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Ml Driven Prediction of Collision of Milky Way & Andromeda

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Abstract: The 3D position of Sun with respect to the galactic center of Milky Way can be used to understand its evolution. After Milky Way collides with Andromeda(M31), the same will hold true. Ensuing sections deal with the implementation of Regressive Analysis to predict the location of Sun in the galactic center after Galactic collision. This model utilizes results of previous studies of black hole mergers to predict the resultant mass of Sagittarius A* and M31's black hole, which had been found to be (1.49±0.16) × 10^8 M$_\odot$. This mass has been used to calculate the centrifugal force that Sun might experience during and after the galactic collision. The current position, inclination, and velocity of Sun (derived from aforementioned predictions) have been used to predict its distance and inclination after the collision which has been predicted as 63,362.83 ly and 32.75°, from the new galactic center and its plane (97.48% and 96.32% accurate) respectively.

Index Terms**: *Sun, Milky Way, Andromeda(M31), Regression Analysis, Galactic collision, Sagittarius A*****.

I. INTRODUCTION

In Universe, the local group of galaxy clusters has been dominated by Andromeda and Milky Way, which have been the most massive galaxies in it. Andromeda Galaxy and Milky Way Galaxies have been hurtling towards each other due to their mutual gravitational pull which will drive them to a collision course in the future [1]. Due to both the galaxies moving at a relative velocity of 120 km/sec, they'll likely collide in the next few billion years. Due to this collision, there has been a possibility of the sun deviating from its current position and moving to an extended tidal tail [2].
Two galaxies (UGC 12914/5 and UGC 813/6) have already gone through a similar process of collision [3] and observations led us to strong synchrotron emission and heavy amount of atomic hydrogen being released when the collision occurred [4]. Contradictory to the original assumptions that had been made, there had been detections of excessively strong carbon dioxide(CO) emissions, which showed that huge quantities of molecular gases had been present. In fact, the CO emission have been five times that of the Milky Way Galaxy. Different types of galactic collisions that can take place are depicted in Figure 1[5]. During the process of galactic collision, there may be an interaction between the dark matter surrounding the galaxies [6]. Due to this, the position of various stars may deviate, this approach aims to predict the position of the sun after the collision.

Figure 1: Different types of Collisions between two galaxies as has been mentioned in [5]

Galaxies may be of various types [7] like the dark galaxy, Type CD galaxy, Type D galaxy, and Ultra Diffuse galaxy. Out of these galaxies, UDG or the ultra-diffuse galaxy had been a galaxy which has very low luminosity. Although Milky way and UDG galaxy share the same mass and size, only 1% of the visible star count has been observed there for UDG galaxy. Their appearance had thus usually been red in colour. UDG's have been formed due to the central collisions between the galaxies [5][8]. After the collision of galaxies, the components which survive the collision (like dark matter and stars) infiltrate or invade each other whereas on the other hands the components that collided like the gaseous part surrounding the galaxy heats up and results in the formation of two galaxies. These two galaxies thus formed, have comparatively unaffected dark matter and a cloud of hot gas separating them which has been noted to be different from the original cloud of hot gas that had separated them.

II. RELATED WORKS

The earliest works pertaining to the collision between the various galaxies date back to the 2nd Millennium. In 1989, [7] demonstrated characteristics related to compact galaxy groups by static Monte-Carlo models as well as by dynamic N-body simulations. The simulations had been run for 2.5 Hubble time H_0^{-1} and had been viewed along different axes out of which the orientations along the axes and have been shown. These different orientations have been shown in Figure 2 [5].

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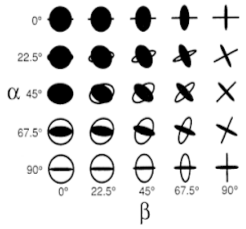

Figure 2: Orientation of galaxy groups along the axes and according to [5].

The most important observation had been that the dark matter either present inside the galaxy halos or in a common envelope. The median virial mass-to-light ratio had also been greater than the ratio of conventional galaxies by an order of magnitude of 40h M_0/L_0. The estimate of the mean time t_m between the simulated groups came out to be (0.2-4) × t_{ff} where t_{ff} has been the half-mass free-fall time of the group and the formula for it as depicted in equation (1).

$$t_{ff}=\frac{\pi\,(R_h^3)}{2\quad GM}^{1/2} \qquad (1)$$

where R_h is the half-mass radius of the group, M is mass of the group, G is the gravitational constant whose value is 6.67408 $\times10^{-11}$ $N{\cdot}m^2/kg^2$.

