

Found In Space, Just In Time: Oracle 23c's Spatio-Temporal Features



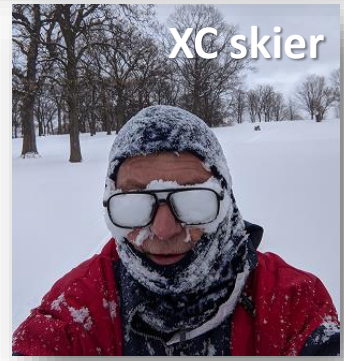
30 May, 2024

Jim Czuprynski

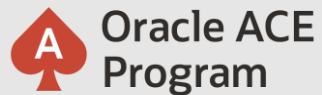
Chief StoryTeller

Zero Defect Computing, Inc.

Who Am I, and What Am I Doing Here?



- E-mail me at jim@jimthewhyguy.com
- Follow me on Mastodon (@JimTheWhyGuy@techfieldday.net)
- Connect with me on LinkedIn (Jim Czuprynski)



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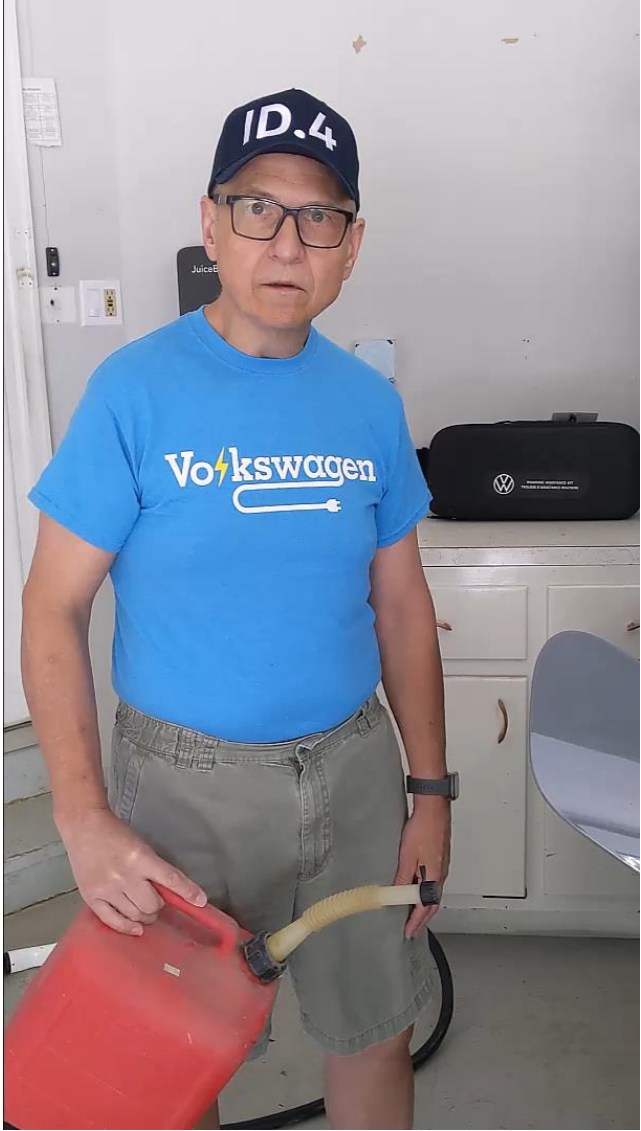
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Goodbye to ICE: Time To Put My Money Where My Mouth Is

In April 2023, we purchased our **first-ever EV**, a **2022 Volkswagen ID.4**



Her name is **EV-A**

2023: The Year That BEVs Truly Became Mainstream



Electric Cars Are Already Upending America

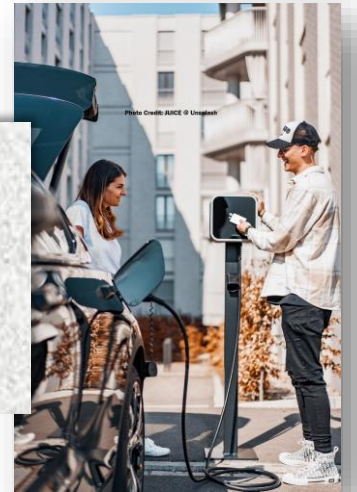
- *The Atlantic*, December 29, 2023

The million-plus new EVs on the road are ushering in a fundamental, maybe existential, change in how to even think about cars—no longer as machines, but **as gadgets that plug in and charge like all the others in our life.**

EV sales climb and are on track to be 9% of US new car purchases in 2023

- *Utility Dive Newsletter*, November 28, 2023

U.S. consumers purchasing new light-duty cars or trucks are increasingly considering electric vehicles, which are on pace to make up **9% of sales this year** ... In the U.S., there were roughly **136,000 EVs sold in September** — a **67% year-over-year increase.**



Tesla Will Open Its Charging Network to G.M.'s Electric Vehicles

- *New York Times*, June 8, 2023

The announcement, two weeks after Ford struck a comparable agreement, is likely to make Tesla's plugs the industry standard and squeeze companies that are racing to build similar networks as sales of electric vehicles surge. The agreements mean that owners of Ford and G.M. vehicles will be able to use Tesla chargers, **which are often the only ones available in many places and have a reputation for reliability.**

So If EVs Are So Great, What's *Really* Stopping Wider Adoption?

Cost?
Surprisingly,
no!

How Much Are Electric Cars?

- **Kelley Blue Book, July 10, 2023**

According to data from Cox Automotive, parent of Kelley Blue Book, the average transaction price for electric cars was **\$53,469** in July 2023, vs. gas-powered vehicles at **\$48,334**. ... The federal government offers qualified buyers electric car incentives of **up to \$7,500** for select new fully electric, plug-in hybrid, and fuel-cell vehicles. That, too, helps lower the price and close the gap in the pricing of electric vehicles compared with their gas counterparts.

Range anxiety?
Nope!

