Dynamic Relational Topic Models

Albert Lee

Advisor: Professor Andrea LaPaugh

Abstract

This paper presents the Dynamic Relational Topic Model, a new dynamic topic model that incorporates both document text and relationships for discovering the underlying topics in document collections and their evolution over time. We derive an approximate variational inference algorithm for our model and demonstrate its effectiveness over previous approaches by analyzing papers in Computer Science from CiteSeerX [5] from 1993 to 2009.

1. Introduction

As digital document collections rapidly continue to grow, it becomes increasingly difficult for humans to navigate through these corpuses and extract the key ideas of each document and understand its relation to what has been written before. Consequently, it becomes increasingly important to develop new techniques to automatically group related documents, uncover the underlying themes in these groups, and understand how they change over time. Applications of such methods can range from automatically discovering and monitoring the development of major topics in the news, to uncovering how trends in social media evolve, to tracking the evolution of different research fields in the scientific literature.

Such applications have motivated the development of many clustering algorithms that work on unannotated data to group related documents together. One class of methods takes a network-based view of the document collection, representing the corpus as a graph in which documents are represented as nodes and relations between documents are represented as edges. For example, in a scientific literature network, nodes can represent research papers and edges can represent one paper citing another or two papers sharing a common author. In this network representation, these methods then try to find clusters based on the link structure between different sets of documents [8].

Another class of methods largely ignore the link structure to focus primarily on the document texts themselves, treating them as bags of words and using various techniques to group semantically similar documents together. One particular set of methods that have been successfully applied across a variety of applications are probabilistic topic models, which represent the underlying themes or topics of a document collection as probability distributions over words, individual documents as mixtures of topics, and assume a generative model for these documents. Inference is then performed over these models to infer the latent topic structures of documents [2, 13].

We take a mixture of both these approaches, in which we incorporate both node data and link structure in a probabilistic topic model to model both document texts and relationships through a generative process. From a network-based perspective, we treat the document corpus as a two-mode network in which one class of source nodes represent documents, outgoing directed edges from each of the document nodes indicate the document's relationships, and the second class of destination nodes represent the related objects themselves, such as cited documents or authors. We'll focus for the rest of the paper on the application of modeling the scientific literature to incorporate both document text and citation relationships, but we note that our model as presented is general enough to be applied to a variety of other applications.

2. Dynamic Relational Topic Model

The Dynamic Relational Topic Model (DRTM) models both the texts and relationships of documents over discrete time. Our model is based off of Blei and Lafferty's Dynamic Topic Model (DTM) [3], which extends the static Latent Dirchlet Allocation (LDA) [4] model to model document texts dynamically over discrete time. By further extending the DTM to also model documents' relationships over time, we are able to uncover both the underlying topics that categorize the collection as well as the underlying relationships. Applying our model to the scientific literature to model document texts and citation relationships, we are able to identify both the key terms categorizing different research sub-fields as well as the milestone papers of each of these fields and how the topics and milestone papers for each field evolve over time.

As in the DTM, we represent topics $\beta_{t,1:K}$ as probability distributions over words, where each $\beta_{t,k}$ is a topic vector of length W representing the probability distribution over the vocabulary at time t for topic k, i.e. $\sum_{w}^{W} \beta_{t,k,w} = 1$, where W is the size of the vocabulary. Between time slices, the topic distributions are assumed to evolve in a linear model with Gaussian noise:

$$\beta_{t,k} \mid \beta_{t-1,k} \sim \mathcal{N}(\beta_{t-1,k}, \sigma^2 I) \tag{1}$$

Within each time slice, documents are represented as a mixture of topics θ_d drawn from a Dirchlet $Dir(\alpha)$, and the document texts are assumed to arise from a generative process in which for an N_d word document d, a topic assignment $z_{d,n}$ is first drawn for each each word from the document's topic mixture θ_d before a word $w_{d,n}$ is then drawn from the corresponding topic distribution $\beta_{t,z_{d,n}}$. In our model, we additionally assume a similar generative process for each of the M_d citations within a document d. We represent citation-specific topics $\rho_{t,1:K}$ as probability distributions over cited papers, and assume that for an M_d citation document d within a time slice, a topic assignment

$\nu_{d,m}$ is drawn for each citation from the document's topic mixture before a citation $c_{d,m}$ is then drawn from the corresponding topic distribution $\rho_{t,\nu_{d,m}}$. Between time slices, we assume that these citation-specific topic distributions evolve in a linear model with Gaussian noise similar to the word-specific topic distributions:

$$\rho_{t,k} \mid \rho_{t-1,k} \sim \mathcal{N}(\rho_{t-1,k}, \delta^2 I) \tag{2}$$

The generative process at time t is thus as follows:

1. Draw word topics $\beta_t \mid \beta_{t-1} \sim \mathcal{N}(\beta_{t-1}, \sigma^2 I)$
2. Draw citation topics $\rho_t \mid \rho_{t-1} \sim \mathcal{N}(\rho_{t-1}, \delta^2 I)$
3. For each document $d \in [1, \ldots, D_t]$ at time-step t:
   (a) Draw topic proportions $\theta_d \sim Dir(\alpha)$
   (b) For each word $n \in [1, \ldots, N]$:
      i. Draw topic assignment $z_{d,n} \sim Mult(\theta_d)$
      ii. Draw word $w_{d,n} \sim Mult(f(\beta_{t,z_{d,n}}))$
   (c) For each citation $m \in [1, \ldots, M]$:
      i. Draw topic assignment $\nu_{d,m} \sim Mult(\theta_d)$
      ii. Draw citation $c_{d,m} \sim Mult(g(\rho_{t,\nu_{d,m}}))$

where f and g map the multinomial natural parameters to mean parameters, i.e. $f(\beta_{t,k,w}) = \frac{exp(\beta_{t,k,w})}{\sum_w exp(\beta_{t,k,w})}$ and $g(\rho_{t,k,c}) = \frac{exp(\rho_{t,k,c})}{\sum_c exp(\rho_{t,k,c})}$. We illustrate the graphical model for this generative process in Figure 1. We note that despite modeling citations symmetrically to how we model words, we make no assumptions about the content of the cited documents, only that there exist link relationships between the citing document whose words we model and its cited documents. This allows us to generalize our model for other types of document relationships beyond scientific literature networks to a broader range of other applications.

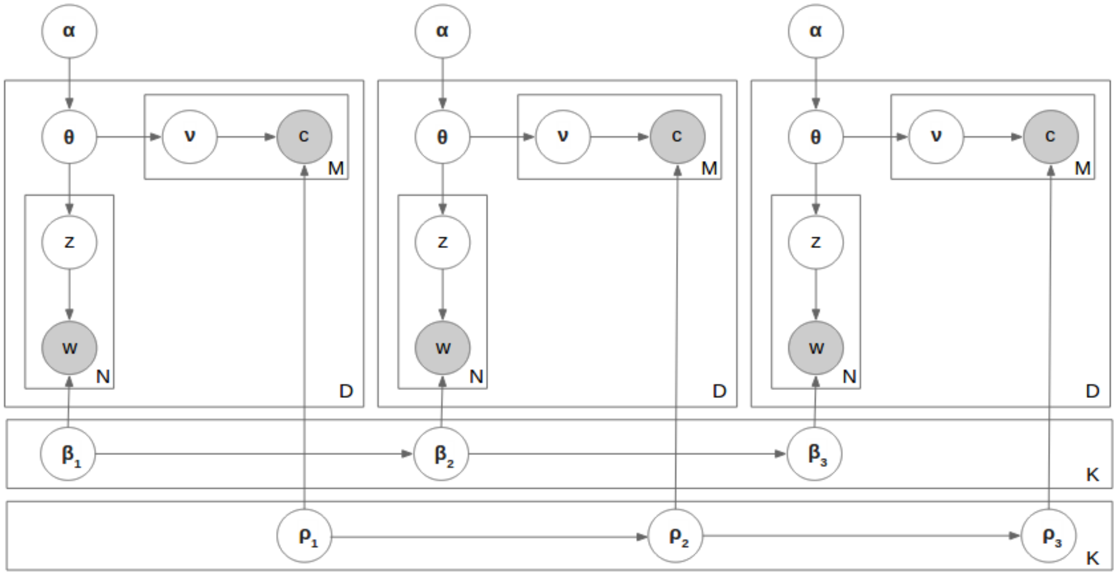

Figure 1: Graphical representation of the DRTM over three time steps

3. Approximate Inference

As noted in [3], due to the non-conjugacy of the Gaussian and multinomial models for time dynamics and topics, posterior inference on the latent topic structure given the observed documents is intractable. We thus turn to variational methods for deriving approximate posterior inference over our model.

Variational methods generally assume a simpler family of distributions over the latent variables indexed by free parameters known as variational parameters, which we then fit to minimize the Kullback-Leibler divergence between the variational distribution and the true posterior. In our model, the latent variables are the word-specific topics $\beta_{t,k}$, the citation-specific topics $\rho_{t,k}$, the document topic proportions θ_d, the word-topic indicators $z_{d,n}$, and the citation-topic indicators $\nu_{d,m}$. For each of the latent variables, we introduce corresponding variational parameters: Dirchlets γ_d for each document's topic proportions, multinomials $\phi_{t,d,n}$ for each word's topic assignment, multinomials $\chi_{d,m}$ for each citation's topic assignment, "observations" $\hat{\beta}_{t,k}$ to a variational Kalman

K	Total number of topics
W	Total number of words in corpus
C	Total number of citations in corpus
D_t	Number of documents with timestamp t
N_d	Number of words in document d
M_d	Number of citations in document d
α	K-dimensional Dirchlet parameter vector
$\beta_{t,k}$	Topic distribution over words at time t for topic k
$\hat{\beta}_{t,k}$	Variational parameters for $\beta_{t,k}$
$\rho_{t,k}$	Topic distribution over citations at time t for topic k
$\hat{\rho}_{t,k}$	Variational parameters for $\rho_{t,k}$
θ_d	Topic proportions for document d
γ_d	Variational parameters for θ_d
$z_{d,n}$	Topic indicator for nth word in document d
$\phi_{d,n}$	Variational parameter for $z_{d,n}$
$w_{d,n}$	Observed nth word in document d
$v_{d,m}$	Topic indicator for mth citation in document d
$\chi_{d,m}$	Variational parameter for $v_{d,m}$
$c_{d,m}$	Observed mth citation in document d

Table 1: Summary of variables in our model

filter for word-specific topic distributions, and "observations" $\hat{\rho}_{t,k}$ to a variational Kalman filter for citation-specific topic distributions. A graphical representation of the variational approximation for the document-level topic model slice at time t is shown in Figure 2.

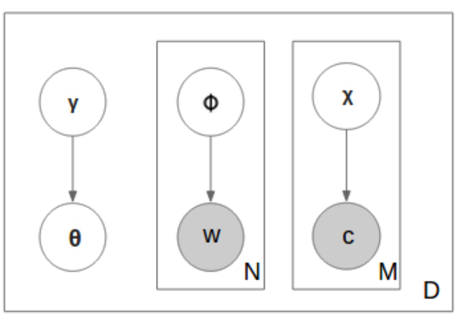

Figure 2: Graphical representation of the variational approximation for the topic model at a time slice t

Within each time slice, we can derive the following update equations for these variational parameters. A full derivation is provided in the Appendix.

$$\phi_{d,n,k} \propto \beta_{k,w_n} exp(\Psi(\gamma_{d,k}) - \Psi(\sum_{j=1}^{K} \gamma_{d,j})) \tag{3}$$

$$\chi_{d,m,k} \propto \rho_{k,c_m} exp(\Psi(\gamma_{d,k}) - \Psi(\sum_{j=1}^{K} \gamma_{d,j})) \tag{4}$$

$$\gamma_{d,k} = \alpha_k + \sum_{n=1}^{N} \phi_{d,n,k} + \sum_{m=1}^{M} \chi_{d,m,k} \tag{5}$$

For the word and citation-specific topic distributions that evolve over time, we use a variational Kalman filter to derive a variational approximation for these parameters. A graphical representation of the variational approximation for the time series parameters β and ρ is shown in Figure 3.

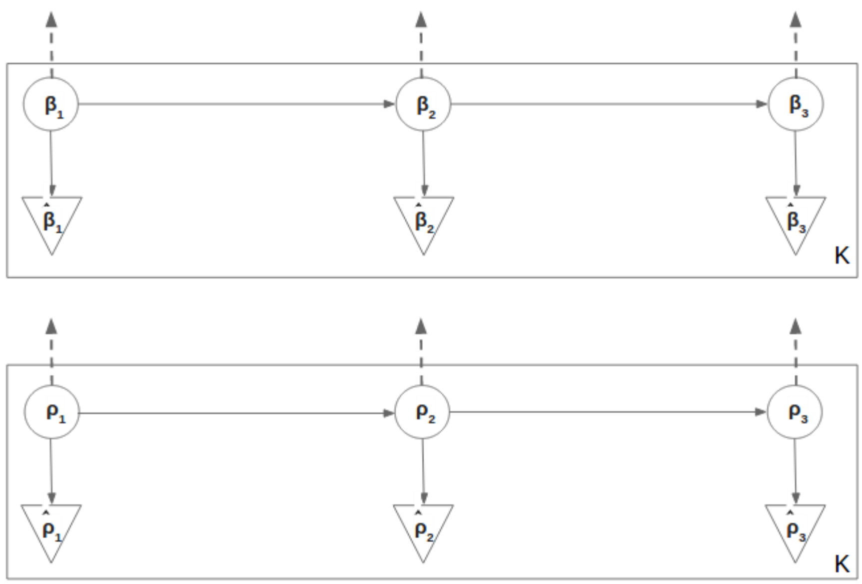

Figure 3: Graphical representation of the variational approximation for the time series parameters

In a variational Kalman filter, we treat the variational parameters as "observations" to the ordinary Kalman filter model while the true latent parameters are viewed as the latent states of the Kalman filter. Our state space model for the word-specific topic distributions is thus:

$$\beta_{t,k} \mid \beta_{t-1,k} \sim \mathcal{N}(\beta_{t-1,k}, \sigma^2 I) \tag{6}$$

$$\hat{\beta}_{t,k} \mid \beta_{t,k} \sim \mathcal{N}(\beta_{t,k}, \hat{\sigma}^2 I) \tag{7}$$

Our state space model for the citation-specific topic distributions is:

$$\rho_{t,k} \mid \rho_{t-1,k} \sim \mathcal{N}(\rho_{t-1,k}, \delta^2 I) \tag{8}$$

$$\hat{\rho}_{t,k} \mid \rho_{t,k} \sim \mathcal{N}(\rho_{t,k}, \hat{\delta}^2 I) \tag{9}$$

We present details for the updates of the variational parameters $\hat{\beta}_{t,k}$ and $\hat{\rho}_{t,k}$ in the Appendix.

4. Evaluation

4.1. Data and Preprocessing

We evaluated our model on a corpus of 500,000 research papers from CiteSeerX, a scientific literature digital library focusing primarily on papers from Computer Science. We work exclusively with papers published between 1993 and 2009 and treat each paper as a document whose words consist of the words in the title and abstract of the paper and whose citations are the papers it cites in its "References" section. Since CiteSeerX automatically harvests research papers from the web and extracts their data [5], there is a significant amount of noise in the data due to errors in the automatic data extraction process, such as incomplete or joined words, or the same references being cited in different forms in different papers. We do our best to reduce some of this noise by preprocessing the collection to remove the least common words occurring less than 20 times in the corpus and stemming all words to their roots. To avoid noise from extremely common words that are not topic specific, we also remove common English stopwords as well as the most frequently occurring words in the corpus ordered by document frequency. We do this because we found from examination that the most frequently occurring terms tended to be generic and not topic-specific, such as "problem" or "results," and thus added noise rather than contributing to topic identification because they were so common. We similarly preprocessed all the citations in the collection, trying to normalize all citations that were slight variations of the same reference to the same canonical citation and removing all citations that cited a reference that appeared less than 20 times in the entire corpus.

To focus on tracking the evolution of Computer Science research, we ran a preliminary stage of LDA with 25 topics and removed all documents that were primarily related to a non-Computer Science topic (e.g. biology). We also removed all papers that contained no words or citations. After preprocessing, our corpus consisted of approximately 400,000 research papers, with 19 million words and 5.5 million citations, and roughly 35,000 of the words and 350,000 of the citations being unique. We used this data to fit our model, in which we assumed 20 topics and treated each year from 1993 to 2009 as one time slice in our dynamic model. Each time slice consisted of approximately 15,000-30,000 documents.

4.2. Results

A subset of our results are shown below. The full results of our model can be found in the Appendix. We can see that the model is successfully able to detect evolving topics, as seen with the topic below pertaining to information retrieval. The model successfully detects the rapid change brought to the field by the Internet, with both the top terms and citations capturing the emergence of ideas like the semantic web or Google's PageRank in the early 2000s.

Year	Top 5 Words	Top 5 Citations
1993	database	Federated database systems for managing distributed, heterogenous, and autonomous databases
	document	Principles of Database and Knowledge-Base Systems, Vol II: The New Technologies
	query	Introducrion to modern information retrieval
	file	Deductive and Object-Oriented Databases
	objectoriented	The ObjectStore Database System

1995	database	Principles of Database and Knowledge-Base Systems, Vol II: The New Technologies
	document	Federated database systems for managing distributed, heterogenous, and autonomous databases
	query	Introducrion to modern information retrieval
	web	Deductive and Object-Oriented Databases
	file	Mediators in the architecture of future information systems: A new approach
1997	database	Introducrion to modern information retrieval
	web	Principles of Database and Knowledge-Base Systems, Vol II: The New Technologies
	document	Federated database systems for managing distributed, heterogenous, and autonomous databases
	query	Object exchange across heterogeneous information sources. To appear in ICDE 95. Available by ftp at db.stanford.edu, file pub/papakonstantinou/1994/icde95.ps
	view	Mediators in the architecture of future information systems: A new approach
1999	web	Introducrion to modern information retrieval
	database	Querying Heterogeneous Information Sources Using Source Descrip tions
	document	The lorel query language for semi-structured data
	query	The anatomy of a large-scale hypertextual Websearch engine
	page	Authoritive sources in a hyperlinked environment
2001	web	The anatomy of a large-scale hypertextual Websearch engine
	database	Authoritive sources in a hyperlinked environment
	document	The lorel query language for semi-structured data
	xml	Introducrion to modern information retrieval
	query	Querying Heterogeneous Information Sources Using Source Descrip tions
2003	web	The anatomy of a large-scale hypertextual Websearch engine
	database	Authoritive sources in a hyperlinked environment
	document	The PageRank citation ranking: Bringing order to the Web, submitted for publication
	xml	eds) The Semantic Web
	query	Introducrion to modern information retrieval
2005	web	The anatomy of a large-scale hypertextual Websearch engine
	ontology	Authoritive sources in a hyperlinked environment
	semantic	The PageRank citation ranking: Bringing order to the Web, submitted for publication
	database	eds) The Semantic Web
	query	Modern Information Retrieval

Examining the full results of all 20 topics over time, we see that our model is overall able to find coherent research sub-fields in Computer Science, with clear topic groupings for fields such as information theory (topic 3), formal program verification (topic 4), computer networks (topic 6), computer vision (topic 10), natural language processing (topic 14), and security (topic 17) among others. In addition, we see that it is also able to detect the evolutions of these sub-fields, such as the shift from rule-based methods to statistical and unsupervised methods like clustering in machine learning (topic 16), or the rise of approximation algorithms and probabilistic methods in the field of computational complexity (topic 13). Interestingly, we see that our model is also able to make rather fine-grained distinctions, such as distinguishing between the logic programming systems used in early artificial intelligence (topic 9) and the logic systems used for formal verification (topic 4). We attribute such behavior to our modeling of link relationships in addition to document texts, since both topics contain "logic" as one of the key terms and are otherwise grouped together in a purely text-based approach. However, the common references cited by these two fields differ, thus enabling us to distinguish between them.