In 1997, Curtis Struck [4] performed SPH (Particle Hydrodynamics) simulations [9] for two modelled galaxies where parameters such as gravitational potential, artificial viscosity, pressure gradient, rotation velocity, scale length potential had been used. Artificial viscosity parameters had been set as α=1.0 and β=2.0. The clipping factor in the radial dependence of artificial viscosity has set as η^2(HK)=0.02. The primary disks gravitation potential has chosen in such a way that the disk particles that had been present on the circular orbits would have a rotation curve given by the formula as in equation (2).

$$v_0 = \sqrt{\frac{GM(\gamma)}{(\gamma)}}\left(\frac{r}{\gamma}\right)^{\frac{1}{n}} \qquad (2)$$

where v_0 is rotation velocity, γ is the scale length potential and M(γ) is the halo mass contained within one scale length.

In 1999, Curtis Struck [5] came to conclusions that large amounts of energy had been involved when two objects of masses in the order of 10^{12} solar masses with relative velocities in the order of 300 km/sec and weight 2×10^{42} kg had been considered. The energy released during collision has found to be in the order of magnitude of 10^{53} J. This had been equivalent to $10^{8\text{-}9}$ Supernovae or the number of supernovas that had been formed after the two colliding galaxies merged. He also stated that galactic collisions have been extremely slow with timescales in the order of 3×10^8 year or 10^{16} s. During the interaction between two galaxies, much of the energy had been redistributed or dissipated. This dissipation rate comes out to be approximately 10^{37} W and has given as the equation (3).

$$L=\frac{E}{\tau} \qquad (3)$$

Later, in 2002, F. Bernardeau et al [10] worked on the non-linear perturbation theory to better understand and find a meaningful explanation behind the colossal structure of universe. For this, they studied the Eulerian and Lagrangian point, non-linear approximations, and numerical simulation techniques. Then in order to represent cosmic fields, basic statistical tools such as correlation functions in real and Fourier space, pdf, cumulants and generating functions were studied by them. Also, the non-gaussianity of the Primordial fields were reviewed and quantitative predictions were made.

J. Braine et al [3] studied the collision between two of the galaxies (UGC 12914/5 and UGC 813/6) and it had been observed that there had a strong synchrotron emission as well as heavy amounts of atomic hydrogen that got released when they collided with each other. Contradictory to the original assumptions, detections of excessively strong carbon dioxide(CO) emissions had also been found. These GMC-GMC collisions happen only in cases where nuclei of both of the galaxies [11] have passed a few kilo parsecs of each other. The column density of 4×10^{21} cm^{-2} has needed to form H_2 in the bridge section. Moreover, it had not been the *HI-HI* collisions that introduced H_2 in the bridge, it has been the GMC since they had been denser than atomic gas clouds, they will be able to quickly ionize after the collision, forming the molecular gas that had been now observe on the bridge.

In 2006, N. Mizuno et al [12] studied the NANTEN observations in the H_{II} regions of the molecular clouds. They speculated that the young OB associations, super shells, supernovae, ultraviolet radiation fields had been responsible for triggering the molecular/star cloud formations and later demonstrated it as well in their research paper. Authors said that this has been a common occurrence in a galaxy-galaxy collision [9] and it impacts most of the interstellar medium surrounding these galaxies [13].

E. Middelberg et al [14] records the monitoring of Seyfert Galaxy NGC 3079 during the interval from 1999 to 2005 and observed this galaxy for eight epochs. This had been done predominately at 5 GHz but in the frequency range of 1.7-22 GHz. The conclusion derived had been that out of the three nuclear radio components, two of them underwent deceleration. During the deceleration process [15], there had been an increase in the flux density of one of the components by the factor of 5 and 2. The interpretation which made [16] had been formulated as, due to the collision with an interstellar medium [17], the radio jet component underwent compression and thus became the reason that led to a strong argument in favour of the existence of jets.

