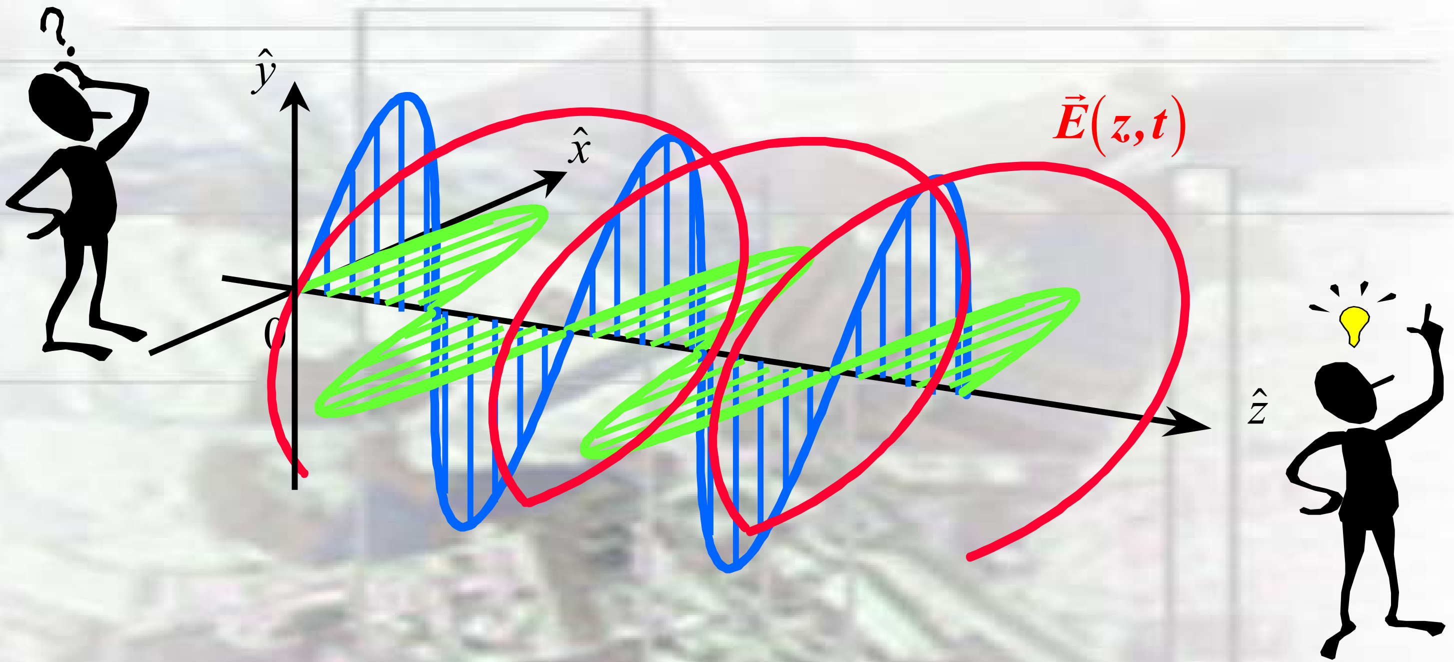
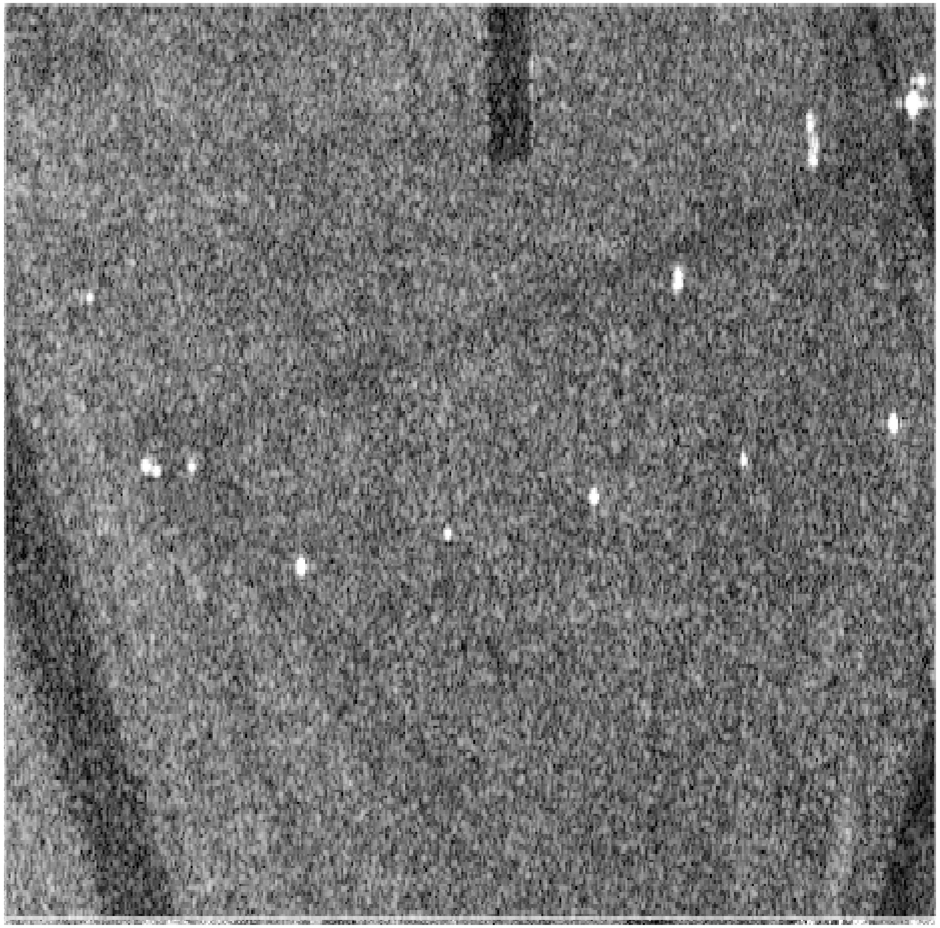
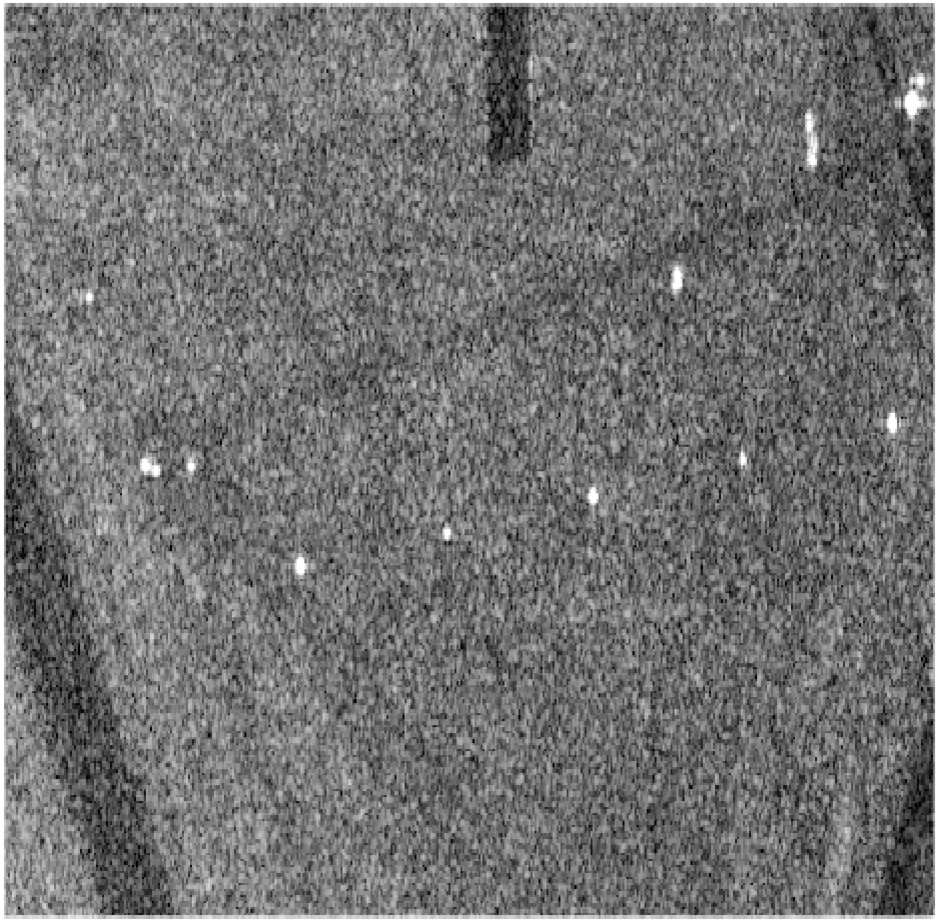


