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

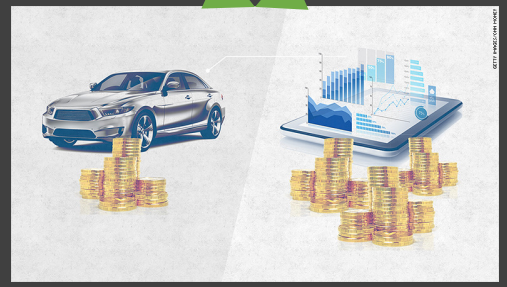
CSE COMPUTER SCIENCE AND ENGINEERING
UNIVERSITY OF MICHIGAN

REAL-TIME COMPUTING LABORATORY
@ UNIVERSITY OF MICHIGAN, ANN ARBOR

Vehicles are getting increasingly connected

Data Generation
~25 GB/h (total)
~170 MB/h (IVN)

Data Connectivity
- 2016: 20%
- 2020: 75%
- 2030: 96%



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

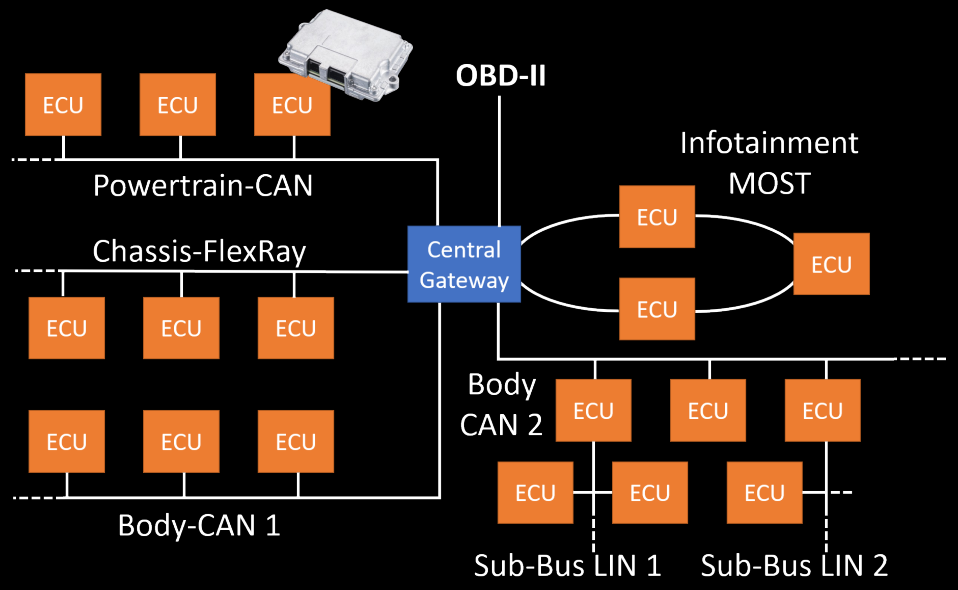
Who collects what data?

Automotive

Powertrain/Kinematic-Related Information		Body-Related Information	
ECU	Signals	ECU	Signals
Powertrain Control Module (PCM)	• Pedal Position • Throttle Position • Engine Oil Temperature • Fuel Level • Oil Pressure • Wheel Speeds • Engine Speed • Torque • Coolant Temperature • Engine Load	**Body Control Module (BCM)**	• HVAC • Turn Signals • Lights • Wipers • Trunk • Doors • Windows • Mirrors • Remote Keyless Entry
Electronic Power Steering (EPS)	• Steering Wheel Torque • Steering Wheel Position • Wheel Speed	**Telematic Control Unit (TCU)**	• Radio • GPS
Advanced Driver Assistance System (ADAS)	• Cameras • Radar • LiDAR	**Supplemental Restraint System (SRS)**	• Airbag Status • Seatbelt Status

How is data collected?

In-Vehicle Network (IVN) Architecture



CAN bus is most prominent & de facto standard

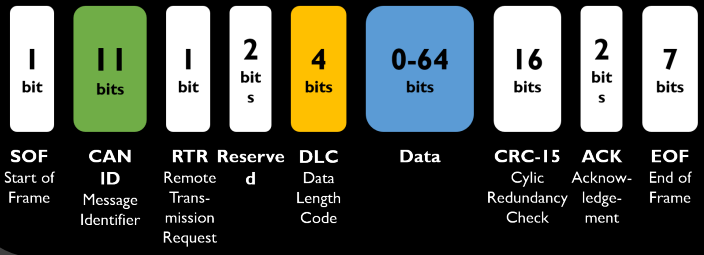
OBD-II Port

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

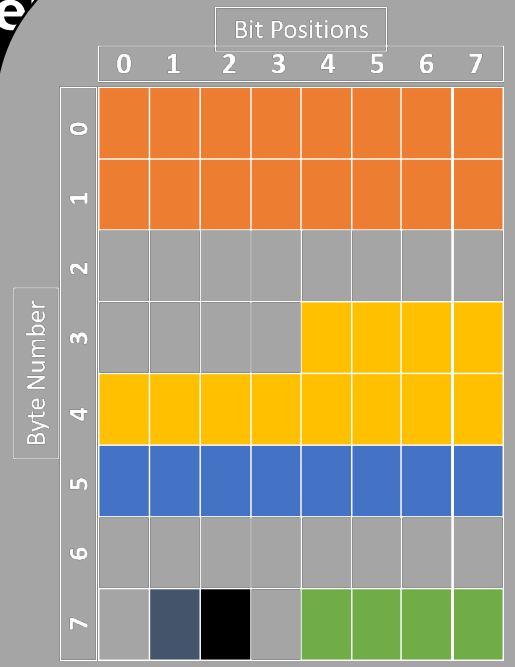
OBD-II Protocol (SAE J1979)

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

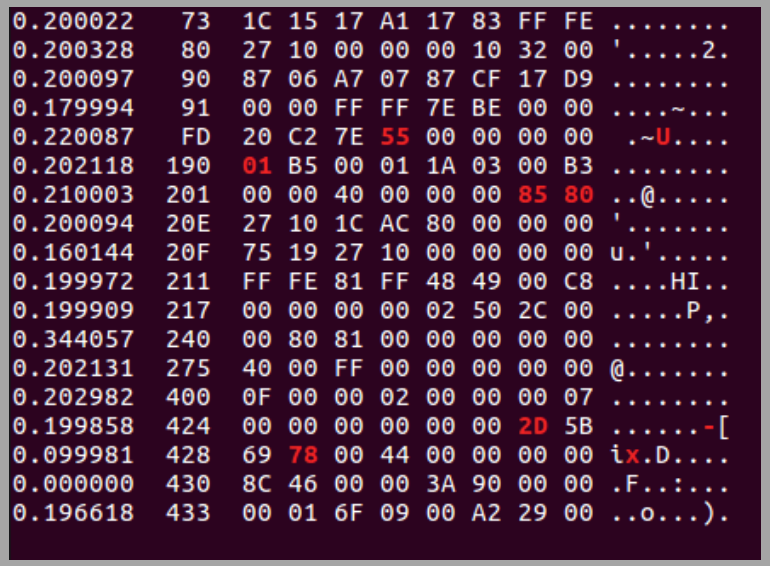
Controller Area Network (CAN)



