Battery Aging Deceleration for Power-Consuming Real-Time Systems

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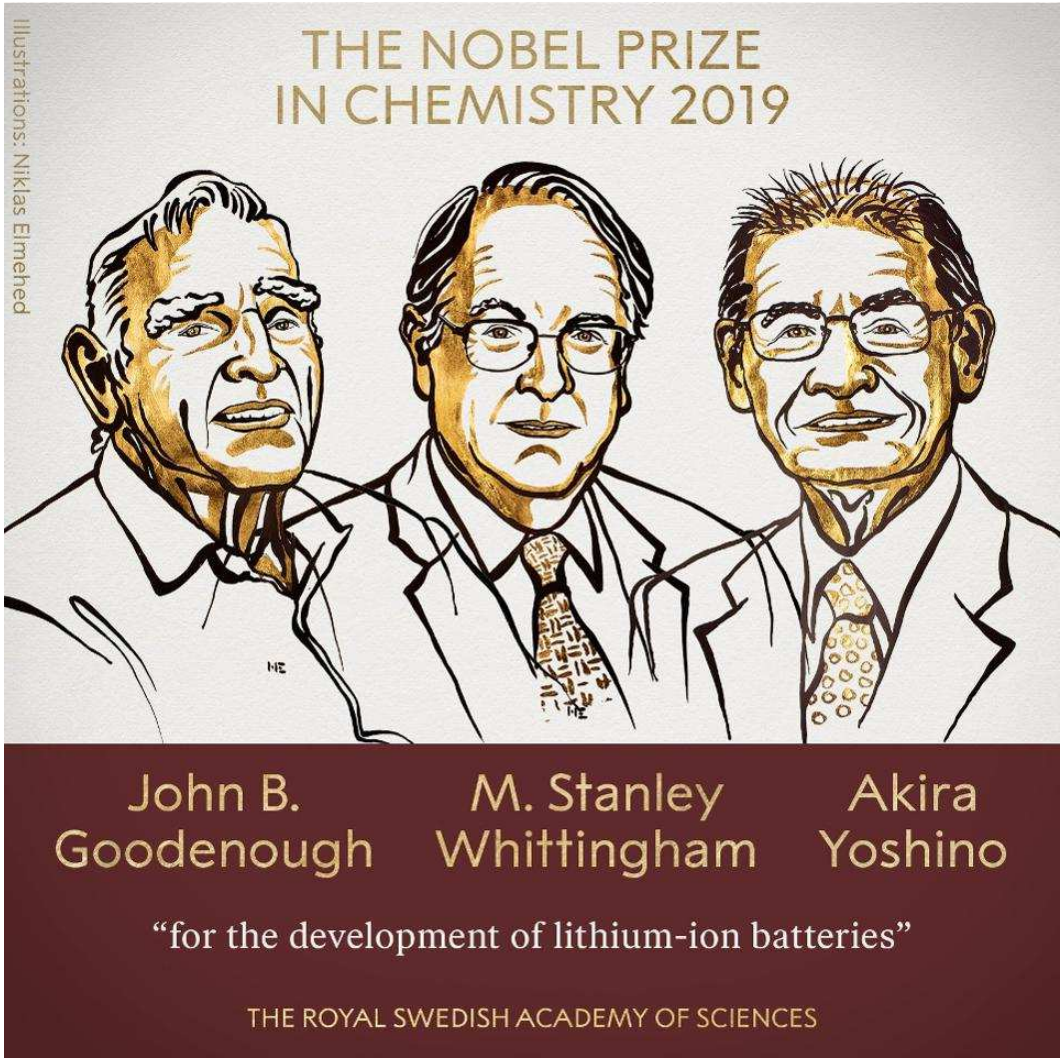
Introduction

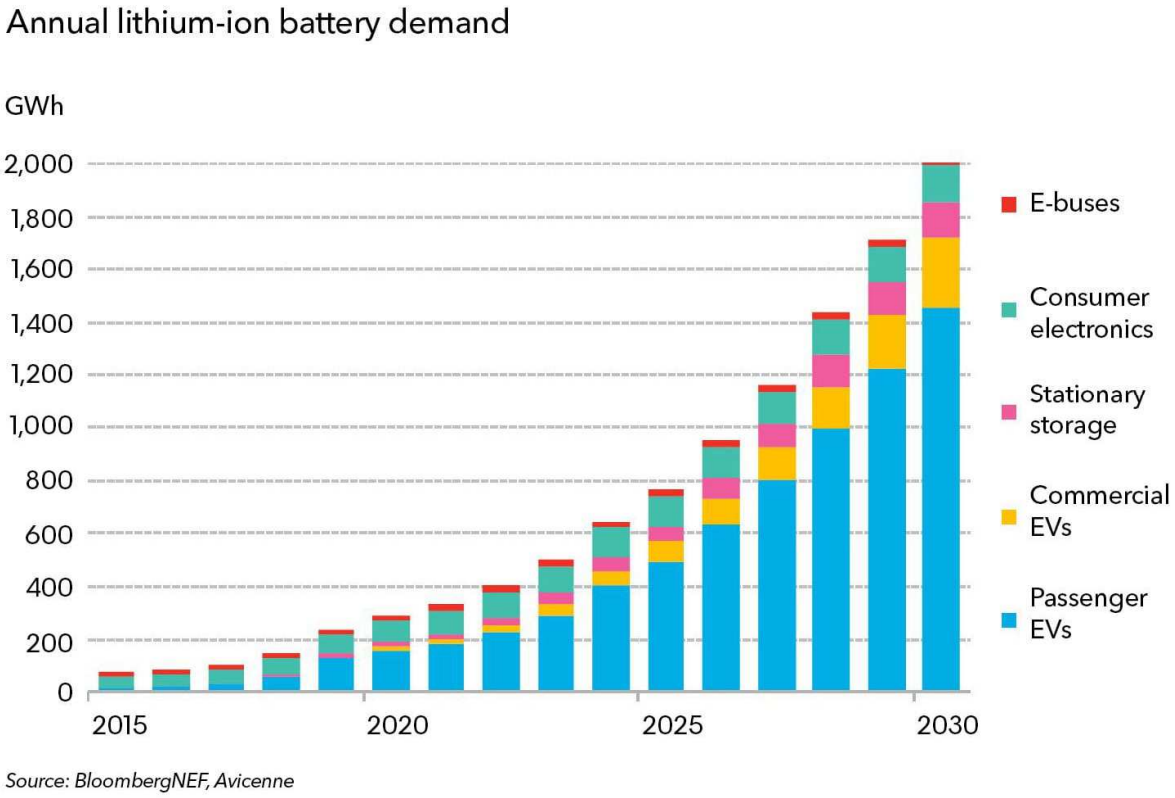
Battery Era Has Begun



Battery Era Has Begun

Li-ion battery demand forecast

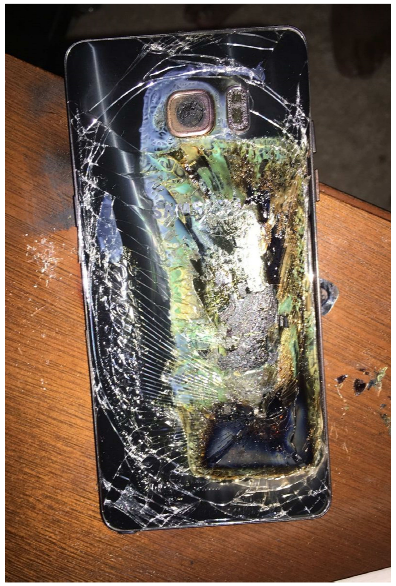
– from Bloomberg NEF 2019



Li-ion Battery Issues

Li-ion battery still has many issues

Slow charging speed

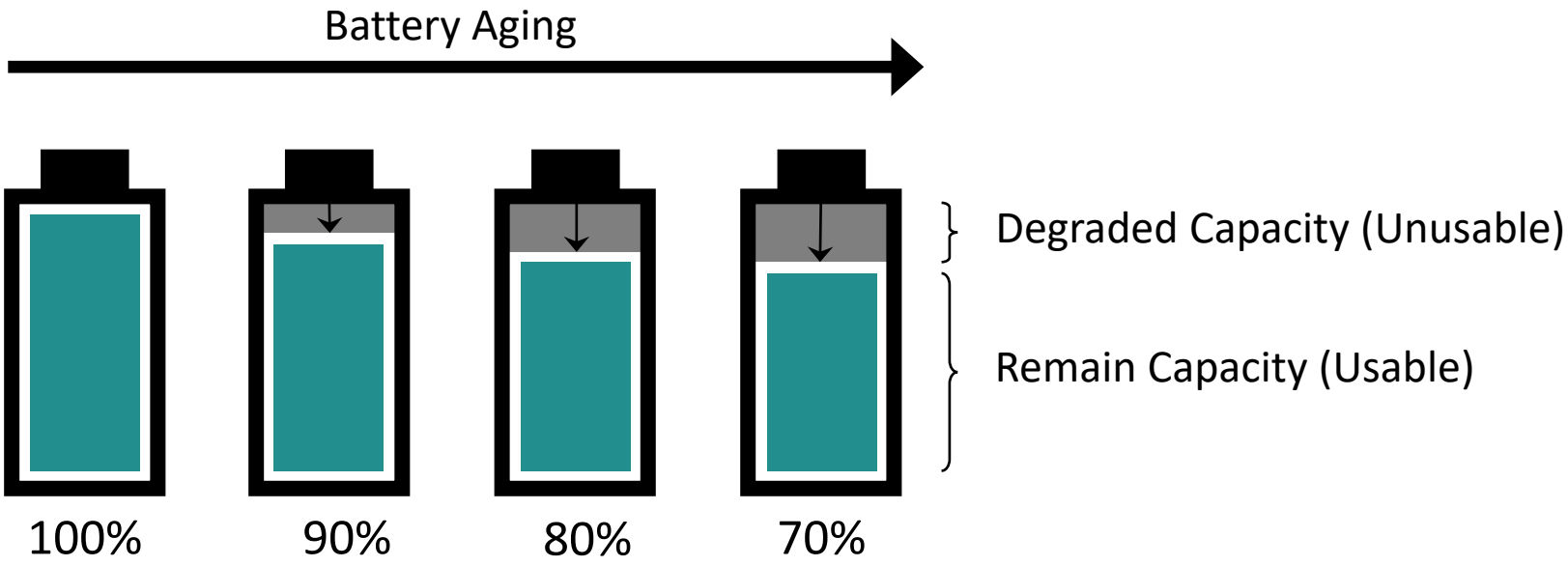


Safety

Swelling

Li-ion Battery Issues

Target issue: battery aging (capacity degradation)



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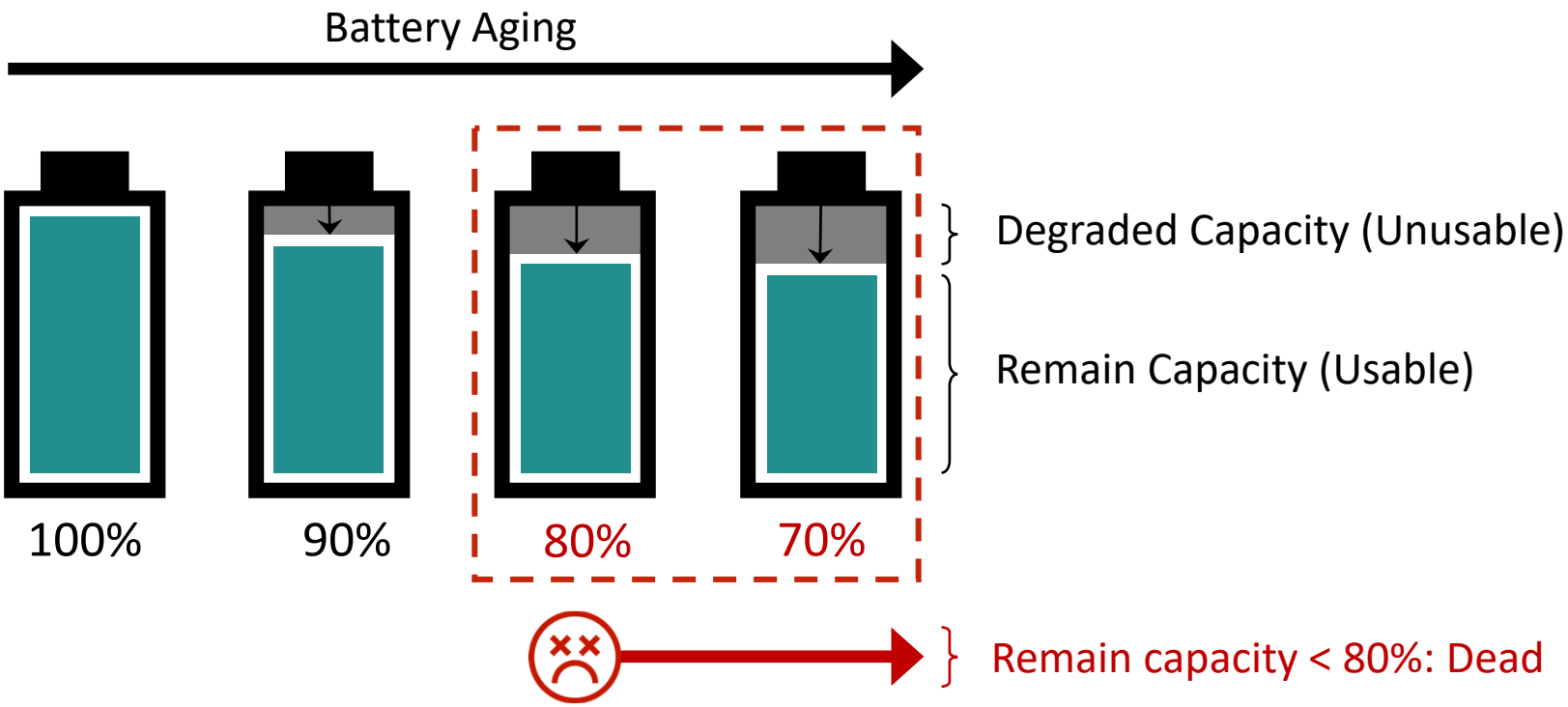
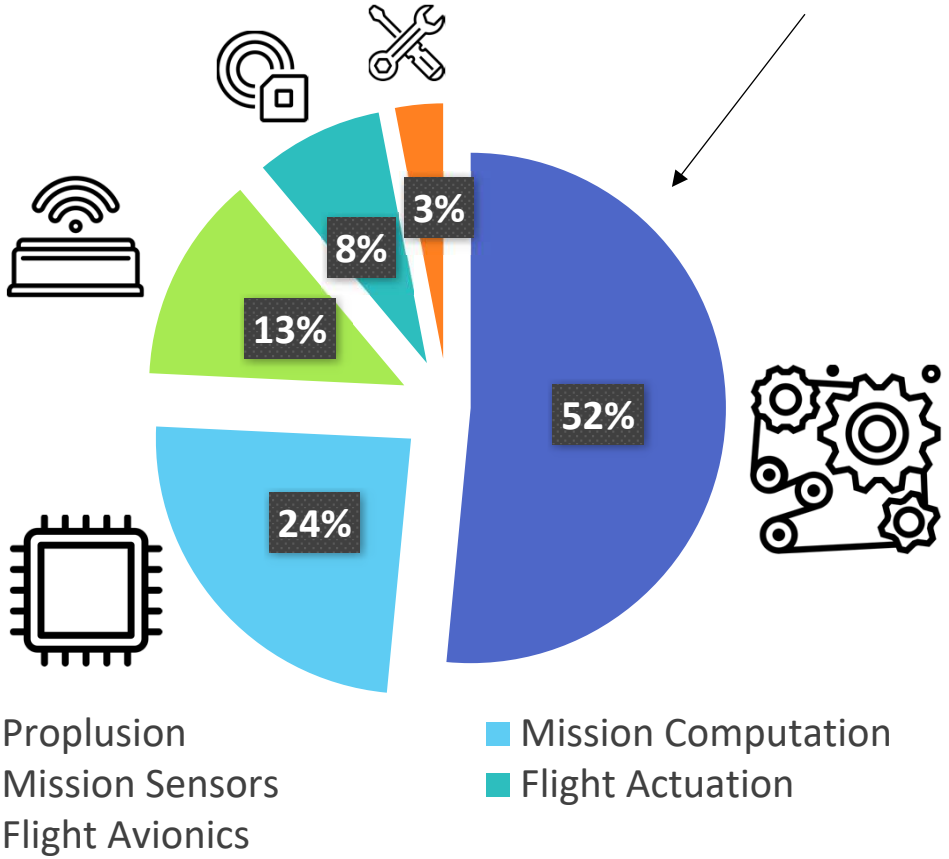


