National Institute for Research and Development of Isotopic and Molecular Technologies

Iterative Algorithms Implementation using FPGA Technology aiming Reduced Computational Time

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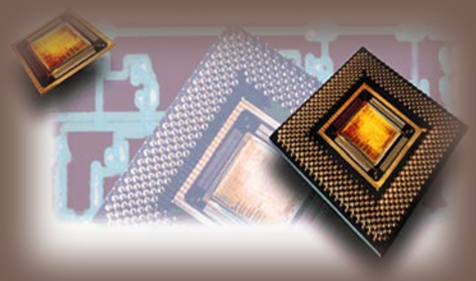

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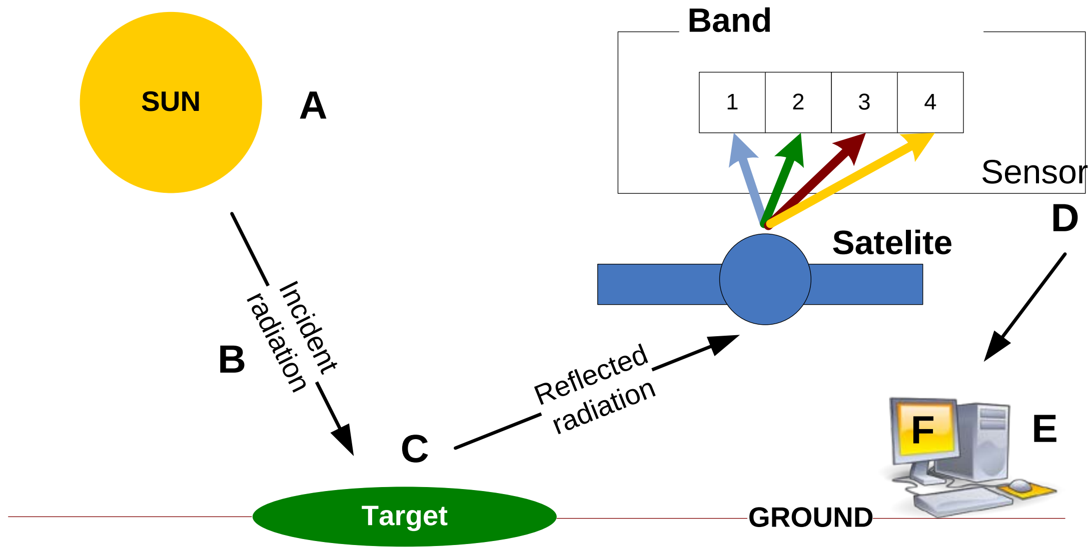
Satellite Imagery within INCDTIM



- The radiation emitted by an energy source (A) covers a distance and interacts with the atmosphere before reaching the target (B)
- (C) The energy interacts with the surface of the target, depending on the characteristics of and radiation properties of the surface. Radiation is reflected or scattered to the sensor
- (D), which registers and then can transmit the energy by remote means to a receiving station (E) where information is transformed into images (digital or photographic).
- A visual interpretation of digital the image (F) is then required to extract the information that is desired on target.

Satellite image resolution

- *spatial resolution*, described by the pixel size of the image
- *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

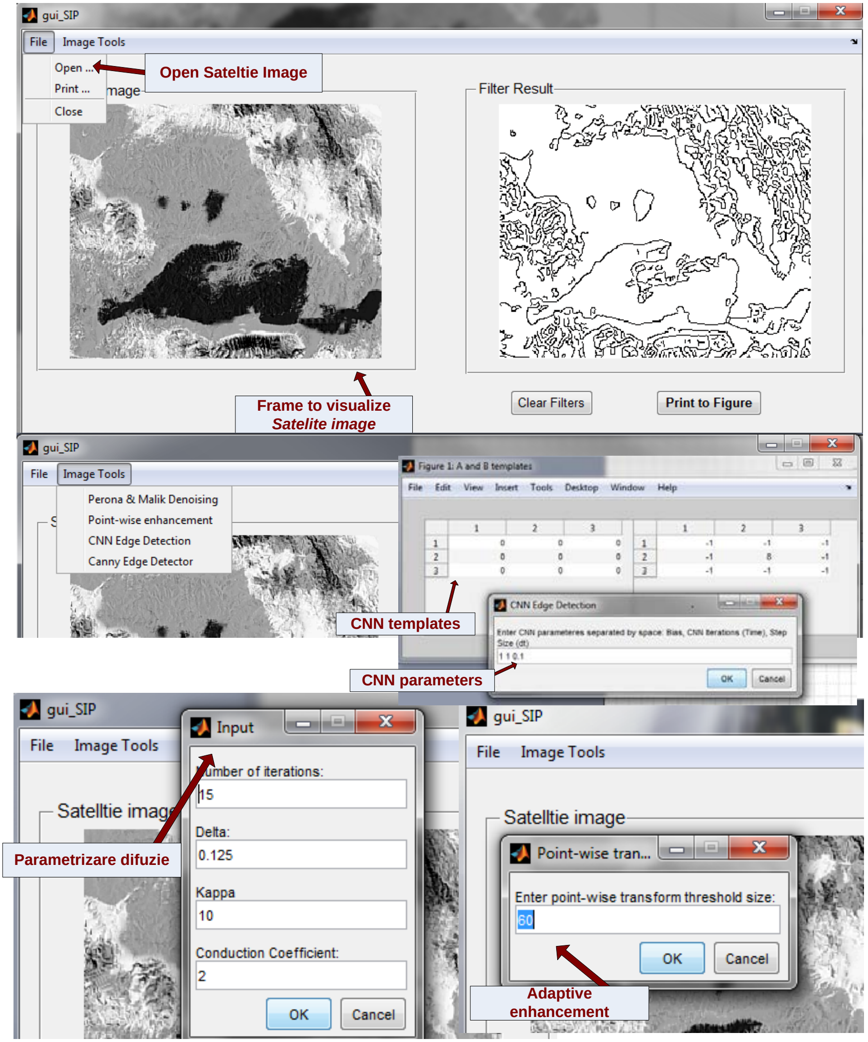
There are many applications of satellite images in fields such as meteorology, agriculture, geology, forestry, landscape, biodiversity conservation, regional planning, education, intelligence and warfare.

