

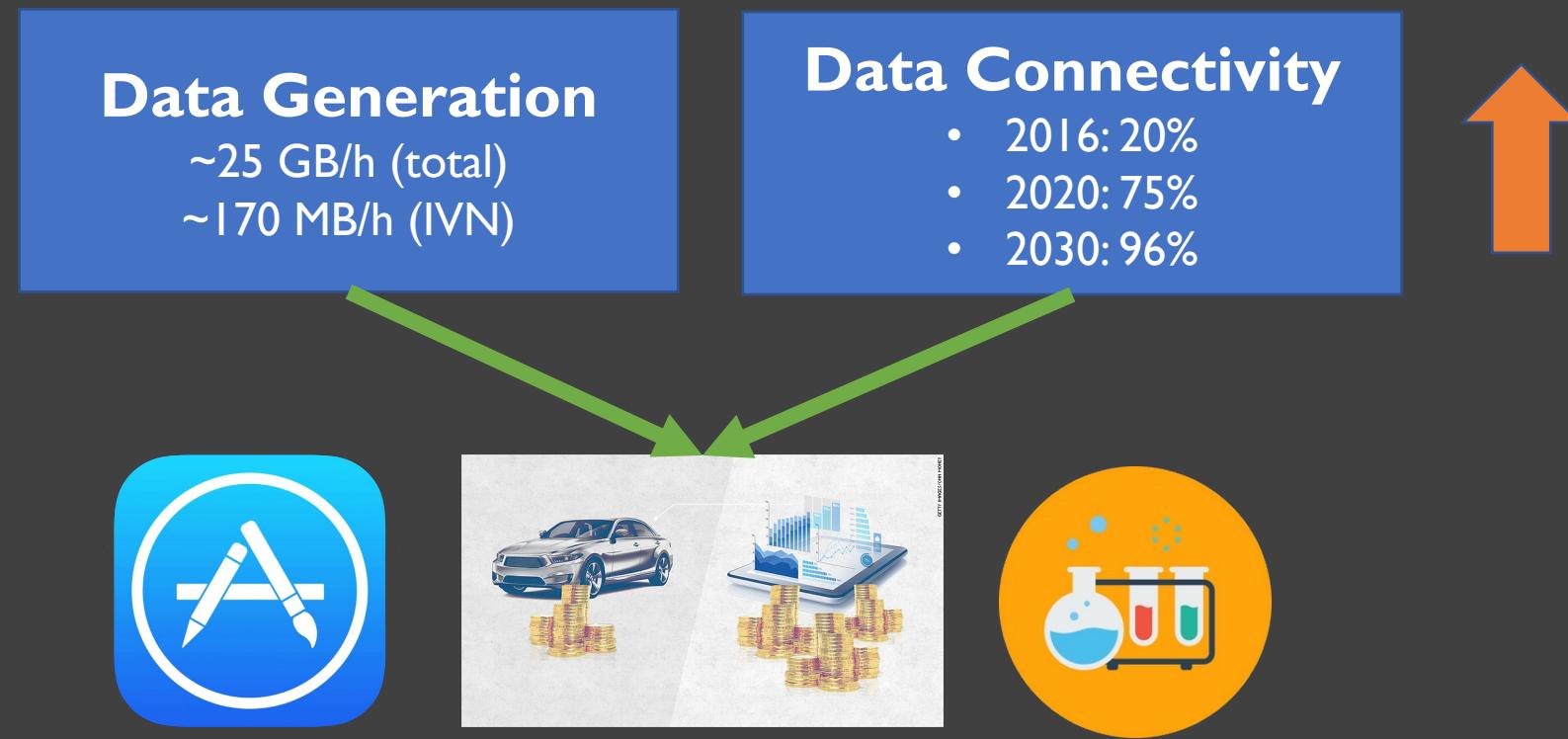
**Mert D. Pesé**, Dongyao Chen, C. Andrés  
Campos, Alice Ying, Troy Stacer and Kang  
G. Shin

# DETROIT: Data Collection, Translation and Sharing for Rapid Vehicular App Development

IEEE SECON 2022, Virtual  
09/20/22



# Vehicles are getting increasingly connected



- Revenue through Advertisements and Third-Party Apps
  - Boost in Academic Research

# Who collects what data?



**PROGRESSIVE**

**State Farm**

**verizon**

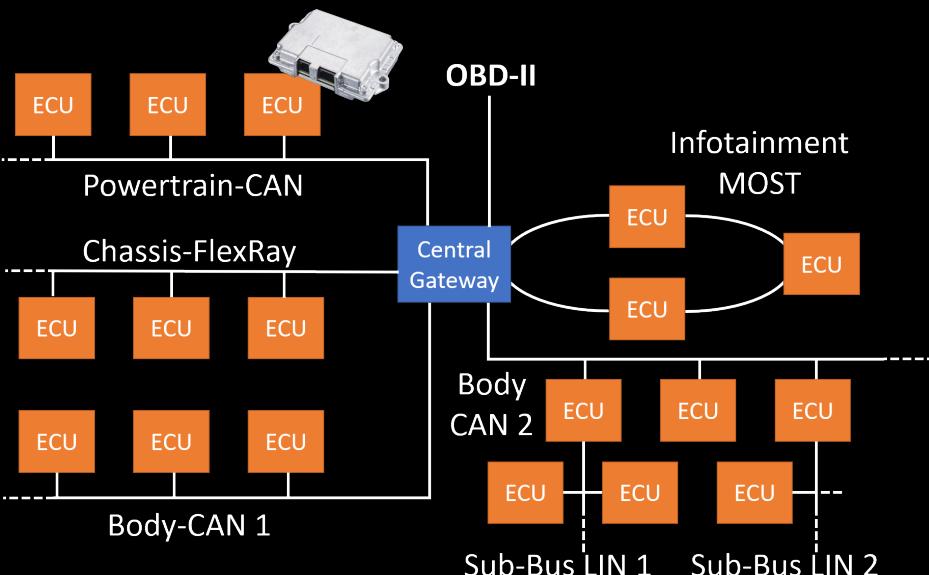
**otonomo**



Powertrain/Kinematic-Related Information		Body-Related Information	
ECU	Signals	ECU	Signals
<b>Powertrain Control Module (PCM)</b>	<ul style="list-style-type: none"> <li>Pedal Position</li> <li>Throttle Position</li> <li>Engine Oil Temperature</li> <li>Fuel Level</li> <li>Oil Pressure</li> <li>Wheel Speeds</li> <li>Engine Speed</li> <li>Torque</li> <li>Coolant Temperature</li> <li>Engine Load</li> </ul>	<b>Body Control Module (BCM)</b>	<ul style="list-style-type: none"> <li>HVAC</li> <li>Turn Signals</li> <li>Lights</li> <li>Wipers</li> <li>Trunk</li> <li>Doors</li> <li>Windows</li> <li>Mirrors</li> <li>Remote Keyless Entry</li> </ul>
<b>Electronic Power Steering (EPS)</b>	<ul style="list-style-type: none"> <li>Steering Wheel Torque</li> <li>Steering Wheel Position</li> <li>Wheel Speed</li> </ul>	<b>Telematic Control Unit (TCU)</b>	<ul style="list-style-type: none"> <li>Radio</li> <li>GPS</li> </ul>
<b>Advanced Driver Assistance System (ADAS)</b>	<ul style="list-style-type: none"> <li>Cameras</li> <li>Radar</li> <li>LiDAR</li> </ul>	<b>Supplemental Restraint System (SRS)</b>	<ul style="list-style-type: none"> <li>Airbag Status</li> <li>Seatbelt Status</li> </ul>

