Real-Time Graph Visualization Tool for Vehicular Ad-Hoc Networks

(VIVAGr: VIsualization tool of VAnet Graphs in real-time)

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Abstract — **In this work we describe VIVAGr, a graphical-oriented real time visualization tool for vehicular ad-hoc network connectivity graphs. This tool enables the effective synthesis of structural, topological, and dynamic characteristics of VANET graphs, with a variety of parameters that affect the shape and characteristics of a vehicular ad hoc network (*wireless range, mobility models, road-network topology, market penetration ratio, and exhibited interference*). Our design allows researchers to explore and understand problems and issues related with vehicular ad-hoc networks that face today significant design challenges. The tool is able to present all active connection of the network in real-time mode using mobility traces. A visual encoding syntax is used to represent semantic meanings and highlight the effect of mobility and topology on vehicular network specific properties.**

Keywords: real-time graph visualization; vehicular ad-hoc netoworks; nodes mobility; interference;

I. INTRODUCTION

Vehicular Ad-hoc NETworks (VANET) are self-organized communication networks providing services for intelligent vehicle-to-vehicle and vehicle-to-infrastructure communications and applications that try to improve active safety, traffic management, and performance [1]. The road-constrained, high mobility of vehicles, their unbounded power source, and the emergence of roadside wireless infrastructure units make VANETs a challenging research topic. The information exchange in VANETs occurs at any time, while moving, and in many small fragments, conveyed by nearby vehicles and static Road Side Units (RSUs). Previous studies explored the dynamics of VANET graphs [2-3], where vehicles correspond to vertices and links to edges, using graph visualization tools [4-9]. Such tools provide structural and statistical measures for graph analysis. However, they do not support informative visualization, which according to our past experience is important for an in- depth analysis of the networking shape and properties of a VANET.

A key challenge to the design and development of efficient VANET protocols and services lies in the knowledge of the topological characteristics of the underlying network. Information visualization can assist researchers towards exploring and understanding problems and issues of wireless vehicular networking.

This paper introduces VIVAGr, a tool for real time Visualization of VAnet Graphs. To the best of our knowledge, VIVAGr is the first tool in the literature allowing researchers to seek answers to several key questions about the shape and the large-scale behavior of vehicular communication network, such as: How the underlying telecommunication systems affects the vehicular network topology? How does the penetration ratio affect the networking shape of VANETs? Which are the "highest-quality" vehicles in terms of connectivity? What are the laws that govern the temporal evolution of VANET-graph properties? How can we identify/define communities in a VANET? How does the road-map topology affect the VANET graph properties? What is the best deployment strategy for RSUs in order to maximize information dissemination?

VIVAGr is a graphical-oriented tool that has a number of features allowing the analysis of the structural, topological, and dynamic characteristics of VANETs talking into account a number of parameters that affect the properties of the networking environment (*wireless range*, *mobility models*, *road-network topology*, *penetration ratio*, *signal propagation* and *experienced interference*). VIVAGr imports mobility traces of nodes and creates the corresponding network connectivity graph representing all active connections of the network. The graph layout module is operating in real-time mode following the mobility patterns of vehicles over urban areas. A visual encoding syntax is used to represent semantic meanings for vehicular network connectivity graphs and to highlight the effect of mobility to node connectivity and the networking specific properties, given the underlying telecommunication system.

The rest of the paper is organized as follows: Section II describes the previous work in this area. In section III we present an overview of VIVAGr. Section IV describes the architecture of VIVAGr and Section V presents a case study of the tool's main features. Section VI has our conclusions.

II. RELATED WORK

Many graph visualization tools, not explicitly designed for vehicular networks, are available today and provide users not only with visualization options but also with a set of features for graph analysis.

GUESS [4] provides infinite plane with infinite zoom capabilities. The tool integrates a language called Gython, enabling the user to edit a graph according to user's needs. However, the visualization of nodes is based on a variety of layout algorithms that do not take into consideration geographic topology of nodes. Although GUESS is a standalone application, it is also integrated with Network Workbench [5] graph analysis tool.

