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Analytical and Technical Analysis of the Computing Concepts and Applications with Emphasis in Predictive Analytics, Lattice Quantum Chromo Dynamics, and Computational Cosmology

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ABSTRACT

The studies related to the Concepts of Advanced Computing have been reviewed and discussed. The applications of Advanced computing in Particle Physics, Networking and Data Handling have been discussed. The facilities required for advanced computing are briefly described. Special emphasis has been placed on the role of Advanced Computing on Science and Engineering. Simulation for Optimization in Predictive Analytics, and also for maximizing the output and profit of the commerce and industry have also been briefly discussed. Design Considerations for Lattice Quantum Chromo Dynamics (QCD) have been discussed, and presented in this paper. The treatment has been based on expressing the strong interaction between quarks mediated by gluons, and considering the space-time lattice to be distributed across all of the nodes. The Lattice QCD (- D meson semileptonic decay amplitudes), as reported in the literature, has been technically discussed. Comparison between Quantum Electrodynamics (QED) and QCD has been briefly brought out. A brief description of the Simulation of large scale structures, cosmic web of dark matter filaments and halos, has also been given. The paper is expected to be useful to the new entrants in the field and also the senior Technology in the scientific fields.

In particle physics the semileptonic decay of a hadron is a decay caused by the weak force in which one lepton (and the corresponding neutrino) is produced in addition to one or more hadrons. An example for this can be: $K^0 \rightarrow e^-$.

Keywords: Advanced Computing, Particle physics, Networking and Data Handling , Lattice Quantum Chromo Dynamics, Quantum Electrodynamics, D meson semileptonic decay amplitudes, and Computational Cosmology.

INTRODUCTION

The consortium on advanced computing was formed in 1991by various giants of Computers like Compaq, Microsoft, MIPS Computer Systems, Digital Equipment Corporation, and the Santa Cruz Operation [1,2]. In this formation, it was widely accepted that the RISC-based systems would maintain a price/performance advantage over the ad hoc Wintel systems. Soon after the initiative was announced, a dissenting faction of seven ACE [3] members declared that the decision to support only little-endian architectures was short-sighted. Compaq was the first company to leave the consortium, stating that with the departure of CEO Rod Canion, one of the primary backers behind the formation of ACE, they were shifting priorities away from higher-end systems [3]. The objective of the paper is to introduce the novel concepts of advanced computing, predictive analysis, Lattice Quantum Chromo Dynamics, and Computational Cosmology.

ADVANCED COMPUTING

In fact, a computer's infrastructure, combined with an operating system (OS), is able to embed and distribute the information throughout a computer's architecture, which ensures the elements working in conjunction with one another for providing the capability of a computer to operate effectively. The IEEE held an Advance Computing Conference; which covered the gamut in technology in the report [4].

ADVANCED COMPUTING IN PARTICLE PHYSICS

It is important to note that the Advanced Computing has been found to be very useful for ensuring the fulfillment of nuclear lab’s (like Fermilab’s) goals at all times. Interestingly, the Computing Divisions have to follow continuous and evolving Strategy for Advanced Computing for developing, innovating and supporting forefront computing solutions and services. In fact, research work in the Particle Physics groups greatly relies on the Computing Divisions for playing an important role in reaching the set goals and mission of the laboratory by providing sufficient computing for all divisions. Their emphasis is mainly on the present and future challenges in the form of significant increase in scale, and Globalization / Interoperation / Decentralization. In addition, its special applications are that the Advanced Computing Strategy invests both in Technology and Know-How for asll the challenges being faced by the laboratories.

SIMULATION FOR OPTIMIZATIONS IN PREDICTIVE ANALYTICS, AND ALSO FOR MAXIMIZING THE OUTPUT AND PROFIT OF THE COMMERCE AND INDUSTRY

Though the advanced computing is mainly applied in science and engineering, it can also be applied very usefully for corporate sector, especially where the data of number of employees, years of work under consideration, wages, and performance incentives , in addition to some unseen situations to achieve the optimum solution in minimum time. The simulation for optimization of learning in scientific and Technical Organizations is similar to the one for Predictive Analytics, and also for maximizing the output and profit of the commerce and industry [5-11].Though simulation used to just focus on learning in Scientific and Technical Organizations is based on computations by using commercially available software, advanced computing can be more important purpose for the base level learning, for which B_i is most important and commonly used parameter of cognitive architecture $ACT-R$. Following the approach [12], the Equation for an estimation of the log odds of all presentations of a group being used , is given as:

$$\boldsymbol{B_i = \ln(\sum_{j=1}^{n} \mathrm{TD}_j^{-dr}) + \mathrm{InAct}} \quad \text{--- (1),}$$

where T_j denotes $(TD_j = T_{now} - T_{presentation})$ when the group is represented in memory, dr denotes the decay rate, and InAct denotes the initial activation.