# How is data collected?

## In-Vehicle Network (IVN) Architecture



CAN bus is most prominent & de facto standard

## OBD-II Port



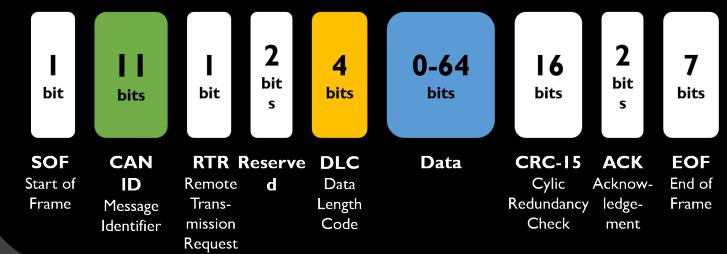
- Diagnostic link connector mandated in all (gasoline) vehicles after 1996 in US
- Communicates with vehicle's internal network, accesses CAN bus

## OBD-II Protocol (SAE J1979)



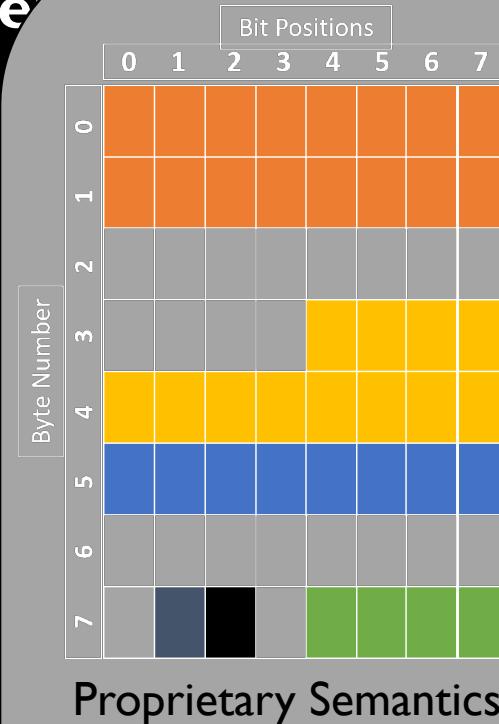
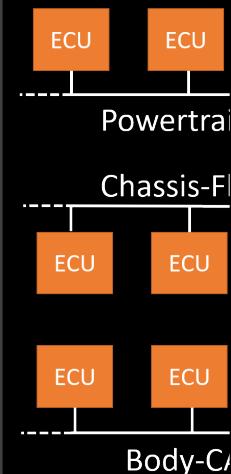
Higher-layer protocol to obtain absolute values of emission-related data, e.g., speed, voltage, etc.

## Controller Area Network (CAN)



# How is data collected?

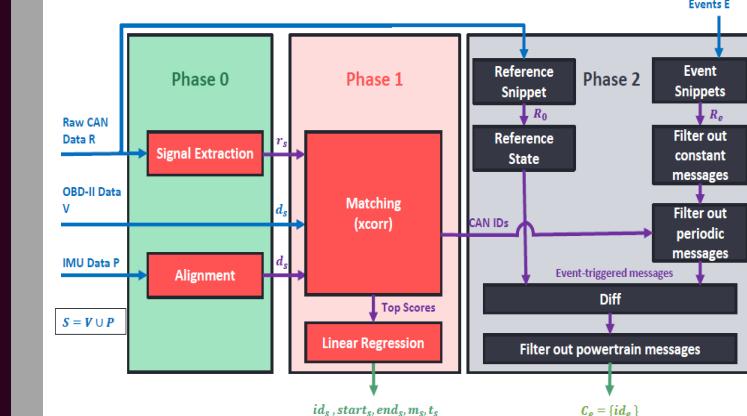
In-Vehicle



	0.200022	73	1C	15	17	A1	17	83	FF	FE	.....
0.200328	80	27	10	00	00	00	10	32	00	'.....	2.
0.200097	90	87	06	A7	07	87	CF	17	D9	.....	
0.179994	91	00	00	FF	FF	7E	BE	00	00	.....	~....
0.220087	FD	20	C2	7E	55	00	00	00	00	.....	~U.....
0.202118	190	01	B5	00	01	1A	03	00	B3	.....	
0.210003	201	00	00	40	00	00	00	85	80	.....	@.....
0.200094	20E	27	10	1C	AC	80	00	00	00	.....	
0.160144	20F	75	19	27	10	00	00	00	00	.....	u.'.....
0.199972	211	FF	FE	81	FF	48	49	00	C8	.....	HI..
0.199909	217	00	00	00	00	02	50	2C	00	.....	P,..
0.344057	240	00	80	81	00	00	00	00	00	.....	.
0.202131	275	40	00	FF	00	00	00	00	00	.....	@.....
0.202982	400	0F	00	00	02	00	00	00	07	.....	
0.199858	424	00	00	00	00	00	00	2D	5B	.....	-[
0.099981	428	69	78	00	44	00	00	00	00	.....	ix.D....
0.000000	430	8C	46	00	00	3A	90	00	00	.....	.F.:....
0.196618	433	00	01	6F	09	00	A2	29	00	.....	o....)

Manual Reverse Engineering

LibreCAN

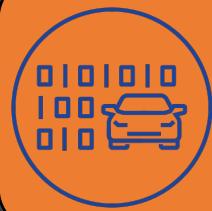


Automated Reverse Engineering

Unlock Valuable Data!

# So many solutions!

	Data Sources	Independent HW & Infrastructure	Data Accessibility
<b>Carloop</b>	OBD-II	No	Limited
<b>Otonomo</b>	CAN	No	Limited
<b>CarTel [Hu06]</b>	OBD-II	Yes	No
<b>CarLog [4]</b>	OBD-II	Yes	Limited



**LIMITED DATA**  
OBD-II only provides data from few standardized sensors



**ECOSYSTEM LOCK**  
Developer and users have to use proprietary resources



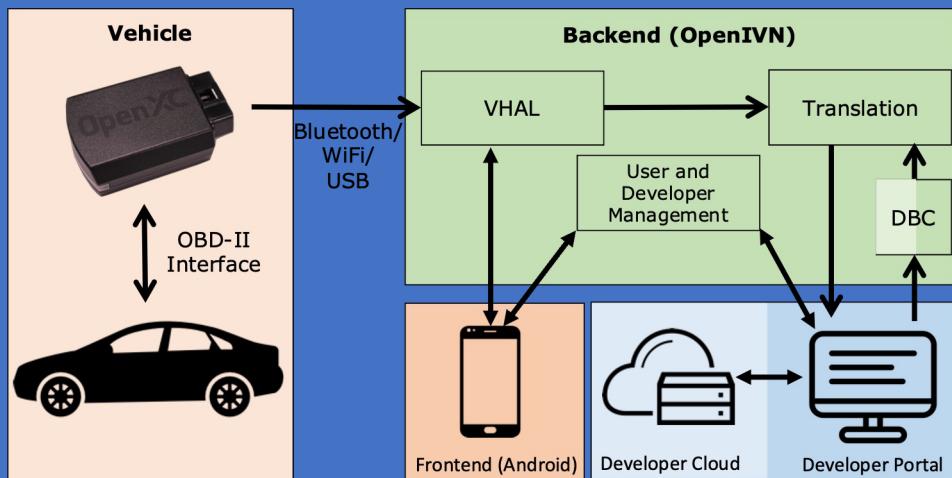
**ACCESSIBILITY**  
No/limited data sharing with third-party apps

