MixMax: Leveraging Heterogeneous Batteries to Alleviate Low Battery Experience for Mobile Users

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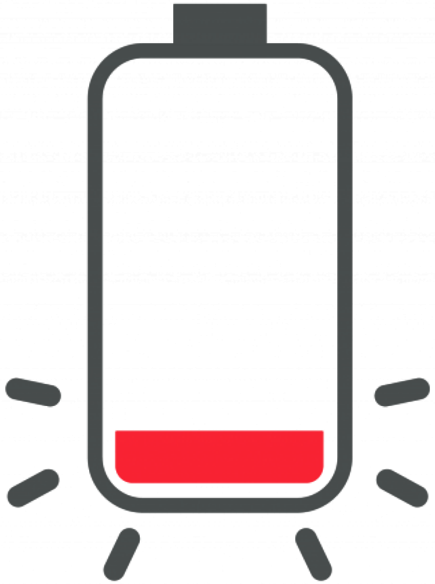
11:37
1,116
TUESDAY
2
No more events today
Calendar
The Athletic
YouTube
Audible
BBC SPORT
SONOS
BBC Sport
Sonos
Twitter
Photography
110/650KCAL
9/30MIN
3/12HRS

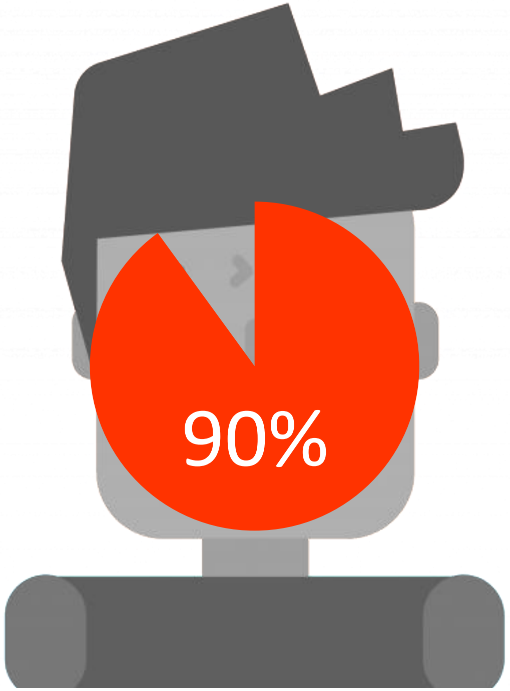

Charging...

Low Battery Anxiety

"Low Battery Anxiety" Grips 9 Out Of Ten People

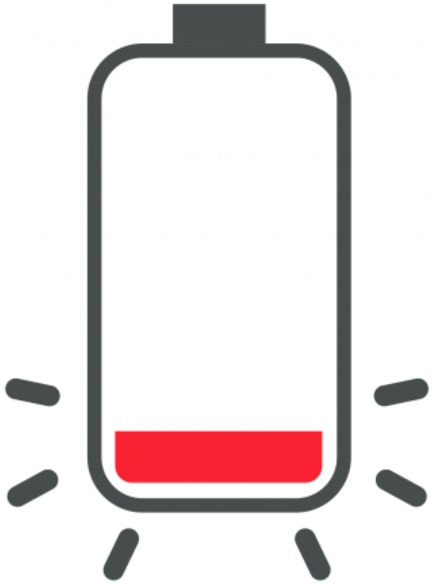
LG Survey Uncovers Questionable Behavior When a Smartphone Battery Drops to 20 Percent or Below

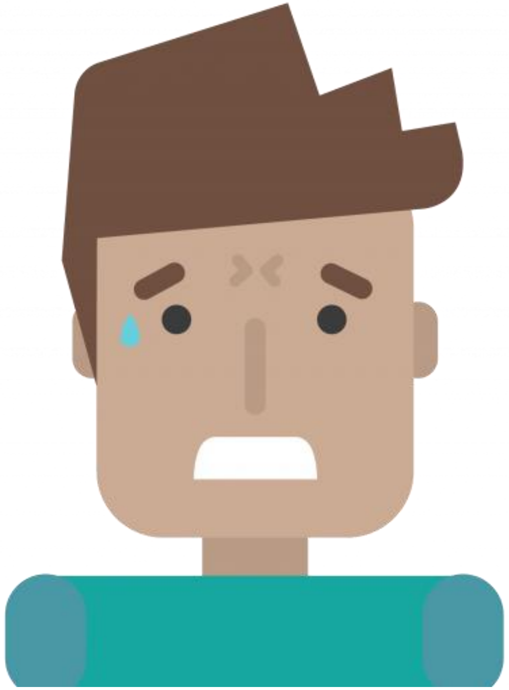




Low Battery Anxiety

Analysis





Low Battery Anxiety

827 days of

battery usage pattern data

from 100 users

The ExtraSensory Dataset

Android dumpsys batterystats

Analysis

Low Battery Anxiety

Analysis →

86% of users
suffers it weekly

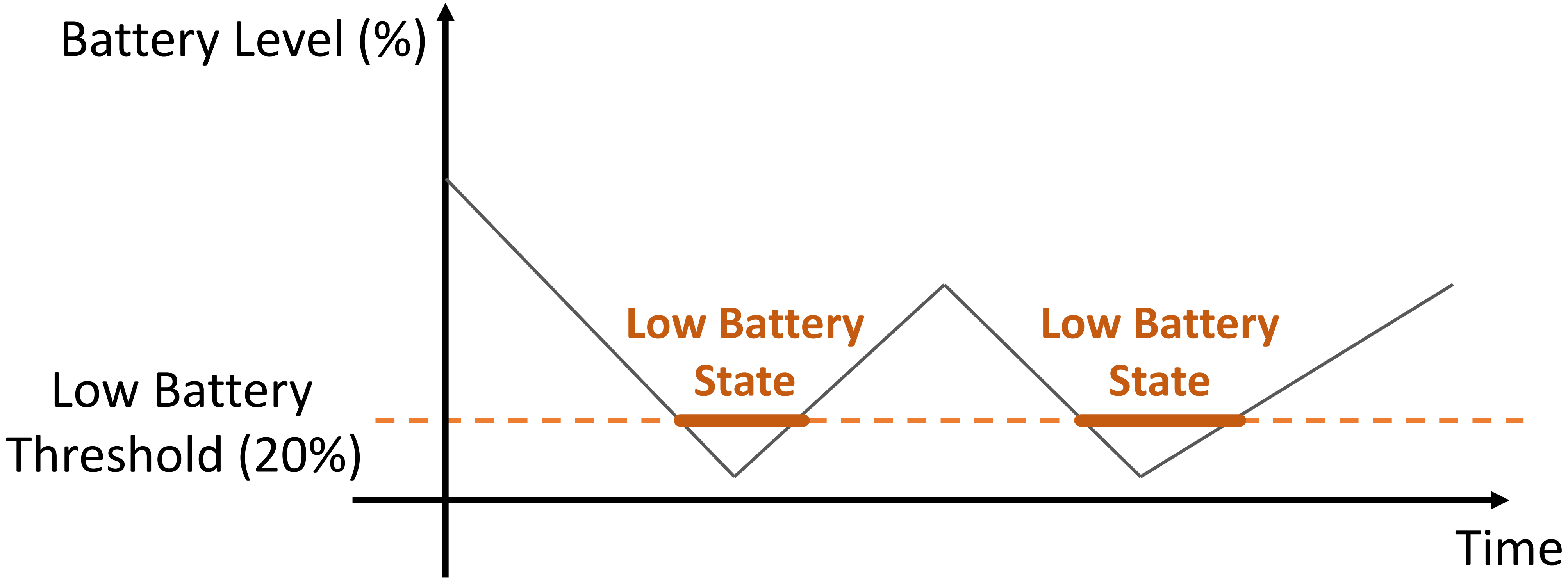
On average, users suffer
1.5 hours daily

Causing more & longer
charging trials

Pervasive &
Annoying Problem

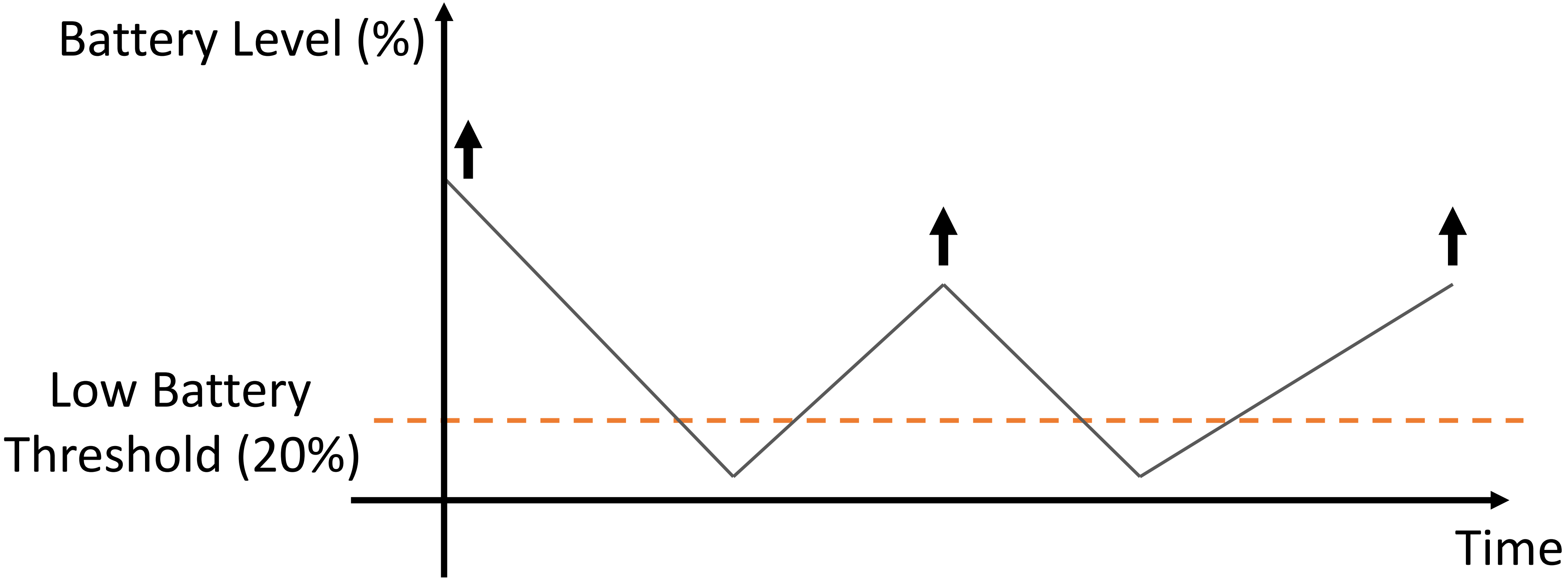
How to Alleviate Low Battery Anxiety

Low Battery Anxiety: Battery Level ≤ Threshold (20%)