It is to be noted that the base-level learning defines a logarithmic power function, which approximates the Power Law of Forgetting, when no chunks are presented and the Power Law of Learning when many consecutive chunks are presented. The manager of the organization has to note that the parameters of the base-level learning equation can assign different rates of degradation of each individual or each group, and thus allowing the individual to forget when no representations of a group take place and also enables it to remember when representations take place. As is expected, the declarative groups are selected on the basis of matching and highest activation, selection being based on the expected gain or utility. If the Manager is involved in solving a goal, the individuals can be asked to solve the problem. But, as $ACT-R$ is a serial processor, the procedure has no choice other than selecting one with the highest expected gain or utility.

In this approach, the utility U of a procedure is defined as:

$$U = (LP * GV - C_{\mathrm{Pr}ocedure} + \sigma) \quad \text{--- (2)}$$

where, P denotes learning probability, GV denotes the goal value i.e. the importance attached by $ACT-R$ to achieve a particular goal, $C_{\mathrm{Pr}ocedure}$ denotes the cost of using the procedures, and σ denotes the stochastic noise variable. It is clear that it is possible to assign a different g-value to each procedure, which influences the $ACT-R$ engine for choosing a specific procedure. However, in general , it is customary to assign the same goal-value to all procedures. in most of the $ACT-R$ simulations. In fact, the probability P of learning is a factor of two sub-probabilities: q, the probability of the successful procedure, and r , the probability of fulfilling the objective of the goal in case the procedure is successful. P is defined as: s not in a position to follow any other procedure having similar parameters .It is important to understand the procedure for learning parameters q and r , since they have strong impact on the behavior in the

$$P = q * r$$ --- (3) ,

which is the Probability of Learning Equation. Also, for Cost $C_{\mathrm{Pr}ocedure}$, generally σ has to be added to the utility for creating the non-deterministic behavior, and not with deterministic behavior. Another important aspect of learning connected with the procedure is that it is of two types: (i) procedural symbolic learning, and (ii) procedural sub-symbolic learning. In the first type, $ACT-R$ distinguishes between specialization and generalization, in the sense that the specialization is used for often recurring problems and become routine and generalized m which is used in analogy problems. Surprisingly, $ACT-R$ has no stable and clear solutions for the problem of this type of procedural learning. In fact, the procedural sub-symbolic learning is more prominently used on such studies. In this technique, the parameters of probability-q and r describe the success ratio of the use of the procedure, and reflect the frequency and occurrence of successes and failures of a production. Obviously, the parameter q is the success-ratio of directly completing the procedure; which in fact keeps record of the the most recent successful execution of the condition and action aspects of a procedure. The parameter r gives the computed success-ratio in the achievements of completing an objective of a goal, after solving all the sub goals and after achieving and popping the current goal level. In other words, all goals that follow the current goal have to be fulfilled successfully to accomplish the current goal. The learning probability is defined as:

$$q, r == \frac{S}{(S + F)}$$ **--- (4),**

which makes it clear that in the beginning , either S (successes) >= 1 or F => 1**.** By default initialization of the procedural parameters**,** S is given a value of 1 and F (failures) a value of 0, which is based on the optimistic view of the success of the procedure being followed. It has to be carefully noted that so far, the simulation treatment has not considered any time component, which implies that the events and efforts in the past are equally weighted as in case of those experienced presently. However, in general the organizers are observed to be more aware of the impact of the present events and experiences than those of the past. Therefore**,** $ACT-R$ is modified by using the functions to discount the impact of the past experiences by incorporating a power-decaying function, which is similar to the base-level learning equation. The modified formula for discounting successes and failures is given by:

$$SvsF = \sum_{j=1}^{m} \mathrm{T}_j^{-d}) \quad \textbf{--- (5),}$$

where m => number of successes or failures, T_j => time difference, and d => the success decay rate . The organizer uses this formula to give different decay (1992-0504). the performance of the organization by optimizing various parameters, for which his experience is very important. On some complicated cases, use of software is also required, which is now commercially available.

