Lecture 1 - Introduction

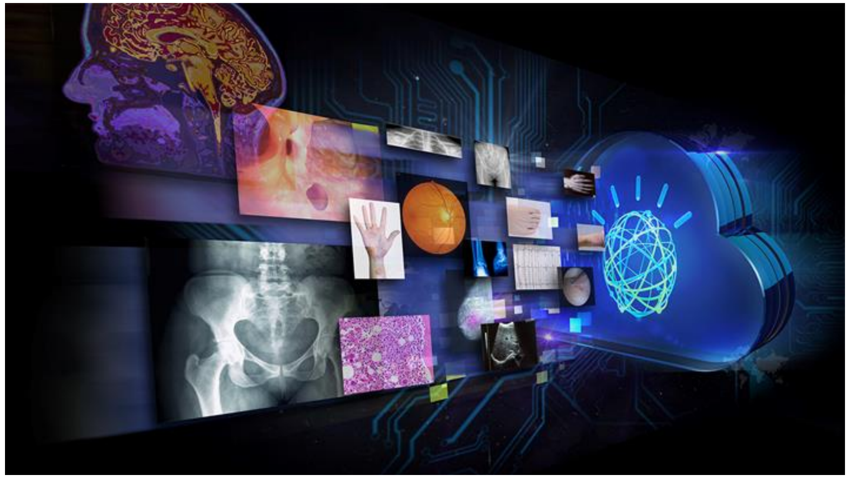
This lecture will cover:

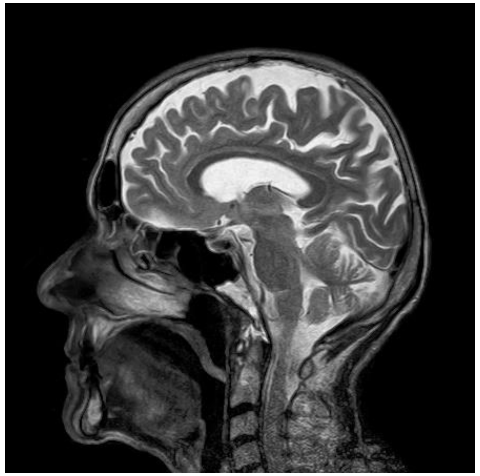
- Introduction to medical imaging
  - What is Medical Imaging?
  - History of Medical Imaging
  - Medical Imaging Modalities
  - Contents of the course
- Fundamentals of medical diagnosis
- Image Acquisition *(CH1.3, CH1.7)*
  - Data acquisition
  - Dynamic range and resolution
  - Sampling frequency and bandwidth

What is Medical Imaging

Medical Imaging

- **Medical visual representation of human in multi-modality and multi-dimension**
  - Revealing internal structures of a body (anatomy)
  - Visual representation of the function of some organs or tissues (physiology).
- **Goals**
  - Clinical analysis (Diagnosis)
  - Medical intervention (Treatment)
  - Establishing a database of normal anatomy and physiology to make it possible to identify abnormalities.





History

CT+MRI, PET+MRI
(Gen. Electric, 2010)
CT tomography
(A. Cormack, G. Hounsfield, 1972)
MRI tomography
(P. Lauterbur, P. Mansfield, 1973
since 80ties)
angiography
(E. Moniz, 1927)
ultrasonography
(I. Edler, C. Hertz, 1953)
radiography
(J. Hall-Edwards, 1896)
Endoscopic capsule
(Given Imaging, 2001)
PET tomography
(M. Ter-Pogossian et.al., 1973)
Thermography
(since 60thies, XX c.)
endoscopy
(B. Hirschowitz, since 70ties)

Categories

- **Imaging content**
  - **Biomedical micro-imaging**
    - ✓ Scanning Electron Microscope (SEM)
    - ✓ Optical microscope
  - **Medical imaging**
    - ✓ **Radioactive:** X ray, CT, Nuclear medicine, PET, SPECT
    - ✓ **Non-radioactive:** MRI, Ultrasound, Thermography, Photoacoustic
- **Functional and Anatomical**

Comparison of Imaging modalities

Imaging modalities	**2D**	**3D**	**Other technology**
X-ray	Planar radiography	CT	Angiography, fluoroscopy,
Nuclear medicine	Gamma camera	SPECT, PET/TOF PET	
MRI		MRI	fMRI
Ultrasound	B-mode, M-mode,	Multi-dimension arrays	Doppler ultrasound

