WELCOME
HALLO
BIENVENUE

SCHÖN, DASS DU DA BIST!

MATLAB EXPO MUNICH 2019

MODULAR BMS DEVELOPMENT

IN RAPID PROTOTYPING OF

AUTOMOTIVE E/E SYSTEMS

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WE TALK ABOUT

MODULAR BMS DEVELOPMENT FOR AUTOMOTIVE E/E SYSTEMS

MATLAB EXPO 2019

- More Than Engineers -

- Future Mobility Trends -

- BMS Functionality and Requirements -

- Modeling Approach -

- Algorithms in Action -

- What does the Future Look Like? -

WHO ARE WE?

MORE
THAN
ENGINEERS

WE ARE

A RELIABLE PARTNER FOR ELECTRONICS

ELECTROMOBILITY

SMART MOBILITY

MECHATRONICS

FUNCTIONAL SAFETY

+ENGINEERING

+CONSULTING

+SOFTWARE

WE WILL WORK TOGETHER

TOWARDS YOUR GOALS WITHOUT MAKING COMPROMISES

ENGENEERS

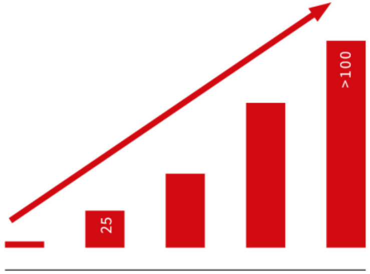
FROM

DUBAI, CHINA, BAVARIA, BADEN AND SWABIA

3-LEVEL DEVELOPMENT APPROACH

9

LOCATIONS



EMPLOYEE DEVELOPMENT

ELECTRONICS

ACTUATORS INTEGRATION
SENSORS INTEGRATION
BATTERY SYSTEM
AUTOMOTIVE ETHERNET
ELECTRONIC INTEGRATION
ALGORITHM/AI
FUNCTIONAL SAFETY

SKILLS

MOTIVATION

FUTURE

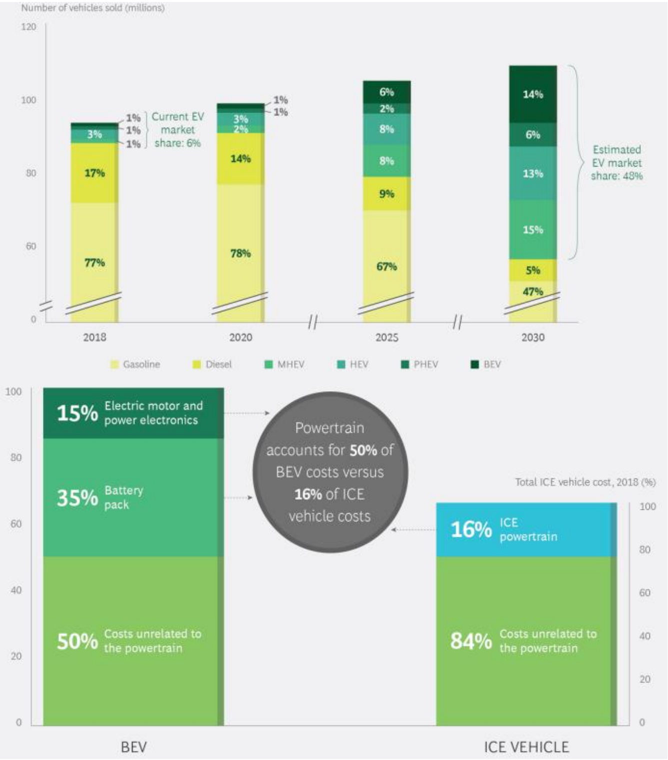
MOBILITY

TRENDS

Motivation

Battery Systems are Expensive

- Battery packs make up ~ 35% of total BEV costs
- Useful to come up with a workflow for battery system development to estimate:
  - Number of cells, modules, packs
  - Series /Parallel configurations
  - Range, capacity
- Goal → To come up with computationally inexpensive, yet accurate battery models/system simulations to avoid error realization deep down in the design process



Source: JPMorganChase; BCG analysis

INTRODUCTION

BMS FUNCTIONALITY

AND

REQUIREMENTS

Introduction

BMS – Basic Idea

- Embedded system ➔ function-built electronics + processing
  - **Protects** user
  - **Protects** battery
  - **Prolongs** life of battery
  - **Maintains** battery in a functional state
  - Tells controller how to use pack **effectively** in **real-time**

Figure 1: Battery pack assembly in automobile

Introduction

BMS – Functionality

- **Sensing/High Voltage Control** - Voltage, current, temp. sensing, precharge, detect ground faults;
- **Protection** - overcharge, over-discharge, over-current, short circuit, extreme temps.
- **Interface** - Range estimation, communications, data recording/reporting
- **Performance Management** - SOC estimation, power limit computation, cell balancing
- **Diagnostics** - Abuse detection, SOH estimation