SNAP [6], and Pajek [7] support visualization and analysis for large-scale networks and provide tools for graph manipulation. They are built to support different research areas integrating a range of different algorithms for processing and analyzing data. SNAP provides a graphical front-end called NodeXL [8]. NodeXL supports a range of functionalities such as zooming, scaling and dynamic filtering. Pajek supports abstraction by factorizing a network into smaller networks and provides visualization and analysis algorithms. LaNet-vi [9] is a powerful graph visualization and analysis tool able to cope with large-scale complex graphs. It has a sophisticated visualization algorithm, based on k-cores decomposition, and can be used in many different application domains. When used for the analysis of network connectivity graphs LaNet-vi does not consider the geographic positions of nodes for visualization.

The ViTAN [10] is designed explicitly to represent ad-hoc networking graphs, using the nodes' locations and the quality of the links (edges) for graph representation. iNSpect [11] allows the visualization and analysis of NS-2 [12] based wireless network simulation environments using node's mobility traces and the corresponding post-processed generated NS-2 trace files. Similarly, the Multi-view communication visualization tool [13] uses simulation traces and visualizes in real-time a given network, but it mainly focuses on the recognition of node communication patterns rather than the network graph analysis.

VIVAGr design approach differs from known graph visualization tools by enabling the effective synthesis of structural and topological characteristics of VANETs with a variety of parameters that affect the shape and the characteristics of a wireless vehicular ad hoc network, *wireless range, mobility models, network topology, market penetration ratio, signal propagation and exhibited interference* (TABLE I).

III. VIVAGr OVERVIEW

VIVAGr allows the visualization and real time drawing of connectivity graphs, based on nodes' mobility patterns and the underlying telecommunication system. In our design we gave emphasis in three key areas for graph visualization: *interactivity*, *visual encoding*, and *real-time representation of nodes' mobility patterns*.

TABLE I. COMPARISON OF EXISTING VISUALIZATION TOOLS IN VANETs

	Penetration Ratio	Graph analysis	Geographical topology	Interference modeling	Real-Time animation of Mobility
Guess		v			
Pajek		v			v
Workbench		v			
LaNet-vi		v			
Vitan			v		
iNSpect		v	v		v
Multi-View			v		v
VIVAGr	v	v	v	v	v

VIVAGr imports trace files describing the mobility patterns of nodes over time. At each time instance a connectivity undirected graph is created. Nodes are depicted as vertices and links as edges between two vertices. As nodes' positions change over, animation is used to show the transition of the newly created graph on canvas. It is able to collect and export specific statistical data for later analysis, focus and monitor the activity of a vehicle (or a group of vehicles) within the networking environment.

The graph layout module is operating in real time mode. The user is able to select specific connectivity models allowing the creation of links between operating nodes. The user is also able to alter the viewing angle of the created graphs and to highlight (navigate on the drawing canvas) specific link and node characteristics (Fig. 1).

A. VIVAGr Implementation

VIVAGr is implemented in MATLAB [14], a high-level technical computing language and multiplatform environment for algorithm development, data visualization, data analysis, and numeric computation, using a modular approach including many different modules/function for creating VANET graphs. The tool is able to operate and used in different operating platforms supported by MATLAB (i.e. MS windows, LINUX, MAC OS).

B. Real time representation of connectivity graphs

An important issue in vehicular networking is the time-evolving characteristics of the created communication graphs and the effect of the mobility patterns, using a geographical map, on the properties of the networking environment. With VIVAGr, the user is able to monitor in real time all corresponding changes in graph topology and connectivity during time as nodes follow a specific mobility pattern. The user can control the networking conditions under which a link can be formed, or not by, changing the properties of the underlying telecommunication system. In the current implementation we employ three different types of connectivity models, which can be enabled using the control panel (Fig. 1), simple wireless range, interference limited range [15] and transmission rate mapping. Using VIVAGr the user is able for a specific mobility scenario to select

different connectivity option and observe the effect of the corresponding graph in real time. For all these cases, during the real time graph visualization process, the user can: i) calculate and represent specific properties and attributes of all vertices and/or edges of the graph; ii) control the time frame of operation, described by the mobility scenario; iii) select the market penetration ratio of the network [2]. Also, all the above graph visualization and animations processes, appearing on the drawing canvas, can be recorded and exported into a video file in order to be available for later studies.

IV. VIVAGr DESIGN

VIVAGr provides a link between formalism for representing network connectivity and graph visualization. It is a portable, multiplatform, and modular tool including various independent modules that could be used jointly or as separate functions, easily modified according to specific needs and requirements. These modules are described in the following section.