<b>DETROIT</b>	CAN	Yes	Yes
----------------	-----	-----	-----

# So many solutions!

## DETROIT: Our SOLUTION

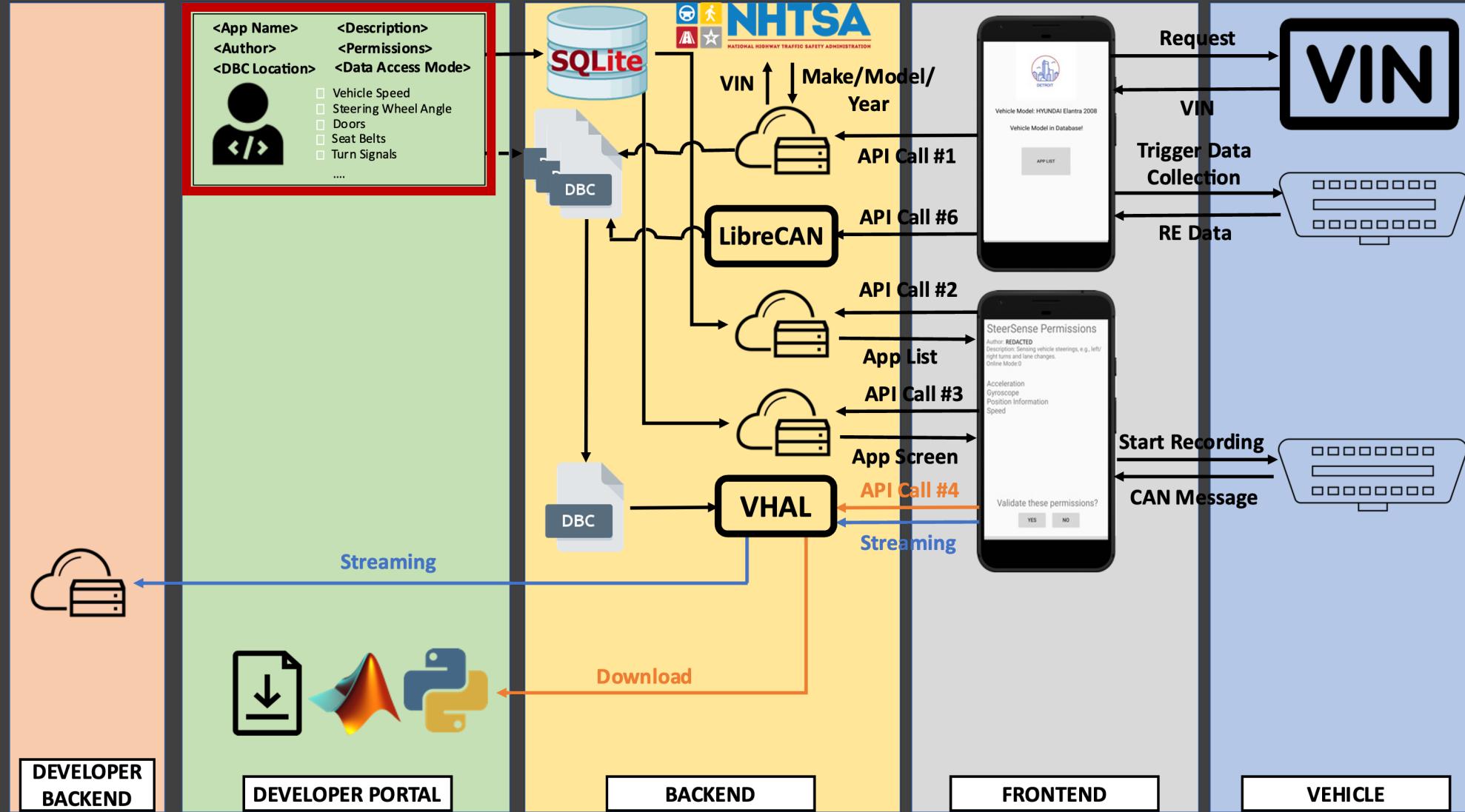
- Open-source vehicle-agnostic end-to-end framework
- Data collection, translation and sharing for rapid vehicular app development
- Light-weight and realistic solution
- Improved accuracy over phone-sensing alone
- Enhanced developer experience