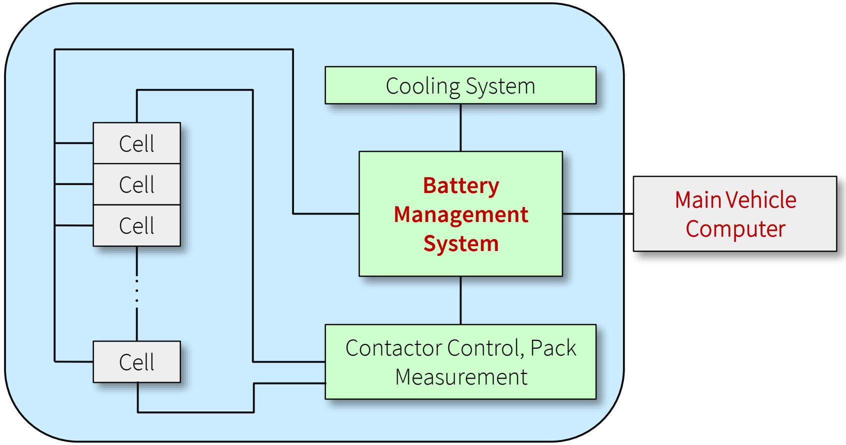
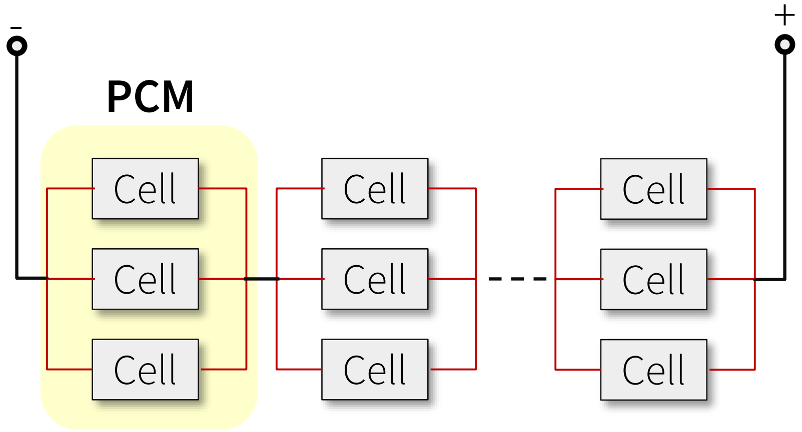


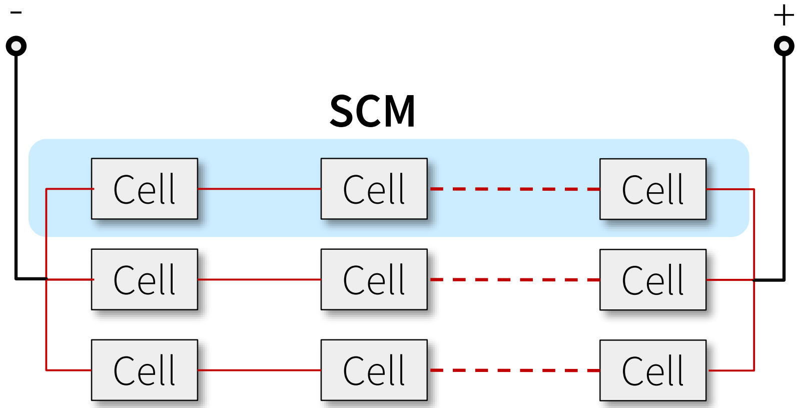
Figure 2: Overview of components involved in a BMS

Introduction

Parallel Connected Modules



Series Connected Modules



MODELING APPROACH

EQUIVALENT

CIRCUIT

MODELING

Modeling Approach

Empirical Modeling

- Equivalent Circuit Models (ECMs) - dynamics of this circuit approximates Li-ion cell behavior
- Accounts for hysteresis voltages
- R_0, C_1, and R_1 represent diffusion processes, functions of SOC, Temperature
- State space representations make implementation of control/estimation algorithms possible