Content

- **What we will learn?**
  - ✓ Imaging physics and theory
  - ✓ Imaging instrumentation
  - ✓ Imaging characteristics
  - ✓ Application of different image modalities
- **What we won’t learn**
  - x Electronic signal acquisition --- 电路基础，模拟数字电路
  - x Signal processing --- 信号与系统，数字信号处理
  - x Image analysis --- 数字图像处理、计算机图形学、计算机视觉、机器学习、深度学习
  - x Medical diagnosis

Knowledge & Requirement

Involved knowledge

- Physics
- Mathematics
- System and signals analysis
- Anatomy and Physiology

Learning outcome

- Understanding the principles of various medical imaging techniques.
- Computing parameters for each imaging modality such as resolution, signal to noise ratio.
- Evaluating data sets from different devices
- Evaluating and analyzing image properties
- Discussing how a specific imaging modality can relate to an imaging scenario in the body.
- Quality control and Health protection

Lecture 1 - Introduction

This lecture will cover:

– Introduction to medical imaging
  - What is Medical Imaging?
  - History of Medical Imaging
  - Medical Imaging Modalities
  - Contents of the course

– Fundamentals of medical diagnosis

– Image Acquisition *(CH1.3, CH1.7)*
  - Data acquisition
  - Dynamic range and resolution
  - Sampling frequency and bandwidth

Fundamentals

- **Diagnostic Test** (*Reference: CH1.2*)
  - Binary Classification
  - Confusion Matrix
  - Evaluation metrics
  - ROC Curve
- **Anatomical Planes**

Binary Classification (二元分类)

		True Condition (真实值)	
		Positive (阳性)	**Negative** (阴性)
Predicted Condition (预测值)	**Positive** (阳性)	**True Positive** (TP) 真阳性	**False Positive** (FP) 伪阳性
	Negative (阴性)	**False Negative** (FN) 伪阴性	**True Negative** (TN) 真阴性

Confusion Matrix (Contingency Table)

<table>
<tr><td colspan="2"></td><td colspan="2">True condition</td><td colspan="3"></td></tr>
<tr><td></td><td>Total population</td><td>Condition positive</td><td>Condition negative</td><td>Prevalence = $\frac{\Sigma \text{ Condition positive}}{\Sigma \text{ Total population}}$</td><td colspan="2">Accuracy (ACC) = $\frac{\Sigma \text{ True positive} + \Sigma \text{ True negative}}{\Sigma \text{ Total population}}$</td></tr>
<tr><td rowspan="2">Predicted condition</td><td>Predicted condition positive</td><td>True positive,
Power</td><td>False positive,
Type I error</td><td>Positive predictive value (PPV), Precision = $\frac{\Sigma \text{ True positive}}{\Sigma \text{ Predicted condition positive}}$</td><td colspan="2">False discovery rate (FDR) = $\frac{\Sigma \text{ False positive}}{\Sigma \text{ Predicted condition positive}}$</td></tr>
<tr><td>Predicted condition negative</td><td>False negative,
Type II error</td><td>True negative</td><td>False omission rate (FOR) = $\frac{\Sigma \text{ False negative}}{\Sigma \text{ Predicted condition negative}}$</td><td colspan="2">Negative predictive value (NPV) = $\frac{\Sigma \text{ True negative}}{\Sigma \text{ Predicted condition negative}}$</td></tr>
<tr><td colspan="2" rowspan="2"></td><td>True positive rate (TPR), Recall, Sensitivity, probability of detection $= \frac{\Sigma \text{ True positive}}{\Sigma \text{ Condition positive}}$</td><td>False positive rate (FPR), Fall-out, probability of false alarm $= \frac{\Sigma \text{ False positive}}{\Sigma \text{ Condition negative}}$</td><td>Positive likelihood ratio (LR+) $= \frac{\text{TPR}}{\text{FPR}}$</td><td rowspan="2">Diagnostic odds ratio (DOR) $= \frac{\text{LR+}}{\text{LR−}}$</td><td rowspan="2">$F_1$ score = $\frac{1}{\frac{\frac{1}{\text{Recall}} + \frac{1}{\text{Precision}}}{2}}$</td></tr>
<tr><td>False negative rate (FNR), Miss rate $= \frac{\Sigma \text{ False negative}}{\Sigma \text{ Condition positive}}$</td><td>Specificity (SPC), Selectivity, True negative rate (TNR) $= \frac{\Sigma \text{ True negative}}{\Sigma \text{ Condition negative}}$</td><td>Negative likelihood ratio (LR−) $= \frac{\text{FNR}}{\text{TNR}}$</td></tr>
</table>

https://en.wikipedia.org/wiki/Receiver_operating_characteristic#Curves_in_ROC_space

