

## Chapter 5

# Data Cube Technology

### 5.1 Bibliographic Notes

Efficient computation of multidimensional aggregates in data cubes has been studied by many researchers. Gray, Chaudhuri, Bosworth, et al. [GCB<sup>+</sup>97] proposed *cube-by* as a relational aggregation operator generalizing group-by, crosstabs, and subtotals, and categorized data cube measures into three categories: *distributive*, *algebraic* and *holistic*. Harinarayan, Rajaraman, and Ullman [HRU96] proposed a greedy algorithm for the partial materialization of cuboids in the computation of a data cube. Sarawagi and Stonebraker [SS94] developed a chunk-based computation technique for the efficient organization of large multidimensional arrays. Agarwal, Agrawal, Deshpande, et al. [AAD<sup>+</sup>96] proposed several guidelines for efficient computation of multidimensional aggregates for ROLAP servers. The chunk-based MultiWay array aggregation method for data cube computation in MOLAP was proposed in Zhao, Deshpande, and Naughton [ZDN97]. Ross and Srivastava [RS97] developed a method for computing sparse data cubes. Iceberg queries are first described in Fang, Shivakumar, Garcia-Molina, et al. [FSGM<sup>+</sup>98]. BUC, a scalable method that computes iceberg cubes from the apex cuboid, downwards, was introduced by Beyer and Ramakrishnan [BR99]. Han, Pei, Dong, Wang [HPDW01] introduced an H-cubing method for computing iceberg cubes with complex measures using an H-tree structure. The Star-Cubing method for computing iceberg cubes with a dynamic star-tree structure was introduced by Xin, Han, Li, and Wah [XHLW03]. MMCubing, an efficient iceberg cube computation method that factorizes the lattice space was developed by Shao, Han, and Xin [SHX04]. The shell-fragment-based cubing approach for efficient high-dimensional OLAP was proposed by Li, Han, and Gonzalez [LHG04].

Aside from computing iceberg cubes, another way to reduce data cube computation is to materialize condensed, dwarf, or quotient cubes, which are variants of closed cubes. Wang, Feng, Lu, and Yu proposed computing a reduced data cube, called a *condensed cube* [WLFY02]. Sismanis, Deligiannakis, Rousopoulos, and Kotidis proposed computing a compressed data cube, called a *dwarf cube*. Lakeshmanan, Pei, and Han proposed a *quotient cube* structure

to summarize the semantics of a data cube [LPH02], which has been further extended to a *qc-tree structure* by Lakshmanan, Pei, and Zhao [LPZ03]. An *aggregation-based* approach, called C-cubing (i.e., *Closed-Cubing*), has been developed by Xin, Han, Shao, and Liu [XHSL06], which performs efficient closed cube computation by taking advantage of a new algebraic measure *closedness*.

There are also various studies on the computation of compressed data cubes by approximation, such as *quasi-cubes* by Barbara and Sullivan [BS97], *wavelet cubes* by Vitter, Wang, and Iyer [VWI98], *compressed cubes* for query approximation on continuous dimensions by Shanmugasundaram, Fayyad, and Bradley [SFB99], using log-linear models to compress data cubes by Barbara and Wu [BW00], and OLAP over uncertain and imprecise data by Burdick, Deshpande, Jayram, et al. [BDJ<sup>+</sup>05].

For works regarding the selection of materialized cuboids for efficient OLAP query processing, see Chaudhuri and Dayal [CD97], Harinarayan, Rajaraman, and Ullman [HRU96], and Sristava, Dar, Jagadish, and Levy [SDJL96], Gupta [Gup97], Baralis, Paraboschi, and Teniente [BPT97], and Shukla, Deshpande, and Naughton [SDN98]. Methods for cube size estimation can be found in Deshpande, Naughton, Ramasamy, et al. [DNR<sup>+</sup>97], Ross and Srivastava [RS97], and Beyer and Ramakrishnan [BR99]. Agrawal, Gupta, and Sarawagi [AGS97] proposed operations for modeling multidimensional databases.

Data cube modeling and computation have been extended well beyond relational data. Computation of *stream cubes* for multidimensional stream data analysis has been studied by Chen, Dong, Han, et al. [CDH<sup>+</sup>02]. Efficient computation of *spatial data cubes* was examined by Stefanovic, Han, and Koperski [SHK00], efficient OLAP in spatial data warehouses was studied by Papadias, Kalnis, Zhang, and Tao [PKZT01], and a map cube for visualizing spatial data warehouses was proposed by Shekhar, Lu, Tan, et al. [SLT<sup>+</sup>01]. A multimedia data cube was constructed in MultiMediaMiner by Zaiane, Han, Li, et al. [ZHL<sup>+</sup>98]. For analysis of multidimensional text databases, *TextCube*, based on the vector space model, was proposed by Lin, Ding, Han, et al. [LDH<sup>+</sup>08], and *TopicCube*, based on a topic modeling approach, was proposed by Zhang, Zhai and Han [ZZH09]. *RFID cube* and *FlowCube* for analyzing RFID data were proposed by Gonzalez, Han, Li, et al. [GHLK06, GHL06]. The *sampling cube* was introduced for analyzing sampling data by Li, Han, Yin, et al. [LHY<sup>+</sup>08]. The *ranking cube* was proposed by Xin, Han, Cheng, and Li [XHCL06] for efficient processing of ranking (top- $k$ ) queries in databases. This methodology has been extended by Wu, Xin, and Han [WXH08] to *ARCube*, which supports the ranking of aggregate queries in partially materialized data cubes. It has also been extended by Wu, Xin, Mei, and Han [WXMH09] to *PromoCube*, which supports promotion query analysis in multidimensional space.

The discovery-driven exploration of OLAP data cubes was proposed by Sarawagi, Agrawal, and Megiddo [SAM98]. Further studies on integration of OLAP with data mining capabilities for intelligent exploration of multidimensional OLAP data were done by Sarawagi and Sathe [SS01]. The construction of multifeature data cubes is described by Ross, Srivastava, and Chatziantoniou [RSC98]. Methods for answering queries quickly by on-line aggregation

are described by Hellerstein, Haas, and Wang [HHW97] and Hellerstein, Avnur, Chou, et al. [HAC<sup>+</sup>99]. A cube-gradient analysis problem, called *cubegrade*, was first proposed by Imielinski, Khachiyan, and Abdulghani [IKA02]. An efficient method for multidimensional constrained gradient analysis in data cubes was studied by Dong, Han, Lam, et al. [DHL<sup>+</sup>01].

Mining cubespace, or integration of knowledge discovery and OLAP cubes, has been studied by many researchers. The concept of online analytical mining (OLAM), or OLAP mining, was introduced by Han [Han98]. Chen, Dong, Han, et al. developed a *regression cube* for regression-based multidimensional analysis of time-series data [CDH<sup>+</sup>02, CDH<sup>+</sup>06]. Fagin, Guha, R. Kumar et al. [FGK<sup>+</sup>05] studied data mining in *multistructured databases*. B.-C. Chen, L. Chen, Lin, and Ramakrishnan [CCLR05] proposed *prediction cubes*, which integrate prediction models with data cubes to discover interesting data subspaces for facilitated prediction. Chen, Ramakrishnan, Shavlik, and Tamma [CRST06] studied the use of data-mining models as building blocks in a multistep mining process, and the use of cube space to intuitively define the space of interest for predicting global aggregates from local regions. Ramakrishnan and Chen [RC07] presented an organized picture of exploratory mining in cube space.



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