We also examine topic groupings that appear less cohesive due often to a mixing of multiple topics. For example, in topic 5, we see a mixture of words and citations relating to computational complexity, game theory, and computer networks across the 17 years. However, some of these mixtures do make intuitive sense, since looking at the computer networks-related terms and references identified with topic 5 rather than topic 6, the primary computer networks topic group, we see that most of these pertain to distributed peer-to-peer systems which often have game-theoretic interpretations and thus could be mistakenly grouped as pertaining more to game-theory than computer networks. We also see that a few topics show more cohesive structure in its citations rather than its terms, and vice-versa. For example, with topic 8, the citations alone strongly suggests the topic of Markov decision processes and reinforcement learning, whereas the initial top terms for the topic such as "science," "university," or "grant" do not reflect this, with only terms in later time slices like "policy," "state," and "action" agreeing with the topic suggested by the citations. We hypothesize that this may be due to the generality of terms like "policy," "state," and "action" common in reinforcement learning that can easily be interpreted in a non-technical context, resulting in papers from a variety of other areas, relating to say public policy or politics, being grouped with the topic. As a result, there is additional noise in the terms that additively may cover up the more relevant terms, while the drastically different citation relationships in these documents from different fields may have less of an additive effect when considering just the link structures and are thus mostly ignored as noise.

To quantitatively assess our model, we used two evaluation metrics to examine our model's performance against previous approaches on the tasks of document clustering and prediction. For document clustering, we evaluate our model against the DTM using the Dunn Index [7] to measure the quality of each model's document clusters with respect to the citation link structure of the corpus. Intuitively, the Dunn Index measures the ratio of the separation between clusters compared to the compactness within a cluster, where a higher score indicates a better clustering with better within cluster compactness and better between cluster separation. Formally, it is defined as:

$$D = \frac{\min\limits_{1 \leq q \leq k} \min\limits_{\substack{1 \leq r \leq k \\ q \neq r}} dist(X_q, X_r)}{\max\limits_{1 \leq p \leq k} diam(X_p)}$$

where k denotes the number of clusters and $\{X_1, \ldots, X_k\}$ denote sets of points corresponding to each of the k clusters. Given a function $d(a,b)$ that calculates the distance between two points a and b, $dist$ is defined to be the function measuring the minimum distance between any pair of points from separate clusters X_a and X_b:

$$dist(X_a, X_b) = \min_{\substack{a \in X_a \\ b \in X_b}} d(a,b)$$

and *diam* is defined to be the function measuring the maximum distance between any pair of points within a cluster X_p

$$diam(X_p) = \max_{\substack{a,b \in X_p \\ a \neq b}} d(a,b)$$

However, the Dunn Index in this form is susceptible to being skewed by outliers within or between clusters, so we instead use a generalization of the Dunn Index proposed in [1]. In this generalization, *dist* is defined to be the function measuring the average distance between every pair of points from separate clusters X_a and X_b:

$$dist(X_a, X_b) = \frac{1}{|X_a||X_b|} \sum_{\substack{a \in X_a \\ b \in X_b}} d(a,b)$$

and *diam* is defined to be the function measuring the average distance between every pair of points within a cluster X_p:

$$diam(X_p) = \frac{1}{|X_p|(|X_p|-1)} \sum_{\substack{a,b \in X_p \\ a \neq b}} d(a,b)$$

We define the distance d between two documents a and b as the smoothed inverse of their bibliographic coupling:

$$d(a,b) = \frac{1}{1 + BC(a,b)}$$

where the bibliographic coupling BC between two documents a and b is the number of common references that a and b both cite. We translate the mixed topic proportions for each document output by the DRTM and the DTM to hard cluster assignments by representing each topic as a cluster and assigning each document to its most likely topic. Since we incorporate document-citation relationships within our model, we expect for our model to show a better clustering index than the DTM, which does not take such network relationships into account. Indeed, clustering the documents over the entire time range of 1993 to 2009, we find that our model's cluster assignments has a Dunn Index of 0.74 while the DTM's cluster assignments only has a Dunn Index of 0.21. This demonstrates that our model is successfully able to cluster documents based on link relationships in a network model while still incorporating the text of the documents for determining topics.

Model	Dunn Index
DRTM	0.74
DTM	0.21

Table 3: Dunn Index for DRTM and DTM

We also evaluate our model compared to the DTM for the task of predicting all papers in the CiteSeerX corpus published in the following year of 2010 given all the papers from 1993 to 2009. For this task, we fit each model with the documents between 1993 and 2009 and compute the likelihood of the words in the heldout documents using the parameters of the last time slice. We only compute the likelihood over the individual words of the heldout documents, since the DTM does not incorporate citations in its model and is thus unable to predict them. A summary of our results is shown in Table 4. We see surprisingly that the DRTM assigns a higher likelihood than the DTM to next year's papers, indicating that incorporating additional link relationship information in our model not only did not diminish its predictive power for just the words of unseen documents but actually improves its ability to predict future document texts over the DTM model that focuses on modeling document texts alone.

Model	Log Likelihood
DRTM	-2.78860e+06
DTM	-2.96804e+06

Table 4: Log likelihood of papers published in 2010 for DRTM and DTM

Finally, we compare the DRTM against a static version of our model estimated from treating all previous years as one time slice (as done in [3]) for the task of predicting all papers in the CiteSeerX corpus published in 2010, including both their texts and citations, given all the papers from 1993 to 2009. Similar to above, we first fit the DRTM with the documents from 1993 to 2009 before using the last time slice to predict the heldout documents, only now we compute the likelihood over both the individual words and citations of each of the heldout documents. We find that the DRTM assigns a higher likelihood than the static model to next year's papers, thus demonstrating the benefits in predictive power by modeling the dynamics of the corpus.

Model	**Log Likelihood**
DRTM	-3.60290e+06
Static model	-3.95807e+06

Table 5: Log likelihood of papers published in 2010 for DRTM and static model

5. Related Work

Many previous approaches have taken a network-based perspective to work exclusively on the link structure of the network to find communities [8]. Such methods have also been extended to the dynamic setting to detect evolving community structure over time [10]. On the other hand, alternative approaches using probabilistic topic models have tended to ignore the network-based interpretation of document corpuses and the underlying link structure to focus primarily on modeling just the document texts. Static models such as LDA have been successfully extended to both the discrete time [3] and continuous time [14] settings. Many other approaches have been taken to model temporal dynamics and explore topic evolution, from performing theme-level word clustering and building theme evolution graphs and analyzing their life cycles [11], to incorporating term volume into a temporal model based off of the DTM to also support trend analysis and prediction [9]. Perhaps the most different approach to modeling temporal dynamics is Wang's Topics Over Time (TOT) model, which rather than discretizing time and assuming topics evolving over time through a Kalman filter model like the DTM and its extensions, assumes continuous timestamps drawn from a beta distribution in an LDA-like model [15]. However, the strong modeling assumption of timestamps being drawn from a beta distribution is hard to justify, as also noted in [9], which is why we choose to model temporal dynamics similar to the DTM in our model.

More recent approaches have worked on incorporating both document nodes and their link structures in probabilistic topic models. Examples of these include the Relational Topic Model (RTM) [6] and the Pairwise Link-LDA model [12]. Both these models are built specifically for the task of modeling both document texts and citations in the scientific literature, and have replicated model slices for each pair of documents in the corpus, with an observed Bernoulli variable indicating whether there is a link between the two documents of that pair. However, both these models suffer from the problem of scaling quadratically with the size of the corpus by modeling relationships on a pairwise basis and neither incorporate time dynamics. A second, alternative model that addresses the problem of quadratic scaling is also presented in [12]. Like our model, it distinguishes between citing and cited documents to scale linearly with the size of the corpus by avoiding having to model the relationship between every pair of documents, but it makes stronger modeling assumptions in trying to model the texts of cited documents with the same topic distribution of the citing document and is thus constrained in modeling only homogeneous document-document relationships and does not handle temporal dynamics. Our model differs from all these approaches in allowing for the modeling of heterogeneous relationships between nodes of different types in a scalable way over time.

6. Conclusions and Future Work

We have presented the DRTM, a probabilistic topic model that incorporates both document texts and relationships to model the evolution of topics over time. We demonstrate both good qualitative and quantitative results in prediction and clustering over previous approaches that modeled just the temporal dynamics of document texts alone.

Future work could include applying the DRTM to other corpuses, such as social media, where documents can represent posts and relationships can represent individuals liking or sharing the post. Other possible extensions include generalizing our model to the continuous time setting or further extending the model to incorporate more heterogeneous node relationships, such as modeling document texts, their citations, and their authors to analyze the scientific literature.

7. Acknowledgments

We want to thank Professor LaPaugh for advising us and for her helpful feedback and advice throughout our research process. We also want to thank CiteSeerX for allowing us to use their data for our analysis.

References

[1] J. Bezdek and N. Pal, "Cluster validation with generalized dunn's indices," in *Artificial Neural Networks and Expert Systems, 1995. Proceedings., Second New Zealand International Two-Stream Conference on*, Nov 1995, pp. 190–193.

[2] D. M. Blei, "Probabilistic topic models," *Communications of the ACM*, vol. 55, no. 4, pp. 77–84, 2012.

[3] D. M. Blei and J. D. Lafferty, "Dynamic topic models," in *Proceedings of the 23rd International Conference on Machine Learning*, ser. ICML '06. New York, NY, USA: ACM, 2006, pp. 113–120.

[4] D. M. Blei, A. Y. Ng, and M. I. Jordan, "Latent dirichlet allocation," *J. Mach. Learn. Res.*, vol. 3, pp. 993–1022, Mar. 2003.

[5] C. Caragea *et al.*, "Citeseerx: A scholarly big dataset," in *Advances in Information Retrieval*, ser. Lecture Notes in Computer Science. Springer International Publishing, 2014, vol. 8416, pp. 311–322.

[6] J. Chang and D. M. Blei, "Relational topic models for document networks," in *International Conference on Artificial Intelligence and Statistics*, 2009, pp. 81–88.

[7] J. C. Dunn, "A fuzzy relative of the isodata process and its use in detecting compact well-separated clusters," *Journal of Cybernetics*, vol. 3, no. 3, pp. 32–57, 1973.

[8] S. Fortunato, "Community detection in graphs," *Physics Reports*, vol. 486, no. 3, pp. 75–174, 2010.

[9] L. Hong *et al.*, “Tracking trends: incorporating term volume into temporal topic models,” in *Proceedings of the 17th ACM SIGKDD international conference on Knowledge discovery and data mining*. ACM, 2011, pp. 484–492.
[10] J. Hopcroft *et al.*, “Tracking evolving communities in large linked networks,” *Proceedings of the National Academy of Sciences*, vol. 101, no. suppl 1, pp. 5249–5253, 2004.
[11] Q. Mei and C. Zhai, “Discovering evolutionary theme patterns from text: An exploration of temporal text mining,” in *Proceedings of the Eleventh ACM SIGKDD International Conference on Knowledge Discovery in Data Mining*, ser. KDD ’05. New York, NY, USA: ACM, 2005, pp. 198–207.
[12] R. M. Nallapati *et al.*, “Joint latent topic models for text and citations,” in *Proceedings of the 14th ACM SIGKDD international conference on Knowledge discovery and data mining*. ACM, 2008, pp. 542–550.
[13] M. Steyvers and T. Griffiths, “Probabilistic topic models,” *Handbook of latent semantic analysis*, vol. 427, no. 7, pp. 424–440, 2007.
[14] C. Wang, D. M. Blei, and D. Heckerman, “Continuous time dynamic topic models,” *CoRR*, vol. abs/1206.3298, 2012.
[15] X. Wang and A. McCallum, “Topics over time: a non-markov continuous-time model of topical trends,” in *Proceedings of the 12th ACM SIGKDD international conference on Knowledge discovery and data mining*. ACM, 2006, pp. 424–433.

Appendix

A. Approximate Inference Derivations

We derive here in more detail the variational inference algorithm for our model. Recall from Figure 2 the following factorized variational distribution for the document-level variational parameters:

$$q(\theta, z, \nu \mid \gamma, \phi, \chi) = q(\theta \mid \gamma) q(z \mid \phi) q(\nu \mid \chi) \tag{10}$$

We try to maximize the following lower bound on the log likelihood of a document with observed words w and observed citations c:

$$\begin{aligned}
\log p(w, c \mid \alpha, \beta, \rho) &= \log \int \sum_{z,\nu} p(w, c, \theta, z, \nu \mid \alpha, \beta, \rho) \mathrm{d}\theta \\
&= \log \int \sum_{z,\nu} q(\theta, z, \nu) \frac{p(w, c, \theta, z, \nu \mid \alpha, \beta, \rho)}{q(\theta, z, \nu)} \mathrm{d}\theta \\
&\geq E_q[\log p(w, c, z, \nu \mid \alpha, \beta, \rho)] - E_q[\log q(\theta, z, \nu)]
\end{aligned}$$

where the last step is derived from Jensen's inequality. This lower bound L can be further expanded to:

$$L = E_q[\log p(\theta \mid \alpha)] + E_q[\log p(z \mid \theta)] + E_q[\log p(w \mid z, \beta)] + E_q[\log p(\nu \mid \theta)] \\ + E_q[\log p(c \mid \nu, \rho)] - E_q[\log q(\theta)] - E_q[\log q(z)] - E_q[\log q(\nu)] \quad (11)$$

We have that

$$p(\theta \mid \alpha) = \frac{\Gamma(\sum_{k=1}^{K} \alpha_k)}{\prod_{k=1}^{K} \Gamma(\alpha_k)} \prod_{k=1}^{K} \theta_k^{\alpha_k - 1}$$

and that

$$E_q[log\theta_k] = \Psi(\gamma_k) - \Psi(\sum_{j=1}^{K} \gamma_j)$$

as shown in [4], where Ψ is the digamma function, the first derivative of the log gamma function.

Expanding $E_q[\log p(\theta \mid \alpha)]$, we get:

$$\begin{aligned} E_q[\log p(\theta \mid \alpha)] &= E_q[\sum_{k=1}^{K} (\alpha_k - 1) \log \theta_k + \log \Gamma(\sum_{k=1}^{K} \alpha_k) - \sum_{k=1}^{K} \log \Gamma(\alpha_k)] \\ &= \sum_{k=1}^{K} (\alpha_k - 1) E_q[\log \theta_k] + \log \Gamma(\sum_{k=1}^{K} \alpha_k) - \sum_{k=1}^{K} \log \Gamma(\alpha_k) \\ &= \sum_{k=1}^{K} (\alpha_k - 1)(\Psi(\gamma_k) - \Psi(\sum_{j=1}^{K} \gamma_j)) + \log \Gamma(\sum_{k=1}^{K} \alpha_k) - \sum_{k=1}^{K} \log \Gamma(\alpha_k) \end{aligned}$$

Expanding $E_q[\log p(z \mid \theta)]$, we get:

$$\begin{aligned} E_q[\log p(z \mid \theta)] &= E_q[\log \prod_{n=1}^{N} \prod_{k=1}^{K} \theta_k^{z_{n,k}}] \\ &= \sum_{n=1}^{N} \sum_{k=1}^{K} E_q[z_{n,k} \log \theta_k] \\ &= \sum_{n=1}^{N} \sum_{k=1}^{K} E_q[z_{n,k}] E_q[\log \theta_k] \\ &= \sum_{n=1}^{N} \sum_{k=1}^{K} \phi_{n,k} (\Psi(\gamma_k) - \Psi(\sum_{j=1}^{K} \gamma_j)) \end{aligned}$$

where we note that $z_{n,k}$ is a multinomial indicator of whether topic k is at position n and that

$$E_q[z_{n,k}] = \sum_{z_n} z_{n,k}\, q(z_n \mid \phi) = \sum_{z_n} z_{n,k} \prod_{j=1}^{K} \phi_{n,j}^{z_{n,j}} = \phi_{n,k}$$

Expanding $E_q[\log p(w \mid z, \beta)]$, we get:

$$
\begin{aligned}
E_q[\log p(w \mid z,\beta)] &= E_q[\log \prod_{n=1}^{N}\prod_{k=1}^{K}\prod_{j=1}^{W}\beta_{k,j}^{w_{n,j},z_{n,k}} \\
&= \sum_{n=1}^{N}\sum_{k=1}^{K}\sum_{j=1}^{W} E_q[w_{n,j}z_{n,k}\log\beta_{k,j}] \\
&= \sum_{n=1}^{N}\sum_{k=1}^{K}\sum_{j=1}^{W} w_{n,j}E_q[z_{n,k}]\log\beta_{k,j} \\
&= \sum_{n=1}^{N}\sum_{k=1}^{K}\sum_{j=1}^{W} w_{n,j}\phi_{n,k}\log\beta_{k,j} \\
&= \sum_{n=1}^{N}\sum_{k=1}^{K} \phi_{n,k}\log\beta_{k,w_n}
\end{aligned}
$$

where we take w_n to be the index j for which the indicator $w_{n,j} = 1$. We next expand $E_q[\log p(\nu \mid \theta)]$

to get:

$$
\begin{aligned}
E_q[\log p(\nu \mid \theta)] &= E_q[\log \prod_{m=1}^{M}\prod_{k=1}^{K}\theta_k^{\nu_{m,k}}] \\
&= \sum_{m=1}^{M}\sum_{k=1}^{K} E_q[\nu_{m,k}\log\theta_k] \\
&= \sum_{m=1}^{M}\sum_{k=1}^{K} E_q[\nu_{m,k}]E_q[\log\theta_k] \\
&= \sum_{m=1}^{M}\sum_{k=1}^{K} \chi_{m,k}(\Psi(\gamma_k) - \Psi(\sum_{j=1}^{K}\gamma_j))
\end{aligned}
$$

and expand $E_q[\log p(c \mid \nu, \rho)]$ to get:

$$
\begin{aligned}
E_q[\log p(c \mid \nu,\rho)] &= E_q[\log \prod_{m=1}^{M}\prod_{k=1}^{K}\prod_{j=1}^{C}\rho_{k,j}^{c_{m,j},\nu_{m,k}} \\
&= \sum_{m=1}^{M}\sum_{k=1}^{K}\sum_{j=1}^{C} E_q[c_{m,j}\nu_{m,k}\log\rho_{k,j}] \\
&= \sum_{m=1}^{M}\sum_{k=1}^{K}\sum_{j=1}^{C} c_{m,j}E_q[\nu_{m,k}]\log\rho_{k,j} \\
&= \sum_{m=1}^{M}\sum_{k=1}^{K}\sum_{j=1}^{C} c_{m,j}\chi_{m,k}\log\rho_{k,j} \\
&= \sum_{m=1}^{M}\sum_{k=1}^{K} \chi_{m,k}\log\rho_{k,c_m}
\end{aligned}
$$

where we take c_m to be the index j for which the indicator $c_{m,j} = 1$. Expanding the final terms of our likelihood bound, we get:

$$E_q[\log q(\theta)] + E_q[\log q(z)] + E_q[\log q(\nu)] = \sum_{k=1}^{K} (\gamma_k - 1)(\Psi(\gamma_k) - \Psi(\sum_{j=1}^{K} \gamma_j)) + \log\Gamma(\sum_{k=1}^{K} \gamma_k) - \sum_{k=1}^{K} \log\Gamma(\gamma_k)$$
$$+ \sum_{n=1}^{N}\sum_{k=1}^{K} \phi_{n,k} \log \phi_{n,k} + \sum_{m=1}^{M}\sum_{k=1}^{K} \chi_{m,k} \log \chi_{m,k}$$

