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# Evolution of Mimics of Algorithms of Nature (E-man) Part 5[#]: Tutorial on Big_Bang–Big_Crunch algorithm

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(Dedicated to Dr P V Subba Rao, former professor of chemistry, Andhra University on his 70th birth anniversary)

## ABSTRACT

*Big_Bang (BB) is one of successful theoretical models with ample high-tech-precise- experimental evidence explaining the origin and present form of the universe while Big_crunch (BC) appears to be plight of future. The scientific scenario is a conglomeration of Nobel Prize winning results of theoretical physicists, unique concerted experimental efforts in CERN, continual upgradation of 'Standard model' and simulations. BB–BC-algorithm for optimisation is a brain child of Erol and Eksin in 2006. This sparkle is inspiration from a splinter of the Mother Nature. In the Big Bang (BB) phase of the algorithm, uniform random solutions are generated enabling a global search. It is a reflection of dissipation of energy resulting in disorder/high entropy. During Big_Crunch (BC), in the second stage, the wide spread (solution set) points traverse towards a single location called here center of mass (i.e. reciprocal of fitness/object function). In other words the order increases and obviously randomness becomes smaller and smaller around the average point. The algorithm after cycling through a large number of sequences of BB and BC converge towards the true solution. This E-man-tool showed accepted performance in classification of IRIS flowers and discrimination of benign versus cancerous breast. The standard mathematical functions like Rosenberg and complex design tasks are tested with success. In the engineering front, the results of civil constructions of reinforced concrete/domes or ribbed domes design, inverse type-2 fuzzy model based electric-controllers and fuzzy cognitive maps with BB-BC are trustworthy. The incorporation of local search directions, local trap recognition with diversity index, mutation operator enabling escape from local optima, trying with uniform population instead of uniform random numbers in BB operation and chaotic patterns against normal distributions during BC stage etc are recent advances rendering BB-BC still powerful. The clubbing of even incomplete/ vague/apriori task-specific constraints/expert-model-knowledge of basic BB-BC, its binary hybridisation with another nature-mimicking algorithm (Harmony_serch, CSS, PSO, ACO, GA), a quaternary hybrid heuristic-BBBC-PSO-ACO-HarmonySerch enhances applicability into more intricate/exploratory domains of research. The state of art of improvements in BB-BC with advances in mathematical algorithms and intricacies of applications in diverse disciplines is presented. The sequences of events from Planck time till to-date after big_bang, futuristic profile, typical mathematical-models along with experimental evidences and open-ended riddles, a perennial source of inspiration, are briefed in appendices.*

**Keywords:** Big_Bang–Big_Crunch algorithm, Theories of origin of universe, Nature mimicking, E-man, optimization.

# Part 4: Journal of Applicable Chemistry, 2013, 2 (5), 1007-1034; Part 3: Journal of Applicable Chemistry, 2013, 2 (4): 698-713.

**Contents_ BB-BC alg.**

## INTRODUCTION

Today, the Universe comprises of planets, stars, galaxies as well as amoeba, viruses, single molecule, atom, subatomic particles (electrons, protons, and neutrons), electromagnetic radiation, gravitational pull, electro-static charges, microscopic species and so on (Appendices 1-3). This entire visible (partly to the naked human eye and mostly through state-of-the-art-instruments) picture is only 4%and the remaining is dark matter and dark energy (Figure A1-1). Life on this planet also has material. Material consists of molecules, which in turn comprise of atoms. And without life/material the world is myriad of myriads of dumps of energy/particles. A human being sees objects only in visible light, while other species perceive in uv-, infrared and other parts of electromagnetic spectrum. The telescopes look distant galaxies and stars. Scientific pursuits were in the direction of probing into basic structure of macrocosm as well as microcosm and prevailing laws in nature. The atoms in the periodic table are made up of only three components viz. protons and neutrons in the nucleus and electrons orbiting around it. The positive charges are accounted by protons and electrons contribute to the negative charge. Thus, radicals, cations, and anions are formed with addition/removal of electrons. The formation, stability and diverse properties of simple diatomic molecules to polyatomic homo (C60)/hetero atoms (insulin), bio-molecules, geo-/marine-/astro/ environmental- materials are a natural consequence of local pressure, temperature and surrounding (electromagnetic) energy, magnetic field and (nuclear) radiation. The cosmic rays rain down many varieties of particles and it necessitated invoking quarks, with spin, charge (-1,0,+1), mass and life-time (time required for decay into light particle). The combination of six types of quarks (up, down, strange, charm, bottom, and top popularly referred as flavors) (Chart A1-2) produce protons and neutrons. A proton has two up quarks and one down quark. This is start of Standard Model of particle physics. In addition to quarks, leptons include popular negatively charged electron responsible for all chemical properties of matter, electron-neutrino, muonic leptons (muon, muon–neutrino) and onic leptons (tau, tau –neutrino). One cannot see with his eye or even comprehend with the other sense organs now what happened during or before origin of universe. What all science does is observing universe through telescopes from the ground or sending state-of-the-art--probes into space through space shuttles. The other activity is trying to achieve primordial conditions in the laboratory and perform experiments with unique detectors. This is essence of LHC facility at CERN in ALTAS experiments, mimicking cosmic ray collisions in the laboratory which is akin almost to big bang.

### 1.1. Origin of universe in nature

The Godly particle (Higg's boson) in theoretical physics, ghost fields in particle physics, ghost sites in biophysical chemistry, mathematically significant wave function ($\psi$) with no physical meaning, physically significant $\psi^2$ of fictious particles with no physical existence in quantum physics/chemistry etc. paved way science to reach higher heights as well as explaining observable phenomena, visible/non-visible universe, their origin, dynamics and future transformations.

The religious beliefs, intuition/thoughts of philosophers/prophets, scientists' hypotheses, recent high-precision experimental results from NASA, CERN, computer simulations, theoretical/model equations and their multiple unique/non-unique solutions intelligently focus in attempting to reveal the origin, sustenance and future plight (Appendix-1-3) of universe, life on earth and human intelligence with high degree of reliability. The universe we perceive (through state-of-the-art-instruments) and that don't know (even to traces) today is a conglomeration of trillions of trillions of micro- and mega-interactions/transformations of systems, species, molecules, atoms, sub-atomic particles, elementary particles responsible for mass, force, radiation in widely varying space and temperatures of $10^{27}$ degrees to $320^o$ through $3^o$ Kelvin during the last 13.7 billion years.

The origin and evolution of universe is probed with String- /M- /Grand Unified-/Superfluid vacuum-/ final-theories and standard-/Steady-state-/bib-bang-big-crunch models. Every particle in the universe was infinitesimally close to every other before thirteen billions years ago. A gigantic explosion - Big Bang - took place [1-6]. The analogy is that galaxies could be similar to dots on a balloon. When the explosion took place, the balloon expands, each dot moves relative to all the others obeying Hubble's law (Chart A3-

1). At that time, it was a fireball of dense mixture of subatomic elementary particles, nuclei and hot radiation. With progress of time from primordial phase, the universe has been expanding, to lower densities and temperatures. After the origin of universe (chart 1), it evolved to the present state (Appendix-2) and continues to evolve (Appendix-3).

Standard model: The Standard model contains fundamental particles of matter what make us and everything. The updated form is now considered as 'theory of almost everything (TOAE)" with experimental evidence from CERN for postulated Higg's boson. It is self consistent and good at prediction. Dirac coined the name Boson after Satyendra Nath Bose for his contributions in Bose-Einstein statistics in postulating properties of elementary particles.

The four fundamental interactions among these particles are gravity, electricity and magnetism (responsible for light and radio waves), strong forces inside nucleus holding its constituents and weak one responsible for radio activity. This is cosmic DNA which includes all information (particles, interactions) for making all visible stuff one thinks of.

The four force carrying gause bosons (photons carrying electromagnetic interaction, W and Z bosons carrying weak interaction, gluons carrying strong interaction), and Higgs boson responsible for mass (fundamental interaction with nature) and fermions belong to this class. Higg's field imparts mass to the fundamental quarks and leptons which make up matter. Gluons glues quarks in the protons/neutrons and holds nucleus together. Abdul Salam contributed to standard model of physics in early niteen sixties. Newton related weight with mass multiplied by gravitational force and Einstein equated energy with product of mass and square of velocity of light.

**Standard model**

- **Does not account for gravity**
- **Does not explain mysterious dark matter**

✓ Remedy: future research using the LHC

The gross missing inquiry in classical/quantum theories and standard model of particle physics is why does matter weigh at all. In other words, the basis explaining where from mass comes? Boson, postulated in 1964 (also called godly particle, Goly Grail of particle physics) by Higgs et al explained origin of mass. The model equation is

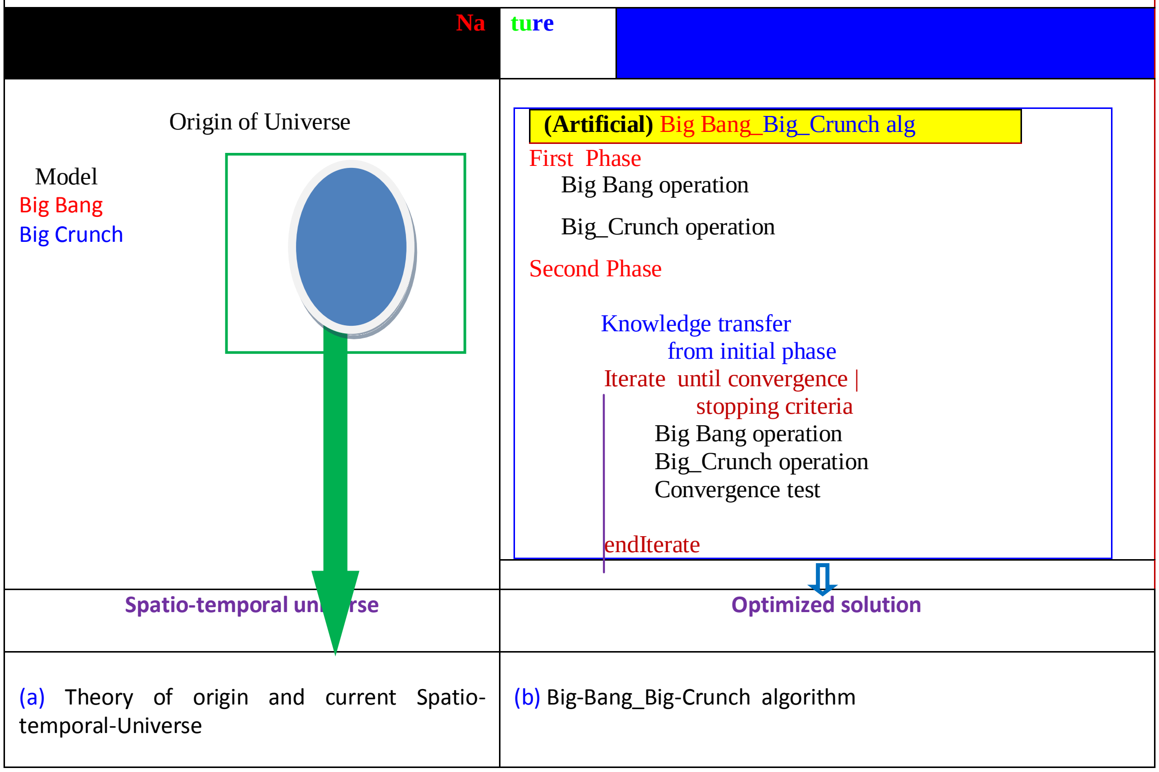
Model = Fundamental interactions
+ How these interactions function on the particles
+ Higg's (boson filed) model

**Higg's (boson filed) model = Higg's particles interaction**
**+ Engineering details**

*Higgs filed:* The Higgs filed consists of uniform, homogeneous, isotropic, infinitely extended massless bosons. It imparts mass to sub-atomic particles interacting with the field when they pass through it. For example, photons do not interact and thus they remain massless. On the other hand, electrons interact and thus posses mass.

*Analogy of Higgs filed:* The analogy starts with a snow filed, water body or group of people. Liquid water consists of trillions of trillions (infinite) water molecules in river/sea/ocean, much in the same way as ice at sub-zero temperatures or at polar regions. In the context of snowfield, ice is another phase of water at low temperatures and consists of flakes which in turn are made up of large geometric structures of water. The skier glides or skies over ice very fast depending upon the slope. He does not sink into the snow looking like moving of a massless (ant, again analogy) particle or he does not interact with the field of snow. On the other hand, if one puts on snow shoes, he slightly sinks or interacts with snow down the surface. Without snow shoes, the hiker sinks deep into lower levels of snow, interacting strongly with the snowfield. The other analogies put forward are a fish/thin man/heavy person swimming in water and a police/celebrity moving through a crowd of people. The celebrity is flocked around all through the passage as everybody likes to interact with him and consequently he moves very slow.

**Chart 1. BB-BC theory of origin of universe and BB-BC algorithm for optimisation**




## 1.2. Nature mimicking algorithms

The nature inspired (E-man) algorithms are heuristic, population based and self starting search procedures. These swarm techniques [7-8] adopt random variation, selection, cross over, elite preservation as well as curtailing its domination, diversity and at the same time preserving signature traits. The selection is based on criteria following the processes in plants, animals, humans etc. Mutation, crop up with all together a new characteristic helping to escape from local optima by looking for a diverse distinct solution. It helps to be adaptive for changing environment to combat with the endangering difficulties and reach structured /chaotic higher order voluntary and involuntary functions and secure brain/mind/consciousness prone micro-/molecular processes. But, expert scientific realist witnessed that the continual refinement and new hypothesis indicate the best scientific theories are at least partially true. An ideal theory has the target of explaining all in toto.

*Heuristic approaches:* The mean/average of the two positions in midpoint procedure of finding optimum can be considered as a heuristic. But, in the last two decades the heuristic / meta-heuristic methods are used only in the context of nature inspired algorithms. PSO, on the other hand is based on stochastic or statistical probability theory. The approximate solution (scalar in tensor notation or a point in geometric space) is the start of non-self-starting (statistical or mathematical) methods. In Eman modules set, a location of point (or approximate solution) is the mass in gravity algorithm, a charge in charged system, centre of mass in BBBC approach, position/location of the pheromone in the ant colony procedure, or position of honeybee in the foraging mimic etc. In particle swarm optimization (PSO), the velocity of movement as well as the position is considered. Coming to interaction, the gravitational attraction is the basis gravity algorithm. The attraction/repulsion forces along with electromagnetic effects are the core of charged system. In Big_Bang Big_Crunch algorithm, the centre of the mass is a typical quantity during explosion into divergent solutions for exploration purposes and convergence towards optimum in the crunching/contraction phase. In firefly model, the attractions between the fireflies promote movement towards a better one. Chart 2 describes popular nomenclature in statistical optimization techniques and the corresponding one in nature inspired algorithms.

**Chart 2: Terminology in statistical optimization techniques and the corresponding one in nature inspired algorithms**

| | Algorithm | | | |
|---|---|---|---|---|
| **Mathematical** | **Gravitational** | **Charge** | **Big_Bang-Bank_Crunch** | **Firefly** |
| x | ■Particle | ⓘ Charged particle | ➔ Planet | ॐ Firefly |
| xapproximate | ■Mass | ⓘ Charge | ➔ Mass | ॐ Position |
| Function | ■Gravitational attraction | ⓘ Coulomb charge | ➔ Mass | ॐ Attraction |
| Number of app solutions | ■Number of particles | ⓘ Number of charges | ➔ Number of planets | ॐ Number of fireflies |

The second to last column contains the vocabulary in terms of terminology of biologist, physicist or chemist. All this exercise is not only to appreciate, but to comprehend the concepts independent of obsolete/current communications of different disciplines.

Every algorithm is developed with a focus, yet the scope being limited. Many sub- procedures are used or hybridized/fused in order to fix/make up the deficiencies of individual components or deriving best of both the worlds. Today, it is not a surprise that no single pure algorithm is used in a standalone mode on a single computer processor. Although, this is a perennial endless effort, the pertinent query 'is it necessary for a chemist/ physicist/ applied scientist to know all about this' is a fairy tale, yet directs towards nearer to truth.

The classical simulated annealing algorithm is a leap in random search or parallel search methods. Instead of search with a single solution, parallel search of multiple solutions in the search space was then a great vision. Random number generators are employed to obtain to approximate solutions, thus rendering them to be self-starting with a leap from the age old practice of non-self starting iterative methods using approximate solution. Now, a plethora of methods including the genetic/evolutionary algorithm and so on proposed around 1970's are now considered as classical. The next era started with emergence of the swarm intelligence and typical multi agent systems sunder this category are ant colony algorithm, honey bee foraging, honeybee mating, firefly attraction, mosquito host-seeking algorithm etc. Here, the multiple solutions, multiple agents, parallel search in the search space etc mean the same. To put in a nut shell, the search space is two dimensional or three dimensional for simplicity or m-dimensional for generality. A figurative appreciation is possible only in one-, two- and three- dimensional geometric space. But, the movement in tensorial system of m-dimensions, human eye is incapable of visual appreciation leave alone comprehension. One has to have a mathematical eye to probe the traversing of the solutions.

### 1.3. Translation of (natural) process into mathematical BB-BC

One of the theories of rational scientific explanation of origin of universe is through Big_Bang process involving dissipation of energy and formation of universe through ultra microscopic to mega time scale (Fig A1-2b). The present one occurred once and the Big_Bang phase feeds the Big_Crunch phase with many inputs. The Big_Crunch phase is the shrinking destiny of the universe into singularity. The science is now in a matured state although it started with intuition, beliefs and incoherent conflicting observations. Yet, the nature's processes and nature-of-nature are understood very little. The translation being a subset of it, the capacity of the product is still diminished. A mathematical formulation further restricts all features reducing drastically the micro-level details. At implementation level, algorithm, software, hardware, time/cost, personal preferences and mental stigmas bring down Eman module alarmingly compared to Mother Nature. Yet, Eman excelled many long cherished and time tested standard mathematical/statistical methods. In the mathematical optimization, the concept of transition of order to disorder is used to transform from the position of a converged solution to the birth of a totally diverse solution candidates with high disorder or chaos. Obviously, it is essential to escape from a local/undesired optimum or even similar global minimum of a set of global minima. It is astounding, but incomprehensible about the potency of hierarchical-hybrid-nature-mimicking algorithms of the future when they hopefully mimic nature as nearly as possible, if not in toto.

