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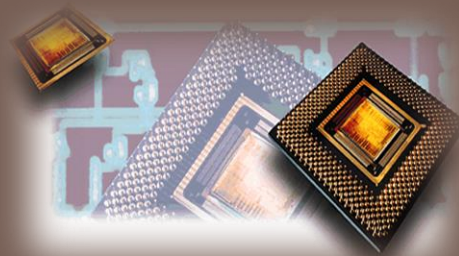


INSTITUTE OF
SPACE SCIENCE
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Efficient search algorithms implementation for SAR image analysis

Authors

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**Ro-LCG “Grid Cloud and Gigh Performance Computing in
Science”**

□ Content

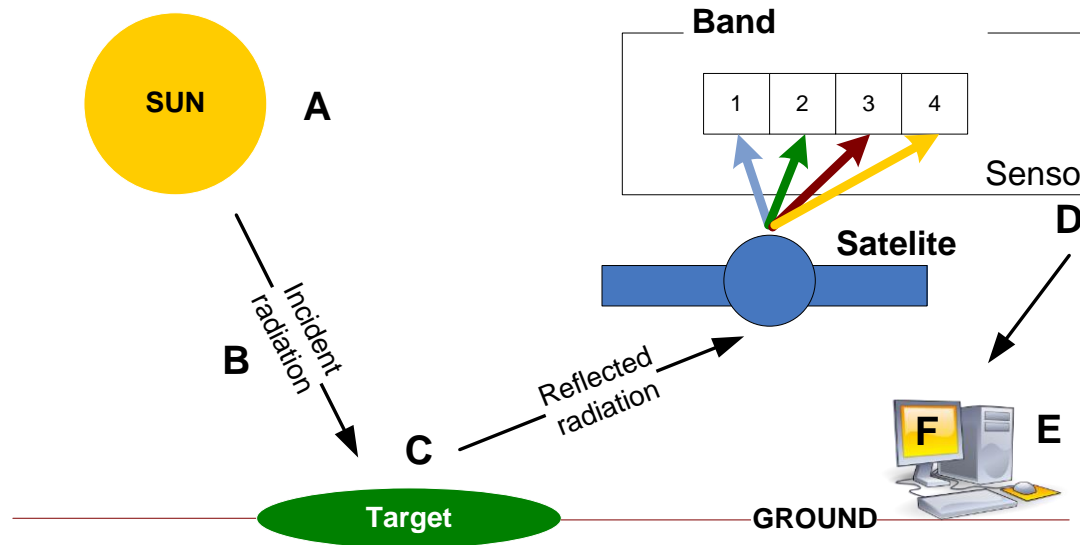
A Introduction to satellite imagery

B High Performance Computing for Satellite Imagery

C Application of FPGA technology in High Performance Computing for Satellite Imagery

- Search Algorithms Optimization
- Iterative algorithms Optimization

D Conclusions



- The radiation emitted by an energy source (A) covers a given distance and interacts with the atmosphere before reaching the target (C)
- (C) The energy interacts with the surface of the target, and depending on the surface characteristics and on the radiation properties, radiation is reflected or scattered to the sensor (D)
- which quantifies and registers the radiation energy; further on the information is transmitted to a receiving station (E), where it information is transformed into images.
- A visual interpretation of digital the image (F) is then required to extract the desired information related to the target in question.

Satellite image resolution

- *spatial resolution*, described by the pixel size of the image related to the physical area
- *spectral resolution* – satellite senses the electromagnetic energy at different wavelengths; spectral resolution is defined by the wavelength interval size within a segment of the electromagnetic spectrum and the number of intervals that the sensor is measuring

Examples: **visible images** – satellite measures sunlight reflected by the earth surface

infrared images – measures the temperature of earth surface with infrared sensor

water vapor images – infrared measurement of the temperature in a layer of the atmosphere about 6 – 10 km above the earth surface.

- *temporal resolution* - defined by the amount of time between two consequent image acquisitions for a given surface location
- *radiometric resolution* - defined as the ability of an imaging system to record many levels of brightness