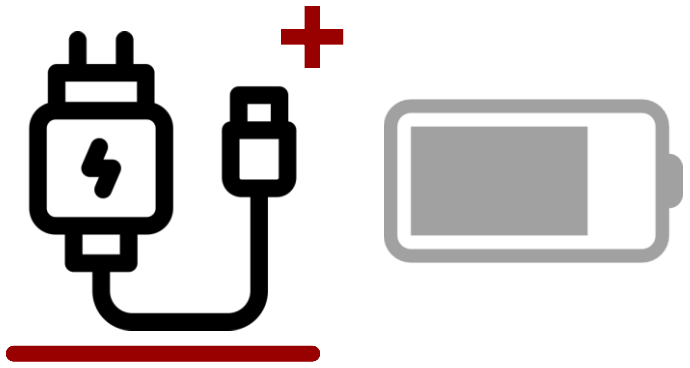
How to Alleviate Low Battery Anxiety

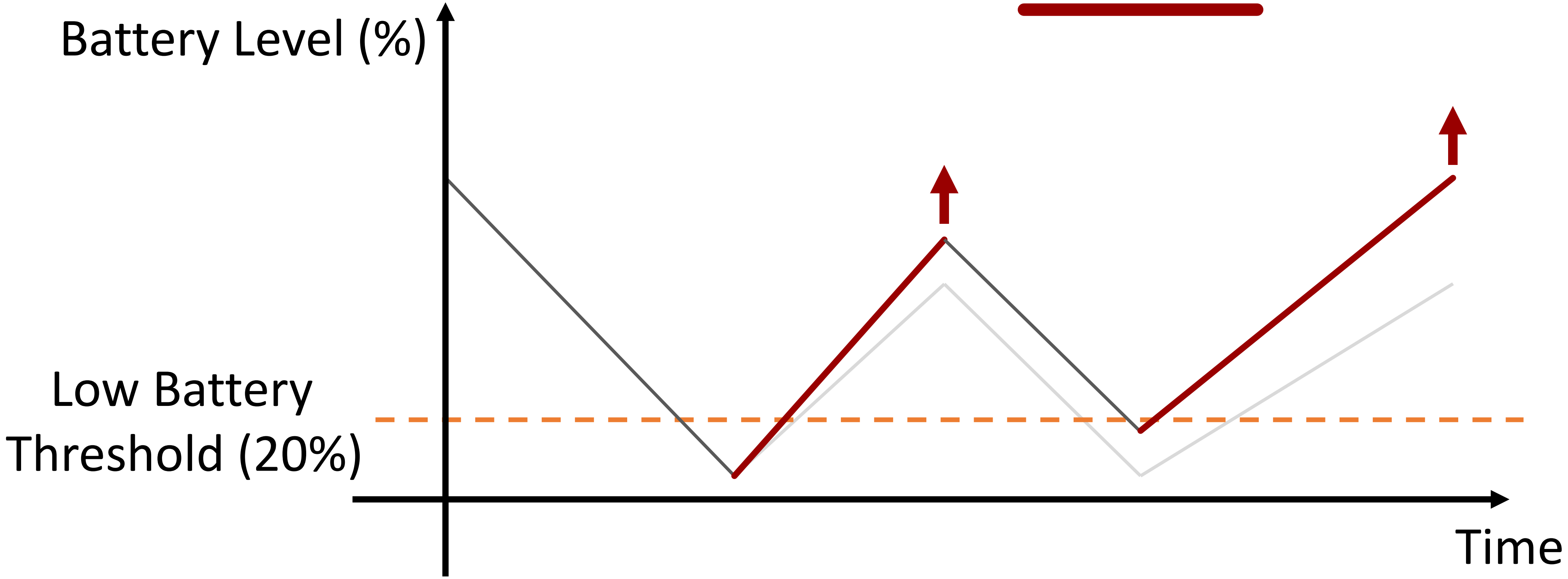
More Remaining Energy → Less Low Battery Anxiety



How to Alleviate Low Battery Anxiety

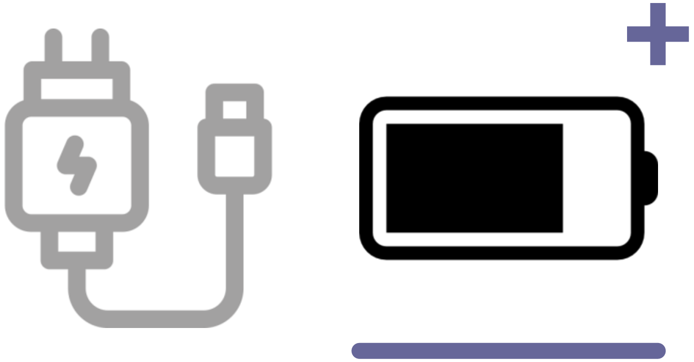
Two Approaches
- **Increasing charging speed**
- Increasing battery capacity

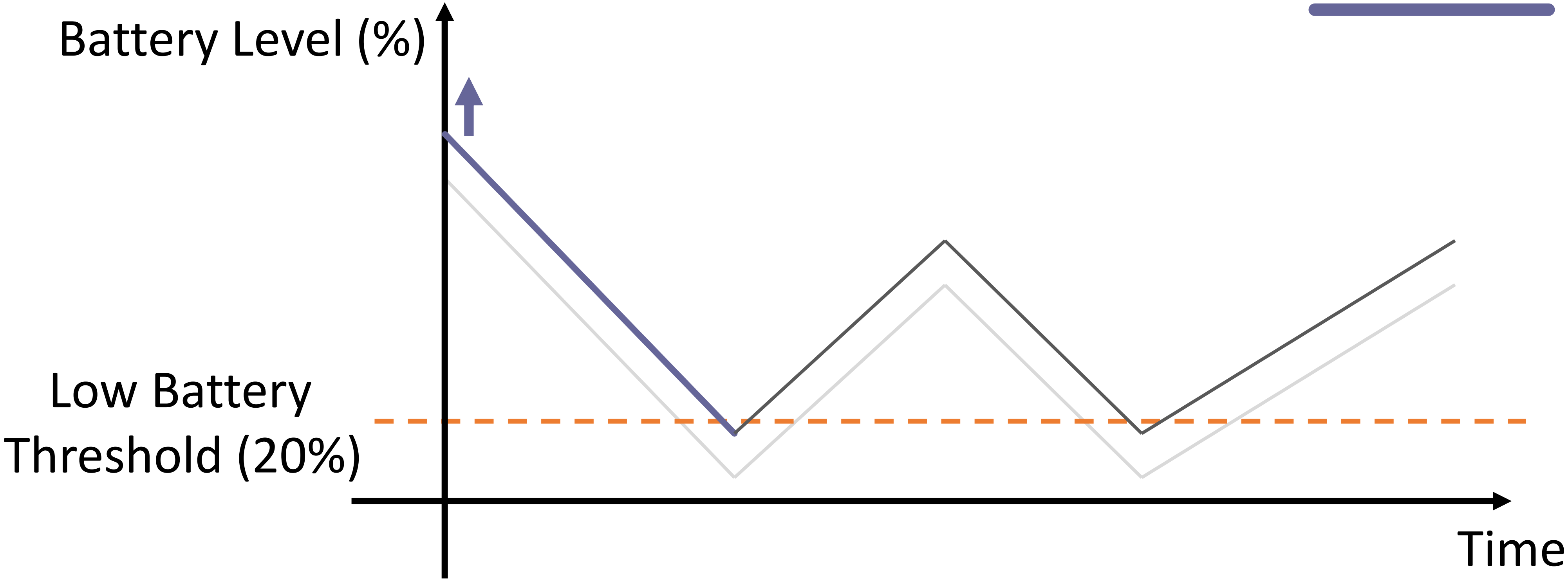




How to Alleviate Low Battery Anxiety

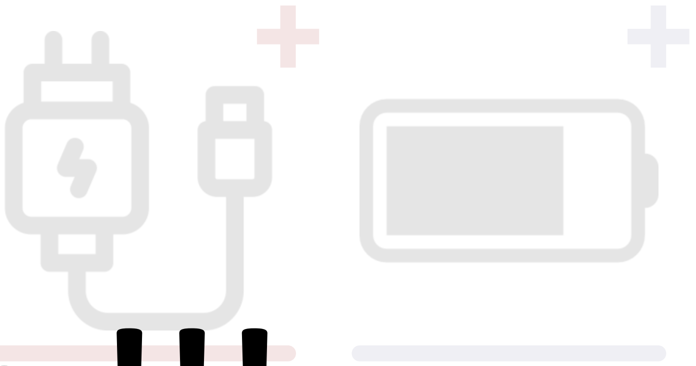
Two Approaches
- Increasing charging speed
- **Increasing battery capacity**

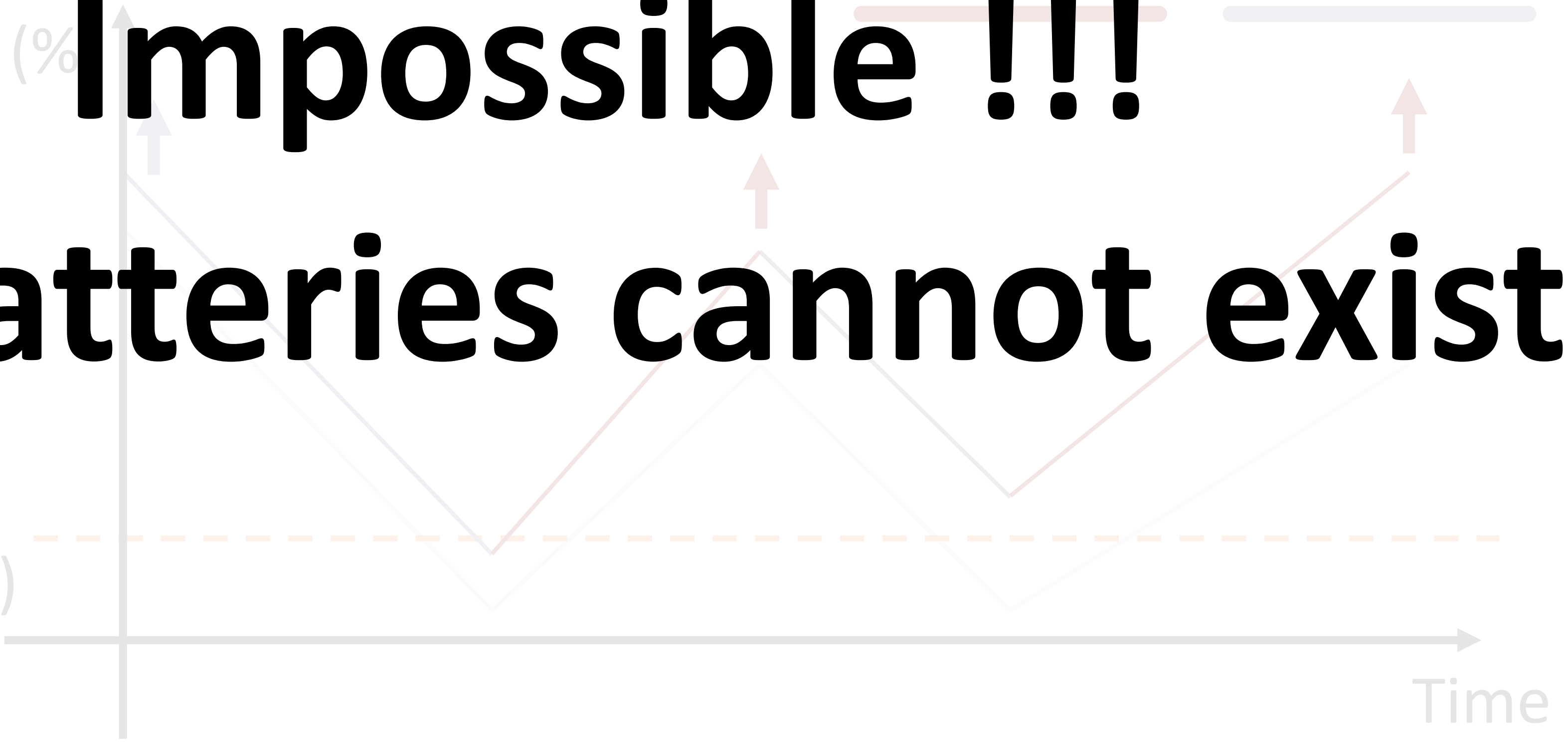




How to Alleviate Low Battery Anxiety

Two Approaches
- **Increasing charging speed**
- **Increasing battery capacity**

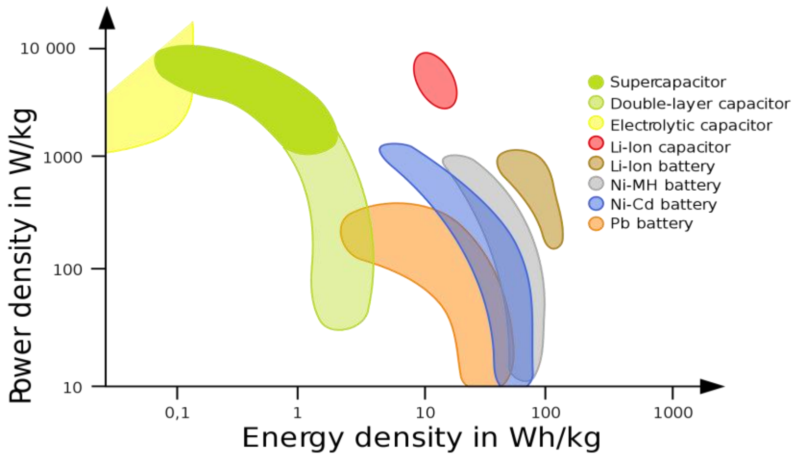




Impossible !!!

