



Serviço de Informática
Instituto do Coração – HC FMUSP

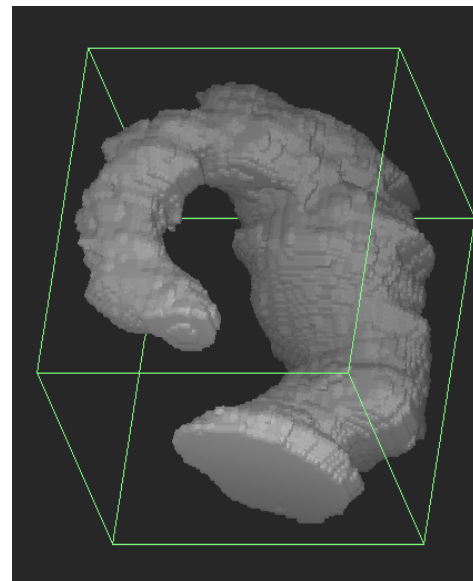
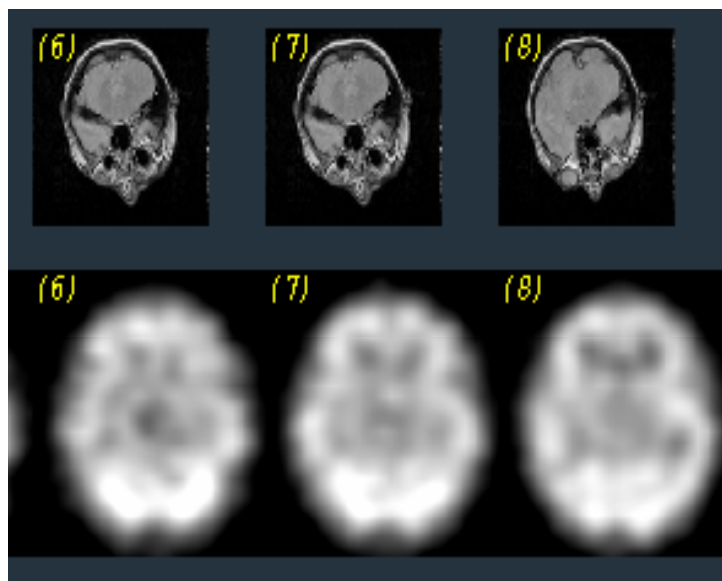
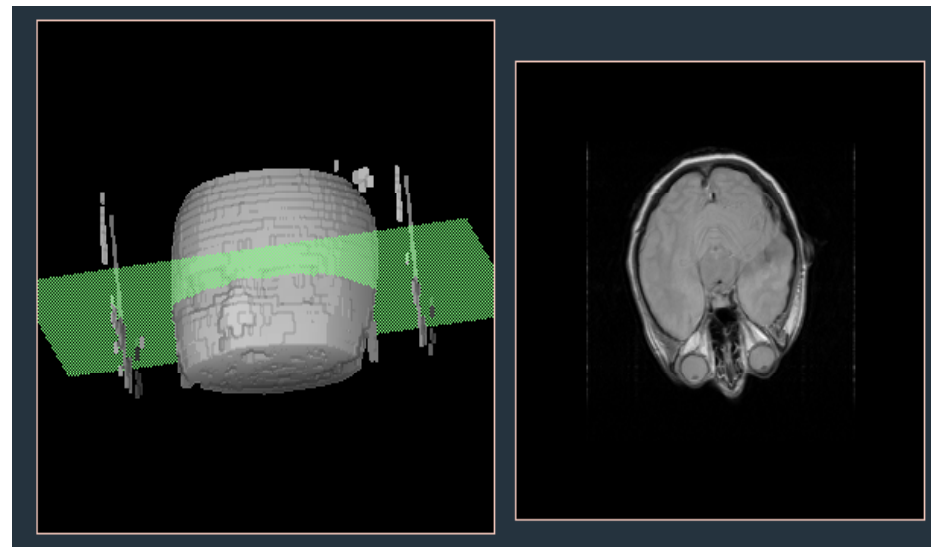
Informática Aplicada a Imagens Médicas

MCP - 5840

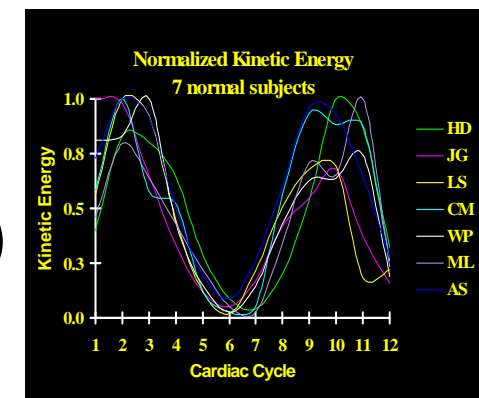
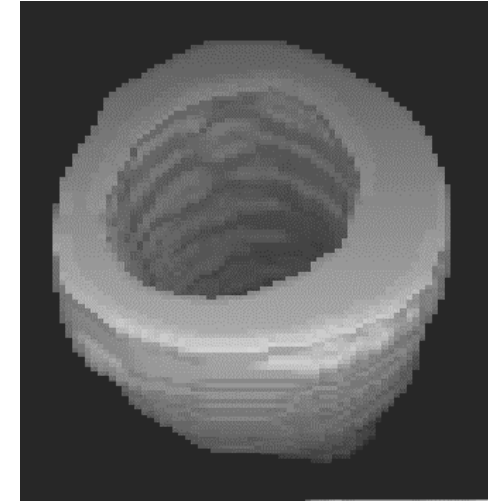
Marco Antonio Gutierrez

Email: marco.gutierrez@incor.usp.br

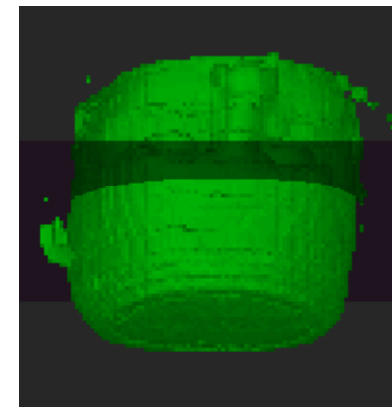
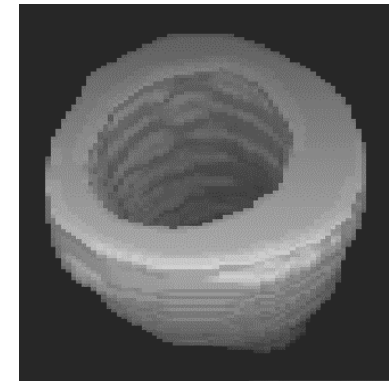
- Seqüências espaciais e temporais
- Estruturas dinâmicas
- Cortes oblíquos



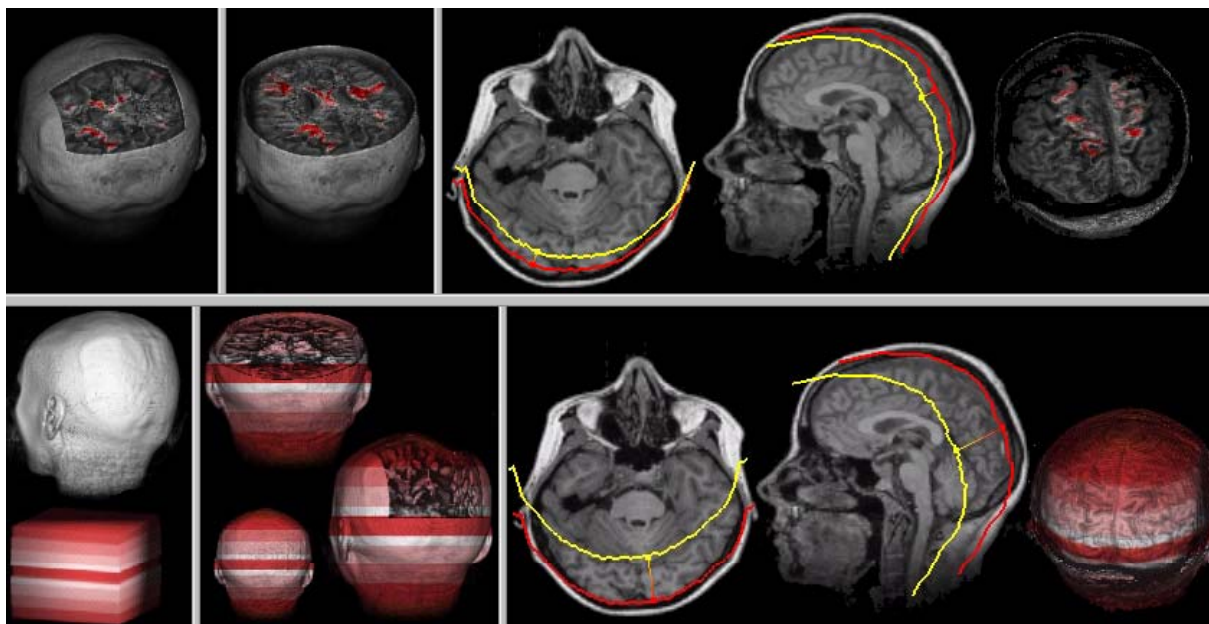
- Área
- Volume
- Distância 3D
- Curva de evolução temporal
- Índices
 - variação (fração de ejeção, ...)
 - derivadas (taxas de enchimento, ...)

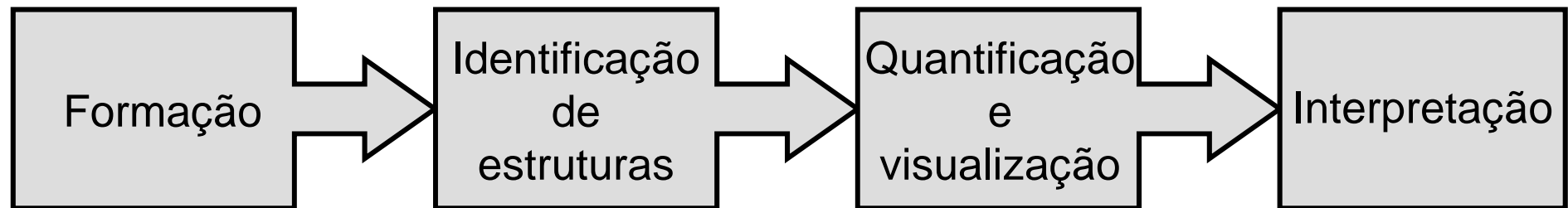


- Visualização 3D, 3D dinâmica (4D)
- Visualização em direções oblíquas
- Aspectos funcionais
 - movimento, contração
 - fisiologia, metabolismo
- Classificação



- Conjugação de imagens para melhorar a sensitividade e sensibilidade diagnóstica (fusão)
- Alinhamento de imagens 3D
 - Estudo multi-modal (CT, MRI, SPECT, ..) quantitativa
 - Aumento da sensibilidade e da especificidade diagnóstica



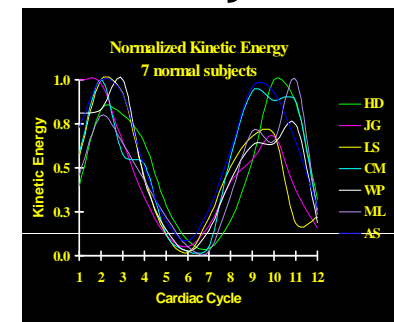
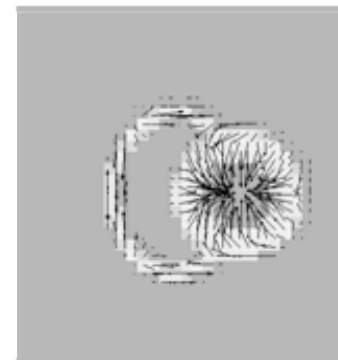
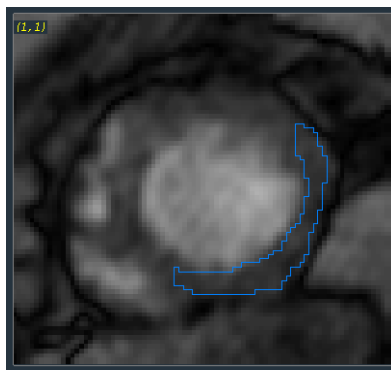


- Aquisição
- Tomografia

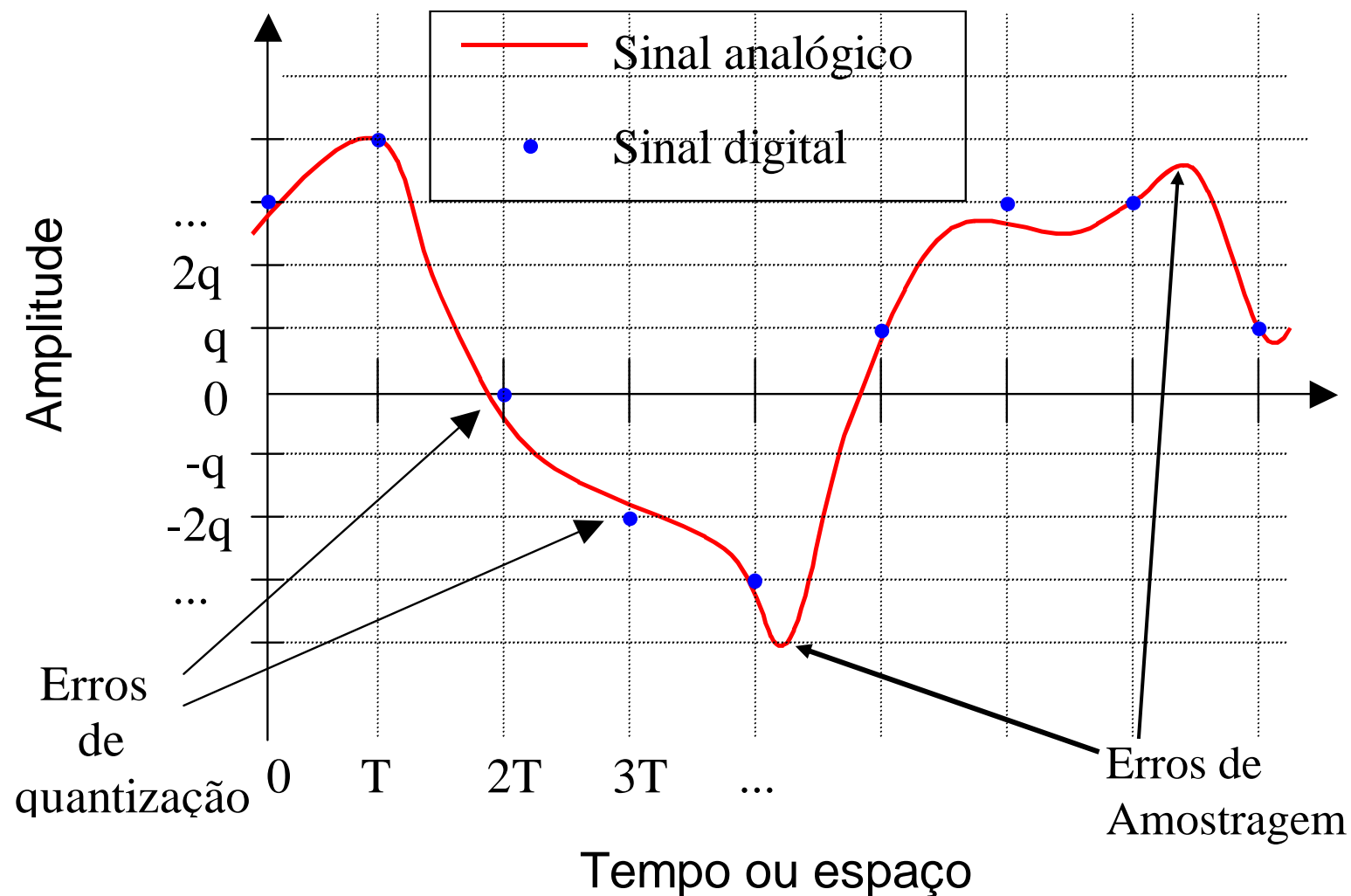
- Pré-processamento
- Segmentação
- Reconhecimento

- Cálculos.
- Parâmetros
- Comp.gráfica

- Classificação
- Intel. Artificial
- Redes neurais
- Informação

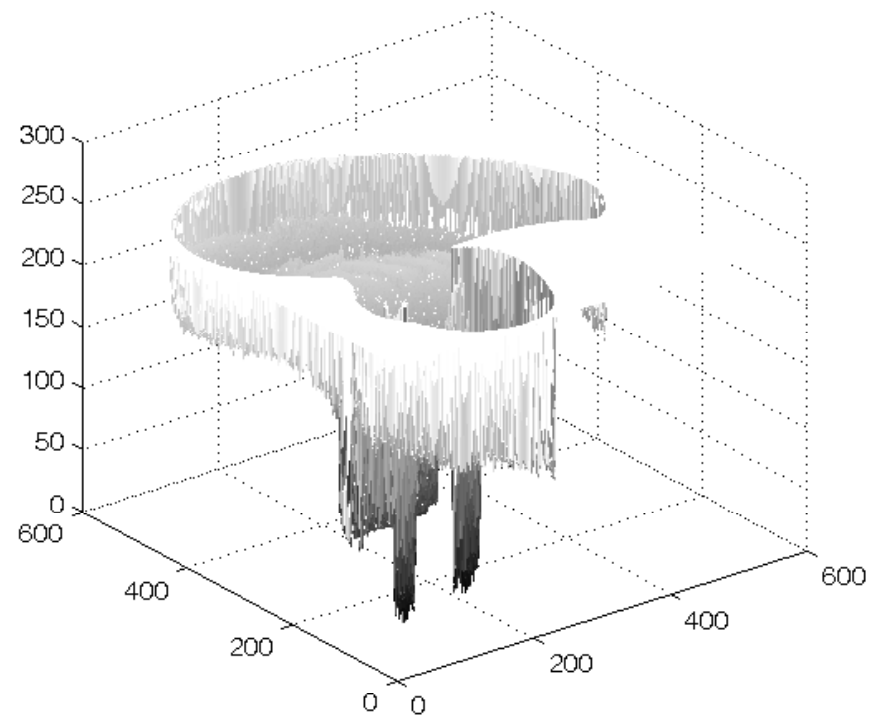
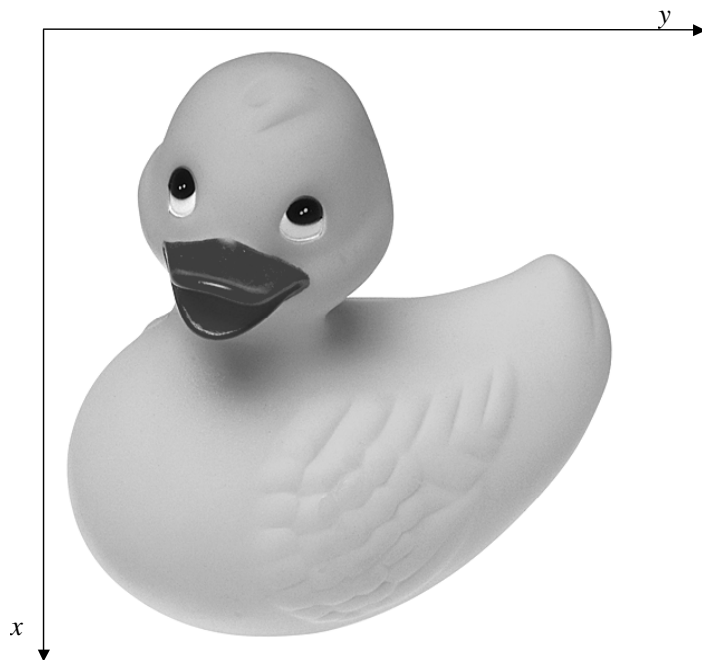


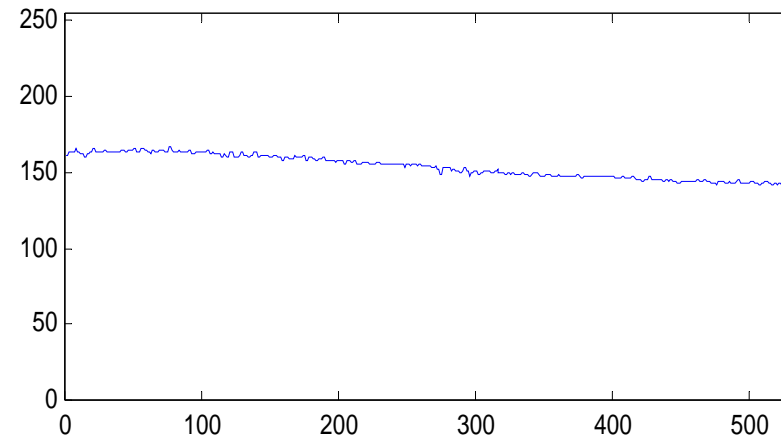
Digitalização: discretização espacial (amostragem) e de intensidade (quantização)



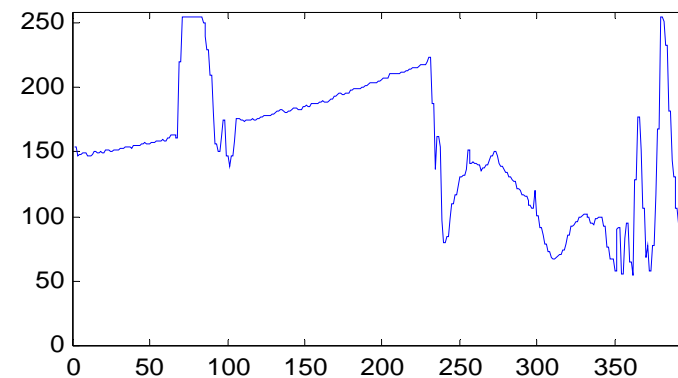
Função $F(x,y)$

- (x, y) : coordenadas espaciais
- $F(x,y)$: intensidade ou brilho da imagem em (x,y)



