Georacle: Enabling Geospatially Aware Smart Contracts

Taha Azzaoui
taha@azzaoui.org

Abstract—Smart contracts [6] have enabled a paradigm shift in computing by leveraging decentralized networks of trust to achieve consensus at scale. Oracle networks further extend the power of smart contracts by solving the so-called “oracle problem” [1]. Such networks enable smart contracts to make use of the vast amount pre-existing data available on the web today without jeopardizing the integrity of the underlying network of trust. By leveraging oracle networks, smart contracts can make decisions based on data corresponding to the physical world. To this end, we introduce Georacle - an oracle service that enables geospatially aware smart contracts in a way that respects the space constrained nature of blockchain environments. Contracts can query the location of objects in a given area, map between street addresses and coordinates, and retrieve the geometry of a desired region of space while conserving gas consumption and avoiding unnecessary data processing.

I. INTRODUCTION

Geospatial data involves data about objects corresponding to a location on the surface of the earth. Spatial information represented as vector data uses geometric shapes such as points, lines, and polygons to represent geographic features in space. This spatial information is usually combined with metadata containing attribute information about the location allowing for efficient indexing and retrieval. Once retrieved, geospatial data is often used for reasoning about points of interest and determining relationships across regions in space.

In the current web landscape, location serves as a fundamental building block for almost every useful application online today. From ride-sharing and vacation rentals to social media and online dating, location has proven essential to fostering digital ecosystems that rely on geospatial data to develop a computational understanding of the outside world. In order for such ecosystems to thrive on the blockchain, decentralized applications must have access to geospatial data on-chain. Native access to geodata empowers smart contracts to coordinate across space in a similar fashion, forming the basis for decentralized location-based experiences far more powerful than their centralized counterparts on the web today. Using the transparency inherent in blockchain-based ledger systems, contracts can make verifiable decisions on the basis of location.

This paper introduces Georacle - an oracle service built on top of the Chainlink [1] network with the goal of providing smart contracts with the ability to query the attributes of arbitrary points in space. Georacle serves as a map oracle, delivering location data to EVM-based blockchains [7] [2]. Among the contributions of this paper is a novel approach for delivering state of the art map data in a way that respects the space constrained nature of blockchain environments. Contracts can query the location of objects in a given area, map between street addresses and coordinates, and retrieve the geometry of a desired region in space while conserving gas utilization and avoiding unnecessary data processing.

II. DATA MODEL

Georacle leverages OpenStreetMap [5] - a community-driven open standard for interacting with geospatial data. The OpenStreetMap project decentralizes the collection of geodata across thousands [4] of community members who serve as cartographers generating and validating geodata across the world. As such, the OSM model replaces a central data authority with a community of voters that discuss propositions to reach consensus on best practices. The project follows a peer-driven approach similar to that of Wikipedia with the goal of providing open access to high quality geospatial data. At its core, the OSM model divides geodata into an object hierarchy of increasing complexity as follows.

A. Nodes

Nodes are an atomic data type in the OpenStreetMap model, they encode a single coordinate in space. A node is completely determined by its latitude and longitude. Each node is assigned a unique identifier such that a contract can refer to a node unambiguously using its ID.
B. Ways

Ways are the next level of abstraction in the OpenStreetMap data model, they encode area features. Ways consist of a collection of nodes that combine to form some geometry. Closed ways (ones that start and end at the same node) are a special type of way called an area. Like nodes, contracts can also reference ways uniquely by their identifier.

C. Tags

Both nodes and ways can be tagged with metadata in the form of key-value pairs that provide the object with some context (e.g. amenity=park, building=residential). For a given object we might want to know if it has a name, what type of location it is, or what its opening hours are. Tags provide contracts with the ability to filter locations according to desired attributes. Figure 1 shows a selection of the available tags for the way representing the Eiffel Tower.

| Key              | Value                        |
|------------------|------------------------------|
| addr:city        | Paris                        |
| addr:housenumber | 5                            |
| addr:postcode   | 75007                        |
| addr:street     | Avenue Anatole France        |
| architect       | Stephen Sauvestre            |
| building        | attraction                   |
| building:colour | #706550                      |
| building:material | iron                     |
| building:shape  | pyramidal                    |
| fee             | 10-25€                       |
| height          | 324                          |