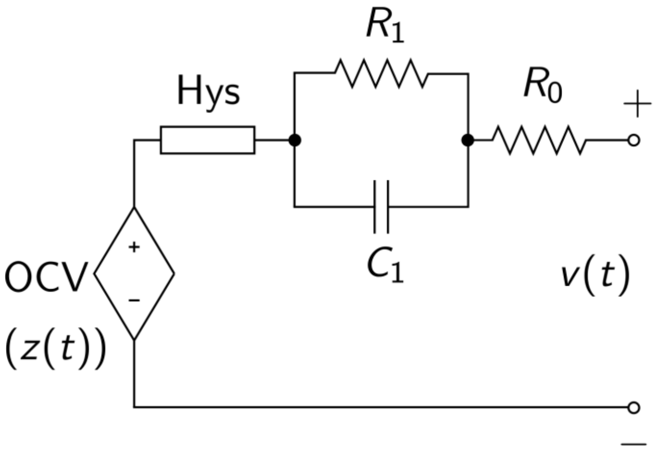
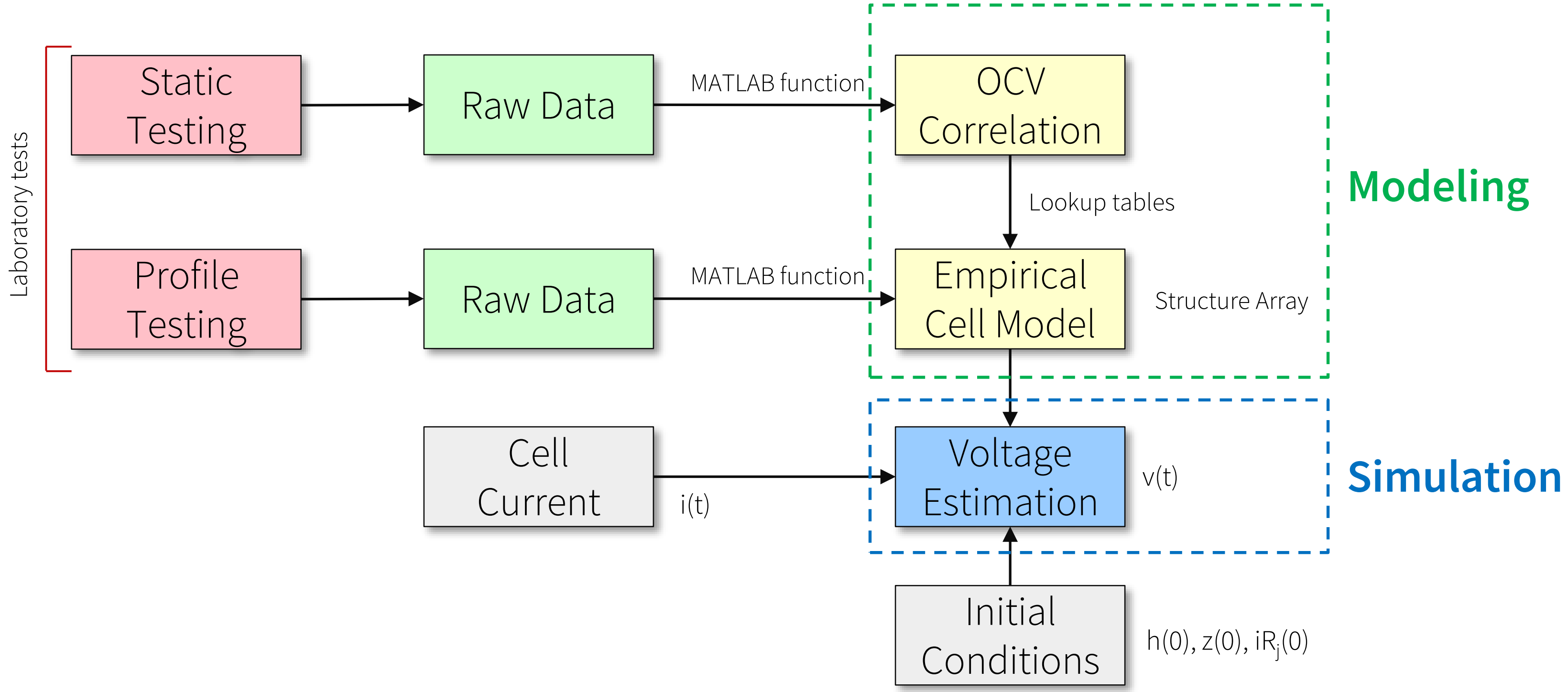


Figure 3: Equivalent Circuit Model Representation

Modeling Approach

Process Overview



ALGORITHM DEVELOPMENT

PERFORMANCE

AND

DIAGNOSTICS

Algorithm Development

BMS Measurement Loop

Voltage, current, temp measurements

- Real time measurements taken using voltage, current and temperature sensors
- When real data unable, state space model used to generate 'real' data

Optimization – fminsearch, fminbnd

SOC Estimation

- Kalman filters (EKFs and SPKFs) applied to state space models of ECMs
- KF methods are optimal for SOC estimation
- Implemented using MATLAB function files

SOH Estimation

- Using SOC estimates from previous step, capacity predictions can be made
- Degradation can be quantified to give an 'SOL'

Cell Balancing

- Active/Passive balancing methods used depending on the application
- Cells can be balanced using **Stateflow™**

Power Limits

- Compute voltage operating limits
- Minimize incremental degradation based on previous state and parameter computation

