ADVANCE OF THE ACCESS METHODS

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Abstract: The goal of this paper is to outline the advance of the access methods in the last ten years as well as to make review of all available in the accessible bibliography methods.

Keywords: Access Methods, Overview of the Access Methods

ACM Classification Keywords: D.4.3 File Systems Management, Access methods

Introduction

The Access Methods (AM) had been available from the beginning of the developing the computer peripheral devices. As many devices there exists so many possibilities for developing different AM we have. Our attention is focused only to the access methods for devices for permanently storing the information with direct access such as magnetic discs, flash memories, etc.

In the beginning, the AM ware functions of the Operational Systems Core or so called Supervisor, and ware executed via corresponded macro-commands in the assembler languages [Stably, 1970] or via corresponding input/output operators in the high level programming languages like FORTRAN, COBOL, PL/I, etc.

Establishing of the first data bases in the 60-ties years of the last century caused gradually accepting the concepts "physical" as well as "logical" organization of the data [CODASYL, 1971], [Martin, 1975]. In 1975 the concepts "access method", "physical" and "logical" are clearly separated. In the same time Christopher Date [Date, 1977] specially remarked:

"The Data Base Management System (DBMS) does not know anything about:

a) physical records (blocks);
b) how the stored fields are integrated in the records (nevertheless that in many cases it is obviously because of theirs physical disposition);
c) how the sorting is realized (for instance it may be realized on the base of physical sequence, using an index or by a chain of pointers);
d) how is realized the direct access (i.e. by index, sequential scanning or hash addressing).

This information is a part of the structures for data storing but it is used by the access method but not by the DBMS. "

Every access method presumes an exact organization of the file which it is operating with and has no relation to the interconnections between the files, respectively – between the records of one file and that in the others files. These interconnections are controlled by the physical organization of the DBMS.

So, in the DBMS we may distinguish four levels:

- access methods of the core (supervisor) of the operation system;
- specialized access methods which upgrade these of the core of the operating system;
- physical organization of the DBMS;
- logical organization of the DBMS.

During the 80-ies years the "Multi-Dimensional Access Methods" had raised. In accordance with them the corresponded "spatial information structures" and the "spatio-temporal information structures" had risen, too. These AM developed the methods of the operating systems via specializing them to the give data models. From different point of view this period had been presented in [Ooi et al, 1993], [Gaede, Günther, 1998], [Arge, 2002], [Mokbel et al, 2003], [Moënne-Loccoz, 2005].

Usually the "one-dimensional" (linear) AM are used in the classical applications, based on the alpha-numerical information, whereas the "multi-dimensional" (spatial) methods are aimed to serve the work with graphical, visual, multimedia information. Now a special attention is given to the multi-dimensional AM.