Fig. 1: A Selection of Tags For the Eiffel Tower (Way 5013364)

III. LOCATION QUERIES

By combining location and metadata, contracts can filter objects by their tags to query regions of interest with desired attributes across space. This direct access to the OSM data model offers contracts a general method for constructing spatially constrained queries with desired levels of complexity. Contracts can search globally for a list of points tagged with some key-value pair or opt for a more local search by specifying an arbitrary bounding box around the region of interest. On the other hand, if the points of interest are known a priori, contracts can filter the latest metadata associated with the specific object to learn more about that region of space.

Armed with these techniques, smart contracts are not only geospatially aware, but can also be made contextually aware with respect to the locations they interact with. That is, metadata allows contracts to learn more about the nature of a place (e.g. is it a building, shop, park, ATM, etc) along with location dependent information such as the opening hours of a given building or any fees associated with entering. Using this information, contracts can make decisions with implications that reach into the physical world by conditioning their logic on the attributes associated with their points of interest. Use cases such as crowd funding and decentralized autonomous organizations can function on the basis of location by tailoring queries to fit their needs.

A. Area

One method of informing contracts about the outside world involves querying nodes or ways confined to a named area that are tagged with a desired description. The nodesInArea function and its corresponding way variant waysInArea both expect a named area (e.g. New York, London, Tokyo, etc) along with a key-value pair of desired attributes and an upper bound on the number of search results. Figure 2 shows an example of searching for \(n\) coffee shops (represented as nodes) within the Boston area by crafting a Chainlink request for Georacle using Solidity [3]. Upon fulfillment, the oracle will respond with an \(\text{int64}\) array of size at most \(n\) representing the matching object identifiers packed according to the EVM ABI specification.

```solidity
req.add("function","nodesInArea");
req.add("key","amenity");
req.add("value","cafe");
req.add("area","Boston");
req.addInt("limit", n);
```

Fig. 2: Finding \(n\) Coffee Shops in the Boston Area

Additionally, contracts can obtain a count of the number of matching identifiers beforehand by using the nodeCountInArea and wayCountInArea functions as shown in Figure 3. Upon fulfillment, the oracle will return a single \(\text{int64}\) value denoting the number of objects tagged with the requested description in the area.
B. Bounding Box

When interacting with less well-defined areas, it can be useful to work with a custom bounding box surrounding some region of concern rather than a named area. Using a bounding box allows contracts to confine their queries to an arbitrary region of space. This is useful if the desired search space crosses the boundaries of multiple named areas. For regions that are known to be some subregion of a named area, using a bounding box will return only the matches within this desired subspace, incurring less data transfer and thus consuming less gas.

Figure 4 searches for \( n \) train stations within a subregion of Manhattan using the bounding box: \((40.7719, -73.9746, 40.7975, -73.9469)\). These coordinates correspond to the south, west, north, and east most points of the bounding box respectively. Note that Georacle scales coordinates by a factor of \( 10^8 \) as the EVM lacks support for floating point arithmetic. Upon fulfillment, the oracle will return a single \( \text{int64} \) value denoting the number of objects tagged with the requested description within the specified bounding box.

Like with named areas, contracts can also retrieve a count of the number of matching identifiers within the bounding box beforehand by using the \text{nodeCountInBB} and \text{wayCountInBB} functions as shown in Figure 5. Upon fulfillment, the oracle will return a single \( \text{int64} \) value denoting the number of objects tagged with the requested description within the specified bounding box.

C. Filtering Tags

If the regions of interest are known a priori, either because they are embedded in the smart contract itself, or because they are the return value of one of the functions introduced previously, the function \text{nodeTagQuery} (along with its way variant \text{wayTagQuery}) provides contracts with a mechanism for filtering the tags of a specific object. Both functions expect a string array of keys along with the known object identifier.

