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LIGO and Grid Computing Final Results

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Abstract
The laser interferometers at LIGO use the fringe pattern of a divided laser beam to measure any lengthening or shortening of space due to gravitational waves. The divided laser beam will travel through two steel vacuum tubes oriented at a right angle. When a gravitational wave distortion causes one beam to lengthen and the other to shrink, the interference pattern of the two beams will. LIGO was first designed to have an effective range of ~70 million light years. LIGO's interferometers are the world's largest precision optical instruments. They are housed in one of the world's largest vacuum systems (volume of nearly 300,000 cubic feet). The beam tubes and associated chambers must be evacuated to a pressure of only one-trillionth of an atmosphere, so that the laser beams can travel in a clear path with a minimum of scattering due to stray gases. To do this they use a steel with a very low dissolved hydrogen content.

Keywords
Interferometers, LIGO, gravitational waves, Grid computing, LISA

I. Introduction

The LIGO laser light comes from high-power, solid-state lasers that must be so well regulated that, over one hundredth of a second, the frequency will vary by less than a few millionths of a cycle. The suspended mirrors must be so well shielded from vibration that the random motion of the atoms within the mirrors and suspension fibers can be detected. More than 30 different control systems are required to hold all the lasers and mirrors in proper alignment and position, to within a tiny fraction of a wavelength over the four-kilometer lengths of both arms of the interferometers.

LIGO is a program with two observatories currently in the United States located in the cities of Hanford, Washington and Livingston, Louisiana. It was cofounded in 1992 by Kip Thorne and Ronald Drever of California Institute of Technology and Rainer Weiss of Massachusetts Institute of Technology, LIGO is a joint project between scientists at MIT and Caltech. The project cost of $365 million dollars and is the largest funding ever received for a project by the National Science Foundation (NSF). Today LIGO is a growing research project with now recording well over 600 researchers working and analyzing data from LIGO.

In Einstein's General Theory of Relativity, gravitation is equivalent to a distortion of space. Therefore, a gravitational disturbance causes an additional distortion that propagates through space and a manner similar to mechanical or electromagnetic waves. When gravitational waves from a disturbance pass by the earth, they create a distortion of the local space. The LIGO apparatus is designed to detect this sort of distortion as shown in following figure (Fig1)

Fig. 1 : The LIGO experiment consists of two laser interferometers located in Livingston, Louisiana and Hanford

Imagine a fishing bob in a still pond. The bob distorts the plane of the pond surface in one location as it floats on the water. When a fish disturbs the bob, waves ripple out in all directions over the surface of the water, distorting the plane across its width. Now, imagine a huge mass in space such as a dying star "bobbing" on the plane of space-time as the star explodes. The resulting waves, which ripple from this disturbance, travel at light-speed in all directions of space. These waves, which will change the space in which they move, can be measured with a laser interferometer. By the time the waves from events such as the death of a star have reached earth, they have traveled thousands, or even millions of light-years. They reach us as diffuse, weak waves that distort space-time and everything in it, but only a little. This miniscule warping effect is measurable; and to do so, we must rely on the fact that gravitational waves can go through any material and warp what they are passing through. When they arrive at earth, they will distort the space along the interferometer beam paths.

II. Interferometer

The interferometer, invented by the American physicist A. A. Michelson (1852–1931), splits a light beam into two parts and then recombines the parts to form an interference pattern. The device can be used to measure wavelengths or other lengths with great precision because a large and precisely measurable displacement of one of the mirrors is related to an exactly countable number of wavelengths of light as shown in Fig-2.

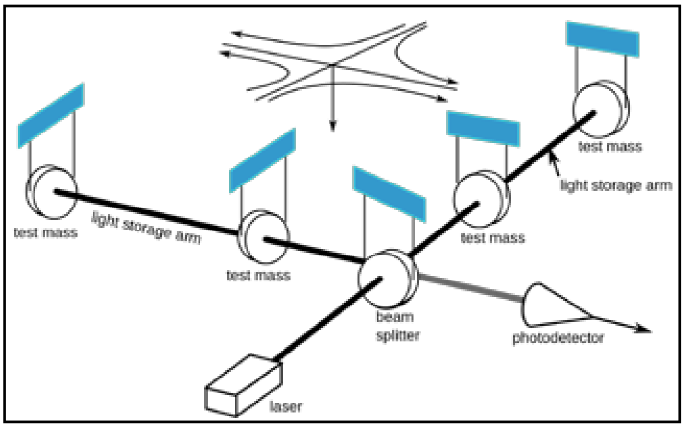

Fig. 2 : A schematic diagram of a laser interferometer. A gravitational-wave observatory

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LIGO Livingston's infrared laser is housed in the corner station and passes through the beam splitter before being channeled into the two beam tube arms. Each arm is 4 km (about 2.5 miles) in length. The LIGO Project thus consists of three interferometers – the 4 km installation at Livingston and a dual 2 km and 4km installation at Hanford, WA. Multiple instruments will help the LIGO scientists sort out genuine gravitational wave signals from 'noise', since a genuine signal should be detected in all three instruments. The LIGO interferometers, along with the European and Japanese instruments will hopefully produce an effective system to identify the locations in the sky of events that release gravitational waves.

