Effects of Gravitational Waves on Modern Computing Systems

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Abstract

We propose a citizen science framework to explore gravitational wave (GW) properties by exploiting modern computing systems as auxiliary detectors. Instead of measuring fractional deviations in raw clock frequency, which are minuscule (order 10^{-12} Hz for GHz clocks), we leverage the computational rate (operations per second) as an amplification mechanism. This approach scales deviations by factors of 10^3 to 10^6, potentially rendering otherwise undetectable effects into measurable statistical signals. The framework includes dummy artificial neural network (ANN) workloads, distributed logging across commodity PCs, and extensions to high-performance computing (HPC) clusters such as EAGLE, with real-time correlation against LIGO/Virgo alerts.

1 Introduction

Gravitational waves (GWs) induce minute spacetime perturbations. Current detectors (LIGO, Virgo) are highly specialized laser interferometers optimized for $10 - 10^3$ Hz bands. Here, we explore whether distributed computing systems—with stable clocks, GPUs, and CPUs—could serve as complementary sensors by monitoring deviations in computational throughput.

2 Theoretical Framework

2.1 Weak-field approximation

In linearized general relativity, the spacetime metric is approximated as:

$$g_{\mu\nu} = \eta_{\mu\nu} + h_{\mu\nu}, \quad |h_{\mu\nu}| \ll 1, \tag{1}$$

where $h_{\mu\nu}$ is the GW perturbation. For a monochromatic GW of strain amplitude $h \sim 10^{-21}$, the fractional frequency shift on a stable clock is

$$\frac{\Delta f}{f} \sim h(t). \tag{2}$$

For a GHz-scale clock ($f \sim 10^9$ Hz), this yields

$$\Delta f \sim 10^{-12} \text{ Hz}, \tag{3}$$

far below detection thresholds.

2.2 Principle of Amplification

We propose shifting from frequency f to computational throughput R (operations per second). If each core performs A operations per cycle, then

$$R = Af. \tag{4}$$

The fractional effect is

$$\frac{\Delta R}{R} \sim h(t), \quad \Delta R \sim Rh(t). \tag{5}$$

Thus,

$$\Delta R \sim Afh(t). \tag{6}$$

2.3 Numerical Example

Consider:

- $f = 10^9$ Hz,
- $h \sim 10^{-21}$,
- $10^3 < A < 10^6$.

Then,

$$\Delta R \sim A \cdot 10^9 \cdot 10^{-21} = A \cdot 10^{-12}. \tag{7}$$

For $A = 10^6$, this yields 10^{-6} fractional deviation, six orders of magnitude larger than Δf.

3 Scaling Laws

3.1 Amplification factor A

The computational parallelism factor A enhances detectability. GPUs, SIMD units, and vectorized cores maximize A.

3.2 Ensemble averaging N

With N independent systems, statistical sensitivity scales as:

$$\text{SNR} \propto \sqrt{N}. \tag{8}$$

Thus, distributed citizen participants provide multiplicative sensitivity improvements.

4 Extension to HPC and Cloud Systems

4.1 EAGLE Supercomputer Example

The EAGLE cluster achieves $R_{tot} \sim 10^{17}$ FLOP/s using $N_{CPU} \sim 1.5 \times 10^5$ CPUs. For GW strain $h \sim 10^{-21}$:

$$\Delta R_{tot} \sim 10^{17} \times 10^{-21} = 10^{-4} \text{ FLOP/s}. \tag{9}$$

While small, HPC systems operate with high stability, allowing correlation over time.

Effective sensitivity is enhanced by parallelism:

$$\Delta R_{eff} \sim \sqrt{N_{CPU}} \cdot \Delta R_{per\,CPU}. \tag{10}$$

For $N_{CPU} \sim 1.5 \times 10^5$, sensitivity improves by factor ~ 400.

5 Noise Models and Confidence

5.1 Thermal jitter

Thermal fluctuations induce timing jitter of order 10^{-6} to 10^{-8} in CPUs. Statistical averaging and temperature sensors can help discard false triggers.

5.2 Matched filtering and whitening

Applying LIGO-style matched filtering and whitening to computational time series data enhances confidence.

6 Proposed Citizen Science Deployment

6.1 Local monitoring

Participants run idle ANN workloads, logging deviations.

6.2 Trigger from LIGO/Virgo

When LIGO/Virgo announce an event, clients enter high-precision mode, logging computational deviations with ultra-stable clocks.

6.3 HPC-triggered experiments

We propose extending this to HPC/cloud systems (e.g., Azure, EAGLE), running workloads triggered by LIGO alerts. These workloads can probe overlapping frequency bands (e.g., 0.1–10 Hz domain), complementing interferometer bands.

7 Feasibility and Novelty

- Novelty: Using computational rate as an *amplification observable*.
- Feasibility: Consumer PCs are noisy, but distributed averaging + HPC triggers may yield statistical sensitivity.
- Complementarity: Provides a stochastic citizen-science verification layer to LIGO.

8 Conclusion

We propose **CitizenGW-Compute**, a distributed computing experiment leveraging computation rate as an amplification of GW strain effects. With extensions to HPC/cloud systems triggered by LIGO alerts, this approach explores new frequency bands, offering citizen scientists and supercomputers alike a complementary path to GW detection.

References

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