Motivation

Example: UAV (Unmanned Aerial Vehicle)

– Avistar UAV Aircraft

Share of power consumption



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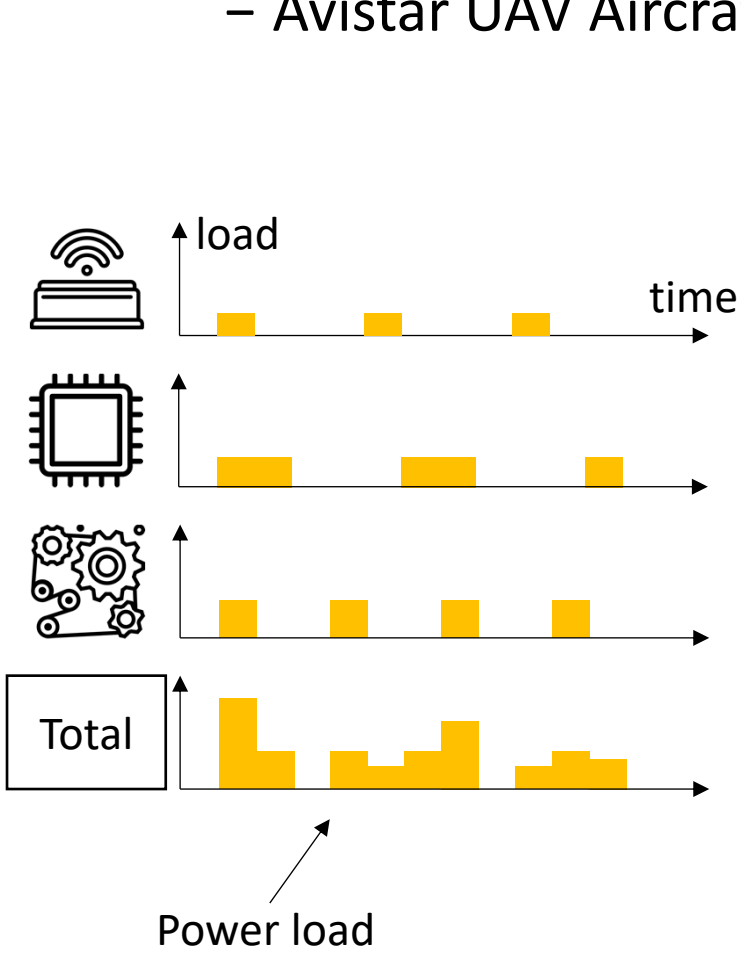

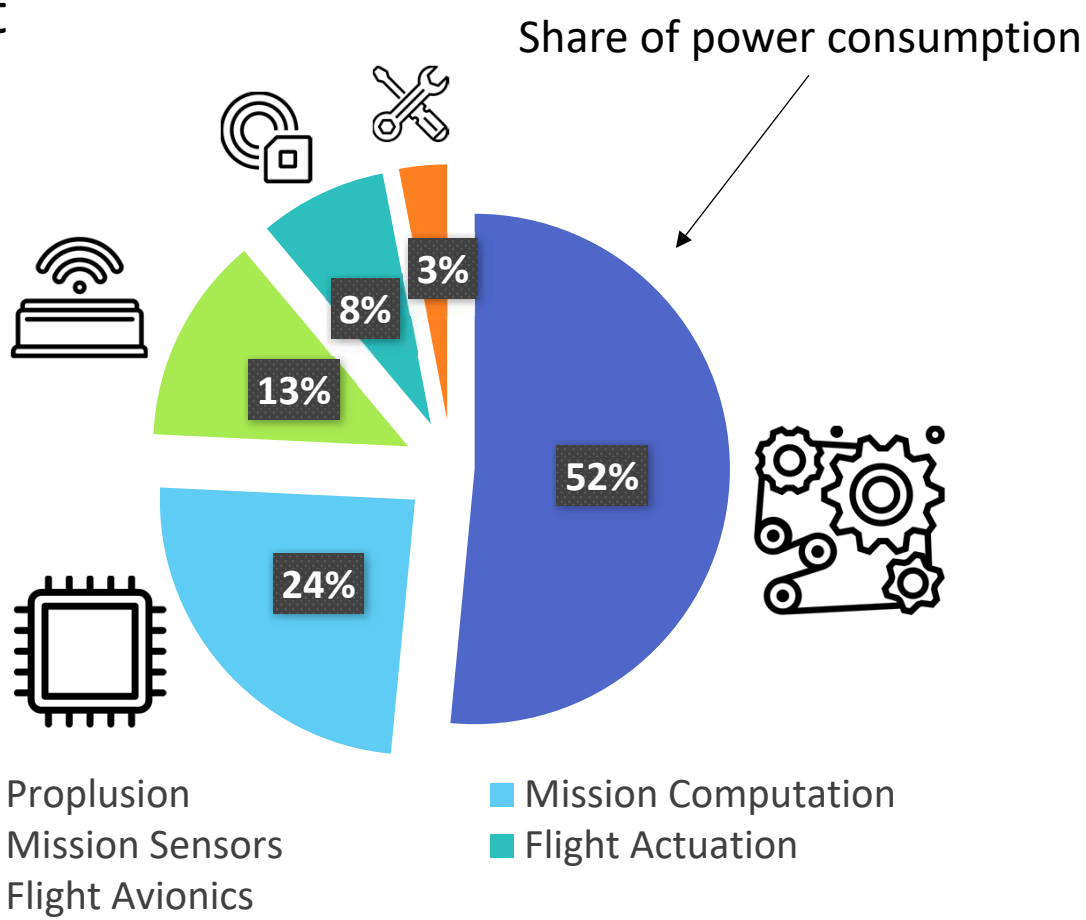

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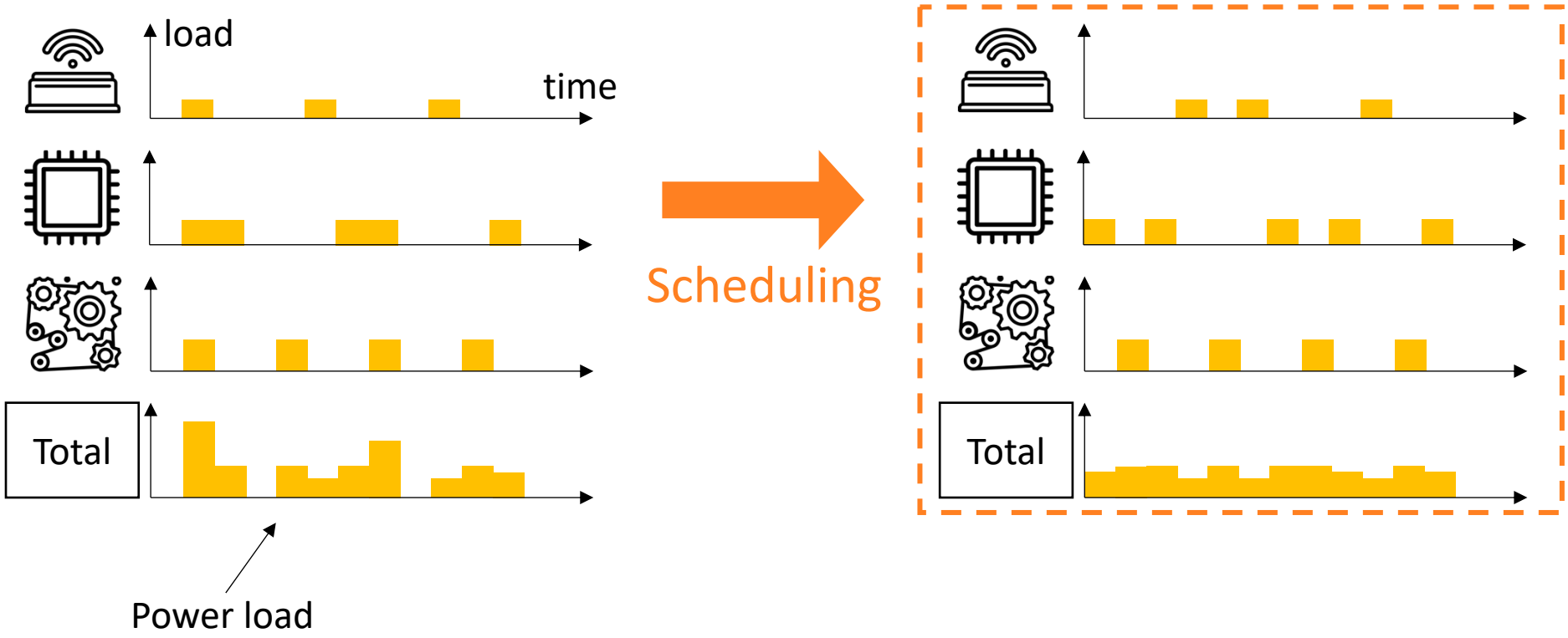
Curiosity

- C1. Can task scheduling decelerate battery aging?
- C2. How can we do that guaranteeing RT constraint?



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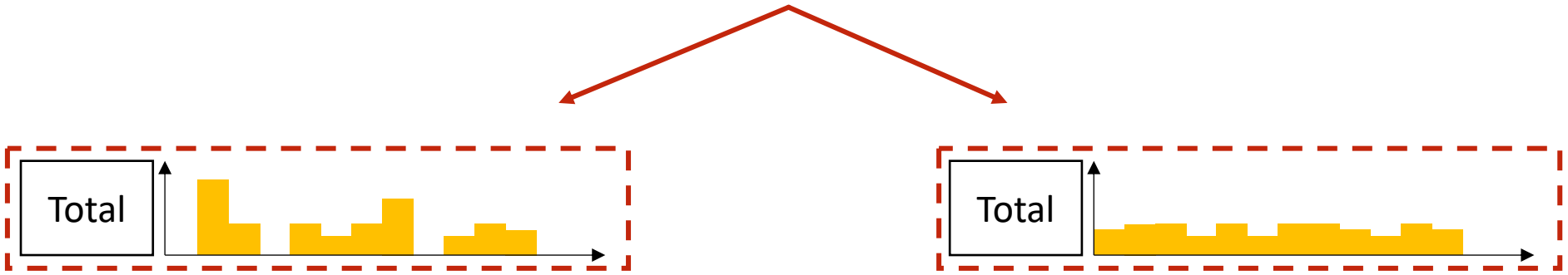
C1: Capacity degradation will be different?
C2: Can we do this in real-time systems?

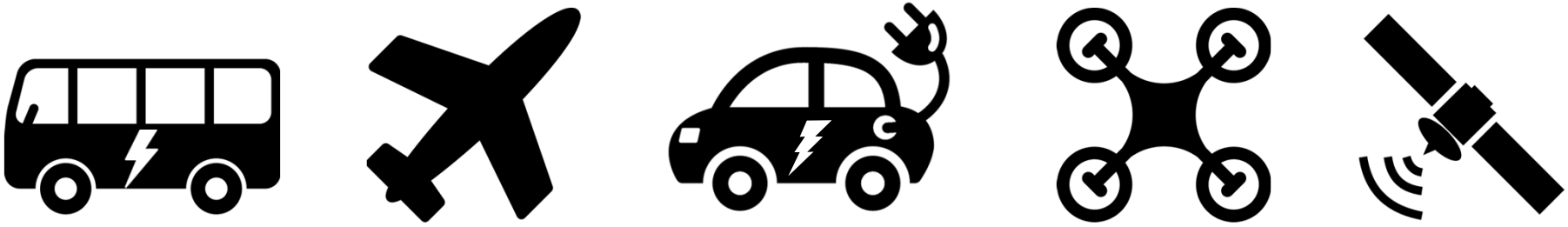


Foundation

System Model

Target system

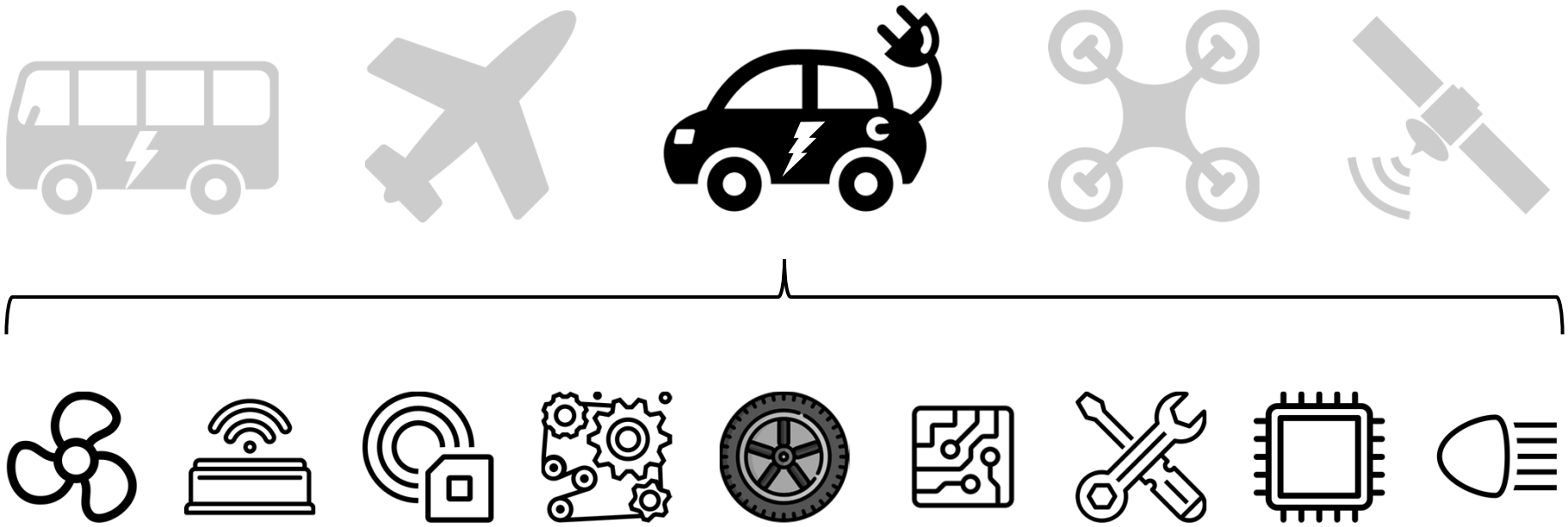
- Battery-operated power-consuming real-time systems



System Model

Target system

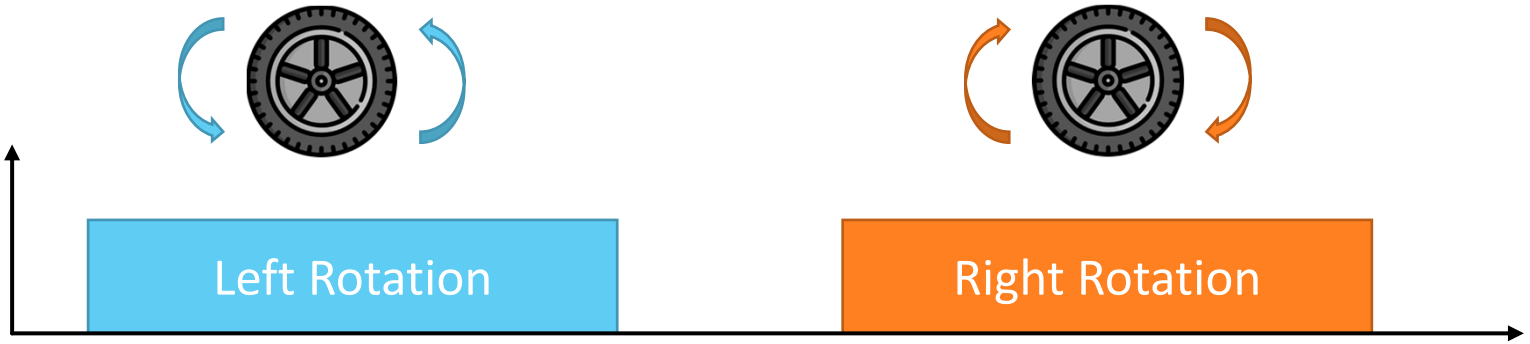
- Battery-operated power-consuming real-time systems
- Which consists of many subsystems



System Model

How to abstract the whole subsystems?