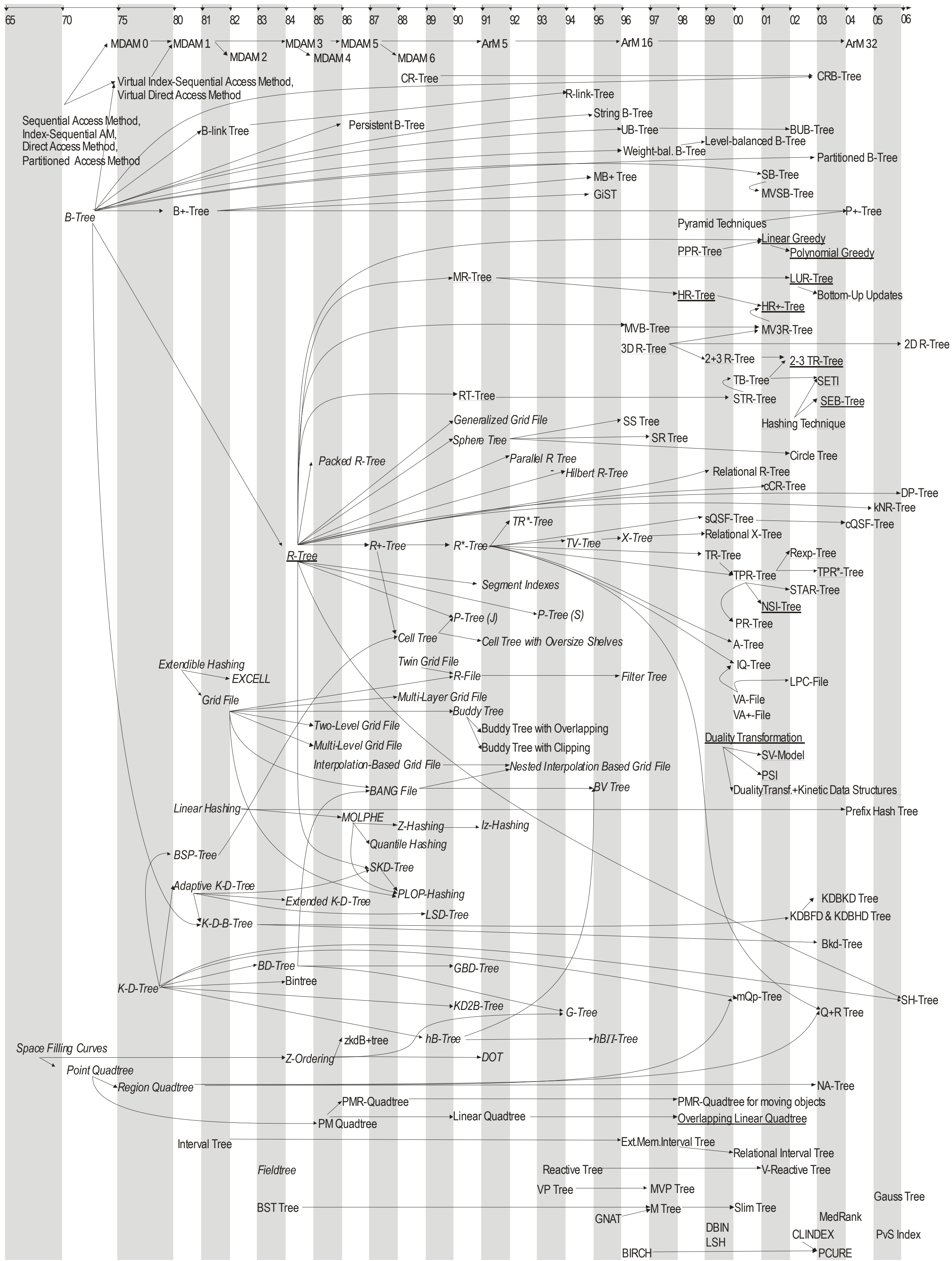

Fig. 1. Genesis of the Access Methods and their modifications
extended variant of [Gaede, Günther, 1998] and [Mokbel et al, 2003]

Maybe one of the most popular analyses is given in [Gaede, Günther, 1998]. The authors presented a scheme of the genesis of the basic multi-dimensional AM and theirs modifications. This scheme firstly was proposed in [Ooi et al, 1993] and it was expanded in [Gaede, Günther, 1998]. An extension in direction to the multi-dimensional spatio-temporal access methods was given in [Mokbel et al, 2003].

This work continues the investigation provided in [Markov, 2006]. The main goal of this paper is to present a new variant of this scheme. It is presented on Fig.1. In it the new access methods created after 1998 are added. The methods presented in [Gaede, Günther, 1998] are marked in italics and methods presented in [Mokbel et al, 2003] are underlined. Access methods, which are given in the two surveys simultaneously, are marked in underlined italics. In the appendix of this paper the corresponded bibliography is given.

The access methods presented on Fig.1 we may classify as follow:

- One-dimensional AM;
- Multidimensional Spatial AM;
- Metric Access Methods;
- High Dimensional Access Methods;
- Spatio-Temporal Access Methods.

One-dimensional Access Methods

One-dimensional AM are based on the concept "record". Let remember that the "record" is a logical sequence of fields which contain data eventually connected to unique identifier (a "key"). The identifier (key) is aimed to distinguish one sequence from another [Stably, 1970]. The records are united in the sets, called "files". There exist three basic formats of the records – with fixed, variable and undefined length.

In the *context-free methods* the storing of the records is not connected to theirs content and depends only on external factors – the sequence, disk address or position in the file. The necessity of stable file systems in the operating systems does not allow a great variety of the context-free AM. There are three main types well known from 60-ies and 70-ies years: *Sequential Access Method (SAM); Direct Access Method (DAM) and Partitioned Access Method (PAM)* [IBM, 1965-68].