*1.3.1. Adaptation of BB-BC **($B^3C$)** algorithm in mathematical optimization:* In the year 2006, Erol and Eksin [9] added BB–BC algorithm into the band wagon of nature inspired mathematical search tools targeted at function optimization and variable selection. The inspiration of this algorithm is from the theoretical abstract model explaining the origin of the universe and its lifespan. Incidentally, this algorithm (E-man module) also has the same name as that in theoretical physics and is now one of the competing nature mimicking procedures in optimisation, selection of variables etc. [9-11, 12-81].

*1.3.2. Physical picture of BB-BC algorithm:* The physical mapping of this population-based heuristic search algorithm is that dissipation of energy transforms an ordered (point) space into a randomly distributed one. The algorithm consists of a finite number of masses (points in m-dimensional space with single object function values) uniformly distributed over the entire search space in the big-bang step (Fig.A1-2). In the follow-up Big_Crunch stage, those points are shrunken to a single representative refined solution i.e. a prospective mass. The co-ordinates of this center of mass are calculated based on the fitness function. The distribution of points now depends upon the standard deviation chosen for normal distribution. With the mass at the centre, new masses are blown off at the start of next Big-Bang. The extent of dispersion is comparatively small as the dispersion space contracts about a center of mass. It is transition from exploration (eagle view for a global optimum) to exploitation (going around the bush) to refine local search. Over successive cycles of Big_Bangs and Big Crunches, the overall search space converges and tightly localized around the best solution, which is as close as to true global optimum (Chart 3).

**Chart 3: Pseudo code of process calls In BB and BC phases**

```
Big_Bang operation

    If   first phase
        rand(0,1)
    else

Randn(mean,sd)
   endif
   Prune to Xlimits
   Cal objFnvalue

Big_Crunch
operation
   Cal center of
   mass
   X of best fit
   solutions
   SD of dispersion
```

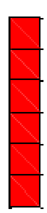
## 2. (Artificial) Big_Bang–Big_Crunch algorithm

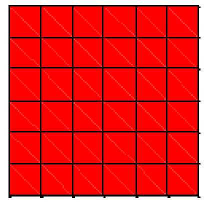
The input data, intermediate variables and method specific constants/variables are incorporated in Chart 4.

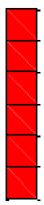
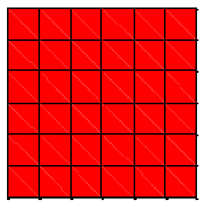
### 2.1. Data structure

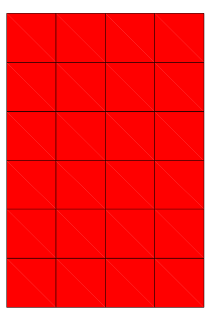
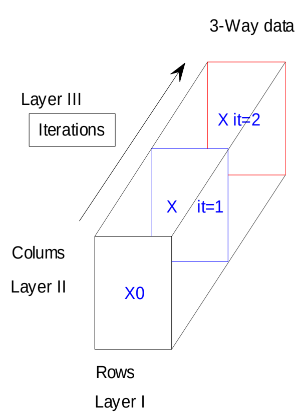
**Chart 4: Data structure of Big_Bang–Big_Crunch ($B^3C$)**

(a) Variables and -

| vectors | | | | |
|---|---|---|---|---|
| | | Nsol | : | Number of solutions |
| $fit \; : \begin{bmatrix} fit_1 \\ fit_2 \\ fit_i \\ fit_{nsol} \end{bmatrix}$ |  | $fit_i$ | : | Objective function value or the fitness of $i$th agent (e.g. ESS) |
| | | $x_{id}$ | : | Coordinates of $i^{th}$ position in $d^{th}$ dimension |

| MATRIX | | |
|---|---|---|
| $position: \begin{bmatrix} x_{1,1} & x_{1,2} & x_{1,d} \\ x_{2,1} & x_{2,2} & x_{2,d} \\ x_{i,1} & x_{i,2} & x_{i,d} \\ x_{nsol,1} & x_{nsol,2} & x_{nsol,d} \end{bmatrix}$ |  | |

| | Size of tensor | |
|---|---|---|
| | nsol x 1 | nsol x iter |
| |  |  |
| | Intial | iterations |
| Fitness | *Fit0* | **Fit_iter** |
| mass | *m* | **m_iter** |

| Intial | Iterations |
|---|---|
| Second order tensor : nsol x ndim | Third order tensor : nsol x ndim x iter |
|  |  |
| X0 | *Xiter* |
| | |

## 2.2. Mass of agent in BB-BC

The center of mass (Chart 5) is the average point calculated from the object function values of all agents. The mass of agent in BB-BC is equal to the reciprocal of fitness/object function. The crunch operator is a MISO (multi input and single output) convergence operator.

### 2.3. Refinement (updating/iteration) of approximate set of solutions

In the algorithm, the first phase consists of BB succeeded by BC. It follows an iterative cycle of BB and BC steps with transfer of knowledge in current BC to the next BB step till convergence (**Chart 3 b)**.

**.Chart 3(b): BB_BC search algorithm**

Maxit = 500;
**Initialisation**
Generate (N) random solutions (Xrand)
Prune with allowable boundaries (Xmin, Xmax)

| | |
|---|---|
| If | initial Big_Bang & all candidates are clustered in a small region of search space |
| Then | Output is not optimum solution **or** with a stuck in a local optimum |

*2.3.1. First Phase of BB-BC algorithm:*

- Big_Bang *step:* The initial population in the first Big-Bang is generated by spreading the candidates all over the search space in a uniform random manner using a statistical uniform random number generator (Figure A4-1). This set of agents or points in m-D space are approximate solutions (of object function /feature space) in the language of mathematical optimisation. It is akin to that in the popular genetic algorithm, an evolutionary strategy. This randomness is regarded as energy dissipation in nature causing chaos/disorder/randomness.

- *Big_Crunch step:* The next leap is Big-Crunch, where in widely dispersed (Chart 5) (disordered) solutions move/shrink to a single representative point called centre of mass or minimal cost function. In order to retain the philosophy of multi-agent system, many points around the center are generated using a normal distribution (Fig. A4-1). This operation or process aims moving to the true optimum or achieving the order which was lost during the Big_Bang phase. The concept of order here is to be comprehended with caution. For classical thermodynamic systems, order increases from gases to solids through liquids and the perfect order with reduced entropy is theoretically at $0^o$ Kelvin.

**Chart 5: Center of the mass**

$$Xcenter(1,j)=\frac{\sum_{j=1}^{ndim} X(i,j)*\frac{1}{fit(i)}}{\sum_{i=1}^{nsol}\frac{1}{fit(i)}}$$

$$intX(1,j)=round(X(1,j))$$

Input→ output

| X = | fit = | 1/fit = | T1 | T2 |
|---|---|---|---|---|
| 1 0 0<br>0 1 0<br>0 0 1 | 0.1000<br>0.0112<br>1.0000 | 10<br>89<br>1 | 10<br>89<br>1 | 10/100<br>89/100<br>1/100 |
| | sum | 100 | | |

$$T1=\sum_{i=1}^{ndim} X(i,j)*\frac{1}{fit(i)}$$

$$T2=\frac{T1}{\sum_{i=1}^{nsol}\frac{1}{fit(i)}}$$

```
%
% om_Xcenter.m     (22-7-2013 R S Rao)
%

function [Xcenter,it] =om_Xcenter(X,fit,iter)
     omcalled('om_Xcenter');
     [nsol,dim] = size(X);
```

output

| Xcenter = | | |
|---|---|---|
| 0.1000 | 0.8900 | 0.0100 |

```
    for j = 1:dim
        Nu = 0.;
        De = 0.;
        for i = 1:nsol
            Nu = Nu + X(i,j) * (1./fit(i));
            De = De + (1./fit(i));
        end
        Xcenter(1,j,iter) = Nu./De;
    end
```

*if chaotic*

$$fact = chaoticFn\left(\alpha\left(iter\right)\right)$$

*else if standard*

$$fact = limitX \ * \ randx\left(i, j\right) \ *$$

*end*

$$\Delta X = \frac{fact * \left[ Xmax\left(1, j\right) - Xmin\left(1, j\right) \right]}{\left(iter + 1\right)}$$

*2.3.2. Second (or Iteration) Phase:* This is core of BB-BC algorithm, but radically differs from nature's process of origin and existence of the universe. From here onwards, Bang and crunch processes are executed until convergence or stopping criteria demands termination of optimisation process.

- *Sequence of BB-BC procedures:* The iteration process consists of creation of new members for the next Big-Bang step. The simplest one is again initializing with random number. This appears to be rational, but introspection reveals that it is nothing but a repeated cycle of random search, time and again. This is like ensemble of solutions, where one looks for central tendency and dispersion of the set of solutions. The limitation persists irrespective of number of times the process is repeated as long as there is no information or knowledge transfer between successive iterations. This shortcoming is eliminated by using the knowledge of preceding iteration. Thus, the utilization of knowledge of previous generations of BBBC-processes is though generating the refined agents around center of mass of the preceding iteration is similar to memory based algorithm (chart 6). A matlab function for Space boundary calculation is incorporated in chart 7.

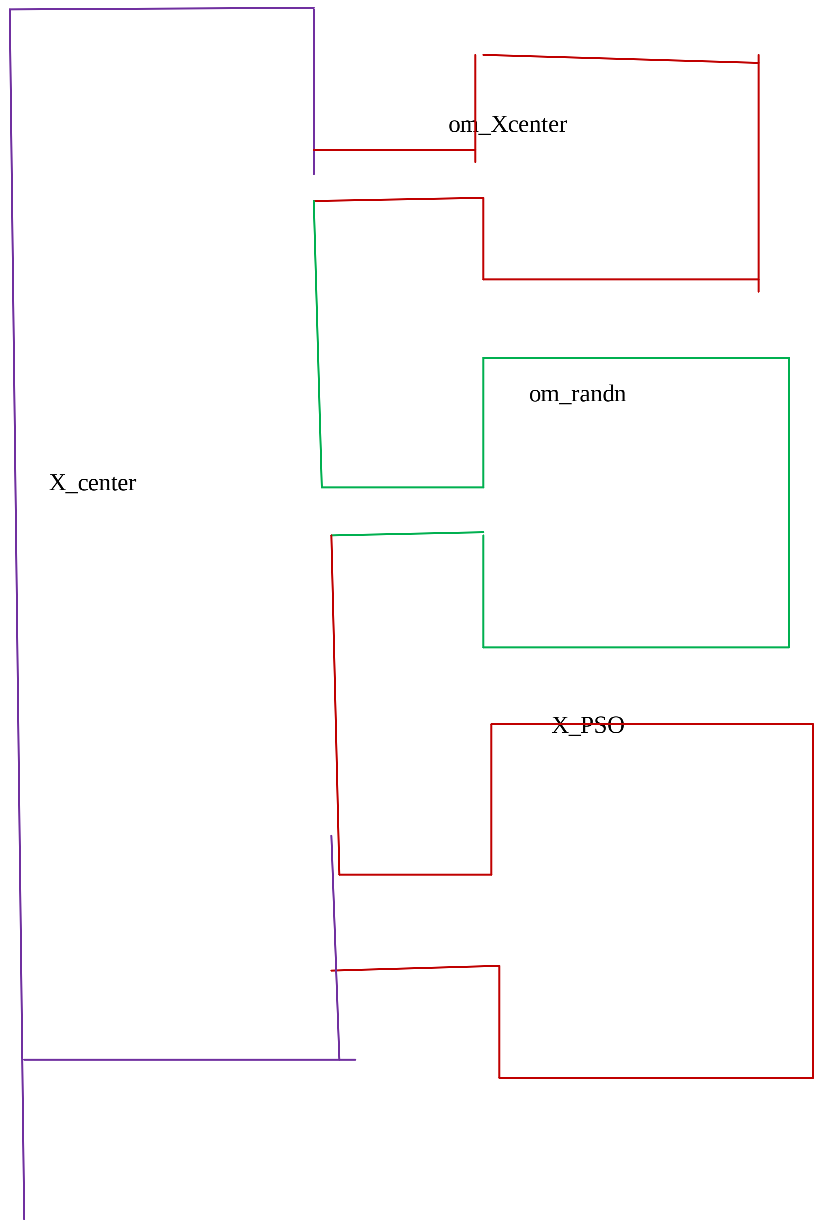



Chart 5b: Modular approach for calculation of X_center

**Chart 6: Iterative BB-BC and matlab function code**

| |
|---|
| **First Phase** |
| ○ **Big-Bang step** |
| ○ **Big-Crunch step** |
| **Second Phase** |

**Iterate until convergence | stopping criteria**

**Big-Bang step**

For each mass (or approximate solution)

Calculate

- Object (/error/fitness/merit) function value
- Center of mass
- Best objFnValue

end

**Big-Crunch step**

Generate new masses around center of the mass
using normal distribution of mean (or center)
and standard deviation
Cal Δx
X(iter+1) = X(iter) +Δx

**Operate convergence/stopping rules**

EndIterate

Matalb program

```
%
% om_Xiter.m     (22-7-2013 R S Rao)
%

 function [Xiter,iter] =
om_Xiter(X,fit,iter)
     omcalled('om_Xiter');
     [nsol,ndim] = size(X);
     X,fit,iter
     [Xcenter,it] = om_Xcenter(X,fit,1)
     Xmax  = X(3,:)
     Xmin  = X(2,:)
     limitX =10;
     sd = 0.2;
     iter = iter +1;

    for i = 1:nsol
    %%%
        for j = 1:ndim
        %%%    %rng('default');
            [randx(i,j)] =
om_randn(Xcenter(1,j),sd,1,1) ;
            deltaX (i,j) = limitX *
randx(i,j) * ....
                         [Xmax(1,j)-
Xmin(1,j)]/(iter+1);
            Xiter(i,j) = X(i,j) +
deltaX(i,j) ;
        end %%%

    end %%%
    randx,deltaX
    omexit('om_Xiter');
```

An ideal and sensitive global optimization algorithm should generate a large number of solutions around a small neighborhood of the optimal point. The remaining few points in the population bed must spread across the search space especially after performing a large number of iteration steps. The trend of ratio of the points around the minimum to those away from the optimum should decrease as the iteration process progresses. In any case, the number may be zero nearer to it reflecting the end of the search.

**Chart 7: Space boundary matlab function**

$$Space\_boundary = \sum_{i=1,j>i}^{i=nsol} \left\| X(i,:) - X(j,:) \right\|$$

$$\frac{(Space\,boundary)_{iter}}{(Space\,boundary)_{iter+1}} > 1$$

| Input | |
|---|---|
| X =<br><br>1 0 0<br>0 1 0<br>0 0 1 | fit =<br><br>0.1000<br>0.0112<br>1.000 |

```
%
% om_spaceBoundary.m      (22-7-2013 R S Rao)
%
function [spaceBoundaryX,normX] =om_spaceBoundary(X,fit,iter)
     omcalled('om_spaceBoundary');
     X,fit,iter
     [nsol,ndim] = size(X);
     spaceBoundaryX  = 0.;
    for i = 1:nsol
    %%%
        for j = 1:ndim
        %%%
            normX(i,j) = 0.
            if j > i
                normX(i,j) = norm(X(i,:)-X(j,:));
                spaceBoundaryX  =  spaceBoundaryX + normX(i,j);
            end
        end
    end
    spaceBoundaryX,normX
    omexit('om_spaceBoundary');
```

| Output |
|---|
| spaceBoundary = 4.2426 |

## 3. Applications_BB-BC

*3.1. Clustering:* Iris, wine, choice of contraceptive method and breast cancer datasets [82] belong to the classification/clustering/discrimination task. The results of BB-BC are compared with k-means, a popular clustering algorithm and two nature mimicking algorithms viz. GA, PSO. The best, worst, average value and standard deviation (sd) for 10 independent runs with each of these algorithms for four datasets from Machine Learning Laboratory of Wisconsin are calculated.

***Dataset.Iris:*** The Iris plant dataset is from original work of Fisher in the year 1936 and is an instance of supervised classification task. The dataset contains three classes of Iris plants viz. IrisSetosa, IrisVirginica, IrisVersicolor. The number of points are 50 for each class totaling to 150 patterns of MISO (multi-input-single-output) type (Table 1a) and the four measured features (sepal length, sepal width, petal length, and petal width). It is used to predict classification type.

**Table 1(a): Iris flowers dataset ; 4-classes-supervised ;**

| Floating point | | | | | Attribute |
|---|---|---|---|---|---|
| dimX: 150 x 4 | | | | | dimy: 150 x 1 |
| No | Sepal length | Sepal width | Petal Length | Petal width | Flower |
| 01 | 5.1 | 3.5 | 1.4 | 0.2 | Setosa |
| 51 | 7 | 3.2 | 4.7 | 1.4 | Versicol |
| 101 | 6.3 | 3.3 | 6 | 2.5 | Virginic |
| 150 | 5.9 | 3 | 5.1 | 1.8 | Virginic |

| Table 1(b): Iris dataset analysis | | | | |
|---|---|---|---|---|
| K-means | GA | PSO | BB-BC | Criteria |
| 97.33 | 113.98 | 96.89 | 96.67718 | Best |
| 106.05 | 125.19 | 97.23 | **96.77319** | Average |
| 120.45 | 139.77 | 97.89 | 97.40443 | Worst |
| 14.63 | 14.56 | 0.347 | **0.22260** | Std |

From the table 1 (b), it is clear that BB-BC arrives at high quality solutions, as the std (standard deviation) is lower compared to GA and PSO.

*Breast cancer dataset:* Wisconsin breast cancer data set (1992) with 699 patterns is rigorously studied to predict the malignant from benign breasts. The features of datasets available for diagnostic, prognostic purposes and time of recurrence in treated breast cancer patients are presented in table (Table 2).