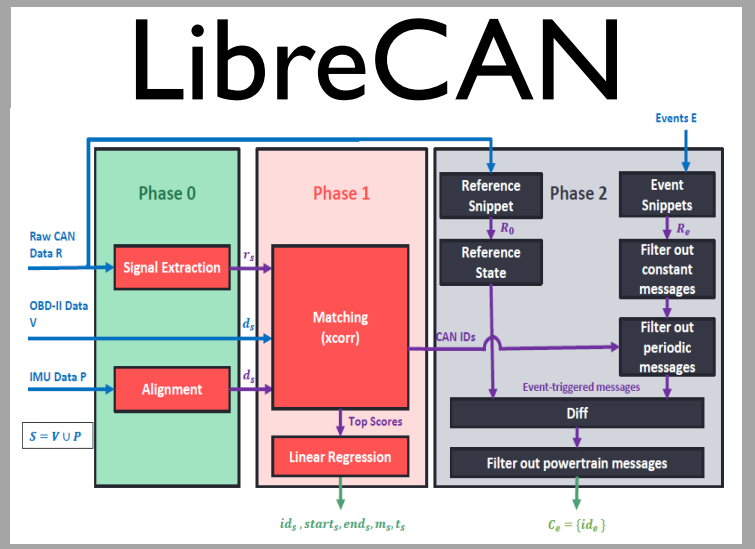
How is data collected?



Proprietary Semantics



Manual Reverse Engineering

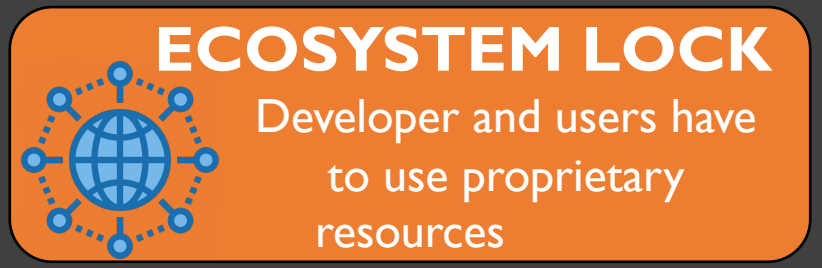


Automated Reverse Engineering

Unlock Valuable Data!

So many solutions!

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

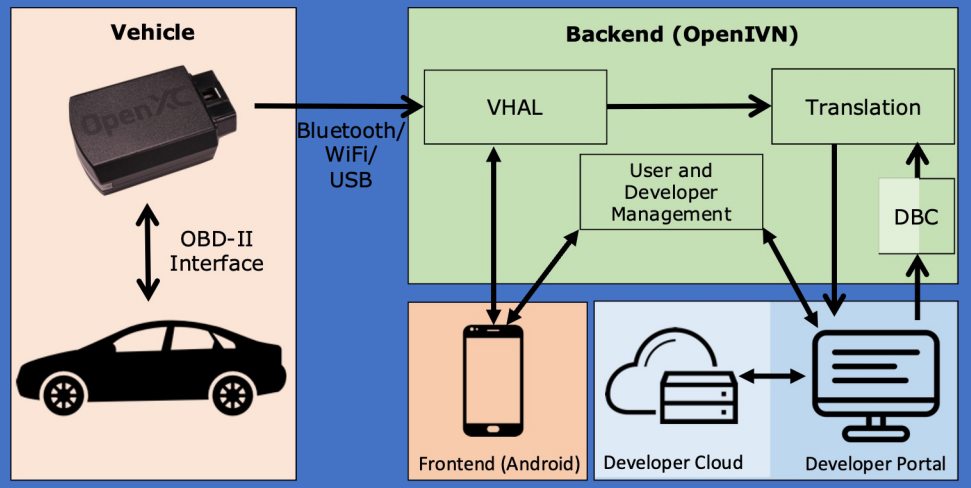


DETROIT	CAN	Yes	Yes

So many solutions!