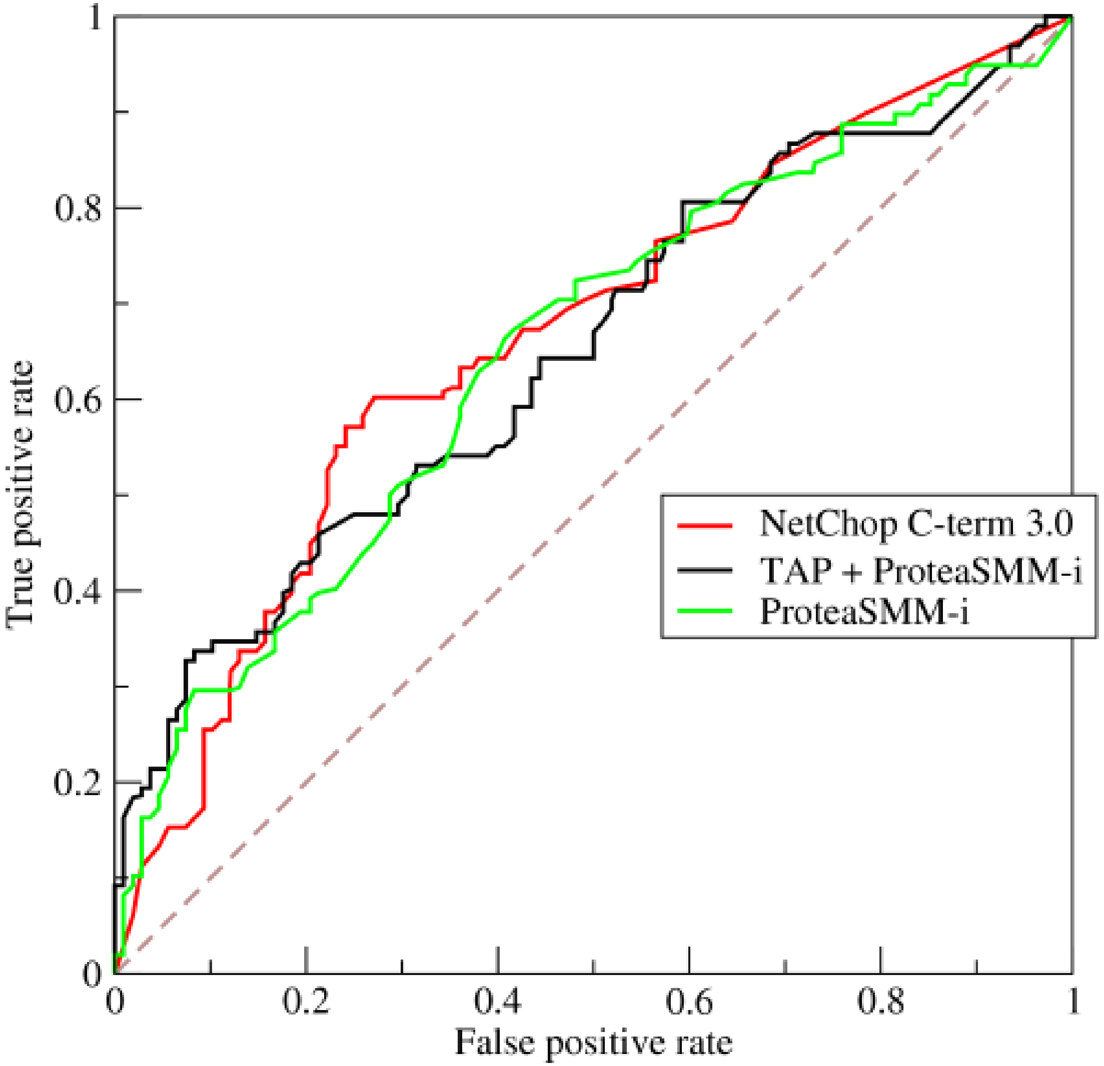
Evaluation Metrics

- **Sensitivity (敏感性) or Recall :** $\mathbf{Sensitivity} = \dfrac{\mathbf{TP}}{\mathbf{TP+FN}}$
- **Precision :** $\mathbf{Precision} = \dfrac{\mathbf{TP}}{\mathbf{TP+FP}}$
- **Specificity (特异性) :** $\mathbf{Specificity} = \dfrac{\mathbf{TN}}{\mathbf{TN+FP}}$
- **Accuracy :** $\mathbf{Accuracy} = \dfrac{\mathbf{TP+TN}}{\mathbf{TP+FP+TN+FN}}$

