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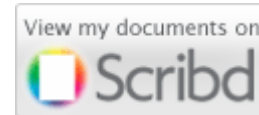
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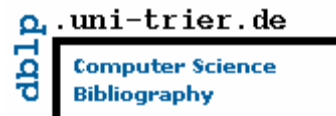
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In this second edition of 2010, we bring forward issues from various dynamic computer science areas ranging from system performance, computer vision, artificial intelligence, software engineering, multimedia, pattern recognition, information retrieval, databases and networking among others.

We thank all our reviewers for providing constructive comments on papers sent to them for review. This helps enormously in improving the quality of papers published in this issue.

IJCSI is still maintaining its policy of sending print copies of the journal to all corresponding authors worldwide free of charge. Apart from availability of the full-texts from the journal website, all published papers are deposited in open-access repositories to make access easier and ensure continuous availability of its proceedings.

We are pleased to present IJCSI Volume 7, Issue 2, split in five numbers (IJCSI Vol. 7, Issue 2, No. 5). The acceptance rate for this issue is 27.55%. Out of the 98 papers submitted for review, 27 were eventually accepted for publication in this month issue.

We wish you a happy reading!

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# Comparison of the Performance of Two Service Disciplines for a Shared Bus Multiprocessor with Private Caches

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## Abstract

In this paper, we compare two analytical models for evaluation of cache coherence overhead of a shared bus multiprocessor with private caches. The models are based on a closed queuing network with different service disciplines. We find that the priority discipline can be used as a lower-level bound. Some numerical results are shown graphically.

Keywords: *Invalidate cache coherence protocols, multiprocessor, queuing network, work conserving*

## 1. Introduction

Caches have been widely used in multiprocessors to improve systems performance. Caching of shared data, however, introduces the cache coherence problem. Simply coherence can be defined as retrieving always the most recent value for any data. Maintaining this feature solely by the software makes the programmer's task extremely difficult. Modern multiprocessors solve the cache coherence problem in hardware by implementing cache coherence protocols [6]. There are two main classes of hardware protocols, snoopy and directory based protocols. Snoopy protocols use broadcast medium and hence apply to a smaller-scale bus-based multiprocessors. In these broadcast systems each cache "snoops" on the bus and watches for transition that affects it. In this paper we consider this class. Coherence requirements can be met in two ways. Invalidate protocols invalidate other cache copies on a write, so the processor has exclusive access to a data before it writes that data. The alternative Update protocols update all the cached copies of the data when that data is written. Most multiprocessors use Invalidate technique rather than Update technique because update transactions are expensive.

Impact on the performance of the cache coherence protocols can be studied using simulation or analytical

models. Simulation is accurate but very time consuming. Analytical models based on queuing theory provide simple but approximate approach for estimating the performance of multiprocessors in the early design cycles. The most commonly used method for this purpose is the Mean Value Analysis (MVA), based on the forced law, i.e. in equilibrium the output rate equals input rate. It offers no possibility to study transient behavior, moreover the assumption of exponential service times is not always adequate [3]. Alternative solution is to describe the system using discrete state continuous time Markov processes. In [4] this approach is applied to a priority discipline where the non-blocking (write-back) requests are served immediately after their arrival, and in [5] a First-Come-First-Served (FCFS) discipline is studied. As shown in [4, 5] this method eliminates the main drawbacks of MVA analysis: inability to deal with transients and the constraints on the service time distributions.

## 2. Description of the models

A multiprocessor consists of several processors connected together to a shared main memory by a common complete transaction bus. Each processor has a private cache. When a processor issues a request to its cache, the cache controller examines the state of the cache and takes suitable action, which may include generating bus transaction to access main memory. Coherence is maintained by having all cache controllers "snoop" on the bus and monitor the transaction. Snoopy cache-coherence protocols fall in two major categories: Invalidate and Update [6]. Invalidating protocols are studied here but the concepts can be applied with some modifications to

updating protocols too. Transactions may or may not include the memory block and the shared bus. Typical transaction that does not include memory block is Invalidate Cache Copy which occurs when a processor requests writing in the cache. All other processors simply change the status bit(s) of their on copies to Invalid. If the memory block is uncached or not clean it can be uploaded from the main memory, but in todays multiprocessors it is rather uploaded from another cache designated as Owner (O) (cache-to cache transfer). Memory-to cache transfer occurs when the only clean copy is in the main memory. A cache block is written back (WB) in the main memory (bus is used) when a dirty copy is evicted [6]. Apparently the bus can be considered as the bottleneck of the system.

For the model in [4] these WB requests are immediately served, that is they have priority over all other transaction types, and for the model presented in [5], WB requests and all other requests are treated equally, i.e. the service discipline is on First Come First Served (FCFS) basis.

In terms of the queuing theory processors can be viewed as customers (clients) and the bus can be viewed as a server. The FCFS queue and the priority queue are illustrated in Fig. 1.a and Fig 1.b, respectively.

Each processor alternates execution (think, compute) phases and phases when it waits for a memory request to be served. The execution phase is assumed exponentially distributed with parameter  $\lambda$ . This assumption is adequate for most applications [3]. Immediately after issuing a coherence request the customer blocks itself. The service time for blocking request has a density function  $f_1(x)$ .

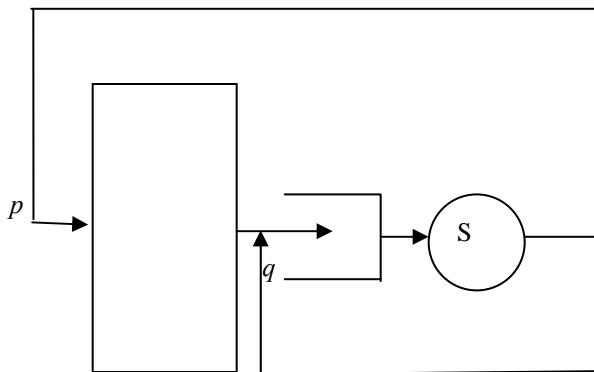


Fig. 1.a

When service is completed the processor (customer) resumes processing with probability  $p$  or resumes processing and generates a new request with probability  $q$  ( $p+q=1$ ). Details on how to obtain the input parameters

are given in [7, 8]. This new request has a different density

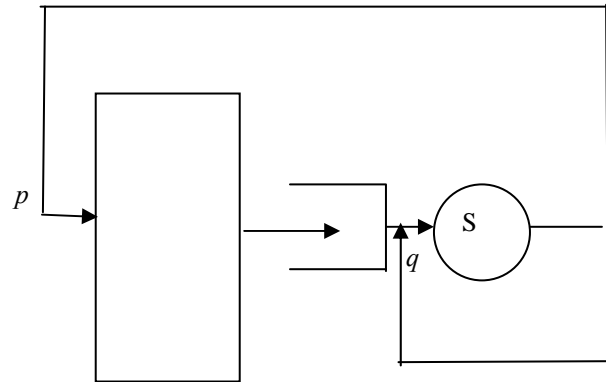


Fig. 1.b

function  $f_2(x)$  and corresponds to WB transaction. It does not block the customer but the server is held until completion of WB transaction therefore adding to the queue. WB request in Fig. 1.a joins the tail of the queue of blocking and non-blocking requests. In Fig. 1.b if a WB request is generated the bus (server) is not relinquished by the processor whose coherence transaction was just completed. The service of the WB request is started immediately for this processor, and only after its completion the first processor in the queue gets access to the bus.

The equations describing these queues and their solutions are given in [4, 5]. We start with fairly complex set of integro-differential equations but the output is a set of linear equations from which the steady-state probabilities and hence the throughput can be determined. For the FCFS discipline, however, the number of linear equations grows enormously for large  $N$ , so the exact solution is too complicated to be practical. The networks in Fig. 1.a and Fig. 1.b are “work conserving” since the server does not go idle if there is a customer in the queue, and the amount of the service time does not depend on the service discipline [2]. The mean waiting time is same for Fig. 1.a and Fig. 1.b according to the conservation law [4, 5]. Distributions of waits, however, are different: in Fig. 1.b non-blocking (WB) requests do not wait at all because they are served immediately after arrival, so that the waiting time is zero, while for the network in Fig. 1.a the waiting time is greater than zero. Blocking requests in Fig. 1.a therefore wait longer and the throughput is smaller than that in Fig. 1.b, thus we can conclude that the priority scheme (Fig. 1.b) can be regarded as lower-level bound for FCFS discipline (Fig. 1.a).

Average Number of Blocked Customers (processors), ANBC, for the two disciplines, computed using the formulas, derived in [4] and [5] are illustrated in Table 1.a through 1.h for blocking caches (BL). For all cases  $f_1(x) = \mu_1 e^{-\mu_1 x}$  and  $f_2(x) = \mu_2 e^{-\mu_2 x}$ , and  $p=0.8$  and  $\mu_1 = 0.1$  [1/t.u.]<sup>1</sup>.

0.010	2.20764176	2.27409559	3.01017303
<i>1.c) N=5, <math>\mu_2 = 0.01</math>[1/t.u.]</i>			

$\lambda$	FCFS	Priority	% difference
0.001	0.07014828	0.07344077	4.69361131
0.002	0.18977920	0.20284240	6.88336661
0.003	0.34289203	0.36860743	7.49956231
0.004	0.51524391	0.55285868	7.30038140
0.005	0.69555280	0.74238917	6.73368933
0.006	0.87572487	0.92861078	6.03910016
0.007	1.05045078	1.10650487	5.33619402
0.008	1.21657142	1.27350263	4.67964332
0.009	1.37245655	1.42859627	4.09045568
0.010	1.51749673	1.57171551	3.57290955
<i>1.a) N=4, <math>\mu_2 = 0.01</math>[1/t.u.]</i>			

$\lambda$	FCFS	Priority	% difference
0.001	0.10346160	0.10967984	6.01018450
0.002	0.29814050	0.32060606	7.53522768
0.003	0.53750740	0.57628734	7.21477436
0.004	0.78870741	0.83859945	6.32579880
0.005	1.03240021	1.08777002	5.36321218
0.006	1.25904105	1.31562088	4.49388283
0.007	1.46505497	1.52011385	3.75814410
0.008	1.65010151	1.70210131	3.15130902
0.009	1.81540668	1.86361092	2.65528566
0.010	1.96283453	2.00700331	2.25025446
<i>1.b) N=4, <math>\mu_2 = 0.006667</math>[1/t.u.]</i>			

$\lambda$	FCFS	Priority	% difference
0.001	0.09793845	0.10393609	6.12389310
0.002	0.27607106	0.29989579	8.62992741
0.003	0.50864514	0.55419819	8.95576169
0.004	0.77068883	0.83443491	8.27131302
0.005	1.04195502	1.11731297	7.23236099
0.006	1.30831803	1.38883665	6.15436121
0.007	1.56119524	1.64188994	5.16877695
0.008	1.79617630	1.87372614	4.31749579
0.009	2.01163620	2.08410558	3.60250972

$\lambda$	FCFS	Priority	% difference
0.001	0.15052080	0.16214798	7.72463209
0.002	0.44663225	0.48738023	9.12338382
0.003	0.80995181	0.87613907	8.17175362
0.004	1.18338340	1.26277196	6.70860895
0.005	1.53527328	1.61736280	5.34689961
0.006	1.85242056	1.93081123	4.23179647
0.007	2.13201057	2.20360391	3.35802017
0.008	2.37611381	2.43985641	2.68264077
0.009	2.58864894	2.64458879	2.16096717
0.010	2.77390615	2.82261385	1.75592431
<i>1.d) N=5, <math>\mu_2 = 0.006667</math>[1/t.u.]</i>			

$\lambda$	FCFS	Priority	% difference
0.001	0.13018580	0.13994358	7.49526844
0.002	0.38029905	0.41883309	10.13256380
0.003	0.71209440	0.78311783	9.97387757
0.004	1.08482965	1.17914296	8.69383567
0.005	1.46496035	1.56995792	7.16726391
0.006	1.83015922	1.93551924	5.75687720
0.007	2.16831417	2.26748158	4.57347954
0.008	2.47457869	2.56422251	3.62258949
0.009	2.74850736	2.82748357	2.87342179
0.010	2.99197323	3.06042246	2.28776217
<i>1.e) N=6, <math>\mu_2 = 0.01</math>[1/t.u.]</i>			

$\lambda$	FCFS	Priority	% difference
0.001	0.20681137	0.22608037	9.31718650
0.002	0.62839527	0.69329368	10.32764113
0.003	1.14251792	1.24085044	8.60665053
0.004	1.65787655	1.76701584	6.58307686
0.005	2.12793843	2.23247579	4.91261212
0.006	2.53767126	2.63056168	3.66045914
0.007	2.88784045	2.96720787	2.74833134
0.008	3.18525763	3.25171044	2.08626186
0.009	3.43809333	3.49318909	1.60250898
0.010	3.65399343	3.69949483	1.24525116
<i>1.f) N=6, <math>\mu_2 = 0.006666</math>[1/t.u.]</i>			

<sup>1</sup> t. u.-time unit

$\lambda$	FCFS	Priority	% difference
0.001	0.16711501	0.18183576	8.80875460
0.002	0.50408229	0.56151276	11.39307364
0.003	0.95693912	1.05819964	10.58170982
0.004	1.46217043	1.58867062	8.65153531
0.005	1.96736551	2.09885671	6.68361840
0.006	2.44010356	2.56304970	5.03856237
0.007	2.86557429	2.97351291	3.76673603
0.008	3.24038821	3.33162878	2.81572935
0.009	3.56716080	3.64255966	2.11369397
0.01	3.85102404	3.91251645	1.59678065
1.g) $N=7,$ $\mu_2=0.01[1/t.u.]$			

$\lambda$	FCFS	Priority	% difference
0.001	0.27284496	0.30228227	10.78902581
0.002	0.84595961	0.94043547	11.16789163
0.003	1.53800360	1.67035363	8.60531312
0.004	2.21148627	2.34637907	6.09964432
0.005	2.80406596	2.92305851	4.24357205
0.006	3.30291100	3.40088073	2.96616340
0.007	3.71635507	3.79441291	2.10038698
0.008	4.05853034	4.11982682	1.51031226
0.009	4.34322475	4.39112053	1.10276991
0.010	4.58205090	4.61947983	0.81685963
1.h) $N=7,$ $\mu_2=0.006667[1/t.u.]$			

Table 1

Since the percentage difference of ANBCs is always positive we can confirm that the priority scheme can serve as a lower-level bound.

If we look more closely at the tables, we find that the difference is smaller for heavier workload ( $\lambda$ ). In spite of the fact that FCFS is more favorable to shorter request than the priority scheme its impact is diminished if the system handles more requests in the case of heavy workload.

It also can be observed that the difference does not vary significantly with  $N$ .

### 3. Some numerical results

We measure the system performance in ANPEC (Average Number of Processors Engaged in Computation) [1]. Obviously from the definition  $ANPEC = N - ANBC$ . Results are illustrated in Fig. 2.