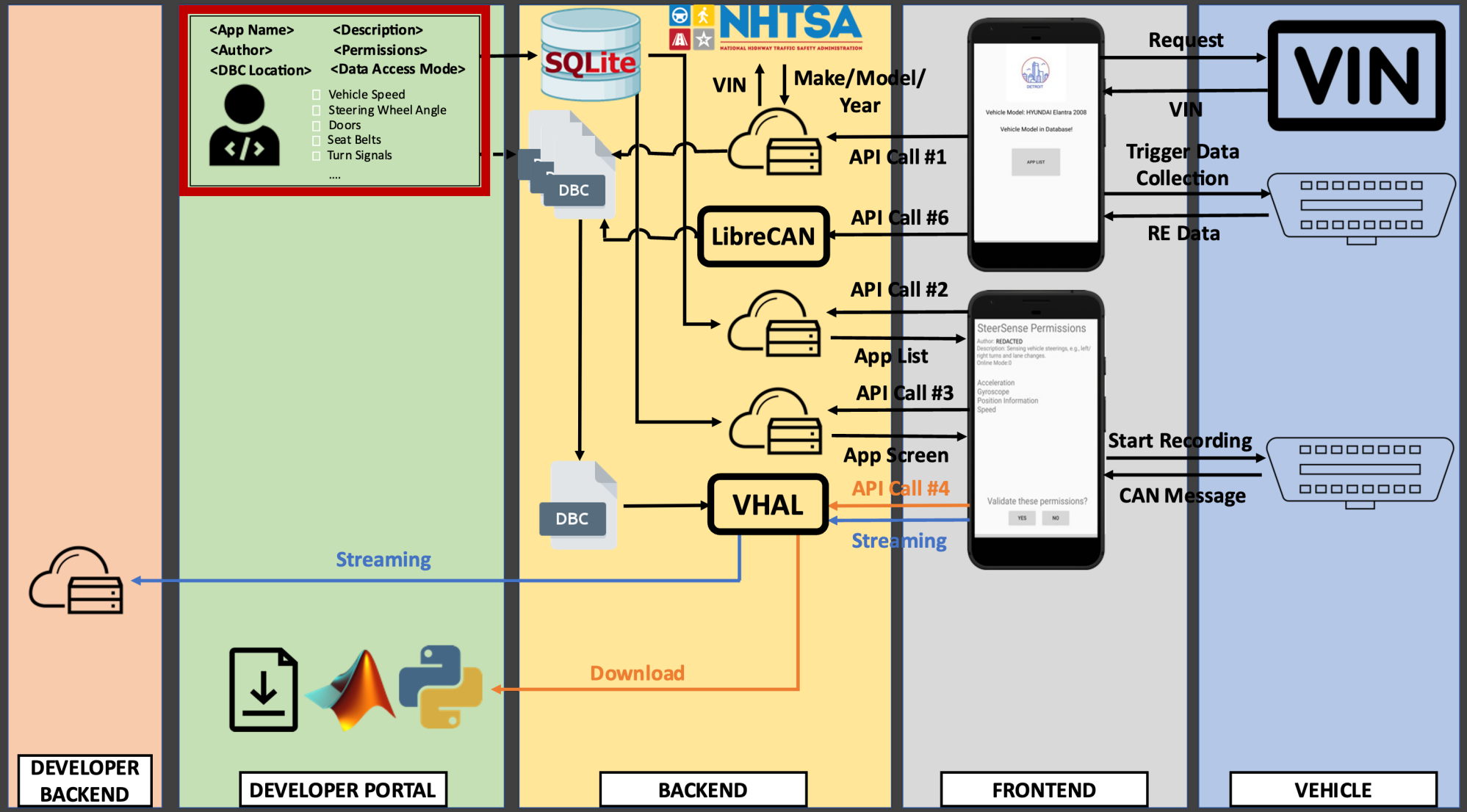
DETROIT: Our SOLUTION

- 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

Overview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Vehicle Speed
Steering Wheel Angle
Doors
Seat Belts
Turn Signals
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SQLite
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Vehicle Model in Database!
SteerSense Permissions
Acceleration
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Position Information
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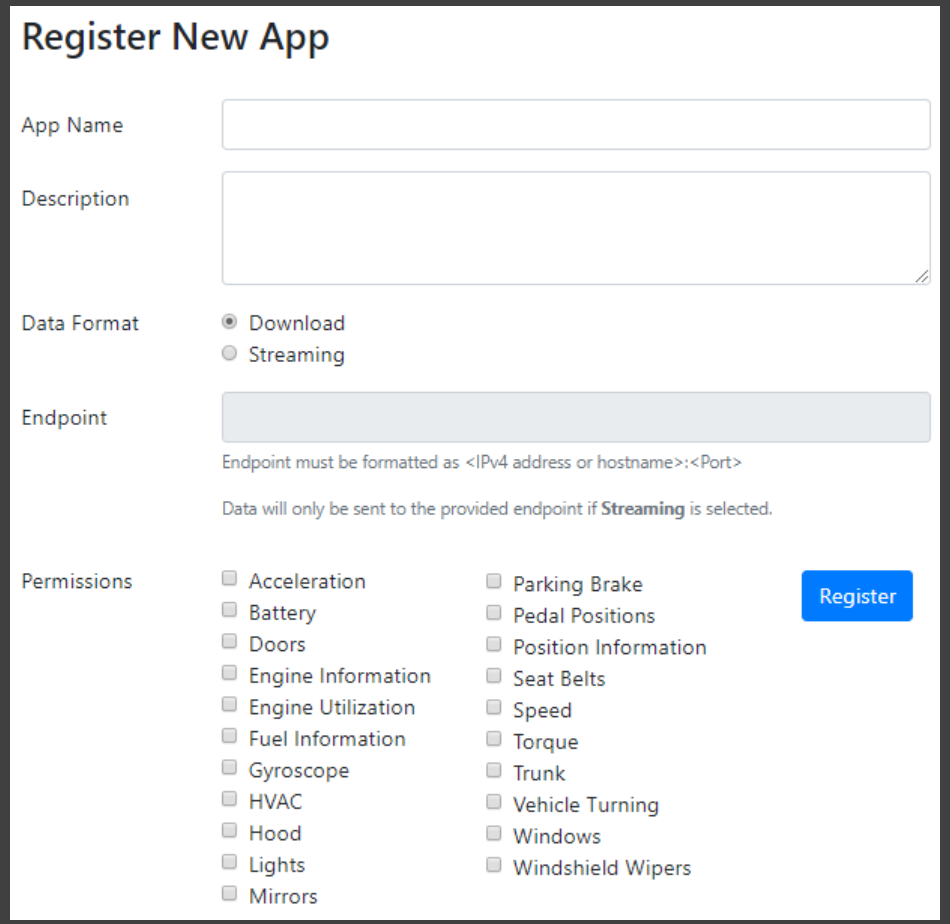
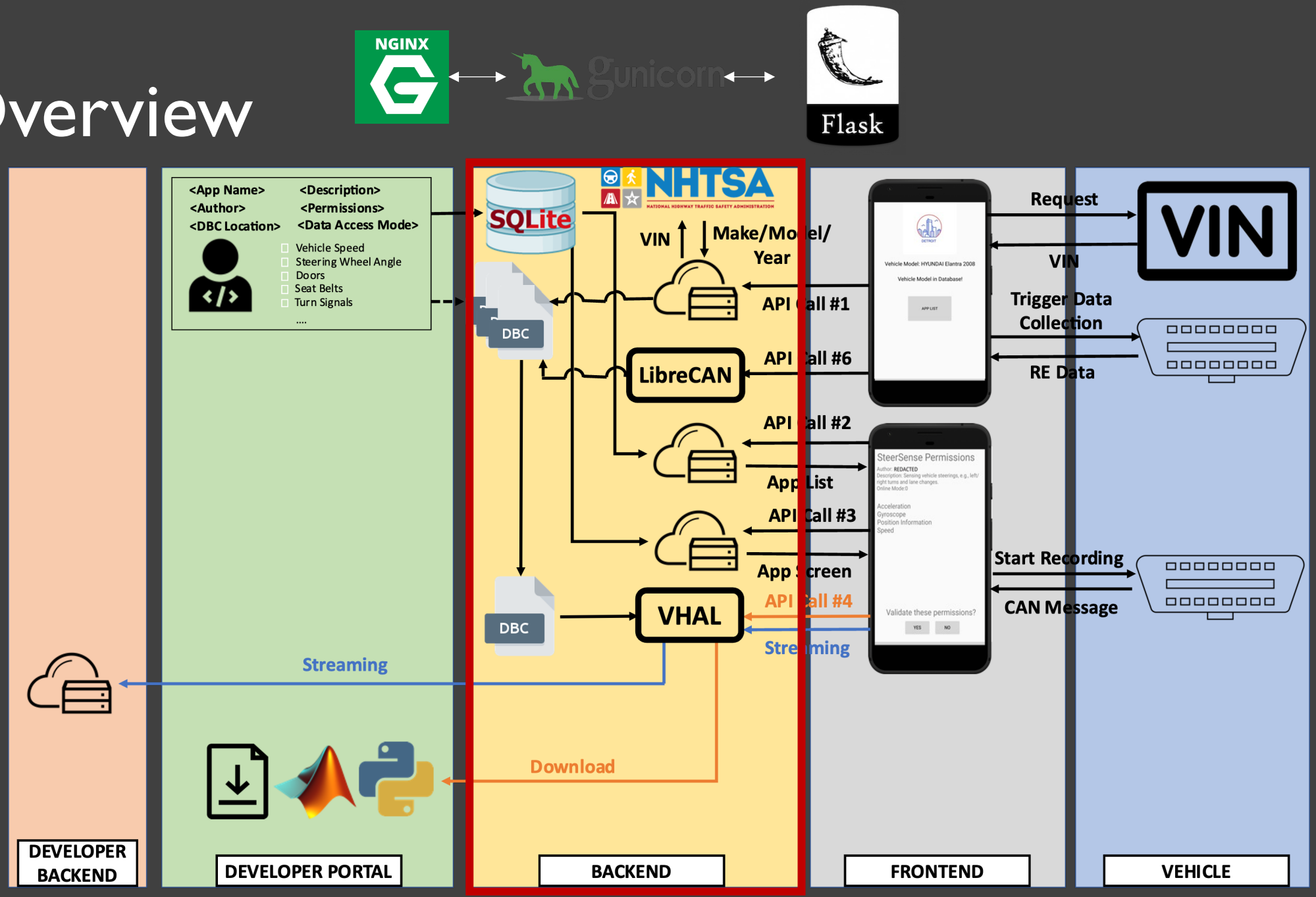
Validate these permissions?
YES
NO
Start Recording
CAN Message
Streaming
Download
DEVELOPER BACKEND
DEVELOPER PORTAL
BACKEND
FRONTEND
VEHICLE