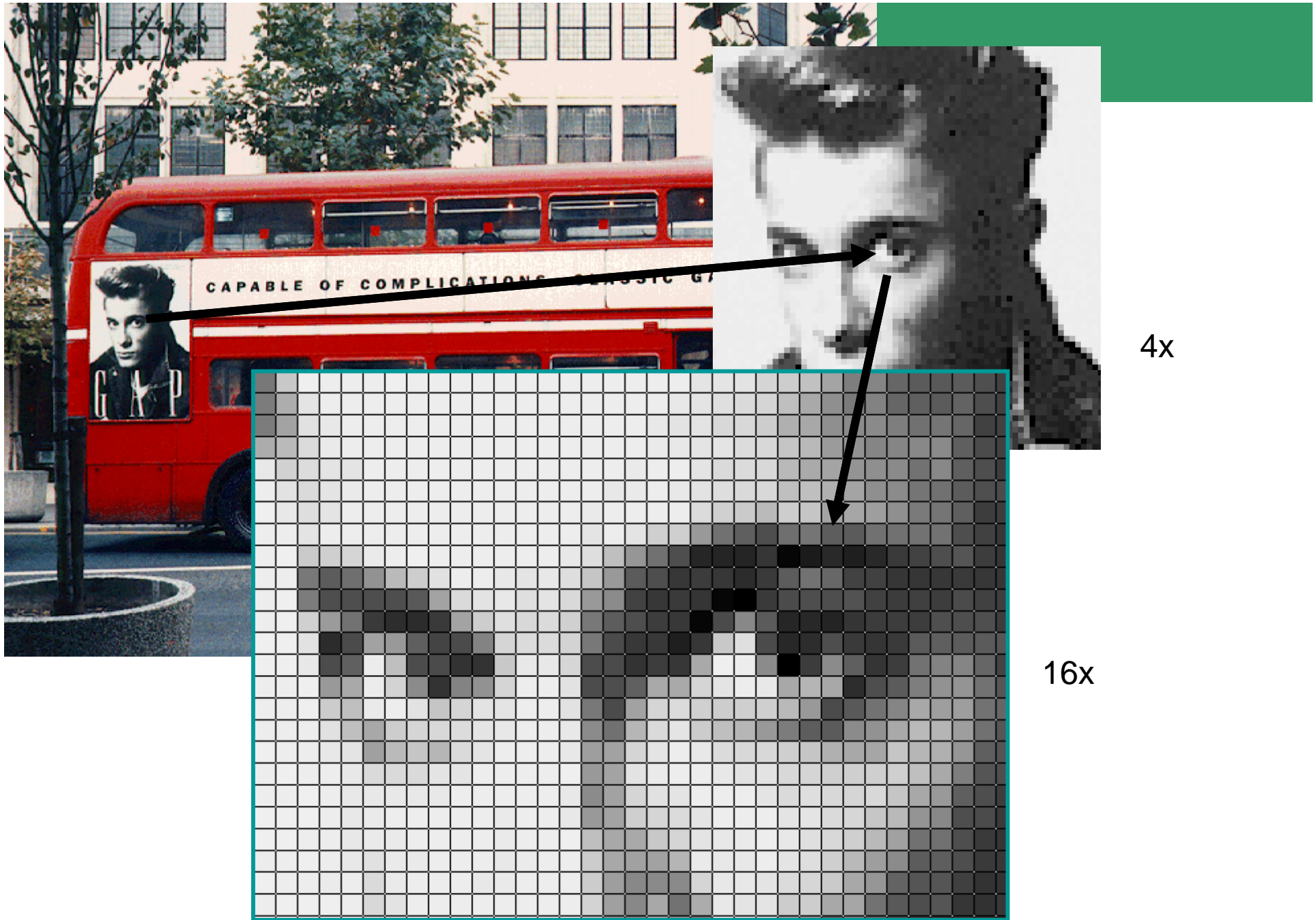


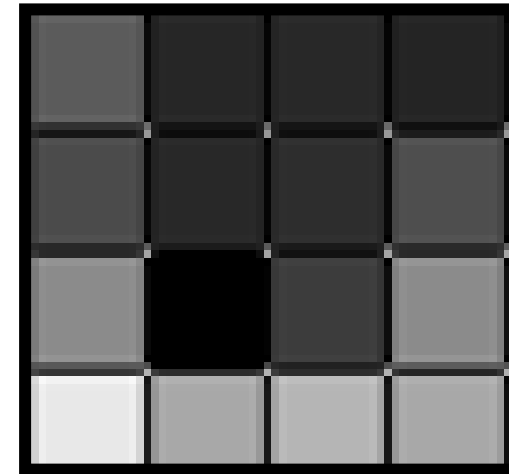
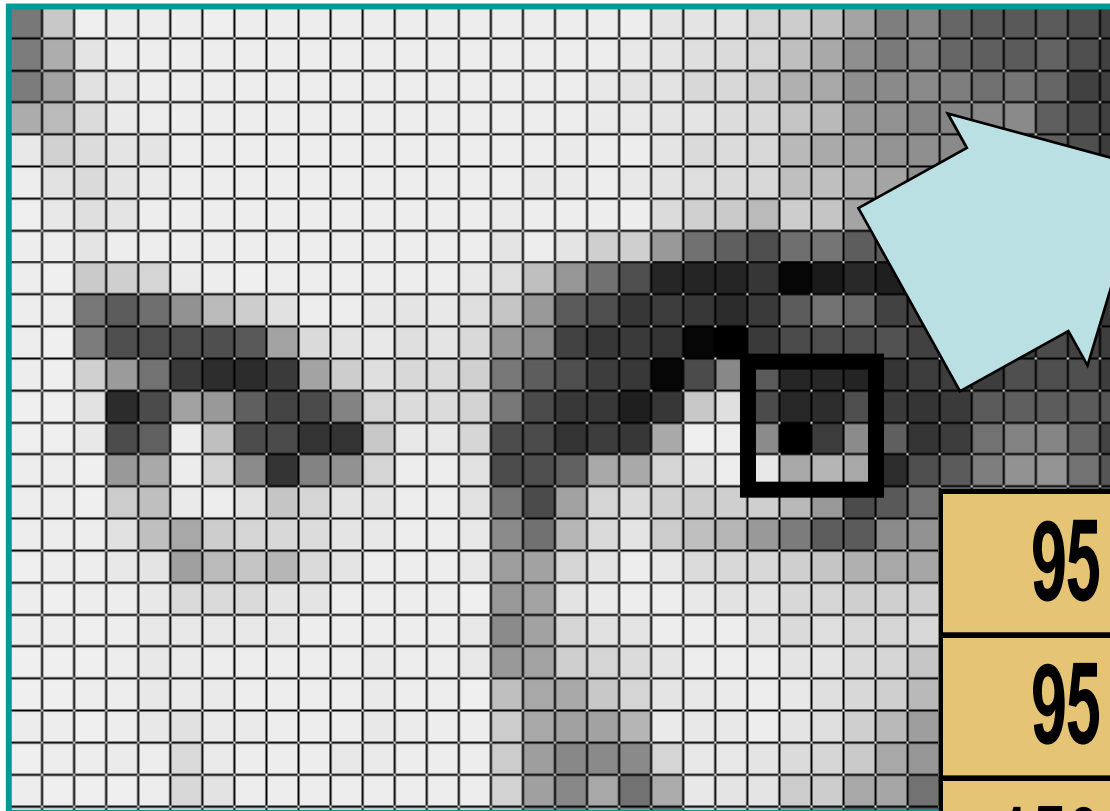
$i = 2$



$j = 266$

$$\begin{bmatrix} 161 & 161 & \dots & 142 \\ 161 & 161 & \dots & 142 \\ \dots & \dots & \dots & \dots \\ 163 & 163 & \dots & 95 \end{bmatrix}$$





256 tons de cinza

95	80	80	80
95	90	90	105
150	20	100	130
220	150	160	150



640h x 480v em 256 cores



320h x 240v em 256 cores



160h x 120v em 256 cores



80h x 60v em 256 cores



40h x 30v em 256 cores



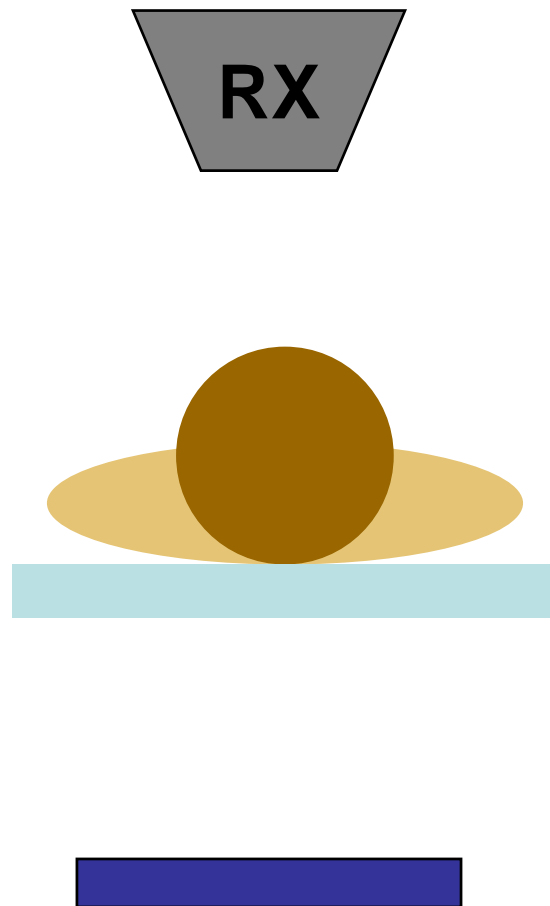
640h x 480v em 256 tons de cinza



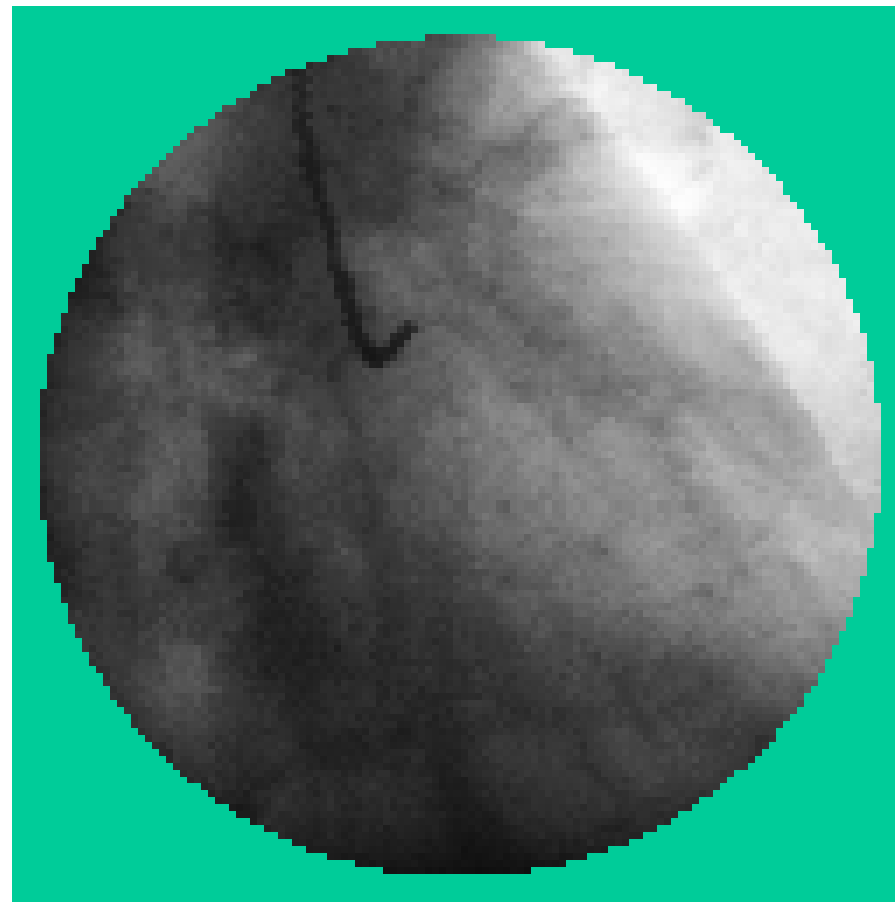
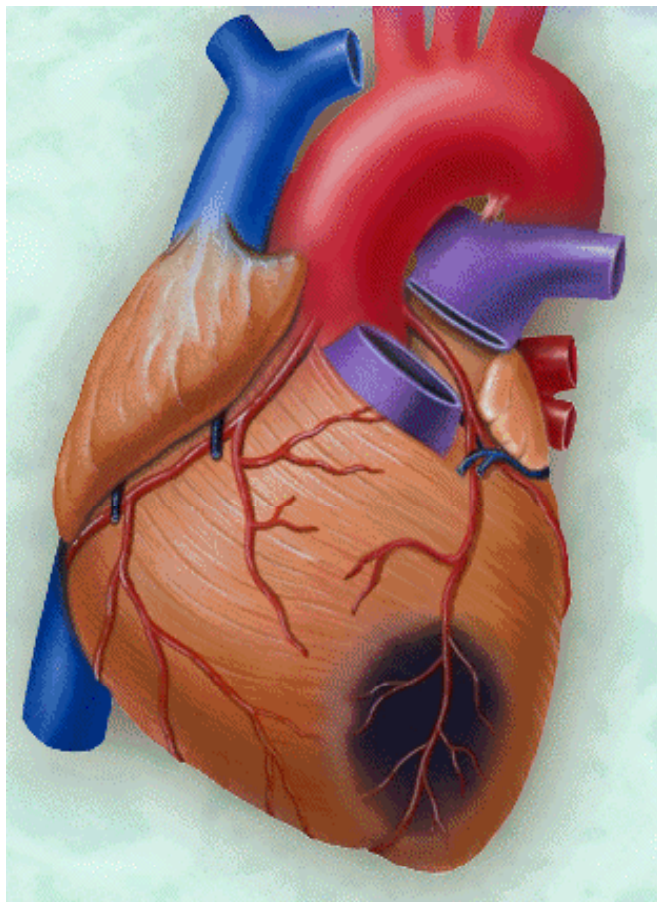
640h x 480v em 8 tons de cinza



640h x 480v - imagem binária

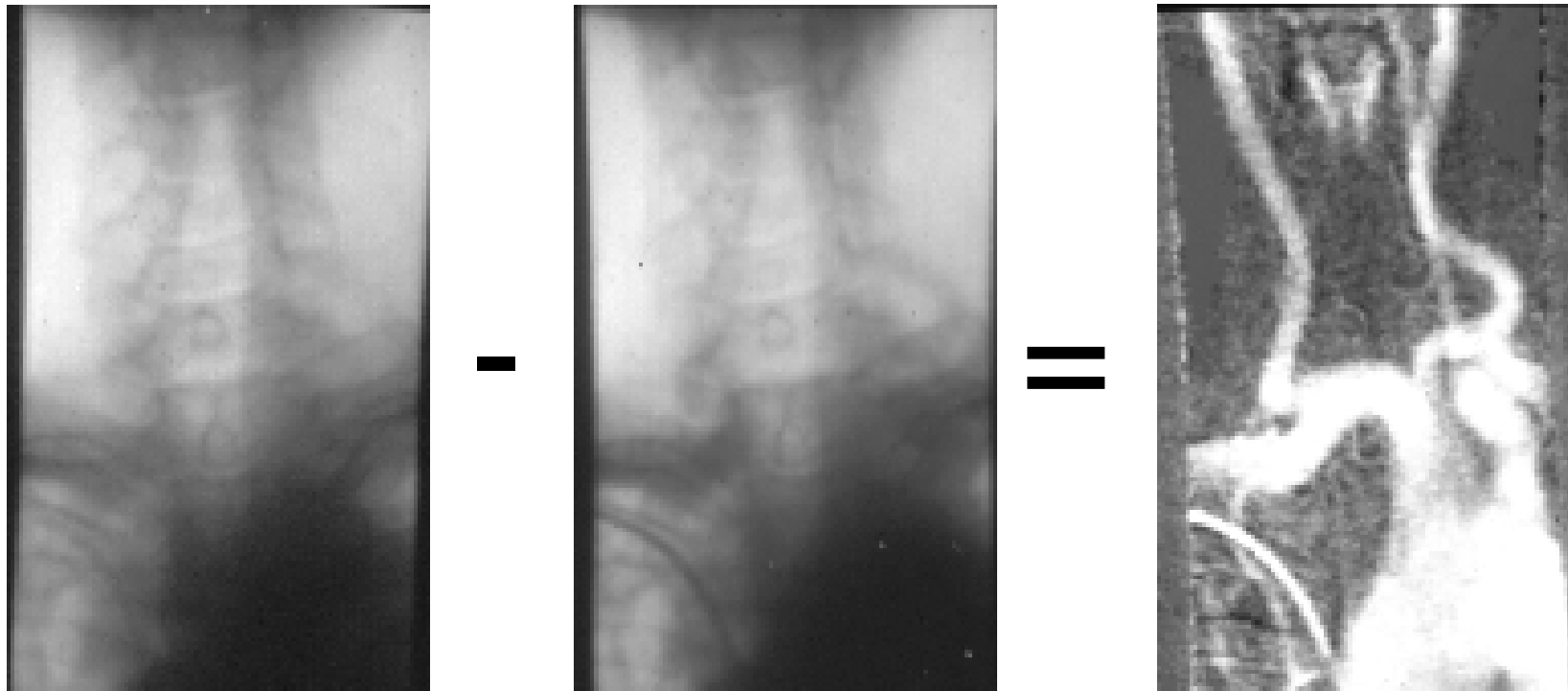


Cine-angio-coronariografia



InCor - HCFUMSP

DSA - Angiografia Digital Subtrativa

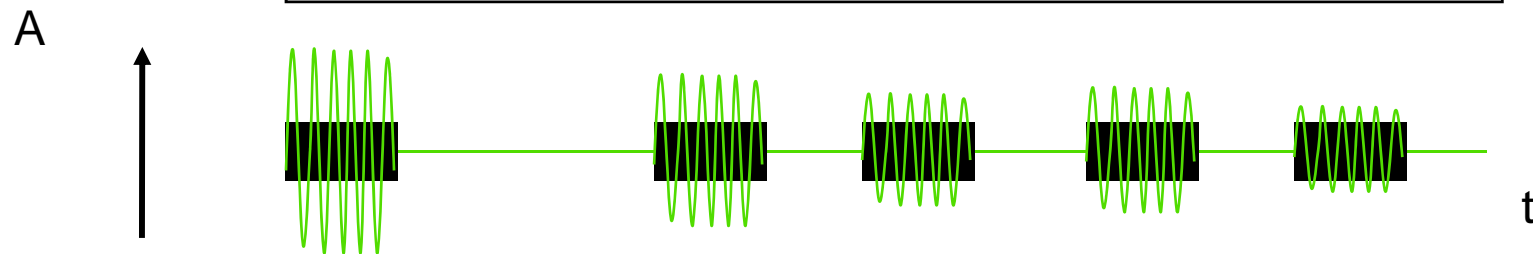
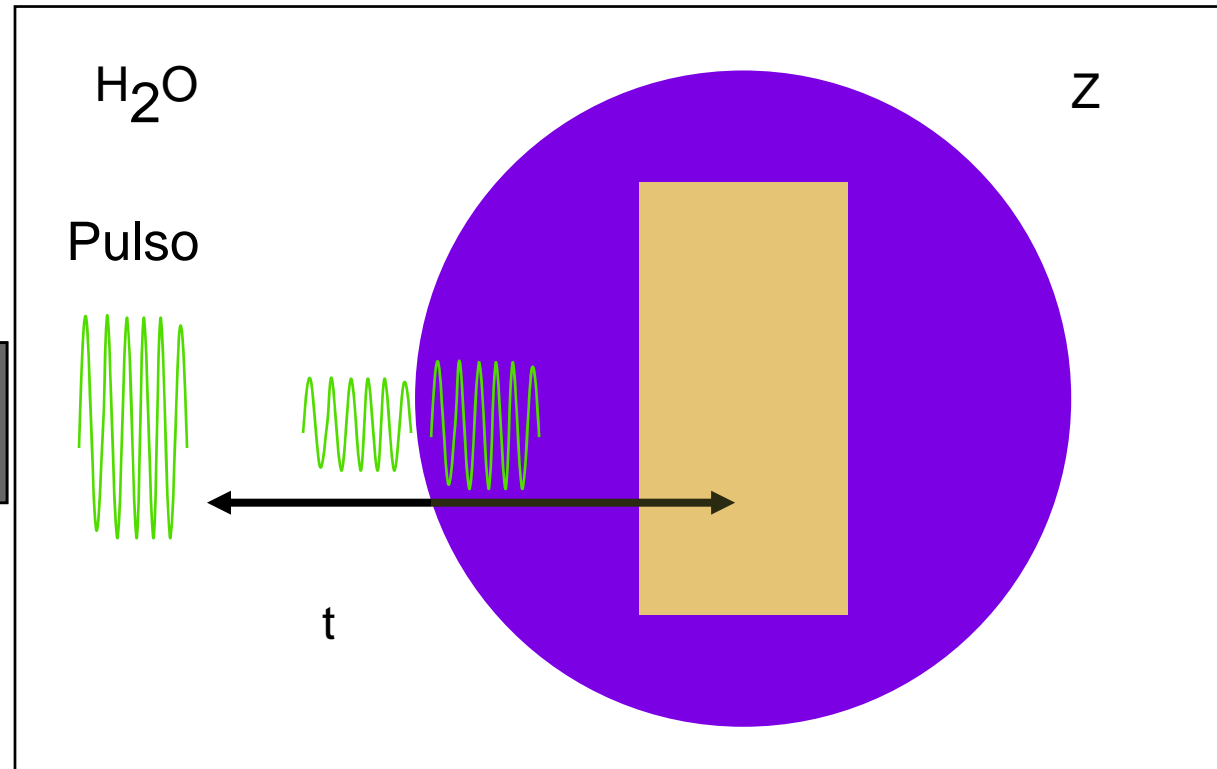


Ultrassom:

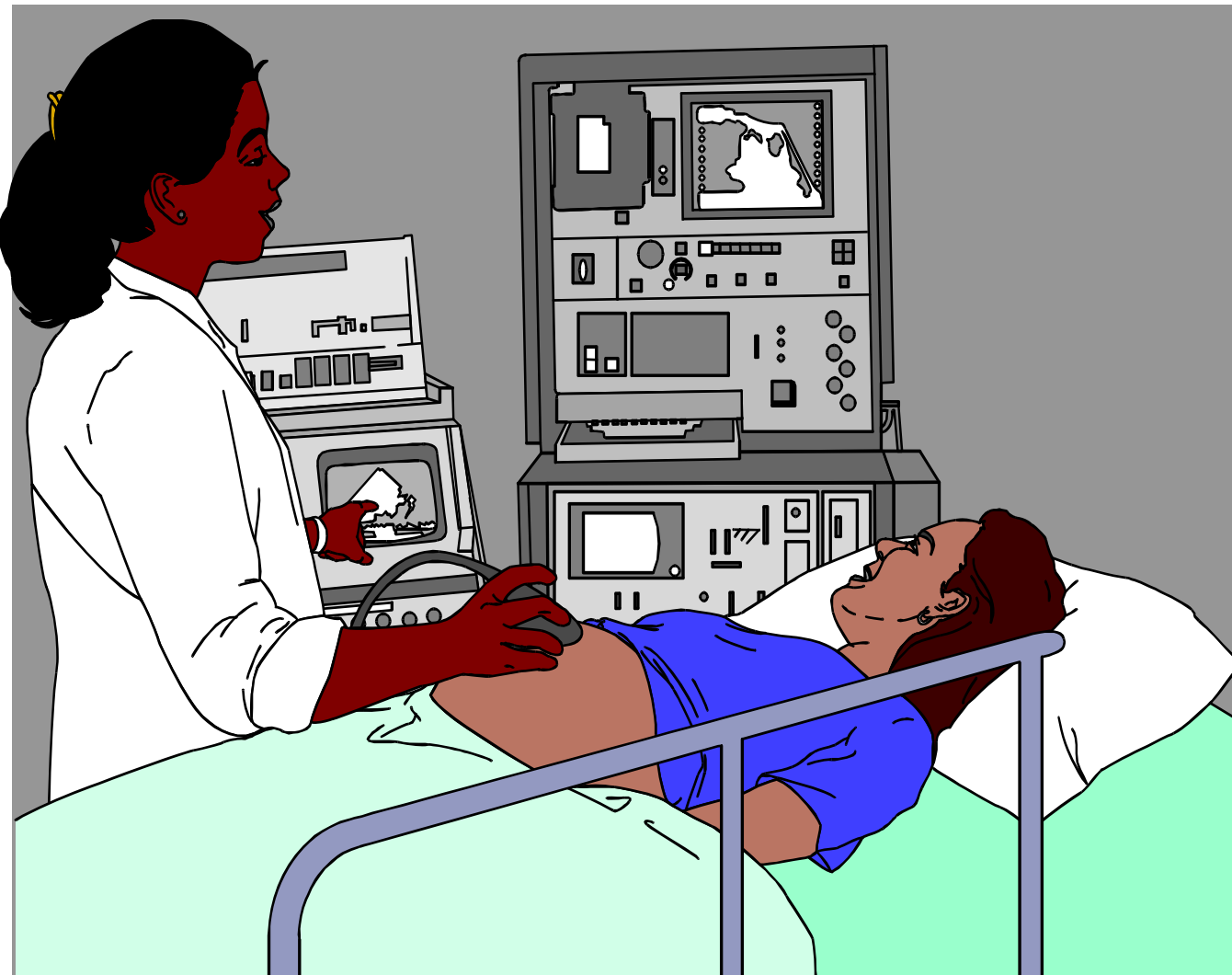
Eco

Onda mecânica

Envia/Escuta



- Ultrassom
Modo B



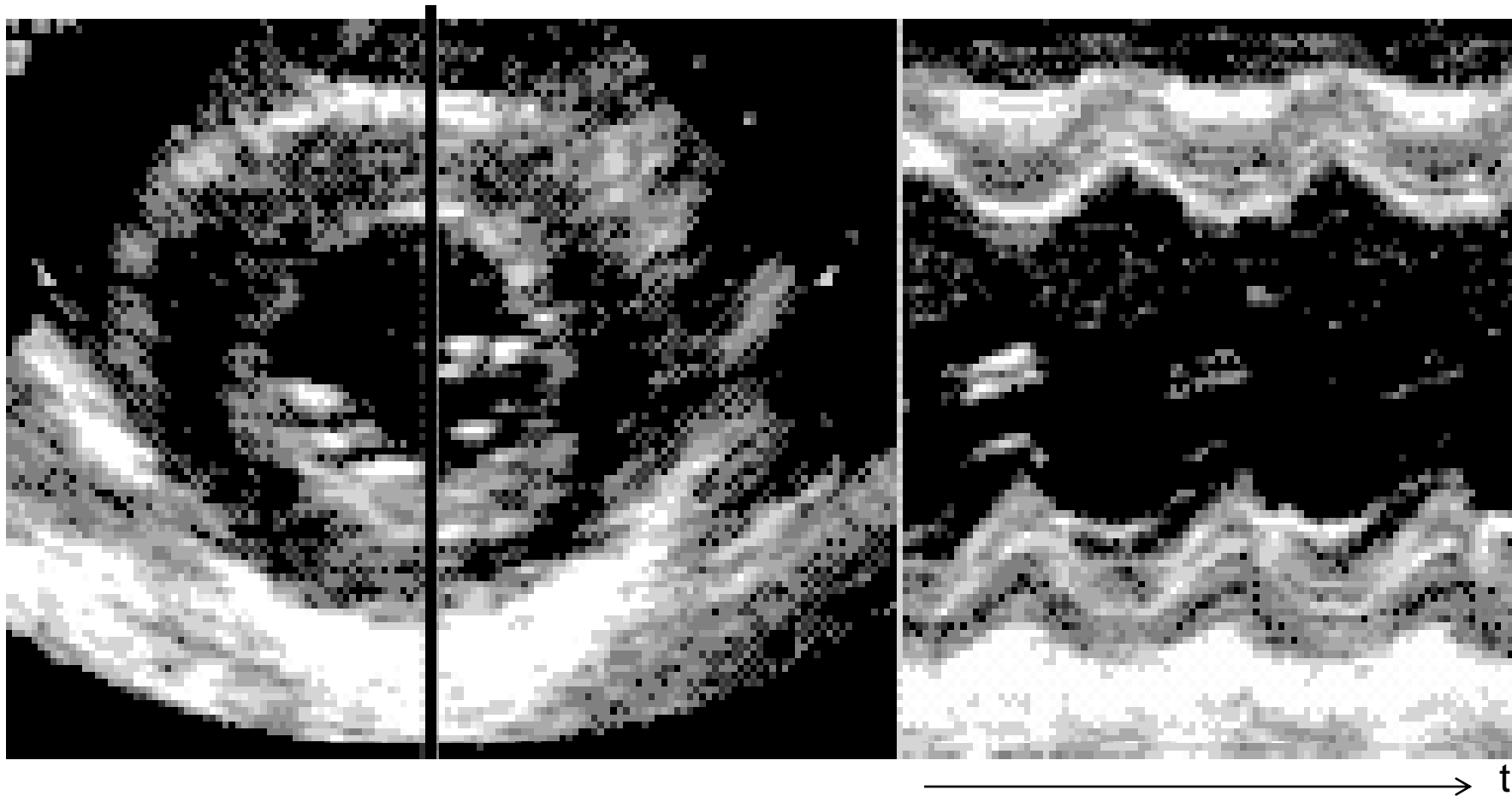
Ultrassom

Modo B

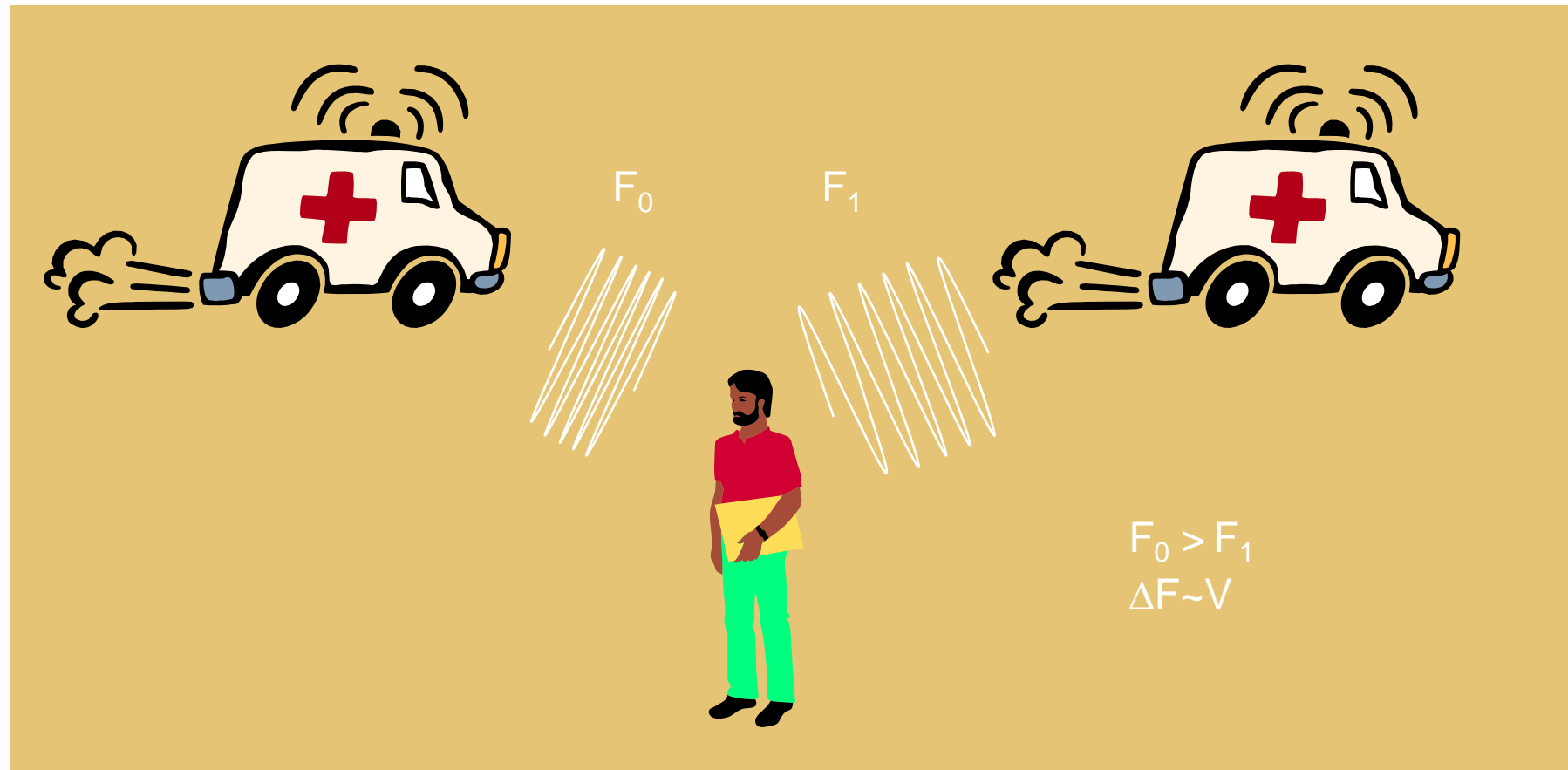


*Virtual Body
B&N Software*

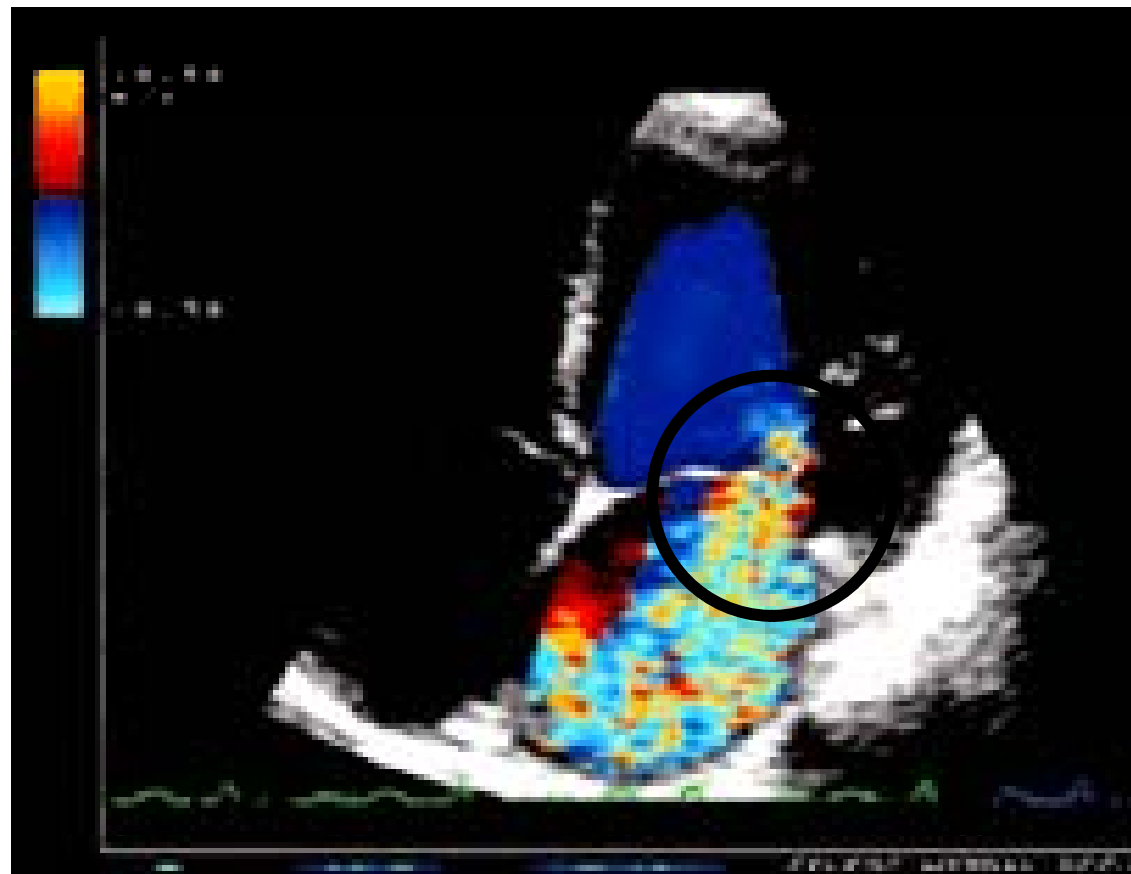
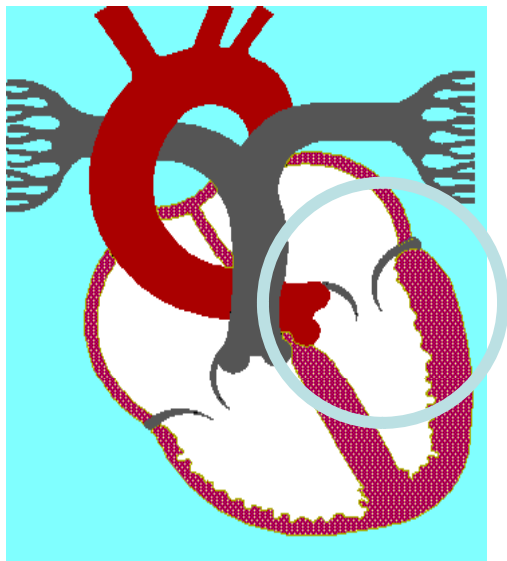
- Ultrassom Modo M



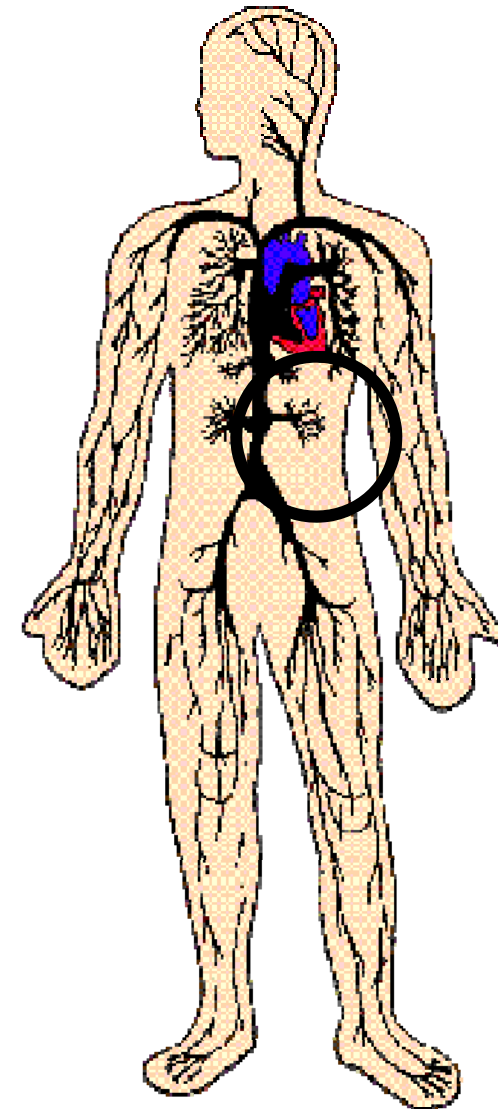
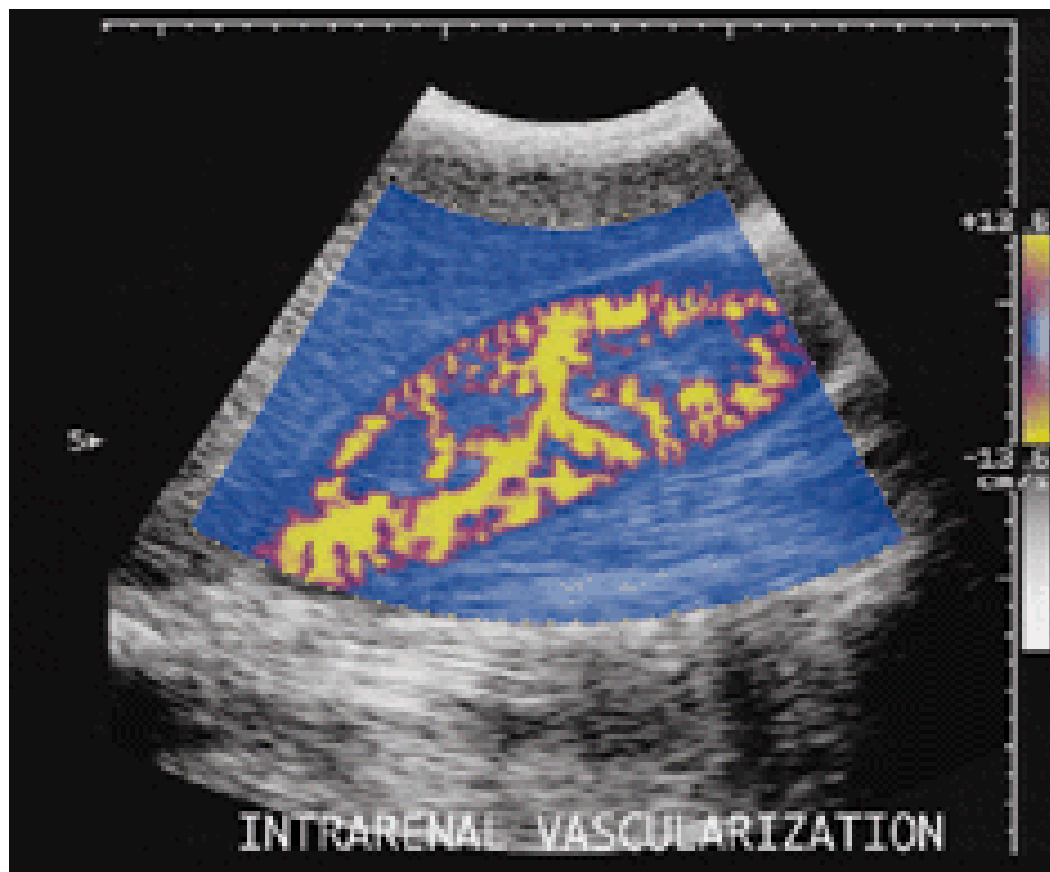
- Ultrassom Modo Doppler: Efeito Doppler