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

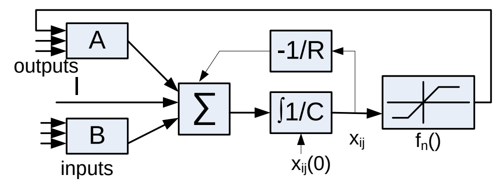
The most common example – **Google Earth** and Google Earth Pro

Satellite Image Processing Platform - INCDTIM



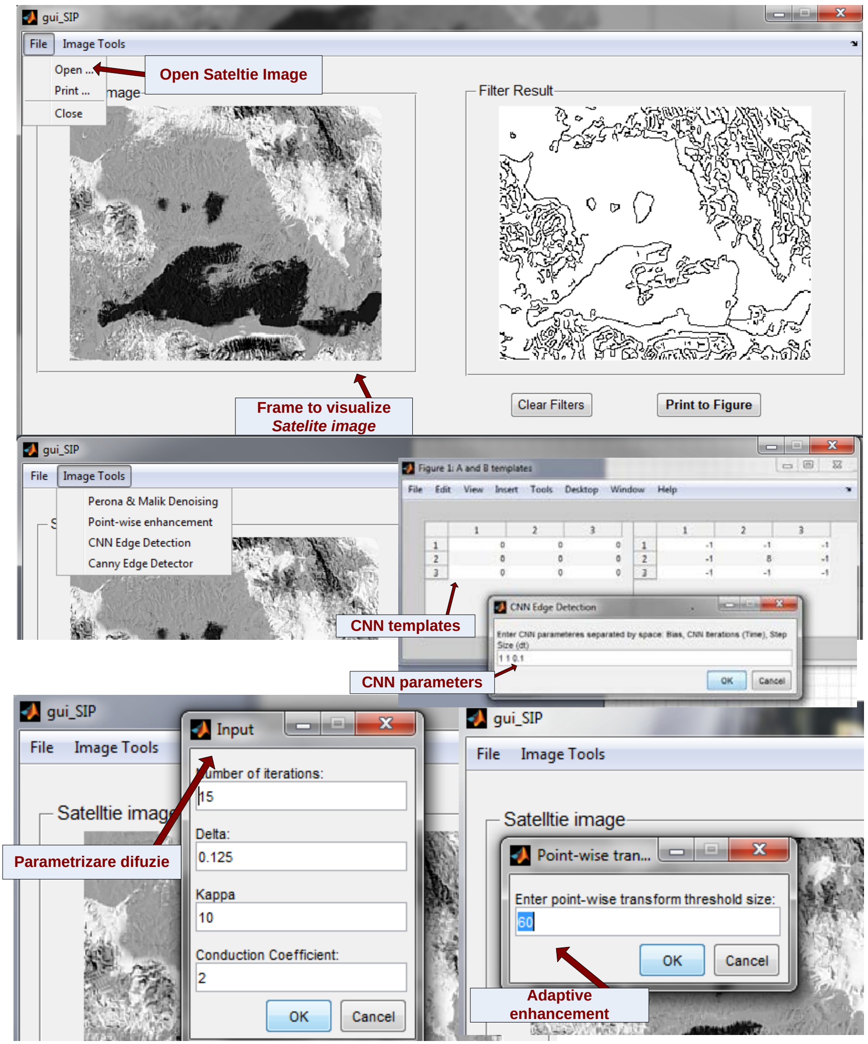
Iterative algorithms

CNN - cellular neural networks



$$C\frac{\partial x_{ij}(t)}{\partial t} = -\frac{1}{R}x_{ij}(t) + \sum_{C_{kl}\in N^r{}_{ij}} A(i,j;k,l)y_{kl}(t) + \sum_{C_{kl}\in N^r{}_{ij}} B(i,j;k,l)u_{kl}(t) + I$$