[DEV] Registering an App



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


NGINX
gunicorn
Flask
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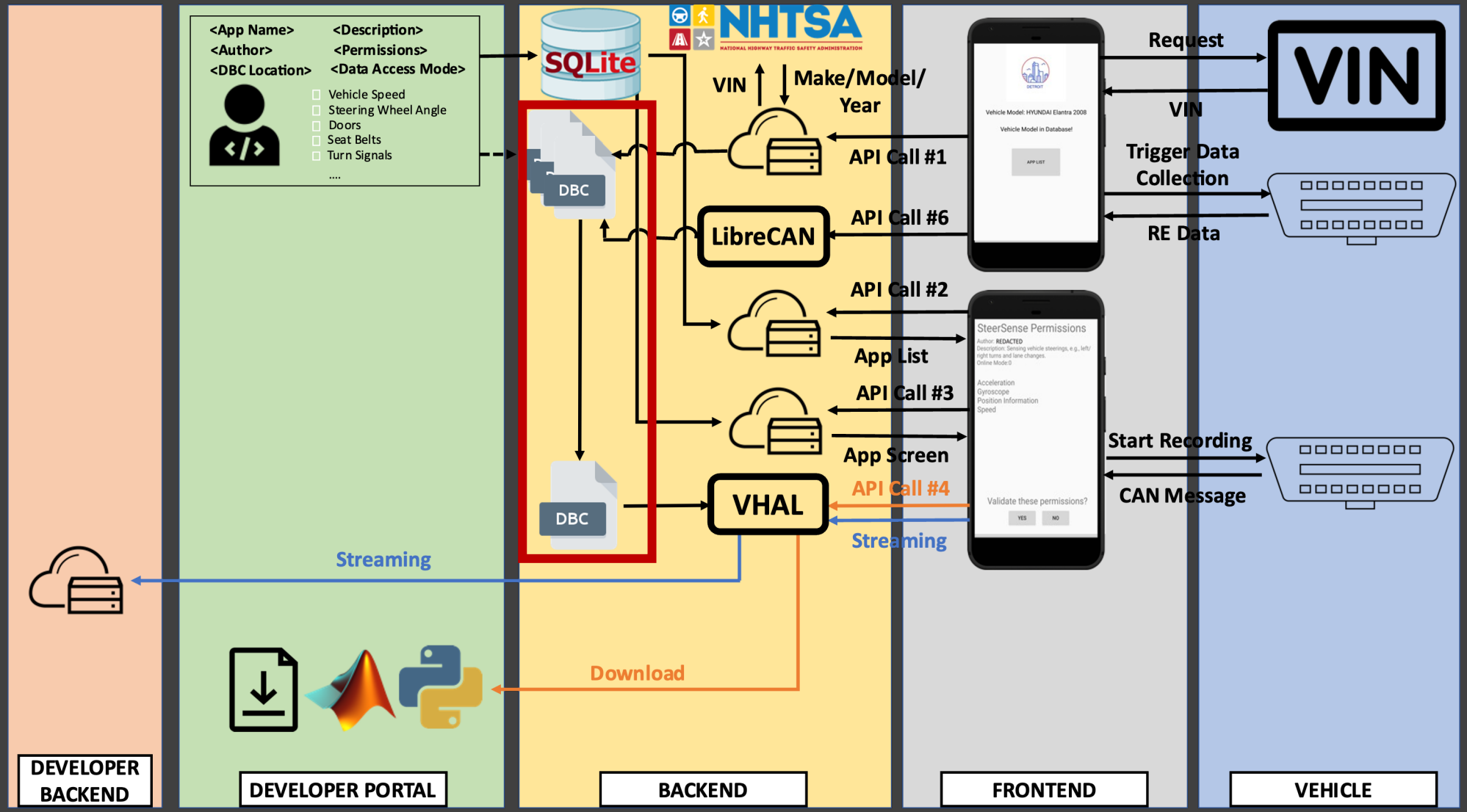
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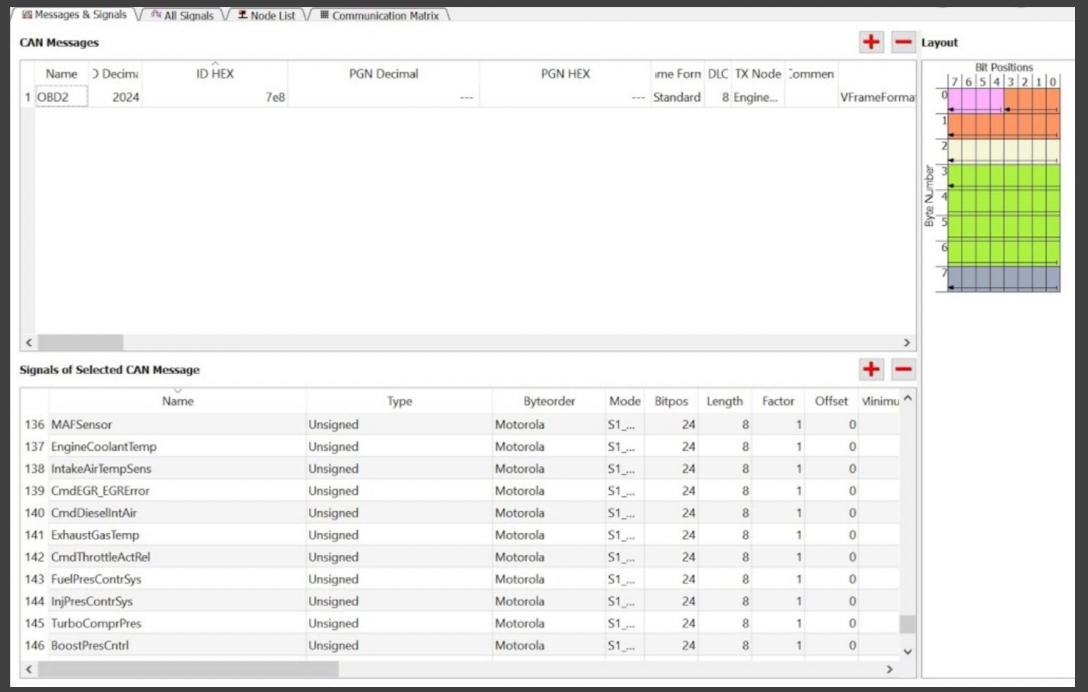
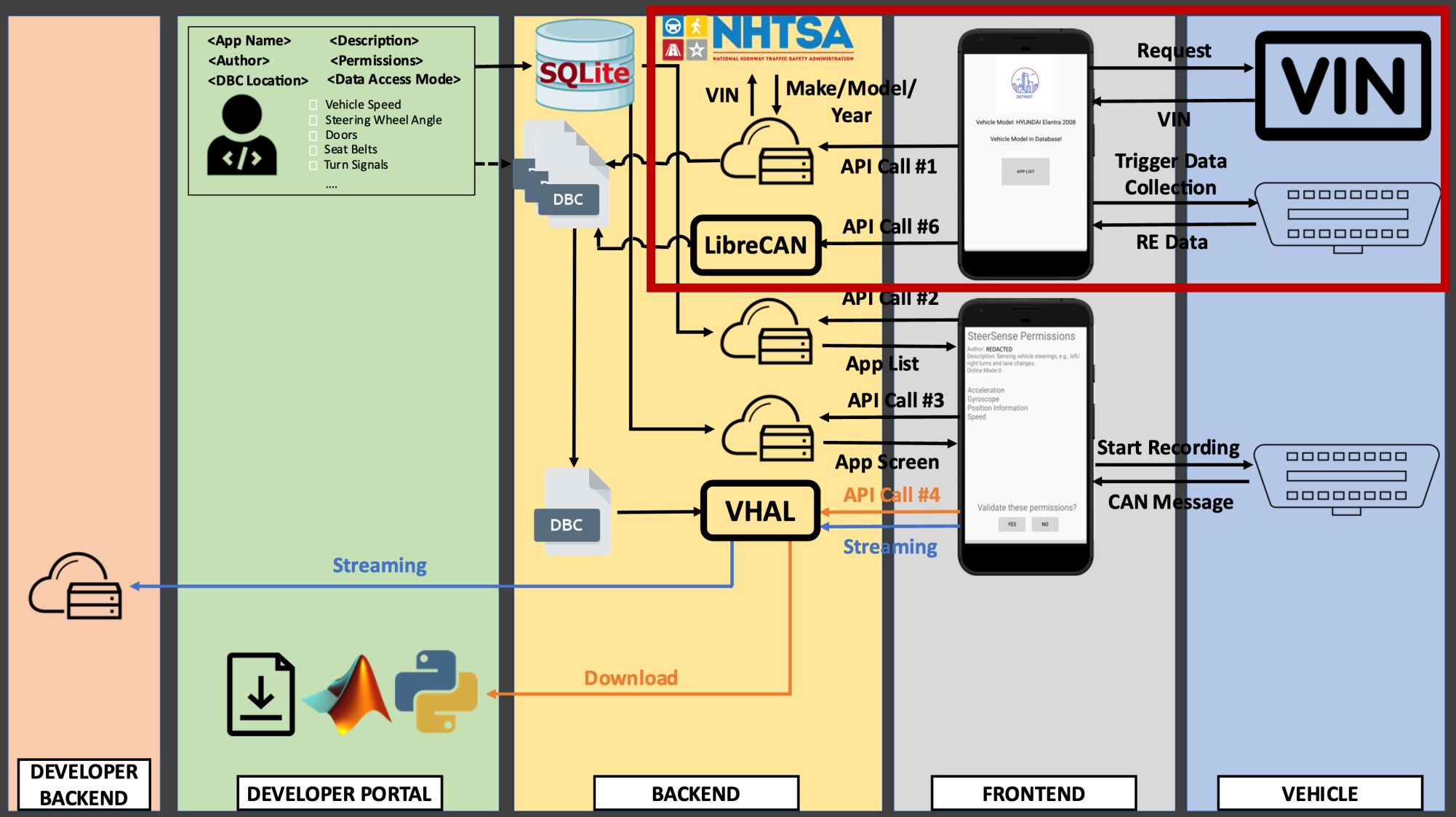
[PO] DBC Repository

