CTIM
CENTRO DE TECNOLOGÍAS DE LA IMAGEN

UNIVERSIDAD DE LAS PALMAS DE GRAN CANARIA

Accurate Subpixel Edge Location Based on Partial Area Effect

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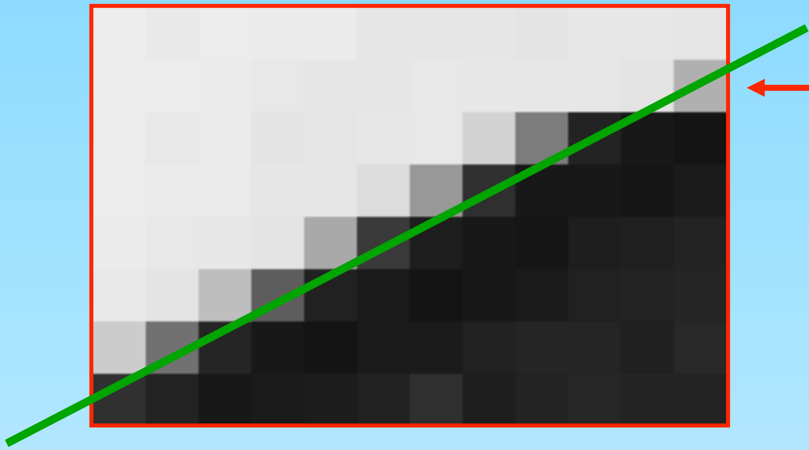
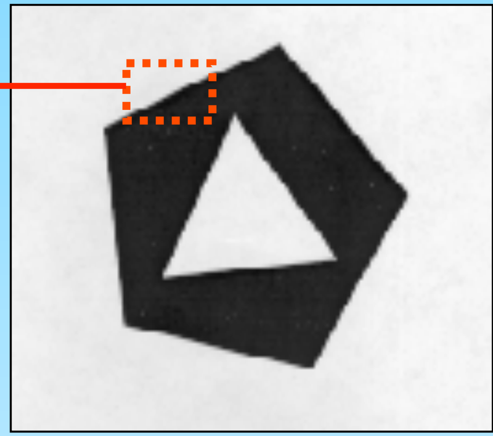
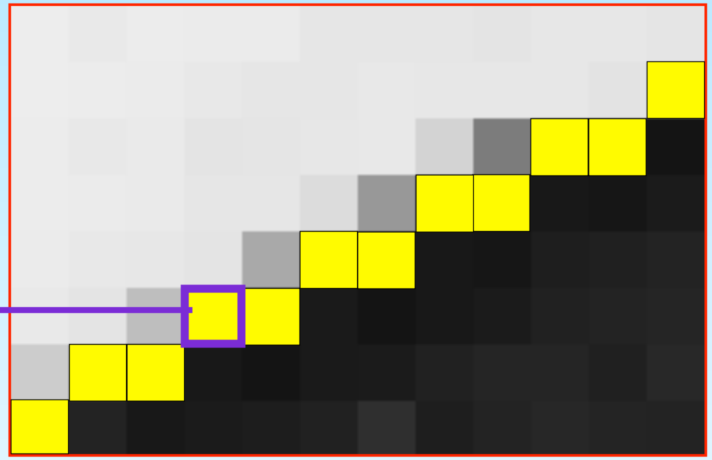
Edge Detection in the pixel level



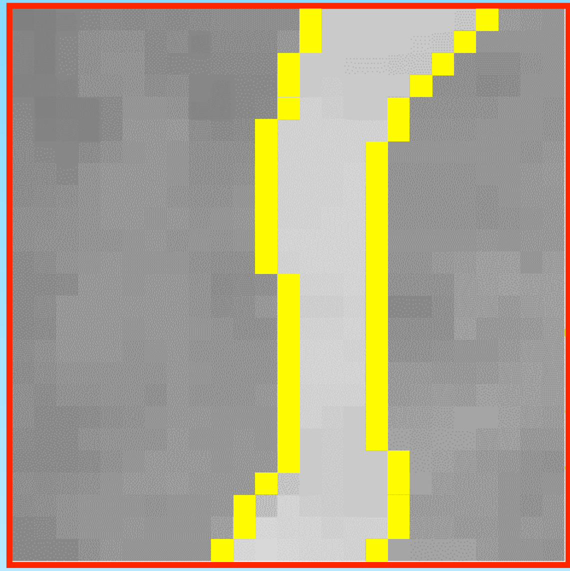


237	233	236	235	235	230	230	230	228	231	231	229
237	236	235	232	230	230	232	231	231	231	227	176
236	232	234	228	229	231	232	211	124	35	24	20
236	235	234	230	230	220	152	47	24	24	22	27
235	232	231	228	169	58	30	24	22	30	32	35
233	228	190	93	33	20	20	24	27	33	35	37
204	113	37	24	24	26	27	33	37	37	32	40
48	35	24	27	29	33	47	30	35	39	36	35

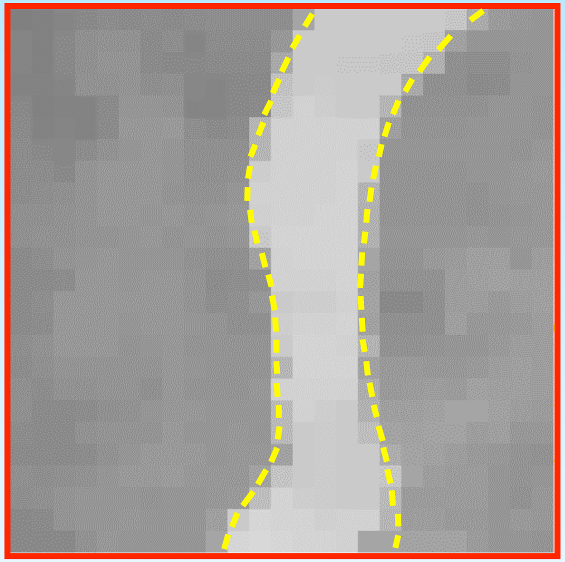


Subpixel Edge Detection

Edge detection in pixel level

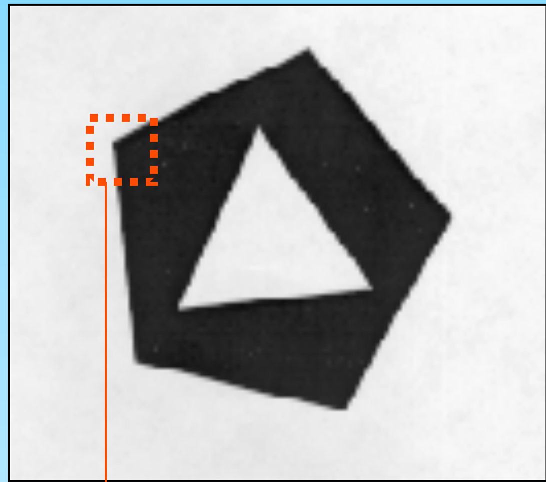


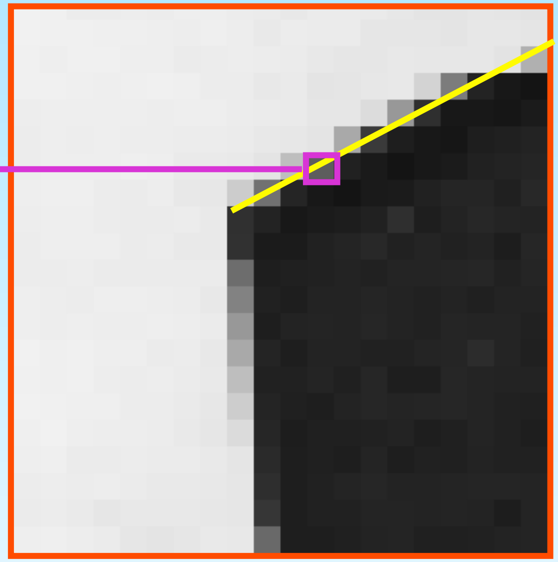
Subpixel edge detection



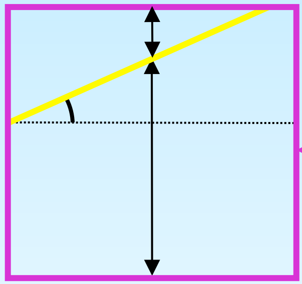
Main goal of this work

- Given an ideal image, locate accurately for every edge pixel the following features:
  - orientation
  - intensity difference at both sides
  - subpixel position
  - curvature