- End User
- Developer
- Platform Operator

LITY  
sharing  
y apps

# Overview



# [DEV] Registering an App

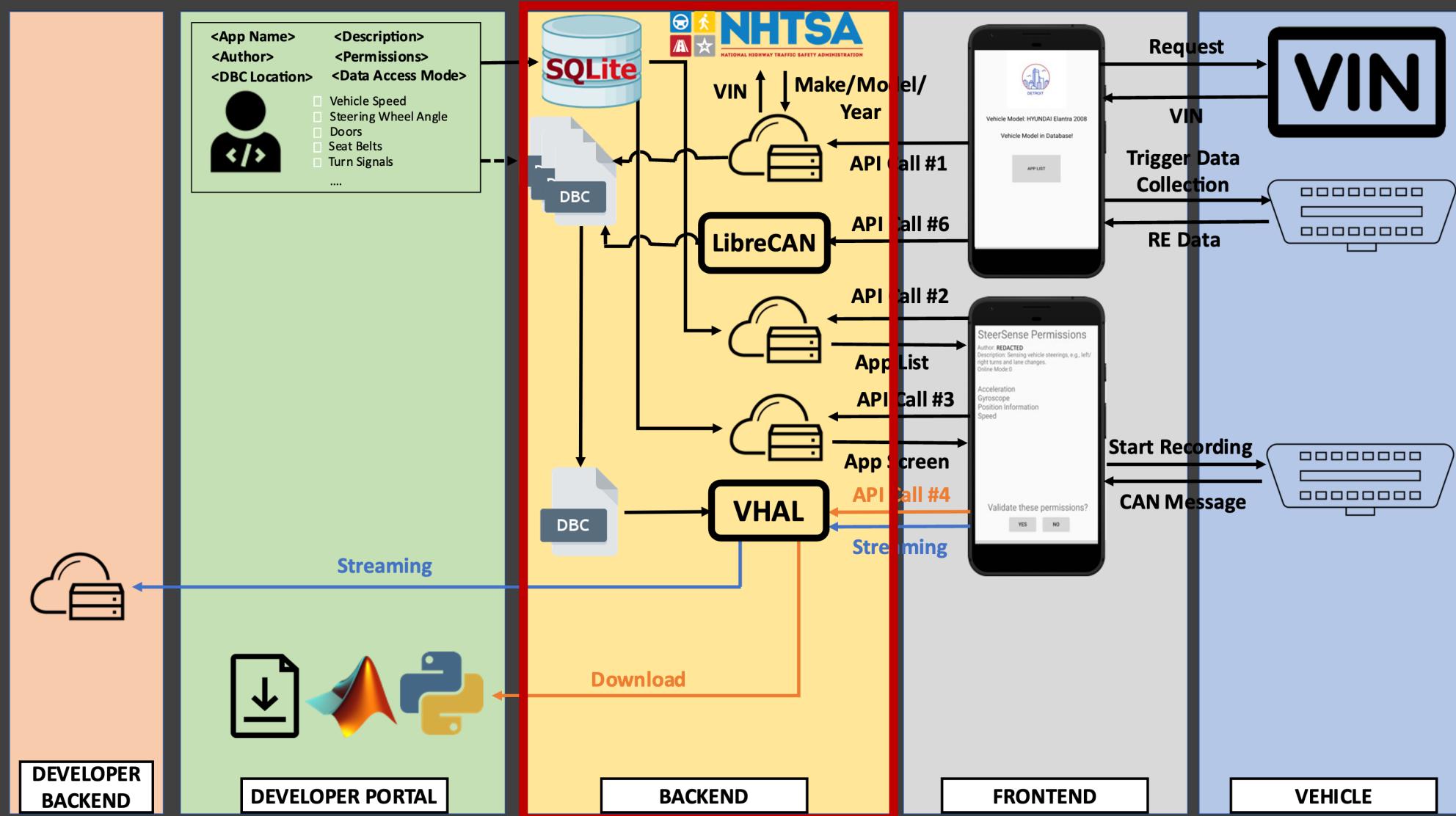
**Register New App**

App Name	<input type="text"/>																						
Description	<input type="text"/>																						
Data Format	<input checked="" type="radio"/> Download <input type="radio"/> Streaming																						
Endpoint	<input type="text"/> Endpoint must be formatted as <IPv4 address or hostname>:<Port>  Data will only be sent to the provided endpoint if <b>Streaming</b> is selected.																						
Permissions	<table border="0"> <tr> <td><input type="checkbox"/> Acceleration</td> <td><input type="checkbox"/> Parking Brake</td> </tr> <tr> <td><input type="checkbox"/> Battery</td> <td><input type="checkbox"/> Pedal Positions</td> </tr> <tr> <td><input type="checkbox"/> Doors</td> <td><input type="checkbox"/> Position Information</td> </tr> <tr> <td><input type="checkbox"/> Engine Information</td> <td><input type="checkbox"/> Seat Belts</td> </tr> <tr> <td><input type="checkbox"/> Engine Utilization</td> <td><input type="checkbox"/> Speed</td> </tr> <tr> <td><input type="checkbox"/> Fuel Information</td> <td><input type="checkbox"/> Torque</td> </tr> <tr> <td><input type="checkbox"/> Gyroscope</td> <td><input type="checkbox"/> Trunk</td> </tr> <tr> <td><input type="checkbox"/> HVAC</td> <td><input type="checkbox"/> Vehicle Turning</td> </tr> <tr> <td><input type="checkbox"/> Hood</td> <td><input type="checkbox"/> Windows</td> </tr> <tr> <td><input type="checkbox"/> Lights</td> <td><input type="checkbox"/> Windshield Wipers</td> </tr> <tr> <td><input type="checkbox"/> Mirrors</td> <td></td> </tr> </table>	<input type="checkbox"/> Acceleration	<input type="checkbox"/> Parking Brake	<input type="checkbox"/> Battery	<input type="checkbox"/> Pedal Positions	<input type="checkbox"/> Doors	<input type="checkbox"/> Position Information	<input type="checkbox"/> Engine Information	<input type="checkbox"/> Seat Belts	<input type="checkbox"/> Engine Utilization	<input type="checkbox"/> Speed	<input type="checkbox"/> Fuel Information	<input type="checkbox"/> Torque	<input type="checkbox"/> Gyroscope	<input type="checkbox"/> Trunk	<input type="checkbox"/> HVAC	<input type="checkbox"/> Vehicle Turning	<input type="checkbox"/> Hood	<input type="checkbox"/> Windows	<input type="checkbox"/> Lights	<input type="checkbox"/> Windshield Wipers	<input type="checkbox"/> Mirrors	
<input type="checkbox"/> Acceleration	<input type="checkbox"/> Parking Brake																						
<input type="checkbox"/> Battery	<input type="checkbox"/> Pedal Positions																						
<input type="checkbox"/> Doors	<input type="checkbox"/> Position Information																						
<input type="checkbox"/> Engine Information	<input type="checkbox"/> Seat Belts																						
<input type="checkbox"/> Engine Utilization	<input type="checkbox"/> Speed																						
<input type="checkbox"/> Fuel Information	<input type="checkbox"/> Torque																						
<input type="checkbox"/> Gyroscope	<input type="checkbox"/> Trunk																						
<input type="checkbox"/> HVAC	<input type="checkbox"/> Vehicle Turning																						
<input type="checkbox"/> Hood	<input type="checkbox"/> Windows																						
<input type="checkbox"/> Lights	<input type="checkbox"/> Windshield Wipers																						
<input type="checkbox"/> Mirrors																							
<input type="button" value="Register"/>																							

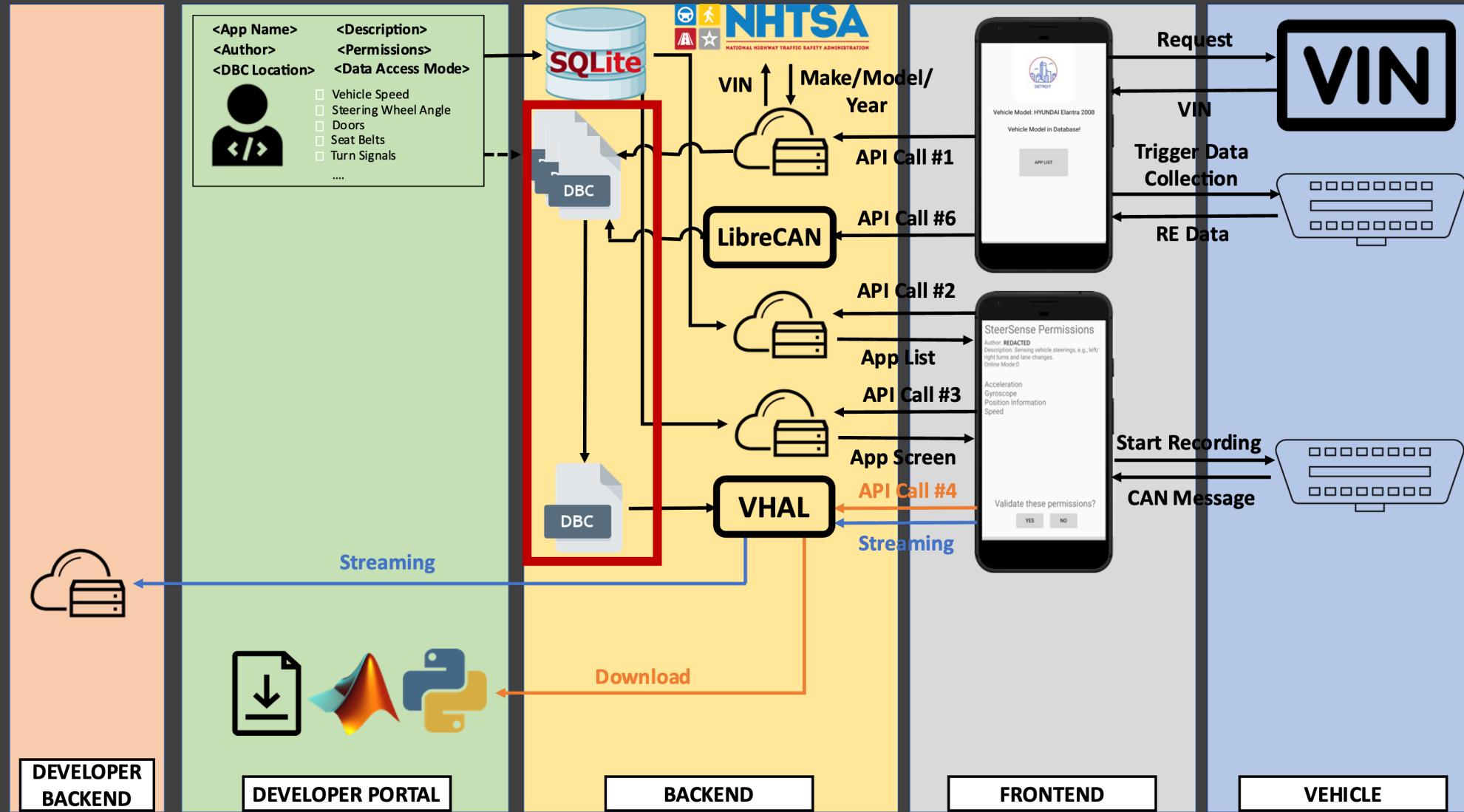
Coarse-Grained Permission (Dev)	Fine-Grained Permission (OpenIVN)
Acceleration	A(x), A(y), A(z)
Battery	Voltage (Control Module)
Doors	(Un)lock driver's side (Un)lock passenger's side Driver door open/close Passenger door open/close Left back door open/close Right back door open/close
Engine Information	Intake Manifold Pressure Intake Air Temperature Engine Coolant Temperature
Engine Utilization	RPM, Absolute Load Turbo Boost & Vacuum
Fuel Information	Rail Pressure, Flow Rate
Gyroscope	G(x), G(y), G(z)
HVAC	Turn on heating/AC Fan Speed, Cabin Temperature Air circulation
Hood	Open/Close hood