The main idea of the *context-depended AM* is that the part of the record is selected as a key which is used for making decision where to store the record and how to search it. This way the content of the record influences on the access to the record.

Historically, from the 60-ies years of the last century the attention is directed mainly to this type of AM. Modern DBMS are built using context-depended AM such as: unsorted sequential files with records with keys; sorted files with fixed record length; static or dynamic hash files; index file and files with data; clustered indexed tables [Connolly, Begg, 2002].

Multidimentional Spatial Access Methods

Multidimensional Spatial Access Methods are developed to serve information about spatial objects, approximated with points, segments, polygons, polyhedrons, etc. The implementations are numerous and include traditional multi-attributive indexing, geographical information systems and spatial databases, content indexing in multimedia databases, etc.

From the point of view of the spatial databases can be split in two main classes of access methods – Point Access Methods and Spatial Access Methods [Gaede, Günther, 1998].

Point Access Methods are used for organizing multidimensional point objects. Typical instance are traditional records, where on every attribute of the relation corresponds one dimension. These methods can be separated in three basic groups:

- Multidimensional Hashing (for instance Grid File and its varieties, EXCELL, Twin Grid File, MOLPHE, Quantile Hashing, PLOP-Hashing, Z-Hashing, etc);
- Hierarchical Access Methods (includes such methods as KDB-Tree, LSD-Tree, Buddy Tree, BANG File, G-Tree, hB-Tree, BV-Tree, etc.);
- Space Filling Curves for Point Data (like Peano curve, N-trees, Z-Ordering, etc).

Spatial Access Methods are used for working with objects which have arbitrary form. The main idea of the spatial indexing of non-point objects is using of the approximation of the geometry of the examined objects to more simple forms. The most used approximation is Minimum Bounding Rectangle (MBR), i.e. minimal rectangle, which sides are parallel of the coordinate axes and completely include the object. There exist approaches for approximation with Minimum Bounding Spheres (SS Tree) or other polytopes (Cell Tree), as well as their combinations (SR-Tree).

The usual problem when one operates with spatial objects is their overlapping. There are different techniques to avoid this problem. From the point of view of the techniques for organization of the spatial objects Spatial Access Methods can be split in four main groups:

- Transformation – this technique uses transformation of spatial objects to points in the space with more or less dimensions. Most of them spread out the space using space filling curves (Peano Curves, z-ordering, Hibert curves, Gray ordering, etc.) and then use some of point access method upon the transformed data set. For instance UB-Tree [Bayer, 1996], is variant of B-Tree, where keys are region addresses, sorted via "≤" and z-ordering;
- Overlapping Regions – here the data set are separated in groups; different groups can occupy the same part of the space, but every space object associates with only one of the groups. The access methods of this category operate with data in their primary space (without any transformations) eventually in overlapping segments. Methods, which use this technique includes R-Tree, R-link-Tree, Hilbert R-Tree, R*-Tree, Sphere Tree, SS-Tree, SR-Tree, TV-Tree, X-Tree, P-Tree of Schiwietz, SKD-Tree, GBD-Tree, Buddy Tree with overlapping, PLOP-Hashing, etc.;
- Clipping – this technique use eventually clipping of one object to several sub-objects, which will be stored. The main goal is to escape overlapping regions. But this advantage can lead tearing of the objects, extending of the resource expenses and decreasing of the productivity of the method. Representatives of this technique are R+-Tree, Cell-Tree, Extended KD-Tree, Quad-Tree, etc.;
- Multiple Layers – this technique can be examining as variant of the techniques of Overlapping Regions, because the regions from different layers can overlap. But there exist some important differences: first – the layers are organizing hierarchically; second – every layer split primary space in different way; third – the regions of one layer never overlaps; fourth – the data regions are separated from space extensions of the objects. Instances for these methods are Multi-Layer Grid File, R-File, etc.

Metric Access Methods

Metric Access Methods deal with relative distances of data points to chosen points, named anchor points, vantage points or pivots [Moënne-Loccoz, 2005]. These methods are designed to limit the number of distance computation, calculating first distances to anchors, and then finding searched point in narrowed region. These methods are preferred when the distance is highly computational, as e.g. for the dynamic time warping distance between time series. Presentatives of these methods are: Vantage Point Tree (VP Tree), Bisector Tree (BST-Tree), Geometric Near-Neighbour Access Tree (GNNAT), as well as the most effective from this group – Metric Tree (M-Tree) [Chavez et al, 2001].