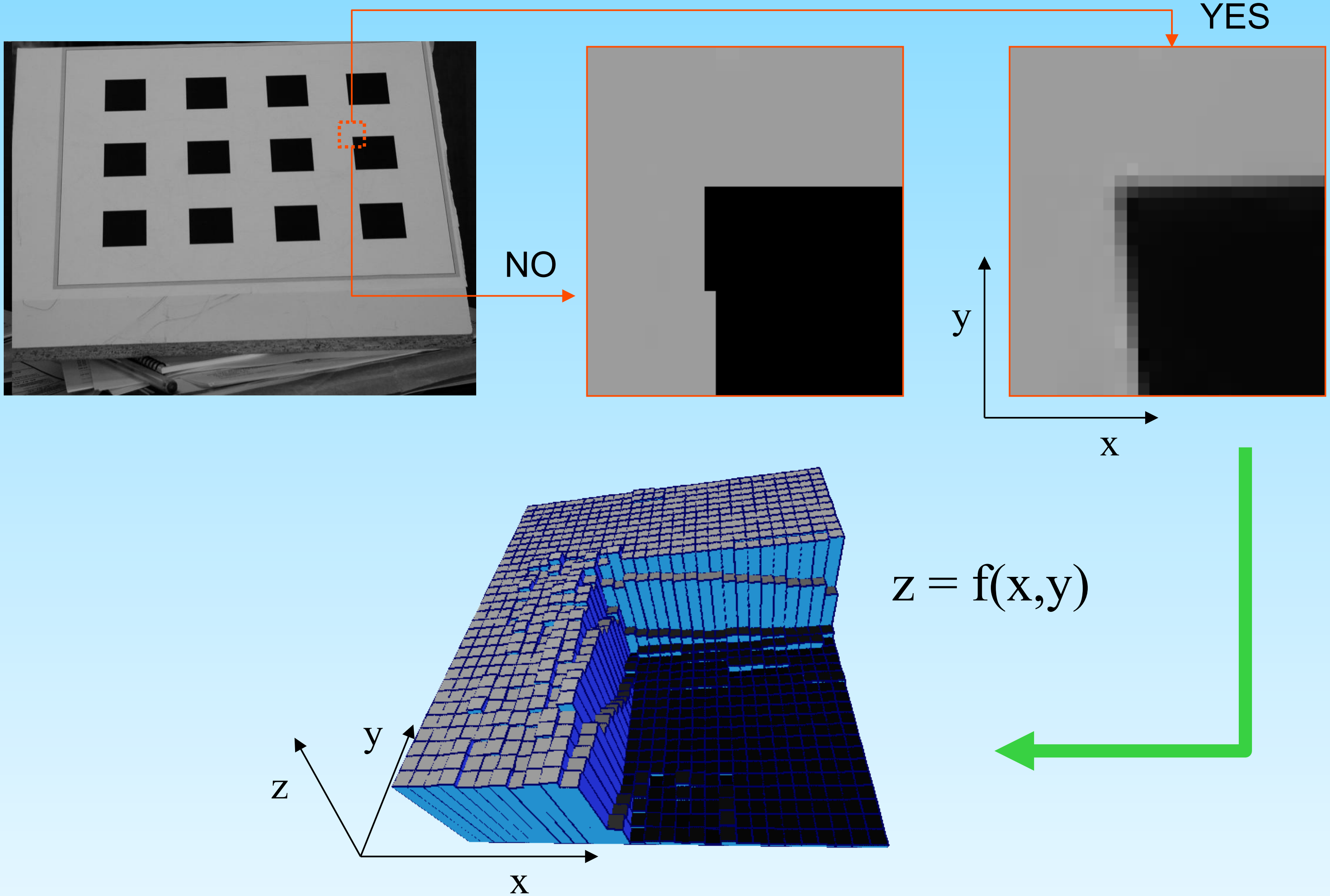




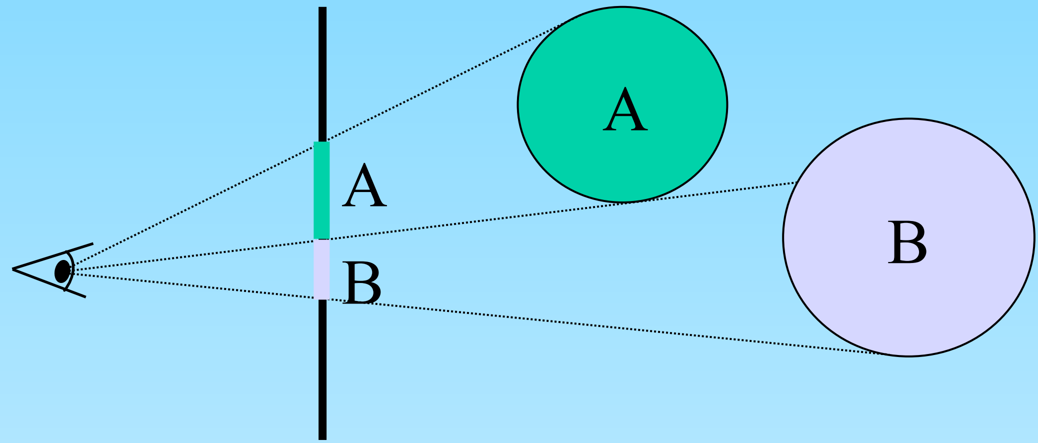
237	233	236	235	235	230	230	230	228	231	231	229
237	236	235	232	230	230	232	231	231	231	227	176
236	232	234	228	229	231	232	211	124	35	24	20
236	235	234	230	230	2[illegible]0	152	47	24	24	22	27
235	232	231	228	169	58	30	24	22	30	32	35
233	228	190	93	33	26	20	24	27	33	35	37
204	113	37	24	24	26	27	33	37	37	32	40
48	35	24	27	29	33	47	30	35	39	36	35

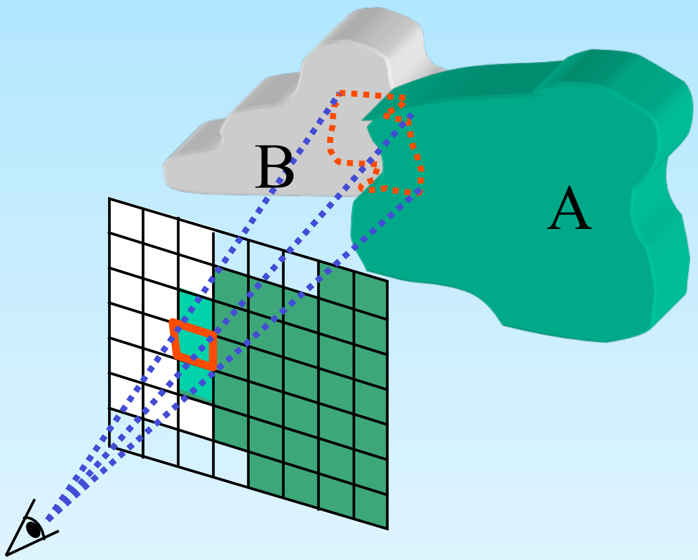


Acquired intensity in edge pixels

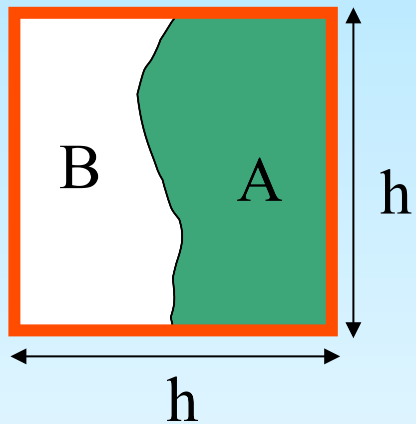


Partial area effect hypothesis

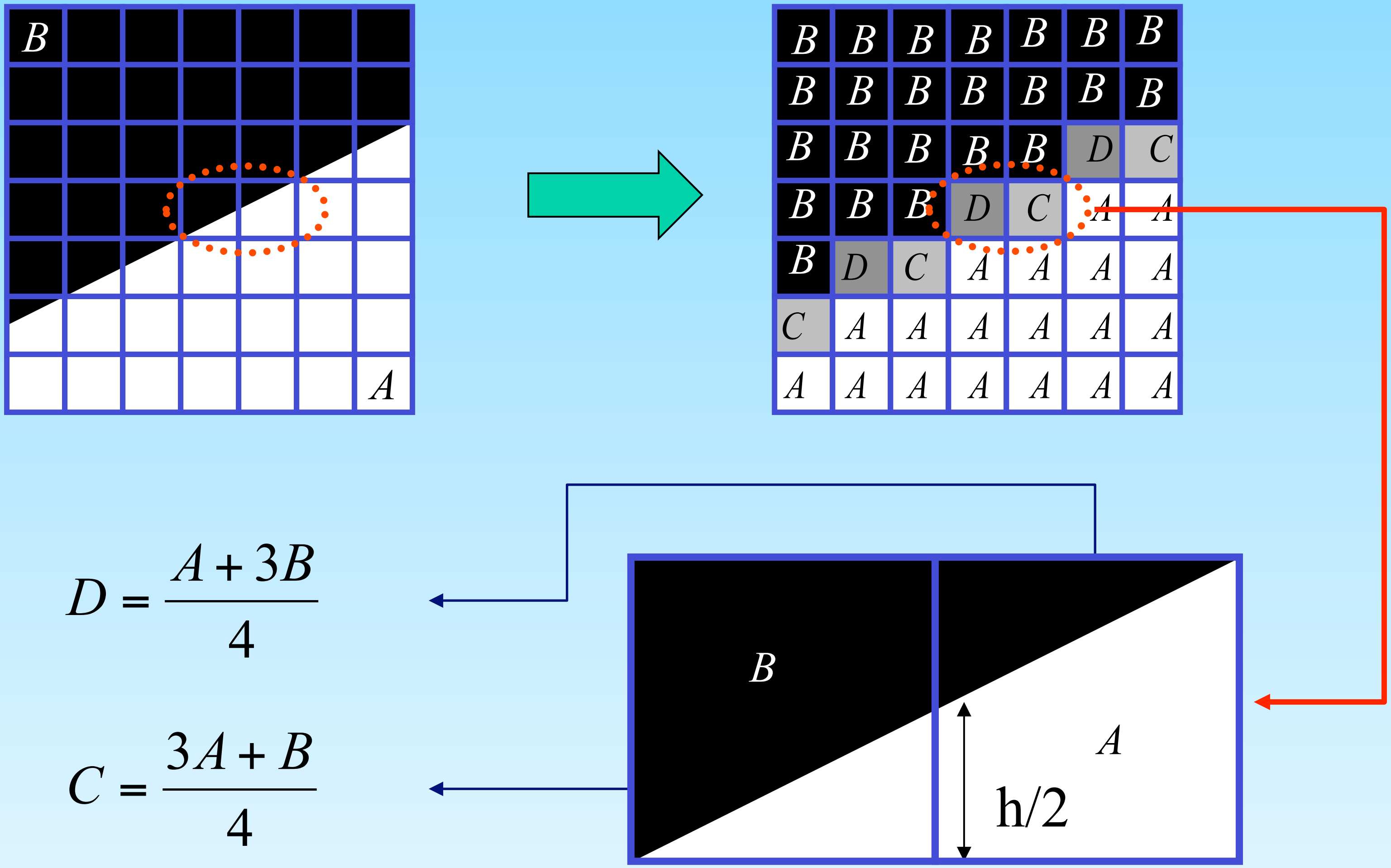




$$F_{i,j} = \frac{AS_A + BS_B}{h^2}$$



Ideal straight edge with slope 1/2



$$D = \frac{A + 3B}{4}$$

$$C = \frac{3A + B}{4}$$

Error when computing intensity change at both sides

B	B	B	B	B	B	B
B	B	B	B	B	B	B
B	B	B	B	B	D	C
B	B	B	D	C	A	A
B	D	C	A	A	A	A
C	A	A	A	A	A	A
A	A	A	A	A	A	A

$$\begin{pmatrix} -1 & 0 & 1 \\ -\alpha & 0 & \alpha \\ -1 & 0 & 1 \end{pmatrix} \rightarrow f_x = \frac{3\alpha+1}{8(\alpha+2)h}(A-B)$$