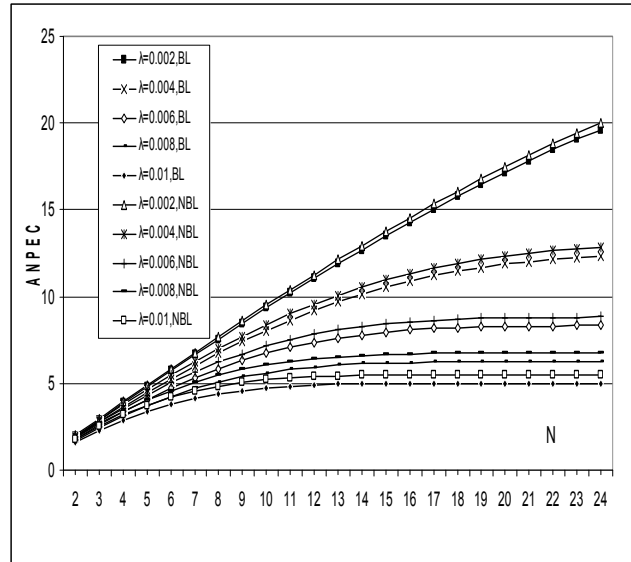


Fig. 2.a.  $p=0.9, \mu_2=0.01[1/t.u.]$

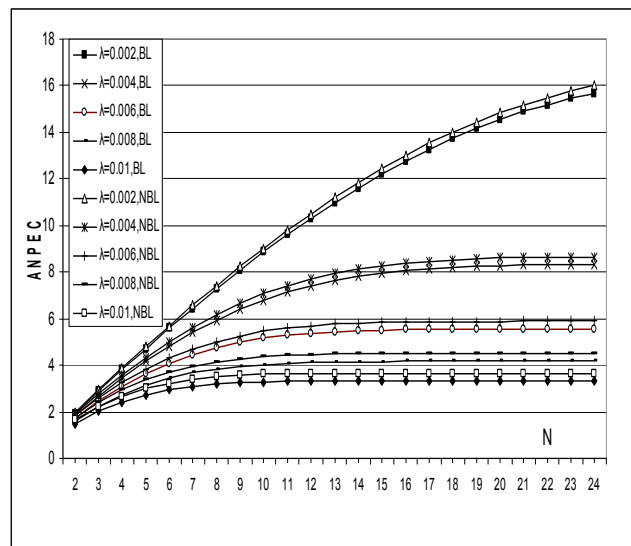


Fig. 2.b.  $p=0.8, \mu_2=0.01[1/t.u.]$

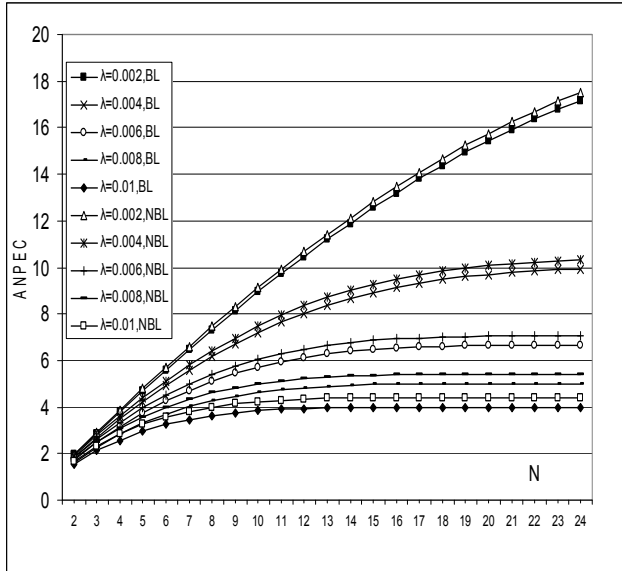


Fig. 2.c.  $p=0.9$ ,  $\mu_2=0.0066666667[1/t.u.]$

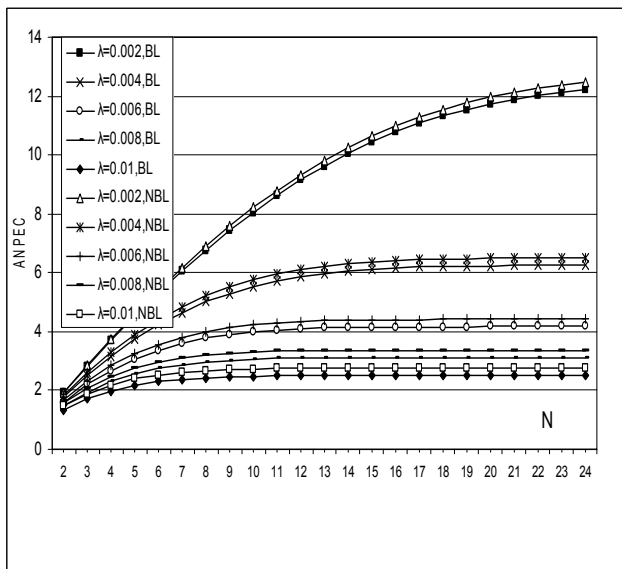


Fig. 2.d.  $p=0.8$ ,  $\mu_2=0.0066666667[1/t.u.]$

From the figures, it can be seen that the performance increases nonlinearly as  $N$  increases and at some point saturation sets in. Saturation depends heavily on the workload ( $\lambda$ ): in all graphics ANPEC saturates quickly with  $\lambda=0.01[1/t.u.]$ , while it still continues to grow with  $\lambda=0.001[1/t.u.]$ . Evidently, with increased main memory traffic (smaller  $p$ ), the performance degradation is more significant (Fig. 2.a and 2.b, and Fig. 2.c and Fig. 2.d). It can also be concluded that the impact of memory access time is also significant, for instance saturation for

$\lambda=0.01[1/t.u.]$ , and  $\mu_2=0.01[1/t.u.]$  sets in for  $N=8$  (Fig. 2.b), while for  $\mu_2=0.0066666667[1/t.u.]$ , and same value of  $\lambda$  (Fig. 2.d) it occurs for  $N=6$ .

Apparently, introduction of NBL caches results in improved overall performance.

#### 4. Concluding Remarks

Based on the work conservation law we conclude that the priority service discipline produces smaller performance than the FCFS. At the early stage of the design this model can be used as a worst-case approximation for the systems performance. Solving these equations requires insignificant computational effort because their number is  $2N+1$  [5].

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# A QoS Provisioning Recurrent Neural Network based Call Admission Control for beyond 3G Networks

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## Abstract

The Call admission control (CAC) is one of the Radio Resource Management (RRM) techniques that plays influential role in ensuring the desired Quality of Service (QoS) to the users and applications in next generation networks. This paper proposes a fuzzy neural approach for making the call admission control decision in multi class traffic based Next Generation Wireless Networks (NGWN). The proposed Fuzzy Neural call admission control (FNCAC) scheme is an integrated CAC module that combines the linguistic control capabilities of the fuzzy logic controller and the learning capabilities of the neural networks. The model is based on recurrent radial basis function networks which have better learning and adaptability that can be used to develop intelligent system to handle the incoming traffic in an heterogeneous network environment. The simulation results are optimistic and indicates that the proposed FNCAC algorithm performs better than the other two methods and the call blocking probability is minimal when compared to other two methods.

**Keywords:** *Radio resource management, Heterogeneous wireless Networks, Call admission control, Call blocking probability, Recurrent radial basis function networks.*

## 1. Introduction

The majority researchers believe that the next stage beyond third-generation(3G) networks will include multiple wireless access technologies, all of which will coexist in a heterogeneous wireless access network environment[1,2] and use a common IP core to realize user-focused service delivery. The coexistence of

Heterogeneous radio access technologies (RATs) will noticeably amplify the intensity different in development of different high-speed multimedia services, such as video on demand, mobile gaming, Web browsing, video streaming, voice over IP and e-commerce etc. Seamless inter system roaming across heterogeneous wireless access networks will be a major feature in the architecture of next generation wireless networks [3]. The future users of mobile communication look for always best connected (ABC) anywhere and anytime in the Complementary access technologies like Wireless Local Area Networks (WLAN), Worldwide Inter operability for Microwave Access (Wi-Max) and Universal Mobile Telecommunication Systems (UMTS) and which may coexist with the satellite networks [4- 6].It is very well evident that no single RAT can provide ubiquitous coverage and continuously high quality service. The mobile users may have to roam among various radio access technologies to keep the network connectivity active and to meet the applications/users requirements. With increase in offered services and access networks, efficient user roaming and management of available radio resources becomes decisive in providing the network stability and QoS provisioning.

The mobile communication networks are evolving into adaptable Internet protocol based networks that can handle multimedia applications. When multimedia data is supported by wireless networks, the networks should meet the quality of service requirements. One of the key challenges to be addressed in this prevailing scenario is the

distribution of the available channel capacity among the multiple traffic ensuring the QoS requirements of the traffic that are operating with different bandwidth requirements.

There are many call admission control(CAC) algorithms proposed in the literature to handle single-class network traffic such as real-time traffic like voice calls [7-10].To serve the multiple classes of traffic we have the Partitioning CAC [11][12] and threshold based CAC [13].The paper proposes the CAC framework for multi traffic based heterogeneous wireless networks . The resource allocation is a challenging task when the resources are always in scarce in a wireless environment. Efficient and intelligent call admission control policies should be in place which can take care of this contradicting environment to optimize the resource utilization. There are works reported on computation intelligence based call admission control algorithms. These algorithms admit or reject the call by applying computational intelligence techniques like fuzzy logic [14], Genetic algorithm [15], and fuzzy logic with Multi Attribute Decision Making (MADM) [16]. The combination of fuzzy and neural networks which forms a hybrid fuzzy neural network (FNN) is used for the radio resource management [17]. These intelligent techniques exhibit better efficiency which leads to higher user's satisfaction.

In this paper we propose a fuzzy neural approach based call admission control in a multi class traffic based Next Generation Wireless Networks (NGWN). The proposed FNCAC scheme is an integrated CAC module that combines the linguistic control capabilities of the fuzzy logic controller and the learning capabilities of the neural networks .The CAC model is developed using fuzzy Neural system based on Recurrent Radial Basis Function Networks (RRBFN) . RRBFN has better learning and adaptability that can be used to develop the intelligent system to handle the incoming traffic in the heterogeneous network environment. The proposed FNCAC can achieve reduced call blocking probability keeping the resource utilisation at an optimal level. In the proposed algorithm we have considered three classes of traffic having different QoS requirements and we have considered the heterogeneous network environment which can effectively handle these traffic. The traffic classes taken for the study are *Conversational traffic*, *Interactive traffic* and *Background traffic* which are with varied QoS parameters.

The further sections of the paper are organized as follows. The section II discusses on the soft computing techniques in RRM. Section III focuses on the Analytical model of the proposed call admission control based on higher order Markov chains. The section IV discusses the proposed intelligent FNCAC model. The section V represents the simulation results and conclusion is presented in section VI.

## 2. Soft Computing Techniques for RRM

The application of intelligent techniques has become wide spread for nonlinear time varying and complex problems that were posing a great challenge to researchers when they used the conventional methods. These soft computing techniques such as fuzzy logic, artificial neural networks and the hybrid systems like fuzzy neural networks have outperformed the conventional algorithmic methods. The advantages of these methods are many, which include most notably learning from experience, scalability, adaptability. Moreover, it has the ability to extract rules, without detailed or accurate mathematical modelling. All these features make the soft computing techniques the best candidates for solving the complex problems in any domain.

### 2.1 Fuzzy Logic

The concept of Fuzzy logic has been extensively applied in characterizing the behaviour of nonlinear systems. The nonlinear behaviour of the system can be effectively captured and represented by a set of Fuzzy rules [18]. Many engineering and scientific applications including time series are not only nonlinear but also non-stationary. Such applications cannot be represented by simple Fuzzy rules, because fixed number of rules can describe only time invariant systems and cannot take in to account the non-stationary behaviour. Recently, a new set of Fuzzy rules have been defined to predict the difference of consecutive values of non-stationary time series [19].

Advantages of Fuzzy Logic approach [20] are, easy to understand and build a predictor for any desired accuracy with a simple set of Fuzzy rules. Due to less computational demand there is no need of mathematical model for estimation and also for fast estimation of future values .The Limitations of Fuzzy Logic approach is, first it works on Single step prediction, second, the fuzzy logic do not have learning capability.

### 2.2. Neural Networks

The neural networks are low-level computational elements that exhibit good performance when they deal with sensory data. They can be applied to the situation where sufficient observation data is available. The Neural network methods are used in problems like control, prediction and classification. Neural Networks are able to gain this popularity because of the commanding capacity that they have in modelling exceptionally complex non linear functions. Neural networks have a biggest advantage in terms of easy to use which is based on training-prediction cycles. Training the neural networks plays a crucial role in the system usage of neural networks. The training pattern that contains a predefined set of inputs and expected outputs is used to train the neural networks.

Next, in prediction cycle, the outputs are supplied to the user based on the input values. To make the neural networks to behave like a physical system or predict or control, the training set used in the training cycle shall consist of enough information representing all the valid cases [21-23].

Neural Networks are flexible soft computing frameworks for modelling a broad range of nonlinear problems [24]. One significant advantage of the neural network based approach over other classes of nonlinear models is that NNs are universal approximation tools that can approximate large class of functions with a high degree of accuracy [25]. This approximation power of Neural Network model comes from several parallel processing elements, called as ‘neurons’. No prior assumption of the model form is required in the model building process. Instead, the network model is largely determined by characteristics of the data. Single hidden layer feed forward network is the most widely used model for prediction and forecasting of time variant functions. The model is characterized by a network of three layers of simple processing unit connected by non-cyclic links. The architecture of feed-forward neural network is shown in Figure 1.

The relationship between the output  $\hat{y}(t)$  and the inputs  $\{y(t-1), y(t-2), \dots, y(t-n)\}$  can be mathematically expressed as [26],

$$\hat{y}(t) = w_0 + \sum_{j=1}^Q w_j g \left( w_{0j} + \sum_{i=1}^n w_{ij} y(t-i) \right) + e(t) \quad (1)$$

Where  $w_{ij} (i = 0, 1, 2, \dots, n, j = 1, 2, \dots, Q)$  and  $w_j (j = 0, 1, 2, \dots, Q)$  are model parameters often called connection weights,  $n$  is the number of input nodes and  $Q$  is the number of hidden nodes.  $g(\cdot)$  Represents a transfer function of the processing element, the transfer function can be logistic or Gaussian [26]. The NN model having a logistic or Gaussian transfer function can perform nonlinear functional mapping from the past observation to the future value  $\hat{y}(t)$  i.e.

$$\hat{y}(t) = f(y(t-1), \dots, y(t-n), W) + e(t) \quad (2)$$

Where  $W$  is a vector of all input parameters and  $f(\cdot)$  is function determined by network structure and connection weights. Thus, the neural network model is equivalent to nonlinear auto regressive model.

The feed forward network can effectively model nonlinear time series. The time-varying wireless network parameters are represented as nonlinear and non-stationary time series. The recurrent connection in NN architecture is

also called as ‘short term memory’ and will process the non-stationary behaviour of the time series.

The feed forward NNs can be divided into two classes: *static (non-recurrent)* and *dynamic (recurrent)*. In *Static NNs*, output is linear or nonlinear function of its inputs and generates the same output for a given input vector. These NNs are suitable for spatial pattern analysis. In this case, the relevant information is distributed throughout the spatial coordinates of the input vector. The spatial dependencies in the input data can be found in the areas of pattern recognition and functional approximation [27].

In contrast, dynamic NNs are capable of implementing memories which gives them the possibility of retaining information to be used later. The network can also generate diverse output in response with the same input vector, because the output may also depend on actual state of the memories. Dynamic NNs have inherent characteristic of memorizing the past information for long term or short term periods. These networks are ideal for processing spatio-temporal data.

The Recurrent Neural Network (RNN) architecture can be classified in to fully interconnected nets, partially connected nets and Locally Recurrent & Globally Feed-forward (LRGF) nets [28]. The fully connected networks do not have distinct input layer/nodes. Each node has input from all other nodes.