POLARIMETRIC SPECKLE FILTERING

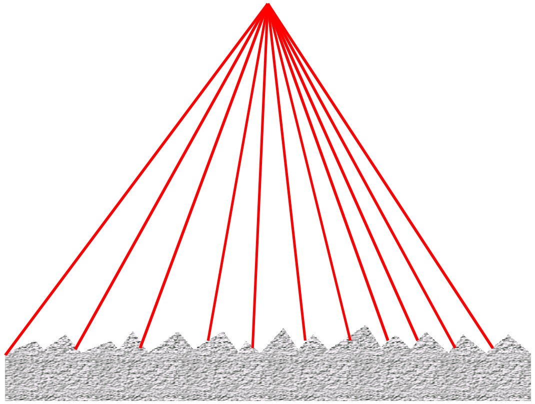


SPECKLE PHENOMENON

SPECKLE FILTERING



OBSERVATION POINT



SURFACE ROUGHNESS
WAVELENGTH

SCATTERING FROM DISTRIBUTED SCATTERERS

⬇

COHERENT INTERFERENCES OF WAVES SCATTERED FROM MANY RANDOMLY DISTRIBUTED ELEMENTARY SCATTERERS INSIDE THE RESOLUTION CELL

⬇

GRANULAR NOISE

⬇

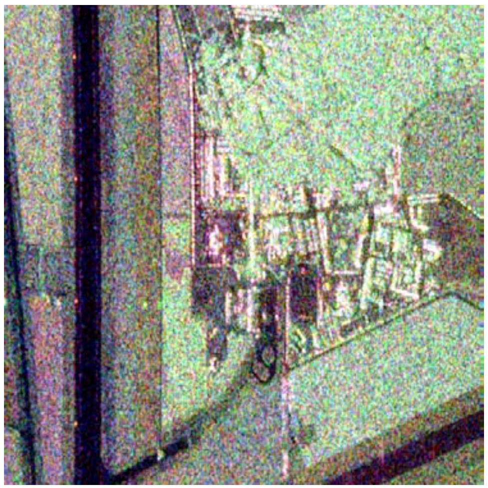
SPECKLE PHENOMENON

SPECKLE FILTERING

SPECKLE PHENOMENON

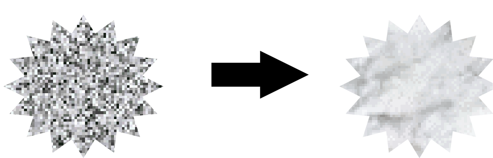
↓

DISTORTION OF THE INTERPRETATION

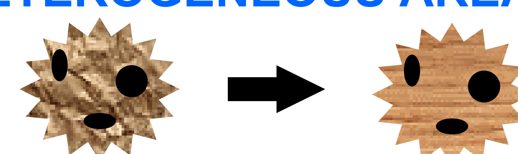


SPECKLE FILTERING

HOMOGENEOUS AREA



HETEROGENEOUS AREA



SPECKLE REDUCTION (RADIOMETRIC RESOLUTION)