Our full lower bound L is thus:

$$L = \sum_{k=1}^{K} (\alpha_k - 1)(\Psi(\gamma_k) - \Psi(\sum_{j=1}^{K} \gamma_j)) + \log\Gamma(\sum_{k=1}^{K} \alpha_k) - \sum_{k=1}^{K} \log\Gamma(\alpha_k)$$
$$+ \sum_{n=1}^{N}\sum_{k=1}^{K} \phi_{n,k}(\Psi(\gamma_k) - \Psi(\sum_{j=1}^{K} \gamma_j)) + \sum_{n=1}^{N}\sum_{k=1}^{K} \phi_{n,k} \log \beta_{k,w_n}$$
$$+ \sum_{m=1}^{M}\sum_{k=1}^{K} \chi_{m,k}(\Psi(\gamma_k) - \Psi(\sum_{j=1}^{K} \gamma_j)) + \sum_{m=1}^{M}\sum_{k=1}^{K} \chi_{m,k} \log \rho_{k,c_m}$$
$$- \sum_{k=1}^{K} (\gamma_k - 1)(\Psi(\gamma_k) - \Psi(\sum_{j=1}^{K} \gamma_j)) - \log\Gamma(\sum_{k=1}^{K} \gamma_k) + \sum_{k=1}^{K} \log\Gamma(\gamma_k)$$
$$- \sum_{n=1}^{N}\sum_{k=1}^{K} \phi_{n,k} \log \phi_{n,k} - \sum_{m=1}^{M}\sum_{k=1}^{K} \chi_{m,k} \log \chi_{m,k}$$

We now optimize the likelihood with respect to $\phi_{n,k}$, $\chi_{m,k}$, and γ_k. First maximizing L with respect to $\phi_{n,k}$ and incorporating Lagrange multipliers λ_n for the constraint $\sum_{k=1}^{K} \phi_{n,k} = 1$, we get that:

$$\frac{\partial L}{\partial \phi_{n,k}} = \Psi(\gamma_k) - \Psi(\sum_{j=1}^{K} \gamma_j) + \log \beta_{k,w_n} - \log \phi_{n,k} - 1 + \lambda_n$$

Equating to zero and solving, we get that

$$\phi_{n,k} = exp(\Psi(\gamma_k) - \Psi(\sum_{j=1}^{K} \gamma_j) + log\beta_{k,w_n} - 1 + \lambda_n)$$
$$= exp(\Psi(\gamma_k) - \Psi(\sum_{j=1}^{K} \gamma_j))\beta_{k,w_n} exp(-1 + \lambda_n)$$
$$\phi_{n,k} \propto \beta_{k,w_n} exp(\Psi(\gamma_k) - \Psi(\sum_{j=1}^{K} \gamma_j))$$

Similarly maximizing with respect to $\chi_{m,k}$ with Lagrange multipliers λ_m for the constraint $\sum_{k=1}^{K} \chi_{m,k} = 1$, we get that

$$\frac{\partial L}{\partial \chi_{m,k}} = \Psi(\gamma_k) - \Psi(\sum_{j=1}^{K} \gamma_j) + \log \beta_{k,w_n} - \log \chi_{m,k} - 1 + \lambda_m$$

And equating to zero and solving,

$$\chi_{m,k} = exp(\Psi(\gamma_k) - \Psi(\sum_{j=1}^{K} \gamma_j))\beta_{k,w_n} exp(-1 + \lambda_m)$$

$$\chi_{m,k} \propto \beta_{k,w_n} exp(\Psi(\gamma_k) - \Psi(\sum_{j=1}^{K} \gamma_j))$$

Finally maximizing with respect to γ_k, we get that

$$\begin{aligned}\frac{\partial L}{\partial \gamma_k} &= (\alpha_k + \sum_{n=1}^{N} \phi_{n,k} + \sum_{m=1}^{M} \chi_{m,k} - \gamma_k)(\Psi'(\gamma_k) - \Psi'(\sum_{j=1}^{K} \gamma_j)) - (\Psi(\gamma_k) - \Psi(\sum_{j=1}^{K} \gamma_j)) - \Psi(\sum_{j=1}^{K} \gamma_j) + \Psi(\gamma_k) \\ &= (\alpha_k + \sum_{n=1}^{N} \phi_{n,k} + \sum_{m=1}^{M} \chi_{m,k} - \gamma_k)(\Psi'(\gamma_k) - \Psi'(\sum_{j=1}^{K} \gamma_j))\end{aligned}$$

And equating to zero and solving,

$$\gamma_k = \alpha_k + \sum_{n=1}^{N} \phi_{n,k} + \sum_{m=1}^{M} \chi_{m,k}$$

These correspond to Equations 3-5. α is updated iteratively using the Newton-Raphson algorithm as described in [4].

We'll now describe the updates for time series variational parameters $\hat{\beta}_{t,k}$ and $\hat{\rho}_{t,k}$ shown in Figure 3. This closely follows the derivation presented in [3]. From our defined state space in Equations 6 and 7 and following standard Kalman filter calculations, we have that the forward mean and variance are given by

$$\begin{aligned}m_t &= E[\beta_t \mid \hat{\beta}_{1:t}] \\ &= \left(\frac{\hat{\sigma}^2}{V_{t-1} + \sigma^2 + \hat{\sigma}^2}\right) m_{t-1} + \left(1 - \frac{\sigma^2}{V_{t-1} + \sigma^2 + \hat{\sigma}^2}\right) \hat{\beta}_t \\ V_t &= E[(\beta_t - m_t)^2 \mid \hat{\beta}_{1:t}] \\ &= \left(\frac{\hat{\sigma}^2}{V_{t-1} + \sigma^2 + \hat{\sigma}^2}\right)(V_{t-1} + \sigma^2)\end{aligned}$$

with initial conditions m_0 and V_0. The marginal mean and variance from the backward recursion calculation is then given as

$$\begin{aligned}
\tilde{m}_{t-1} &= E[\beta_{t-1} \mid \hat{\beta}_{1:T}] \\
&= \left(\frac{\sigma^2}{V_{t-1}+\sigma^2}\right) m_{t-1} + \left(1 - \frac{\sigma^2}{V_{t-1}+\sigma^2}\right) \tilde{m}_t \\
\tilde{V}_{t-1} &= E[(\beta_{t-1} - \tilde{m}_{t-1})^2 \mid \hat{\beta}_{1:T}] \\
&= V_{t-1} + \left(\frac{V_{t-1}}{V_{t-1}+\sigma^2}\right)^2 (\tilde{V}_{t-1} - (V_{t-1}+\sigma^2))
\end{aligned}$$

As described in [3], we then maximize with respect to $\hat{\beta}_{t,k,w}$ by gradient ascent on the following:

$$\frac{\partial \ell}{\partial \hat{\beta}_{t,k,w}} = -\frac{1}{\sigma^2} \sum_{t=1}^{T} (\tilde{m}_{t,w} - \tilde{m}_{t-1,w}) \left(\frac{\partial \tilde{m}_{t,w}}{\partial \hat{\beta}_{t,k,w}} - \frac{\partial \tilde{m}_{t-1,w}}{\partial \hat{\beta}_{t,k,w}}\right) + \sum_{t=1}^{T} (n_{t,w} - n_t \hat{\zeta}^{-1} exp(\tilde{m}_{t,w} + \tilde{V}_{t,w}/2)) \frac{\partial \tilde{m}_{t,w}}{\partial \hat{\beta}_{t,k,w}}$$

where $\hat{\zeta}_t$ are additional variational parameters used to lower bound $E_q[\log \sum_w exp(\beta_{t,k,w})]$ with update equation

$$\hat{\zeta}_t = \sum_w exp(\tilde{m}_{t,w} + \tilde{V}_{t,w}/2)$$

and $\frac{\partial \tilde{m}_{t,w}}{\partial \hat{\beta}_{t,k,w}}$ is calculated from the recurrence derived from differentiating the forward-backward equations above:

$$\begin{aligned}
\frac{\partial m_{t,w}}{\partial \hat{\beta}_{s,k,w}} &= \left(\frac{\hat{\sigma}^2}{V_{t-1}+\sigma^2+\hat{\sigma}^2}\right) \frac{\partial m_{t-1,w}}{\partial \hat{\beta}_{s,k,w}} + \left(1 - \frac{\sigma^2}{V_{t-1}+\sigma^2+\hat{\sigma}^2}\right) I(s == t) \\
\frac{\partial \tilde{m}_{t-1,w}}{\partial \hat{\beta}_{s,k,w}} &= \left(\frac{\sigma^2}{V_{t-1}+\sigma^2}\right) \frac{\partial m_{t-1,w}}{\partial \hat{\beta}_{s,k,w}} + \left(1 - \frac{\sigma^2}{V_{t-1}+\sigma^2}\right) \frac{\partial \tilde{m}_{t,w}}{\partial \hat{\beta}_{s,k,w}}
\end{aligned}$$

The updates for $\hat{\rho}_{t,k}$ follow symmetrically from our defined state space model in Equations 7 and 8.

B. Results

We present here the full results from our model fit on the documents in the CiteSeerX corpus from 1993 to 2009. We list the top 5 words and citations for each topic.

Topic 1:

Year	Top 5 Words	Top 5 Citations
1993	parallel	Computer Architecture : A Quantitative Approach
	memory	Performance Fortran Forum: High Performance Fortran (HPF) Language Specification, Version 1.0. Center for Research
	processor	Splash Stanford parallel applications for shared memory
	machine	Active Messages: a mechanism for integrated communication and computation
	communication	Memory Coherence in a Shared Virtual Memory System
1994	parallel	Computer Architecture : A Quantitative Approach
	memory	Performance Fortran Forum: High Performance Fortran (HPF) Language Specification, Version 1.0. Center for Research
	processor	Active Messages: a mechanism for integrated communication and computation
	communication	Splash Stanford parallel applications for shared memory
	machine	Memory Coherence in a Shared Virtual Memory System
1995	parallel	Computer Architecture : A Quantitative Approach
	memory	Active Messages: a mechanism for integrated communication and computation
	processor	Performance Fortran Forum: High Performance Fortran (HPF) Language Specification, Version 1.0. Center for Research
	communication	Splash Stanford parallel applications for shared memory
	machine	Memory Coherence in a Shared Virtual Memory System
1996	parallel	Computer Architecture : A Quantitative Approach
	memory	Active Messages: a mechanism for integrated communication and computation
	processor	Performance Fortran Forum: High Performance Fortran (HPF) Language Specification, Version 1.0. Center for Research
	communication	Splash Stanford parallel applications for shared memory
	architecture	Memory Coherence in a Shared Virtual Memory System
1997	parallel	Computer Architecture : A Quantitative Approach
	memory	Active Messages: a mechanism for integrated communication and computation
	processor	Performance Fortran Forum: High Performance Fortran (HPF) Language Specification, Version 1.0. Center for Research
	architecture	Splash Stanford parallel applications for shared memory

	communication	Intro. to Algorithms
1998	memory	Computer Architecture : A Quantitative Approach
	parallel	Active Messages: a mechanism for integrated communication and computation
	processor	Myrinet: a gigabit-per-second local-area network
	architecture	Intro. to Algorithms
	circuit	ATOM: A system for building customized program analysis tools, WRL
1999	memory	Computer Architecture : A Quantitative Approach
	parallel	Globus: A metacomputing infrastructure toolkit. Int'l
	processor	Myrinet: a gigabit-per-second local-area network
	architecture	Intro. to Algorithms
	cache	The simplescalartool set, version 2.0
2000	memory	Computer Architecture : A Quantitative Approach
	parallel	The simplescalartool set, version 2.0
	processor	Globus: A metacomputing infrastructure toolkit. Int'l
	architecture	Intro. to Algorithms
	cache	Myrinet: a gigabit-per-second local-area network
2001	memory	Computer Architecture : A Quantitative Approach
	processor	The simplescalartool set, version 2.0
	parallel	Globus: A metacomputing infrastructure toolkit. Int'l
	architecture	Intro. to Algorithms
	cache	Myrinet: a gigabit-per-second local-area network
2002	memory	Computer Architecture : A Quantitative Approach
	processor	The simplescalartool set, version 2.0
	architecture	Globus: A metacomputing infrastructure toolkit. Int'l
	parallel	Condor : A hunter of idle workstations
	cache	Intro. to Algorithms
2003	memory	Computer Architecture : A Quantitative Approach
	processor	The simplescalartool set, version 2.0
	architecture	Globus: A metacomputing infrastructure toolkit. Int'l
	parallel	Condor : A hunter of idle workstations
	cache	Wattch: A Framework for Architectural–Level Power Analysis and Optimizations
2004	memory	Computer Architecture : A Quantitative Approach
	processor	The simplescalartool set, version 2.0
	architecture	Wattch: A Framework for Architectural–Level Power Analysis and Optimizations
	parallel	Condor : A hunter of idle workstations
	cache	Globus: A metacomputing infrastructure toolkit. Int'l
2005	memory	Computer Architecture : A Quantitative Approach
	processor	The simplescalartool set, version 2.0
	architecture	Wattch: A Framework for Architectural–Level Power Analysis and Optimizations
	parallel	Condor : A hunter of idle workstations

	cache	A.The SPLASH-2 programs: Characterization and methodological considerations
2006	memory	Computer Architecture : A Quantitative Approach
	processor	The simplescalartool set, version 2.0
	parallel	Wattch: A Framework for Architectural–Level Power Analysis and Optimizations
	architecture	A.The SPLASH-2 programs: Characterization and methodological considerations
	cache	E.: Transactional memory: Architectural support for lock-free data structures
2007	memory	Computer Architecture : A Quantitative Approach
	processor	The simplescalartool set, version 2.0
	parallel	E.: Transactional memory: Architectural support for lock-free data structures
	architecture	Wattch: A Framework for Architectural–Level Power Analysis and Optimizations
	hardware	A.The SPLASH-2 programs: Characterization and methodological considerations
2008	memory	Computer Architecture : A Quantitative Approach
	parallel	E.: Transactional memory: Architectural support for lock-free data structures
	processor	The simplescalartool set, version 2.0
	architecture	Wattch: A Framework for Architectural–Level Power Analysis and Optimizations
	hardware	The Google file system
2009	memory	Computer Architecture : A Quantitative Approach
	parallel	E.: Transactional memory: Architectural support for lock-free data structures
	processor	The Google file system
	architecture	The simplescalartool set, version 2.0
	hardware	MapReduce: Simplified data processing on large clusters, in

Topic 2:

Year	Top 5 Words	Top 5 Citations
1993	genetic	Genetic Algorithms
	boolean	Adaption in Natural and Artificial Systems
	evolutionary	Atheory of the learnable
	evolution	Genetic Programming: On the Programming of Computers By the Means of Natural Selection
	circuit	L.? Handbook of Genetic Algorithms
1994	genetic	Genetic Algorithms
	boolean	Adaption in Natural and Artificial Systems
	evolutionary	Genetic Programming: On the Programming of Computers By the Means of Natural Selection

	evolution	Atheory of the learnable
	circuit	L.? Handbook of Genetic Algorithms
1995	genetic	Genetic Algorithms
	evolutionary	Adaption in Natural and Artificial Systems
	boolean	Genetic Programming: On the Programming of Computers By the Means of Natural Selection
	evolution	Atheory of the learnable
	circuit	L.? Handbook of Genetic Algorithms
1996	genetic	Genetic Algorithms
	evolutionary	Genetic Programming: On the Programming of Computers By the Means of Natural Selection
	boolean	Adaption in Natural and Artificial Systems
	evolution	Atheory of the learnable
	circuit	Computers and Intractability: A Guide the Theory of NP-Completeness
1997	genetic	Genetic Algorithms
	evolutionary	Genetic Programming: On the Programming of Computers By the Means of Natural Selection
	boolean	Adaption in Natural and Artificial Systems
	evolution	Computers and Intractability: A Guide the Theory of NP-Completeness
	circuit	Atheory of the learnable
1998	genetic	Genetic Algorithms
	evolutionary	Genetic Programming: On the Programming of Computers By the Means of Natural Selection
	evolution	Adaption in Natural and Artificial Systems
	boolean	Computers and Intractability: A Guide the Theory of NP-Completeness
	circuit	Z.:Genetic Algorithms + Data Structures = Evolution Programs
1999	genetic	Genetic Algorithms
	evolutionary	Genetic Programming: On the Programming of Computers By the Means of Natural Selection
	evolution	Adaption in Natural and Artificial Systems
	boolean	Z.:Genetic Algorithms + Data Structures = Evolution Programs
	population	Computers and Intractability: A Guide the Theory of NP-Completeness
2000	evolutionary	Genetic Algorithms
	genetic	Genetic Programming: On the Programming of Computers By the Means of Natural Selection
	boolean	Adaption in Natural and Artificial Systems
	evolution	Z.:Genetic Algorithms + Data Structures = Evolution Programs
	quantum	Computers and Intractability: A Guide the Theory of NP-Completeness
2001	evolutionary	Genetic Algorithms
	genetic	Genetic Programming: On the Programming of Computers By the Means of Natural Selection
	boolean	Adaption in Natural and Artificial Systems
	quantum	Z.:Genetic Algorithms + Data Structures = Evolution Programs

	evolution	An Introduction to Kolmogorov Complexity and Its Applications, second ed
2002	evolutionary	Genetic Algorithms
	genetic	Genetic Programming: On the Programming of Computers By the Means of Natural Selection
	boolean	Adaption in Natural and Artificial Systems
	quantum	An Introduction to Kolmogorov Complexity and Its Applications, second ed
	evolution	Z.:Genetic Algorithms + Data Structures = Evolution Programs
2003	evolutionary	Genetic Algorithms
	genetic	Genetic Programming: On the Programming of Computers By the Means of Natural Selection
	quantum	Adaption in Natural and Artificial Systems
	boolean	An Introduction to Kolmogorov Complexity and Its Applications, second ed
	sat	Engineering an efficient SAT Solver
2004	evolutionary	Genetic Algorithms
	genetic	Genetic Programming: On the Programming of Computers By the Means of Natural Selection
	quantum	Engineering an efficient SAT Solver
	boolean	Adaption in Natural and Artificial Systems
	sat	An Introduction to Kolmogorov Complexity and Its Applications, second ed
2005	evolutionary	Genetic Algorithms
	genetic	Genetic Programming: On the Programming of Computers By the Means of Natural Selection
	quantum	Engineering an efficient SAT Solver
	boolean	Adaption in Natural and Artificial Systems
	circuit	An Introduction to Kolmogorov Complexity and Its Applications, second ed
2006	evolutionary	Genetic Algorithms
	genetic	Engineering an efficient SAT Solver
	bound	Genetic Programming: On the Programming of Computers By the Means of Natural Selection
	quantum	Adaption in Natural and Artificial Systems
	boolean	An Introduction to Kolmogorov Complexity and Its Applications, second ed
2007	bound	Genetic Algorithms
	circuit	Engineering an efficient SAT Solver
	polynomial	Genetic Programming: On the Programming of Computers By the Means of Natural Selection
	evolutionary	Adaption in Natural and Artificial Systems
	proof	Structure in Monotone Complexity
	bound	Genetic Algorithms