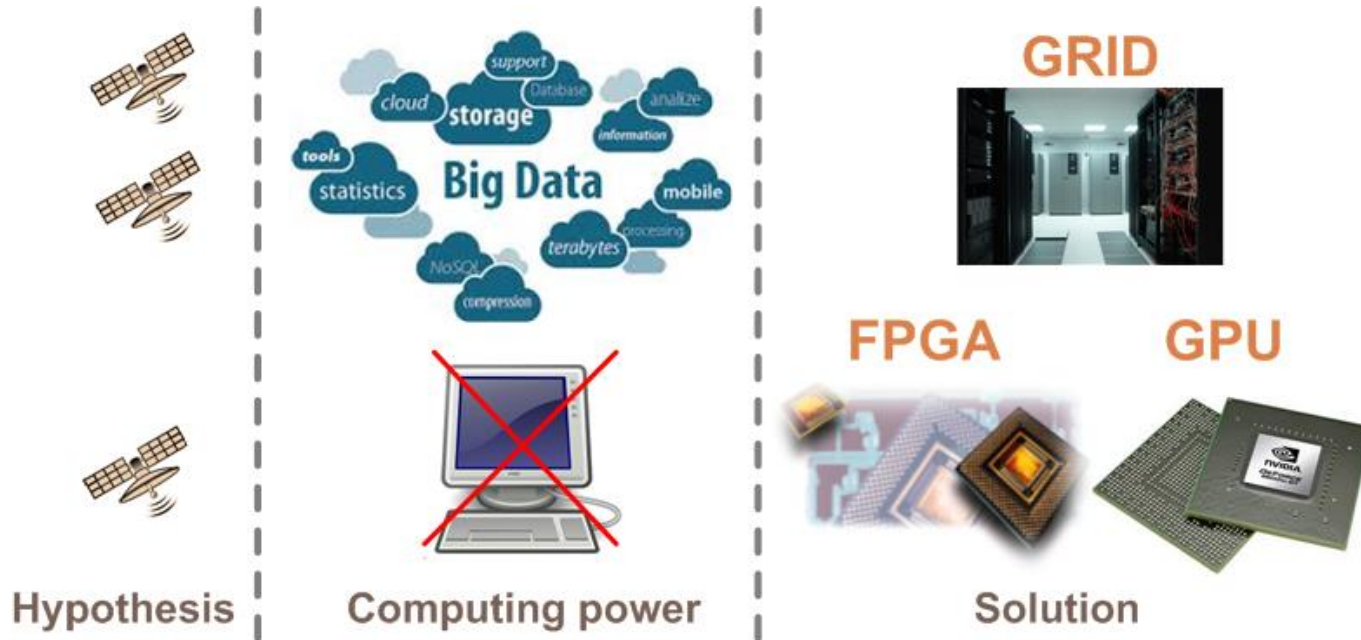
Applications of satellite imagery

There are many applications of satellite images in fields such as meteorology, agriculture, geology, forestry, landscape, biodiversity conservation, regional planning, education, intelligence and warfare.

Commercial applications of satellite imagery:

- Insurance companies – before and after images to estimate damages
- Mass Media - news reports to illustrates where important events occurred
- Software developers – incorporate images in flight simulators, games
- Combined with GPS for localization in geographic information systems

The most common example – Google Earth / Pro



- Hypothesis - increasing the number of high resolution satellites into orbit and the number of applications which use satellite images lead to “big data” to be processed
- Local computing infrastructure offer reduce computing power
- Solution
 - the use of GRID computing power - adopted by UNOSAT and CERN
 - use of application specific hardware architectures (FPGA and GPU)



- Since **2002** – collaboration CERN and UNOSAT

Satellite images are:

- Compressed,
- Stored and
- Processed.

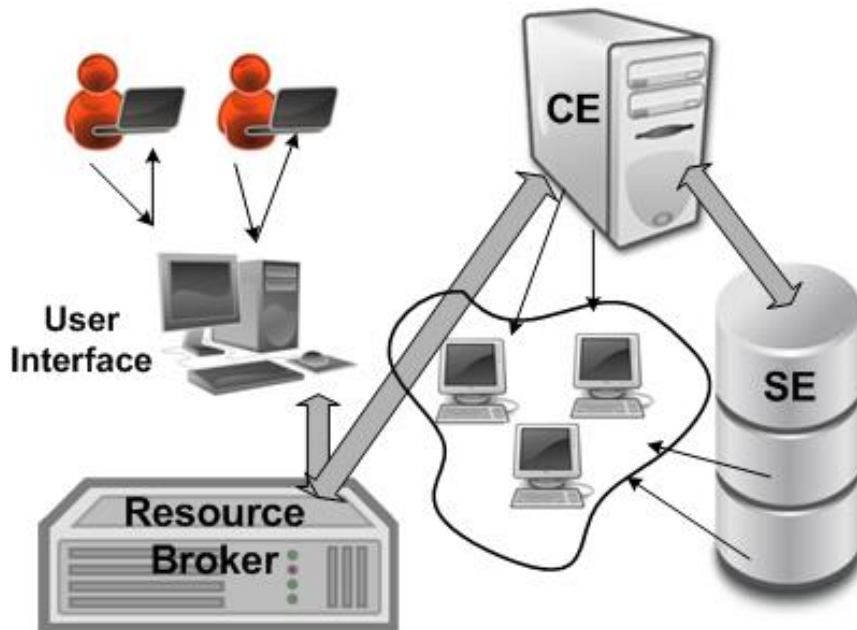
GRID - The Worldwide LHC Computing Grid (WLCG)

- launched in **2002**
- distributed computing infrastructure arranged **in tiers**
- provides a resource to **store, distribute and analyze** thousands of petabytes of data generated every year by the Large Hadron Collider (LHC).