$$\begin{pmatrix} -1 & -\alpha & -1 \\ 0 & 0 & 0 \\ 1 & \alpha & 1 \end{pmatrix} \rightarrow f_y = \frac{4\alpha+7}{8(\alpha+2)h}(A-B)$$

$$\|G\| = \frac{(A-B)}{8(\alpha+2)h}\sqrt{25\alpha^2+62\alpha+50}$$

A=100
B=0
h=1
$\alpha = \sqrt{2}$

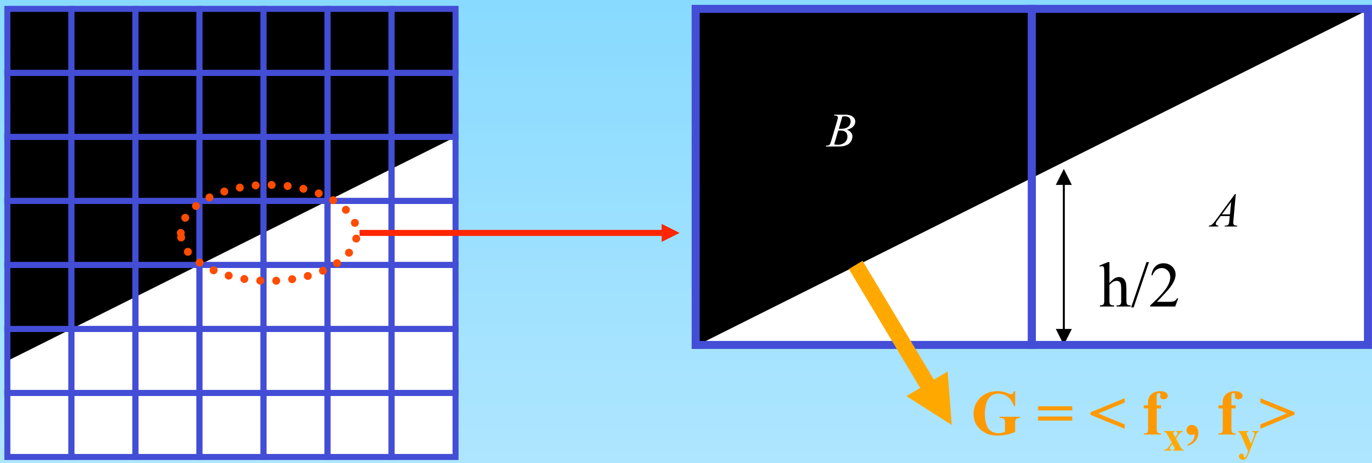
$\Rightarrow$ $\|G\| =$

0	0	0	0	0	0	5
0	0	0	0	5	19	37
0	0	5	19	37	51	51
5	19	37	51	51	37	19
37	51	51	37	19	5	0
51	37	19	5	0	0	0
19	5	0	0	0	0	0

WRONG INTENSITY DIFFERENCE

$$\|G\| \neq \frac{A-B}{2h}$$

Error when computing orientation



$f_x =$

0	0	0	0	0	0	3
0	0	0	0	3	11	16
0	0	3	11	16	19	19
3	11	16	19	19	16	11
16	19	19	16	11	3	0
19	16	11	3	0	0	0
11	3	0	0	0	0	0

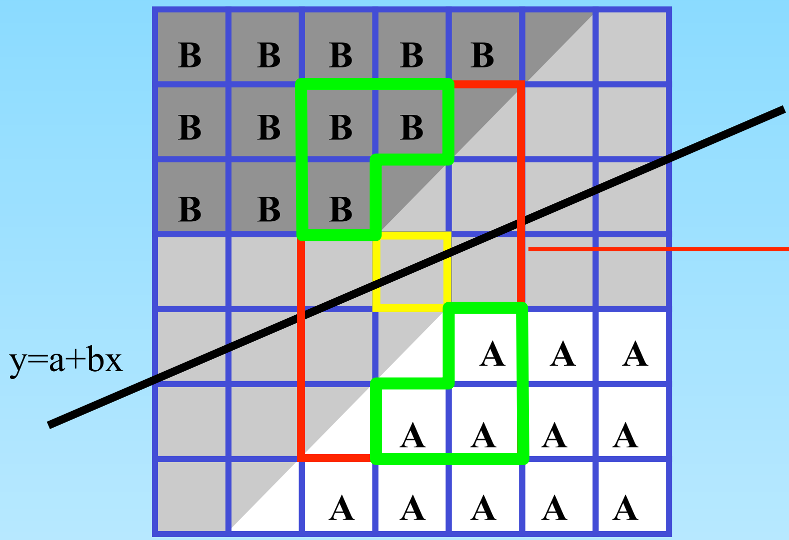
$f_y =$

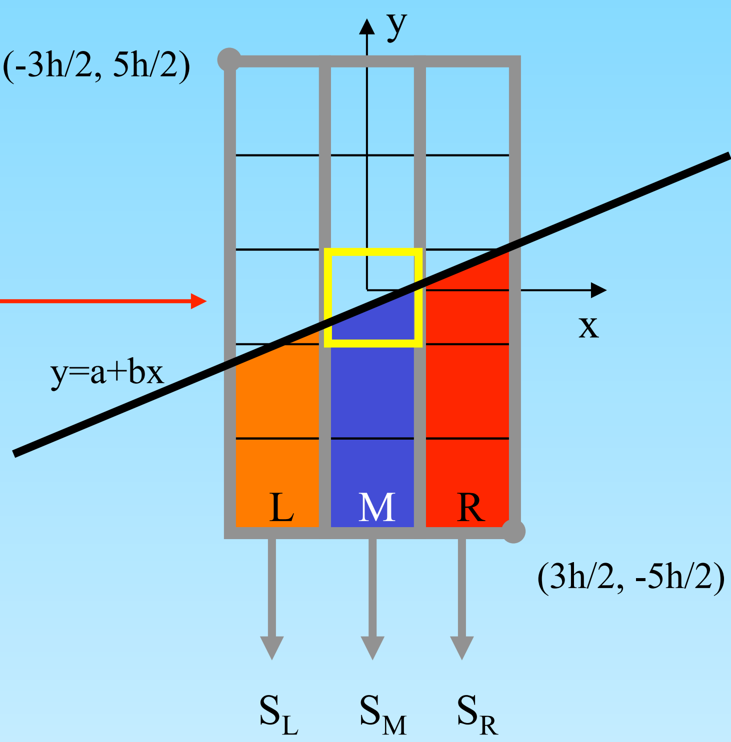
0	0	0	0	0	0	3
0	0	0	0	3	16	33
0	0	3	16	33	46	46
3	16	33	46	46	33	16
33	46	46	33	16	3	0
46	33	16	3	0	0	0
16	3	0	0	0	0	0