Satellite Image Processing Platform - INCDTIM



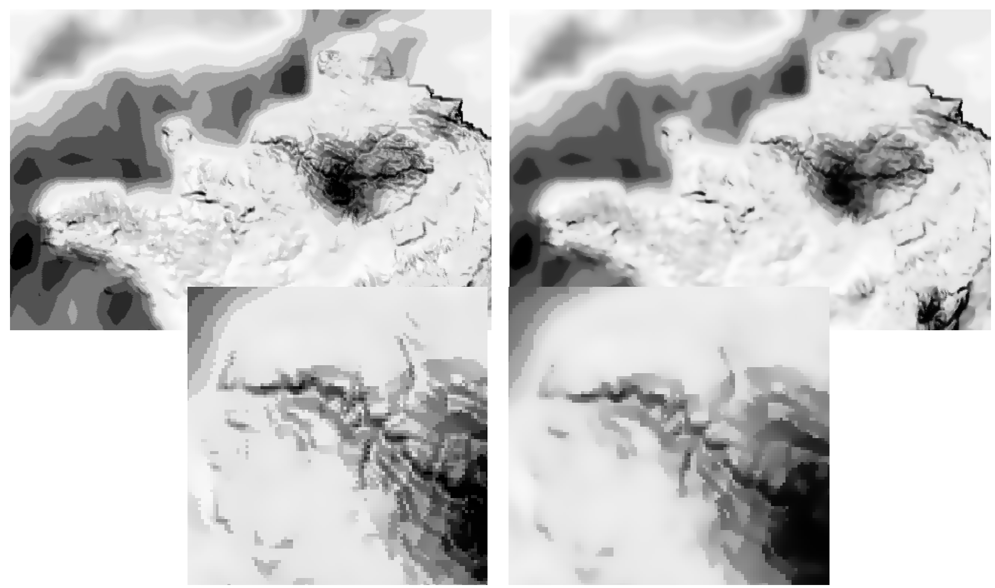
Anisotropic difussion

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

$$g(s^2) = e^{-s^2\lambda^2} \qquad g(s^2) = \frac{1}{1 + s^2\lambda^2}$$

high-contrast *edges are privileged over low-contrast ones*

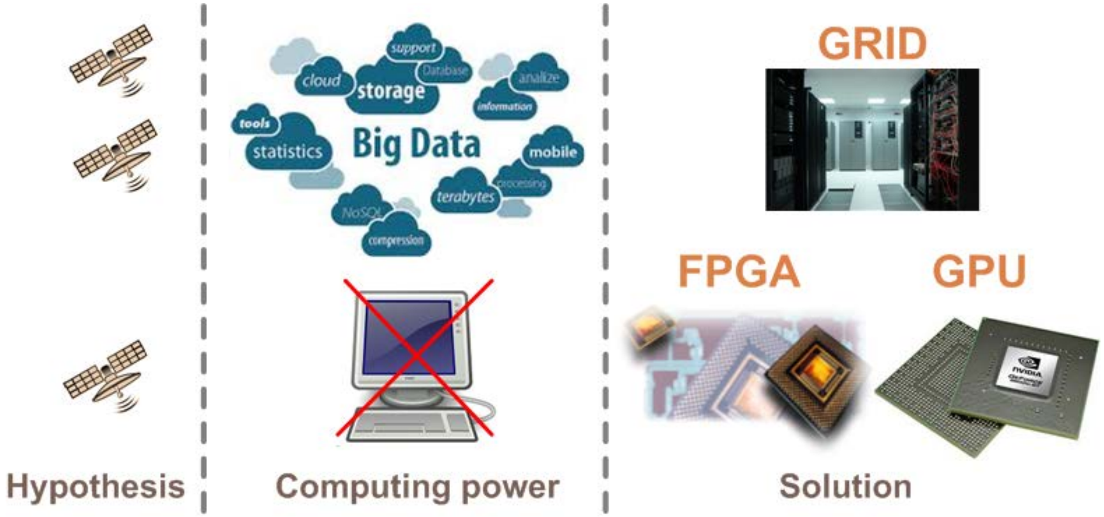
wide regions are privileged over the smaller ones



c) d)

Satellite Imagery within **INCDTIM**

- **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)

GRID based approach for satellite imagery – UNOSAT

The UNOSAT project is a United Nations program through which the international community has access to high quality satellite imagery and Geographic Information System (GIS) services. Satellite imagery and geographic information are to be used by worldwide users for the planning of sustainable development or to monitor and become helpful in case of natural disasters.

- *Use case 1.* During natural catastrophes and disasters, UNOSAT has peaks of usage due to the high number of requests for images of the affected regions. Large amount of computing usage and storage are needed.
- *Use case 2.* In case it is desired to grant access through www. to the satellite image database and imagery techniques (at least compression and cropping are used when interrogating UNOSAT resources) to an increased number of users, UNOSAT resources are bottlenecked. So in order for the resources can be visualized from the mobile device of the field worker, additional computing and storage resources are needed.
- *Use case 3.* The following use case should also be taken into account: UNOSAT administrators periodically perform updates by uploading images in the databases. Moreover, is commonly they perform searches and different processing tasks on the satellite image database. In order to ease this browsing and updating procedures, and, meanwhile, to save UNOSAT resources it is of high interest to use additional resources. Thus, additional databases and processing units could help in planning and managing UNOSAT resources for an efficient use.
- *Use case 4.* Users having slow internet connection may need storage and computing resources from UNOSAT, which lead to a supplementary load on UNOSAT resources.