UNOSAT

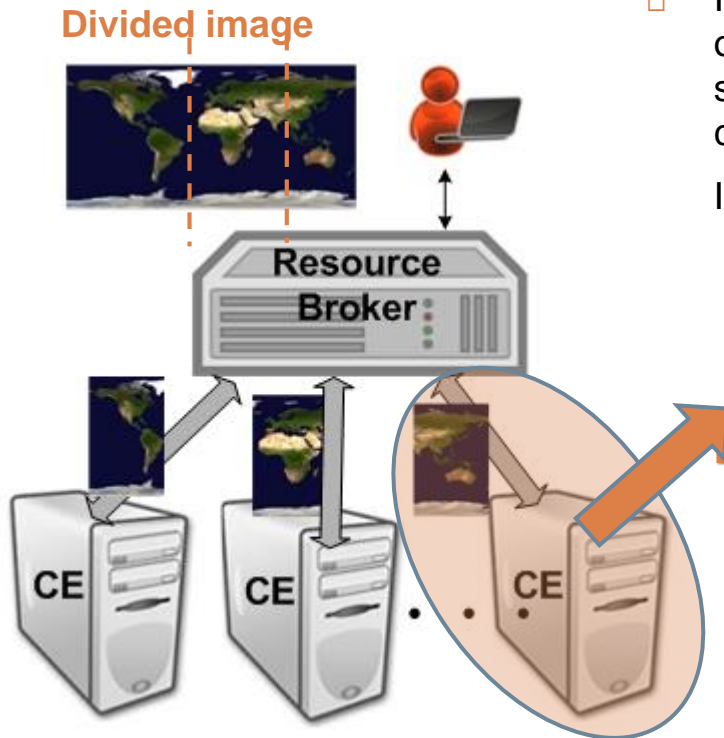
- The UNITAR Operational Satellite Applications Programme
- is a technology-intensive programme delivering imagery analysis and satellite solutions to help make a difference in critical areas such as humanitarian relief, human security, strategic territorial and development planning.
- Mission - delivering integrated satellite-based solutions for human security, peace and socio-economic development

How LCG GRID operates

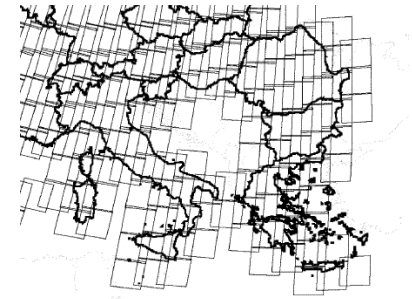


- The process begins with an individual user accessing a user interface (UI) through a personal account, with a user security certificate installed.
- The user describes a job that will run on the Grid. The job arrives at the Resource Broker (RB).
- A set of services running on the RB machine contribute to match job requirements to the available resources, schedule the job for execution to an appropriate Computing Element – CE (i.e. worknode).
- Each output of the user job performed by the CE is stored on a Grid Storage Element (SE).

Approach for GRID based satellite image processing



- In [B1, B2, B3] The satellite images are divided in sub-image in order to reduce size to be processed, and each sub-image can be send for processing to a different computing element within the grid.
- In [B1] Thiessen polygons are used to divide the satellite image



LIMITATION (more likely things to be improved)

- In case of iterative algorithms for processing 1 sub-image - the computation power is limited by 1 Computing Element
- The computing elements are General Purpose Processors (e.g. **Intel® Xeon® Processor E5**)
- In case of iterative algorithms general purpose processors are limited regarding parallel processing strategies to be applied

[B1] F. Javier Gallego, *Stratified sampling of satellite images with a systematic grid of points*, *ISPRS Journal of Photogrammetry & Remote Sensing* 59 (2005) 369–376

[B2] Gregory Giuliani, Nicolas Ray, Anthony Lehmann, *Grid-enabled Spatial Data Infrastructure for environmental sciences: Challenges and opportunities*, *Future Generation Computer Systems*, 27 (2011) 292–303

[B3] Sauravjyoti Sarmah, Dhruva K. Bhattacharyya, *A grid-density based technique for finding clusters in satellite image*, *Pattern Recognition Letters* 33 (2012) 589–604.

