PEFs applied to FPGAs and TPWM

Robert G. Clapp, Haohuan Fu, William Osborne, and Oskar Mencer

How trying to solve a problem on this .....

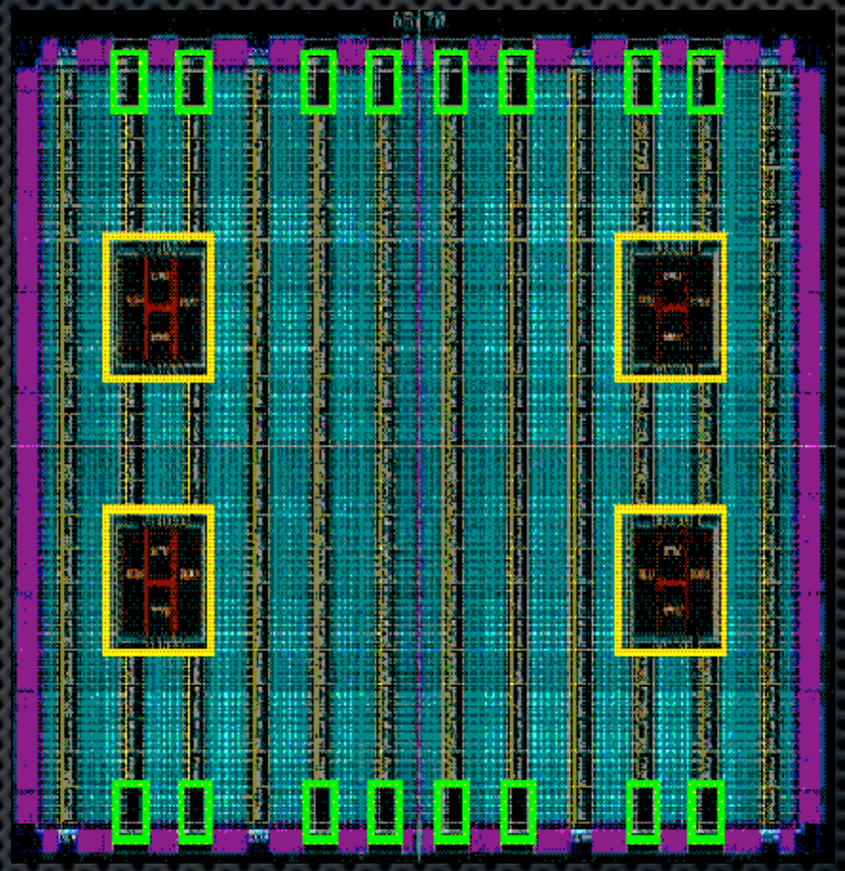
FPGA

PEFs

Applications

Scalar

Vector



led to an interesting result on this

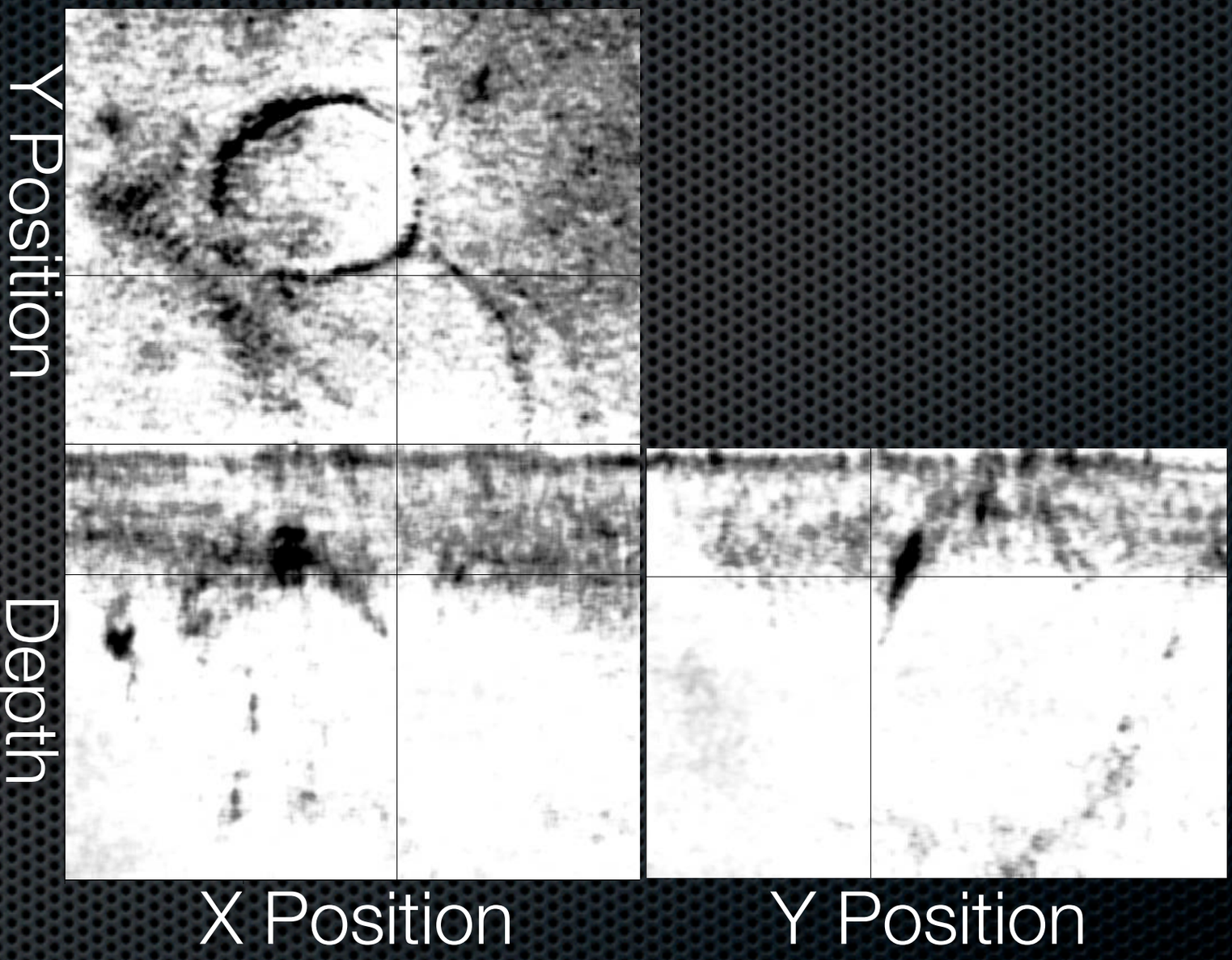
FPGA

PEFs

Applications

Scalar

Vector



FPGA

FPGA

PEFs

Applications

Scalar

Vector

- Processor vs FPGA design
- Programming model
- Precision, space vs speed

Processor

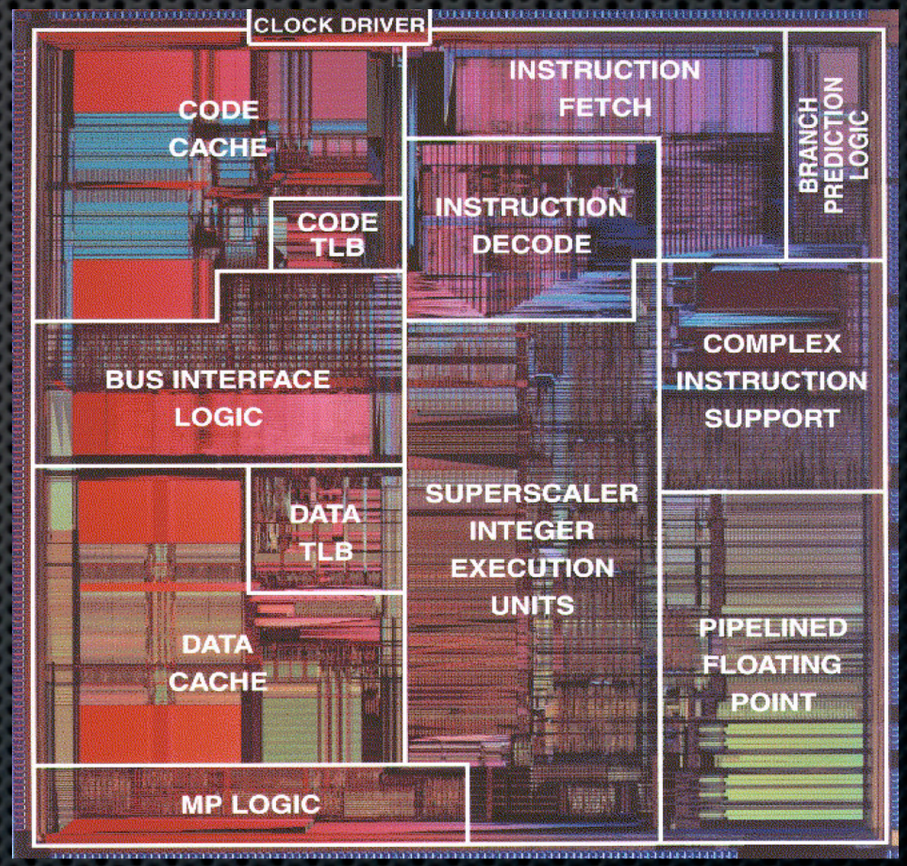
FPGA

PEFs

Applications

Scalar

Vector



FPGA vs Processor

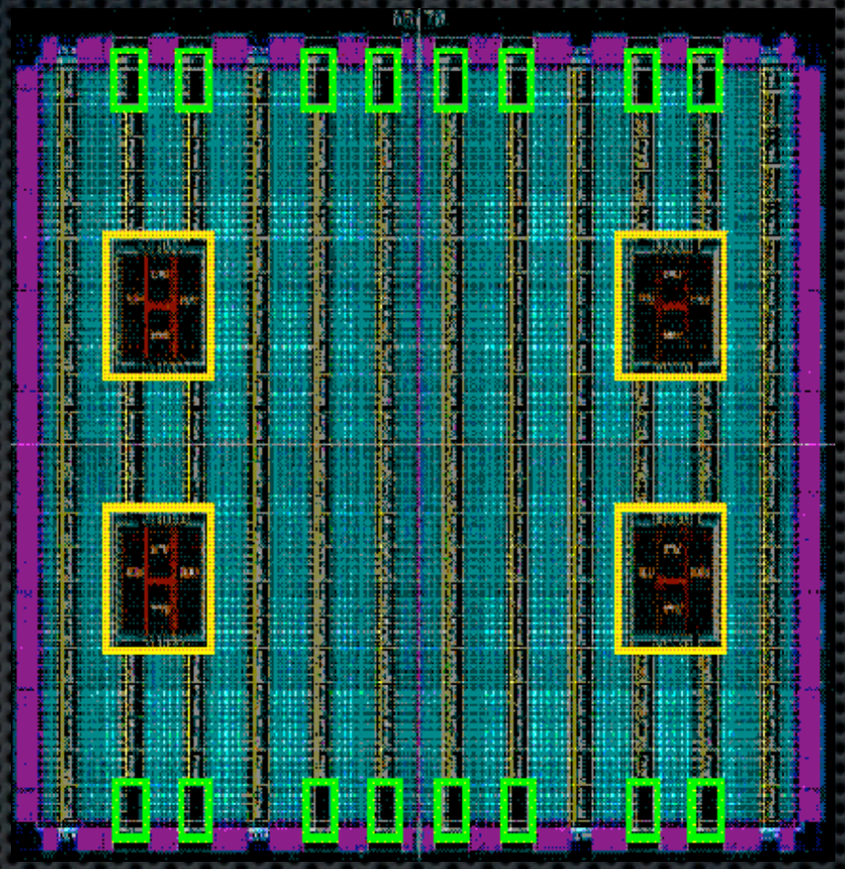
FPGA

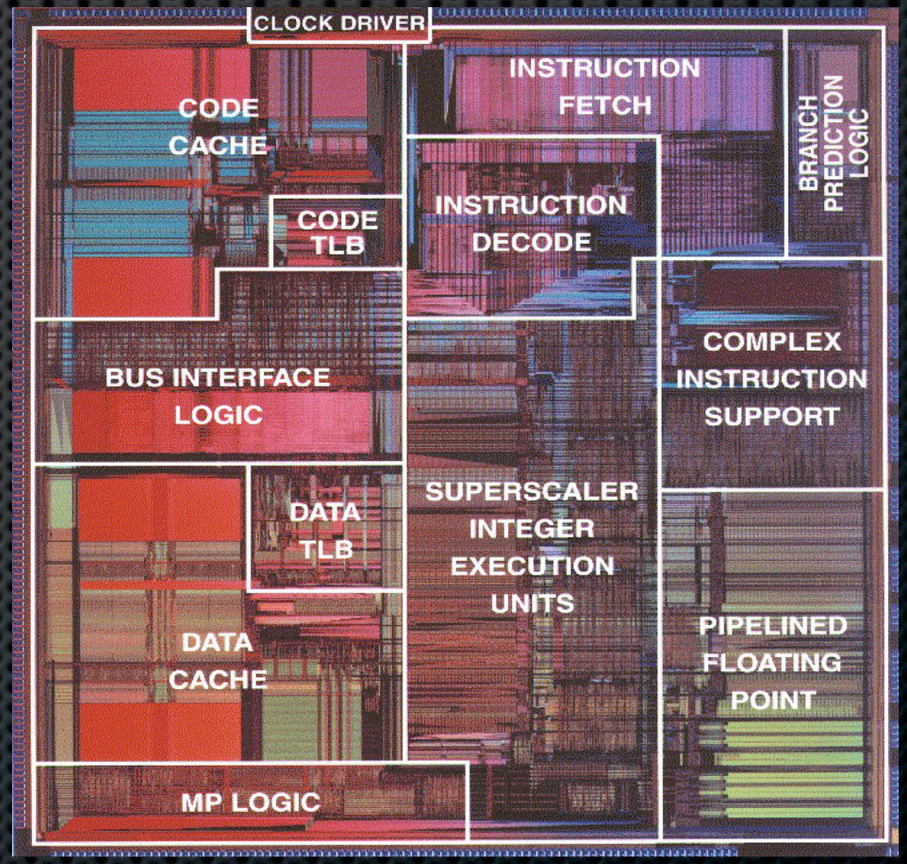
PEFs

Applications

Scalar

Vector





FPGA vs Processor

Processor	FPGA
Clock speed:	10X Faster
Flexible (easy to program)	

FPGA vs Processor

Processor	FPGA
• Clock speed: 10X Faster	• Clock speed: Slower (less power)
• Flexible (easy to program)	• Flexible (can do things more efficiently)

Speed up opportunities

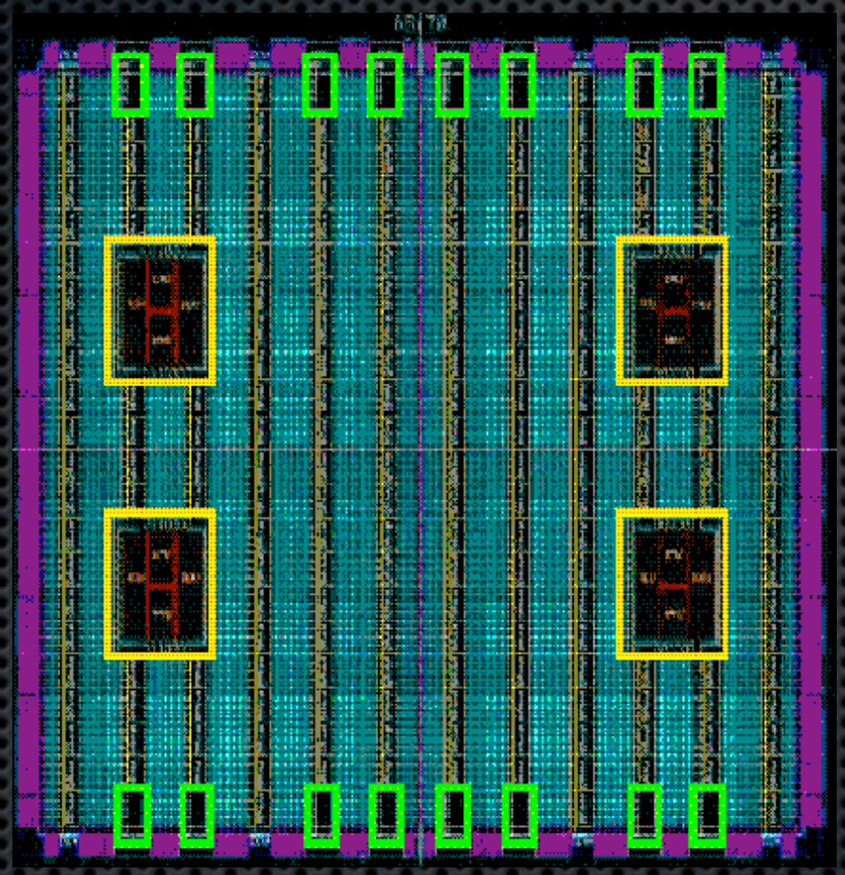
FPGA

PEFs

Applications

Scalar

Vector



- Memory management (streaming)

