Developing Onboard SOH Estimation Using DVA and ICA for LFP Batteries

MathWorks AUTOMOTIVE CONFERENCE 2022

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2022/04/07

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Degradation Mechanism

Most dominant

Anode

Lithium Plating, Solid-Electrolyte-Interphase (SEI)

Cathode

Structural Stress, Transition Metal Dissolution

Electrolyte

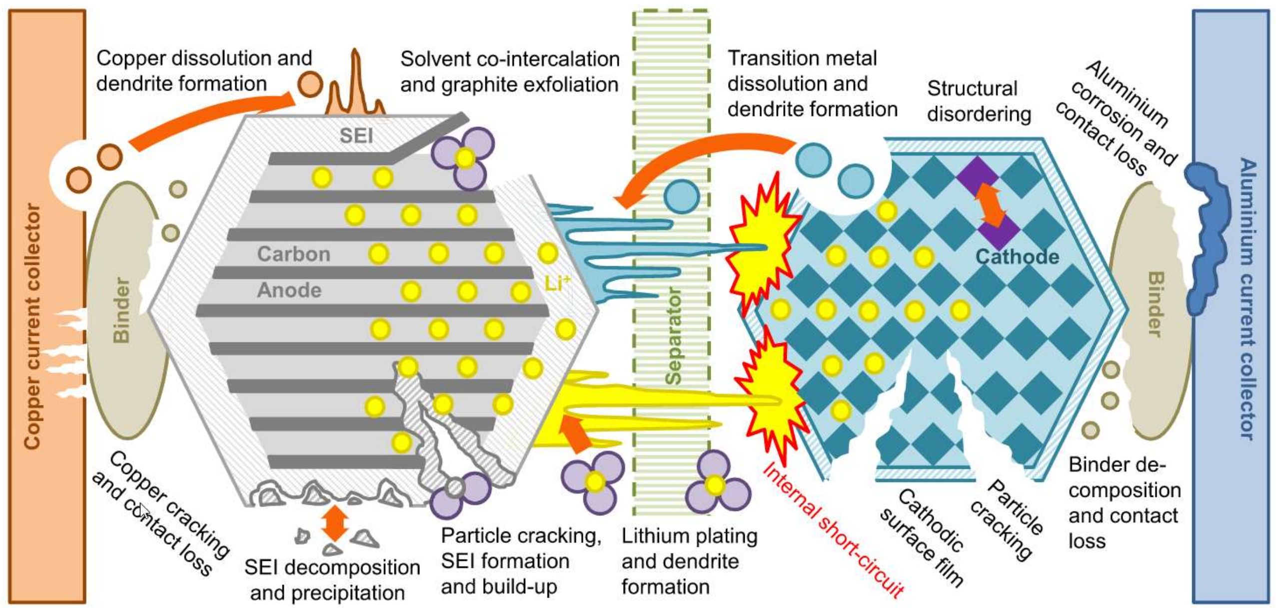
Electrolyte Decomposition

Collector

Collector Corrosion

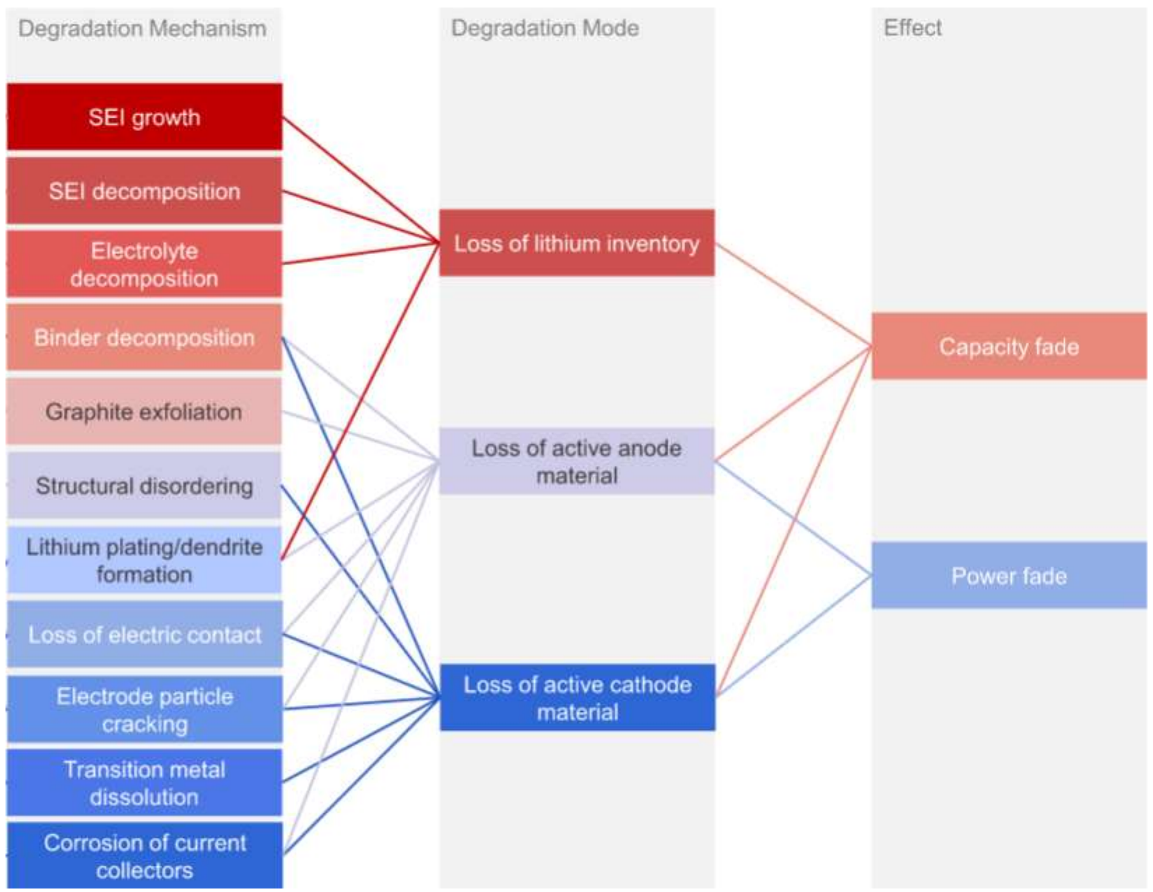
Separator

Clogged Pores



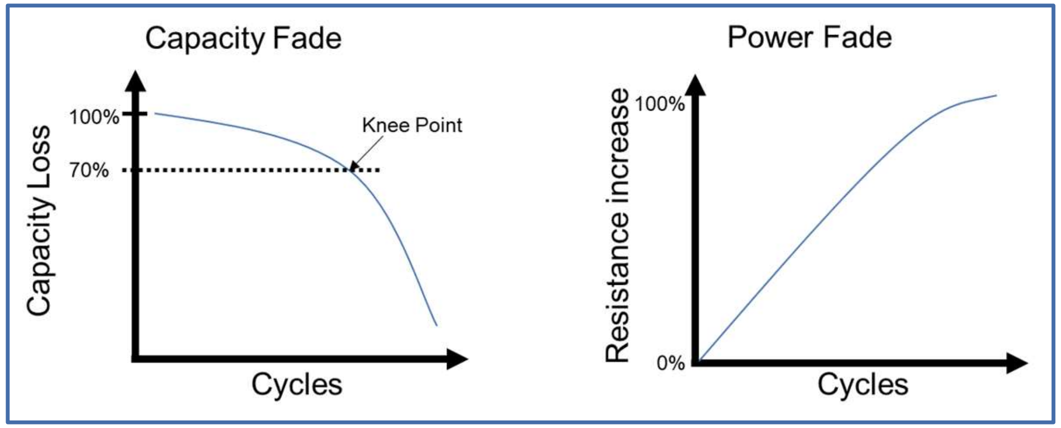
Li-Ion Batteries suffer from a variety of degradation mechanism

