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Zone Overlap Behavior Analysis

Sub-Problem Analysis

Abstract

This is a report of the behaviors of a zone alert service that 1) reports if each zone is separately reported upon for undesired entry or exit, and 2) the behavior if al keep-out zones and keep-in zones are merged in the same way as for the route planning service.

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1. Introduction

Keep-in zones and keep-out zones have the following intended semantics with respect to overlaps:

* **Keep Out Zone Overlap**: When two or more keep-out zones overlap, the area to stay out of is all the area of each zone, including any overlapping areas.
  + Thus, if two or more keep-out zones overlap, a vehicle that starts outside the zones can obey keep out zones by assuring that they separately stay outside each zone. It can consider edge traversal of each keep-out zone independently.
* **Keep In Zone Overlap:** When two or more keep-in zones overlap, the area to stay within is the collective area of each zone, including any overlapping areas.
  + Thus, if two or more keep-in zones overlap, a vehicle that starts in one or more of the zones must only stay within at least 1 of the overlapping zones at all points in time to be obeyance. It cannot consider edge traversal of each keep-in zone independently.
* **Keep In and Keep Out Zone Overlap**: When one or more keep in zone overlaps with one or more keep out zones, the keep out zones take precedence. The area in which the vehicle can operate is the area of the union of keep in zones with the keep out zones removed therefrom.
  + Thus, if the vehicle considers keep in and keep out zones separately, the behavior will be acceptable so long as keep out zones are observed irrespective of keep in zone boundaries.
    - This analysis does not consider when there is no flight solution to the constraints of zone boundaries.

1. Naïve Zone Check Behavior

If each announced keep in and keep out zone is maintained in data, and an algorithm checks the current linear velocity of a vehicle for a lookahead time window against each zone, then with a combination of:

1. Knowing whether the vehicle is currently inside or outside the zone, and
2. Knowing whether the vehicle encounters an edge of the zone on the trajectory line segment defined above.

Then the service can alert when a vehicle is about to violate a currently unviolated zone.

However, this behavior is not good enough given the desired semantics of overlapping zones.

We now consider how this naïve behavior would affect the desired overlapping zone semantics if implemented as is:

* 1. Keep Out Zone Checks

The behavior of naïve keep out zone checking assuming computation occurs when a vehicle reports its state via OpenUxAS message is as follows:

* Each zone is checked. Simple optimizations can be applied to quickly discard or ignore far away zones.
* If a vehicle reported state is currently within a given keep-out zone, the service ignores the zone, as any report of a future violation would be redundant and potentially confusing.
* If a vehicle reported state is currently outside the given keep-out zone, then the service checks if the trajectory vector intersects a zone boundary. If it does, it reports it with the time and position of intersection, as a emitted message to subscribers.
  1. Keep In Zone Checks

The behavior of naïve keep in zone checking assuming computation occurs when a vehicle reports its state via OpenUxAS message is as follows:

* Each zone is checked. Simple optimizations can be applied to quickly discard or ignore far away zones.
* If the vehicle is currently not in the given keep-in zone, it ignores the zone as reporting future entries and later exits within the length of the trajectory would be potentially confusing.
* If the vehicle is current in the given keep-in zone, it checks for any first intersection of the trajectory vector with the zone’s boundary. If there is such an intersection, it reports it with the time and position of first intersection.

1. Analysis of Naive Behavior Against Intended Overlapping Zone Semantics

Given the naïve behavior of the intended solution design, we consider how this succeeds or fails with respect to overlapping zone semantics.

1. **Keep Out Zone Overlaps**: If two or more keep-out zones overlap:
   1. If the vehicle is outside all of them
      1. If the trajectory vector intersects one or more keep-out zone boundaries, then the service will report as a separate message each zone’s first violation with its time and position of intersection.
         1. This behavior is acceptable in the concept of union, in that it sends more alerts than needed for overlapping keep out zone semantics, but this is OK.
   2. If the vehicle is within at least one keep-out zone
      1. If the trajectory vector intersects one or more other keep-out zone’s boundaries before it exits the current keep out zone, then it reports the additional zone violations per the intersection semantics
         1. This is acceptable, for the same reasons as above
      2. If the trajectory vector leaves the keep out zone before intersecting one or more keep-out zone boundarie
         1. It does not report the zone it is leaving, but does report the intersections with the zone again or any other zones in the trajectory.
            1. This is also acceptable behavior. Leaving the zone is not reported. Entering the zone again is. Entering any other zones in the time window also is reported. This is desired behavior.
2. **Keep In Zone Overlaps:** If two or more keep in zones overlap:
   1. If the vehicle is inside none of them
      1. If the trajectory vector intersects to enter any of them, and then leaves again in the time window, it will ignore future entry and leaves.
         1. This is the desired behavior.
   2. If the vehicle is inside all of them
      1. If the trajectory vector leaves a given zone, but remains inside at least one other, it will report leaving the zone.
         1. **This is not the desired behavior, as the semantics are that it is still in the collective zone, and this is of no concern.**
      2. If the trajectory vector leaves all the zones, it will report leaving all of them at different times.
         1. **This is not the desired behavior, again because of keep-in zone semantics. It is only important to report when the last zone is left.**
   3. If the vehicle is inside less than all of them (perhaps 1)
      1. If the trajectory enters another zone before leaving the current zone while remaining that or other zones, it will report the leave.
         1. **This is not desired behavior, again because of keep-in zone semantics.**
3. **Keep Out, Keep In Zone Overlaps:** If one or more keep out zones overlap with one or more keep in zones
   1. If the vehicle is not in any keep in zones
      1. If the vehicle is not in any keep out zones
         1. If the vehicle trajectory encounters keep out zone boundaries
            1. It will report the keep out violations.

This is the desired behavior.

* + - 1. If the vehicle trajectory encounters keep in zone boundaries
         1. **The behavior is erroneous as for just overlapping keep in zones, see above.**
    1. If the vehicle is in one or more keep out zones
       1. If the vehicle encounters keep out zone boundaries
          1. The vehicle will report only entry into new keep out zones

Desired behavior.

* + - 1. If the vehicle encounters keep in zone boundaries
         1. Behavior is same as previously reported for keep in zones, and is correct in ignoring future entry and exits of the trajectory in the time window.
  1. If the vehicle is in one or more keep in zones
     1. If the vehicle is not in any keep out zones
        1. If the vehicle encounters keep out zone boundaries it reports them
           1. This is the expected behavior
        2. If the vehicle encounters keep in zone boundaries, it reports them in the manner specified previously.
           1. No different problems
     2. If the vehicle is in on or more keep out zones
        1. If the vehicle encounters keep out zone boundaries, it reports them except for the keep out zones it is in
           1. This is the expected behavior
        2. If the vehicle encounters keep in zone boundaries, it reports them in the manner specified previously.
           1. No different problems.

1. Identified Problems

It is not appropriate to separately report on leaving a given keep-in zone. Staying within at least one zone always is the real semantic constraint against which warnings should be issued.

1. Recommendations

The above analysis might be better as a table with embedded sub-tables.

The above “thought analysis” is incomplete, cursory, and subject to error. The better analysis would apply **model checking**, as the specification of behavior and required behavior seems like a quintessential use case for model checking capabilities.