- Strict and elastic system model
- Non-preemptive scheduling
- Executing one task at once on a one system



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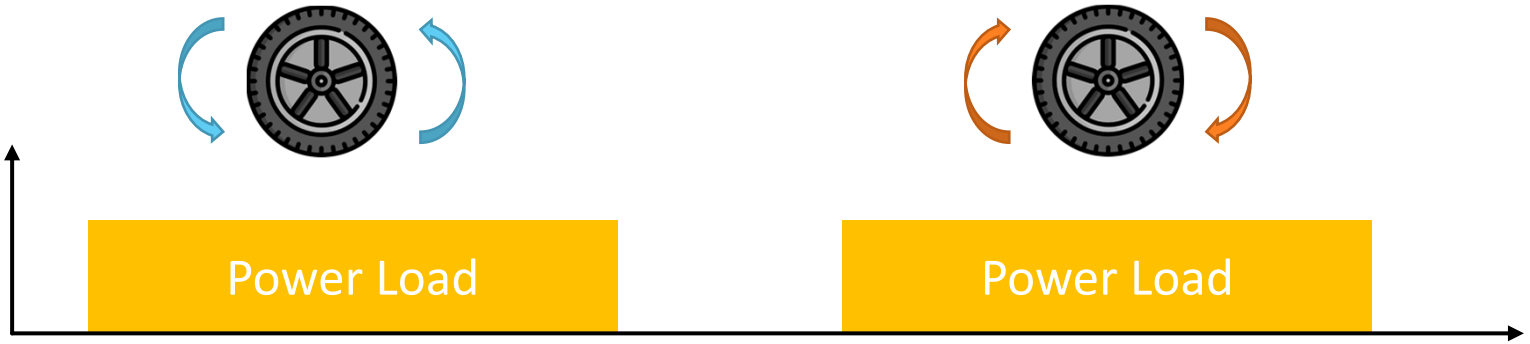

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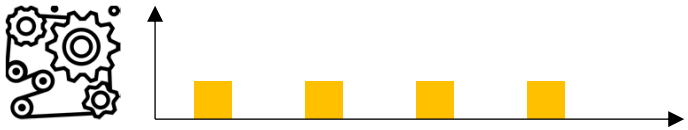

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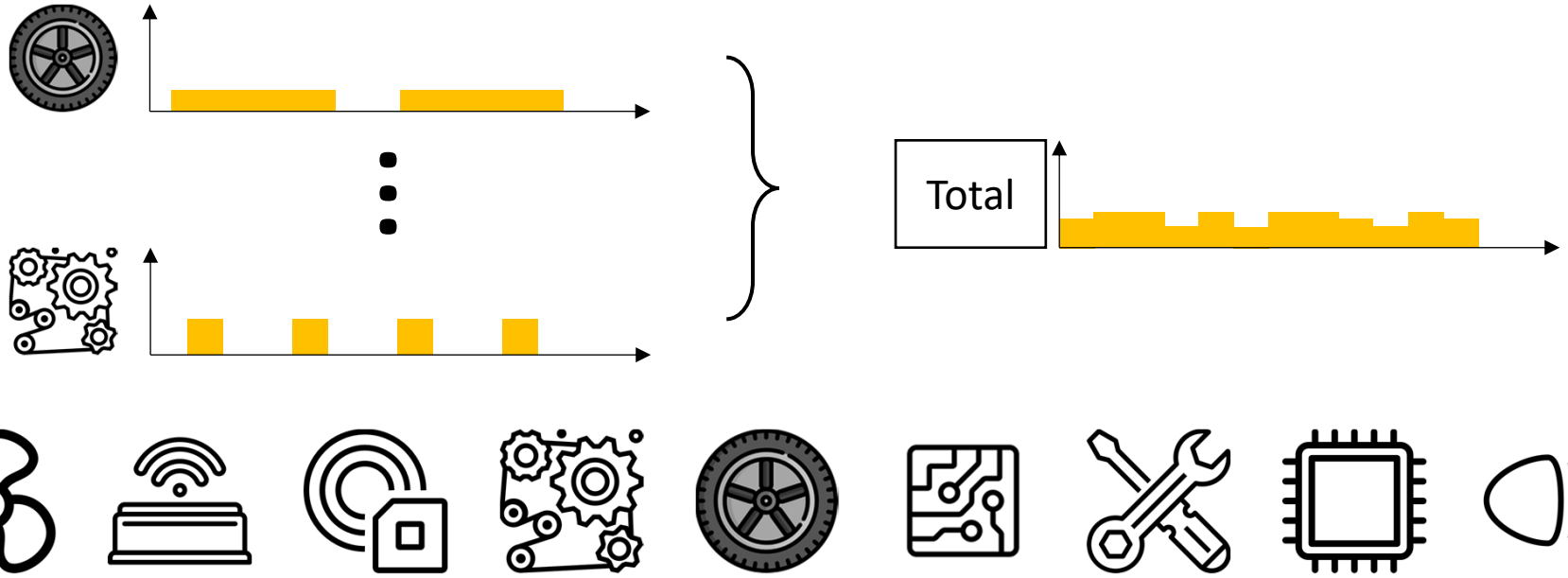

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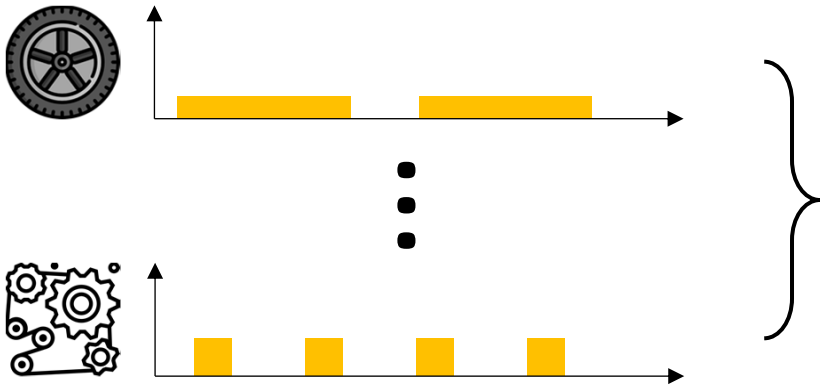

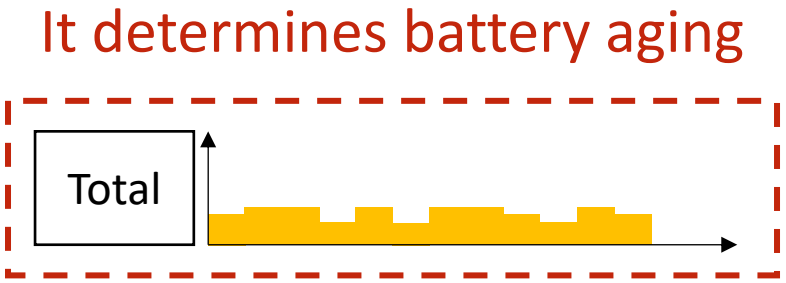

Battery Aging Principles

Back to the curiosity

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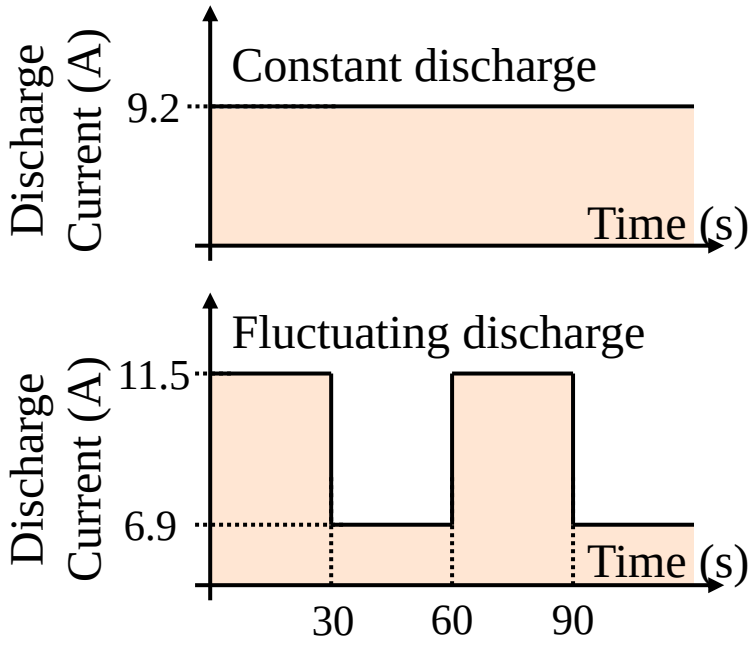
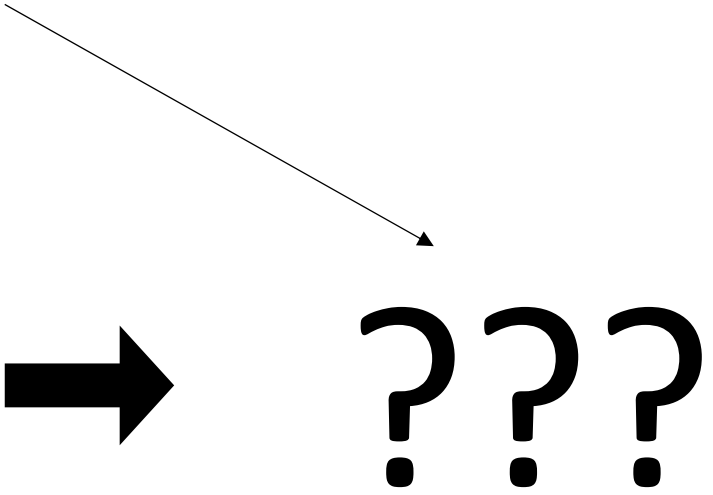


(a) Discharge with different patterns



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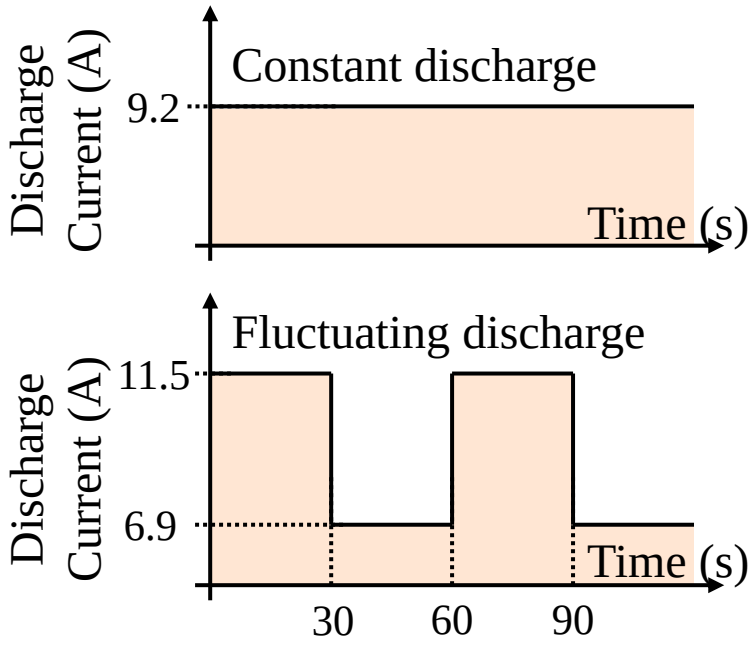

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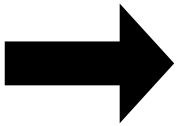
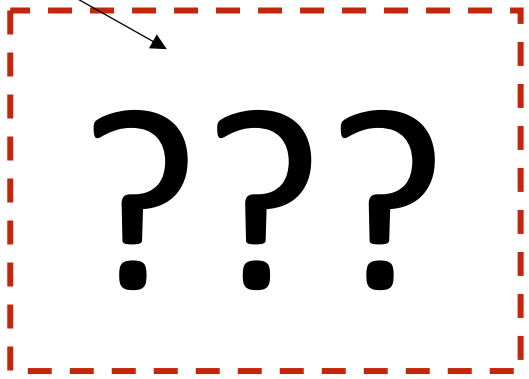


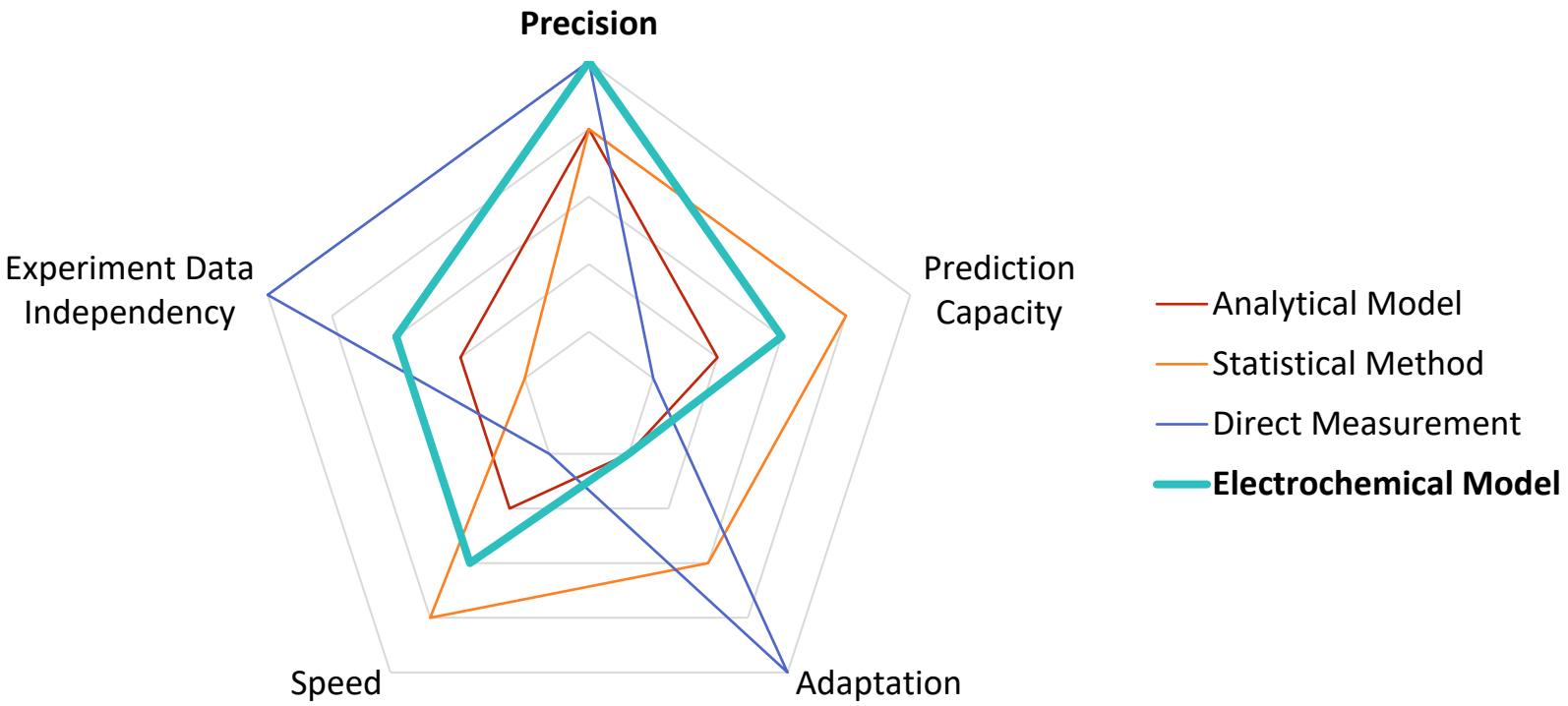


Accurate battery aging Simulator → Checking C1

Battery Aging Principles

How can we predict battery aging?