Algorithm Development

Kalman Filtering

- KF based SOC estimation methods are very robust in comparison to voltage/current based methods
- Different implementations of the Kalman Filter possible – Extended Kalman Filter (EKF), SPKF (Sigma Point Kalman Filter), etc.
- Choice depends on complexity/system requirements

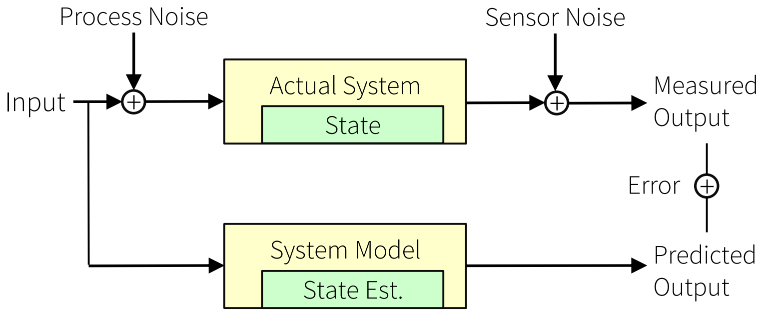
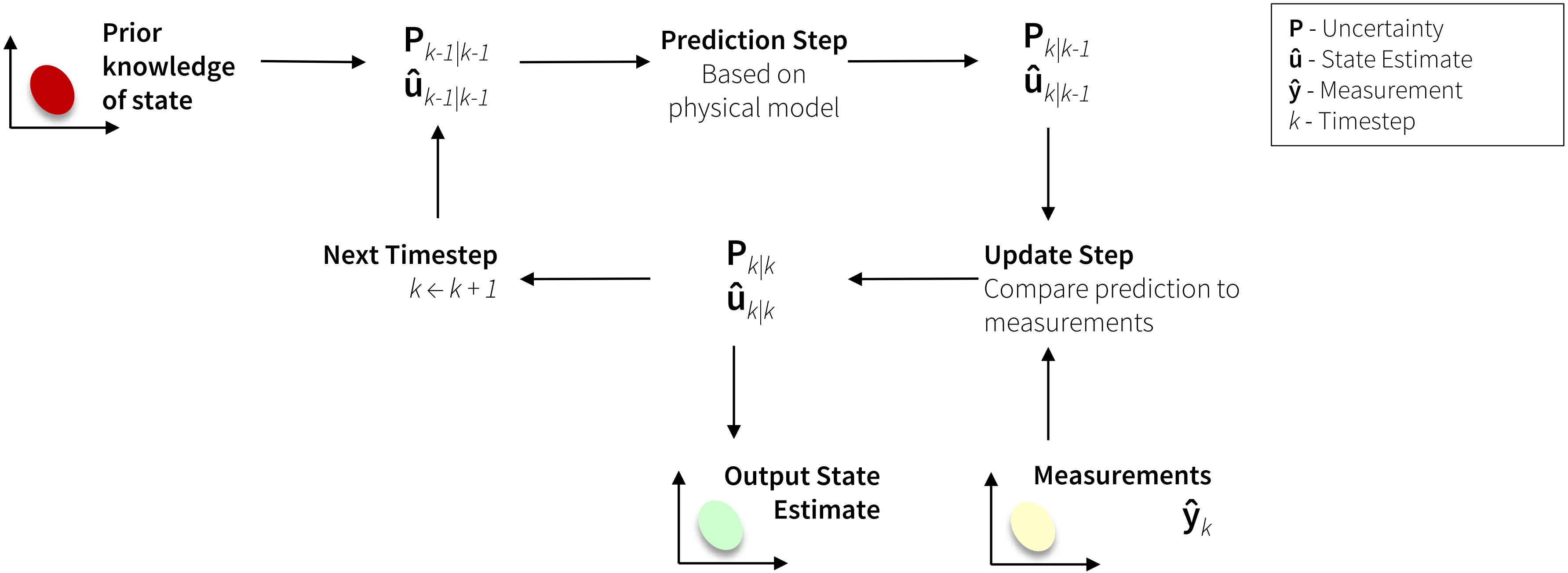