Lights	Headlights on/off Hazard lights on/off Interior lights on/off
Mirrors	Change driver's mirror Change passenger's mirror
Parking Brake	Activate/release parking brake
Pedal Positions	Accelerator Pedal Positions B,D,E
Position Information	Air Pressure, Air Temperature Altitude, Bearing, GPS
Seat Belts	Driver (un)buckled
Speed	Vehicle Speed
Torque	Torque
Trunk	Open/Close trunk
Vehicle Turning	Left/right turn signal on/off Steering Wheel Angle
Windows	Driver window up/down Passenger window up/down Left back window up/down Right back window up/down
Windshield Wipers	Windshield wipers settings Windshield wiper fluid

# Overview

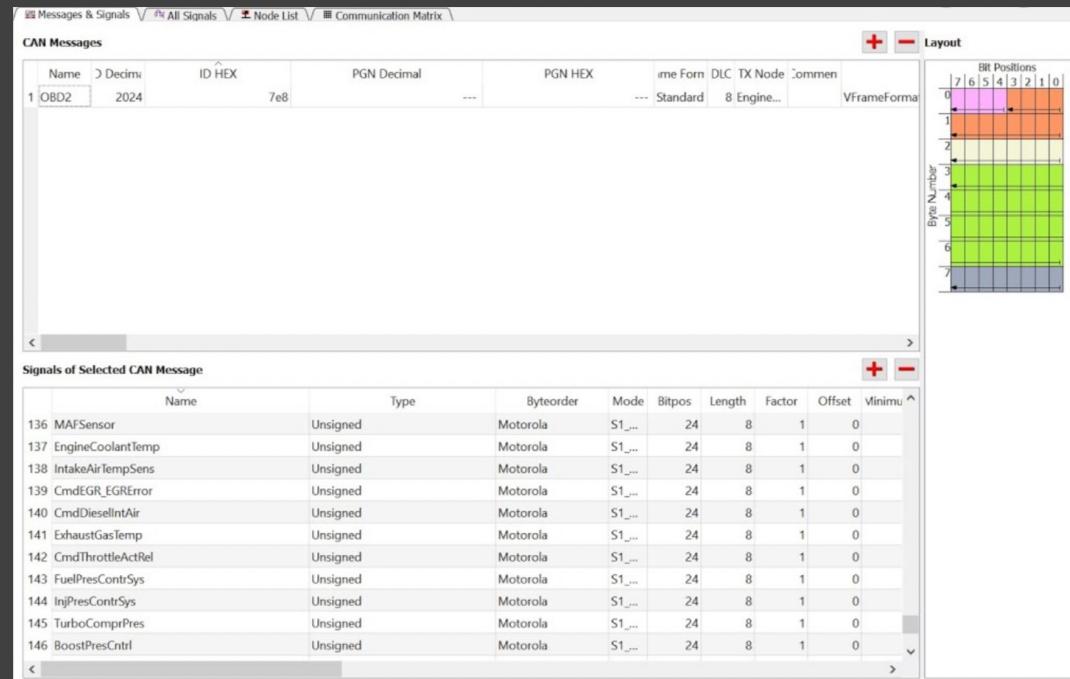


# Overview



# [PO] DBC Repository

- DBC: Translation table unique to each vehicle model
- Maintain database of DBCs
  - Only accessed by *Platform Operator* (liability!)
- Dynamically extended by deployment of LibreCAN for new/unknown vehicles



The screenshot shows a software interface for managing DBC files. At the top, there are tabs for 'Messages & Signals', 'All Signals', 'Node List', and 'Communication Matrix'. Below the tabs, the main area is divided into two sections: 'CAN Messages' and 'Signals of Selected CAN Message'.

**CAN Messages:**

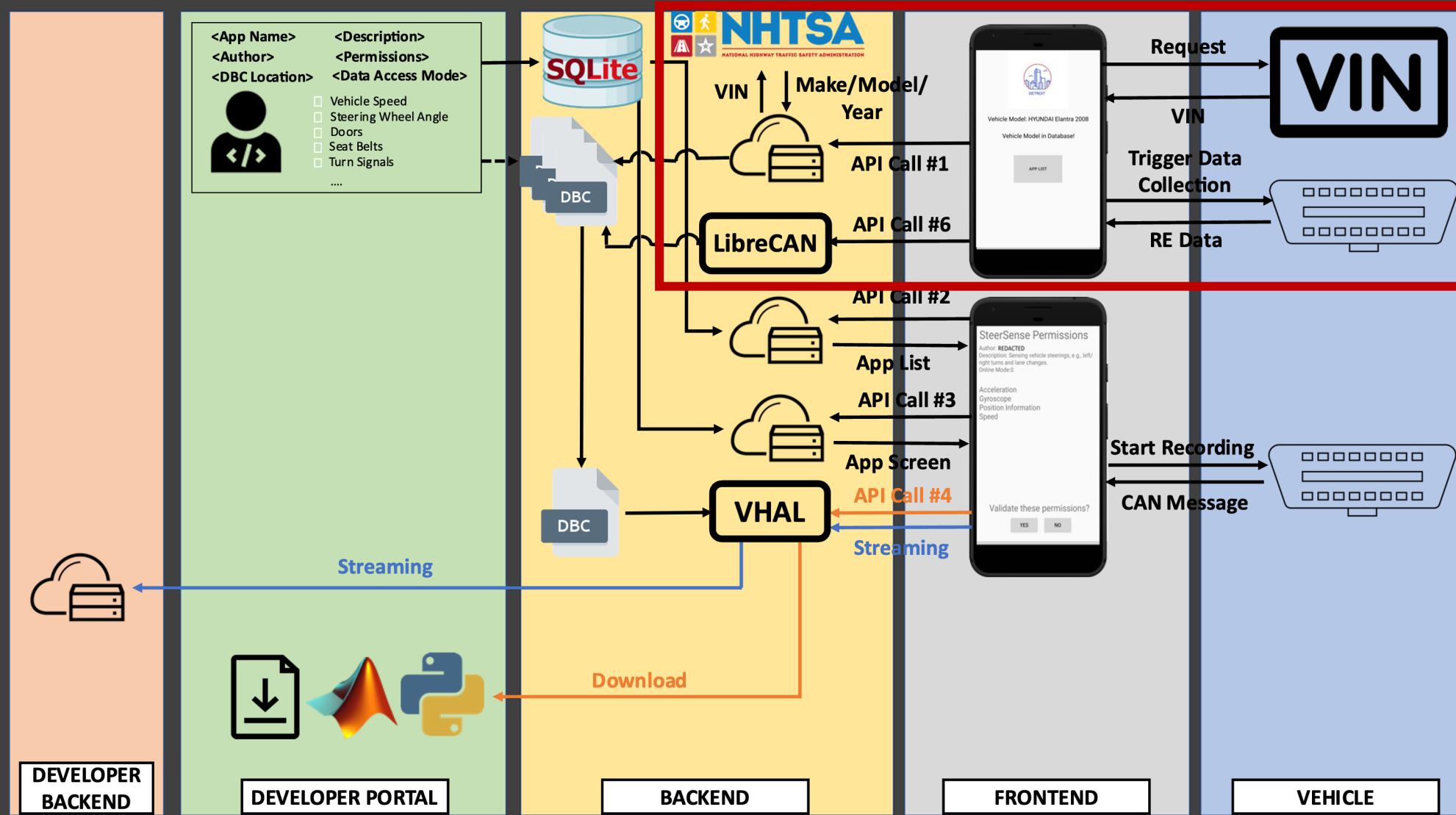
Name	Decim	ID HEX	PGN Decimal	PGN HEX	ime Form	DLC	TX Node	Commen
OBD2	2024	7e8	---	---	---	Standard	8 Engine...	VFrameForma