It is important to note that in certain cases, it is possible to extend this analysis. By including the individual experiences and memory of past experiences, by using a simple form of learning, based on the utility function of $ACT - R$ given by the following equation:

$$Utility = \{\frac{(1+S)}{(1+S+F)}\} \quad \text{--- (6),}$$

where each employee remembers its present score and adapts its strategy in the firm from time to time. It is obvious that at $\mathrm{T}=0$, the individual has no preferences and hence selects based on his experience or randomly. However, In the $ACT - R$ simulation, the utility computation is quite complicated, and Noise has to be added to compensate for the variance in decision making. In addition, in the simulation experiment, the individuals are provided with an equal personal construct, which means that the initialization parameters of the employees are equal; implying that they have equal decay rates, equal utility-preferences, equal motivation value to solve the goals, and equal procedural, declarative memory and noise.

DESIGNER CONSIDERATIONS OF LATTICE QUANTUM CHROMO DYNAMICS (QCD)

Advanced Computing has helped in the rapid evolution and growth of Lattice Quantum Chromo Dynamics, and Computational Cosmology, which are briefly discussed below:

As we know, in nature, we come across four types of force: (i) Gravity which explains the celestial motion , and is explained by the general theory of relativity; (ii) The Electromagnetic force, due to the interaction between the nucleus and electrons;(iii) The Weak force, which explains the beta decay of a nucleus ; and (iv) The Strong force, that acts between the quarks and gluons, which form protons and neutrons. It is important to note that the leading Research organization- RIKEN BNL Research Center (RBRC) has focused on many types of complex phenomena caused by the Strong Force, including the matter-creating process after the Big Bang. Interestingly, this Strong Force is explained by a theory called Quantum Chromodynamics (QCD). The RBRC has been pursuing it's research projects for explaining various physical phenomena brought by the Strong Force, on the basis of the principles of QCD. RBRC is engaged in exploring as to how the matter was formed after Big Bang i.e. understanding the origin of matter and universe, implying to establish a new field of Physics by coordinating theoretical and experimental research.

It has now been well established that (i) the nucleons and the parity symmetry breaking, are two of the foundations of contemporary particle and nuclear physics; and (ii) the other important property of Strong Force is the Spontaneous symmetry breaking, which plays an important part in the research being carried out for understanding the ultimate law of physics comprising gravity. In fact, these Symmetry breakings in QCD have been the main focus of the research efforts being made by the RBRC. It is worth mentioning here that the electromagnetic force and the weak force are explained in the unified weak theory.

It is to be noted that in theoretical physics, the quantum theory explains the strong interaction between quarks and gluons, the fundamental particles that make up composite hadrons such as the proton, neutron and pion. In a similar manner, QCD is a type of quantum field theory called a non-abelian gauge theory, having symmetry group SU(3). Advanced computing is widely recognized as an expansive term used for portraying (i) the QCD analog of electric charge is a property called color, and (ii) Gluons are the force carriers of the theory, just like the photons, which are for the electromagnetic force in quantum electrodynamics. The importance of the underlying physics can be judged from the fact that this theory is an important part of the Standard Model of particle physics. On the basis of many theoretical and experimental investigations, a lot of experimental evidence has been obtained for the QCD. It is important to note that QCD is an important concept as it exhibits two important properties given below:

(i) Color confinement, which is due to the constant force between two color charges as they are separated. This is explained as :With an increase in the separation between two quarks within a hadron, increasing amounts of energy are required, which finally results in the production of a quark–antiquark pair, and thus turning the initial hadron into a pair of hadrons instead of producing an isolated color charge. Due to the color confinement, quarks can not be directly observed or found in isolation, and can only be found within hadrons, which include baryons such as protons and neutrons, and mesons. This is why the quarks have been mainly studied by observing hadrons.

(ii) Asymptotic freedom, which in fact is a steady reduction in the strength of interactions between quarks and gluons as the energy scale of such interactions , thereby decreasing the corresponding length scale.