A. Mobility module

For creating the connectivity graph we need to import information about the mobility pattern of the vehicles. This information is described in pre-processed mobility trace files on a regional or urban area. We implemented a component able to transform these data into a structured common format in MATLAB, with all required information about nodes' position over time: (i) the Cartesian coordinates of vehicles in every time interval that describe the nodes position from the beginning to the end of the mobility scenario in time; (ii) information about the: number of vehicles, number of RSUs, size of the networking area, density of RSUs, etc. These data can be imported by VIVAGr in order for the graph drawing module to create the corresponding connectivity graph. An animation of the nodes movement is created allowing the user to observe how and in what extend different topographical layouts influence the spatio-temporal characteristics of a VANET communication graph.
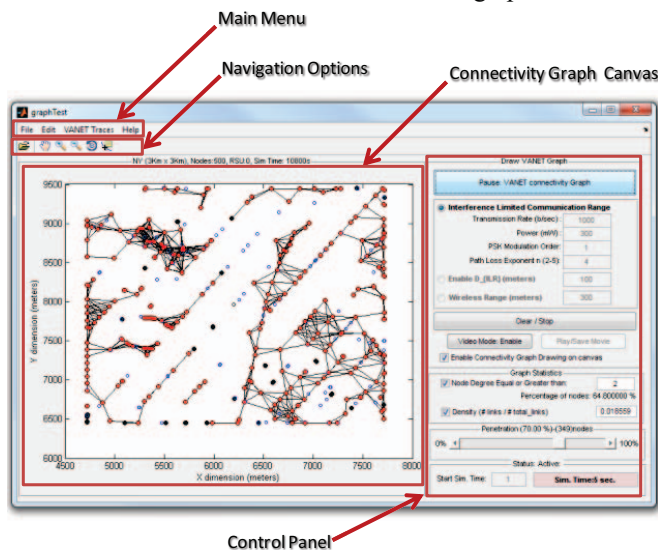

Figure 1. VANET Graph Visualization Tool - Main Screen

B. User interface module

VIVAGr interface module is presented in Fig. 1. It allows the users to: *observe* the created graphs in real time through the drawing canvas; *control*, during the real time visualization process the networking conditions and properties of the created VANET graph; *observe changes* in shape and topology through the control panel; and *navigate* within the created graph using the navigation menu. From the control panel the user can select different options for creating a graph, pause, stop, clear the visualization, monitor statistical properties, enable and/or disable drawing and define the market penetration ratio. All these can affect the created graph and the extracted statistical results. Also, a *video capture* option is embedded in order to create video files showing exactly what has been drowned on the graph canvas for later use and study.

In the user interface module we have given great attention to interactivity, one of the most important issues in graphical user interface design. Our implementation has a number of visualization options and choices that can affect the display of the corresponding graphs: *(i)* enable navigation for changing the viewpoint of an object in the drawing scene (canvas); *(ii)* allow smooth animated transitions following nodes mobility patterns and newly created or destroyed links; *(iii)* allow focus option (zoom in/out) on a specific region of the networking area where a group of nodes is located (i.e. a cross-road, a roundabout, a parking lot) to clearly observe the properties of this group; and *(iv)* formalize all user interaction commands in a VCR-style format (start, pause, and stop) to avoid user errors and command conflicts.

A visual encoding syntax is used to represent the above semantics and to highlight the effect of mobility to network properties, given the underlying telecommunication system. Each node is represented with a solid round dot and its position is updated as time evolves. When another node is in proximity, given the selected connectivity model, a connection is possible and a straight solid line is drawn between them. To recognize not moving nodes (or other entities) we use different shapes for each one of them (i.e. RSU are depicted as rectangles).

Our tool differs from similar implementations since we recognize that the above visual encoding is not created equally for all the objects. Thus, coloring is used to highlight each entity or object (node or a link) which either has different attribute values and properties (i.e. node connectivity) with different role in the network operation (i.e. RSUs are colored with green color), or is not participating in the network but only affects vehicle's traffic patterns (network penetration ratio).