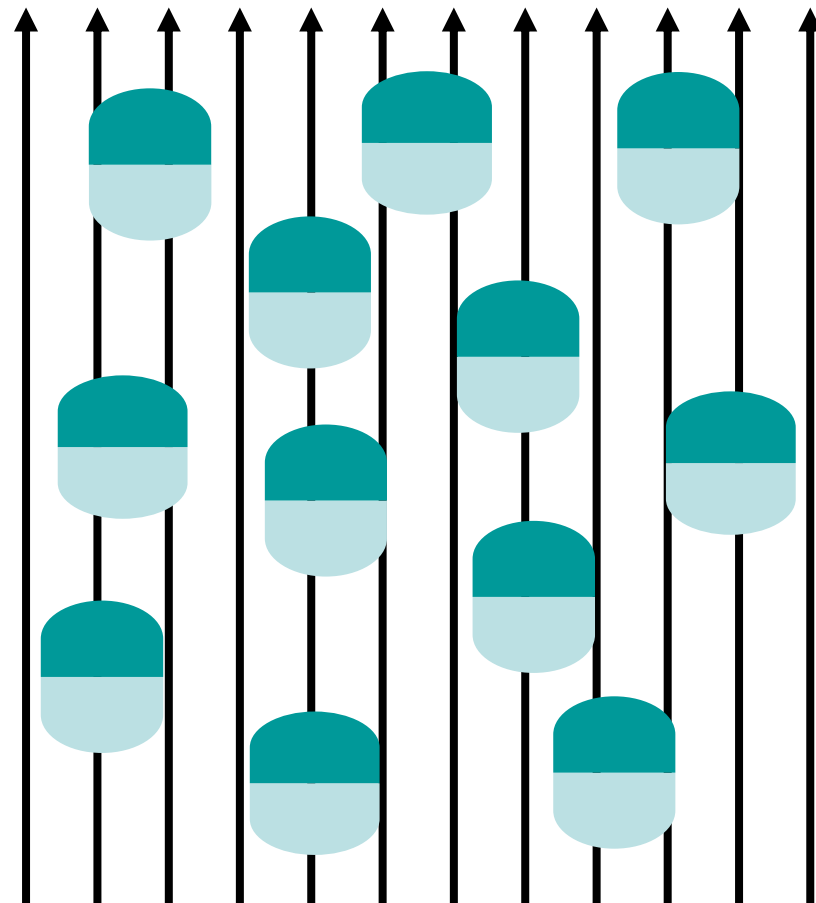
- Ultrassom Modo Color-Flow Map



Ultrassom Modo Color-Flow Map

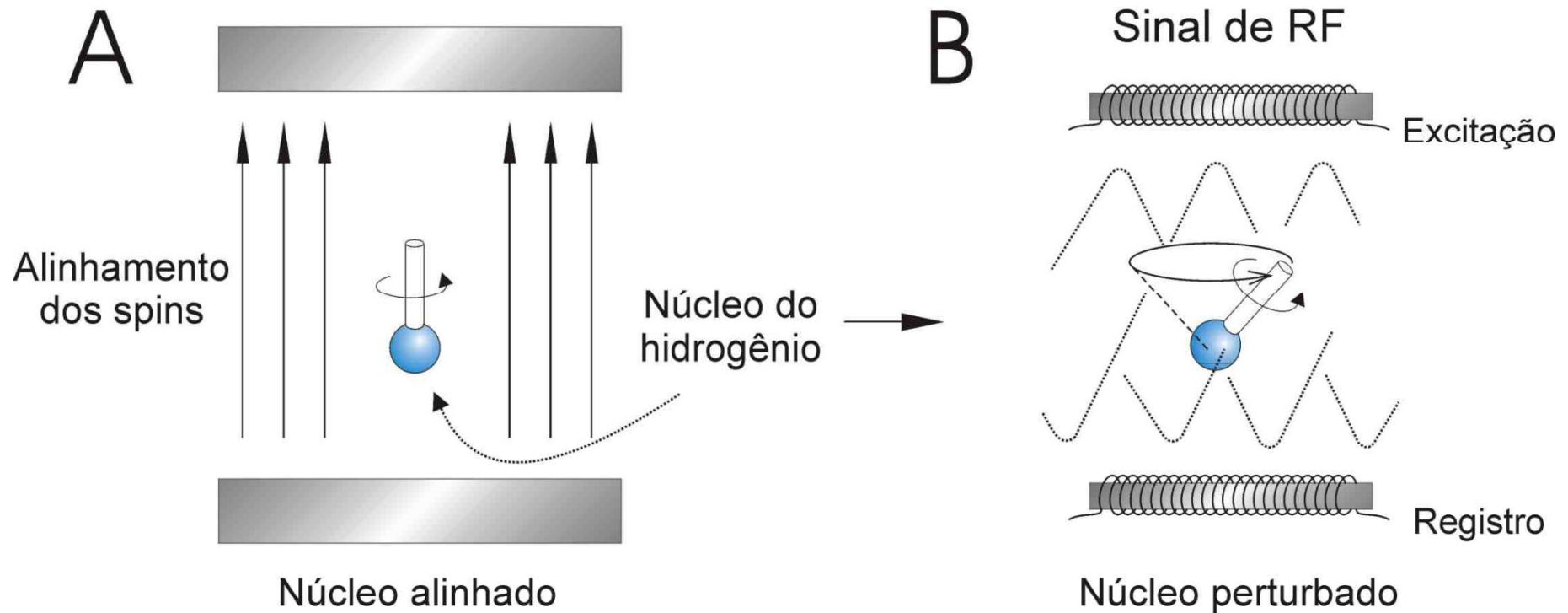


Ressonância Magnética

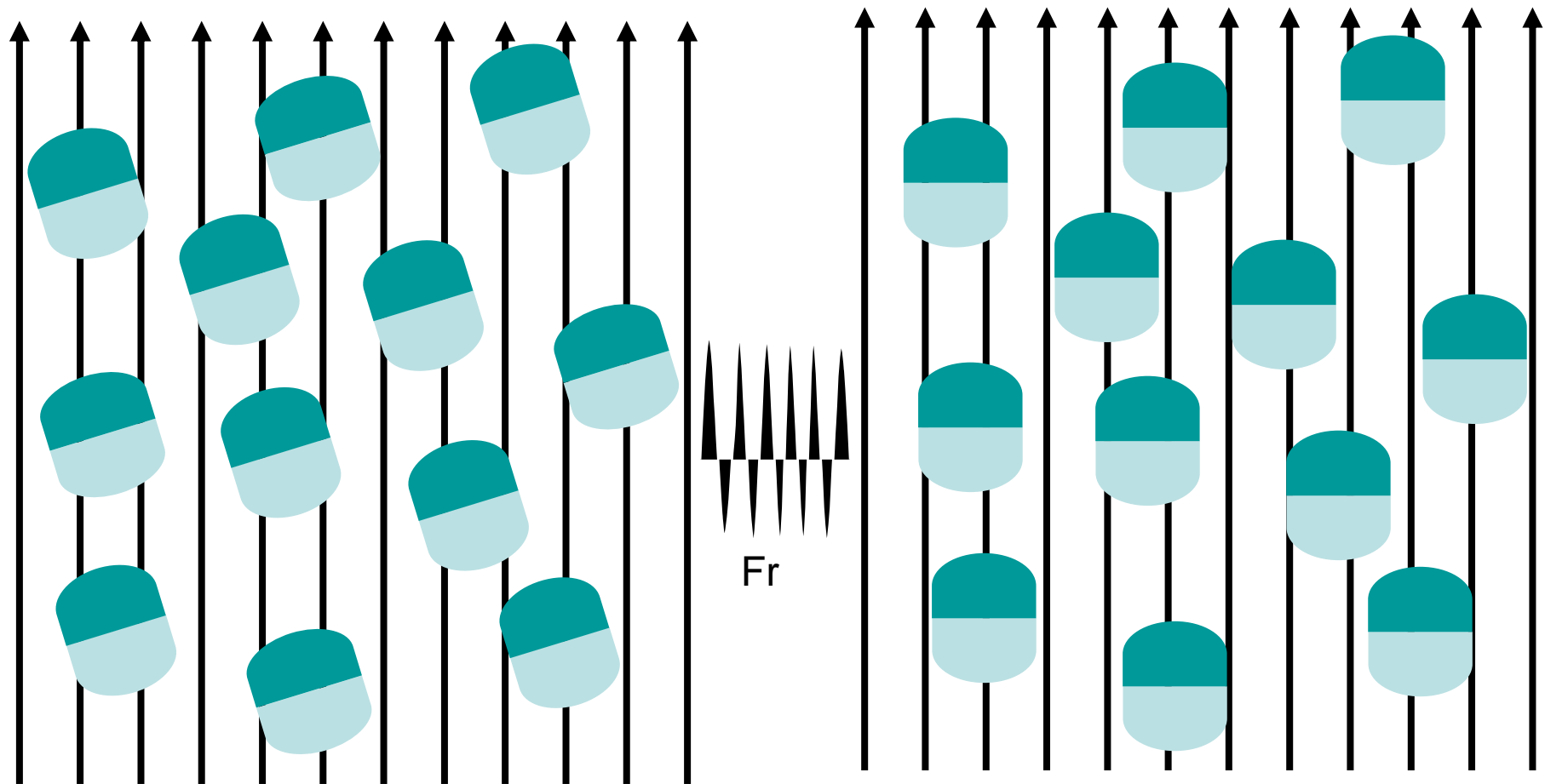


Ressonância Magnética

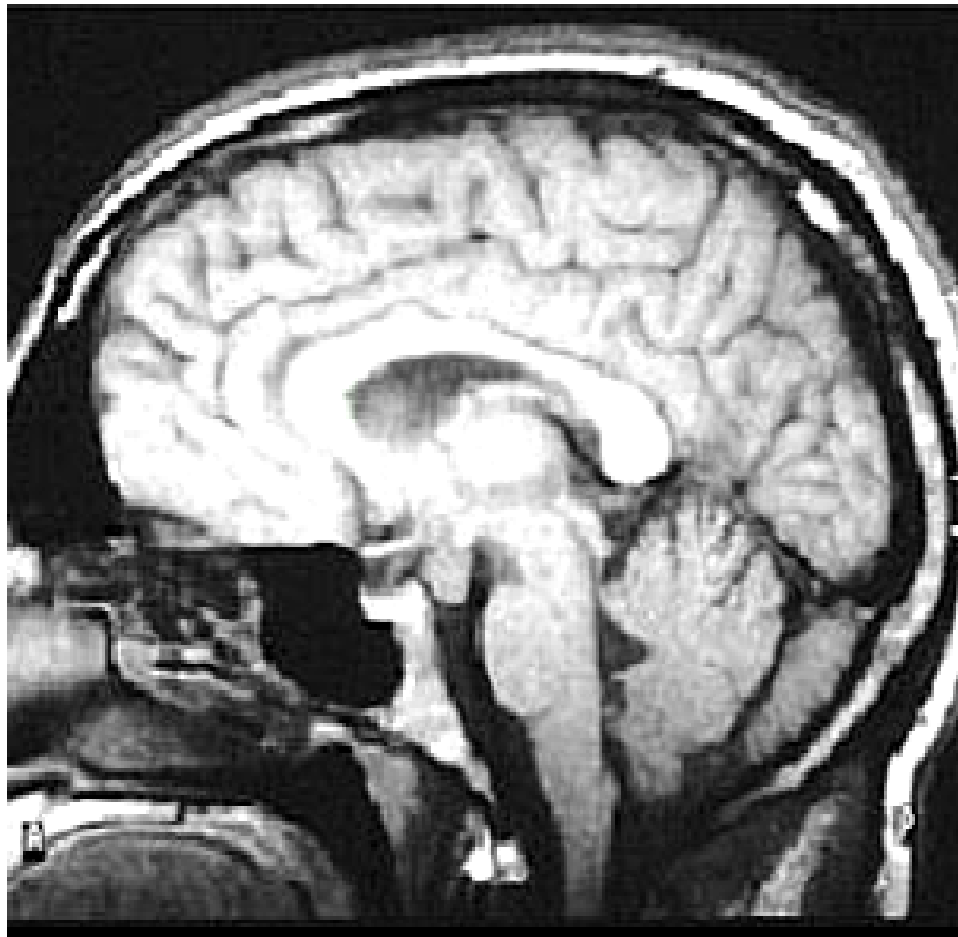
CAMPO MAGNÉTICO FORTE



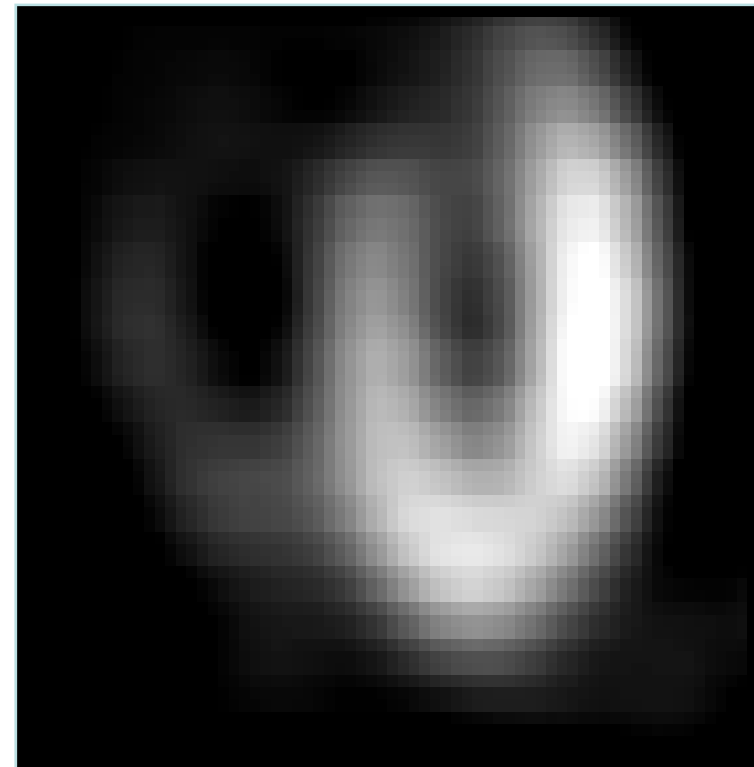
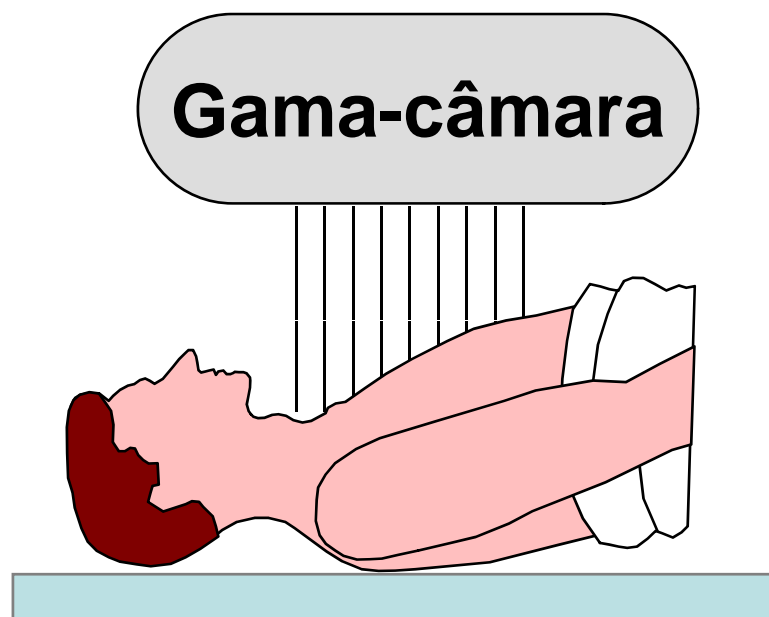
Ressonância Magnética



- Ressonância Magnética

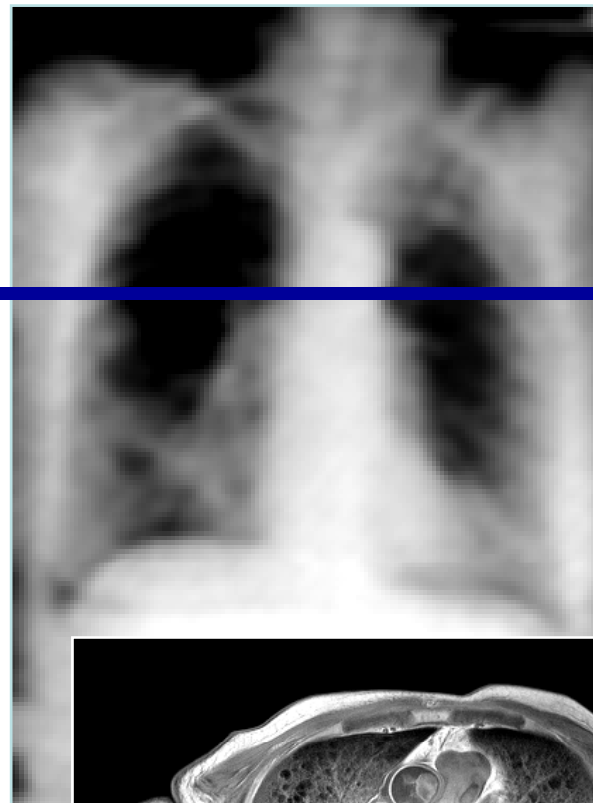
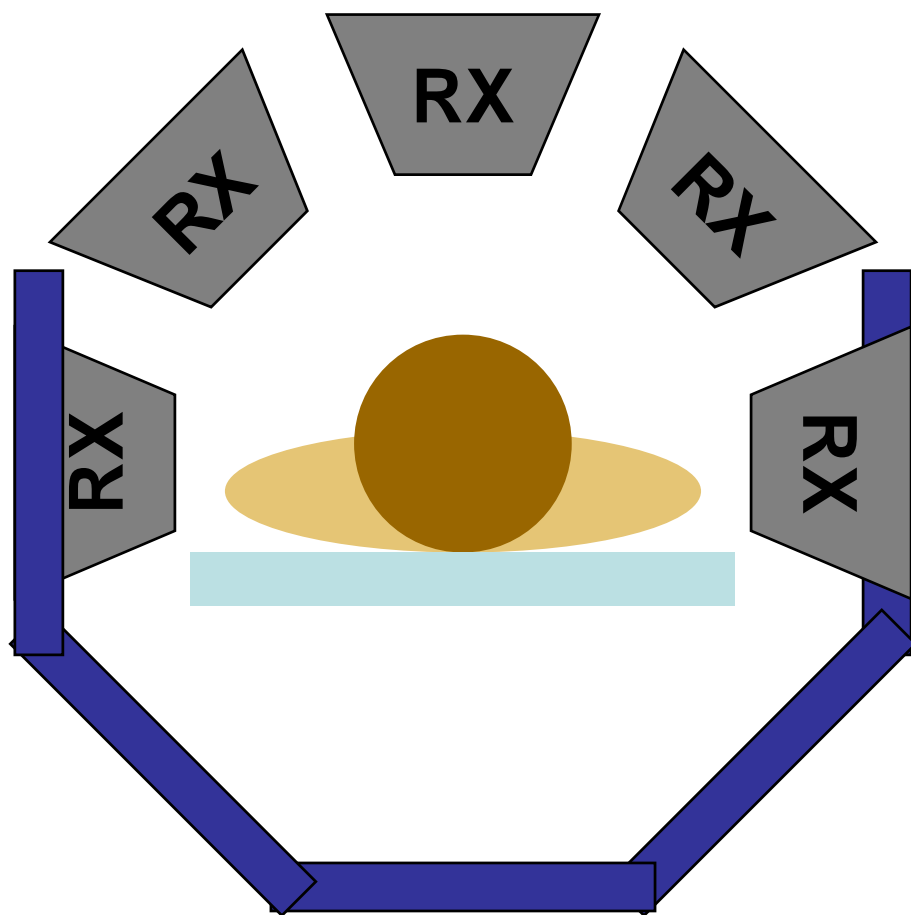


Reconstrução Tomográfica: Modalidade SPECT

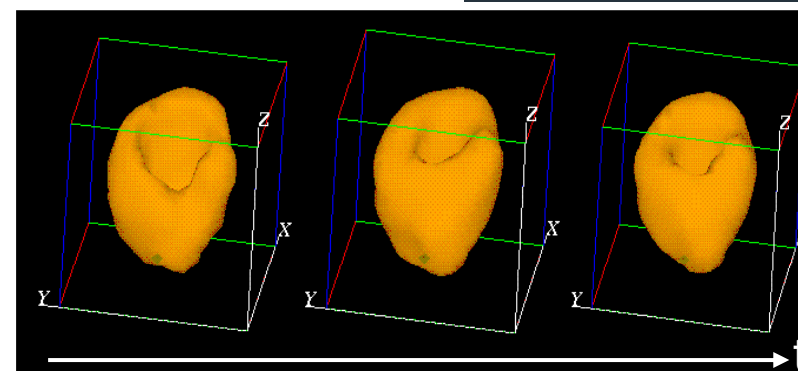
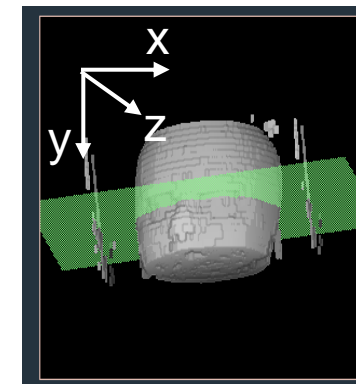


**Miocárdio marcado com
material radioativo (Tc)**

Reconstrução Tomográfica: Modalidade de Emissão de Raio-X



- Imagem digital => matriz n-dimensional
- 2D => pixel (**p**icture **e**lement)
 - raio X - CR (4096 x 4096 x 2B)
 - short f[4096][4096]
- 3D => voxel (**v**olume **e**lement)
 - CT multi-slice (700cortes x 512 x 512 x 2B)
 - XA (1000 quadros x 512 x 512 x 1B)
 - byte f[1000][512][512]
- 4D => spel (**s**pace **e**lement)
 - gated SPECT, MRI,...





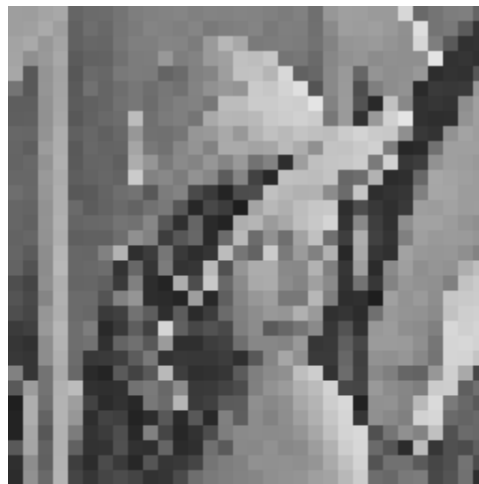
256x256 / 256 níveis



256x256 / 64 níveis



256x256 / 2 níveis



32x32 / 256 níveis

nível de cinza l ocorre n_l vezes em
imagem com n pixels $P(l) = \frac{n_l}{n}$

Imagem

1	0	0	3	3
0	0	3	3	3
1	1	1	3	3

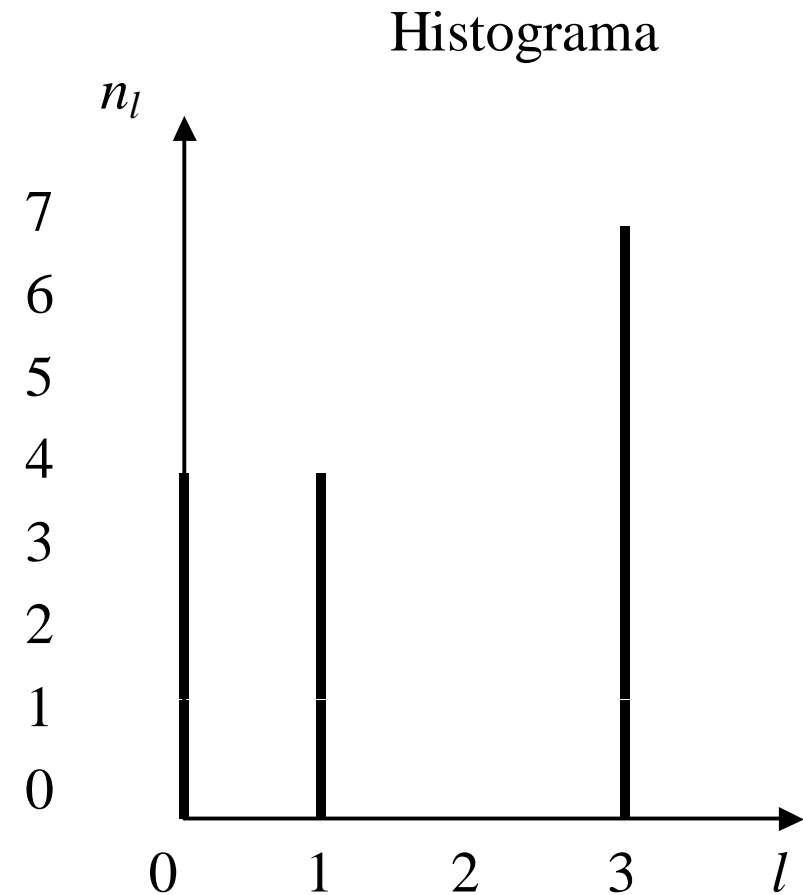
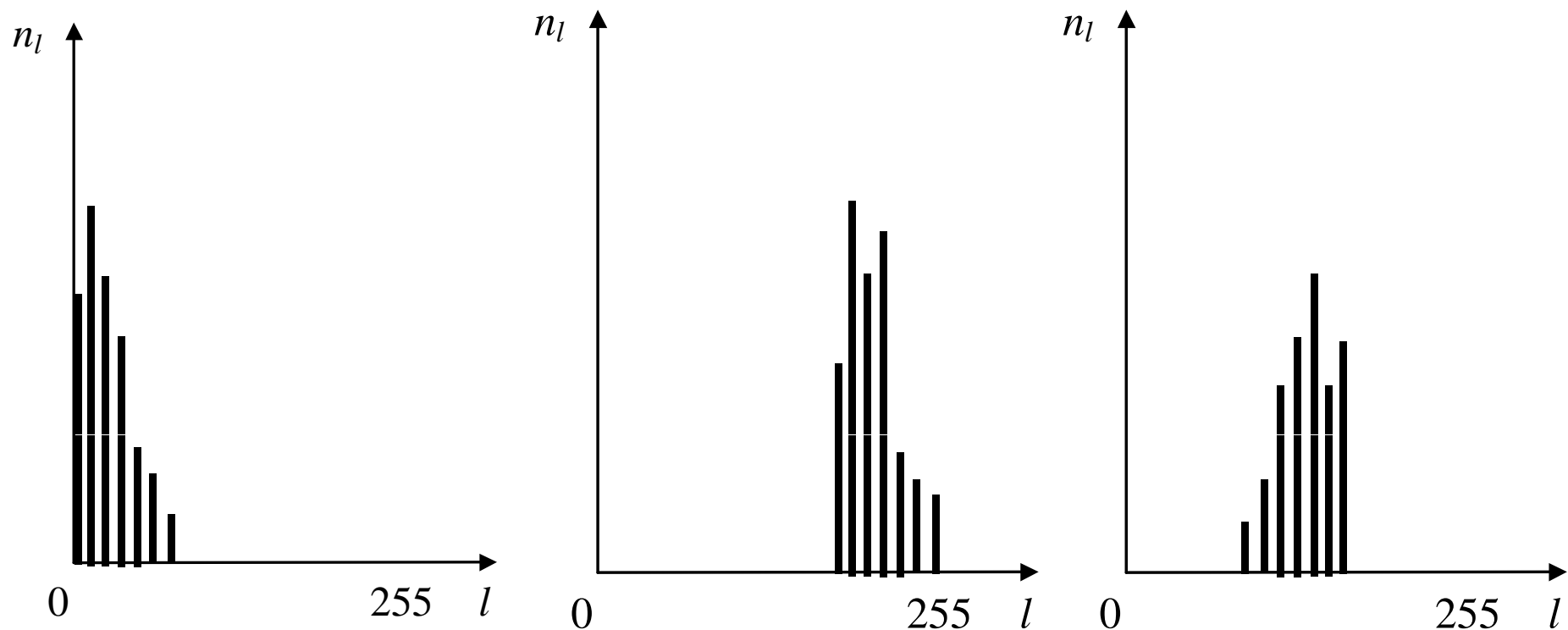
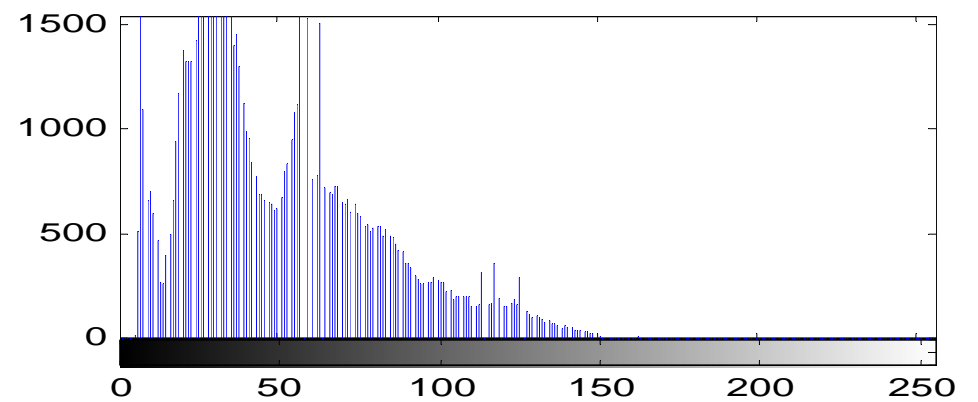
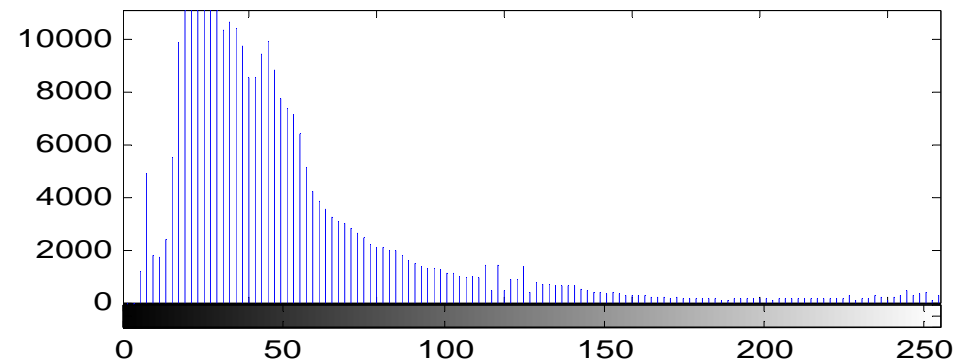


Imagem 3 x 5 ($L = 4$) e seu histograma

- O histograma representa a distribuição estatística de níveis de cinza de uma imagem





- Resolução Espacial
 - Define riqueza de detalhes da imagem
- Resolução de Profundidade
 - Define riqueza de meios-tons
 - Define cores
- Histograma
 - Distribuição estatística dos níveis de cinza em uma imagem

- Degradação
 - Não homogeneidade dos sensores
 - Não linearidade
 - Difração
 - Movimento e/ou Deslocamento

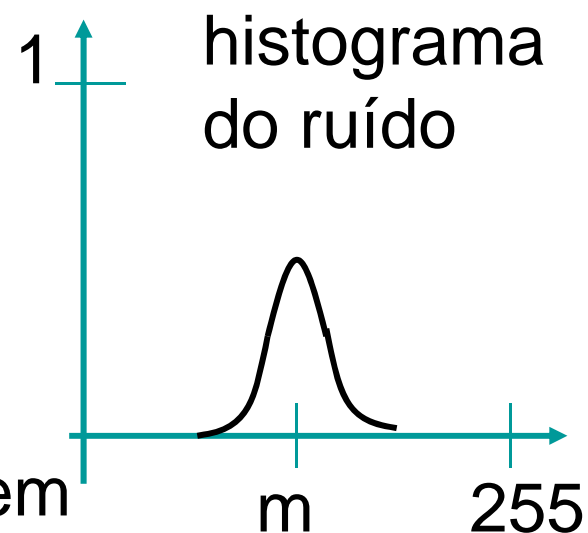
- Ruídos
 - Térmico
 - Estático
 - Quantização