High Dimensional Access Methods

Increasing of the dimensionality strongly aggravates the qualities of the multidimensional access methods. Usually these methods exhaust their possibilities till dimensions around 15. Only X-Tree reaches the boundary of 25 dimensions, after then this method gives worse results then sequential scanning [Chakrabarti, 2001].

The exit of this situation is based on the data approximation and query approximation in sequential scan. These methods form a new group of access methods – High Dimensional Access Methods.

Data approximation is used in VA-File, VA+-File, LPC-File, IQ-Tree, A-Tree, P+-Tree, etc.

Because in high dimensional access methods the selectivity of the methods makes worse, it is allowed some answers inaccuracy. For query approximation two strategies can be used:

- examine only a part of the database, which is more probably to contain resulting set – as a rule these methods are based on the clustering of the database. Some of these methods are: DBIN, CLINDEX, PCURE;
- splitting the database to several spaces with fewer dimensions and searching in each of them. Here two main methods are used:

1) Random Lines Projection (presentatives of this approach are MedRank, which uses B+-Tree for indexing every arbitrary projection of the database, and PvS Index, which consist of combination of iterative projections and clustering);

2) Locality Sensitive Hashing, which is based on the set of local-sensitive hashing functions [Moënne-Loccoz, 2005].

Spatio-Temporal Access Methods

The Spatio-Temporal Access Methods have additional defined time dimensioning. [Mokbel et al, 2003]. They operate with objects, which change their form and/or position during the time. According to position of time interval in relation to present moment the Spatio-Temporal Access Methods are divided to:

- indexing the past, i.e. methods for operating with historical spatio-temporal data. The problem here is continuously increasing of the information over time. To overcome the overflow of the data space two approaches are used – sampling the stream data at certain time position or update the information only when data is changed. Spatio-temporal indexing schemes for historical data can be split in three categories: first category includes methods that manages spatial and temporal aspects into already existing spatial methods; second can be explained as snapshots of the spatial information in each time instance; the third category focus on trajectory-oriented queries, while spatial dimension lag on second priority. Presentatives of this group are: RT-Tree, 3DR-Tree, STR-Tree, MR-Tree, HR-Tree, HR+-Tree, MV3R-Tree, PPR-Tree, TB-Tree, SETI, SEB-Tree;
- indexing the present. In contrast to previous methods, where all movements are known, here current positions are neither stored nor queried. Some of the methods, which answer of the questions of the current position of the objects are 2+3R-Tree, 2-3TR-Tree, LUR-Tree, Bottom-Up Updates, etc.;
- indexing the future. These methods have to answer on the questions about current and future position of moving object – here are embraced the methods like PMR-Quadtree for moving objects, Duality Transformation, SV-Model, PSI, PR-Tree, TPR-Tree, TPR*-tree, NSI, VCIR-Tree, STAR-Tree, R^{EXP}-Tree.

Conclusion

In this paper we presented a short overview of the current state in the field of development of the access methods. During the last four decades the access methods have been developed toward plenty of modifications of small number basic ideas. It is important to remark that the research has been provided on software as well as on hardware levels. For instance, in [Schlosser et al, 2005] a technology for storing of multi-dimensional data with physically preserving the multi-dimensionality of the data is presented

The developed multi-dimensional index structures are effective for the small number of dimensions (from 2 – 5 up to 10 -15) and are uncomfortable for multi-dimensional spaces which are typical for the contemporary practical problems and the linear scanning may be preferable in many cases [Chakrabarti, 2001]. This is known as "Curse of dimensionality".

The concept of "curse of dimensionality" was first coined by Richard Bellman [Bellman 1961]. He employed it to describe the problem caused by the exponential increase of the volume with the augmentation of the space dimension when addressing the problem of optimizing functions with several variables. Later, the term was used to indicate, more generally, non-intuitive phenomena observed when the dimension of data increases [Bouteldja et al, 2006].

The survey of the access methods suggests that the context-free multi-dimensional access methods practically are not available. One step in developing such methods is the Multi-domain Access Method introduced in [Markov, 2004].

We have no place to present all access methods in details. The main goal was to collect the basic publications of the most popular access methods. The further survey needs to be provided to present current state of the art in this area.

