1. Introduction

We describe an implementation of a low-latency, stream-based approach to CBC searches, an application of the gstlal library. Our approach addresses the computational problems posed by long templates (~10^5 s), large template banks (~10^12 templates) and long lock stretches (~12 hr) needed to do analysis in the era of advanced detectors. Our solution to these problems involve down-sampling templates, eliminating overlap in the template bank and filtering across gaps in data.

The stream-based approach has the added benefit that the same code is capable of both offline, batch-mode processing and online, low-latency processing (~1 s). The prompt emission of many EM transients fades quickly, so catching them early will maximize the flux available to rapid-response telescopes and give access to the early lightcurve, which encodes more of the central engines’ processes and less of the free expansion into the progenitors’ surrounding medium.

2. Dealing with long templates

Long duration templates are computationally problematic for CBC searches. With current detector sensitivity (\( f \leq 40 \text{Hz} \)), CBC waveforms in the worst case 1.0–1.0 \( M_\odot \) are a mere 45 seconds long. By contrast, with advanced detector sensitivity (\( f \geq 15 \text{Hz} \)), template waveforms will reach up to 600 seconds long. This effect and the concomitant 10-fold increase in the template bank size imply a 100-fold increase in the computational scale of advanced LIGO/Virgo data analysis.

We take advantage of the frequency evolution of chirp waveforms and the linearity of the filtering operation by breaking up templates into pieces and down-sampling each piece of the waveform (see figure left). Each of the template pieces flows through the pipeline as if it were itself a complete template bank (see figure below). These pieces are recombined after filtering to obtain the SNR time series for the original bank.

3. Eliminating template overlap

To reduce the number of needed templates, we stack the whitened templates from a template bank into a matrix \( A \) and apply a singular value decomposition (SVD) to this matrix. The SVD expansion

\[
A \approx \sum_{k=0}^{r} \sigma_k |v_k\rangle \langle u_k|,
\]

determines the (numerical) dimension \( r \) of the space spanned by the templates and picks out a set of \( r \) orthonormal vectors \( |u_k\rangle \) that span the same space.

Typically, SVD analysis results in a 10-fold reduction in the size of the bank. When applied to low-frequency portions of inspiral waveforms, the reduction can be 100-fold or greater.

4. Conditional computation

After computing the SVD, we filter the data (denoted \( \hat{\mathbf{p}} \)) against the smaller, orthogonal bank to form the “orthogonal SNRs”

\[
\hat{\mathbf{p}}_{\text{orthogonal}} = \langle v_k| \hat{\mathbf{p}} \rangle = \sigma_k \langle u_k| \mathbf{v}_k \rangle.
\]

Construction of the physical SNRs from the orthogonal SNRs requires the application of a unitary transform:

\[
\mathbf{p}_{\text{physical}} = \sum_{k=0}^{r} |v_k\rangle \langle v_k| \mathbf{p}_{\text{orthogonal}}.
\]

The computational cost of this transformation scales like \( T_r \), where \( T \) is the size of the original (physical) template bank and \( r \) is the size of the reduced (orthogonal) bank.

In order to avoid the costly construction step, we compute a composite detection statistic from the orthogonal SNRs. We contrast the physical SNRs for parameter estimation only when the detection statistic indicates that a signal is present.

References:
SVL: arXiv:1005.0012
Conditional reconstruction: arXiv:1101.0584

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