$$\frac{f_x}{f_y} = \frac{5\sqrt{2}-4}{6+\sqrt{2}} \neq \frac{1}{2}$$

WRONG ORIENTATION

Proposed method for isolated edges of first order





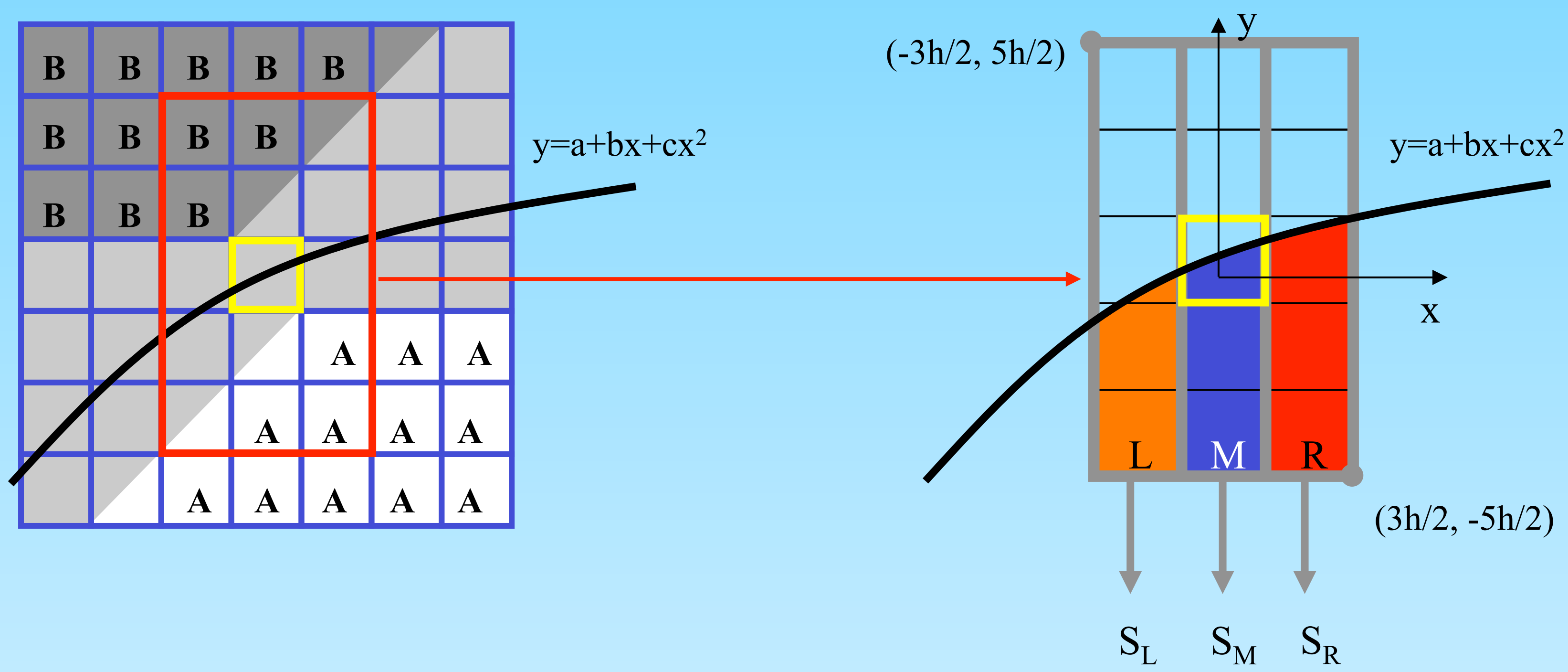
$$a = \frac{2S_M - 5(A+B)}{2(A-B)}$$

$$b = \frac{S_R - S_L}{2(A-B)}$$

$$S_M = 5B + \frac{A-B}{h^2} M \qquad M = \int_{-h/2}^{h/2} (a + bx + 5h/2)\, dx$$

$$\begin{cases} S_L = 5B + \dfrac{A-B}{h^2} L \\[2ex] S_R = 5B + \dfrac{A-B}{h^2} R \end{cases} \qquad L = \int_{-3h/2}^{-h/2} (a + bx + 5h/2)\, dx \qquad R = \int_{h/2}^{3h/2} (a + bx + 5h/2)\, dx$$

Proposed method for isolated edges of second order



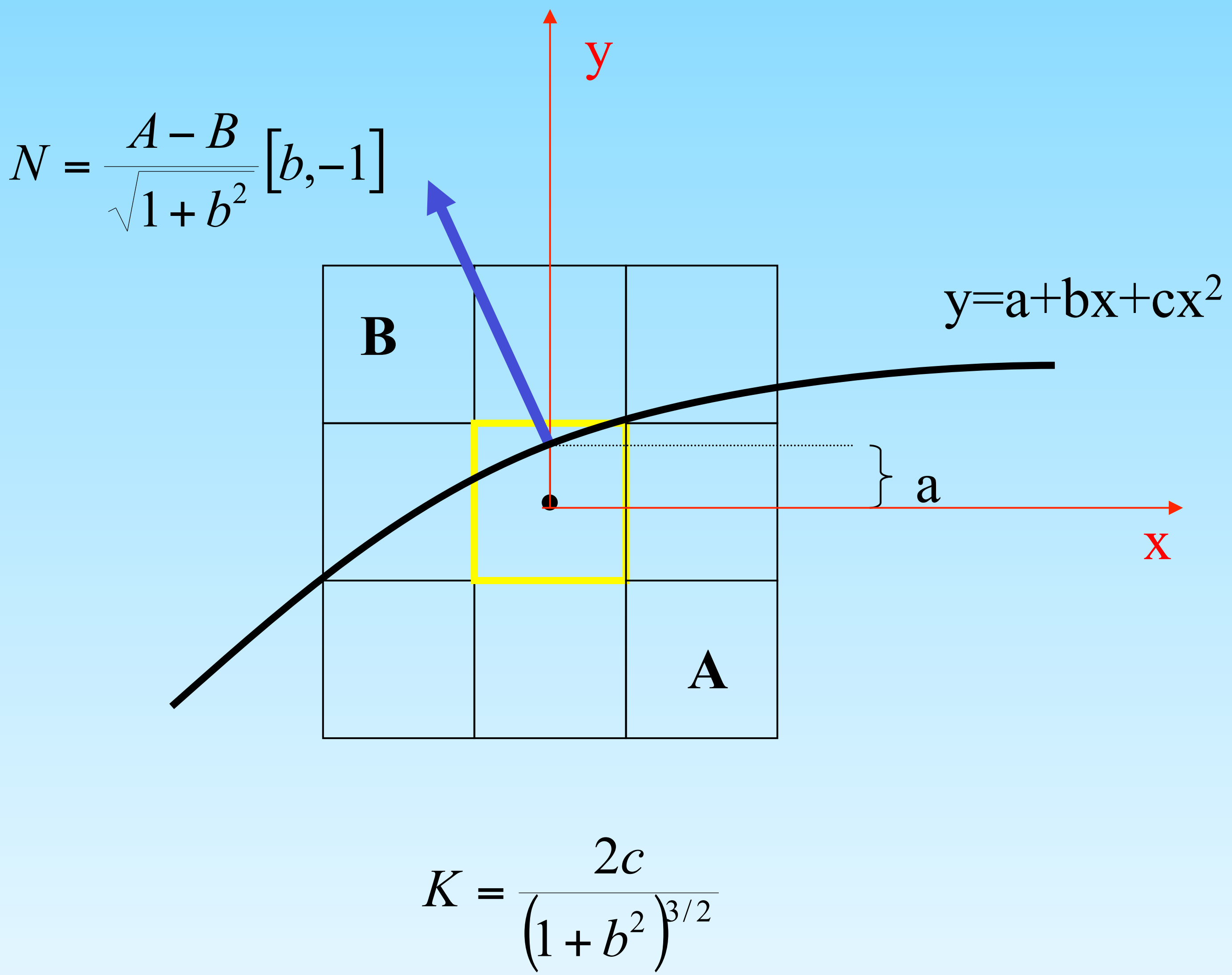
$$a = \frac{26S_M - S_L - S_R - 60(A+B)}{24(A-B)}$$

$$b = \frac{S_R - S_L}{2(A-B)}$$

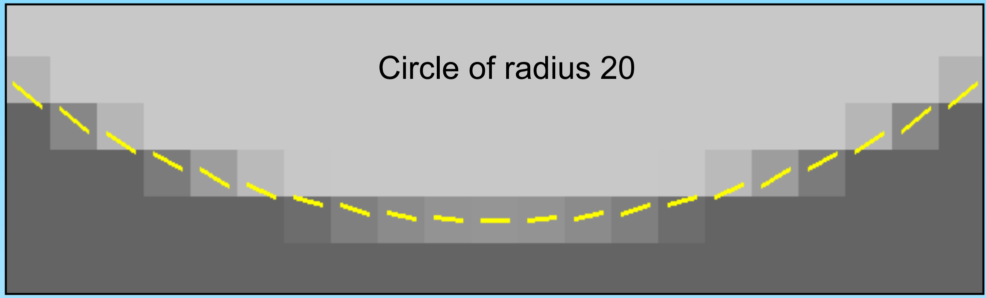
$$c = \frac{S_L + S_R - 2S_M}{2(A-B)}$$

$$\begin{cases} S_L = 5B + \dfrac{A-B}{h^2} L & L = \displaystyle\int_{-3h/2}^{-h/2} \left(a + bx + cx^2 + 5h/2\right) dx \\ S_M = 5B + \dfrac{A-B}{h^2} M & M = \displaystyle\int_{-h/2}^{h/2} \left(a + bx + cx^2 + 5h/2\right) dx \\ S_R = 5B + \dfrac{A-B}{h^2} R & R = \displaystyle\int_{h/2}^{3h/2} \left(a + bx + cx^2 + 5h/2\right) dx \end{cases}$$

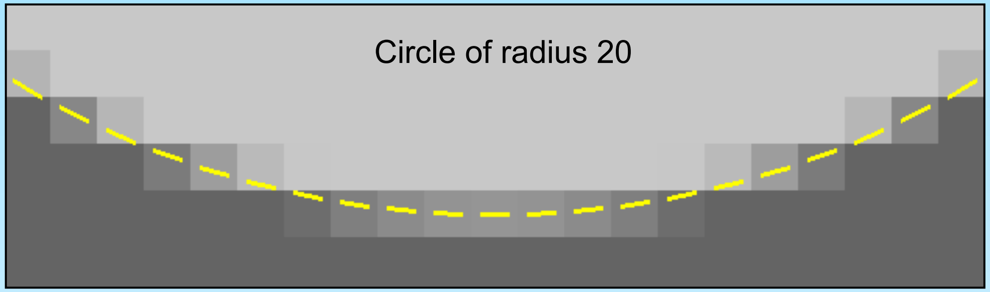
Estimating edge features



Edge detection in an ideal circle

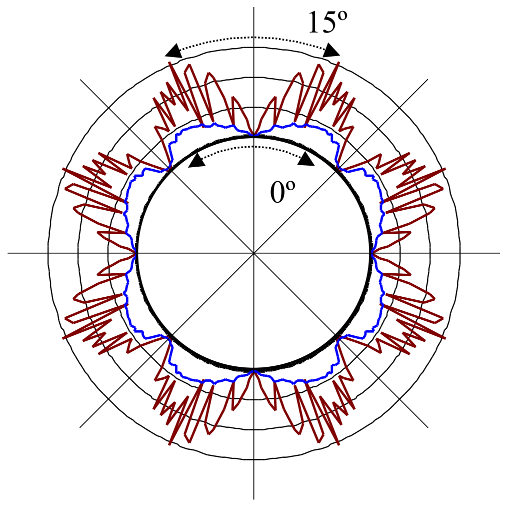


Traditional method

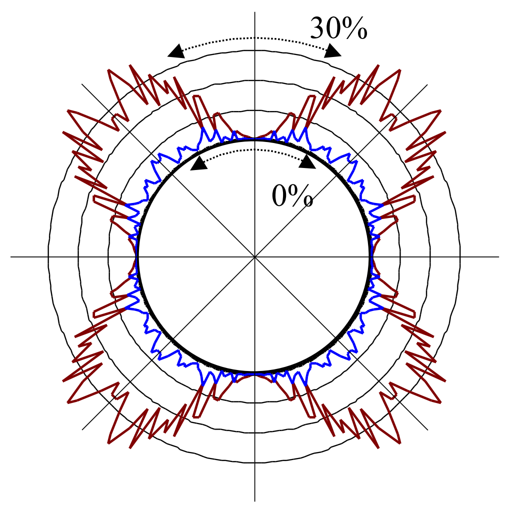


Proposed method

Radius of curvature	Mean	Minimum	Maximum
Second derivatives	28.32	12.49	32.45
Analitic expression	24.32	15.69	25.43
Proposed method	19.98	19.96	19.98