Figure 4: Model-based state estimation

Algorithms in Action

Kalman Filtering



Source: https://wikipedia.org/wiki/Kalman_filter

SAMPLE USE CASE

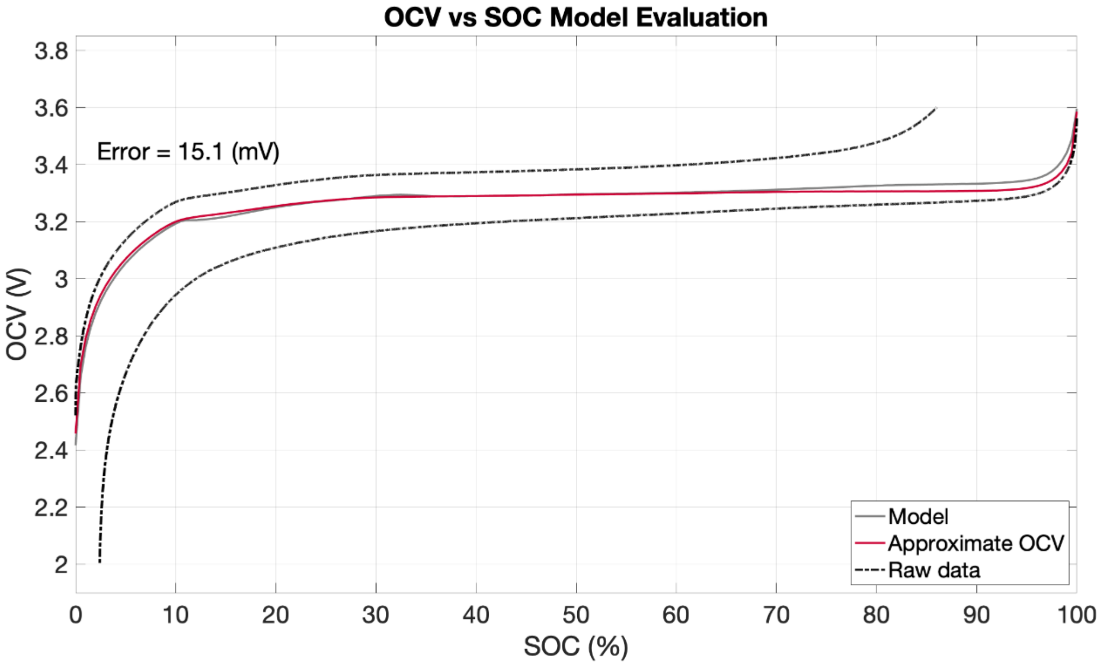
ALGORITHMS

IN

ACTION

Algorithms in Action

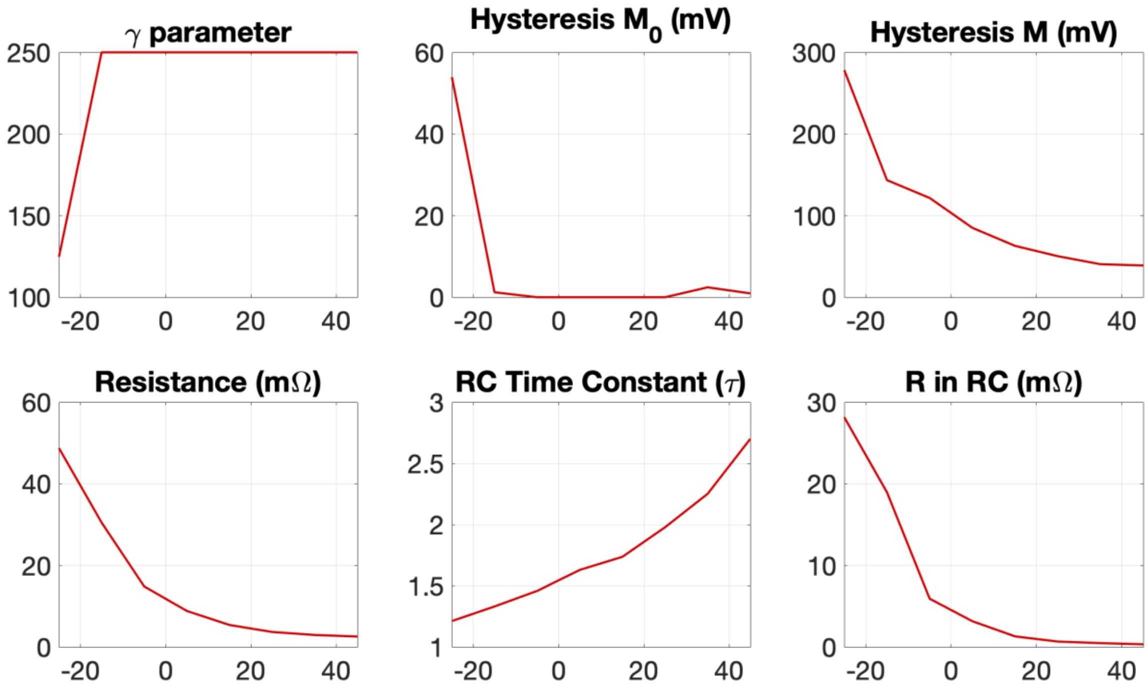
OCV vs SOC Correlation



*Tests done on a 30Ah automotive battery cell

Algorithms in Action

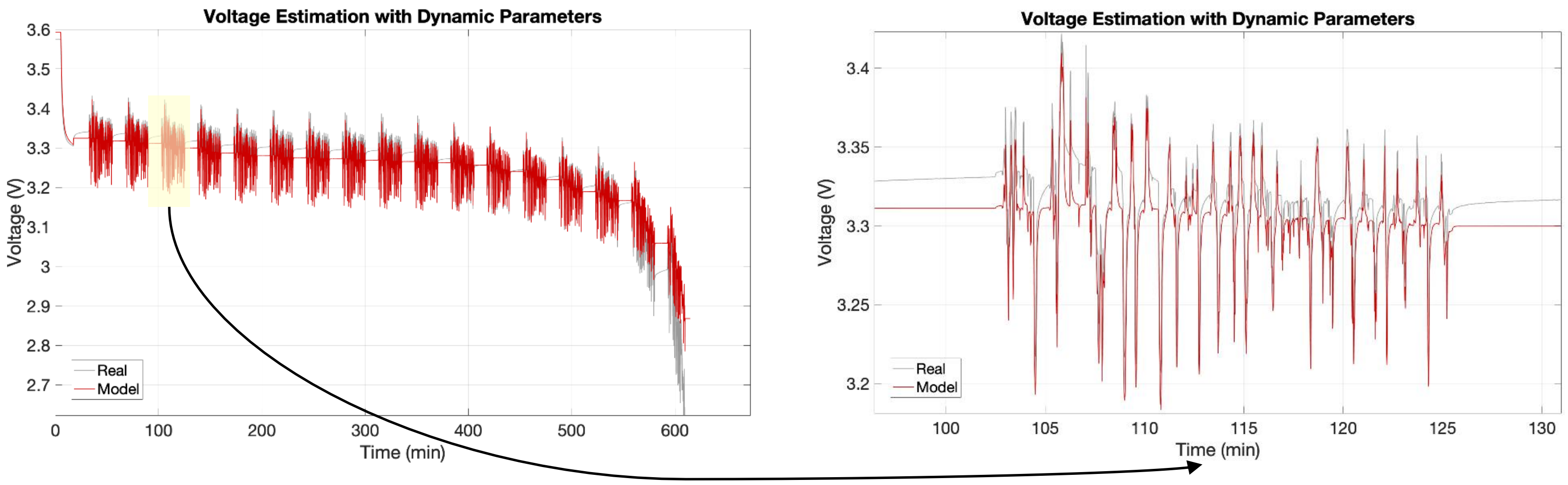
Dynamic Cell Parameters



*All graphs plotted against temperature

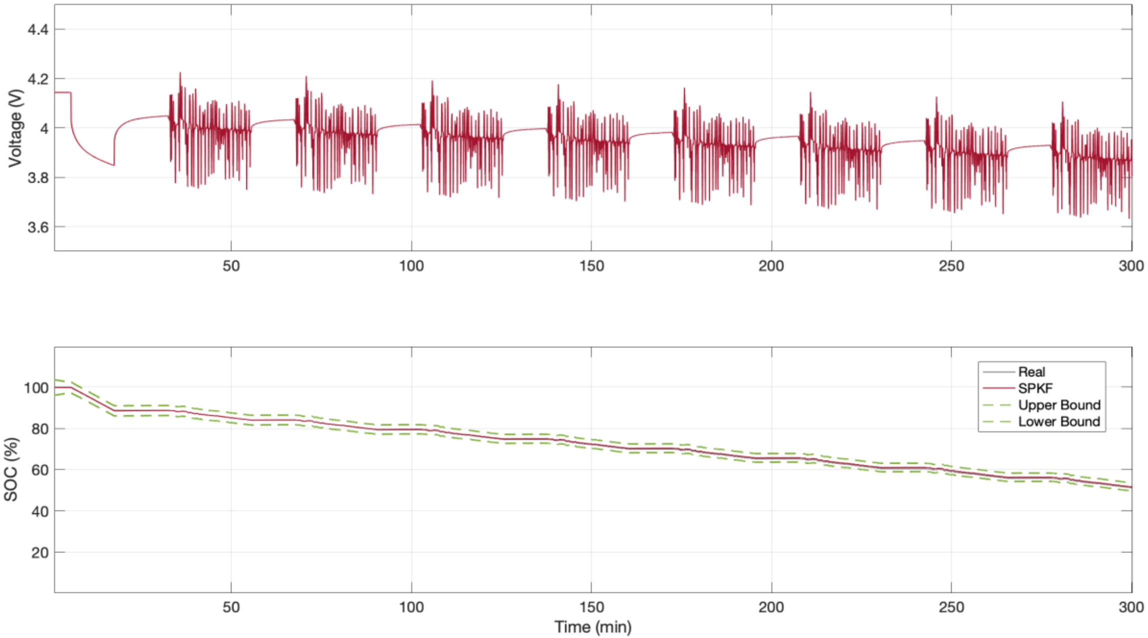