To this end, we represent as black empty dots the nodes that are not participating in the network, but could be part of it when the connectivity requirements are satisfied (i.e. the transmission range) and as blue empty dots the nodes that given the network penetration ratio, cannot participate in the network (i.e. have turned off their wireless communication devices or are not equipped with one at all). When a link is feasible and can operate in high transmission rate it is

colored in a red like color and when the networking conditions indicate that a link operates in a lower rate we use blue like colors for it. If the user selects to highlight specific properties of the connectivity graph (i.e. node degree) then the tool keeps the drawing graph edges in a neutral color (i.e. black) and highlights (i.e. with red color) the desired property for each active network node (vertices) for which this property stands.

C. Graph Analysis module

VIVAGr allows users to extract results on a number of metrics used to describe the shape and the properties of a vehicular network. These metrics [2] (i.e. Node degree, Effective Diameter, Density, Betweenness Centrality, Lobby Index, Link duration, Connected periods, Link re-healing time, number of clusters and communities) can be used to identify the "highest-quality" vehicles in terms of connectivity (i.e., nodes with high betweenness centrality/lobby index values), as well as identify the laws that govern the temporal evolution of VANET-graph properties. The tool is able either to present them during the visualization process or to export structured data that could be analyzed in a later time, even using other graph analysis tools.

D. Connectivity graph module

VIVAGr connectivity module allows the user to select different models for network connectivity and observe how the underlying telecommunication networking system affects the corresponding connectivity graph and network topology. In our implementation new modules can easily be added if required. Using the control panel the user can define the networking conditions under which a link can be feasible or not. When selecting the "Wireless Range" option, links are forced to be created between vehicles in proximity of a specific, user defined, distance (Fig. 2).

Considering that we have knowledge of the underlying telecommunication system and that interference is the critical limiting factor for communication then the *"Interference Limited Communication Range"* option allows the formation of links for which the nodes are close enough so this limiting critical communication range factor is satisfied. The theoretical analysis in [16] describes how the interference limited communication range (d_{ILR}) is affected by: *(i)* the modulation scheme, *(ii)* the accepted target BER of the network, *(iii)* the systems' bandwidth, *(iv)* the propagation model that takes into account degradation of transmission power in respect of distance, shadowing and reflection effects, and most importantly on *(v)* the transmission rate.

From the control panel the user is able to select the values for these parameters and observe the differences in the corresponding created communication graph. For these values the tool, using the methodology presented in [16], calculates the critical communication range given the surrounding interference for every node in the network. Every other node with in this distance is said to form a feasible link. Observing Fig. 2, we can see how the underlying telecommunication system affects network connectivity.
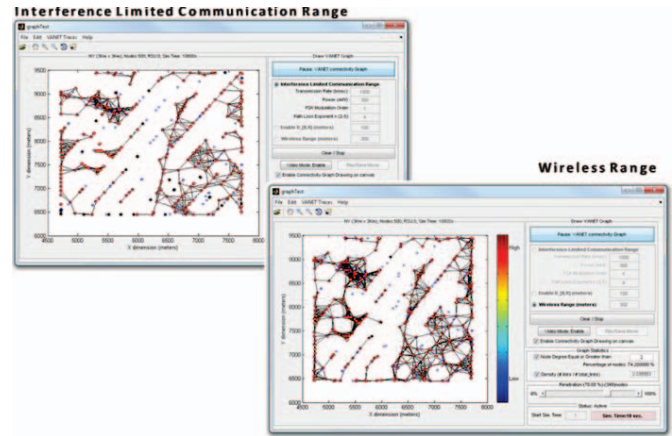

Figure 2.   VANET Graph Visualization Tool:
Different Connectivity Graph

The created graph in the latter case (upper left picture) is much sparse in respect of the first case (lower right picture) since it does not allow the creation of links probable of causing transmission errors, given the souring interference and signal attenuation due to physical obstacles (cross-layer design). In the case of the interference limited communication range the connectivity graph seems to follow the road-map topology of the city area much more constant than the case of wireless range. We can also see that in these two cases we can identify different types and sets of node communities in the vehicular network.