- 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



Crowdsourcing Effort!

Overview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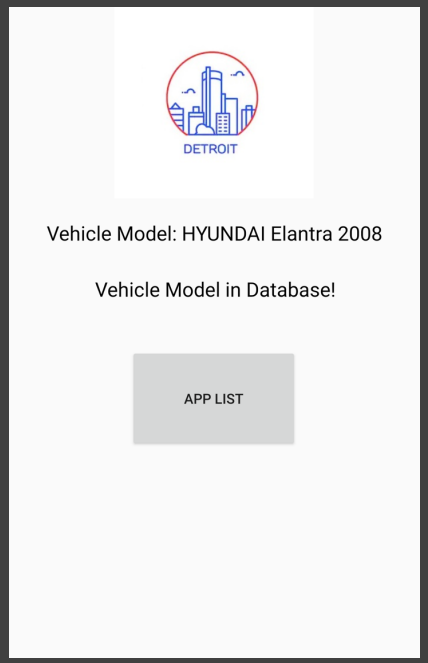
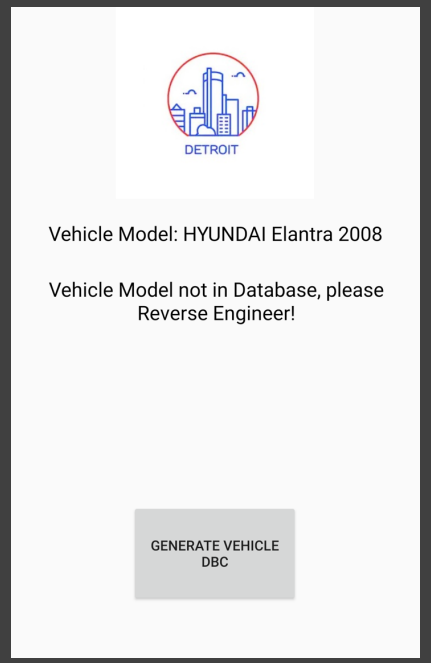
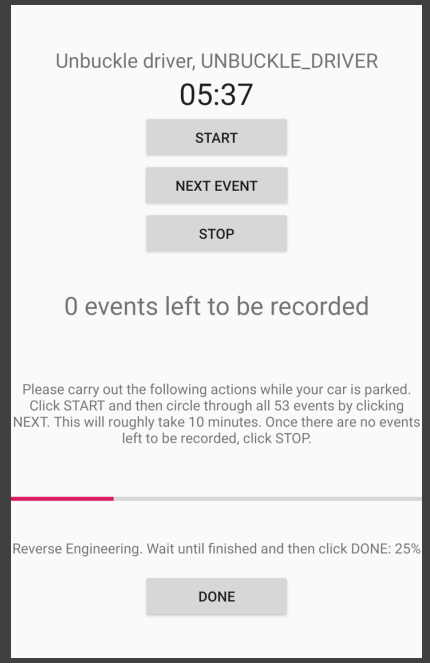
[USER] Initialize Android App