GRID based approach for satellite imagery – UNOSAT

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

  Satellite images are:
  - Compressed,
  - Stored and
  - Processed.

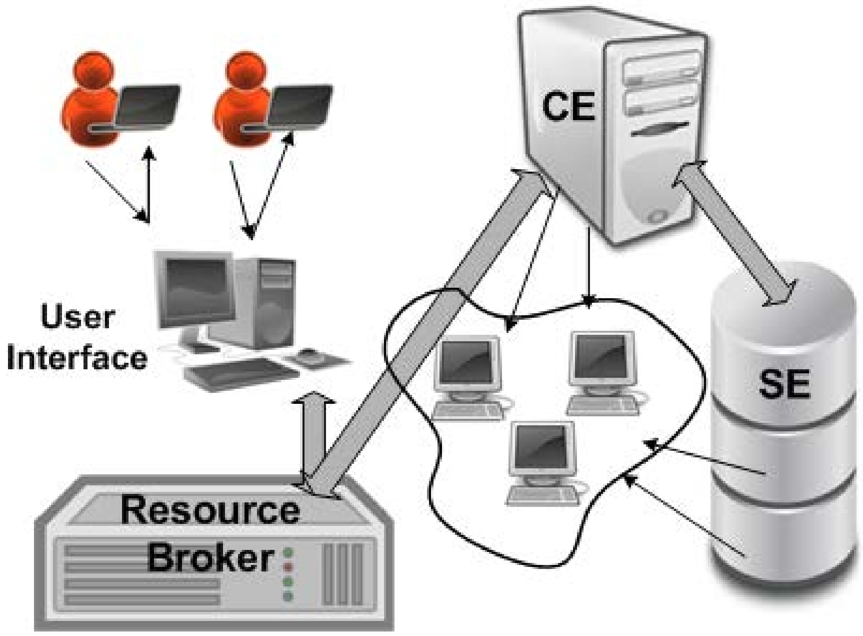
GRID - The Worldwide LHC Computing Grid (WLCG)

- launched in **2002**
- distributed computing infrastructure arranged **in tiers**
- provides a resource to **store, distribute and analyze** the 15 millions gigabytes of data generated every year by the Large Hadron Collider (LHC).

UNOSAT

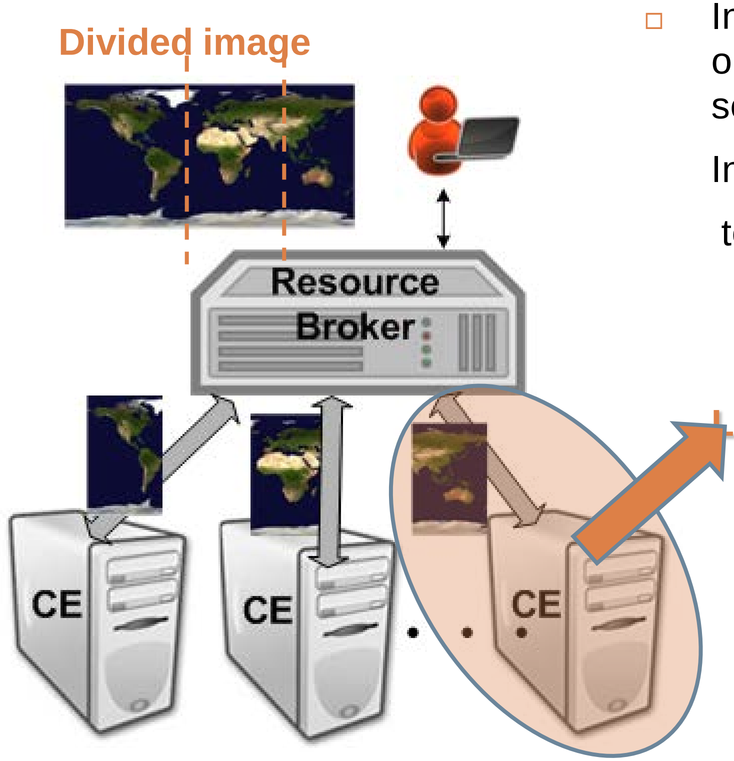
- The UNITAR Operational Satellite Applications Programme
- is a technology-intensive programme delivering imagery analysis and satellite solutions to help make a difference in critical areas such as humanitarian relief, human security, strategic territorial and development planning.
- Mission - delivering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

How LCG GRID operates



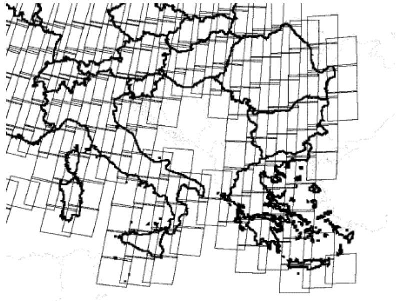
- The process begins with an individual user accessing a user interface (UI) through a personal account a personal account, with a user security certificate installed.
- The user describes a job that will run on the Grid. The job arrives at the Resource Broker (RB).
- A set of services running on the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

- 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, Dhruba K. Bhattacharyya, *A grid-density based technique for finding clusters in satellite image*, **Pattern Recognition Letters** 33 (2012) 589–604.