The partially connected RNN can be implemented by

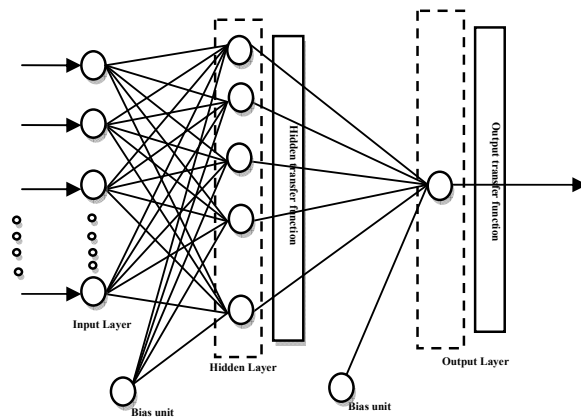


Figure 1 Feed forward neural networks

adding a feedback connection to the existing feed-forward NN to process the temporal information of the data. The feedback connection may be from hidden layer (Elman net) or from the output layer (Jordan net) [28, 29]. In the LRGF nets, self connecting neuron layer is either present in the input or on the output side of the feed-forward NN to process temporal information. The advantage of LRGF lies in its training algorithm. The standard gradient decent algorithm can be used to train the feed-forward NN for nonlinear functional approximations. A delayed input or the output from self connected neuron will act as short term memory to process the time-varying information

There are good amount of work reported on the combination of neural and fuzzy logic approaches. This paper concentrates on the recurrent neural networks (RNNs) that have superior capabilities than the feed forward neural networks [31-32]. Since a recurrent neuron has an internal feedback loop to capture the dynamic response of a system without external feedback through delays, RNNs have the ability to deal with time-varying input or output through their own natural temporal operation [31]. Moreover; the RNNs are dynamic mapping and demonstrate good control performance in the presence of un modelled dynamics, parameter variations, and external disturbances [31-32]. The Radial Basis Function Network (RBFN) has a faster convergence property than a multilayer Perceptron (MLP) because the RBFN has a simple structure. Additionally, the RBFN has a similar feature to the fuzzy system. First, the output value is calculated using the weighted sum method. Then, the number of nodes in the hidden layer of the RBFN is the same as the number of 'if-then' rules in the fuzzy system. Finally, the receptive field functions of the RBFN are similar to the membership functions of the premise part in the fuzzy system. This makes the RBFN a very useful technique to be applied to control the dynamic systems. The implementation of RBFN bases using RBFN for recurrent RBFN based FNN improves the accuracy of the approximation function.

The benefits of neural network approach [24] are as follows. First, the NN Prediction accuracy is much superior to conventional approaches. Second, NN Model can be used for single and Multi step forecasting. Third, they are capable of learning the system and demands low computation structures. The limitations of NN approach are: The optimal choice of number of layers and number of neurons in each layer is by a heuristic process and it requires expertise in the field of NNs for a model designer. The deciding of the weights to the non-cyclic links will determine the accuracy of forecasting. Deciding the appropriate weights to the link is once again a heuristic process.

### 3. Analytical Model for CAC

In this paper we propose a novel analytical model admission control mechanism for reducing the call blocking probability there by increasing the resource utilization. This would achieve the Objective of guaranteeing the user QoS requirements. The proposed model is able to handle three types of the applications considered for the study which involves *conversation traffic*, *interactive traffic* and *background traffic*. All of these represent different QoS class of traffic with the required QoS parameters.

The Conversational traffic is sensitive to transfer delay and jitter. It demands guaranteed bit rate and low bit error rate. The examples of the applications belonging to this

category are Video-conferencing and Audio conferencing. The Interactive traffic is a QoS Class that is not sensitive to Transfer Delay and Jitter but demands low Bit Error rate. The applications of this QoS class do not need Guaranteed Bit Rate, for example Web browsing, Interactive chats and Interactive Games. The Background traffic QoS class is not sensitive to transfer delay and jitter but needs low bit error rate from the network and these applications do not depend on guaranteed bit rate. The examples belonging to this group are E-mail, SMS applications. The assumption made for the design and development of analytical CAC model was type3 traffic which would require three channels to be assigned in the system and type2 traffic demands two channels and type1 traffic needs one channel.

The proposed model is developed keeping in mind the WCDMA, Wi-Fi, and Wi-Max. The CAC mechanism proposed is focused only on the system's ability to accommodate newly arriving users in terms of the total channel capacity which is needed for all terminals after the inclusion of the new user. In case when the channel load with the admission of a new call was precompiled (or computed online) and found to be higher than the capacity of the channel, the new call is rejected, if not, the new call could be admitted. The decision of admitting or rejecting a new call in the network will be made only based on the capacity needed to accommodate the call.

We consider a heterogeneous network which comprises a set of RATs  $R_n$  with co-located cells in which radio resources are jointly managed. Cellular networks such as Wireless LAN and Wi-Max can have the same and fully overlapped coverage, which is technically feasible, and may also save installation cost.  $H$  is given as  $H \{RAT 1, RAT 2, RAT k\}$  where  $K$  is the total number of RATs in the heterogeneous cellular network. The heterogeneous cellular network supports  $n$ -classes of calls, and each RAT in set  $H$  is optimized to support certain classes of calls.

The Analytical model for CAC mechanism in heterogeneous wireless networks is modelled using Higher order Markov Model. In the proposed model it is assumed that, whenever a new user enters the network, it will originate the network request at the rate  $\lambda_i$  and is assumed to follow a Poisson process. The service time of the different class of traffic and types of calls is  $\mu_i$ . The mean service time of all types of users were assumed to follow negative exponential distribution with the mean rate  $1/\mu$ . The Voice traffic is Erlang distributed, the condition that is considered for simulation is Negative Exponential distribution. The total number of virtual channels in the system are  $N$ . When the numbers of available channels are below the specified threshold the system will drop the calls. The threshold limit is determined by three positive integers  $A_1, A_2$  and  $A_3$ .

These are called as *Utilization rates* where  $A$  is represented as  $A = \frac{\lambda}{\mu}$ . Similarly,

$$A_1 = \frac{\lambda_1}{\mu_1}, \quad A_2 = \frac{\lambda_2}{\mu_2}, \quad A_3 = \frac{\lambda_3}{\mu_3}$$

are the *utilisation rate* of *type1* traffic, *type2* traffic and utilisation rate of *type3* traffic respectively. In general the values of the utilisation rate in a steady state system will be with in 1.

When the available number of channels falls below the threshold  $A_3$  the proposed system will accept only the voice calls and web browsing. When the available number of channels falls below the threshold  $A_2$  the proposed system will accept only the voice calls. If the available number of channels falls below the threshold  $A_1$  the proposed system will not accept any calls as it reaches the stage where there will be no channels available to allocate to the incoming calls and leads to system blocking. The  $P(0)$  is the probability that there are no allocated channels in the designated system. The parameters of analytical performance model are also called as Performance model parameters. The parameters are number of *virtual channels* ( $N$ ), *user arrival rate* ( $\lambda$ ), *arrival rate of type 1 call* ( $\lambda_1$ ), *arrival rate of type 2 call* ( $\lambda_2$ ), *arrival rate of type 3 call* ( $\lambda_3$ ) and *service time* of the calls is taken as  $\mu_1$ ,  $\mu_2$  and  $\mu_3$ .

Assuming that the arrival time of all the types of traffic are equal i.e.  $\lambda_1 = \lambda_2 = \lambda_3 = \lambda$  and the service time for the types of traffic are equal i.e.  $\mu_1 = \mu_2 = \mu_3 = \mu$ , the call blocking probability for type1 traffic could be expressed as

$$P_n = \frac{a}{3} (P_{n-1} + P_{n-2} + P_{n-3}) \quad (3)$$

Where  $a = \lambda / \mu$  which should be generally less than one for the system stability. Similarly, the call blocking probability for type2 traffic  $P_{n-1}$  is

$$P_{n-1} = \frac{a}{3} (P_{n-2} + P_{n-3} + P_{n-4}) \quad (4)$$

And the call blocking probability for type3 traffic  $P_{n-2}$  is represented as

$$P_{n-2} = \frac{a}{3} (P_{n-3} + P_{n-4} + P_{n-5}) \quad (5)$$

The call blocking probability for the overall system traffic  $P_{nb}$  can be expressed as

$$P_{nb} = \frac{a}{3} (P_n + P_{n-1} + P_{n-2}) \quad (6)$$

#### 4. Fuzzy Neural Call Admission Controller (FNCAC)

Our proposal to deal with the complex problem of call admission control in heterogeneous wireless network environment supporting multimedia traffic is developed using the hybrid model. This hybrid model is evolved by combining the fuzzy logic which is easy to understand and uses simple linguistic terms and if-then rules with the neural networks which are smart enough to learn the system characteristics. Therefore the Fuzzy neural networks combine the benefit of both neural networks and the fuzzy systems to solve the CAC problem. This research work particularly uses the feed forward neural networks which has the ability to map any nonlinear and non-stationary function to an arbitrary degree of accuracy [24]. One such popular feed-forward network is the Radial Basis Function Network (RBFN). It is a single hidden layer feed-forward network. Each node in the hidden layer has a parameter vector called as *centre*. These *centres* are used to compare with network input and produce radically symmetrical response. These responses are scaled by connection weights of the output layer and then produce network output, where Gaussian basis function is used and given by equation (7).

$$\hat{y} = \sum_{i=1}^n w_i \exp \left( - \frac{\|y - \mu_i\|^2}{2\sigma_i} \right) \quad (7)$$

Radial Basis Function (RBF) has achieved considerable success in nonlinear function prediction but the performance of RBF is less satisfactory for the nonlinear and non-stationary function prediction [27]. Recurrent Radial Basis Function Network (RRBFN) is a class of locally recurrent & globally feed-forward (LRGF) RNN. In LRGF network the recurrent/self-connection is either in the input layer or in the output layer. RRBFN is having recurrent connection at the input layer. Where  $\sigma_i$  is the dimension of the influence field of hidden layer neuron,  $y$  and  $\mu_i$  are input and prototype vector respectively. The Recurrent Radial basis function network considers the time as an internal representation and the non-stationary aspect of nonlinear function can be obtained by having self-connection on the input neuron of sigmoidal firing function. The recurrent weights are in the range [-1, +1] with normal distribution. This is a special case of locally recurrent, globally feed-forward neural network [28]. The RRBFN output for Gaussian basis function is as indicated in (8). Where  $\hat{y}(\cdot)$  is the predicted time series,  $n$  is the number of step prediction and  $j$  is the number of neurons in the input layer of RRBFN system

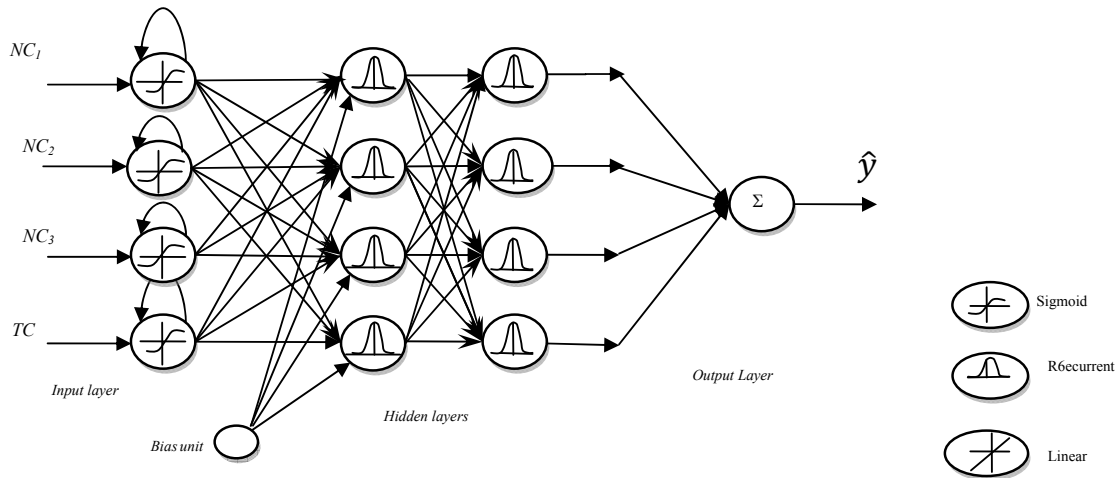


Figure 3 Fuzzy Neural CAC (FNCAC) model

$$\hat{y}(n) = \sum_{i=1}^n w_i \exp \left( - \frac{\sum_{j=1}^m (y^j - \mu_i^j)^2}{\sigma_i} \right) \quad (8)$$

The proposed architecture of RRBFN based FNCAC model is shown in Figure 3. The FNCAC takes the network characteristics of the three networks taken for the study and the requirements of the incoming traffic is taken as inputs. The cost is considered as the bias input. The neural network based Call admission control involves training and testing of RRBFN based CAC controller. The training and testing samples are randomly picked from the sample size of 1000. The RRBFN network has four layers: input, two hidden layers and output layer. For the training and testing, we have used 250 neurons in the input layer with sigmoid activation function and with the recurrent connections. The range of recurrent weights is -1 to +1. The hidden RRBF layers have 200 neurons with RBF activation function and output layer has single neuron with linear activation.

## 5. Simulation Results and Discussion

In this section, we present the numerical results and compare the call blocking probabilities of the different types of traffic. The set of experiments were conducted with varying the aggregate traffic and individual traffic of the network and the call blocking probability of Fuzzy neural technique was compared with the conventional CAC and Fuzzy based CAC. The aggregate utilization rate of the calls was considered with the call blocking probability of the FNCAC, conventional CAC and Fuzzy

based CAC. As the combined traffic intensity increases the utilization rate also increases. The Fuzzy neural CAC model exhibits better performance in reducing the call blocking probability of the aggregate traffic which is assumed to have the varied traffic component of *type1*, *type2* and *type3* traffic. The performance comparison of fuzzy neural method, convention CAC and fuzzy based CAC is plotted in figure 4.

The next set of experiments was conducted to compare the call blocking probabilities of the individual traffic in Fuzzy neural based CAC. The *type1* traffic has minimal call blocking probability when compared *type2* and *type3* traffic and also *type3* traffic has higher call blocking probability when compared to *type2* and *type1* traffic. The simulation results in figure 5 shows that the call blocking probability of the individual types of traffic will increase with the increase in the utilisation rate. The next set of experiments were conducted by considering only one type of traffic and the call blocking probability of the system was plotted for Fuzzy neural technique in comparison with the conventional CAC and Fuzzy based CAC. The graph in figure 6 considers only *type1* traffic in the system, figure 7 indicates the blocking probability of *type2* traffic for all the three systems. *Type3* traffic is considered independently in the system and call blocking probability was studied and is represented in figure 8. The study clearly indicates that the performance of the FNCAC is better than the other two CAC methods in terms of reduced call blocking probability.

## 6. Conclusion

In this paper, the performance of FNCAC system for next generation networks is compared and validated with the performance of fuzzy based CAC and conventional CAC. The Performance of FNCAC model in the heterogeneous RATs supporting multimedia traffic is

studied pitching upon the call blocking probability by varying the utilization rate of the aggregate traffic and the individual traffic. The simulation study conducted records the following observations. The increase in the utilisation rate increases the call blocking probability of the system for both the aggregate traffic and the individual traffic. The experiment results indicate that the fuzzy neural CAC reduces the blocking probability by around 20% less compared to other two methods.