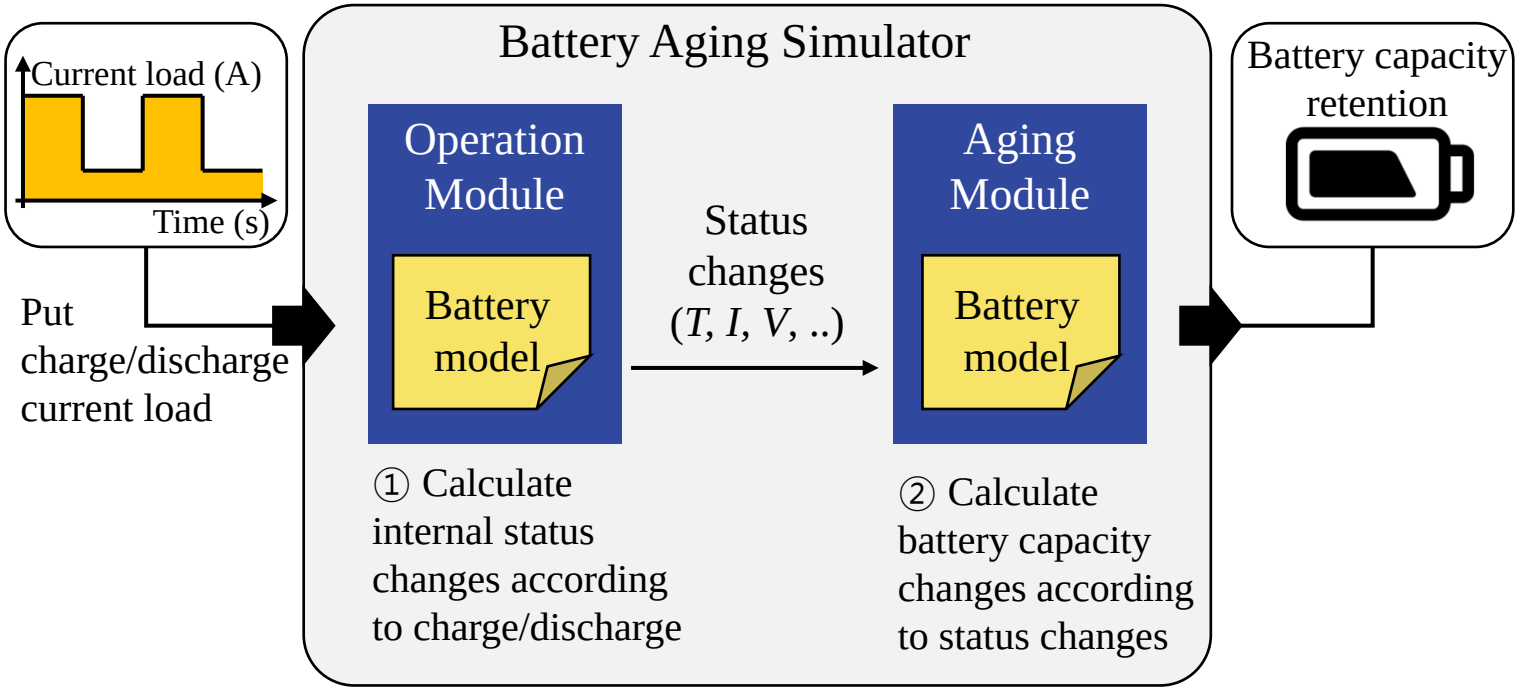
- Simulation with electrochemical model



Battery Aging Principles

Developed battery aging simulator

- Two modules: operation & aging



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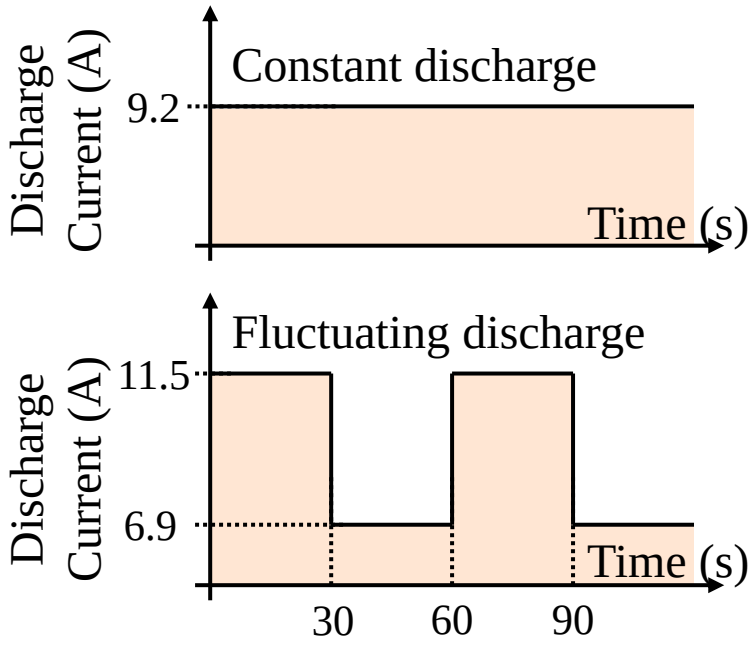

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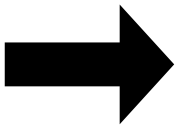

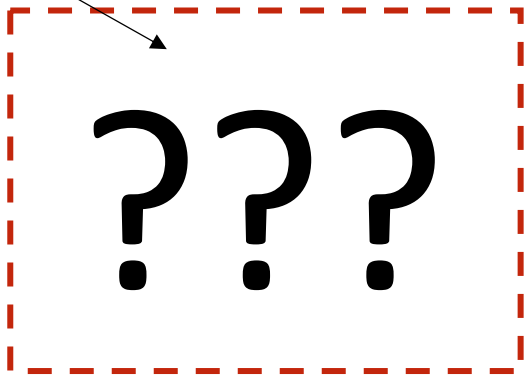

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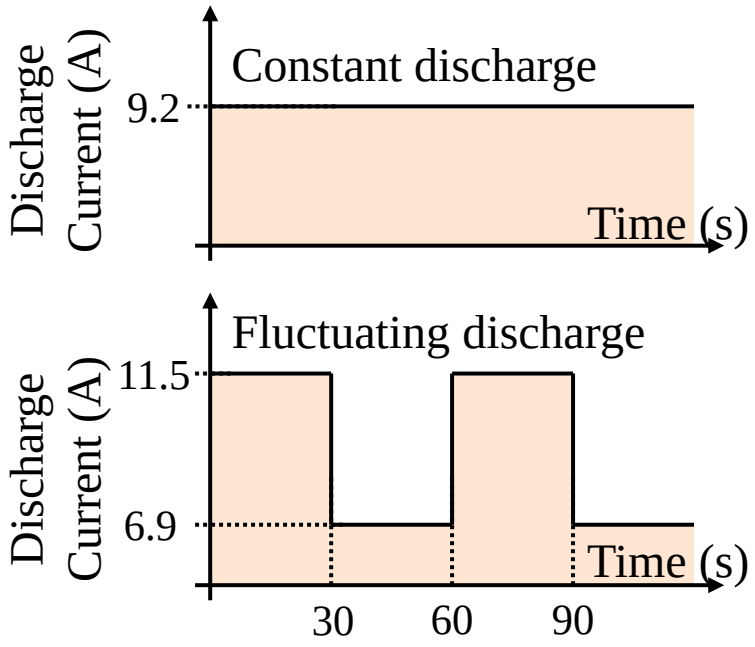
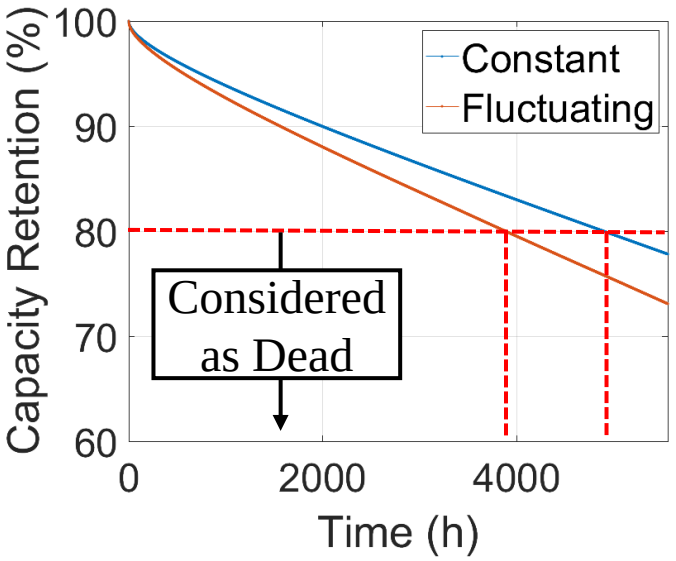


(a) Discharge with different patterns

Task scheduling affects battery aging!



(b) Capacity retention for discharge patterns in (a)

Connection with Scheduling

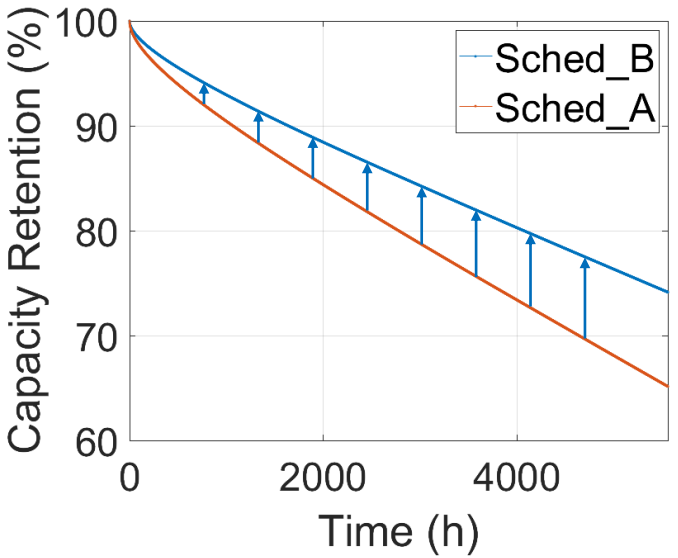
Back to the curiosity

- C1. Can task scheduling **decelerate** battery aging?

How can we decelerate battery aging?

???

Deep understanding of battery aging

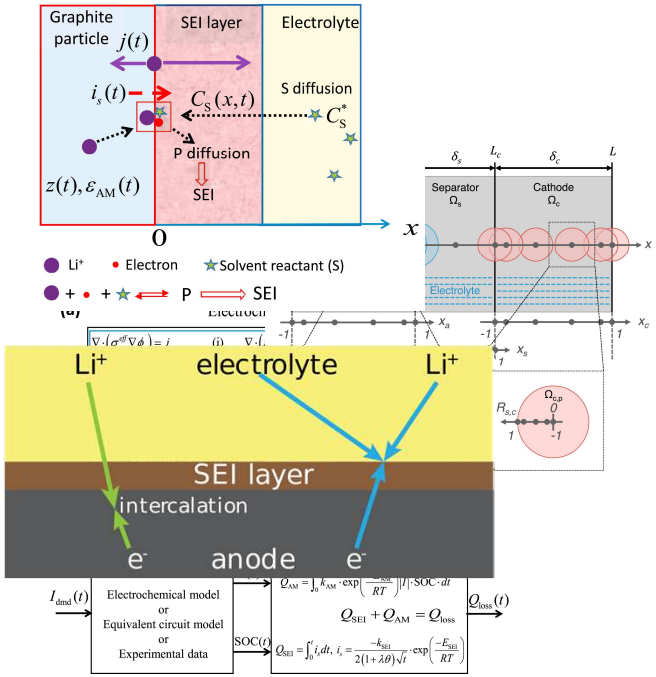


(d) Capacity retention for discharge patterns in (c)

Connection with Scheduling

What causes battery aging?

- **SEI** layer growth (Q_{SEI}) and **A**ctive **M**aterial loss (Q_{AM})
- Key Factors: **Temperature**, Current, State of Charge



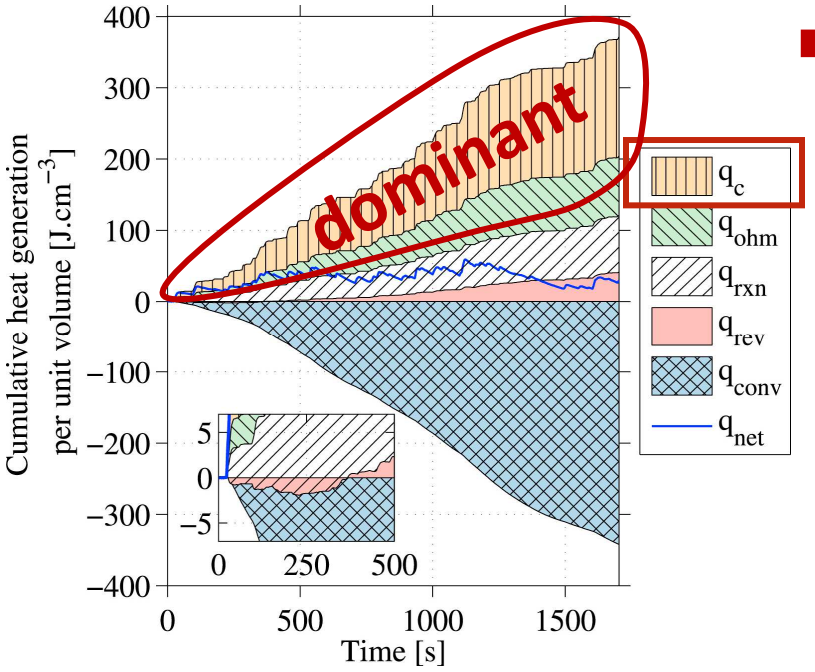
$$Q_{SEI} = \int_0^L \frac{k_{SEI}}{2\sqrt{t}} \exp\left(-\frac{E_{SEI}}{R_{gas}\boldsymbol{T}}\right) dt$$

$$Q_{AM} = \int_0^L k_{AM} \exp\left(-\frac{E_{AM}}{R_{gas}\boldsymbol{T}}\right) SoC|I|dt$$

Connection with Scheduling

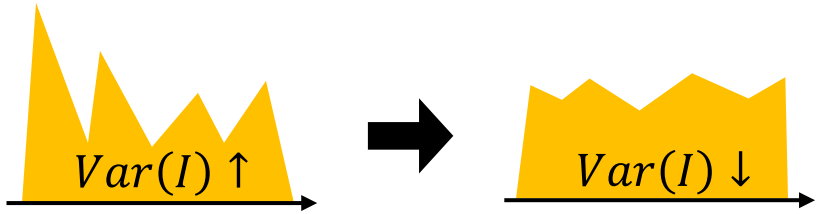
Reducing the temperature

- Decreasing a key heat generation factor
- Ohmic heat generation from current collector resistance



$$q_c = I^2 \cdot R_c$$

$$Minimizing\ Var(I)$$



Connection with Scheduling

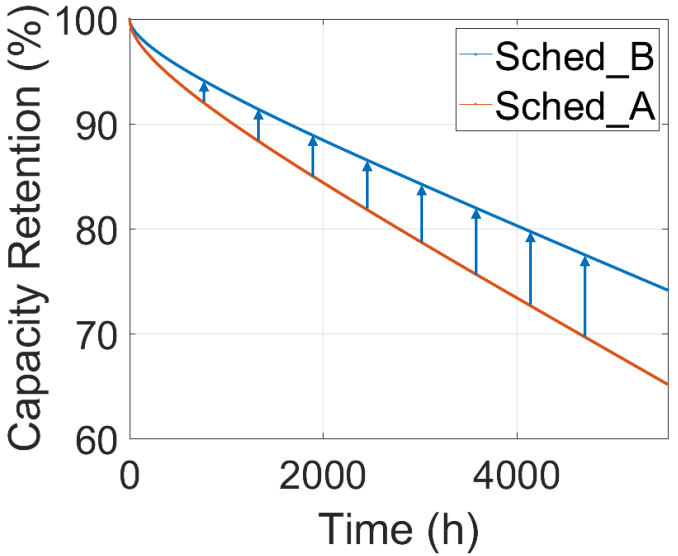
Back to the curiosity

- ~~C1. Can task scheduling decelerate battery aging?~~ Solved!