SOLUTION - 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

- Partially Differential Equations PDE envolve development of iterative algorithms, a big challenge to be parallelized
- E.g. Shock filters (Osher and Rudin) or Perona and Malik filters
- Perona and Malik will be described next

C

Perona and Malik filter description

- PDE-based image processing - smoothing and restoration purposes.
- In image processing:
  - original image ⇔ initial state of a parabolic (diffusion like process)
  - The diffusion is known as a physical process that equilibrates concentration differences without creating or destroying mass. The mathematical formulation :

$$j = -D \cdot \nabla u$$

- 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 $|\nabla u|^2$. The Perona–Malik equation is :

$$\partial_t u = div(g(|\nabla u|^2) \cdot \nabla u) \quad \text{where} \quad g(s^2) = e^{-s^2 \lambda^2}$$

$$\operatorname{div} \vec{u} = \nabla \cdot \vec{u} = \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z}$$

$$\frac{\partial U(x,t)}{\partial x} = \frac{U(x+k,t) - U(x-k,t)}{2|k|}$$

Perona and Malik filter description

- 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 η_N, η_S, η_E, ... η_{NW} using the following computational masks

  hN = [0 1 0; 0 -1 0; 0 0 0]; hS = [0 0 0; 0 -1 0; 0 1 0];
  ……………………. hNW = [1 0 0; 0 -1 0; 0 0 0];

  - equivalent with 8 additions

- b) **STEP 2** - compute diffusion function

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

  - 8 computations of the exponential function

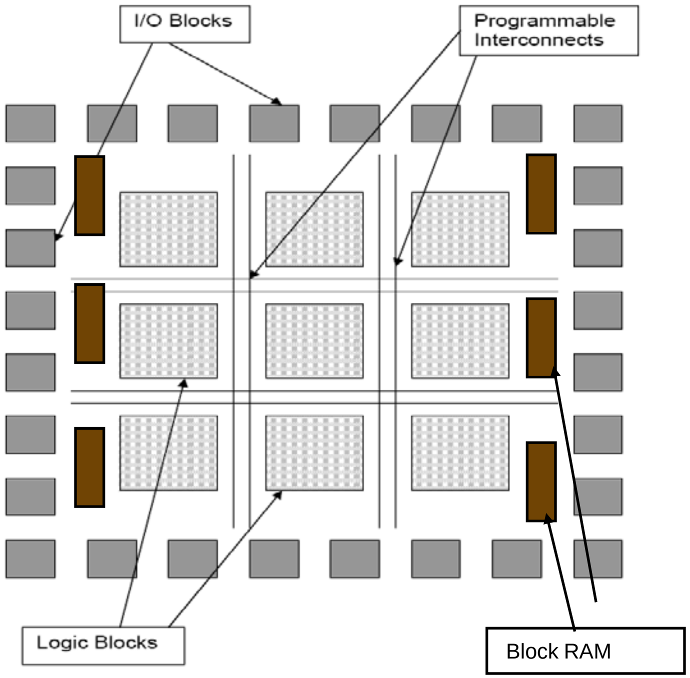
- c) **STEP 3** - the p(i,j) pixel within the resulted image after 1 iteration is computed as follows

  $$p(i,j) = p(i,j) + c_N\eta_N + c_S\eta_S + c_E\eta_E + c_W\eta_W + \\ + 0.5c_{NE}\eta_{NE} + 0.5c_{SE}\eta_{SE} + 0.5c_{NW}\eta_{NW} + 0.5c_{SW}\eta_{SW}$$

  - 8 multiplications
  - 8 additions

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

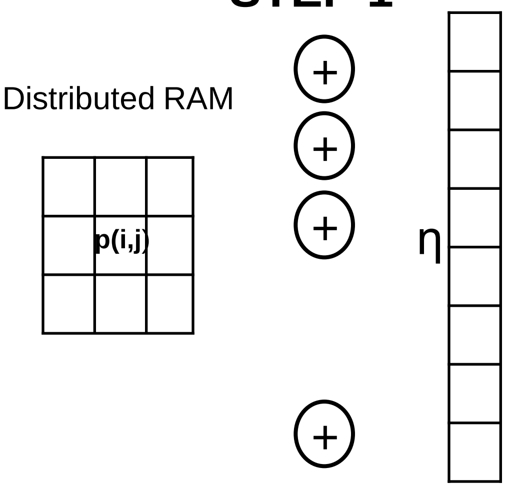
- **Field Programmable Gate Arrays = digital logic chips containing:**
  - Configurable Logic Blocks (CLB)
  - Programmable interconnects
  - I/O Bocks (programmable)
  - Block RAMs
  - Processors (Power PC)



- **Parallel computing capabilities; possibility to exploit:**
  - Spatial parallelism (e.g multiple computing units)
  - Temporal parallelism (pipeline approaches)

