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AUTHENTICATE LOCATION BASED SKYLINE QUERIES IN CAPRICIOUS SUBSPACES

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ABSTRACT

Location-based services (LBSs) have experienced explosive growth in the past few years with the ever-increasing use of smartphones and tablet devices. To scale up services, there has been a rising trend of outsourcing data management to Cloud service providers, which provide query services to clients on behalf of data owners. However, in this data-outsourcing model, the service provider can be untrustworthy or compromised, thereby returning incorrect or incomplete query results to clients, intentionally or not. Therefore, empowering clients to authenticate query results is imperative for outsourced databases. In this paper, we study the authentication problem for location-based arbitrary-subspace skyline queries (LASQs), which represent an important class of LBS applications. We propose a basic Merkle Skyline R-tree method and a novel Partial S4-tree method to authenticate one-shot LASQs. For the authentication of continuous LASQs, we develop a prefetching-based approach that enables clients to compute new LASQ results locally during movement, without frequently contacting the server for query re-evaluation. Experimental results demonstrate the efficiency of our proposed methods and algorithms under various system settings. We also proposed the work to road network environments. The query distance is defined by network distance in a road network, the skyline scope defined in this paper no longer works, which calls for new authentication methods

1 INTRODUCTION

Location-based services (LBSs) have prospered. Users carrying location-aware mobile devices are able to query LBSs for surrounding points of interest (POIs) anywhere and at any time. Among the many types of location-based queries, one important class is location-based skyline queries. Location-based services (LBSs) have prospered. Users carrying location-aware mobile devices are able to query LBSs for surrounding points of interest (POIs) anywhere and at any time. Among the many types of location-based queries, one important class is location-based skyline queries. Moreover, different users may have different preferences—e.g., Mary prefers taste, whereas Tom is concerned about hygiene, environment, and price. In this paper, we call these skyline queries location-based arbitrary-subspace skyline queries (LASQs). To scale up LBSs along with their ever-growing popularity, a rising trend is to outsource data management and service provisioning to Cloud service providers (CSPs) such as Amazon EC2 and Google App Engine. The data owner obtains, through a certificate authority (e.g., VeriSign), a pair of private and public keys of digital signatures. Before delegating a spatial dataset to the CSP, the data owner builds an authenticated data structure (ADS) of the dataset. To support efficient query processing, the ADS is often a tree-like index structure, where the root is signed by the data owner using his/her private key. The CSP keeps the spatial dataset, as well as the ADS and its root signature. Upon receiving a query from the client, the CSP returns the query results, the root signature, and a verification object (VO), which is constructed based on the ADS. The client can authenticate the correctness of the query results using the returned VO, the root signature, and the data owner's public key.

In this paper, we extend this study to the general problem of authenticating location-based skyline queries in arbitrary subspaces of attributes (i.e., LASQs). Because a basic solution that returns all results in the full space is inefficient, we propose a new authentication method based on the notion of signed sub-space skyline scope (S4). We devise a data structure, called Partial-S4-tree, which pre-computes, signs, and stores the skyline scopes of some subspaces, so that many redundant objects can be easily identified and safely removed from the VO, thereby minimizing its size and saving the server processing time. To improve the filtering effects, we further propose a storage-budget allocation policy to construct the Partial-S4-tree for each spatial object. For continuous LASQs, the concept of clear area is introduced to enable a moving client to re-evaluate new results locally. Moreover, we propose an approach to prolong the client's residence time inside a clear area.

In a preliminary study, we have investigated the authentication problem for location-based skyline queries in a fixed space of attributes. In this paper, we extend this study to the general problem of authenticating location-based skyline queries in arbitrary subspaces of attributes (*i.e.*, LASQs). Because a basic solution that returns all results in the full space is useless, we proposed a new validation method based on the notion of *signed sub-space skyline scope (S4)*. We devise a data structure, called *Partial-S4-tree*, which pre-compute sign, and store the skyline scopes of some subspace, so that many superfluous objects can be easily identified and safely distant from the VO, thereby minimize its size and saving the server processing time. To improve the filtering effects, we fur-ther propose a storage-budget allocation policy to construct the Partial-S4-tree for each spatial thing. For unbroken LASQs, the concept of *clear area* is introduced to enable a moving client to re-evaluate new consequences locally. furthermore we proposed an approach to prolong the client's residence time inside a clear area.