Stream programing

FPGA

PEFs

Applications

Scalar

Vector

b(i)=a(i)*c2+a(i-1)*c1

Stream programing

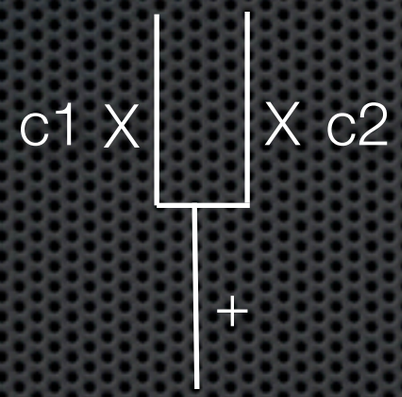
FPGA

PEFs

Applications

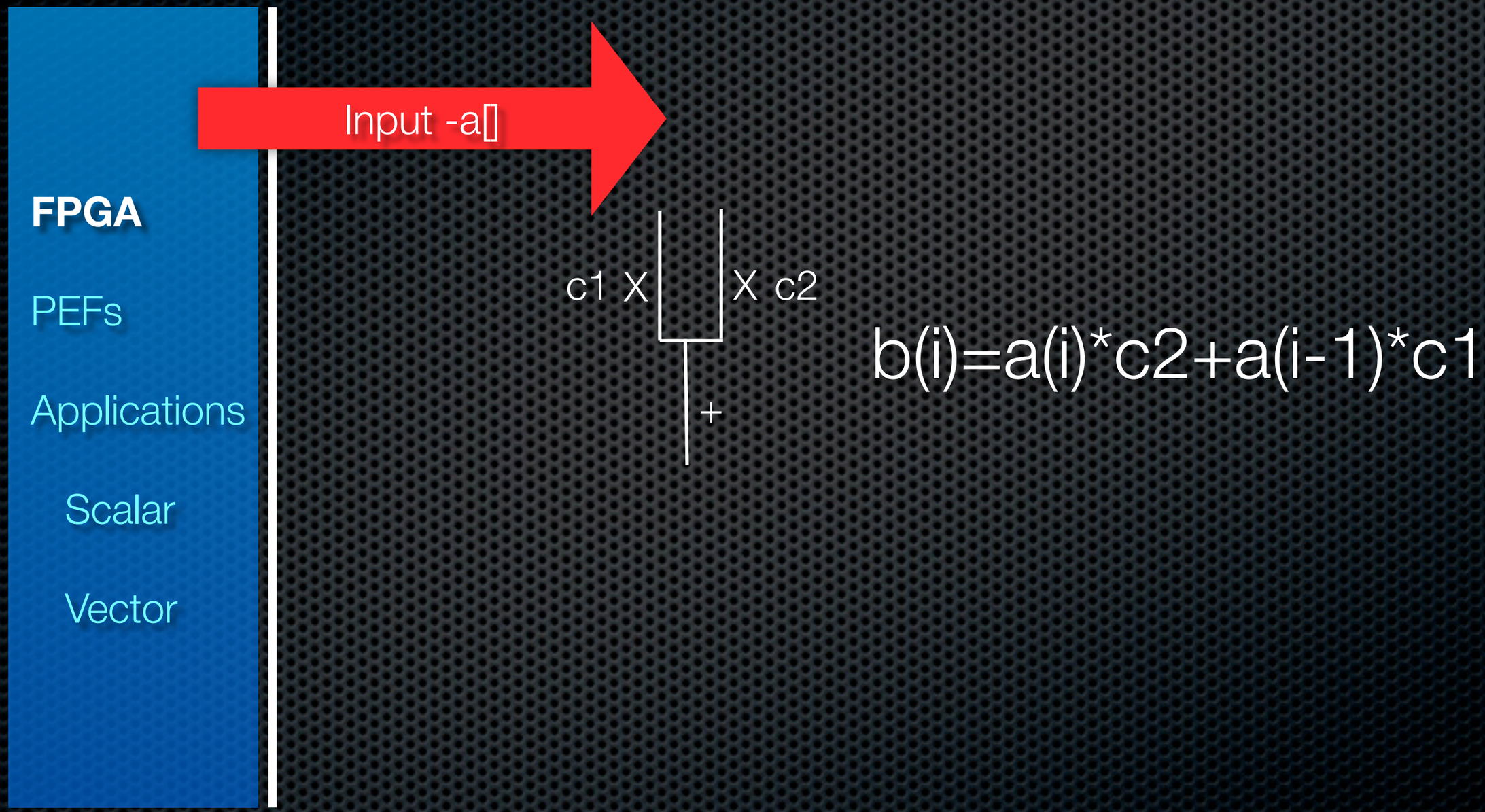
Scalar

Vector

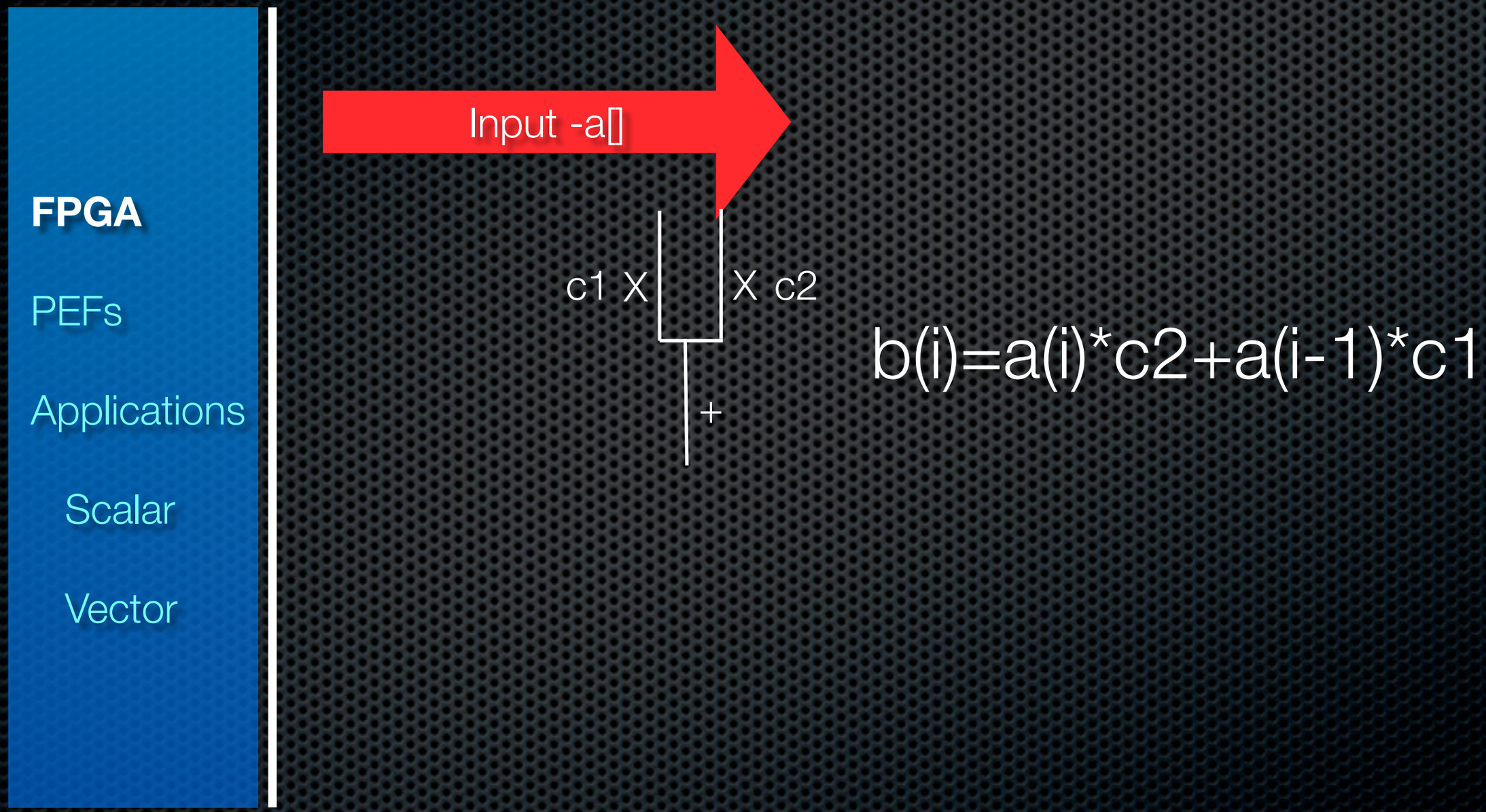


$$b(i)=a(i)*c2+a(i-1)*c1$$

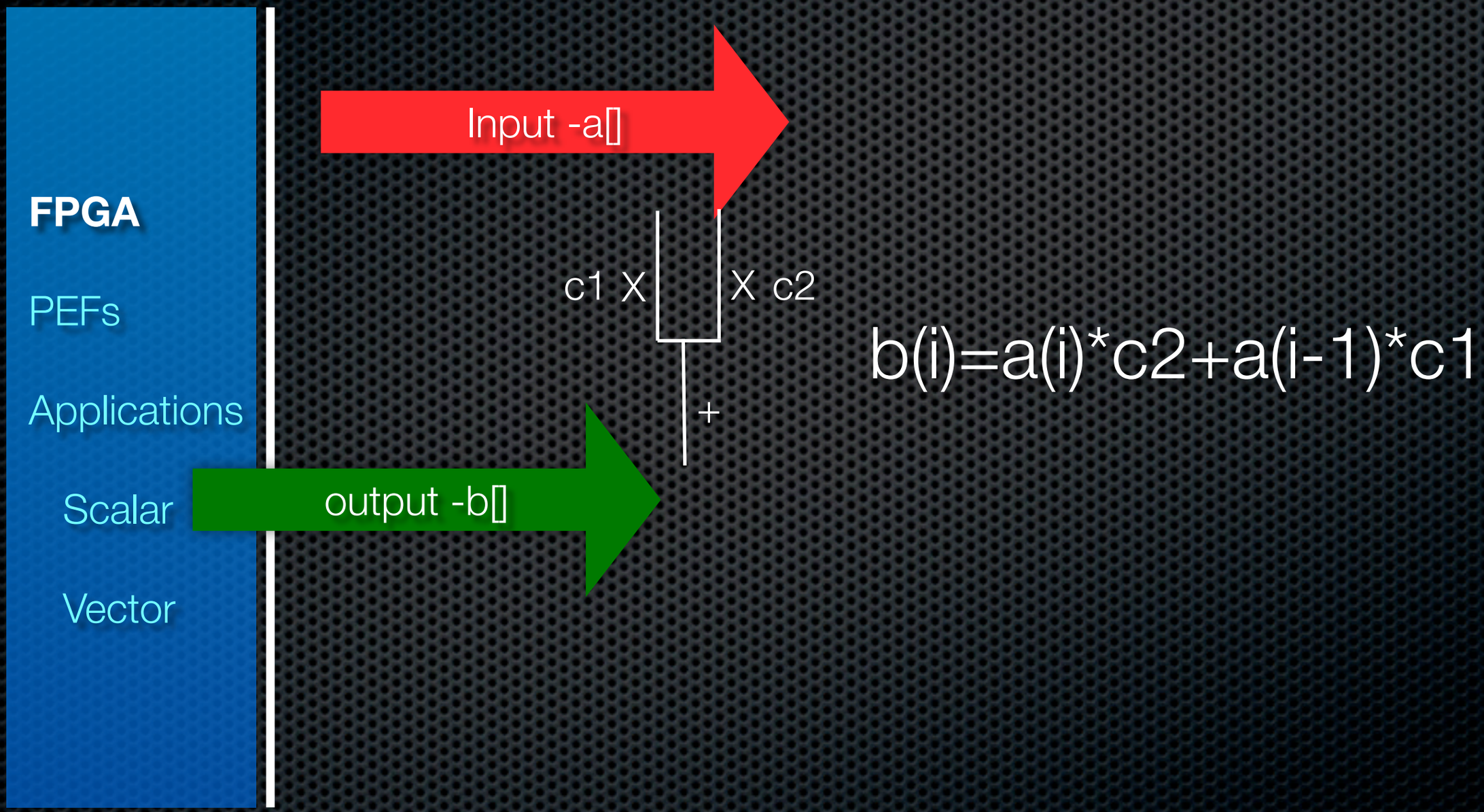
Stream programing



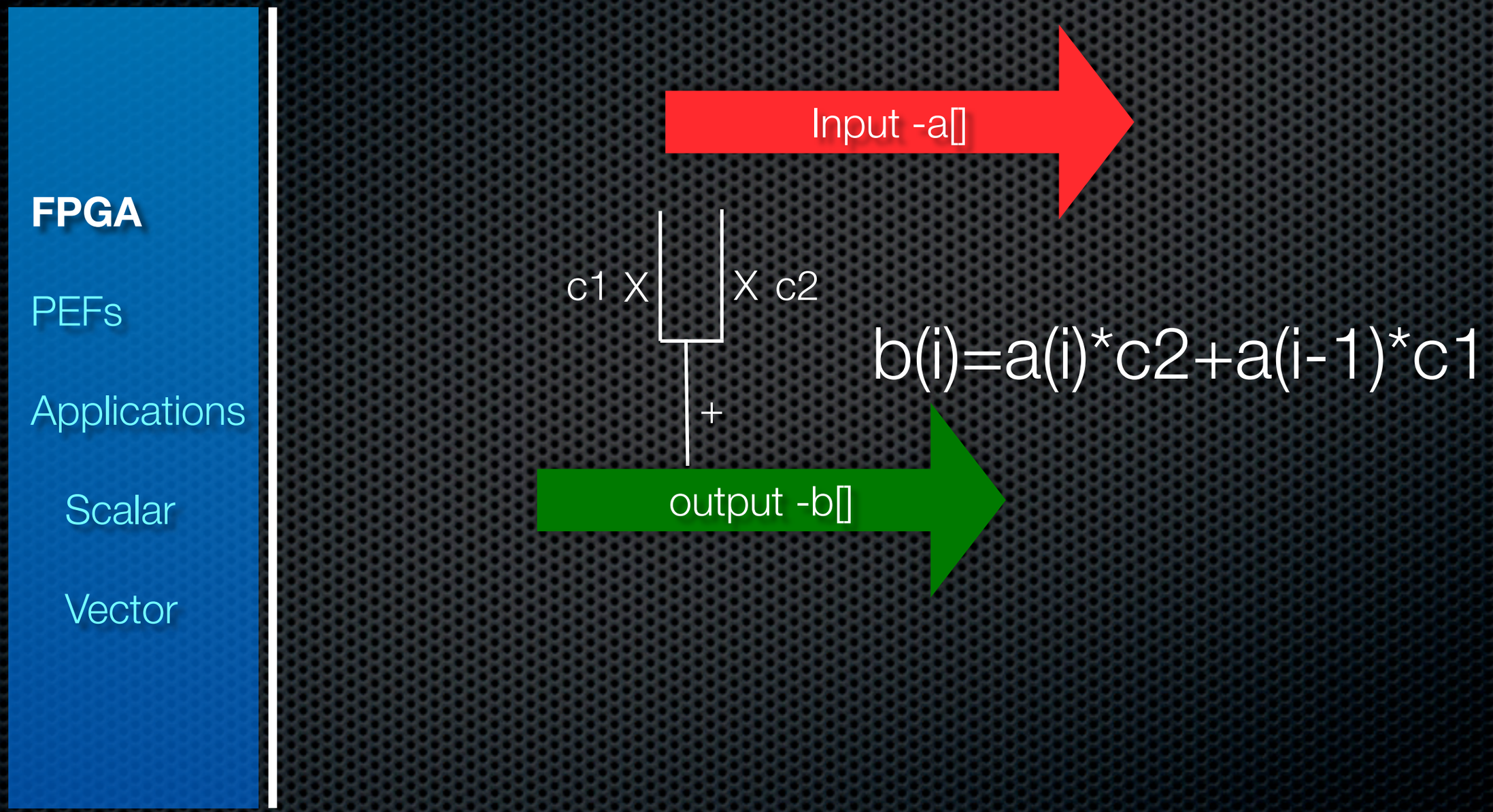
Stream programing



Stream programing



Stream programing



Speed up opportunities

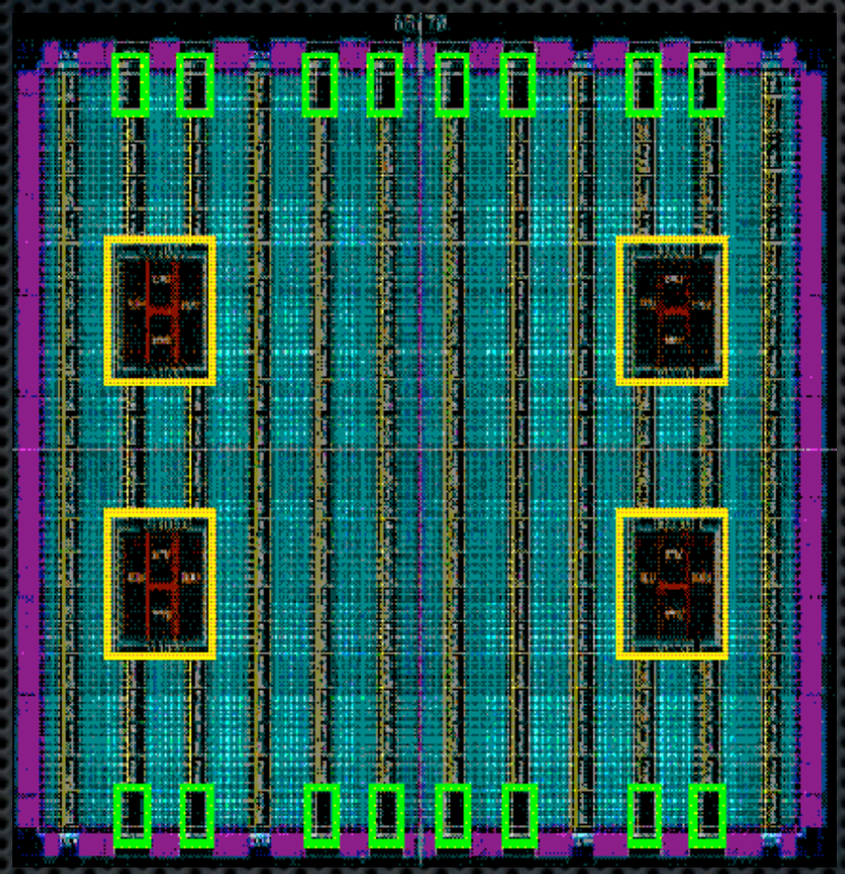
FPGA

PEFs

Applications

Scalar

Vector



- Memory management (streaming)
- Number representation (compression)

Speed up opportunities

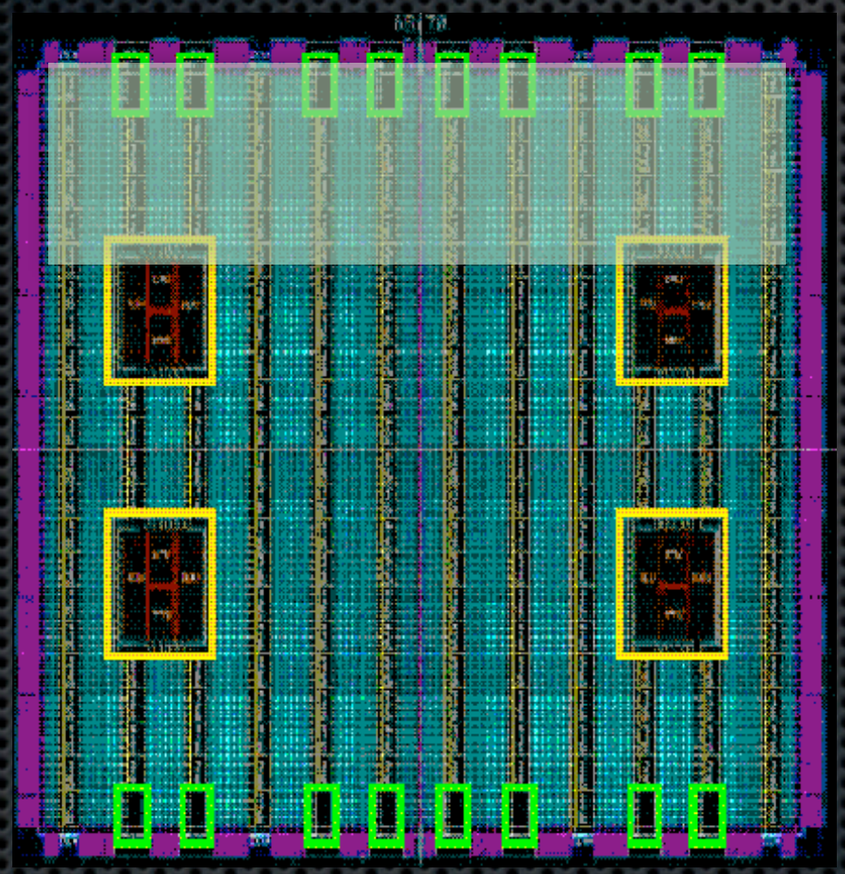
FPGA

PEFs

Applications

Scalar

Vector



- Memory management (streaming)
- Number representation (compression)