In 2008, T. J. Cox and Abraham Loeb [18], on the basis of observational constraints such as relative distance, relative velocity and mass concluded that the MW and M31 would collide in the next few billion years. The different properties have been given in Table 1[18].

Table I: Test model Specifications and test conditions

Property	MW	Andromeda
V200 (km s^{-1})	145	170
M_{200} (10^{12} MO)	1.0	1.6
C	12	12
Λ	0.031	0.0359
m_d	0.0421	0.0439

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R_d	2.19	3.56
F	0.29	0.3
m_b	0.079	0.0132
a	0.41	0.72
N_{dm}	475,500	755,220
N_{disc}	14,350	26,640
N_{gas}	6,150	10,560

In 2014, Yusuke Fujimoto et al [19], concluded the result that SFE in the spiral arms has been greater than that the SFE in the bar. The star formation depends on the complex structures that were present inside the galaxy and have been known to vary between the disc region and the nucleus. It has been given as equation (4).

$$SFE = \Sigma_{SFR}/\Sigma_{gas} \tag{4}$$

The research does not include active star formation, but on the basis of gas properties, the SFE had been estimated. They found that the SFR per cloud can be similar to the equation (5).

$$SFR_c = \epsilon_{ff}\left(\frac{\alpha_{vir}}{1.3}\right)^{-0.68}\left(\frac{M}{100}\right) w^{-0.32}\frac{M_c}{t_{ff}} \tag{5}$$

where the ϵ_{ff}=0.014, the virial parameter $\alpha_{vir}=\frac{5\sigma_c^2 R_c}{GM_c}$, R_c is the cloud radius, M_c is cloud mass, σ_c is ID velocity dispersion, t_{ff} is cloud free-fall time.

In 2017, Yuriy Mishchenko and Chueng-Ryong Ji [20], hypothesized that when two galaxies collide with each other, there would be an interaction between the dark matter surrounding the galaxies [21]. Dark matter has been known for causing subtle but prominent changes in the mass distribution of the two galaxies without causing much disruption to the halos surrounding the galaxy clusters [22]. Much of the important information regarding the galaxy collision can be found in this dark matter halo distributions [23] which thus results in a clear indication of the self-interacting nature of the dark matter [24]. The three parameters [25] that have been used are the kinetic parameter, Halo's mass, radius present between the two separated galaxy clusters. The kinetic parameter has been represented in the equation (6).

$$k = |E_K/E_G| \tag{6}$$

where *k* is the kinetic parameter, E_K is colliding galactic cluster energy, E_G is mutual gravitational energy at the point of closest approach. The halo mass *a* has been given by the equation (7).

$$a = 2N_{12}/(N_1 + N_2) = (\delta M_1 + \delta M_2)/M_{tot} \tag{7}$$

where N_{12} is the number of particle-particle scattering events during the collision, $N_1 + N_2$ had been the total number of particles in a collision. The third parameter radius present between the two separated galaxy clusters has been defined as the ratio of the distance between the outgoing galaxy clusters and the core radius of the larger galaxy clusters' core radii r/r_c.

In 2018, A.N. Baushev [26] came to the conclusion that the UDG's or Ultra Diffuse Galaxies have been formed due to the central collisions between the galaxies. After the collision, the components which have been collision persistent (like dark matter and stars) infiltrate or invade each other whereas, on the other hand, the components that collided like the gaseous part surrounding the galaxy heats up and result in the formation of two galaxies. These two galaxies that had been thus formed have comparatively unaffected dark matter [27] and a cloud of hot gas separating them which has been different from the original cloud of hot gas that had separating them. The model that has been considered predicts that UDG's space distribution [28] follows the density profile in accordance with the king's model and has given as in equation (8).

$$\rho^2(r) = n(r)\alpha((r/r_k)^2 + 1)^{-3} \tag{8}$$

The corresponding projected density has found to be in equation (9).

$$\eta_s = \eta_s\alpha((l/r_k)^2 + 1)^{-5/2} \tag{9}$$

where *l* is the projection length of *r*. The probability to find UGD in angular distance interval from the cluster center $\psi(\theta)$ has been given by the equation (10).

