A “Spiffy” Trigger for Gamma-Ray Bursts

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Abstract.

The traditional design of trigger algorithms for GRB experiments requires the specification of the background and burst samples in terms of acquisition times that are of fixed duration and of fixed elapsed time from each other. One such set of acquisition times is required for each characteristic timescale of GRB variation that one desires to detect. One then slides each set through the trigger data searching for samples that maximize the signal-to-noise of the background-subtracted burst sample.

Here we describe a new triggering approach in which the times at which the background and burst samples are acquired are allowed to vary dynamically. Two background samples bracket a burst sample. The background and burst durations and elapsed time between them are allowed to be free parameters, which are maximized using the downhill simplex method. This produces great flexibility in the timescales that are available for detecting GRBs.

INTRODUCTION

The search for untriggered GRBs is has been an active field of research at least since the public release of BATSE data. Most recently, Komsers et al. [1] and Stern et al. [2] have described searches of BATSE data directed at revealing GRBs that occurred without being detected by the BATSE on-board triggers, either for operational reasons or because their spectral or temporal morphologies were poor fits to the on-board trigger criteria.

Naturally, the same considerations apply to GRB detection by HETE. The HETE mission deploys an unprecedentedly varied set of trigger criteria — the FREGATE DSP trigger [3] uses four timescales and operates in two energy bands, while the WXM XG trigger [4, 5] is typically configured to apply thirty or so criteria, some on WXM data and others on FREGATE data. Nevertheless the variety of GRB morphologies, and operational considerations, can result in GRBs that are not detected in flight. It is important to develop a strategy to mine HETE survey data for such untriggered GRBs.

Typical ground searches for untriggered bursts use detection methods that largely mirror on-board trigger algorithms [1, 2]. Background and burst samples are specified in terms of acquisition times that are of fixed duration and of fixed elapsed time from each other. Each GRB timescale — risetime or duration — is probed by a different fixed choice of these parameters. Each such fixed set of time windows is then swept through the time series being probed for transient events, searching for samples that maximize the signal-to-noise of the background-subtracted burst sample.

This scheme has the disadvantage of being rather inflexible about the the timescales that are probed. This inflexibility is especially troublesome when seeking weak signals, for which inaptly chosen burst or background samples may lead to a signal dilution that prevents detection.

In this work we describe an alternative approach that has been quite successful in identifying extremely weak events. In this approach, the background and burst samples are treated as free parameters, which are varied using the downhill simplex method of Nelder & Mead [6] to maximize the signal-to-noise ratio of the background-subtracted burst sample.

IMPLEMENTATION

The operation of the code, spiffy-trigger, is illustrated in Figure 1.

FIGURE 1. Illustration of the definition of the time parameters that are varied to search for transient events.
The trigger operates as a simplified “bracket trigger” [4, 5], in that the background is estimated using samples before and after the burst sample. The background is assumed constant, so no interpolation (linear or otherwise) is performed to obtain the background rate during the burst sample.

This restriction is not an essential feature of the method, but rather merely a simplification. The two background intervals are restricted to remain equidistant from the burst sample, so as to prevent the maximization procedure from exploiting a monotonic increase or decrease in the background rate to estimate an erroneously low background, by driving one of the background samples to a region of lower background without driving the other to a region of higher background.

The code operates on a time-series of integer counts. It advances a trigger window of fixed duration through the time series by steps of size \( \tau_{\text{skip}} \). It sets up a burst sample interval, of duration \( \tau_{\text{bu}} \), bracketed at an elapsed time \( \tau_{\text{el}} \) by two background sample intervals of duration \( \tau_{\text{bk}} \), the second of which ends at time \( t_{\text{end}} \). It calculates the SNR for the burst sample, assuming a background rate calculated by a weighted average of the count rates in the two background intervals.

The SNR is computed as follows: Assume for the sake of generality that the two background accumulation times may differ, so that we accumulate \( n_{\text{bk}1} \) counts in the first background during an accumulation time \( \tau_{\text{bk}1} \), and \( n_{\text{bk}2} \) counts in the later background accumulation time \( \tau_{\text{bk}2} \). Denoting the estimated background counts during the burst sample by \( \mu_{\text{bu}} \), and assuming the Gaussian approximation to the Poisson distribution, it is a straightforward exercise in Gaussian estimation to show that

\[
\begin{align*}
\mu_{\text{bu}} &= \frac{\tau_{\text{bk}1} + \tau_{\text{bk}2}}{\tau_{\text{bu}}} \Sigma^2, \\
\Sigma^2 &= \tau_{\text{bu}}^2 \left( \frac{\tau_{\text{bk}1}}{n_{\text{bk}1}} + \frac{\tau_{\text{bk}2}}{n_{\text{bk}2}} \right)^{-1},
\end{align*}
\]

where \( \Sigma^2 \) is the variance in the estimate \( \mu_{\text{bu}} \).