**Table 2(a): Breast Cancer ; UCI ; classification ;**

Integer

Dim.X = 7 Dim.y:1

| x1 | x2 | x3 | x4 | x5 | x6 | x7 | x8 | x9 | |
|---|---|---|---|---|---|---|---|---|---|
| 5 | 1 | 1 | 1 | 2 | 1 | 3 | 1 | 1 | 2 |
| 5 | 4 | 4 | 5 | 7 | 10 | 3 | 2 | 1 | 2 |
| 3 | 1 | 1 | 1 | 2 | 2 | 3 | 1 | 1 | 2 |
| 6 | 8 | 8 | 1 | 3 | 4 | 3 | 7 | 1 | 2 |
| 4 | 1 | 1 | 3 | 2 | 1 | 3 | 1 | 1 | 2 |
| 8 | 10 | 10 | 8 | 7 | 10 | 9 | 7 | 1 | 4 |

| x1 | x2 | x3 | x4 | x5 |
|---|---|---|---|---|
| Clump | Unif_Cell_Size | Unif_Cell_Shape | Marginal_Adh | Single_Cell_Size |

| x6 | x7 | x8 | x9 |
|---|---|---|---|
| Bare_Nuclei | Bland_Chromatine | Normal_Nucleoi | Mitoses |

| Table 2(b): *Breast cancer dataset results* | | | | |
|---|---|---|---|---|
| K-means | GA | PSO | BB-BC | Criteria |
| 2999.19 | 2999.32 | 2973.50 | 2964.38764 | Best |
| 3251.21 | 3249.46 | 3050.04 | **2964.38813** | Average |
| 3521.59 | 3427.43 | 3318.88 | 2964.38894 | Worst |
| 251.14 | 229.73 | 110.80 | **0.00050 -** | Std |

The variation in average of replicate runs remarkably less dispersed as seen from very low standard deviation.

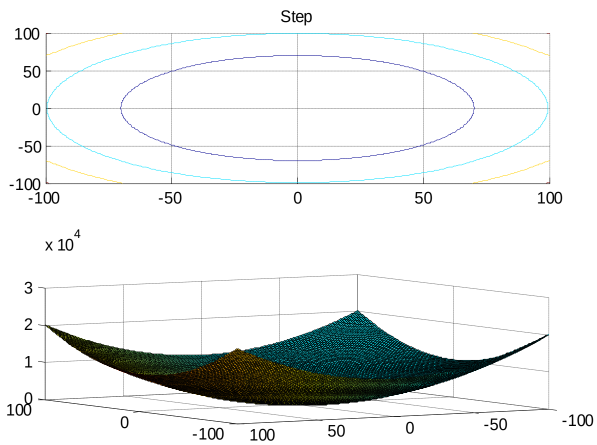
## 3.2. Mathematical functions

BBBC outperforms [10] Comb-GA (combat genetic algorithmMethod) for the Rosenbrock and Ackley functions. BB–BC outputs exact global optimum solutions within 500 cycles for the sphere, step, Rastrigin functions. Several improvements have been introduced to combat with these shortcomings.

Rosenberg function: It is a uni-modal function with a deep minimum. It posed difficulty for solving by classical optimization methods. BB-BC successfully arrived at the true optimum. An inspection of progress of iteration revealed for thirty widely spread approximate solutions, convergence for are all (except one) is around a point with coordinates (1,1) after 500 iterations. The outlier is quite far away from converged cluster, which also merges with the global optimum, but after a large number of iteration. It is not worth to continue till that point. Big_Bang–Big_Crunch algorithm is suitable for optimum of complex functional design space with multimodality [63].

### 3.3. Engineering

Within a short span since the proposal of BB-BC, it has been successfully applied in civil, electrical and mechanical engineering. BB-BC is used in fabrication of reinforced concrete and design of domes [20]. The domes are lightweight, elegant and cost-effective structures to cover large areas and the results are compared with heuristic PSO, ACO, HS, Heuristic_Particle_Swarm_ACO. The exponential BBBC [60] was applied in design of discrete steel frame structures. It is successful in robotized glass cutting [73], inverse type-2 fuzzy model controller [74 27] and time table preparation of academic courses [36, 4]. BB-BC was applied to arrive at optimal power flow in valve-point effects in IEEE 30-bus system with different fuel cost characteristics [79] and voltage stabilization [81].




```
fnName ='Step'
```

If ndim = 2

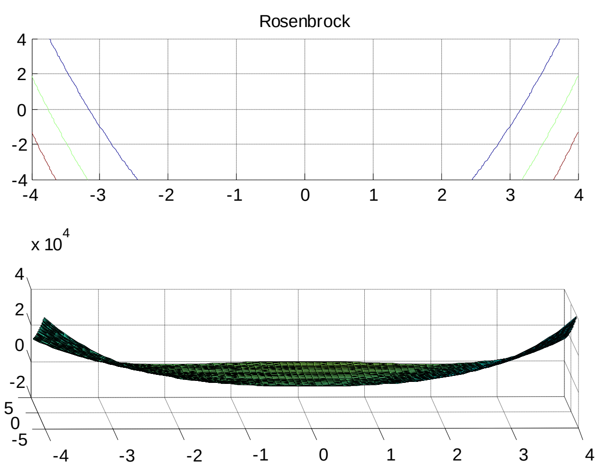
$$fn102 = \left[\left\{\left|x_1+0.5\right|\right\}\right]^2 + \left[\left\{\left|x_2+0.5\right|\right\}\right]^2$$

else

$$fn102 = \sum_{i=1}^{n\dim}\left[\left\{\left|x_i+0.5\right|\right\}.\wedge 2\right], \text{ ndim} = 30$$

$$range: -100 \le x_i \le -100$$

```
% min.FnValue = ndim*[0.25,0.25]
% min.x       = [0   0 …  0;
                 -1 -1 … -1]
```



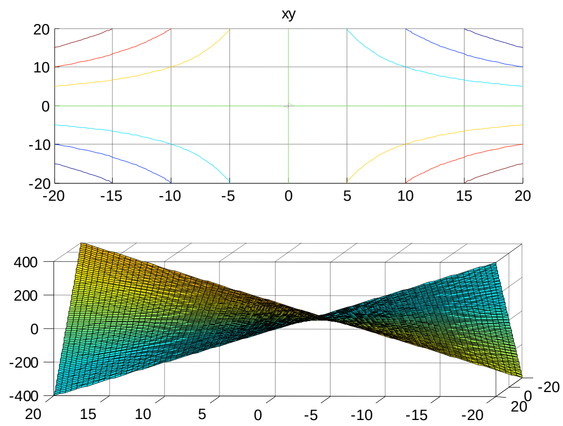

```
fnName ='Rosenbrock'
```

$$fn102 = \sum_{i=1}^{n\dim}\left[100.0*\left\{x_i^2 - x_{i+1}\right\}^2 + \left\{1.0 - x_i^2\right\}\right]$$

```
% ndim=10,           % -10 <= xi <= 10
% min.globalFnValue = 0
% min.global.x      =[1]
 If ndim =2
```

$$fn102\_2D = \left[100.0*\left\{x_1^2 - x_2\right\}^2 + \left\{1.0 - x\right.\right.$$

global minimum at (xi)=(1) ; fmin=0




$$fn101 = \sum_{i=1}^{n\dim} -x_i * y_i$$

```
% ndim=2,
% -20 <= xi <= 20
```

**Fig 1: Simulation of 3D-surface and 2D-contours of non-linear-functions amenable for BB-BC algorithm**

*Fuzzy cognitive maps:* Fuzzy logic is a powerful tool to represent nonlinear systems, which do not adhere to either deterministic or probabilistic processes. They were dealt by proportional errors and statistical/stochastic methods in yester years. Yesil and Urbas [40] applied for the first time BBBC to automated development of fuzzy cognitive maps with the existing historical data. This approach is applied with great success in process control system, radiation therapy process and data from synthetic model. The contributions of Kumbasar [77,75] are remarkable in fuzzy control systems using BBBC. Inverse fuzzy models result in perfect control of the open loop system. The limitations of open loop systems are applicability within certain conditions, modeling mismatches and disturbances causing the system progress. IMC (Internal Model Control) is a remedial measure, which compensates the modeling errors and disturbances. The solution of inverse fuzzy model with BBBC is used as a controller wherein there is no disturbance or parameter variation in the system. Here, the BBBC optimized output is used to simulate inverse fuzzy model control signals. The process is very fast and BBBC used within the sample period of time. BBBC [75 ,65] was also used in inverse fuzzy model based on IMC with an on-line model adaptation scheme. Formally on-line adaptation was formed with recursive LS. Camp [37] used BBBC (discrete and continuous variables optimization technique) in designing low weight space trusses. The objective function is total weight (cost) of structure with constraints regarding the material and performances which are reflected in stress and deflection limits. The fitness here is penalized structural weight which represents the actual truss weight the degree to which the design constraints are violated. The outcome is compared with classical and evolutionary tools for a set of bench mark test cases.

## 4. Advantages and limitations of BB-BC

The positive features and lacuna with remedial reports of BB-BC are briefly documented in chart 8**.**

## 5. Similarity of $B^3C$ with other nature mimicking swarm approaches

The results of optimization with BB-BC and its hybrid versions are extensively compared with competing nature-inspired methods viz. PSO, binary PSO [63], GA, ACO, HarmSerch, non-linear programming, heuristic_particle evolution, swarm_ACO, exponential_BBBC and EKF (extended Kalman Filter).

**Chart 8: Highlights and limitations_BB-BC**

**BBBC_ advantageous features**

+ Handles mixture of discrete and continuous variables
+ Good exploitation (i.e. fine search in and around a local optimum)
+ Multi-agent and randomized search technique amenable for parallel

computation
+ High convergence speed
+ Low computational time
+ Better performance compared to improved/enhanced GA for many bench mark test functions

**BBBC_**does not require
+ explicit relationship between the objective function and constraints

**BBBC_limitations**
– **Does not possess high exploration characteristic (global search of the search place)**
  ✓ Remedy: Large number for candidates avoids this defect
    – increase in the function evaluations
      ✓ Remedy: PSO

## 6. Recent advances_BB-BC

BB-BC algorithm tends to become more robust, efficient, and versatile by bringing forth best features in hybridizing with harmony search, PSO and incorporating vague and incomplete expert knowledge [11]. In a hybrid technique, harmony search is used for variable constraints while BBBC for global optimization. It is used to optimise input/output scaling factors of fuzzy controllers in inverted pendulum [26], automatic generation of fuzzy cognitive maps [42,64], calculation of co-variance matrix in EKF [31] and upper bounds. Kaveh [14, 24] introduced a user chosen convergence factor and used for automatic refinement of parameters of metaheuristic (PSO, ACO, GA and BBBC) algorithms. The performance of BBBC is enhanced with sub-optimization mechanism (Appendix-5) of Kaveh et al. [59,73] and using local and global best solutions like in PSO.

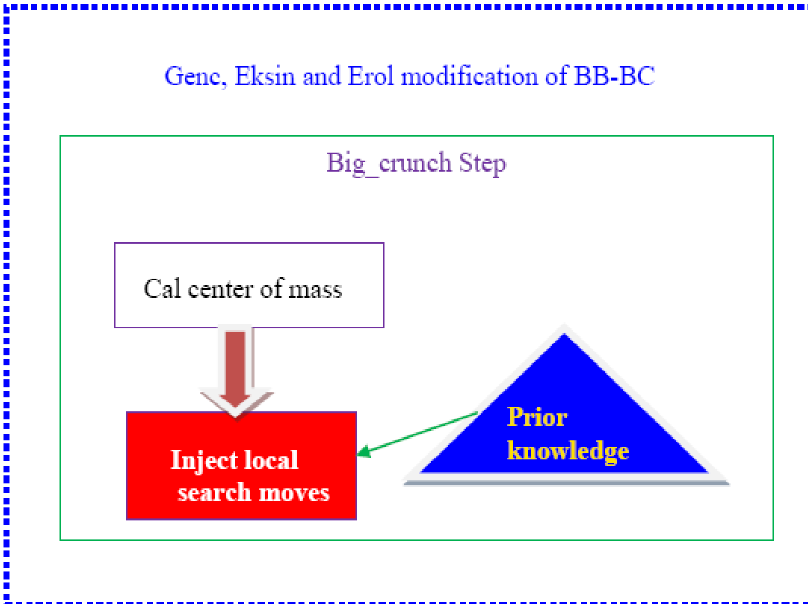
*6.1. Discrete BBBC:* Kaveh and Talatahari [17] proposed discrete BBBC and applied to optimize different types of skeletal structures with discrete variables like trusses and frames. The efficiency is found to be better compared to other heuristic algorithms. Philip and Pal [31] applied BBBC to model reduction tasks. The numerator polynomial is the reduced model is obtained by the BBBC. The denominator interval is calculated from the differentiation method of model reduction of Kharitonov polynomials. This method is useful to reduce higher order interval systems to corresponding lower order models. It is a hybrid of the differentiation and BBBC.

*6.2. Local search moves:* Genc, Eksin and Erol [11] injected local search moves after calculation of center of mass in the crunching p rocess. The injected local directional moves are based on the knowledge of previous representative points. It promotes smoothening of the path resulting in decreasing the CPU time and increasing accuracy in reaching the global optimum.

*6.3. Local trap recognition criteria:* The diversity index is the fraction of the search space spanned by the agents at each step to the complete search space considered. It reflects how agents distribute in the current iteration around the best solution. The KB for diversity index in first order predicate logic format is in Chart 9.

**Chart 9: Diversity index (a) KB_ diversity index**

| | |
|---|---|
| If | No change in diversity index for predefined number of iterations (eg. 5) |
| Then | Algorithm is in trap |
| If | particles got trapped in a diminutive region of the search space and could not get out of it |
| Then | diversity index is low |




✓ Remedy: diversity index is lower bounded (0.05) or adaptive

| | |
|---|---|
| If | particles are fixed in a specific arrangement (straight line for 250iterations) and the algorithm fails to change their positions |
| Then | diversity index holds a constant value for a predefined number of iterations |

**Chart 9(b): Diversity index and illustration**

$$Num = \frac{\sum_{i=1}^{nsol} \left\| X_i - X_{best} \right\|}{nsol}$$

$$De = \left\| X_{best} - X_{worst} \right\|$$

| | | |
|---|---|---|
| Xi | : | vector representing the ith solution |
| Xbest | : | X coordinates for best objfnValue |
| Xmin | : | lower bound of X |
| Xmax | : | upper bound of X |

$$diversInd = \frac{\frac{\sum_{i=1}^{nsol} \left\| X_i - X_{best} \right\|}{nsol}}{\left\| X_{best} - X_{worst} \right\|}$$

**X =**

| | |
|---|---|
| **1** | **1** |
| **4** | **4** |
| **2** | **2** |

```
function objFnValue =om_objFn2(x)
      objFnValue =  x(:,1).^2 + x(:,2).^2;
```

```
objFnValue =

   2
  32
   8
```

```
function [yXasc ] = om_Xyasc(X,y)
%
[yXasc] = sortz([y,X],1,1);
```

```
yX =

   2    1    1
   8    2    2
  32    4    4
```

```
T1 =

   4.2426
        0
   2.8284
```

```
Sum =

   7.0711
```

```
%
% om_diversind(X,fit)
%
function [DiversInd ] =om_diversind(X,fit)
omcalled('om_diversind');

[yX] = om_Xyasc(X,fit)
[nsol,ndim] = size(yX);
Xbest = yX(nsol,2:ndim);
Xworst = yX(1,2:ndim);
De  = norm( Xbest - Xworst )
Num =0.
%%%
for i = 1:nsol
    T1(i,1) =  norm([X(i,:)-Xbest])
    Num = Num +  T1(i,1)
end
%%%
DiversInd = Num/De
```

```
DiversInd =

   0.5556
```

**6.4.** *Uniform-Big_Bang~Chaotic-Big_Crunch (UBB–CBC) alg.:* Here, **i**n the Big_Bang phase, uniform population method, a mathematical technique is substituted for uniform random generator. The crunching in Big_Crunch phase is affected by chaos by Alatas [28] instead of normal distribution to rapidly shrink the wide spread points via the center of mass. This swarm method is named as Uniform Big_Bang–Chaotic Big_Crunch (UBB–CBC). The performance of the UBB–CBC optimization algorithm demonstrates its superiority over the BB–BC optimization for the benchmark functions.

*6.5 Hybrid-nature mimicking algorithms:* Mathematical models of the yesteryears or even of the advanced ones these days are not adequate to represent complex multivariate-multi-modal processes dynamic in time or space. Hence, there is a need for making use of human cognitive representative and expression abilities i.e. knowledge coupled with one's experience/skills in successfully tackling, partially solving and even facing failures with the real systems. Nature mimicking algorithms are one such diverse approach. As the data doesn't adhere to the stipulations of error/parameter distribution of classical mathematical /statistical methods, they are not ideal for application in toto. But, recently, they are used to obtain a first guess in hybrid neural networks/ hybrid E-man techniques [40] advantageously at appropriate stages of finding final solution. What happens here is an inadequate method is used to get approximate solutions. Therefore a wild guess, intelligent or even approximate model is definitely inferior to otherwise inappropriate standard algorithm. Yet, the hybridisation in many of recent reports appears to be loose coupled and in fact a part of the job is done by one method and other part is by another [31].

The binary hybridization of well nurtured algorithms continued with BB-BC also. BBBC is hybridized with CSS, ACO, harmony search, probabilistic-NN etc in dealing with real time dynamic and constrained non-linear multimodal systems. Kaveh and Talatahari [21] applied the hybrid BBBC to topology design of Schwedler and ribbed domes. The advantage is domes to cover large areas without intermediate support. The optimal reactive power [57, 80] was studied with BBBC-PSO. The power load shedding [43] in constrained multi-dimensional variable space was optimized with BBBC-PNN.

- BBBC + CSS-with trap recognition heuristic

The diversity index is calculated in every iteration. If a trap in the local minimum is detected, Big_Bang operator produces a disturbance facilitating the solutions to escape from pit. The center of mass till that point is assumed as the best solution vector. The choice of parameters (c1 and c2) are strategic both in standard and enhanced CSS.

The algorithm (chart 10) is very sensitive with respect to these parameters and therefore it is to be run with different values until the best values are identified. This is a disadvantage and many optimization techniques suffer from this problem. On the contrary, the algorithm proposed here is not that sensitive with respect to these parameters.