Degradation Mechanism



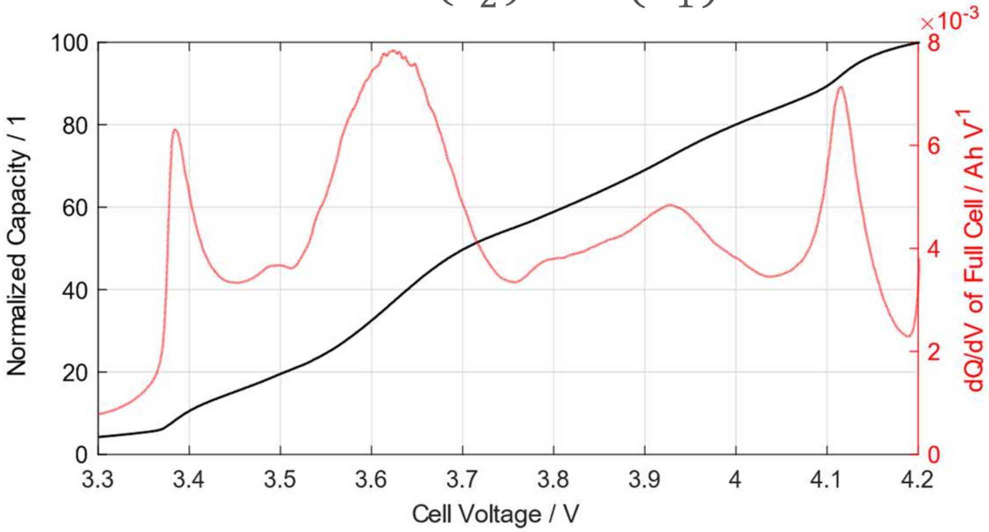
Mechanism can be organized in three degradation modes:

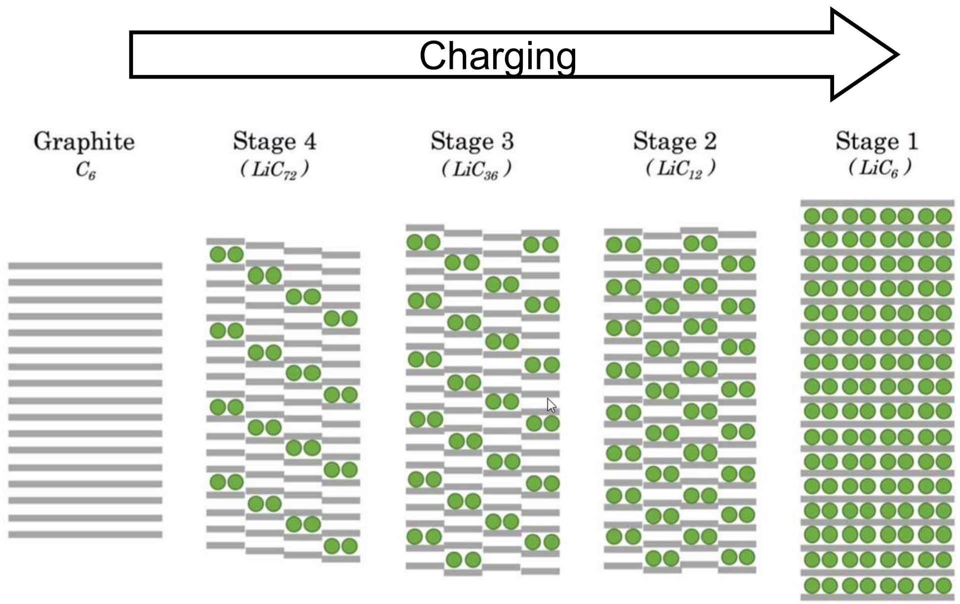
- Loss of Lithium Inventory LLI
- Loss of active anode material LAM_A
- Loss of active cathode material LAM_C



Incremental Capacity Analysis

$$\frac{dQ}{dV} \approx \frac{Q(t_2) - Q(t_1)}{V(t_2) - V(t_1)}$$





The ICA converts the voltage plateaus of a two-phase transition into detectable peaks.