I Drove 1,400 Miles on Starbucks' New Electric Vehicle Charging Route

- **Newsweek, December 13, 2023**

Utilizing hotels with charging stations, all unaffiliated with Volvo and Starbucks, was a key to the success of this journey and something that BEV drivers should consider while they're planning their road trips.

#1 concern:
Will this charger actually ... charge?

VW spent \$2B to build America a charging network. It's ranked dead last.

- **Washington Post, December 13, 2023**

[E]ven among a group of struggling companies, Electrify America stands out. In a recent J.D. Power study, the **company ranked last in consumer satisfaction** among fast-charging networks, scoring a 538 on a 1,000-point scale. (In comparison, Tesla's network scored a 739.)

Charging (Super)stations: Electrons Flowing 24 x 7 x 365 (In Theory)



A **spectacular** example: **ElectrifyAmerica** superstation in **San Jose, California**

Offers **24 charging stations** for **Teslas** and **other BEVs** just outside a large luxury shopping mall

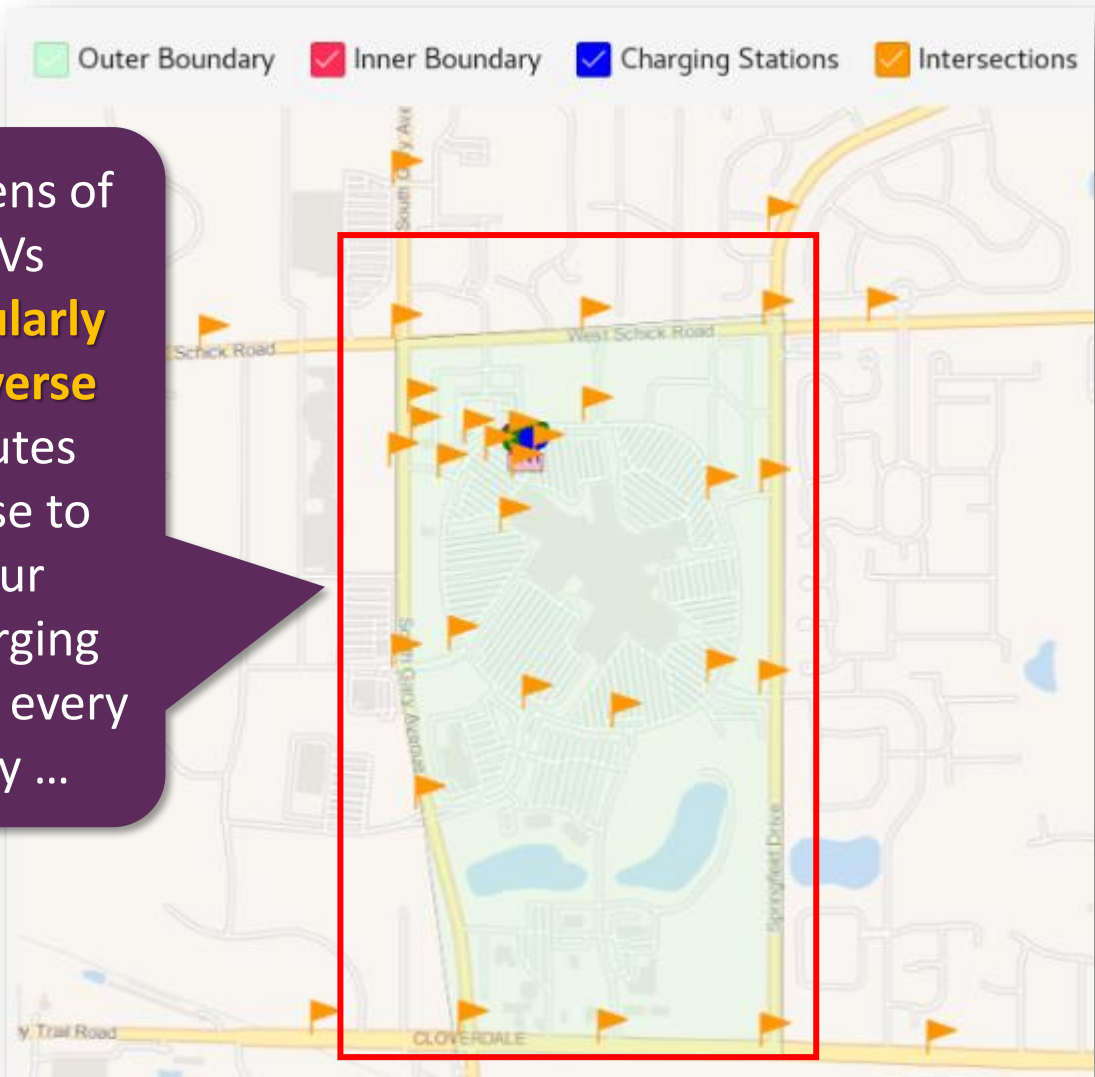


Every station is **available 24/7** and the facility itself is **managed remotely**