**Signals of Selected CAN Message:**

Name	Type	Byteorder	Mode	Bitpos	Length	Factor	Offset	Minimu
136 MAFSensor	Unsigned	Motorola	S1_...	24	8	1	0	0
137 EngineCoolantTemp	Unsigned	Motorola	S1_...	24	8	1	0	0
138 IntakeAirTempSens	Unsigned	Motorola	S1_...	24	8	1	0	0
139 CmdEGR_EGRError	Unsigned	Motorola	S1_...	24	8	1	0	0
140 CmdDieselIntAir	Unsigned	Motorola	S1_...	24	8	1	0	0
141 ExhaustGasTemp	Unsigned	Motorola	S1_...	24	8	1	0	0
142 CmdThrottleActRel	Unsigned	Motorola	S1_...	24	8	1	0	0
143 FuelPresContrSys	Unsigned	Motorola	S1_...	24	8	1	0	0
144 InjPresContrSys	Unsigned	Motorola	S1_...	24	8	1	0	0
145 TurboComprPres	Unsigned	Motorola	S1_...	24	8	1	0	0
146 BoostPresContr	Unsigned	Motorola	S1_...	24	8	1	0	0

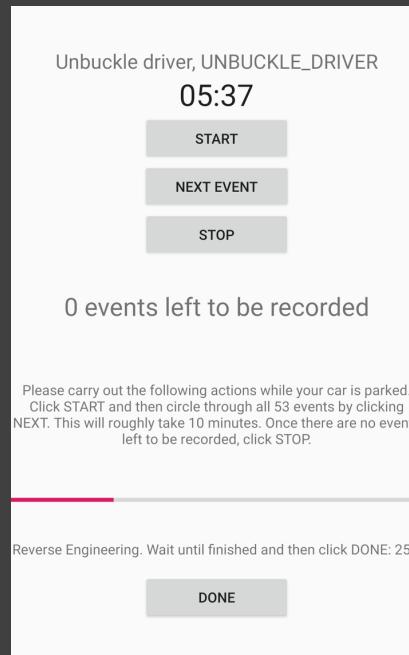
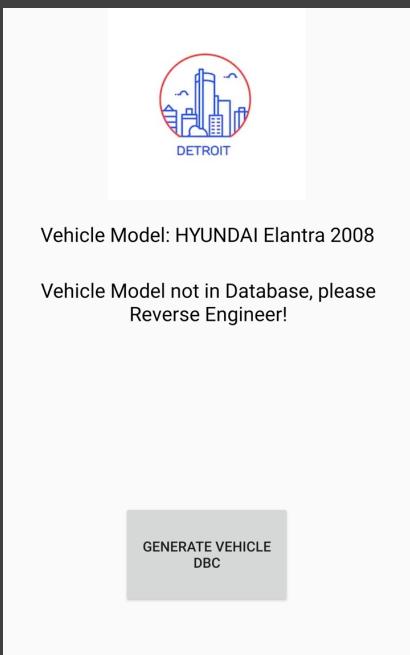
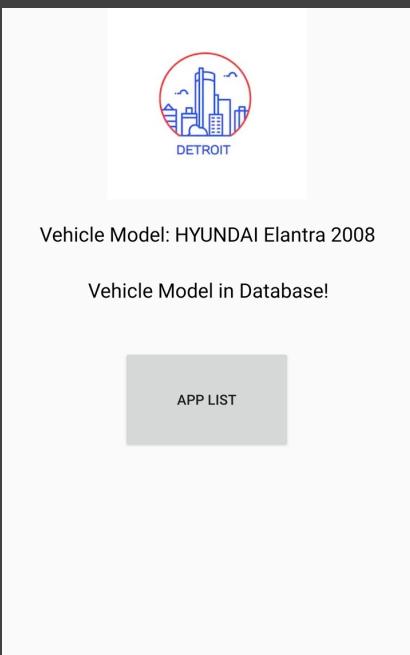
Crowdsourcing Effort!