Integration of ASHA - **Application Specific Hardware Architectures** for grid based satellite imagery

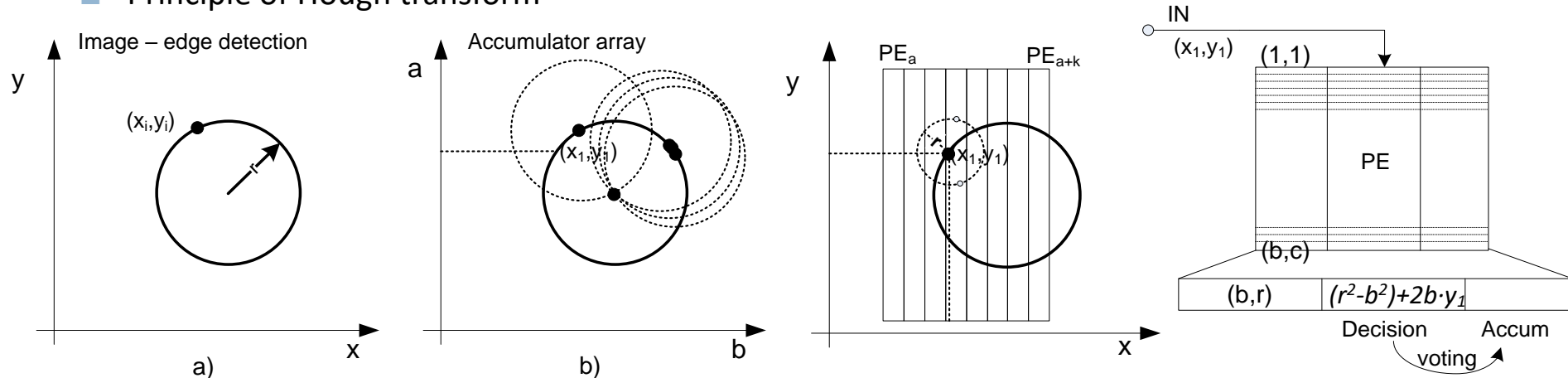
- GPU and FPGA represent a solution for parallel processing of satellite images
 - They can be used in conjunction with the **grid based approach** for fast processing
 - **temporal** parallelism
 - **spatial** parallelism
 - Anisotropic diffusion for feature enhancement and edge preserving
 - Edge detection
 - Circular and linear Hough Transforms



- **Efficient search algorithms optimization**
- **Partially Differential Equations PDE involve development of iterative algorithms**, a big challenge to be parallelized

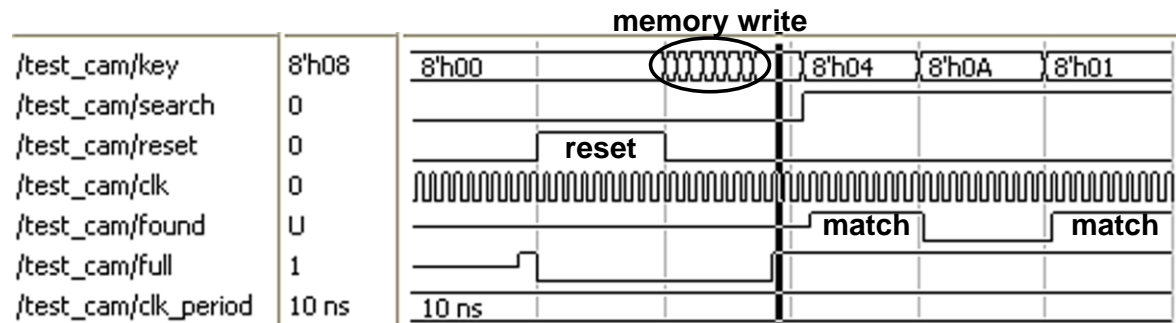
□ Hough transform implementation

□ Principle of Hough transform



□ CAM memories

- Value as input
- Returns the address



- Let C be the total number of computational steps for processing
 - One computational step is composed of a memory read operation m_R , arithmetic operation o_{ALU} or a memory write m_W operation.
 - Xeon Processor from E5 families [6]: 12 execution cores with two threads.
 - processor frequency is up to $f_a = 3$ GHz.
-
- 120 PE can be considered for the FPGA implementation
 - processor frequency is up to $f_b = 0.3$ GHz.
-

$$\Rightarrow P \times T_{clk}^a$$

$$P = 10 \times b \times c \times Q$$

$$\Rightarrow Q \times T_{clk}^b$$

$$\text{speed-up factor } F = P \times T_{clk}^b / Q \times T_{clk}^a = (10 \times b \times c) Q \times f_{clk}^a / Q \times f_{clk}^b \approx 3 \times b \times c$$

