LIGO SURF Project Plan
CWB Optimization for GW Signal Waveform Reconstruction Stage

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Introduction/Background

September 14, 2015, marked the historical gravitational wave signal detection, GW150914 [1], by the Advanced Laser Interferometric Gravitational Wave Observatories. Two different types of searches independently confirmed the strong signals from binary black hole mergers. We will focus on profiling and optimizing the runtime performance of a key routine in one search, the Coherent Waveburst (CWB) pipeline.

CWB identifies transient gravitational wave (GW) events, from a broad range of generic transient signals and determines which events could be considered significant above a certain level of standard deviation. Events are tagged with likelihood a value that ranks their probability of being a gravitational-wave signal. The significance of an event with given likelihood, is determined by a background rate—the rate at which detector noise produces events with a likelihood value equal to or higher than the candidate event. The bulk of compute time in the CWB pipeline is consumed by estimating these background rates, where time-frequency analysis and time-shift analysis over 10s of thousands of sky locations are performed.

Objectives

The aim of this project is to understand and address cause(s) for a section of CWB known to be time consuming, and a probable candidate for porting to execution on a GPU or Many Integrated Core (MIC) architecture. The initial target routine is the most CPU consuming step in the reconstruction, according to prior profiling runs, of the GW signal waveforms. These waveforms are constructed as a superposition of Wilson-Daubechies-Meyer wavelets. The function under consideration computes the weight of each wavelet in the reconstructed signal. Figure 1 shows the pseudo code for this function.

We will target our initial profiles and porting efforts to available GPUs and Intel Phis on LIGO resources, using short and production length runs, studying overall runtime performance throughout the code, but focusing first on the key waveform reconstruction loop.

```
Algorithm
//CalculationPreparation
1.*mk <- pAVX[1]
2.wavearray<float>norm(NIFO+1)
3.*nn <- norm_data
//Calculation
4.for m <- 0 to M
a.     for j <- 0 to J
b.        NETX_CALCULATION()
//SaveData
5.for n <- 1 to XIFO
a.     q[n-1][M+5]<-nn[n]
b.     e<-q[n-1][M+4]*q[n-1][M+4]
c.     nn[n]<-e/nn[n]
d.     nn[0]<-nn[0]+nn[n]
6.return norm
```

Figure 1: Calculating the weight of each wavelet

Optimization potentials we see in this algorithm are in sections, CalculationPreparation and Calculation. Efforts for optimizing will mostly focus on changing the way data is transferred, minimizing time delay, parallelizing for loops and the NETX_CALCULATION step.

Profiling and analysis will produce the following project deliverables:

- **Identify areas of opportunity** – minimize data transfers to and from the GPU, restructure loops, overlap communications with computation, experiment with compiler flags to leverage special instructions, explore appropriate CUDA libraries and directives.
- **Timings on various hardware –** runtimes across different GPUs and MICs will be generated and analyzed.
- **Feedback to code developers** – as analysis and code optimizations are in progress, primary code authors will be asked to review our findings. The hope is some of the code porting and optimization techniques will be useful enough to incorporate into a production version of CWB.

Approach

The approach to the project is the following:

- Weeks 1 – 2: Run the identified version of CWB software and gain familiarity with how to profile using a simple but meaningful data set. The compute platforms will be Caltech LIGO head nodes, hosting P[4,40,100], GTX [750Ti,1050Ti,1070,1080] GPUs and an Intel Xeon Phi test node.
- Weeks 3 – 7: Analyze the profiled runs and decide where and how improvements can be made in our target function. We will consider various CUDA routines for array manipulation, compilers (PGI, Intel) and optimization flags (e.g. AVX-512 instructions, architecture specific tuning), data structure modifications, etc. Effort to implement each optimization and porting approach will be assessed, making sure we stay on track to try the most promising ideas.

✐! Weeks 8 – 10: the results will be analyzed, a final summary will be submitted and presented, and ideally solutions, which can be integrated into the main CWB pipeline, are approved.

References

[1] B.P. Abbott et al. (LIGO Scientific Collaboration and Virgo Collaboration). Characterization of transient noise in Advanced LIGO relevant to gravitational wave signal GW150914. *arXiv:1602.03844* (2016)