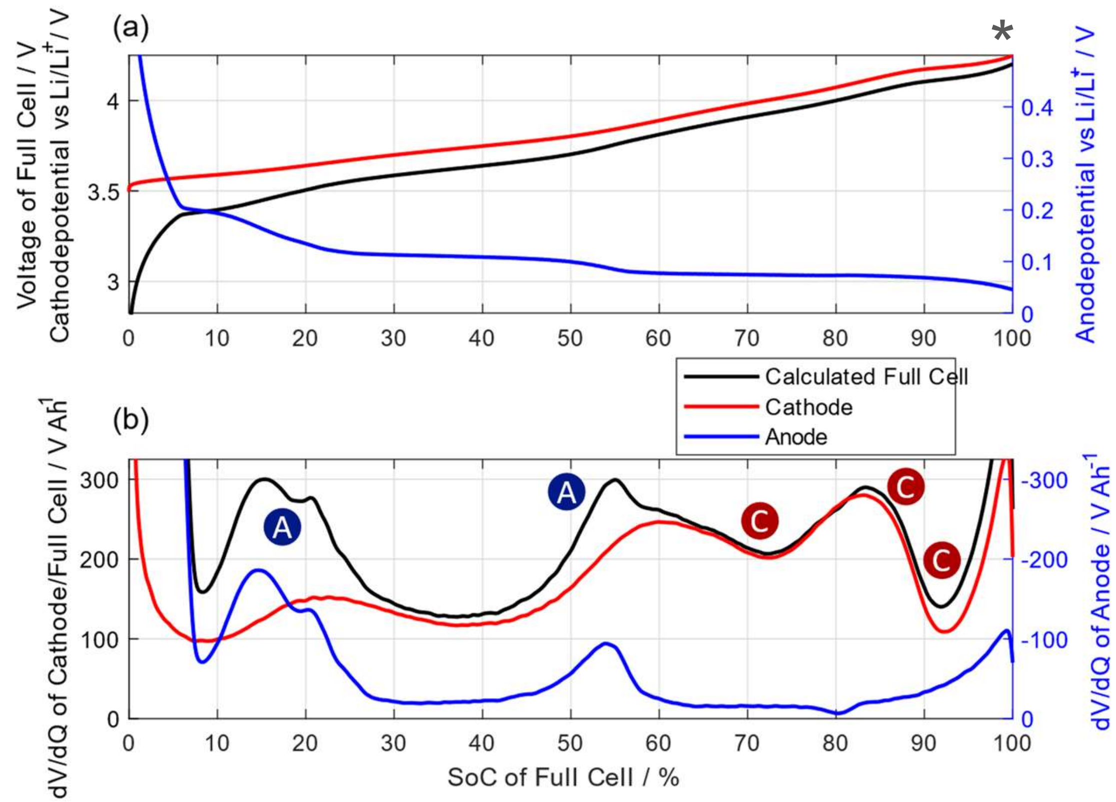
Graphite undergoes several phase transition during charging/discharging process.

Differential Voltage Analysis

$$\frac{dV}{dQ} = \left(\frac{dQ}{dV}\right)^{-1} \approx \frac{V(t_2) - V(t_1)}{Q(t_2) - Q(t_1)}$$

The distance between two peaks of the DV curve represents the amount of charge involved in a two-phase transition.

$$\frac{dV}{dQ} = \frac{d(\varphi_{cathode} - \varphi_{anode})}{dQ} = \frac{d\varphi_{cathode}}{dQ} - \frac{d\varphi_{anode}}{dQ}$$