Appendix 1. Access Methods and Corresponded Publications

Access Method	Publicated in
2+3 R-Tree	[Nascimento, 1999] M. A. Nascimento, J.R.O. Silva, Y. Theodoridis. *Evaluation of Access Structures for Discretely Moving Points*. In Proc. of the Intl. Workshop on Spatio-Temporal Database Management, STDBM, pages 171–188, Sept. 1999.
2-3 TR-Tree	[Abdelguerfi et al, 2002] M. Abdelguerfi, J. Givaudan, K. Shaw, R. Ladner. *The 2-3 TR-tree, A Trajectory-Oriented Index Structure for Fully Evolving Valid-time Spatio-temporal Datasets*. In Proc. of the ACM workshop on Adv. in Geographic Info. Sys., ACM GIS, pages 29–34, Nov. 2002.
2D R-Tree	[Osborn, Barker, 2006] W. Osborn, K. Barker. *Searching through Spatial Relationships using the 2DR-tree*. The IASTED Conference on Internet and Multimedia Systems and Applications Honolulu, Hawaii, USA August 14-16, 2006
3D R-tree	[Theodoridis et al, 1996] Y. Theodoridis, M. Vazirgiannis, T. Sellis. *Spatio-Temporal Indexing for Large Multimedia Applications*. In Proc. of the IEEE Conference on Multimedia Computing and Systems, ICMCS, June 1996.
Adaptive K-D-Tree	[Bentley, Friedman, 1979] J. L. Bentley, J. H. Friedman. *Data structures for range searching*. ACM Comput. Surv. 11, 1979, 4, 397–409.
A-Tree (Approximation Tree)	[Sakurai et al, 2000] Y. Sakurai, M. Yoshikawa, S. Uemura, H. Kojima. *The a-tree: An index structure for high-dimensional spaces using relative approximation*. In VLDB, pages 516–526, 2000.
B+-tree	[Comer, 1979] D. Comer. *The ubiquitous B-tree*. ACM Comput. Surv. 11, 2, 1979, 121–138.
Balanced Multidimensional Extendible Hash Tree	[Otoo, 1985] E.J. Otoo. *Balanced multidimensional extendible hash tree*. In Proceedings of the fifth ACM SIGACT-SIGMOD symposium on Principles of database systems, Cambridge, Massachusetts, United States, 1985, Pages: 100 – 113
BANG File	[Freeston, 1987] M. Freeston. *The BANG file: A new kind of grid file*. In Proceedings of the ACM SIGMOD International Conference on Management of Data, 1987, pp. 260–269.
BD-Tree	[Ohsawa, Sakauchi, 1983] Y. Ohsawa, M. Sakauchi. *BD-tree: A new n-dimensional data structure with efficient dynamic characteristics*. In Proceedings of the Ninth World Computer Congress, IFIP 1983, 1983, pp. 539–544.
Bintree	[Tamminen, 1984] M. Tamminen. *Comment on quad- and octrees*. Commun. ACM 30, 3, 204–212. 1984
BIRCH	[Zhang et al, 1996] T. Zhang, R. Ramakrishnan, M. Livny. *BIRCH: an efficient data clustering method for very large databases*. pages 103–114, 1996.
Bkd-Tree	[Procopiuc et al, 2003] O. Procopiuc, P. K. Agarwal, L. Arge, J.-S. Vitter. *Bkd-tree: A Dynamic Scalable kd-tree*. In Proceedings of International Symposium on Spatial and Temporal Databases, 2003
B-link Tree	[Lehman, Yao, 1981] P. Lehman, S. Yao. *Efficient locking for concurrent operations on B-trees*. ACM Trans. Database Syst. 6, 4, 1981, 650–670.
Bottom-up Updates	[Lee et al, 2003] M. Lee, W. Hsu, C. Jensen, B. Cui, K. Teo. *Supporting Frequent Updates in R-Trees: A Bottom-Up Approach*. In Proc. of the Intl. Conf. on Very Large Data Bases, VLDB, Sept. 2003.
BSP-Tree	[Fuchs et al, 1980] H. Fuchs, Z. Kedem, B. Naylor. *On visible surface generation by a priori tree structures*. Computer Graph. 14, 3, 1980.
BST-Tree (Bisector Tree)	[Kalantari, McDonald, 1983] I. Kalantari, G. McDonald. *A data structure and an algorithm for the nearest point problem*. IEEE Trans. Software Eng., 9(5):631–634, 1983.
B-Tree	[Bayer, McCreicht, 1972] R. Bayer, E. M. McCreicht. *Organization and maintenance of large ordered indices*. Acta Inf. 1, 3, 1972, pp. 173–189.
BUB-Tree (Bounding UB Tree)	[Fenk, 2002] R. Fenk. *The BUB-Tree*. In Proceedings of VLDB Conf. Hongkong, 2002
Buddy Tree	[Seeger, Kriegel, 1990] B. Seeger, H.-P. Kriegel. *The buddy-tree: An efficient and robust access method for spatial data base systems*. In Proceedings of the Sixteenth International Conference on Very Large Data Bases, 1990, pp. 590–601.
Buddy Tree with Clipping	[Seeger, 1991] B. Seeger. *Performance comparison of segment access methods implemented on top of the buddy-tree*. In Advances in Spatial Databases, O. Gu¨ nther and H. Schek, Eds., LNCS 525, Springer-Verlag, Berlin/Heidelberg/New York, 1991, 277–296.
Buddy Tree with Overlapping	[Seeger, 1991] B. Seeger. *Performance comparison of segment access methods implemented on top of the buddy-tree*. In Advances in Spatial Databases, O. Gu¨ nther and H. Schek, Eds., LNCS 525, Springer-Verlag, Berlin/Heidelberg/New York, 1991, 277–296.
Buffer Tree	[Arge, 1995] L. Arge. *The buffer tree: a new technique for optimal I/O-algorithms*. In Proc.Workshop on Algorithms and Data Structures, pages 334–345. LNCS 955. Springer-Verlag, Berlin, 1995. [Arge, 2003] Lars Arge. *The Buffer Tree: A Technique for Designing Batched External Data Structures.* Algorithmica, Springer-Verlag New York Inc. 2003

