Comparing 2-Level and Time Next Neighbor Cleaning Protocols for Optimizing CTA Image Cleaning

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Cherenkov Telescope Array (CTA)

- Applications of studying VHE gamma rays

Artist’s concept of active galactic nuclei (AGN): http://www2.le.ac.uk/departments/physics/research/xroa/images/black-hole.jpg/image_preview

Artist’s concept of a binary black hole merger, like the one that generated the first GW transient detection in fall 2015: http://www.nasa.gov/sites/default/files/thumbnails/image/ns_gw_art.jpg
Cherenkov Telescope Array (CTA)

• Why ground-based telescopes?

This image shows that most wavelengths of radiation do not penetrate Earth’s atmosphere: https://www.e-education.psu.edu/astro801/files/astro801/image/atmos_windows_KL.jpg
Cherenkov Telescope Array (CTA)

• Next generation of ground-based gamma-ray telescopes

• Improving upon its predecessors
  
  • **Factor of 10** greater telescope sensitivity

  • **50-100 telescopes** in the array offers wider range of energies
Schwarzschild-Couder Telescopes (SCTs)

• 3 different sized-telescopes
  • ~4 LSTs (~24 m) → lower energies <100 GeV
  • ~30 MSTs (~12 m) → core energies 0.1-10 TeV
  • ~50 SSTs (~4 m) → higher energies >10 TeV

• SCT concept
  • Large field-of-view
  • reduced plate scale focal surface with a highly pixelated (11328) Silicon photomultiplier camera
  • compact camera close to the secondary mirror

• SCT design planned for MSTs

• prototype SCT (pSCT) under construction
Gamma-Ray Showers

Artist’s rendering of the gamma-ray interactions with atmospheric nuclei that produce Cherenkov light: http://imagine.gsfc.nasa.gov/Images/science/atmosphere_cerenkov_full.png
Gamma-Ray Showers and Imaging Atmospheric Cherenkov Technique

Comparison of gamma-ray and cosmic ray particle tracks [4].

Production of Cherenkov light and the stereoscopic reconstruction method [3].
Method

• Calibration
  • Quantify the NSB
  • Classifying pixels during image cleaning

• Trace Integration
  • Double-pass method calculates charge in each pixel
  • Direct impact on image cleaning
  • Default trace integration: 6-sample windows

A typical trace integration window, with samples on the x-axis and charge in d.c. units on the y-axis [2].
Image Cleaning

• Gamma-ray sources against backgrounds: cosmic rays, night sky background (NSB)

• Remove noisy pixels

• Variety of methods
  • 2LC, TNN
    • Cluster, time cluster, time 2LC

• Avg. pedestal value = 25 d.c.
Two-Level Cleaning (2LC)

• Double-pass system to classify pixels based on pulse charge threshold
  • Image? Border? Noise?
  • What makes a “neighboring” pixel?
  • Vary the upper/lower thresholds
  • Default = 300/150 d.c.
  • Notation system: factor multiplied by avg pedestal
  • 8.4, 10.4, 10.6, 12.4, 12.6, 12.8, 14.6, 14.8, 16.6, 16.8

Moving clockwise: image of simulated CTA camera from eventdisplay; image of VERITAS camera from McGill’s DQM viewer; what makes a “neighboring” pixel for square pixels?
Time Next Neighbor (TNN) Cleaning

• Considers charge in the pixel AND arrival time differences

• Looks for next neighbor (NN) groups in a time coincidence window

• Three NN groups
  • 2NN, 3NN, 4NN
  • Wider range of conditions

  • *Preserve as many events as possible, especially in the lower energies!*

• Vary fake probability
  • 0.03%, 0.04%, 0.05%, 0.06%, 0.07%
MC Simulations/Software Packages

• Simulations vs. Real data

• What are MC sims?
  • CORSIKA = air showers/cosmic ray background
  • sim_telarray = telescope response
  • eventdisplay = analyze sims

• Simulation Conditions
  • 1 p-SCT (MST) in the center of the array
  • Assume all showers arrive in the center of the camera

https://www.mpi-hd.mpg.de/hfm/CTA/CTA_arrays.html
Copy sim_tel files

Convert to ROOT files

eventdisplay with 15 different parameter files*

Process 147 GB proton

Process 86 GB gamma

Histo comparing cleanings for all proton

Histo comparing cleanings for all gamma

*2LC 8.4, 10.4, 10.6, 12.4, 12.6, 12.8, 14.6, 14.8, 16.6, 16.8
TNN 0.03%, 0.04%, 0.05%, 0.06%, 0.07%
Quantifying the Comparison

• No. of events that pass the cleaning (10^-2-10^2 TeV on log scale)

• Compare to no. of events that trigger telescopes

\[ r = \frac{n_c}{n_t} \]

• Uncertainty

\[ \delta n = \sqrt{n} \]

\[ \delta r = \sqrt{\left(\frac{\delta n_c}{n_t}\right)^2 + \left(\frac{-n_c \times \delta n_t}{n_t^2}\right)^2 + \frac{-2n_c \times \delta n_c n_t}{n_t^3}} \]
Comparing Default 2LC, TNN

Gamma simulations

Proton simulations
Comparing ALL 2LC, TNN

Gamma simulations

Proton simulations
Gamma simulations
Proton simulations
Quantifying Efficiency Ratio Comparison