- PDE-based image processing - smoothing and restoration purposes.
- In image processing:
 - original image $\mathbf{u}(\mathbf{x},\mathbf{y})$ \Leftrightarrow initial state of diffusion like process
 - The diffusion is known as a physical process that equilibrates concentration differences without creating or destroying mass. The mathematical formulation :

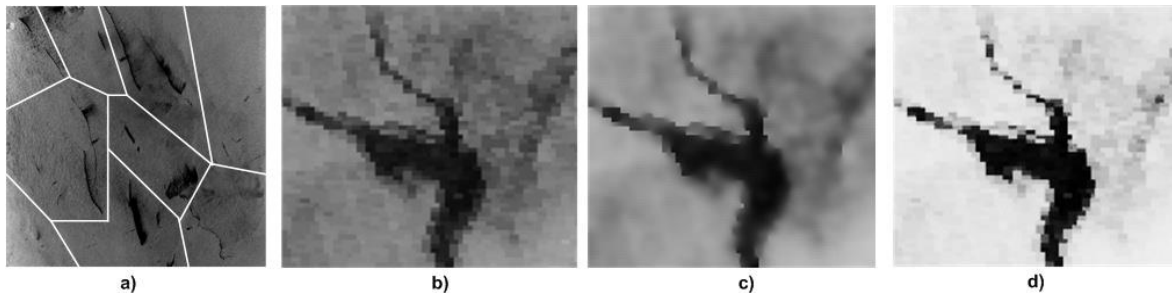
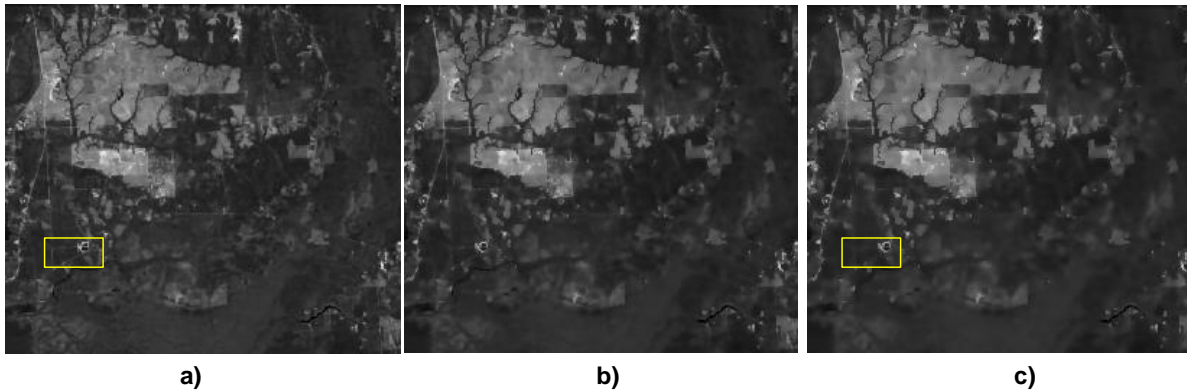
$$\partial_t u = \text{div}(g(|\nabla u|^2) \cdot \nabla u)$$

$$g(s^2) = e^{-s^2 \lambda^2}$$

- Perona and Malik propose a nonlinear diffusion method for avoiding the blurring and localization problems, by applying an inhomogeneous process that reduces the diffusivity at those locations which have a larger likelihood to be edges. The probability for a specific area to be edge is denoted by $|\nabla u|^2$.
- Finite difference for derivative approximation

$$f'(x) = \lim_{h \rightarrow 0} [(f+h) - f(x)] / h$$

- Results of the conventional anisotropic diffusion (Perona & Malik) upon a gray scale image aiming edge enhancement are presented next. (Parameters are: the number of iterations Num_Iter , integration constant ΔT which is set usually to maximum value and the gradient modulus threshold that controls the conduction denoted by $Kappa$).



Anisotropic diffusion applied for edge enhancement in case of original image *Florida* :

a) $Num_iter = 5$, $Kappa = 10$, b) $Num_iter = 15$, $Kappa = 10$, c) $Num_iter = 25$, $Kappa = 10$,

d) $Num_iter = 5$, $Kappa = 30$, e) $Num_iter = 15$, $Kappa = 30$, f) $Num_iter = 25$, $Kappa = 30$.