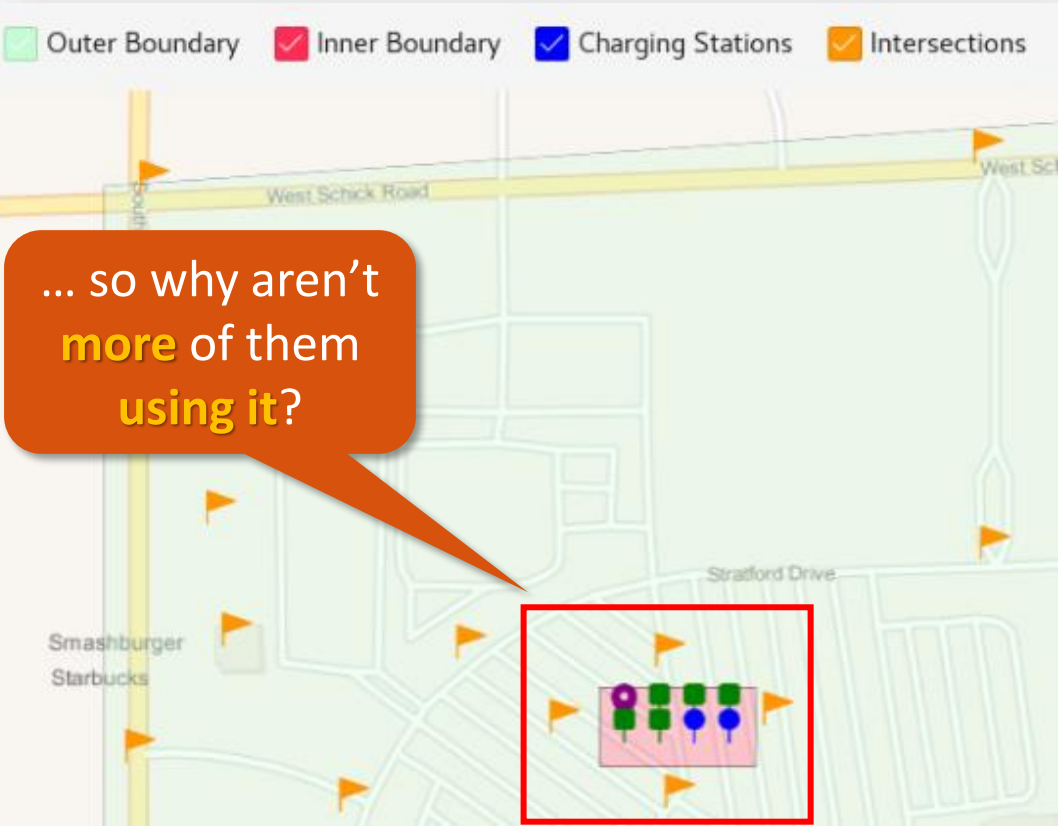


Business Use Case: Why Aren't More EVs Using Our Charging Plaza?

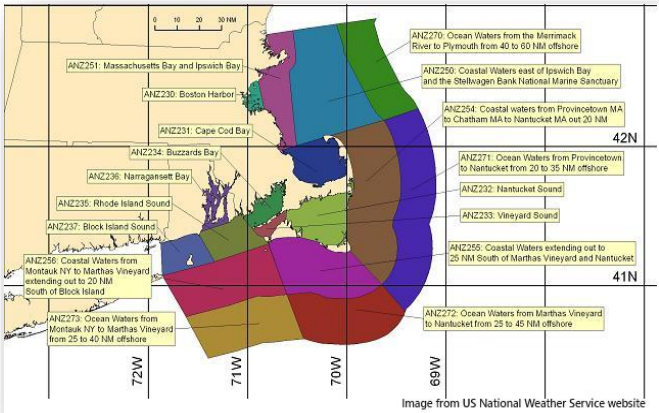
Dozens of EVs **regularly traverse** routes close to our charging plaza every day ...



This charging plaza has 5 **CCS2**, 2 **Tesla**, and 1 **CHADEMO** chargers **always available**



Essentially, These Are All Spatio-Temporal Problems!



Boats and ships at sea **leaving or entering local, state, or international waters**

Delivery vehicles **approaching, stopping at, and eventually leaving** a designated drop-off target

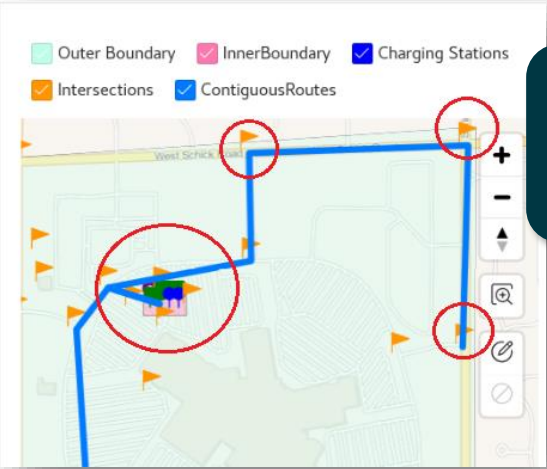


Elderly parents traversing **unusual routes** or **getting lost** when shopping or running errands

A close-up photograph of a person's hands holding a paper map. The map is slightly out of focus, showing a grid of streets and some labels in Polish, such as 'Marszałkowska' and 'Poznańska'. The text 'Tracking Point-by-Point Interactions Within Regions' is overlaid in the center of the image in a dark blue, sans-serif font. The background is a soft, out-of-focus light gray.

Tracking Point-by-Point Interactions Within Regions

Spatio-Temporal Feature Sets



SDO_TRKR API handles **entry / exit of an object** within defined polygon(s)

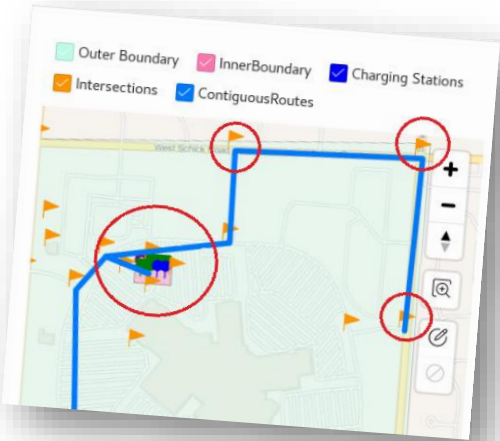
SDO_OBJ_TRACING API handles spatio-temporal **proximity**, like **contact tracing**



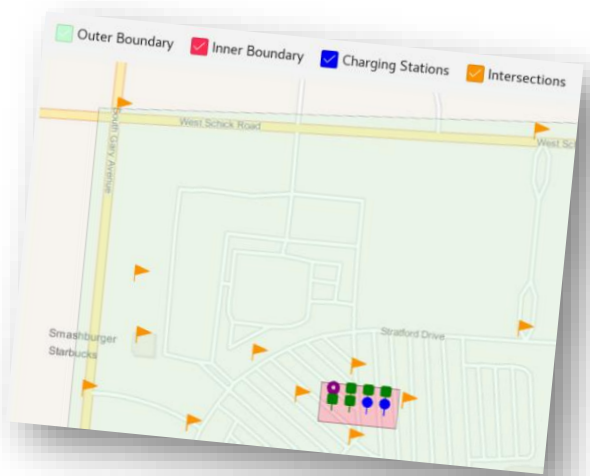
SDO_LRS (short for **L**inear **R**eferencing **S**ystem) API handles line geometries associated with a **measure**, like **calories** burned over time as runner **traverses a route**