→ Minimizing the variance of current

???

Deep understanding of battery aging



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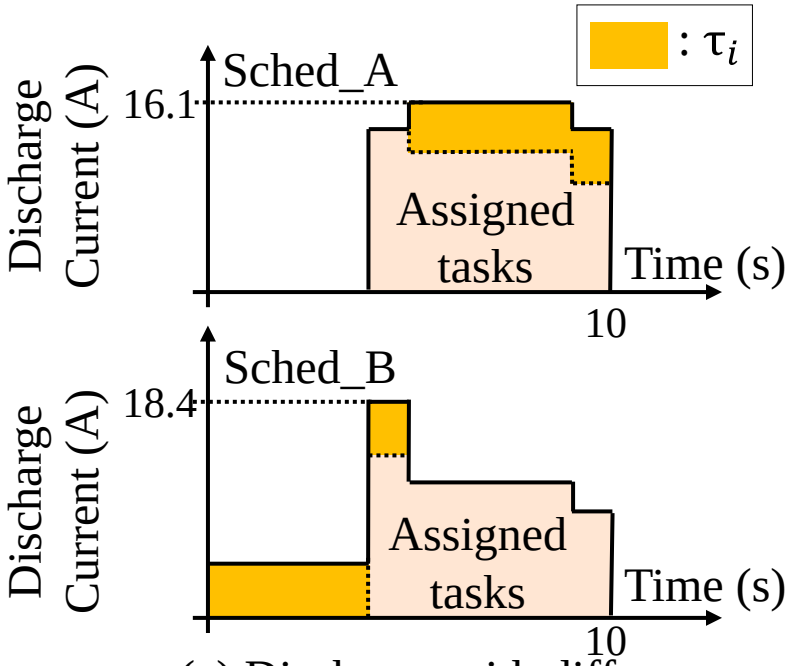
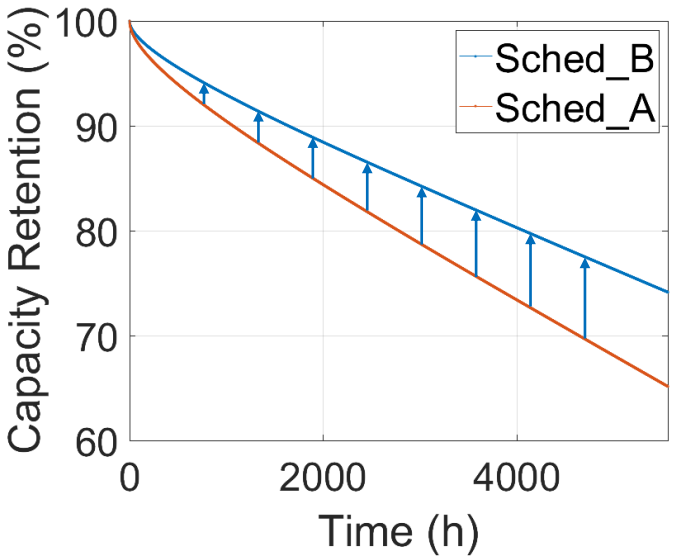


(c) Discharge with different task assignments



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Connection with Scheduling

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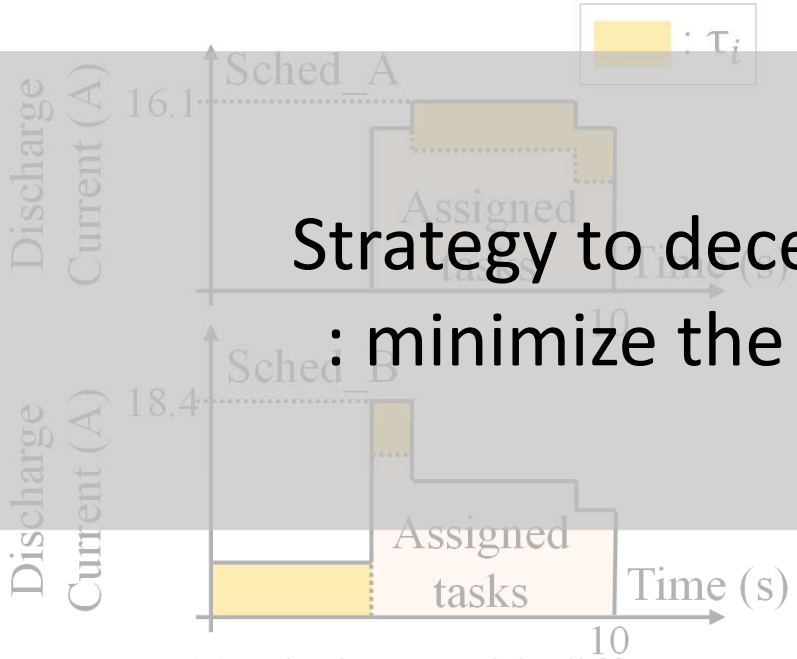
→ Minimizing the variance of current

Strategy to decelerate battery aging
: minimize the variance of current



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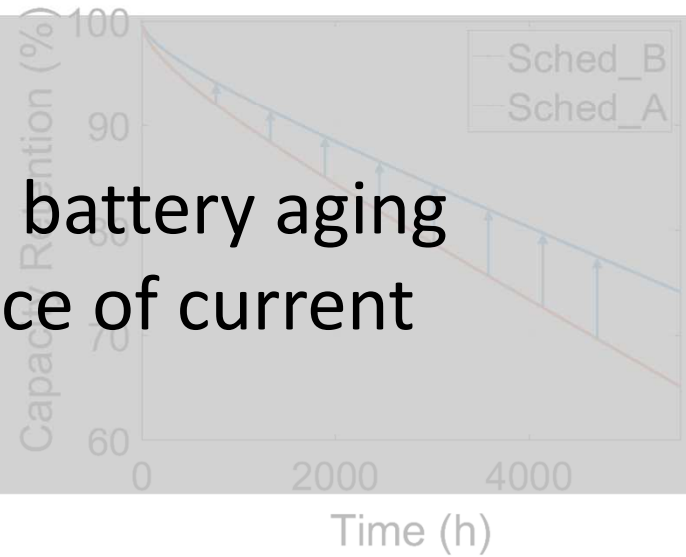

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Solution

Challenge

Back to the curiosity again

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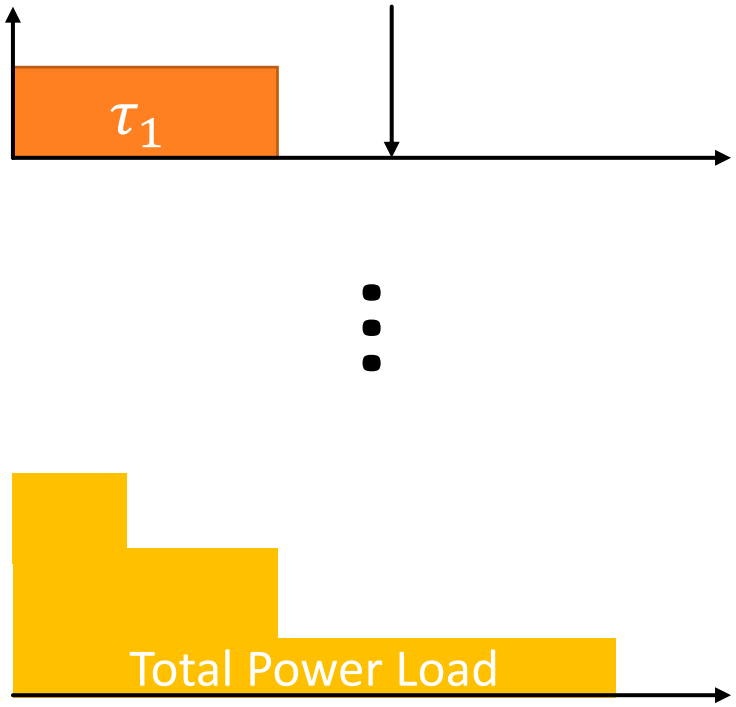

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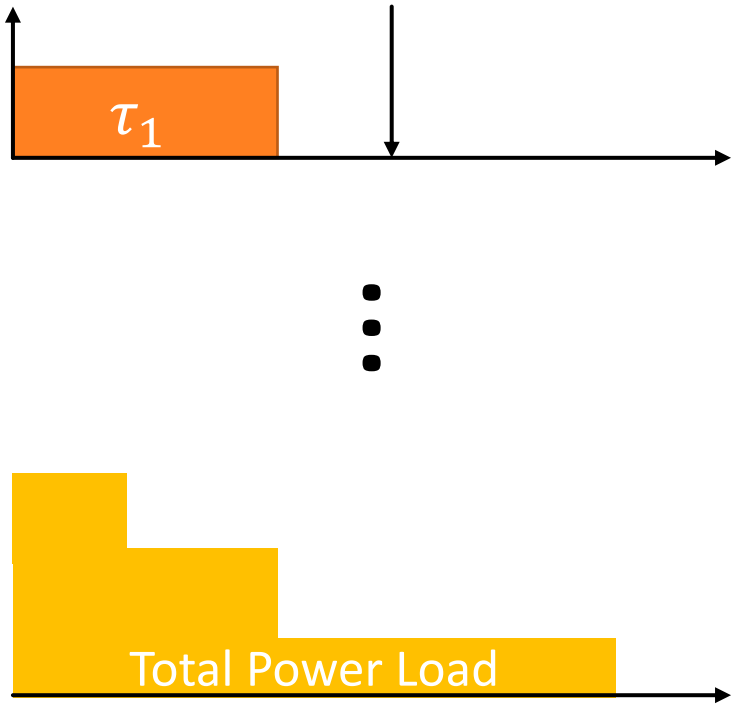

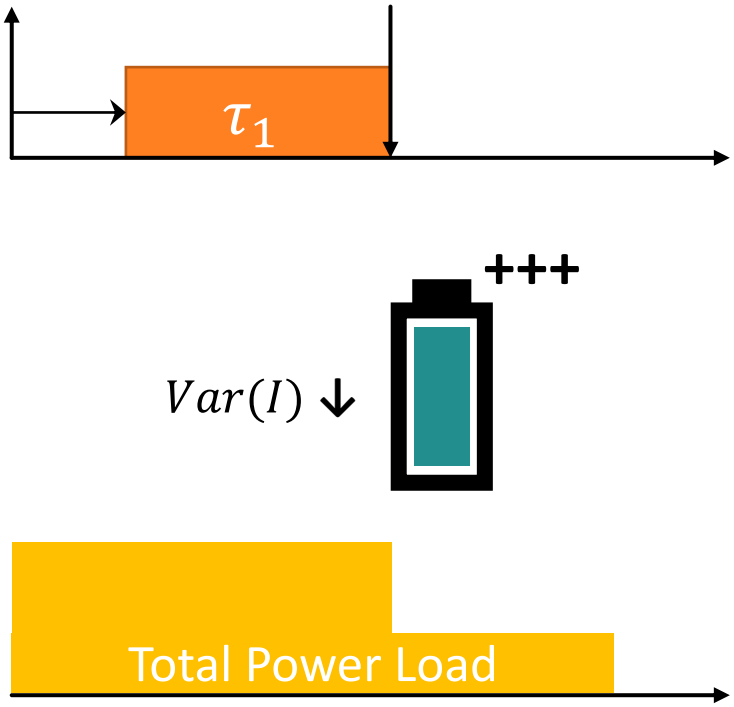

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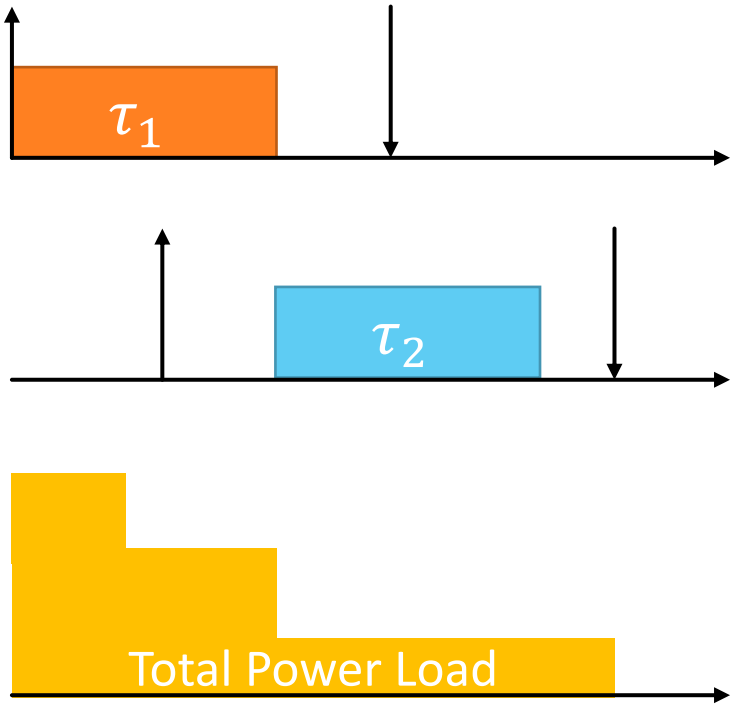