# Overview

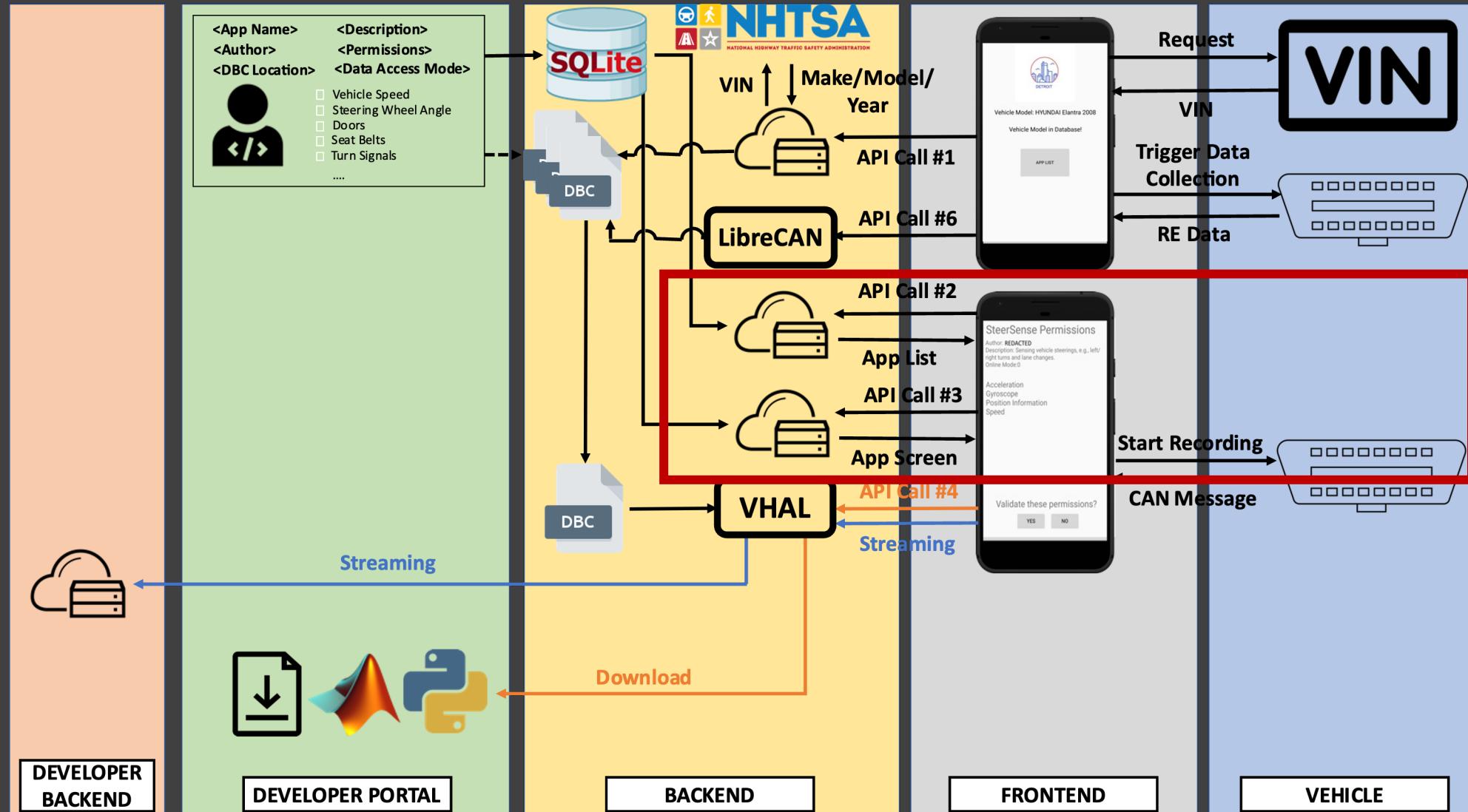


# [USER] Initialize Android App

- Decode Vehicle Identification Number (VIN) from Vehicle using NHTSA API
- If not in DBC Repository, ask user to kick off reverse engineering using LibreCAN



# Overview



# [USER] Enabling a 3rd Party App

DETROIT

Mert Dieter Pese | Log Out

[Log Out](#)

## Developer Dashboard

Documentation
Register New App
<b>My Apps</b>

SteerSense	Edit
<b>Description</b>	
testing for mmmjx	
<b>Permissions</b>	
<ul style="list-style-type: none"><li>Doors</li><li>Engine Information</li></ul>	
<b>Data Format</b>	
<a href="#">Download Data</a>	

TurnSense	<a href="#">Edit</a>
<b>Description</b>	online test dummy
<b>Permissions</b>	<ul style="list-style-type: none"><li>Speed</li></ul>
<b>Data Format</b>	Streaming to <a href="#">0.0.0.0:1234</a>

# Backend

# Frontend

## SteerSense Permissions

Author: REDACTED

Description: Sensing vehicle steerings, e.g., left/right turns and lane changes.  
Online Mode:0

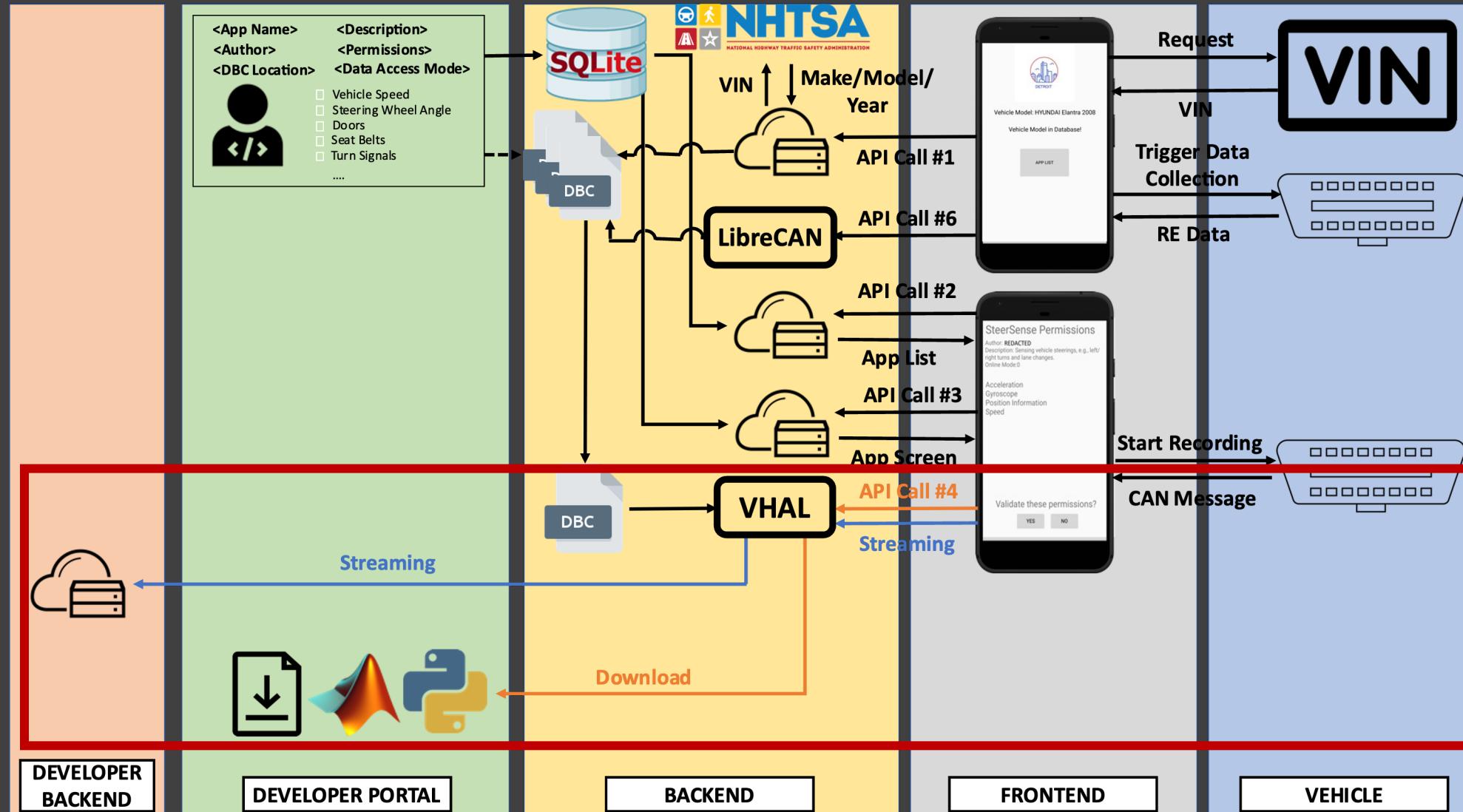
Acceleration  
Gyroscope  
Position Information  
Speed

## Validate these permissions?

YES

NO

# Overview



# [PO] Data Collection, Translation and Sharing

## Data Collection

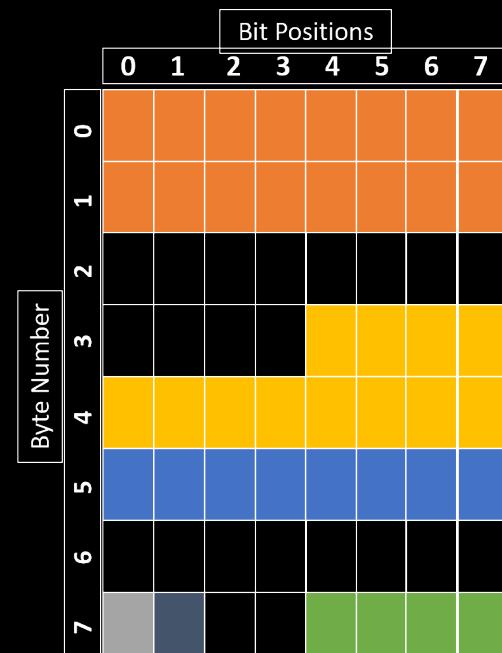


All hardware dongles/vehicle interfaces(VIs) work with DETROIT

< long : EPOCH\_TIME > , < int : CAN\_ID > ,  
< int : BUS\_ID > , < str : PAYLOAD >