Location Tracking Services With SDO_TRKR: Preparations

Define **regions of interest** in polygon format



Define **objects to track** as they **enter** or **leave** regions of interest



Report on which objects **first entered, stayed within,** and then **eventually left** regions of interest ... and **when** this all happened

OBJECT_ID	REGION_ID	ALERT_WHEN
3000001	17100101	TU
3000001	17100102	TU
3000002	17100101	TU
3000002	17100102	TU
5000001	17100101	TU
5000001	17100102	TU
5000002	17100101	TU
5000002	17100102	TU
5000003	17100101	TU
5000003	17100102	TU
5000004	17100101	TU
5000004	17100102	TU
9000001	17100101	TU
9000001	17100102	TU
10000001	17100101	TU
10000001	17100102	TU

Capturing Vehicle Interactions With Charging Plazas & Charging Stations

Table / View	Purpose
CHARGING_PLAZAS	Charging plazas in the geography of interest
CHARGING_PLAZA_BOUNDARIES	Spatial boundaries of each charging plaza
CHARGING_STATIONS	Individual charging stations within each charging plaza
CHARGING_STATION_USAGE	Usage statistics about individual charging stations
VEHICLES	Electric vehicles to be tracked
VEHICLE_TRACKING	Tracks vehicle traversal through charging plaza boundaries, intersection by intersection
MAPPED_TRACKS	Corresponding line geometry for each set of vehicle tracks through charging plaza boundaries

Note: Objects and tables used to **simulate charging station usage** and vehicles **traversing charging plaza boundaries** are excluded for sake of brevity!

Establishing Geometries for Entry and Exit Tracking

```
INSERT INTO charging_plaza_boundaries (  
  cpb_id, cpb_description, cpb_region)  
VALUES (  
  17100102  
  , 'Near Charging Stations'  
  , SDO_GEOMETRY (  
    2003  
    , 4326  
    , NULL  
    , MDSYS.SDO_ELEM_INFO_ARRAY(1, 1003, 1)  
    , MDSYS.SDO_ORDINATE_ARRAY (  
      -88.116824, 41.95091  
      , -88.117750, 41.95091  
      , -88.117750, 41.95056  
      , -88.116824, 41.95056  
      , -88.116824, 41.95091  
    )  
  )  
);  
COMMIT;
```

This **innermost** region tightly surrounds boundaries of the charging plaza itself

Establishing Geometries for Entry and Exit Tracking

```
INSERT INTO charging_plaza_boundaries (  
cpb_id, cpb_description, cpb_region)  
VALUES (  
    17100101  
    , 'Approaching Charging Plaza'  
    , SDO_GEOMETRY (  
        2003  
        , 4326  
        , NULL  
        , MDSYS.SDO_ELEM_INFO_ARRAY (1, 1003, 1, 15, 2003, 1)  
        . . .  
        , MDSYS.SDO_ORDINATE_ARRAY (  
            -88.116824, 41.95091  
            , -88.116824, 41.95091  
        )  
    )  
);  
COMMIT;
```

This specifies that the outermost region surrounds the innermost region as a **polygon with a hole**

This **innermost** region tightly surrounds boundaries of the charging plaza itself

Establishing Geometries for Entry and Exit Tracking

```
INSERT INTO charging_plaza_boundaries (  
cpb_id, cpb_description, cpb_region)  
VALUES (  
17100101  
, 'Approaching Charging Plaza'  
, SDO_GEOMETRY (  
2003  
, 4326  
, NULL  
, MDSYS.SDO_ELEM_INFO_ARRAY (1, 1003, 1, 15, 2003, 1)  
...
```

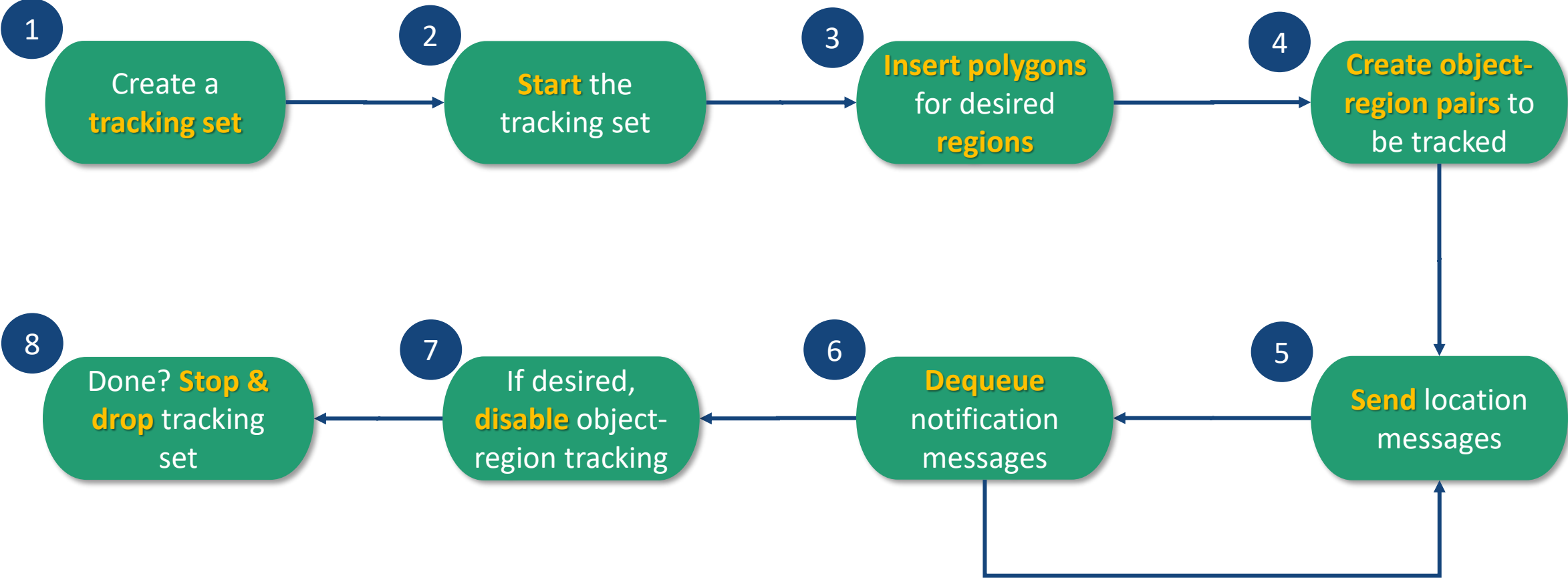
The outermost region is specified **first**, and its boundary coordinates are specified in anti-**clockwise** order

```
...  
, MDSYS.SDO_ORDINATE_ARRAY (  
-88.120709, 41.953133  
,-88.120711, 41.946860  
,-88.120001, 41.943856  
,-88.119124, 41.939127  
,-88.110555, 41.939054  
,-88.110480, 41.953639  
,-88.120709, 41.953133  
,-88.117750, 41.95091  
,-88.116824, 41.95091  
,-88.116824, 41.95056  
,-88.117750, 41.95056  
,-88.117750, 41.95091  
)  
)  
);  
COMMIT;
```