$$\psi(\theta) = \alpha\frac{\theta}{((\theta/\theta_k)^2+1)^{5/2}} \tag{10}$$

Another aspect of the computation supporting galactic collision has been the simulation supporting the collision [29]. It can not only help us in accommodating past theories but can also help us to simulate various variables to check their accuracy for future references [30]. To simulate the N-body collision of two big galaxies [31] requires high computational and graphics power and optimizations to define positions with respect to light years on current processors. Yohei Miki and Masayuki Umemura proposed a hybrid Gravitational oct-tree code accelerated by hierarchical time step controlling model GOTHIC [32] to improvise the computing power of GPUs by a factor of 3-5 by adopting both the tree method and the hierarchical time step and memoization, to simulate all the stars of galaxies and their collision trajectories.

III. RESEARCH METHODOLOGY

There are more than a trillion of galaxies in the observable universe, and each galaxy consists of a plethora stars, gas, black holes, which have been held together by the force of gravity of a central supermassive black hole. Every galaxy has its own shape and size depending upon its stellar distribution in space and can be of the spiral, elliptical or irregular shape. A galactic collision can be the result of an imbalance between the force exerted by dark energy and the gravitational pull by the involved galaxies. Also, galactic collision can have said to be a precursor to the star formation or a chance merger between several star systems or objects such as black holes, pulsars, or neutron stars.

A galactic head-on collision of Milky Way Galaxy and Andromeda has expected to happen in around 4.5 billion years from now [19].

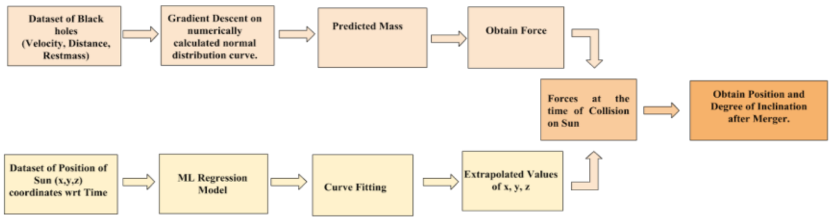
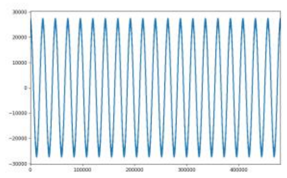


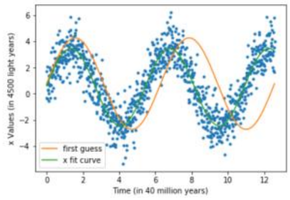
Figure 3: Schematic diagram of the proposed methodology

It has been estimated that Andromeda Galaxy contains 1 trillion (10^{12}) stars while the Milky Way contains 300 billion (3×10^{11}), the chance of two stars colliding had been trivial because of the immense separation between the celestial objects but the merging of the galaxy's respective black holes (Sagittarius A* & M31's Black Hole) has bound to happen in a few millions of years after the galaxies' outer edges of each galaxy start interacting with each other.

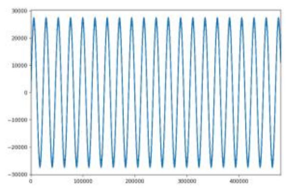
According to Muir and Hazel [20], the collision has not been expected to affect the solar system, except its displacement in the opposite direction to the galactic center. The resultant merged galaxy might have an elliptical shape as supported by Loeb et al [14]. This can also suggest that major challenge that scientist may face would be that of predicting the Sun's position at that point of time.



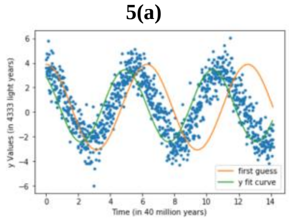
4(a)



5(a)



4(b)



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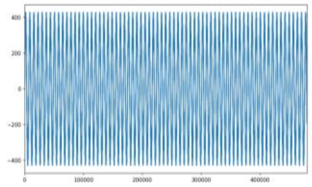
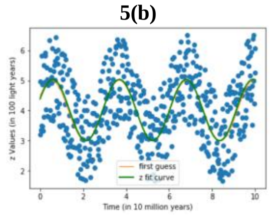


4(c)



5(c)