Compression

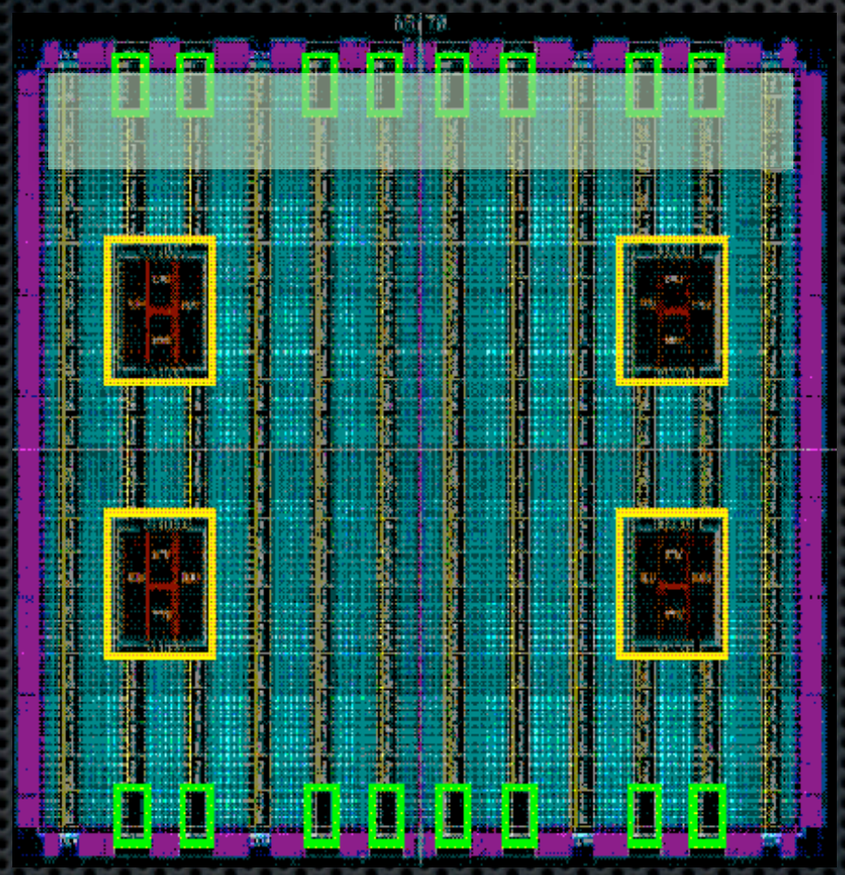
FPGA

PEFs

Applications

Scalar

Vector



- Compression is space rather than time
- Wider stream (more processing power)
- More space for compute

FPGA gurus

FPGA

PEFs

Applications

Scalar

Vector

FPGA gurus

FPGA

PEFs

Applications

Scalar

Vector

- "Your images are incomprehensible"

FPGA gurus

FPGA

PEFs

Applications

Scalar

Vector

- "Your images are incomprehensible"
- "I don't see any difference between your before and after pictures"

FPGA gurus

FPGA

PEFs

Applications

Scalar

Vector

- "Your images are incomprehensible"
- "I don't see any difference between your before and after pictures"
- "I want a difference measure"

FPGA gurus

FPGA

PEFs

Applications

Scalar

Vector

- "Your images are incomprehensible"
- "I don't see any difference between your before and after pictures"
- "I want a difference measure"
- "I want a single number"

If you are from SEP

FPGA

PEFs

Applications

Scalar

Vector

If you are from SEP

FPGA

PEFs

Applications

Scalar

Vector

it sounds like something I can do with a Prediction Error Filter

PEF estimation

FPGA

PEFs

Applications

Scalar

Vector

$$\mathbf{Da} \approx \mathbf{0}$$

D -Convolution with data
a -Compact filter

Incomprehensible image

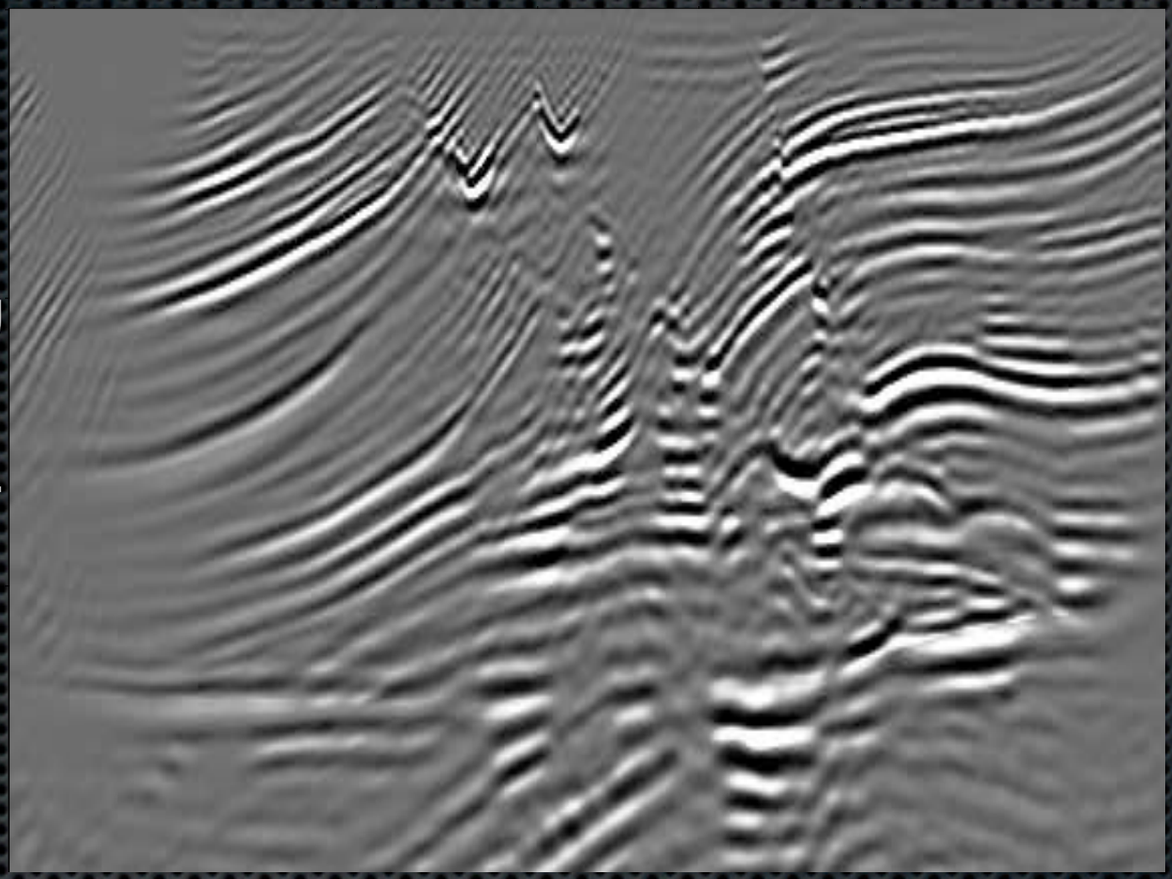
FPGA

PEFs

Applications

Scalar

Vector



Not a stationary problem

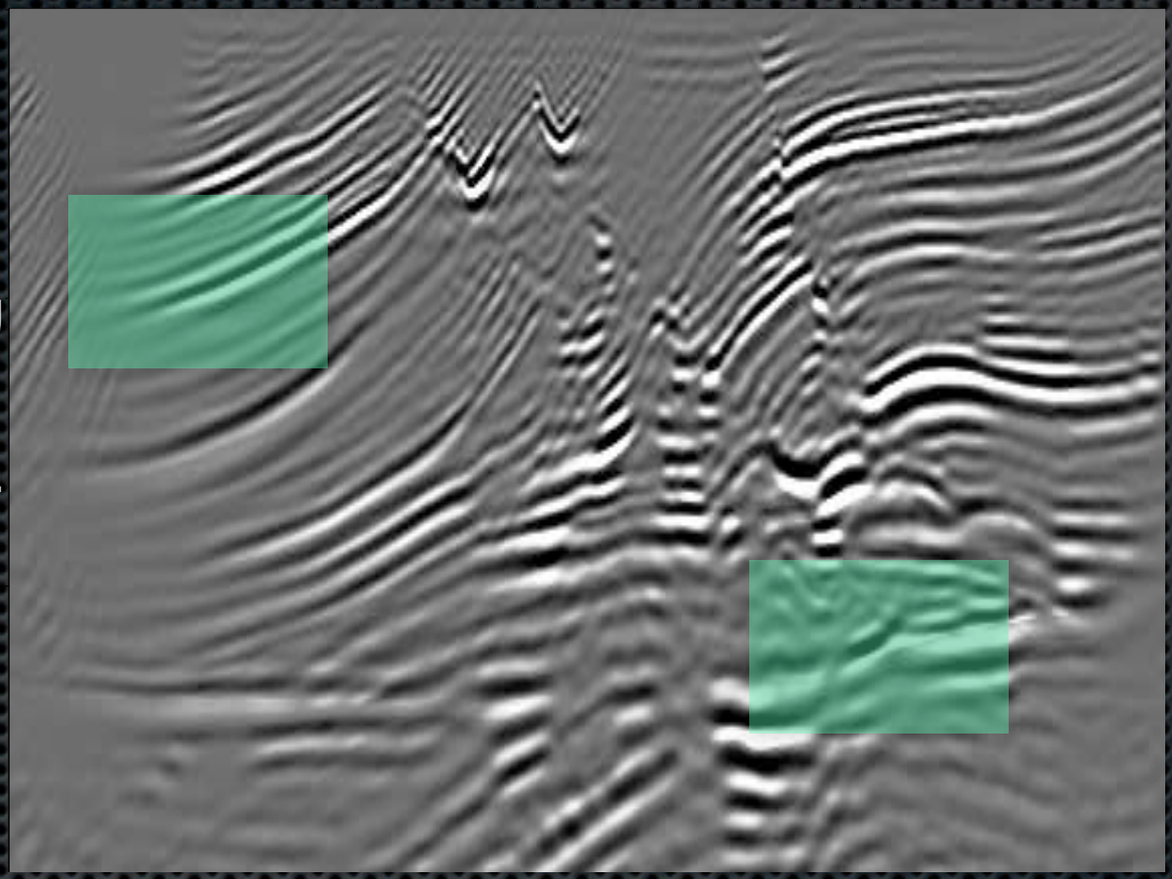
FPGA

PEFs

Applications

Scalar

Vector



Non-stationarity: Patching

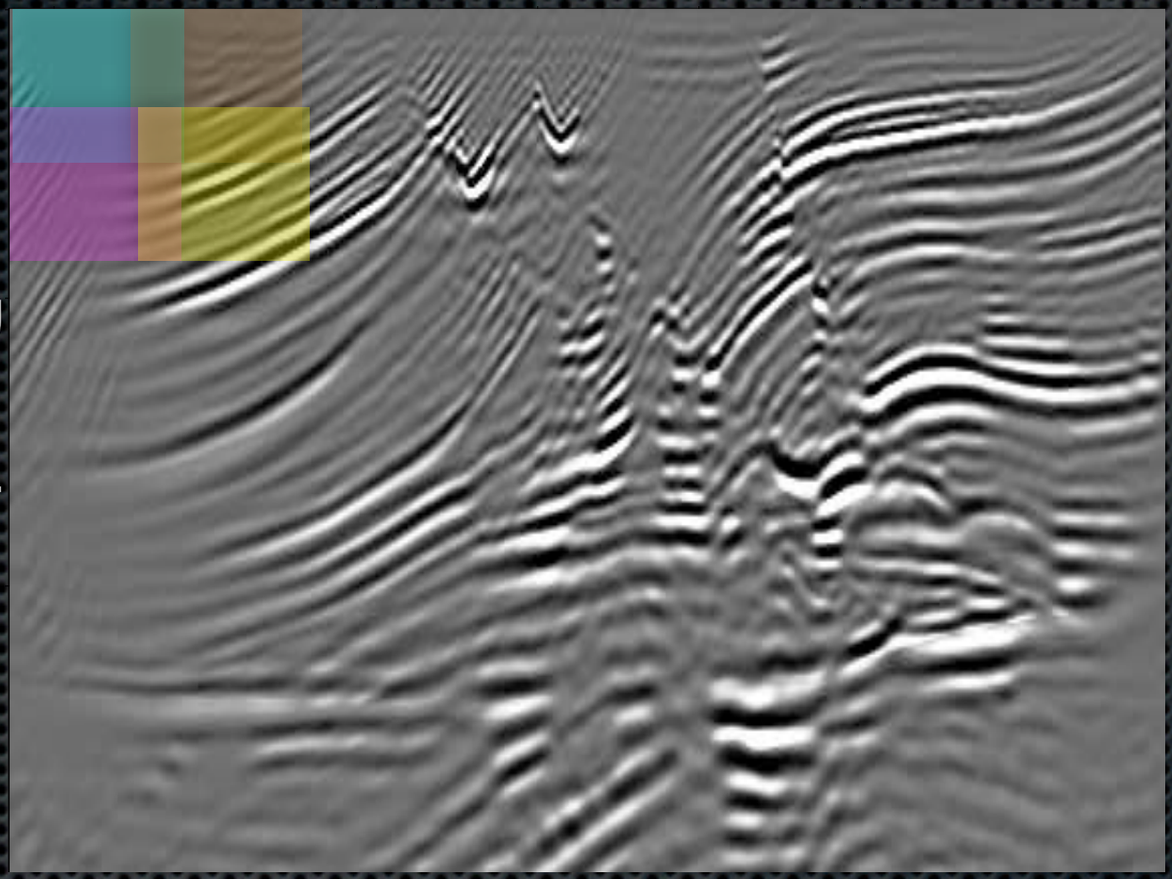
FPGA

PEFs

Applications

Scalar

Vector



PEF estimation

FPGA

PEFs

Applications

Scalar

Vector

$$\mathbf{Da} \approx \mathbf{0}$$

D -Convolution with data
a -Compact filter

PEF estimation

FPGA

PEFs

Applications

Scalar

Vector

$$\mathbf{Da} \approx \mathbf{0}$$

D -Convolution with data
a -Compact filter

PEF estimation

FPGA

PEFs

Applications

Scalar

Vector

$$\mathbf{Da = r}$$

D -Convolution with data
a -Compact filter
r -Unpredictable portion

Isn't predicted by PEF
(random, non-stationary)