In summary, our contributions in this paper are four-fold:

- We identify the problem of authenticating LASQs in outsourced databases. To the best of our knowl-edge, this study is the first attempt to investigate this problem.
- For a one-shot LASQ verification we proposed a basic Merkle Skyline R-tree methods and a Partial-S4-tree methods, aiming to reduce the server processing time and minimize the VO size.
- We develop a prefetching-based approach for authenticating continuous LASQs. This approach enables the clients to reconsider new LASQ results locally during movement, thus reducing both com-munication and computation costs.
- We conduct extensive experiments to evaluate the performance of the proposed methods and algo-rithms. The results show that our proposed meth-ods substantially outperform the basic authentication algorithm by up to 69% in terms of the overall query latency and up to 74% in terms of the VO size.

2 RELATED WORK

In this section, we review the related work on query authentication and skyline query processing.

Query Authentication

Authenticated query processing has been studied extensively. Most studies on query authentication are based on ADS called Merkle Hash Tree (MH-tree). In MH-tree, the digests of index nodes are recursively computed from the leaf nodes to the root. After that, the root digest is signed by the data owner's private key and stored on the outsourced database server. For each user query, this signature is returned to the client along with the query results and a VO for result verification. In contrast, an alternative method is to employ signature aggregation , which signs every object in the dataset and generates a VO by aggregating the signatures of the result objects along with some non-result objects (*e.g.*, the objects immediately beyond a query range). However, as the aggregate signature is generated on-the-fly, this method incurs high overhead in query processing and client-side verification. Therefore, in this paper, we focus on authentication methods based on MH-tree.

2.2 Skyline Query Processing

Skyline query processing was first introduced into the database community by Borzonyi *et al.* A number of algorithms have been developed since then. These algorithms can be divided into two categories. The first category is non-index-based algorithms. The representatives are Black-Nested-Loop (BNL) and Divide-and-Conquer (D&C) . BNL scans the dataset sequentially and com-pares each new object to the skyline candidates obtained so far. D&C partitions the dataset into several parts, processes them part by part, and finally merges all partial skylines. SFS improves BNL by pre-sorting the dataset. In the Bitmap approach, each data point is encoded in a bit string and the skyline is computed on the bit matrix of all data points.

The other category of skyline algorithms is index-based. In a high-dimensional dataset is converted into a one-dimensional dataset and a B^{+}-tree is built to accelerate query processing. In an algorithm called NN was proposed based on depth-first nearest-neighbor search via R*-tree. Papadias *et al.* proposed an optimal algorithm, called Branch-and-Bound Skyline (BBS), which is based on best-first nearest-neighbor search. More recently, in, a subset of skyline points is collected to approximately represent the distribution of an entire set of skyline points. Lee *et al.* proposed a new index structure called ZBtree to index data points based on a Z-order curve, and developed a novel algorithm Z Search to process skyline queries.

3 PROBLEM DEFINITION AND PRELIMINARIES

In this section, we give the formal problem definition and present some preliminaries on skyline query processing.

3.1 Problem Definition

We consider a set of spatial objects *O*. Each object *oO* is associated with one spatial attribute (*i.e.*, location, denoted by *o.l*) and several non-spatial attributes (*e.g.*, food quality and price, denoted by $o.x_i$ for the *i*-th non-spatial attribute). Assuming _ is the full set of non-spatial attributes and _⁻ is an arbitrary subset of _, we say _⁻ is a ***subspace*** of the ***full space*** _. In this paper, we adopt the Euclidean distance metric to measure spatial proximity.

Definition 1 (Non-spatial Subspace Dominance). *Given two objects o and o⁻, o⁻ non-spatially dominates o in a sub-space _⁻ (denoted as oo) iff* x_i $o.x_i$ *is no worse than* $o.x_i$*. The set of o's non-spatial subspace dominators is denoted as DOM(o, _⁻).*

Definition 2 (Subspace Dominance). *Given a query point q and two objects o and o⁻, if (1) oo and (2) o⁻ is closer to q than o (*i.e.*, o⁻ also spatially dominates o), then we say o⁻ dominates o in subspace w.r.t. the query point q. Formally, it is denoted as oo.*

Definition 3. (Location-based Arbitrary-subspace Skyline Query (LASQ)). *Given a dataset O and a query point q, the query LASQ(O, q) returns a subset of objects in O, each of which is not dominated by any other object in O in the subspace w.r.t. q.*