Such batteries cannot exist !!!

Other Battery Choices

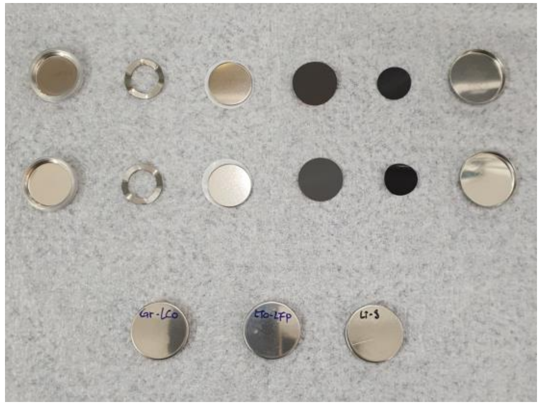


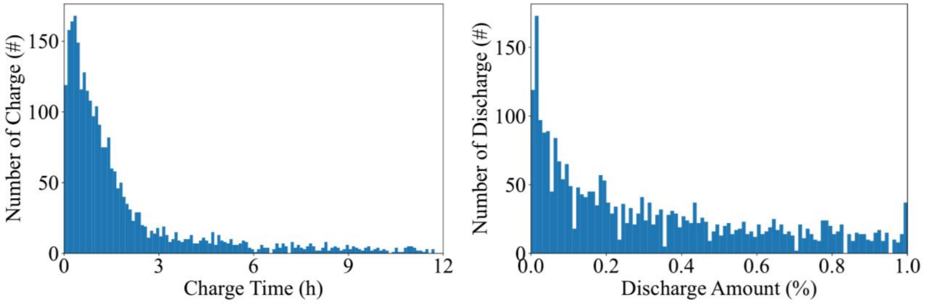
Fundamental Law of Batteries

→ Charging speed and capacity are <u>inversely proportional</u>

	A-type	B-type	C-type
Types	LTO, Super Capacitor	LCO, LFP, LMO	Li-S, High Nickel NMC/NCA, Li-Air
Capacity	★	★★★	★★★★★
Charging speed	★★★★★	★★★	★
	???	Current Choice	???

Other Battery Choices





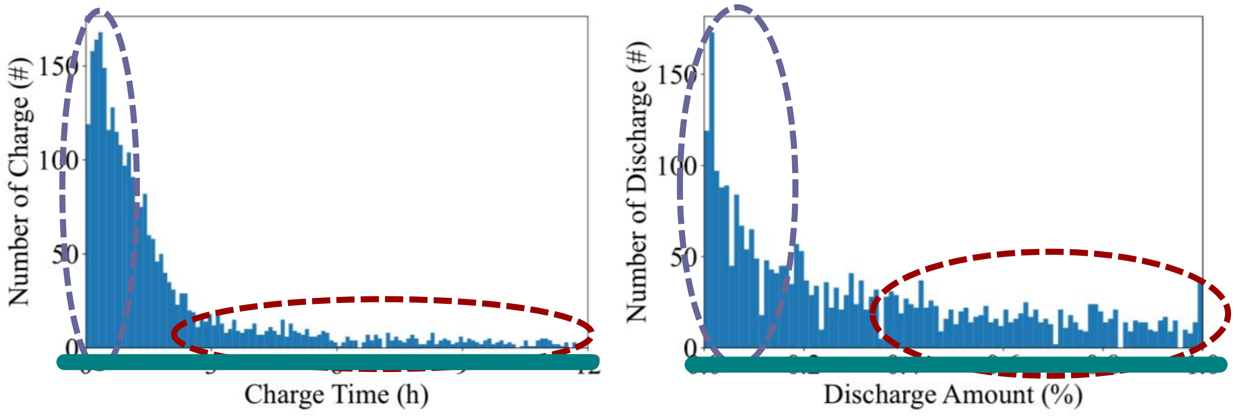
(a) Charge time distribution (b) Discharge amount distribution

Figure 2: Battery usage patterns of 100 mobile users

Coin-Cell Fabrication
& Battery Usage Pattern Data
→ Precise LTO, LCO, and Li-S
battery emulators

	A-type	B-type	C-type
Types	LTO, Super Capacitor	LCO, LFP, LMO	Li-S, High Nickel NMC/NCA, Li-Air
Capacity	★	★★★	★★★★★
Charging speed	★★★★★	★★★	★
Low Battery	**Bad**	**Moderate**	**Bad**

Other Battery Choices

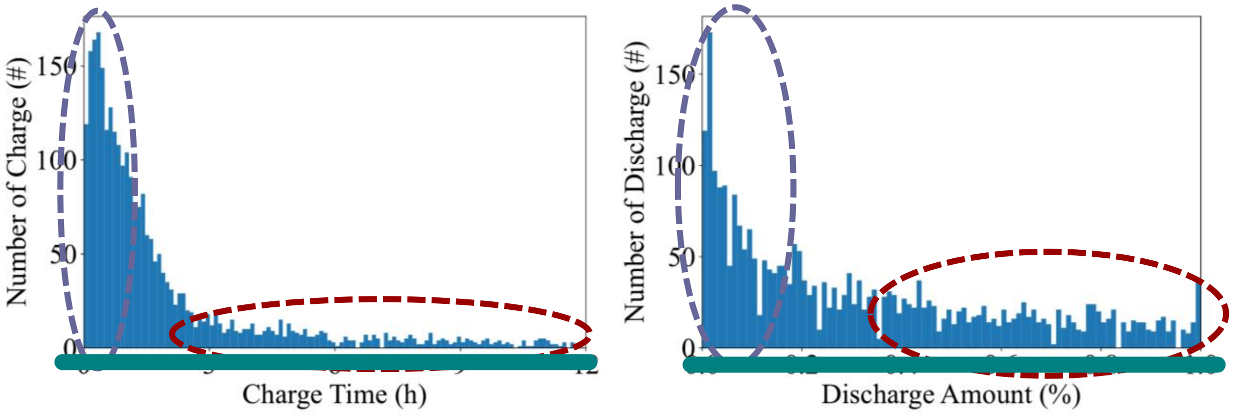


(a) Charge time distribution (b) Discharge amount distribution

Figure 2: Battery usage patterns of 100 mobile users

	A-type	B-type	C-type
Short charging & discharging	★★★★★	★★★	☆
Long charging & discharging	☆	★★★	★★★★★
Low Battery	**Bad**	**Moderate**	**Bad**

Other Battery Choices



(a) Charge time distribution (b) Discharge amount distribution

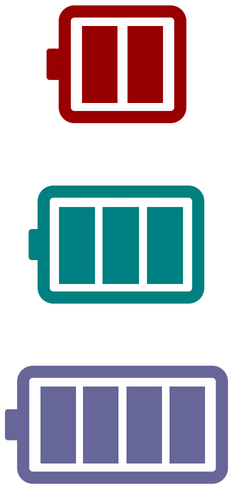
Figure 2: Battery usage patterns of 100 mobile users

Mix

A + B + C

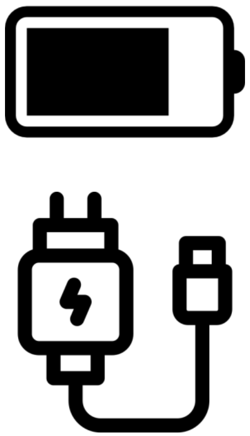
	A-type	B-type	C-type	A + B + C
Short charging & discharging	★★★★★	★★★	☆	★★★★
Long charging & discharging	☆	★★★	★★★★★	★★★★
Low Battery	**Bad**	**Moderate**	**Bad**	**Good**