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







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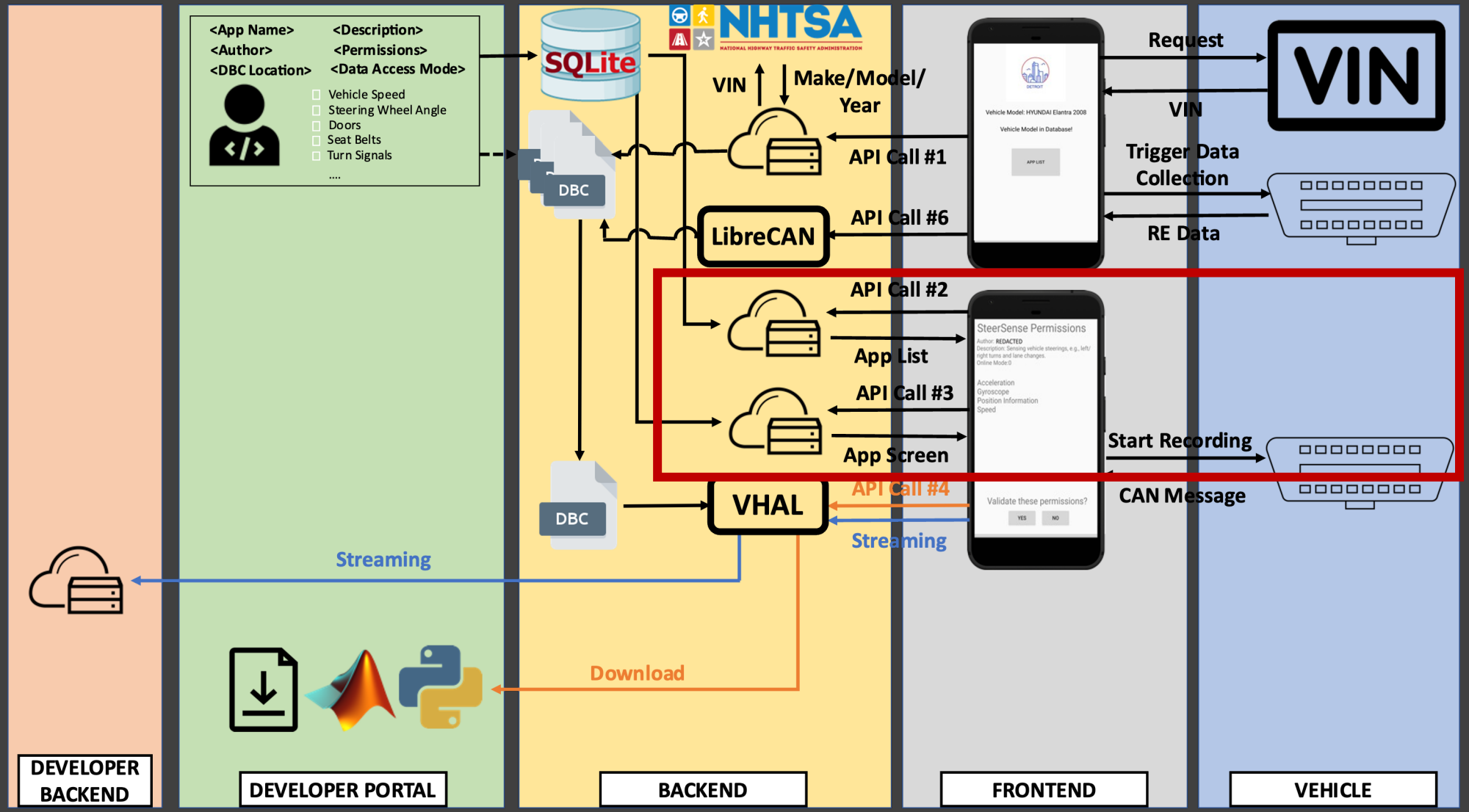
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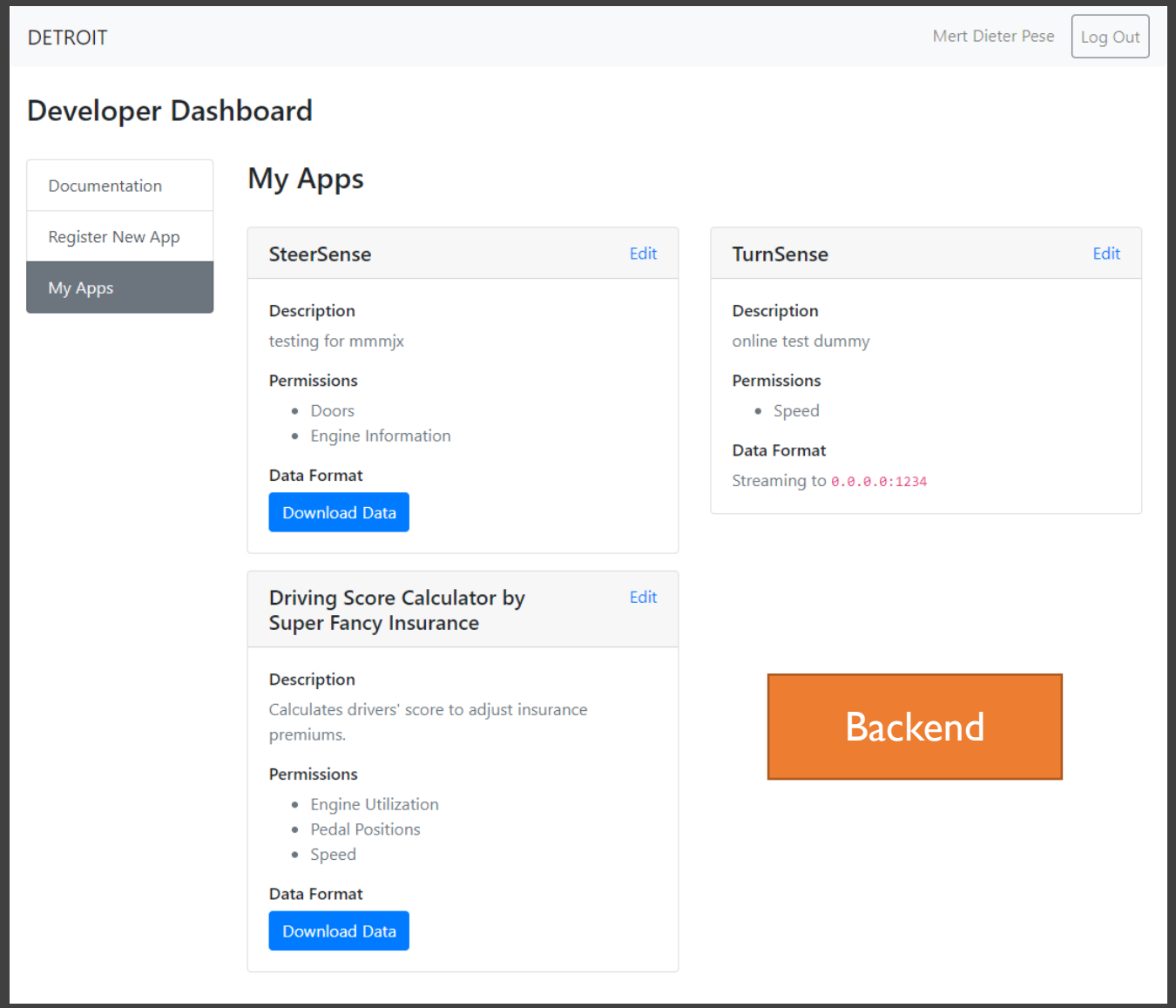
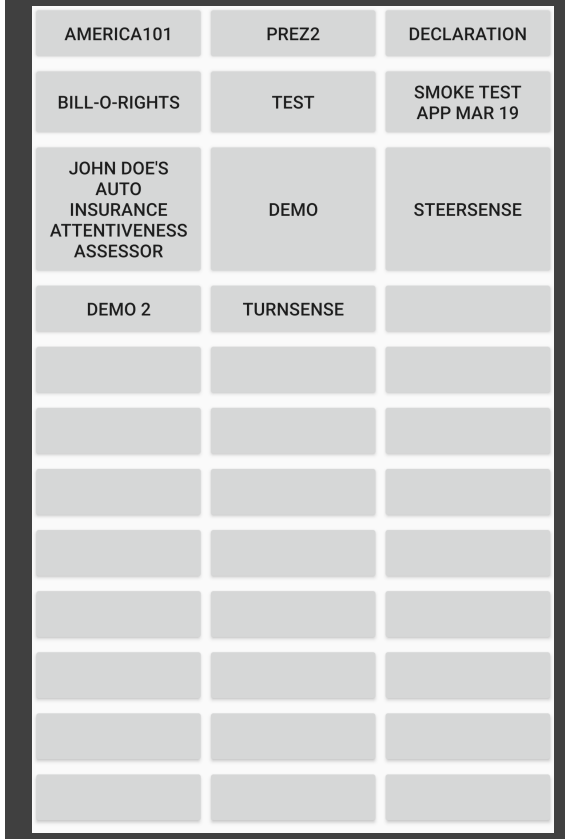
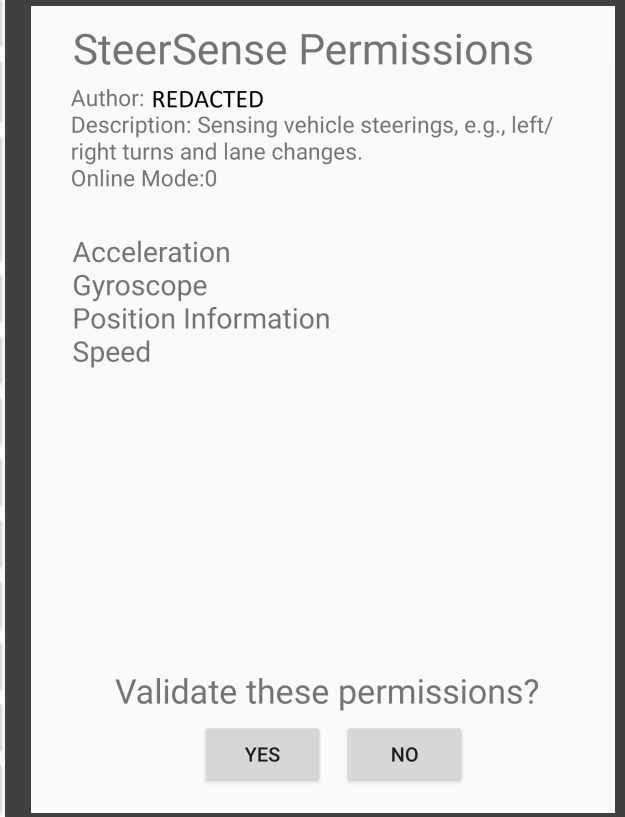
[USER] Enabling a 3rd Party App