Estimation residual

FPGA

PEFs

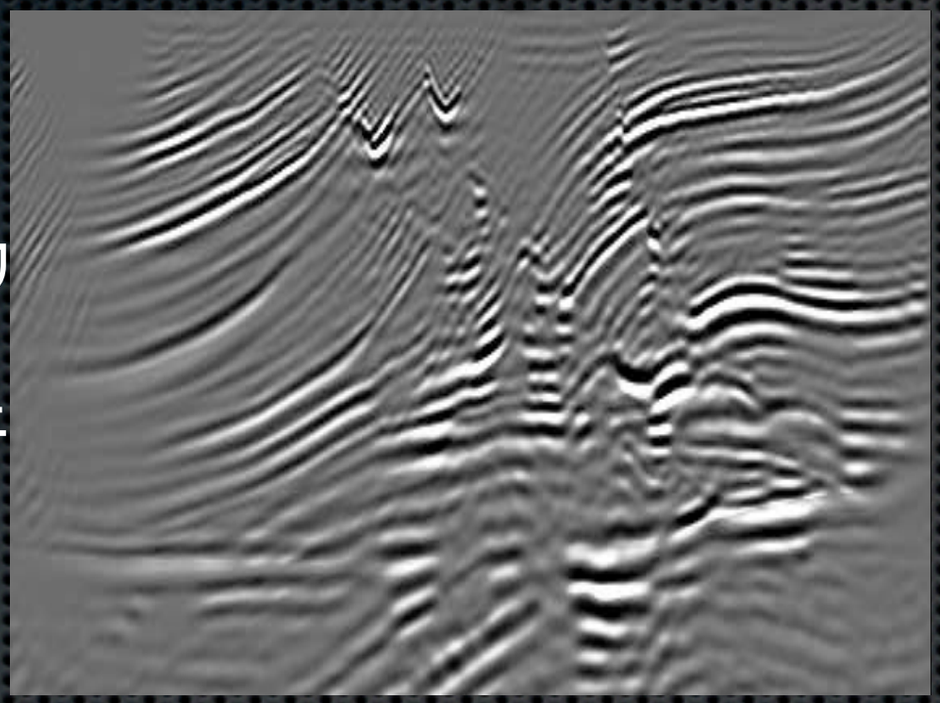
Applications

Scalar

Vector

Depth

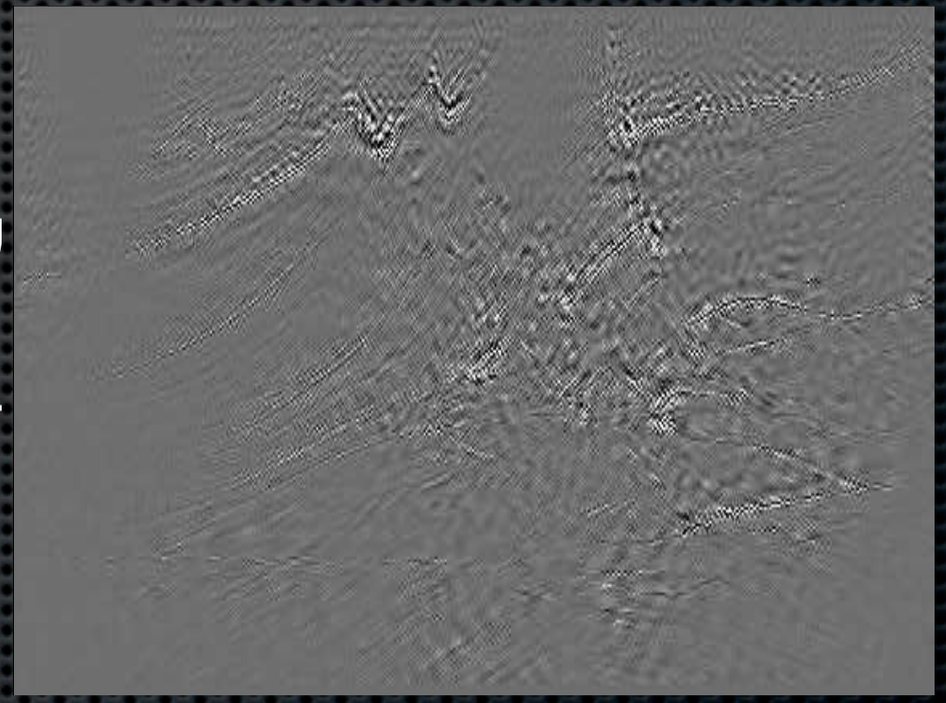
Image



X Position

Depth

Estimation residual



X Position

Estimation residual

FPGA

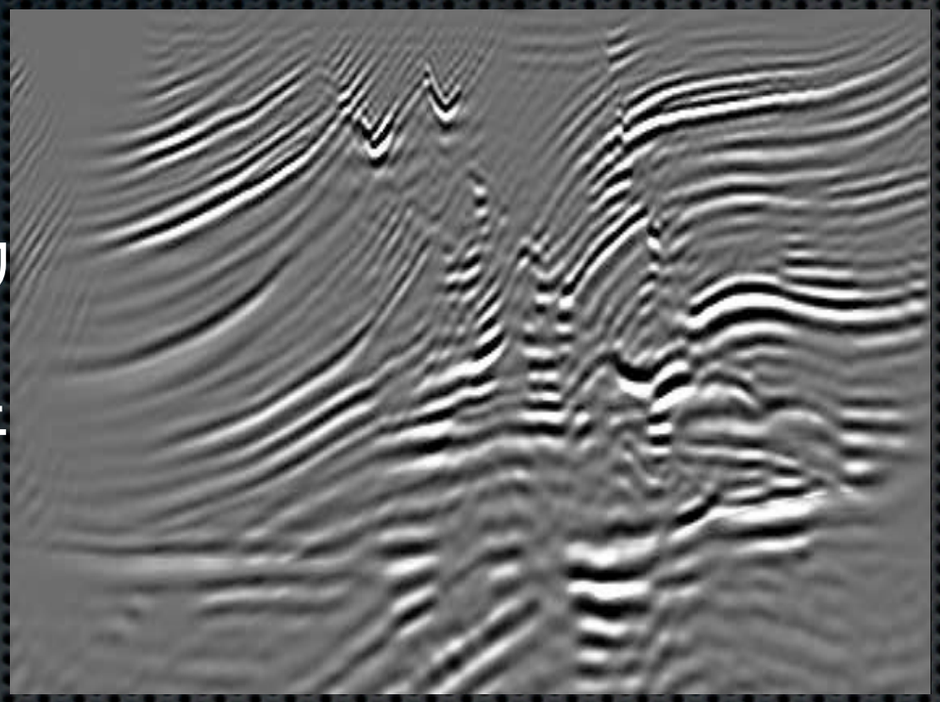
PEFs

Applications

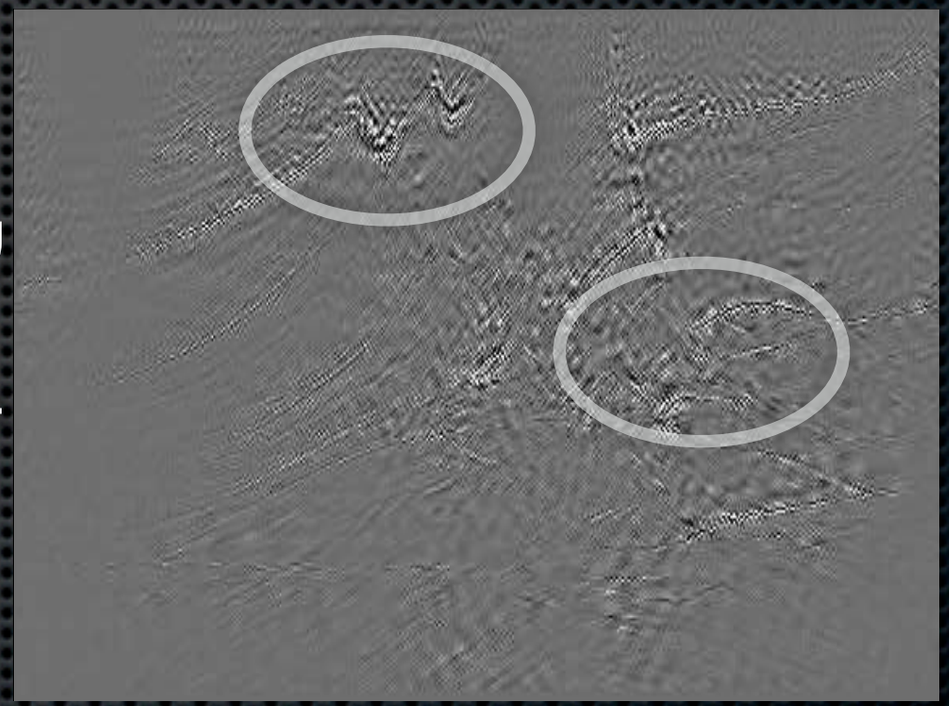
Scalar

Vector

Image



Estimation residual



PEF: Second dataset

FPGA

PEFs

Applications

Scalar

Vector

$$\mathbf{D_1 a} = \mathbf{r_1} \approx \mathbf{0}$$

Estimate from first dataset

$$\mathbf{D_2 a} = \mathbf{r_2}$$

$\mathbf{D_1}$ -Convolution with data 1
$\mathbf{D_2}$ -Convolution with data 2
$\mathbf{a}$ -Compact filter
$\mathbf{r_1}$ -Unpredictable portion
$\mathbf{r_2}$ -Prediction error on dataset 2

PEF: Second dataset

FPGA

PEFs

Applications

Scalar

Vector

$$\mathbf{D_1 a} = \mathbf{r_1} \approx \mathbf{0}$$

$$\mathbf{D_2 a} = \mathbf{r_2}$$

Estimate from first dataset

Apply filter to dataset 2

$\mathbf{D_1}$ -Convolution with data 1

$\mathbf{D_2}$ -Convolution with data 2

$\mathbf{a}$ -Compact filter

$\mathbf{r_1}$ -Unpredictable portion

$\mathbf{r_2}$ -Prediction error on dataset 2

Using a different covariance model

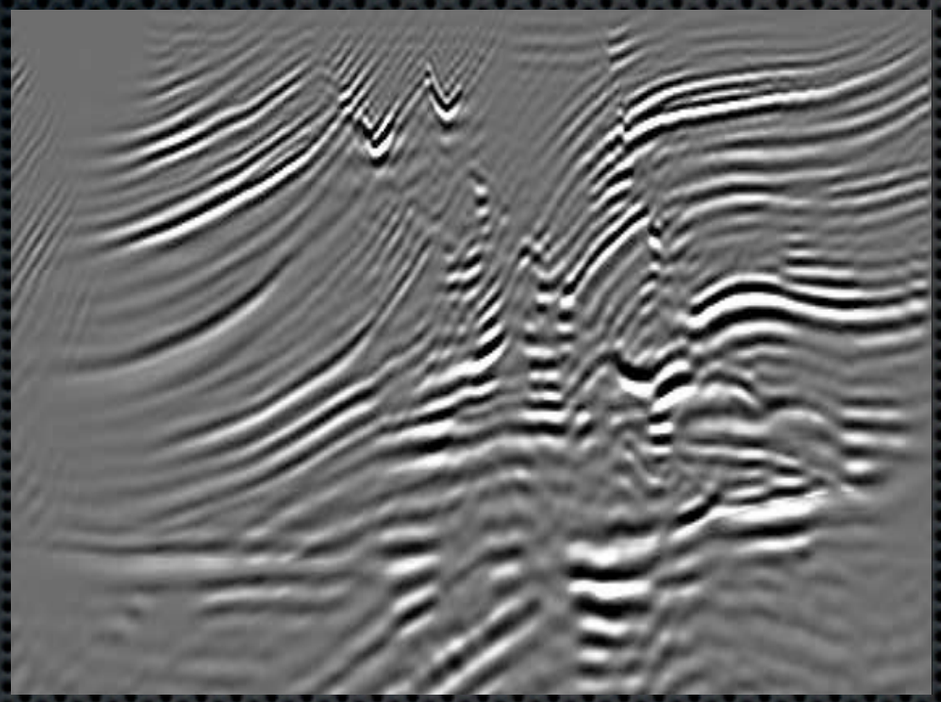
FPGA

PEFs

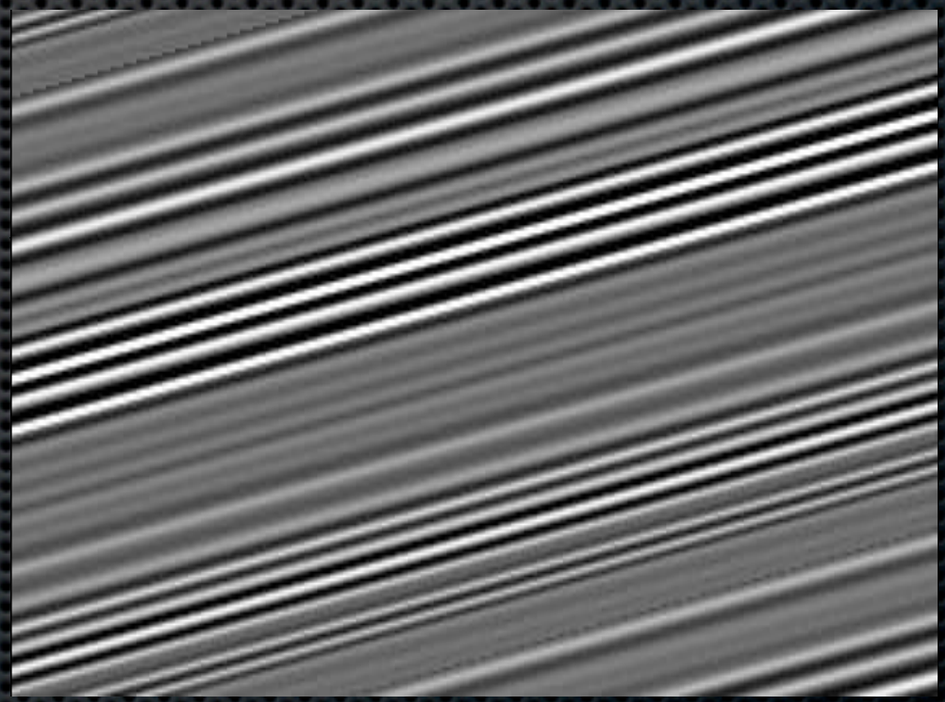
Applications

Scalar

Vector



Estimate PEF on



Apply PEF on

Different covariances

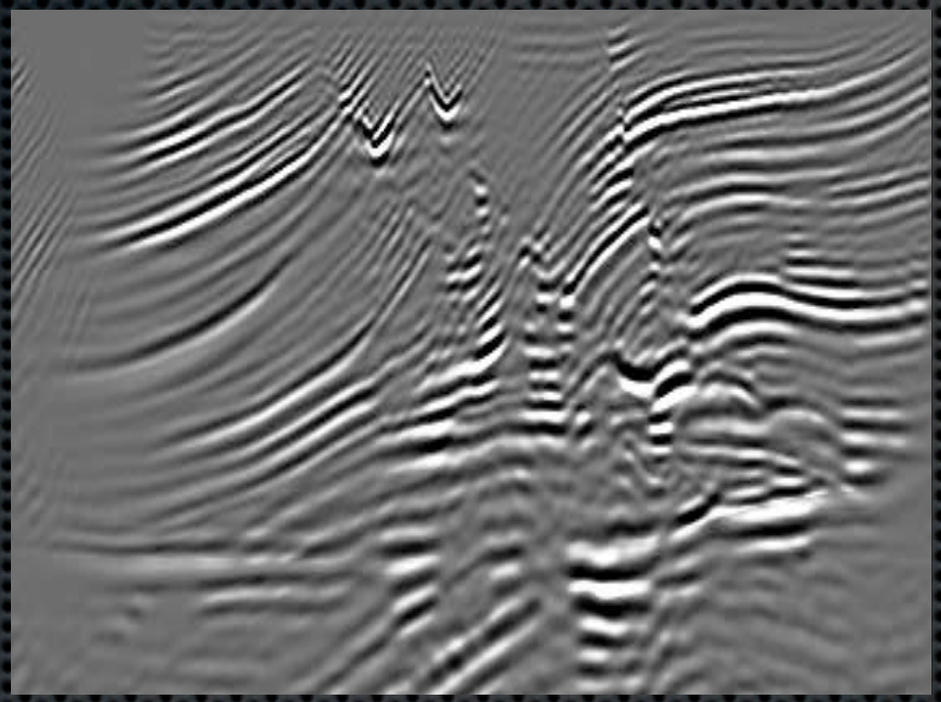
FPGA

PEFs

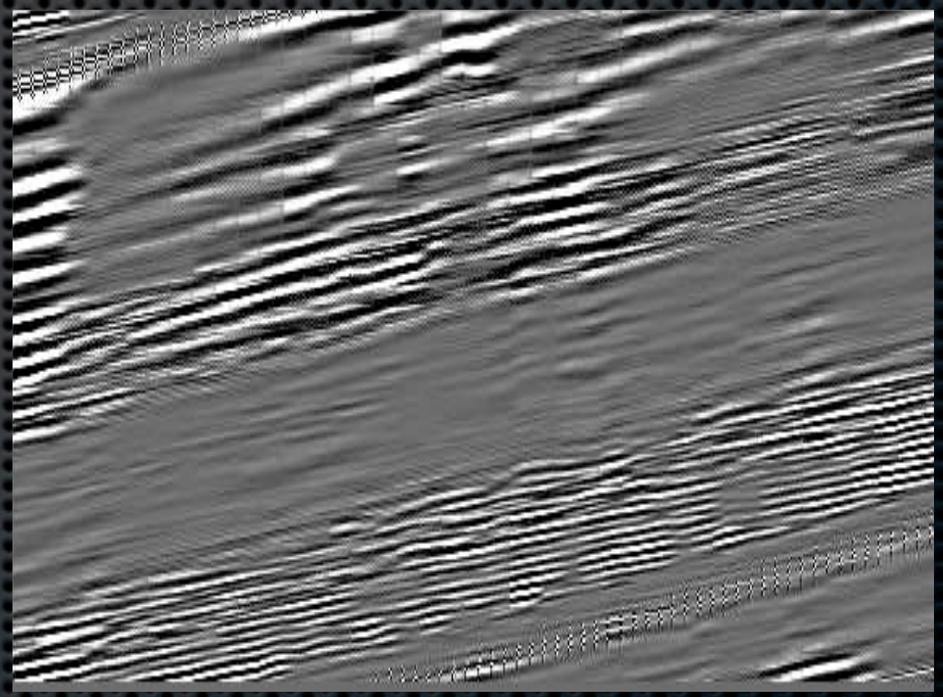
Applications

Scalar

Vector



Estimate PEF on



Residual

Error estimate

FPGA

PEFs

Applications

Scalar

Vector

$$e = \frac{\mathbf{r_2}}{\mathbf{r_1}} - 1$$

r_2 -Error applying filter to dataset 2

r_1 -Error applying filter to dataset 1

e -Error estimate

Error estimate

FPGA

PEFs

Applications

Scalar

Vector

$$e = \frac{\mathrm{abs}(\mathbf{r_2})}{\mathrm{abs}(\mathbf{r_1})} - 1$$

$\mathbf{r_2}$ -Error applying filter to dataset 2

$\mathbf{r_1}$ -Error applying filter to dataset 1

e -Error estimate

abs()-Take absolute value

Error estimate

FPGA

PEFs

Applications

Scalar

Vector

$$e = \sum \frac{\mathbf{S} * \mathrm{abs}(\mathbf{r_2})}{\mathbf{S} * \mathrm{abs}(\mathbf{r_1})} - 1$$

$\mathbf{r_2}$ -Error applying filter to dataset 2

$\mathbf{r_1}$ -Error applying filter to dataset 1

e -Error estimate

abs()-Take absolute value

S - Smooth

PEF: Second dataset

FPGA

PEFs

Applications

Scalar

Vector

$$\mathbf{D_1 a} = \mathbf{r_1} \approx \mathbf{0}$$

$$\mathbf{D_2 a} = \mathbf{r_2}$$

$\mathbf{D_1}$ -Convolution with 8 reference velocities
$\mathbf{D_2}$ -Convolution with 1 reference velocity
$\mathbf{a}$ -Compact filter
$\mathbf{r_1}$ -Unpredictable portion
$\mathbf{r_2}$ -Prediction error on dataset 2