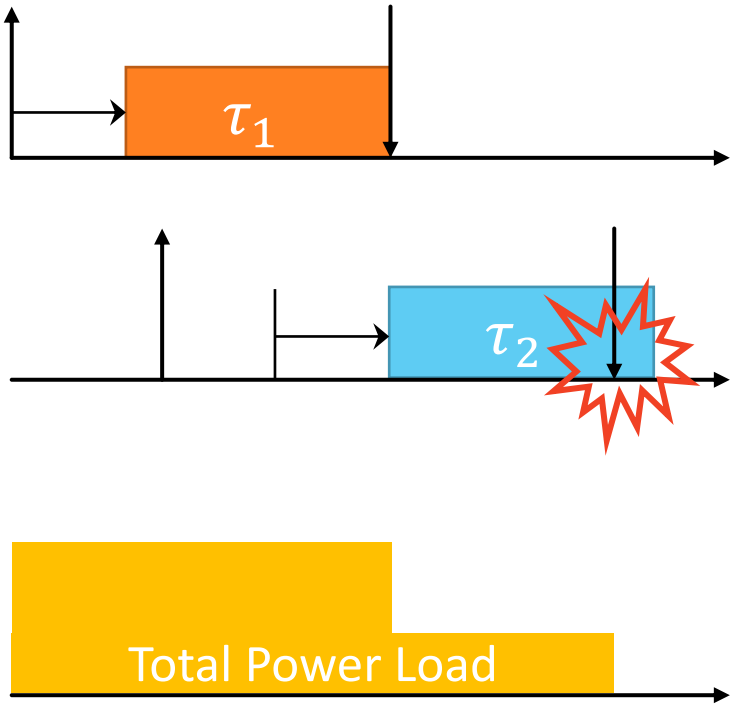

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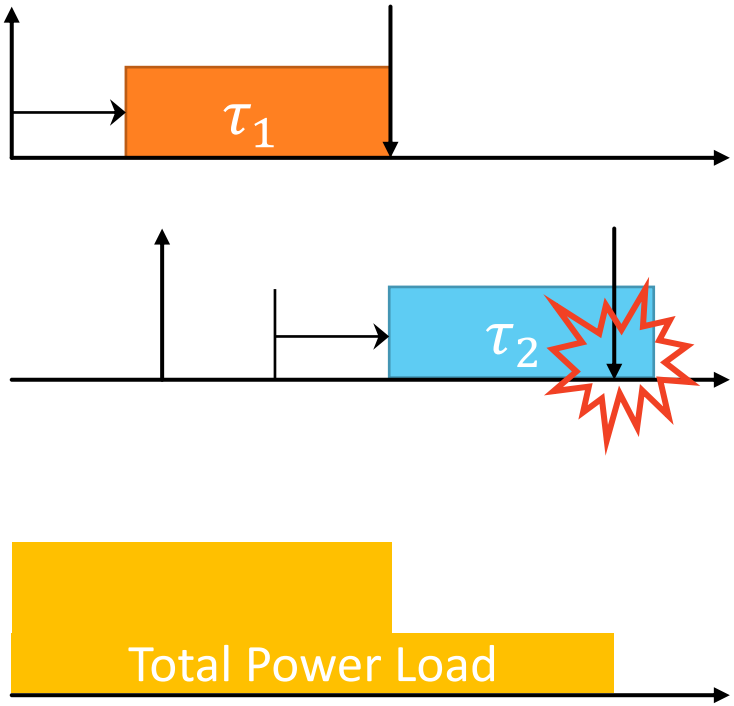
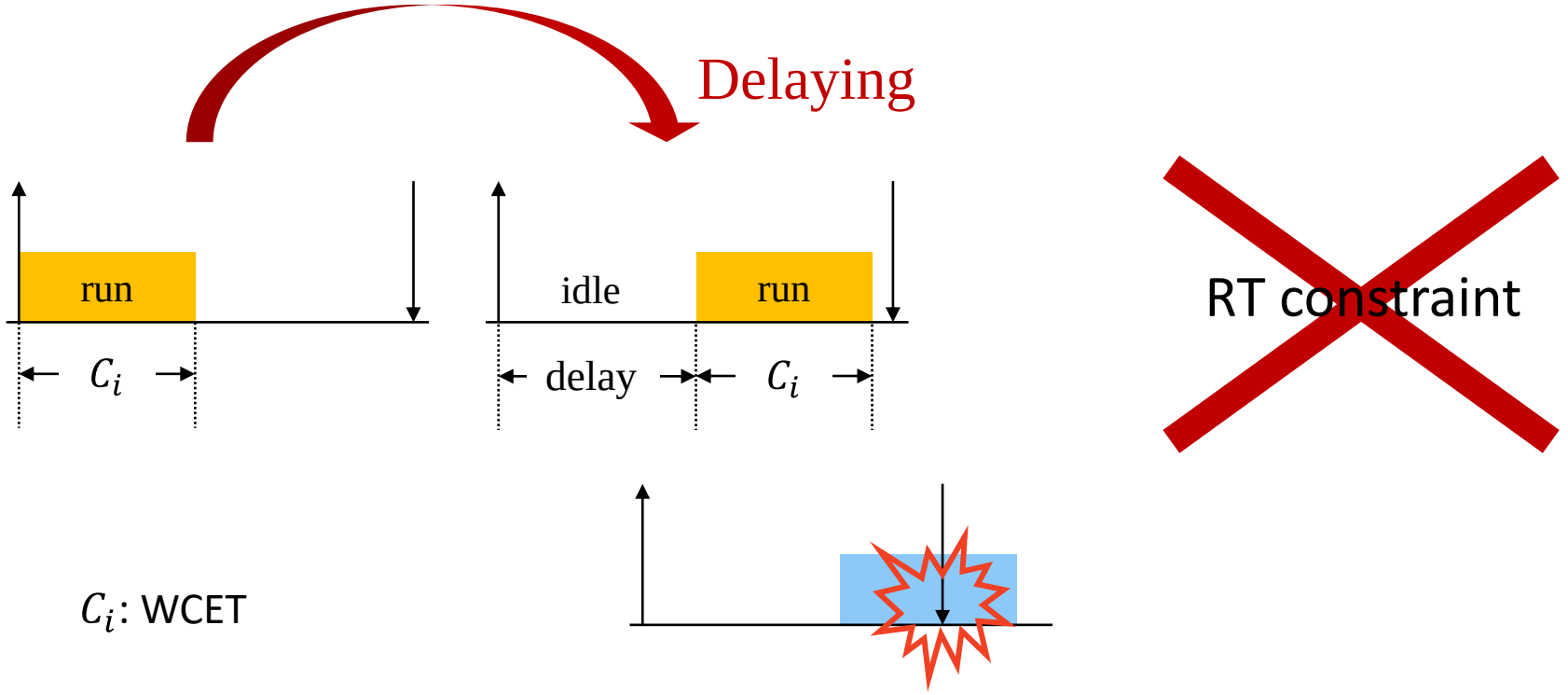


RET Framework

Key idea

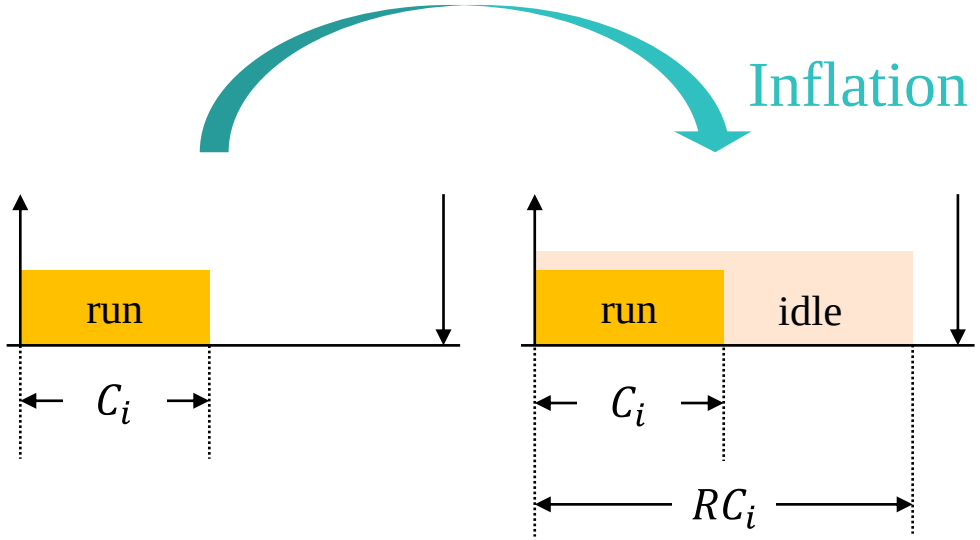
- Just delaying execution will break RT constraint

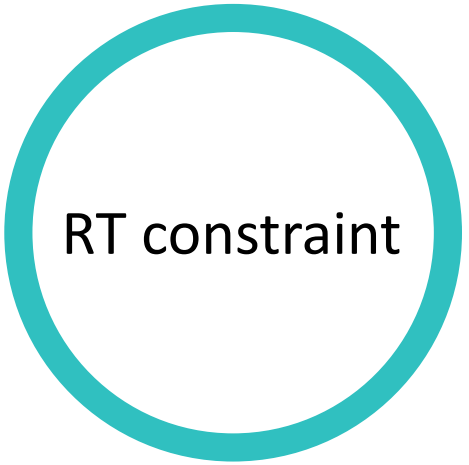


RET Framework

Key idea

- Inflate execution time under the RT constraint



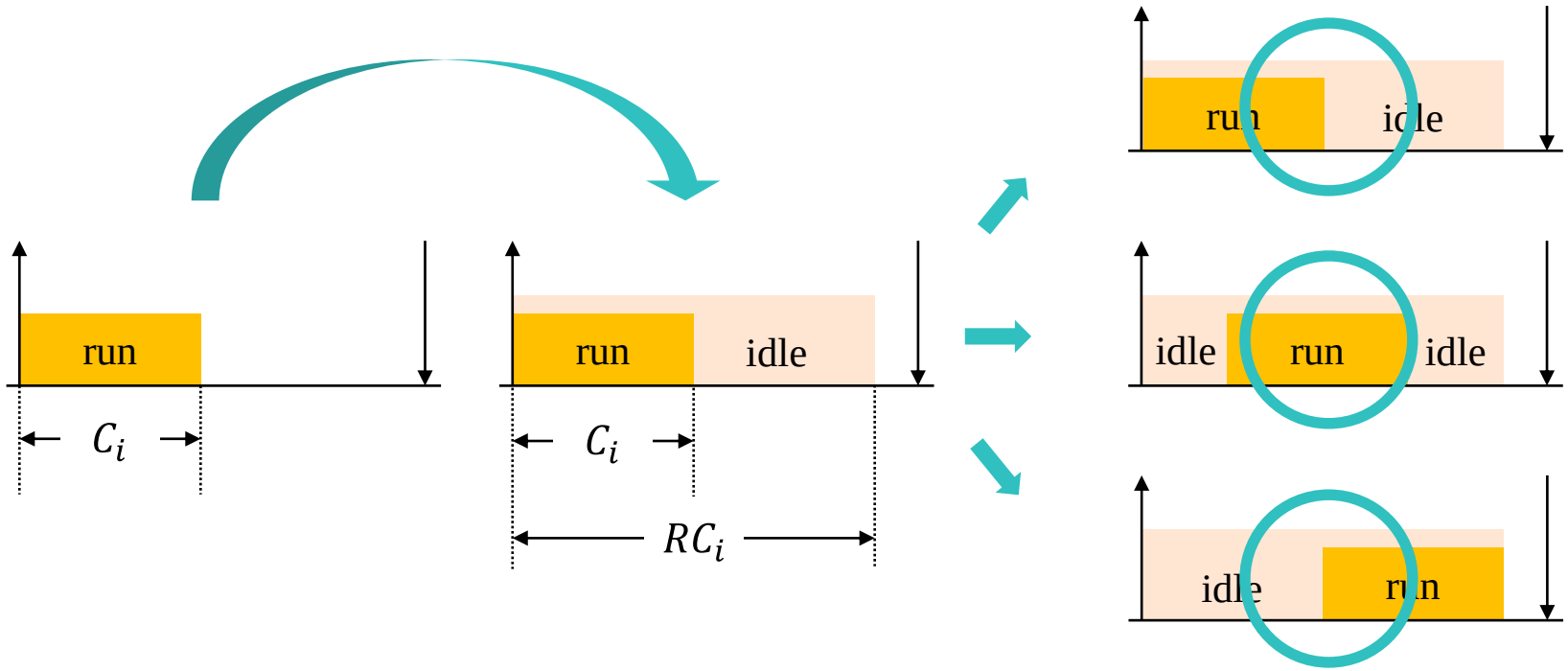


C_i: WCET
RC_i: Reserved Execution Time

RET Framework

Key idea

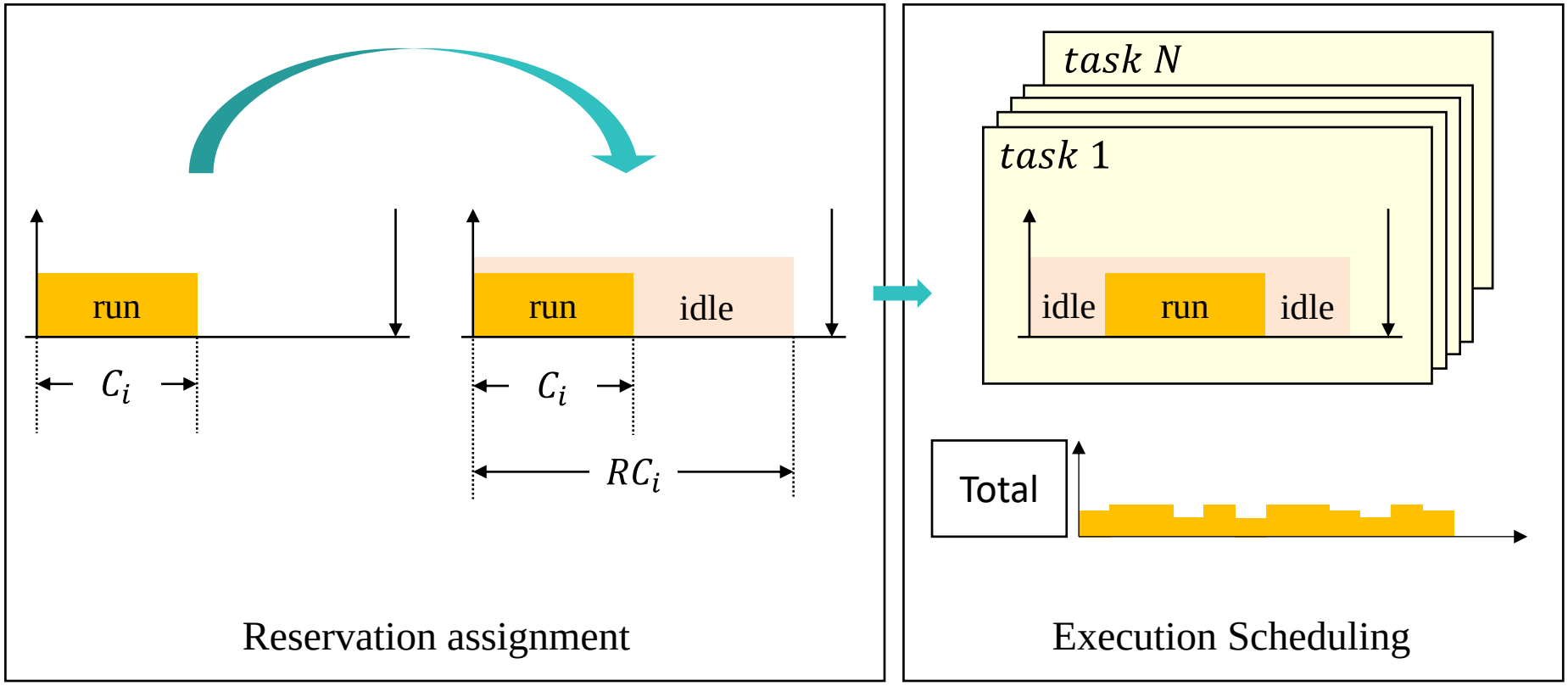
- Now we can control execution start time



RET Framework

Overview

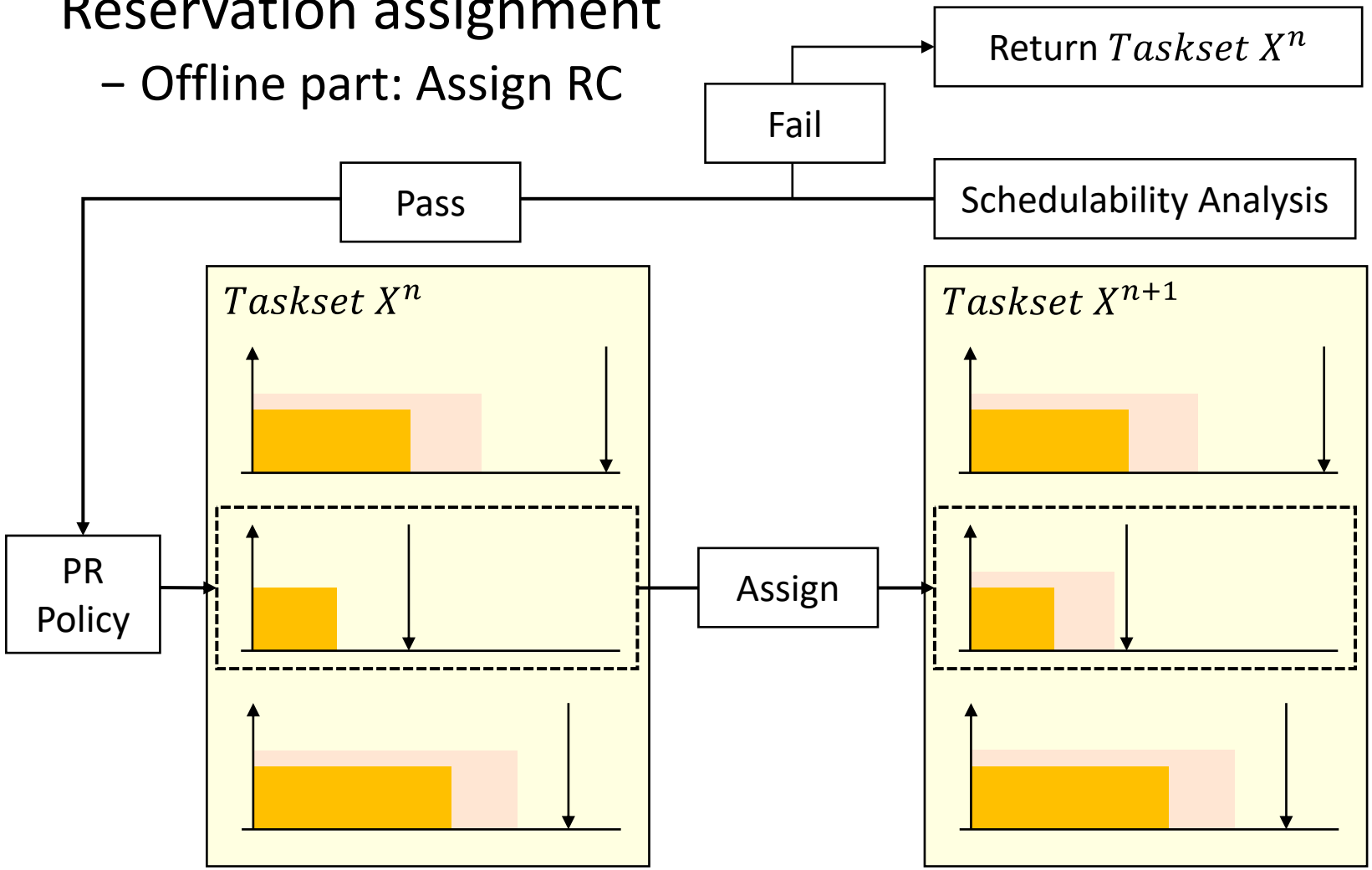
– RET (Reserved Execution Time) framework