DETAILS PRESERVATION (SPATIAL RESOLUTION)

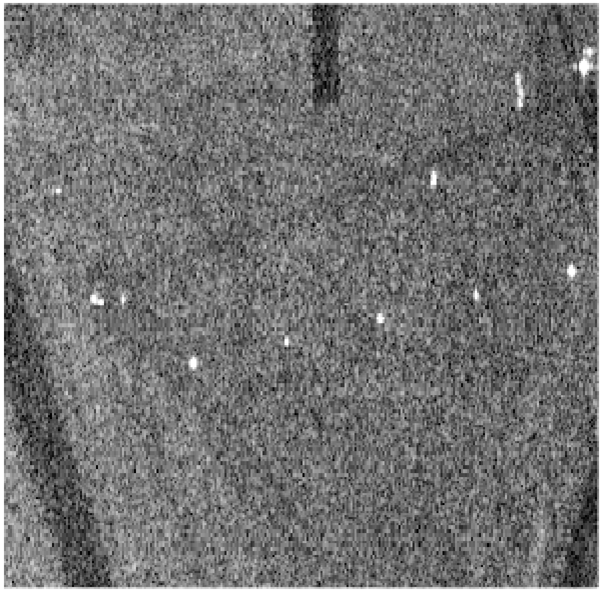
SPECKLE REDUCTION

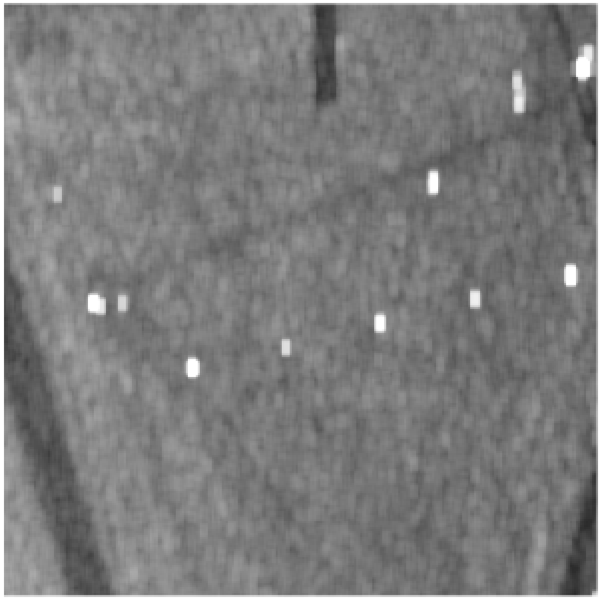
MULTI-LOOK SAR PROCESSING (BoxCar)

Averaging Amplitude / Intensity (Not complex images) of neighboring pixels

Good Noise Smoothing

Spatial Resolution Loss - blurring edges - erasing thin lines
Loss of linear or point features …





LINEAR SPECKLE FILTERS

Median Filter
MAP Filter (Kuan)
Gradient Filter
Nagao Filter (Nagao)
Sigma Filter (Lee)
Frost Filter (Frost)
Geometrical Filter (Crimmins)
Morphological Filter (Safa, Flouzat)

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Local Statistics Filter (Lee 80)

SPECKLE : MULTIPLICATIVE NOISE MODEL

« SPECKLE is a scattering phenomenon and not a noise. However, from the image SAR processing point of vue, the speckle can be modeled as multiplicative noise for extended target » (Lee, IGARSS-98)

$$\underline{y} = \begin{bmatrix} y_{HH} \\ y_{HV} \\ y_{VV} \end{bmatrix} = \begin{bmatrix} n_{HH} & 0 & 0 \\ 0 & n_{HV} & 0 \\ 0 & 0 & n_{VV} \end{bmatrix} \begin{bmatrix} x_{HH} \\ x_{HV} \\ x_{VV} \end{bmatrix} = \begin{bmatrix} x_{HH} n_{HH} \\ x_{HV} n_{HV} \\ x_{VV} n_{VV} \end{bmatrix}$$

SCATTERING FIELD — NOISE — REFLECTIVITY DENSITY

$$Y_{pqpq} = y_{pq} y^{*}_{pq} = X_{pqpq} v_{pqpq}$$

INTENSITY

$$A_{pqpq} = \sqrt{Y_{pqpq}} = \sqrt{y_{pq} y^{*}_{pq}}$$

AMPLITUDE

SPECKLE FILTERING

HOMOGENEOUS AREA

→ NUMBER OF ELEMENTARY SCATTERERS IS IMPORTANT

↓

CENTRAL LIMIT THEOREM

$$n_{pq} = n_{pq}^{I} + j n_{pq}^{Q} \quad \Rightarrow \quad n_{pq}^{I,Q} \in N(0, \tfrac{1}{2}) \quad \Rightarrow \quad \begin{cases} E\left(n_{pq}^{I}\right) = E\left(n_{pq}^{Q}\right) = 0 \\ E\left(n_{pq}^{I} n_{pq}^{Q}\right) = 0 \\ E\left(n_{pq}^{I}\right)^{2} = E\left(n_{pq}^{Q}\right)^{2} = \frac{1}{2} \end{cases}$$

CIRCULAR GAUSSIAN

→ NOISE INTENSITY

$$v_{pq} = n_{pq} n_{pq}^{*} = \left(n_{pq}^{I}\right)^{2} + \left(n_{pq}^{Q}\right)^{2} \quad \Rightarrow \quad E\left(v_{pq}\right) = 1$$