Fig 4(a) Plot depicts X position of Sun (y-axis) w.r.t. time (x-axis); (b) Plot depicts Y position of Sun (y-axis) w.r.t. time (x-axis); and (c) Plot depicts Z position of Sun (y-axis) w.r.t. time (x-axis)

Fig 5(a) Fitted plot depicts X pos. of Sun (y-axis) w.r.t. time (x-axis); (b) Fitted plot depicts Y pos. of Sun (y-axis) w.r.t. time (x-axis); and (c) Fitted plot depicts Z pos. of Sun (y-axis) w.r.t. time (x-axis)

The graphs plotted in Figure 4(a)-(c) showcase the output of the Sun's position (i.e. x, y, z) w.r.t. time. This has been in respect to the research done in [33] where edges are considered for Image Analysis. These graphs have been fitted using the Regressive Model which has been shown in Figure 5(a)-(c). As can be observed from the graphs, coordinates x and y have a 90^{o} phase shift, this can help us conclude that the graphs have almost been identical to the actual calculated position of the Sun. Also, the graph in Figure 4(c) represents the position of the Sun in z-direction or with respect to the meridional plane of Milky Way galaxy, which has been comparatively less distant as have been the values in the x- and y-direction from the galactic center. Furthermore, it takes multiple iterations to fit a curve to the exact observed values as can be seen in accordance with the graphs in Figure 5(a)-(c) where the green line has been found to be the fitted line with respect to the graphs in Figure 5(a) & Figure 5(b).

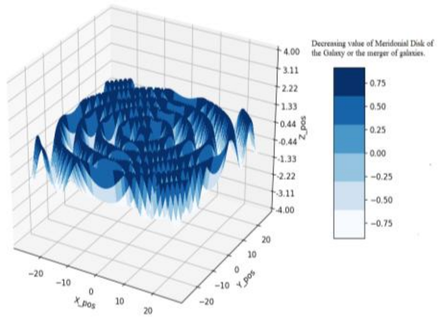


Fig 6: The relationship of coordinate z to that of the coordinates x and y.

The graph in Figure 6 depicts that the value of the z-direction had been found to be directly dependent on the x- and y-values of Sun's position. This can be seen with varying colours in the graph which depicts a 3D representation of z position with respect to the meridional plane of the galaxy which has been discussed above. Considering all these constraints, the model obtains certain results which will be discussed in the next section.

IV. RESULTS

The mass of the merger of Sagittarius A* and M31's black hole has been calculated in this model. This has been done using the curved plane defined in Figure 7(a). This graph depicts the mass distribution with respect to the velocity of approach of both the black bodies and their combined rest mass. This signifies that the resultant mass of the black hole shall lie on the narrow region of the curve plane. Furthermore, as mass has been equivalent to energy according to the equation $E = mc^2$, it has been hypothesized that the resultant mass tends to acquire a mass where

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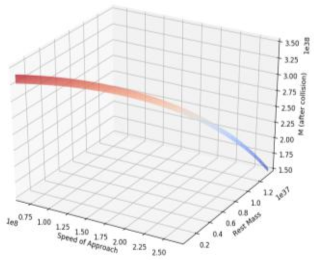
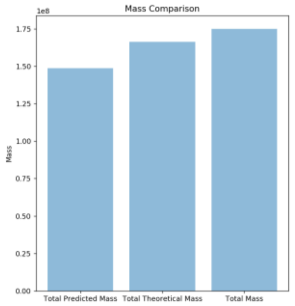
it can have the lowest possible state of energy in accordance with the aforementioned mass-energy relation. This graph has been generated in accordance with the resultant mass equation depicted in equation (11).

$$M_r = \left(\sqrt{1 - \frac{v^2}{c^2}}\right) \cdot \left((M_a + M_b) - \mu - \frac{M_a \cdot R_{Sch_a} + M_b \cdot R_{Sch_b}}{8 \cdot d}\right) \quad (11)$$

where M_r is the resultant mass of the Black Holes' merger, v is the resultant velocity of approach of both Black holes towards each other, M_a and M_b are the masses of the Sagittarius A* and M31's Black Hole (i.e. Andromeda's Black Hole). From Fig 7(a), it can be conferred that a statistically normally distributed value across specific values of v and μ are desirable. For specific v and μ, statistical Gradient Descent had been used to get an array of resultant masses and on this extracted array of values, and Gradient Descent had been used to reach the specific values of the mass of the resultant Black Hole. Fig 7(b) also helps us in reaching the specific radius of the Black Hole that would be formed at that time after the merger. This can be calculated as Schwarzschild Radius, information about which has been depicted through a graph.