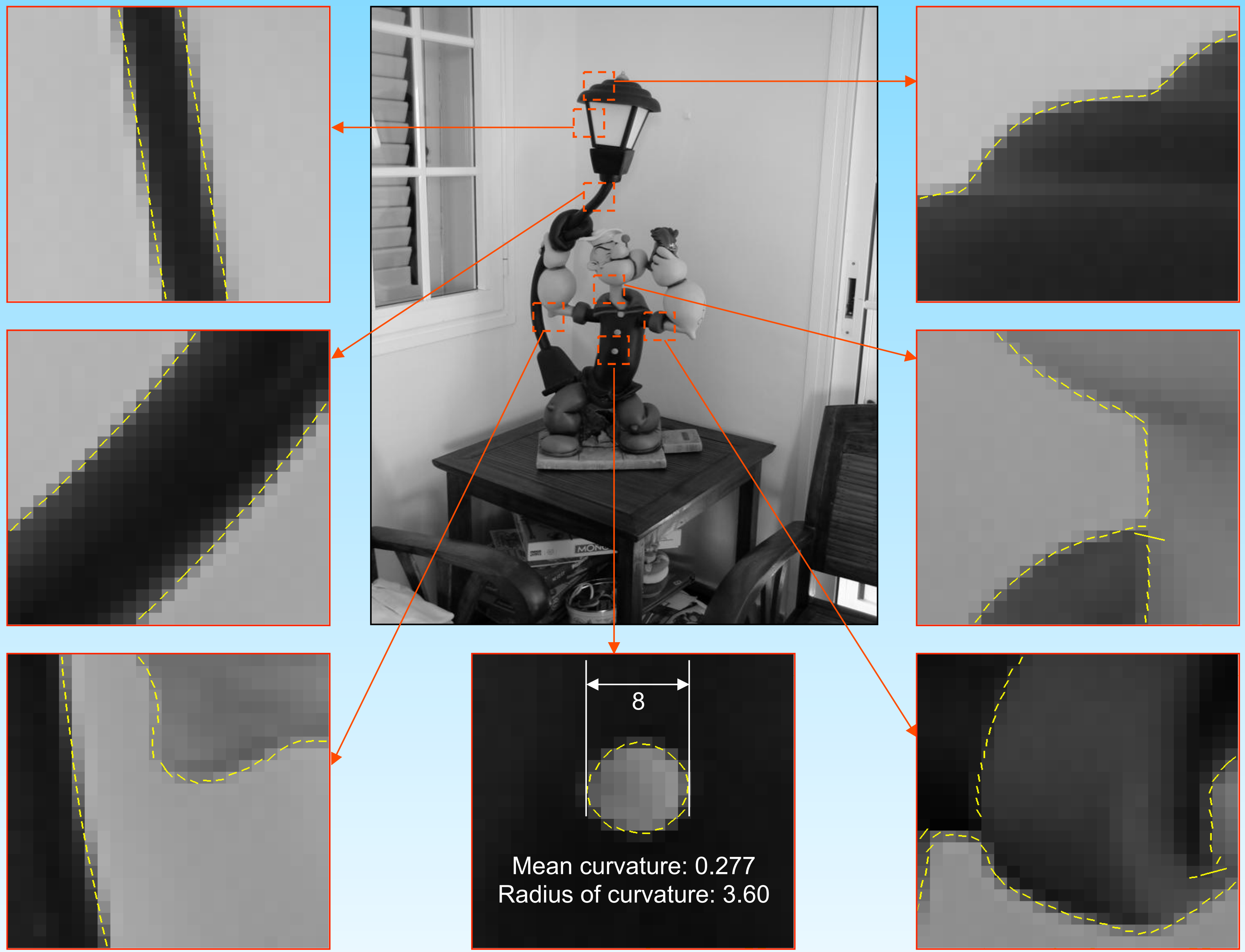


Orientation error

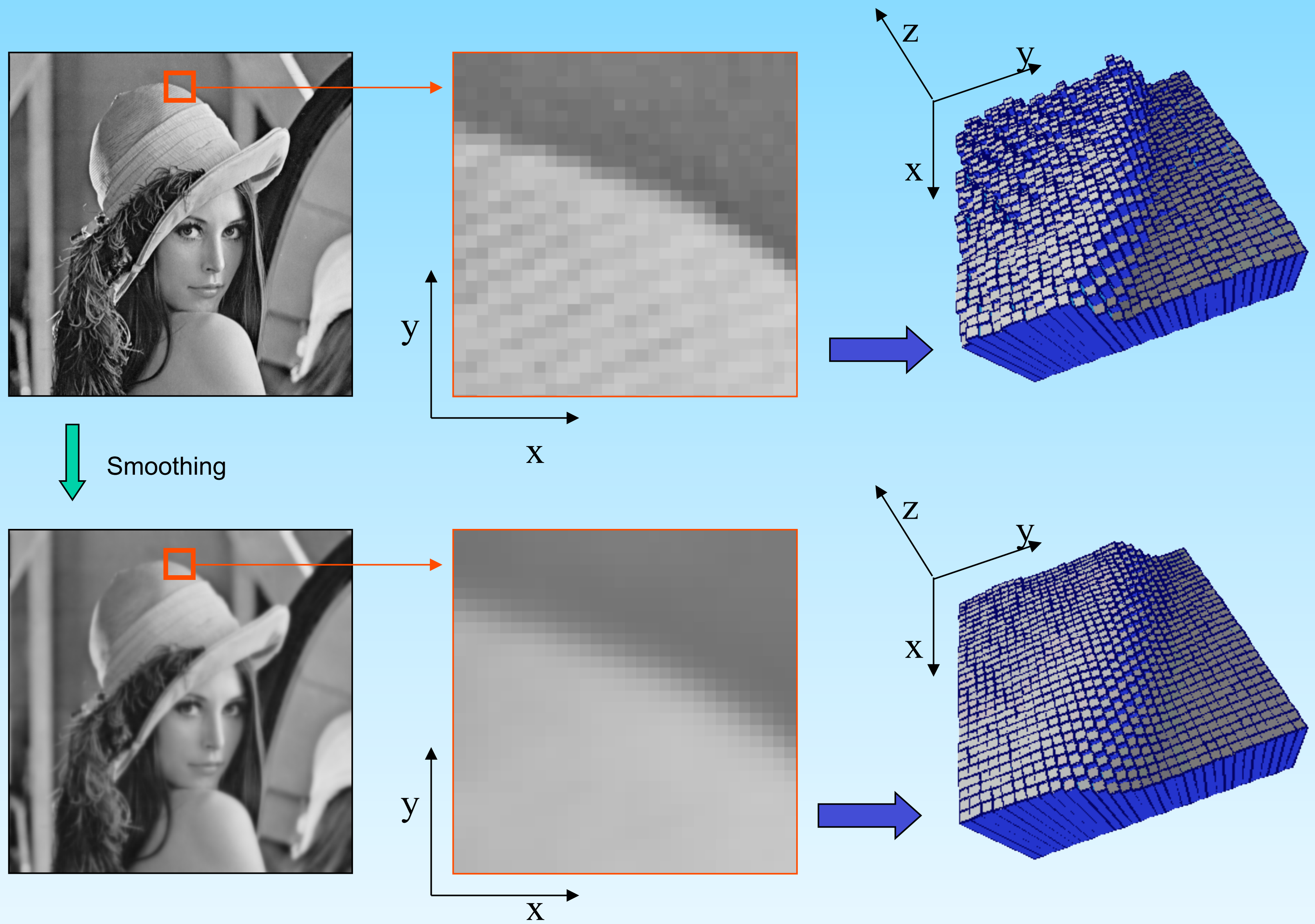


Error in computing intensity change

Experiment with real image

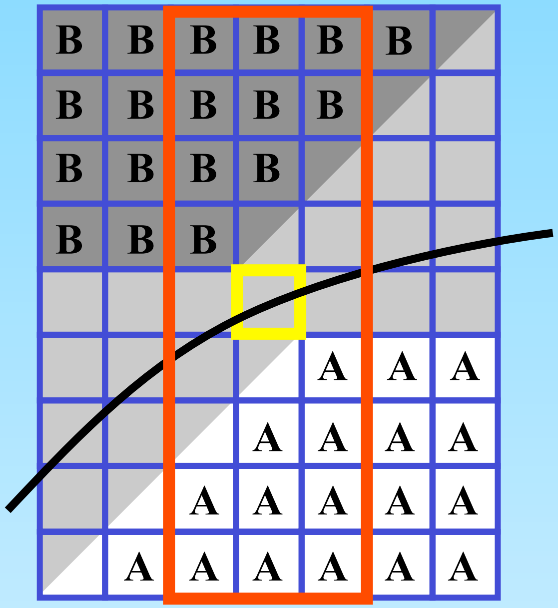


Traditional image smoothing



Edge detection in smooth images

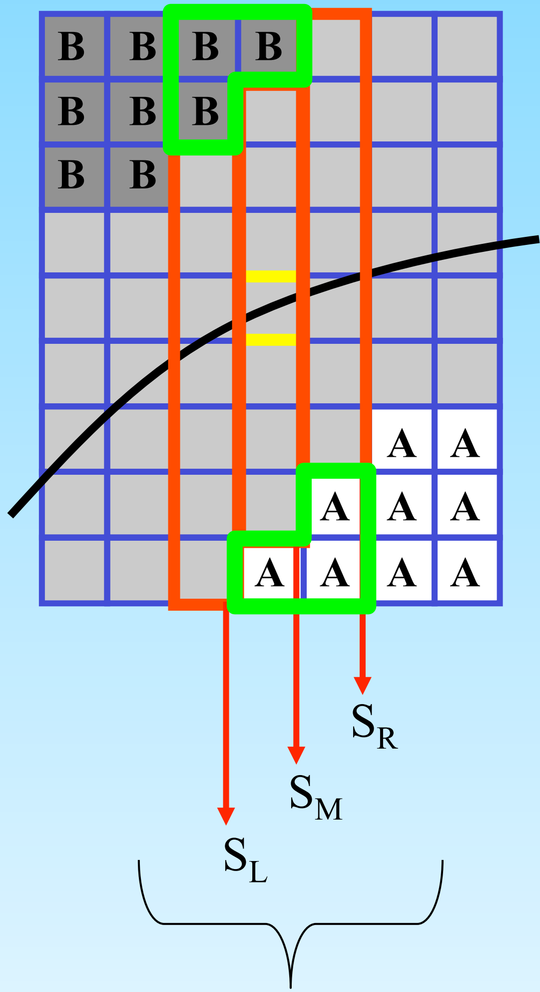
Original image F



$$* \begin{pmatrix} a_{11} & a_{01} & a_{11} \\ a_{01} & a_{00} & a_{01} \\ a_{11} & a_{01} & a_{11} \end{pmatrix} =$$