**Chart 10 : hybridized CSS-BBBC with trap recognition heuristic**

ॐ Initialisation
- Parameters
  - CSS, BBBC
- Random initial population

Iterate until convergence | stopping criteria
  Execute CSS
  For each iteration
    Big_Bang steps
    Cal diversity index
    If trap recognition criteria
    Then create disturbance in Big_Bang operator
    endif
  endfor
EndIterate
Output

If constraints are within allowable limits
Then penalty is zero
Else $penalty = \frac{violation\ of\ allowable\ limit}{limit}$

## BB_BC + PSO algorithm

Particle swarm optimization (PSO) is also a nature inspired algorithm. It is a member of the toolbox of E-man making use of the experience of individual searches and the experience of the entire population till that iteration. The experience of individual in that iteration is helpful to search locally. The richest experience of the entire population corresponds to global best solution. The knowledge, intelligence or nature's intelligence or upgraded knowledge processes over evolution for the best of the (hyper/super/rare) intelligent experience of that species in that spacio-time frame is the inspiration. The intercontinental travel of the flock of the birds to places which they never visited and school of fish are the source of inspiration of the scientists in proposing PSO. In a nut shell particles moves in the direction computed from the best visited position of the individual and global best position of all the particles (agents). In hybrid BBBC-PSO (chart 11), not only the centre of the mass but also the best position of the candidate (local best) and best global position are also employed to calculate the new or iterated solution.

**Chart 11: Hybrid_BB_BC_PSO search algorithm**
(a)Initialisation

Maxit = 500;
**Initialisation**
BB–BC parameters ; SOM parameters ; PSO parameters

*Cal Acc(uracies)*

BBBC_PSO
Output

Chart 11(b): Pseudo code for Hybrid BBBC-PSO

```
kSOM =1
        Generate initial candidates in a random manner
Iterate Until
        Accu_lastStage Accu(i,nc) ≤ Accu_primary_task

        k = 1
        Evaluate the boundaries of the design variables
        Evaluate the allowable sets of the design variables

        If          kSOM > 1
        Then        initial candidates ← previous solutions

        Do20        until termination criteria
                    Cal  the Merit function values X
                    Cal center of mass
                    Update  solutions  X
                    k = k+1
        endDO20

        kSOM = kSOM +1
EndIterate
```

*Heuristic-BBBC-PSO-ACO-HarmonySearch algorithm:* Kaveh [16] proposed a hybrid algorithm named heuristic-BBBC-PSO-ACO-HarmonySearch and applied for discrete optimization of total cost of the frame of reinforced concrete planar frames. The hybridization of BBBC with harmony search deals with variable constraints. Heuristic- particle-swarm-ACO is a combination of particle swarm with passive congregation, ACO and harmony search. Here, BBBC is used in the ACO stage.

Chart 11(c): Equations and matlab object module for calculation of $\Delta X$ in Hybrid BBBC-PSO

$$sd_{j,iter} = \frac{nrand * \{XCenter(j,\text{iter}), sd\}}{nBB} * \lim\_sizeX * \{ultX(j,1) - lltX(j,1)\} \quad \text{Eqn.1}$$

$$j = 1, 2, \ldots \text{ndim};$$

$$X(i,j,iter+1) = Xcenter(j,iter) + sd_{j,iter} \quad \text{Eqn.2}$$

$$\text{int}\, X(i,j,iter+1) = round\left[X(i,j,iter+1)\right] \quad \text{Eqn.3}$$

$$X(i,j,iter+1) = w1 * Xcenter(j,iter) + (1-w1)*\left[w2 * Xlbest(j,1) + (1-w2)* Xgbest(j,1)\right] + sd_{j,iter} \quad \text{Eqn.4}$$

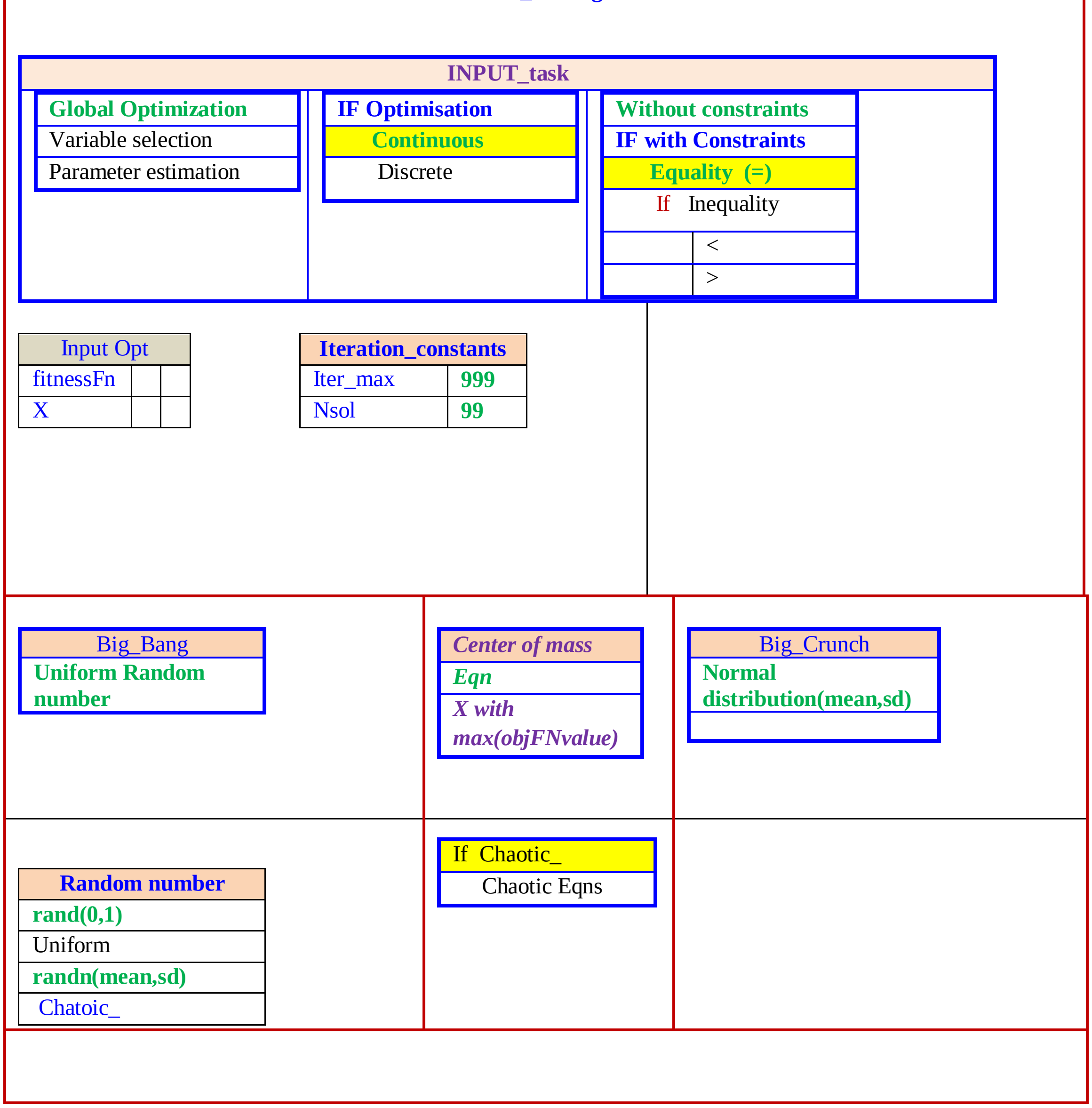
$$\text{int}\, X(i,j,iter+1) = round\left[X(i,j,iter+1)\right] \quad \text{Eqn.5}$$

| | | |
|---|---|---|
| Lim_sizeX | : | Parameter limiting size of search space |
| N | : | Normal random number |
| ultX | : | Upper limit of X |
| lltX | : | lower limit of X |
| nBB | : | Number of Big_Bang iterations |
| w1,w2 | : | Influencing factors of local and best solutions |

## 7. Future scope

BB-BC outputs either discrete or continuous values depending upon I/O data structure of a task. The application of BB-BC in diverse disciplines of chemical/biological/computer sciences and engineering certifies its prospects in optimisation, clustering, selection of variables and inverse modelling. The state-of-art-of-BB_BC amenable for implementation in matlab (open source high performance language/paradigm for technical computing and visualization) and object modules (Oms) (chart 12) helps to develop knowledge-based/self-adaptive/ exhaustive- combinations with Eman modules.

**Chart 12. State-of-art-of-BB_BC algorithm in research mode**



**MethodBase_ BB_BC**

| Modified_ BB_BC |
|---|
| None |
| Discrete BBBC |
| Exponential_ |
| Chaotic_ |
| uniform population |
| sub-optimization |

| Local minima |
|---|
| No special method |
| Trap recognition |

| Binary Hybrid systems |
|---|
| BB_BC + |
| None |
| Harmony search |
| CSS |
| PSO |
| ACO |
| ProbNN |
| |
| PSO + ACO + HarmonySearch |

| Systems with BB_B |
|---|
| None |
| Automated fuzzy cogniti maps |
| Co-variance matrix in El |
| Automatic refinement of parameters ■ PSO ■ ACO ■ GA ■ BBBC |

| Compared with |
|---|
| None |
| PSO_binary |
| ACO_Swarm |
| Heuristic_Particle_ evolution_ strategy |
| GA |
| NLprogramming |
| |
| EKF |
| |
| |

**Default in green**

This is a test-bed for validation of results of standard data/function bases of increasing complexity from research stand point leading to generation of vistas in algorithms/software/parallel implementations. They finally result in tools that work on an integrated chip. The abbreviations of E-man modules considered here (Chart 13) are a subset of object oriented database with definitions, equations, solution methods and literature cited discipline wise tasks. The comparison of results in ranking nature inspired swarm intelligent techniques should focus in choosing the latest (but not the earliest form eg GA in 1975 or ACO of 1990s) algorithm of a method and also typical data sets. The traces of movement of (multi-dimensional-multi-modal) error-surface with constraints towards optimum when approximate solution is far away from the true optimum will help in improving the robustness, reaching true global minimum with a fringe benefit of lower CPU-time.

**Chart 13: Abbreviation and acronyms**
**(a)Terminology of BBBC model in physics**

| Abbreviation | | Acronym |
|---|---|---|
| ALICE | : | A Large Ion Collider Experiment |
| Boomerang | : | Balloon Observations Of Millimetric Extragalactic Radiation and Geophysics |
| CMB | : | Cosmic microwave background |
| CMS | : | Compact Muon Solenoid Experiment |
| COBE | : | Cosmic Background Explorer satellite |
| LHCb | : | Large Hadron Collider beauty experiment |
| LHCf | : | Large Hadron Collider forward experiment |
| PSP | : | Planck space probe |
| TOTEM | | TOTal Elastic and diffractive cross section Measurement experiment |
| WMAP | : | Wilkinson Microwave Anisotropy Probe |

**(b) Nature mimicking swarm algorithms**

| Abbreviation | | Acronym |
|---|---|---|
| ACO | : | Ant colony optimisation |
| BB_BC | : | Big_Bang Big crunch |
| Eman | : | Evolutionary mimics of natures' algorithms |
| GA | : | Genetic algorithm |

| | | |
|---|---|---|
| Harmo.serch | : | Harmony search |
| HBFA | : | Honey-Bee-Foraging |
| HBMA | : | Honey-Bee-Mating |
| Name | : | Nature's Algorithms Mimics Evolution |
| PSO | : | Particle Swarm Optimization |

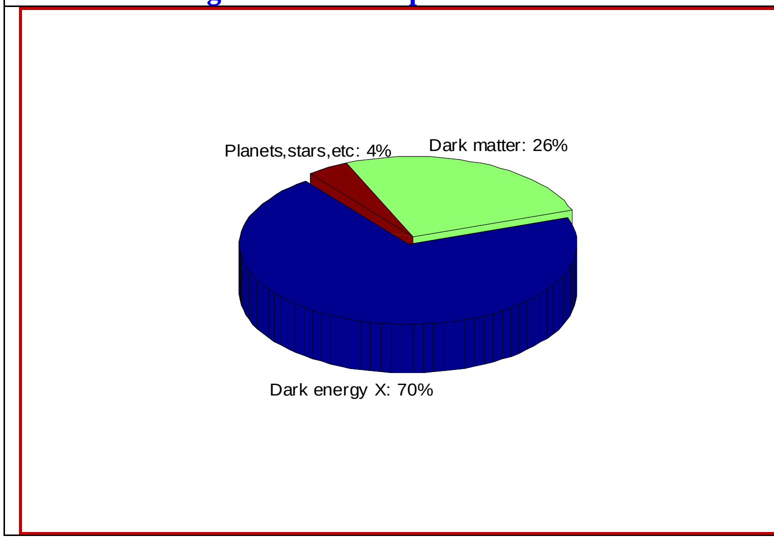
**Acknowledgements:** The authors thank many researchers for providing the copies of publications and preprints including unpublished data.

## 8. Appendices

### Appendix-1: Big_bang-Big_crunch model of universe

*Scientific theories of origin of universe in nature:* The planet sun belongs G2V class star indicating that it is in the yellow spectrum (G), a dwarf star (V) and relatively hot (2). It has abundant of hydrogen, protons, helium, helium ions etc. undergoing billions of micro chemical/physical processes with a consequence of down pouring light and (heat) energy in space. The mother earth has atmosphere, abundant water in oceans, minerals/fuel/precious metals deep under the surface and a variety of carbon based life in water, earth surface and up in the atmosphere. Very recently, a first carbon rich world never observed is discovered with WASP-12b+. The physical sciences along with bio-geo-astronomical paradigms had the target of searching for electrons/protons/ or neutrons on one hand, bosons to probe further into unexplained riddles of nature and (precise and reproducible) scientific observations. The existence of intuitive (Godly) particle 'Higg's boson' is experimentally confirmed in 2012 at CERN, Geneva.

**Figure A1-1: Composition universe**




Structure, order, low energy, low entropy etc., represent comparatively a stable state, while randomness, high entropy, dissipation of energy and so on is associated with processes of instability. It is a big question whether the nature or natural processes grow from stable state to unstable state (i.e. structure to randomness) or unstable state to a stable state (i.e., low energy to higher energy) through meta stable state. Whenever there is release of energy or dissipation, the trends are to disorder the particles from order. Today, we have the technology to prepare very high energy materials which are stable under normal conditions. The nature (Fig. A1-2) has already performed all these feats long ago.

In seventeenth century Galileo opined that the language of nature is mathematics. Thus, mathematics mirrors nature. However, the eternal permanency of mathematical proof is virtually impossible to think of in mathematical physics, as iterative refinement of theories and experiments go hand in hand. In fact, newer theories/ paradigms emerge, shift, and fall off from nature's grace continuously. The universe is more complicated than even the subtlety of mathematics.

**Big Bang model**

The Big Bang occurred approximately 13.798 (± 0.037) billion years ago (Fig. A1-2a). Penzias and Wilson were awarded a Nobel Prize in 1978 for the theory.

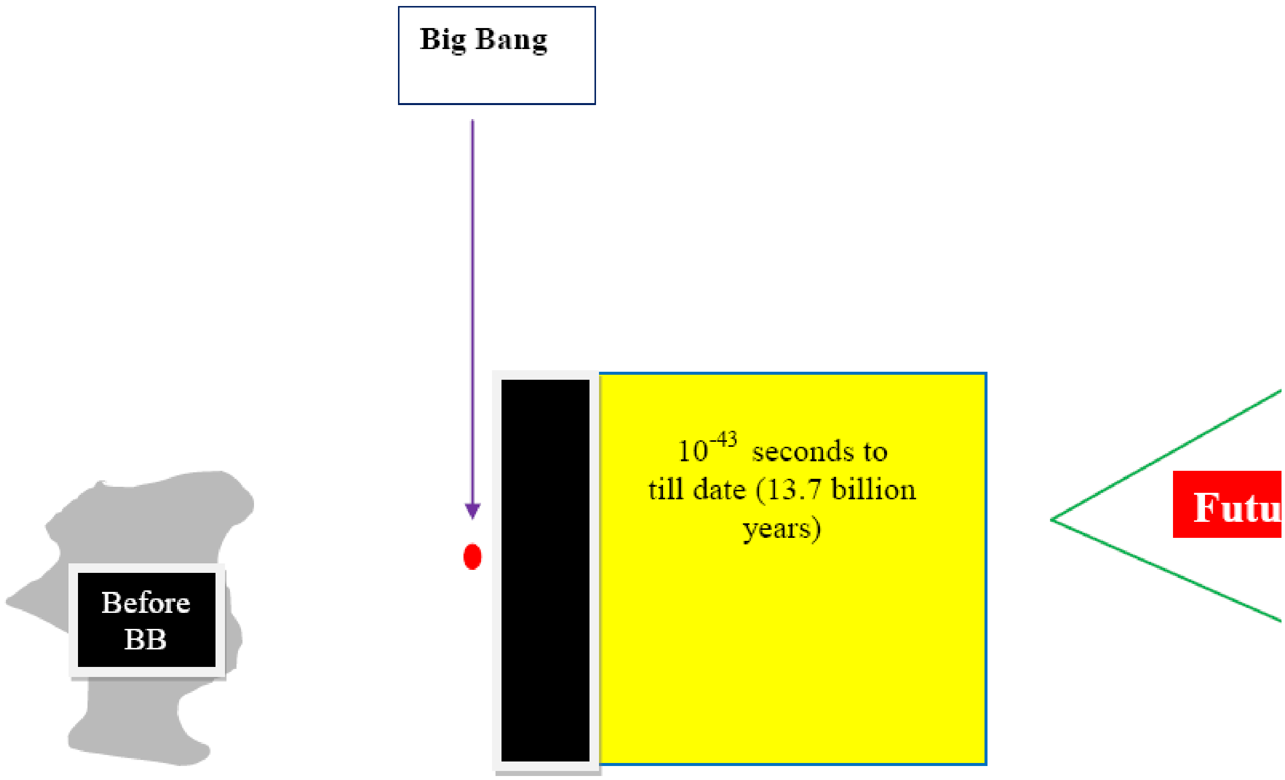



Fig A1-2(a) Time history origin of universe

The assumptions of Big Bang theory are universe is homogeneous/ isotropic on a large scale and physical laws are applicable. It refers to expansion of the early hot, dense phase continuously, which on mathematical parlance to singularity. This can be deemed as a cause for birth of our Universe. The size of the universe at the time of big bang was about $10^{-32}$ cm and now expanded to $10^{+28}$ cms. The complexity in time and space of what happened within Plancktime ($10^{-43}$ sec), in one second, three minutes and billions of years after Big_Bang (Fig. A1-2) are comparable to this accidental incidence only.