MixMax Overview



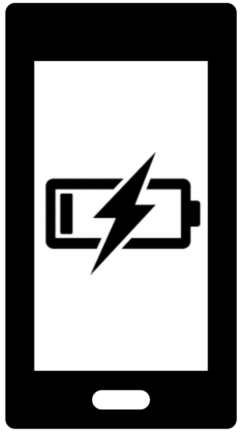
Heterogeneous Batteries

→



Increasing Capacity & Charging Speed

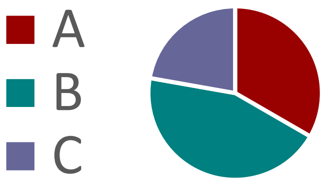
→



Alleviate Low Battery

MixMax

MixMax Overview



Ratio Optimization

Charge Policy

Discharge Policy

→

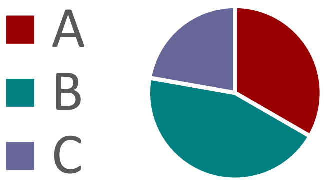
Increasing Capacity & Charging Speed

→

Alleviate Low Battery

MixMax

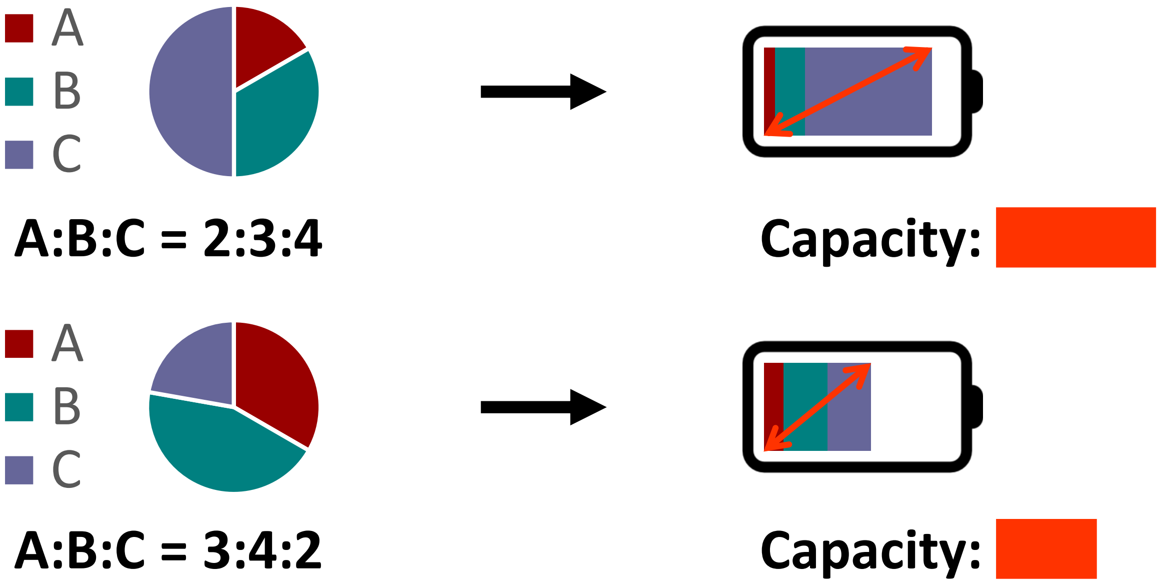
MixMax Overview



Ratio Optimization

Charge Policy

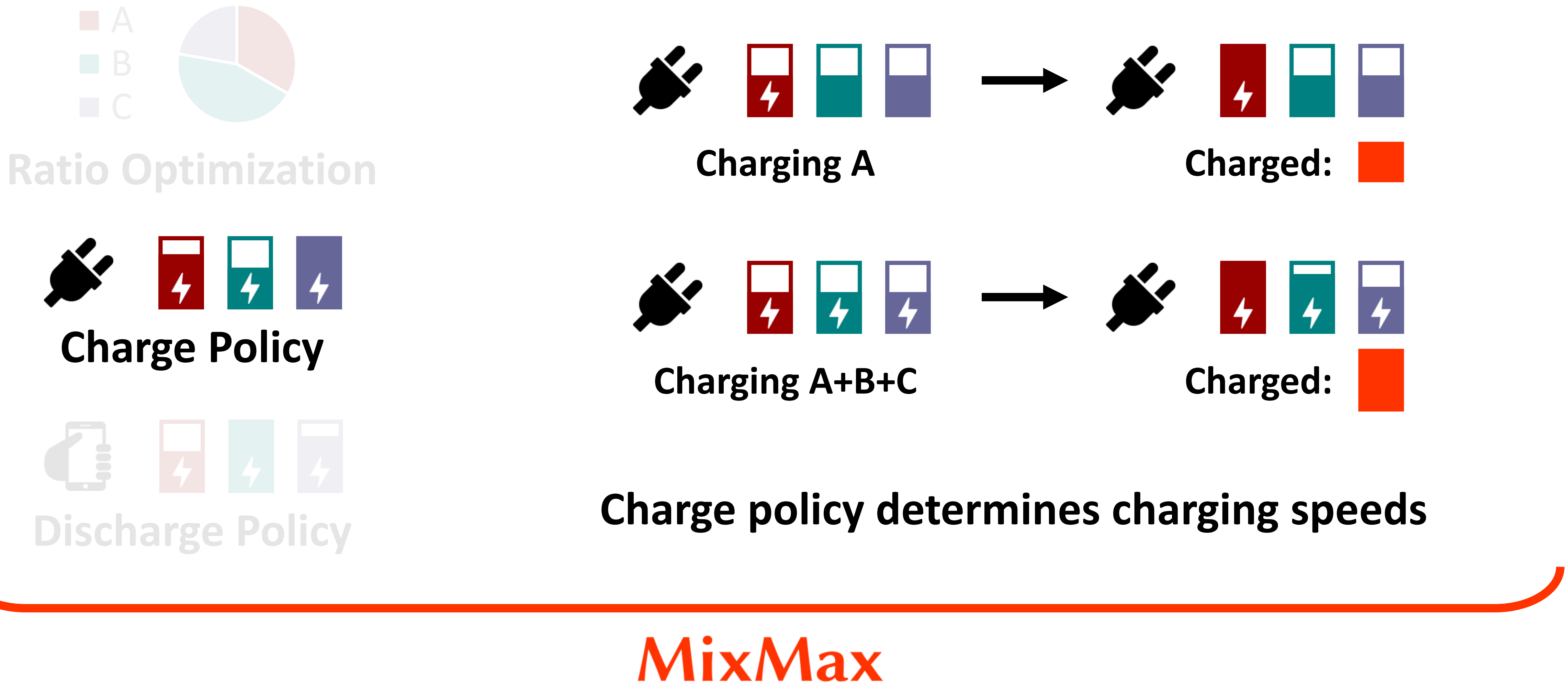
Discharge Policy



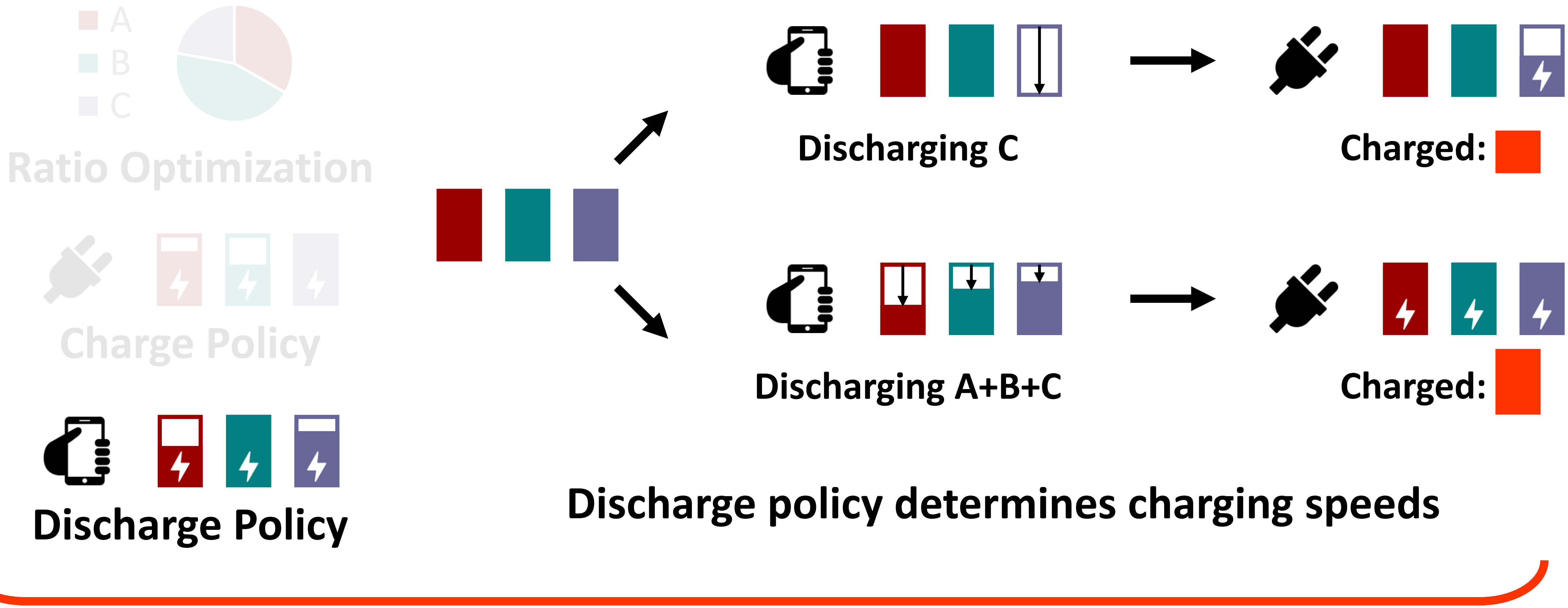
Battery ratios determine total battery capacity