Different number of reference velocities

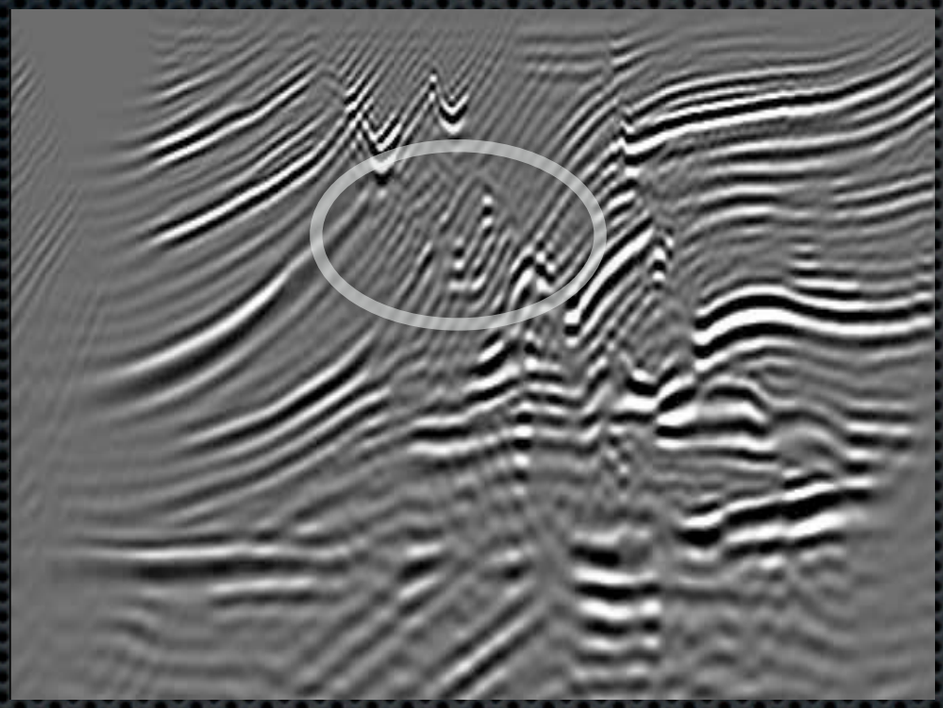
FPGA

PEFs

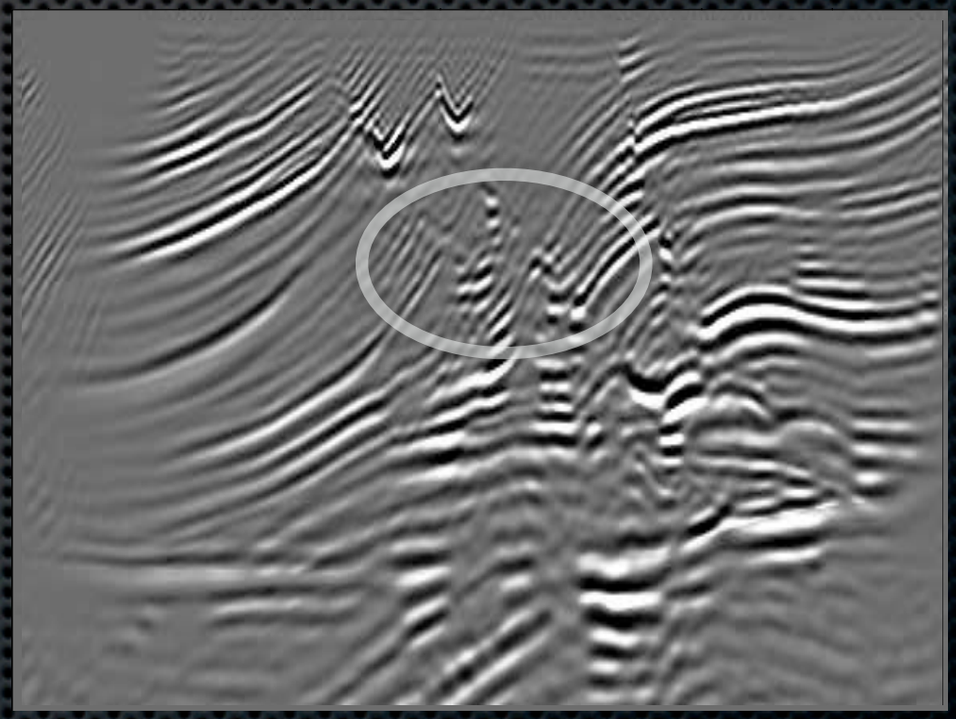
Applications

Scalar

Vector



Eight reference velocity image



One reference velocity image

Different number of reference velocities

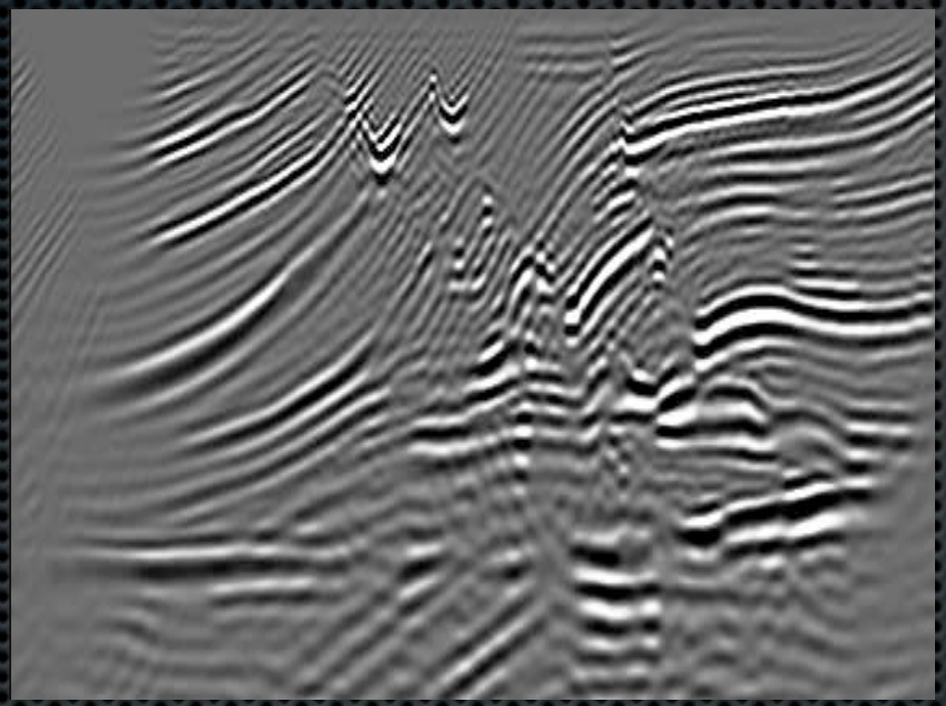
FPGA

PEFs

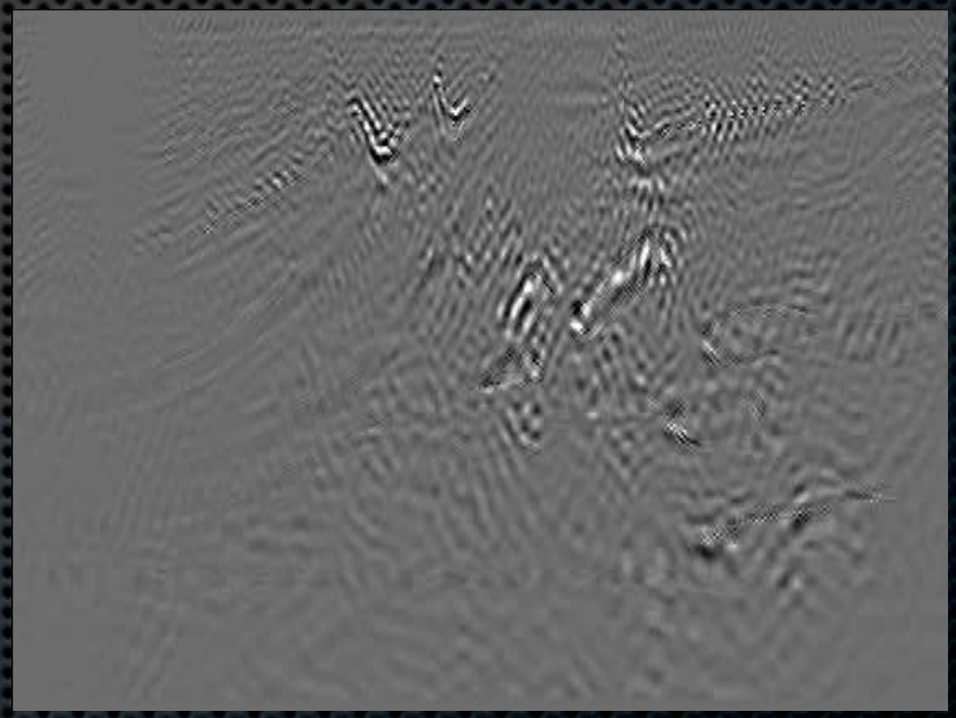
Applications

Scalar

Vector



Eight reference velocity image



Fitting residual

Different number of reference velocities

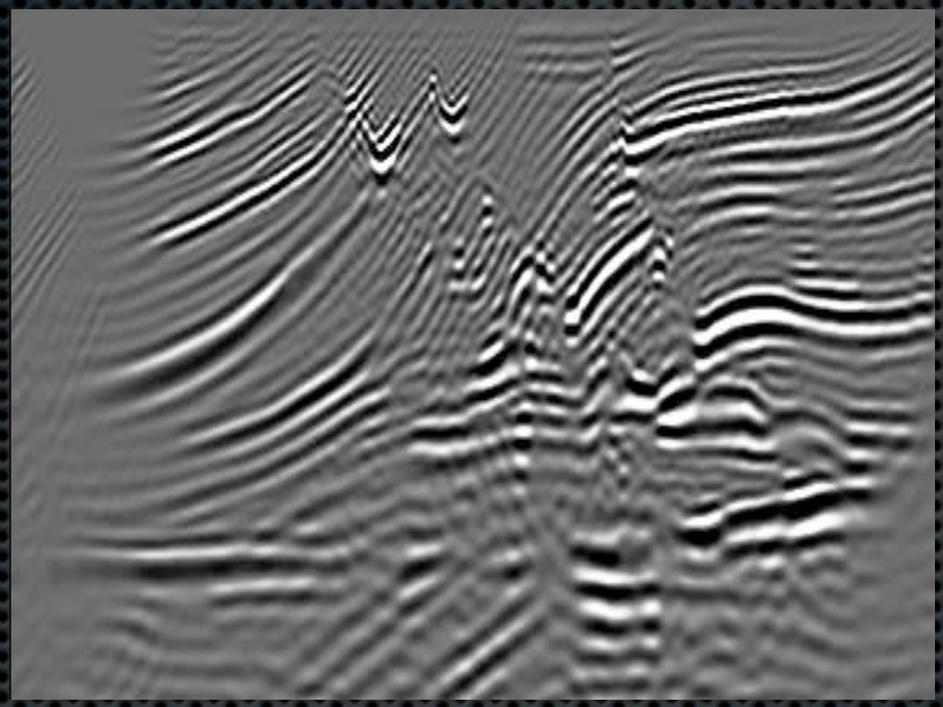
FPGA

PEFs

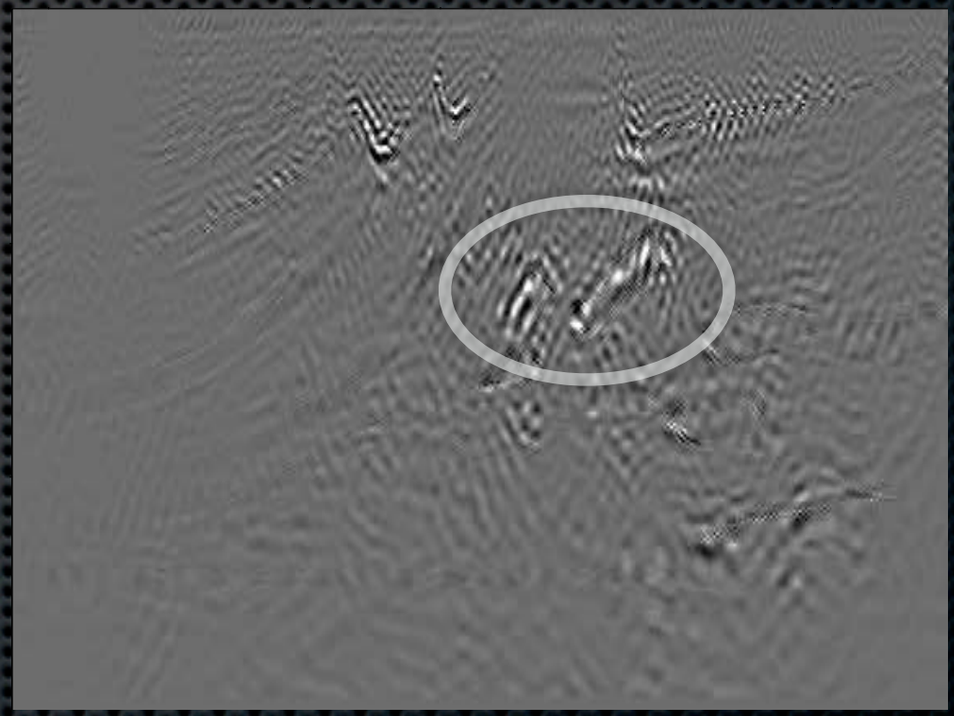
Applications

Scalar

Vector



Eight reference velocity image



Fitting residual

Reference velocity errors

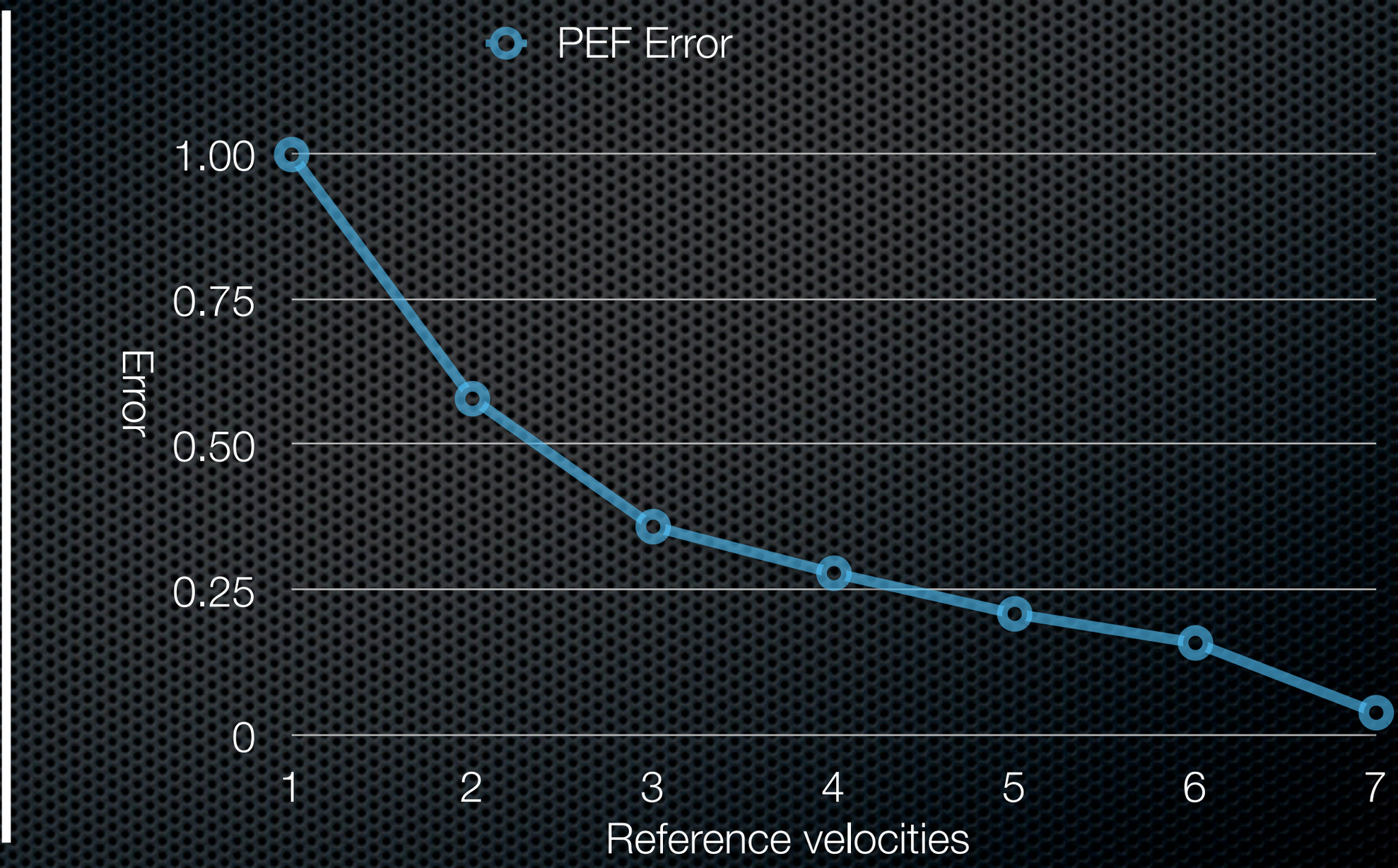
FPGA

PEFs

Applications

Scalar

Vector



Histogram matching

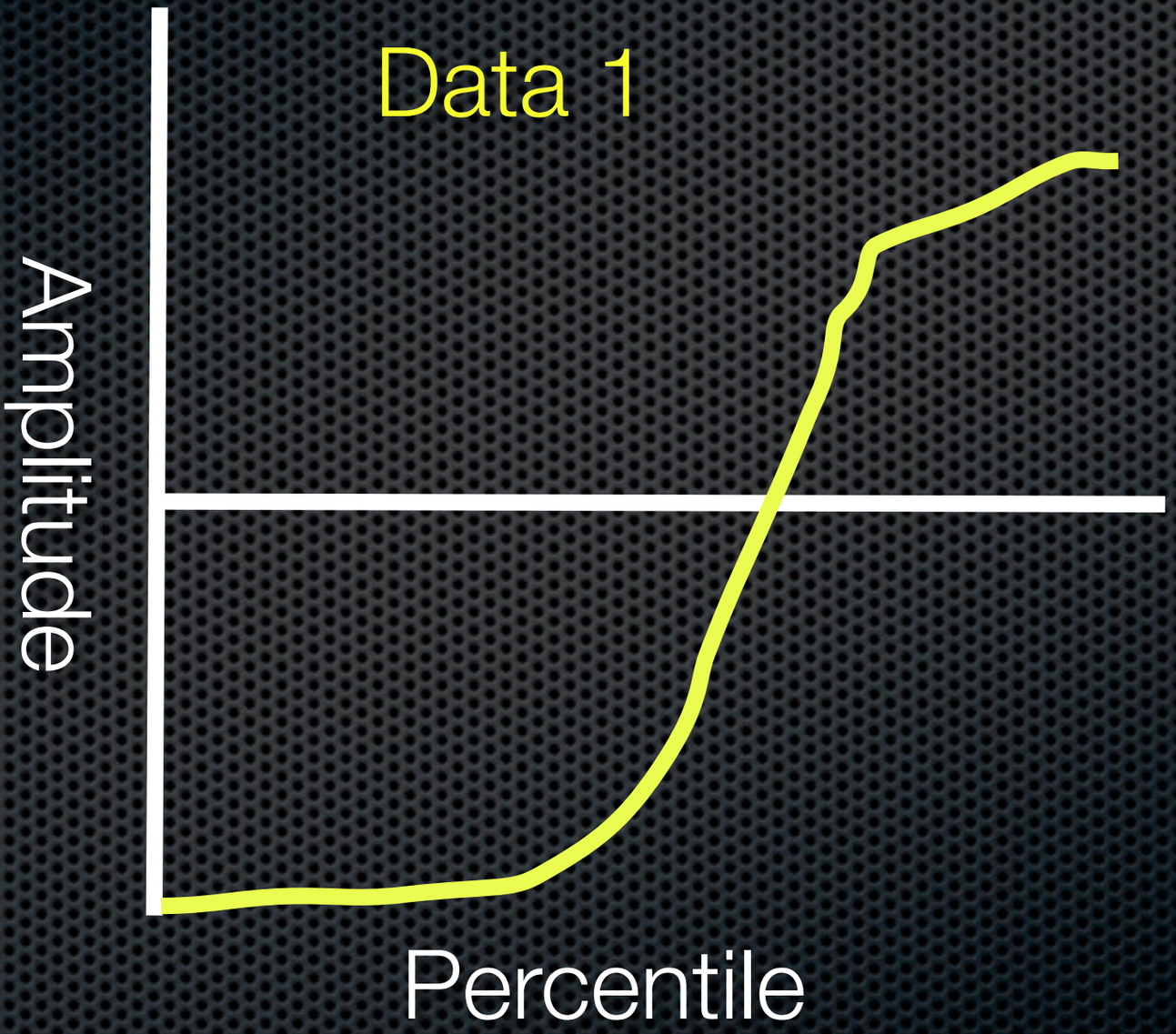
FPGA

PEFs

Applications

Scalar

Vector



Histogram matching

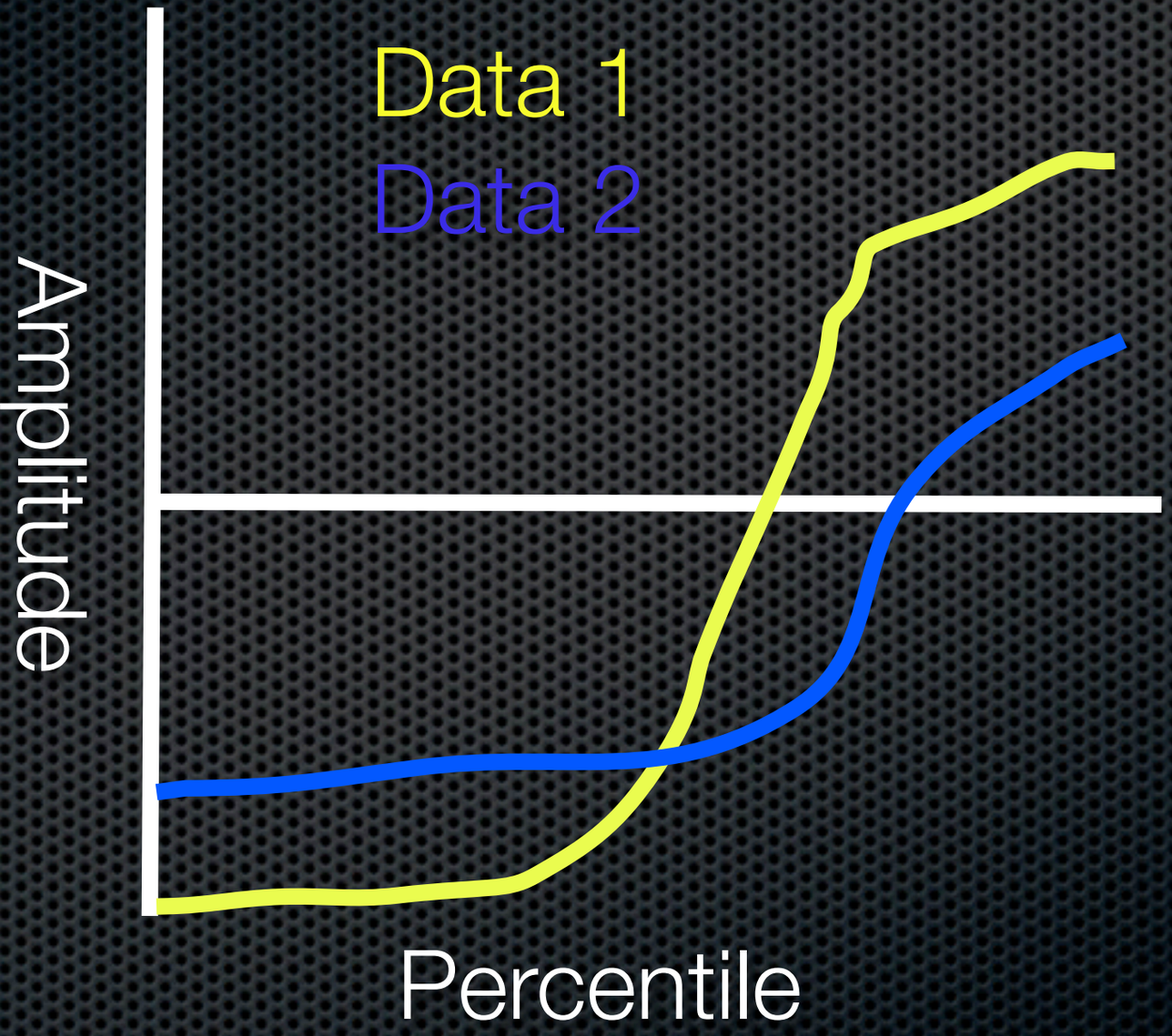
FPGA

PEFs

Applications

Scalar

Vector



Histogram matching

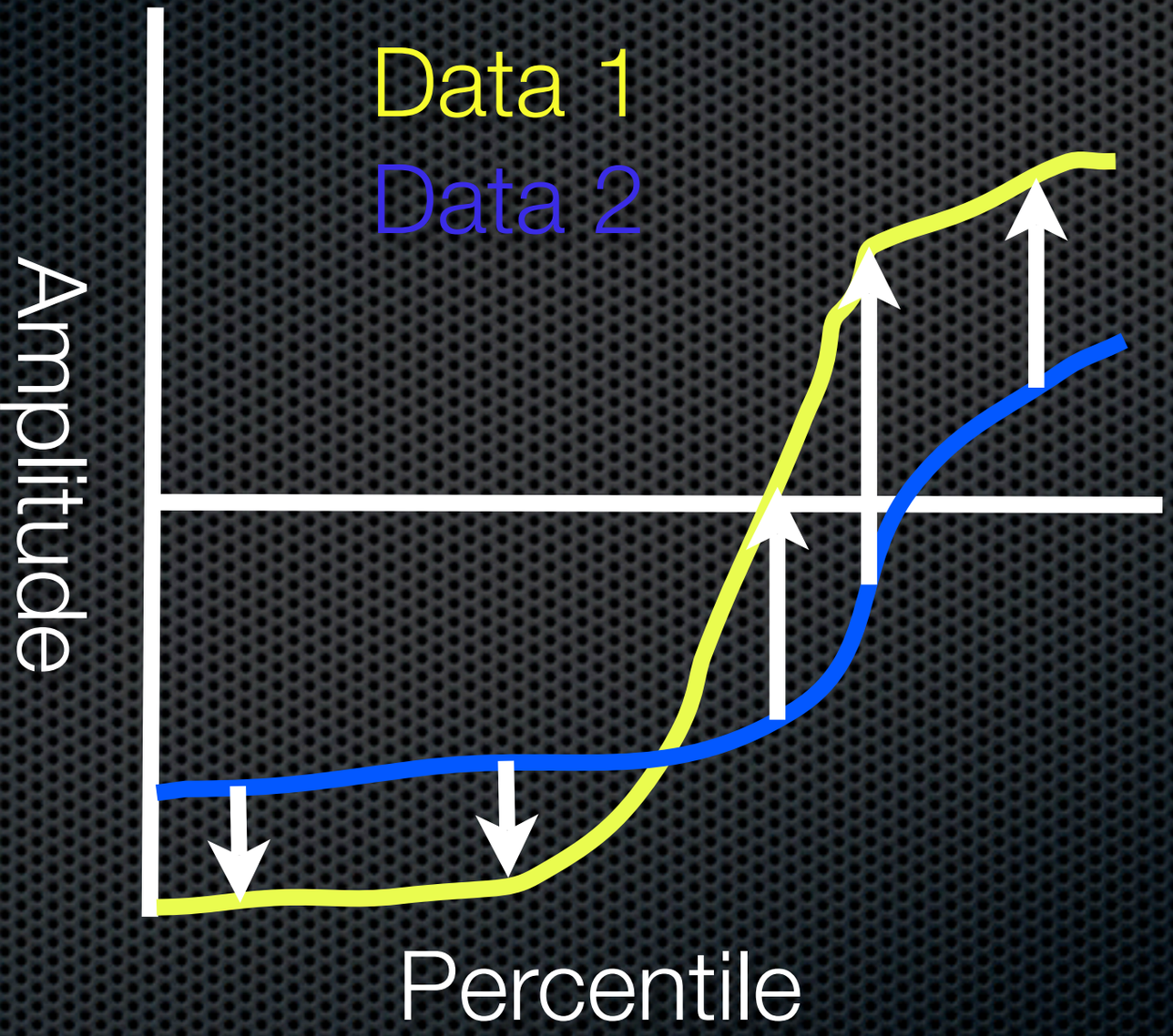
FPGA

PEFs

Applications

