Improving the Stochastic Template Bank Algorithm for aLIGO

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SURF LIGO 2016

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Summary

- LIGO's anticipated increase in signal events will require performance improvements to template bank generation
- The Metropolis-Hastings algorithm provides an intelligent method for stochastic template placement
- Parallel computing provides significant runtime improvement with access to large, multi-threaded machines

Matched Filtering can yield a Positive Signal from Noise

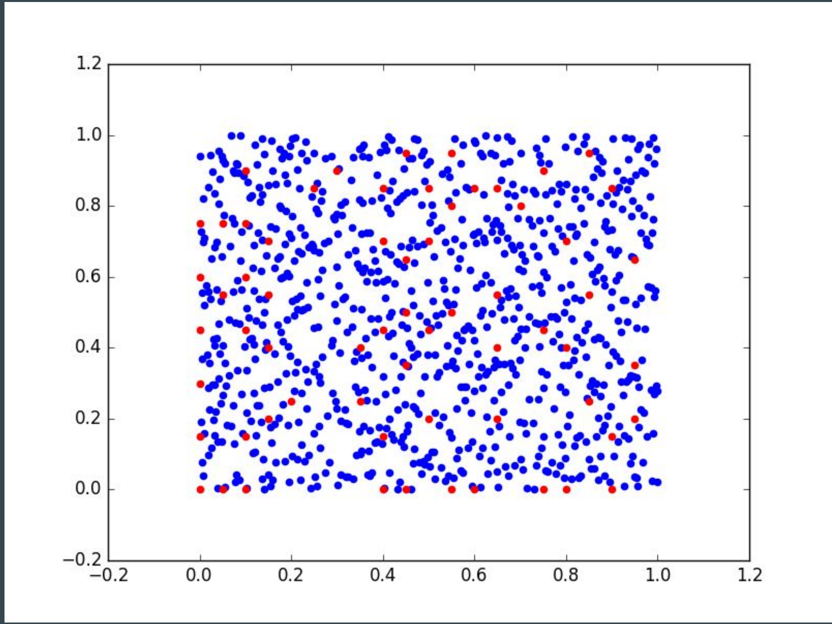
- Post-Newtonian approximations provide accurate models of the inspiraling compact two-body model
- Models are user-defined and can span the physical parameter space
- Raw data is filtered through an array of modeled waveforms, called a ***Template Bank***

Increasing Need for Faster Template Bank Generation

- The continued advance of GW detection methods constantly improve the sensitivity and range of aLIGO and aVIRGO for their next engineering runs
- LIGO anticipates between tens and hundreds of GW detections within the next few years
- A more efficient form of analysis will be required to digest this volume of data

Conceptual Model

- Place points in a non-linear space with fixed range
- Require a minimum distance between adjacent points
- Randomly propose new points for the space
- Keep track of coverage and runtime for all trials