Algorithms in Action

Voltage Estimation



Algorithms in Action

SOC Estimation using Kalman Filtering



*Tests done on a 30Ah automotive battery cell

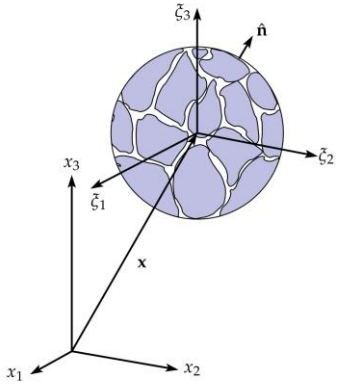
OUTLOOK

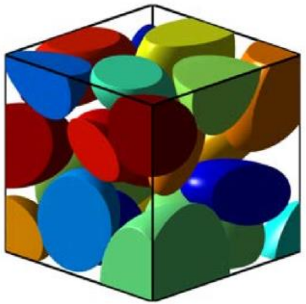
WHAT DOES THE FUTURE LOOK LIKE?

Outlook

Physics Based Models (PBMs)

- Empirical approach is good, but physics based cell models (PBM) are optimal for developing a robust BMS
- Deal with diffusion, kinetics down to the molecular level
- Computation costs for PBMs are high, research going into obtaining reduced order models (ROM)
- Next generation BMS will be driven by control/estimation algorithms developed around PBMs





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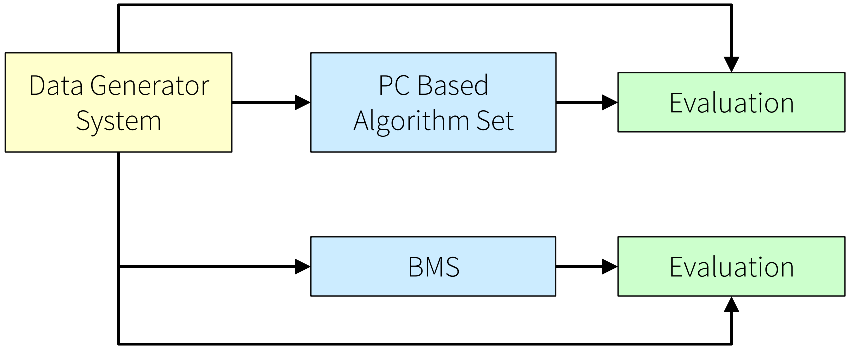
Algorithms in Action

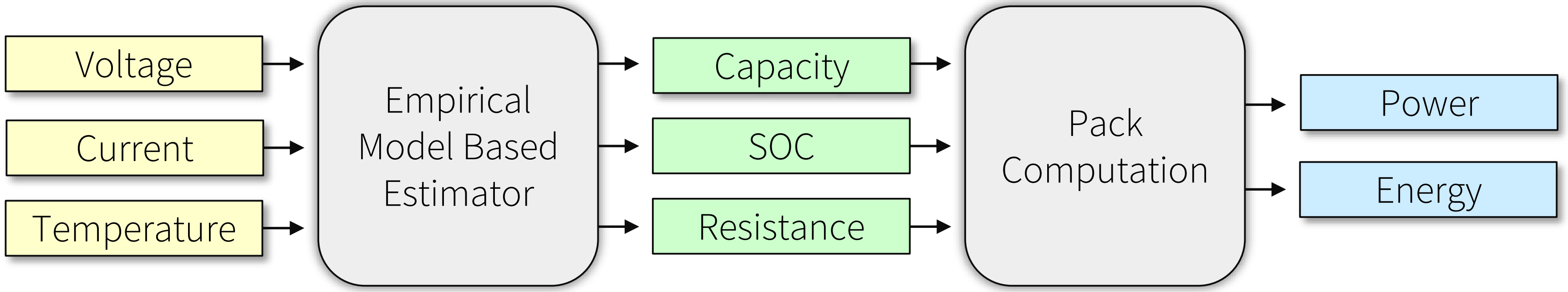
Desktop Validation

- Use model of cell to create synthetic test data.
- Allows access to “truth” of all cell and algorithm states
- Validity of results limited by the accuracy of cell model.