3.2 Subspace Skyline Scope

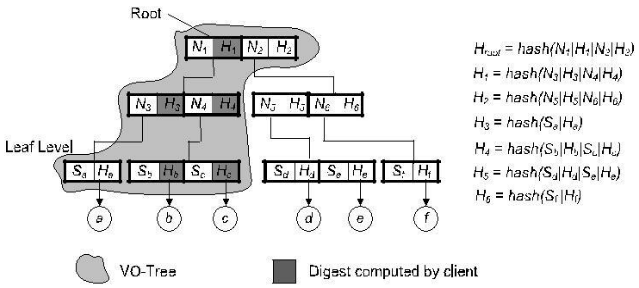
Before we present the detailed authentication techniques, we introduce an important concept, *subspace skyline scope*, which facilitates subspace skyline query processing. Extended from the notion of *skyline scope* we proposed in , the subspace skyline scope of an object *o* is defined as the spatial area in which *o* is a skyline result in the designated subspace. It is formally defined as follows:

Definition 4 (Subspace Skyline Scope). *Given a subspaceand a 2D plane* P*, the* subspace skyline scope *of an object o O is* S_o*= {q | q P o LASQ(O, q)}.*

If *o* has no non-spatial dominators in subspace , *i.e.*, *DOM*(*o*) is empty, then *o* must be a skyline result of any query point *q*. That is, *o*'s subspace skyline scope is the entire plane P. Otherwise, *o* will be a skyline result of a query point *q* only if it is closer to *q* than all of its non-spatial dominators in *DOM(o, _⁻)*; hence, the corresponding skyline scope is a Voronoi cell of *o* in the object set {*o*} ∪ *DOM(o, _⁻)*, which can be computed in O(|*O*|*log*|*O*|) time.

4 BASIC LASQ AUTHENTICATION METHOD

In this section, we propose a basic LASQ authentication method. We start with the authentication problem in a fixed subspace, and then extend it to arbitrary subspaces.



4.1 LASQ Authentication in a Fixed Subspace

Design of Authenticated Index Structure. To expedite query processing, we index all the objects' subspace skyline scopes by an R*-tree, where the subspace skyline scopes are stored in the leaf nodes as data entries. Additionally, to support query authentication, we follow similar ideas of MB-tree and MR-tree to maintain a series of digests for all index nodes in the tree structure. More specifically, each entry in a leaf node stores a pointer to the actual object o, the object's subspace skyline scope S_o, and the object's digest H_o.[2] Formally,

$$H_o = hash(o),$$

where $hash(\cdot)$ is a one-way cryptographic hash function, such as SHA-1. Each entry in a non-leaf node is composed of a pointer to its child node, a minimum bounding rect-angle (MBR) denoted by N_i, and a digest H_i of the child node. The digest is formally defined as:

$$H_i = hash(E_{c1}\ |H_{c1}\ |E_{c2}\ |H_{c2}\ | \cdots |E_{cn}\ |H_{cn}\ ),$$

where "|" is a concatenation operator, E_{ck} ($k = 1, 2, . . . , n$) represents the k-th entry in the child node, and H_{ck} repre-sents the digest of the corresponding entry.

5 PARTIAL-S4-TREE METHOD

The basic method proposed in the previous section is easy to implement. However, the communication cost would be prohibitively high if the full space is large, because the VO must include all results for the full space, most of which however are not actual results (hereafter called *redundant objects*). In fact, our experimental results show that when |_| = 8 and |_⁻ | = 3, such redundant objects account for nearly 95% of all returned objects. Moreover, the basic method computes the actual subspace skyline results by identifying the redundant objects on the fly, which incurs a high server processing cost. In this section, we propose a Partial-S4-tree scheme to more efficiently identify the redundant objects and filter out as many of them as possible from the VO.

6 CONCLUSION AND FUTURE WORK

In this paper, we have studied the problem of authenticating location-based skyline queries in arbitrary subspaces (LASQs). We have proposed a basic MSR-tree authentication method by extending our previous work on skyline query authentication. To enable authentication for large-scale datasets and subspaces, we have further proposed a Partial-S4-tree method, in which most of the redundant objects can be easily identified and filtered out from the VO. For authenticating continuous LASQs, we have proposed a prefetching-based solution to avoid frequent query issuances and VO transmissions. Extensive experimental results demonstrate the efficiency of our pro-posed methods and algorithms under various system set-tings. In particular, our proposed Partial-S4-tree method outperforms the basic authentication method by up to 69% in terms of the overall query latency and up to 74% in terms of the VO size. We are extend this work to road network environments. Since the query distance is defined by network distance in a road network, the skyline scope defined in this paper no longer works, which calls for new authentication methods. Moreover, we are also interested in studying the authentication problem for dynamic objects, where how to guarantee the freshness of query results is a very challenging issue.

As for the future work, we will extend this work to road network environments. Since the query distance is defined by network distance in a road network, the skyline scope defined in this paper no longer works, which calls for new authentication methods. Moreover, we are also interested in studying the authentication problem for dynamic objects, where how to guarantee the freshness of query results is a very challenging issue.

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