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$$S_{Dirac=}\bar{\psi}(D^{*}+m)\psi \quad \text{--- (7),}$$

where the Dirac operator **(** $\not{D}$) is given by**:**

$$D*\psi = \sum_{\mu} \gamma_{\mu}(\partial_{\mu} + igA_{\mu}(x))\psi(x) \quad \text{--- (8).}$$

It can be visualized that the Lattice QCD uses discretized space and time, and as given in the literature, a very simple discretized form of the Dirac operator is:

$$D*\psi(x) = \frac{1}{2a}\sum_{\mu} \gamma_{\mu}[U_{\mu}(x)\psi(x + a\hat{\mu}) - U_{\mu}^{\dagger}(x - a\hat{\mu})\psi(x - a\hat{\mu})] \quad \text{--- (9),}$$

where *a* is the lattice spacing, and ψ(x) is a quark, which depends upon ψ(x + aμ) and the local gluon fields Uμ. Clearly, ψ(x) is complex 3x1 vector, and the Uμ are complex 3x3 matrices. It has to be noted that the interactions are computed via matrix algebra, and on a supercomputer, the space-time lattice can be considered to be distributed across all of the nodes, which as reported in the literature have been shown below:

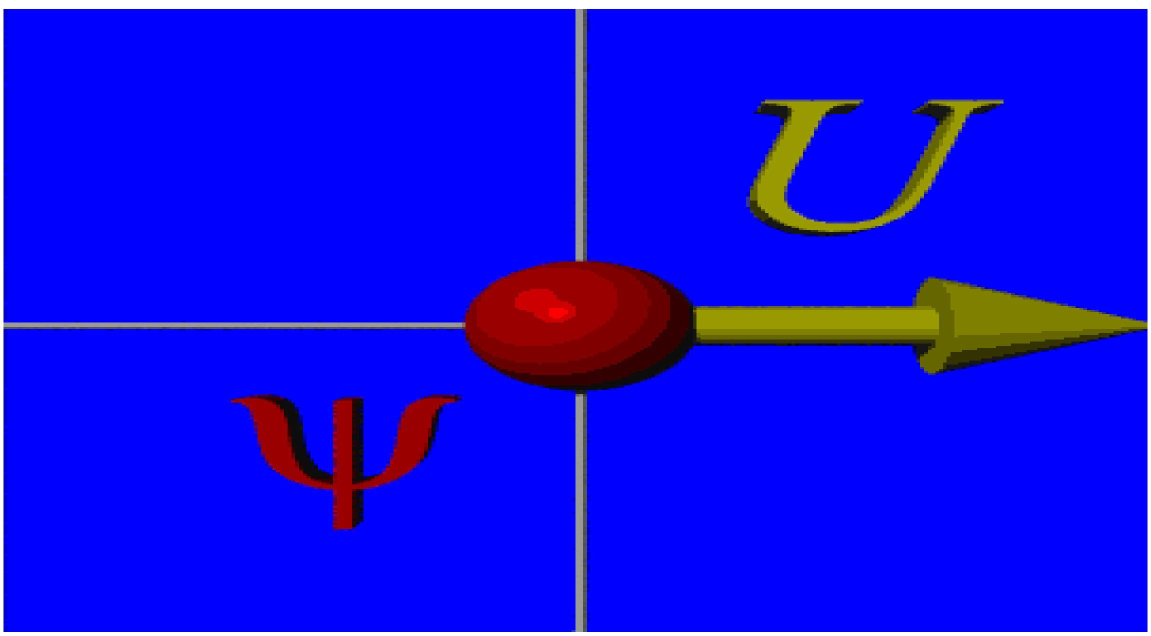

Figure 1 Distribution of the space-time lattice across all the nodes.

It has now been well understood that for achieving the desired results, the Lattice QCD codes (MILC, expressed by the MIMD Lattice Computation Collaboration; Chroma using C++ and running on any MPI machine; and CPS using C++ and running on QMP machine) require (i) excellent single and double precision floating point performance, in which it has been observed that the majority of Flops are consumed by small complex matrix-vector multiplies - SU(3) algebra formulation; (ii) High memory bandwidth , which in fact has been observed to be the main problem; and (iii) Low latency, high bandwidth communications, which are found to be implemented with MPI or similar message passing APIs, and associated with clusters like Infiniband, Myrinet, and gigE mesh. It has to be noted that (i) Bridge++ is a code set for numerical simulations of lattice gauge theories including QCD; and (ii) according to the object-oriented design, the code is described in C++ programming language.Thus the designer is faced with a daunting task of taking all these points into consideration, which require not only great skill and experience on his part, but also help from computers. The Lattice QCD computations require multicore optimizations, automated workflows, reliability and fault tolerance, and visualizations. Lattice QCD requires computers consisting of hundreds of processors working together via high performance network fabrics.