The LIGO interferometers work by splitting a laser beam into two beams that travel through vacuum tubes situated at a right angle. The original beam directly from the laser is modified by various optical elements in the corner station to produce a working beam of exceedingly high uniformity and stability. The vacuum chambers are 4 km in length and are constructed of welded steel tubes that are 1.3m (4 ft.) in diameter and 3mm. (1/8 in.) thick. The 250 mm. (10 in.) mirrors are suspended at the end stations. The mirrors are suspended on wires from tables that are designed to eliminate any movement caused by other forces such as earthquakes, wind, earth tidal motion, etc. The vacuum tubes and optical chambers where the mirrors are housed are designed to create a "clean" pathway through which the laser light can travel.

LIGO's interferometers have additional mirrors besides those shown in the Michelson drawing above. Fabry-Perot mirrors, which are located in the corner station, cause the laser light to bounce back and forth within each arm a number of times as more light is added to the arms, building up the light power in each arm before the light is able to escape. A recycling mirror, also in the corner station, sends returned light back to these Fabry-Perot cavities. The additional light power created by these features allows the interferometer to detect weaker signals.

As the laser beam travels back and forth between the mirrors up to 100 times in a millisecond, any shift of the mirrors by a gravitational wave will be detected by changes in the interference pattern that will be seen at the interferometer's detector.

The LIGO mission (or objective) is to observe gravitational waves of cosmic origin. Here are some of the possible sources of gravitational radiation or waves – (1) The supernova collapse of stellar cores to form neutron stars or black holes, (2) The collisions and coalescences of neutron stars or black holes, (3) The wobbly rotation of neutron stars with deformed crusts and (4) The remains of radiation (gravitational) created in the early universe.

III. The Future of LIGO

Despite LIGO being very young, they have already begun in advancements of LIGO, recently there was more funding granted to LIGO to expand and improve upon LIGO creating: LIGO ADVANCED (LIGO 2)

This improvement should increase the accuracy considerably and bandwidth of the interferometer and allow for much greater possibilities in the future of its research. LIGO 2 should be completed in the year 2014.

LISA, the Laser Interferometer Space Antenna, is a proposed joint project of NASA and the European Space Agency to build a laser interferometer gravitational wave detector consisting of three spacecraft in solar orbit. LISA will receive different types of readings than LIGO(LISA receives the readings in higher frequency than LIGO), so the two experiments will complement each other.

IV. Grid Computing

Large-scale science and engineering are done through the interaction of people, heterogeneous computing resources, information systems, and instruments, all of which are geographically and organizationally dispersed. The overall motivation for "Grids" is to facilitate the routine interactions of these resources in order to support large-scale science and Engineering. Challenging Technical Requirements is Dynamic formation and management of virtual organizations, Online negotiation of access to services: who, what, why, when, how, Establishment of applications and systems able to deliver multiple qualities of service, and Autonomic management of infrastructure elements.

Analogy with the electrical power grid is "On-demand" access to ubiquitous distributed computing, transparent access to multi-petabyte distributed data bases, and easy to plug resources into complexity of the infrastructure is hidden. When the network is as fast as the computer's internal links, the machine disintegrates across the net into a set of special purpose appliances. E-Science and information utilities of Science is increasingly done through distributed global collaborations between people, enabled by the Internet using very large data collections, terascale computing resources, and high performance visualisation; are derived from instruments and facilities controlled and shared via the infrastructure, and scaling x1000 in processing power, data, bandwidth.

Aspects of the Problem involves need for interoperability when different groups want to share resources, need for shared infrastructure services to avoid repeated development, installation and a common need for protocols & services.

A software toolkit addressing key technical problems in the development of Grid-enabled tools, services, and applications. Offer a modular set of orthogonal services enable incremental development of grid-enabled tools and applications, implement standard Grid protocols and APIs, be available under liberal open source license with large community of developers & users, and give commercial support.

Grid computing is a form of distributed computing whereby a "super and virtual computer" is composed of a cluster of networked, loosely coupled computers, acting in concert to perform very large tasks. Grid computing (Foster and Kesselman, 1999) is a growing technology that facilitates the executions of large-scale resource intensive applications on geographically distributed computing resources. It provides facilitates flexible, secure, coordinated large scale resource sharing among dynamic collections of individuals, institutions, and resource. It enables communities ("virtual organizations") to share geographically distributed resources as they pursue common goals. Criteria for a Grid includes coordinating resources that are not subject to centralized control, using standard, open, general-purpose protocols and interfaces, and delivering nontrivial qualities of service. Benefits are exploiting underutilized resources, taking resource load balancing, virtualizing resources across an enterprise, using Data Grids, Computing Grids and enabling collaboration for virtual organizations.