Backend

Frontend





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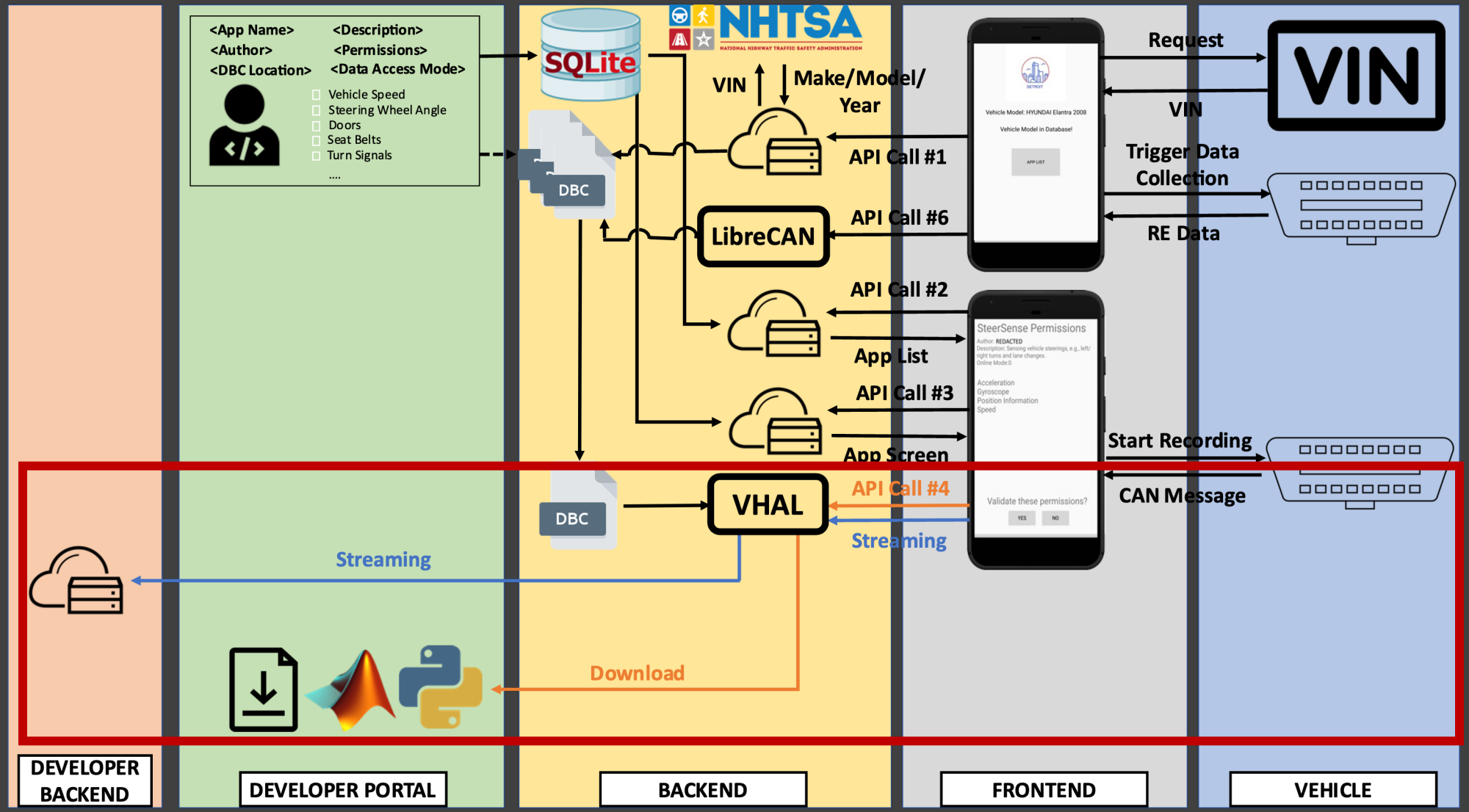
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[PO] Data Collection, Translation and Sharing