QCD is the theory of the strong interaction, in the form of a non-abelian gauge theory invariant under SU(3); and therefore, (i)The interaction is governed by massless spin 1 objects called gluons; (ii) Gluons couple only to objects having color, implying quarks and gluons; (iii) There are three different charges i.e. colors : red, green, and blue. in contrast to the fact that in QED there is only one charge i.e. electric charge; (iv)There are eight different gluons, which can change the color of a quark but not its flavor by exchanging glucon, as a red u-quark can become a blue u-quark; and (v) Due to the fact that gluons have color, there are couplings involving 3 and 4 gluons.

where m^q =quark mass, j=color (1,2,3),k=quark type It is important to note that for discovering the asymptotic freedom of QCD by David Gross and Frank Wilczek, in the year 1973, and independently by David Politzer in the same year, Noble Prize in Physics was shared by them in the year the 2004 [1-6], q=quark spinor. $g(\bar{q}_{jk}\gamma^u \lambda_a q_{jk})G_u^a$ is the quark-gluon interaction, and $\frac{1}{4}G_{uv}^a G_a^{uv}$ is the gluon-gluon interaction (3g and 4g). However, for both QED and QCD the effective coupling constant (a) depends on the momentum or distance scale, and it is evaluated as:

COMPARISON BETWEEN QUANTUM ELECTRODYNAMICS (QED) AND QCD

The main difference between QED and QCD is that QED is an abelian gauge theory with U(1) symmetry, and QCD is a non-abelian gauge theory with SU(3) symmetry:

$$L = \bar{\psi}(i\gamma^u \partial_u - m)\psi + e\bar{\psi}\gamma^u A_u \psi - \frac{1}{4}F^{uv}F_{uv} \quad \text{--- (10).}$$

where m=electron mass, γ =electron spinor, $e\bar{\psi}\gamma^{u}A_{u}\psi$ is the electron-g interaction, Au=photon field , and Fuv=¶uAv-¶vAu/;
and

$$L=\bar{q}_{jk}(i\gamma^{u}\partial_{u}-m^{q})q_{jk}+g(\bar{q}_{jk}\gamma^{u}\lambda_{a}q_{jk})G_{u}^{a}-\frac{1}{4}G_{uv}^{a}G_{a}^{uv} \quad (11),$$

where m^{q} = quark mass, j=color (1,2,3),k=quark type (1-6), q=quark spinor. $g(\bar{q}_{jk}\gamma^{u}\lambda_{a}q_{jk})G_{u}^{a}$ is the quark-gluon interaction, and $\frac{1}{4}G_{uv}^{a}G_{a}^{uv}$ **is the gluon**-gluon interaction (3g and 4g). However, for both QED and QCD the effective coupling constant (a) depends on the momentum or distance scale, and it is evaluated as:

$$\alpha(p^{2})=\frac{\alpha(0)}{1-X(p^{2})} \quad \textbf{--- (12),}$$

where a(0)=fine structure constant »1/137. For the case of the QED, it can be shown that:

$$X(p^{2})=(\sum_{i=1}^{N_{f}}(\frac{q_{i}}{e})^{2})\frac{\alpha(\mu^{2})}{3\pi}\ln(\frac{p^{2}}{\mu^{2}}) \quad \textbf{--- (13),}$$

where X(p2)>0, Nf is the number of fundamental fermions with masses below ½|p|, and m is the mass of the heaviest fermion in the energy region under consideration. It has to be mentioned here that the situation for QCD is very different than QED. Because of the non-abelian nature of QCD, it can be seen that

$$X(p^{2})=\frac{\alpha_{s}(\mu^{2})}{12\pi}\ln(\frac{p^{2}}{\mu^{2}})[2N_{f}-11N_{c}] \quad \textbf{--- (14),}$$

where Nf is the number of quark flavors with masses below ½|p|, m is the mass of the heaviest quark in the energy region under consideration, and Nc is the number of colors [3]. It can be seen that for 6 flavors and 3 colors 2Nf-11Nc < 0, and therefore, a(p2) decreases with increasing momentum or shorter distances. Thus, it is very surprising result that the force between quarks decreases at short distances, and increases as the quarks move away from each other. Another important result is the fact that gluons carry color and couple to themselves, which leads to asymptotic freedom. In fact, the strong force decreases at very small quark-quark separation and increases as quarks move away from each other. It has been established that the asymptotic freedom leads to quark confinement.