$$G_{x,y} = \sum_{i,j} a_{i,j} F_{x+i,y+j}$$

Smooth image G



$$a = \frac{2S_M - 7(A+B)}{2(A-B)} - \frac{1 + 24a_{01} + 48a_{11}}{12} c$$

$$b = 1 + \frac{S_R - S_L}{2(A-B)}$$

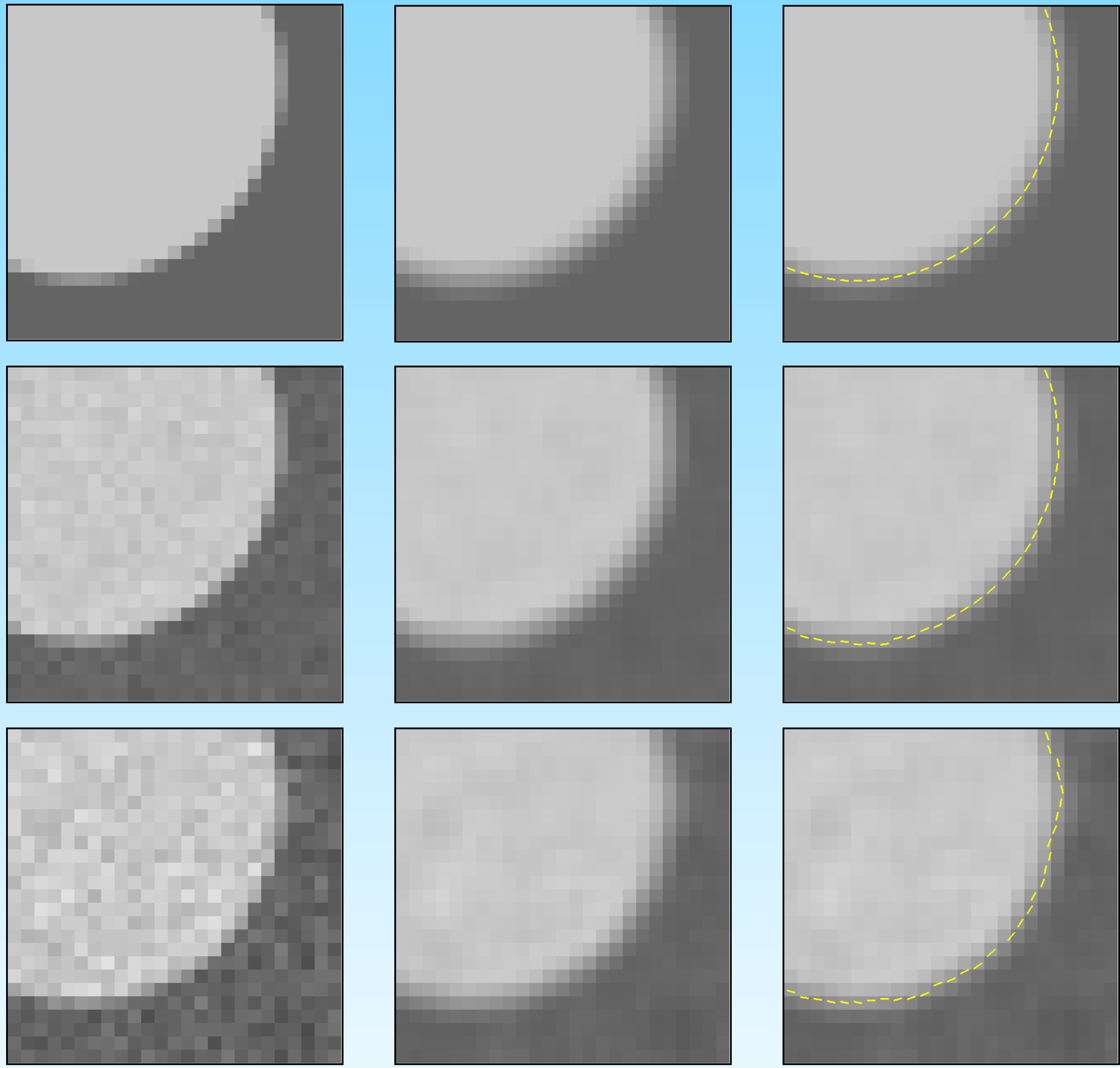
$$c = \frac{S_L + S_R - 2S_M}{2(A-B)}$$

Experiment with noisy synthetic images

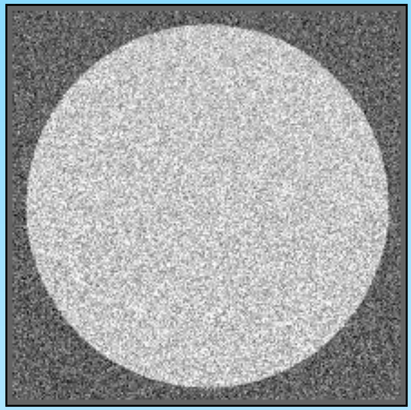
Noise 0

Noise 5

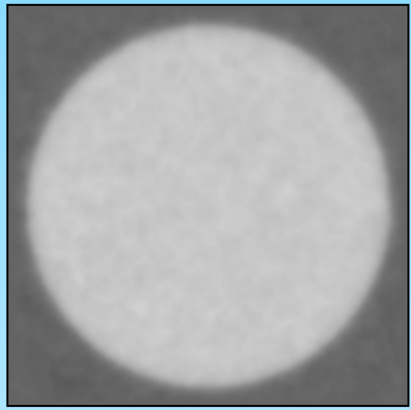
Noise 10



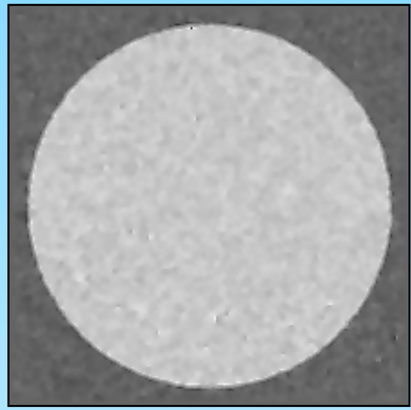
Tradition image restoration