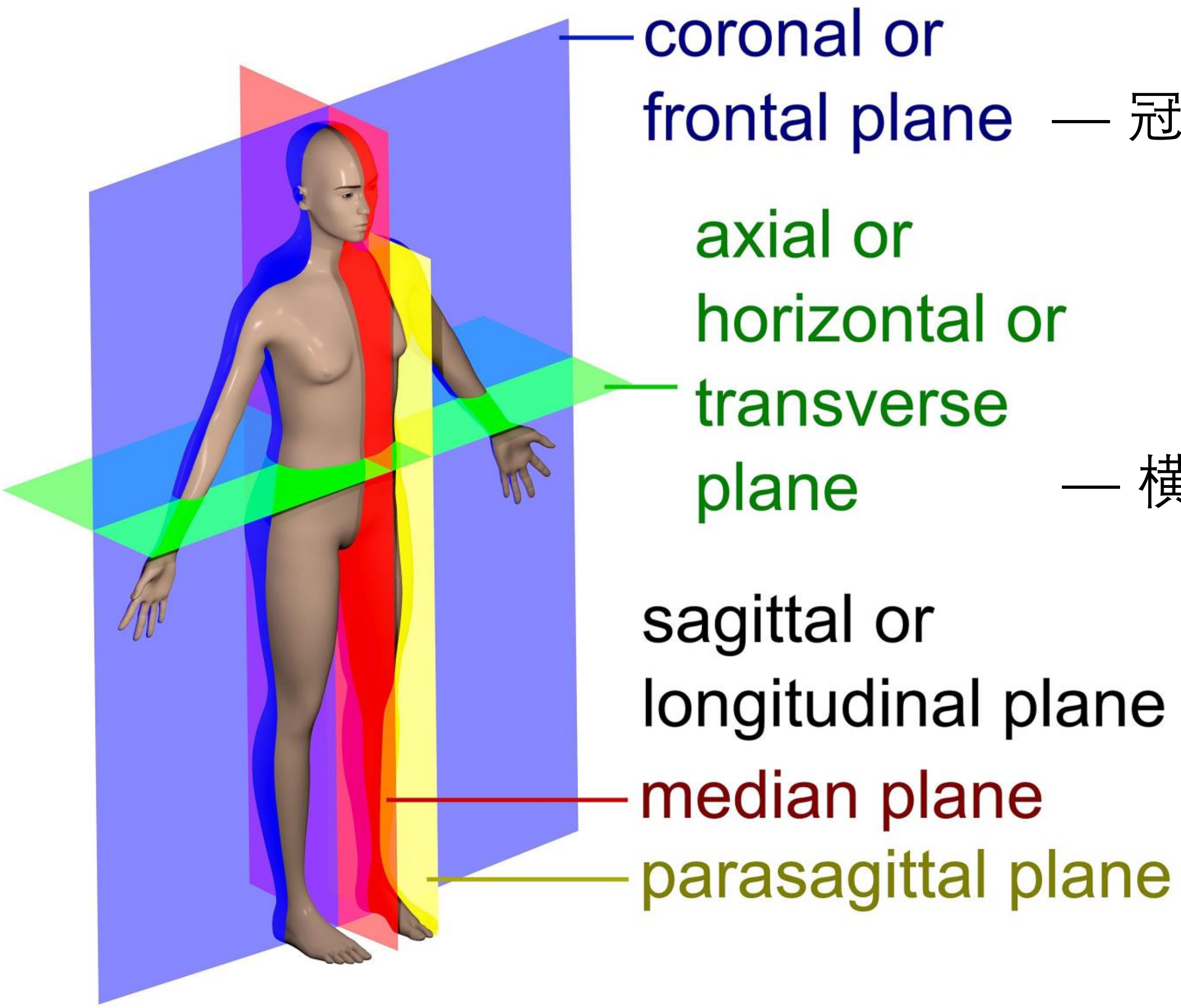
ROC Curve

Receiver Operating Characteristic (ROC) Curve

(受试者操作特性曲线)



Anatomical Planes



— 冠状面

— 横截面

— 矢状面

Lecture 1 - Introduction

This lecture will cover:

- Introduction to medical imaging
  - What is Medical Imaging?
  - History of Medical Imaging
  - Medical Imaging Modalities
  - Contents of the course
- Fundamentals of medical diagnosis
- **Image Acquisition** ***(CH1.3, CH1.7)***
  - **Data acquisition**
  - **Dynamic range and resolution**
  - **Sampling frequency and bandwidth**