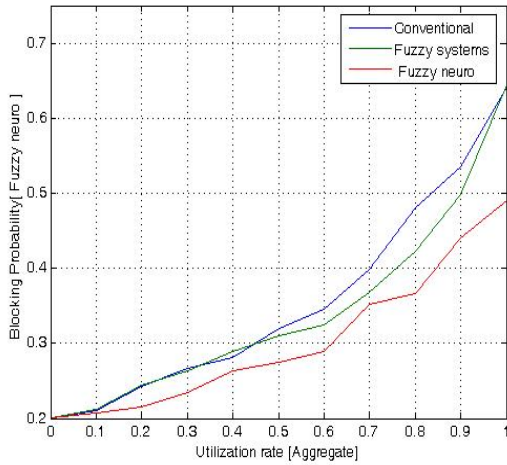


Figure 4 Call blocking probability for the Utilization rate (aggregate)

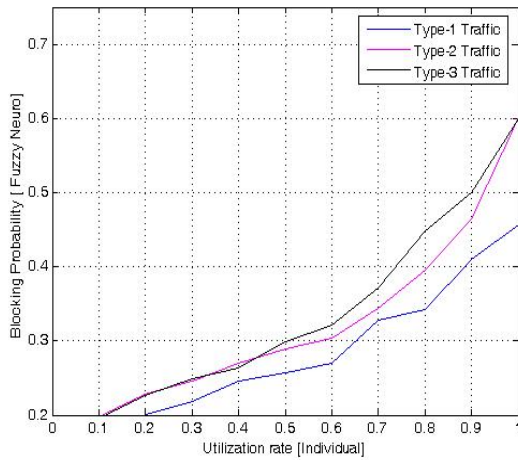


Figure 5 Individual traffic utilisation rate v/s FNCAC call blocking probability

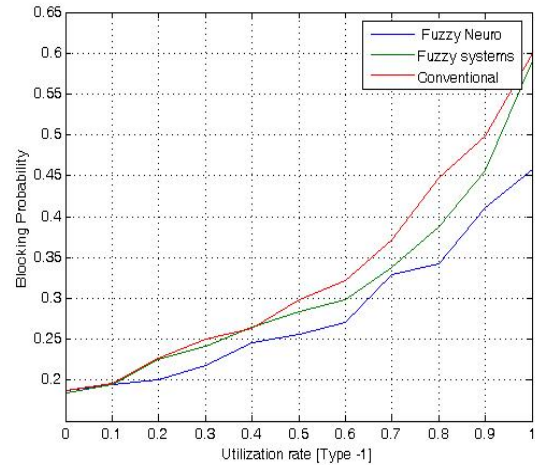


Figure 6 Call blocking probability for Type1 Traffic

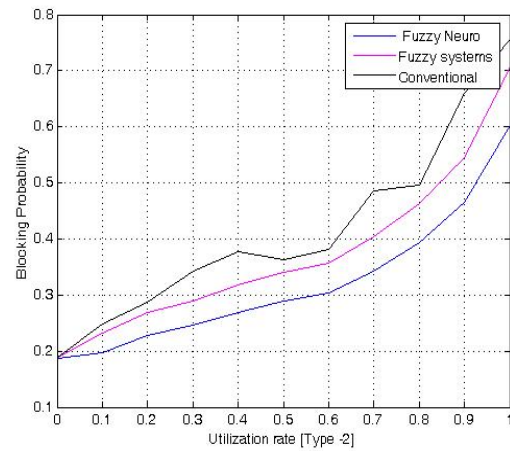


Figure 7 Call blocking probability for type 2 traffic

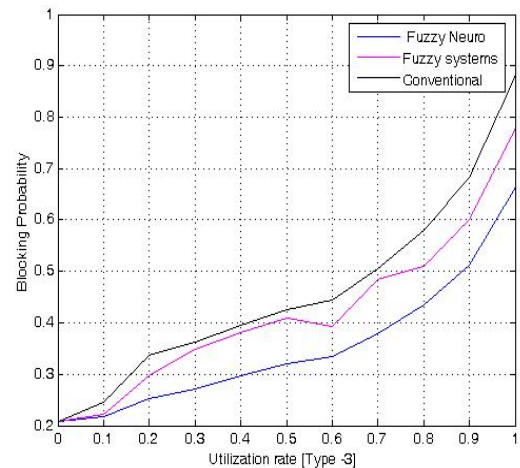


Figure 8 Call blocking probability for type3 traffic

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# An Optimized Weighted Association Rule Mining On Dynamic Content

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## Abstract

Association rule mining aims to explore large transaction databases for association rules. Classical Association Rule Mining (ARM) model assumes that all items have the same significance without taking their weight into account. It also ignores the difference between the transactions and importance of each and every itemsets. But, the Weighted Association Rule Mining (WARM) does not work on databases with only binary attributes. It makes use of the importance of each itemset and transaction. WARM requires each item to be given weight to reflect their importance to the user. The weights may correspond to special promotions on some products, or the profitability of different items.

This research work first focused on a weight assignment based on a directed graph where nodes denote items and links represent association rules. A generalized version of HITS is applied to the graph to rank the items, where all nodes and links are allowed to have weights. This research then uses enhanced HITS algorithm by developing an online eigenvector calculation method that can compute the results of mutual reinforcement voting in case of frequent updates. For Example in Share Market Shares price may go down or up. So we need to carefully watch the market and our association rule mining has to produce the items that have undergone frequent changes. These are done by estimating the upper bound of perturbation and postponing of the updates whenever possible. Next we prove that enhanced algorithm is more efficient than the original HITS under the context of dynamic data.

**Keywords:** Association Rule Mining, Weighted Association Rule Mining, HITS, Online HITS, Dynamic Content

## 1. Introduction

Association Rule Mining aims to explore large transaction databases for association rules, which may reveal the implicit relationships among the data attributes [1]. It has number of practical applications, including classification, text mining, Web log analysis, Share Market and recommendation systems. The classical model of association rule mining employs the support measure, which treats every transaction equally. In contrast, different transactions have different weights in real-life data sets. For example, in the market basket data, each transaction is recorded with some profit. Much effort has been dedicated to association rule mining with preassigned weights. However, most data types do not come with such preassigned weights, such as Web site click-stream data. There should be some notion of importance in those data. For instance, transactions with a large amount of items should be considered more important than transactions with only one item. Current methods, though, are not able to estimate this type of importance and adjust the mining results by emphasizing the important transactions [1].

The concept of association rule mining proposes the support-confidence measurement framework and reduced association rule mining to the discovery of frequent item sets. WARM generalizes the traditional model to the case where items have weights. WARM requires for each item to be given weight to reflect their

importance to the user. The weights may correspond to the profitability of different items. As more data is gathered, which are frequently getting updated, the construction of the graph should be dynamic instead of static. Using Online Hits algorithm, the graph can be constructed dynamically and the cost can be reduced by postponing updates whenever possible. By calculating Eigen values we are enforcing the mutual reinforcement relationship between the items.

This HITS algorithm is suitable only for static content.

- 1) They work well in environments where no dynamic update is possible.
- 2) They fail to capture the rich informations that lie within the patterns of user access or in the structure that can be defined by user group implicitly.

In this paper, we propose to replace the HITS algorithm with Online HITS algorithm which reduces the cost by postponing the updates whenever possible and makes it more suitable for Dynamic environments. HITS algorithm normally used for web pages, but it can also be used for transactional datasets from which we can calculate the hub and authorities, based on which the graph is constructed. The general HITS algorithm is too costly to run on every update. When the updates are accumulated we run online HITS once. This way cost is reduced. Another advantage of online HITS is that service of user queries, updating the Eigen vector of the given Matrix A and running of Online HITS can be made as separate activities.

The rest of the paper is arranged as follows: section II Introduction to the basic concepts of Online HITS algorithm; Section III gives an evaluation and analysis of the HITS algorithm in dynamic Environment; section IV addresses the evaluation and analysis of Online HITS algorithm in Dynamic Environments. Section V concludes the paper.

## 2. Basic concept of Online HITS algorithm

Consider the Matrix A, which is created based on the transactions and the items within each of those transactions. It will be having the values of the rules that are going to be considered for mining. The rankings say, x and y, correspond to

the principal eigenvectors of the matrix  $A^T A$  and  $AA^T$ , respectively. Even a single update to the user access will correspond to a perturbation of the A matrix. Depending on the weight function selected, it can change the behaviour of a single element or a row of elements of the matrix A. In either case the changes to the behaviour are local. These changes in behaviour may cause variations to the principal eigenvector of  $A^T A$  (and  $AA^T$ ). If we can find the relationship between the variation of x and y and the behavioural changes to the matrix A, we can check each update to see whether it will cause too much changes to x and y. If the change is within acceptable precision, we can postpone applying the update thus avoid running Online HITS for it. When the accumulated updates cause too many changes to the behaviour, we apply all the changes together and run Online HITS once. In this way the cost of running the algorithm frequently can be reduced. Such an algorithm is called as Online HITS. Another advantage of this approach is that service of user queries and updating the matrix A and running of Online HITS can be made separate. The system can update the matrix A and run Online HITS in background, and continue servicing user queries with old results that we are confident to be within certain range from the latest ones. Users can enjoy the service without any disturbances. For us, the continued accumulation of data and constructing the graph based on that is an inherent feature and the results we produce are the best guess based on the data we have so far. It is too good for the results to undergo dramatic change, which reflects the update of the latest trends and techniques about the world. Rather, we are interested in the bound of the change so that we can perform the tasks more efficiently. In addition, the conclusions are considered only to apply to unweighted graphs represented by adjacency matrices. Online HITS algorithm uses 2 main concepts, namely the computations of eigengap and perturbation. They have to be performed efficiently otherwise the cost of computing them would affect the saving of not running HITS. They will be addressed in the following subsections.

## 3. Computation of Eigengap

Eigengap is nothing but the difference between the largest and second largest Eigen values namely  $\lambda_1$  and  $\lambda_2$ . The original HITS algorithm is essentially a power method to compute the principal eigenvector of S. It can be revised

easily, without adding complexity, to produce  $\lambda_1$  and  $\lambda_2$  as byproducts.

Two modifications to the original HITS algorithm are introduced:

1. Find the two eigenvectors  $\lambda_1$  and  $\lambda_2$ , instead of finding only the principal eigenvector. This can be done by using the block power method. Initially, start with two orthogonal vectors, multiply them all by S, then apply Gram-Schmidt to orthogonalize them. This is a single step. Iterate until they converge. In the HITS algorithm replace this step with the step that calculates principle Eigen vector.

2. HITS ensure convergence by normalizing the vector at each step to unit length. Instead, we normalize each vector by dividing them by their first non-zero element. They still converge to the two eigenvectors and the scaling factors converge to  $\lambda_1$  and  $\lambda_2$ .

The above modifications introduce extra computation of one eigenvector and Gram-Schmidt orthogonalization. The Extra computation doubles the work of HITS and the order of doing orthogonalization is  $O(n)$ . The total complexity is the same as HITS which is  $O(mn)$ .

#### 4. Evaluation and Analysis of HITS in Dynamic Environments

The usage of HITS lies in the hope that the updates may not cause too many changes (too much perturbation) to the ranking so that recomputation is avoided. In the situations where data is accumulating, running the HITS only once may not provide the correct support values since ranking of items is done only once and it is not updated frequently. The other disadvantage is that sometimes a transaction with few items may be a good hub, which is ignored by HITS. It also does not consider the difference between transactions. We have taken the customer complaints database where the updates are more frequent.

HITS Algorithm will first discover the authoritative between 2 transaction items. Given the set of n items, HITS first construct the n-by-n adjacency matrix A. The elements in row i and column j of the Matrix is 1 if there exists a relation between these 2 items, otherwise the value will be 0.

We have tested the HITS Algorithm against the Customer Complaints Database. The results of which are shown below.

Table1: Results of Complaint database using HITS Algorithm

Complaint Type	Support Values
Complaint 1	0.97
Complaint 2	0.95
Complaint 3	0.98
Complaint 4	0.97
Complaint 5	0.98
Complaint 6	0.99
Complaint 7	1.00
Complaint 8	0.95

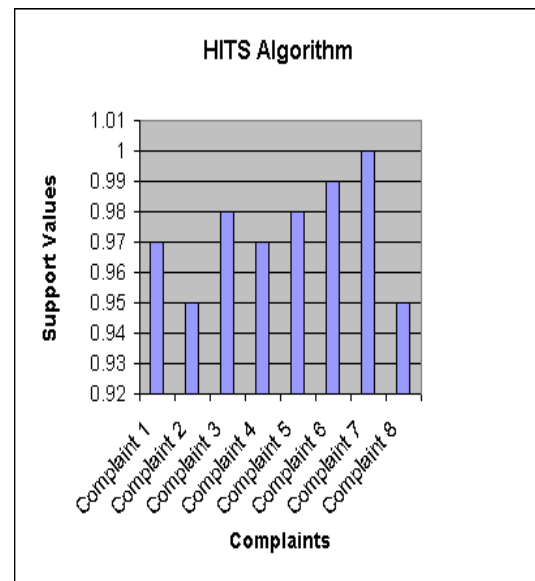


Fig 1: Graph using HITS

#### 5. Evaluation and Analysis of Online HITS in Dynamic Environments

The Online HITS algorithm is nothing but a process of constructing an access based graph. Each single update of a user or every change of the item is taken to correspond to a perturbation to a matrix A. The weight function selected can perturbate a single element of the matrix A or row of elements in the matrix A. In any of these cases the Perturbation is always local. This will affect the Eigen vector of the matrix  $A^T A$  and  $AA^T$ . If we can find the relationship between the changes of the ranking to principle eigen vector of  $A^T A$  and  $AA^T$  which are called as x and y values, we can check each update to see if it will cause too much changes to x and y. On verifying

that the variation is within acceptable threshold level of precision, we can postpone applying the update thus avoid running Online HITS for it. Thus the Online HITS takes into account the current variations that happen dynamically, and the algorithm reflects a true dramatically changed, updated system knowledge of the current world. Online HITS constantly monitors the changes and performs operations. The results of our test are shown in the following figures.

Table2: Results of Complaint database using Online HITS Algorithm

Complaint Type	Support Values
Complaint 1	0.98
Complaint 2	0.96
Complaint 3	0.99
Complaint 4	0.99
Complaint 5	0.99
Complaint 6	0.99
Complaint 7	1.00
Complaint 8	0.97

For the above table the figure is shown as below:

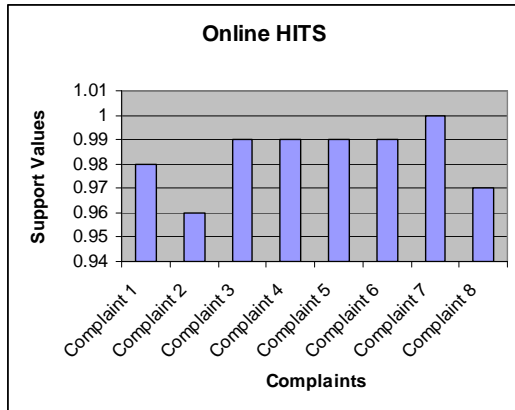


Fig2: Graph using Online HITS

Note that we are not testing how well the ranking produced by Online HITS (or HITS) fits the real ranking which is a rather qualitative and subjective measure. Instead, we are examining Online HITS's algorithmic properties and how it performs more efficient than original HITS in a dynamic system.