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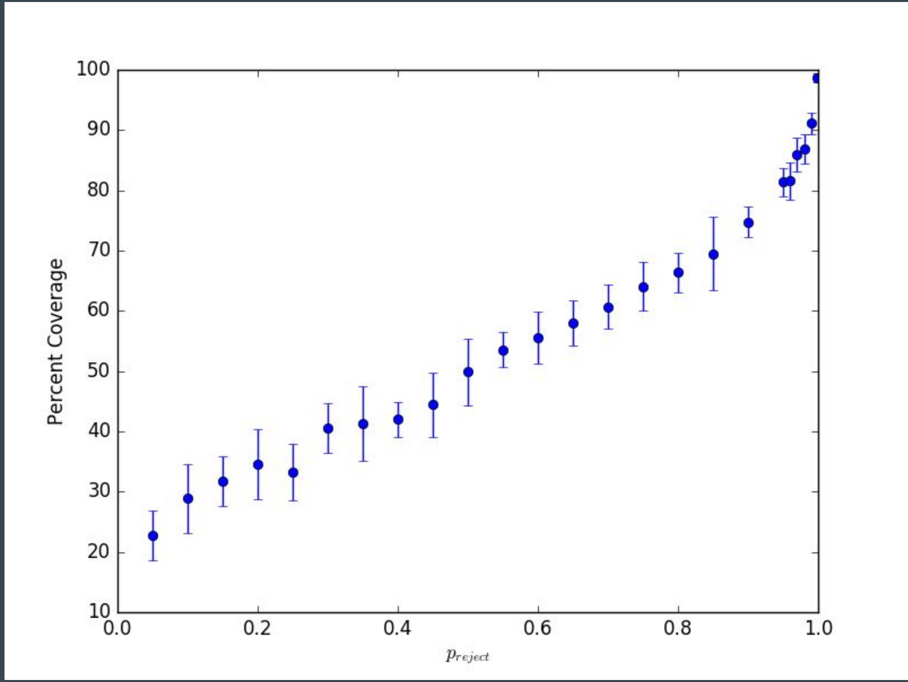
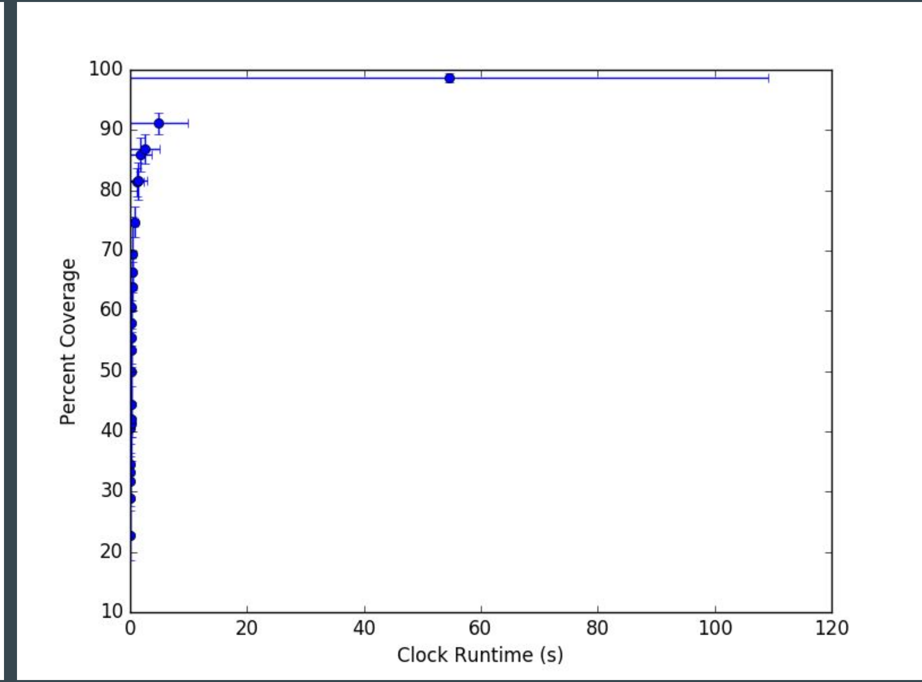
Conceptual Model: Metropolis-Hastings

1. Divide the grid into cells of equal area (volume)
2. Keep track of the number of accepted and rejected proposals in each cell
3. For every new proposal:
    a. Calculate the ratio between rejections and total proposals in that cell
    b. If this ratio is less than a uniform random variate on (0,1], then test this point
    c. Otherwise, test a new proposal (repeat 3)
4. Continue this looping process until all cells have a ratio exceeding a user-defined value, ρ_{reject}