Data Acquisition

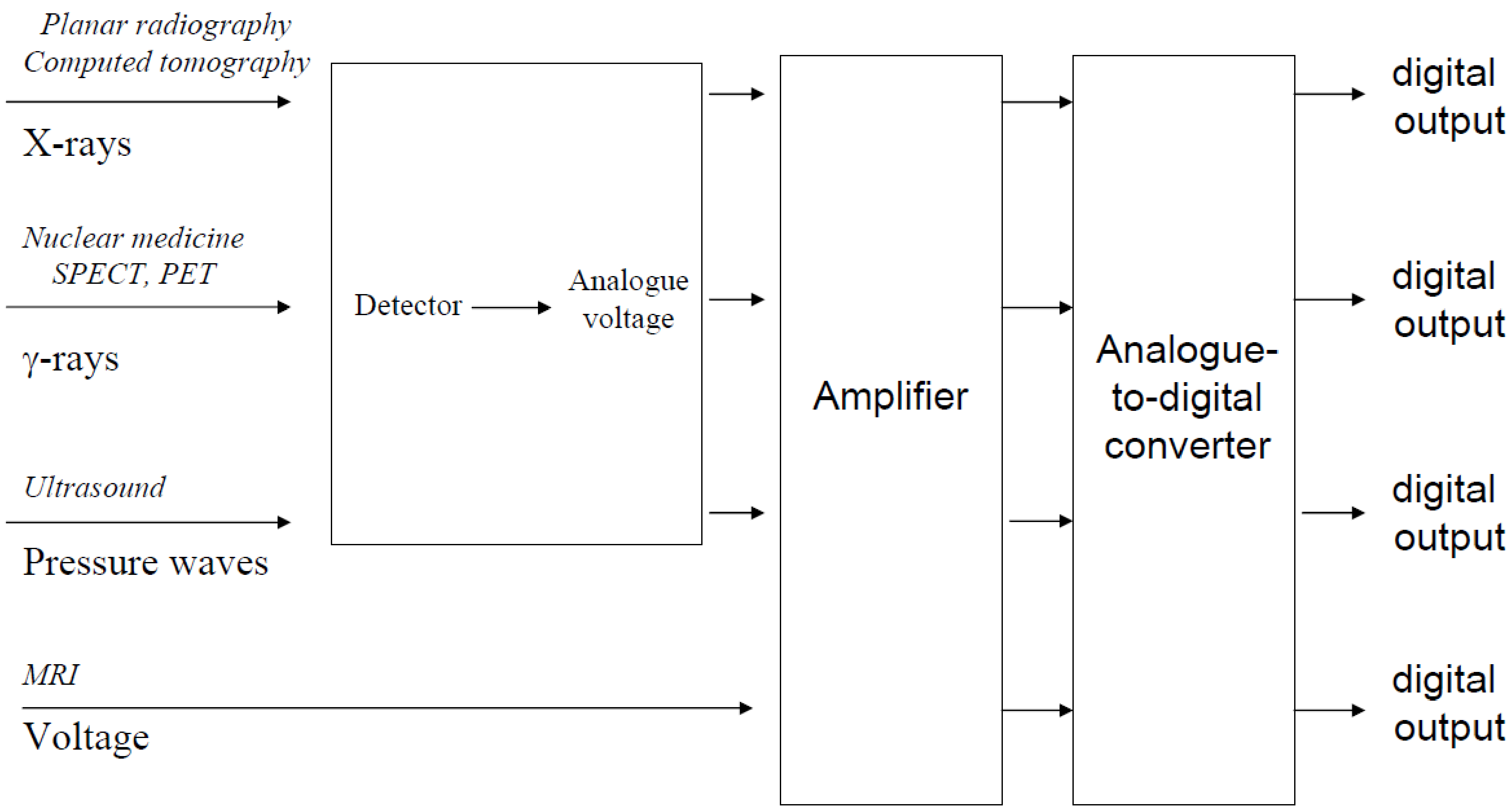


Figure. Data flow from different medical imaging modalities to produce a digital output.

Dynamic Range (动态范围)

- Color level or gray level
- Measured in bits : N bits ~ 2^N levels
- Resolution: difference between levels