2008	polynomial	Engineering an efficient SAT Solver
	circuit	Genetic Programming: On the Programming of Computers By the Means of Natural Selection
	proof	Adaption in Natural and Artificial Systems
	solver	Structure in Monotone Complexity
2009	bound	Genetic Algorithms
	proof	Engineering an efficient SAT Solver
	polynomial	Genetic Programming: On the Programming of Computers By the Means of Natural Selection
	circuit	Structure in Monotone Complexity
	solver	Adaption in Natural and Artificial Systems

Topic 3:

Year	Top 5 Words	Top 5 Citations
1993	signal	The Theory of Error-Correcting Codes
	coding	Thomas J.: Elements of Information Theory
	channel	RM(1992) Vector Quantization and Signal Compression
	code	The MUthemdica! Theory of Communication
	frequency	Embedded imaging coding using zerotrees of wavelet coefficients
1994	signal	The Theory of Error-Correcting Codes
	coding	Thomas J.: Elements of Information Theory
	channel	RM(1992) Vector Quantization and Signal Compression
	code	The MUthemdica! Theory of Communication
	frequency	Embedded imaging coding using zerotrees of wavelet coefficients
1995	signal	The Theory of Error-Correcting Codes
	channel	Thomas J.: Elements of Information Theory
	coding	RM(1992) Vector Quantization and Signal Compression
	code	The MUthemdica! Theory of Communication
	frequency	Embedded imaging coding using zerotrees of wavelet coefficients
1996	channel	Thomas J.: Elements of Information Theory
	coding	The Theory of Error-Correcting Codes
	signal	RM(1992) Vector Quantization and Signal Compression
	code	Embedded imaging coding using zerotrees of wavelet coefficients
	frequency	The MUthemdica! Theory of Communication
1997	channel	Thomas J.: Elements of Information Theory
	coding	The Theory of Error-Correcting Codes
	signal	RM(1992) Vector Quantization and Signal Compression
	code	Embedded imaging coding using zerotrees of wavelet coefficients
	noise	Near Shannon limit error-correction coding and decoding: Turbo codes
1998	channel	Thomas J.: Elements of Information Theory
	coding	The Theory of Error-Correcting Codes
	code	Near Shannon limit error-correction coding and decoding: Turbo codes
	signal	Embedded imaging coding using zerotrees of wavelet coefficients
	noise	RM(1992) Vector Quantization and Signal Compression

1999	channel	Thomas J.: Elements of Information Theory
	code	The Theory of Error-Correcting Codes
	coding	Near Shannon limit error-correction coding and decoding: Turbo codes
	signal	RM(1992) Vector Quantization and Signal Compression
	noise	Embedded imaging coding using zerotrees of wavelet coefficients
2000	channel	Thomas J.: Elements of Information Theory
	code	The Theory of Error-Correcting Codes
	coding	Near Shannon limit error-correction coding and decoding: Turbo codes
	signal	InformationTheory and Reliable Communication
	noise	The MUthemdica! Theory of Communication
2001	channel	Thomas J.: Elements of Information Theory
	code	The Theory of Error-Correcting Codes
	coding	Near Shannon limit error-correction coding and decoding: Turbo codes
	signal	Capacity of multi-antenna Gaussian channels, AT&T-Bell Laboratories Internal Tech
	noise	Space-time codes for high data rate wireless communications: Performance criteria in the presence of channel estimation errors, mobility and multiple paths
2002	channel	Thomas J.: Elements of Information Theory
	coding	Capacity of multi-antenna Gaussian channels, AT&T-Bell Laboratories Internal Tech
	code	On limits of wireless communication in a fading environment when using multiple antennas, Wireless Personal Commun., submitted for publication
	signal	Space-time codes for high data rate wireless communications: Performance criteria in the presence of channel estimation errors, mobility and multiple paths
	capacity	Near Shannon limit error-correction coding and decoding: Turbo codes
2003	channel	Thomas J.: Elements of Information Theory
	coding	Capacity of multi-antenna Gaussian channels, AT&T-Bell Laboratories Internal Tech
	code	On limits of wireless communication in a fading environment when using multiple antennas, Wireless Personal Commun., submitted for publication
	signal	Space-time codes for high data rate wireless communications: Performance criteria in the presence of channel estimation errors, mobility and multiple paths
	capacity	InformationTheory and Reliable Communication
2004	channel	Thomas J.: Elements of Information Theory
	coding	Capacity of multi-antenna Gaussian channels, AT&T-Bell Laboratories Internal Tech
	code	On limits of wireless communication in a fading environment when using multiple antennas, Wireless Personal Commun., submitted for publication

	capacity	InformationTheory and Reliable Communication
	signal	Space-time codes for high data rate wireless communications: Performance criteria in the presence of channel estimation errors, mobility and multiple paths
2005	channel	Thomas J.: Elements of Information Theory
	coding	Capacity of multi-antenna Gaussian channels, AT&T-Bell Laboratories Internal Tech
	code	InformationTheory and Reliable Communication
	capacity	On limits of wireless communication in a fading environment when using multiple antennas, Wireless Personal Commun., submitted for publication
	signal	Space-time codes for high data rate wireless communications: Performance criteria in the presence of channel estimation errors, mobility and multiple paths
2006	channel	Thomas J.: Elements of Information Theory
	coding	Capacity of multi-antenna Gaussian channels, AT&T-Bell Laboratories Internal Tech
	code	InformationTheory and Reliable Communication
	capacity	Networkinformation flow
	signal	On limits of wireless communication in a fading environment when using multiple antennas, Wireless Personal Commun., submitted for publication
2007	channel	Thomas J.: Elements of Information Theory
	coding	Capacity of multi-antenna Gaussian channels, AT&T-Bell Laboratories Internal Tech
	code	Networkinformation flow
	capacity	InformationTheory and Reliable Communication
	interference	Numerical Analysis
2008	channel	Thomas J.: Elements of Information Theory
	coding	Capacity of multi-antenna Gaussian channels, AT&T-Bell Laboratories Internal Tech
	code	Networkinformation flow
	capacity	InformationTheory and Reliable Communication
	interference	Numerical Analysis
2009	channel	Thomas J.: Elements of Information Theory
	coding	Capacity of multi-antenna Gaussian channels, AT&T-Bell Laboratories Internal Tech
	code	Networkinformation flow
	capacity	InformationTheory and Reliable Communication
	interference	Numerical Analysis

Topic 4:

Year	Top 5 Words	Top 5 Citations
	specification	R.The Definition of Standard ML

1993	functional state logic semantics	Communication n Concurrency. d Communicatin Sequential Processes Imperative functional programming 1992], Compiling with continuations
1994	specification state functional semantics logic	R.The Definition of Standard ML Communication n Concurrency. d Communicatin Sequential Processes Imperative functional programming 1992], Compiling with continuations
1995	specification state functional verification formal	Communication n Concurrency. d R.The Definition of Standard ML Communicatin Sequential Processes Imperative functional programming 1986], Graph-based algorithms for Boolean function manipulation
1996	specification state verification formal semantics	Communication n Concurrency. d R.The Definition of Standard ML Communicatin Sequential Processes 1986], Graph-based algorithms for Boolean function manipulation Imperative functional programming
1997	specification state verification formal semantics	Communication n Concurrency. d R.The Definition of Standard ML Communicatin Sequential Processes 1986], Graph-based algorithms for Boolean function manipulation Imperative functional programming
1998	specification verification state formal semantics	Communication n Concurrency. d 1986], Graph-based algorithms for Boolean function manipulation R.The Definition of Standard ML Communicatin Sequential Processes A ConjunctivelyDecomposedBooleanRepresentation for Symbolic Model Checking
1999	specification verification state formal java	Communication n Concurrency. d 1986], Graph-based algorithms for Boolean function manipulation A ConjunctivelyDecomposedBooleanRepresentation for Symbolic Model Checking Perturbed timed automata Communicatin Sequential Processes
2000	specification verification state formal java	Communication n Concurrency. d 1986], Graph-based algorithms for Boolean function manipulation A ConjunctivelyDecomposedBooleanRepresentation for Symbolic Model Checking Perturbed timed automata Communicatin Sequential Processes
	specification	Compositional model checking

	verification	A ConjunctivelyDecomposedBooleanRepresentation for Symbolic Model Checking
2001	java	Communication n Concurrency. d
	state	Perturbed timed automata
	checking	1986], Graph-based algorithms for Boolean function manipulation
	specification	Compositional model checking
	verification	Perturbed timed automata
2002	checking	The moel checker SPIN
	state	1986], Graph-based algorithms for Boolean function manipulation
	java	A ConjunctivelyDecomposedBooleanRepresentation for Symbolic Model Checking
	specification	Compositional model checking
	verification	Perturbed timed automata
2003	checking	The moel checker SPIN
	state	1986], Graph-based algorithms for Boolean function manipulation
	java	Abstract interpretation : a unified lattice model for static analysis of programs by construction of approximation of fixpoints
	specification	Compositional model checking
	verification	Perturbed timed automata
2004	checking	Abstract interpretation : a unified lattice model for static analysis of programs by construction of approximation of fixpoints
	state	The moel checker SPIN
	automaton	1986], Graph-based algorithms for Boolean function manipulation
	specification	Compositional model checking
	verification	Abstract interpretation : a unified lattice model for static analysis of programs by construction of approximation of fixpoints
2005	checking	Perturbed timed automata
	state	The moel checker SPIN
	automaton	1986], Graph-based algorithms for Boolean function manipulation
	specification	Compositional model checking
	verification	Abstract interpretation : a unified lattice model for static analysis of programs by construction of approximation of fixpoints
2006	checking	Perturbed timed automata
	state	The moel checker SPIN
	automaton	1986], Graph-based algorithms for Boolean function manipulation
	specification	Compositional model checking
	verification	Abstract interpretation : a unified lattice model for static analysis of programs by construction of approximation of fixpoints
2007	checking	Perturbed timed automata
	state	Separation Logic: a logic for shared mutable datastructures
	automaton	The moel checker SPIN
	specification	Compositional model checking
	verification	Abstract interpretation : a unified lattice model for static analysis of programs by construction of approximation of fixpoints

2008	checking state automaton	Perturbed timed automata Separation Logic: a logic for shared mutable datastructures Introduction to Automata Theory, Languages and Computation. Addition-Wesley Pub
2009	specification verification checking state automaton	Compositional model checking Abstract interpretation : a unified lattice model for static analysis of programs by construction of approximation of fixpoints Perturbed timed automata Separation Logic: a logic for shared mutable datastructures Introduction to Automata Theory, Languages and Computation. Addition-Wesley Pub

Topic 5:

Year	Top 5 Words	Top 5 Citations
1993	scheduling constraint strategy game heuristic	Computers and Intractability: A Guide the Theory of NP-Completeness K.: Consistency in Networks of Relations Amortized Effi-ciency of List Update and Paging Rules M.: 'Where the Really Hard Problems Are Intractability and time-dependent planning, in
1994	scheduling constraint strategy game heuristic	Computers and Intractability: A Guide the Theory of NP-Completeness K.: Consistency in Networks of Relations Amortized Effi-ciency of List Update and Paging Rules M.: 'Where the Really Hard Problems Are Intractability and time-dependent planning, in
1995	scheduling constraint strategy game heuristic	Computers and Intractability: A Guide the Theory of NP-Completeness K.: Consistency in Networks of Relations Amortized Effi-ciency of List Update and Paging Rules Foundations of Constraint Satisfaction M.: 'Where the Really Hard Problems Are
1996	scheduling constraint strategy game heuristic	Computers and Intractability: A Guide the Theory of NP-Completeness K.: Consistency in Networks of Relations Amortized Effi-ciency of List Update and Paging Rules Foundations of Constraint Satisfaction M.: 'Where the Really Hard Problems Are
1997	scheduling constraint strategy game heuristic	Computers and Intractability: A Guide the Theory of NP-Completeness K.: Consistency in Networks of Relations Amortized Effi-ciency of List Update and Paging Rules Foundations of Constraint Satisfaction M.: 'Where the Really Hard Problems Are
1998	scheduling constraint game strategy	Computers and Intractability: A Guide the Theory of NP-Completeness K.: Consistency in Networks of Relations Amortized Effi-ciency of List Update and Paging Rules Foundations of Constraint Satisfaction

	job	Counterspeculation, auctions and competitive sealed tenders. The Journal of Finance, 16:8–37
1999	scheduling	Computers and Intractability: A Guide the Theory of NP-Completeness
	game	K.: Consistency in Networks of Relations
	constraint	Counterspeculation, auctions and competitive sealed tenders. The Journal of Finance, 16:8–37
	strategy	Foundations of Constraint Satisfaction
	auction	Amortized Effi-ciency of List Update and Paging Rules
2000	game	Computers and Intractability: A Guide the Theory of NP-Completeness
	constraint	Counterspeculation, auctions and competitive sealed tenders. The Journal of Finance, 16:8–37
	scheduling	K.: Consistency in Networks of Relations
	strategy	A Theory
	auction	A Scalable Content-Addressable Network
2001	game	A Scalable Content-Addressable Network
	auction	Chord: A scalable peer-to-peer lookup service for internet applications. Submission to
	constraint	Counterspeculation, auctions and competitive sealed tenders. The Journal of Finance, 16:8–37
	strategy	Computers and Intractability: A Guide the Theory of NP-Completeness
	agent	Freenet: A distributed anonymous information storage and /etrieval system
2002	game	Chord: A scalable peer-to-peer lookup service for internet applications. Submission to
	agent	A Scalable Content-Addressable Network
	auction	Counterspeculation, auctions and competitive sealed tenders. The Journal of Finance, 16:8–37
	strategy	Pastry: Scalable, distributed object location and routing for large-scale peer-to-peer systems. Accepted for Middleware
	constraint	Tapestry: An infrastructure for fault-tolerant wide-arealocation and routing
2003	game	Chord: A scalable peer-to-peer lookup service for internet applications. Submission to
	agent	A Scalable Content-Addressable Network
	strategy	Pastry: Scalable, distributed object location and routing for large-scale peer-to-peer systems. Accepted for Middleware
	peertopeer	Tapestry: An infrastructure for fault-tolerant wide-arealocation and routing
	auction	Counterspeculation, auctions and competitive sealed tenders. The Journal of Finance, 16:8–37
	game	Chord: A scalable peer-to-peer lookup service for internet applications. Submission to
	agent	A Scalable Content-Addressable Network

2004	strategy	Pastry: Scalable, distributed object location and routing for large-scale peer-to-peer systems. Accepted for Middleware
	peertopeer	Counterspeculation, auctions and competitive sealed tenders. The Journal of Finance, 16:8–37
	p2p	Tapestry: An infrastructure for fault-tolerant wide-arealocation and routing
2005	game	Chord: A scalable peer-to-peer lookup service for internet applications. Submission to
	agent	A Scalable Content-Addressable Network
	strategy	Pastry: Scalable, distributed object location and routing for large-scale peer-to-peer systems. Accepted for Middleware
	equilibrium	Game Theory
	p2p	Counterspeculation, auctions and competitive sealed tenders. The Journal of Finance, 16:8–37
2006	game	Chord: A scalable peer-to-peer lookup service for internet applications. Submission to
	agent	A Scalable Content-Addressable Network
	strategy	Game Theory
	equilibrium	Counterspeculation, auctions and competitive sealed tenders. The Journal of Finance, 16:8–37
	mechani	Pastry: Scalable, distributed object location and routing for large-scale peer-to-peer systems. Accepted for Middleware
2007	game	Chord: A scalable peer-to-peer lookup service for internet applications. Submission to
	agent	Game Theory
	strategy	A Scalable Content-Addressable Network
	equilibrium	Counterspeculation, auctions and competitive sealed tenders. The Journal of Finance, 16:8–37
	mechanism	A Theory
2008	game	Game Theory
	agent	Chord: A scalable peer-to-peer lookup service for internet applications. Submission to
	strategy	A Scalable Content-Addressable Network
	mechanism	Counterspeculation, auctions and competitive sealed tenders. The Journal of Finance, 16:8–37
	equilibrium	A Theory
2009	game	Game Theory
	agent	Chord: A scalable peer-to-peer lookup service for internet applications. Submission to
	mechanism	A Scalable Content-Addressable Network
	strategy	Counterspeculation, auctions and competitive sealed tenders. The Journal of Finance, 16:8–37
	equilibrium	A Theory

Topic 6:

Year	Top 5 Words	Top 5 Citations
	communication	A Scheme for Real?Time Channel Establishment in Wide?Area Networks
	traffic	A Generalized Processor Sharing Approach to Flow Control? The Single Node Case
1993	routing	Supporting real-time applications in an integrated services packet network: Architedure and mechanism
	mobile	Congestion Avoidance and Control
	video	Multicast Routing in a Datagram Internetworks
	traffic	A Generalized Processor Sharing Approach to Flow Control? The Single Node Case
	communication	A Scheme for Real?Time Channel Establishment in Wide?Area Networks
1994	routing	Congestion Avoidance and Control
	video	Supporting real-time applications in an integrated services packet network: Architedure and mechanism
	mobile	Multicast Routing in a Datagram Internetworks
	traffic	A Generalized Processor Sharing Approach to Flow Control? The Single Node Case
	communication	Congestion Avoidance and Control
1995	routing	A Scheme for Real?Time Channel Establishment in Wide?Area Networks
	video	Multicast Routing in a Datagram Internetworks
	mobile	Supporting real-time applications in an integrated services packet network: Architedure and mechanism
	traffic	A Generalized Processor Sharing Approach to Flow Control? The Single Node Case
	routing	Congestion Avoidance and Control
1996	communication	Multicast Routing in a Datagram Internetworks
	mobile	Analysis and simulation of a fair queueing algorithm, Inremet
	video	Zappala: RSVP: A New Resource ReSerVation Protocol
	traffic	A Generalized Processor Sharing Approach to Flow Control? The Single Node Case
	routing	Congestion Avoidance and Control
1997	mobile	Orr the self-similar nature of Ethernet traffic
	packet	Zappala: RSVP: A New Resource ReSerVation Protocol
	communication	Analysis and simulation of a fair queueing algorithm, Inremet
	traffic	Congestion Avoidance and Control
	routing	A Generalized Processor Sharing Approach to Flow Control? The Single Node Case
1998	internet	RTP: A Transport Protocol for Real-Time Applications, Internet Draft draft-ietf-avt-rtp-06.txt, work in progress
	packet	Random Early Detection gateways for congestion avoidance, in preparation

	mobile	Orr the self-similar nature of Ethernet traffic
	internet	Congestion Avoidance and Control
	traffic	Random Early Detection gateways for congestion avoidance, in preparation
1999	routing	A Generalized Processor Sharing Approach to Flow Control? The Single Node Case
	packet	RTP: A Transport Protocol for Real-Time Applications, Internet Draft draft-ietf-avt-rtp-06.txt, work in progress
	multicast	Orr the self-similar nature of Ethernet traffic
	routing	Random Early Detection gateways for congestion avoidance, in preparation
	internet	Congestion Avoidance and Control
2000	traffic	RTP: A Transport Protocol for Real-Time Applications, Internet Draft draft-ietf-avt-rtp-06.txt, work in progress
	packet	A Generalized Processor Sharing Approach to Flow Control? The Single Node Case
	multicast	Orr the self-similar nature of Ethernet traffic
	routing	Random Early Detection gateways for congestion avoidance, in preparation
	packet	Congestion Avoidance and Control
2001	traffic	Dynamic Source Routing in Ad Hoc Wireless Networks, Mobile Computing, edited by Tomasz Imielinski and Hank Korth, chapter 5
	internet	A Generalized Processor Sharing Approach to Flow Control? The Single Node Case
	node	RTP: A Transport Protocol for Real-Time Applications, Internet Draft draft-ietf-avt-rtp-06.txt, work in progress
	node	Random Early Detection gateways for congestion avoidance, in preparation
	routing	Dynamic Source Routing in Ad Hoc Wireless Networks, Mobile Computing, edited by Tomasz Imielinski and Hank Korth, chapter 5
2002	packet	Congestion Avoidance and Control
	traffic	A Performance Comparison of Multi-Hop Wireless Ad-Hic Network Routing Protocols
	wireless	Directed Diffusion: A Scalable and Robust Communication Paradigm for. Sensor Networks
	node	Dynamic Source Routing in Ad Hoc Wireless Networks, Mobile Computing, edited by Tomasz Imielinski and Hank Korth, chapter 5
	routing	Directed Diffusion: A Scalable and Robust Communication Paradigm for. Sensor Networks
2003	wireless	Ad hoc On-Demand Distance Vector Routing
	sensor	Random Early Detection gateways for congestion avoidance, in preparation
	traffic	Congestion Avoidance and Control

2004	node	Directed Diffusion: A Scalable and Robust Communication Paradigm for. Sensor Networks
	sensor	Dynamic Source Routing in Ad Hoc Wireless Networks, Mobile Computing, edited by Tomasz Imielinski and Hank Korth, chapter 5
	wireless	System architecture directions for networked sensors. of Wireless Sensor Networks for Habitat Monitoring 25
	routing	The capacity of wireless networks
	traffic	Ad hoc On-Demand Distance Vector Routing
2005	sensor	Directed Diffusion: A Scalable and Robust Communication Paradigm for. Sensor Networks
	node	The capacity of wireless networks
	wireless	Dynamic Source Routing in Ad Hoc Wireless Networks, Mobile Computing, edited by Tomasz Imielinski and Hank Korth, chapter 5
	routing	GPSR: Greedy perimeter stateless routing for wireless networks
	traffic	System architecture directions for networked sensors. of Wireless Sensor Networks for Habitat Monitoring 25
2006	sensor	The capacity of wireless networks
	node	Directed Diffusion: A Scalable and Robust Communication Paradigm for. Sensor Networks
	wireless	GPSR: Greedy perimeter stateless routing for wireless networks
	routing	Dynamic Source Routing in Ad Hoc Wireless Networks, Mobile Computing, edited by Tomasz Imielinski and Hank Korth, chapter 5
	traffic	System architecture directions for networked sensors. of Wireless Sensor Networks for Habitat Monitoring 25
2007	node	The capacity of wireless networks
	sensor	GPSR: Greedy perimeter stateless routing for wireless networks
	wireless	Directed Diffusion: A Scalable and Robust Communication Paradigm for. Sensor Networks
	routing	Dynamic Source Routing in Ad Hoc Wireless Networks, Mobile Computing, edited by Tomasz Imielinski and Hank Korth, chapter 5
	traffic	System architecture directions for networked sensors. of Wireless Sensor Networks for Habitat Monitoring 25
2008	node	The capacity of wireless networks
	sensor	GPSR: Greedy perimeter stateless routing for wireless networks
	wireless	Directed Diffusion: A Scalable and Robust Communication Paradigm for. Sensor Networks
	routing	Dynamic Source Routing in Ad Hoc Wireless Networks, Mobile Computing, edited by Tomasz Imielinski and Hank Korth, chapter 5
	traffic	System architecture directions for networked sensors. of Wireless Sensor Networks for Habitat Monitoring 25
2009	node	The capacity of wireless networks
	sensor	GPSR: Greedy perimeter stateless routing for wireless networks
	wireless	Dynamic Source Routing in Ad Hoc Wireless Networks, Mobile Computing, edited by Tomasz Imielinski and Hank Korth, chapter 5

routing	Directed Diffusion: A Scalable and Robust Communication Paradigm for. Sensor Networks
traffic	System architecture directions for networked sensors. of Wireless Sensor Networks for Habitat Monitoring 25

Topic 7:

Year	Top 5 Words	Top 5 Citations
	market	The Valuation of Options and Corporate Liabilities
	policy	Large Sample Properties of Generalized Method of Moments Estimators." Econometrica 50 (uly
1993	price	A Theory of the Term Structure of Interest Rates, Econometrica, vol 53, pgs
	economic	C .,"The Theory of Rational Option Pricing
	bank	Martingales and Arbitrage in Multiperiod Securities
	market	The Valuation of Options and Corporate Liabilities
	policy	Large Sample Properties of Generalized Method of Moments Estimators." Econometrica 50 (uly
1994	price	A Theory of the Term Structure of Interest Rates, Econometrica, vol 53, pgs
	economic	C .,"The Theory of Rational Option Pricing
	bank	Martingales and Arbitrage in Multiperiod Securities
	market	The Valuation of Options and Corporate Liabilities
	policy	Large Sample Properties of Generalized Method of Moments Estimators." Econometrica 50 (uly
1995	price	A Theory of the Term Structure of Interest Rates, Econometrica, vol 53, pgs
	economic	C .,"The Theory of Rational Option Pricing
	bank	Martingales and Arbitrage in Multiperiod Securities
	market	The Valuation of Options and Corporate Liabilities
	policy	Large Sample Properties of Generalized Method of Moments Estimators." Econometrica 50 (uly
1996	price	A Theory of the Term Structure of Interest Rates, Econometrica, vol 53, pgs
	economic	Tirne series analysis
	bank	Martingales and Arbitrage in Multiperiod Securities
	market	The Valuation of Options and Corporate Liabilities
	price	Large Sample Properties of Generalized Method of Moments Estimators." Econometrica 50 (uly
1997	policy	A Theory of the Term Structure of Interest Rates, Econometrica, vol 53, pgs
	economic	Tirne series analysis
	bank	A Heterascedasticity-Consistent Covariance Matrix Estimator and a Direct Test for Heteroscedasticity, Econometrica
	market	The Valuation of Options and Corporate Liabilities

	price	Large Sample Properties of Generalized Method of Moments Estimators." Econometrica 50 (uly
1998	policy	A Theory of the Term Structure of Interest Rates, Econometrica, vol 53, pgs
	economic	Tirne series analysis
	risk	A Heterascedasticity-Consistent Covariance Matrix Estimator and a Direct Test for Heteroscedasticity, Econometrica
	market	The Valuation of Options and Corporate Liabilities
	price	Large Sample Properties of Generalized Method of Moments Estimators." Econometrica 50 (uly
1999	policy	A Theory of the Term Structure of Interest Rates, Econometrica, vol 53, pgs
	risk	Tirne series analysis
	economic	A Heterascedasticity-Consistent Covariance Matrix Estimator and a Direct Test for Heteroscedasticity, Econometrica
	market	The Valuation of Options and Corporate Liabilities
	price	Large Sample Properties of Generalized Method of Moments Estimators." Econometrica 50 (uly
2000	policy	A Theory of the Term Structure of Interest Rates, Econometrica, vol 53, pgs
	firm	Tirne series analysis
	risk	The Econometrics of Financial Markets
	market	The Valuation of Options and Corporate Liabilities
	price	Large Sample Properties of Generalized Method of Moments Estimators." Econometrica 50 (uly
2001	firm	A Theory of the Term Structure of Interest Rates, Econometrica, vol 53, pgs
	policy	Tirne series analysis
	risk	Prospect Theory: An Analysis of Decision Under Risk. Econometrica 47(March
	market	The Valuation of Options and Corporate Liabilities
	price	Large Sample Properties of Generalized Method of Moments Estimators." Econometrica 50 (uly
2002	risk	Tirne series analysis
	firm	Prospect Theory: An Analysis of Decision Under Risk. Econometrica 47(March
	policy	A Theory of the Term Structure of Interest Rates, Econometrica, vol 53, pgs
	market	The Valuation of Options and Corporate Liabilities
	price	Large Sample Properties of Generalized Method of Moments Estimators." Econometrica 50 (uly
2003	risk	Prospect Theory: An Analysis of Decision Under Risk. Econometrica 47(March
	firm	Tirne series analysis

	policy	A Theory of the Term Structure of Interest Rates, Econometrica, vol 53, pgs
2004	market	The Valuation of Options and Corporate Liabilities
	risk	Prospect Theory: An Analysis of Decision Under Risk. Econometrica 47(March
	price	Large Sample Properties of Generalized Method of Moments Estimators." Econometrica 50 (uly
	firm	Tirne series analysis
	policy	On The Pricing of Corporate Debt: The Risk Structure of Interest Rates, The Journal of Finance 29
2005	market	The Valuation of Options and Corporate Liabilities
	risk	Prospect Theory: An Analysis of Decision Under Risk. Econometrica 47(March
	price	Large Sample Properties of Generalized Method of Moments Estimators." Econometrica 50 (uly
	firm	Tirne series analysis
	policy	On The Pricing of Corporate Debt: The Risk Structure of Interest Rates, The Journal of Finance 29
2006	market	The Valuation of Options and Corporate Liabilities
	risk	Prospect Theory: An Analysis of Decision Under Risk. Econometrica 47(March
	price	Large Sample Properties of Generalized Method of Moments Estimators." Econometrica 50 (uly
	firm	Tirne series analysis
	policy	On The Pricing of Corporate Debt: The Risk Structure of Interest Rates, The Journal of Finance 29
2007	market	The Valuation of Options and Corporate Liabilities
	price	Prospect Theory: An Analysis of Decision Under Risk. Econometrica 47(March
	risk	Large Sample Properties of Generalized Method of Moments Estimators." Econometrica 50 (uly
	policy	Staggered Prices in a Utility-Maximizing Framework, Journal of Monetary Economics 12, 383-98. and the aggregate demand and expectations channels to domestic ination, respectively. A third alternative is to impose some partial adjustment of import prices.
	firm	By Force of Habit: A Consumption-Based Explanation of Aggregate Stock Market Behavior, Federal Reserve Bank of Philadelphia Research Working Paper
2008	market	The Valuation of Options and Corporate Liabilities
	price	Prospect Theory: An Analysis of Decision Under Risk. Econometrica 47(March
	risk	Staggered Prices in a Utility-Maximizing Framework, Journal of Monetary Economics 12, 383-98. and the aggregate demand and expectations channels to domestic ination, respectively. A third alternative is to impose some partial adjustment of import prices.

	policy	By Force of Habit: A Consumption-Based Explanation of Aggregate Stock Market Behavior, Federal Reserve Bank of Philadelphia Research Working Paper
	firm	Large Sample Properties of Generalized Method of Moments Estimators." Econometrica 50 (uly
2009	market	Prospect Theory: An Analysis of Decision Under Risk. Econometrica 47(March
	price	The Valuation of Options and Corporate Liabilities
	risk	Staggered Prices in a Utility-Maximizing Framework, Journal of Monetary Economics 12, 383-98. and the aggregate demand and expectations channels to domestic ination, respectively. A third alternative is to impose some partial adjustment of import prices.
	policy	By Force of Habit: A Consumption-Based Explanation of Aggregate Stock Market Behavior, Federal Reserve Bank of Philadelphia Research Working Paper
	financial	Risk Aversion, and the Temporal Behavior of Consumption and Asset Returns: A Theoretical Framework,# Econometrica, XLVII

Topic 8:

Year	Top 5 Words	Top 5 Citations
	science	Learning from Delayed Rewards
	university	Learning to predict by the method of temporal differences
1993	supported	Dynamic Programming
	grant	Integrated architecture for learning, planning, and reaction based on approximating dynamic programming
	department	Automatic Programming of Behavior-based Robots, using Reinforcement Learning. AAAI-91
	science	Learning from Delayed Rewards
	university	Learning to predict by the method of temporal differences
1994	supported	Dynamic Programming
	grant	Integrated architecture for learning, planning, and reaction based on approximating dynamic programming
	department	Automatic Programming of Behavior-based Robots, using Reinforcement Learning. AAAI-91
	science	Learning from Delayed Rewards
	university	Learning to predict by the method of temporal differences
1995	supported	Dynamic Programming
	grant	Integrated architecture for learning, planning, and reaction based on approximating dynamic programming
	department	Learing to Act Using Real-Time Dynamic Programming
	science	Learning from Delayed Rewards
	university	Learning to predict by the method of temporal differences
1996	supported	Dynamic Programming

	grant	Integrated architecture for learning, planning, and reaction based on approximating dynamic programming
	department	Learing to Act Using Real-Time Dynamic Programming
1997	science	Learning from Delayed Rewards
	university	Learning to predict by the method of temporal differences
	supported	Dynamic Programming
	grant	Reinforcementlearning: A survey
	department	Reinforcement Learning, An Introduction
1998	science	Learning from Delayed Rewards
	university	Dynamic Programming
	supported	Learning to predict by the method of temporal differences
	grant	Reinforcementlearning: A survey
	state	Reinforcement Learning, An Introduction
1999	science	Reinforcement Learning, An Introduction
	university	Reinforcementlearning: A survey
	state	Learning from Delayed Rewards
	human	Dynamic Programming
	agent	Learning to predict by the method of temporal differences
2000	science	Reinforcement Learning, An Introduction
	university	Reinforcementlearning: A survey
	human	Dynamic Programming
	social	Learning from Delayed Rewards
	state	Learning to predict by the method of temporal differences
2001	science	Reinforcement Learning, An Introduction
	social	Reinforcementlearning: A survey
	university	Learning from Delayed Rewards
	human	Dynamic Programming
	agent	R W: Affective Computing
2002	human	Reinforcement Learning, An Introduction
	social	Reinforcementlearning: A survey
	science	Learning from Delayed Rewards
	university	Dynamic Programming
	cognitive	R W: Affective Computing
2003	human	Reinforcement Learning, An Introduction
	social	Reinforcementlearning: A survey
	cognitive	Learning from Delayed Rewards
	state	Dynamic Programming
	science	R W: Affective Computing
2004	human	Reinforcement Learning, An Introduction
	social	Reinforcementlearning: A survey
	cognitive	R W: Affective Computing
	state	Learning from Delayed Rewards
	action	Dynamic Programming
	human	Reinforcement Learning, An Introduction

2005	social state cognitive action	Reinforcementlearning: A survey R W: Affective Computing Learning from Delayed Rewards Dynamic Programming
2006	human social state cognitive action	Reinforcement Learning, An Introduction Reinforcementlearning: A survey R W: Affective Computing Markov Decision Processes— Discrete Stochastic Dynamic Programming Dynamic Programming
2007	human social state cognitive action	Reinforcement Learning, An Introduction Reinforcementlearning: A survey Markov Decision Processes— Discrete Stochastic Dynamic Programming R W: Affective Computing Dynamic Programming
2008	human social policy cognitive state	Reinforcement Learning, An Introduction Markov Decision Processes— Discrete Stochastic Dynamic Programming Reinforcementlearning: A survey Dynamic Programming R W: Affective Computing
2009	human policy social cognitive state	Reinforcement Learning, An Introduction Markov Decision Processes— Discrete Stochastic Dynamic Programming Reinforcementlearning: A survey Dynamic Programming Reinforcement Learning

Topic 9:

Year	Top 5 Words	Top 5 Citations
1993	logic reasoning semantics planning action	Foundation of Logic Programming STRIPS: A new approach to the application of theoremproving to problem-solving A logic for default reasoning 83 Maintaining Knowledge About Temporal Intervals J.F. Allen Some philosophical problems from the standpiont of artificial intelligence
1994	logic reasoning semantics planning	STRIPS: A new approach to the application of theoremproving to problem-solving Foundation of Logic Programming A logic for default reasoning 83 Maintaining Knowledge About Temporal Intervals J.F. Allen

	action	Some philosophical problems from the standpiont of artificial intelligence
1995	logic	STRIPS: A new approach to the application of theoremproving to problem-solving
	reasoning	Foundation of Logic Programming
	semantics	A logic for default reasoning
	planning	83 Maintaining Knowledge About Temporal Intervals J.F. Allen
	action	Some philosophical problems from the standpiont of artificial intelligence
1996	logic	STRIPS: A new approach to the application of theoremproving to problem-solving
	reasoning	Foundation of Logic Programming
	semantics	A logic for default reasoning
	planning	Some philosophical problems from the standpiont of artificial intelligence
	action	83 Maintaining Knowledge About Temporal Intervals J.F. Allen
1997	logic	STRIPS: A new approach to the application of theoremproving to problem-solving
	reasoning	Foundation of Logic Programming
	planning	The stable model semantics for logic programming
	semantics	Some philosophical problems from the standpiont of artificial intelligence
	calculus	A logic for default reasoning
1998	logic	STRIPS: A new approach to the application of theoremproving to problem-solving
	reasoning	The stable model semantics for logic programming
	planning	Foundation of Logic Programming
	semantics	Some philosophical problems from the standpiont of artificial intelligence
	calculus	A logic for default reasoning
1999	logic	STRIPS: A new approach to the application of theoremproving to problem-solving
	reasoning	The stable model semantics for logic programming
	planning	Some philosophical problems from the standpiont of artificial intelligence
	semantics	Foundation of Logic Programming
	calculus	Fast planning through planning graph analysis. Arti?cial Intelligence 90?1?2?:281?300
2000	logic	The stable model semantics for logic programming
	reasoning	STRIPS: A new approach to the application of theoremproving to problem-solving
	planning	Fast planning through planning graph analysis. Arti?cial Intelligence 90?1?2?:281?300
	semantics	M.Y.Vardi.1995.Reasoning about Knowledge

	calculus	Some philosophical problems from the standpiont of artificial intelligence
2001	logic reasoning planning semantics calculus	The stable model semantics for logic programming M.Y.Vardi.1995.Reasoning about Knowledge Fast planning through planning graph analysis. Arti?cial Intelligence 90?1?2?:281?300 STRIPS: A new approach to the application of theoremproving to problem-solving Foundation of Logic Programming
2002	logic reasoning planning semantics calculus	The stable model semantics for logic programming M.Y.Vardi.1995.Reasoning about Knowledge Fast planning through planning graph analysis. Arti?cial Intelligence 90?1?2?:281?300 STRIPS: A new approach to the application of theoremproving to problem-solving Foundation of Logic Programming
2003	logic reasoning planning semantics calculus	The stable model semantics for logic programming M.Y.Vardi.1995.Reasoning about Knowledge Fast planning through planning graph analysis. Arti?cial Intelligence 90?1?2?:281?300 A Mathematical Theory of Evidence STRIPS: A new approach to the application of theoremproving to problem-solving
2004	logic reasoning planning semantics calculus	M.Y.Vardi.1995.Reasoning about Knowledge The stable model semantics for logic programming Fast planning through planning graph analysis. Arti?cial Intelligence 90?1?2?:281?300 A Mathematical Theory of Evidence Classical negation in logic programs and disjunctive databases', New Generation Computing 9(3–4
2005	logic reasoning semantics planning rule	M.Y.Vardi.1995.Reasoning about Knowledge The stable model semantics for logic programming A Mathematical Theory of Evidence Fast planning through planning graph analysis. Arti?cial Intelligence 90?1?2?:281?300 Classical negation in logic programs and disjunctive databases', New Generation Computing 9(3–4
2006	logic reasoning semantics rule planning	M.Y.Vardi.1995.Reasoning about Knowledge The stable model semantics for logic programming A Mathematical Theory of Evidence Fast planning through planning graph analysis. Arti?cial Intelligence 90?1?2?:281?300 Classical negation in logic programs and disjunctive databases', New Generation Computing 9(3–4

	logic	The stable model semantics for logic programming
	reasoning	M.Y.Vardi.1995.Reasoning about Knowledge
2007	semantics	A Mathematical Theory of Evidence
	rule	Classical negation in logic programs and disjunctive databases', New Generation Computing 9(3–4
	planning	Fast planning through planning graph analysis. Arti?cial Intelligence 90?1?2?:281?300
	logic	The stable model semantics for logic programming
	reasoning	M.Y.Vardi.1995.Reasoning about Knowledge
2008	semantics	A Mathematical Theory of Evidence
	rule	Classical negation in logic programs and disjunctive databases', New Generation Computing 9(3–4
	planning	Fast planning through planning graph analysis. Arti?cial Intelligence 90?1?2?:281?300
	logic	The stable model semantics for logic programming
	reasoning	M.Y.Vardi.1995.Reasoning about Knowledge
2009	semantics	A Mathematical Theory of Evidence
	rule	Classical negation in logic programs and disjunctive databases', New Generation Computing 9(3–4
	planning	The FF planning system: Fast planning generation through heuristic search