LATTICE QCD - D MESON SEMILEPTONIC DECAY AMPLITUDES

Some interesting studies [14] on D meson decay constants, and D meson semileptonic decay amplitudes have already been carried out. These results have been reproduced; and technically discussed below:

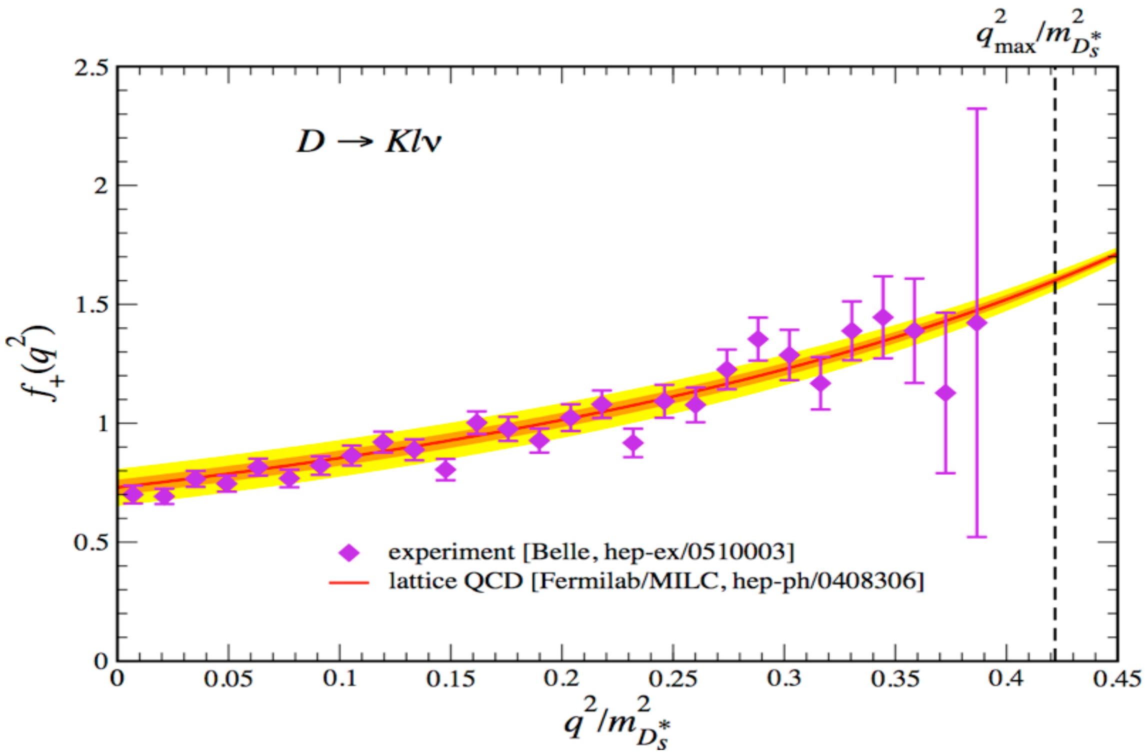

Figure 2 Figure showing D meson semileptonic decay amplitudes. Figure courtesy B´alint Jo´o, SciDAC-2 Software Infrastructure for Lattice QCD, Journal of Physics: Conference Series, 78 (2007) 012034.

The figure shows the results of the variation of f+(q2) with q2/m2D*S in the form of the curves. Interestingly, the experimental results of Belle are very close to those of Lattice QCD by Fermilab (Fermilab is a member of the SciDAC-2 Computational Infrastructure for the LQCD project). The value of f+(q2) rises quite linearly from 0.75 tp 1.75 with q2/m2D*S varying from 0 to 0.45, So for achieving the desired D meson semileptonic decay amplitudes for the Lattice QCD, the designer of the experiment has to choose the values of f+(q2) and q2/m2D*S carefully by studying the variation between them, separately for the various cases, and then doing the optimization.