Figure 6 shows the process of retrieving the name, address and opening hours of a specific coffee shop in the Boston area. Upon fulfillment, the oracle will respond with an ABI-packed \text{string} array of values corresponding to each key.

D. Geometry

In addition to querying discrete points, contracts can also interact with the physical geometry of a given region. Recall that ways are simply a collection of nodes (points in space). The \text{wayGeometry} function can be used to obtain the coordinates of the underlying collection of nodes that represent a given way. These nodes form some geometry which can then be used to compute geometric properties like area or input into common computational geometric algorithms such as nearest neighbor or segment intersection. Figure 7 shows the retrieval of the way geometry representing
the Great Pyramid of Giza. This geometry consists of 10 nodes which combine to form the rectangular base of the pyramid.

```
req.add("function", "wayGeometry");
req.addInt("ID", 4420397);
```

Fig. 7: Obtaining the Geometry of the Great Pyramid of Giza (way 4420397)

Upon fulfillment, the oracle will return a list of pairs of int64 values representing the latitude and longitude coordinates of each node. Due to the topology of large areas however, geometric data can sometimes be prohibitively expensive to store completely on chain. To gauge gas consumption, it can be useful to obtain the size of the geometry beforehand by using the wayCount function as shown in figure 8. Upon fulfillment, the oracle will return a single int64 value representing the number of nodes that form the way geometry.

```
req.add("function", "wayCount");
req.addInt("ID", 4420397);
```

Fig. 8: Retrieving the Number of Nodes in the Geometry of the Great Pyramid of Giza (way 4420397)

IV. GECODING

While coordinates lend themselves well to geometric reasoning, it can be convenient for users to refer to a location based on its canonical street addresses. Smart contracts can use the geocode function to map an area description (i.e. street address) to the coordinates of its representative OSM object. Figure 9 obtains the coordinates of a street address in the United Kingdom.

```
req.add("function", "geocode");
req.add("address", "221B Baker St, London NW1 6XE, UK");
```

Fig. 9: Mapping a Street Address to a Point in Space

Upon fulfillment, the oracle will respond with an ABI-packed struct consisting of two int64 values representing an object type flag (0 = node, 1 = way), the object identifier, and the corresponding latitude and longitude of the area respectively. This output can then be used to perform spatial analysis on user-provided location information, which is most commonly in the form of a description.

```
req.add("function", "reverseGeocode");
req.addInt("lat", 5152338790);
req.addInt("lon", -15823670);
```

Fig. 10: Mapping a Coordinate Pair to an Area Description

Upon fulfillment the oracle will respond with an ABI-packed struct consisting of two int64 values representing an object type flag and the corresponding object identifier along with a string description of the object.

V. GAS CONSIDERATIONS

As the demand for block space increases, optimizing gas consumption is of primary concern for the practical usage of decentralized applications. The OSM data model outlined in the previous sections is well-suited for blockchain environments where data storage is at a premium, since contracts need only interact with objects that fit their desired description. Application developers can assess gas consumption beforehand by simulating oracle queries off-chain and determining the subset of data necessary to manipulate on chain. Contracts can then optimize for gas by fine-tuning their search space and imposing an upper bound on the number of returned search results. This upper bound can be computed dynamically based on the count variant associated with each query function.

VI. CONCLUSION

Building location aware smart contracts involves bringing geodata on-chain in a manner that respects the space constrained nature of modern blockchains. The OSM data model and its hierarchy of uniquely identified object types is well-suited for this task as location representation reduces to the corresponding object identifier. The metadata associated with each object allows for flexible queries that can be confined to a named area or fine-tuned to a specific region in space on the fly.

While named areas can be a convenience for users, the ability to specify an arbitrary search space allows smart contract developers to narrow down the regions
that matter most and avoid filtering through unnecessary data on chain. Geocoding gives smart contracts the ability to translate between sets of coordinates and human readable area descriptions better suited for interfacing with users. Smart contracts that leverage geospatial data by combining these mechanisms can coordinate across space, creating an ecosystem with global implications. By querying the attributes of specific points of interest, contracts are no longer insulated from the outside world as they gain a better sense of their surroundings.

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