<table>
<thead>
<tr>
<th>log10(E (TeV))</th>
<th>Cleaning</th>
<th>Efficiency ($\frac{n_{\text{events}}}{n_{\text{predicted}}}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10^{-2}−10^{-1.8}</td>
<td>2LC 8.4</td>
<td>1 ± 0</td>
</tr>
<tr>
<td>10^{-2}−10^{-1.8}</td>
<td>2LC 12.4</td>
<td>1 ± 0</td>
</tr>
<tr>
<td>10^{-2}−10^{-1.8}</td>
<td>2LC 12.6</td>
<td>0.951 ± 0.003</td>
</tr>
<tr>
<td>10^{-2}−10^{-1.8}</td>
<td>2LC 12.8</td>
<td>0.82 ± 0.01</td>
</tr>
<tr>
<td>10^{-2}−10^{-1.8}</td>
<td>2LC 14.6</td>
<td>0.66 ± 0.02</td>
</tr>
<tr>
<td>10^{-2}−10^{-1.8}</td>
<td>2LC 14.8</td>
<td>0.62 ± 0.02</td>
</tr>
<tr>
<td>10^{-2}−10^{-1.8}</td>
<td>2LC 16.8</td>
<td>0.54 ± 0.02</td>
</tr>
<tr>
<td>10^{-2}−10^{-1.8}</td>
<td>TNN 0.0005</td>
<td>0.951 ± 0.003</td>
</tr>
<tr>
<td>10^{-1.8}−10^{-1.6}</td>
<td>2LC 8.4</td>
<td>1 ± 0</td>
</tr>
<tr>
<td>10^{-1.8}−10^{-1.6}</td>
<td>2LC 12.4</td>
<td>0.9802 ± 0.0005</td>
</tr>
<tr>
<td>10^{-1.8}−10^{-1.6}</td>
<td>2LC 12.6</td>
<td>0.918 ± 0.002</td>
</tr>
<tr>
<td>10^{-1.8}−10^{-1.6}</td>
<td>2LC 12.8</td>
<td>0.847 ± 0.004</td>
</tr>
<tr>
<td>10^{-1.8}−10^{-1.6}</td>
<td>2LC 14.6</td>
<td>0.772 ± 0.0005</td>
</tr>
<tr>
<td>10^{-1.8}−10^{-1.6}</td>
<td>2LC 14.8</td>
<td>0.728 ± 0.0006</td>
</tr>
<tr>
<td>10^{-1.8}−10^{-1.6}</td>
<td>2LC 16.8</td>
<td>0.564 ± 0.009</td>
</tr>
<tr>
<td>10^{-1.8}−10^{-1.6}</td>
<td>TNN 0.0005</td>
<td>0.9678 ± 0.0008</td>
</tr>
</tbody>
</table>

Gamma table snippet

<table>
<thead>
<tr>
<th>log10(E (TeV))</th>
<th>Cleaning</th>
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<tr>
<td>10^{-2}−10^{-1.8}</td>
<td>2LC 8.4</td>
<td>1 ± 0</td>
</tr>
<tr>
<td>10^{-2}−10^{-1.8}</td>
<td>2LC 12.4</td>
<td>0.959 ± 0.003</td>
</tr>
<tr>
<td>10^{-2}−10^{-1.8}</td>
<td>2LC 12.6</td>
<td>0.878 ± 0.008</td>
</tr>
<tr>
<td>10^{-2}−10^{-1.8}</td>
<td>2LC 12.8</td>
<td>0.84 ± 0.01</td>
</tr>
<tr>
<td>10^{-2}−10^{-1.8}</td>
<td>2LC 14.6</td>
<td>0.73 ± 0.02</td>
</tr>
<tr>
<td>10^{-2}−10^{-1.8}</td>
<td>2LC 14.8</td>
<td>0.67 ± 0.02</td>
</tr>
<tr>
<td>10^{-2}−10^{-1.8}</td>
<td>2LC 16.8</td>
<td>0.55 ± 0.03</td>
</tr>
<tr>
<td>10^{-2}−10^{-1.8}</td>
<td>TNN 0.0005</td>
<td>0.980 ± 0.001</td>
</tr>
<tr>
<td>10^{-1.8}−10^{-1.6}</td>
<td>2LC 8.4</td>
<td>1 ± 0</td>
</tr>
<tr>
<td>10^{-1.8}−10^{-1.6}</td>
<td>2LC 12.4</td>
<td>0.9888 ± 0.0003</td>
</tr>
<tr>
<td>10^{-1.8}−10^{-1.6}</td>
<td>2LC 12.6</td>
<td>0.964 ± 0.001</td>
</tr>
<tr>
<td>10^{-1.8}−10^{-1.6}</td>
<td>2LC 12.8</td>
<td>0.922 ± 0.002</td>
</tr>
<tr>
<td>10^{-1.8}−10^{-1.6}</td>
<td>2LC 14.6</td>
<td>0.897 ± 0.003</td>
</tr>
<tr>
<td>10^{-1.8}−10^{-1.6}</td>
<td>2LC 14.8</td>
<td>0.863 ± 0.003</td>
</tr>
<tr>
<td>10^{-1.8}−10^{-1.6}</td>
<td>2LC 16.8</td>
<td>0.791 ± 0.005</td>
</tr>
<tr>
<td>10^{-1.8}−10^{-1.6}</td>
<td>TNN 0.0005</td>
<td>0.99721 ± 0.00007</td>
</tr>
</tbody>
</table>

Proton table snippet
Comparing Event Images: Run 2222, Event 227801

Event image generated using 2LC 8.4

Event image generated using TNN 0.05% cleaning
Conclusion and Outlook

• TNN 0.05% poses no loss of information compared to default 2LC

• Always performs better than the default 2LC but also generates less noisy images → most efficient at keeping TRUE events

• Potential problems
  • Keep more low energy showers → harder to classify the shower primary
  • Generate instrument response functions (IRFs) —→ TNN’s impact on telescope sensitivity
References


Acknowledgments

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- From VERITAS: Reshmi Mukherjee, Marcos Santander
- From CTA: *Brian Humensky, Daniel Nieto, Abhineet Agarwal*