MixMax

MixMax Overview



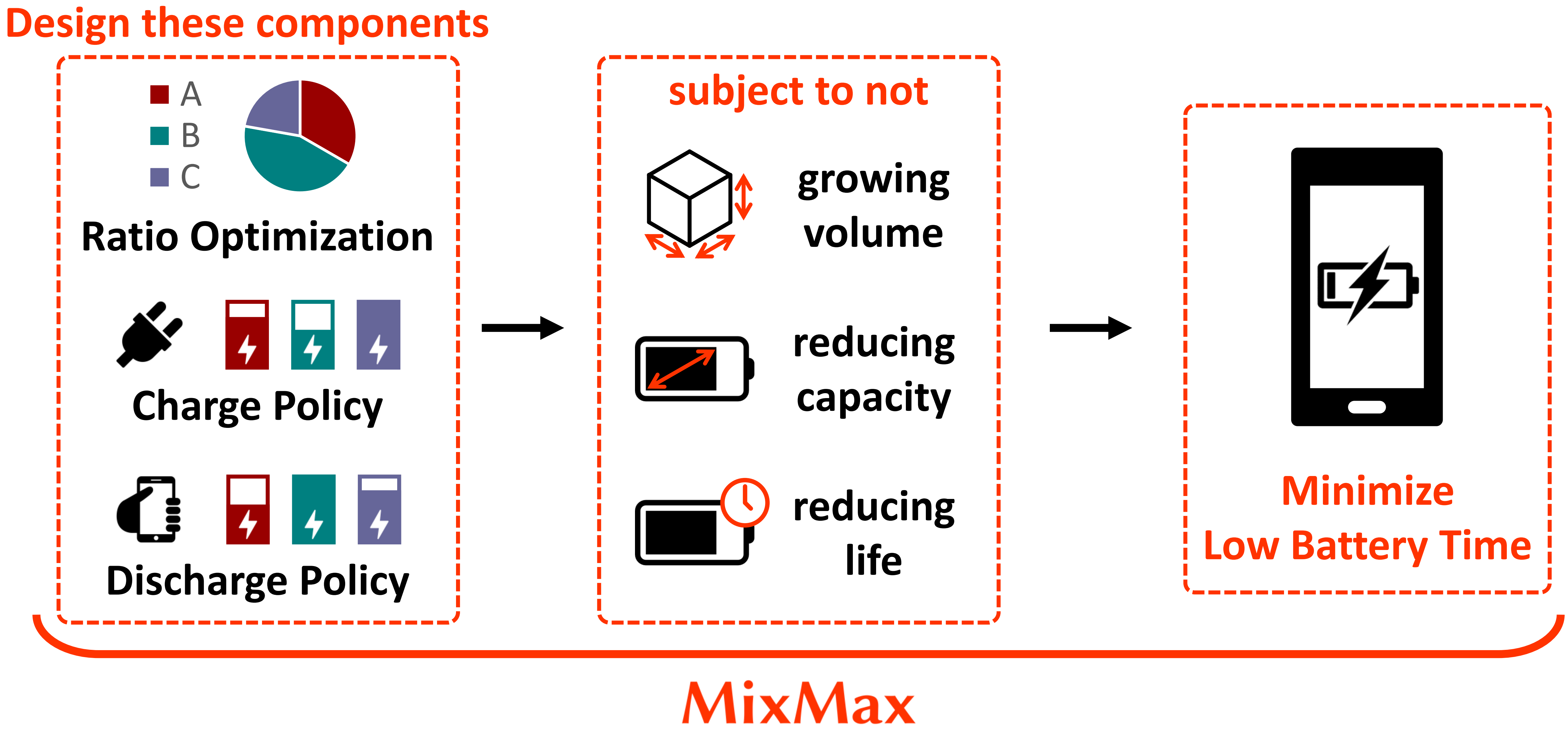
MixMax Overview



Discharge policy determines charging speeds

MixMax

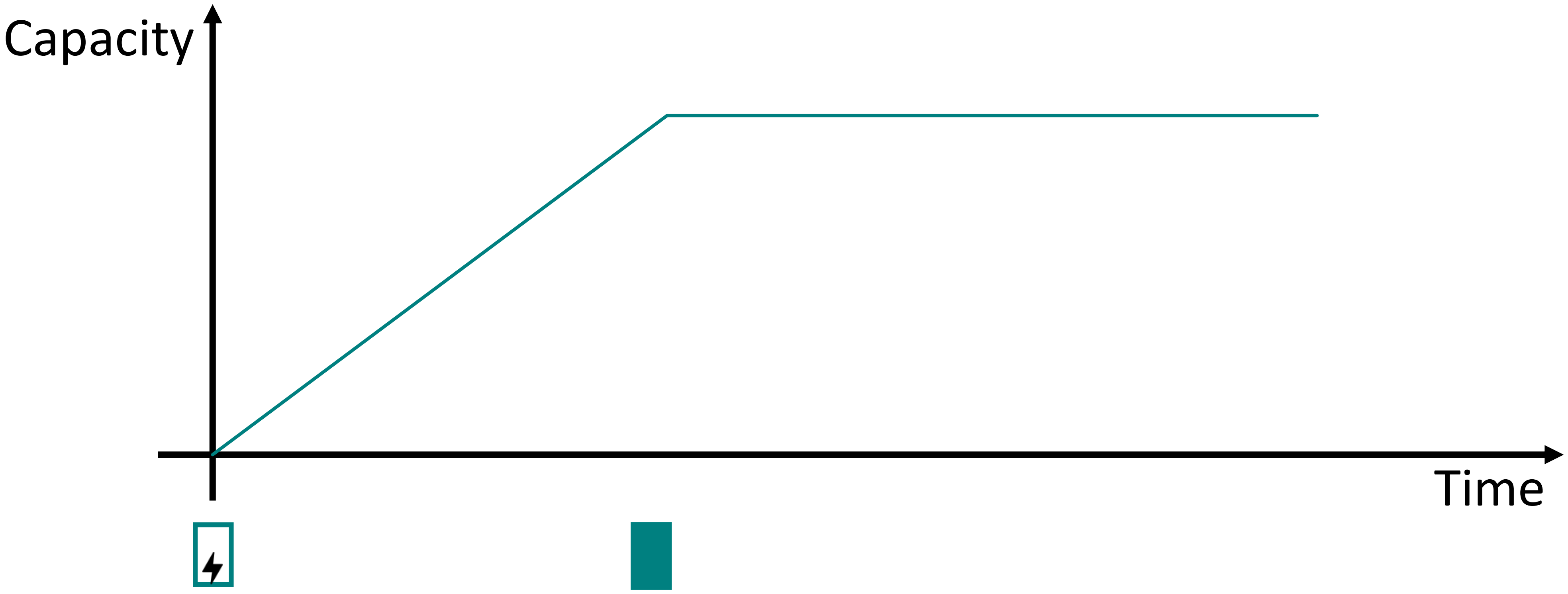
Problem Statement



Challenges and Solution Approach

Challenge 1

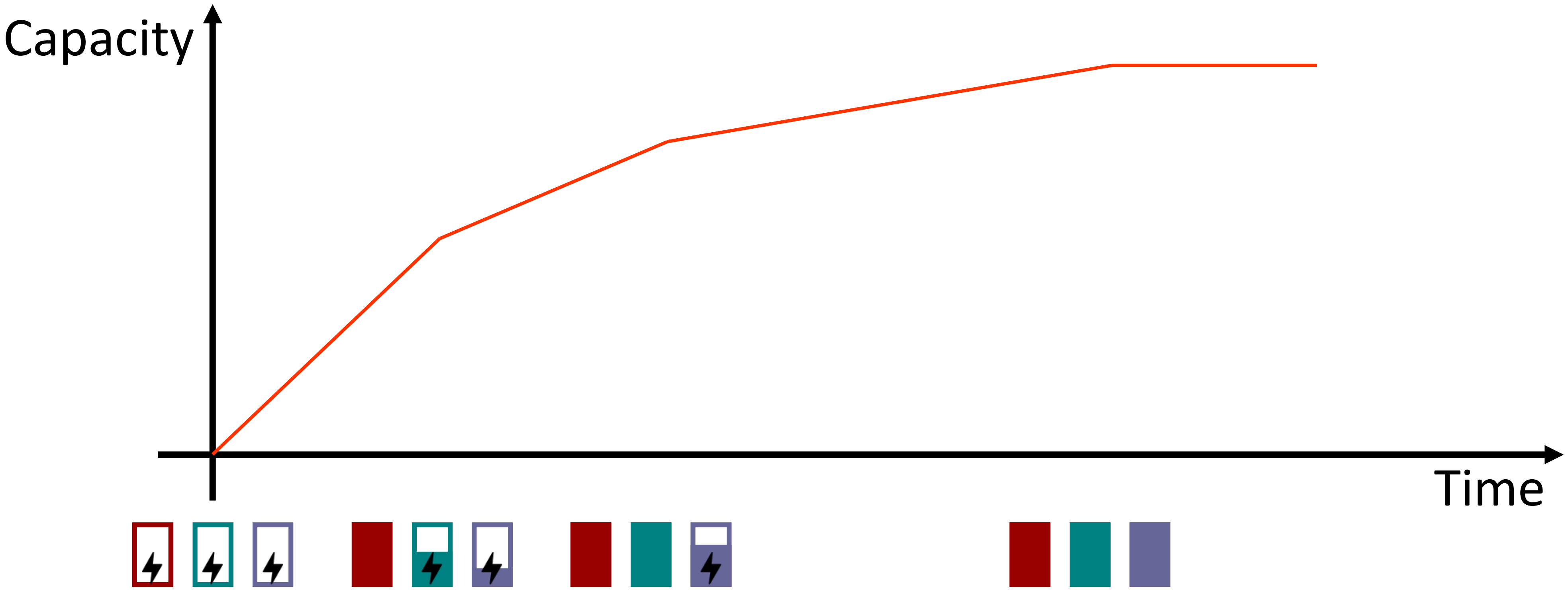
- **Complex characteristics of heterogeneous batteries**
  - Charging A Single Battery: <u>Constant Charging speed</u>



Challenges and Solution Approach

Challenge 1

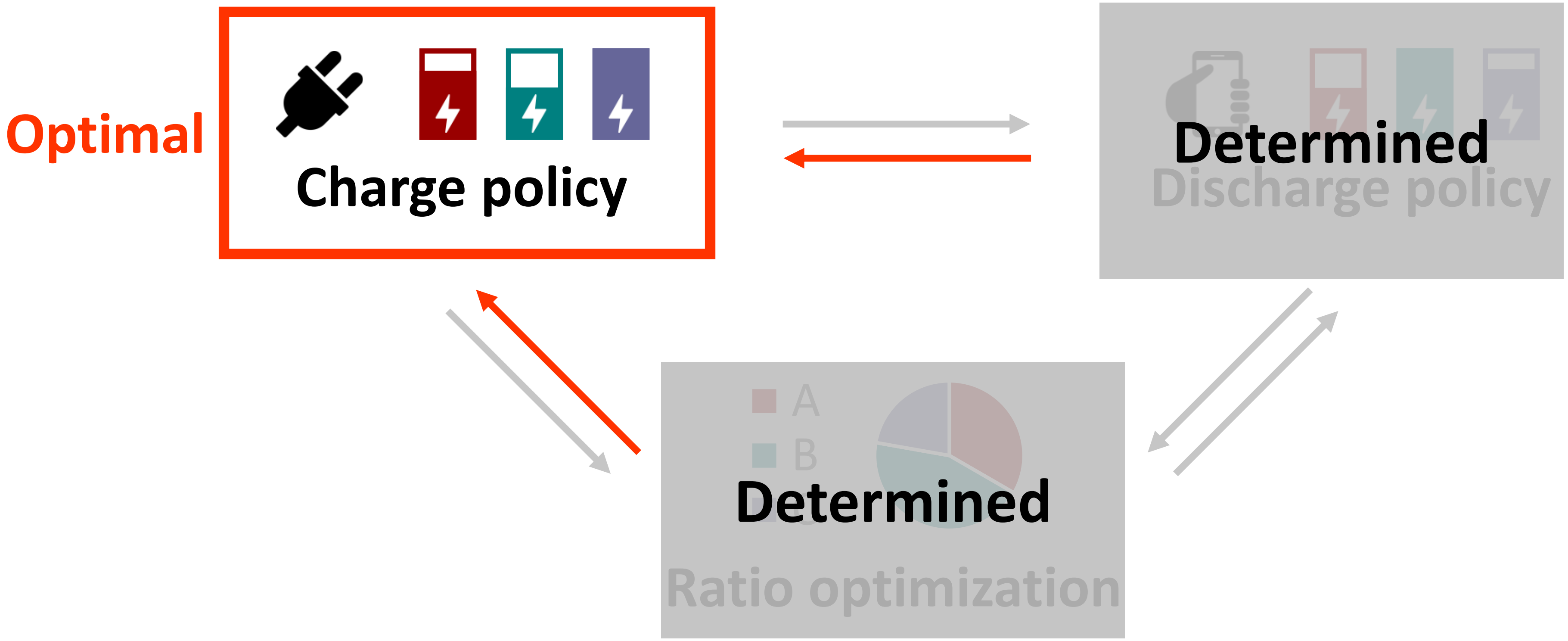
- **Complex characteristics of heterogeneous batteries**
  - Charging Heterogeneous Batteries: Multi-Stage Charging Speed



Challenge and Solution Approach

Challenge 2

- **All components are interdependent and affect each other**
  - Designing one component requires the completed designs of the others



Challenge and Solution Approach

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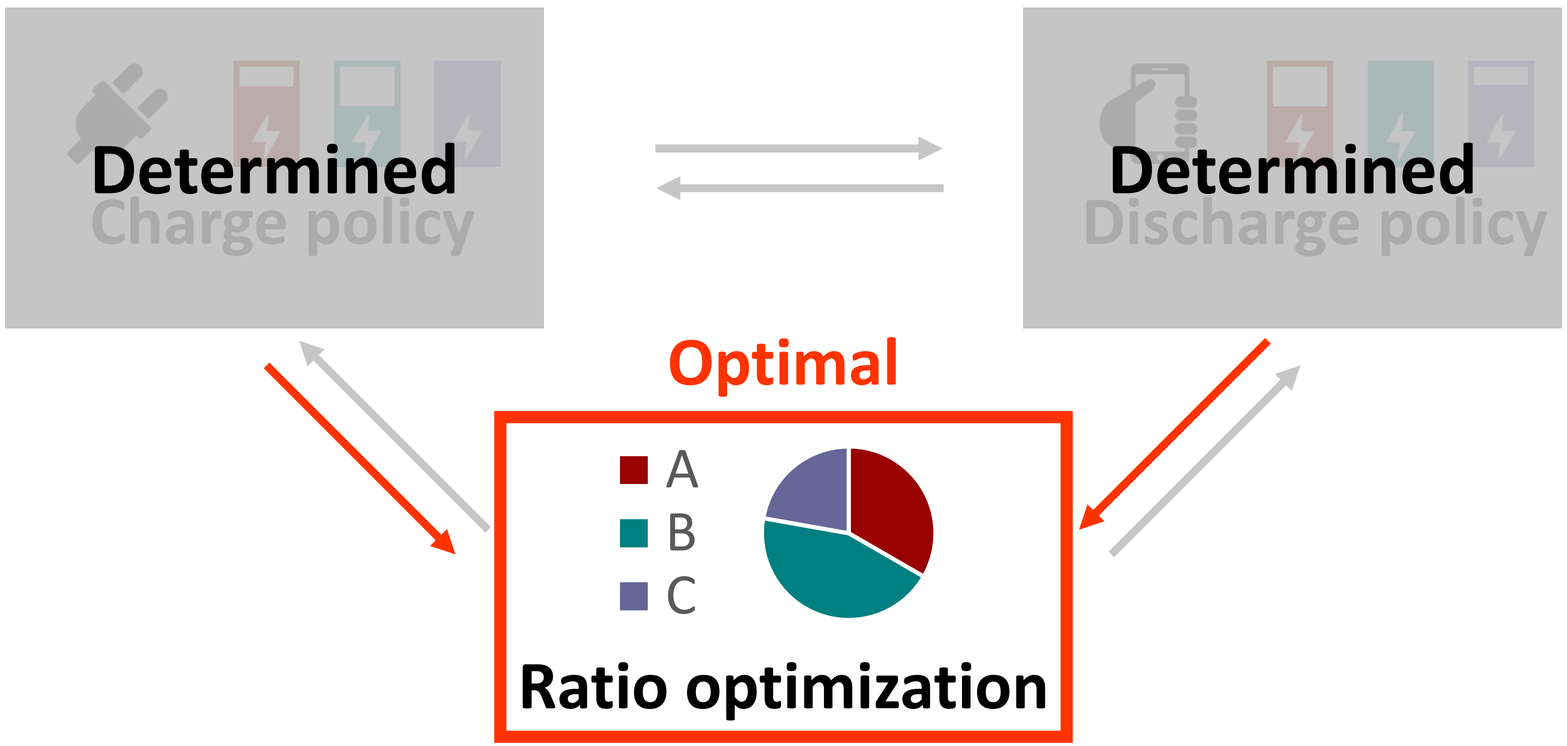
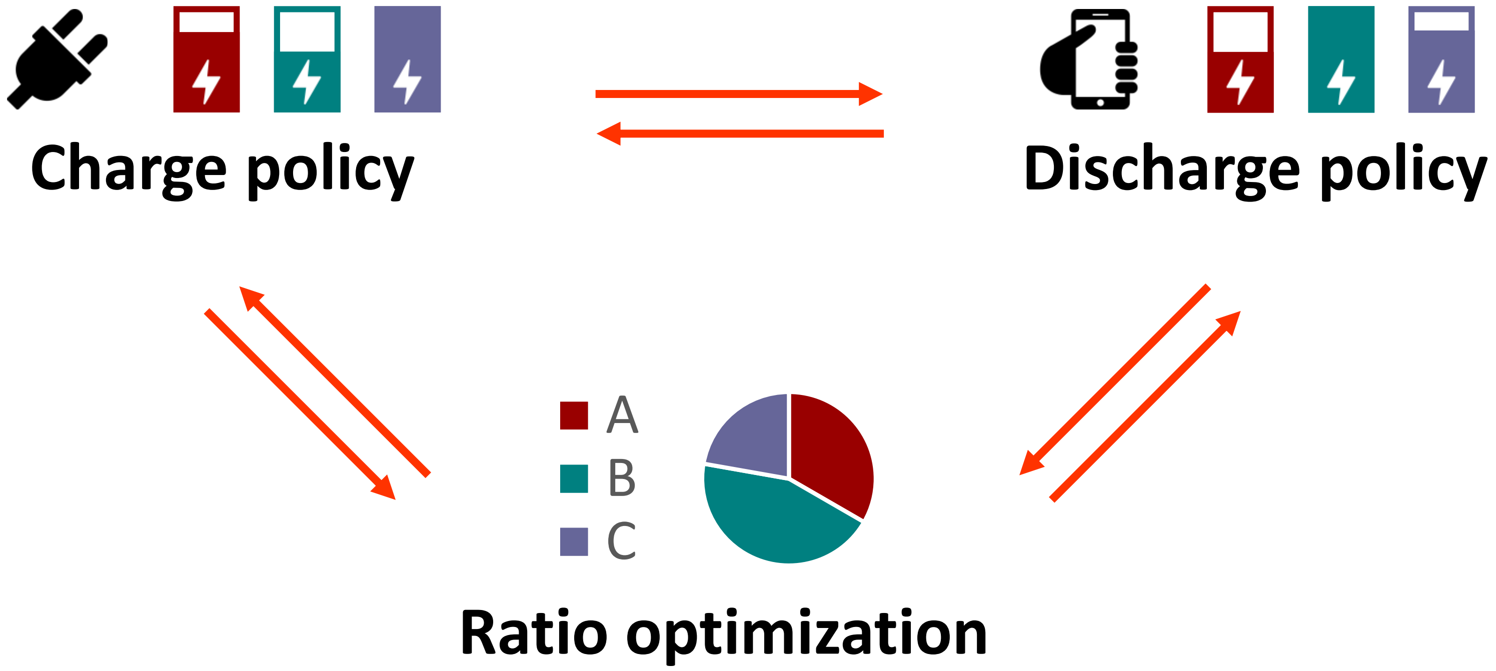