This specifies that the outermost region surrounds the innermost region as a **polygon with a hole**

The hole for the innermost region is specified **last**, and its boundary coordinates specified in **clockwise** order

Location Tracking Server: Implementation Flow



Creating and Starting a Tracking Set

```
GRANT AQ_ADMINISTRATOR_ROLE TO hol23c;  
GRANT CREATE_JOB TO hol23c;  
GRANT MANAGE_SCHEDULER TO hol23c;  
GRANT EXECUTE ON DBMS_AQ TO hol23c;  
GRANT EXECUTE ON DBMS_AQADM TO hol23c;  
GRANT EXECUTE ON DBMS_LOCK TO hol23c;  
GRANT EXECUTE ON DBMS_AQIN TO hol23c;  
GRANT EXECUTE ON DBMS_AQJMS TO hol23c;
```

These are the minimum privileges required for any user to **create, maintain, and operate** SDO Tracking sets

This creates and starts a tracking set named **TRAVELERS** within the user's schema

```
BEGIN  
  -- Create the tracking set: 1  
  SDO_TRKR.CREATE_TRACKING_SET(  
    tracking_set_name => 'TRAVELERS'  
    ,num_trkr_queues => 1  
    ,num_loc_queues => 1);  
  
  -- Start the tracking set: 2  
  SDO_TRKR.START_TRACKING_SET(  
    tracking_set_name => 'TRAVELERS');  
END;  
/
```

Location Tracking Server: Data Structures

These database objects are created automatically whenever a Location Tracking Server is created, and destroyed when it is dropped:

Table	Purpose
TRAVELERS_TRACKING_REGIONS	Defines the geographic regions monitored for object tracking
TRAVELERS_TRACKER	Maps the relationships between objects and the regions in which they are tracked
TRAVELERS_TRACKER_QUEUES	Contains information about queues the Location Tracking Server uses using to track objects as they traverse regions
TRAVELERS_TRACKER_LOG	Logs messages from the Location Tracking Server whenever a tracking set is created or dropped , or whenever tracking is enabled or disabled
TRAVELERS_NOTIFICATIONS	Stores notification queue messages about when an object has moved either INSIDE or OUTSIDE the regions being tracked
Advanced Queuing (AQ) objects	Multiple Advanced Queuing database objects the Location Tracking Server uses to manage location, tracking and notification messages

Inserting Polygons and Establish Object-Polygon Pairs

```
INSERT INTO TRAVELERS_TRACKING_REGIONS
SELECT cpb_id, cpb_region
FROM charging_plaza_boundaries;

COMMIT;
```

3

This adds the **inner and outer charging plaza boundaries** into the **TRAVELERS_TRACKING_REGIONS** table ...

... and this **activates tracking** for all vehicles whenever they **(T)averse** inside or outside either of the two **charging plaza boundaries**

```
DECLARE
CURSOR curTrackedVehicles IS
SELECT v_id FROM vehicles;
BEGIN
FOR v IN curTrackedVehicles
LOOP
SDO_TRKR.SEND_TRACKING_MSG(
'TRAVELERS', MDSYS.TRACKER_MSG(v.v_id, 17100101, 'T'));
SDO_TRKR.SEND_TRACKING_MSG(
'TRAVELERS', MDSYS.TRACKER MSG(v.v id, 17100102, 'T'));
END LOOP;
END;
```

4

/

Sending Location Tracking Messages

5

```
DECLARE
  tLocMsg  MDSYS.LOCATION_MSG;
  CURSOR cur_locations IS
    SELECT vt_id, vt_dt, vt_lat, vt_lng
    FROM vehicle_tracking
    ORDER BY vt_dt, vt_id;
BEGIN
  FOR cl IN cur_locations
  LOOP
    SDO_TRKR.SEND_LOCATION_MSGS (
      'TRAVELERS'
    ,MDSYS.LOCATION_MSG_ARR(
      MDSYS.LOCATION_MSG(
        cl.vt_id, cl.vt_dt, cl.vt_lng, cl.vt_lat)) );
  END LOOP;
END;
/
```

After all vehicle tracking activity has **started** ...

... this captures any traversals of the charging plaza boundaries and **enqueues** them as **tracking location messages**

Dequeuing Location Tracking Messages

6

```
DECLARE
  message  MDSYS.NOTIFICATION_MSG;
BEGIN
  LOOP
    SDO_TRKR.GET_NOTIFICATION_MSG(
      tracking_set_name => 'TRAVELERS', message => message, deq_wait => 0);
    IF (message IS NULL) THEN
      EXIT;
    END IF;
    INSERT INTO travelers_notifications (
      object_id, region_id, time, x, y, state)
    (SELECT
      message.object_id, message.region_id, message.time
      ,message.x, message.y, message.state
    );
  END LOOP;
END;
/
```

This **dequeues** any messages created when tracked vehicles have traversed either charging station boundary . . .