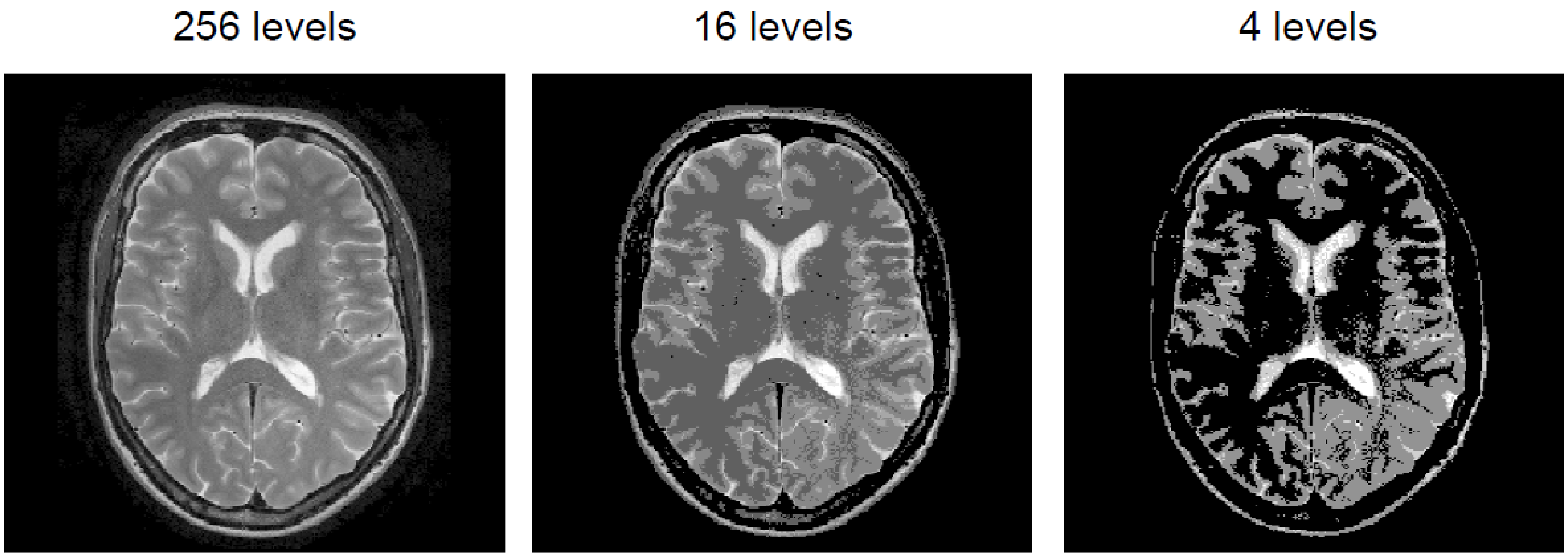


Figure. Representation of an MR image with a maximum of 256, 16 and 4 gray tone levels, corresponding to 8, 4 and 2-bit ADCs. The image quality is already significantly reduced at 16 levels.

Quantization Error (量化误差)

- The difference between the true analogue input signal and the digitized output.
- Lie between 0 and ±1/2 of the ADC resolution

