False discovery rate (FDR) $= \frac{\Sigma \text{ False positive}}{\Sigma \text{ Predicted condition positive}}$	
	Predicted condition negative	**False negative,** Type II error	**True negative**	False omission rate (FOR) $= \frac{\Sigma \text{ False negative}}{\Sigma \text{ Predicted condition negative}}$	Negative predictive value (NPV) $= \frac{\Sigma \text{ True negative}}{\Sigma \text{ Predicted condition negative}}$	
		True positive rate (TPR), Recall, Sensitivity, probability of detection, Power $= \frac{\Sigma \text{ True positive}}{\Sigma \text{ Condition positive}}$	False positive rate (FPR), Fall-out, probability of false alarm $= \frac{\Sigma \text{ False positive}}{\Sigma \text{ Condition negative}}$	Positive likelihood ratio (LR+) $= \frac{\text{TPR}}{\text{FPR}}$	Diagnostic odds ratio (DOR) $= \frac{\text{LR+}}{\text{LR−}}$	F_1 score $= 2 \cdot \frac{\text{Precision} \cdot \text{Recall}}{\text{Precision} + \text{Recall}}$
		False negative rate (FNR), Miss rate $= \frac{\Sigma \text{ False negative}}{\Sigma \text{ Condition positive}}$	Specificity (SPC), Selectivity, True negative rate (TNR) $= \frac{\Sigma \text{ True negative}}{\Sigma \text{ Condition negative}}$	Negative likelihood ratio (LR−) $= \frac{\text{FNR}}{\text{TNR}}$		

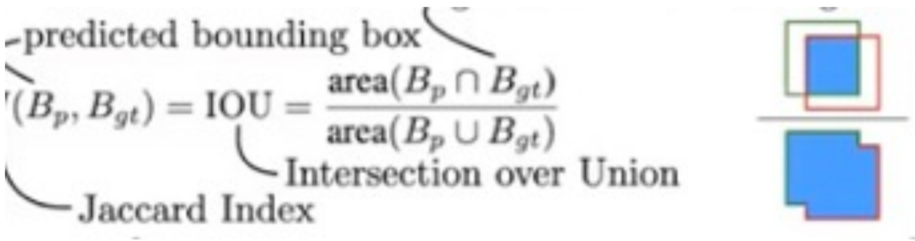
IV Detection

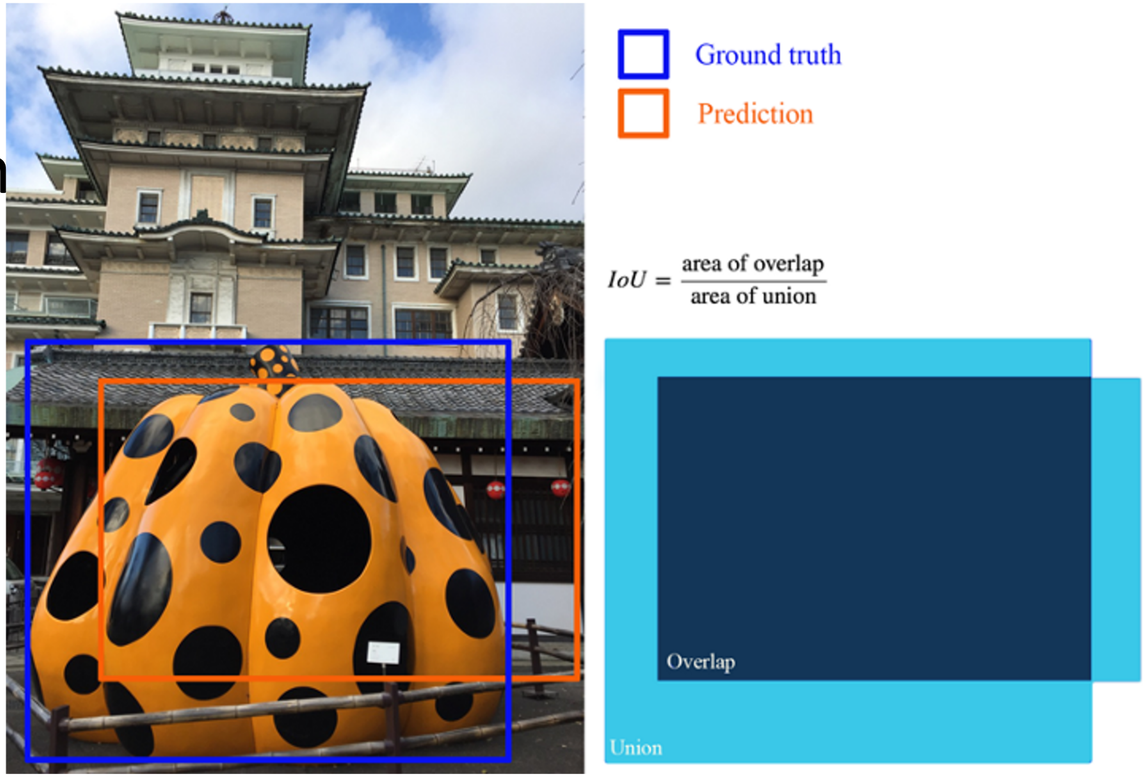
Detecction is the task of finding and localizng an object(s) in an image i.e. given an image return for each object:

1. bounding box (x1,y1,x2,y2)/(x,y,width,height)
2. Box type
3. Cononfidence

Metrics Definitions: Intersection over Union(IOU)

- IoU Values would be in [0, 1].
- 0 - no overlap at all. 1- exact match.
- Therefore, hit threshold should be chosen
- IoU>0.5 - detections tasks standard.
- IoU>0.1 - sufficient for CAD since the radiologist would see a box adjacent the lesion.





https://medium.com/@jonathan_hui/map-mean-average-precision-for-object-detection-45c121a31173

V.a. F1 score

$$\text{F1-score} = 2 \times \frac{\text{Precision} \times \text{Recall}}{\text{Precision} + \text{Recall}}$$

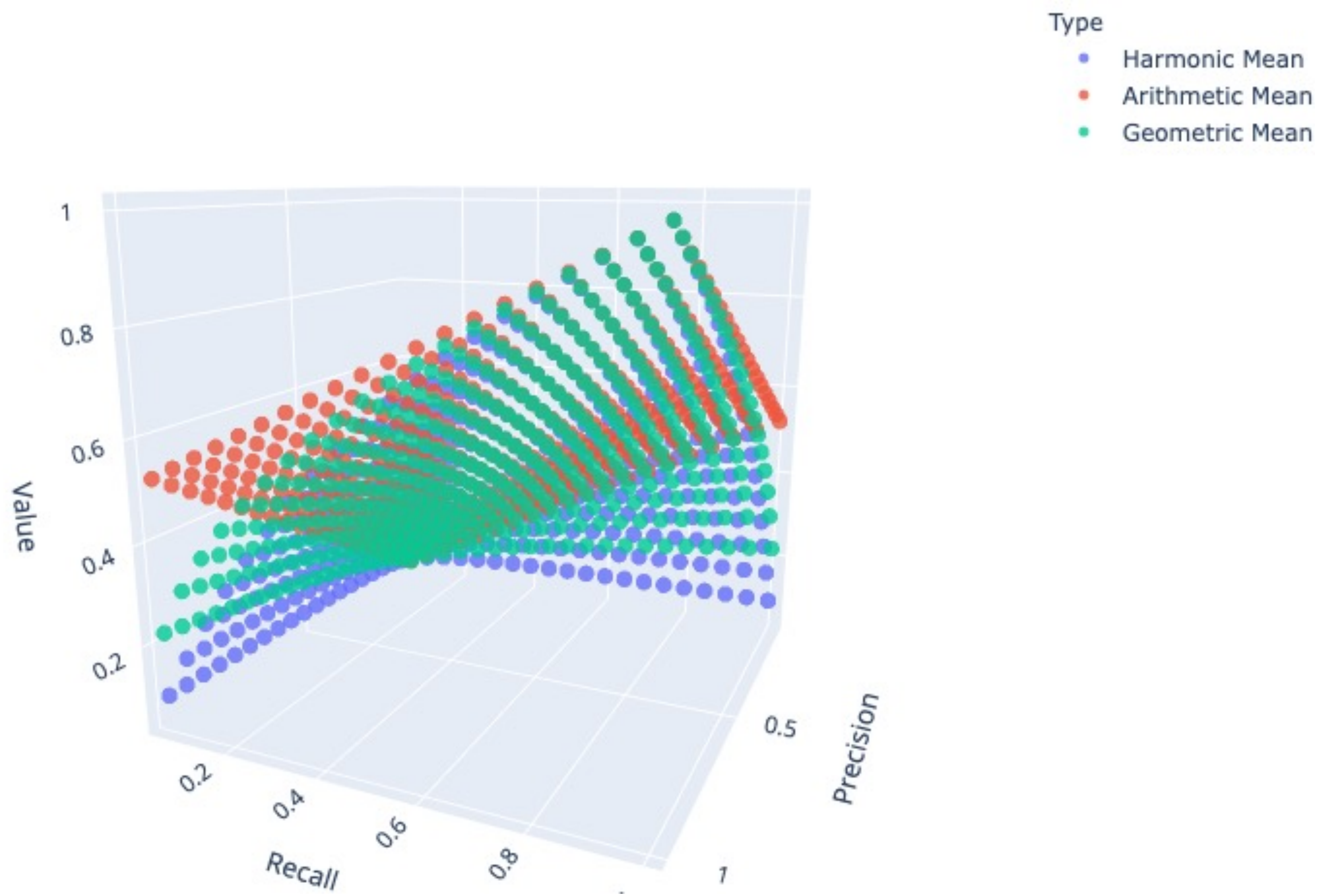
$$\text{F1-score} = \frac{2}{\frac{1}{\text{Precision}} + \frac{1}{\text{Recall}}}.$$