Scalar

Vector



Reference velocity errors

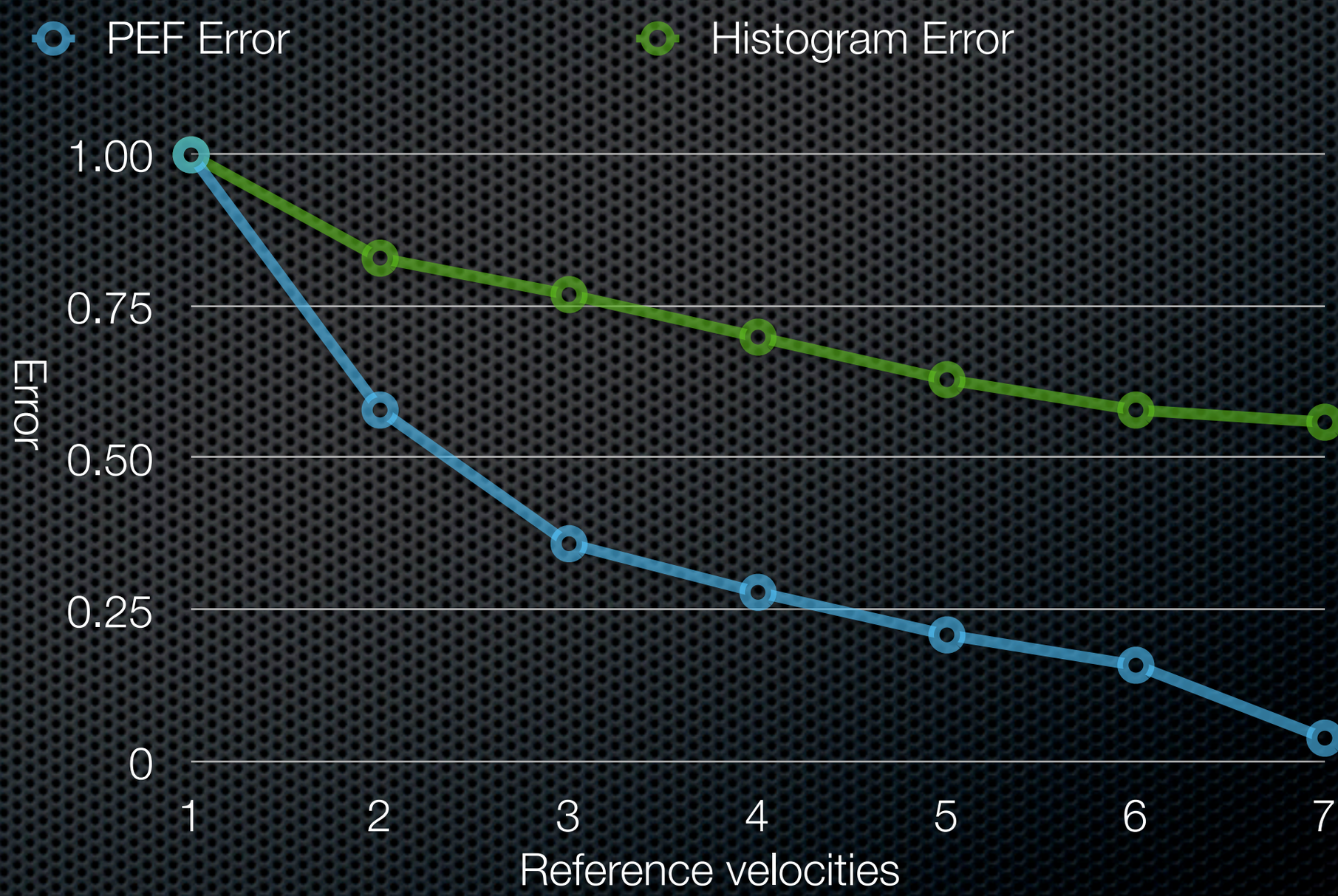
FPGA

PEFs

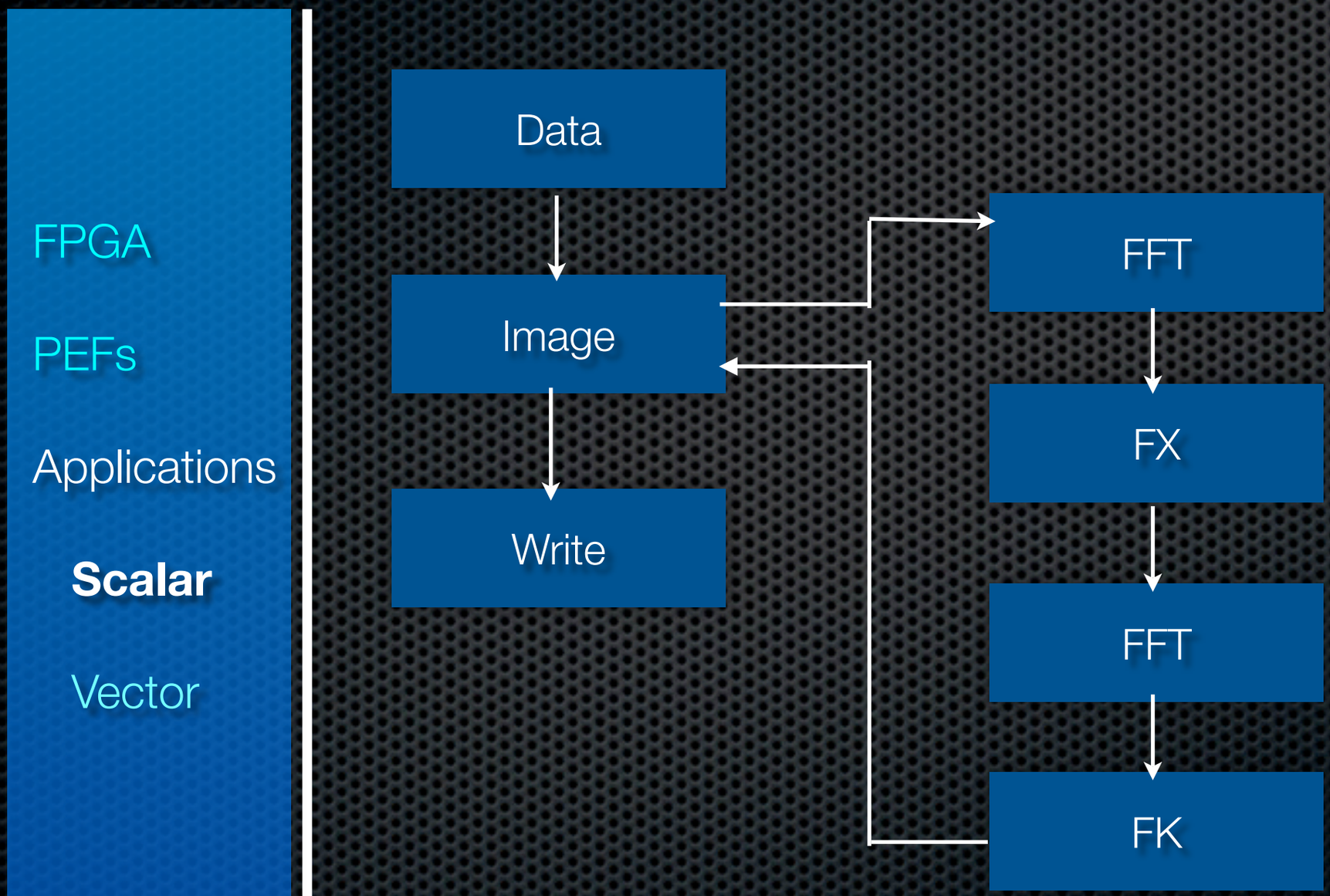
Applications

Scalar

Vector



Testing methodology: PSPI



Testing methodology: PSPI

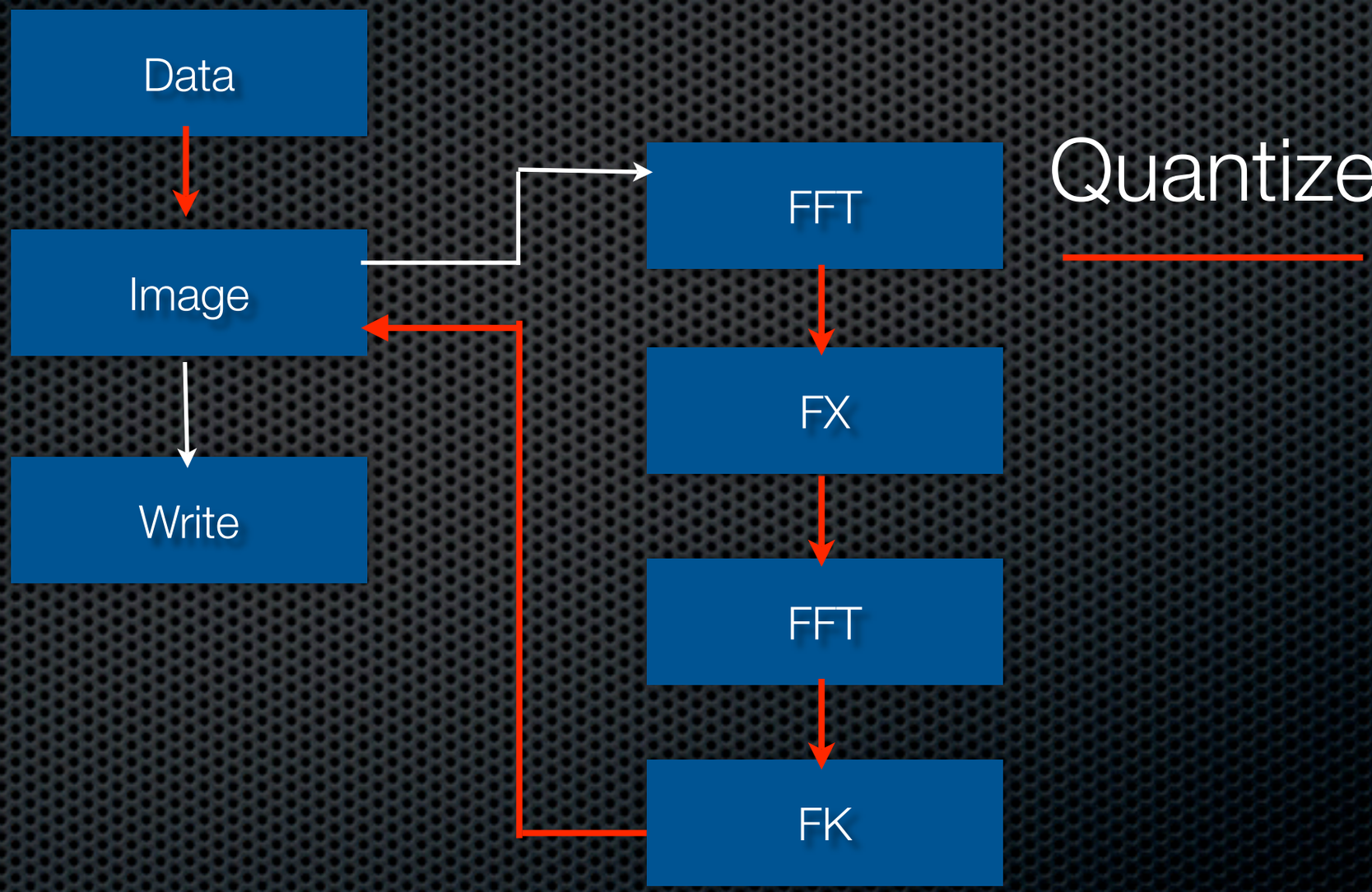
FPGA

PEFs

Applications

Scalar

Vector



Precision Error

FPGA

PEFs

Applications

Scalar

Vector

Bits in complex exponential

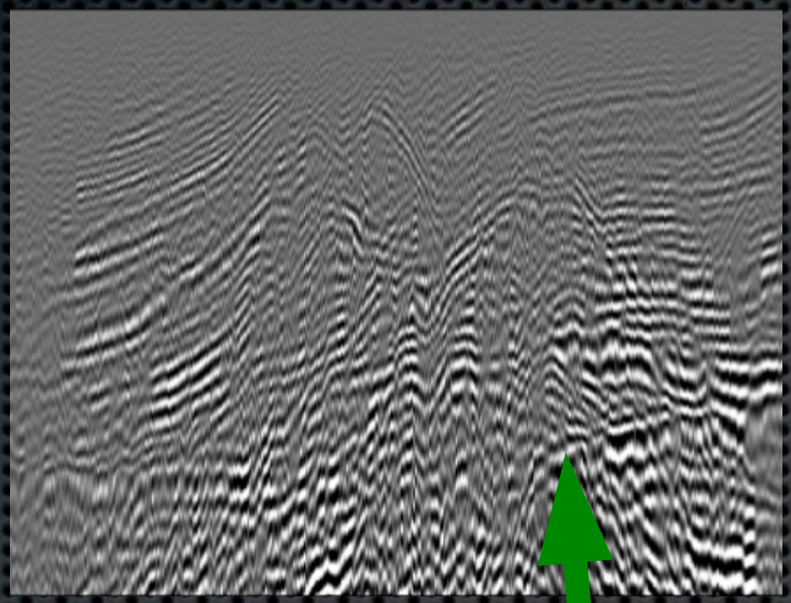
FPGA

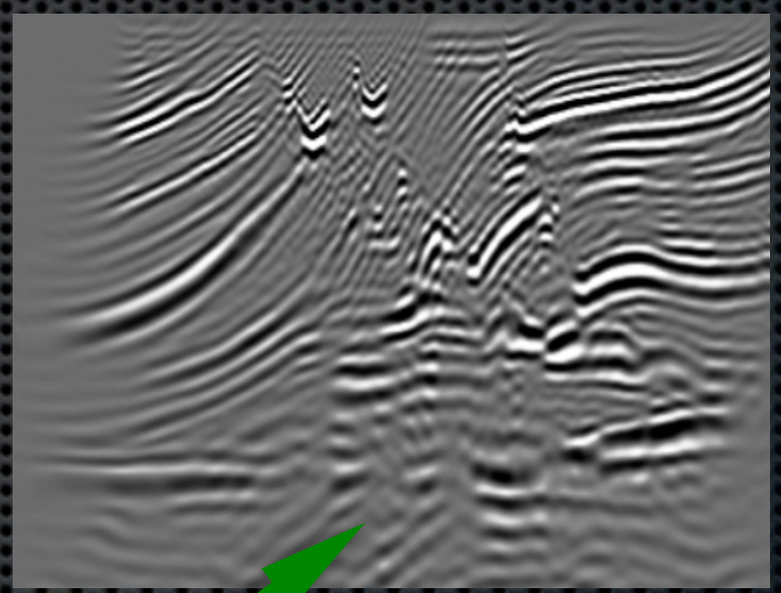
PEFs

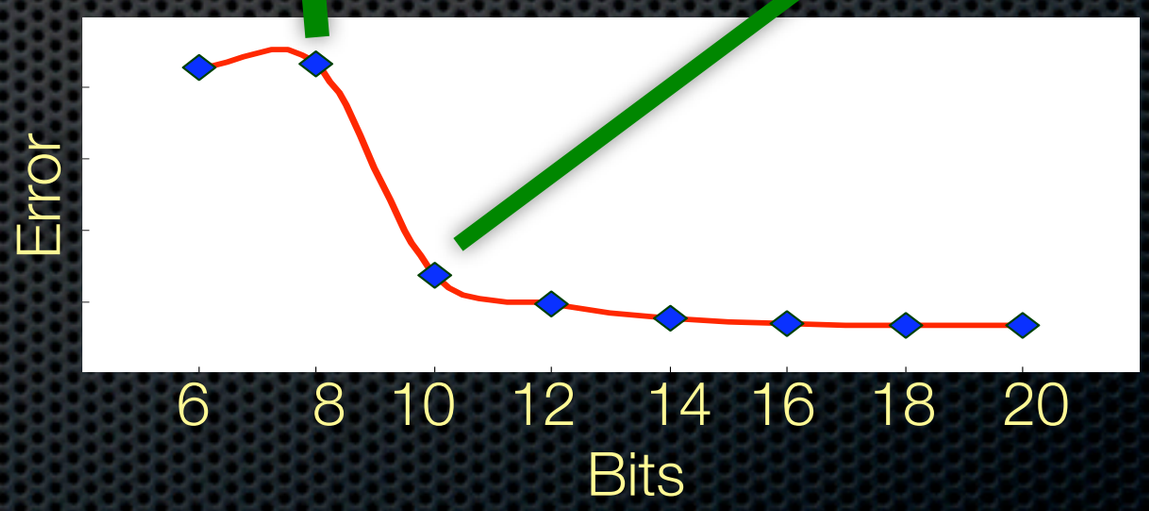
Applications

Scalar

Vector







Error estimate

FPGA

PEFs

Applications

Scalar

Vector

$$e = \sum \frac{\mathbf{S} * \mathrm{abs}(\mathbf{r_2})}{\mathbf{S} * \mathrm{abs}(\mathbf{r_1})} - 1$$

$\mathbf{r_2}$ -Error applying filter dataset 2

$\mathbf{r_1}$ -Error applying filter dataset 2

e -Error estimate

abs()-Take absolute value

S - Smooth

Vector error field

FPGA

PEFs

Applications

Scalar

Vector

$$\mathbf{e} = \frac{\mathbf{S} * \mathrm{abs}(\mathbf{r_2})}{\mathbf{S} * \mathrm{abs}(\mathbf{r_1})} - \mathbf{1}$$