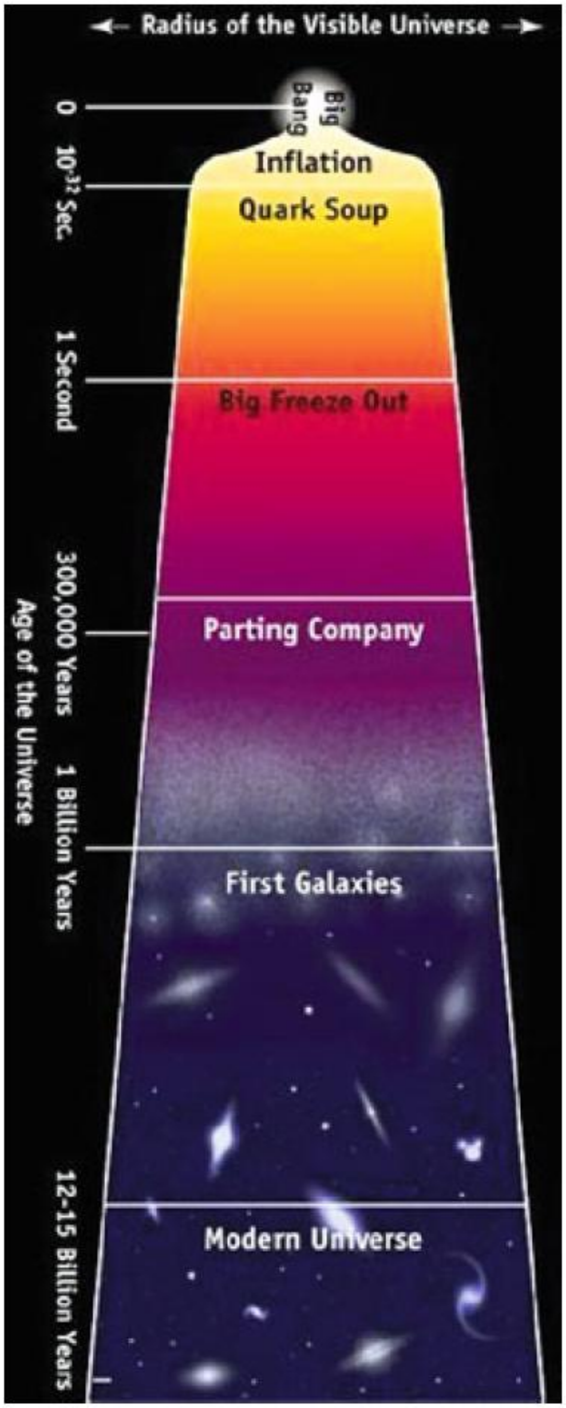



Fig A1-2(b) Timeline for the evolution of the modern universe (Image courtesy of ESA)

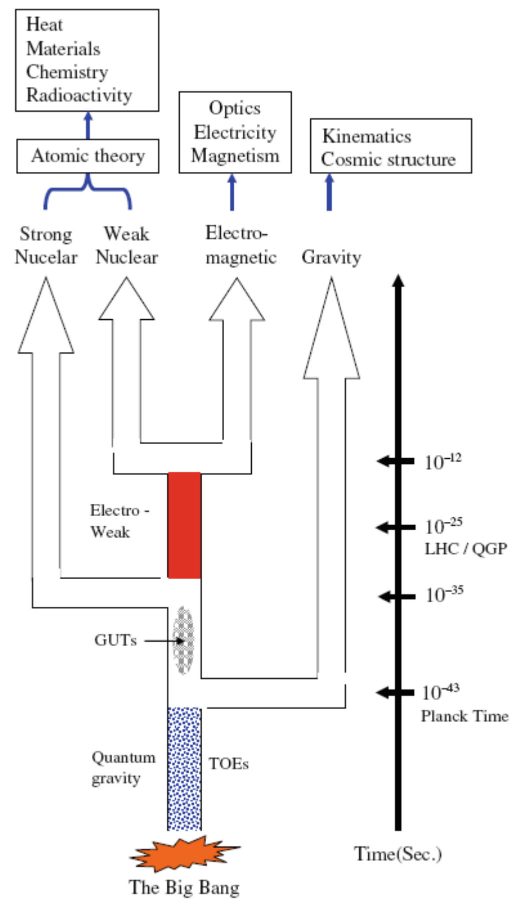



Fig A1-2(c): The Big_Bang and the First 380,000 Years

Fig.A1-2(d ) The Earth fromApollo flights (courtesy of NASA, Apollo 17)

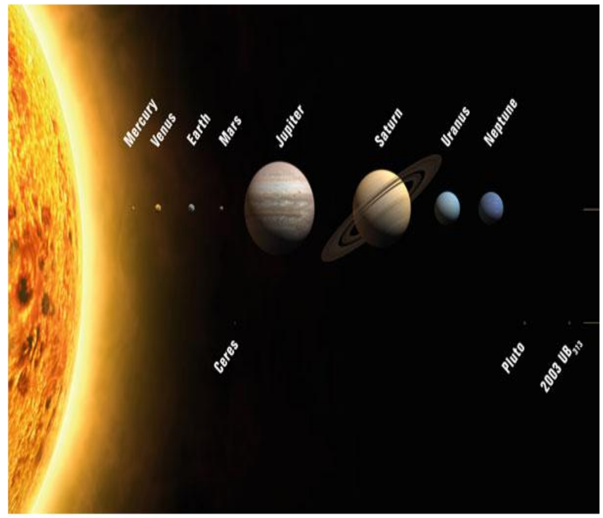



Fig. A1-2(e) Sun, Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Pluto (from left to right) (courtesy of IAU)

The other miracles to human race are the brain and life including his. The first hypothesis of origin of the universe is the 'primordial atom' of Georges Lemaître, which underwent refinement phase wise. Albert Einstein's general relativity is the framework to work with and Alexander Friedmann formulated the relevant equations of the model. The current framework is its parameterization as the Lambda-CDM model. The cosmic microwave background radiation, its spectrum (intensity of radiation at each wavelength) matching with thermal radiation from a black body is a confirmation of this theory.

*Experimental evidence:* The experimental measurements of expansion using Type Ia supernovae, temperature fluctuations in the cosmic microwave background, and correlation function of galaxies unequivocally support the 13.772 (± 0.059) billion years age of universe computed with ΛCDM model making use of two independent frameworks viz. quantum mechanics and Einstein's General Relativity. The large particle accelerators replicate the then conditions and the abundance of light elements, large scale structures, and the Hubble diagram produced further vote for big-bang model.

*Applications:* The relative concentration abundances of helium-4, helium-3, deuterium and lithium-7 in the Universe can be calculated from ratio of photons to baryons. A detailed model of CMB fluctuations output (0.25 for $^4$He /H, about 10−3 for $^2$H /H, about 10−4 for $^3$He /H and about 10−9 for 7Li/H) is in agreement with observations.

**Big Bang theory**

+ Describes and explains origin and evolution of the universe

− **Does not provide any explanation for the initial conditions of the universe i.e. before Planck time ($10^{-43}$ sec)**

✓ Remedy: new unified theory of quantum gravitation

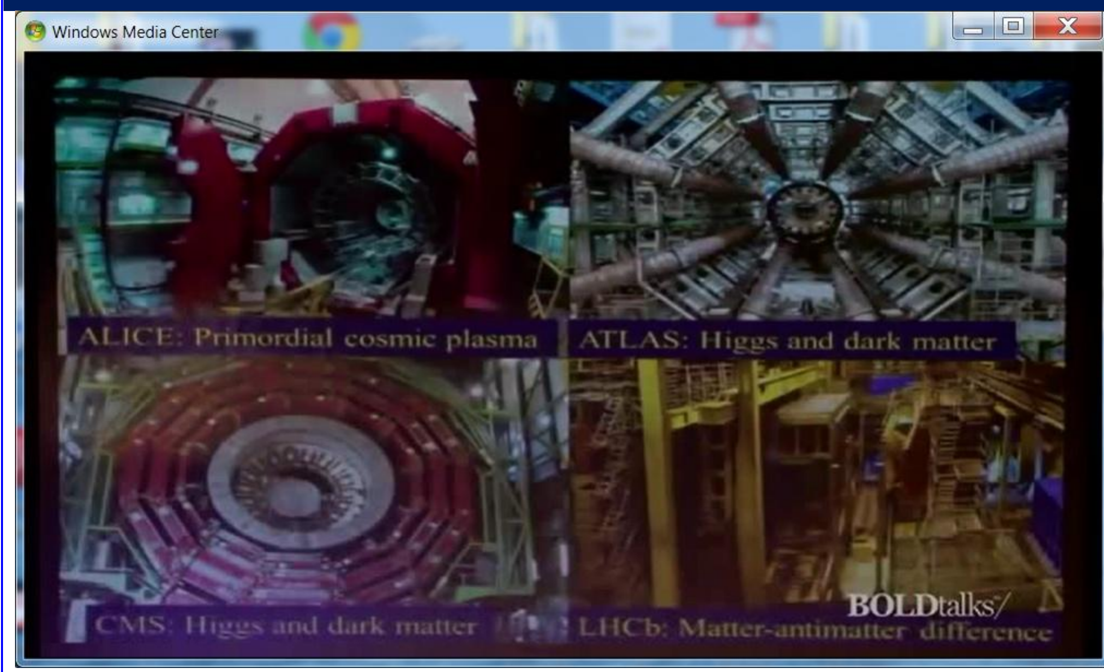
## Appendix-2: A bird's eye view of universe $10^{-43}$ sec (Plank time) after big bang until present (13 billion years of) time

### Experiments at CERN leading to detection of theoretically contemplated boson

The existence of massless-bosons imparting mass to sub-atomic particles is a great deal for the very existence of atoms and consequently molecules, life (insects to dinosaurs) as well as lifeless entities. The objectives of this mega-unique experimental episode at CERN are in Fig. A2-1. In the experiments, several trillions of protons moving with approximately 99.9999 991 of speed of light (photon) orbit 11,000 trips around 27 kilometers ring of LHC (Large Hadron Collider). It undergoes a billion collisions per second. The vacuum attained is similar to interplanetary space, the pressure being ten times lower than that on the moon. The temperature maintained in this experiment is 1.9$^o$K[=-271$^o$K], while that in the outer space is 2.7$^o$K[=-270$^o$K]on average. When particles collide in LHC, within a tiny volume the temperature goes up. It is billion times higher than in the core (heart) of the planet sun (G2V star) loosely referred as a planet, but the volume is miles.

The concerted efforts through ATLAS and CMS experiments using LHC resulted in the experimental confirmation of this coveted Higgs Boson (a long awaited fundamental sub atomic particle) which is a milestone in particle physics. On 4$^{th}$ July 2012, European Organization for Nuclear Research (CERN) reported unequivocally experimental existence of Higgs boson. In 2013, Englert and Higgs are awarded Nobel Prize for "theoretical discovery of (Higgs) boson which explains the origin of mass of subatomic particles'. Earlier around twenty Nobel Prizes are awarded for the intensive pursuits of this mega venture and typical ones are in table A2-1. The incident was celebrated as HiggsDependenceDay (HDD) with a slogan of mass-Higgsteria. This expands boundaries of standard model to probe further. But, super-symmetry, dark matter, extra dimensions, strings etc are to be resolved to the core and thus saga continues.

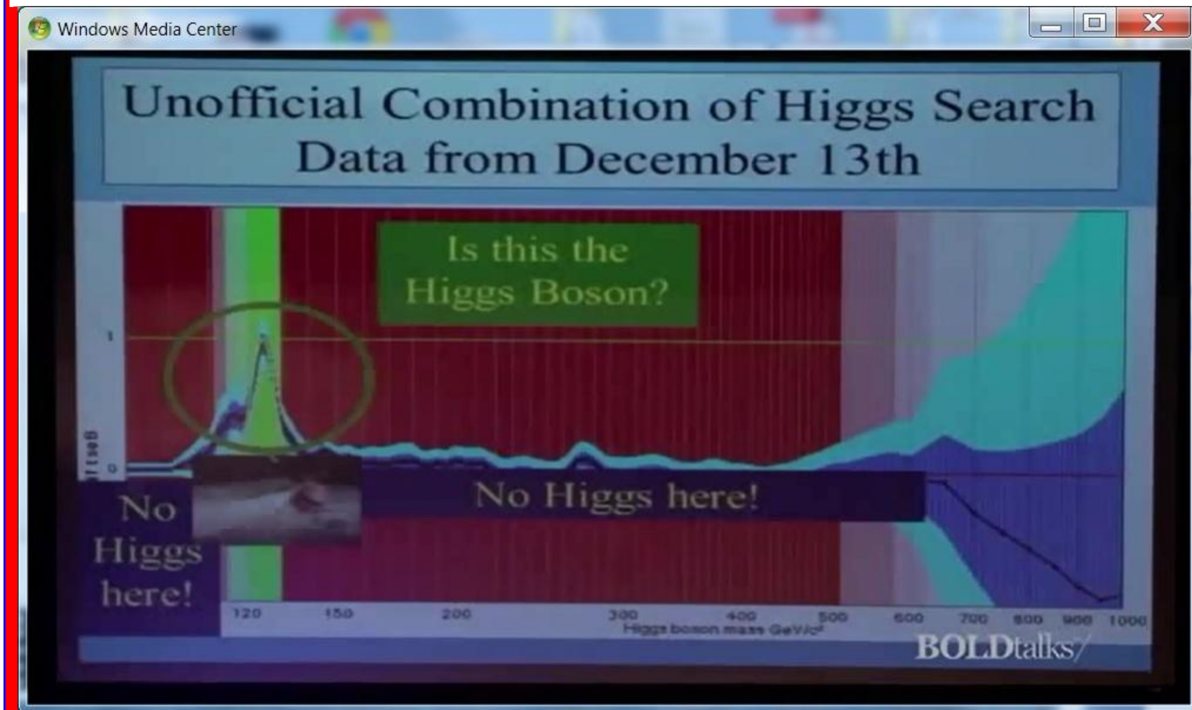
**Fig.A2-1: LHC facility at CERN**




**Goals of LHC-experiment**

- ॐ Origin of mass
- ॐ Nature of dark matter
- ॐ Primordial plasma
- ॐ Matter vs antimatter

**Fig.A2-1b: Experimental signal of Higgs boson**




**What if Boson does not exist ?**

| | | | |
|---|---|---|---|
| If | there are no Higgs boson | Then | electrons won't have mass<br>electrons escape from nucleus at speed of light |
| If | electrons would escape | Then | no atoms there will be only nuclei |
| If | there is no Higgs boson | Then | Weak interactions causing radio activity are not weak<br>i.e. they are as strong as electricity<br>Everything would flow into dark |

**Table A2-1: Typical list of Nobel prize winning pursuits in theory/models/experiments of particle physics**

| Nobel Prize | Contribution | Nobel Lauretes | Year of contribution |
|---|---|---|---|
| 2013 | Higgs Boson | ❖ Englert<br>❖ Higgs | 1964 |
| 2008 | Mathematics for spontaneous symmetry breaking | ❖ Yoichiro Nambu | 1960 |
| 1999 | Renormalization of electroweak theory | ❖ Martinus Veltman<br>Gerardus't Hooft | 1972 |
| 1979 | Unification of weak and electromagnetic interactions with a Higgs mechanism for electroweak symmetry breaking | ❖ Steven Weinberg<br>❖ Abdus Salam<br>❖ Sheldon Glashow | 1967 |
| 1977 | Condensed–matter physics | ❖ Anderson | |

**Time history after big_bang i.e. origin and subsistence of universe (nature)**

The sequence of consequences from $10^{-43}$ seconds to 1.7 billion years is described in a nutshell here. The concept of time started with occurrence of big bang.

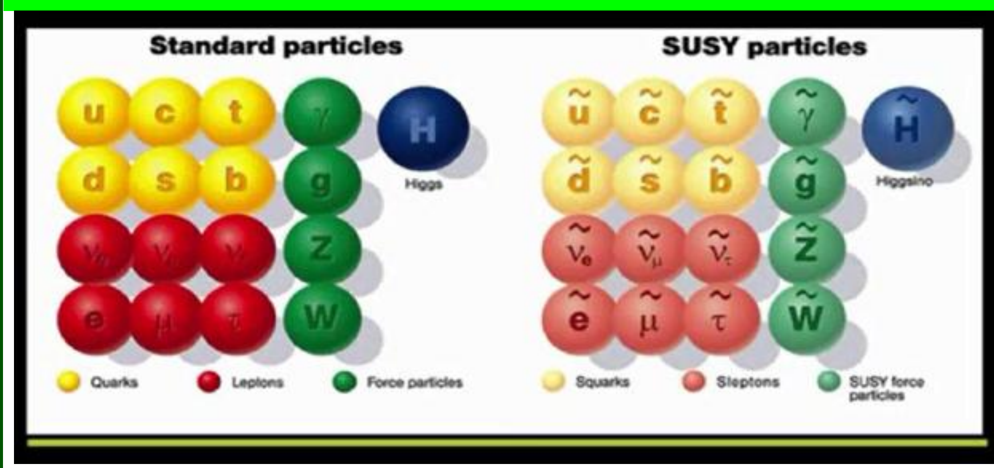
Super string era [up to $10^{-44}$ sec]: Not much is unequivocally established.

Planck era [$10^{-44}$ to $10^{-43}$ sec]: The cosmos undergoes a superfast inflation. The expansion can be compared to that of atom to growing to the size of a grapefruit.