SPECKLE FILTERING

HOMOGENEOUS AREA

→ CONSTANT SPATIAL REFLECTIVITY $X_{pqpq} = X_0$

$$Y_{pqpq} = X_{pqpq} v_{pqpq}$$

$$E(Y_{pqpq}) = E(X_{pqpq} v_{pqpq}) = E(X_{pqpq}) = X_0$$

$$var(Y_{pqpq}) = var(X_{pqpq} v_{pqpq}) = X_0^2 \, var(v_{pqpq})$$

$$CV_Y = \frac{\sqrt{var(Y_{pqpq})}}{E(Y_{pqpq})} = \sqrt{var(v_{pqpq})} = CV_v$$

→ $$CV_v = CV_Y \qquad var(v_{pqpq}) = CV_Y^2$$

HOMOGENEOUS AREA — N LOOK CASE

	INTENSITY		AMPLITUDE
	$Y_{pqpq} = y_{pq} y^*_{pq}$		$A_{pqpq} = \sqrt{y_{pq} y^*_{pq}}$
N LOOK	$Y = \frac{1}{N}\sum_i Y_i$	N LOOK	$A = \sqrt{\frac{1}{N}\sum_i Y_i}$
DENSITY	$P_{NY}(Y/X_0) = \frac{N^N Y^{N-1}}{\Gamma(N) X_0^N} e^{-\frac{NY}{X_0}}$	DENSITY	$P_{NA}(A/X_0) = \frac{2N^N A^{2N-1}}{\Gamma(N) X_0^N} e^{-\frac{NA^2}{X_0}}$
MEAN	$E(Y) = X_0$	MEAN	$E(A) = \sqrt{\frac{X_0}{N}} \frac{\Gamma(N+\frac{1}{2})}{\Gamma(N)}$
VARIANCE	$var(Y) = \frac{X_0^2}{N}$	VARIANCE	$var(A) = \frac{X_0}{N}\left(N - \frac{\Gamma^2(N+\frac{1}{2})}{\Gamma^2(N)}\right)$
COEFFICIENT OF VARIATION	$CV_{NY} = \frac{1}{\sqrt{N}}$	COEFFICIENT OF VARIATION	$CV_{NA} = \sqrt{\frac{N\Gamma^2(N)}{\Gamma^2(N+\frac{1}{2})} - 1} \approx \frac{0.523}{\sqrt{N}}$

SPECKLE FILTERING

LOCAL STATISTICS LINEAR FILTER

$$\hat{X}_{i,j} = aE(Y) + bY_{i,j} = a\mu_Y + bY_{i,j}$$

with: $Y = \nu X \quad \mu_Y = \mu_\nu \mu_X \quad EY^2 = E\nu^2 EX^2$

$$CV_Y^2 = \frac{var(Y)}{\mu_Y^2} \qquad EY^2 = \mu_Y^2\left(CV_Y^2 + 1\right)$$

M.M.S.E $(a,b) \quad \backslash \quad \min_{(a,b)} J = E\left\|\hat{X}_{i,j} - X_{i,j}\right\|^2$

$$J = a^2\mu_Y^2 + 2ab\mu_Y^2 - 2a\mu_X\mu_Y + b^2EY^2 + EX^2\left(1 - 2b\mu_\nu\right)$$

$$\frac{\partial J}{\partial a} = 0 \quad \Rightarrow \quad a = \frac{1}{\mu_\nu} - b \qquad\qquad \frac{\partial J}{\partial b} = 0 \quad \Rightarrow \quad b = \mu_\nu \frac{var(X)}{var(Y)}$$

SPECKLE FILTERING

$$\hat{X}_{i,j} = \frac{E(Y)}{\mu_v} + b\left(Y_{i,j} - E(Y)\right)$$

with: $$b = \mu_v \frac{var(X)}{var(Y)} = \frac{1}{\mu_v}\frac{CV_X^2}{CV_Y^2}$$

and: $$CV_X^2 = \frac{EX^2 - \mu_X^2}{\mu_X^2} = \frac{1}{\mu_X^2}\left(\frac{EY^2}{Ev^2} - \frac{\mu_Y^2}{\mu_v^2}\right) = \frac{\mu_Y^2}{\mu_X^2 Ev^2}\left(CV_Y^2 - CV_v^2\right)$$
$$= \frac{\mu_v^2}{Ev^2}\left(CV_Y^2 - CV_v^2\right) = \frac{\left(CV_Y^2 - CV_v^2\right)}{\left(CV_v^2 + 1\right)}$$

$$b = \mu_v \frac{var(X)}{var(Y)} = \frac{1}{\mu_v}\frac{CV_Y^2 - CV_v^2}{CV_Y^2\left(1 + CV_v^2\right)}$$

or: $\mu_v = E(v) = 1$

LOCAL STATISTICS LINEAR FILTER

$$\hat{X}_{i,j} = E(Y) + k\left(Y_{i,j} - E(Y)\right)$$

$$k = \frac{var(X)}{var(Y)} = \frac{CV_Y^2 - CV_v^2}{CV_Y^2\left[1 + CV_v^2\right]} = \frac{var(Y) - E^2(Y)\sigma_v^2}{var(Y)\left[1 + \sigma_v^2\right]}$$

LOCAL STATISTICS $E^2(Y)\,,\; var(Y) = E\left(Y^2\right) - E^2(Y)$

A PRIORI INFORMATION $\sigma_v^2 = var(v) = CV_Y^2 = \dfrac{1}{N}$

IMAGE NUMBER OF LOOK

POLSAR SPECKLE FILTERING

VECTORIAL SPECKLE FILTER

$$[C] = \underline{y}\,\underline{y}^{*T} \longrightarrow \boxed{\text{FILTER}} \longrightarrow [\hat{C}] = \underline{\hat{x}}\,\underline{\hat{x}}^{*T}$$