Runtime and Coverage trade-off with ρ_{reject}





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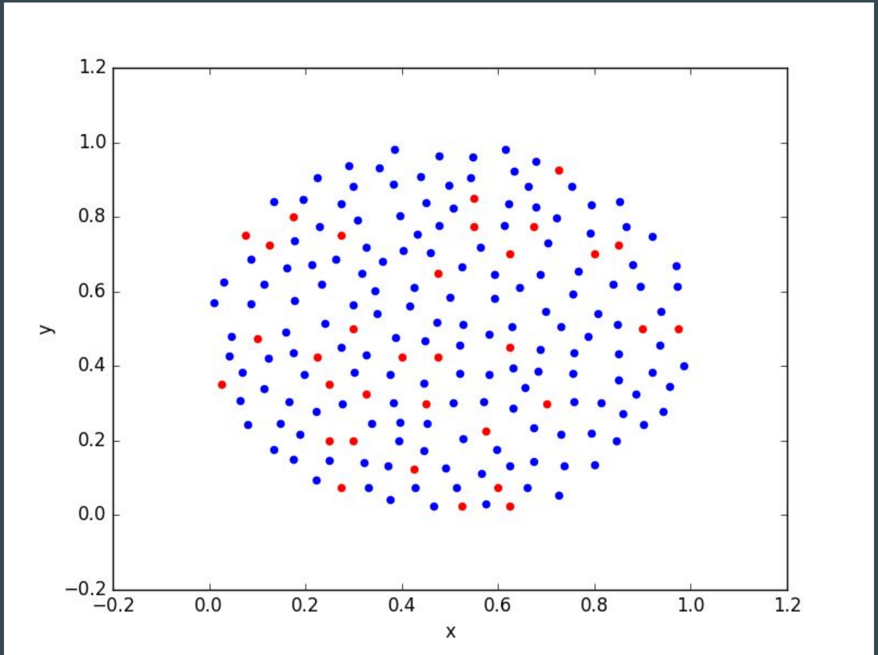
Conceptual Model: Parallelization

1. Parameter space is divided into cells of equal size
2. Each cell is assigned a thread for computation
3. Create and test proposals until the thread encounters a user-defined consecutive number of rejections

This method provides roughly two orders of magnitude improvement in runtime with no sacrifice to coverage.



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Our Stochastic Template Bank Algorithm

- Follows the same process as the Metropolis-Hastings algorithm from the conceptual model
- Several computational threads will be generating and testing proposals
- Remove cells once they have exceeded the user-defined rejection ratio
- When all cells have been removed, write templates to an XML file for plotting and manipulation

OpenMP

- Open-source framework for Multi-Processing
- Interfaces with C/C++ and Fortran
- Provides simple compiler flags and directives for parallelism
- The programmer (NOT user) defines the number of threads used by the program