Ideal image with noise added



Gaussian smoothing



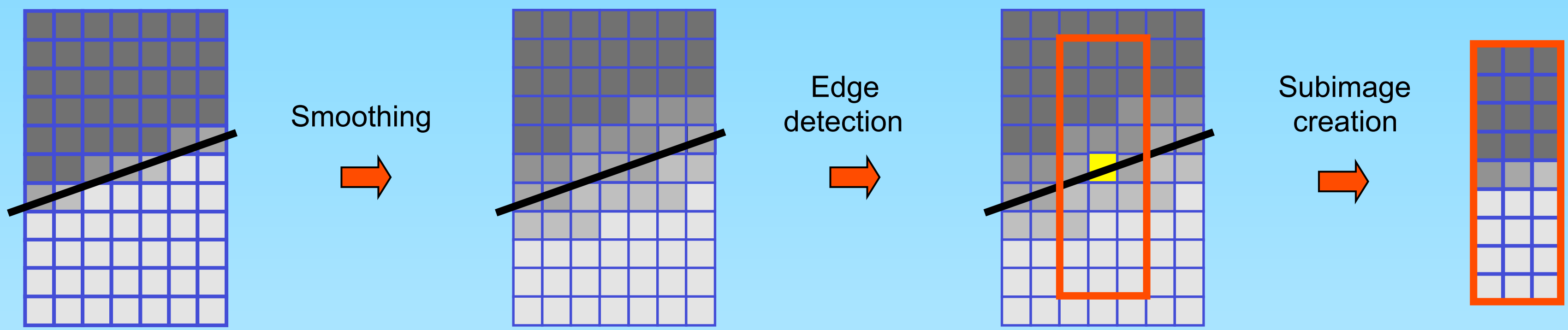
Anisotropic diffusion

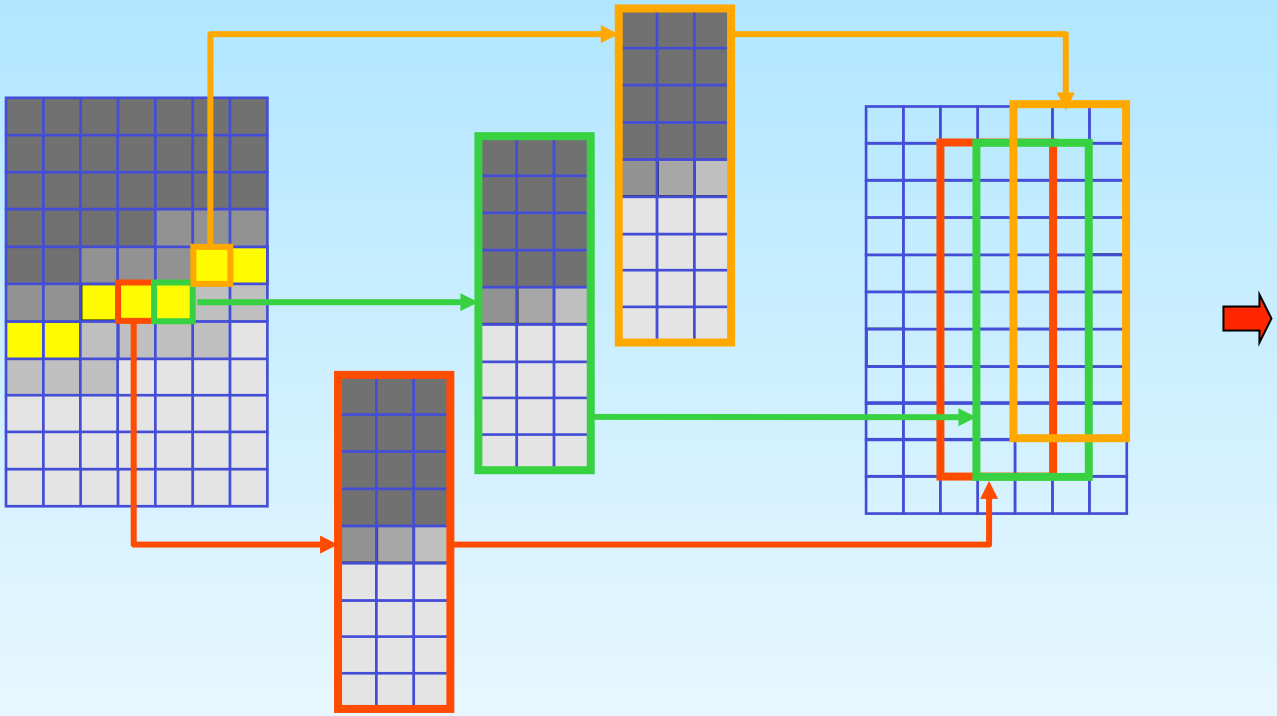
Real image

Gaussian smoothing

Anisotropic diffusion

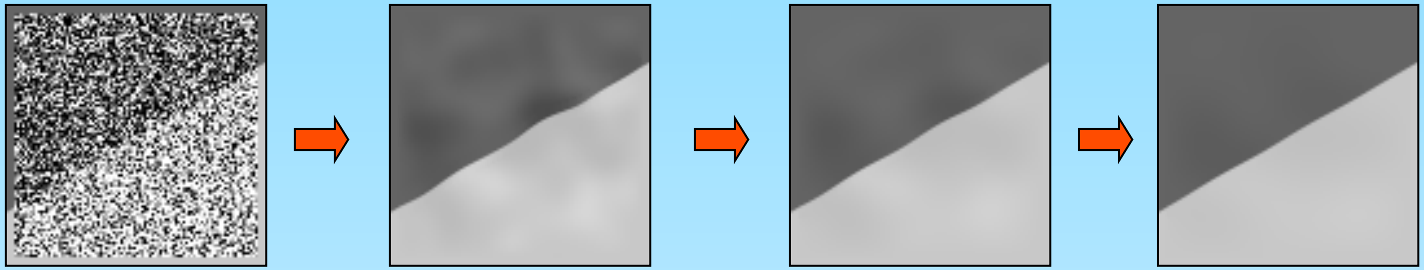
Restoration proposed method



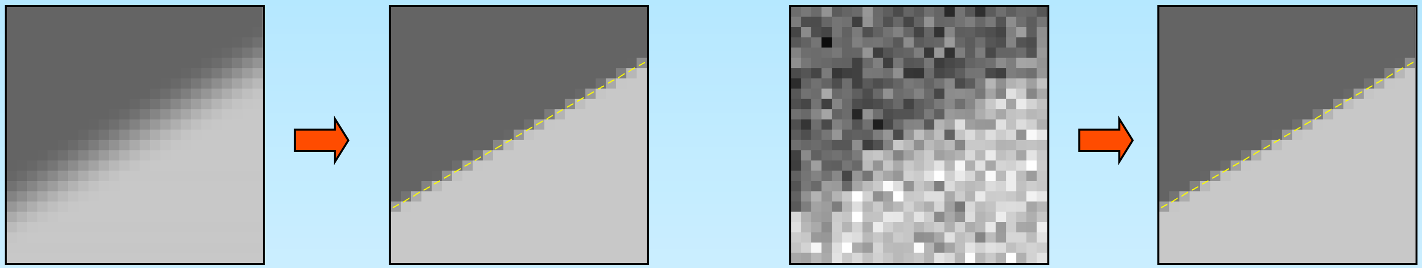


Features of the restoration proposed method

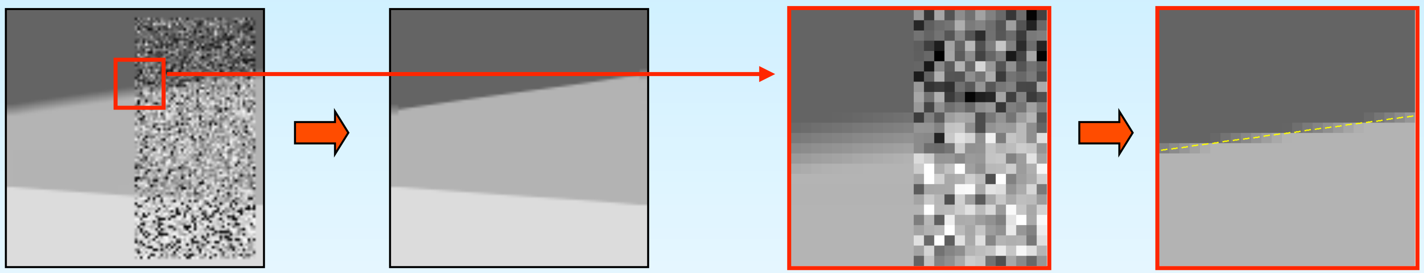
- Ideal images remain unchanged
- Effective noise removal