COVARIANCE MATRIX

LOPES - GOZE - NEZRY - TOUZY (1990 - 1992) and SERY (1997) FILTERS, LEE FILTER (1997)

- POLARIMETRIC SPECKLE FILTERING SHOULD FILTER ALL ELEMENTS OF THE COVARIANCE MATRIX
- AVOIDING CROSS-TALK BETWEEN CHANNELS DUE TO THE FILTERING PROCESS
- PRESERVING POLARIMETRIC INFORMATION AND THE STATISTICAL CORRELATION BETWEEN THE CHANNELS
- PRESERVING SPATIAL RESOLUTION, FEATURES, EDGE SHARPNESS AND POINT TARGETS

EXTENSION OF THE LOCAL STATISTIC LINEAR FILTER

VECTORIZATION OF THE COVARIANCE MATRIX

$$[C] = \underline{y}\,\underline{y}^{T*} = \begin{bmatrix} Y_{HHHH} & Y_{HHHV} & Y_{HHVV} \\ Y^{*}_{HVHV} & Y_{HVHV} & Y_{HVVV} \\ Y^{*}_{HHVV} & Y^{*}_{HVVV} & Y_{VVVV} \end{bmatrix} \Rightarrow \underline{Y} = \begin{bmatrix} Y_{HHHH} \\ Y_{HHHV} \\ Y_{HHVV} \\ Y_{HVHV} \\ Y_{HVVV} \\ Y_{VVVV} \end{bmatrix}$$

VECTORIAL MULTIPLICATIVE MODEL

$$\underline{Y} = [V]\underline{X}$$

VECTORIAL MULTIPLICATIVE MODEL

$$\underline{Y} = [V]\underline{X}$$

$$\underline{Y} = \begin{bmatrix} Y_{HHHH} \\ Y_{HHHV} \\ Y_{HHVV} \\ Y_{HVHV} \\ Y_{HVVV} \\ Y_{VVVV} \end{bmatrix} = \begin{bmatrix} v_{HHHH} & 0 & 0 & 0 & 0 & 0 \\ 0 & v_{HHHV} & 0 & 0 & 0 & 0 \\ 0 & 0 & v_{HHVV} & 0 & 0 & 0 \\ 0 & 0 & 0 & v_{HVHV} & 0 & 0 \\ 0 & 0 & 0 & 0 & v_{HVVVV} & 0 \\ 0 & 0 & 0 & 0 & 0 & v_{VVVV} \end{bmatrix} \begin{bmatrix} X_{HHHH} \\ X_{HHHV} \\ X_{HHVV} \\ X_{HVHV} \\ X_{HVVV} \\ X_{VVVV} \end{bmatrix}$$

VECTORIAL LOCAL STATISTICS LINEAR FILTER

$$\underline{\hat{X}} = [A]E(\underline{Y}) + [B]\underline{Y}$$

M.M.S.E

$$([A],[B]) \min_{([A],[B])} J = E\left\| \underline{\hat{X}} - \underline{X} \right\|^2 = E\left[(\underline{\hat{X}} - \underline{X})^T (\underline{\hat{X}} - \underline{X})^* \right]$$

$$\frac{\partial J}{\partial [A]} = 0 \quad \Rightarrow \quad [A] = [Id] - [B] E([V])$$

$$\frac{\partial J}{\partial [B]} = 0 \quad \Rightarrow \quad [B] = cov(\underline{X}) E([V])^{T*} cov^{-1}(\underline{Y})$$

⬇

$$\underline{\hat{X}} = E(\underline{Y}) - [k](E(\underline{Y}) - \underline{Y})$$