□ Perona and Malik computational steps

Considering I the initial image which is evolved as follows for **N iterations** (empirically $N = 10$ to 20)

- N iterations**
- for each $p(i,j)$
- a) **STEP 1** - compute finite differences $\eta_N, \eta_S, \eta_E, \dots, \eta_{NW}$ using the following computational masks

$$hN = [0 \ 1 \ 0; 0 \ -1 \ 0; 0 \ 0 \ 0]; \quad hS = [0 \ 0 \ 0; 0 \ -1 \ 0; 0 \ 1 \ 0];$$

$$\dots \dots \dots \quad hNW = [1 \ 0 \ 0; 0 \ -1 \ 0; 0 \ 0 \ 0];$$

- equivalent with 8 additions
 - b) **STEP 2** - compute diffusion function

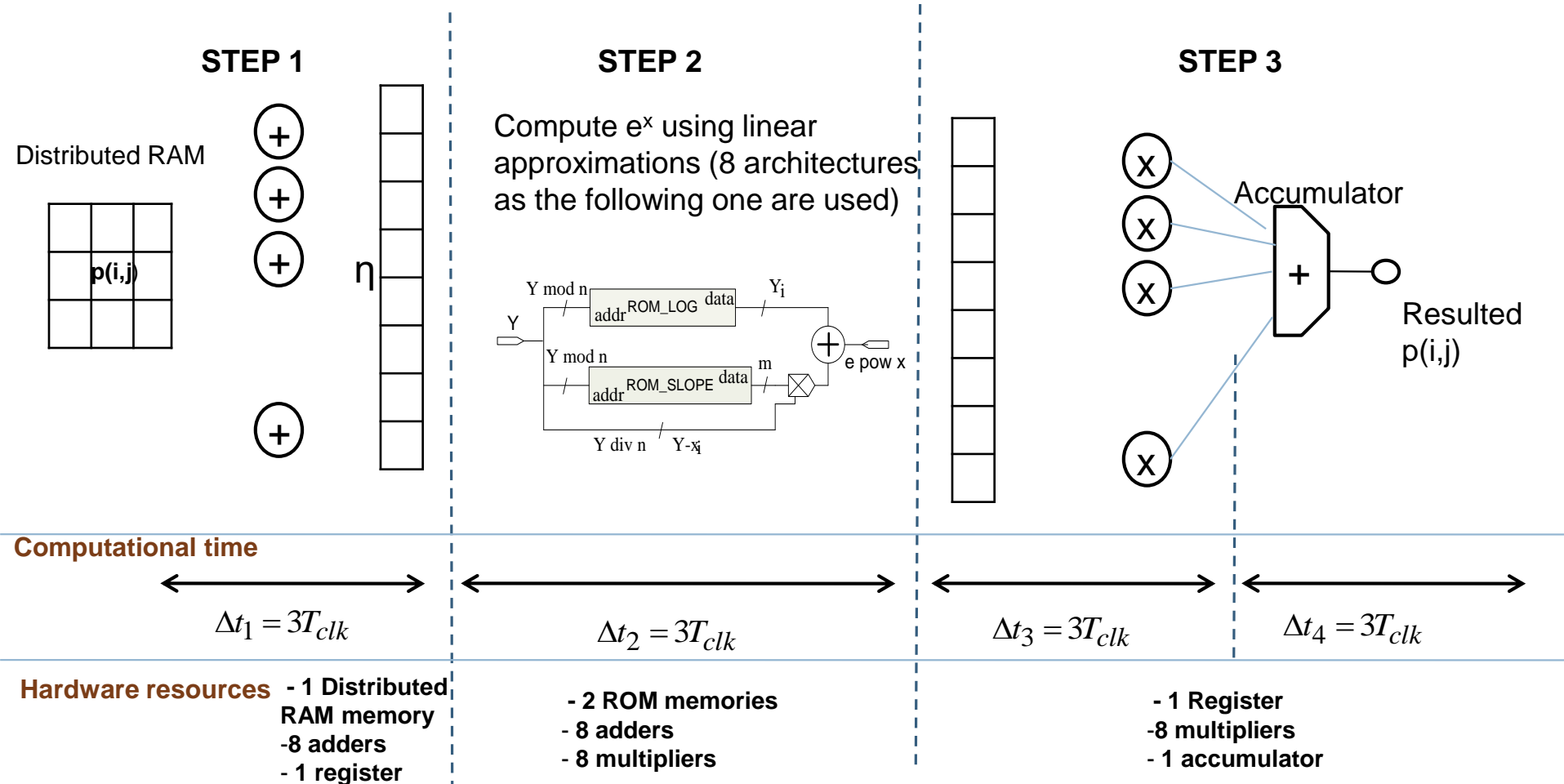
$$c_N = e^{-(\eta_N/k)^2} \quad c_S = e^{-(\eta_S/k)^2} \quad \dots \quad c_{NW} = e^{-(\eta_{NW}/k)^2}$$