Challenge and Solution Approach

Challenge 2

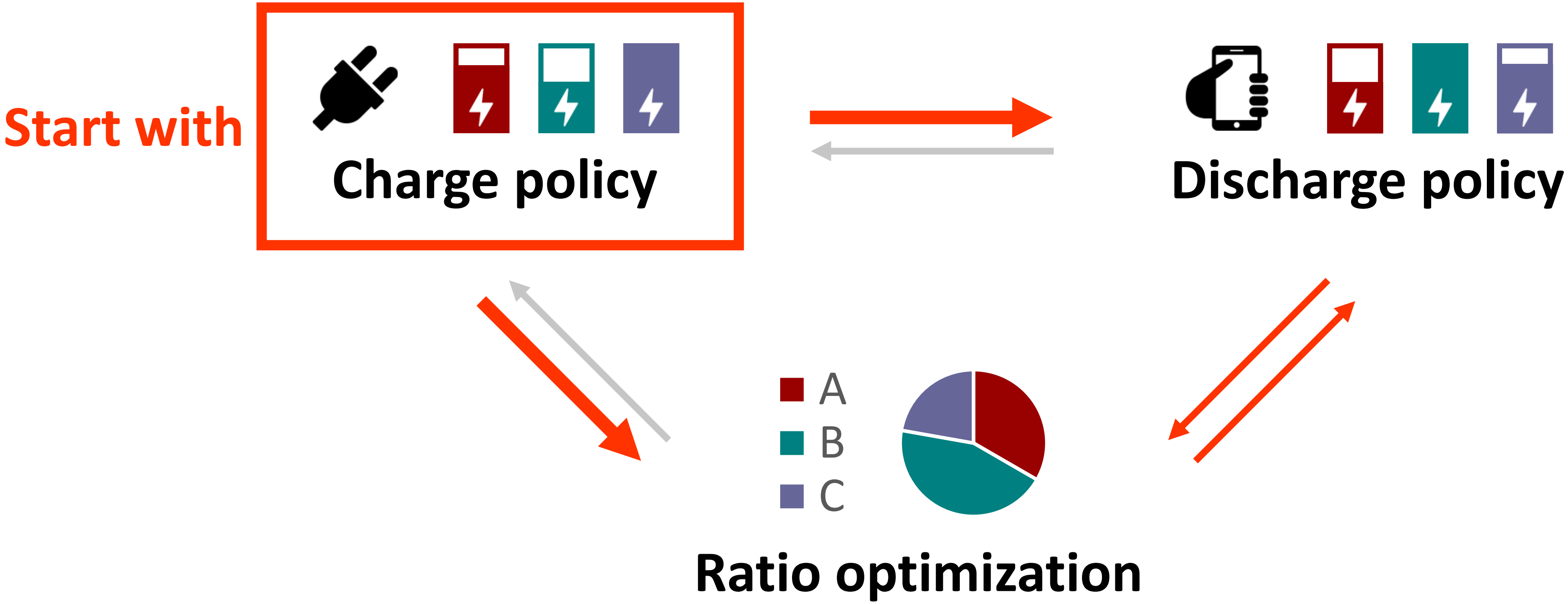
- **All components are interdependent and affect each other**
  - Designing one component requires the completed designs of the others
  - But, it is difficult to design all things at once



Challenge and Solution Approach

Our Solution Approach

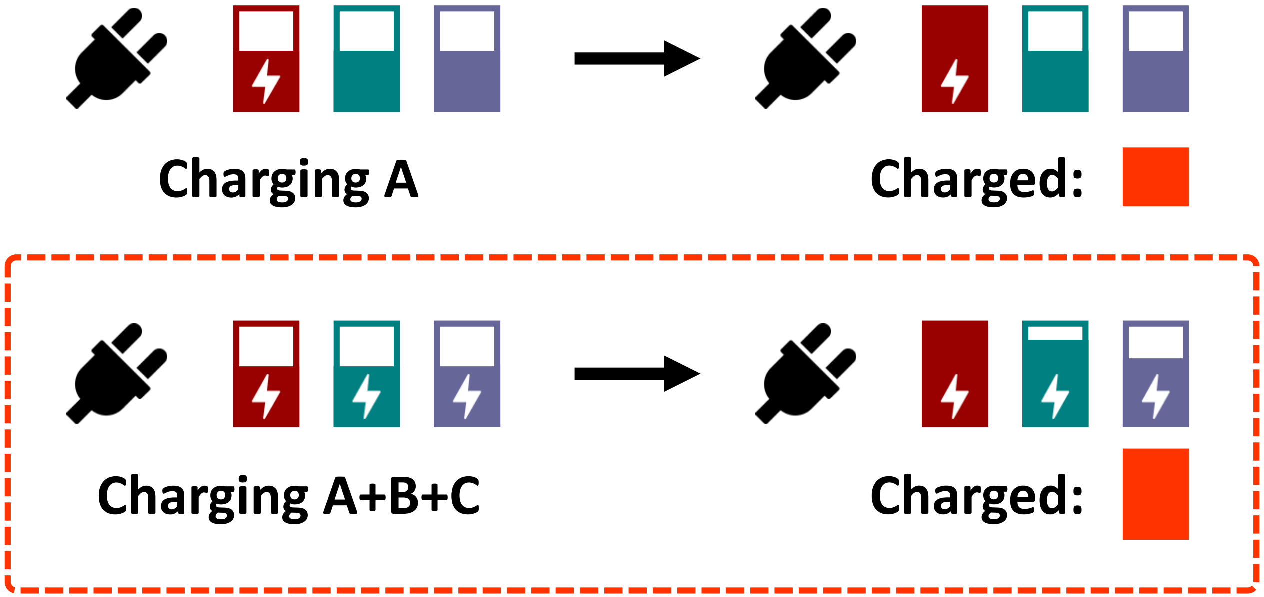
- **Divide and conquer**
- Start with an intuitive and easy component design

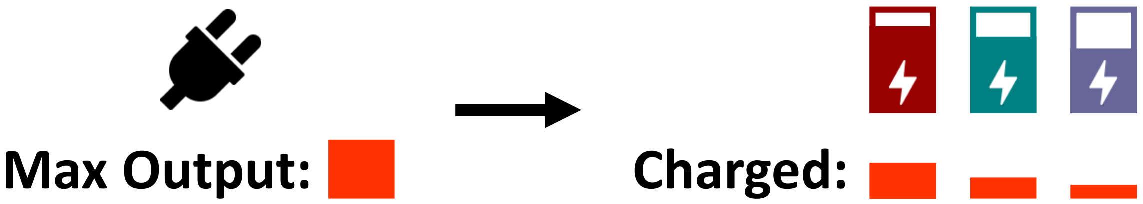


Charge Policy

Best-Effort Charge Policy

- **Trying to maximize charging speed**
  - e.g., charging all chargeable batteries
- Power is distributed proportionally to each charging speed
  - i.e., guaranteeing <u>consistency</u> in the charging results

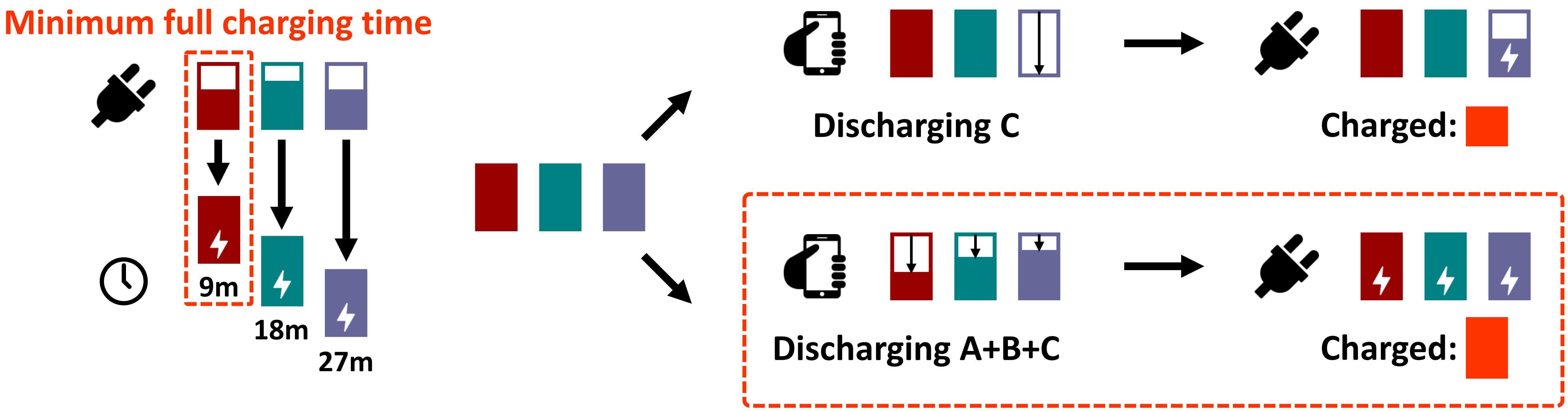




Discharge Policy

MaxiMin Discharge Policy

- **Maxi**mizing the **Min**imum full charging time
- Trying to utilize the charging speeds of all batteries
- A subsequent charging shows <u>the optimal fastest charging speed</u>