- Tipo de ruído mais freqüente em imagens

$$h_i = \frac{\exp\left\{-\frac{(f_i - m)^2}{2\sigma^2}\right\}}{\sigma\sqrt{2\pi}}, \text{ para } -\infty < f_i < \infty$$

f_i : valor do i-ésimo pixel da imagem

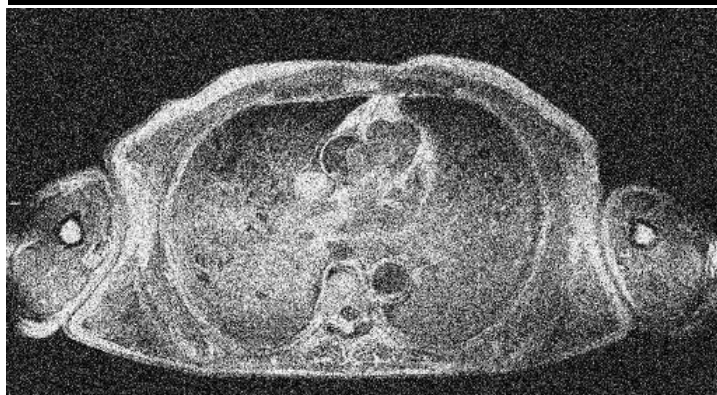
m, σ : média e desvio padrão do ruído



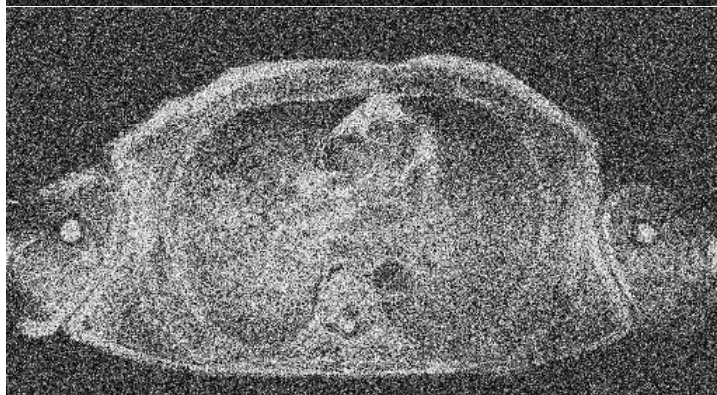
Original



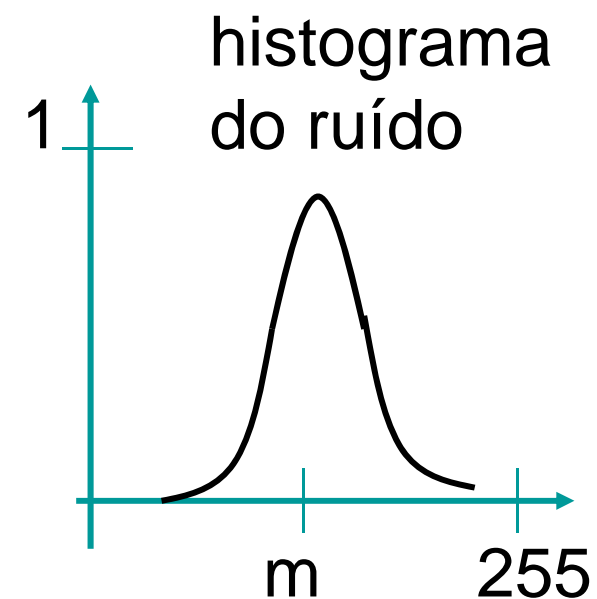
$\sigma = 50$



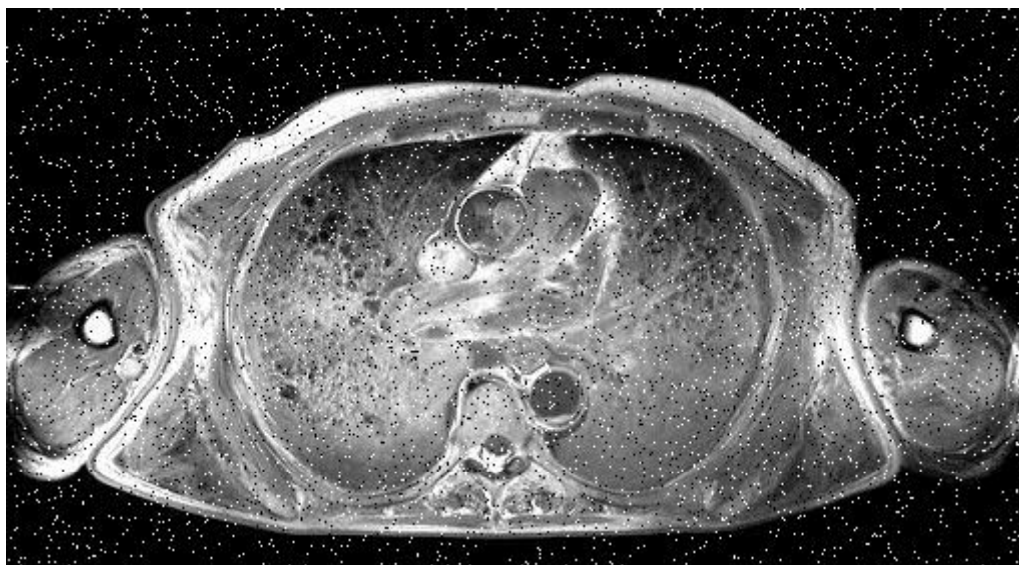
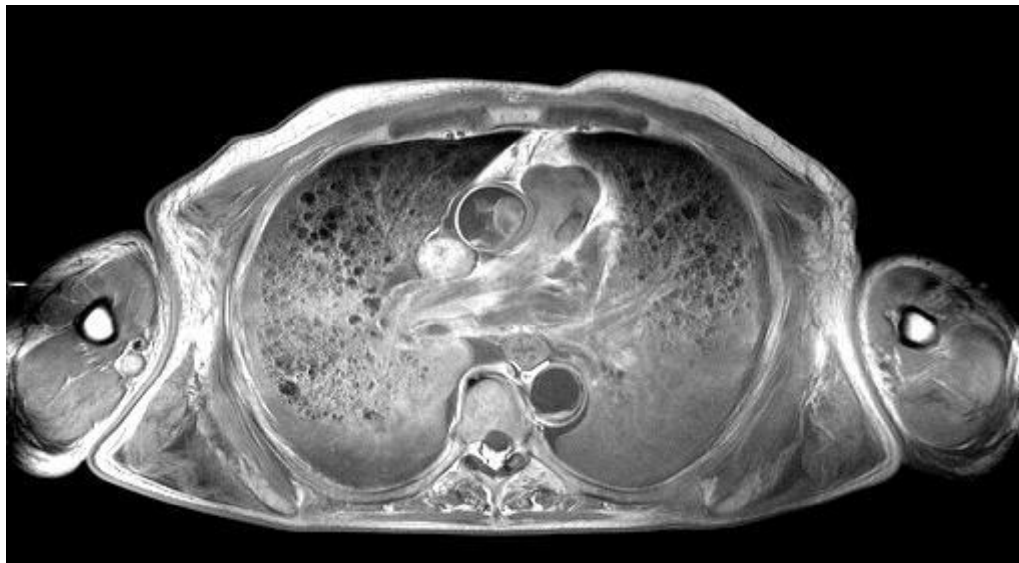
$\sigma = 75$



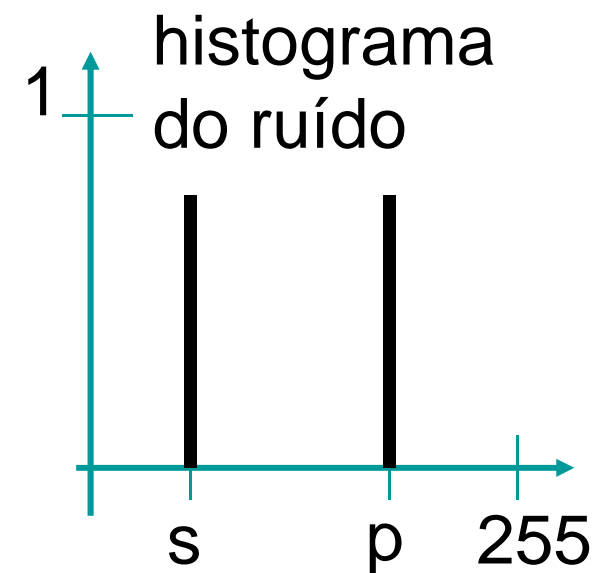
|



Ruído “Sal e Pimenta”



Mal funcionamento dos detectores



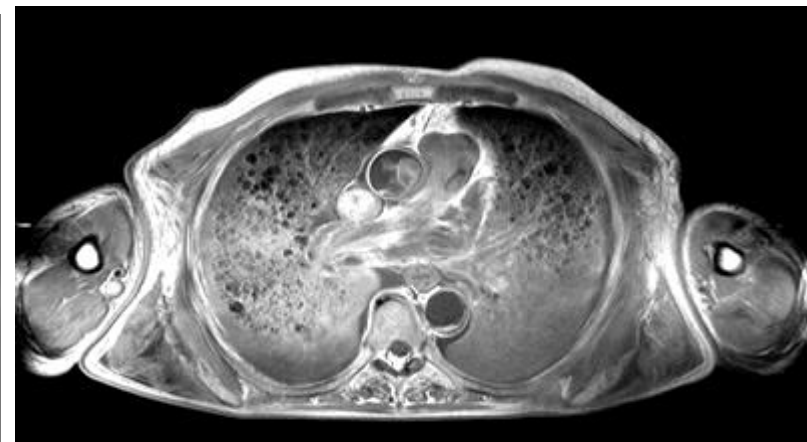
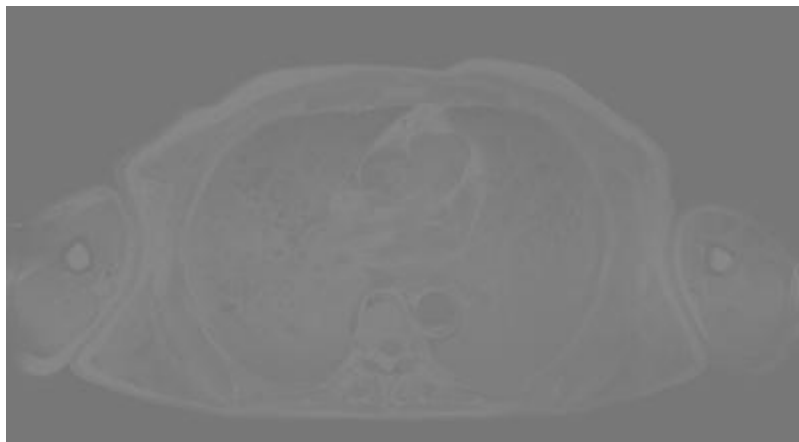
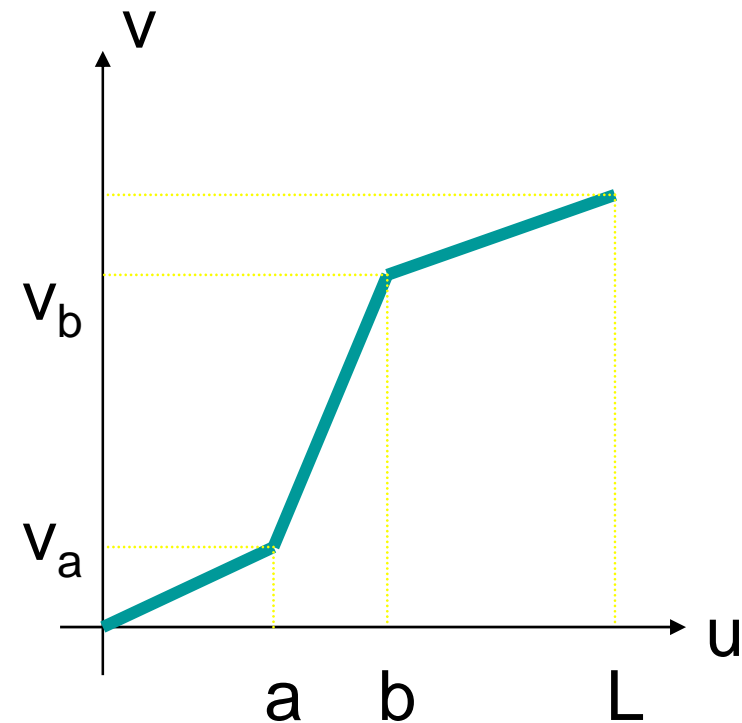
- Operações pontuais
 - remoção de ruído
 - equalização do histograma
- Operações espaciais
 - suavização do ruído
 - filtros

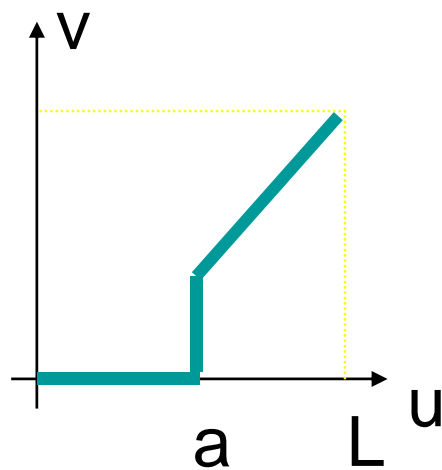
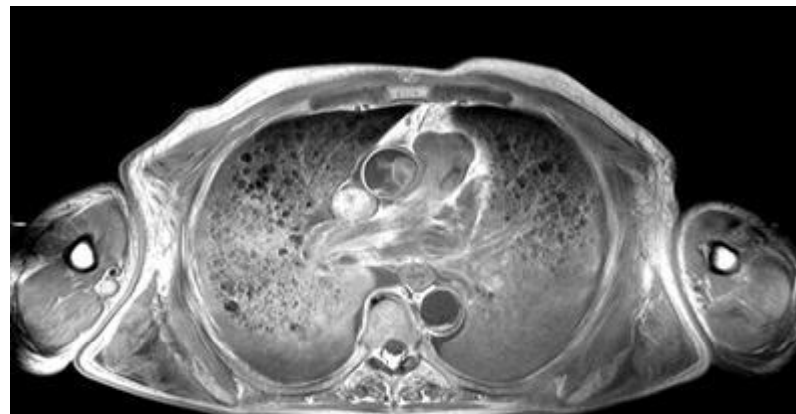
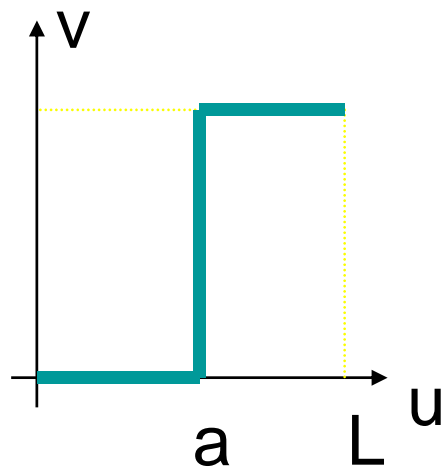
- Alteram a escala de tons de cinza através de uma transformação:

$$v = f(u) \begin{cases} u \in [0, L] \\ v \in [0, L] \end{cases}$$

- Alargamento do Contraste
- Limiar (Thresholding)
- Equalização do histograma

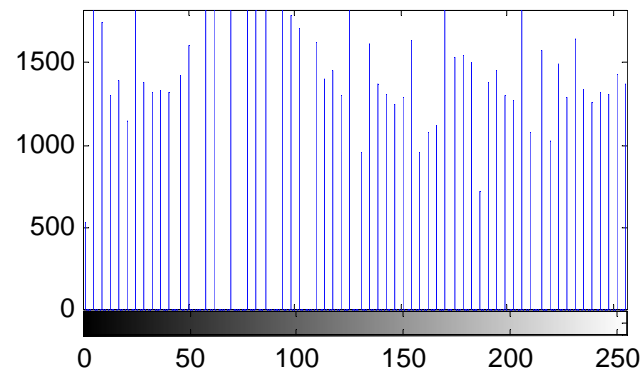
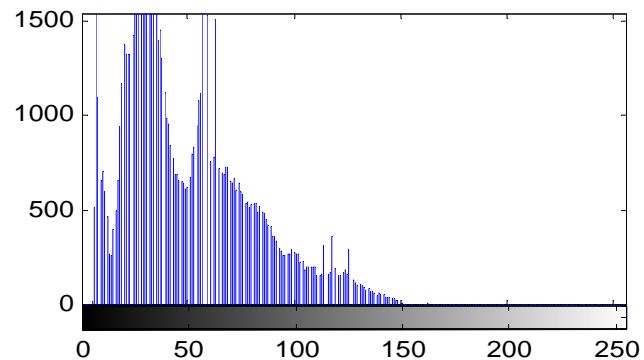
$$v = \begin{cases} \alpha u & 0 \leq u < a \\ \beta(u-a) + v_a & a \leq u < b \\ \gamma(u-b) + v_b & b \leq u < L \end{cases}$$





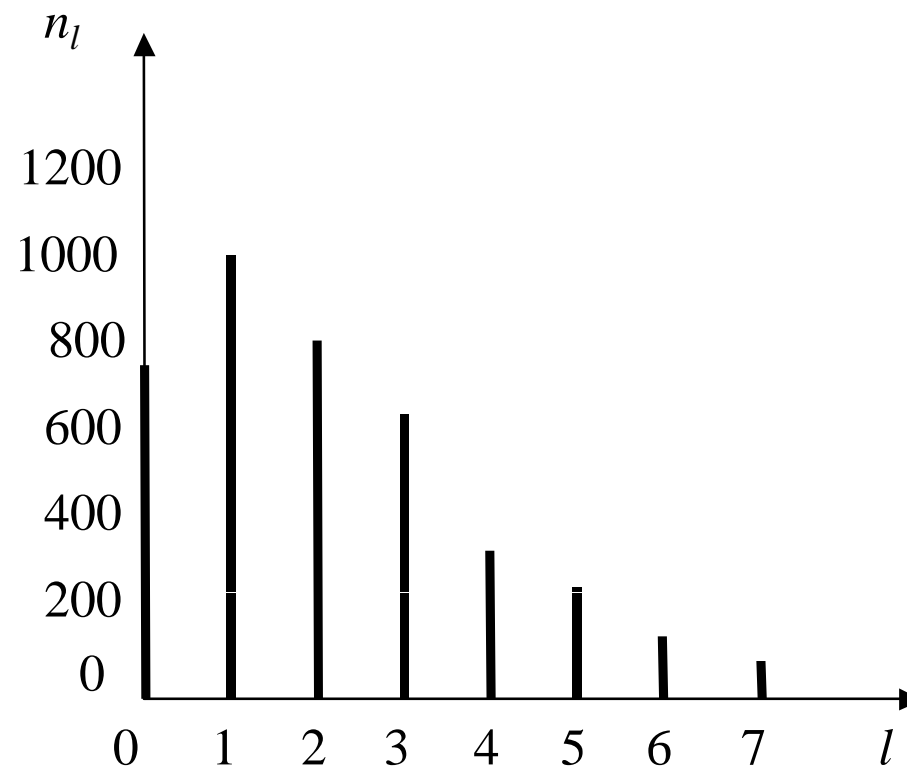
Equalização de Histograma

$$s = T(r) = \text{round}\left(\frac{L-1}{RC} \sum_{l=0}^r n_l\right)$$



- Exemplo: imagem 64 x 64, $L = 8$

l	n_l
0	790
1	1023
2	850
3	656
4	329
5	245
6	122
7	81



Equalização de Histograma

- $r = 0 \rightarrow s = \text{round} (790 \times 7 / 4096) = 1$
- $r = 1 \rightarrow s = \text{round} (1813 \times 7 / 4096) = 3$
- $r = 2 \rightarrow s = \text{round} (2663 \times 7 / 4096) = 5$
- $r = 3 \rightarrow s = \text{round} (3319 \times 7 / 4096) = 6$
- $r = 4 \rightarrow s = \text{round} (3648 \times 7 / 4096) = 6$
- $r = 5 \rightarrow s = \text{round} (3893 \times 7 / 4096) = 7$
- $r = 6 \rightarrow s = \text{round} (4015 \times 7 / 4096) = 7$
- $r = 7 \rightarrow s = \text{round} (4096 \times 7 / 4096) = 7$

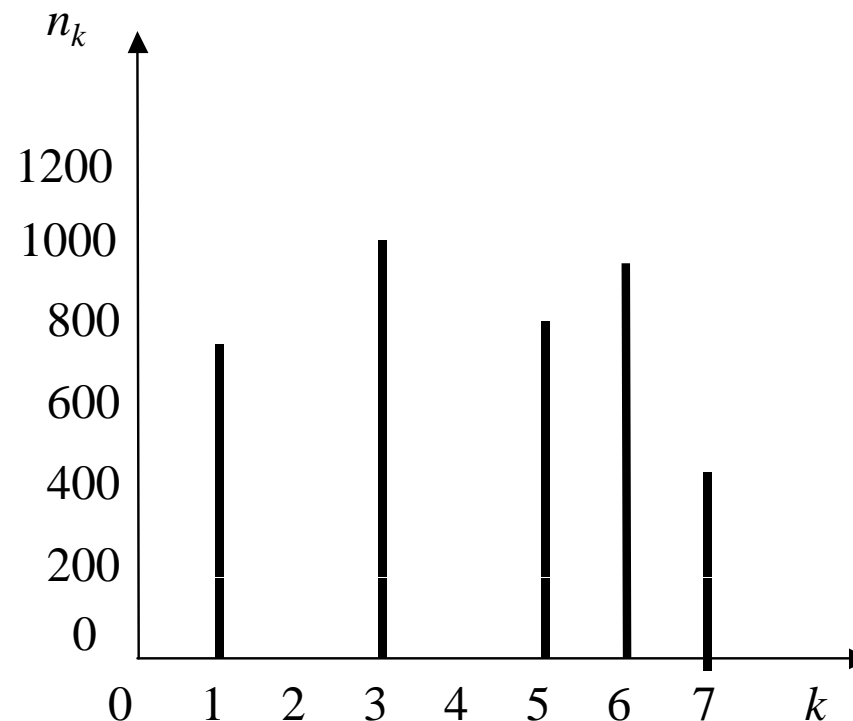
$$s = T(r) = \text{round} \left(\frac{L-1}{RC} \sum_{l=0}^r n_l \right)$$