The tool is also featured with an option of showing the transmission rate mapping of all links (Fig. 3). In this case, the user selects a specific communication distance and the connectivity module is responsible for calculating the appropriate transmission rate to be used for the transmission distance to meet the value of the *interference limited communication range*, making communication feasible [15]. A color map is then created for all links according to the achieved rate (a red like color maps to a high rate while a rate closer to blue indicates to a lower rate link). Our results show that there are regions where the use of high quality services is possible since high transmission rate is possible where on the other hand the levels of experienced interference make impossible the use of high transmission rate VANET services.
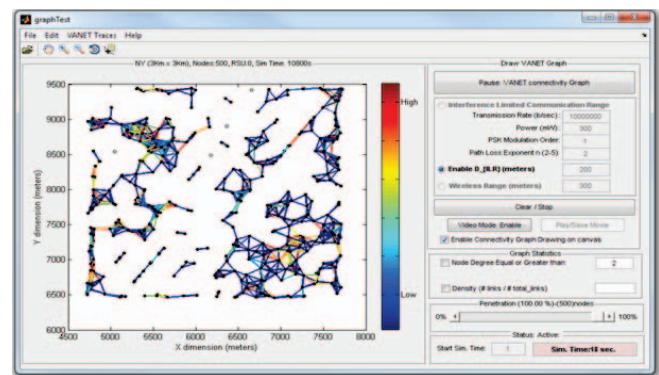

Figure 3.   VANET Graph Visualization Tool:
Transmission Rate mapping

V. USE CASE STUDY

In this section we describe a case study using realistic mobility traces generated using the VanetMobiSim [17]. The realism of the mobility models utilized in VanetMobiSim has been validated extensively using benchmark tests from vehicular traffic flow theory which are highly accepted by the transportation community. Our goal is to show how the tool can be used in order to get answers on critical issues about VANET design.

A. Mobility traces

The traces used describe the position of nodes in specific time intervals (of one second) and follow a steady state behavior where the number of vehicles in a given region remains constant over time. In our disposal we had two different vehicular mobility scenarios referring to central regions of two big US cities, namely a: 3Km**3Km area in upper-east Manhattan of New York and a 4Km**4Km area in and around the city center of Los Angeles. These sets describe the mobility of 500 and 700 vehicles for the Manhattan and Los Angeles respectively.

We used the software component from VIVAGr to translate the mobility data into a structured MATLAB vector form. Then these data were imported back to the application allowing the user to create, in real time, the corresponding connectivity graphs for these examples and observe the shape and the properties of the network talking advantage of the tool's features (as we describe above).

B. Navigation

With the navigation capabilities of the tool, the user can change the viewing angle and position on the drawing graph canvas, using the available options from the menu bar (Fig. 1) and continue monitoring the animation of drawing graph in time. In Fig. 5, we see such an example. For the NY scenario, the user wants to focus on a designated area so as to observe a community of nodes. The user can change the communication model (more than once) for this set of nodes and observe the evolution of the vehicular network related properties for this area of interest and finally reset the view to the original position.

C. Market Penetration

Market penetration describes the number of vehicles, physically located in the area of interest, able to actively participate in the formation of the VANET. The tool allows the user to select any desired penetration ratio, which reflects in the creation of the corresponding connectivity graph. The vehicles that do not participate in the network are depicted with a different visual syntax (blue circles) and they only act as moving obstacles for the rest of the vehicles in the network. From our experience with the tool, this feature allows us to investigate how the background vehicle traffic affects the VANET graph properties (i.e., density, node degree). Our observations show that even when the penetration ratio is low, the created connectivity graphs, describing the set of feasible links, seem to follow the road map topology.

D. Interference Limited Communication Range

In Fig. 2, we showed for the same mobility scenario the graphs for both of these two cases in two continuous time intervals. We observe that when interference phenomenon is taken into account, the connectivity and network density of the corresponding graph is much lower. In order to increase network connectivity we must be able to ensure higher values for the interference limited communication range and thus select a lower transmission rate to compensate with exhibited interference (for more details see [16]).

In Fig. 3, we can also see how node connectivity is affected by the road-map topology on which the vehicles move. Especially in the case were we take into consideration the propagation loss factor and interference we can clearly observe that the feasible set of created links follows the road-map of the networking area (upper-east Manhattan of New York in this case).