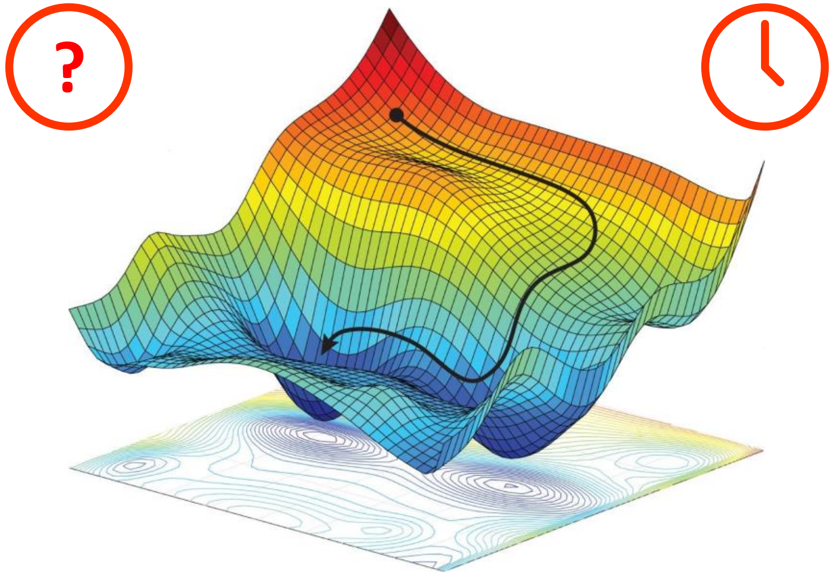
Battery Ratio Optimization

Problem

- **Finding the optimal ratios of A-, B-, and C-type batteries** (denoted by $\underline{R_A, R_B, \text{and } R_C}$)

Our Solution: Utilizing constraints and battery usage patterns

1. Narrowing Search Space
2. Convex Optimization



Battery Ratio Optimization

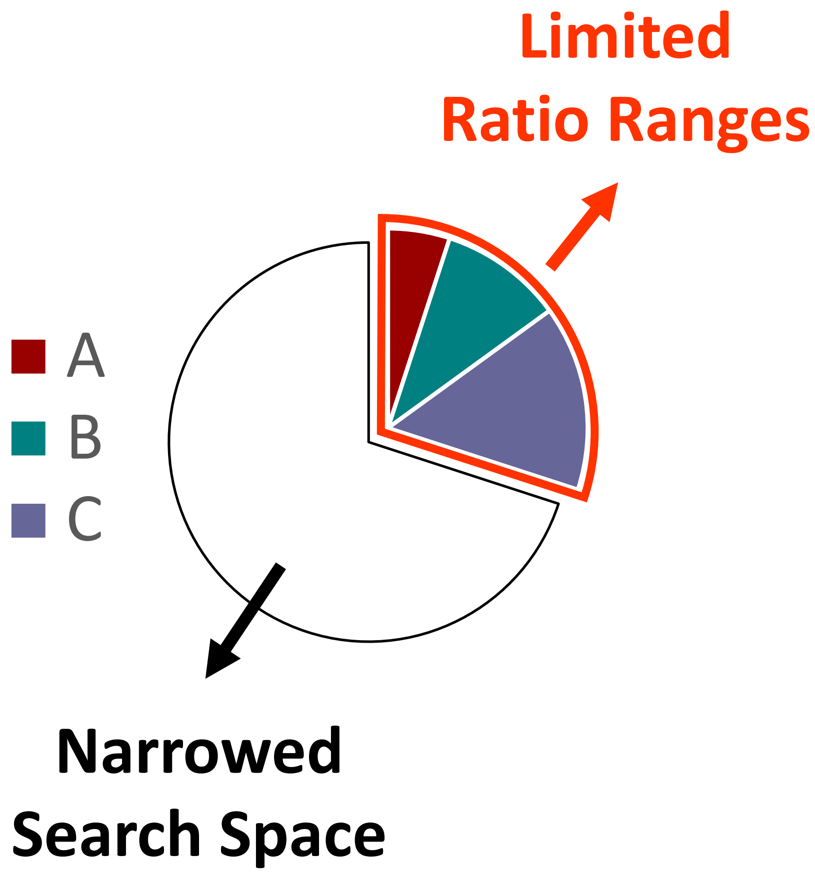
1. Narrowing Search Space
   - Considering the imperative constraints
   - Limiting the range of battery ratios

   - C1. MixMax's capacity must be larger than a single B-type battery

$$(1)\ \ R_A/R_C > 2.0$$

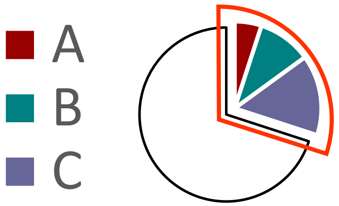
   - C2. Each battery must have sufficient power output to operate the system independently

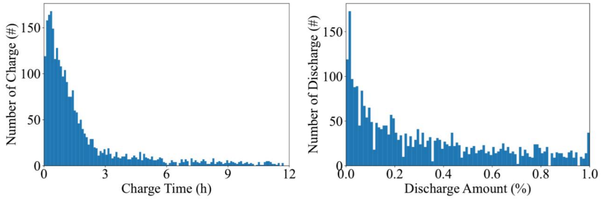
$$(2)\ \ R_A \geq 5\%, R_B \geq 9\%, R_C \geq 18\%$$



Battery Ratio Optimization

2. Convex Optimization
   - Based on the narrowed search space
   - Based on battery usage patterns





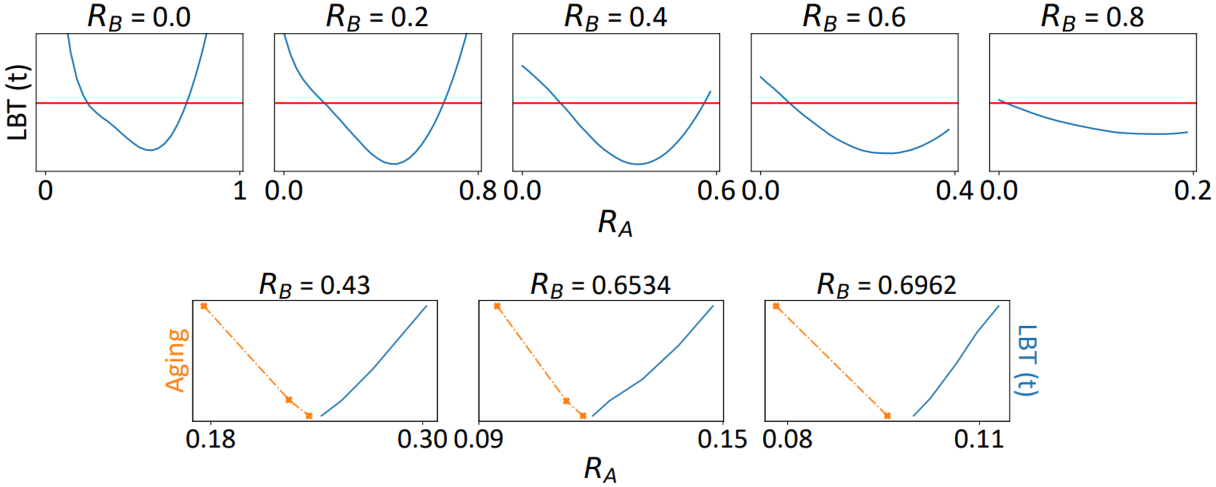
(a) Charge time distribution (b) Discharge amount distribution

Figure 2: Battery usage patterns of 100 mobile users

Observed convexities
   - Low battery time VS R_B
   - Low battery time VS R_A/R_C
   - Battery aging VS R_A/R_C

$\therefore R_A : R_B : R_C = 1:7:2$

Convexities



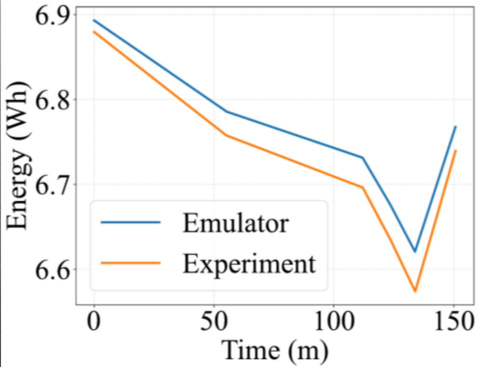
Implementation

Coin-cell battery fabrication

- Could not find commercial A, B, and C-type batteries with the same formfactor and size
- Fabricated LCO, LTO, and Li-S cells

Battery emulator development

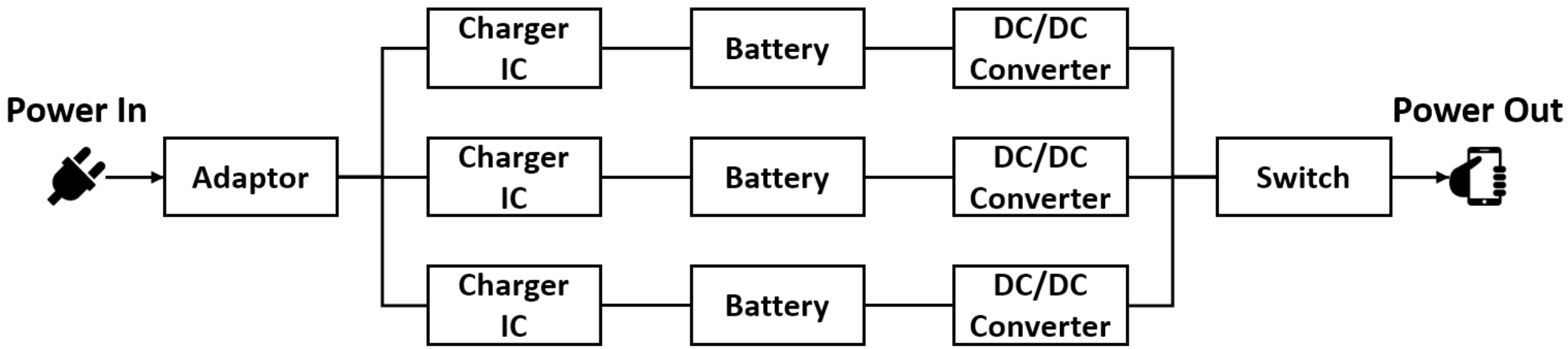
- An accurate battery emulator
- Modeled LTO (coin), LCO, Li-S, LTO (cylindrical), LFP, and NCA batteries
- Average error ≤ 0.3%