$$RC = 64 \times 64 = 4096$$

$$L = 8$$

- Exemplo: imagem 64 x 64, $L = 8$

l	n_l
0	0
1	790
2	0
3	1023
4	0
5	850
6	985
7	448



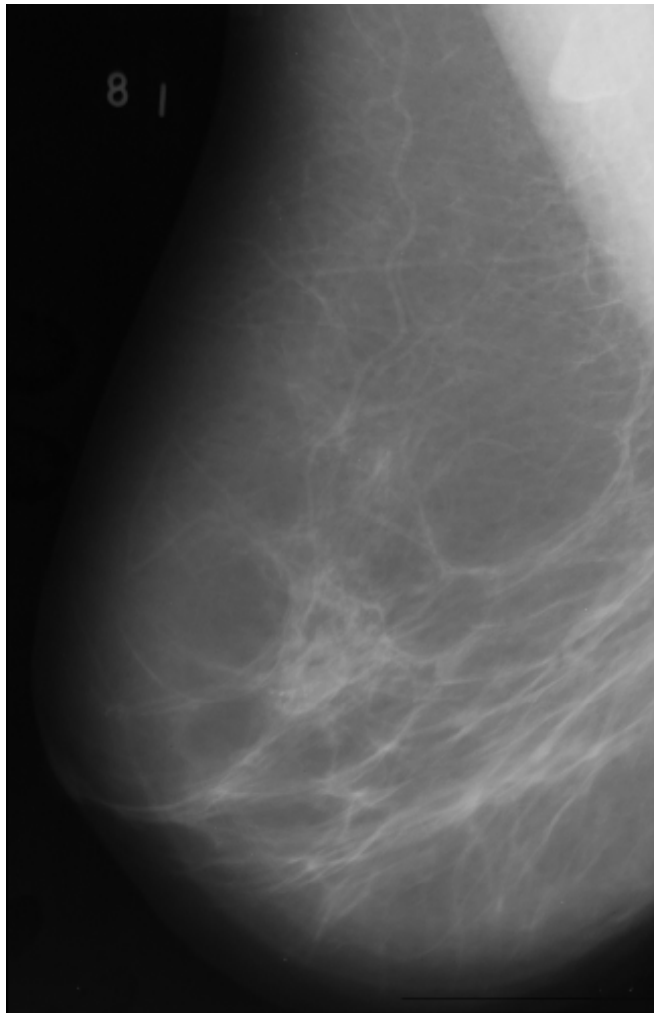


Imagem original

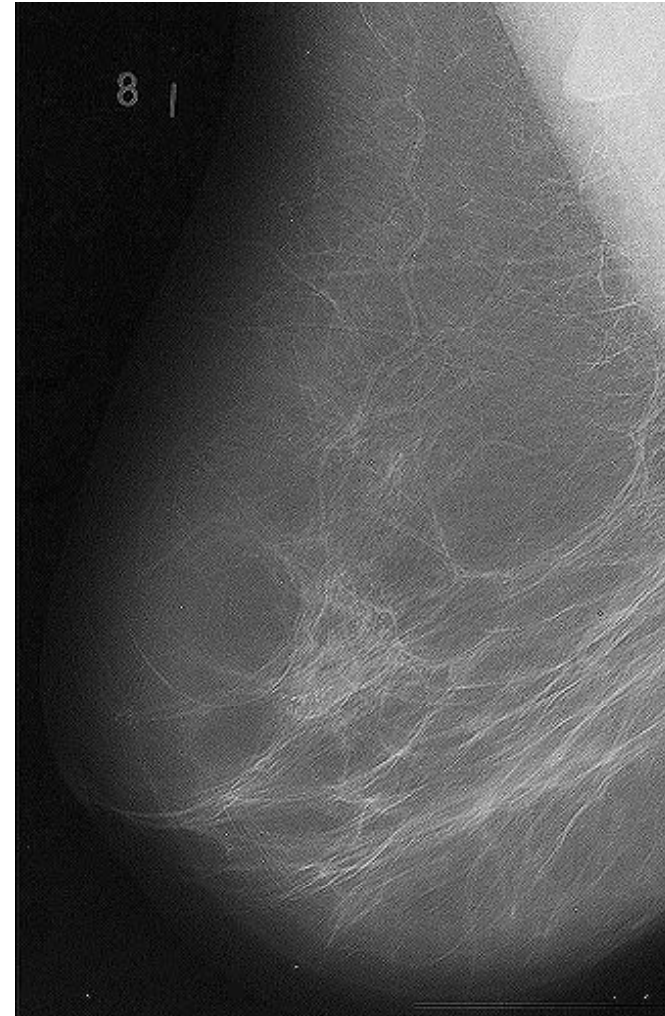
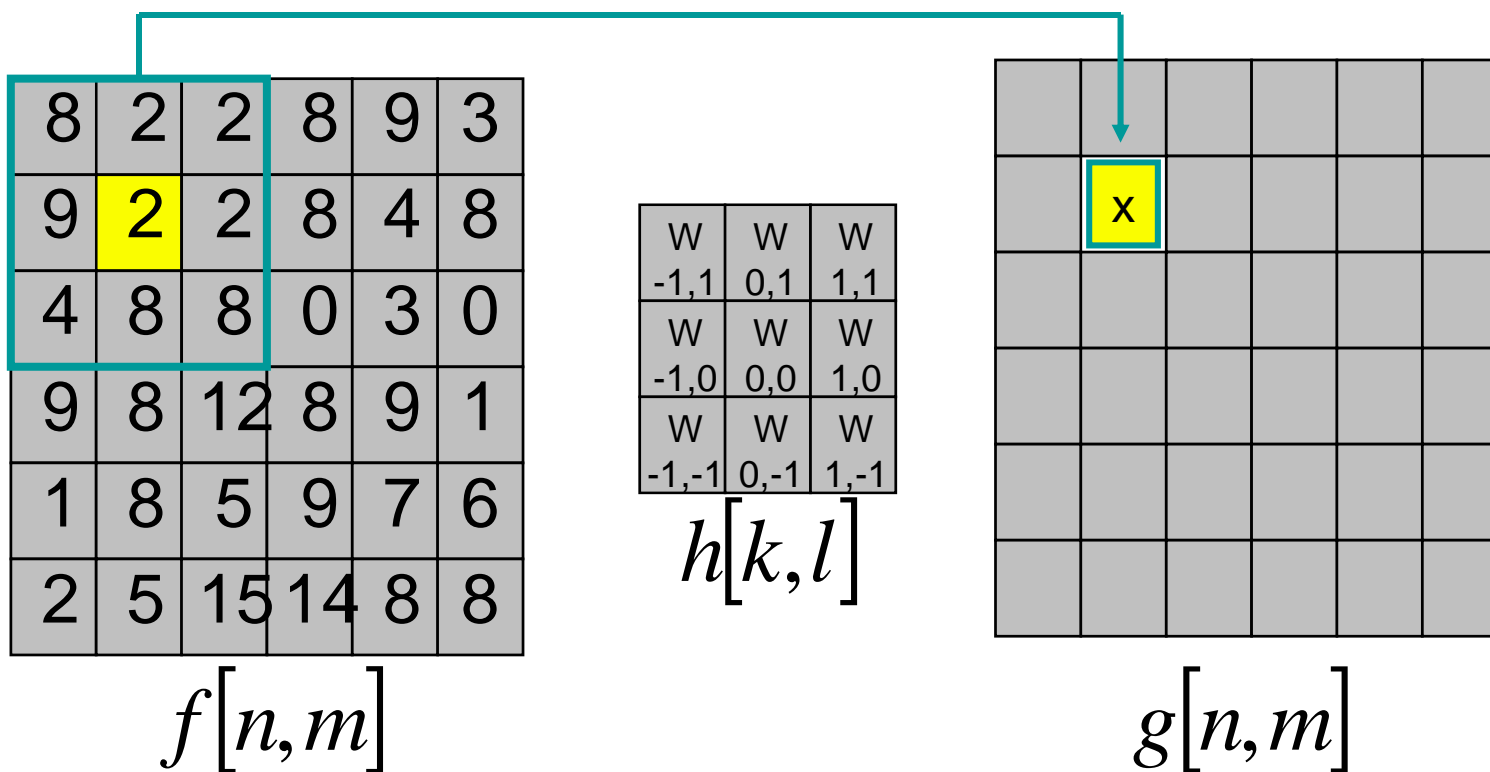


Imagem após equalização

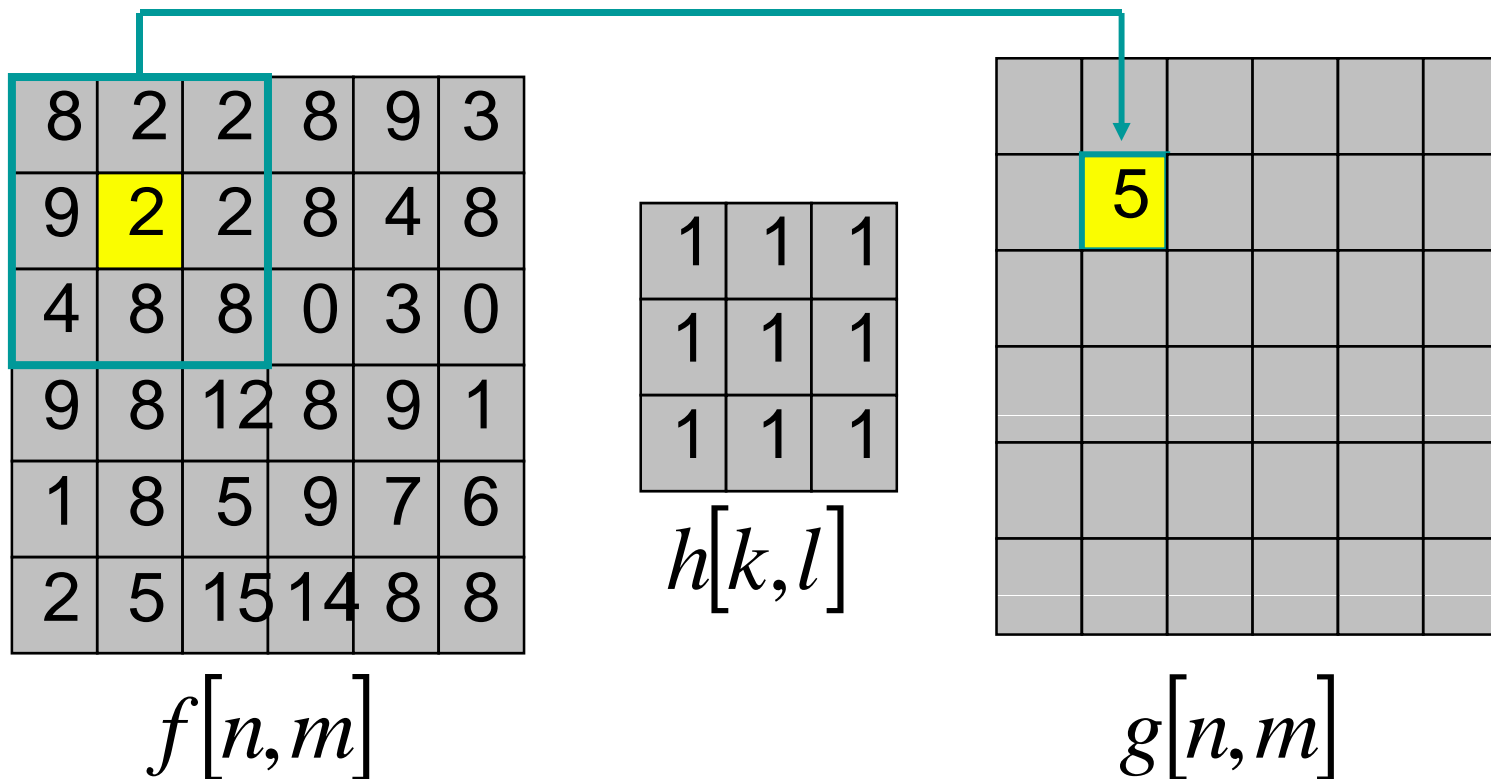
- Operações realizadas com informações da vizinhança de cada pixel da imagem original
- Convolução da imagem original com filtro de resposta ao impulso finita (máscara de convolução)
- Operadores: Média ponderada, Gaussiano, Laplaciano, Sobel, Mediana, etc,

$$g[n,m] = \sum_{k=-1}^1 \sum_{l=-1}^1 h[k,l] \cdot f[n-k, m-l]$$



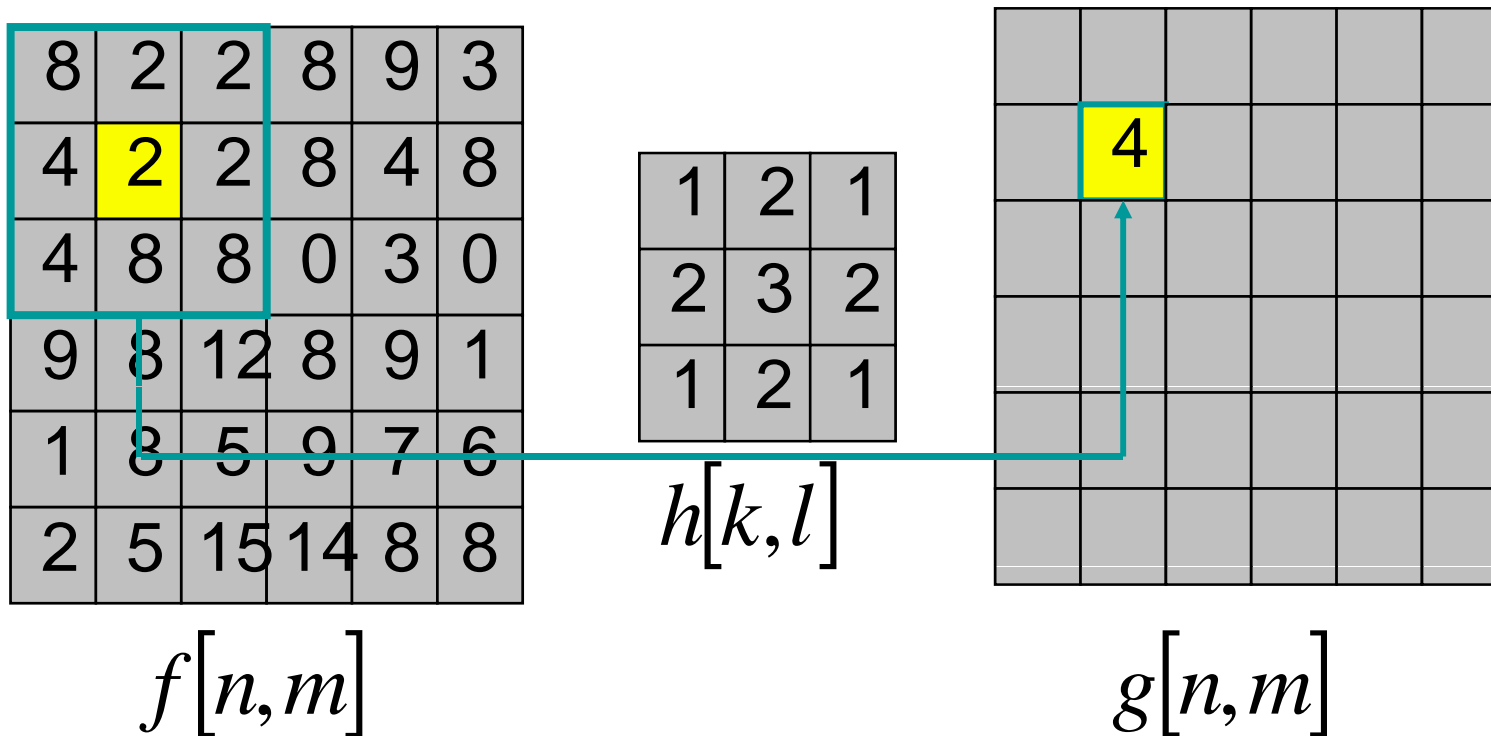
Filtro Média Espacial (passa-baixa)

$$g[n,m] = \frac{1}{N_{kl}} \sum_{k=-1}^1 \sum_{l=-1}^1 h[k,l] \cdot f[n-k, m-l]$$



Filtro Média Ponderada (passa-baixa)

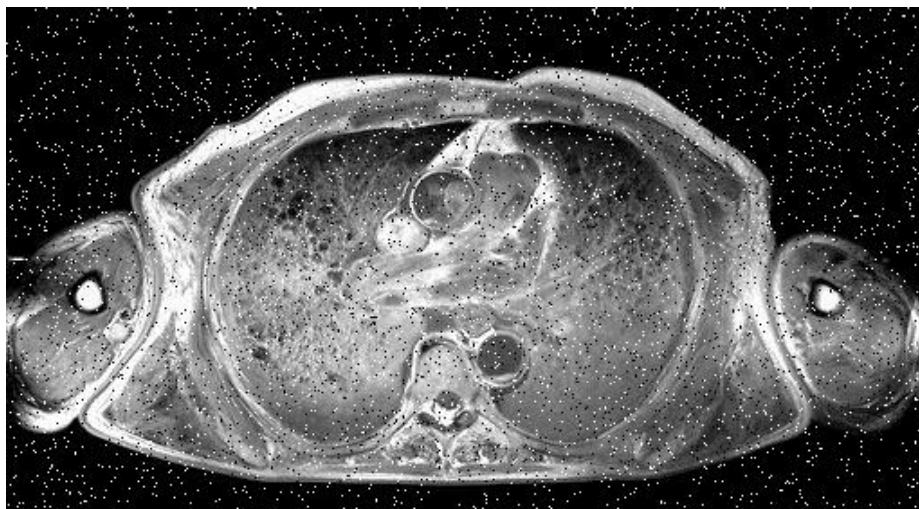
$$g[n, m] = \sum_{k=-1}^1 \sum_{l=-1}^1 h[k, l] \cdot f[n-k, m-l]$$



$$g[n, m] = \sum_{k=-1}^1 \sum_{l=-1}^1 h[k, l] \cdot f[n-k, m-l]$$

1	2	1
2	3	2
1	2	1

$h[k, l]$



Original

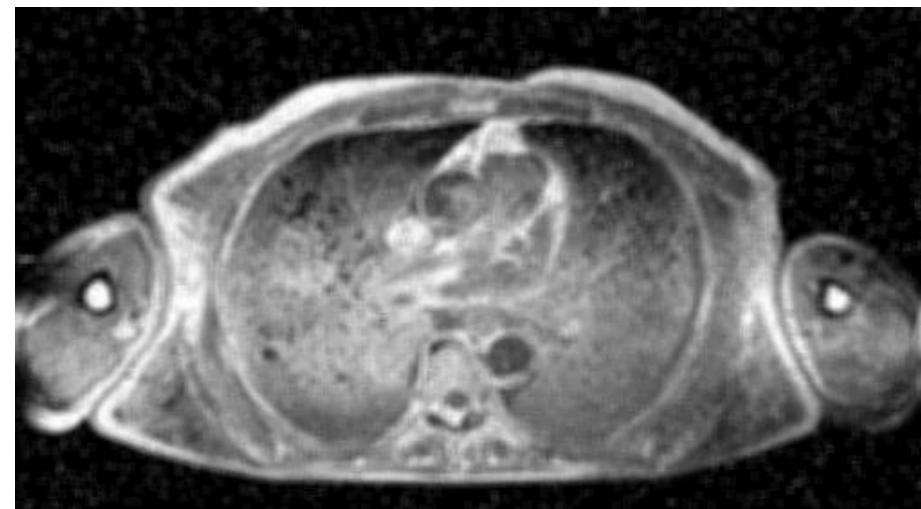


Imagem Filtrada

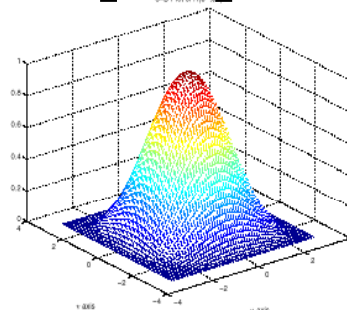
Filtro Gaussiano (passa-baixa)

8	2	2	8	9	3	3
9	2	2	8	4	8	8
4	1	8	4	3	0	0
9	3	1	2	3	1	1
1	4	5	3	1	2	6
2	5	7	1	2	0	8
5	1	10	12	3	2	1

$f[n,m]$

1	1	2	1	1
1	2	4	2	1
2	4	8	4	2
1	2	4	2	1
1	1	2	1	1

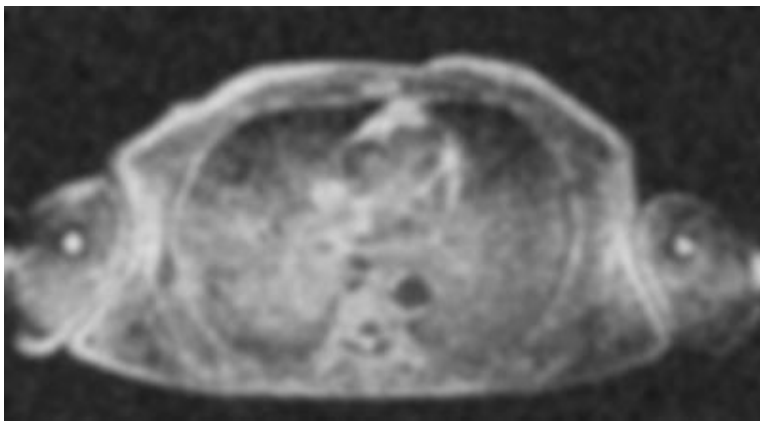
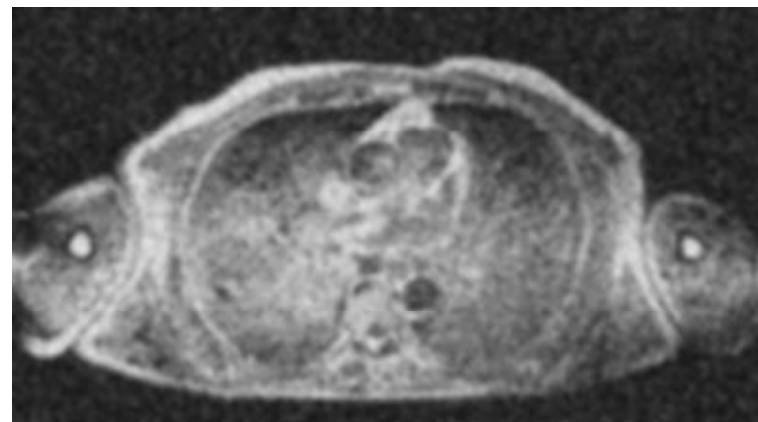
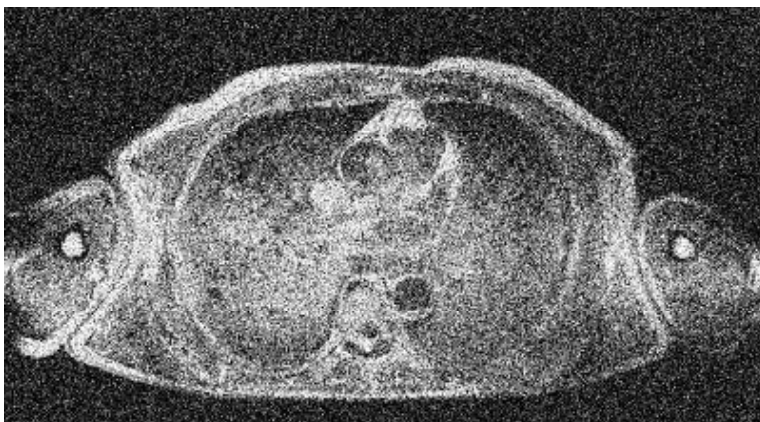
$h[k,l]$



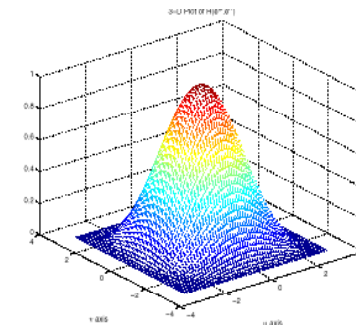
8	2	2	8	9	3	3
9	2	2	8	4	8	8
4	8	8	0	3	0	0
9	8	12	3	9	1	1
1	8	5	9	7	6	6
2	5	15	14	8	8	8
5	1	10	12	3	2	1