The model you select depends greatly on the evaluation metric you choose, which in turn depends on the relative impacts of errors of FPs and FNs in your use-case.

Why Harmonic Mean?

Harmonic Mean	Arithmetic Mean	Geometric Mean
$\frac{2}{\left(\frac{1}{x}\right)+\left(\frac{1}{y}\right)}$	$\frac{x+y}{2}$	$\sqrt{xy}$

https://towardsdatascience.com/essential-things-you-need-to-know-about-f1-score-dbd973bf1a3#d3cf



harmonic mean discourages hugely unequal values and extremely low values. We would want F1-score **to give a *reasonably* low score when either precision or recall is low** and only harmonic mean enables that

V.b. Precision@k & Recall@k

- *Precision at k is the proportion of recommended items in the top-k set that are relevant*
  - Its interpretation is as follows. Suppose that my precision at 10 in a top-10 recommendation problem is 80%. This means that 80% of the recommendation I make are relevant to the user.
- Precision@k = (# of recommended items @k that are relevant) / (# of recommended items @k)
- *Recall at k is the proportion of relevant items found in the top-k recommendations*
  - Suppose that we computed recall at 10 and found it is 40% in our top-10 recommendation system. This means that 40% of the total number of the relevant items appear in the top-k results.
- Mathematically defined as follows:
- Recall@k = (# of recommended items @k that are relevant) / (total # of relevant items)

https://medium.com/@m_n_malaeb/recall-and-precision-at-k-for-recommender-systems-618483226c54#:~:text=Precision%20at%20k%20is%20the,are%20relevant%20to%20the%20user.

Kappa statistics –reliability

Cohen's kappa statistic measures interrater reliability (sometimes called interobserver agreement). Interrater reliability, or precision, happens when your data raters (or collectors) give the same score to the same data item.
Historically, percent agreement (number of agreement scores / total scores) was used to determine interrater reliability.
However, chance agreement due to raters guessing is always a possibility .The Kappa statistic takes this into account .

κ	Interpretation
< 0	No agreement
0.0 — 0.20	Slight agreement
0.21 — 0.40	Fair agreement
0.41 — 0.60	Moderate agreement
0.61 — 0.80	Substantial agreement
0.81 — 1.00	Almost perfect agreement

$$\text{Kappa} = \frac{\left(\text{Percent Observed Agreement}\right) - \left(\text{Percent Agreement Expected by Chance Alone}\right)}{100\% - \left(\text{Percent Agreement Expected by Chance Alone}\right)}$$

$$\text{הסכמה \%} = \frac{\text{סך הבדיקות עליהם הסכימו}}{\text{סך הבדיקות מבוצעו}} \times 100$$

- מונה : האם ההסכמה שבין הבודקים טובה יותר מהסכמה מקרית?
- מכנה : עד כמה יכולה ההסכמה להשתפר לעומת הסכמה צפויה באופן מקרי?

שיטת עבודה :

1. מחשבים % הסכמה מטבלת 2*2 של Obs
2. משלימים טבלת 2*2 של Exp (ע"פ הTotal במעטפת אשר זהה לטבלת Obs) ומחשבים % הסכמה של Exp
4. מחשבים Kappa ע"פ הנוסחא וקובעים מידת הסכמה ע"פ טבלת פירוש ערכי Kappa (>0.4, 0.4-0.75, <0.75)

הערות :

- בהמצאות נמוכה, ההסכמה יכולה להיות גבוהה וKappa נמוכה
- ניתן לקבל ערכים שליליים של Kappa, כאשר % ההסכמה הנצפה נמוך מן הצפוי