HW output needs to be standardized to be VI-agnostic

## Data Translation



Absolute Value = Scale \* CAN Value  
+ Offset

## Data Sharing

### Downloads

[< My Apps](#)

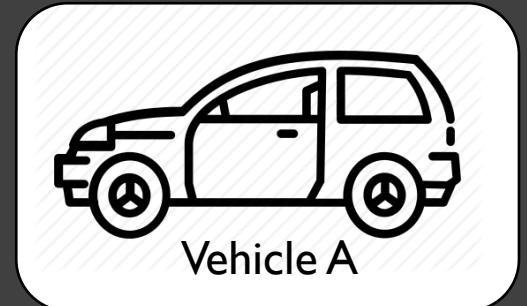
The following traces are available for **SteerSense**:

#### LINCOLN\_MKZ\_2020

- 2020-06-28 19:35:55 [JSON](#) [MATLAB](#) [NUMPY](#)
- 2020-06-28 20:39:50 [JSON](#) [MATLAB](#) [NUMPY](#)
- 2020-06-28 20:57:54 [JSON](#) [MATLAB](#) [NUMPY](#)
- 2020-06-28 21:09:38 [JSON](#) [MATLAB](#) [NUMPY](#)
- 2020-06-28 21:32:07 [JSON](#) [MATLAB](#) [NUMPY](#)
- 2020-06-28 21:33:03 [JSON](#) [MATLAB](#) [NUMPY](#)
- 2020-06-28 23:07:58 [JSON](#) [MATLAB](#) [NUMPY](#)
- 2020-06-28 23:10:47 [JSON](#) [MATLAB](#) [NUMPY](#)

# Experimental Setup

- 1-hour data collected from full-size crossover SUV
  - Official DBC file available



- Raw CAN Data



OpenXC VI

- OpenIVN on Ubuntu server

2x Intel Xeon E5-  
2683 V4 CPUs +  
128GB RAM



- Two phones

- Each phone recorded one 1-hour trace
  - 15/55 fine-grained permissions used



Google Pixel XL



Samsung S10+

# Benchmark

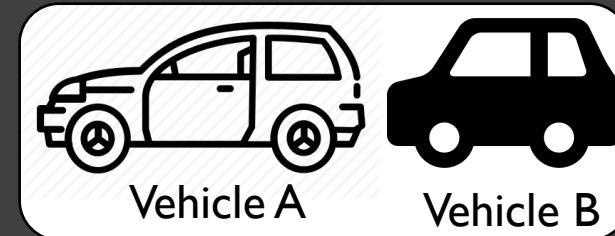
		<b>Trace 1</b>	<b>Trace 2</b>
<b>Frontend</b>	Compress and Upload	26.157 s	21.582 s
<b>Backend</b>	Store File and Extract	0.289 s	0.270 s
	Translate	5.334 s	5.237 s
	Total Backend	6.305 s	6.220 s
<b>DETROIT</b>	Total Time	<b>32.462 s</b>	<b>27.802 s</b>

<b>Access Mode</b>	<b>Metric</b>	<b>Trace 1</b>	<b>Trace 2</b>
Offline	Compressed Recording Size	10.46 MB	9.77 MB
	Battery Drain	1.33 %	1.09 %
	Average CPU Usage	11.17 %	4.69 %
Online	Uncompressed Recording Size	77.46 MB	74.47 MB
	Battery Drain	1.82 %	3.20 %
	Average CPU Usage	9.62 %	10.87 %

- Offline Mode Latency: ~30 seconds per hour
  - Online Mode Latency : 5-7 ms delay

- Online Mode Bandwidth: ~1 hour Spotify Premium
- Total battery drain <7%, phone can easily last a day
  - Low computational overhead

# Using CAN Data for Mobility Apps



- Steering Detection [Ch15]
  - Replace gyroscope from smartphone by steering wheel angle from CAN

- Improve accuracy by >10%
- Reduce LOC by >10%

- Turn Signal Detection
  - Replace microphone from smartphone by turn signal indicator from CAN

- Improve accuracy by >11%
- Reduce LOC by >36%

		Accuracy: 84.27%				
		1	2	3	4	5
Detected Steering Types	1	90.3% 28	0.0% 0	0.0% 0	0.0% 0	10.0% 1
	2	0.0% 0	92.9% 26	0.0% 0	0.0% 0	0.0% 0
Detected Steering Types	3	0.0% 0	0.0% 0	75.0% 9	0.0% 0	10.0% 1
	4	0.0% 0	0.0% 0	0.0% 0	75.0% 6	20.0% 2
Detected Steering Types	5	9.7% 3	7.1% 2	25.0% 3	25.0% 2	60.0% 6
	1	1	2	3	4	5
		Actual Steering Types				

Smartphone Data

		Accuracy: 94.38%				
		1	2	3	4	5
Detected Steering Types	1	96.8% 30	0.0% 0	0.0% 0	0.0% 0	0.0% 0
	2	0.0% 0	96.4% 27	0.0% 0	0.0% 0	0.0% 0
Detected Steering Types	3	0.0% 0	0.0% 0	75.0% 9	0.0% 0	0.0% 0
	4	0.0% 0	0.0% 0	0.0% 0	100.0% 8	0.0% 0
Detected Steering Types	5	3.2% 1	3.6% 1	25.0% 3	0.0% 0	100.0% 10
	1	2	3	4	5	
		Actual Steering Types				

CAN Data

Method	Vehicle	Precision	Recall	Accuracy
Sound Detection	Veh.A	1.0	0.82	0.89
	Veh. B	0.92	0.94	0.88
DETROIT	Both	1.0	1.0	1.0

# Conclusion

**Simple, Scalable & Secure Automotive Data Access Tool for Industry & Academia**

## Light-Weight



Small overhead on phone, real-time performance possible

## Improved Accuracy



Accuracy of mobility apps improved through higher-quality CAN data

## Improved UX



Developers can save lines of code and time by eliminating redundancy

# Q & A



Mert D. Pesé



Dongyao Chen



C. Andrés Campos



Alice Ying



Troy Stacer



Kang G. Shin



# References

- [Hu06] B. Hull, V. Bychkovsky, Y. Zhang, K. Chen, M. Goraczko, A. Miu, E. Shih, H. Balakrishnan, and S. Madden, “Cartel: a distributed mobile sensor computing system,” in *Proceedings of the 4th international conference on Embedded networked sensor systems*. ACM, 2006, pp. 125–138.
- [Ji14] Y. Jiang, H. Qiu, M. McCartney, W. G. Halfond, F. Bai, D. Grimm, and R. Govindan, “Carlog: A platform for flexible and efficient automotive sensing,” in *Proceedings of the 12th ACM Conference on Embedded Network Sensor Systems*, 2014, pp. 221–235.
- [Ch15] D. Chen, K.-T. Cho, S. Han, Z. Jin, and K. G. Shin, “Invisible sensing of vehicle steering with smartphones,” in *Proceedings of the 13th Annual International Conference on Mobile Systems, Applications, and Services*. ACM, 2015, pp. 1–13.