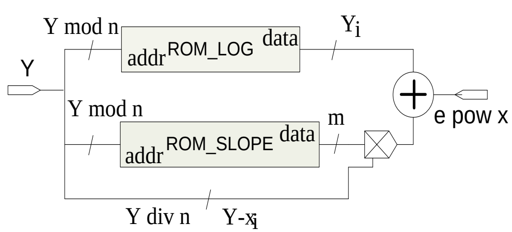
Hardware Architecture for Perona and Malik filter

STEP 1

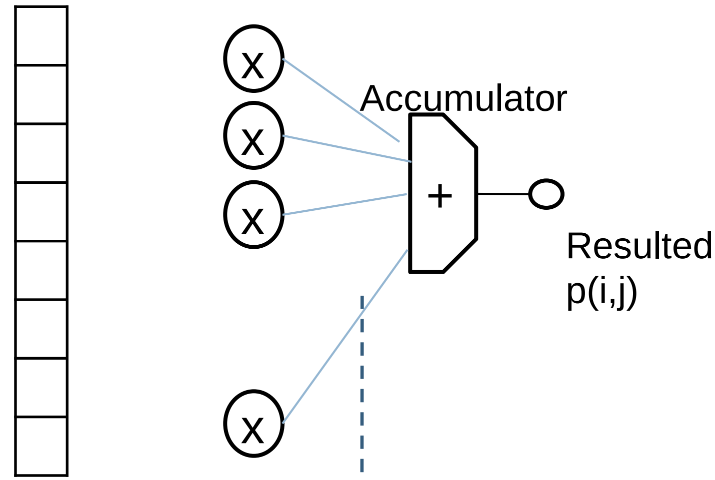


STEP 2

Compute e^x using linear approximations (8 architectures as the following one are used)



STEP 3



Computational time

$$\Delta t_1 = 3T_{clk}$$

$$\Delta t_2 = 3T_{clk}$$

$$\Delta t_3 = 3T_{clk}$$

STEP 3a

$$\Delta t_4 = 3T_{clk}$$

STEP 3b

Hardware resources

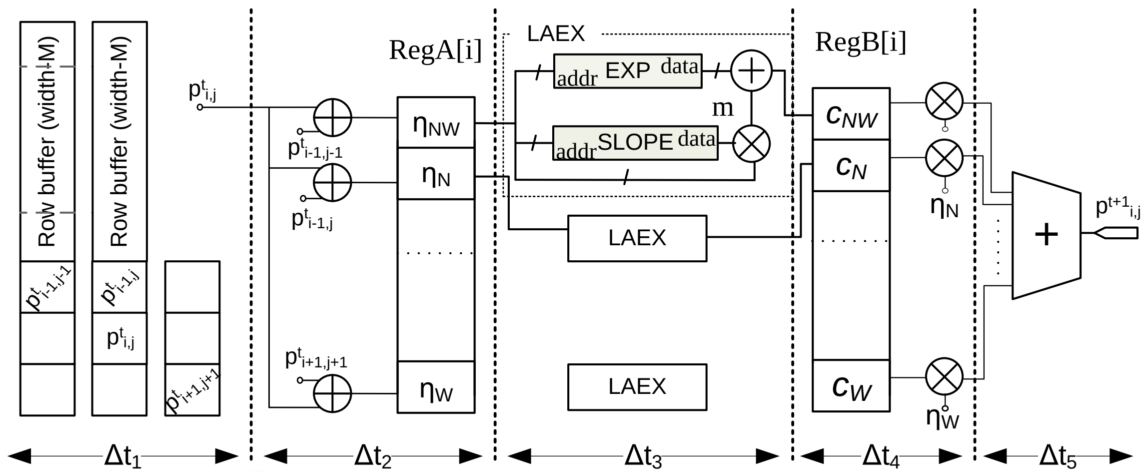
- 1 Distrbuted RAM memory
-8 adders
- 1 regster

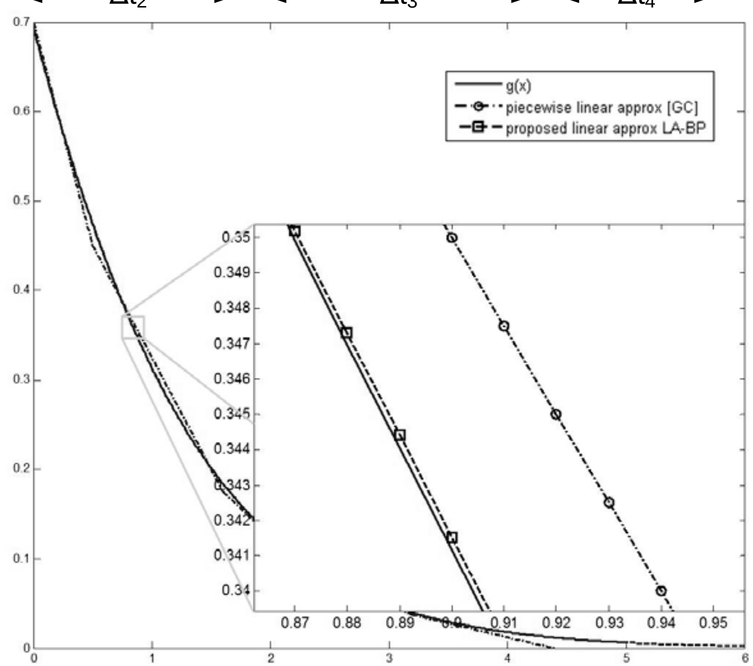
- 2 ROM memories
- 8 adders
- 8 multipliers