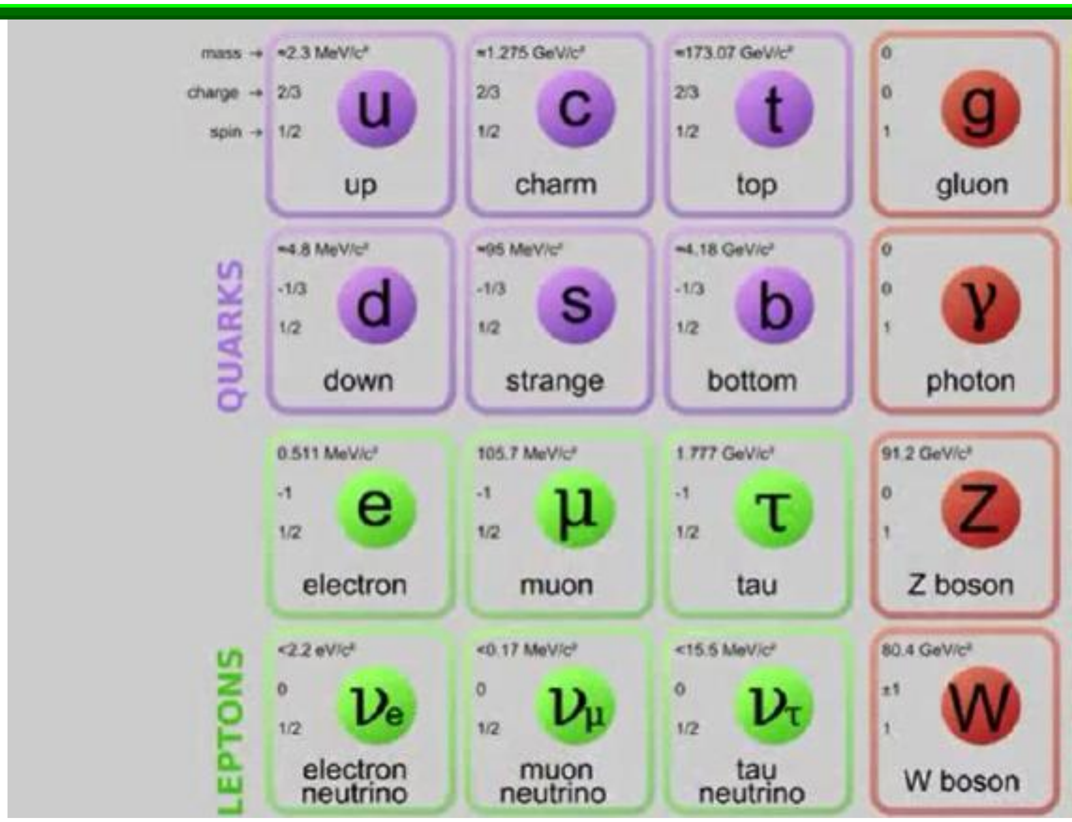
GUT (**Grand Unified Theories)** era [$10^{-43}$ to $10^{-38}$ sec]: The strong forces become distinct and thus, inflation of universe occurred.

Post inflation: The universe is a seething (churning and foaming as if boiling) of hot soup of electrons, quarks etc (chart A2-1).

**Chart A2-1. Particles; (a) Standard; (b) SUper Symmetry (SUSY); (c ) Interaction; (d) Classification**

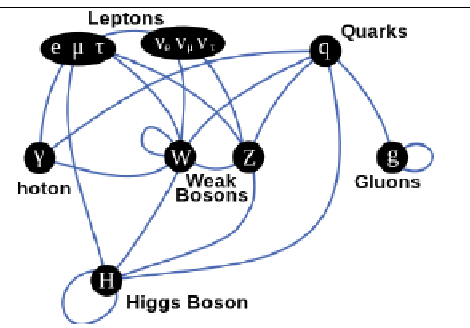



(a ) Fundamental particles and their super symmetry counter (anti) particles.

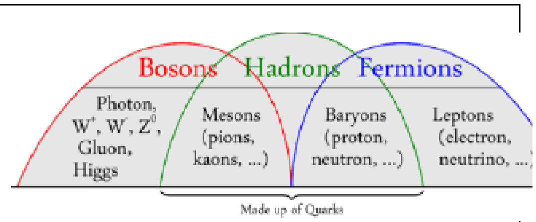



\

(b) Subclassication of quarks, leptons, guage bosons




(c )




(d)

| Net representation of particle trasformations | Overlapping picture of particles |
|---|---|

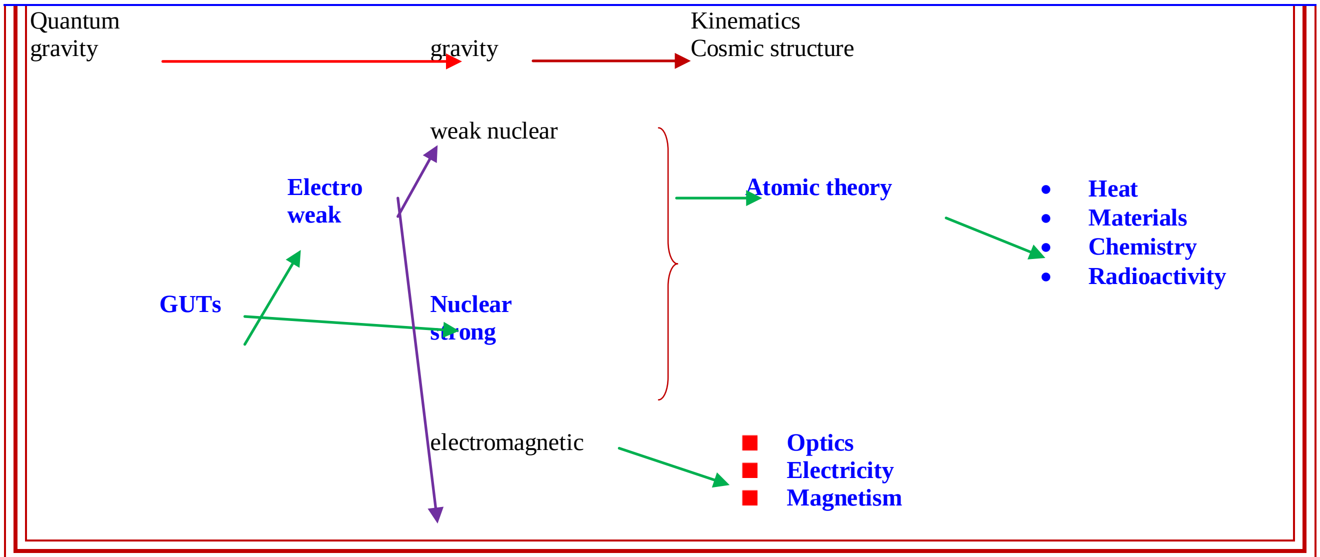
| Fundamental particles | | | |
|---|---|---|---|
| Quarks | | | |
| Up | down | $e-$ neutrino | Electron |
| Charm | strange | $\mu-$ neutrino | Muon |
| Top | bottom | $\lambda-$ neutrino | Tau |
| | | | |
| Fundamental Interactions | | | |
| | | Inside nucleus | |

| Gravity<br><br>Quantum<br><br>Newton | Electricity<br>&<br>Magnetism | Strong force | Weak force |
|---|---|---|---|
| | | | |
| Pull | Light & Radio waves | Stability of nucleus | Radio activity |
| (e ) Fundamental sub-atomic particles and interactions | | | |

$10^{-32}$ seconds: Cosmic inflation ends

Electroweak era [$10^{-38}$ to $10^{-10}$ sec]: The electromagnetic and weak forces became distinct (chart A2-2).

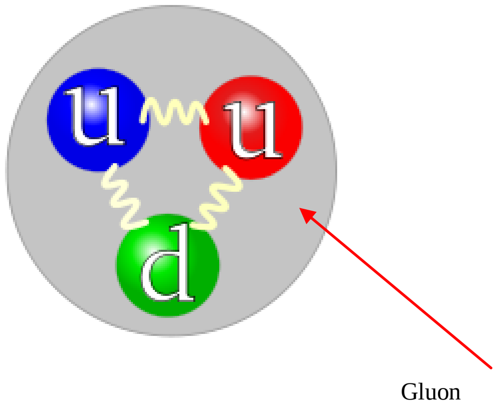
**Chart A2-2: Macroscopic manifestations from primordial soup**



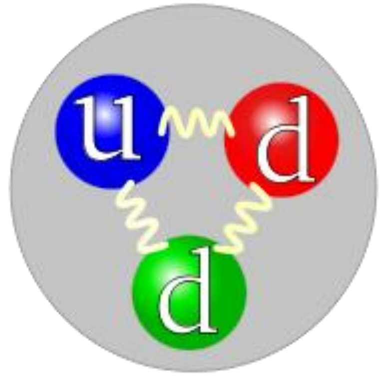

1 micro-second: As the temperature falls from $10^{27}$ to $10^{13}$ during the time (to $10^{-6}$) period, quarks in the cosmos clump into protons and neutrons (chart A2-3).

Particle era [$10^{-10}$ to $10^{-3}$ sec]: Matter annihilates antimatter. Elementary particles and antimatter are common in this era.

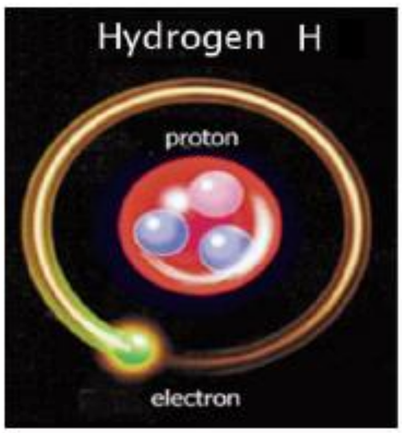
Chart A2-3. Proton/ neutron (a,b) and hydrogen and antihydrogen (c,d) in terms of quarks



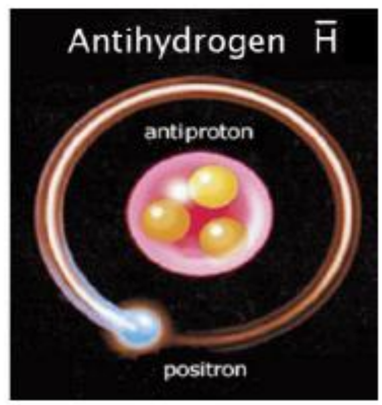

(a ) Proton ($10^{-15}$m): 2 Up and 1D quarks (< $10^{-20}$m); binding gluons




(b ) Neutron: 1 Up and 2D quarks; binding gluons




(c ) Hydrogen (atom): proton and electron (Particles)




(d ) Antihydrogen (anti-atom): Antiproton and antielectron (positron) [anti-particles]

Nucleosynthesis era [$10^{-3}$ to 180 sec]: The universe is a superhot fog after three minutes of big bang since the temperature is still high ($10^{8}$ ). Protons, neutrons, electrons and neutrinos prevail, while antimatter was rare. The normal matter is 75% hydrogen and 25% helium. Thus, nuclei (protons) and electrons do not interact and also prevent light from shining.

3 minutes to three hundred thousand years: Here, there is a pool of plasma of hydron/helium nuclei and electrons. At 10,000°C, electrons combine with nuclei (protons and helium nucleus, an admixture of protons and neutrons) resulting in atoms (hydrogen and helium). The light starts finally shining then onwards. The photons fly freely and become microwave background.

Atoms era [Five hundred thousand to One billion years]: Gravity started operating and hydrogen and helium coalesce forming giant clouds (-270°C) which became galaxies. Smaller clumps of gas collapse resulting in first stars.

Galaxies era [One to fifteen billion years]: The atoms and plasma started interacting with each other. The temperature fell down to -270°C and galaxies clustered together under gravitational force. The first born stars died spewing (ejecting forcefully in large amounts) heavy elements into space. This is the start of planets and new stars.

## Appendix-3: Future plight of planets, universe

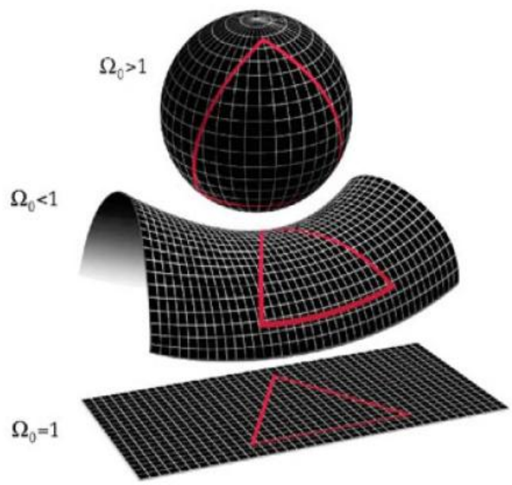
WMAP observations support that the universe contains 4.6% regular matter, 73% dark energy, 23% dark matter and less than 1% neutrinos (Fig A1-1). Still, earth quakes and space quakes require deeper preventive/control measures. The Unsolved riddles of physics challenging today's state-of-the-art of science are dark matter, direct detection of dark energy, cuspy halo/dwarf galaxy problem of cold dark matter, Inflation and baryogenes and predominance of more matter compared to antimatter in the Universe.

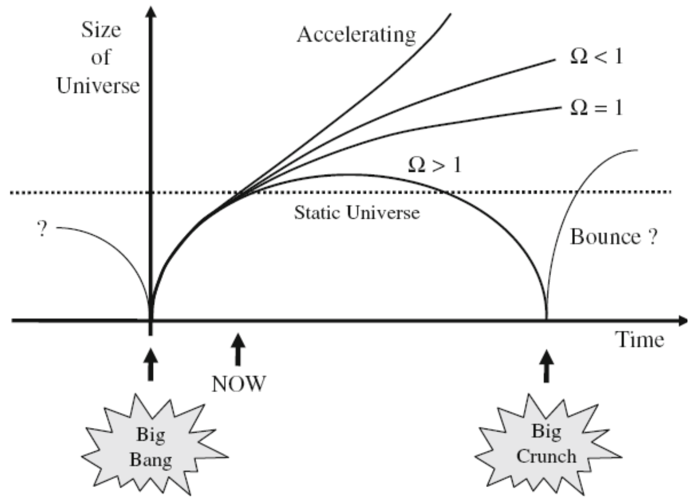
The universe can either expand forever, or undergo a collapse and Big Crunch, and possibly even undergo repeated collapse and expansion cycles (Fig. A3-1). The future of the universe is determined according to the parameter $\Omega_0$ , the ratio of the density of matter in the universe to the critical density (Chart A3-1). Schwarzchild radius (Chart A3-2) indicates the conditions for formation of black holes and Chandrasekhar limit ($2.864 \times 10^{30}$ kg) is the mass (Chart A3-3) above which electron degeneracy pressure in the star's core is insufficient to balance the star's own gravitational self-attraction.

Chart A3-1: Hubble constant and shape of universe

$$Hubble\_const = \Omega_0 = \frac{actual\ density\ of\ (baryonic)\ matter\ in\ the\ universe}{critical\ density} 0$$

$$= \frac{0.2}{6}\ to\ \frac{0.2}{5} = 0.033 \text{ to } 0.04$$




**If** Hubble_const < 1
**Then** Universe is negatively curved and open.
[Under this geometry the universe will expand forever (Fig. A3-1a) ]

**If** Hubble_const > 1
**Then** universe is positively curved closed

[all possible universes are transitory and will collapse to undergo a Big Crunch end-phase within
a finite amount of time]

**If** Hubble_const = 1

**Then** universe is said to be flat, or Euclidian

[while the rate of expansion gradually slows down, it never actually stops (to There after undergo collapse) within a finite amount of time. favored by many theoreticians]

Chart A3-2: Schwarzschild radius and formation of black holes

$$Schwarzschild\_radius = \frac{2*G}{c} * mass$$

C: speed of light in vacuum
G: gravitational constant

If Radius_ object < Schwarzschild_ radius
Then Blackhole

| | Radius_Sch (m) | Density_Sch (g/cm$^3$) |
|---|---|---|
| Universe | $4.46\times10^{25}$ (~10B ly) | $8\times10^{-29}$ \ ($9.9\times10^{-30}$) |
| Milky Way | $2.08\times10^{15}$ (~0.2 ly) | $3.72\times10^{-8}$ |
| Sun | $2.95\times10^{3}$ | $1.84\times10^{16}$ |

| | | |
|---|---|---|
| Earth | $8.87\times10^{-3}$ | $2.04\times10^{27}$ |

Sch :Schwarzschild

**Chart A3-3: Chandrasekhar limit of mass forming a black hole**

If Mass-white-dwarf > Chandrasekhar limit
Then undergo further gravitational collapse &
evolving into a different type of stellar remnant
(Ex: neutron star or black hole)
Else remain stable as white dwarf
-------
If Size of car is crushed to neutrino (1e-24 m wide)
Then Car turns into a black hole.