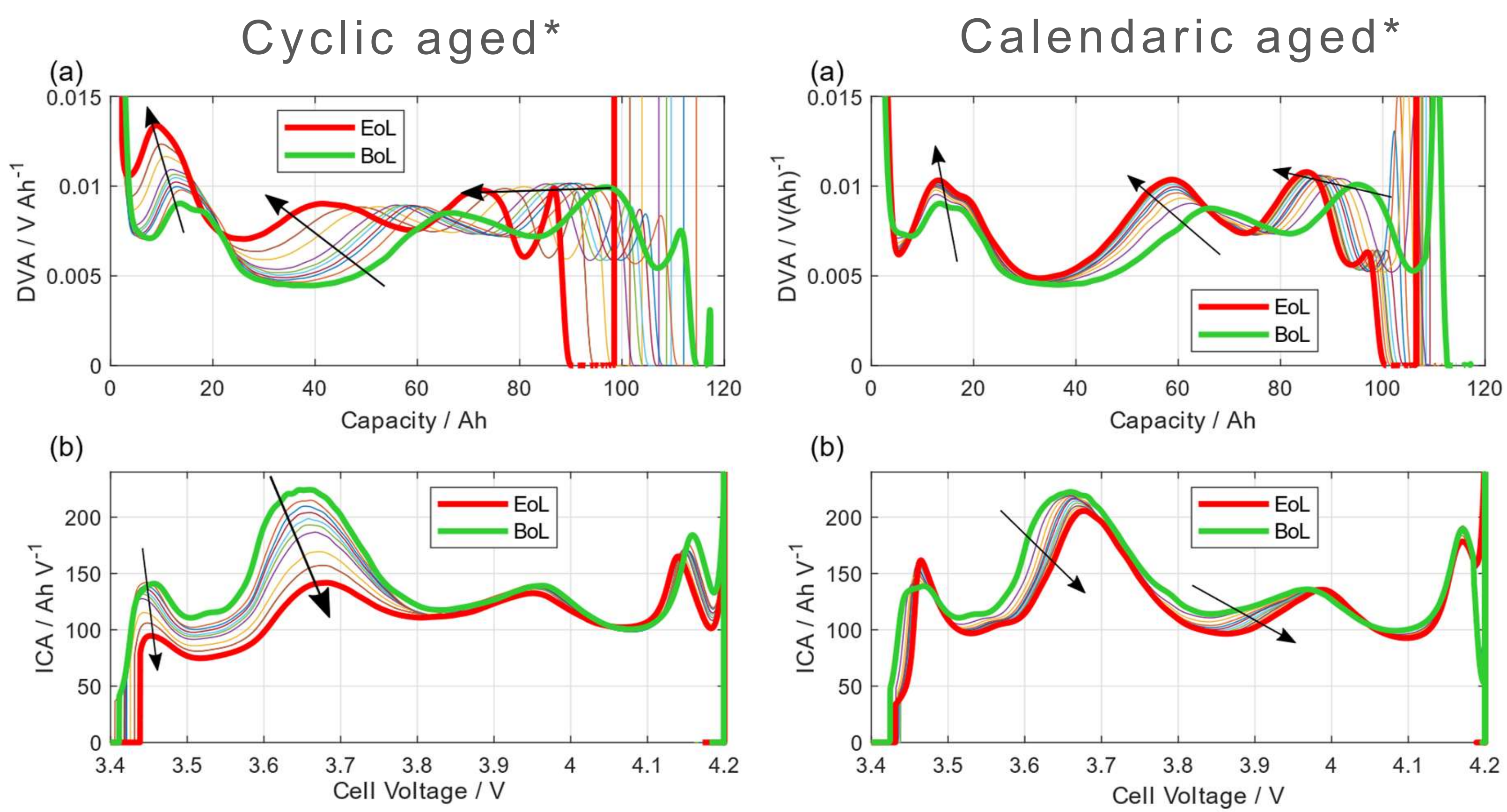


*NMC

Cyclic & Calendaric Aging

Due to LLI, LAM_C & LAM_A, caused by cyclic ageing, the position and height of observable peaks and valleys shift in various directions.