... and captures any dequeued messages into table **TRAVELERS_NOTIFICATIONS**

What Gets Returned?

TRAVELERS_TRACKER_LOG:

MESSAGE_LEVEL	MESSAGE	TS
I	Started tracking set.	07-JAN-24 08.20.24.930652000 PM GMT
I	Started job TRAVELERS_loc_job_1	07-JAN-24 08.20.24.930516000 PM GMT
I	Started job TRAVELERS_trkr_job_1	07-JAN-24 08.20.24.926013000 PM GMT
I	Started notification queue.	07-JAN-24 08.20.24.917331000 PM GMT
I	Starting notification queue...	07-JAN-24 08.20.
I	Started location queues.	07-JAN-24 08.20.
I	Starting location queues...	07-JAN-24 08.20.
I	Started tracker and proc queues.	07-JAN-24 08.20.
I	Starting tracker and process queues...	07-JAN-24 08.20.
I	Starting tracking set TRAVELERS	07-JAN-24 08.20.
I	Tracking set created.	07-JAN-24 08.20.21.610591000 PM GMT
I	Created notification queue.	07-JAN-24 08.20.21.610372000 PM GMT
I	Creating notification queue...	07-JAN-24 08.20.21.467922000 PM GMT
I	Created location queues.	07-JAN-24 08.20.21.467666000 PM GMT
I	Creating location queues...	07-JAN-24 08.20.21.276364000 PM GMT
I	Created tracker and process queues.	07-JAN-24 08.20.21.275694000 PM GMT
I	Creating tracker and process queues...	07-JAN-24
I	Creating tracking set... TRAVELERS	07-JAN-24
I	Created required tables and indexes.	07-JAN-24
I	Creating required tables and indexes...	07-JAN-24

TRAVELERS_TRACKER_QUEUES:

NAME	QUEUE_TYPE	ENQ_ON	DEQ_ON	DESCRIPTION
TRAVELERS_LOCATION_Q_1	NORMAL_QUEUE	YES	YES	SDO object tracker: Location Queue
TRAVELERS_NOTIFICATION_Q	NORMAL_QUEUE	YES	YES	SDO object tracker: Notification Queue
TRAVELERS_PROC_Q_1	NORMAL_QUEUE	YES	YES	SDO object tracker: Process Queue
TRAVELERS_TRACKER_Q_1	NORMAL_QUEUE	YES	YES	SDO object tracker: Tracking Queue

TRAVELERS_TRACKER_NOTIFICATIONS:

BEV	WHEN	Charging Plaza Boundary	STATUS
2024 Genesis GV70	2024-01-01 12:33:26	Approaching Charging Plaza	OUTSIDE (INIT)
2024 Genesis GV70	2024-01-01 12:33:26	Near Charging Stations	OUTSIDE (INIT)
2024 Genesis GV70	2024-01-01 12:33:41	Approaching Charging Plaza	INSIDE
2024 Genesis GV70	2024-01-01 13:07:01	Approaching Charging Plaza	OUTSIDE
2024 Genesis GV70	2024-01-01 13:07:01	Near Charging Stations	INSIDE
2024 Genesis GV70	2024-01-01 13:07:17	Approaching Charging Plaza	INSIDE
2024 Genesis GV70	2024-01-01 13:07:17	Near Charging Stations	OUTSIDE

Disabling Tracking and Stopping & Dropping Tracking Sets

```
SET SERVEROUTPUT ON
DECLARE
    CURSOR curTrackedVehicles IS
        SELECT v_id FROM vehicles;
BEGIN
    FOR v IN curTrackedVehicles
    LOOP
        SDO_TRKR.SEND_TRACKING_MSG(
            'TRAVELERS', MDSYS.TRACKER_MSG(v.v_id, 17100101, 'D'));
        SDO_TRKR.SEND_TRACKING_MSG(
            'TRAVELERS', MDSYS.TRACKER_MSG(v.v_id, 17100102, 'D'));
    END LOOP;
END;
/
```

7

This (d)isable tracking for the **TRAVELERS** tracking set, but the tracking set still exists and tracking can be resumed