$g[n,m]$

Filtro Gaussiano



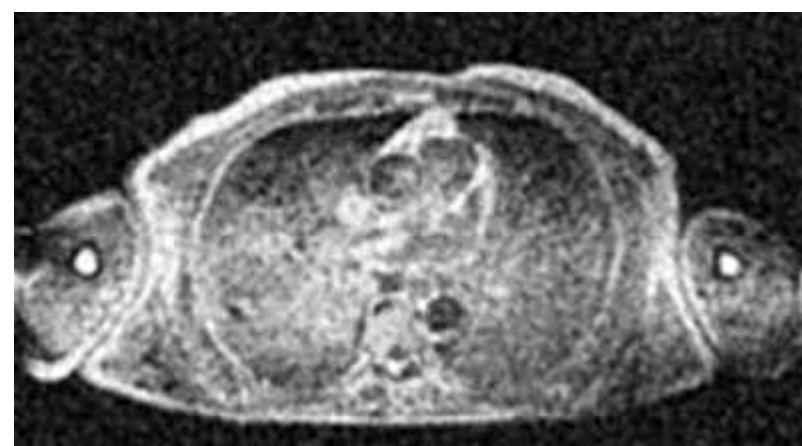
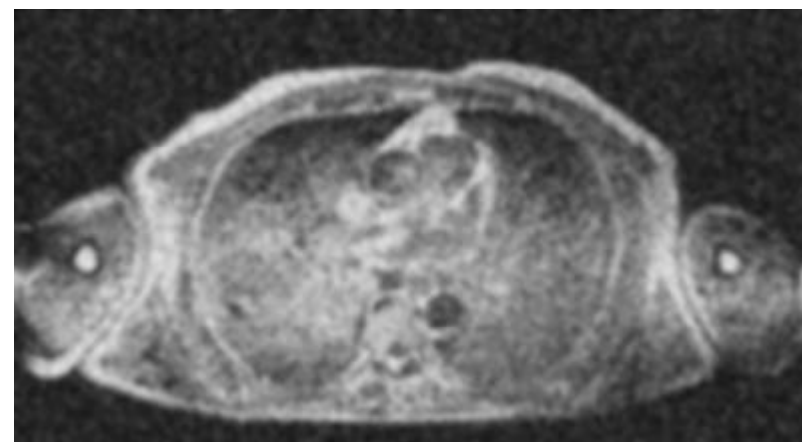
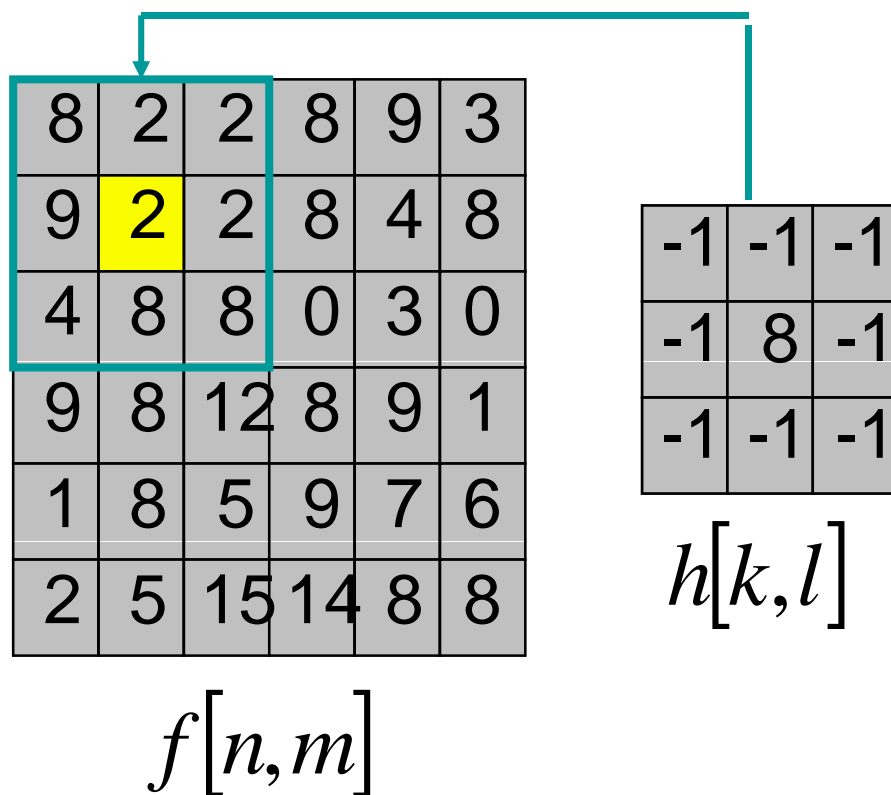
3x3



5x5

Sharpening (passa-alta)

$$g[n,m] = \frac{1}{N_{kl}} \sum_{k=-1}^1 \sum_{l=-1}^1 h[k,l] \cdot f[n-k, m-l]$$



Filtro Derivada Horizontal (passa-alta)

$$g[n, m] = \sum_{k=-1}^1 \sum_{l=-1}^1 h[k, l] \cdot f[n - k, m - l]$$

0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	16	16	16	16
0	0	0	16	16	16	16
0	0	0	16	16	16	16
0	0	0	16	16	16	16

$f[n, m]$

2	0	-2
4	0	-4
2	0	-2

$h[k, l]$

0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	2	2	0	0	-2
0	0	6	6	0	0	-6
0	0	8	8	0	0	-8
0	0	8	8	0	0	-8
0	0	6	6	0	0	-6

$g[n, m]$

Filtro Derivada Vertical (passa-alta)

$$g[n, m] = \sum_{k=-1}^1 \sum_{l=-1}^1 h[k, l] \cdot f[n - k, m - l]$$

0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	16	16	16	16
0	0	0	16	16	16	16
0	0	0	16	16	16	16
0	0	0	16	16	16	16

$f[n, m]$

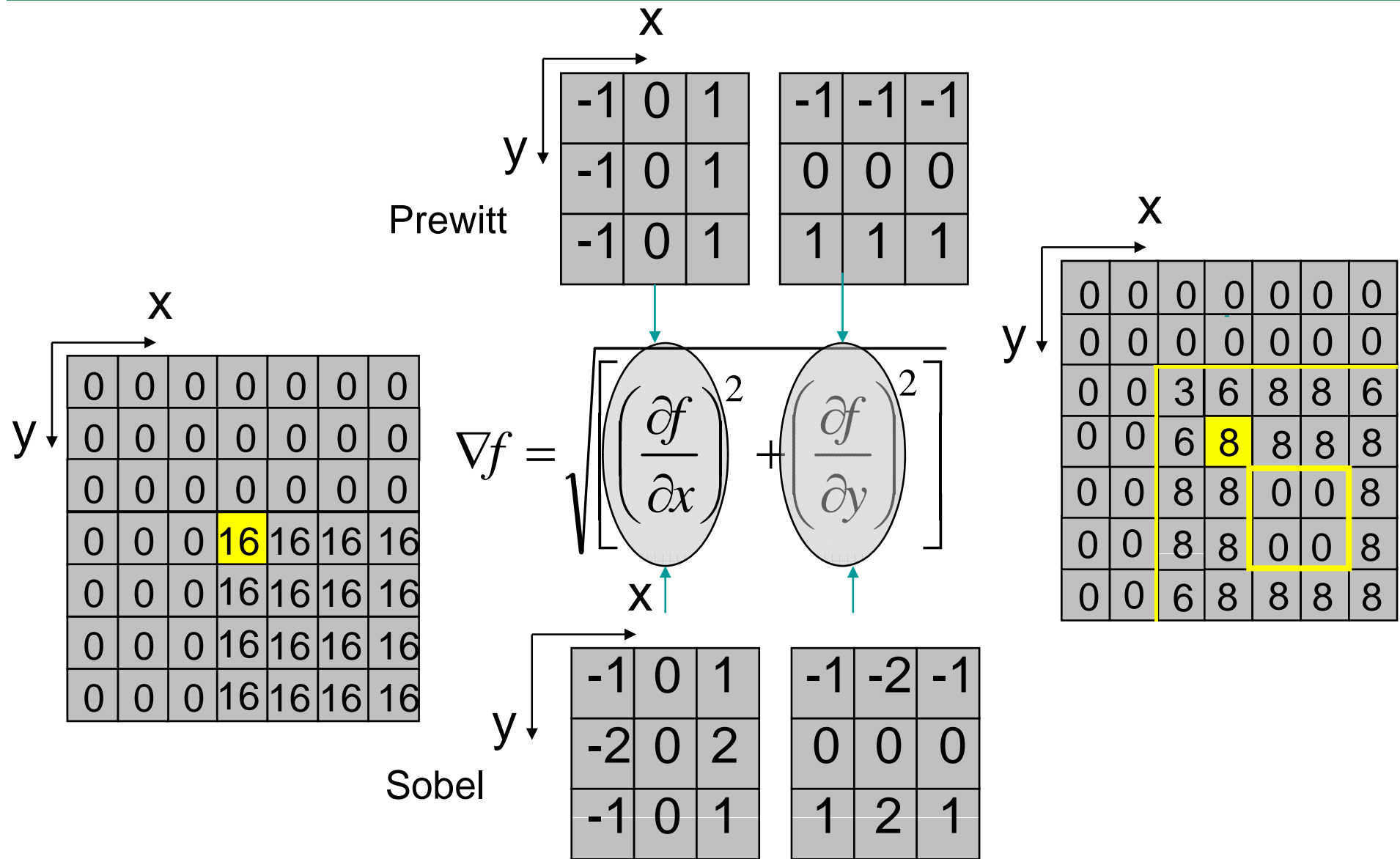
2	4	2
0	0	0
-2	-4	-2

$h[k, l]$

0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	2	6	8	8	6
0	0	2	6	8	8	6
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	-2	-6	-8	-8	-6

$g[n, m]$

Filtro Gradiente (passa-alta)

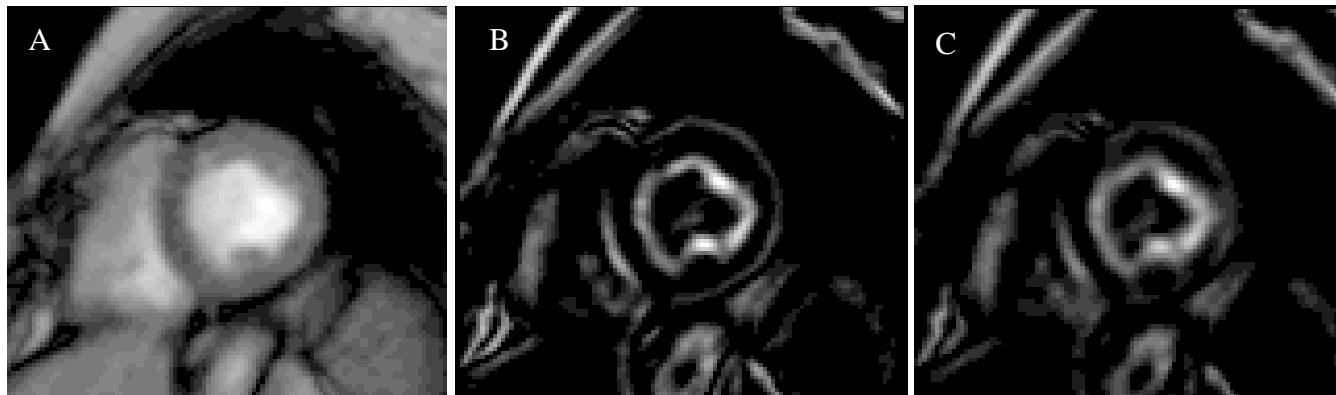


Filtro Gradiente (Máscara de Sobel)

$$Gauss[x, y] = \exp\left(-\frac{x^2 + y^2}{2\sigma^2}\right)$$

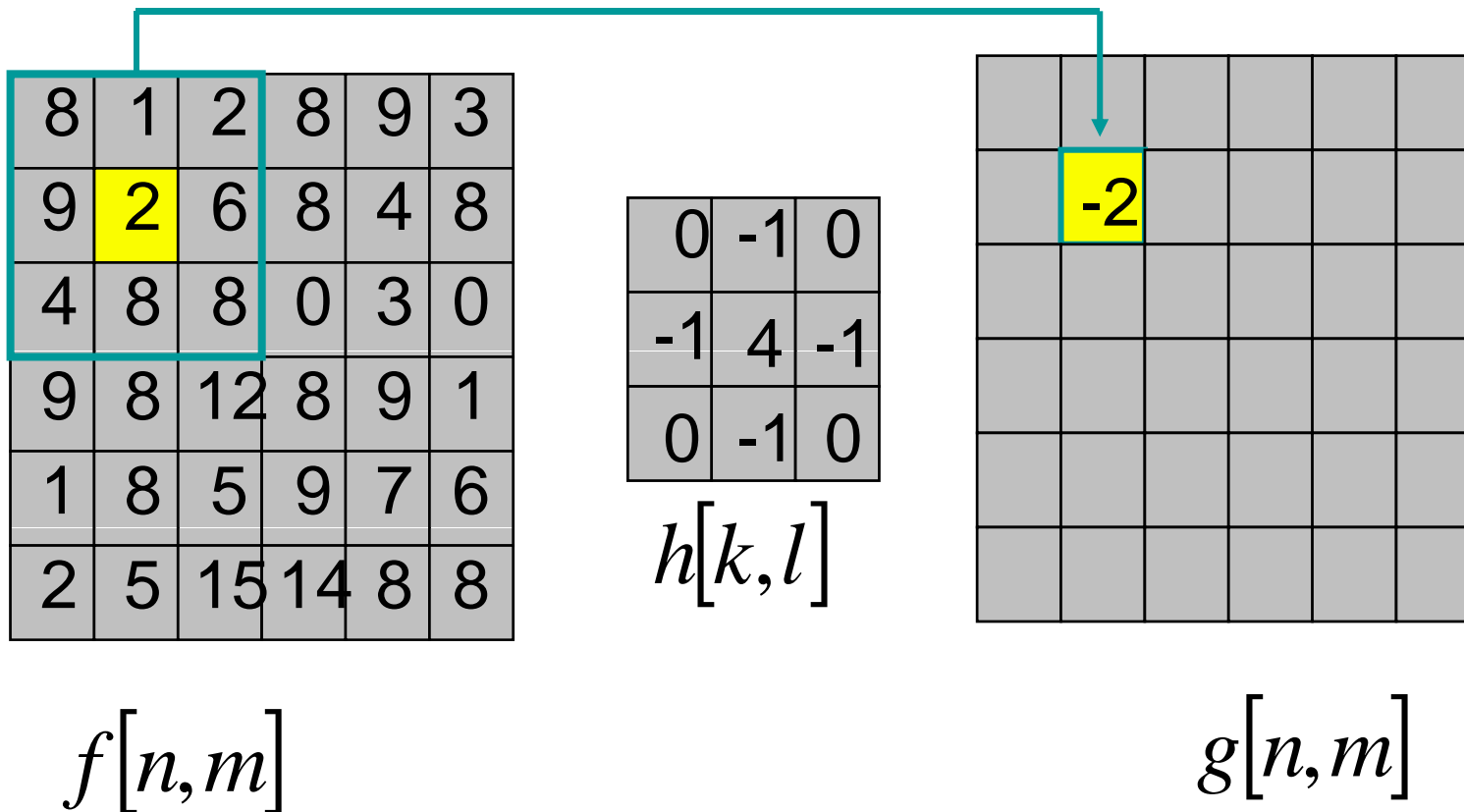
$$g[x, y] = \nabla Gauss[x, y] * f[x, y]$$

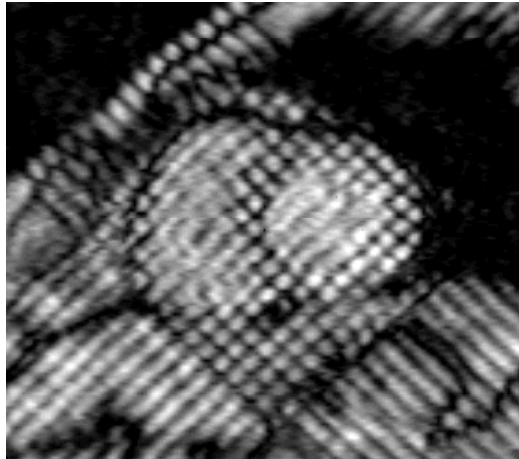
$$\nabla G = \sqrt{\left[\left(\frac{\partial G}{\partial x}\right)^2 + \left(\frac{\partial G}{\partial y}\right)^2\right]}$$



Filtro Laplaciano (segunda derivada)

$$g[n, m] = \sum_{k=-1}^1 \sum_{l=-1}^1 h[k, l] \cdot f[n - k, m - l]$$

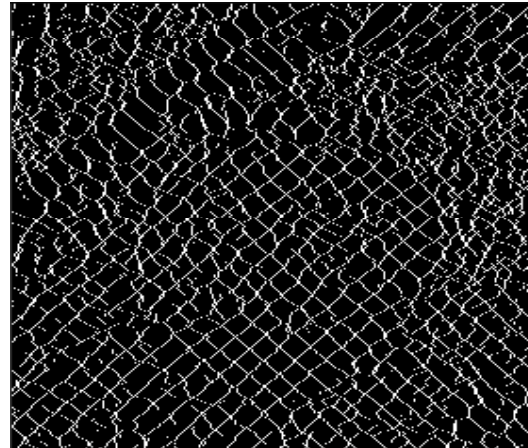




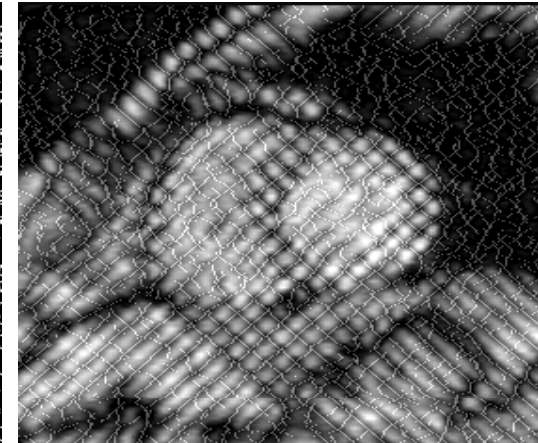
original

0	-1	0
-1	4	-1
0	-1	0

$h[k, l]$



$g[x, y]$



$g[x, y] + \text{original}$

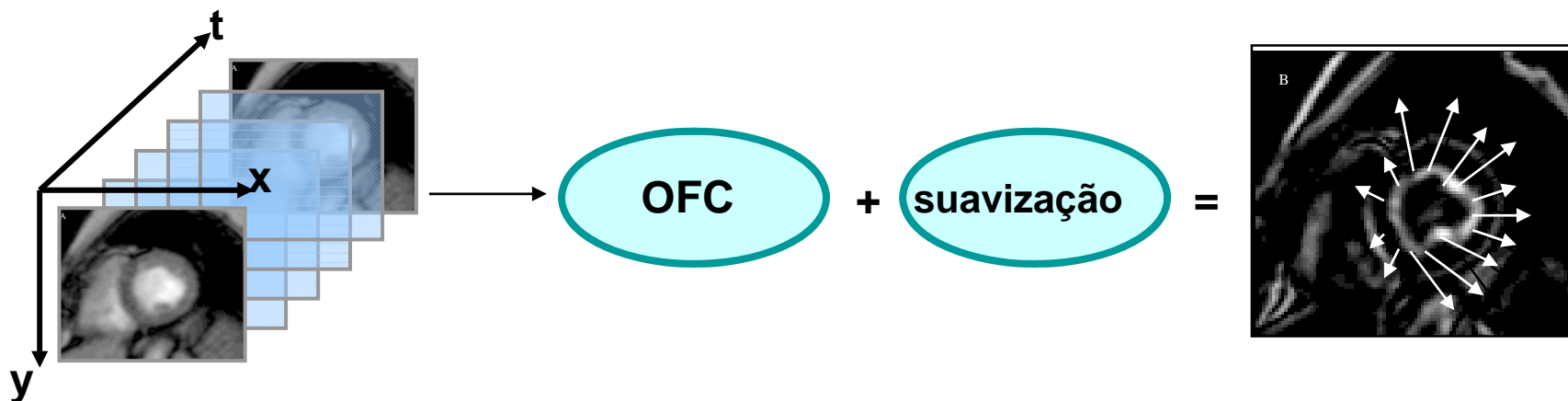
$$Gauss[x, y] = \exp\left(-\frac{x^2 + y^2}{2\sigma^2}\right)$$

$$g[x, y] = \nabla^2 Gauss[x, y] * f[x, y]$$

i) $\nabla f \bullet \vec{v} = -f_t$ (OFC)

ii) $|\nabla v_x|^2 + |\nabla v_y|^2 + |\nabla v_z|^2 = 0$ (suavização)

iii) $\iint [(\nabla f \bullet \vec{v}) + f_t]^2 + \alpha^2 \left[\left(\frac{\partial \vec{v}}{\partial x} \right)^2 + \left(\frac{\partial \vec{v}}{\partial y} \right)^2 \right] dx dy$ (regularização)



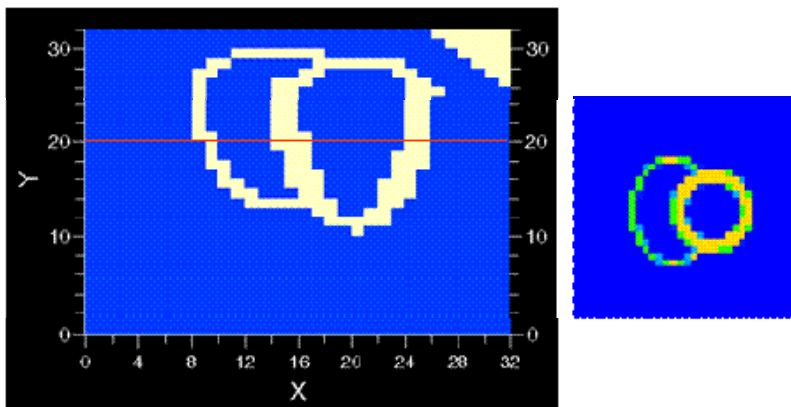
2D

$$\left\{ \begin{array}{l} v_x = \bar{v}_x - \frac{E_x (E_x \bar{v}_x + E_y \bar{v}_y + E_t)}{\alpha^2 + E_x^2 + E_y^2} \\ v_y = \bar{v}_y - \frac{E_y (E_x \bar{v}_x + E_y \bar{v}_y + E_t)}{\alpha^2 + E_x^2 + E_y^2} \end{array} \right.$$

3D

$$\left\{ \begin{array}{l} v_x = \bar{v}_x - \frac{E_x (E_x \bar{v}_x + E_y \bar{v}_y + E_z \bar{v}_z + E_t)}{\alpha^2 + E_x^2 + E_y^2 + E_z^2} \\ v_y = \bar{v}_y - \frac{E_y (E_x \bar{v}_x + E_y \bar{v}_y + E_z \bar{v}_z + E_t)}{\alpha^2 + E_x^2 + E_y^2 + E_z^2} \\ v_z = \bar{v}_z - \frac{E_z (E_x \bar{v}_x + E_y \bar{v}_y + E_z \bar{v}_z + E_t)}{\alpha^2 + E_x^2 + E_y^2 + E_z^2} \end{array} \right.$$

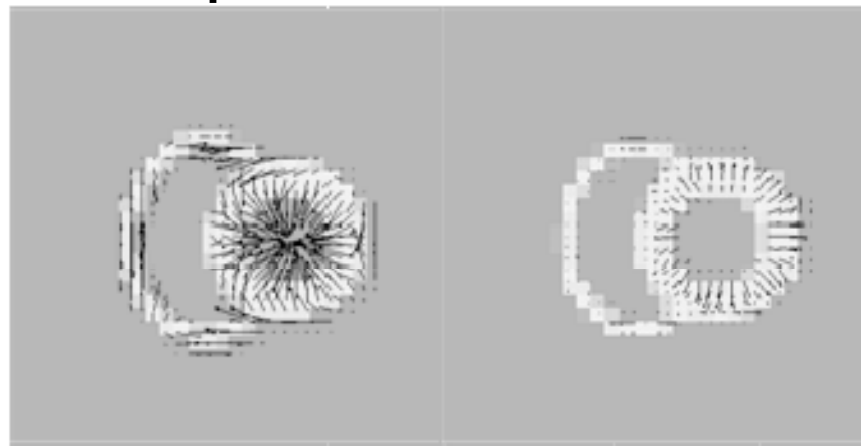
- Imagem 2D 64x64, 8.192 incógnitas;
- Imagem 3D 64x64x64, 786.432 incógnitas;
- ART, Gradiente Conjugado, etc;



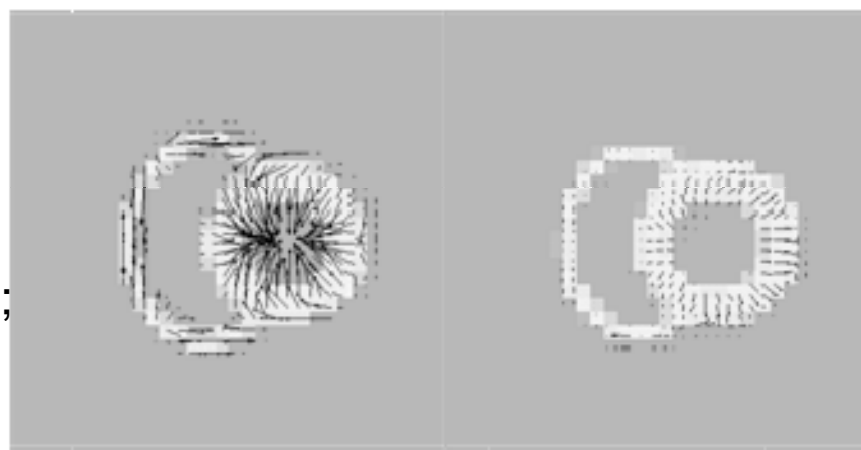
4D Mathematical Cardiac-Torso Phantom
Pretorius, et al. Medical Physics, 26:2323-2331, 1999

1. Imagens 3D dinâmicas (4D)
2. Simula as câmaras cardíacas e estruturas do tórax (dimensões, volumes, massa, etc);
3. Simula movimentos das estruturas;
4. Inclui o movimento relativo à respiração;