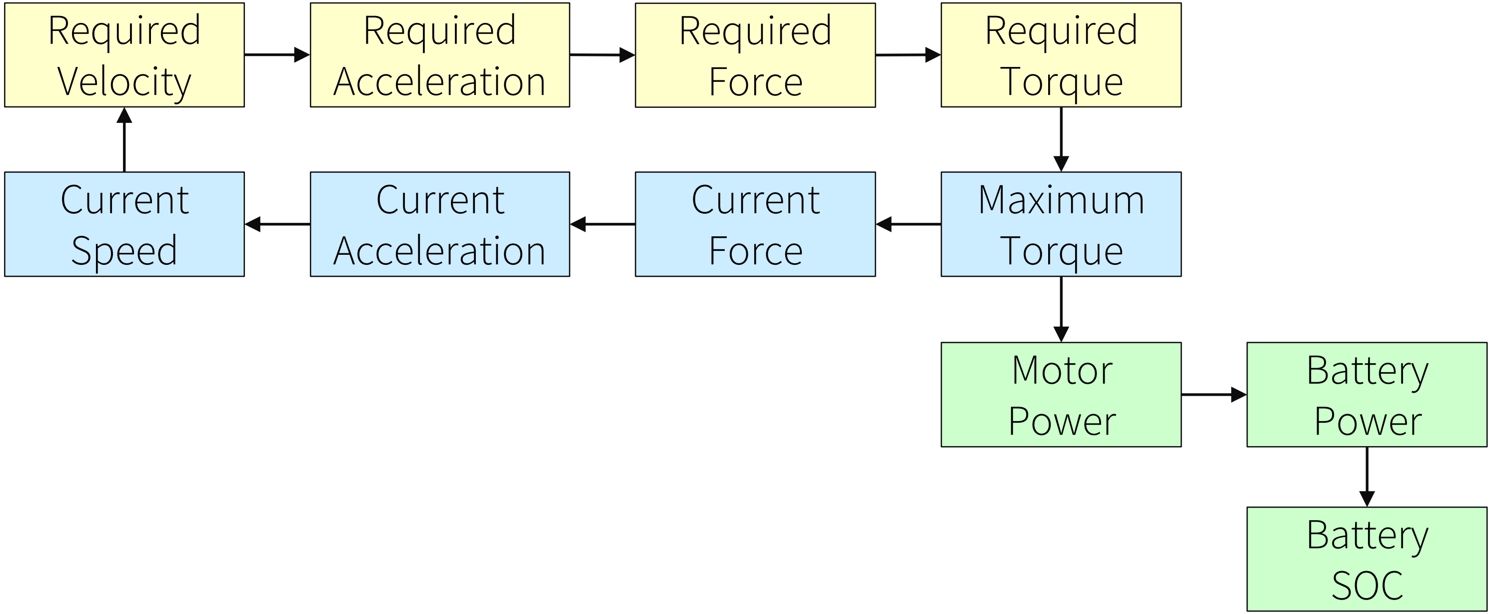
Algorithm Development

In a Nutshell:



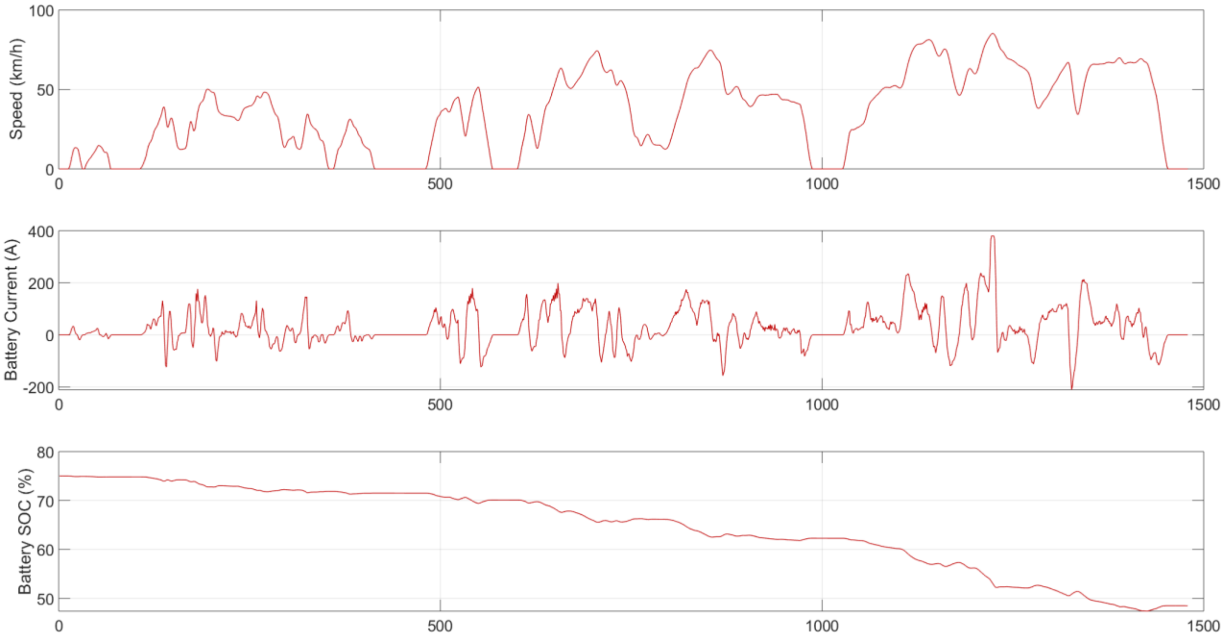
Algorithms in Action

Simple Application to a Battery Electric Vehicle (BEV)



Algorithms in Action

Results



Algorithms in Action

Results