E. Road Side Units

The presence of RSUs influences the structure and evolution of the VANET communication graph [2]. VIVAGr has the ability to annotate, as Fig. 4 shows, all stationary RSUs in the area of interest. The RSUs inherit the properties of the vehicular nodes and thus the visualization used is similar as the one discussed above and only the shape is different (rectangles). In our implementation we have the ability of selecting the relative position and the density of RSU in the network. The optimal strategy for maximizing dissemination information thus can be taken into account (i.e. maximize the number of serving nodes in time by the road side units). As an example we see (Fig. 4) that when placing an RSU in high density area, then nodes that were not connected are able to relay information through the RSUs even in the interference limited communication range example.
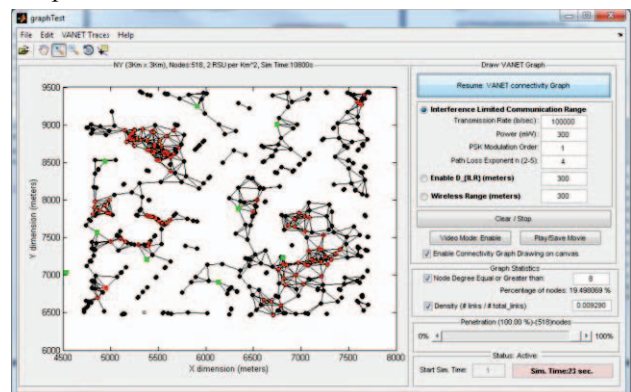

Figure 4.   VANET Graph Visualization Tool: Road Side Units (RSUs) are highlighted with green color
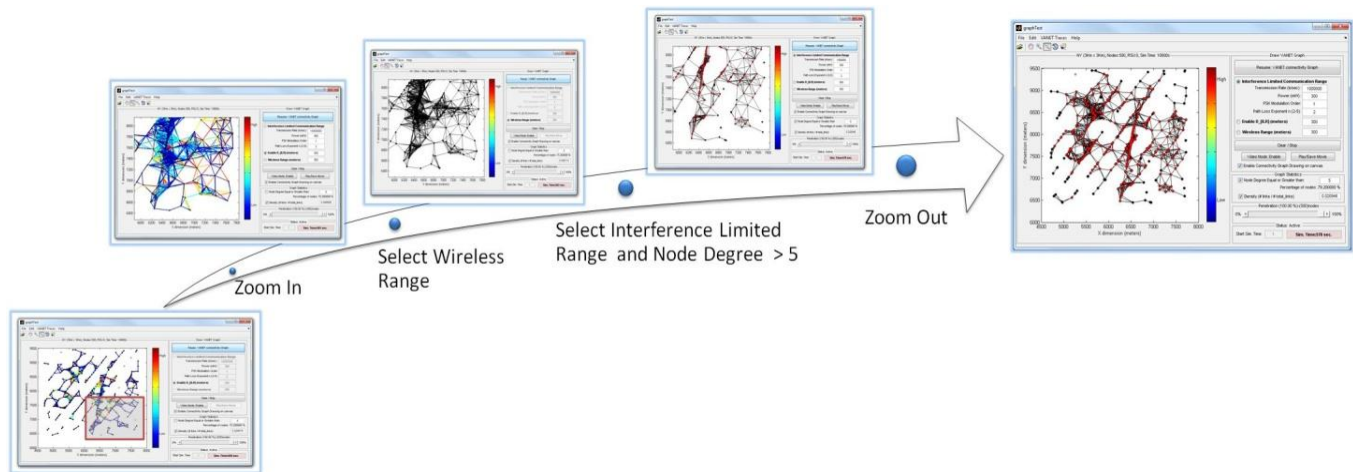
Figure 5. VANET Graph Visualization Tool: Road Side Units (RSUs) are highlighted with green color

VI. CONCLUSION

In this work, we presented a connectivity graph visualization tool designed specifically to represent the structure and behavior of a VANET. VIVAGr imports mobility traces of nodes and creates a connectivity graph each time nodes change positions over time. The graph represents all active connections of the network at each time instance. VIVAGr shows how the various topological characteristics evolve over time under specific mobility patterns and affects network connectivity for vehicular ad-hoc networks. The graph layout module is operating in real time following realistic placement of vehicles over urban areas using specific mobility traces. Our focus was given in allowing user to be able to answer several key questions for VANET graphs. A visual encoding syntax is used to represent semantics for vehicular network connectivity graphs and to highlight, in real-time mode, and given the underlying telecommunication system, the effect of mobility to node connectivity and the networking specific properties.

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