$$[k] = cov(\underline{X}) E([V])^{T*} cov^{-1}(\underline{Y})$$

SAPHIR

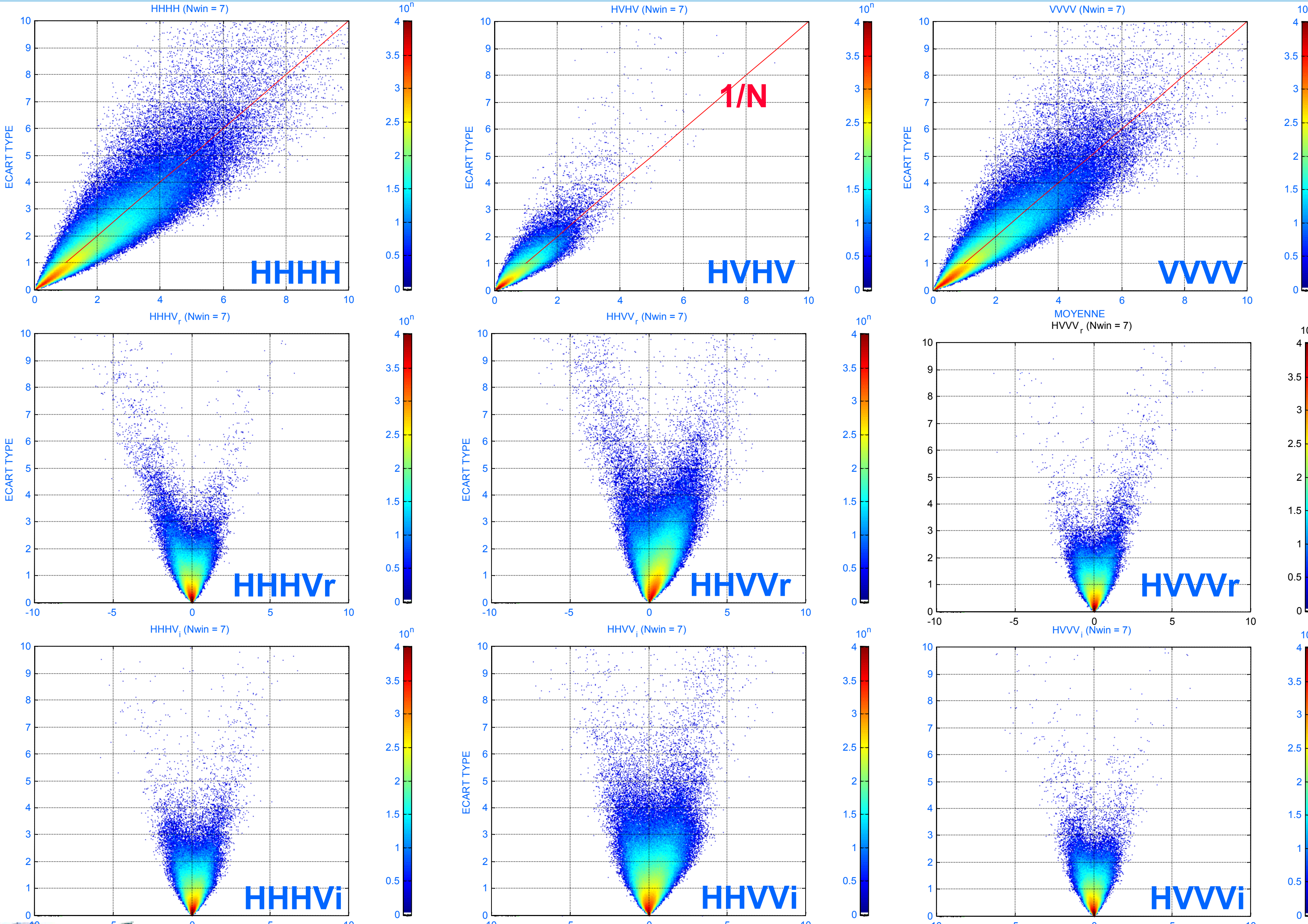
VECTORIAL LOCAL STATISTICS LINEAR FILTER

$$\underline{\hat{X}} = E(\underline{Y}) - [k](E(\underline{Y}) - \underline{Y})$$

$$[k] = cov(\underline{X})E([V])^{T*} cov^{-1}(\underline{Y})$$

- DERIVATION AND COMPUTATION OF THE COV(X) MATRIX IS RATHER COMPLICATED (ILL-CONDITIONING)
- IN THE COVARIANCE MATRIX, THE CO-POL INTENSITIES CHANNELS CAN BE MODELED AS MULTIPLICATIVE NOISE MODEL.
- BUT THE CROSS-POL (OFF-DIAGONAL) INTENSITIES CHANNELS ARE DIFFICULT TO DEFINE : NEITHER MULTIPLICATIVE NOR ADDITIVE

POLSAR SPECKLE FILTERING



POLSAR SPECKLE FILTERING

POLARIMETRIC VECTORIAL SPECKLE FILTER

$$[C] = \underline{y}\,\underline{y}^{*T}$$

$$[\hat{C}] = E([C]) - k[E([C]) - [C]]$$

$$[\hat{C}] = \underline{\hat{x}}\,\underline{\hat{x}}^{*T}$$

SPAN IMAGE

$$S_S = Y_{HHHH} + 2Y_{HVHV} + Y_{VVVV}$$

$$k = \frac{var(S)}{var(S_S)} = \frac{CV_{S_S}^2 - \sigma_v^2}{CV_{S_S}^2\left[1+\sigma_v^2\right]}$$

LINEAR SCALAR LEE FILTER

$$\hat{S} = E(S_S) - k[E(S_S) - S_S]$$

J.S. LEE

Homogeneous Areas

$$var(S) \approx 0 \quad \Rightarrow \quad k = 0 \quad \Rightarrow \hat{S} = E(S_S)$$

Highly Inhomogeneous Areas

$$var(S) \mapsto var(S_s) \quad \Rightarrow \quad k = 1 \quad \Rightarrow \hat{S} = S_S$$

REFINED FILTER

POLSAR SPECKLE FILTERING

POLARIMETRIC VECTORIAL SPECKLE LEE FILTER

$$[\hat{C}] = E([C]) - k[E([C]) - [C]]$$

EACH ELEMENT OF THE COVARIANCE MATRIX IS FILTERED

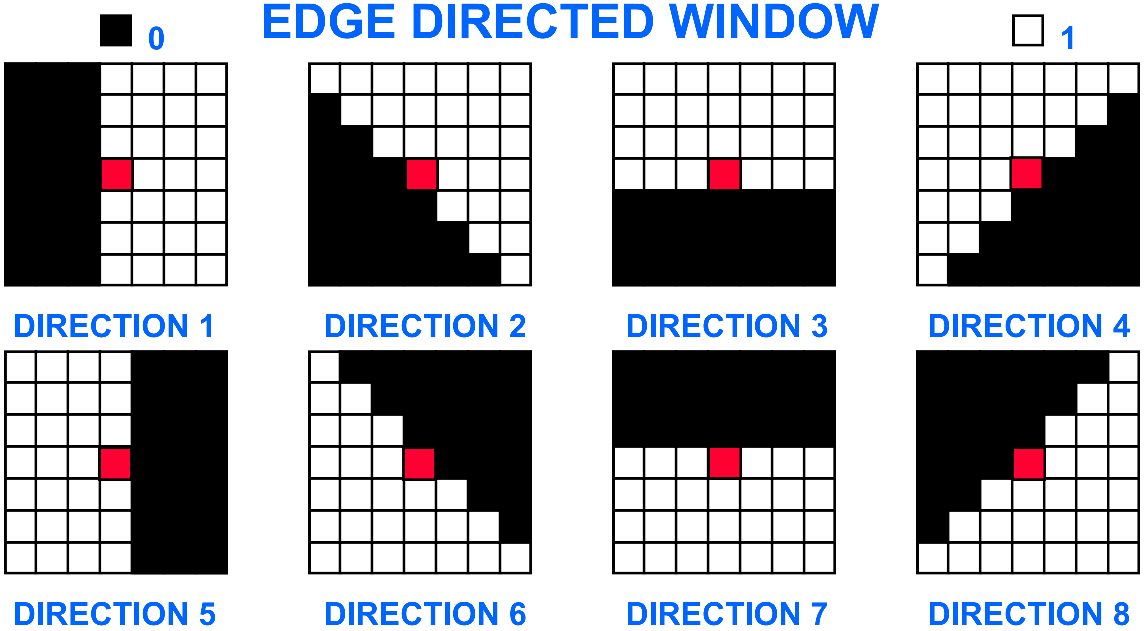
- BY THE SAME AMOUNT AVOIDING CROSS-TALK AND PRESERVING POLARIMETRIC INFORMATION AND CORRELATIONS

