A Neural Solution for the Level 2 Trigger in Gamma Ray Astronomy

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ETIS

23 avril 2007
Contents

1 The HESS Project
2 Future: The HESS2 experiment
3 Algorithms for the L2 trigger system
   - Approach based on Hillas parameters
   - Approach based on a neural system
4 Results
5 Conclusion and perspectives
Context

The HESS Project

- Objectives
  - Detection of High-energy gamma rays
  - Collecting interesting events (gammas) and reject all others (Protons, Muons)

- Based on 4 Cherenkov Telescopes located in Namibia
  - Cherenkov light
    - As a high energy cosmic ray particle hits the atmosphere it creates an extensive air shower by interaction with the atmosphere.
Examples of collected images

- After HESS1 trigger, only binary information available for each Pixel → A decision regarding the nature of a particle is difficult to make
- The HESS collaboration has decided to improve the performances of this project in a new version (HESS 2)
Objectives
→ Improve the HESS1 experiment by
  • Adding a new HESS2 event class (E from 10GeV to 50GeV)
  • Increasing sensitivity for E~50 to 100GeV
  • Improving resolution for E>100GeV

Means
→ A Very Large Cherenkov Telescope added in the center of the 4 existing ones
  • Much more collected information
  • Possible Stereoscopy
Issues
→ Huge amount of data to be processed on-line
  • 240 GBauds in approximately $10 \mu s$

Envisaged solution
→ Efficient Trigger system to minimize the data flow
→ Adding a Level 2 trigger to make a decision about the interest of a physical event
Examples of simulated images (HESS2)

- Observations

- Finest granularity
  → 2048 pixels (instead of 960 pixels)

- More Information
  → 3 levels of energies per pixels (instead of 2)
The global HESS2 Trigger System

- The trigger System is Composed of 2 levels:
  - L1: eliminates the NSB
  - L2: classifies particles (G,M,P)
- Input data are stored in an analog memory (SAM)
- L1 applies threshold on the images and delivers a L1A/L1R signal (100 KHz).
- PreL2 thresholds the L1A images and transmits the resulting images to L2.
- L2 implements more complex processing on the input images and generates a L2A/L2R signal (3.5 KHz).
The Level2 Trigger

- **Goal:**
  - Implement pattern recognition algorithms to accept photons and reject all other particles
  - Generation of a L2A/L2R signal

- **Structure:**
  - Multilevel processing chain
    - Pipelining
    - Multiple decisions
  - Latency
    - A window of $10 \mu s$ is available to compute all the algorithms.

- **Two approaches:**
  - Filter based on Hillas parameters (classical method)
  - Neural System
The rejection block

- Common to both approaches
- Goal:
  → Reject all images that contain less than 4 active pixels
  → Because it is difficult to make a decision with such poor information
1st classical approach: Utilization of Hillas parameters

**Principles**

→ According to the particles signature, the idea is to adjust a bidimensional ellipse on the image.

→ Compute the COG, length, width, surface, area and $\alpha$.

→ According to the obtained parameter values, classify the particles in 3 classes (G,M,P).

![Diagram showing the adjustment of a bidimensional ellipse and classification process.](image-url)
2nd approach: The Neural solution

- **Input**
  - Images containing more than 4 pixels

- **Composed of 2 stages**
  - Preprocessing
  - Neural classifier
    - L2A/R generation

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Diagram:

- **Rejection**
- **Preprocessing**
- **Hillas**
  - L2A/L2R
- **RN**
  - L2A/L2R
Neural solution (preprocessing)

- **Assertion**
  → 99% of all images are contained in a 21*21 square.

- **Role**
  → Find the biggest cluster within an entire image
  → Isolate a ROI
  → Center the particle signature within the square
Neural solution (classifier)

- **Structure**
  - Classical Multi-layer Perceptron
  - 441 inputs corresponding to 21*21 pixels (ROI)
  - 3 outputs corresponding to the 3 classes to identify
    - Gamma
    - Muon
    - Proton

- **Neural Networks Properties**
  - Powerful computational model
  - Inherent parallelism $\Rightarrow$ Suitable for hardware implementation
Comparisons between both approaches in terms of rejection rate
→ Mean on all energies
→ On the same data
→ NN System
→ Hillas Parameters

Performances of NN are better than those of Hillas parameters.

<table>
<thead>
<tr>
<th></th>
<th>Gamma</th>
<th>Muon</th>
<th>Proton</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neural solution</td>
<td>80%</td>
<td>75%</td>
<td>75%</td>
</tr>
<tr>
<td>Hillas filter</td>
<td>60%</td>
<td>56%</td>
<td>37%</td>
</tr>
</tbody>
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Conclusion

- Hillas approach is satisfactory
  → Fast computation
  → But strong cuts in the final decision
- The neural approach has already shown efficient results in Physics experiments
  «The H1 Neural Network Trigger Project» ACAT 2000
- Promising results in the HESS2 project but
  → Pre-processing has to be improved
    - Dimension reduction of the parameters space
    - Faster computation of the NN
- Challenging hardware implementation
  → Strong real time constraints (10\(\mu\)s) to execute the neural system (preprocessing + NN)
  → Need of a massive paralell architecture
Towards an « intelligent preprocessing »
→ Exploiting images properties to help the NN in its tasks
  • Geometrical moments (Zernike, Hu moments)
  • Pattern recognition (particle signature identification)
→ Reduce the dimension of the input space (PCA. . .)
→ Get information from the Hillas parameters
→ Other algorithms
  • SVM

Hardware implementation of the L2 algorithms
→ Develop an optimal (massively parallel) hardware architecture to implement
  • Preprocessing
  • Classifier
→ Target implementation chip such as FPGAs
  • Very fast circuits
  • Flexible