(a)



(b)

Fig 7: (a) Mass relationship between Rest Mass, Velocity of approach of two galaxies, and Mass of Galactic center after collision (b) Comparing total, theoretical and predicted mass

Figure 7(b) A value of 148,741,092.82 solar masses had been found using above methods as opposed to the values obtained in theoretical results which can be accounted to 166,269,000 solar masses and total mass (if Gravitational Waves have not been released from the merger) which accounts to 175,020,000 solar masses. Also, the aforementioned methodology had been used to obtain the distance of the Sun from the galactic center after the collision as 63,362.8275 light years which have been approximately double to that of its current location from the current galactic center called the Sagittarius A*. Meanwhile, this model had been used to obtain the inclination of the Solar system's plane to be that of 32.7945^o after the merger of the Black holes at the center of both the Galaxies.

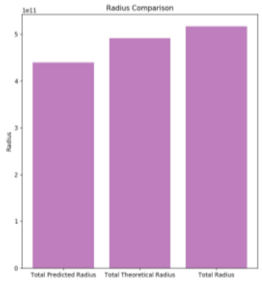


Fig 8: A comparison of radius (total, theoretical & predicted)

The aforementioned results have been used to predict an approximation to the mass of the merger of the Black Holes. This can help us to conclude the radius of the merger of aforementioned Black Holes. This has been depicted through Figure 8, which represents the radius of the resulting Black Hole that will be formed after the collision of the Galaxies. The radius of the resultant Black Hole has been estimated around 4.39×10^{11} km (0.04643 light year) while the theoretical value and total radius (if Gravitational Waves have not released from the merger) were found to be 4.91×10^{9} km (0.051×10^{-14} light year) and 5.16×10^{9} km (0.054×10^{-14} light year), respectively.

The mass and radius of the resultant black hole, and distance from the center and inclination from galactic plane, along with the accuracy of the models used to calculate all these measures has been tabulated below.

Table 2: Properties of the Sun and center of Galaxy after possible collision of Milky Way and Andromeda after collision of Sgr A* and M31's Black Hole (if the collision behaves as stellar Black Hole collision) [18]

Metrics calculated	Experimental Value	Accuracy
Mass $_{\text{resulting Black Hole}}$	1.49×10^{8} M⊙	89.46%
Radius $_{\text{resulting Black Hole}}$	4.39×10^{11} km	89.46%
Distance $_{\text{center}}$	63,362.8275 ly	97.48%
Inclination $_{\text{center}}$	32.7945^o	96.32%

V.CONCLUSION AND DISCUSSION

The sinusoidal regressive model [34] utilized Gaia Data Archive, giving parameters such as x-, y-, z-coordinates, angular velocity, classified spiral arm and the inclination with respect to time. The research has been concluded with the following.

- Mass of the merger of black holes had been calculated to be ~$1.49\text{x}10^{8}$ M⊙ while, the radius of the resultant black hole had found to be ~ $4.39\text{x}10^{11}$ km ($4.64\text{x}10^{-2}$ light year);
- an accuracy of 89.46% had been achieved for the mass and radius calculation of the resultant; and
- an accuracy of 97.48% and 96.32% for position and degree of inclination w.r.t. galactic center and its plane had been achieved.

Furthermore, one limitation this model faces has been that it doesn't take into account the gravitational pull applied by other galaxies in the local group of galaxies.

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The model has been limited in discussing the effects of the Great attractor whilst discussing the result of the collision of Milky Way and Andromeda Galaxy. Another consideration that has been overlooked had been that the collision for supermassive black holes will be the same as the collision for stellar black holes. To overcome the aforesaid difficulties, this research can be extrapolated by utilizing Reservoir Learning as it can prove to be a better approach to deal with the problem domain. This is because it facilitates usage of artificial intelligence while considering causality and butterfly effect (both of which re branch of Chaos Theory) using its reservoir-like networks for better simulation.

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