If desired, this **stops** and then **drops** the **TRAVELERS** tracking set

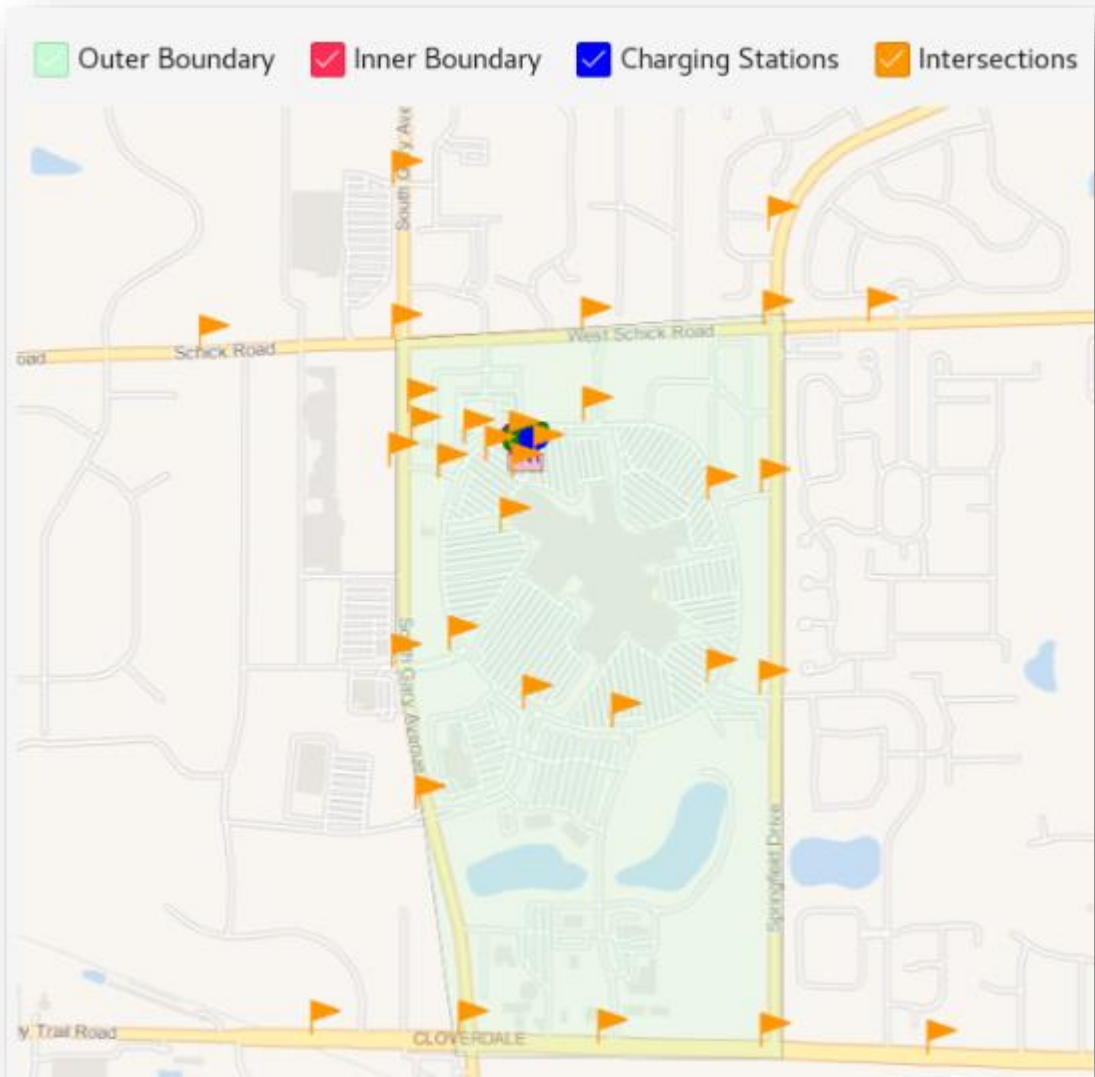
```
TRUNCATE TABLE travelers_notifications;
BEGIN
    -- Halt the tracking set:
    SDO_TRKR.STOP_TRACKING_SET(tracking_set_name => 'TRAVELERS');
    -- Destroy the tracking set:
    SDO_TRKR.DROP_TRACKING_SET(tracking_set_name => 'TRAVELERS');
END;
/
```

8

A close-up photograph of a person's hands holding a smartphone. The phone's screen displays a map application with a street grid and various colored overlays. The background is a blurred, light-colored wall. The text "Demonstration: Using APEX With Location Tracking Sets" is overlaid in the center of the image.

Demonstration: Using APEX With Location Tracking Sets

Demonstration: Tracking EVs Traversing Charging Plaza Regions



Demonstration: Displaying Mapping Tracks and Region Ingress/Egress

≡ STP

Filters

Refresh

Start
2024-01-03 07:01

End
2024-01-03 09:45:00

Specify the start and end periods in YYYY-MM-DD HH24:MI:SS format

Q Search: All Text Columns Go Actions

Beg	End	Bev
2024-01-03 09:20:16	2024-01-03 09:21:01	2022 Chevrolet Bolt
2024-01-03 09:23:11	2024-01-03 09:24:10	2024 Chevrolet Equinox
2024-01-03 09:03:41	2024-01-03 09:05:11	2024 Chevrolet Silverado
2024-01-03 08:10:27	2024-01-03 08:11:12	2022 Ford eMustang
2024-01-03 08:38:16	2024-01-03 08:38:59	2021 Ford F-150 Lightning
2024-01-03 08:24:27	2024-01-03 08:59:05	2023 Genesis GV60
2024-01-03 08:40:33	2024-01-03 09:18:23	2024 Genesis GV70

1 rows selected

Demonstration: Displaying Mapping Tracks and Region Ingress/Egress

STP

Filters

Refresh Start 2024-01-03 07:01 End 2024-01-03 09:45:00

Specify the start and end periods in YYYY-MM-DD HH24:MI:SS format

Search: All Text Columns Go Actions

Beg	End	Bev
2024-01-03 09:20:16	2024-01-03 09:21:01	2022 Chevrolet Bolt
2024-01-03 09:23:11	2024-01-03 09:24:10	2024 Chevrolet Equinox
2024-01-03 09:03:41	2024-01-03 09:05:11	2024 Chevrolet Silverado
2024-01-03 08:10:27	2024-01-03 08:11:12	2022 Ford eMustang
2024-01-03 08:38:16	2024-01-03 08:38:59	2021 Ford F-150 Lightning
2024-01-03 08:24:27	2024-01-03 08:59:05	2023 Genesis GV60
2024-01-03 08:40:33	2024-01-03 09:18:23	2024 Genesis GV70

1 rows selected

Selecting any one of these rows ...

Demonstration: Displaying Mapping Tracks and Region Ingress/Egress

Filters

Refresh

Start: 2024-01-03 07:01

End: 2024-01-03 08:59:05

Specify the start and end periods in YYYY-MM-DD HH:MM:SS

Search: All Text Columns

Go Actions

Beg	End	Bev
2024-01-03 08:24:27	2024-01-03 08:59:05	2023 Genesis GV60
		2024 Genesis GV70

1 - 7 of 7

... retrieves the track of the selected vehicle withing a specific timeframe ...