Grid applications involves data and computationally intensive applications. This technology has been applied to computationally-intensive scientific, mathematical, and academic problems like drug discovery, economic forecasting, seismic analysis back office data processing in support of e-commerce. A chemist may utilize hundreds of processors to screen thousands of compounds per hour. Teams of engineers worldwide pool resources to analyze terabytes of structural data. Meteorologists seek to visualize and analyze petabytes of climate data with enormous computational demands. It includes resource sharing with Computers, storage, sensors, networks. Sharing always conditional: issues of trust policy, negotiation, payment. Coordinated problem solving be done with distributed data analysis, computation, collaboration.

V. Grid Topologies

Grid Topologies have 3 types, intragrid, extragrid and intergrid. Intragrid includes local grid within an organisation, and trust based on personal contracts. Extragrid includes resources of a consortium of organisations connected through a (Virtual) Private Network, and trust based on Business to Business contracts. Intergrid includes global sharing of resources through the internet, and trust based on certification.

A data grid is a grid computing system that deals with data — the controlled sharing and management of large amounts of distributed data. Data Grid is the storage component of a grid environment. Scientific and engineering applications require access to large amounts of data, and often this data is widely distributed. A data grid provides seamless access to the local or remote data required to complete compute intensive calculations. Examples are Biomedical informatics Research Network (BIRN), and the Southern California earthquake Center (SCEC).

Methods of Grid Computing are Distributed Supercomputing, High-Throughput Computing, On-Demand Computing, Data-Intensive Computing, Collaborative Computing, and Logistical Networking. Combining multiple high-capacity resources on a computational grid into a single, virtual distributed supercomputer, that tackles problems that cannot be solved on a single system. High-Throughput Computing uses the grid to schedule large numbers of loosely coupled or independent tasks, with the goal of putting unused processor cycles to work. On-Demand Computing uses grid capabilities to meet short-term requirements for resources that are not locally accessible. It models real-time computing demands. Collaborative Computing is concerned primarily with enabling and enhancing human-to-human interactions. Applications are often structured in terms of a virtual shared space. Data-Intensive Computing is concerned with that the focus is on synthesizing new information from data that is maintained in geographically distributed repositories, digital libraries, and databases. It is particularly useful for distributed data mining. Logistical Networking Logistical networks focus on exposing storage resources inside networks by optimizing the global scheduling of data transport, and data storage, contrasts with traditional networking, which does not explicitly model storage resources in the network, makes high-level services for Grid applications Called "logistical" because of the analogy it bears with the systems of warehouses, depots, and distribution channels.

Grids are typically managed by grid ware - a special type of middleware that enable sharing and manage grid components based on user requirements and resource attributes (e.g., capacity, performance) Software that connects other software components or applications to provide the following functions: running applications on suitable available resources, brokering, Scheduling, providing uniform, high-level access to resources, providing semantic interfaces– Web Services, Service Oriented Architectures, address inter-domain issues of security, policy, etc, Federated Identities, providing application-level status, and monitoring and control.

VI. Computational Grid

A computational grid is a hardware and software infrastructure that provides dependable, consistent, pervasive, and inexpensive access to high-end computational capabilities. A computational grid is a hardware and software infrastructure that provides dependable, consistent, pervasive, and inexpensive access to high-end computational capabilities. A computational grid is a hardware and software infrastructure that provides dependable, consistent, pervasive, and inexpensive access to high-end computational capabilities. A computational grid is a hardware and software infrastructure that provides dependable, consistent, pervasive, and inexpensive access to high-end computational capabilities.

The major motivation was that these high performance computing resources were expensive and hard to get access to, so the starting point was to use federated resources that could comprise compute, storage and network resources from multiple geographically distributed institutions, and such resources are generally heterogeneous and dynamic.

Grids focused on integrating existing resources with their hardware, operating systems, local resource management, and security infrastructure. In order to support the creation of the so called "Virtual Organizations"—a logical entity within which distributed resources can be discovered and shared as if they were from the same organization, Grids define and provide a set of standard protocols, middleware, toolkits, and services built on top of these protocols. Interoperability and security are the primary concerns for the Grid infrastructure as resources may come from different administrative domains, which have both global and local resource usage policies, different hardware and software configurations and platforms, and vary in availability and capacity.

VII. Conclusions

A gravitational disturbance causes an additional distortion that propagates through space and a manner similar to mechanical or electromagnetic waves. LIGO Livingston's infrared laser is housed in the corner station and passes through the beam splitter before being channeled into the two beam tube arms. Aspects of the Problem involves need for interoperability when different groups want to share resources, need for shared infrastructure services to avoid repeated development, installation and a common need for protocols & services. A computational grid is a hardware and software infrastructure that provides dependable, consistent, pervasive, and inexpensive access to high-end computational capabilities.

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