Denote by \( n_{\text{bu}} \) the counts that we accumulate during the burst sample. Then the net signal in the burst sample is \( s = n_{\text{bu}} - \mu_{\text{bu}} \). The variance in \( s \) is the sum of \( \Sigma^2 \) and the variance in \( n_{\text{bu}} \). Triggering is essentially hypothesis testing, with the null hypothesis consisting of the assumption that the count rate in the burst sample is the same as what is estimated using the background samples. Thus the appropriate choice for the variance of \( n_{\text{bu}} \) is “model variance”, that is \( \sigma^2_{\text{bu}} = \mu_{\text{bu}} \). Thus the SNR of the burst sample is

\[
\text{SNR} = \frac{n_{\text{bu}} - \mu_{\text{bu}}}{\left( \mu_{\text{bu}} + \Sigma^2 \right)^{1/2}}.
\]

This is the quantity that spiffy-trigger endeavors to maximize.

The code uses the simplex method to vary the four parameters \( t_{\text{end}} \), \( \tau_{\text{bk}} \), \( \tau_{\text{el}} \), and \( \tau_{\text{bu}} \), which are viewed by the simplex minimization routine as continuous parameters. A very lax convergence criterion is imposed — the absolute variation of the SNR must be less than 0.1 across the simplex — because in triggering there is no point in determining the SNR to great accuracy, and because we don’t want to spend many CPU cycles chasing noise.

The parameter \( t_{\text{end}} \) is constrained to be later than the end of the trigger window in the previous invocation. Consequently, the arrangement of burst and background samples “accordions out” backwards in time from the current time, without repeating choices of intervals made during previous iterations.

When there is no transient event in the data, the simplex will typically not wander very far from its initial configuration. On the other hand if there is a transient event, and the initial simplex includes a vertex corresponding to a configuration in which the burst sample even partially includes the event, the simplex will rapidly climb the SNR slope, dynamically adjusting its timescales until the event is well-bracketed.

Since the simplex does not wander far if it doesn’t find much at the outset, it is important to ensure that \( \tau_{\text{skip}} \) is not so large that a short event may “fall between the cracks” — that is, fail to have any of its constituent time samples included in a burst sample probed by the initial simplex. It is therefore a good idea to ensure that at simplex initialization, \( \tau_{\text{bu}} > \tau_{\text{skip}} \), for at least one of the simplex vertices. This ensures that every data sample passes through the burst sample of at least one initial simplex parameter vertex.

Constraints on the time parameters are imposed by making the SNR function return a large negative value when the constraints are violated. The previously-discussed constraint on the parameter \( t_{\text{end}} \) is enforced in this way. The code also uses this parameter-constraint mechanism to prevent intervals from encroaching upon each other, to ensure that \( \tau_{\text{bk}} \), \( \tau_{\text{el}} \), and \( \tau_{\text{bu}} \) remain positive-valued, and to keep all intervals inside the current trigger window.

Other useful constraints that it is good practice to enforce are a minimum value for \( \tau_{\text{el}} \) (so that burst and background samples are well-separated), a minimum duration for \( \tau_{\text{bk}} \) (so as to minimize the risk of the background nestling into a low fluctuation), and a maximum...
FIGURE 2. GRB detected by the trigger robot on 19 June 2001 at 15:17:01 UTC. The SNR of this event was 6.1, the duration was 3.7 s. This event was also detected by BeppoSax.

duration $\tau_{\text{bu}}$ (so as to minimize the risk of triggering on very long duration trends in the background).

DEPLOYMENT

spiffy-trigger is currently used in three different contexts within the HETE project:

- The Chicago ground location pipeline [7] uses spiffy-trigger to identify the burst sample time with maximal signal-to-noise in the WXM data. This sample is used throughout the subsequent location analysis.
- A robot script that runs after every downlink uses spiffy-trigger to search for untriggered bursts in FREGATE band C (40-300 keV) 1.3s resolution survey data. During normal HETE operation, it tends to see about 1 possible GRB per week, above and beyond detecting all triggers picked up in flight that are sufficiently hard, and long (or short but bright) to register at this timescale and in this energy band. Figure 2 shows an example of such an event, which was confirmed by BeppoSax.
- The general untriggered burst search described by Butler & Doty [8] uses spiffy-trigger in parallel to Butler & Doty’s wavelet trigger, and runs on all survey data products. GRB011212 was in fact detected on the ground in this pipeline, by both the wavelet algorithm and by spiffy-trigger.

CONCLUSIONS

The spiffy-trigger algorithm can probe a wide spectrum of burst timescales. It is still possible that initialization with a very short $\tau_{\text{bu}}$ might miss a very long, slow-rising event, or that a very long initial $\tau_{\text{bu}}$ might cause the SNR of a weak, short event to be too diluted to register before convergence is reached. However, careful choice of the range of $\tau_{\text{bu}}$ spanned by the initial simplex can address this issue to a large extent.

In any event, the algorithm may be re-run with radically different initial values of $\tau_{\text{bu}}$. For example, re-running the algorithm three times, with $\tau_{\text{bu}}$ set initially to 0.1s, 3s, and 100s — with suitably chosen initial simplices — one may probe a range of timescales that would probably require hundreds of criteria for a traditional trigger algorithm to examine.

In principle, there is no reason the spiffy-trigger algorithm could not be deployed in flight in a future mission. The floating-point operations that it performs are not particularly expensive, particularly for modern space computing hardware. While more complex than a traditional trigger, it is not vastly more so, and its complexity is offset by its great flexibility, configurability, and dynamic range of burst timescales to which it is sensitive.

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