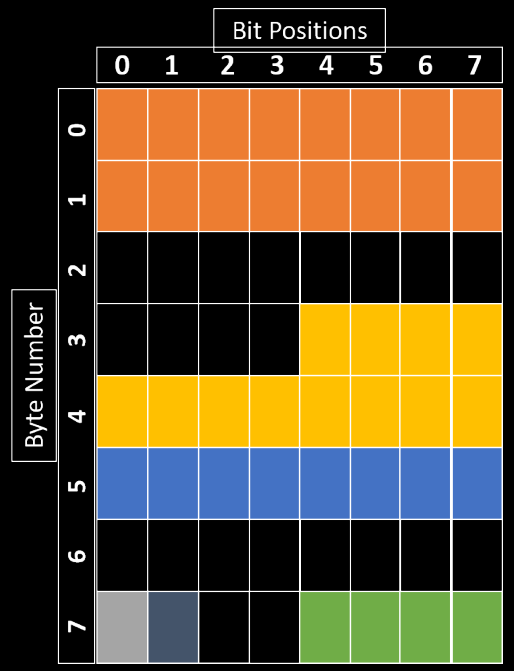
Data Collection

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

< long : EPOCH_TIME > , < int : CAN_ID > , < int : BUS_ID > , < str : PAYLOAD >

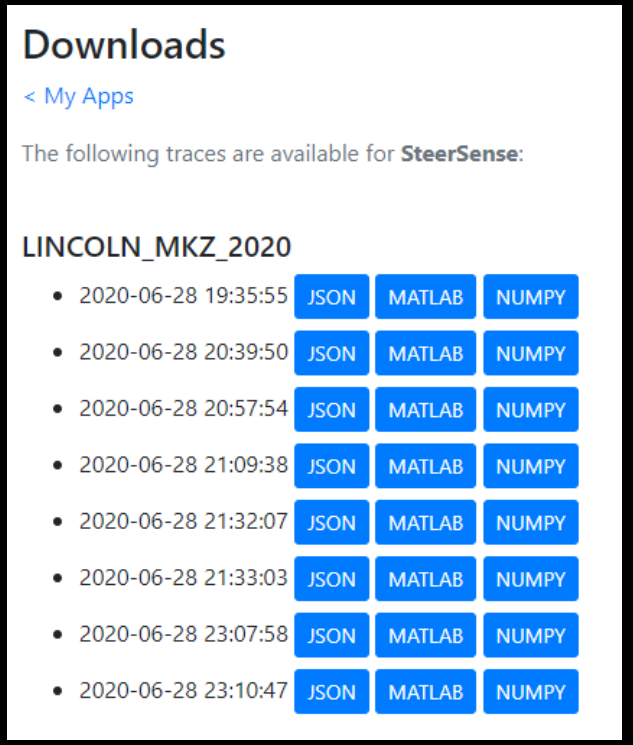
HW output needs to be standardized to be VI-agnostic

Data Translation



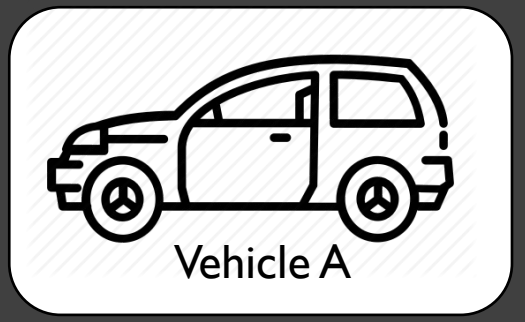
Absolute Value = Scale * CAN Value + Offset

Data Sharing



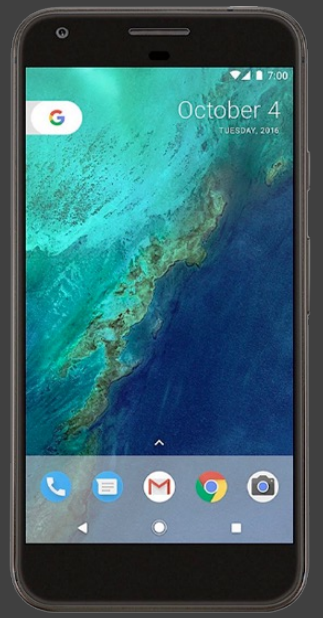
Experimental Setup

- 1-hour data collected from full-size crossover SUV
  - Official DBC file available
- Raw CAN Data
- OpenIVN on Ubuntu server
- Two phones
  - Each phone recorded one 1-hour trace
  - 15/55 fine-grained permissions used



OpenXC VI

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



Google Pixel XL

Samsung S10+

Benchmark

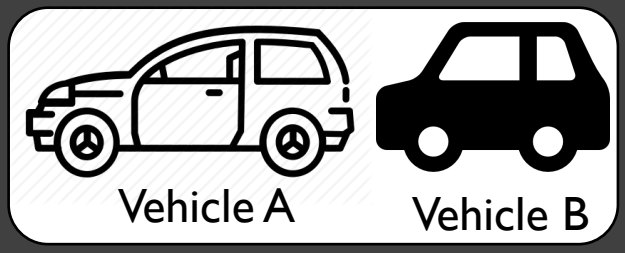
		Trace 1	Trace 2
Frontend	Compress and Upload	26.157 s	21.582 s
Backend	Store File and Extract	0.289 s	0.270 s
	Translate	5.334 s	5.237 s
	Total Backend	6.305 s	6.220 s
DETROIT	Total Time	**32.462 s**	**27.802 s**

Access Mode	Metric	Trace 1	Trace 2
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 %

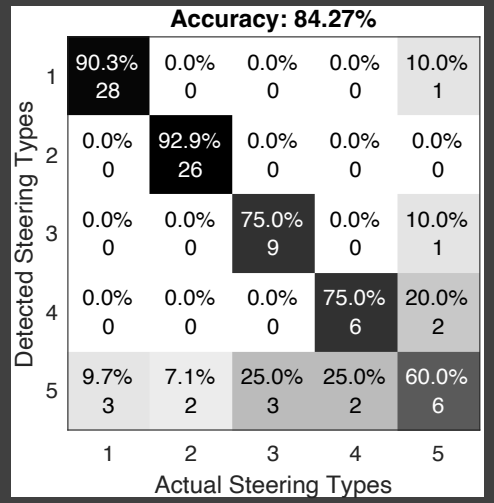
- Offline Mode Latency: ~30 seconds per hour
- Online Mode Latency : 5-7 ms delay

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

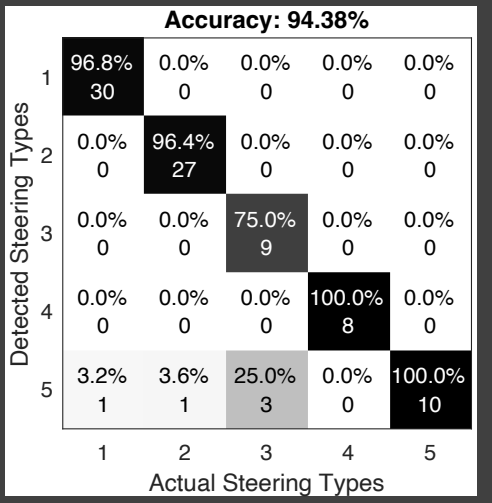
Using CAN Data for Mobility Apps



- Steering Detection [Ch15]
  - Replace gyroscope from smartphone by steering wheel angle from CAN
    - **Improve accuracy by >10%**
    - **Reduce LOC by >10%**



Smartphone Data



CAN Data

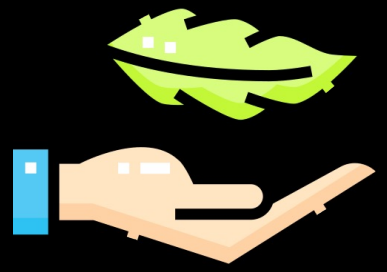
- Turn Signal Detection
  - Replace microphone from smartphone by turn signal indicator from CAN
    - **Improve accuracy by >11%**
    - **Reduce LOC by >36%**

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

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[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.