Peak and Valleys have simple correlation with capacity fade

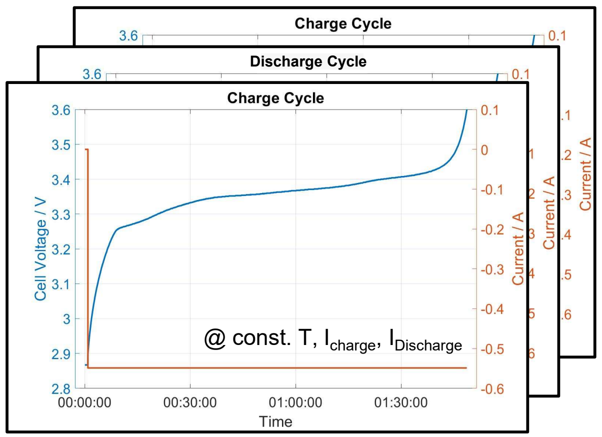


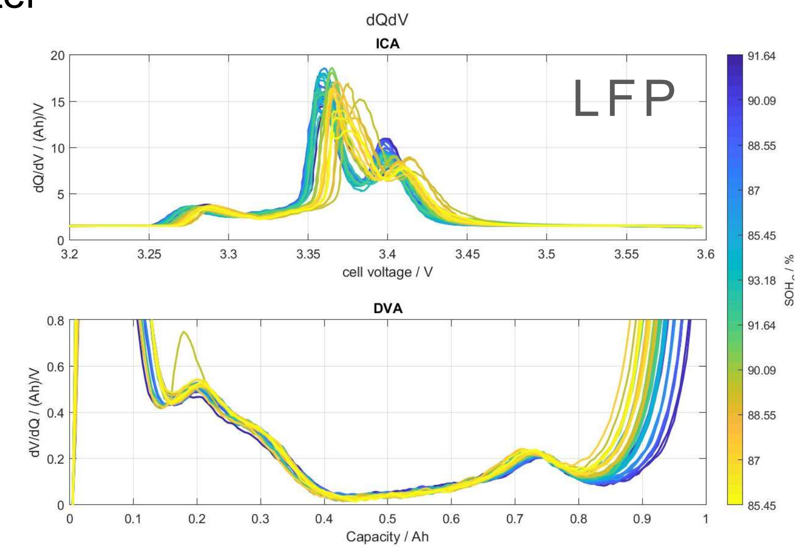
*NMC
EOL = End of Life
BOL = Begin of Life

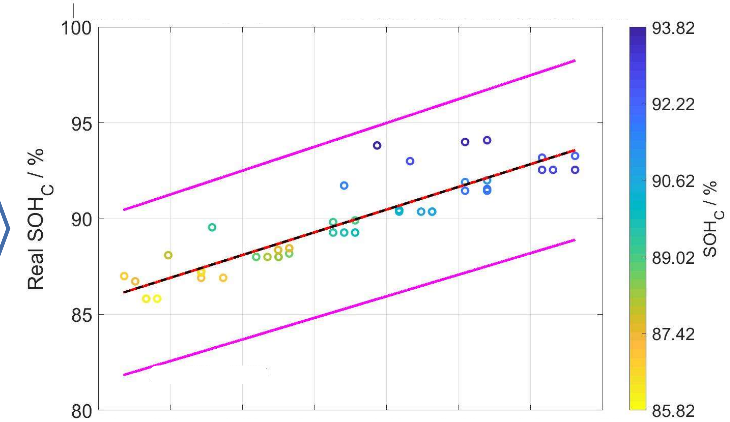
SOH LUT Generation

DVA & ICA Calculation & Filter

Feature Extraction





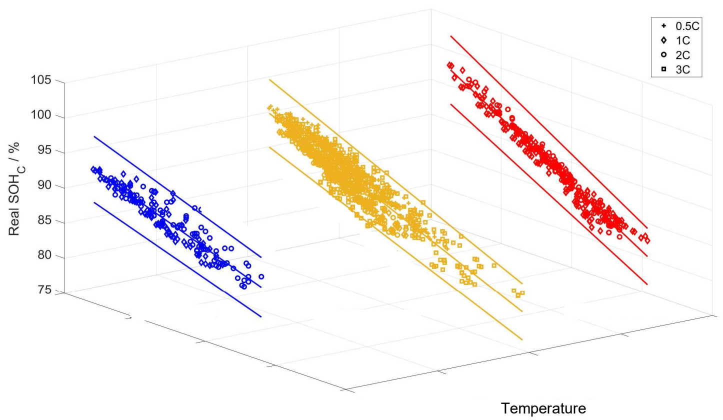


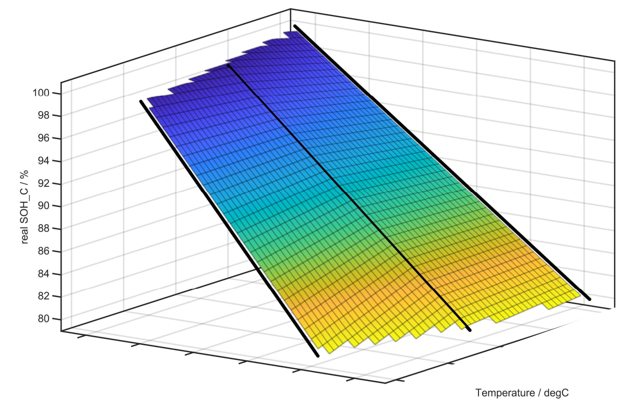
- Battery cycled at constant temperature, charging and discharging current
- Conduct every n cycles Check-up cycle