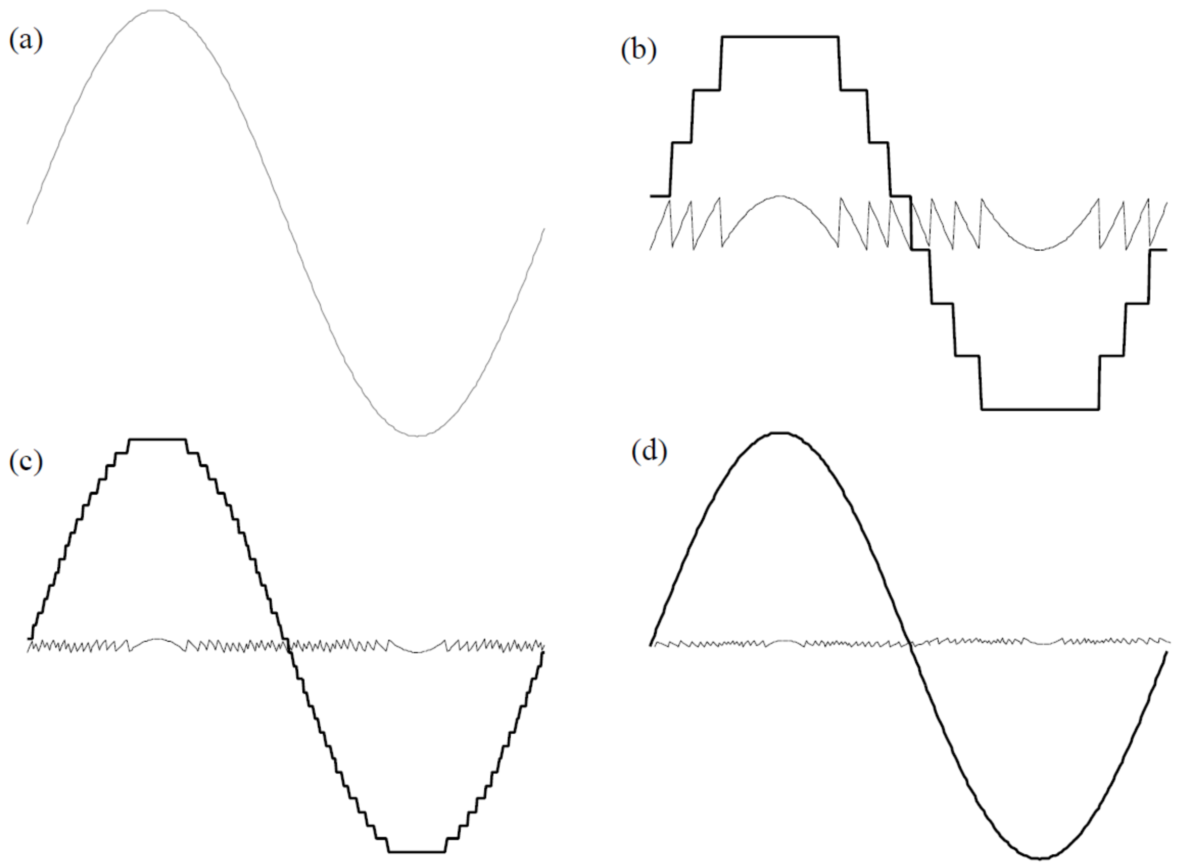


Figure. Dynamic range and quantization error. (a) The analogue sinusoidal signal which is to be digitized. (b) The signal recorded by a three-bit ADC (dark line) and the quantization error (dashed line). (c) Corresponding plot for a five-bit ADC, and (d) a six-bit ADC.

Sampling Frequency and Bandwidth

- Sampling - digitization in time domain or space domain
- The characteristics of ADC: 1) Bandwidth 2) sampling rate & resolution

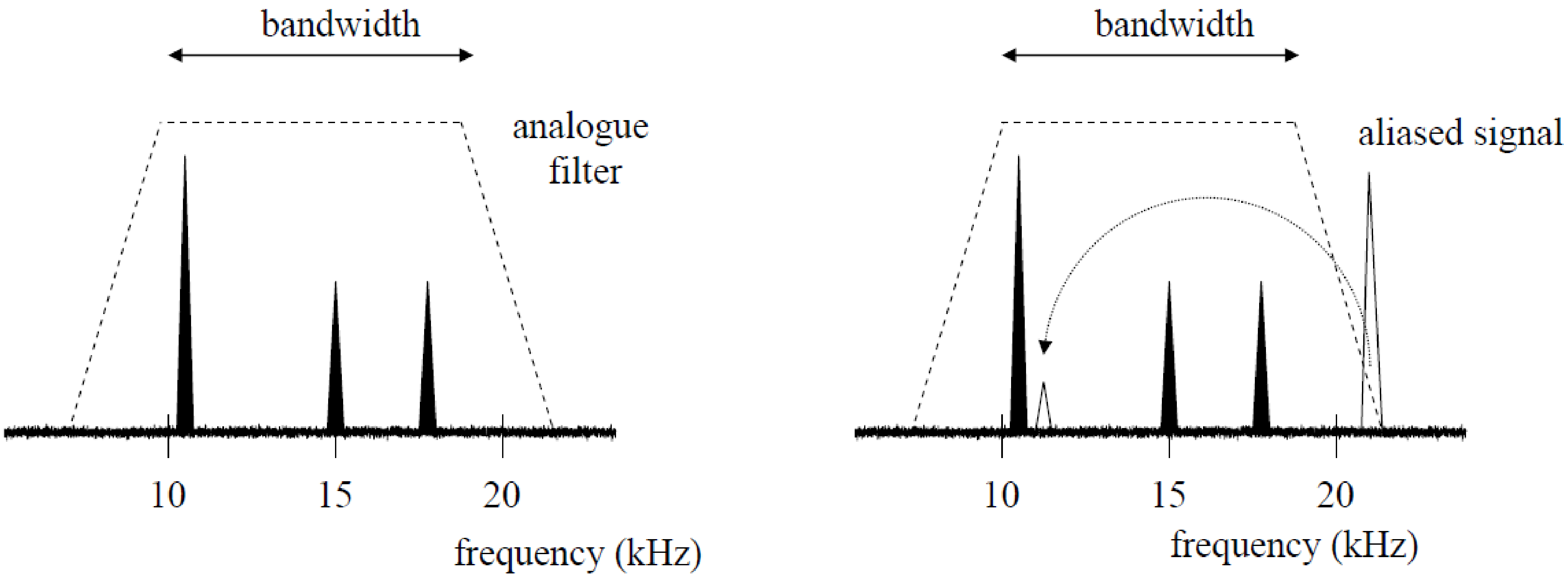


Figure. (left) A set of signals between 10 and 20 kHz is acquired by setting the central frequency of the ADC to 15 kHz with a 10 kHz bandwidth. (right) If an unexpected signal is present outside the bandwidth at 22 kHz, it is aliased back into the spectrum. Since the signal is partially filtered out by the analogue filter, the intensity of the aliased signal is reduced compared to its true intensity..