- 8 computations of the exponential function
 - c) **STEP 3** - the $p(i,j)$ pixel within the resulted image after 1 iteration is computed as follows

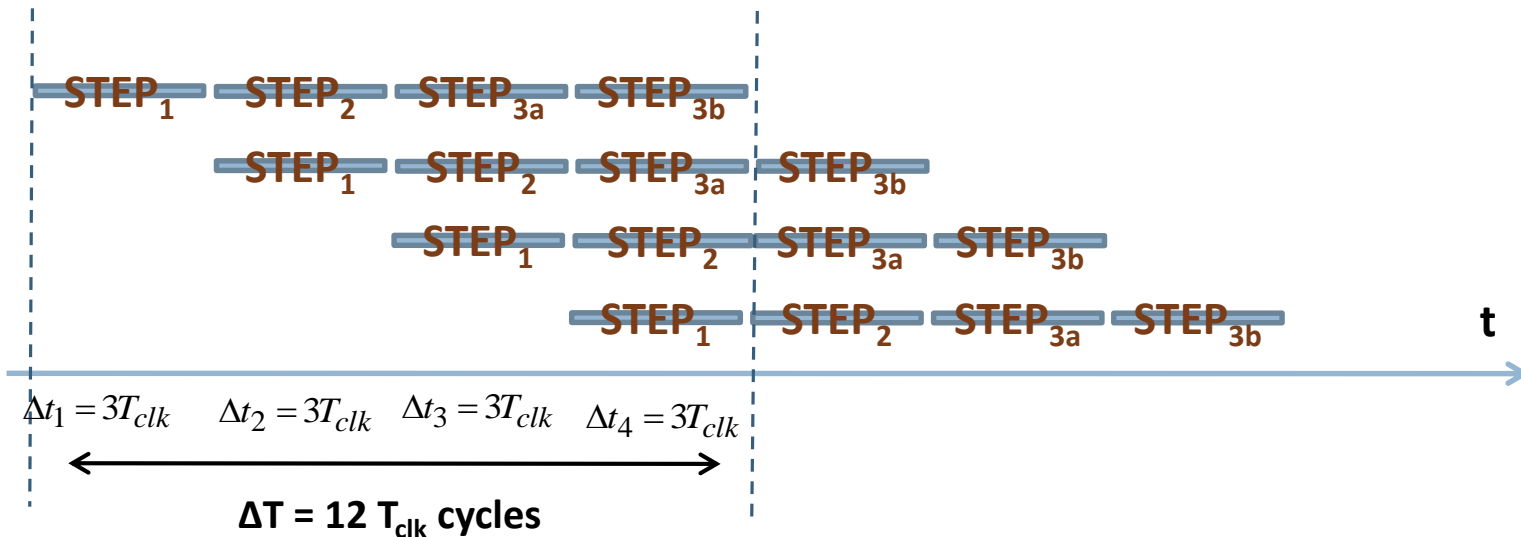
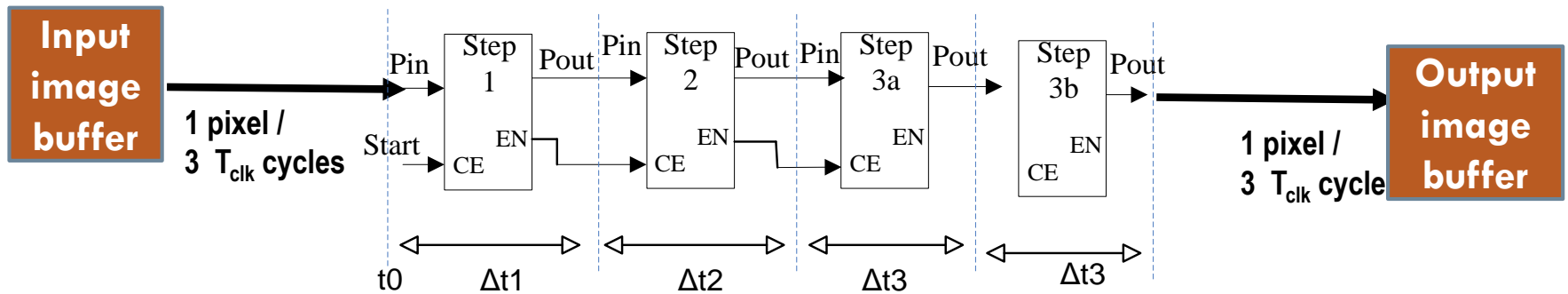
$$p(i, j) = p(i, j) + c_N \eta_N + c_S \eta_S + c_E \eta_E + c_W \eta_W +$$

$$+ 0.5 c_{NE} \eta_{NE} + 0.5 c_{SE} \eta_{SE} + 0.5 c_{NW} \eta_{NW} + 0.5 c_{SW} \eta_{SW}$$