$\mathbf{r_2}$ -Error applying filter dataset 2

$\mathbf{r_1}$ -Error applying filter dataset 2

e -Error estimate

abs()-Take absolute value

S - Smooth

Estimation residual

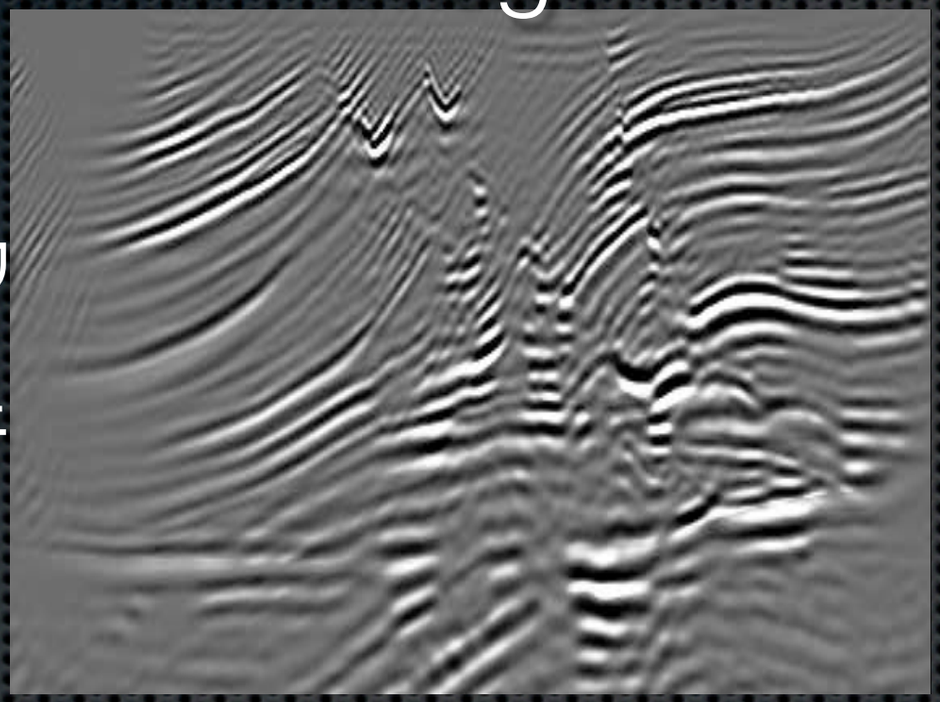
FPGA

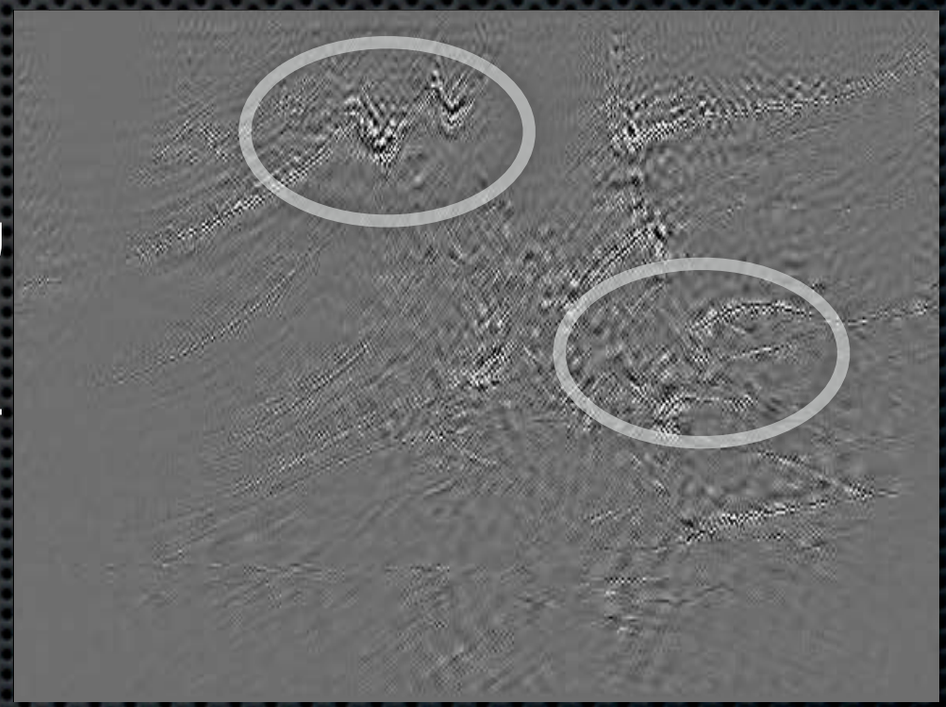
PEFs

Applications

Scalar

Vector





Estimation residual

FPGA

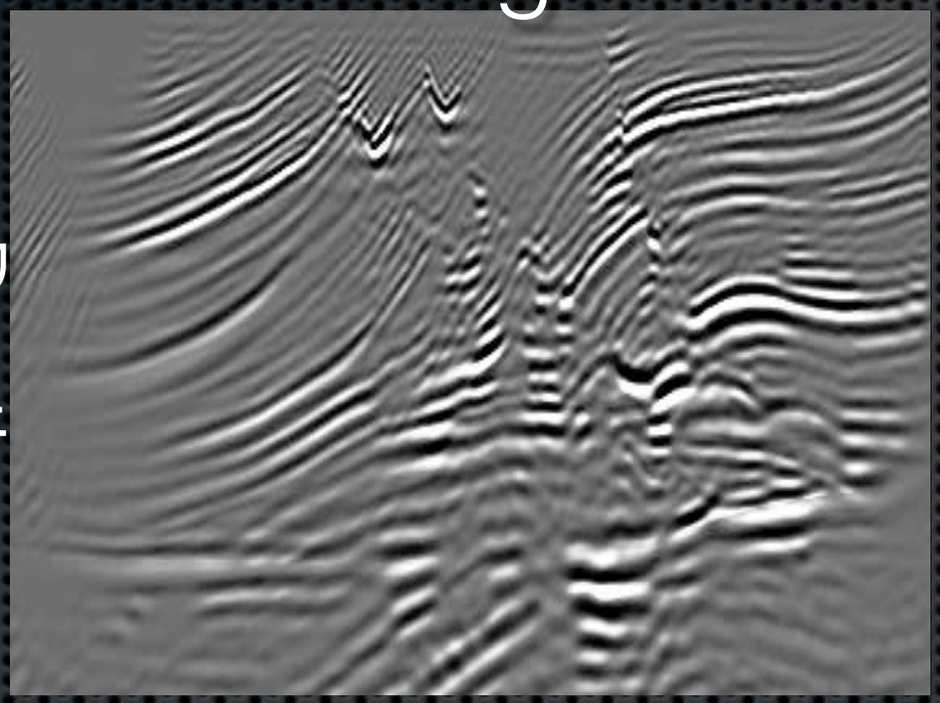
PEFs

Applications

Scalar

Vector

Image



Estimation residual

Tilted plane-wave migration

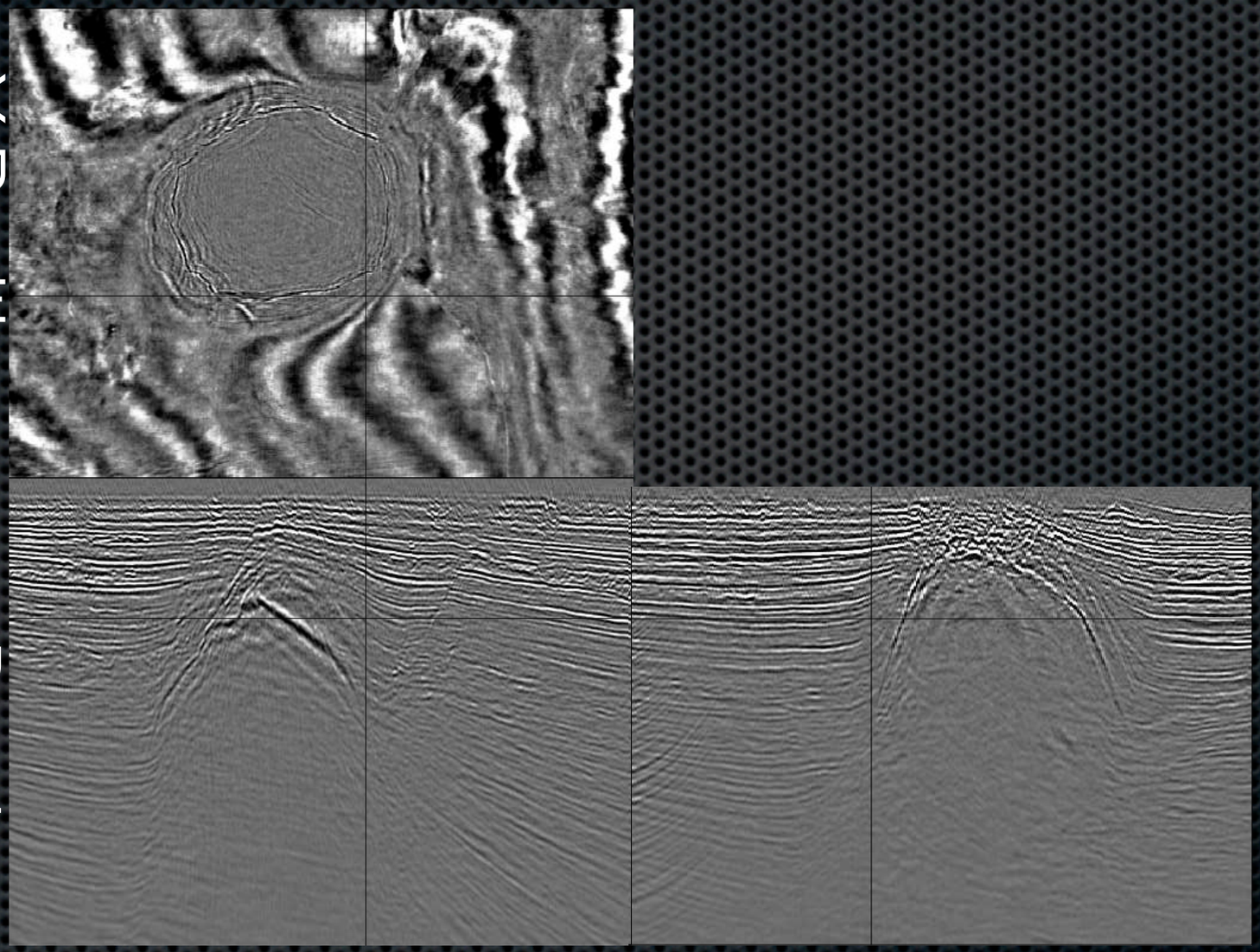
FPGA

PEFs

Applications

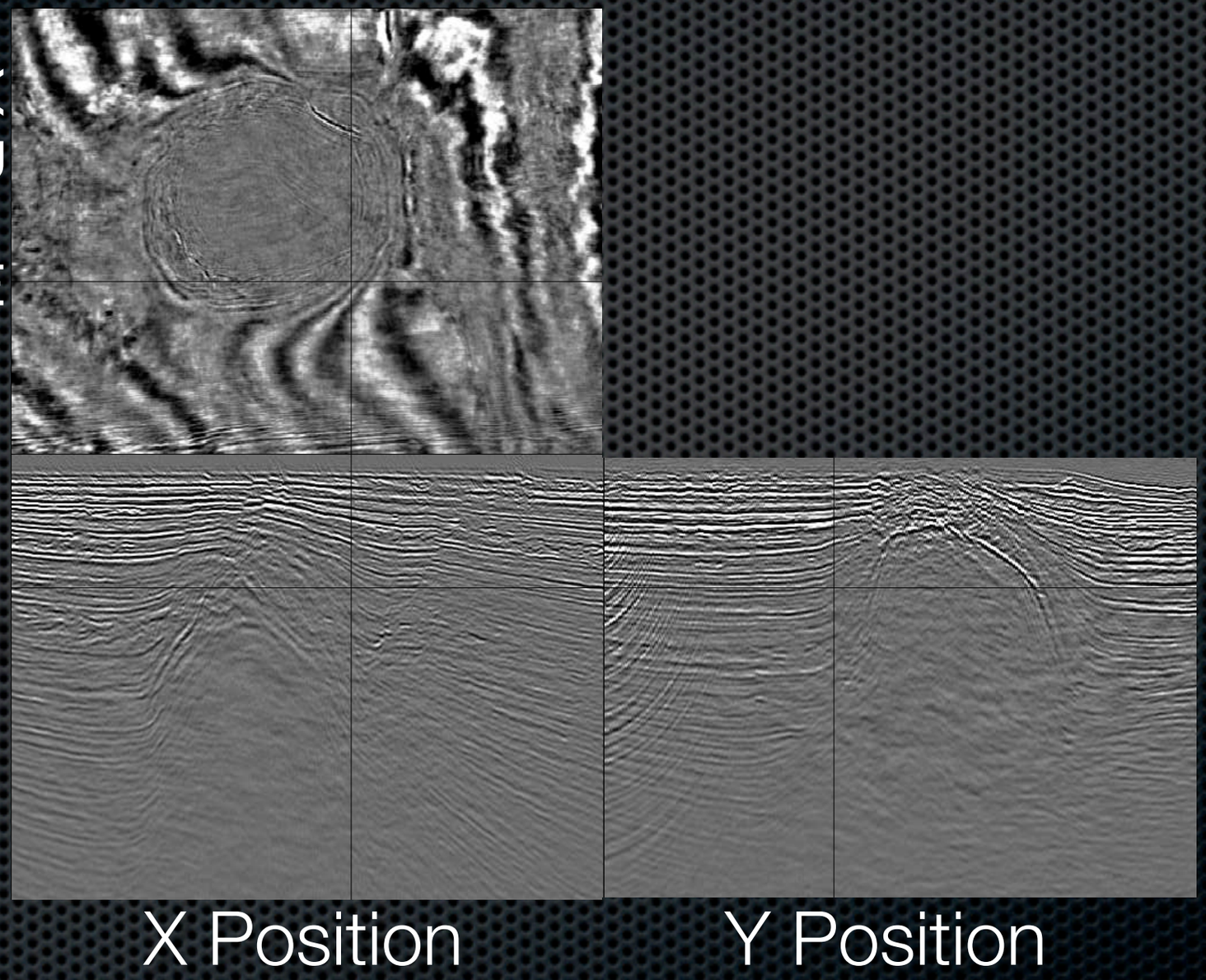
Scalar

Vector



Plane-wave migration

- FPGA
- PEFs