Topic 10:

Year	Top 5 Words	Top 5 Citations
	motion	D.: Snakes: Active contour models
	shape	A conputational approach to edge detection
1993	surface	What can be seen in three dimensions with an uncalibratedstereo rig
	3d	Stochastic relaxation, gibbs distributions, and the bayesian restoration of imgaes
	vision	Computer Vision
	motion	D.: Snakes: Active contour models
	shape	A conputational approach to edge detection
1994	3d	What can be seen in three dimensions with an uncalibratedstereo rig
	surface	Stochastic relaxation, gibbs distributions, and the bayesian restoration of imgaes
	camera	Computer Vision
	motion	D.: Snakes: Active contour models
	shape	A conputational approach to edge detection
1995	3d	Stochastic relaxation, gibbs distributions, and the bayesian restoration of imgaes
	surface	What can be seen in three dimensions with an uncalibratedstereo rig
	scene	Computer Vision
	motion	D.: Snakes: Active contour models

1996	shape	A conputational approach to edge detection
	3d	Stochastic relaxation, gibbs distributions, and the bayesian restoration of imgaes
	surface	Three-Dimensional Computer Vision: A Geometric Viewpoint, chapter 4: Edge Detection
	scene	What can be seen in three dimensions with an uncalibratedstereo rig
1997	motion	D.: Snakes: Active contour models
	shape	Stochastic relaxation, gibbs distributions, and the bayesian restoration of imgaes
	3d	A conputational approach to edge detection
	segmentation	Three-Dimensional Computer Vision: A Geometric Viewpoint, chapter 4: Edge Detection
	scene	Computer Vision
1998	motion	D.: Snakes: Active contour models
	shape	Stochastic relaxation, gibbs distributions, and the bayesian restoration of imgaes
	3d	A conputational approach to edge detection
	segmentation	Three-Dimensional Computer Vision: A Geometric Viewpoint, chapter 4: Edge Detection
	scene	Computer Vision
1999	motion	D.: Snakes: Active contour models
	shape	Stochastic relaxation, gibbs distributions, and the bayesian restoration of imgaes
	3d	A conputational approach to edge detection
	segmentation	Three-Dimensional Computer Vision: A Geometric Viewpoint, chapter 4: Edge Detection
	scene	Shape and motionfrom image streams under orthography: afactorizationmethod. InternationalJournalof ComputerVision,9(2):137154,November1992
2000	shape	D.: Snakes: Active contour models
	motion	Stochastic relaxation, gibbs distributions, and the bayesian restoration of imgaes
	3d	A conputational approach to edge detection
	segmentation	Three-Dimensional Computer Vision: A Geometric Viewpoint, chapter 4: Edge Detection
	color	Shape and motionfrom image streams under orthography: afactorizationmethod. InternationalJournalof ComputerVision,9(2):137154,November1992
2001	shape	D.: Snakes: Active contour models
	motion	Stochastic relaxation, gibbs distributions, and the bayesian restoration of imgaes
	3d	A conputational approach to edge detection
	segmentation	Three-Dimensional Computer Vision: A Geometric Viewpoint, chapter 4: Edge Detection

	color	A Method for Registration of 3?D shapes
2002	shape	D.: Snakes: Active contour models
	3d	Stochastic relaxation, gibbs distributions, and the bayesian restoration of imgaes
	motion	Multiple View Geometry in Computer Vision. Second Edition
	segmentation	A conputational approach to edge detection
	scene	A Method for Registration of 3?D shapes
2003	shape	D.: Snakes: Active contour models
	3d	Multiple View Geometry in Computer Vision. Second Edition
	segmentation	Stochastic relaxation, gibbs distributions, and the bayesian restoration of imgaes
	motion	A conputational approach to edge detection
	video	A Method for Registration of 3?D shapes
2004	shape	Multiple View Geometry in Computer Vision. Second Edition
	3d	D.: Snakes: Active contour models
	segmentation	A Method for Registration of 3?D shapes
	motion	Random sample consensus: a paradigm for model fitting with applicatio ns to image analysis and automated cartography
	video	Stochastic relaxation, gibbs distributions, and the bayesian restoration of imgaes
2005	shape	Multiple View Geometry in Computer Vision. Second Edition
	3d	Distinctive image features from scale-invariant keypoints, cascade filtering approach
	segmentation	D.: Snakes: Active contour models
	video	Random sample consensus: a paradigm for model fitting with applicatio ns to image analysis and automated cartography
	motion	A Method for Registration of 3?D shapes
2006	3d	Distinctive image features from scale-invariant keypoints, cascade filtering approach
	shape	Multiple View Geometry in Computer Vision. Second Edition
	segmentation	D.: Snakes: Active contour models
	video	Random sample consensus: a paradigm for model fitting with applicatio ns to image analysis and automated cartography
	camera	A Method for Registration of 3?D shapes
2007	3d	Distinctive image features from scale-invariant keypoints, cascade filtering approach
	shape	Multiple View Geometry in Computer Vision. Second Edition
	segmentation	Random sample consensus: a paradigm for model fitting with applicatio ns to image analysis and automated cartography
	camera	Fast Approximate Energy Minimization via Graph Cuts, Proc
	video	D.: Snakes: Active contour models
	3d	Distinctive image features from scale-invariant keypoints, cascade filtering approach
	shape	Multiple View Geometry in Computer Vision. Second Edition

2008	segmentation	Random sample consensus: a paradigm for model fitting with applicatio ns to image analysis and automated cartography
	camera	Fast Approximate Energy Minimization via Graph Cuts, Proc
	scene	Mean shift: A robust approach toward feature space analysis, PAMI
2009	3d	Distinctive image features from scale-invariant keypoints, cascade filtering approach
	shape	Multiple View Geometry in Computer Vision. Second Edition
	segmentation	Random sample consensus: a paradigm for model fitting with applicatio ns to image analysis and automated cartography
	camera	Fast Approximate Energy Minimization via Graph Cuts, Proc
	scene	Mean shift: A robust approach toward feature space analysis, PAMI

Topic 11:

Year	Top 5 Words	Top 5 Citations
1993	database	Federated database systems for managing distributed, heterogenous, and autonomous databases
	document	Principles of Database and Knowledge-Base Systems, Vol II: The New Technologies
	query	Introducrion to modern information retrieval
	file	Deductive and Object-Oriented Databases
	objectoriented	The ObjectStore Database System
1994	database	Federated database systems for managing distributed, heterogenous, and autonomous databases
	document	Principles of Database and Knowledge-Base Systems, Vol II: The New Technologies
	query	Introducrion to modern information retrieval
	file	Deductive and Object-Oriented Databases
	management	The ObjectStore Database System
1995	database	Principles of Database and Knowledge-Base Systems, Vol II: The New Technologies
	document	Federated database systems for managing distributed, heterogenous, and autonomous databases
	query	Introducrion to modern information retrieval
	web	Deductive and Object-Oriented Databases
	file	Mediators in the architecture of future information systems: A new approach
1996	database	Introducrion to modern information retrieval
	document	Principles of Database and Knowledge-Base Systems, Vol II: The New Technologies
	web	Federated database systems for managing distributed, heterogenous, and autonomous databases
	query	Mediators in the architecture of future information systems: A new approach

	view	Object exchange across heterogeneous information sources. To appear in ICDE 95. Available by ftp at db.stanford.edu, file pub/papakonstantinou/1994/icde95.ps
1997	database	Introducrion to modern information retrieval
	web	Principles of Database and Knowledge-Base Systems, Vol II: The New Technologies
	document	Federated database systems for managing distributed, heterogenous, and autonomous databases
	query	Object exchange across heterogeneous information sources. To appear in ICDE 95. Available by ftp at db.stanford.edu, file pub/papakonstantinou/1994/icde95.ps
	view	Mediators in the architecture of future information systems: A new approach
1998	web	Introducrion to modern information retrieval
	database	Principles of Database and Knowledge-Base Systems, Vol II: The New Technologies
	document	Querying Heterogeneous Information Sources Using Source Descrip tions
	query	Object exchange across heterogeneous information sources. To appear in ICDE 95. Available by ftp at db.stanford.edu, file pub/papakonstantinou/1994/icde95.ps
	view	Mediators in the architecture of future information systems: A new approach
1999	web	Introducrion to modern information retrieval
	database	Querying Heterogeneous Information Sources Using Source Descrip tions
	document	The lorel query language for semi-structured data
	query	The anatomy of a large-scale hypertextual Websearch engine
	page	Authoritive sources in a hyperlinked environment
2000	web	The anatomy of a large-scale hypertextual Websearch engine
	database	Authoritive sources in a hyperlinked environment
	document	The lorel query language for semi-structured data
	query	Introducrion to modern information retrieval
	page	Querying Heterogeneous Information Sources Using Source Descrip tions
2001	web	The anatomy of a large-scale hypertextual Websearch engine
	database	Authoritive sources in a hyperlinked environment
	document	The lorel query language for semi-structured data
	xml	Introducrion to modern information retrieval
	query	Querying Heterogeneous Information Sources Using Source Descrip tions
2002	web	The anatomy of a large-scale hypertextual Websearch engine
	database	Authoritive sources in a hyperlinked environment
	document	Introducrion to modern information retrieval

	xml	The lorel query language for semi-structured data
	query	The PageRank citation ranking: Bringing order to the Web, submitted for publication
2003	web	The anatomy of a large-scale hypertextual Websearch engine
	database	Authoritive sources in a hyperlinked environment
	document	The PageRank citation ranking: Bringing order to the Web, submitted for publication
	xml	eds) The Semantic Web
	query	Introducrion to modern information retrieval
2004	web	The anatomy of a large-scale hypertextual Websearch engine
	semantic	Authoritive sources in a hyperlinked environment
	database	The PageRank citation ranking: Bringing order to the Web, submitted for publication
	ontology	eds) The Semantic Web
	query	Modern Information Retrieval
2005	web	The anatomy of a large-scale hypertextual Websearch engine
	ontology	Authoritive sources in a hyperlinked environment
	semantic	The PageRank citation ranking: Bringing order to the Web, submitted for publication
	database	eds) The Semantic Web
	query	Modern Information Retrieval
2006	web	The anatomy of a large-scale hypertextual Websearch engine
	ontology	Authoritive sources in a hyperlinked environment
	database	The PageRank citation ranking: Bringing order to the Web, submitted for publication
	query	Modern Information Retrieval
	semantic	eds) The Semantic Web
2007	web	The anatomy of a large-scale hypertextual Websearch engine
	query	Authoritive sources in a hyperlinked environment
	database	The PageRank citation ranking: Bringing order to the Web, submitted for publication
	ontology	Modern Information Retrieval
	semantic	A survey of approaches to automatic schema matching. Very Large Database
2008	web	The anatomy of a large-scale hypertextual Websearch engine
	query	Authoritive sources in a hyperlinked environment
	database	The PageRank citation ranking: Bringing order to the Web, submitted for publication
	ontology	Modern Information Retrieval
	semantic	A survey of approaches to automatic schema matching. Very Large Database
	web	The anatomy of a large-scale hypertextual Websearch engine
	query	Authoritive sources in a hyperlinked environment

2009	database	The PageRank citation ranking: Bringing order to the Web, submitted for publication
	ontology	Modern Information Retrieval
	semantic	A survey of approaches to automatic schema matching. Very Large Database

Topic 12:

Year	Top 5 Words	Top 5 Citations
	robot	A robust layered control-system for a mobile robot
	motion	Robot Motion Planning
1993	visual	Eipenfaces for recognition
	planning	hal-time obstacle avoidance for manipulators and mobile robots
	virtual	Animated vision
	robot	A robust layered control-system for a mobile robot
	motion	Robot Motion Planning
1994	visual	Eipenfaces for recognition
	virtual	hal-time obstacle avoidance for manipulators and mobile robots
	planning	Animated vision
	robot	A robust layered control-system for a mobile robot
	motion	Robot Motion Planning
1995	virtual	Eipenfaces for recognition
	visual	hal-time obstacle avoidance for manipulators and mobile robots
	human	and Modular Eigenspaces for Face Recognition
	robot	A robust layered control-system for a mobile robot
	motion	Robot Motion Planning
1996	virtual	Eipenfaces for recognition
	human	and Modular Eigenspaces for Face Recognition
	face	hal-time obstacle avoidance for manipulators and mobile robots
	robot	Robot Motion Planning
	motion	A robust layered control-system for a mobile robot
1997	virtual	Eipenfaces for recognition
	human	Pfinder: Real-time tracking of the humanbody
	tracking	and Modular Eigenspaces for Face Recognition
	robot	Robot Motion Planning
	virtual	A robust layered control-system for a mobile robot
1998	motion	Eipenfaces for recognition
	tracking	Pfinder: Real-time tracking of the humanbody
	human	A robot exploration and mapping strategy based on semantic hierachy of spacial representation
	robot	Robot Motion Planning
	virtual	A robust layered control-system for a mobile robot
1999	tracking	Eipenfaces for recognition
	motion	Pfinder: Real-time tracking of the humanbody

	face	Tangible Bits: Towards Seamless Interfaces behwen People, Bits, and Atoms
2000	robot	Robot Motion Planning
	tracking	Eipenfaces for recognition
	virtual	A robust layered control-system for a mobile robot
	motion	Pfinder: Real-time tracking of the humanbody
	face	Tangible Bits: Towards Seamless Interfaces behwen People, Bits, and Atoms
2001	robot	Robot Motion Planning
	tracking	Eipenfaces for recognition
	face	A robust layered control-system for a mobile robot
	sensor	Pfinder: Real-time tracking of the humanbody
	motion	Condensation - conditional density propagation for visual tracking. InternationalJournal of Computer Vision
2002	robot	Robot Motion Planning
	tracking	Eipenfaces for recognition
	face	Pfinder: Real-time tracking of the humanbody
	sensor	Condensation - conditional density propagation for visual tracking. InternationalJournal of Computer Vision
	motion	A robust layered control-system for a mobile robot
2003	robot	Eipenfaces for recognition
	tracking	Robot Motion Planning
	face	Condensation - conditional density propagation for visual tracking. InternationalJournal of Computer Vision
	motion	Pfinder: Real-time tracking of the humanbody
	sensor	Eigenfaces vs. Fisherfaces: Recognition using class specific linear projection
2004	robot	Eipenfaces for recognition
	tracking	Robot Motion Planning
	face	Condensation - conditional density propagation for visual tracking. InternationalJournal of Computer Vision
	motion	Eigenfaces vs. Fisherfaces: Recognition using class specific linear projection
	mobile	Pfinder: Real-time tracking of the humanbody
2005	robot	Eipenfaces for recognition
	tracking	Robot Motion Planning
	motion	Eigenfaces vs. Fisherfaces: Recognition using class specific linear projection
	face	Condensation - conditional density propagation for visual tracking. InternationalJournal of Computer Vision
	mobile	Pfinder: Real-time tracking of the humanbody
	robot	Eipenfaces for recognition
	tracking	Robot Motion Planning

2006	motion	Eigenfaces vs. Fisherfaces: Recognition using class specific linear projection
	face	Rapid object detection using a boosted cascade of simple classifiers
	mobile	Probabilistic roadmaps for path planning in high-dimensional con space
2007	robot	Eipenfaces for recognition
	tracking	Robot Motion Planning
	motion	Eigenfaces vs. Fisherfaces: Recognition using class specific linear projection
	mobile	Rapid object detection using a boosted cascade of simple classifiers
	face	Probabilistic roadmaps for path planning in high-dimensional con space
2008	robot	Eipenfaces for recognition
	motion	Robot Motion Planning
	tracking	Eigenfaces vs. Fisherfaces: Recognition using class specific linear projection
	mobile	Rapid object detection using a boosted cascade of simple classifiers
	human	Probabilistic roadmaps for path planning in high-dimensional con space
2009	robot	Eipenfaces for recognition
	motion	Robot Motion Planning
	tracking	Eigenfaces vs. Fisherfaces: Recognition using class specific linear projection
	human	Rapid object detection using a boosted cascade of simple classifiers
	mobile	Probabilistic roadmaps for path planning in high-dimensional con space

Topic 13:

Year	Top 5 Words	Top 5 Citations
1993	tree	Computers and Intractability: A Guide the Theory of NP-Completeness
	bound	Intro. to Algorithms
	log	ULLMAN,The design and analysis of computer algorithms
	path	Shamos, Computational Geometry: An Introduction
	edge	The Probabilislic Method
1994	tree	Computers and Intractability: A Guide the Theory of NP-Completeness
	bound	Intro. to Algorithms
	log	ULLMAN,The design and analysis of computer algorithms
	path	Shamos, Computational Geometry: An Introduction
	edge	The Probabilislic Method
1995	tree	Computers and Intractability: A Guide the Theory of NP-Completeness
	bound	Intro. to Algorithms
	log	Shamos, Computational Geometry: An Introduction
	path	ULLMAN,The design and analysis of computer algorithms
	edge	The Probabilislic Method
1996	tree	Computers and Intractability: A Guide the Theory of NP-Completeness
	bound	Intro. to Algorithms
	path	Shamos, Computational Geometry: An Introduction
	log	ULLMAN,The design and analysis of computer algorithms

	edge	The Probabilislic Method
1997	tree	Computers and Intractability: A Guide the Theory of NP-Completeness
	bound	Intro. to Algorithms
	path	Shamos, Computational Geometry: An Introduction
	edge	ULLMAN,The design and analysis of computer algorithms
	log	The Probabilislic Method
1998	tree	Computers and Intractability: A Guide the Theory of NP-Completeness
	bound	Intro. to Algorithms
	path	Shamos, Computational Geometry: An Introduction
	edge	The Probabilislic Method
	vertex	ULLMAN,The design and analysis of computer algorithms
1999	tree	Computers and Intractability: A Guide the Theory of NP-Completeness
	bound	Intro. to Algorithms
	path	The Probabilislic Method
	edge	Shamos, Computational Geometry: An Introduction
	approximation	ULLMAN,The design and analysis of computer algorithms
2000	tree	Computers and Intractability: A Guide the Theory of NP-Completeness
	bound	Intro. to Algorithms
	path	The Probabilislic Method
	edge	Shamos, Computational Geometry: An Introduction
	approximation	Random Graphs
2001	tree	Computers and Intractability: A Guide the Theory of NP-Completeness
	bound	Intro. to Algorithms
	path	The Probabilislic Method
	edge	Random Graphs
	approximation	AND RAGHAVAN,P.Randomized Algorithms
2002	tree	Computers and Intractability: A Guide the Theory of NP-Completeness
	bound	Intro. to Algorithms
	path	AND RAGHAVAN,P.Randomized Algorithms
	edge	The Probabilislic Method
	approximation	Random Graphs
2003	tree	Computers and Intractability: A Guide the Theory of NP-Completeness
	bound	Intro. to Algorithms
	path	AND RAGHAVAN,P.Randomized Algorithms
	approximation	Random Graphs
	edge	The Probabilislic Method
2004	tree	Computers and Intractability: A Guide the Theory of NP-Completeness
	bound	Intro. to Algorithms
	approximation	AND RAGHAVAN,P.Randomized Algorithms
	edge	Random Graphs
	path	The Probabilislic Method
2005	tree	Computers and Intractability: A Guide the Theory of NP-Completeness
	bound	Intro. to Algorithms
	approximation	AND RAGHAVAN,P.Randomized Algorithms

	edge log	Parametrized Complexity Random Graphs
2006	tree bound approximation edge log	Computers and Intractability: A Guide the Theory of NP-Completeness Intro. to Algorithms Parametrized Complexity AND RAGHAVAN,P.Randomized Algorithms Improved approximation algorithms for maximum cut and satis - ability problems using semide nite programming
2007	tree bound approximation edge log	Computers and Intractability: A Guide the Theory of NP-Completeness Intro. to Algorithms Parametrized Complexity AND RAGHAVAN,P.Randomized Algorithms Improved approximation algorithms for maximum cut and satis - ability problems using semide nite programming
2008	tree bound approximation log edge	Computers and Intractability: A Guide the Theory of NP-Completeness Intro. to Algorithms Parametrized Complexity Improved approximation algorithms for maximum cut and satis - ability problems using semide nite programming AND RAGHAVAN,P.Randomized Algorithms
2009	tree bound approximation log edge	Computers and Intractability: A Guide the Theory of NP-Completeness Intro. to Algorithms Parametrized Complexity Improved approximation algorithms for maximum cut and satis - ability problems using semide nite programming Approximation algorithms

Topic 14:

Year	Top 5 Words	Top 5 Citations
1993	word text speech grammar natural	Stochastic Parts Program an Noun Phrase Parser for Unrestricted Text Attention. intentions, and the structure of discourse Building a large annotated corpus of English: the Penn Trccbank Introduction to WordNet: An on-line lexical database. Available by ftp to clarity. princeton.edu Esitmation of probabilities from sparse data for the language model component of a speech recognizer
1994	word text speech grammar natural	Stochastic Parts Program an Noun Phrase Parser for Unrestricted Text Attention. intentions, and the structure of discourse Building a large annotated corpus of English: the Penn Trccbank Introduction to WordNet: An on-line lexical database. Available by ftp to clarity. princeton.edu Esitmation of probabilities from sparse data for the language model component of a speech recognizer
	word	Stochastic Parts Program an Noun Phrase Parser for Unrestricted Text

1995	speech	Attention. intentions, and the structure of discourse
	text	Building a large annotated corpus of English: the Penn Trccbank
	grammar	Introduction to WordNet: An on-line lexical database. Available by ftp to clarity. princeton.edu
	natural	Esitmation of probabilities from sparse data for the language model component of a speech recognizer
1996	speech	Stochastic Parts Program an Noun Phrase Parser for Unrestricted Text
	word	Building a large annotated corpus of English: the Penn Trccbank
	text	Attention. intentions, and the structure of discourse
	grammar	Introduction to WordNet: An on-line lexical database. Available by ftp to clarity. princeton.edu
	natural	Esitmation of probabilities from sparse data for the language model component of a speech recognizer
1997	speech	Building a large annotated corpus of English: the Penn Trccbank
	word	Stochastic Parts Program an Noun Phrase Parser for Unrestricted Text
	text	Introduction to WordNet: An on-line lexical database. Available by ftp to clarity. princeton.edu
	grammar	Attention. intentions, and the structure of discourse
	corpus	Esitmation of probabilities from sparse data for the language model component of a speech recognizer
1998	speech	Building a large annotated corpus of English: the Penn Trccbank
	word	Introduction to WordNet: An on-line lexical database. Available by ftp to clarity. princeton.edu
	text	Stochastic Parts Program an Noun Phrase Parser for Unrestricted Text
	grammar	Attention. intentions, and the structure of discourse
	corpus	Esitmation of probabilities from sparse data for the language model component of a speech recognizer
1999	speech	Building a large annotated corpus of English: the Penn Trccbank
	word	Introduction to WordNet: An on-line lexical database. Available by ftp to clarity. princeton.edu
	text	Maximum likelihoodfromincomplete data via the EM algorithm
	document	Introducrion to modern information retrieval
	corpus	Stochastic Parts Program an Noun Phrase Parser for Unrestricted Text
2000	text	Building a large annotated corpus of English: the Penn Trccbank
	speech	Introduction to WordNet: An on-line lexical database. Available by ftp to clarity. princeton.edu
	word	Maximum likelihoodfromincomplete data via the EM algorithm
	document	Introducrion to modern information retrieval
	corpus	R.Harshman. Indexing by latent semantic analysis
2001	text	Building a large annotated corpus of English: the Penn Trccbank
	word	Introduction to WordNet: An on-line lexical database. Available by ftp to clarity. princeton.edu
	speech	Text categorization with support vector macgines: learning with many relevant features

	document	Maximum likelihoodfromincomplete data via the EM algorithm
	corpus	R.Harshman. Indexing by latent semantic analysis
2002	text	Building a large annotated corpus of English: the Penn Trccbank
	word	Text categorization with support vector macgines: learning with many relevant features
	speech	WordNet ? An Electronic Lexical Database
	document	Introduction to WordNet: An on-line lexical database. Available by ftp to clarity. princeton.edu
	corpus	R.Harshman. Indexing by latent semantic analysis
2003	text	Building a large annotated corpus of English: the Penn Trccbank
	word	Text categorization with support vector macgines: learning with many relevant features
	speech	WordNet ? An Electronic Lexical Database
	document	R.Harshman. Indexing by latent semantic analysis
	corpus	Conditional random fields: Probabilistic models for segmenting and labeling sequence data, ICML
2004	text	Building a large annotated corpus of English: the Penn Trccbank
	word	Conditional random fields: Probabilistic models for segmenting and labeling sequence data, ICML
	speech	WordNet ? An Electronic Lexical Database
	document	Text categorization with support vector macgines: learning with many relevant features
	corpus	R.Harshman. Indexing by latent semantic analysis
2005	text	Conditional random fields: Probabilistic models for segmenting and labeling sequence data, ICML
	word	WordNet ? An Electronic Lexical Database
	speech	Building a large annotated corpus of English: the Penn Trccbank
	document	Head-drivenstatistical models for natural language parsing. Doctoral Dissertation
	corpus	R.Harshman. Indexing by latent semantic analysis
2006	word	Conditional random fields: Probabilistic models for segmenting and labeling sequence data, ICML
	text	WordNet ? An Electronic Lexical Database
	speech	Building a large annotated corpus of English: the Penn Trccbank
	document	BLEU: A Method for Automatic Evaluation of Machine Translation. ACL
	corpus	Latent Dirichlet allocation
2007	word	Conditional random fields: Probabilistic models for segmenting and labeling sequence data, ICML
	text	WordNet ? An Electronic Lexical Database
	speech	Building a large annotated corpus of English: the Penn Trccbank
	document	Latent Dirichlet allocation
	semantic	BLEU: A Method for Automatic Evaluation of Machine Translation. ACL

2008	word	Conditional random fields: Probabilistic models for segmenting and labeling sequence data, ICML
	text	WordNet ? An Electronic Lexical Database
	document	Latent Dirichlet allocation
	speech	Building a large annotated corpus of English: the Penn Trccbank
	semantic	BLEU: A Method for Automatic Evaluation of Machine Translation. ACL
2009	word	Conditional random fields: Probabilistic models for segmenting and labeling sequence data, ICML
	text	Latent Dirichlet allocation
	document	WordNet ? An Electronic Lexical Database
	translation	Building a large annotated corpus of English: the Penn Trccbank
	semantic	BLEU: A Method for Automatic Evaluation of Machine Translation. ACL

Topic 15:

Year	Top 5 Words	Top 5 Citations
1993	agent	Lorenzen: Object-Oriented Modeling and Design
	architecture	Tcl and the Tk Toolkit
	interface	Design Patterns: Elements of Reusable Object- Oriented Software
	engineering	Agentoriented programming
	interaction	EPTD DISCUSSION PAPERS 65 The Role of Trees for Sustainable Management of Less-favored Lands: The Case of Eucalyptus in Ethiopia, by Pamela Jagger
1994	agent	Lorenzen: Object-Oriented Modeling and Design
	architecture	Design Patterns: Elements of Reusable Object- Oriented Software
	interface	Tcl and the Tk Toolkit
	engineering	An Introductionto Software Architecture
	interaction	Agentoriented programming
1995	agent	Lorenzen: Object-Oriented Modeling and Design
	architecture	Design Patterns: Elements of Reusable Object- Oriented Software
	interface	Tcl and the Tk Toolkit
	engineering	An Introductionto Software Architecture
	management	Agentoriented programming
1996	agent	Design Patterns: Elements of Reusable Object- Oriented Software
	architecture	Lorenzen: Object-Oriented Modeling and Design
	engineering	Tcl and the Tk Toolkit
	management	An Introductionto Software Architecture
	interface	Evaluating KQML as an agent communication language in
1997	agent	Design Patterns: Elements of Reusable Object- Oriented Software
	architecture	Lorenzen: Object-Oriented Modeling and Design
	management	Tcl and the Tk Toolkit
	engineering	Evaluating KQML as an agent communication language in

	interaction	Agents that reduce work and information overload./n
1998	agent architecture management technology engineering	Design Patterns: Elements of Reusable Object- Oriented Software Lorenzen: Object-Oriented Modeling and Design Tcl and the Tk Toolkit Evaluating KQML as an agent communication language in Software Architecture: Perspectives on an Emerging Discipline
1999	agent architecture management technology interaction	Design Patterns: Elements of Reusable Object- Oriented Software Lorenzen: Object-Oriented Modeling and Design Software Architecture: Perspectives on an Emerging Discipline Evaluating KQML as an agent communication language in I.: The Unified Modeling Language: A User Guide
2000	agent architecture management technology interaction	Design Patterns: Elements of Reusable Object- Oriented Software I.: The Unified Modeling Language: A User Guide Software Architecture: Perspectives on an Emerging Discipline Lorenzen: Object-Oriented Modeling and Design Evaluating KQML as an agent communication language in
2001	agent architecture technology management interaction	Design Patterns: Elements of Reusable Object- Oriented Software I.: The Unified Modeling Language: A User Guide Software Architecture: Perspectives on an Emerging Discipline Evaluating KQML as an agent communication language in Lorenzen: Object-Oriented Modeling and Design
2002	agent architecture technology management interaction	Design Patterns: Elements of Reusable Object- Oriented Software I.: The Unified Modeling Language: A User Guide Software Architecture: Perspectives on an Emerging Discipline Component Software: Beyond Object-Oriented Programming. Addison-Wesley. University of Oregon, a. TAU Portable Profiling. http://www.cs.uoregon.edu/research/paracomp/tau Aspect-oriented programming
2003	agent architecture technology management interaction	Design Patterns: Elements of Reusable Object- Oriented Software I.: The Unified Modeling Language: A User Guide Aspect-oriented programming Software Architecture: Perspectives on an Emerging Discipline Component Software: Beyond Object-Oriented Programming. Addison-Wesley. University of Oregon, a. TAU Portable Profiling. http://www.cs.uoregon.edu/research/paracomp/tau
2004	agent architecture technology management interaction	Design Patterns: Elements of Reusable Object- Oriented Software I.: The Unified Modeling Language: A User Guide Aspect-oriented programming Refactoring: Improving the Design of Existing Code Software Architecture: Perspectives on an Emerging Discipline
2005	agent architecture technology interaction	Design Patterns: Elements of Reusable Object- Oriented Software Refactoring: Improving the Design of Existing Code Aspect-oriented programming I.: The Unified Modeling Language: A User Guide

	management	Software Architecture: Perspectives on an Emerging Discipline
2006	architecture technology interaction agent social	Design Patterns: Elements of Reusable Object- Oriented Software Refactoring: Improving the Design of Existing Code Aspect-oriented programming I.: The Unified Modeling Language: A User Guide Component Software: Beyond Object-Oriented Programming. Addison-Wesley. University of Oregon, a. TAU Portable Profiling. http://www.cs.uoregon.edu/research/paracomp/tau
2007	social architecture interaction technology community	Design Patterns: Elements of Reusable Object- Oriented Software Refactoring: Improving the Design of Existing Code Aspect-oriented programming I.: The Unified Modeling Language: A User Guide Social Network Analysis: Methods and Applications (Cambridge Univ
2008	social community interaction technology architecture	Design Patterns: Elements of Reusable Object- Oriented Software Refactoring: Improving the Design of Existing Code Aspect-oriented programming Social Network Analysis: Methods and Applications (Cambridge Univ I.: The Unified Modeling Language: A User Guide
2009	social community interaction technology architecture	Design Patterns: Elements of Reusable Object- Oriented Software Refactoring: Improving the Design of Existing Code Aspect-oriented programming Social Network Analysis: Methods and Applications (Cambridge Univ Software Architecture: Perspectives on an Emerging Discipline

Topic 16:

Year	Top 5 Words	Top 5 Citations
1993	rule pattern classification fuzzy clustering	Probabilistic decision trees 5: Programs for Machine Learning Classzfication and Regression Trees Pattern Classification and Scene Analysis Noise?Tolerant Instance?based Learning Algorithms
1994	rule pattern classification fuzzy database	Probabilistic decision trees 5: Programs for Machine Learning Classzfication and Regression Trees Pattern Classification and Scene Analysis UCI repository of machine learning databases, http://www.ics.uci.edu/ mlearn/MLRepository.html
1995	rule pattern classification database clustering	Probabilistic decision trees 5: Programs for Machine Learning Classzfication and Regression Trees Pattern Classification and Scene Analysis UCI repository of machine learning databases, http://www.ics.uci.edu/ mlearn/MLRepository.html
	rule	Probabilistic decision trees

1996	pattern	5: Programs for Machine Learning
	classification	Classzfication and Regression Trees
	database	Pattern Classification and Scene Analysis
	clustering	R-trees,: A Dynamic Index Structure for Spatial Searching
1997	pattern	5: Programs for Machine Learning
	rule	Probabilistic decision trees
	classification	Classzfication and Regression Trees
	database	Pattern Classification and Scene Analysis
	clustering	R-trees,: A Dynamic Index Structure for Spatial Searching
1998	pattern	5: Programs for Machine Learning
	rule	Probabilistic decision trees
	database	Pattern Classification and Scene Analysis
	classification	Classzfication and Regression Trees
	clustering	R-trees,: A Dynamic Index Structure for Spatial Searching
1999	pattern	5: Programs for Machine Learning
	rule	Probabilistic decision trees
	clustering	Pattern Classification and Scene Analysis
	mining	Fast algorithms for mining association rules
	database	Mining association rules between sets of items in large databases. SIGMOD1993
2000	pattern	5: Programs for Machine Learning
	clustering	Fast algorithms for mining association rules
	mining	Mining association rules between sets of items in large databases. SIGMOD1993
	rule	Probabilistic decision trees
	classification	Pattern Classification and Scene Analysis
2001	pattern	5: Programs for Machine Learning
	clustering	Fast algorithms for mining association rules
	mining	Mining association rules between sets of items in large databases. SIGMOD1993
	rule	Dubes R. C.: Algorithms for Clustering Data
	cluster	Pattern Classification and Scene Analysis
2002	pattern	5: Programs for Machine Learning
	clustering	Fast algorithms for mining association rules
	mining	Dubes R. C.: Algorithms for Clustering Data
	detection	Mining association rules between sets of items in large databases. SIGMOD1993
	cluster	Laaksonen, Variants of selforganizing maps
2003	pattern	Fast algorithms for mining association rules
	clustering	5: Programs for Machine Learning
	mining	Dubes R. C.: Algorithms for Clustering Data
	detection	Mining association rules between sets of items in large databases. SIGMOD1993
	cluster	Laaksonen, Variants of selforganizing maps

2004	clustering pattern mining detection cluster	Fast algorithms for mining association rules 5: Programs for Machine Learning Dubes R. C.: Algorithms for Clustering Data 2000, ‘Normalized cuts and image segmentation Mining association rules between sets of items in large databases. SIGMOD1993
2005	clustering pattern detection mining cluster	Fast algorithms for mining association rules 2000, ‘Normalized cuts and image segmentation 5: Programs for Machine Learning Dubes R. C.: Algorithms for Clustering Data Mining association rules between sets of items in large databases. SIGMOD1993
2006	clustering pattern detection mining cluster	2000, ‘Normalized cuts and image segmentation Fast algorithms for mining association rules 5: Programs for Machine Learning On spectral clustering, analysis and an algorithm Mining association rules between sets of items in large databases. SIGMOD1993
2007	clustering pattern detection mining cluster	2000, ‘Normalized cuts and image segmentation On spectral clustering, analysis and an algorithm Fast algorithms for mining association rules Emergenge of scaling in random networks Mean- The structure and function of complex networks field solution of the small-world network
2008	clustering pattern detection cluster mining	2000, ‘Normalized cuts and image segmentation On spectral clustering, analysis and an algorithm Mean- The structure and function of complex networks field solution of the small-world network Emergenge of scaling in random networks Fast algorithms for mining association rules
2009	clustering pattern detection cluster mining	2000, ‘Normalized cuts and image segmentation On spectral clustering, analysis and an algorithm Mean- The structure and function of complex networks field solution of the small-world network Emergenge of scaling in random networks Fast algorithms for mining association rules