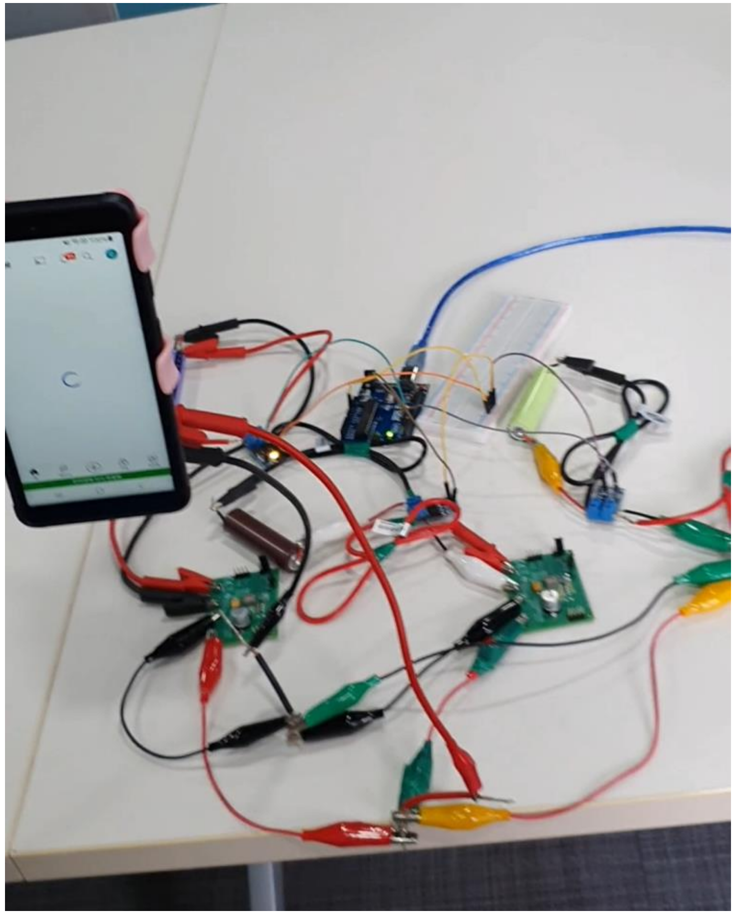


Implementation

Field test of a demo smartphone

- Implemented our discharge policy on a smartphone
- Interconnected three cylindrical batteries
- Demonstrated MixMax's practicality





Evaluation

Evaluation methods

- Used the developed battery emulator
- Used battery usage data of 827 days of 100 users

- Train data set (70%): for searching optimal battery ratios
- Test data set (30%): for evaluation

Evaluation criteria

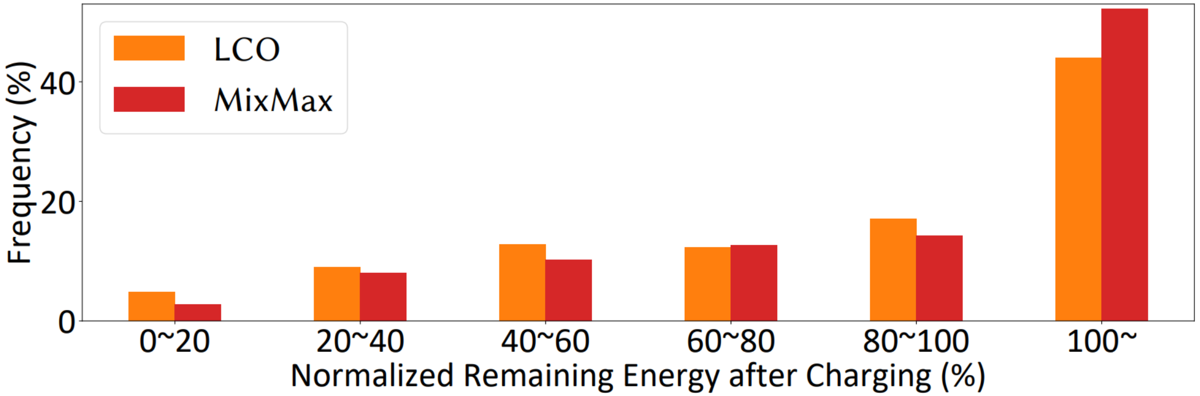
- Performance: Tracking the changes in remaining energy and low battery time
- Competitiveness : comparing with other studies
- Adaptiveness: testing under different low battery threshold and battery types

Evaluation

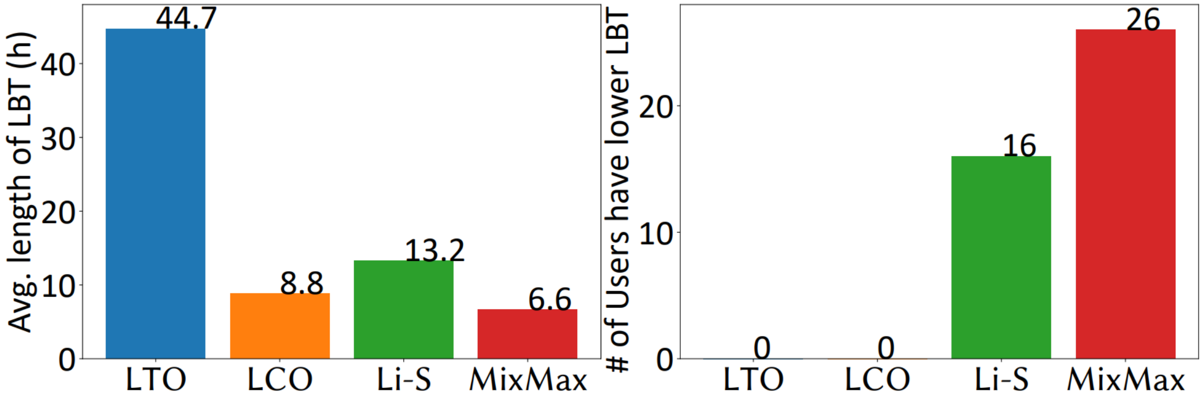
Performance evaluation

- Average remaining energy was increased (16.7 % ↑)
- Low battery time was decreased (24.6 % ↓)
- Low battery time was reduced in 26 out of 30 users

* LBT (t) = Low Battery Time



Average Remaining Energy Increment



Low Battery Time Decrement

Evaluation

Competitiveness evaluation

- Our MaxiMin discharge policy and battery ratio optimization VS others
- Both showed superiority in reducing low battery time

Average of Low Battery Time per Week (hours)

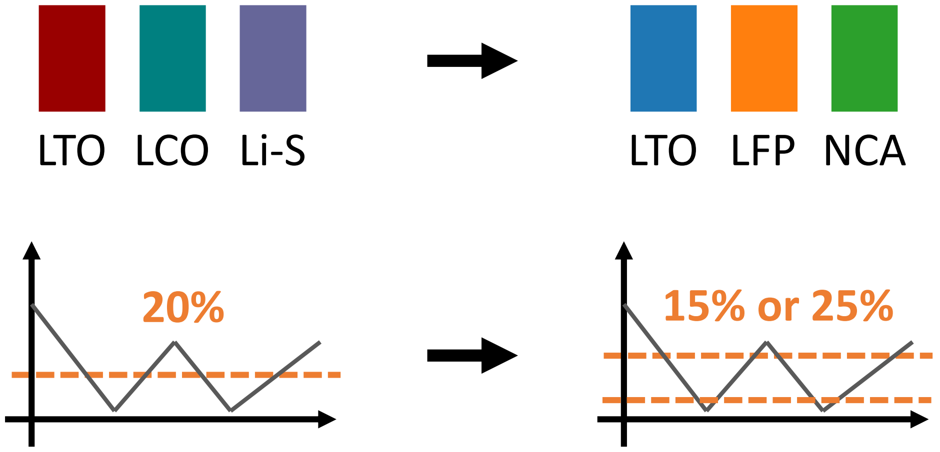
Discharge policies:	(ours)	other discharge policies			
Battery ratios:	MaxiMin	CCB	RBL	Bal	EV
w/o optimization (1:1:1)	9.5	9.6	17.4	17.0	31.4
w/ optimization* (ours)	6.6	7.1	8.6	18.7	30.8

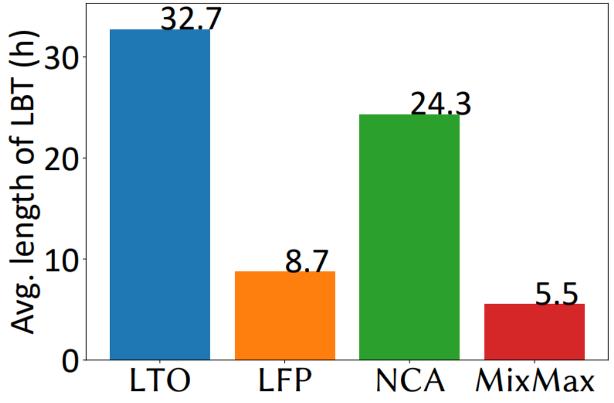
*optimized for each discharge policy

Evaluation

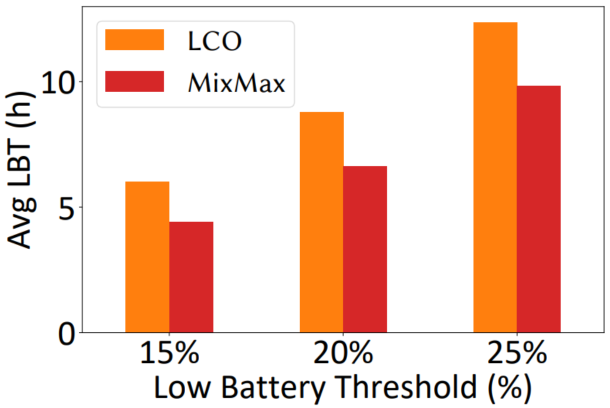
Adaptiveness evaluation

- Changed battery composition (cylindrical LTO, LFP, and NCA batteries)
- Changed low battery threshold (20% → 15%, 25%)
- Robustly reduced low battery time under all changes





Different Composition



Different Thresholds

Conclusion

We designed MixMax:

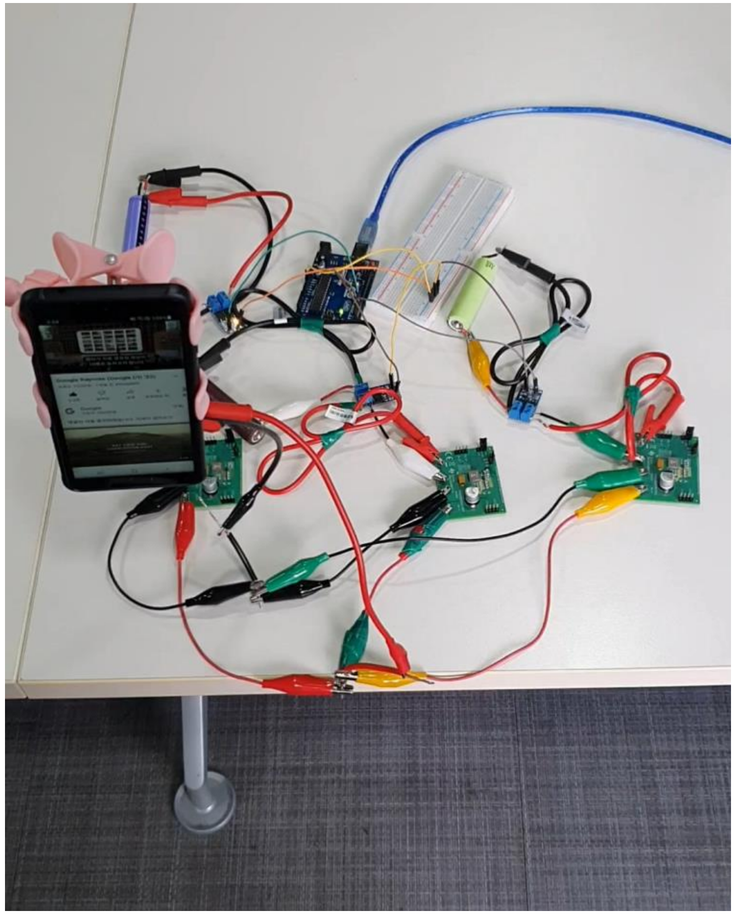
- leverages heterogeneous batteries
- to alleviate low battery anxiety

For MixMax, we:

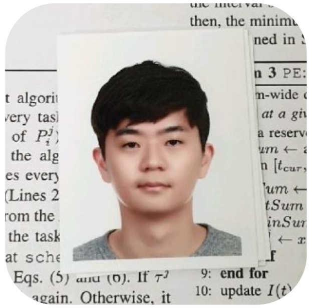
- developed charge & discharge policies
- searched optimal battery ratios
- made coin-cell batteries and a demo smartphone

We expect MixMax to be:

- evolved through prediction, customizing, and so on
- applied to other domains (like EVs, drones)



Thank You!



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