## 6. Conclusion

We extended the HITS hyperlink analysis algorithm to make it applicable for analyzing weighted graphs. Our

generalizations are in two directions. First, we replaced the construction of static graph to the construction of dynamic graph by finding out the Eigengap. Second, we created an online eigenvector calculation method that can compute the results of mutual reinforcement voting efficiently in case of frequent updates by estimating the upper bound of perturbation and postponing applying the updates whenever possible. Ie. Till the variations are within the applicable limit, we won't run the Online HITS algorithm. Both theoretical analysis and experiments show that our generalized online algorithm is more efficient than the original HITS under the context of dynamic data.

We are going to enhance the association rule for dynamic content based on fuzzy logic and mutual reinforcement voting.

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# An Economic-based Resource Management and Scheduling for Grid Computing Applications

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## Abstract

Resource management and scheduling plays a crucial role in achieving high utilization of resources in grid computing environments. Due to heterogeneity of resources, scheduling an application is significantly complicated and challenging task in grid system. Most of the researches in this area are mainly focused on to improve the performance of the grid system. There were some allocation model has been proposed based on divisible load theory with different type of workloads and a single originating processor. In this paper we introduce a new resource allocation model with multiple load originating processors as an economic model. Solutions for an optimal allocation of fraction of loads to nodes obtained to minimize the cost of the grid users via linear programming approach. It is found that the resource allocation model can efficiently and effectively allocate workloads to proper resources. Experimental results showed that the proposed model obtained the better solution in terms of cost and time.

**Keywords:** Grid Scheduling, Resource management, Workload distribution, Economic model, Cost Optimization

## 1. Introduction

One of the most complicated task in Grid computing is the allocation of resources for a process; i.e., mapping of jobs to various resources. This may be a NP-Complete (Non-deterministic Polynomial time) problem. For example, mapping of 50 jobs into 10 resources produces  $10^{50}$  possible mappings. This is because every job can be mapped to any of the resources. In our case the allocation is in terms of co-allocation which means that the job is executed on a number of resources instead of single resource. Here resource means processors which are involved in the scheduling process. We used resources and processors simultaneously. The other complexity of resource allocation is the lack of accurate information about the status of the resources. Load balancing and scheduling play a crucial role in achieving utilization of resources in grid environments [20].

Much of the work was done on finding an optimal allocation of resources in Grid computing environments. The scheduling schemes are divided into two main categories; conventional and economical. The conventional strategies consider the overall performance

of the system as a metric for determining the system quality. It does not take the cost as factor for scheduling jobs on resources and treat all resources as the same at all. Some examples are SmartNet, AppleS Project, Condor-G, NetSolve etc. In economic strategy, cost is considered as essential factor for scheduling jobs. The user is charged based on the utility of the resources in the Grid system. Some of the works consider the economic strategies which deals with the price of resources when it needs to allocate jobs to resources and that price usually reflects the value of the resource to the user.

Task scheduling is an integrated part of parallel and distributed computing. The Grid scheduling is responsible for resource discovery, resources selection, job assignment and aggregation of group of resources over a decentralized heterogeneous system; the resources belong to multiple administrative domains. The resources are requested by a Grid application, which use to computing, data and network resources etc. However, Scheduling an applications of a Grid system is absolutely more complex than scheduling an applications of a single computer. Because to get the resources information of single computer and scheduling is easy, such as CPU frequency, number of CPU's in a machine, memory size, memory configuration and network bandwidth and other resources connected in the system. But Grid environment is dynamic resources sharing and distributing. Then an application is hard to get resources information, such as CPU load, available memory, available network capacity etc. And Grid environment also hard to classify jobs characteristic, that run in Grid. There are basically two approaches to solve this problems, the first is based on jobs characteristic and second is based on a distributed resources discovery and allocation system. It should optimize the allocation of a job allowing the execution on the optimization of resources. The scheduling in Grid environment has to satisfy a number of constraints on different problems.

The existing scheduler used in TeraGrid and other notable computing grids are dedicated for research purpose and based on deadlines, resource availability, and the description of resources required by a job. Because TeraGrid and most other grid computing implementations are not employed in profit seeking

firms, the dollar cost of running jobs is not taken into account in arriving at the optimal schedule. Instead, the scheduling is evolved by matching resources and applications with the objective of improving the hardware performance. As grid computing migrates from scientific to business uses, the allocation of workloads to resources to meet business objectives, such as overall time, cost, or revenue becomes important aspect. This paper introduces a novel frame work for economic scheduling in Grid computing using the mathematical model.

This paper is organized as follows: section 2 presents the related works, the resource allocation model is discussed in the section 3, section 4 describes the design of resource allocation, the experimental results for the proposed model and the conclusion are discussed in the section 5 and section 6 respectively.

## 2. Related works

To date several grid scheduling algorithms have been proposed to optimize the overall grid system performance. The study of managing resources in the Grid environment started from 1960s. The economic problem [14] results from having different ways for using the available resource, so how to decide what is the best way to use them. Utilization of Grid must be cheaper for the Grid user than purchasing their own resources [10] and must satisfy their requirements. On the other hand, resource providers must know if it is worth to provide their resources for usage by the Grid users. Also the pricing of resources should not be per time unit or slot (eg. cost per minutes) [9]. Because it leads to big difference in speeds of processors, so the price per unit time of a processor might cheaper, but the user must pay large amount of money due to slow processing resources. Moreover the users have to know how many time units they need to finish their jobs. Thus the cost of Grid user must be determined based on the tasks the resource is processing.

Deadline scheduling algorithm [18] is one of the algorithms which follow the economic strategy. In aim of this algorithm, to decrease the number of jobs that doesn't meet their deadlines. The resources are priced according to their performance. This algorithm also has a facility of fallback mechanism; which can inform the grid user to resubmit the jobs again, the jobs which are not met the deadline of the available resources. Nimrod/G [3, 4] includes four scheduling algorithms which are cost, time, conservative time and cost-time. Cost scheduling algorithm tries to decrease the amount of money paid for executing the jobs with respect to the deadline. Time scheduling algorithm attempt to minimize the time required to complete the jobs with respect to their budget allotment. The conservative time scheduling algorithm aims to execute the jobs within the stipulated budget and the deadlines. The cost-time scheduling algorithm works

as cost scheduling algorithm except that when there are two or more resources with the same price, it employs time scheduling algorithm. It is not dealing with co-allocation.

The effective workload allocation model with single source has been proposed [1] for data grid system. Market-based resource allocation for grid computing [8] supports time and space shared allocations. Furthermore it supports co-allocation. It is supposed that resources have background load which changes with time and that has the highest priority for execution, so they are not fully dedicated to the grid. Gridway [11] is an agent based scheduling system. It aims that to minimize the execution time, total cost and the performance cost ratio of the submitted job. Market economy based resource allocations in Grids [16] are an auction based user scheduling policies for selecting resources were proposed. GridIs [20] a P2P decentralized framework for economic scheduling using tender model. The author tries to perform the process without considering the deadline and the algorithm is implemented with the help of a variable called conservative degree, its value between 0 and 1.

The time and cost trade-off has been proposed [7] with two meta-scheduling heuristics algorithms, that minimize and manage the execution cost and time of user applications. Also they have presented a cost metric to manage the trade-off between the execution cost and time. Compute power market [6] is architecture responsible for managing grid resources, and mapping jobs to suitable resources according to the utility functions used. Parallel virtual machine [2, 17] enables the computational resources to be used as if they are a single high performance machine. It supports both execution on a single and multiple resources by splitting the task into subtasks. Grid scheduling by using mathematical model was proposed [12, 13] with equal portion of load to all the processors; ie., the entire workload received from a source is equally divided and a portion of load is assigned to a processor with the help of random numbers to divide the entire workload from a source. The work closest to ours is [3] where the authors proposed the algorithm that claims to meet budget and deadline constraints of jobs. However, the algorithm proposed is ad-hoc and does not have an explicit objective.

## 3. Resource Allocation Model

A generic grid computing system infrastructure considered here comprises a network of supercomputers and/or a cluster of computers connected by local area networks, as shown in Figure. 1. We consider the problem of scheduling large-volume loads (divisible loads) within a cluster system, which is part of a grid infrastructure.

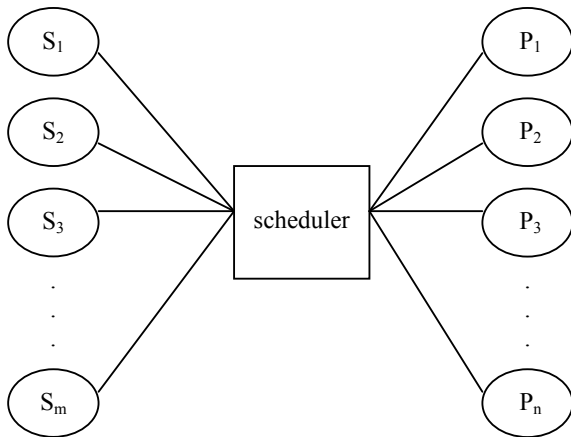


Fig 1: Resource Allocation Model

We envisage this cluster system as a cluster node comprising a set of computing nodes. Communication is assumed to be predominant between such cluster nodes and is assumed to be negligible within a cluster node. The underlying computing system within a cluster can be modeled as a fully connected bipartite graph comprising sources, which have computationally intensive loads to be processed (very many operations are performed on them) and computing elements called sinks, for processing loads (data). To organize and coordinate distributed resources participating in the grid computing environment, we utilize the resource model which contain more than one sources and resources, based on which the uniform and scalable and allocating computational resources are identified.

We assume a star like structure with a scheduler as the central component; acts as a controller to the model. The right side of the scheduler is a set of processors (processing elements) to execute the jobs assigned by the scheduler. The other side of the scheduler are a set of sources; grid users. The scheduler collects the load from all the sources and distribute to a set of processors  $p_1, p_2, \dots, p_n$ . Initially all the loads are held by the scheduler. All the communications are starts from the scheduler and there is no direct communication between the processors. For simplicity here we are assuming that the scheduler is only communicating with processors to distribute the loads and get back the result. In a dynamic Grid environment, nodes may join or leave frequently, and nodes status may change dynamically. In our model, we are considering the environment as static; i.e. once the node joined in the scheduling process it has to active in the entire processing schedule. But in divisible load theory all the resources has to involve or process all source's workload portion. In this model we are not compelling all the resources to process the entire source's workload portion, instead only the selected set of resources can participate to perform the portion of load from a source. The contribution of this paper is that we

propose unequal division of load from a resource with respect to the processor capacity and the availability and the divisible load is assign to a set of processors participated in the scheduling process. Now, we shall formally define the problem that we address.

#### 4. Workload Distribution Model

We assume that a star like structure with a set of  $p$ -processors (processing elements). The central component is the scheduler/broker. The scheduler collects the loads from all the grid users called as sources and distribute to a set of processors  $p_1, p_2, \dots, p_n$ . The sources are the grid users; who need to use the grid system to perform some task. Initially all the loads are held by the scheduler. All the communications are starts from the scheduler and there is no direct communication between the processors. For simplicity here we are assuming that the scheduler is only communicating element with resources/processors to distribute the loads and get back the result.

In our system we are considered that there is no communication delay to submit a portion of load to a processor. Also the result returning time is negligible. All the processor starts processing only after receiving entire workload which is assigned by the scheduler to them with their capacity. Also we assume that processors have independent communication hardware which allows for simultaneous communications and computations on the previously received loads. Additional constraints may be imposed on the processors to the existence of other more urgent computations or maintenance periods the availability of processor  $p_i$  may be restricted to some interval  $[r_i, d_i]$ . Where  $r_i$  be the release time of the processor  $p_i$  and  $d_i$  be the deadline of the processor  $p_i$ . By such a restriction we mean that computations may take place only in the interval  $[r_i, d_i]$ . A message with the load may arrive or start arriving before  $r_i$ . We assume that computations start immediately after the later of the two events:  $r_i$  or the load arrival. The computation time must be fit between the later of the above two events.

Here we are assuming that the loads are received from different sources with different capacity and each load become divisible without any restriction. Each loads received from the different sources are divided into set of different tasks (portion of workload). Maximum of one task may be assigned or allotted to a processor. The load portion is depends upon the capacity of the processor. Suppose, if there are  $m$  number of sources  $\{S_1, S_2, \dots, S_m\}$  and  $n$  number of processors  $\{P_1, P_2, \dots, P_n\}$  and the workloads from each sources become  $L = \{L_1, L_2, \dots, L_m\}$ . Where  $L_1$  be the total workload received from the source  $S_1$  and so on. Each workload  $L_i$  may be divided into  $T_1, T_2, \dots$ . The load  $L$  can be reordered by the scheduler to achieve good performance of the computation. The scheduler splits the workload into tasks and sends them to processors to perform the specified

process. Only a set of processors may be used to perform the workload of a source.

We will denote  $\alpha_{ij}$  be the size of the task assigned to the processor  $p_j$ . It is expressed in load units (eg. in bytes). If  $\alpha_{ij}=0$  implies that  $p_j$  is not in the set of processor selected to perform the process of  $i^{\text{th}}$  source workload. The total workload from a source is the sum of sizes of the workload parts. ie.  $\sum \alpha_{ij} = L_i$ . Not only  $p_j$  selected by the scheduler, but also the sequence of activating the processors in  $p_j$  and the division of load  $L_i$  into chunks  $\alpha_{ij}$ . Here we are considered the processors are unrelated processors, its communication links and start-up time are specific for the task. Similarly the processor computing rates depends on the processor and the task. Let  $z_j$  be the communication rate of the link to processor  $p_j$  perceived by task  $T_j$ . Transferring the portion of workload unit  $\alpha_{ij}$  to  $p_j$  takes  $z_j \alpha_{ij}$  time units. Let  $t_j$  be the processing rate of processor  $p_j$  perceived by task  $T_j$ . To process  $\alpha_{ij}$  portion of load by processor  $p_j$  takes  $t_j \alpha_{ij}$  time units. Let  $c_j$  the processing cost to process the portion of workload  $T_j$ . The total processing cost to process a portion of workload  $\alpha_{ij}$  by the processor  $p_j$  becomes  $c_j \alpha_{ij}$  cost units.

In this work we analyze the complexity of scheduling the divisible loads  $L_1, L_2, \dots, L_m$  of sizes  $T_1, T_2, \dots$  on  $n$  parallel processors  $P_1, P_2, \dots, P_n$  which are interconnected together. We assume that the processors have sufficient memory buffers to store the received portion of workloads and computations. All the processor will start processing immediately after receiving their

entire portion of workloads. One processor can process more than one source's portion of workload.