- Detect Features in Check-up cycles
- Add information of cell temperature, SOC and voltage of detected feature

- Bring features into correlation with Capacity Fade
- Calculate linear regression model

SOH LUT Generation





- Repeat previous steps for different cells at various temperatures and C-rates

- Calculate Feature-map by linear interpolation of all linear regression models at various temperatures

- Convert Feature-Map into 2D Look-up Table

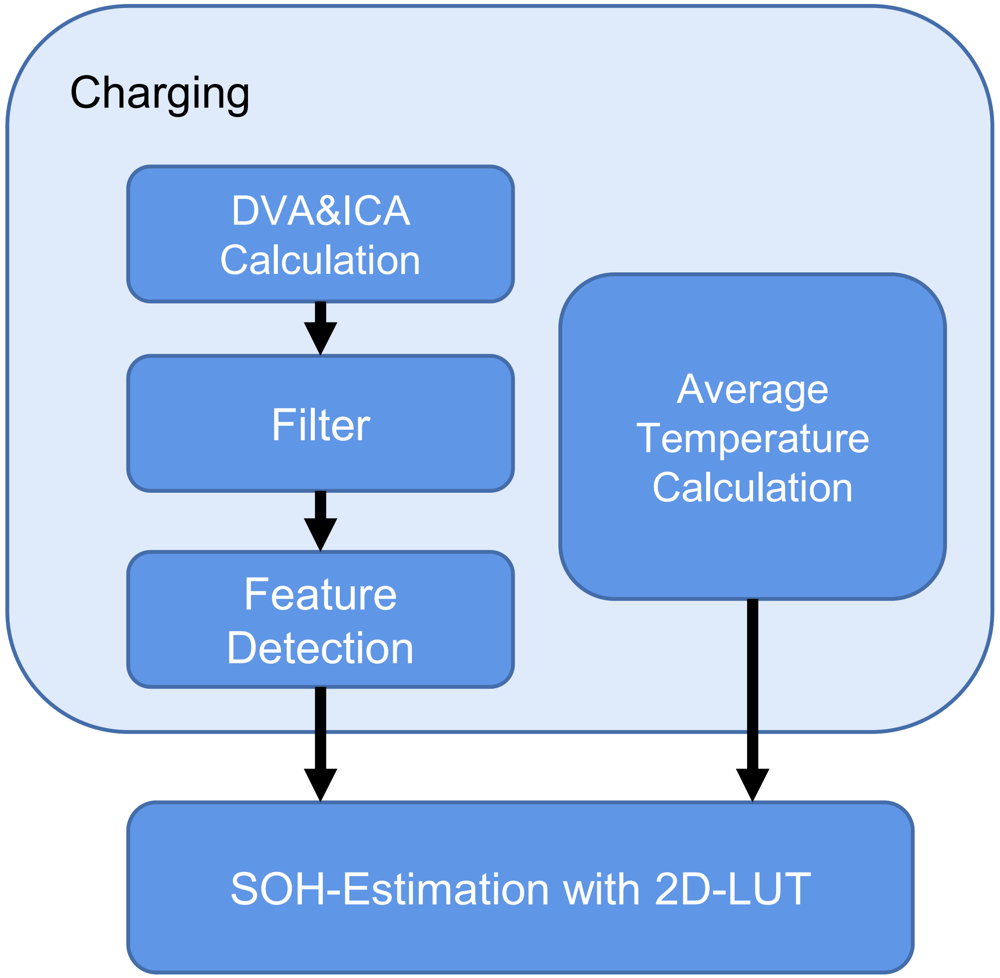
Simulink Model

Implementation in Simulink

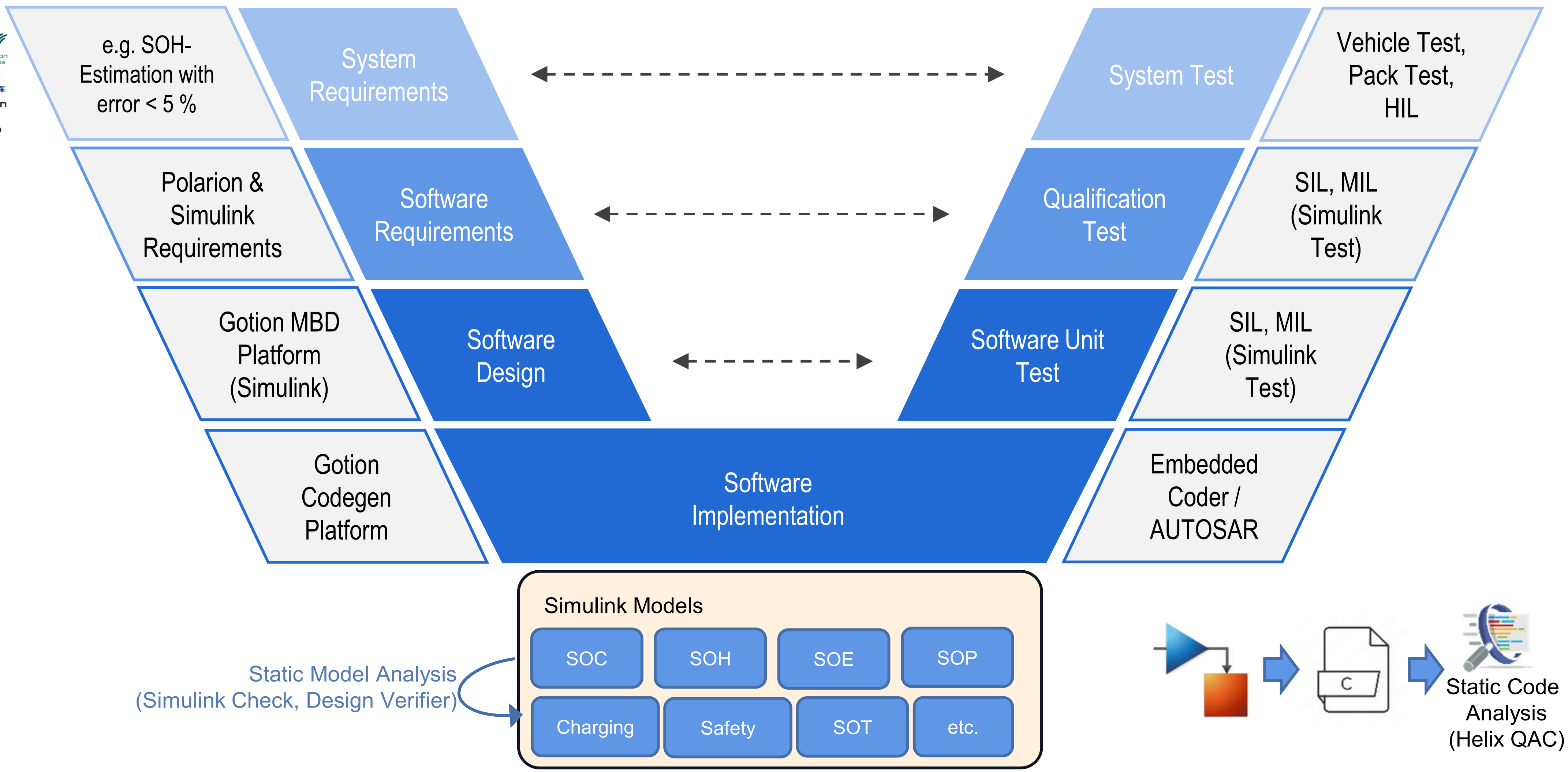
- State-Machine in Stateflow
- Feature Detection as MATLAB-Function
- Model reference
- C-Code Generation with Embedded Coder

Unit Testing

- Definition of test cases in Simulink Test



Development Workflow



Summary

ICA & DVA

- Data Analysis with MATLAB
- e.g. plots, peak detection

- User friendly
- Various helper functions
- Simple visualization

Onboard Implementation

- MBD
- Unit Test with Simulink Test
- C-Code Generation

- V-model coverage through MathWorks products, e.g. Simulink Requirements, Simulink Test, etc.
- ISO26262 & IEC61508 coverage through IEC Certification Kit
- Flexible integration through Code Generation

Next Steps

Onboard Implementation

- Data-Generation
- HIL-Testing
- Vehicle Integration

Research & Development

- Enhance Algorithm with ML through MATLAB ML Toolbox