If Size of earth is reduced to large mosquito
Then Earth turns into a black hole

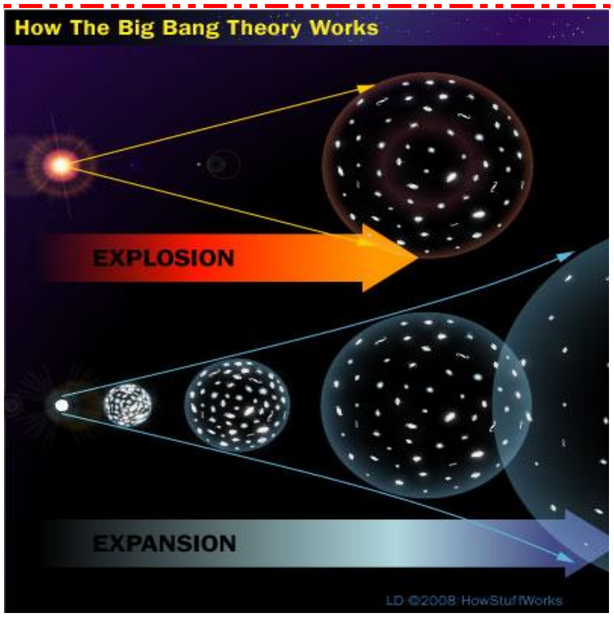


Fig. A3-1(a): Continuous expansion versus explosion

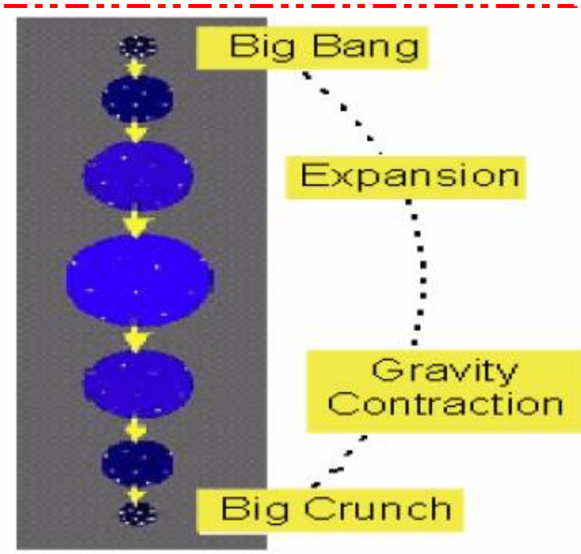


Fig. A3-1(b): Oscillating universe

## Appendix-4: Random number generator

Normal distribution to generate agents in Big-Crunch step: The input for the normal distribution generator is the centre of the mass of previous step and standard deviation which decreases with progress of iterations. This, in fact, increases exploitation and is the best choice when exploration is thorough in the beginning of cycle.

```
%
% om_randn.m     (22-7-2013 R S Rao)
%

function [randnx =
om_randn(meanx,sdx,rows,cols)
     %omcalled('om_randn');
     if nargin == 0
         rows=6;cols=1;
         meanx =zeros(1,2);
         sdx =  eye(2,2);
      end

     % rng('default');randn(2,3)
     [rsd,csd = size(sdx);
      covx= inv(sdx.^2);
      T1= repmat(meanx,rows,1);
      T2 =  randn(rows,csd)*covx;
      randnx= T1+T2 ;
      meanx,sdx,covx
      T1,T2
    %omexit('om_randn');
end
```

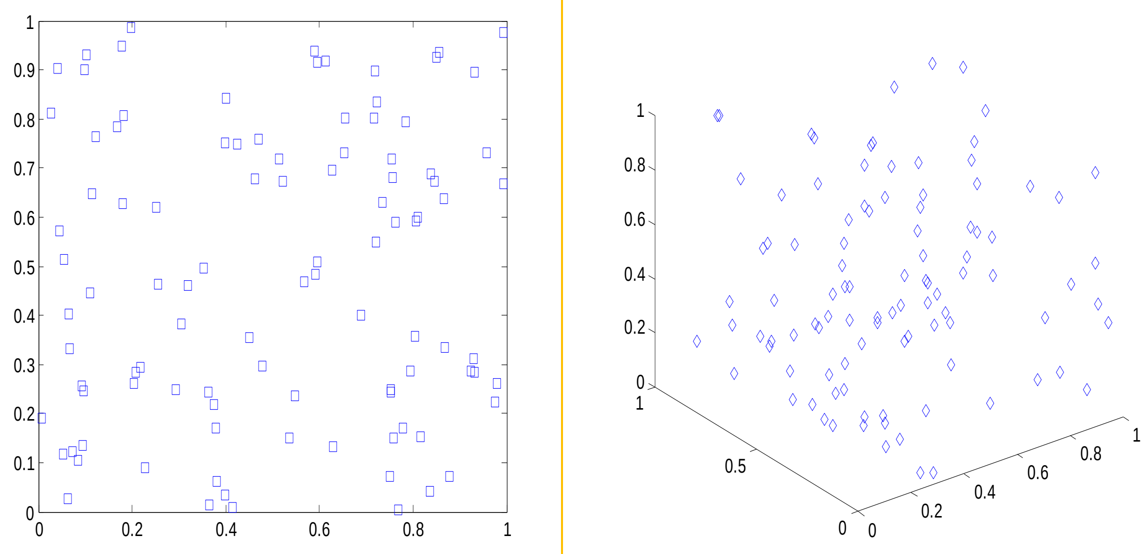
```
%
% randnfig.m   09-09-13
%
clean
meanx = [0 0;
%
meanx = [0 0 0 ;
[rm,cm = size(meanx);sdx = eye(cm);
%
sdvec = [1.5;2;3;4;5;7.4;10;100
%
for i = 1:length(sdvec)

    s = sdvec(i,1)
    if length(meanx) == 2
       sdx = [s 0.;0.0 s
    else
       sdx = [s 0. 0.;0. s 0.; 0. 0. s
    end
%
rows = 100; cols = cm;
%%%%
[randnx = om_randn(meanx,sdx,rows,cols)
%%%%
 [r,c = size(randnx)
 if i>1, figure,end
 if c ==1
     y = randnx(:,1);
     x = [1:r';
     plot(x,y,'bo')
 end
%
 if c ==2
     x = randnx(:,1);
     y = randnx(:,2);
     plot(x,y,'bo')
     a= 1;b = 1;axis([-a a -b b)
 end
%
 if c ==3
     x = randnx(:,1);
     y = randnx(:,2);
     z = randnx(:,3);
     plot3(x,y,z,'bs')
     a= 1;b = 1;c= 1;axis([-a a -b b -c
c)
 end
 title(['SD = ',num2str(1./s),'  ')
end
```

```
ndim = 3; Xminmax = repmat([0
1,ndim,1);
nsol =6;nsol = 100
[x0cpLU,x0cp01 =
om_initcpx(Xminmax,nsol);
```

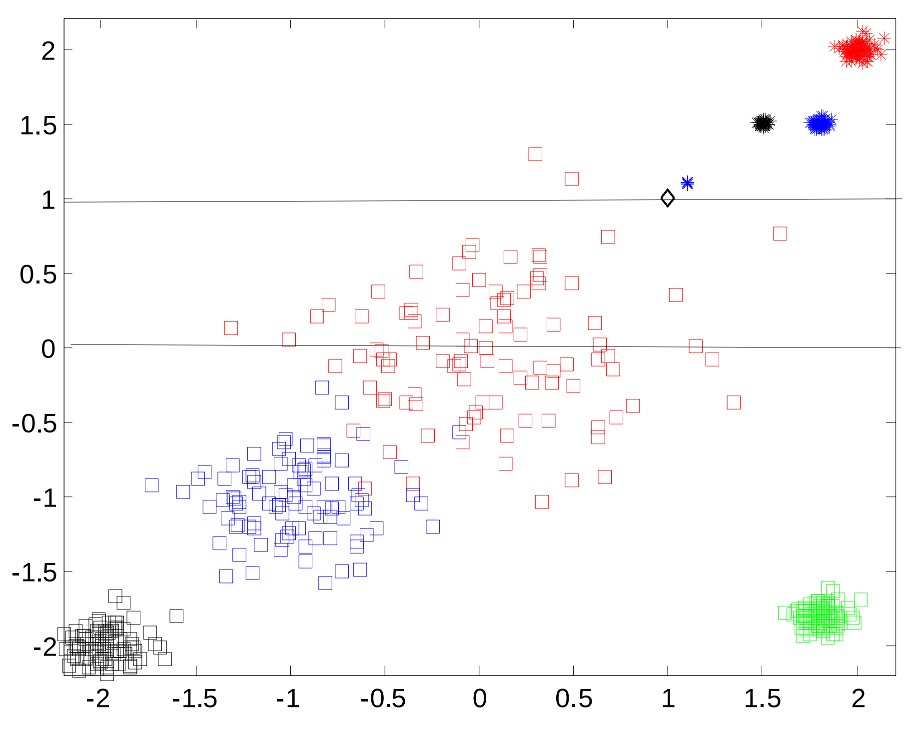
Reference : `om_initcpx.m`

K RamaKrishna, Ch V Kameswara Rao and R Sambasiva Rao
J. Applicable Chem. 2013, 2 (5):1007-1034
E-man Part 4: Tutorial on prospects of charged system search (CSS) algorithm in chemical sciences

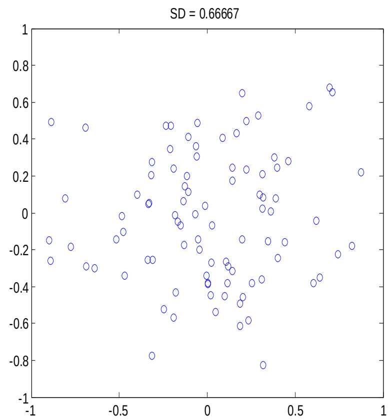
**Hundred (2D- and 3D-) uniform random numbers [ 0.0 to 1.0]**




**(a) No_of random numbers : 100**

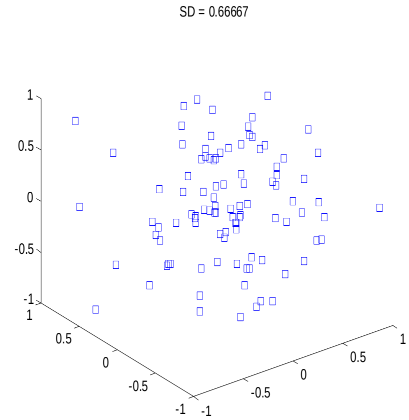


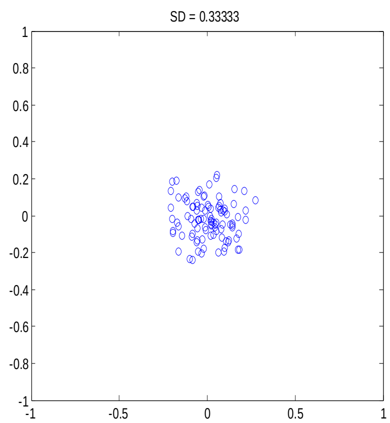
**Hundred (2D- and 3D-) normal random numbers in arrange of varying sds**



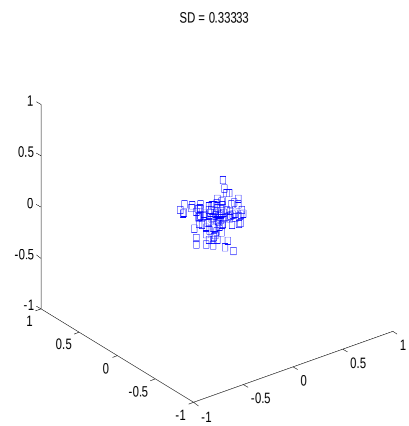

**(c ) Sd = 0.66;**

**(d)**

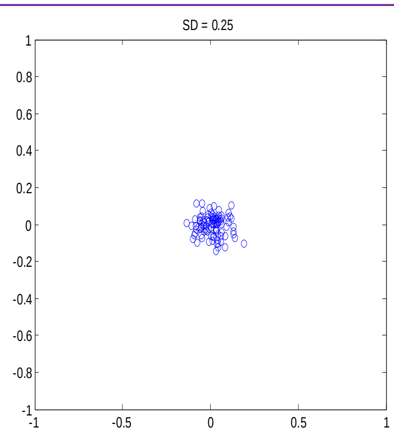


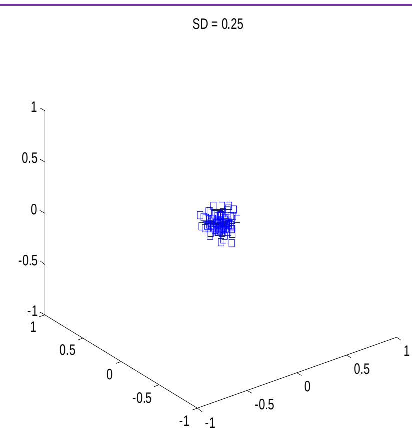

**(e) Sd = 0.33;**



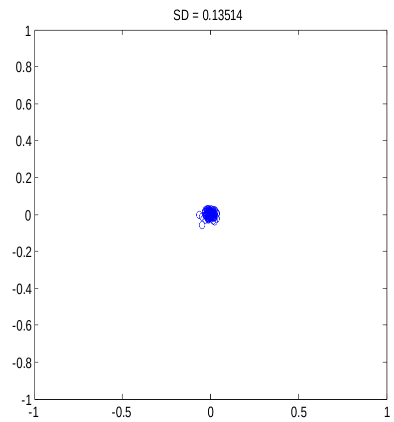

(f)



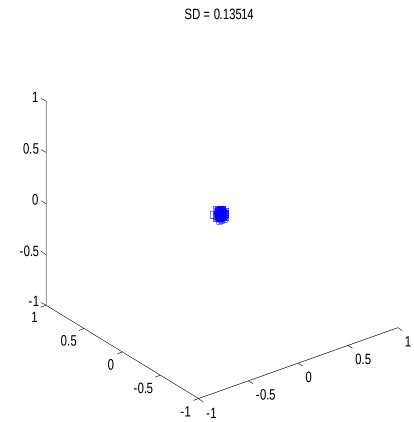

**(g) Sd = 0.25;**



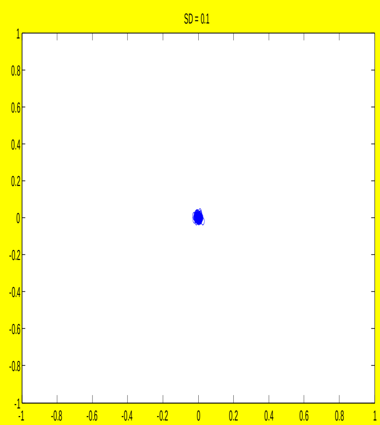

(h)



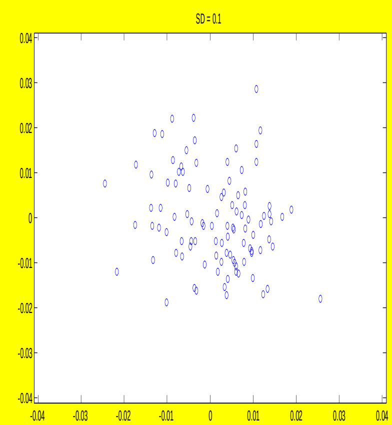

**(i) Sd = 0.14;**



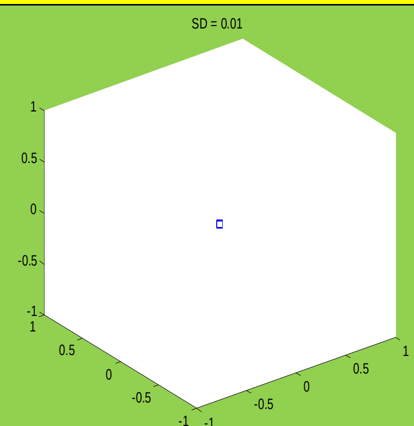

(j)



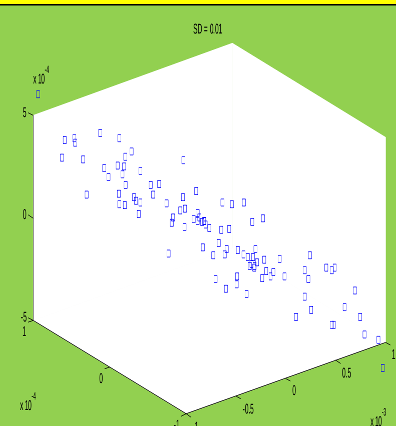

**(k) Sd = 0.01; scale -1 to +1**




**(l) Sd = 0.01; scale -0.04 to +0.04**

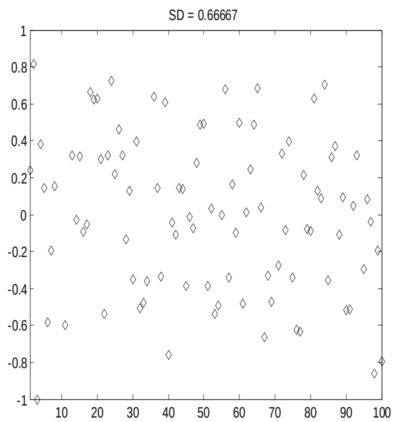



**(m) Sd = 0.01; scale -1 to +1**

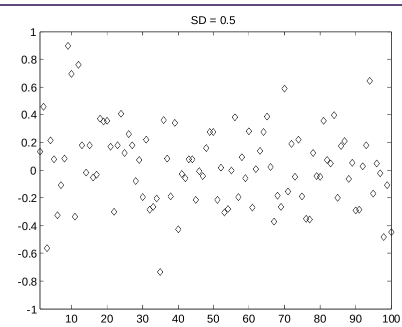



**(n) Sd = 0.01; scale -5.0e-3 to 5.0e-3**

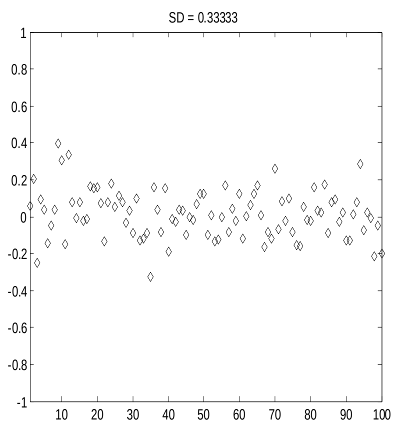
**Hundred (1D-) normal random numbers in arrange of varying sds**