By constructing a schedule the scheduler decides on the sequence of the tasks, the set of processors assigned to each portion of workloads, the sequence of processor activation and the size of the load parts. Our objective is to minimize the usage of the grid user cost. In this paper we assumed that there no separate start-up time for individual processors and there is no fixed cost to utilize the processors. All the processors are dedicated processors. But practically it is not possible, to simplify our model as well as reduce the number of variables and constraints. The following notations are used to formulate the mathematical model

- $c_j$  - Amount to spend to utilize  $j^{\text{th}}$  processor
- $\alpha_{ij}$  - Portion of workload from  $i^{\text{th}}$  source to  $j^{\text{th}}$  processor
- $x_{ij}$  - Binary variable
- $d_i$  - Deadline to complete the  $i^{\text{th}}$  source job
- $b_i$  - Budget allotted for the  $i^{\text{th}}$  source job
- $s_j$  - Schedule period of  $j^{\text{th}}$  processor
- $t_j$  - Time required to perform operation on one unit of job by  $j^{\text{th}}$  processor
- $\omega_i$  - Total workload of  $i^{\text{th}}$  source
- $z_j$  - Time taken to transfer a unit of workload to  $j^{\text{th}}$  processor
- $s_j$  - Scheduled time  $i^{\text{th}}$  source

Minimize

$$\sum_i \sum_j c_j \alpha_{ij} x_{ij} \dots \dots \dots (1)$$

Subject to

$$\sum_i \sum_j z_j \alpha_{ij} x_{ij} + \sum_i \sum_j t_j \alpha_{ij} x_{ij} \leq d_i \dots \dots \dots (2)$$

$$\sum_i \sum_j z_j \alpha_{ij} x_{ij} + \sum_i \sum_j t_j \alpha_{ij} x_{ij} \leq s_i \quad ; \quad \forall j \dots \dots \dots (3)$$

$$\sum_i \sum_j c_j \alpha_{ij} x_{ij} \leq b_i \dots \dots \dots (4)$$

$$\sum_j \alpha_{ij} = \omega_i \quad ; \quad \forall i \dots \dots \dots (5)$$

$$\sum_i x_{ij} = 1 \quad ; \quad \forall j \dots \dots \dots (6)$$

$$\alpha_{ij} \geq 0 \quad ; \quad \forall i, j \dots \dots \dots (7)$$

$$x_{ij} = \{0,1\} \quad ; \quad \forall i, j \dots \dots \dots (8)$$

$$s_j \geq 0 \quad ; \forall_j \dots\dots\dots (9)$$

$$z_j \geq 0 \quad ; \forall_j \dots\dots\dots (10)$$

The objective is to minimize the total cost of the grid user those who are assigning job to the grid system. The equation (1) represent the cost of all jobs that are being assigned to a resource is the objective function. The equation (2) to (8) specifies the constraints used the mathematical model. The constraints (2) represent the deadline associated with each sources. Constraints (3) match the workload within the availability of resources. Constraints (4) are the budget for each source's workload. Constraint (5) represents the total workload of each sources involved in the scheduling process. Constraints (6) makes sure that a portion of workload is assigned to only one resource; ie., there is no overlap between processing of workloads. Constraint (7) makes sure that a portion of workload divided from the total workload becomes a whole number. Constraint (8) is to set the binary value either 0 or 1. The constraints (9 and 10) are non-negativity constraints.

allotted to the each sources to complete their workloads and the expected time to complete the process of each workloads. Using the details given in the table we have formed the mathematical model and solved the equation using LINGO package. After execution of the mathematical model, the maximum cost to spend for processing all the three sources workloads are Rs.1457.

### 5. Experimental results

Let us assume that the Grid system consists of five processors (resources) namely P<sub>1</sub>, P<sub>2</sub>, P<sub>3</sub>, P<sub>4</sub>, and P<sub>5</sub> with four sources S<sub>1</sub>, S<sub>2</sub>, and S<sub>3</sub> are trying to utilize the grid system to execute their workloads.

Table I : Details of Processors Capacity

Processor	Processing time/ unit workload (min)	Processing cost (Rs.)	Available time (min.)
P <sub>1</sub>	3	4	60
P <sub>2</sub>	4	3	60
P <sub>3</sub>	5	2	80
P <sub>4</sub>	4	3	110
P <sub>5</sub>	3	5	110

Table I shows that the processor's involved in the Grid system, the processing capacity of each processor per unit workloads, the processing cost of each processor to execute a unit workload and available time of each processors. Table II shows that the details of the different sources which are trying to utilize the grid system, total workload of each sources and the budget

Table II : Details of Workloads of sources, Budget and Finish Time

Sources	Work Loads (MB)	Budget (Rs)	Dead Line (min.)
S <sub>1</sub>	30	120	100
S <sub>2</sub>	35	135	130
S <sub>3</sub>	45	180	175

Table III : Allocation of Processors

Sources	Processor Allotted	Allotted Workloads	Time taken to complete
S <sub>1</sub>	P <sub>1</sub>	18	100
	P <sub>2</sub>	10	
	P <sub>5</sub>	2	
S <sub>2</sub>	P <sub>3</sub>	7	129
	P <sub>4</sub>	10	
	P <sub>5</sub>	18	
S <sub>3</sub>	P <sub>2</sub>	5	174
	P <sub>3</sub>	9	
	P <sub>4</sub>	16	
	P <sub>5</sub>	15	

Table III shows the details of workload allotment to the processors involved in the process. From the table it is clear that the total workload of S<sub>1</sub> is divided into three parts, the total workload of S<sub>2</sub> is divided into three parts and the total workload of S<sub>3</sub> is divided into four parts and allotted into processors. Also it shows that the completion time of each source's workloads

## 6. Conclusion

In this study, we have developed an effective iterative model for optimal workload allocation. The proposed model is proposed for load allocation to processors and links for scheduling divisible workload applications. The experimental results showed that the proposed model is capable of producing almost optimal solution for multiple sources scheduling with static and dedicated resources. Hence the proposed model can balance the processing loads efficiently. We are planning to adapt the proposed model in dynamic environments. With such improvements the proposed model can be integrated in the existing grid scheduler in order to improve their performance.

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# Integrating User's Domain Knowledge with Association Rule Mining

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## Abstract

This paper presents a variation of Apriori algorithm that includes the role of domain expert to guide and speed up the overall knowledge discovery task. Usually, the user is interested in finding relationships between certain attributes instead of the whole dataset. Moreover, he can help the mining algorithm to select the target database which in turn takes less time to find the desired association rules. Variants of the standard Apriori and Interactive Apriori algorithms have been run on artificial datasets. The results show that incorporating user's preference in selection of target attribute helps to search the association rules efficiently both in terms of space and time.

**Keywords:** Domain, association rule, data mining, Apriori, interactive Apriori.

## 1. Introduction

Association rule is described as an associational relationship between a group of objects in a database [13]. Let  $D$  be a transaction database and  $I = \{i_1, i_2, \dots, i_m\}$  be an itemset. Transaction database  $D$  contains a sequence of transactions  $T = \{t_1, t_2, \dots, t_n\}$  (where  $T \subseteq I$ ) with a sole identifier. An association rule  $X \rightarrow Y$  may be discovered in the data where  $X$  and  $Y$  are conjunctions of items and  $X \cap Y = \Phi$ . The intuitive meaning of such a rule is that transactions in the database which contains the items in  $X$  tend to also contain the items in  $Y$ . The user supplies minimum support and confidence thresholds. The support of the rule  $X \rightarrow Y$  represents the percentage of transactions from the original database that contain both  $X$  and  $Y$ . The confidence of the rule  $X \rightarrow Y$  represents the percentage of transactions containing items in  $X$  that also contains items in  $Y$ . A rule that satisfies both minimum support and minimum confidence at the same time has been described as strong rule in the literature [2].

All the rules that meet the confidence threshold are reported as rules mined by the algorithm. The process of mining of association rules is broken up into two steps [3]:

(i) Find all the frequent itemsets in the database (i.e. the itemsets with support greater than the minimum support).

(ii) The confidence of the rule  $X \rightarrow Y$  that satisfy minimum support is calculated as follows:

$$\text{Confidence}(X \rightarrow Y) = \frac{\text{support}(XY)}{\text{support}(Y)}$$

## 1.1 Literature Survey

Association rules were first introduced by Agarwal et. al. in [1]. Their subsequent paper [3] discusses Apriori algorithm that is considered as one of the most important contributions to the subject of data mining. Although, other algorithms such as AIS [2] and SETM [7] are also available for mining association rules, yet Apriori remains the most widely used approach for generating frequent itemsets. The algorithm accomplishes the searching of frequent itemsets in recursive order. It first scans the database  $D$  and calculates the support of each single item in every record  $I$  in  $D$ , and denotes it as  $C_1$ . Out of the itemsets in  $C_1$ , the algorithm computes the set  $L_1$  containing the frequent 1-itemsets. In the  $k^{\text{th}}$  scan of the database, it generates all the new itemset candidates using the set  $L_{k-1}$  of frequent  $(k-1)$  itemsets discovered in the previous scanning and denotes it as  $C_k$ . And the itemsets whose support is greater than the minimum support threshold are kept in  $L_k$ . This process is repeated until no new frequent itemsets are found.

Table 1: Dataset D

T <sub>id</sub>	Items
10	AB
20	ABE
30	ABCE
40	CD

The Apriori approach of searching frequent itemsets is explained with the database of Table 1. The algorithm assumes the minimum support threshold to be "2". Firstly, it initializes  $C_1$  as the set of all items, takes count of elements in it, and puts in  $L_1$  the elements satisfying the minimum support. Thereafter, set  $C_2$  is generated using  $L_1$  and count of the elements is computed from the scan of database  $D$ . The frequent itemsets from  $C_2$  are kept in the set  $L_2$ . In the similar way,  $L_3$  is generated. As

there is a single itemset in  $L_3$ , the set  $C_4$  is empty. So, this arithmetic comes to an end ( $\text{min\_support} = 2$ ). This has been explained in figure 1.

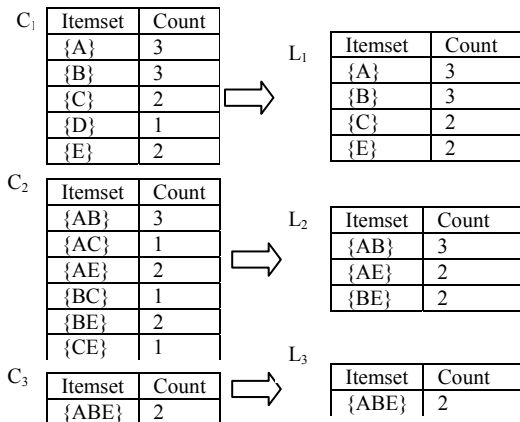


Fig. 1. Finding set of candidate and frequent itemsets with Apriori.

### 1.2 Generation of Association Rules

With the generation of frequent itemsets, the process of finding association rules begins. For every frequent itemset  $X$ , take non-empty subsets  $Y$  ( $Y \subset X, Y \neq \Phi$ ) such that confidence ( $Y \rightarrow (X-Y)$ )  $\geq \text{minconf}$ , an association rule " $Y \rightarrow (X-Y)$ " is reported where confidence can be ascertained with Equation (1).  $\text{support\_count}(Y \cup X-Y)$  is the number of transactions containing itemsets ( $Y \cup X-Y$ ) and  $\text{support\_count}(Y)$  is the number of transactions containing itemset  $Y$ .

$$\text{confidence}(Y \rightarrow (X-Y)) = \frac{\text{sup port\_count}(Y \cup (X - Y))}{\text{sup port\_count}(Y)} \quad (1)$$

## 2. Mining with User's Guidance

Association rules are useful in data mining only if the mining analyst has a prior rough idea of what it is he is looking for. The key to knowledge discovery, therefore, is the user's domain knowledge. The domain expert has useful knowledge about the database which is not explicitly presented in the database [9]. This highlights the fact that there is no algorithm that will automatically furnish everything that is of interest in the database. An algorithm that finds a lot of useful rules will probably also find a lot of useless rules, while an algorithm that finds only a limited number of associations will probably also miss a lot of interesting information.

This discussion indicates that domain user must be involved in the process of finding association rules in the

data sets. The domain user provides his suggestions and demands on the data mining result that tunes the process of rule discovery instead of proceeding in an unguided manner. A modification of Apriori that contains user's intervention in the processing of the algorithm is presented in the next section. The user at the first step provides some demands on the mining result that basically indicates what the user wants to see in the result. Accordingly the database is scrutinized on the particular attributes and it becomes the working database of the algorithm. Then the algorithm searches for associations among the attributes selected by the user. In this manner the user gets the association rules without exploring the whole database.

## 3. Interactive Association Rule Mining

The approach of user interactive association rule mining is embodied in IAR algorithm. The IAR is a variation of Apriori algorithm. The Apriori algorithm typically identifies the patterns that occur in the whole database. But what if the user is interested in particular attributes and wants to check if there is some associational relationship containing the attributes in the database. In such case it is irrelevant to do exhaustive search in the database. The IAR algorithm includes interaction points for the domain user to give attribute specification if any. The database is then scrutinized according to the specified attribute(s) i.e. the transactions not containing the attributes given by the user are excluded and a working database is created. With this subset of the dataset, the Apriori procedure searches for frequent large itemsets. Although the search dataset is scrutinized but the support for the potential large itemsets is calculated with respect to the original database. The Interactive Association Rule (IAR) algorithm is presented in Fig 2.

```

D' := subset of D containing transactions having the
      attributes specified by the user.
      // (D' is the working database)
L1 := {frequent 1-itemsets};
k := 2; //k represents the pass number.
while(L_{k-1} ≠ Φ)
    C_k := new candidates of size k
           generated from L_{k-1}
           for all transactions t ∈ D
           increment count of all candidates in C_k
           that are contained in t
    L_k := all candidates in C_k
           with minimum support
    k := k+1
Report U_k L_k as the discovered frequent itemsets
    
```

Fig. 2. The Interactive Apriori Algorithm (IAR).

Since searching the database for associational relationship is heavy task in large datasets, the time is saved as irrelevant records (in which user is not interested) are excluded from the database. The attributes in the database are randomly distributed; it may reduce the size of working dataset from half to even more fraction.

Considering the same example database of Table 1, here is how IAR algorithm works. At first it takes attribute preferences from the user. Suppose the user is interested in attribute B and wants to see if there is any frequent itemset containing itemset B. The IAR algorithm, at the first step, scrutinizes the database and creates a working database  $D'$  from  $D$ .  $D'$  contains transactions containing attribute B only (table 2).  $D'$  contains 3 transactions,  $T_{id}$  40 is not included in  $D'$  as this doesn't contain B. Size of the working database is thus reduced and it takes less time in all the scans of the database in the searching process of the algorithm. As shown in figure 3, the size of  $C_k$  and  $L_k$  get reduced starting from the first step. In this way there is no need to do an exhaustive search of the database if the user is interested in knowing the associational relationship containing a particular attribute.

Table 2: Dataset  $D'$

$T_{id}$	Items
10	AB
20	ABE
30	ABCE

### 3.1 Generation of Association Rules using frequent itemsets

The frequent itemsets found in the previous step are used to generate association rules. All the permutations and combinations of the items present in the frequent itemsets are considered as candidates for strong rules. A lot of rules will be generated in this way. A strong rule is one which has atleast minimum confidence which is computed by the Eq. (1) (see section 1.1).

It is important to note that the discovered rules contain the user specified attributes on the LHS and derives other attributes in the database. If such a rule possesses high confidence level then it could be valuable in the marketing context for the organization. In this way a lot of time can be saved and the user trusts more in the discovered rules.

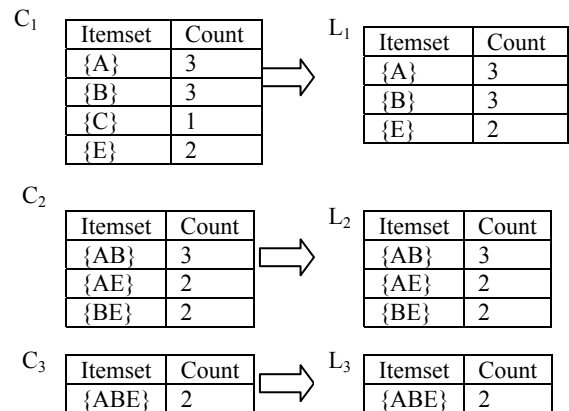


Fig. 3. Finding set of candidate and frequent itemsets with IAR.