- 1 Register
-8 multipliers
- 1 accumuter

C

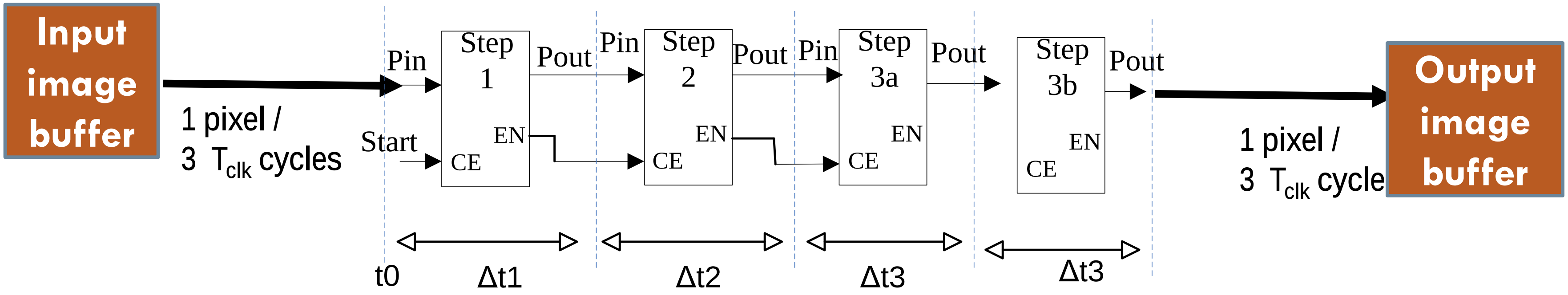
Hardware Architecture for Perona and Malik filter