RET Framework

Reservation assignment

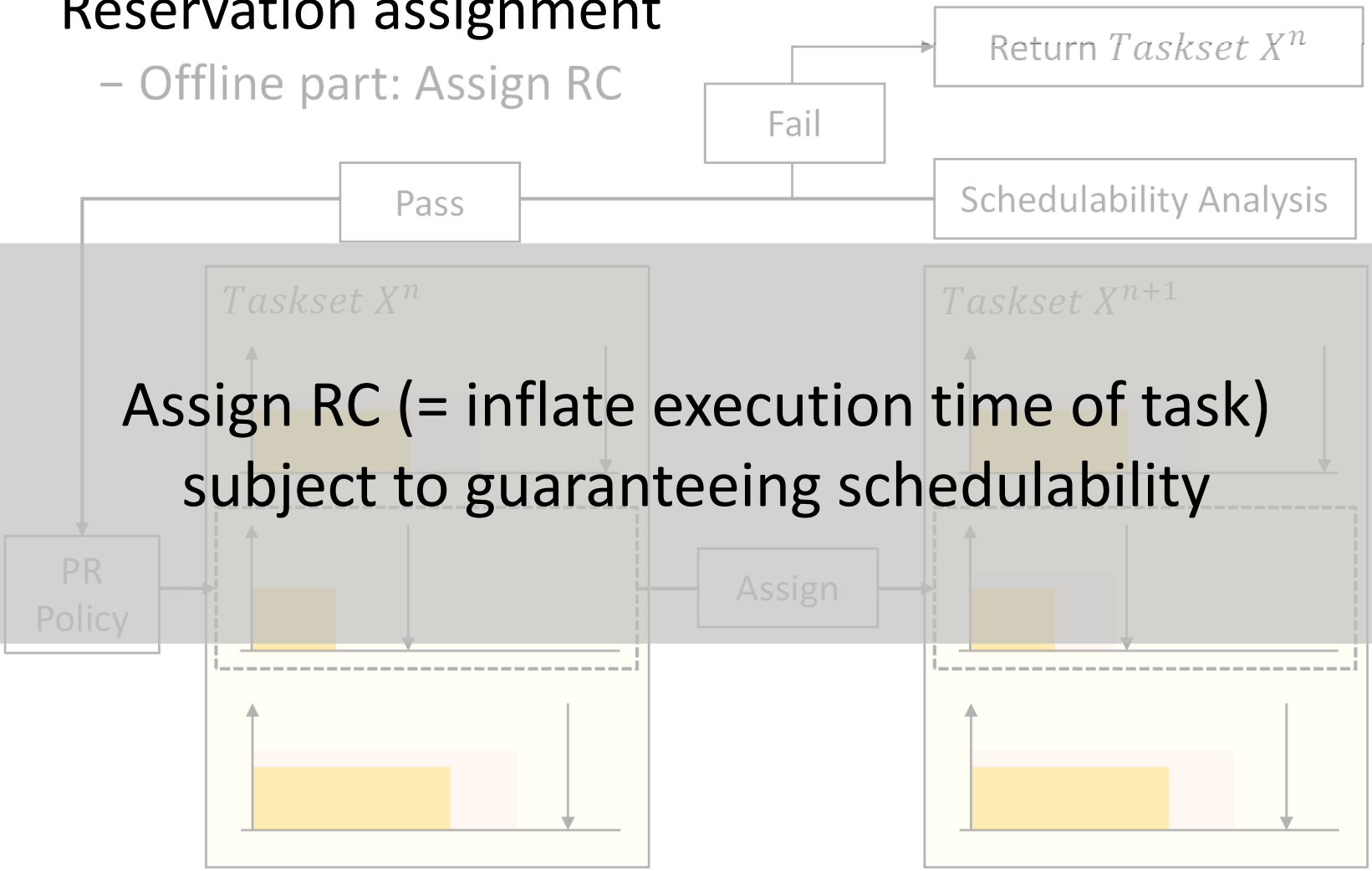
– Offline part: Assign RC



RET Framework

Reservation assignment

– Offline part: Assign RC

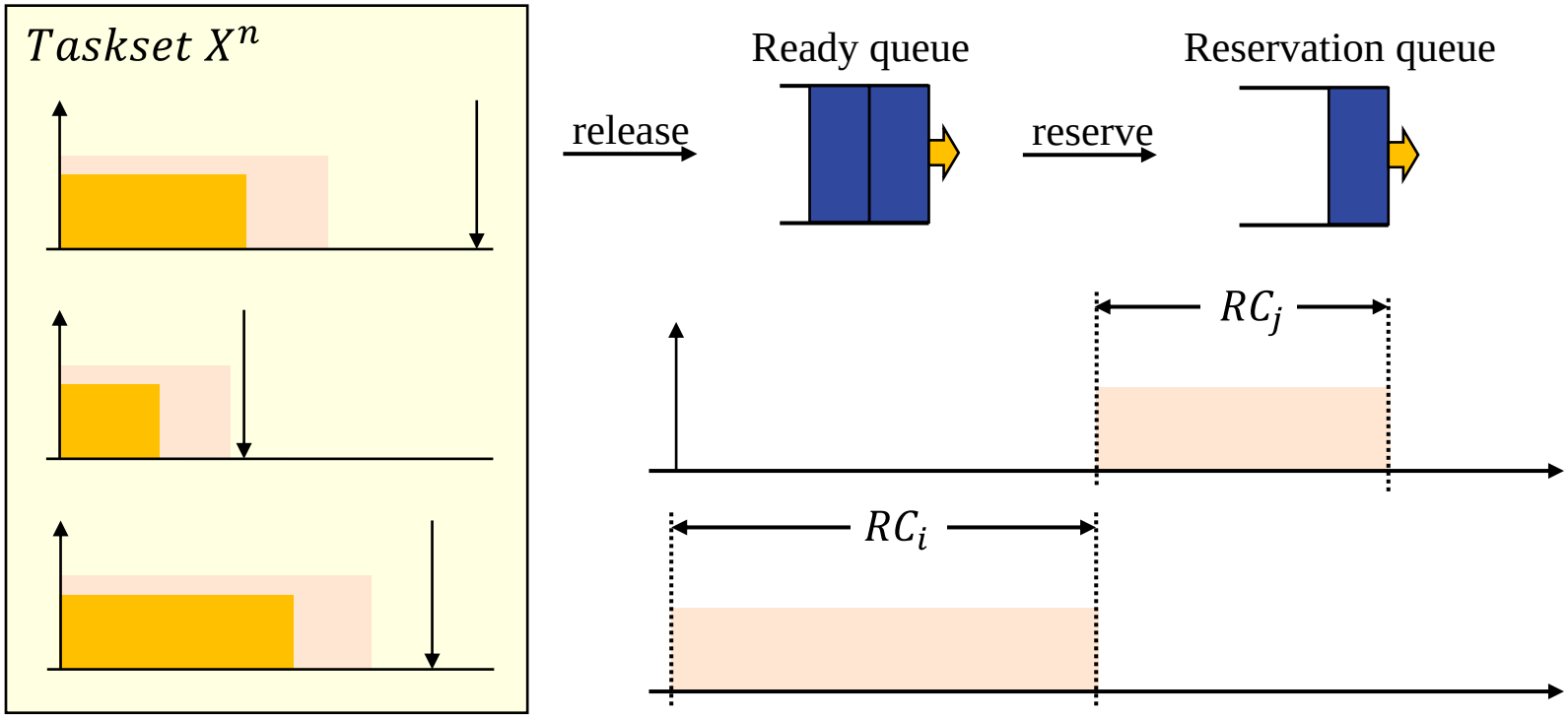


Assign RC (= inflate execution time of task) subject to guaranteeing schedulability

RET Framework

Reservation assignment

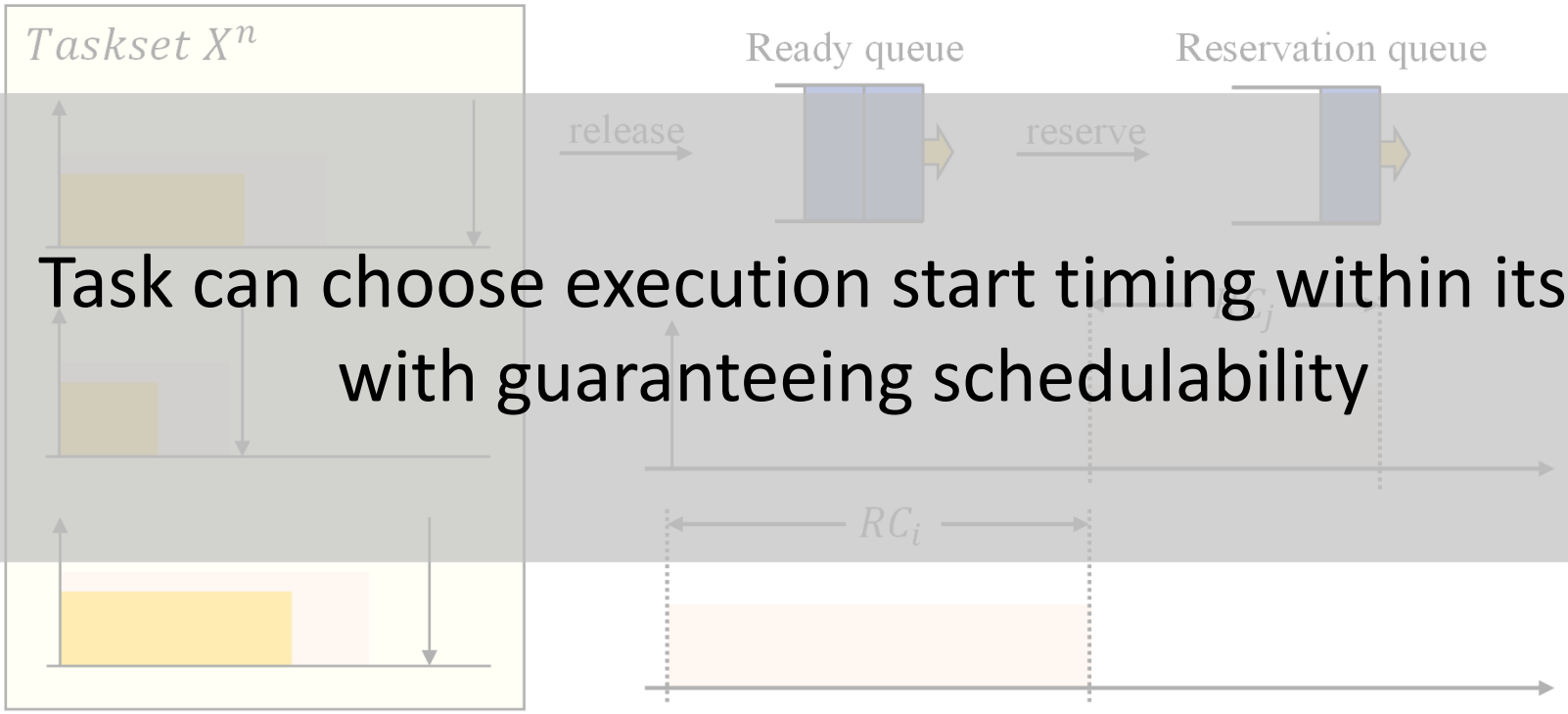
– Online part: Reserve execution



RET Framework

Reservation assignment

- Online part: Reserve execution

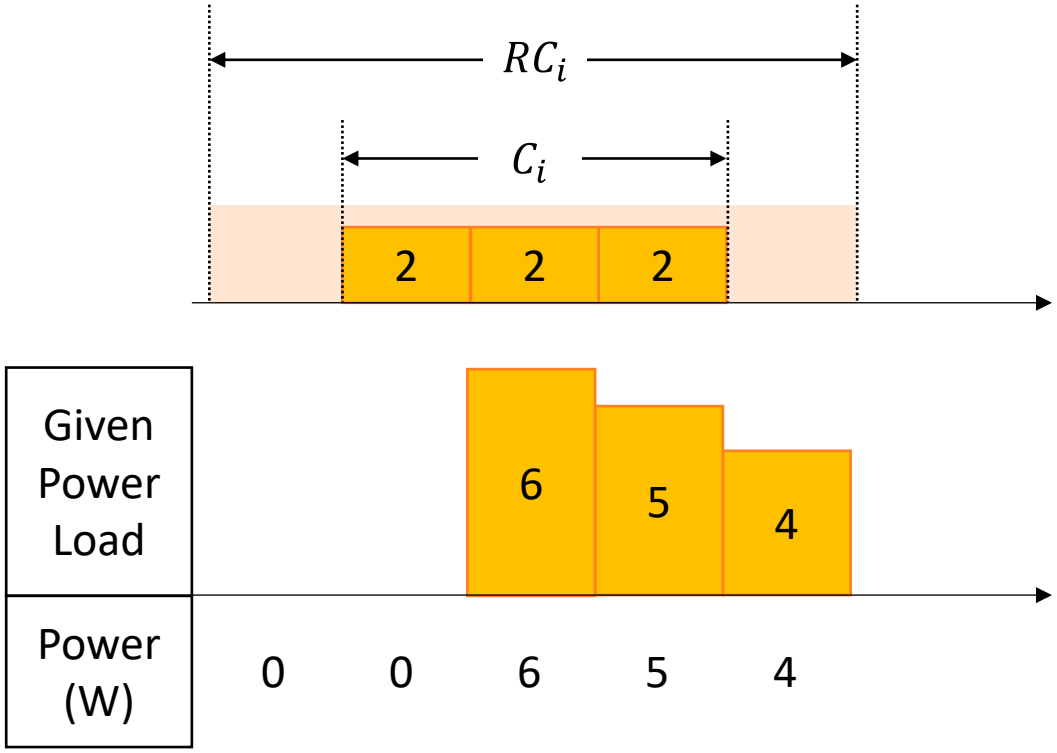


Task can choose execution start timing within its RC with guaranteeing schedulability