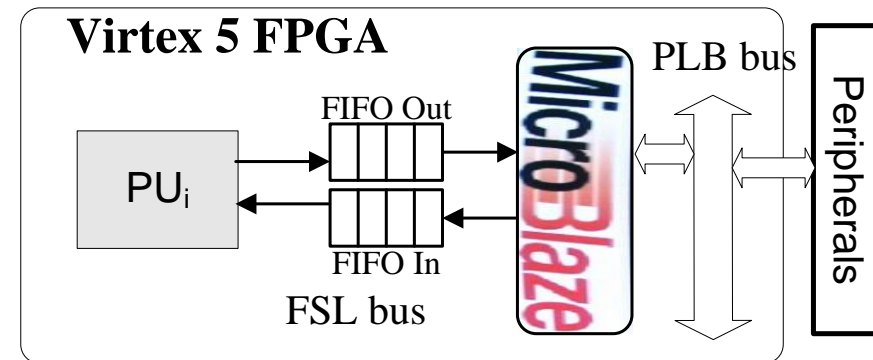
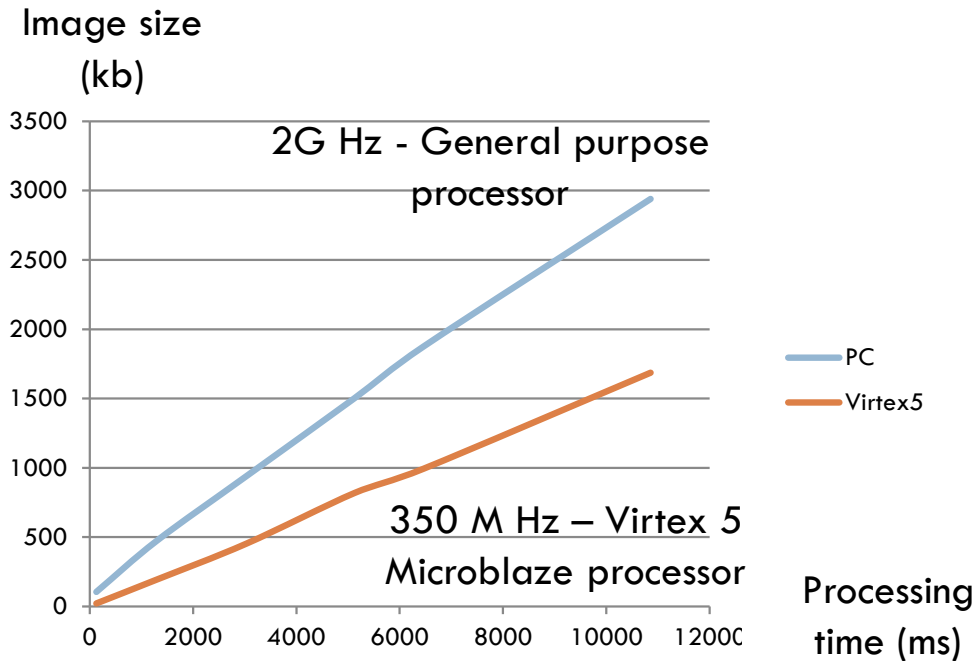
- 8 multiplications
- 8 additions
- **STEP 1, STEP 2 and STEP 3 are to be parallelized for efficient computation**



- Previously described computational steps are arranged in a **pipeline** architecture:
 - Each computational step has assigned a FPGA based architecture



- *The microarray image is delivered pixel by pixel to the computing unit PU with the help of a MICROBLAZE processor, through the FSL data bus*



Grid based high performance computing in satellite imagery. Case study — Perona–Malik filter, Belean B., Belean C., Floare C., Varodi C., Bot A., Adam G., **Computer Research and Modeling**, **2015**, (7)3:399-406

FPGA based SoC for automated cDNA microarray image processing, Belean B., Borda M., LeGal B., Terebes R., **Computerized Medical Imaging and Graphics**, **2011**, (36)5: 419-429

- Field Programmable Gate Arrays represent a solution for both iterative and search algorithms implementation (shortcomings: iterative algorithms are difficult to be parallelized whereas search algorithms need increased resources)
- General purpose processors are surpassed by Application Specific Hardware Architectures regarding computational time
- Future works aim to compare an GPU implementation of the same algorithm with the presented FPGA based implementation
- In case of “Big Data” grid computational power together with Application Specific Hardware Architectures represent a solution for efficient and fast processing.