BV Tree	[Freeston, 1995] M. Freeston. A *general solution of the n-dimensional B-tree problem*. In Proceedings of the ACM SIGMOD International Conference on Management of Data, 1995, pp. 80–91.
cCR-tree (Cache-Conscious R-Tree)	[Kim et al, 2001] K. Kim, S.K. Cha, K. Kwon. *Optimizing multidimensional index trees for main memory access*. International Conference on Management of Data Proceedings of the 2001 ACM SIGMOD international conference on Management of data, Santa Barbara, California, United States, 2001, Pp: 139 – 150
Cell Tree	[Günther, 1988] O. Günther. *Efficient Structures for Geometric Data Management*. LNCS 337, Springer-Verlag, Berlin/Heidelberg/New York. 1988.
Cell Tree with Oversize Shelves	[Günther, Noltemeier, 1991] O. Günther, H. Noltemeier. *Spatial database indices for large extended objects*. In Proceedings of the Seventh IEEE International Conference on Data Engineering, 1991, 520–526.
Circle Tree	[Moore, 2002] A.Moore. *The circle tree – a hierarchical structure for efficient storage, access and multi-scale representation of spatial dat*a. Presented at SIRC 2002 – The 14th Annual Colloquium of the Spatial Information Research Centre University of Otago, Dunedin, New Zealand, December 3-5th 2002
CLINDEX	[Li et al, 2002] C. Li, E. Chang, H. Garcia-Molina, G. Wiederhold. *Clustering for approximate similarity search in high-dimensional spaces*. IEEE Transactions on Knowledge and Data Engineering, 14(4):792–808, 2002.
cQSF Tree (Scalable QSF Tree)	[Orlandic, Yu, 2004] R. Orlandic, B. Yu. *Scalable QSF-Trees: Retrieving Regional Objects in High-Dimensional Spaces*. Journal of Database Management (JDM, IDEAS Group Publishing) Vol. 15☹in press), 15-page, 2004
CRB-Tree (Compressed Range B-Tree)	[Govindarajan et al, 2003] S. Govindarajan, P. K. Agarwal, L. Arge. *CRB-Tree: An Efficient Indexing Scheme for Range-Aggregate Queries*. Proceedings of the 9th International Conference on Database Theory, 2003, Pp:143-157
CR-Tree (Compressed Range Tree)	[Chazelle, 1988] B. Chazelle. *A functional approach to data structures and its use in multidimensional searching*. SIAM J. Comput., 17(3):427–462, June 1988
DBIN (Density Based Indexing)	[Bennett et al, 1999] K. P. Bennett, U. Fayyad, D. Geiger. *Density-based indexing for approximate nearestneighbor queries*. In KDD '99: Proceedings of the fifth ACM SIGKDD international conference on Knowledge discovery and data mining, pages 233–243, New York, NY, USA, 1999. ACM Press.
DOT	[Faloutsos, Rong, 1991] C. Faloutsos, Y. Rong. *DOT: A spatial access method using fractals*. In Proceedings of the Seventh IEEE International Conference on Data Engineering, 1991, pp. 152–159.