- SIMILAR TO THE MULTI LOOK PROCESSING BY AVERAGING THE COVARIANCE MATRICES OF NEIGHBORING PIXELS

- BY WEIGHTING THE COVARIANCE MATRIX OF THE CENTER PIXEL OF THE SLIDING WINDOW WITH THE MEAN OF COVARIANCE MATRICES FROM SELECTED NEIGHBORING PIXELS PRESERVING SPATIAL RESOLUTION, FEATURES, EDGES … REFINED LEE FILTER

POLSAR SPECKLE FILTERING

EDGE DIRECTED WINDOW



LOCAL HETEROGENEITY & NOISY EDGE BOUDARIES

THE EDGE DIRECTED WINDOWS ARE USED TO COMPUTE THE LOCAL MEAN AND VARIANCE

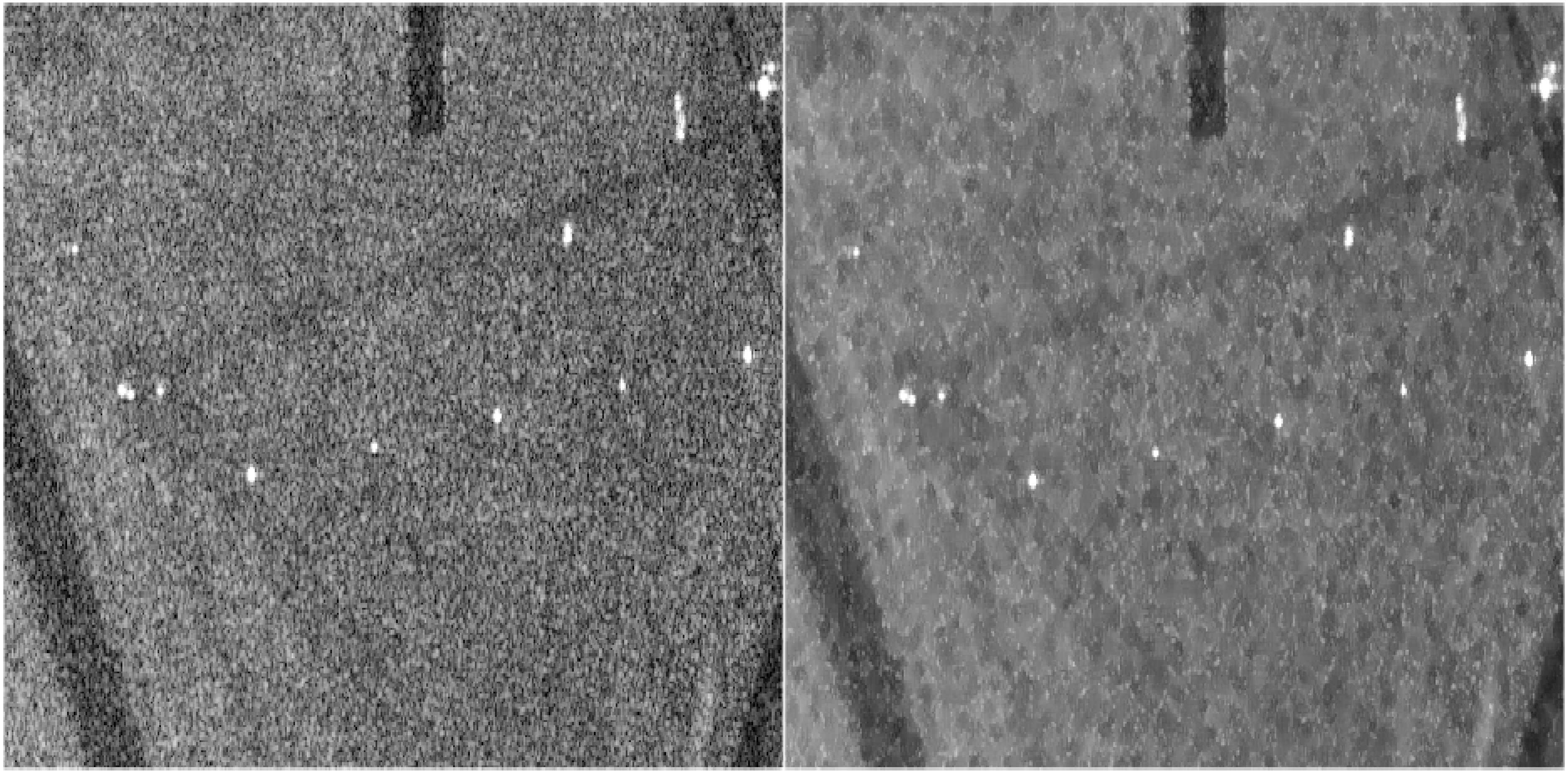
POLARIMETRIC LEE FILTER

$$[\hat{C}] = E([C]) - k\left[E([C]) - [C]\right]$$

$$k = \frac{var(S)}{var(S_S)} = \frac{CV_{S_S}^2 - \sigma_v^2}{CV_{S_S}^2\left[1 + \sigma_v^2\right]}$$