Confining The τ_0-τ_3 Space

$$\tau_3 < \frac{A_3}{A_0^{2/5}} \frac{\tau_0^{2/5}}{\eta_{min}^{3/5}}$$

$$\tau_3 > \frac{A_3}{A_0^{2/5}} \frac{\tau_0^{2/5}}{\eta_{max}^{3/5}}$$

$$\tau_3 > \frac{A_3}{A_0} \tau_0 M_{min}$$

$$\tau_3 < \frac{A_3}{A_0} \tau_0 M_{max}$$

$$\tau_3 < \frac{A_3}{A_0} \tau_0 x^3 \bigg|_{m_e = m_{1,min}}$$

$$\tau_3 < \frac{A_3}{A_0} \tau_0 x^3 \bigg|_{m_e = m_{1,max}}$$

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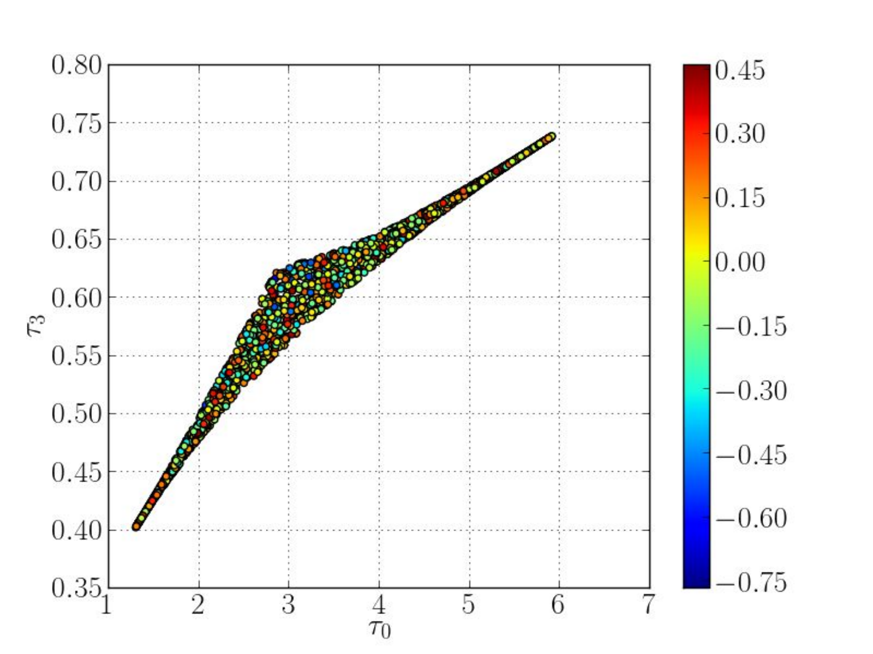
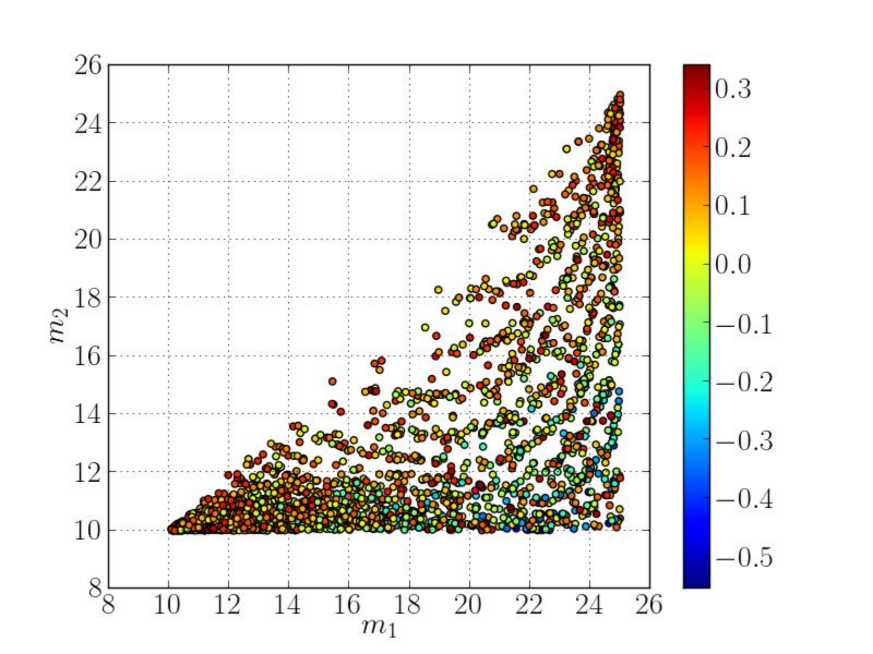
- Template density is roughly in chirp-time space
- Provides benefit to parallel method and random generation
- Boundaries can be expressed in terms of m_1 and m_2
- However, Some boundaries are difficult to constrain, requiring numerical solutions

Brent's Algorithm

- Used for a quick and low-iteration numerical (bracketed) root finder
- Utilizes superlinear numerical methods when possible, and corrects with bisection
- Implemented to constrain the bounds on τ_0

Parallel Generated Template Bank





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Concluding Remarks

- Implementing Metropolis-Hastings with parallel methods will provide the best improvement to runtime at no cost of coverage and precision
- Running parallel threads on all cells allows for full usage of parallel techniques while eliminating the possibility of one process finishing early.
- This algorithm will open the powerful computational tools to other necessary scripts, allowing for a greater digestion of events by the LDG

Acknowledgements

- Dr. Kent Blackburn
- Dr. Alan Weinstein
- The LIGO Scientific Colaboration
- California Institute of Technology
- Rochester Institute of Technology
- 2016 SURF Students

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Questions?

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Julia

- Up-and-Coming numerical computing language developed at MIT
- Functions with python libraries and utilizes open-source C and Fortran functions for performance
- Operates parallel computing by remote calls and *message passing*
    - Not suitable for the stochastic bank implementation

Van Wijngaarden-Dekker-Brent Method

- Bisection method is very reliable and will converge towards a bracketed root
- less-reliable secant method and inverse quadratic interpolation are much more ambitious but can fail at times
- This algorithm provides a balance between reliability and speed for quick convergence

The Metropolis-Hastings Algorithm

- Markov chain Monte Carlo (MCMC) method of generating random variates from a given distribution
- Best used for when direct sampling is difficult
  - High-dimensional problems suffer in time complexity from direct sampling
- Can potentially suffer from auto-correlation between consecutive samples
  - Adaptive rejection sampling is a direct non-correlated alternative

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