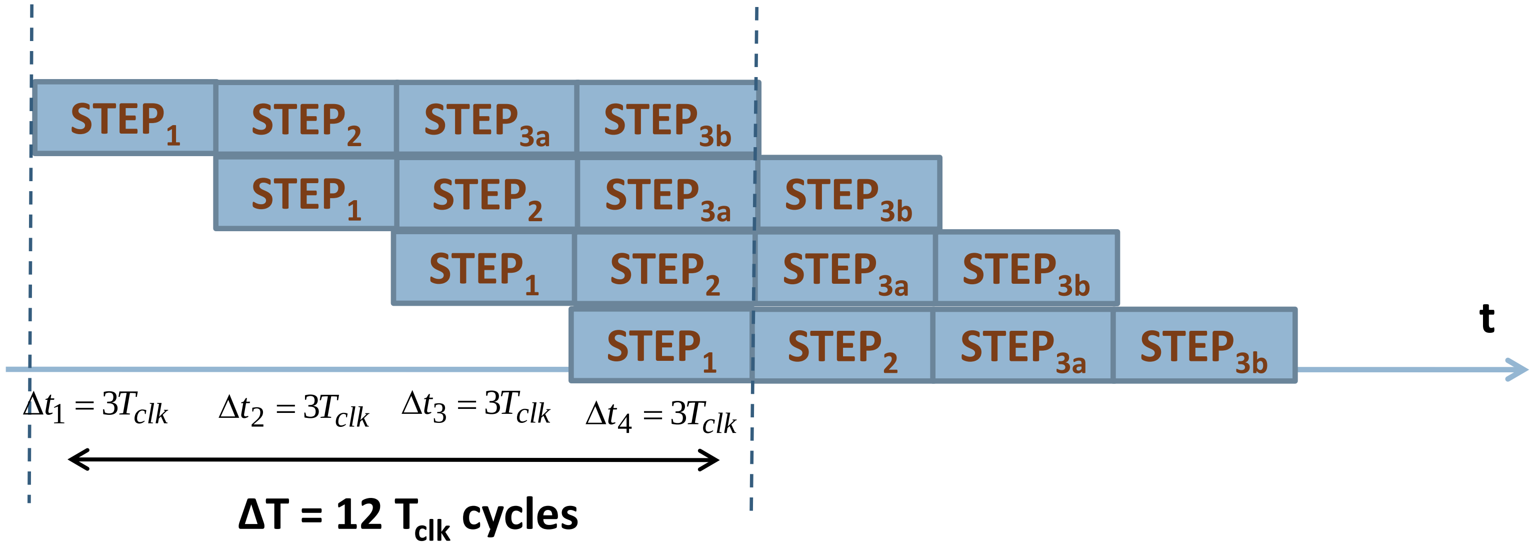




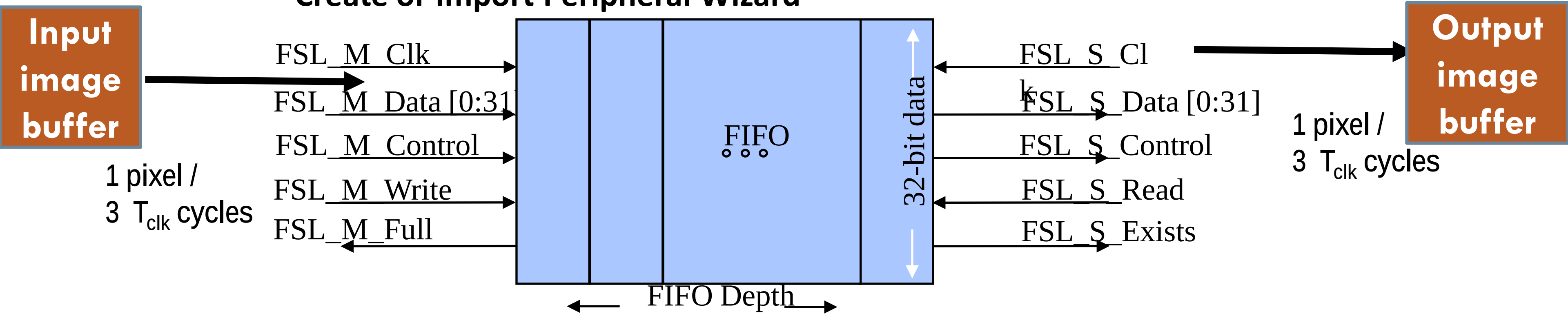
Hardware Architecture for Perona and Malik filter

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

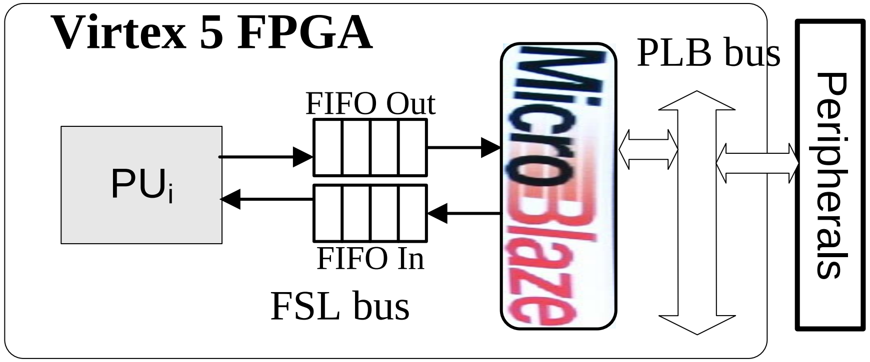


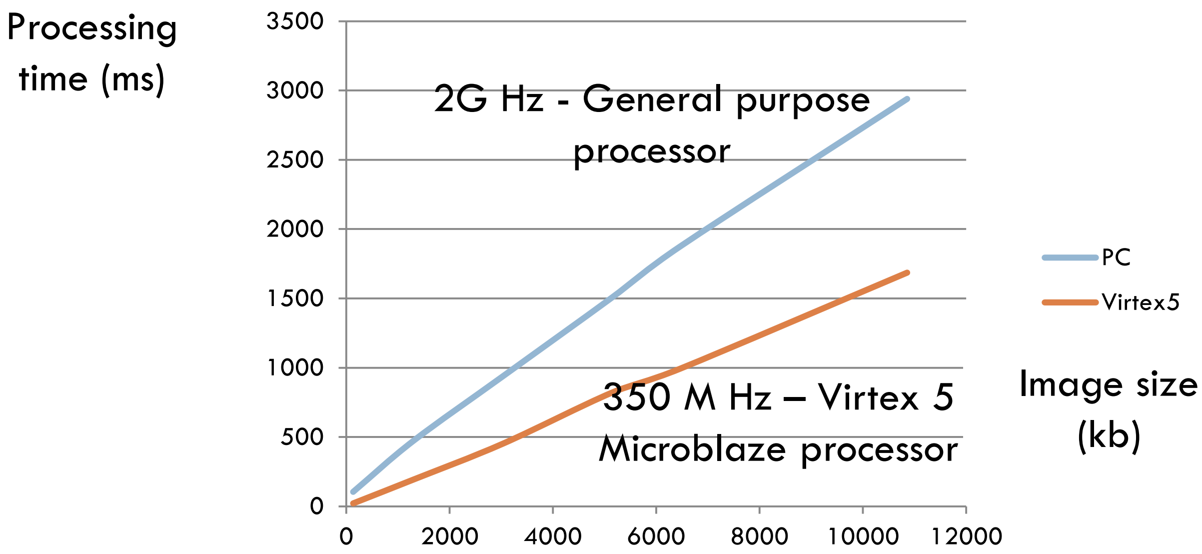


- FSL data bus
  - Unidirectional point-to-point FIFO-based communication
  - Dedicated (unshared) and nonarbitrated architecture
  - Dedicated MicroBlaze™ C and ASM instructions for easy access
  - High speed, access in as little as two clocks on processor side, 600 MHz at hardware interface
  - Available in Xilinx Platform Studio (XPS) as a bus interface library core from **Hardware → Create or Import Peripheral Wizard**



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





Conclusions

- Field Programmable Gate Arrays represent a solution for iterative algorithms implementation
- 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 Specfic Hardware Architectures represent a solution for efficient and fast processing.