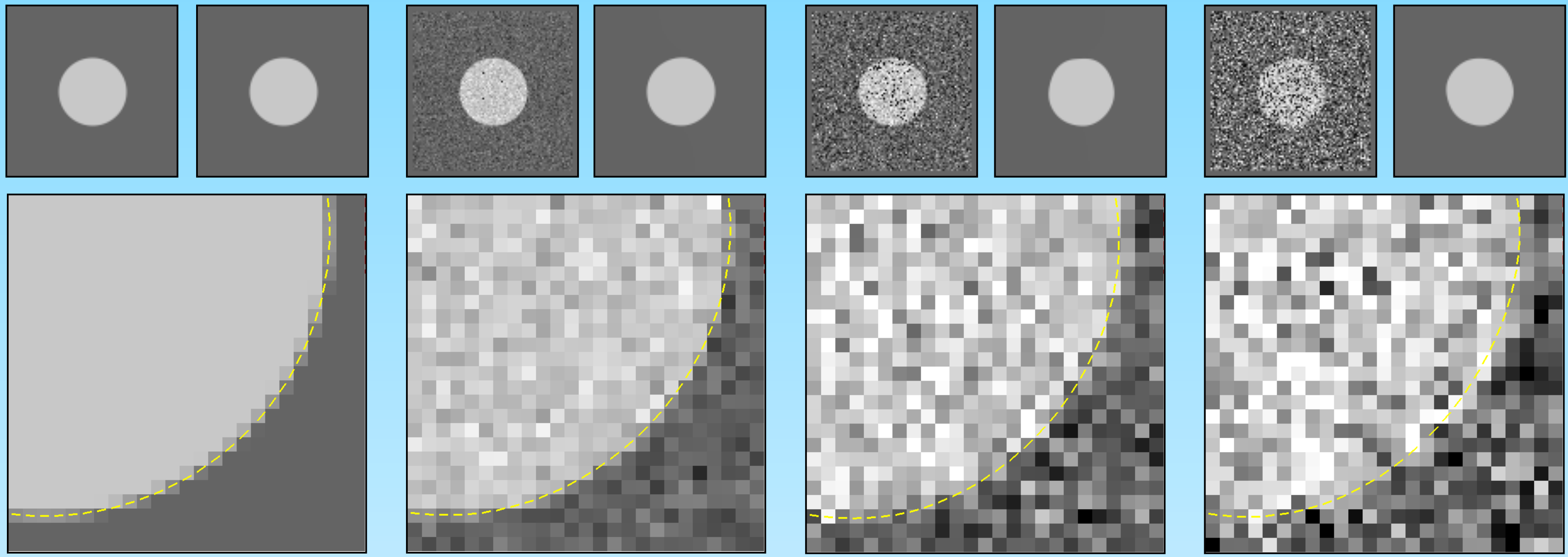
- Autofocus



- Robustness to different noise and intensity levels



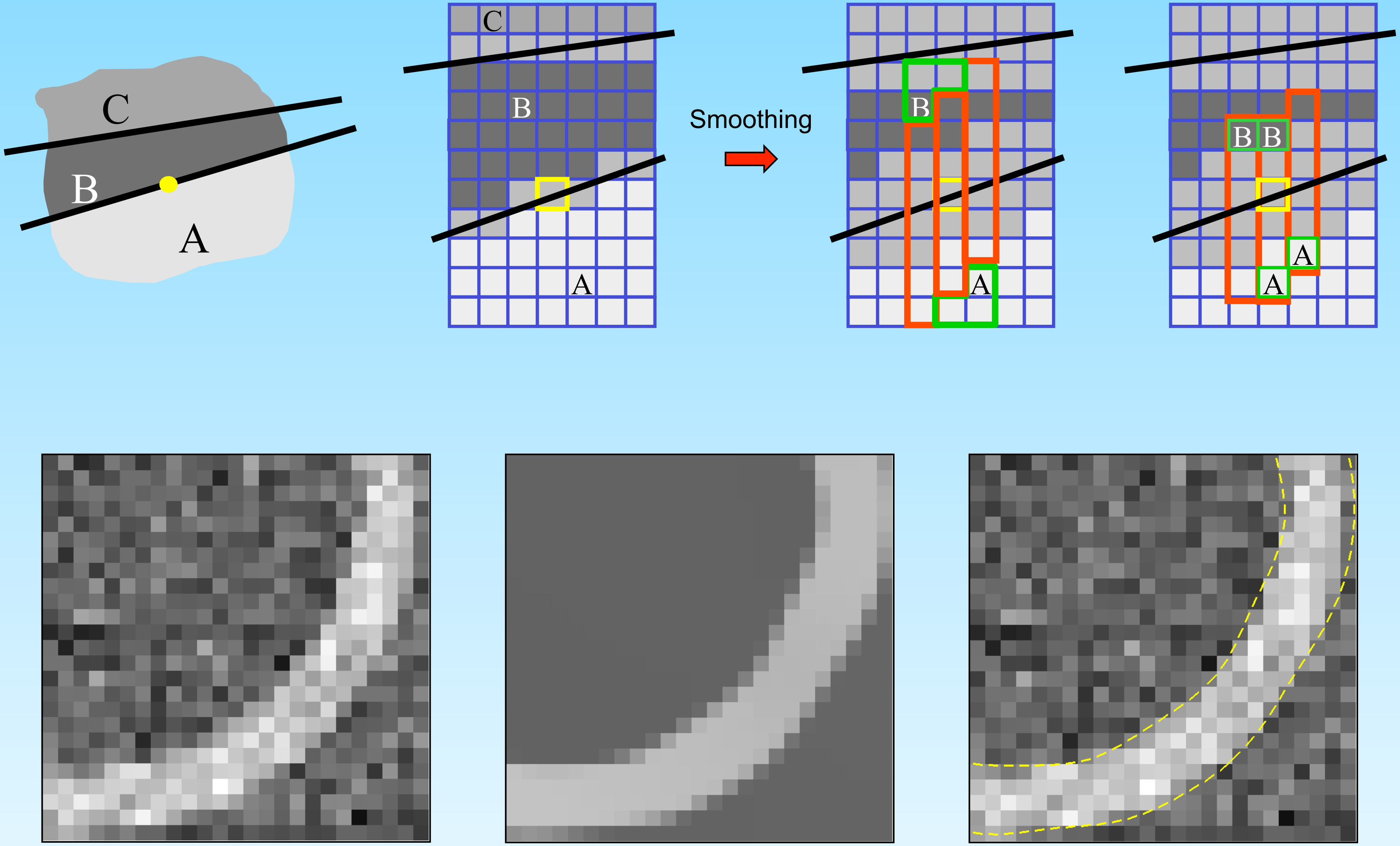
Experiments with synthetic circle of radius 20



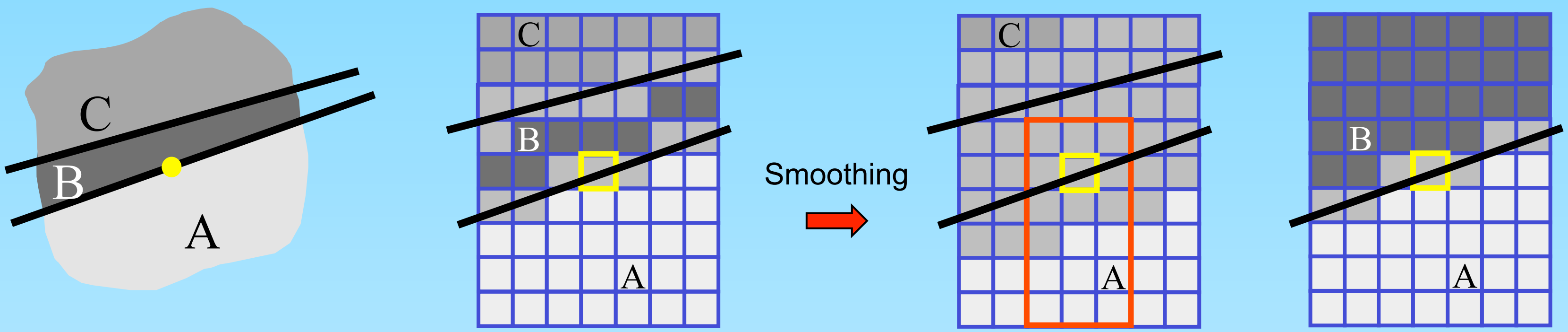
Noise 0 | Noise 20 | Noise 40 | Noise 60

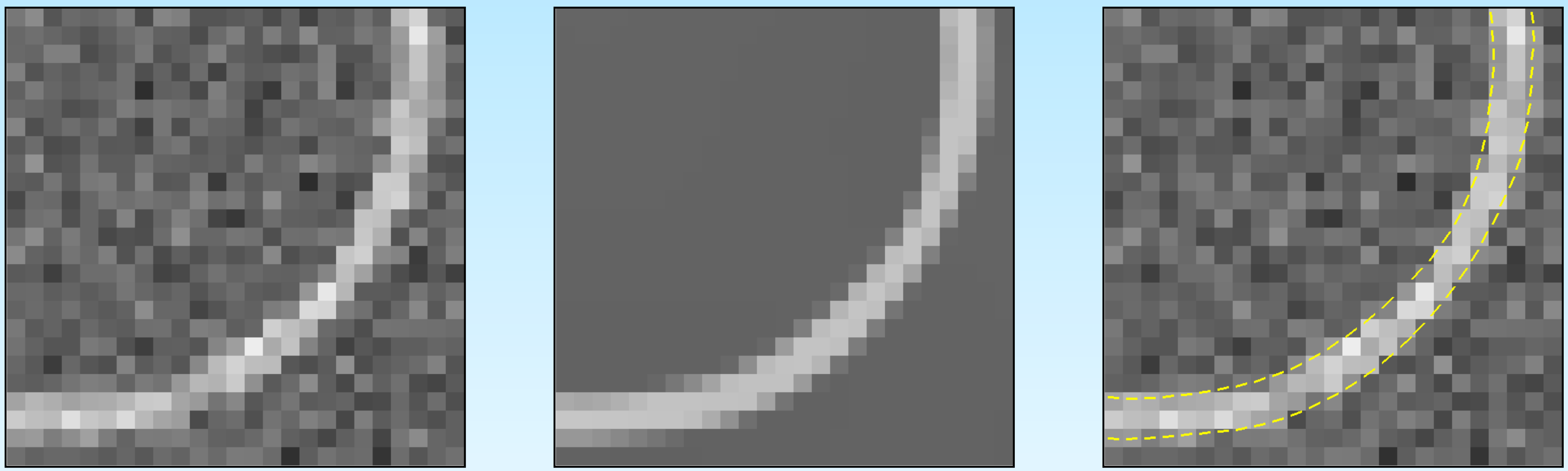
Noise	Inten. chan.		Orientation		Position		Radius of curvat.		
	Mean	Max	Mean	Max	Mean	Max	Mean	Min	Max
0	0.00	0.00	0.00	0.00	0.00	0.00	20.0	20.0	20.0
20	0.48	0.66	0.76	2.00	10.8	25.2	20.0	17.2	22.9
40	0.74	0.94	1.54	4.25	26.8	67.8	19.9	15.1	30.5
60	1.06	1.30	1.92	5.31	30.4	85.2	19.8	15.2	35.4

Nearby edge location

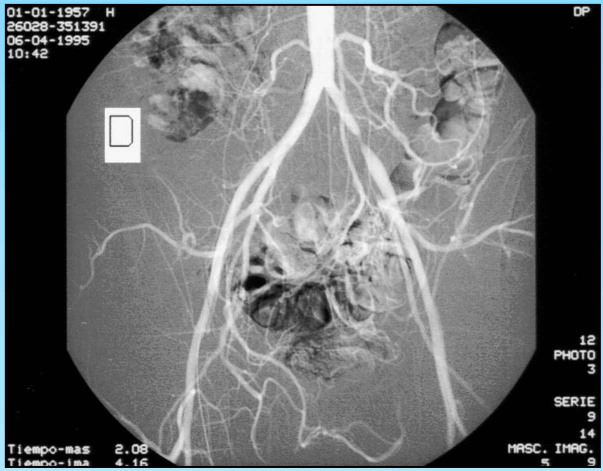


Tackling very close edges





Experiments with real angiographic image



Restoration