## 4. Experimentation

For the purpose of performance evaluation IAR algorithm in discovering frequent itemsets, both Apriori and IAR have been run on the same platform under same conditions. Various parameters were computed for the purpose of comparison and the results have been shown in tables 3 and 4 and figure 4. The experimental runs have been conducted with two support levels and different sized datasets. It has been found that the IAR algorithm always takes less time and storage space than the standard Apriori. The interesting information can be mined in a shorter time. The test dataset has 7 attributes. The data was generated by artificial transactions to evaluate the performance of the algorithm over a range of data characteristics. The attributes are numbered starting from 1 and going in sequence. Any database of real world can be used with this algorithm by converting the attribute names to 1, 2, 3 and so on.

The algorithms use T-tree data structure to store frequent item set information. A T-tree is a "reverse" set enumeration tree where each level of the tree is defined in terms of an array. The storage requirement for each node (representing a frequent item set) in the T-tree is 12 bytes for a) reference to T-tree node structure (4 Bytes), b) support count field in T-tree node structure (4 Bytes) and c) reference to child array field in T-tree node structure (4 Bytes) [8].

Both the algorithms were compared with respect to the number of nodes in the T-tree structure, updates required to in T-tree to find large itemsets and the storage of T-tree in bytes as shown in Table 3 and 4. However the

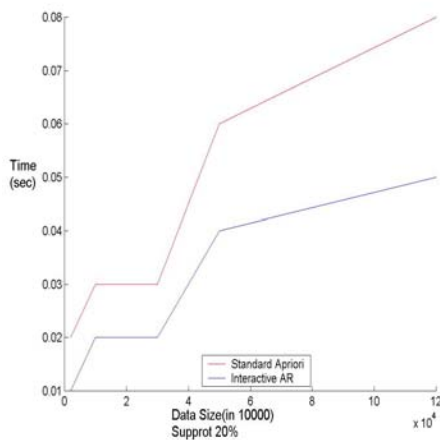
Table 3: Values of parameters with support level 20 percent

Data Size	Number of frequent itemsets		Number of nodes in T-tree		Number of Updates required in T-tree		Storage of T-tree in bytes	
	Apriori	IAR	Apriori	IAR	Apriori	IAR	Apriori	IAR
2K	31	15	43	20	26458	11722	496	244
10K	32	13	45	19	132503	48566	504	212
30K	28	13	41	19	336547	128218	476	248
50K	30	15	42	18	574843	240544	484	272
120K	28	15	41	21	1346085	589970	476	280

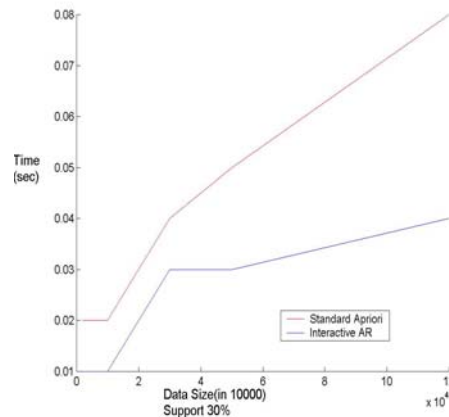
Table 4: Values of parameters with support level 30 percent

Data Size	Number of frequent itemsets		Number of nodes in T-tree		Number of Updates required in T-tree		Storage of T-tree in bytes	
	Apriori	IAR	Apriori	IAR	Apriori	IAR	Apriori	IAR
2K	20	9	33	14	22630	8883	324	148
10K	17	7	33	13	110607	40556	276	144
30K	15	5	30	10	291806	85866	240	140
50K	15	5	30	10	482533	141980	240	140
120K	15	5	30	10	1167228	342575	240	140

most important factor is time. IAR always takes less time than Apriori. The time comparison of both the algorithms is shown in Figure 4. It must be noted that the time taken and other parameters may differ for different runs as the data is generated randomly. Also the behaviour of IAR need not be same for different attributes specified by the user. But it always takes less time and storage than Apriori. It must also be noted that IAR does not do exhaustive search instead it finds association rule containing the attributes specification given by the user.



(a) Support level 20%



(b) Support level 30%

Fig. 4. Temporal performance of Apriori (red - upper) and IAR (blue – lower) ((a) & (b)).

## 5. Conclusion

Among the various data mining techniques, rules are the most appropriate for integrating human opinions, because human thoughts can be converted into rules relatively easier than into some other form. User's

suggestions and demands can be incorporated in the process to transfer domain knowledge that results in less and shorter iterations within the knowledge discovery loop.

This paper presents IAR algorithm that is a variation of standard Apriori algorithm to include user's role in finding interesting association among items in a database. The two algorithm are compared using different data sizes and support levels. The IAR always outperforms Apriori and the performance enhances as the data size increases. The domain user's knowledge may contribute the discovery of interested patterns.

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# Computer Aided Design Modeling for Heterogeneous Objects

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## Abstract

Heterogeneous object design is an active research area in recent years. The conventional CAD modeling approaches only provide geometry and topology of the object, but do not contain any information with regard to the materials of the object and so can not be used for the fabrication of heterogeneous objects (HO) through rapid prototyping. Current research focuses on computer-aided design issues in heterogeneous object design. A new CAD modeling approach is proposed to integrate the material information into geometric regions thus model the material distributions in the heterogeneous object. The gradient references are used to represent the complex geometry heterogeneous objects which have simultaneous geometry intricacies and accurate material distributions. The gradient references helps in flexible manipulability and control to heterogeneous objects, which guarantees the local control over gradient regions of developed heterogeneous objects. A systematic approach on data flow, processing, computer visualization, and slicing of heterogeneous objects for rapid prototyping is also presented.

**Keywords:** HO, Gradient Reference, Visualization, Slicing, Rapid Prototyping.

## 1. Introduction

The recent research focuses on computer-aided design issues involved in rapid prototyping of heterogeneous object. The primary goal of the present research is to develop systematic methodologies for heterogeneous object representations, visualizations, constructions and manipulations. The term 'heterogeneous object' is defined such that it can have different material composition within an object. There are three subclasses of heterogeneous object e.g. [12]:

- Multiple materials object.
- Object with sub-objects embedded.
- Object without clear material boundary (Functionally graded materials, FGM).

Traditional CAD systems, used for conventional design method, can only represent the geometry and topology of an object. No material information is available within the representation which is required for heterogeneous objects. With the capability to fabricate heterogeneous objects, functionally efficient and cost reducing designs can be realized. Rapid prototyping (RP) techniques allow heterogeneous material objects to be produced using 3D CAD models by varying material composition region-wise, layer-wise, or point-wise. The required 3D CAD model should have not only the geometric information but also the information of materials, property, etc. at each point inside an object. In order to take full advantage of the greatest potential of heterogeneous objects, one must have matching capabilities for their computer modeling, analysis, design optimization and visualization. The primary focus of the recent research development in these fields is on the computer representation schemes for heterogeneous objects, by extending the mathematical models and computer data structures of the modern solid modeling techniques to include discrete material regions of interfacial boundaries and heterogeneous properties. Recent studies show that an effective heterogeneous CAD modeling system should at least meet the following specifications e.g. [4]:

- Intuitive in representing geometry, topology and material information simultaneously.
- Capable of representing complex solids: the solids to be modeled may be complex in geometry as well as in material variations.
- Compact and exact: the representation should be compact, and both the geometry and material

information can be retrieved accurately and efficiently.

- The representation of material properties must be compatible with current or proposed standards for geometric modeling representations as described in ISO 10033. This is essential to exchange data among design, analysis and manufacturing process plan domains.

This paper is organized as follows: in section 2, the previous work is reviewed; Section 3 is brief representation of procedure for CAD data flow and processing of HO; Section 4 represents developed mathematical model and address different gradient references for the local control of gradient regions; heterogeneous object visualization related issues are studied in section 5; slicing procedure for the fabrication of heterogeneous objects is discussed in section 6 and the final section is conclusion with future scope to extend this work.

## 2. Review of Research Work

Approaches of modeling of HO have been extensively studied in computer and manufacturing community. Kumar and Dutta proposed an approach to model multi-material objects based on R-m sets and R-m classes primarily for application in layered manufacturing. Boolean operators were defined to facilitate the modeling process e.g. [5-6]. Jackson et al. proposed a local composition control (LCC) approach to represent heterogeneous object in which a mesh model is divided into tetrahedrons and different material compositions are evaluated on the nodes of the tetrahedrons by using Bernstein polynomials e.g. [3],[7]. Chiu developed material tree structure to store different compositions of an object e.g. [2]. The material tree was then added to a data file to construct a modified format being suitable for RP manufacturing. Siu and Tan developed a scheme named 'source-based' method to distribute material primitives, which can vary any material with an object e.g. [12]. The feature-based modeling scheme was extended to heterogeneous object representation through boundary conditions of a virtual diffusion problem in the solid, and then designers could use it to control the material distribution e.g. [10-11]. Liu extended his work in by taking parameterized functions in terms of distance(s) and functions using Laplace equation to smoothly blend various boundary conditions, through which designers could edit geometry and composition simultaneously [4],[10]. Kou and Tan suggested a hierarchical representation for heterogeneous object modeling by using B-rep to represent geometry and a heterogeneous feature tree to express the material distributions e.g. [4]. Various

methods for designing and optimizing objects composed of multiple regions with continuously varying material properties have been developed. Wang and Wang proposed a level-set based variational scheme [12]. Biswas et al. presented a mesh-free approach based on the generalized Taylor series expansion of a distance field to model and analyze a heterogeneous object satisfying the prescribed material conditions on a finite collection of material features and global constraints [13-14]. However, almost all of the research interests are mainly focused on the computer representation of heterogeneous object, rather than the whole procedure for rapid prototyping fabrication of heterogeneous object. The approaches were verified in commercial software packages, such as Solidworks and Unigraphics [7],[10]. A commercial CAD package independent system is developed to deal with the HO modeling, but not including the slicing procedure for RP manufacturing [11]. In this paper, we just address the CAD gradient reference model with systematic methodologies for visualization and manipulation of heterogeneous objects.

## 3. CAD Data Flow and Processing of HO

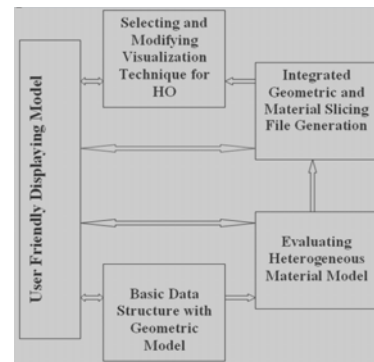


Fig. 1 CAD data flow for the development of HO.

The structure of CAD data flow system of HO contains five main modules;(1) basic data structure module;(2) evaluating heterogeneous material information model;(3) HO dataset visualization module;(4) Slice generation with gradient material information; and (5) display module e.g. figure (1).

The data processing module mainly copes with the data structure set up for geometric model and the subdivision surfaces for improving the smoothness of meshes. The second module evaluates material information of a gradient region within a CAD model according to the specifications of the users. In our system, we exploit the geometric model to describe the shape information. In terms of material information, it describes material composition in terms of material space. Third module

mainly provides visualization and rendering information for visualizing heterogeneous objects. Rapid prototyping technique offers a possibility to manufacture heterogeneous object. The accuracy and quality of the final part fabricated by rapid prototyping depends on the 2D geometric slices of a model. Fourth module gives the slice generating information by describing the material information in a layer. Fifth module displays the complete information on user friendly display.

The RP processes are dependent on a CAD model of the heterogeneous object which generates the required information for driving the RP machine. The necessary tasks to generate this information are termed as process planning tasks. RP processes can fabricate heterogeneous objects by selectively depositing various materials in a point-wise fashion using 3D-CAD data representation without special tooling. In these processes, a uniform layer of powder is spread over the built area and the different layers are joined together by different methods to form the prototype. The information flow for processing the heterogeneous describes the necessity of developing material modeling system along with the geometric model e.g. figure (2).

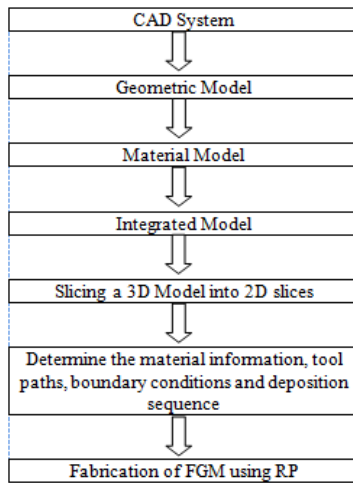


Fig. 2 Processing of the HO.

#### 4. Mathematical Representation of HO

The proposed model represents intricate geometries as well as material variation simultaneously; assures smooth material variations throughout the complex object and local material alterations. A noteworthy point to be emphasized here is that in the proposed model, the topological information is utilized to ensure smooth material variations throughout the complex geometry heterogeneous object. In current work, mathematically the heterogeneous object is defined as:

$$P = (G, M) = (P_1, P_2, \dots, P_n) \tag{1}$$

$$P_i = (G_i, M_c) \tag{2}$$

$$\sum_{i=1}^n G_i = P \text{ and } G_i = \sum_{j=1}^m G_{ij} \tag{3}$$

Where P is the heterogeneous object with geometric information G and material information M. P is also a set of n number of cells, where P<sub>i</sub> represents i<sup>th</sup> cell in the object with the geometric information (G<sub>i</sub>), occupied by a m number of sub volumes and specific material distribution for each cell (M<sub>c</sub>). M<sub>c</sub> represents material composition of pre-defined number of primary materials in P<sub>i</sub><sup>th</sup> cell with G<sub>i</sub><sup>th</sup> geometric information. The accuracy of the model is increased by having local control on sub volumes (G<sub>ij</sub>) in a cell at various identified locations which also results in less huge storage space problem.

#### 4.1 Material Composition Function

Material composition function f(s) is a function of distance from the end point of first homogeneous region to the first differential geometric point (where the material gradient becomes zero). Either linear or non-linear analytical function that fall on real domain can be use, with the distance from point to the grading reference as variable, therefore it is exact, e.g. the material distribution function with FGM at a distance ‘a’ & up to a distance ‘(1-a)’ is described e.g. Eq. (4).

$$f(s) = \begin{cases} 0, & s \leq a \\ f(s), & a < s < (1 - a) \\ 1, & s \geq (1 - a) \end{cases} \tag{4}$$

The effect of logarithmic and power functions on material distribution in a gradient region can be visualized e.g. figure (3).

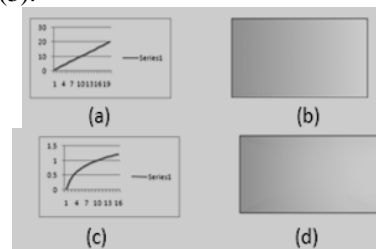


Fig.3 Material distribution for different functions: (a) power function, (b) material distribution for power function, (c) logarithmic function, (d) material distribution for logarithmic distribution. which also results in less huge storage space problem.