Search: All Text Columns

Go Actions

Beg	End
2024-01-03 09:20:16	2024-01-03 09:21:01
2024-01-03 09:23:11	2024-01-03 09:24:10
2024-01-03 09:03:41	2024-01-03 09:05:11
2024-01-03 08:10:27	2024-01-03 08:11:12
2024-01-03 08:38:16	2024-01-03 08:38:59
2024-01-03 08:24:27	2024-01-03 08:59:05
2024-01-03 08:40:33	2024-01-03 09:18:23

1 rows selected

TrackMapping

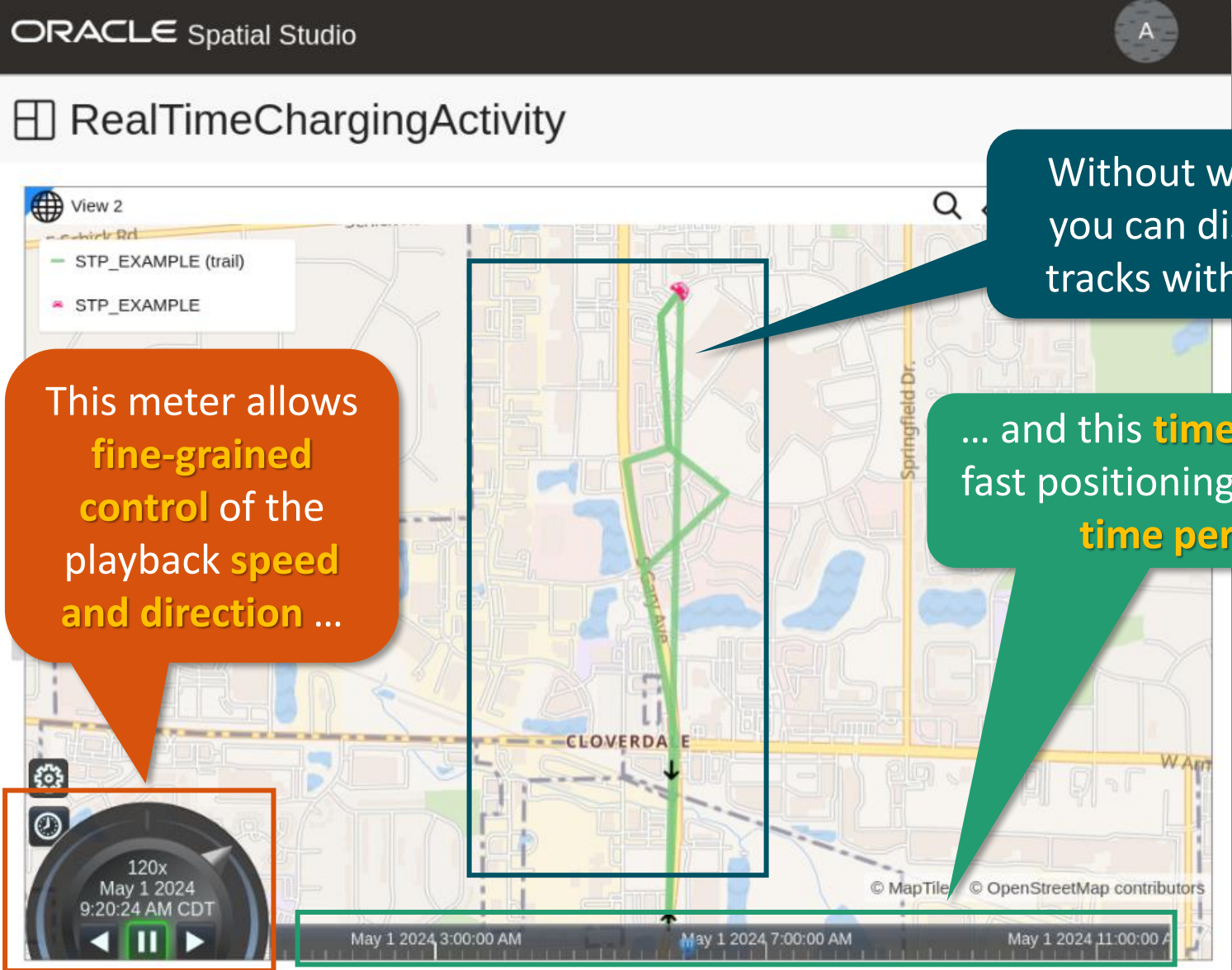
- Outer Boundary
- InnerBoundary
- Charging Stations
- Intersections
- ContiguousRoutes

Bev	When	Charging Plaza Boundary	Status
2024 Genesis GV70	2024-01-03 08:41:04	Approaching Charging Plaza	INSIDE
2024 Genesis GV70	2024-01-03 09:16:47	Approaching Charging Plaza	OUTSIDE
2024 Genesis GV70	2024-01-03 09:16:47	Near Charging Stations	INSIDE
2024 Genesis GV70	2024-01-03 09:17:02	Approaching Charging Plaza	INSIDE
2024 Genesis GV70	2024-01-03 09:17:02	Near Charging Stations	OUTSIDE
2024 Genesis GV70	2024-01-03 09:18:23	Approaching Charging Plaza	OUTSIDE

1 - 6

... as well as details of entry into and exit from the tracked regions

Demonstration: Visualizing Tracks In Real Time With Spatial Studio



This meter allows **fine-grained control** of the playback **speed and direction** ...

Without writing **any** code, you can display a vehicle's tracks within geographies!

... and this **time bar** allows fast positioning to **specific time periods**

Development time: **15 minutes**
... without writing a **single line of code!**

Plans for Future Development



Analyze **how often** EVs leave charging plaza vicinity because **no stations are available** ... and **why** they're unavailable!



Experiment with **SDO_OBJ_TRACING** features to determine which types of EVs **pass each other frequently** on the same roads



Build a web application “hook” to **Spatial Studio** within APEX to display vehicle tracking results with **live animation**

Spatio-Temporal Feature Sets: Useful Resources

Oracle 23c Spatial Developer's Guide:

<https://docs.oracle.com/en/database/oracle/oracle-database/23/spatl/index.html>

Oracle 23c Spatial Location Tracking Server (LTS):

<https://docs.oracle.com/en/database/oracle/oracle-database/23/spatl/location-tracking-server-concepts.html>

Try It Yourself: Live Lab on Spatial Data Within Oracle Autonomous Database:

<https://apexapps.oracle.com/pls/apex/r/dbpm/livelabs/view-workshop?wid=736>