- Applications
- Scalar
- **Vector**



Error estimate

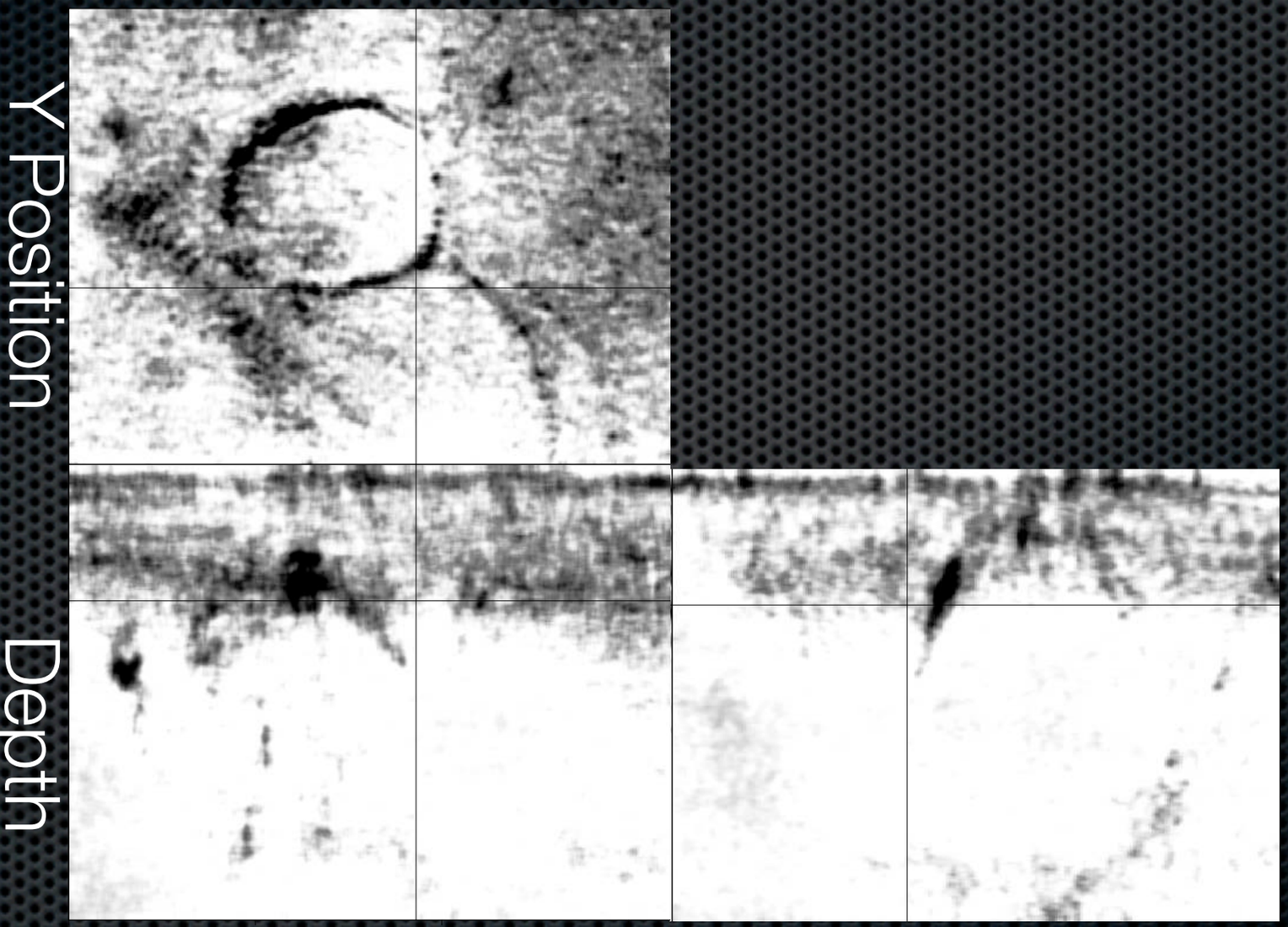
FPGA

PEFs

Applications

Scalar

Vector



Conclusions

FPGA

PEFs

Applications

Scalar

Vector

- PEFs can be used to measure the level of differences between two images
- PEFs can be used to highlight differences

Histogram matching

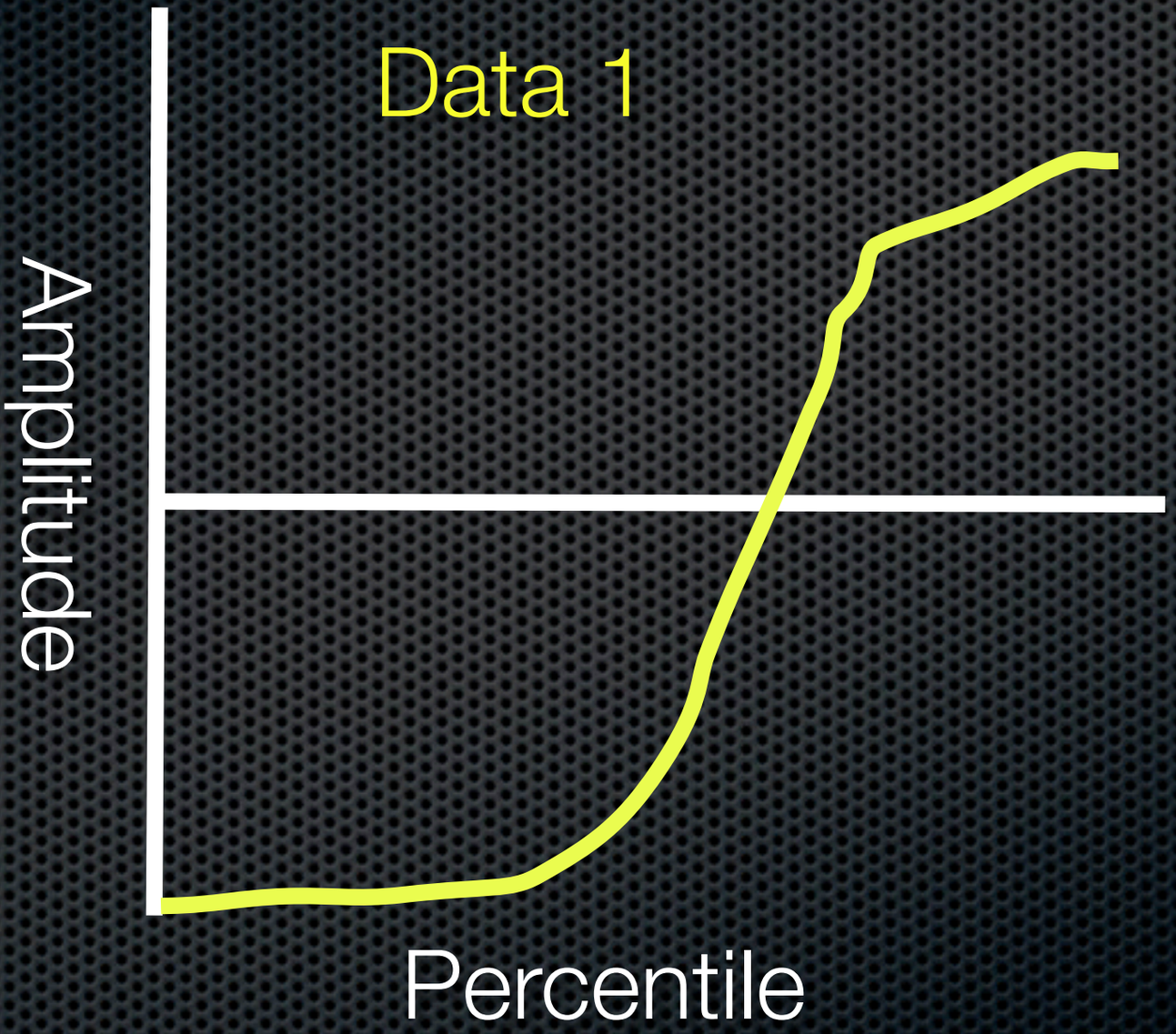
FPGA

PEFs

Applications

Scalar

Vector



Histogram matching

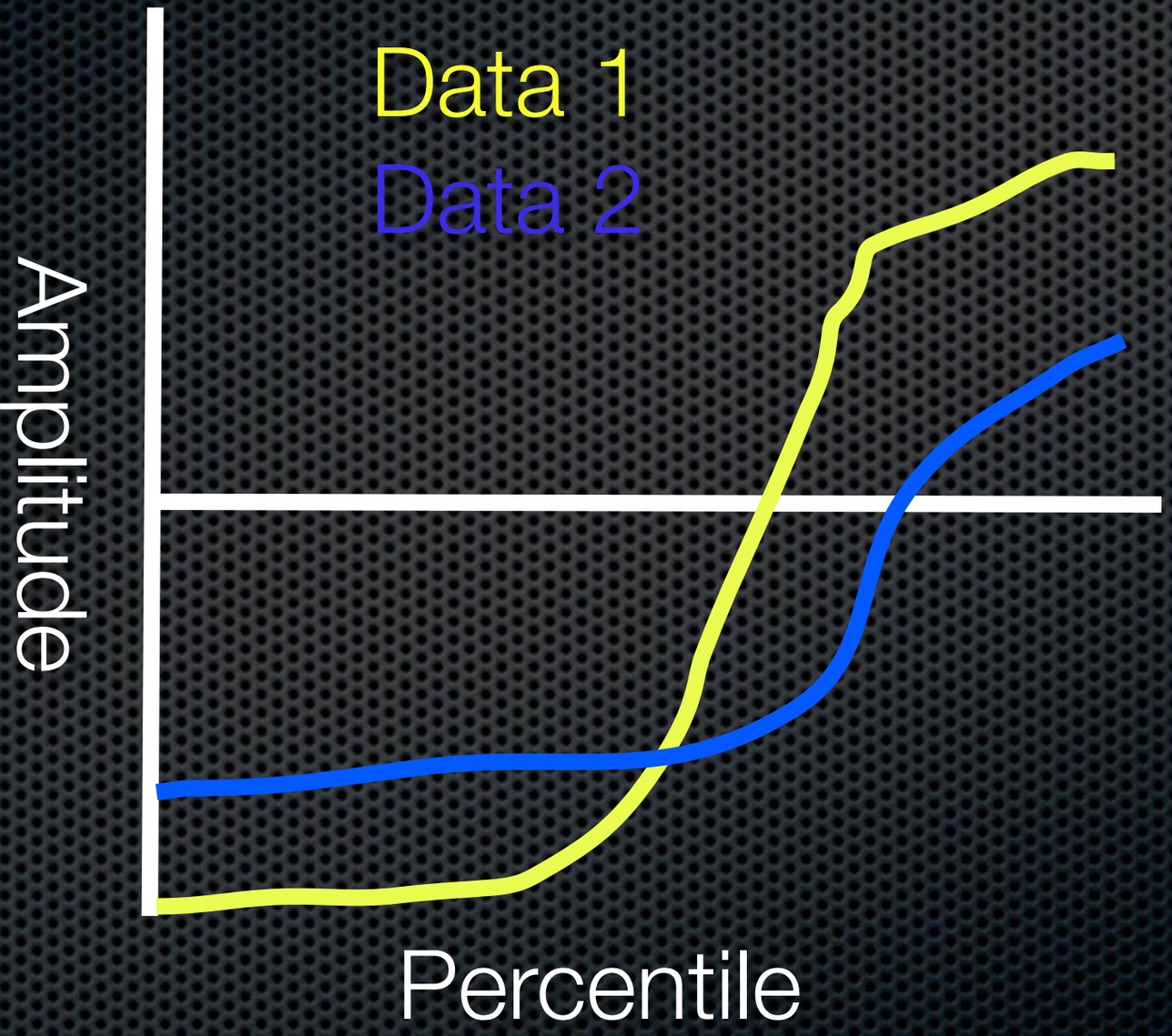
FPGA

PEFs

Applications

Scalar

Vector

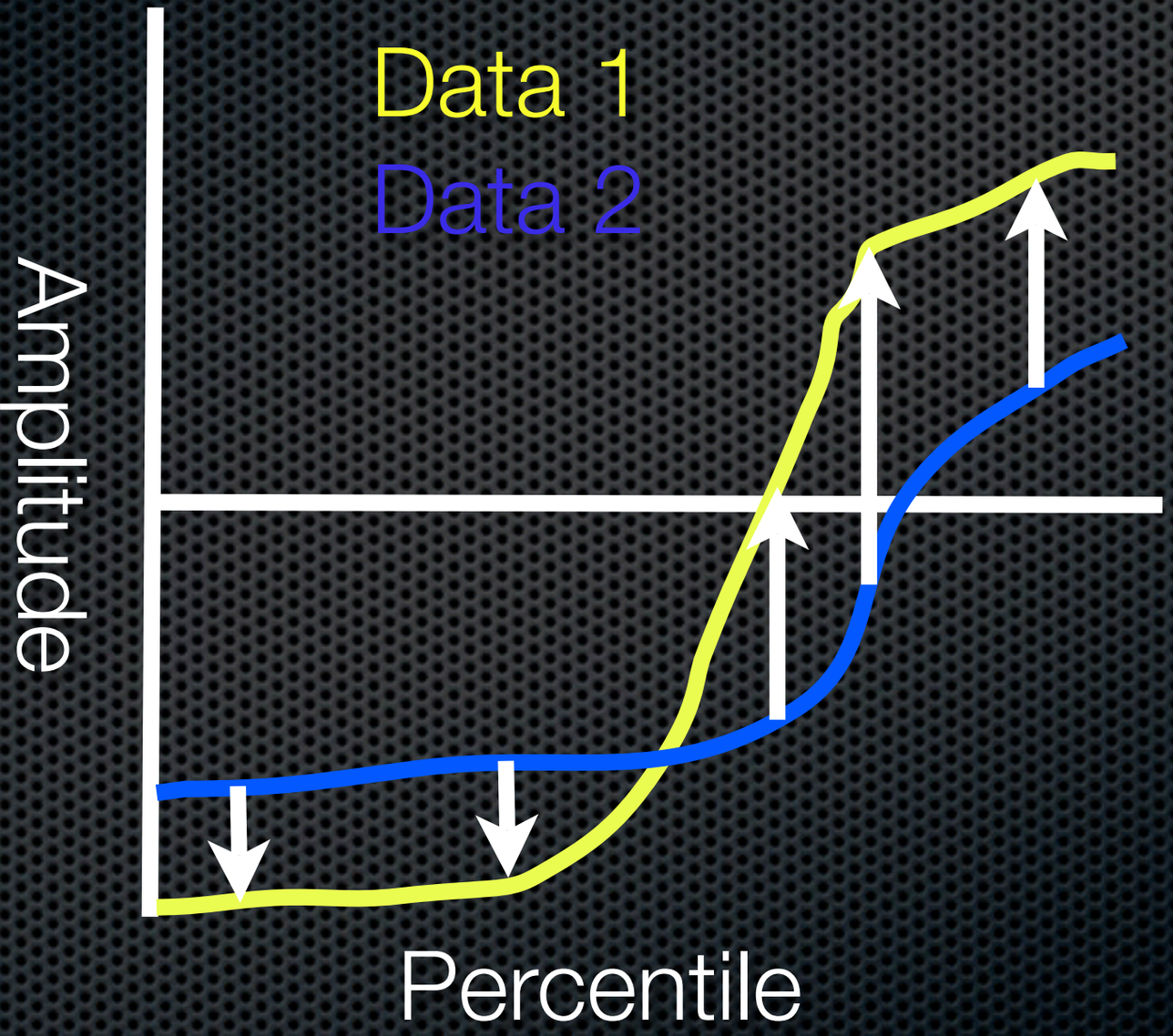


Histogram matching

FPGA

PEFs

Applications

Scalar

Vector