DP-Tree	[Li et al, 2006] M. Li, W.-C. Lee, A. Sivasubramaniam. *DPTree: A balanced tree based indexing framework for peer-to-peer systems*. in Proceedings of the 14th International Conference on Network Protocols (ICNP 2006), pages 12-21, November, 2006
Duality Transformation	[Kollios et al, 1999] G. Kollios, D. Gunopulos, V. J. Tsotras. On Indexing Mobile Objects. In Proc. of the ACM Symp. on Principles of Database Systems, PODS, pages 261–272, June 1999.
Duality Transformation with Kinetic Data Structure	[Agarwal et al, 2000] P. K. Agarwal, L. Arge, and J. Erickson. *Indexing Moving Points*. In Proc. of the ACM Symp. on Principles of Database Systems, PODS, pages 175–186, May 2000.
EXCELL (Extendible Cell)	[Tamminen, 1982] M. Tamminen. *The extendible cell method for closest point problems*. BIT 22, 1982, pp. 27–41.
Extended K-D-Tree	[Matsuyama et al, 1984] T. Matsuyama, L.V. Hao, M. Nagao. *A file organization for geographic information systems based on spatial proximity*. Int. J. Comput. Vis. Graph. Image Process. 26, 3, 1984, pp. 303–318.
Extendible Hashing	[Fagin et al, 1979] R. Fagin, J. Nievergelt, N. Pippenger, R. Strong. *Extendible hashing: A fast access method for dynamic files*. ACM Trans. Database Syst. 4, 3, 1979, pp. 315–344.
Fieldtree	[Frank, 1983] A. Frank. *Problems of Realizing LIS: Storage Methods for Space Related Data: The Field Tree*. Technical Report 71, Institut for Geodesy and Photogrammetry, Swiss Federal Institut of Technology, Zurich, Switzerland, 1983.
Filter Tree	[Sevcik, Koudas, 1996] K. Sevcik, N. Koudas. *Filter trees for managing spatial data over a range of size granularities*. In Proceedings of the 22th International Conference on Very Large Data Bases (Bombay), 1996, pp. 16–27.
Gauss-Tree	[Bohm et al, 2006] C. Bohm, A. Pryakhin, M. Schubert. *The Gauss-Tree: Efficient Object Identification in Databases of Probabilistic Feature Vectors*. 22nd Int. Conf. on Data Engineering (ICDE'06), Atlanta, GA, 2006
GBD-Tree	[Ohsawa, Sakauchi, 1990] Y. Ohsawa, M. Sakauchi. *A new tree type data structure with homogeneous node suitable for a very large spatial database*. In Proceedings of the Sixth IEEE International Conference on Data Engineering, 1990, pp. 296–303.
Generalized Grid File	[Blanken et al, 1990] H. Blanken, A. Ijbema, P. Meek, B. Van den Akker. *The generalized grid file: Description and performance aspects*. In Proceedings of the Sixth IEEE International Conference on Data Engineering, 1990, pp. 380–388.
GiST (Generalizad Search Tree)	[Hellerstein et al, 1995] J. M. Hellerstein, J. F. Naughton, A. Pfeffer. *Generalized Search Trees for Database Systems*. Proc. 21st Int. Conf. on Very Large Databases, September 1995, pp. 562-573.