Topic 17:

Year	Top 5 Words	Top 5 Citations
1993	realtime security operating	J.W.1973.Scheduling algorithms for multiprogramming in a hard real-time environment A Method of Obtaining Digital Signatures and Public-Key New Directions in Cryptography

	secure	Priority Inheritance Protocols: An Approachto Real-Time Synchronization
	signature	1989], A logic of authentication
1994	realtime	J.W.1973.Scheduling algorithms for multiprogramming in a hard real-time environment
	security	A Method of Obtaining Digital Signatures and Public-Key
	operating	New Directions in Cryptography
	secure	Priority Inheritance Protocols: An Approachto Real-Time Synchronization
	signature	1989], A logic of authentication
1995	realtime	J.W.1973.Scheduling algorithms for multiprogramming in a hard real-time environment
	security	A Method of Obtaining Digital Signatures and Public-Key
	secure	New Directions in Cryptography
	operating	Priority Inheritance Protocols: An Approachto Real-Time Synchronization
	signature	1989], A logic of authentication
1996	security	J.W.1973.Scheduling algorithms for multiprogramming in a hard real-time environment
	realtime	A Method of Obtaining Digital Signatures and Public-Key
	secure	New Directions in Cryptography
	attack	1989], A logic of authentication
	signature	Priority Inheritance Protocols: An Approachto Real-Time Synchronization
1997	security	A Method of Obtaining Digital Signatures and Public-Key
	realtime	J.W.1973.Scheduling algorithms for multiprogramming in a hard real-time environment
	secure	New Directions in Cryptography
	attack	1989], A logic of authentication
	signature	Probabilistic Encryption
1998	security	A Method of Obtaining Digital Signatures and Public-Key
	secure	New Directions in Cryptography
	attack	J.W.1973.Scheduling algorithms for multiprogramming in a hard real-time environment
	signature	1989], A logic of authentication
	realtime	Probabilistic Encryption
1999	security	A Method of Obtaining Digital Signatures and Public-Key
	attack	New Directions in Cryptography
	secure	of applied cryptography
	signature	J.W.1973.Scheduling algorithms for multiprogramming in a hard real-time environment
	message	Probabilistic Encryption
	security	A Method of Obtaining Digital Signatures and Public-Key
	attack	of applied cryptography

2000	secure	New Directions in Cryptography
	signature	Random Oracles are Practical: a Paradigm for Designing Efficient Protocols
	message	Probabilistic Encryption
2001	security	of applied cryptography
	attack	A Method of Obtaining Digital Signatures and Public-Key
	secure	New Directions in Cryptography
	signature	Random Oracles are Practical: a Paradigm for Designing Efficient Protocols
	message	Probabilistic Encryption
2002	security	of applied cryptography
	attack	Random Oracles are Practical: a Paradigm for Designing Efficient Protocols
	secure	A Method of Obtaining Digital Signatures and Public-Key
	signature	New Directions in Cryptography
	policy	Probabilistic Encryption
2003	security	of applied cryptography
	attack	Random Oracles are Practical: a Paradigm for Designing Efficient Protocols
	secure	New Directions in Cryptography
	signature	A Method of Obtaining Digital Signatures and Public-Key
	policy	A (1979) How to Share a Secret
2004	security	of applied cryptography
	attack	Random Oracles are Practical: a Paradigm for Designing Efficient Protocols
	secure	New Directions in Cryptography
	signature	A Method of Obtaining Digital Signatures and Public-Key
	policy	A (1979) How to Share a Secret
2005	security	Random Oracles are Practical: a Paradigm for Designing Efficient Protocols
	attack	New Directions in Cryptography
	secure	of applied cryptography
	signature	A Method of Obtaining Digital Signatures and Public-Key
	policy	Probabilistic Encryption
2006	security	Random Oracles are Practical: a Paradigm for Designing Efficient Protocols
	attack	New Directions in Cryptography
	secure	of applied cryptography
	signature	A Method of Obtaining Digital Signatures and Public-Key
	policy	A (1979) How to Share a Secret
2007	security	New Directions in Cryptography
	attack	Random Oracles are Practical: a Paradigm for Designing Efficient Protocols
	secure	of applied cryptography

	signature	Identity-based encryption from the Weil Pairing, Crypto 01
	policy	A (1979) How to Share a Secret
	security	New Directions in Cryptography
	attack	Random Oracles are Practical: a Paradigm for Designing Efficient Protocols
2008	secure	Identity-based encryption from the Weil Pairing, Crypto 01
	policy	A (1979) How to Share a Secret
	signature	of applied cryptography
	security	New Directions in Cryptography
	attack	Random Oracles are Practical: a Paradigm for Designing Efficient Protocols
2009	secure	A (1979) How to Share a Secret
	policy	Probabilistic Encryption
	signature	Identity-based encryption from the Weil Pairing, Crypto 01

Topic 18:

Year	Top 5 Words	Top 5 Citations
	algebra	ymmetcic functions and Hall polynomials
	quantum	Algebraic Geometry
1993	polynomial	G.: Quantum groups, in
	operator	Exactly Solved Models in Statistical Me-chanics
	theorem	Non-Commutative Geometry
	algebra	ymmetcic functions and Hall polynomials
	quantum	Algebraic Geometry
1994	polynomial	Non-Commutative Geometry
	operator	G.: Quantum groups, in
	theorem	Exactly Solved Models in Statistical Me-chanics
	algebra	ymmetcic functions and Hall polynomials
	quantum	Algebraic Geometry
1995	polynomial	Non-Commutative Geometry
	operator	G.: Quantum groups, in
	theorem	Principles of algebraic geometry
	quantum	ymmetcic functions and Hall polynomials
	algebra	Algebraic Geometry
1996	polynomial	Non-Commutative Geometry
	operator	Principles of algebraic geometry
	theorem	G.: Quantum groups, in
	algebra	Non-Commutative Geometry
	quantum	Algebraic Geometry
1997	polynomial	ymmetcic functions and Hall polynomials
	operator	Commutative Algebra with a View Toward Algebraic Theory
	theorem	Principles of algebraic geometry
	algebra	Non-Commutative Geometry
	quantum	Algebraic Geometry

1998	polynomial	The Large N Limit Of Superconformal Field Theories And Supergravity, hep-th/971120
	operator	Commutative Algebra with a View Toward Algebraic Theory
	theorem	ymmetcic functions and Hall polynomials
	algebra	Non-Commutative Geometry
	quantum	The Large N Limit Of Superconformal Field Theories And Supergravity, hep-th/971120
1999	polynomial	Algebraic Geometry
	group	Commutative Algebra with a View Toward Algebraic Theory
	operator	Introduction to Intersection Theory
	algebra	Non-Commutative Geometry
	quantum	The Large N Limit Of Superconformal Field Theories And Supergravity, hep-th/971120
2000	polynomial	Commutative Algebra with a View Toward Algebraic Theory
	manifold	Algebraic Geometry
	group	Linear partial differential operators 3
	algebra	Non-Commutative Geometry
	quantum	The Large N Limit Of Superconformal Field Theories And Supergravity, hep-th/971120
2001	polynomial	Commutative Algebra with a View Toward Algebraic Theory
	manifold	Algebraic Geometry
	curve	Linear partial differential operators 3
	algebra	Non-Commutative Geometry
	quantum	Commutative Algebra with a View Toward Algebraic Theory
2002	polynomial	The Large N Limit Of Superconformal Field Theories And Supergravity, hep-th/971120
	manifold	Algebraic Geometry
	curve	Linear partial differential operators 3
	algebra	Non-Commutative Geometry
	quantum	The Large N Limit Of Superconformal Field Theories And Supergravity, hep-th/971120
2003	polynomial	Commutative Algebra with a View Toward Algebraic Theory
	manifold	Algebraic Geometry
	curve	Linear partial differential operators 3
	algebra	The Large N Limit Of Superconformal Field Theories And Supergravity, hep-th/971120
	quantum	Non-Commutative Geometry
2004	polynomial	Commutative Algebra with a View Toward Algebraic Theory
	manifold	Algebraic Geometry
	curve	Linear partial differential operators 3
	algebra	The Large N Limit Of Superconformal Field Theories And Supergravity, hep-th/971120
	quantum	Non-Commutative Geometry
2005	polynomial	Commutative Algebra with a View Toward Algebraic Theory

	group	Algebraic Geometry
	manifold	Linear partial differential operators 3
2006	algebra	The Large N Limit Of Superconformal Field Theories And Supergravity, hep-th/971120
	quantum	Non-Commutative Geometry
	polynomial	Commutative Algebra with a View Toward Algebraic Theory
	group	Algebraic Geometry
	manifold	Linear partial differential operators 3
2007	algebra	The Large N Limit Of Superconformal Field Theories And Supergravity, hep-th/971120
	quantum	Non-Commutative Geometry
	polynomial	Commutative Algebra with a View Toward Algebraic Theory
	group	Algebraic Geometry
	curve	Linear partial differential operators 3
2008	algebra	The Large N Limit Of Superconformal Field Theories And Supergravity, hep-th/971120
	polynomial	Non-Commutative Geometry
	quantum	Commutative Algebra with a View Toward Algebraic Theory
	group	Algebraic Geometry
	curve	Linear partial differential operators 3
2009	algebra	The Large N Limit Of Superconformal Field Theories And Supergravity, hep-th/971120
	polynomial	Commutative Algebra with a View Toward Algebraic Theory
	quantum	Non-Commutative Geometry
	group	Algebraic Geometry
	curve	Linear partial differential operators 3

Topic 19:

Year	Top 5 Words	Top 5 Citations
1993	equation	GMRES: A generalized minimal residual algorithm for solving unsymmetric linear systems
	matrix	Convex Analysis
	numerical	The Algebraic Eigenvalue Problem
	nonlinear	The finite element method for elliptic problems
	convergence	Numerical Analysis
1994	equation	GMRES: A generalized minimal residual algorithm for solving unsymmetric linear systems
	matrix	Convex Analysis
	numerical	The Algebraic Eigenvalue Problem
	nonlinear	The finite element method for elliptic problems
	convergence	Numerical Analysis
	equation	GMRES: A generalized minimal residual algorithm for solving unsymmetric linear systems
	matrix	Convex Analysis

1995	numerical	The finite element method for elliptic problems
	nonlinear	The Algebraic Eigenvalue Problem
	convergence	Convergence of Probability Measures J
1996	equation	GMRES: A generalized minimal residual algorithm for solving unsymmetric linear systems
	matrix	Convex Analysis
	numerical	The finite element method for elliptic problems
	nonlinear	Convergence of Probability Measures J
	convergence	The Algebraic Eigenvalue Problem
1997	equation	Convex Analysis
	matrix	GMRES: A generalized minimal residual algorithm for solving unsymmetric linear systems
	numerical	Convergence of Probability Measures J
	nonlinear	The finite element method for elliptic problems
	convergence	Numerical Analysis
1998	equation	Convex Analysis
	numerical	Convergence of Probability Measures J
	matrix	GMRES: A generalized minimal residual algorithm for solving unsymmetric linear systems
	nonlinear	Numerical Analysis
	convergence	The finite element method for elliptic problems
1999	equation	Convex Analysis
	numerical	Convergence of Probability Measures J
	nonlinear	Numerical Analysis
	matrix	GMRES: A generalized minimal residual algorithm for solving unsymmetric linear systems
	convergence	The finite element method for elliptic problems
2000	equation	Convergence of Probability Measures J
	numerical	Convex Analysis
	nonlinear	Numerical Analysis
	matrix	GMRES: A generalized minimal residual algorithm for solving unsymmetric linear systems
	convergence	Iterative Methods for Sparse Linear Systems
2001	equation	Convergence of Probability Measures J
	numerical	Convex Analysis
	nonlinear	Numerical Analysis
	matrix	Iterative Methods for Sparse Linear Systems
	stochastic	GMRES: A generalized minimal residual algorithm for solving unsymmetric linear systems
2002	equation	Convergence of Probability Measures J
	numerical	Convex Analysis
	nonlinear	Numerical Analysis
	stochastic	Iterative Methods for Sparse Linear Systems

	matrix	GMRES: A generalized minimal residual algorithm for solving unsymmetric linear systems
2003	equation numerical stochastic nonlinear matrix	Convergence of Probability Measures J Convex Analysis Numerical Analysis Iterative Methods for Sparse Linear Systems GMRES: A generalized minimal residual algorithm for solving unsymmetric linear systems
2004	equation stochastic numerical matrix convergence	Convergence of Probability Measures J Numerical Analysis Convex Analysis Iterative Methods for Sparse Linear Systems An Introduction to Probability Theory and Its Applications, Volume I, Second edition
2005	equation stochastic numerical convergence matrix	Convergence of Probability Measures J Numerical Analysis Convex Analysis Robust Uncertainty Principles: Exact Signal Reconstruction from Highly Incomplete Frequency Information, to appear 2005) Extensions of compressed sensing
2006	equation stochastic convergence numerical matrix	Numerical Analysis Convergence of Probability Measures J 2005) Extensions of compressed sensing Robust Uncertainty Principles: Exact Signal Reconstruction from Highly Incomplete Frequency Information, to appear Convex Analysis
2007	equation convergence matrix stochastic numerical	2005) Extensions of compressed sensing Robust Uncertainty Principles: Exact Signal Reconstruction from Highly Incomplete Frequency Information, to appear Numerical Analysis Convergence of Probability Measures J Near Optimal Signal Recovery from Random Projections: Universal Encoding Strategies?, manuscript submitted for publication
2008	equation convergence matrix stochastic numerical	2005) Extensions of compressed sensing Robust Uncertainty Principles: Exact Signal Reconstruction from Highly Incomplete Frequency Information, to appear Near Optimal Signal Recovery from Random Projections: Universal Encoding Strategies?, manuscript submitted for publication Numerical Analysis Convergence of Probability Measures J
	equation convergence	2005) Extensions of compressed sensing Robust Uncertainty Principles: Exact Signal Reconstruction from Highly Incomplete Frequency Information, to appear

2009	matrix	Near Optimal Signal Recovery from Random Projections: Universal Encoding Strategies?, manuscript submitted for publication
	numerical	Convergence of Probability Measures J
	stochastic	Numerical Analysis

Topic 20:

Year	Top 5 Words	Top 5 Citations
	fault	Orthonormal bases of compactly supported wavelets. Commun. Purr ppl
	wavelet	Maximum likelihoodfromincomplete data via the EM algorithm
1993	estimation	A theory for multi-resolution signal decomposition, the wavelet representation
	parameter	Impossiblity of Distributed Consensus with One Faulty Process
	compression	Ten lectures on wavelets
	fault	Orthonormal bases of compactly supported wavelets. Commun. Purr ppl
	wavelet	Maximum likelihoodfromincomplete data via the EM algorithm
1994	estimation	A theory for multi-resolution signal decomposition, the wavelet representation
	parameter	Impossiblity of Distributed Consensus with One Faulty Process
	compression	Ten lectures on wavelets
	wavelet	Orthonormal bases of compactly supported wavelets. Commun. Purr ppl
	estimation	Maximum likelihoodfromincomplete data via the EM algorithm
1995	fault	A theory for multi-resolution signal decomposition, the wavelet representation
	parameter	Ten lectures on wavelets
	estimate	Impossiblity of Distributed Consensus with One Faulty Process
	wavelet	Maximum likelihoodfromincomplete data via the EM algorithm
	estimation	Orthonormal bases of compactly supported wavelets. Commun. Purr ppl
1996	parameter	A theory for multi-resolution signal decomposition, the wavelet representation
	fault	Thomas J.: Elements of Information Theory
	estimate	Ten lectures on wavelets
	wavelet	Maximum likelihoodfromincomplete data via the EM algorithm
	estimation	Orthonormal bases of compactly supported wavelets. Commun. Purr ppl
1997	parameter	Statistical Learning Theory
	estimate	A theory for multi-resolution signal decomposition, the wavelet representation
	filter	Thomas J.: Elements of Information Theory
	wavelet	Statistical Learning Theory
	estimation	Maximum likelihoodfromincomplete data via the EM algorithm

1998	parameter estimate filter	Thomas J.: Elements of Information Theory Neural neural networks for pattern recognition Orthonormal bases of compactly supported wavelets. Commun. Purr ppl
1999	estimation wavelet parameter vector estimate	Statistical Learning Theory Maximum likelihoodfromincomplete data via the EM algorithm Neural neural networks for pattern recognition Thomas J.: Elements of Information Theory A theory for multi-resolution signal decomposition, the wavelet representation
2000	estimation vector parameter wavelet estimate	Statistical Learning Theory Maximum likelihoodfromincomplete data via the EM algorithm Neural neural networks for pattern recognition Thomas J.: Elements of Information Theory and V.Vapnik. Support vector network
2001	estimation vector parameter estimate wavelet	Statistical Learning Theory Maximum likelihoodfromincomplete data via the EM algorithm Neural neural networks for pattern recognition Thomas J.: Elements of Information Theory and V.Vapnik. Support vector network
2002	estimation vector parameter classifier classification	Statistical Learning Theory Maximum likelihoodfromincomplete data via the EM algorithm Thomas J.: Elements of Information Theory Neural neural networks for pattern recognition Bagging predictors
2003	estimation vector kernel classification classifier	Statistical Learning Theory Maximum likelihoodfromincomplete data via the EM algorithm Thomas J.: Elements of Information Theory Neural neural networks for pattern recognition Online learning with kernels
2004	estimation kernel vector classification classifier	Statistical Learning Theory Thomas J.: Elements of Information Theory Maximum likelihoodfromincomplete data via the EM algorithm Online learning with kernels Neural neural networks for pattern recognition
2005	estimation kernel vector classification parameter	Statistical Learning Theory Online learning with kernels Thomas J.: Elements of Information Theory Maximum likelihoodfromincomplete data via the EM algorithm Neural neural networks for pattern recognition
2006	estimation kernel parameter sample	Statistical Learning Theory Online learning with kernels Thomas J.: Elements of Information Theory Maximum likelihoodfromincomplete data via the EM algorithm

	vector	Atomic decomposition by basis pursuit
2007	estimation	Statistical Learning Theory
	kernel	Atomic decomposition by basis pursuit
	sample	Online learning with kernels
	parameter	Thomas J.: Elements of Information Theory
	regression	Maximum likelihoodfromincomplete data via the EM algorithm
2008	estimation	Statistical Learning Theory
	kernel	Atomic decomposition by basis pursuit
	sample	Online learning with kernels
	signal	Regression shrinkage and selection via Lasso
	sparse	Convex Optimization
2009	estimation	Statistical Learning Theory
	sparse	Atomic decomposition by basis pursuit
	signal	Regression shrinkage and selection via Lasso
	sample	Convex Optimization
	kernel	Online learning with kernels