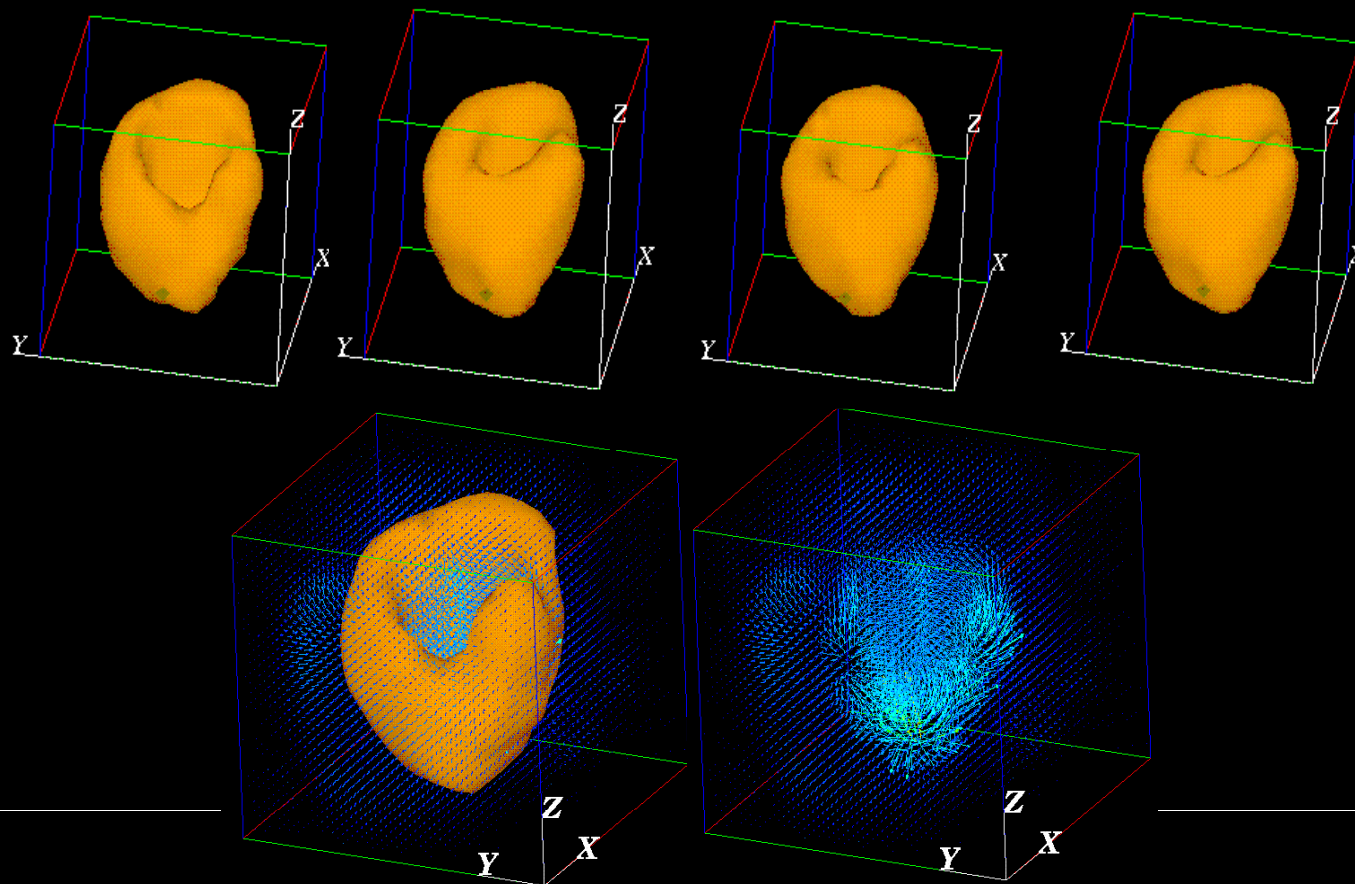
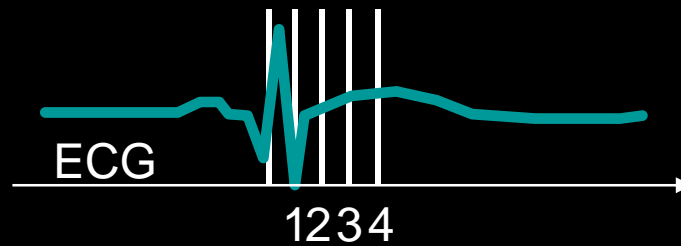
Campo de vetores de velocidade obtido aplicando a DWV

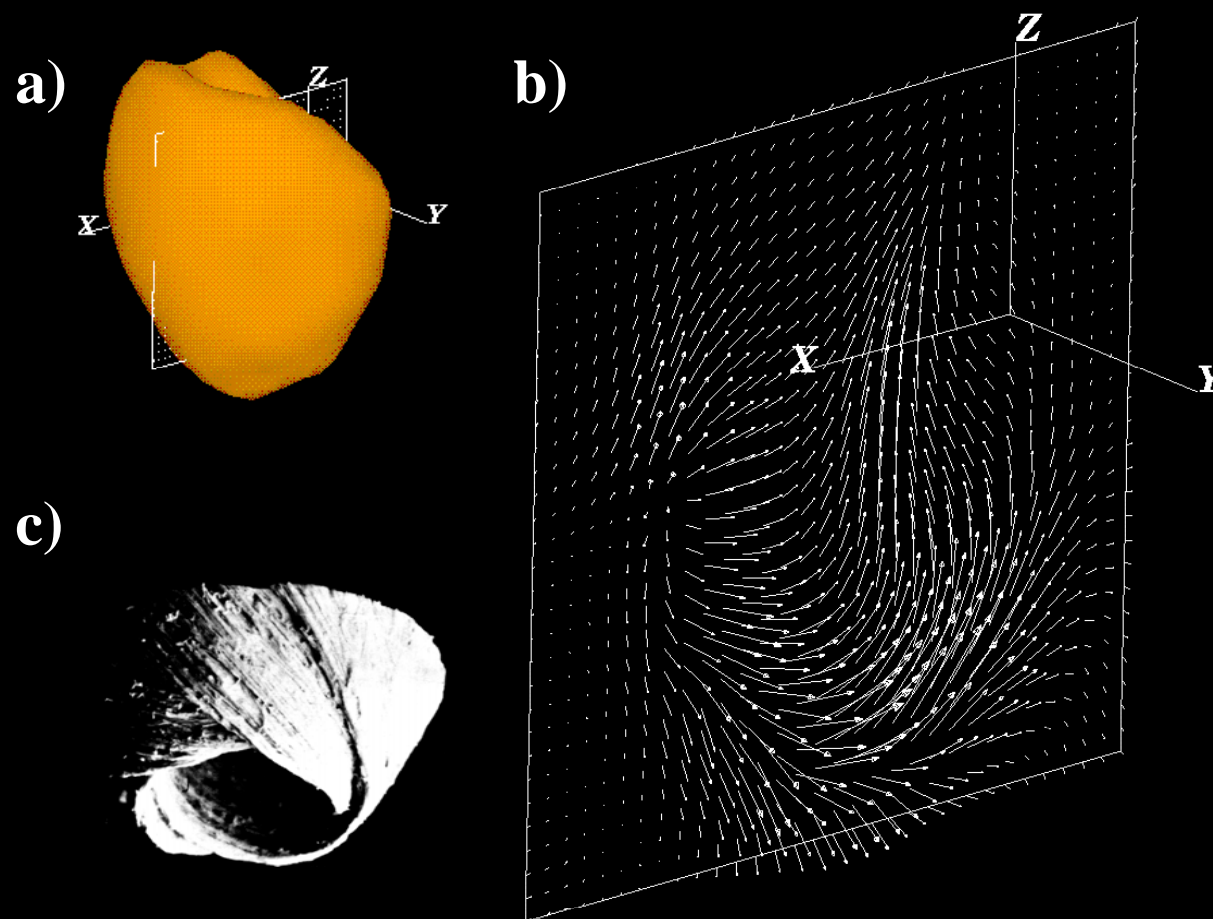


Campo de vetores de velocidade obtido aplicando a DCW



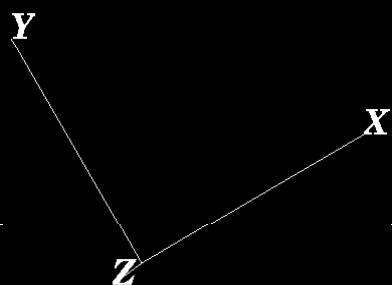
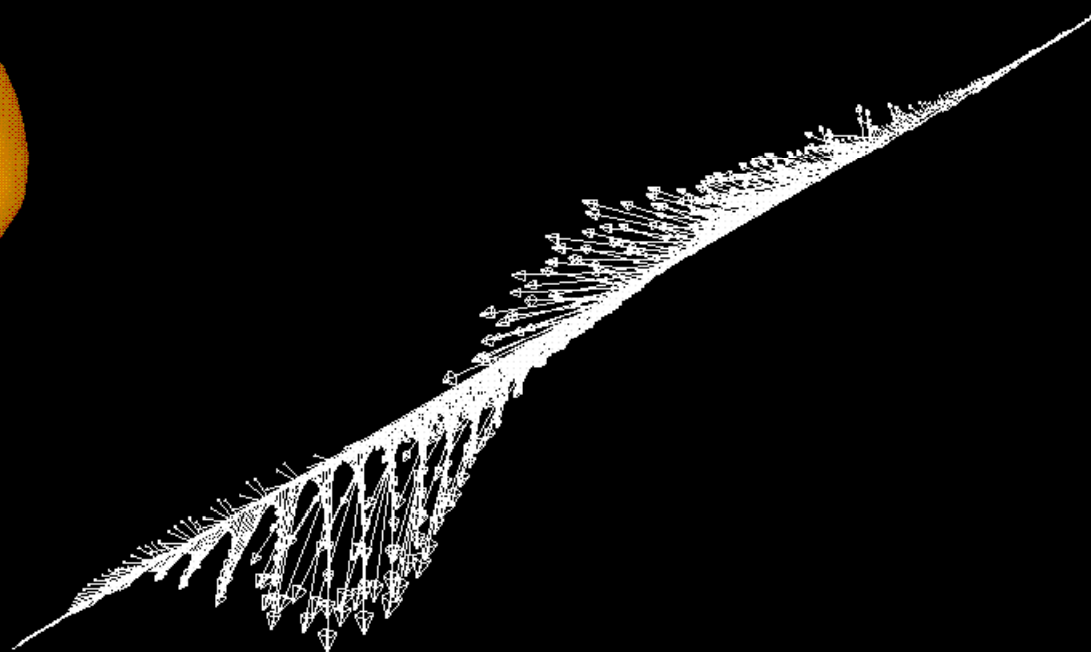
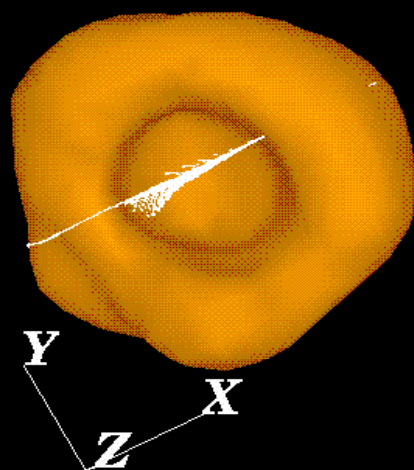
Quantificação em Gated-SPECT (99^mTc-MIBI)



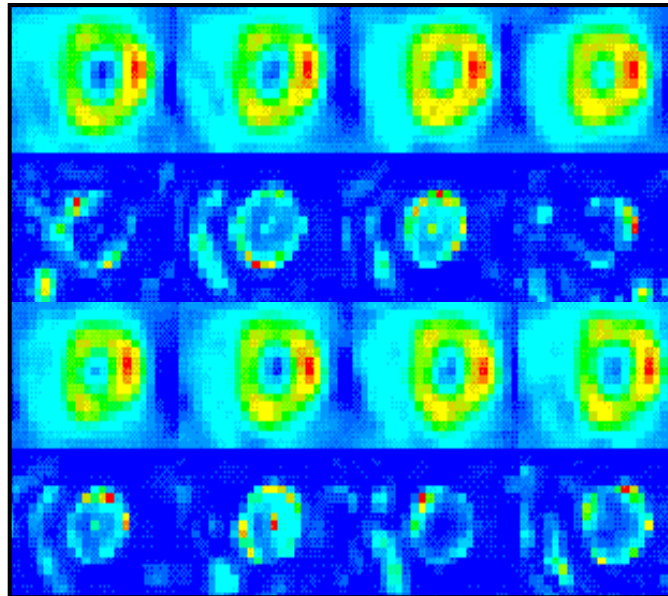


a) Imagem 3D do ventrículo esquerdo; **b)** campo de vetores de velocidade para um plano de interesse sobre a imagem em a); **c)** estruturas das fibras em um ventrículo dessecado

Quantificação em Gated-SPECT (99^mTc-MIBI)

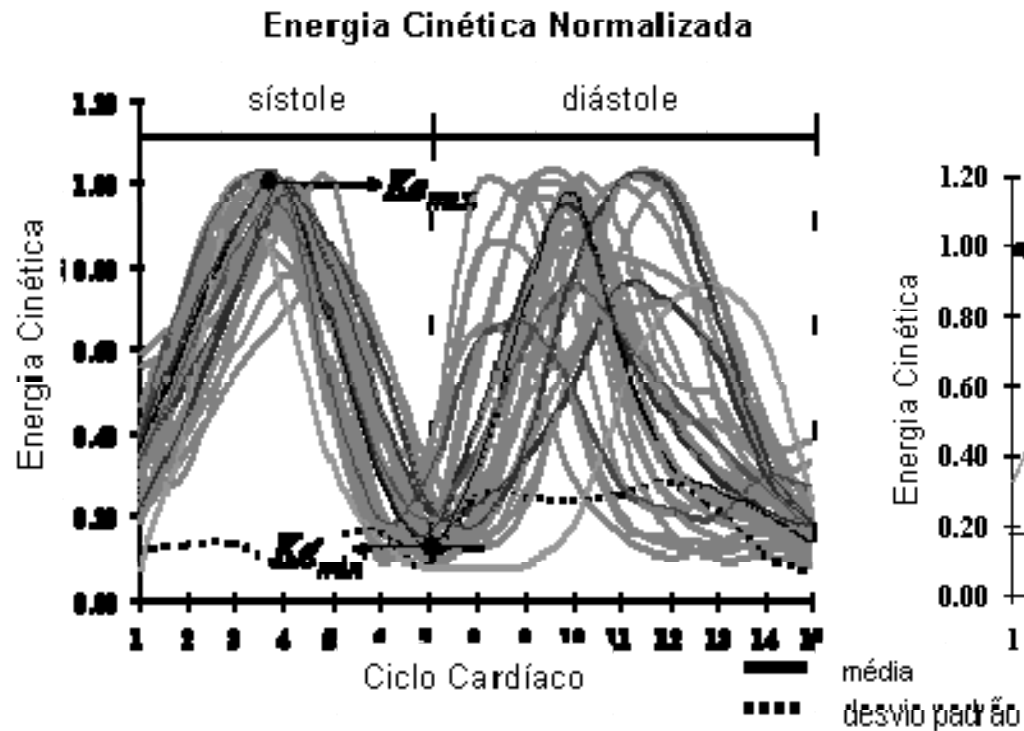


- Seção transversal (2D) de um estudo Gated-SPECT e a da Energia Cinética obtida com base na estimativa de velocidade

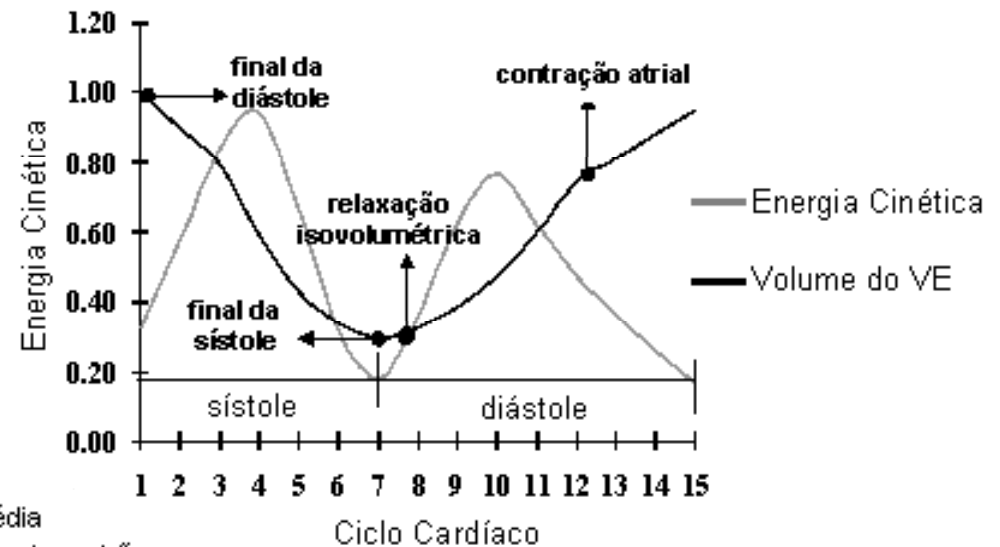


$$Ke = \frac{1}{2} m (v_x^2 + v_y^2 + v_z^2)$$

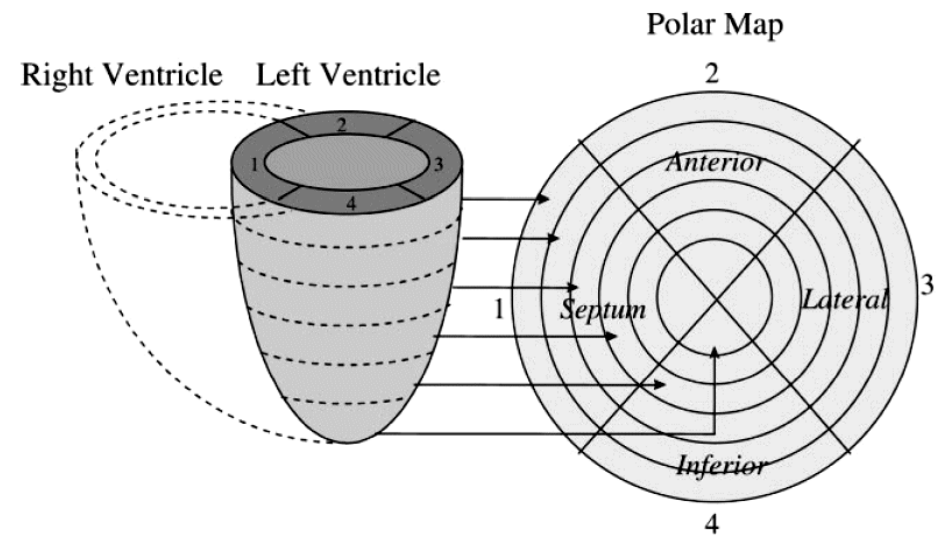
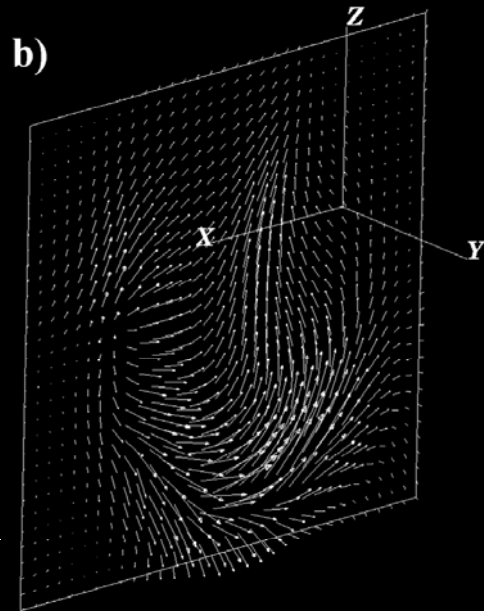
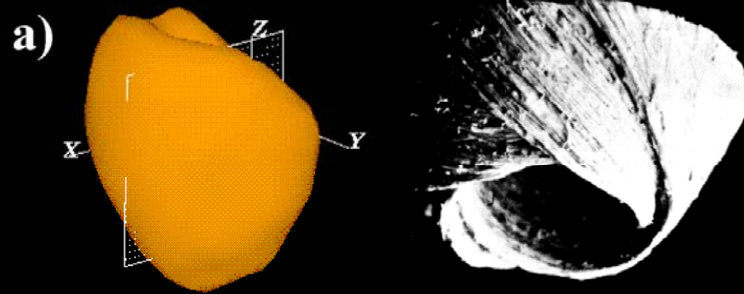
Energia Cinética Normalizada



Energia Cinética e Volume do VE

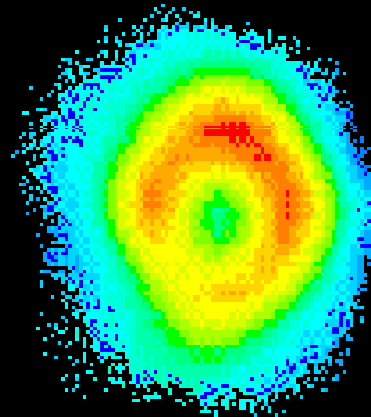


Campo de Vetores de Velocidade

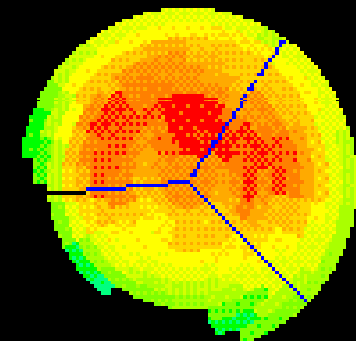


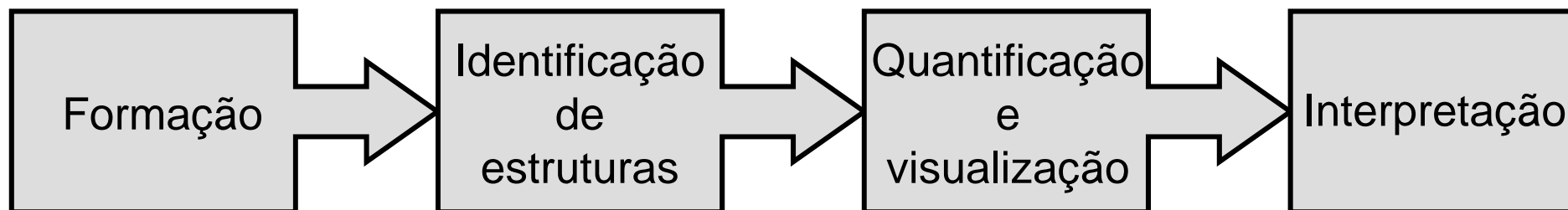
Energia Cinética do VE

Seção transversal
2D

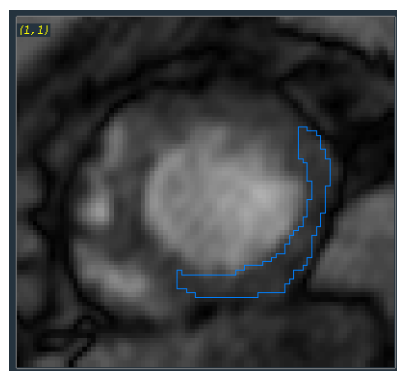


Mapa Polar
3D->2D





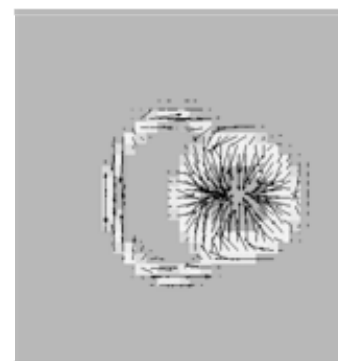
- Aquisição
- Tomografia



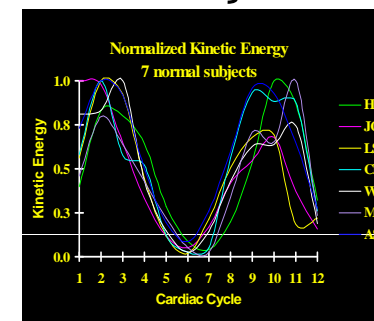
- Pré-processamento
- Segmentação
- Reconhecimento



- Cálculos.
- Parâmetros
- Comp.gráfica



- Classificação
- Intel. Artificial
- Redes neurais
- Informação



Saiba o que procurar em uma imagem



$$g[x, y] = \nabla Gauss[x, y] * f[x, y]$$