COMPUTATIONAL COSMOLOGY

It has been observed that the High-performance computing (HPC) has proved to be an integral and indispensable part of cosmological research, and during the last 10-15 years , has become one of the most important tools in explaining the most fundamental problems in cosmology. The huge data collected from various investigations has to be analyzed for cosmological information, and this is being done by the State-of-the-art cosmological simulations, requiring millions of CPU hours of supercomputing time and tens of terabytes of storage. The Computational Cosmology MA has been created with the objective of making available the high-performance computing framework required for such investigations. In fact, this MA is a cross-cutting, science enabling MA, which interacts with various research MAs for helping them to achieve their goals.

The Hubble Extreme Deep Field (XDF), as reported in the literature, has been reproduced below :

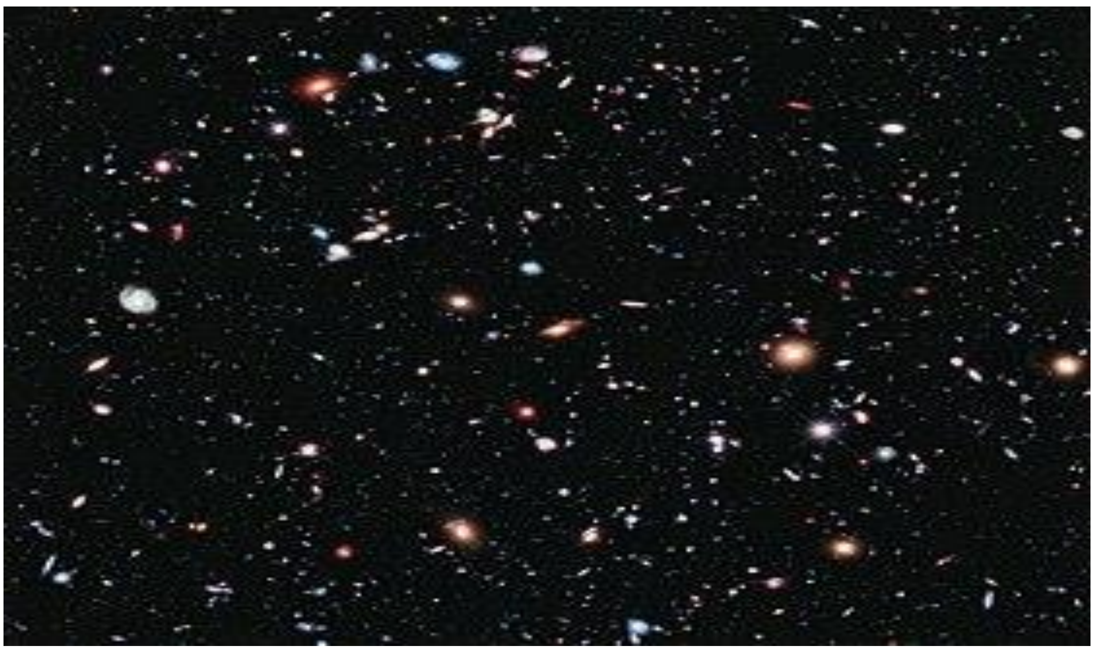

Figure 3 The Hubble Extreme Deep Field (XDF).Figure courtesy Hubble Observatory.

It is to be noted that this XDF was completed in 2012. Some galaxies are 13.2 billion years old, and there are 2 trillion galaxies.

It has to be appreciated that the modern state-of-the art cosmological simulations require more inter-communication between processes as compared to the Lattice QCD. Its magnitude can be judged from the fact that these simulations for certain sizes take even > 1,000,000 CPU-hours, which require computational platforms with wide (multi-CPU), large-memory nodes. This requires very high class Performance Computing (HPC) support, and studies based on Astrophysics. Some of the Simulation of the cosmic web of dark matter filaments, as reported in the literature, have been reproduced below:

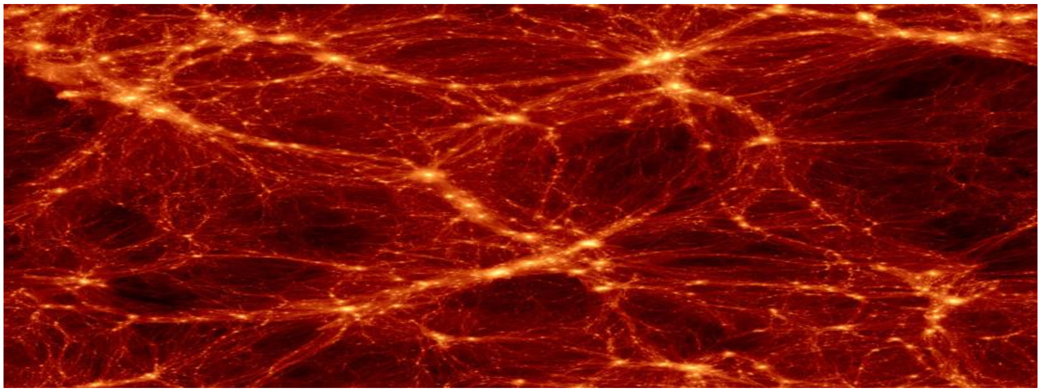

Figure 4 The cosmic web of dark matter filaments and halos. Figure courtesy http://cfcp.uchicago.edu/research/computationalcosmology/

It can be clearly seen that the cosmic web of dark matter filaments and halos prepared by the Simulation based on Advanced computing gives a very clear understanding of the Cosmology.

In addition, in the field of Advanced computing, many new efforts are taking place for the advancement of Aerospace Industry by application of Advanced Computing. The virtual 2021 AIAA SciTech Forum [15] is going to be held, which will be a significant event for this industry. At present, collaboration and technical exchange is paramount to overcoming challenges and achieving stability. The 2021 forum is expected to explore the role and importance of Advanced computing in the Arrospace systems. The diversification of teams, industry sectors, technologies, design cycles, and perspective have led to many innovations. Also, courses on this are attracting Researhers e.g. ISU's Aerospace Engineering Program [16] offers research opportunities that go beyond traditional aircraft and spacecraft. Turbulence research, icing physics, aviation electronics, tornado simulation, and UAS formation flight control are only a few of the topics. In addition, applications of Advanced computing for cutting-edge research in nondestructive evaluation, computational fluid dynamics, wind engineering and experimental aerodynamics, guidance and control, and rotorcraft/UAS/MAV, turbine science and technology are being taught and explained. Esposito et al [17] have discussed that the mproving processes in a company start from a deep knowledge of the current context, of the needs for improvement and of the objectives to be satisfied; and that sometimes, traditional processes can benefit from a techno-organizational innovation that changes the way of work by introducing new routines and solutions. Esposito et al [17] have characterized the service industry related to maintenance, repair and overhaul (MRO) by performance linked with the knowledge about the components involved. It has been emphasized that the emerging technologies and the need for enhanced competitiveness has led to transform and innovate this kind of industry, introducing changes in organizational and technological aspects; and the MRO processes are characterized by high variability, It has been reported that New Disruptive Computing & Networks organization will operate as part of Boeing Engineering, Test & Technology: and a new Disruptive Computing and Networks (DC&N) organization will develop computing and communications solutions for advanced commercial and government aerospace applications [18]. The applications of Advanced Computing in Control

Engineering in Aerospace Industry have recently picked up. It is interesting to note that Boeing has launched a new business tasked with researching and development of solutions in artificial intelligence (AI), secure communications and complex systems optimization for commercial and government applications. They have formed a group called Disruptive Computing and Networks (DC&N), for operating out of Southern California as part of Boeing Engineering, Test and Technology. Intelligent Flight Controls are being used for developing a flight control concept, using neural network technology for identifying aircraft stability and control derivatives, that allow optimal aircraft performance under a wide range of flight conditions. However, the challenge is to develop a learning neural network, which can update aircraft stability and control derivatives during flight, and in response to off nominal events of piloted flights. Also In Aerospace Industry,

CONCLUSION

Quantum Computing is showing great potential to solve computational challenges in aircraft modelling, simulation and many related problems, including speeding up aircraft design, debugging millions of lines of software code and resolving complex computational challenges. In addition, Educational Institutes and Research Agencies have been showing more interest in this field. Thus, it can be safely concluded that this field is on a firm, and evolving fast.

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