GNAT (Geometric Near-Neighbor Access Tree)	[Brin, 1995] S. Brin. *Near neighbor search in large metric spaces*. In VLDB '95: Proceedings of the 21th International Conference on Very Large Data Bases, pages 574–584, San Francisco, CA, USA, 1995. Morgan Kaufmann Publishers Inc.
Grid File	[Nievergelt et al, 1981] J. Nievergelt, H. Hinterberger, K. Sevcik. *The grid file: An adaptable, symmetric multikey file structure*. In Proceedings of the Third ECI Conference, A. Duijvestijn and P. Lockemann, Eds., LNCS 123, Springer-Verlag, Berlin/Heidelberg/New York, 1981, pp. 236–251.
G-Tree	[Kumar, 1994] A. Kumar. *G-tree: A new data structure for organizing multidimensional data*. IEEE Trans. Knowl. Data Eng. 6, 2, 1994, pp. 341-347.
Hana Tree	[Kwon, Jeong, 2000] Y. Kwon, C. Jeong. *Hana Tree: A Dynamic and Robust Access Method for Spatial Data Handling*. Lecture Notes in Computer Science, Springer Berlin / Heidelberg, Volume 1846/2000. Proceedings of Web-Age Information Management: First International Conference, WAIM 2000, Shanghai, China, June 21-23, 2000.
Hashing Technique	[Song, Roussopoulos, 2001] Z. Song, N. Roussopoulos. *Hashing Moving Objects*. In Mobile Data Management, pages 161–172, Jan. 2001.
hBP-Tree	[Evangelidis et al, 1995] G. Evangelidis, D. Lomet, B. Salzberg. *The hBP-tree: A modified hB-tree supporting concurrency, recovery and node consolidation*. In Proceedings of the 21st International Conference on Very Large Data Bases, 1995, pp. 551–561.
hB-Tree	[Lomet, Salzberg, 1989] D.B. Lomet, B. Salzberg. *The hBtree: A robust multiattribute search structure*. In Proceedings of the Fifth IEEE International Conference on Data Engineering, 1989, pp. 296–304.
Hilbert R-Tree	[Kamel, Faloutsos, 1994] I. Kamel, C. Faloutsos. *Hilbert R-tree: An improved R-tree using fractals*. In Proceedings of the Twentieth International Conference on Very Large Data Bases, 1994, pp. 500–509.
HR+-Tree	[Tao, Papadias, 2001a] Y. Tao, D. Papadias. *Efficient Historical R-trees*. In Proc. of the Intl. Conf. on Scientific and Statistical Database Management, SSDBM, pages 223–232, July 2001.
HR-Tree (Historical R-Tree)	[Nascimento, Silva, 1998] M. A. Nascimento, J.R.O. Silva. *Towards historical R-trees*. In Proc. of the ACM Symp. on Applied Computing, SAC, pages 235–240, Feb. 1998.
Interpolation-Based Grid File	[Ouksel, 1985] M. Ouksel. *The interpolation based grid file*. In Proceedings of the Fourth ACM SIGACT –SIGMOD Symposium on Principles of Database Systems, 1985, pp. 20–27.
Interval Tree	[Edelsbrunner 1980] H. Edelsbrunner. *Dynamic Rectangle Intersection Searching*. Institute for Information. Processing Report 47, Technical University of Graz, Austria, 1980.
IQ-Tree (Independent Quantization Tree)	[Berchtold et al, 2000] S. Berchtold, C. Bohm, H. V. Jagadish, H.-P. Kriegel, J. Sander. *Independent quantization: An index compression technique for high-dimensional data spaces*. In ICDE '00: Proceedings of the 16th International Conference on Data Engineering, page 577, Washington, DC, USA, 2000. IEEE Computer Society.
KD2B-Tree	[Oosterom, 1990] P. Oosterom. *Reactive data structures for geographic information systems*. Ph.D. Thesis, University of Leiden, The Netherlands. 1990.
KDB_{FD}-Tree KDB_{HD}-Tree	[Orlandic, Yu, 2002] R. Orlandic, B. Yu. *A retrieval technique for high-dimensional data and partially specified queries*. Data & Knowledge Engineering 2002; 42(2):1-21.
KDB_{KD}-Tree	[Yu et al, 2003] B. Yu, R. Orlandic, T. Bailey, J. Somavaram. KDBKD-Tree: A Compact KDB-Tree Structure for Indexing Multidimensional Data. International Conference on Information Technology: Computers and Communications, 2003.
K-D-B-Tree	[Robinson, 1981] J.T. Robinson. *The K-D-B-tree: A search structure for large multidimensional dynamic indexes*. In Proceedings of the ACM SIGMOD International Conference on Management of Data, 1981, pp. 10-18.
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