#### 4.2 Material Composition Array

Each element of the material composition array M<sub>c</sub> represents the volume fraction of pre-defined primary materials in G<sub>i</sub><sup>th</sup> cell. The total volume fraction of the

primary materials for the material composition arrays should be summed up to one. The end material composition arrays of heterogeneous region are denoted by  $M_{cs}$  and  $M_{cf}$ , for start and final boundary of heterogeneous region respectively. Generally, if k materials are included in the object, then:

$$\sum_{r=1}^k M_{csr} = 1 \text{ and } \sum_{r=1}^k M_{cfr} = 1 \quad (5)$$

Where,  $M_{csr} = r^{\text{th}}$  material element of the material composition  $M_{cs}$   
 $M_{cfr} = r^{\text{th}}$  material element of the material composition array  $M_{cf}$ .  
 k = number of primary materials including air

So, material composition of any primary material  $V_j$  for a sub volume  $G_{ij}$  is find out e.g. Eq.(6).

$$V_j = f(s) \times (M_{csr} - M_{cfr}) + M_{cfr}, \begin{cases} M_{csr} \in M_{cs} \\ M_{cfr} \in M_{cf} \\ 0 \leq f(s) \leq 1 \end{cases} \quad (6)$$

The property of heterogeneous unit volume is determined using Voigt's rule e.g. Eq. (7).

$$S = \sum_{j=1}^m \sum_{r=1}^k V_j S_r \quad (7)$$

S is the property of heterogeneous volume fraction  
 $V_j$  is the volume fraction of each material in unit volume  
 $S_r$  is the property of  $r^{\text{th}}$  material.  
 For two materials composition, the heterogeneous property is defined e.g. Eq. (8).

$S = V_1 S_1 + (1 - V_1) S_2$  (8)  
 Sub-volume creation algorithm results in sharp material changes along the component boundaries, which potentially result in abrupt property (e.g. thermal expansion coefficient and stiffness) variations. So for the smooth material transition properties, one of the available blending functions may be used. In our case, the constant blending functions are incorporated at end positions and in between, a blending function,  $f_b$ , along with the distance function is used to avoid the sharp change in material properties e.g. figure (4).

$$S = f(s) V_1 S_1 + (1 - V_1) (1 - f(s)) f_b S_2 \quad (9)$$



Fig. 4 Heterogeneous object with blended function.

### 4.3 Gradient Reference and Control

The gradient references are start and end boundaries of gradient region which may be controlled locally and provide the required information about gradient origins and respective material distributions. The grading references may be classified into three categories:

- Basic gradient references.
- Offset gradient references.
- Hybrid gradient references.

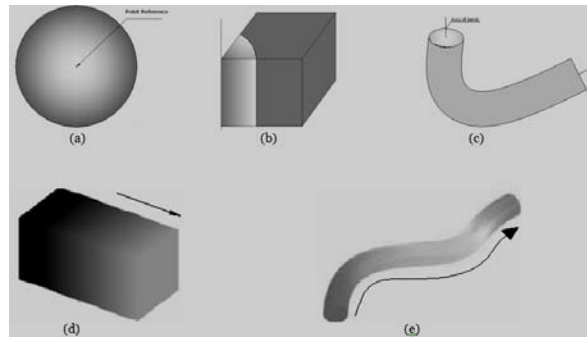


Fig.5 Basic gradient references: (a) point gradient reference, (b) linear axis gradient references, (c) flexible axis gradient reference, (d) linear plane gradient references, and (e) flexible axis plane gradient reference.

The basic gradient references includes user defined point, line and plane or may be any 3D object entity i.e. axis, vertex, edge, axis, any surface of the object. The material distribution for these basic grading references is shown in figure (5). The flexibility in axis and plane gradient references is provided by introducing local control using sweep operation.

The region with offset grading references is divided into a number of sub-regions; further sub-division may be required in order to represent the complex gradient in the local area as shown in figure (6). This can be done by applying recursive sub-division algorithm to either boundary of each sub-region and material composition array ( $M_c$ ) for  $i^{\text{th}}$  sub-region with  $r^{\text{th}}$  contour ( $S_{br}$ ) is derived e.g. Eq. (10).

$$M_c(S_{br}, i) = \frac{i \times (M(C_r) - M(C_{r+1}))}{r_m} + M(C_{r+1}) \quad \text{for inwards sub - division}$$

$$= \frac{(r_m - i) \times (M(C_r) - M(C_{r+1}))}{r_m} + M(C_{r+1}) \quad \text{for outwards sub - division} \quad (10)$$

Where r represents the  $r^{\text{th}}$  contour of total  $r_m$  contours,  $i = 1, 2, \dots, r-1$ , and  $M(C_r)$  represents material composition associated with  $r^{\text{th}}$  contour.

Specifically, this algorithm can be applied to any of two adjacent contours. However, for sub-regions due to the consideration of material continuity and homogeneity on the surface, only boundaries should be chosen as the geometrical offset reference. The step width array ( $w$ ) of the composition change in sub-region can be calculated e.g. Eq. (11).

$$w(S_{br}) = M_c(S_{br}, i+1) - M_c(S_{br}, i) \quad (11)$$

$w(S_{br})$  is a constant vector in the same 2D sub-region since a linear interpolation algorithm is applied between two adjacent contours. In addition to this step width array, the other information needed for fabrication of each sub-region is the material composition array corresponding to either of the two adjacent contours and the number of sub-regions. The computer memory is greatly saved as linear composition gradient within each sub-region is adopted. With the proposed recursive material evaluation algorithm, the material composition of any point inside the object can be exactly evaluated at runtime.

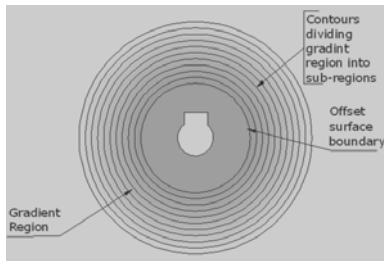
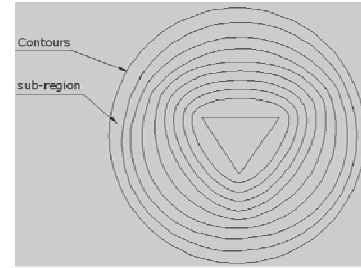
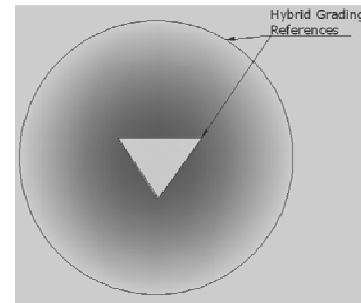


Fig.6 Offset gradient reference with sub-division of region.

The object with dissimilar boundary closures results in requirement of hybrid gradient references. The region with hybrid references is divided into a number of sub-regions as described above in case of offset gradient references e.g. figure (7(a)). However distance blending function with linear interpolation smoothing function is used to develop continuous gradient regions. Blending functions for the object region formed by a local  $C^1$  smooth transition between two or more primary surfaces, which may or may not intersect, are used. These blending functions allow the construction of constant radius blends for any type of surfaces as long as their offset surfaces are smooth, without singularities and self intersections. Edge blends are created by sweeping rational quadratic curves. Corner blends are created by a convex combination of Taylor interpolants. The resultant material distribution in hybrid region HO is shown figure (7(b)).



(a)



(b)

Fig.7 Hybrid gradient references: (a) sub-division of hybrid reference region, (b) material distribution of hybrid reference HO.

The proposed heterogeneous object model has local and universal control over the gradient references. The current model is an unevaluated representation, which is independent of universal co-ordinate system. The effect of grading on the properties of heterogeneous objects can be easily modified by controlling the respective gradient references. Moreover different material composition functions i.e. linear, exponential, parabolic, power or any other type of functions are used for different grading effects. The effect of changing the gradient references only is shown in figure (8(a)) and figure (8(b)) and the effect of changing the gradient references with the application of recursive sub-division algorithm, distance blending function and smoothing function using linear interpolation is also shown figure 8(c), figure 8(d). The material distribution is remained linear e.g. figure 8(b), while adapt the shape of changed gradient reference as shown in figure 8(d).

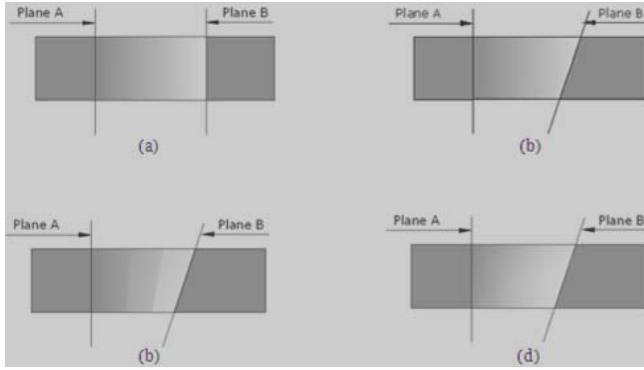


Fig. 8 Local control: (a) linear material distribution between parallel gradient reference planes, (b) effect of changing the gradient references only i.e. linear material distribution exists, (c) sub-division of gradient region using distance blending function, and (d) smoothing of sub-regions using linear interpolation functions.

## 5. Data Processing and Visualization of HO

It includes two main sub-modules called data processing and visualization. The data processing module mainly copes with the data structure set up for geometric model and the subdivision surfaces for improving the smoothness of meshes if a rough mesh model is the input object. In this case, a recursive algorithm is used to subdivide the surfaces while maintaining the sharp features of the object. Triangular meshes are used for sub-division of sub-regions of all geometric models. The geometric and material model are integrated to describe the shape and material information in a three dimensional HO space. At the end the dataset output files are displayed on the windows graphical user interface using many input-output functions and open graphical languages.

Effective and efficient visualization of heterogeneous objects is important to computer-aided design of heterogeneous objects. In the past few decades, visualization of homogeneous solids has undergone extensive studies and a variety of 3D visualization toolkits have been available. In recent years, great attentions have also been paid to volume renderings, which attempt to represent the entire 3D data in 2D images.

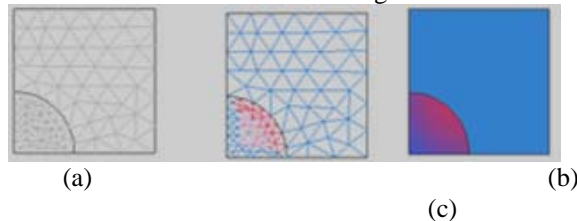


Fig.9: Visualization of HO: (a) sub-division of sub-region using triangular mesh, (b) material evaluation and color mapping of mesh, (c) filling of color to obtain HO gradient region.

However, most of these volume visualization schemes are targeted for rendering volume data obtained by samplings techniques (e.g. MRI or CT images); general issues on efficient visualization of heterogeneous (homogeneous, multi-material, functionally graded material) objects have

not been thoroughly studied before. Two major considerations, the visualization efficiency and rendering fidelity, are considered while finalizing the visualization for heterogeneous objects.

Boundary visualization scheme, e.g. figure 9(a), is used to render the external and internal parts of heterogeneous objects. Boundary visualization is intuitive to convey both the shapes and the material distributions of the objects. To render the shapes, the exact boundaries of the objects are first faceted into discrete elements, which are generally termed as boundary meshes. The material distributions within each element are then rendered by using colors or grey values to represent the material compositions. All the rendered facets provide an approximate polygonal view of the heterogeneous objects, in both geometries and material distributions. Efforts to generate faithful, high quality computer visualizations at interactive rate are presented to avoid abrupt material transition effects. The boundary mesh generation is extensively used in traditional solid modeler for homogeneous object renderings. Each face of the object is faceted into triangle meshes and these triangles are then transferred to rendering engines (OpenGL) to generate graphical outputs. Boundary sub-faceting approaches are used; to speed up the visualization process, adaptive boundary sub-faceting scheme and repetitive computation eliminations are introduced. All these approaches show that the proposed visualization scheme can generate effective visualizations in interactive heterogeneous object design.

Once the boundary meshes of the object are obtained, the material compositions of the mesh nodes are then evaluated by using the proposed recursive material evaluation algorithm. The evaluated material composition at a given location is represented with a  $k$ -dimensional vector  $[r_1, r_2, \dots, r_k]$ , whose element  $r_i$  represents the material volume fraction of the  $i^{\text{th}}$  predefined primary material ( $k$  is the total number of predefined primary materials). A color mapping which maps the material composition to a system color is shown in figure (9(b)). The most commonly used color mapping techniques include RGB (red-green-blue) color mapping and the HLS (hue-lightness-saturation) mapping. Finally, respective colors are filled to obtain heterogeneous objects e.g. figure (9(c)). All these approaches show that the proposed visualization scheme can generate effective visualizations in interactive heterogeneous object design.

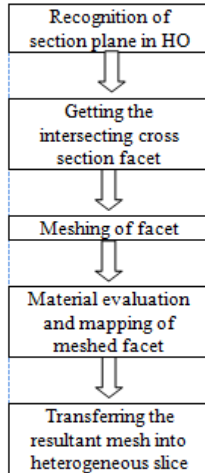


Fig.10 Procedure of sliced generation of the HO.

## 6. Slice Generation of Heterogeneous Objects

Rapid prototyping technique offers a possibility to manufacture HO. The accuracy and quality of the final part fabricated by rapid prototyping depends on the 2D geometric slices of a model. The slices of the geometric model and the layers of the material dataset can be used to construct the 2D slices of heterogeneous object, which is called material resample with geometric constraint. The slicing algorithms are studied extensively in rapid prototyping community. There are mesh-based, direct, adaptive and hybrid slicing algorithms. In our framework, a mesh model slicing algorithm is developed. Sliced generation procedure is proposed to display the internal structures and material distributions in each region of the HO e.g. figure (10) and (11).

The heterogeneous object is first intersected with a section plane and the intersection curves are obtained e.g. figure (11(b)). Then 2D region is faceted (sub-faceted when needed) into meshed region as shown e.g. figure (11(c)). Material evaluation and mapping of meshed facet are sequentially applied e.g. figure (11(d)). The evaluated meshes are then transferred to the heterogeneous slice e.g. figure (11(e)).

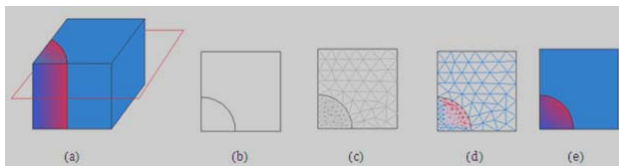


Fig.11: Slice generation procedure: (a) HO with intersection plane, (b) 2D extracted region, (c) meshed region, (d) color mapping against material information, (e) slice of HO. bottom of the page and column where it is cited. Footnotes should be rare.

## 7. Conclusion and Future Scope

This work presents a CAD modeling approach for heterogeneous object with complex geometry and simple material variations. The sequence of CAD data flow for HO and procedure for processing of HO for rapid prototyping processes are discussed. The distribution of material is obtained by using different grading references with local control. Data processing and visualization methods for heterogeneous objects are proposed. Slice generation methodology, necessary required for rapid prototyping of HO is evaluated. The proposed CAD modeling approach represents intricate geometries as well as material variation simultaneously; ensures smooth material variations throughout the complex object; imposes only local material alterations on the cells so that their original properties can be properly retained in the resultant object; offers flexible material variation; consistent in data representations; and computationally robust and efficient.

The present work can be further extended and implemented complex and irregular material distributions. The approach can be extended to object modeling i.e. solid modeling with other physical attributes such as mechanical properties, material distribution etc. Dynamic heterogeneous objects (DHO) are the new class of heterogeneous objects. Unlike current heterogeneous object modeling, DHO deals with space dependent heterogeneities and time dependent shapes and material distributions. By taking time into consideration, more realistic process simulation can be achieved. DHO technology has emerging applications in life science domain, biomedical applications, dynamic process simulation and bio-CAD etc.

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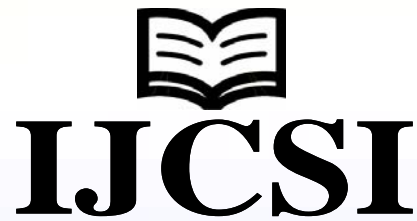
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