FOR EACH PIXEL, THE k VALUE IS COMPUTED IN AN EDGE DIRECTED WINDOW

POLSAR SPECKLE FILTERING



OP-AIRFIELD L-Band

POLSAR SPECKLE FILTERING

POLARIMETRIC SPECKLE FILTERING IS NOT AN EXACT SCIENCE
SUBJECTIVE, IMAGE DEPENDENT

Quantitative Criteria (J.S. Lee - IGARSS 98)

- Speckle Reduction (E.N.L)
- Edge Sharpness Preservation
- Line and Point Target Contrast Preservation
- Retention of Mean Values in Homogeneous Regions
- Retention of Texture Information
- Retention of Polarimetric Information (co, cross-correlations)
- Computational Efficiency
- Implementation Complexity

$$[\hat{C}] = E([C]) - k[E([C]) - [C]]$$

THE POLARIMETRIC SPECKLE LEE FILTER
IS TODAY A GOOD COMPROMISE

POLSAR SPECKLE FILTERING

$[C] = \underline{y}\,\underline{y}^{*T}$ → FILTER → $[\hat{C}] = \hat{\underline{x}}\,\hat{\underline{x}}^{*T}$

AVERAGING DATA

↓

SECOND ORDER STATISTICS

↓

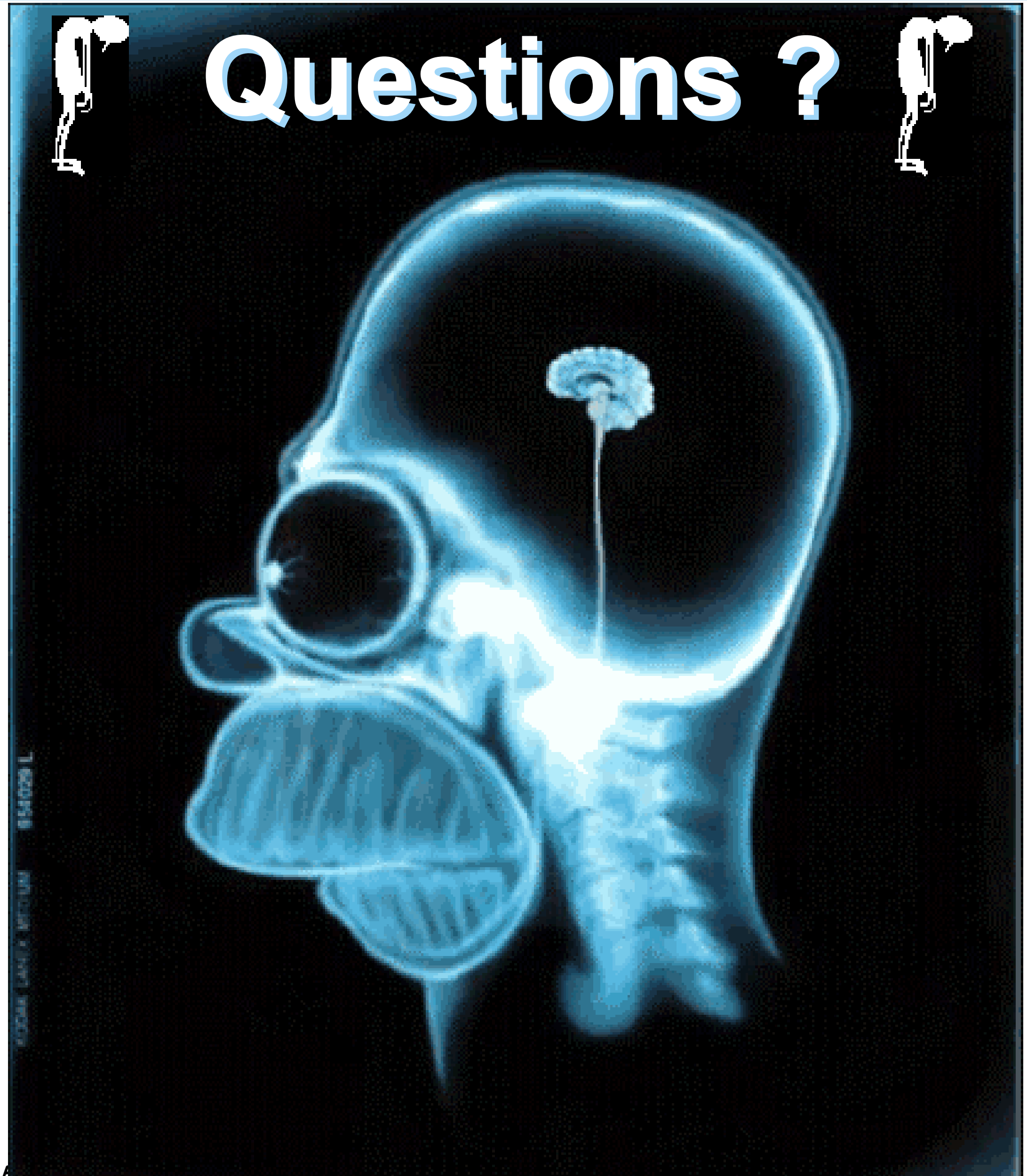
COVARIANCE / COHERENCY MATRICES

SMOOTHING AVERAGING

↓

CONCEPT OF THE

DISTRIBUTED TARGET


Questions ?