2D Sampling Theorem

- $f(t,z)$ is band-limited (带限函数) if $F(\mu,\nu)=0,\ |\mu|\geq\mu_{\max}$ and $|\nu|\geq\nu_{\max}$
- The sampling rate: $\frac{1}{\Delta T}>2\mu_{\max}$, $\frac{1}{\Delta Z}>2\nu_{\max}$

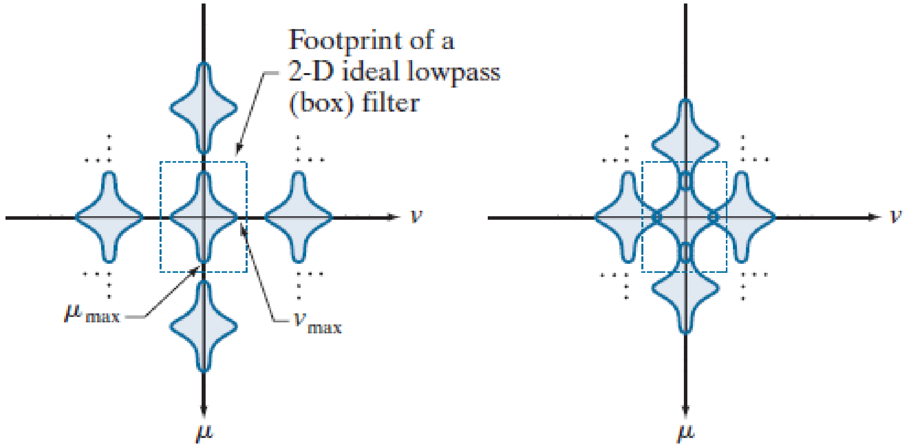


Figure. Two-dimensional Fourier transforms of (a) an over-sampled, and (b) an under-sampled, band-limited function.

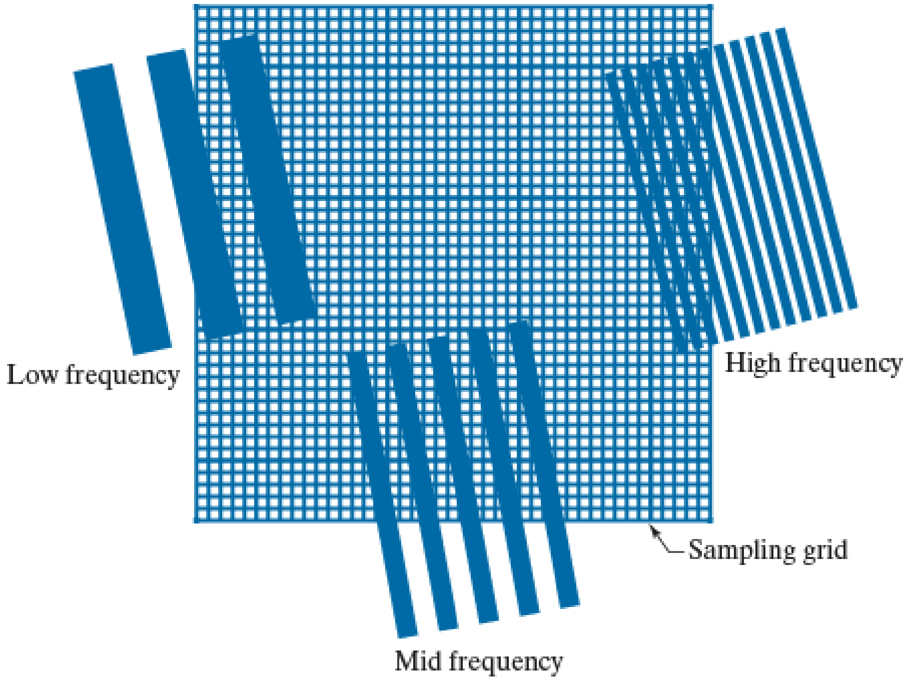


Figure. Various aliasing effects resulting from the interaction between the frequency of 2-D signals and the sampling rate used to digitize them. The regions outside the sampling grid are continuous and free of aliasing.