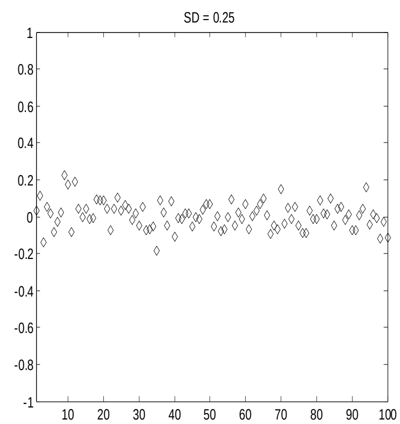

**(o) Sd = 0.66**



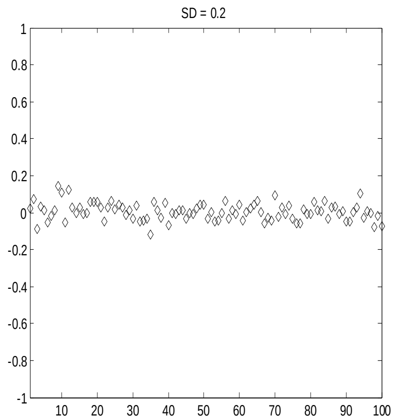

**(o) Sd = 0.50**



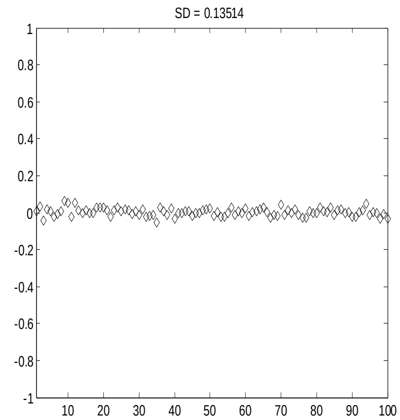

**(o) Sd = 0.33**



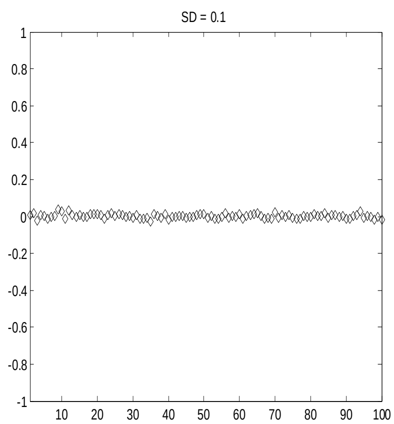

**(p) Sd = 0.25**



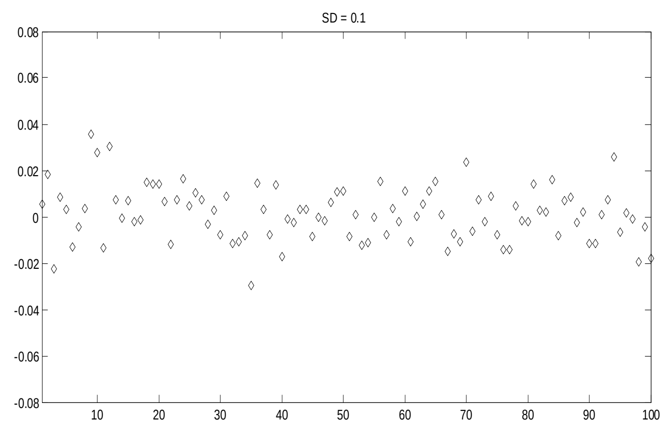

(q) Sd = 0.2



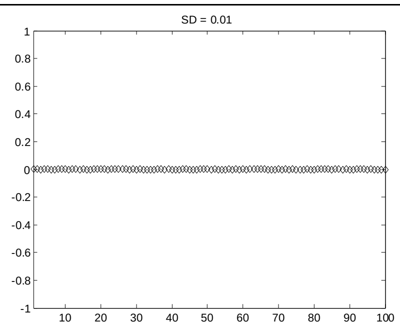

(r) Sd = 0.135



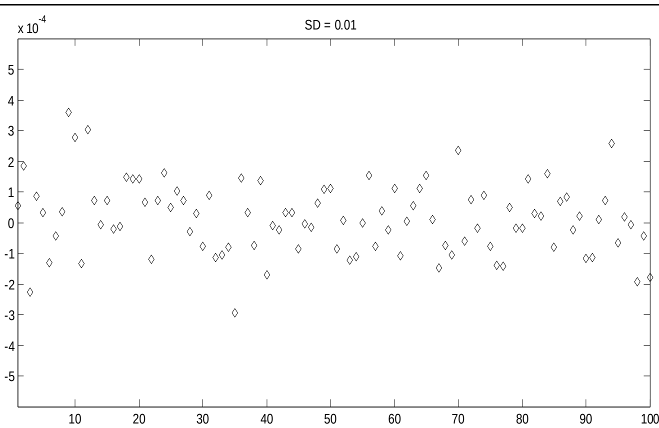

(s) Sd = 0.1




(t) Sd = 0.1;Scale: [-0.08 to 0.08]




(u) Sd = 0.01




(v) Sd = 0.01;Scale: [-0.0005 to 0.0005]

**Fig A4-1: Uniform and (1D-, 2D- and 3D-) normal random numbers of decreasing variance**

2D- normal random numbers : c,e,g,i,k, m

3D- normal random numbers :b,d,f,h,j,k

## Appendix-5

**Sub-optimization mechanism of Kaveh et al.** In finite element method, the search space domain is divided into a number of sub-domains [9,12-13]. The analysis/search is performed in these patches rather than entire domain in one spell. The sub-optimisation approach is similar to finite element procedure for updating search space. This heuristic was successfully deployed in (ant colony optimisation) improvement ACO performance. This method is adapted for BB-BC with some marked changes.

**Chart A1(a): Optimization algorithm**

```
Do while space < required size satisfying accuracy

    Divide search space into n sub-domains

    for each sub-domain
        Do optimization

    endFor

    Delete undesirable sub-domains
endDO
Output
```

## Appendix-6: Definition-base of particle physics

| Scientific vocabulary | Definition |
|---|---|
| Antimatter | Consists of only antiparticles |
| Antiparticles | Same mass as particles of ordinary matter opposite charge |
| Black hole | An area in space where gravity very high. Nothing (including light) can escape from it. So, invisible and called a black hole |
| Baryonic matter | Matter that can either emit or absorb electromagnetic radiation |
| Electron volt (eV) | Kinetic energy gained by an electron when accelerated through one volt of electric potential $Temperature = \frac{1 eV}{Boltzman\_const} = \frac{1.60217653(14) e-19 J}{1.3806505(24) e-23 \; J/K}$ $= 11,604.505(20) K \approx 10,000^{o} K$ |
| Hadron | A composite particle made of quarks and held together by the strong force <br>■ Baryons (such as protons and neutrons, made of three quarks) – stable in atomic nucleus. Free neutrons decay in 15 minutes. <br>■ Mesons (such as pions, made of one quark and one antiquark) <br>♠ Astetraquarks (or exotic mesons) <br>♠ Pentaquarks (exotic baryons) |
| Vacuum | A space wherein matter is emptied |

Vacuum_ Quantum

- Matter is emptied from the space
- Temperature is lowered to absolute zero

Produces **quantum vacuum state**

## REFERENCES


[1] P. W. Higgs, *Phys. Let.*, **1964**, 12(2), 132-133.
[2] F. Englert, R. Brout, *Phys. Rev. Let.*, **1964**, 13(9), 321-323.
[3] J.T. Trevors, *Thoery in biosci.*, **2006**, 124,403-412.
[4] A. Ashtekar, *Gen Relativ. Gravit*, **2009**, 1, 707-741.
[5] B. Tinsley, *Resonance*, **2004**, Oct, 91-95.
[6] M. Gauci, T. J. Dodd, R. Grob, *Nat. Comput.*, **2012**, 11, DOI 10.1007/s11047-012-9322-0
[7] A.A. Mousa, M.A. El-Shorbagy, W.F. Abd-El-Wahed, Swarm and evolutionary computation, **2012**,3,1-14.
[8] E. Bonabeau, M. Dorigo, G. Theraulaz, Swarm intlelligence from Natural to artificial systems, Oxford University press, **1999**.
[9] A. Kaveh, S. Talatahari, *Acta Mechanica*, **2011**, 221 (1-2), 99-118.
[10] O.K. Erol, I. Eksin, *Advances in Engineering Software*, **2006**, 37 (2), 106-111.
[11] H.M. Genç, I. Eksin, O.K. Erol, Conference Proceedings - IEEE International Conference on Systems, Man and Cybernetics, **2010**, art. no. 5641871, 881-887.
[12] A. Kaveh, A. Zolghadr, *Computers and Structures*, **2012**, 102-103, 14-27.
[13] A. Kaveh, B. Eftekhar, *Asian Journal of Civil Engineering*, **2012**, 13 (4), 465-487.
[14] A. Kaveh, N. Farhoudi, *Journal of Constructional Steel Research*, **2011**, 67 (10), 1453-1462.
[15] A. Kaveh, O. Sabzi, *International Journal of Civil Engineering*, **2012**, 10 (3), 189-200.
[16] A. Kaveh, O. Sabzi, *International Journal of Civil Engineering*, **2011**, 9 (3), 193-206.
[17] A. Kaveh, S. Talatahari, *Asian Journal of Civil Engineering*, **2010**, 11 (1), 103-122.
[18] A. Kaveh, S. Talatahari, B. Farahmand Azar, *Asian Journal of Civil Engineering*, **2010**, 12 (2), 133-141.
[19] A. Kaveh, S. Talatahari, *Computers and Structures*, **2009**, 87 (17-18), 1129-1140.
[20] A. Kaveh, S. Talatahari, *International Journal of Space Structures*, **2010**, 25 (4), 217-227.
[21] A. Kaveh, S. Talatahari, *Journal of Constructional Steel Research*, **2010**, 66 (3), 412-419.
[22] A. Kaveh, S. Talatahari, M.T. Alami, *Asian Journal of Civil Engineering*, **2012**, 13 (6), 705-717.
[23] A.Kaveh, H. Abbasgholiha, *Asian Journal of Civil Engineering*, **2011**, 12 (3), 293-317.
[24] A. Hatamlou, S. Abdullah, M. Hatamlou, *Communications in Computer and Information Science 241 CCIS*, **2011**, 383-388.
[25] A. Wang, Y. Wu, *Journal of Cosmology and Astro particle Physics*, **2009** (7), art. no. 012 77.
[26] Aydin, M., Gokasan, M., Bogosyan, S. International Review on Modelling and Simulations, **2011**, 4(5), 2111-2121.
[27] B. Alatas, *Communications in Nonlinear Science and Numerical Simulation*, **2011**, 16 (9), 3696-3703.
[28] B. J. Carr, A.A. Coley, *International Journal of Modern Physics D*, **2011**, 20 (14), 2733-2738.
[29] B. Philip, J. Pal, 2010 IEEE International Conference on Computational Intelligence and Computing Research, ICCIC 2010, **2010**, art. no. 5705729, 59-66.
[30] B. Philip, J. Pal, Proceedings of the IASTED International Conference on Modelling, Identification, and Control, MIC, **2009**, 90-95.
[31] C. Dariescu, M.A. Dariescu, *Solitons and Fractals*, **2007**, 32 (1), 8-14.
[32] C. Massa, *Astrophysics and Space Science*, **2006**, 305 (4), 377-384.
[33] C.F. Kucuktezcan, V.M.I. Genc, IEEE PES Innovative Smart Grid Technologies Conference Europe, **2012**, art. no. 6465773.

[34] C.V. Camp, A. Akin, *Journal of Structural Engineering (United States)*, **2012**, 138 (3), 438-448.
[35] C.V. Camp, A. Assadollahi, *Structural and Multidisciplinary Optimization*, **2013**, 1-16.
[36] C.V. Camp, *Journal of Structural Engineering*, **2007**, 133 (7), 999-1008.
[37] D. Cremades, F. Quevedo, A. Sinha, *Journal of High Energy Physics*, **2005**, (10), 2557-2594.
[38] D.S. Hajdukovic, *Astrophysics and Space Science*, **2011**, 334 (2), 219-223.
[39] E. Yesil, L. Urbas, *Engineering and Technology*, **2010**, 71, 815-824.
[40] E. Minassian, *Classical and Quantum Gravity*, **2002**, 19 (23), 5877-5900.
[41] E. Yesil, L. Urbas, World Academy of Science, *Engineering and Technology*, **2010**, 47, 816-825.
[42] F. Kucuktezcan, I.Genc, Proceedings of the IASTED International Conference on Power and Energy Systems and Applications, PESA 2011, **2011**, 36-42.
[43] G.M. Jaradat, M. Ayob, Proceedings of the 2010 10th International Conference on Intelligent Systems Design and Applications, ISDA'10, **2010**, art. no. 5687114, 1448-1452.
[44] H. Tang, J. Zhou, S. Xue, L. Xie, *Mechanical Systems and Signal Processing*, **2010**, 24 (8), 2888-2897.
[45] H.M. Genc, SOFA 2010 - 4th International Workshop on Soft Computing Applications, Proceedings, **2010**, art. no. 5565618, 95-100.
[46] H.M.Genc, A.K. Hocaoglu, Proc. - The 3rd Int. Multi-Conf. Computing in the Global Information Technology, ICCGI 2008 in Conjunction with ComP2P 2008: The 1st Int. Workshop on Computational P2P Networks: Theory and Practice, **2008**, art. no. 4591373, 229-233.
[47] I. Bars, S.-H. Chen, P.J. Steinhardt, N. Turok, *Physics Letters, Section B: Nuclear, Elementary Particle and High-Energy Physics*, **2012**, 715 (1-3), 278-281.
[48] I. Licata, L. Chiatti, *International Journal of Theoretical Physics*, **2009**, 48 (4), 1003-1018.
[49] J.R. Albright, *Zygon*, **2000**, 35 (1), 173-180.
[50] K.J. Epstein, *Physics Essays*, **2009**, 22 (4), 432-434.
[51] L.Senyurek, S. Koksal, H.M. Genc, D. Aldogan, M. Haklidir, 2008 International Conference on Computational Intelligence for Modelling Control and Automation, CIMCA 2008, **2008**, art. no. 5172733, 832-837.
[52] M. A., Dariescu, C. Dariescu, *Solitons and Fractals*, **2009**, 39 (5), 2522-2529.
[53] M. Aliasghary, I. Eksin, M. Guzelkaya, International Conference on Intelligent Systems Design and Applications, ISDA, **2011**, art. no. 6121685, 380-384.
[54] M. Bouhmadi-Lopez, L.P. Chimento, *Gravitation and Cosmology*, **2010**, 82 (10), art. no. 103506.
[55] M. Sedighizadeh, D. Arzaghi-Haris, International Review of Electrical Engineering, **2011**, 6 (4), 2013-2019.
[56] M. Sedighizadeh, S. Ahmadi, M. Sarvi, *Electric Power Components and Systems*, **2013**, 41 (1), 75-99.
[57] M. Znojil, Journal of Physics: Conference Series 343, **2012**, art. no. 012136.
[58] K RamaKrishna, Ch V Kameswara Rao, R Sambasiva Rao, *J. Applicable Chem.*,
[59] **2013**, 2,698-713, 1007-1034; **2012**, 1,109-124.
[60] O. Hasançebi, S. Kazemzadeh Azad, *Computers and Structures*, **2012**, 110-111, 167-179.
[61] O. Hasançebi, S. Kazemzadeh Azad, *Engineering Optimization*, **2013**.
[62] P. Prudhvi, Canadian Conference on Electrical and Computer Engineering, **2011**, art. no. 6030410, 000069-000072.
[63] P.Y. Tabakov, *World Academy of Science, Engineering and Technology*, **2011**, 77, 835-839.
[64] R. Salomon, P. Heydebreck, L.R. Krueger, 2012 IEEE Conference on Computational Intelligence for Financial Engineering and Economics, CIFEr 2012 - Proceedings, **2012**, art. no. 6327774, 69-76.
[65] S. Calogerot, J.M. Heinzle, *SIAM Journal on Applied Dynamical .Systems*, **2010**, 9 (4), 1244-1262.

[66] S. Elitzur, A. Giveon, D. Kutasov, E. Rabinovici, *Journal of High Energy Physics,* **2002**, 6 (6), 313-343.
[67] S. Nojiri, S.D. Odintsov, *Physics Letters, Section B: Nuclear, Elementary Particle and High-Energy Physics,* **2002**, 540 (3-4), 167-172.
[68] S.Kazemzadeh Azad, O. Hasançebi, S. Kazemzadeh Azad, *Advances in Engineering Software,* **2013**, 57, 19-32.
[69] S.R. Das, *Journal of Physics:* Conference Series, **2008**, 140, art. no. 012010.
[70] S.R. Desai, R. Prasad, *Applied Mathematical Modelling*, **2013**.
[71] T. Quella, V. Schomerus, Fortschritte der Physik, **2003**, 51 (7-8), 843-849.
[72] T. Ha, Y. Huang, Q. Ma, K.D. Pechan, T.J. Renner, Z. Wu, G.A. Benesh, A. Wang, General Relativity and Gravitation, **2012**, 44 (6), 1433-1458.
[73] Incirci, D. Tukel, IEEE Symposium on Emerging Technologies and Factory Automation, ETFA, **2011**, art. no. 6059197.
[74] T. Kumbasar, I. Eksin, M. Guzelkaya, E. Yesil, IFAC Proceedings Volumes (IFAC-PapersOnline) 18 (PART 1), **2011**, 5308-5313.
[75] T. Kumbasar, E. Yeşil, I. Eksin, M. Guzelkaya, 2008 3rd International Symposium on Communications, Control, and Signal Processing, ISCCSP 2008, **2008**, art. no. 4537313, 697-702.
[76] T. Kumbasar, I. Eksin, M. Guzelkaya, E. Yesil, Expert Systems with Applications, **2011**, 38 (10), 12356-12364.
[77] T. Kumbasar, I. Eksin, M. Guzelkaya, E. Yeşil, Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics) 5317 LNAI, **2008**, 732-740.
[78] Y. Hikida, R.R. Nayak, K.L. Panigrahi, *Journal of High Energy Physics*, **2005**, (5), 337-382.
[79] Y. Labbi, D.B. Attous, *Journal of Theoretical and Applied Information Technology*, **2010**, 16 (1), 48-56.
[80] Z. Zandi, E. Afjei, M. Sedighizadeh, *Journal of Theoretical and Applied Information Technology*, **2013**, 47 (2), 537-546.
[81] Z. Zandi, E. Afjei, M. Sedighizadeh, PECon 2012 - 2012 IEEE International Conference on Power and Energy, **2012**, art. no. 6450215, 239-244.
[82] E. Rashedi, H. Nezamabadi-pour, S. Saryazdi, *Information Sciences,* **2009**, 179, 2232– 2248.
[83] E. Rashedi, H. Nezamabadi-pour, S. Saryazdi, *Nat. Comput.*, **2010**, 9, 727–745.
[84] M. Sheikhan, M. Sharifi Rad, *Neural Computing and Applications,* **2012**, 1-13.
[85] S. Mirjalili, S.Z. Mohd Hashim, H. Moradian Sardroudi, *Applied Mathematics and Computation,* **2012**, 218(22), 11125-11137.