RET Framework

Execution scheduling

- Minimize Var(I) in O(n) time



Choice (A) 0 + 0 + 6 = **6**

Choice (B) 0 + 6 + 5 = **11**

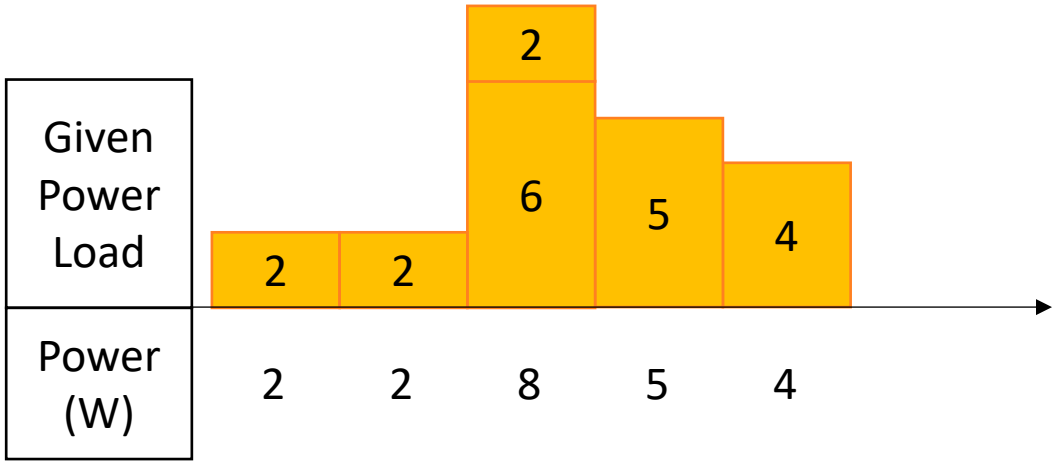
Choice (C) 6 + 5 + 4 = **15**

RET Framework

Execution scheduling

- Minimize Var(I) in O(n) time

solution ← minimum sum



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RET Framework

Execution scheduling

- Minimize Var(I) in O(n) time

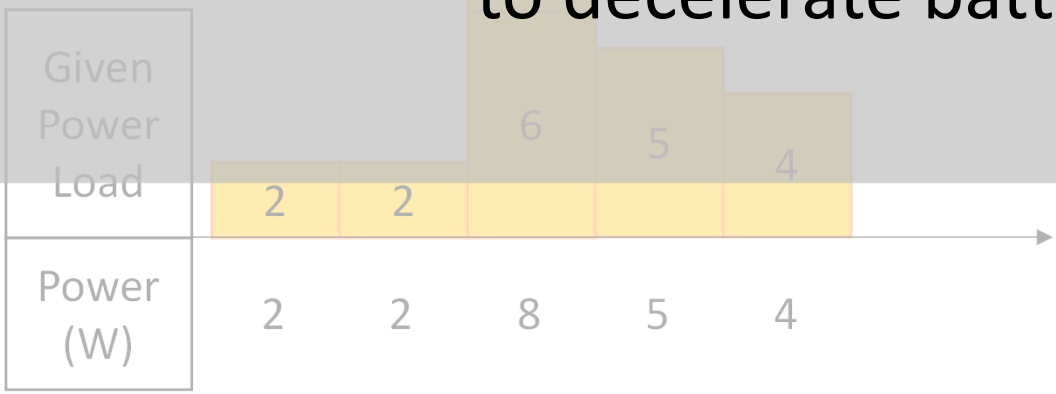
solution ← minimum sum

Choice (A) 0 + 0 + 6 = **6**

Choice (B) 0 + 6 + 5 = **11**

Choice (C) 6 + 5 + 4 = **15**

Minimizing the variance of current (I)
to decelerate battery aging

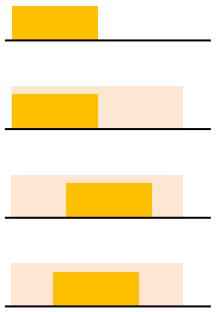


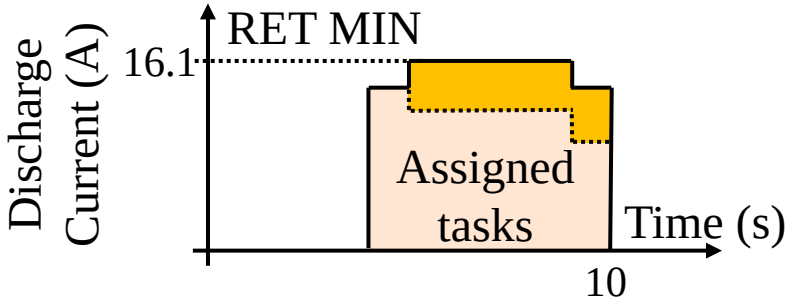
Evaluation

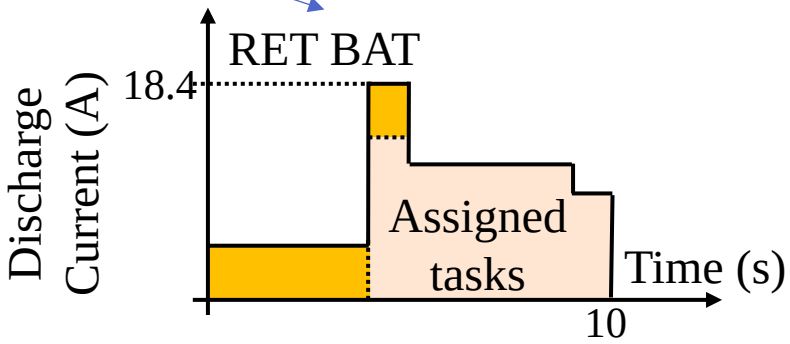
Evaluation Setup

Comparison

- Vanilla EDF
- RET EDF (assign RC but does not handle it)
- RET MIN (goal: Minimizing peak power)
- RET BAT (goal: Decelerating battery aging)



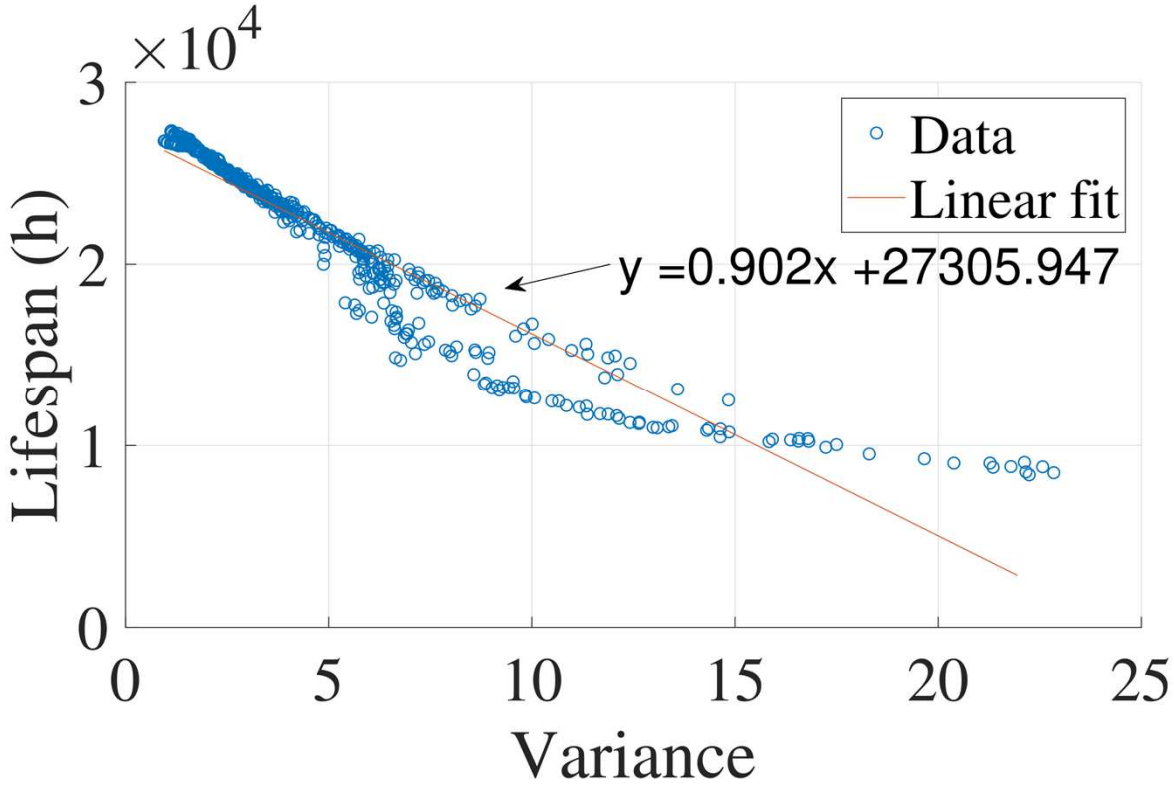




Evaluation Result

Variance vs Aging

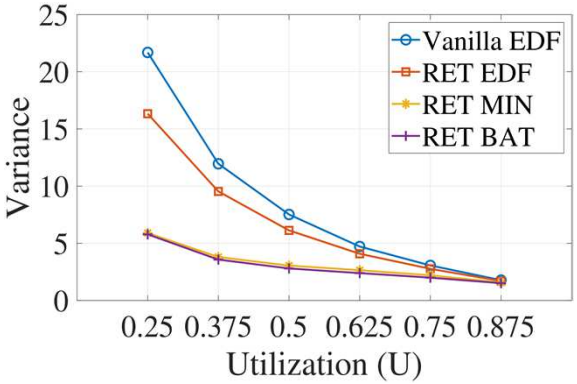
- Strong relationship (correlation coefficient = 0.902)
- Minimizing Var(I) is effective to decelerate battery aging

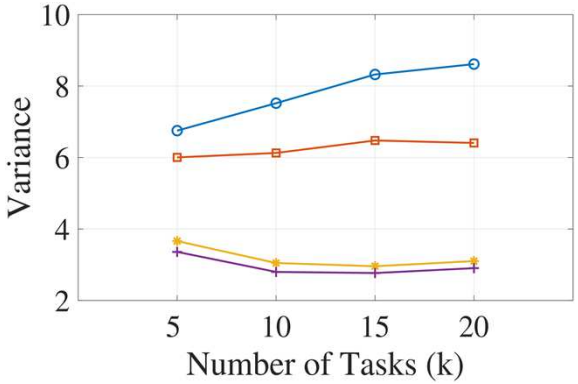


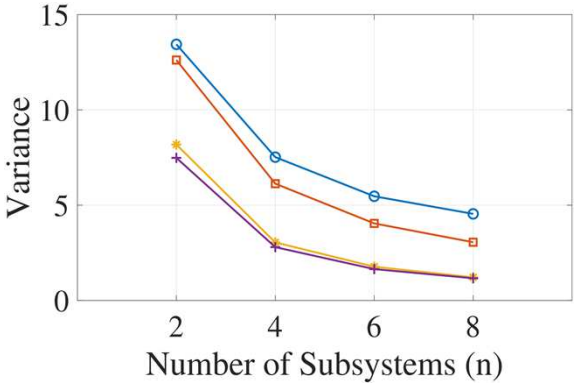
Evaluation Result

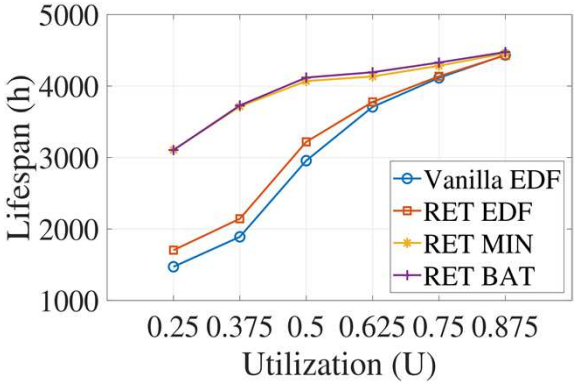
Aging – general tests

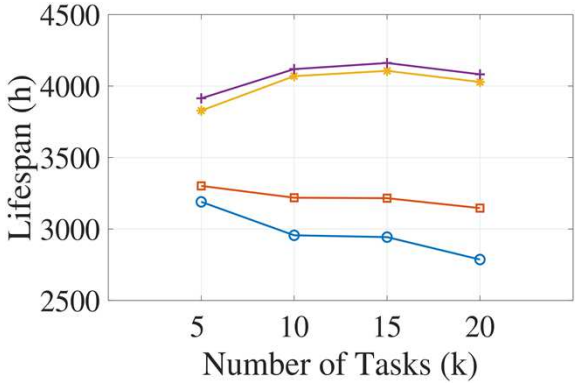
- Up to 144.43% battery lifespan extension

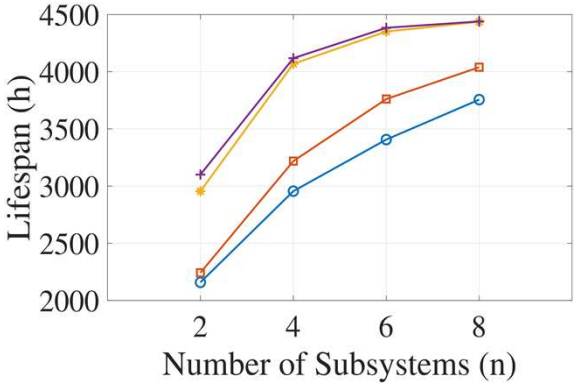












k = 10 and n = 4

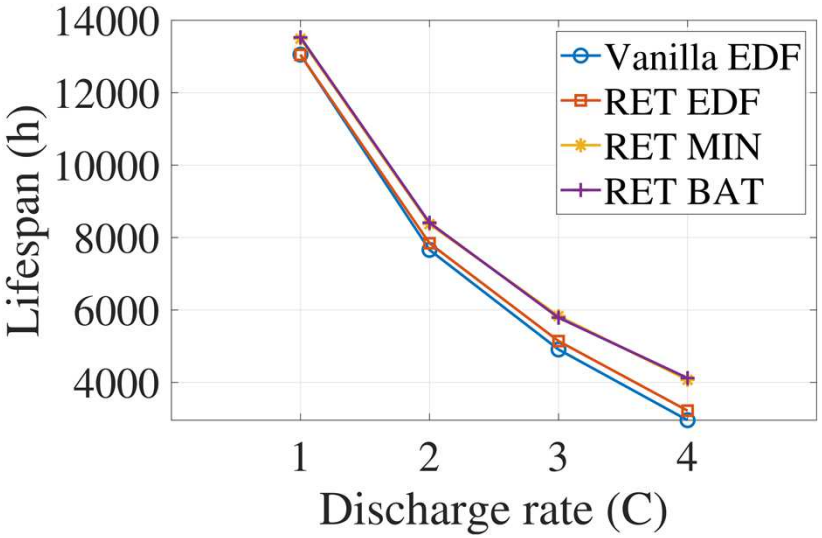
U = 0.5 and n = 4

U = 0.5 and k = 10

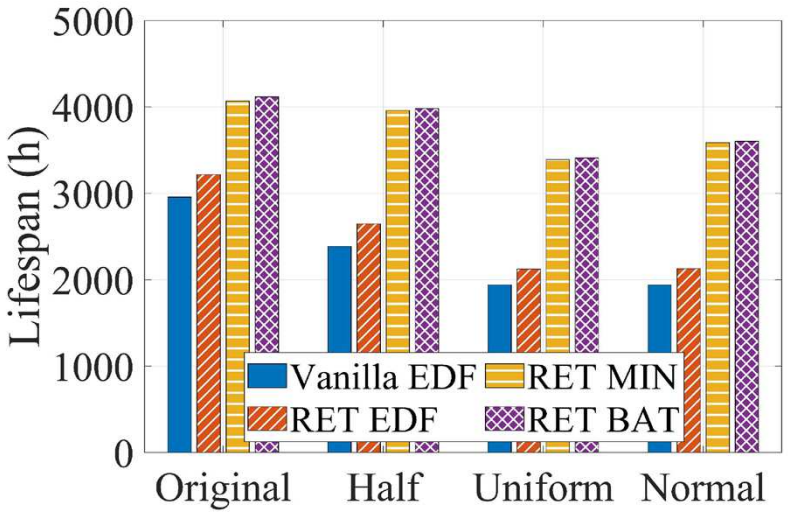
Evaluation Result

Aging – additional tests

- Superior than other methods in various environment



Variate discharge rate



Variate execution time
Original: WCET = constant
Half: WCET = ½ WCET
Uniform: WCET follows uniform distribution
Normal: WCET follows normal distribution

Conclusion

Conclusion

Summary

- Battery aging analysis & simulator
- Battery aging decelerating scheduling strategy (minimizing the variance of current)
- Battery aging decelerating framework guaranteeing real-time constraint (RET framework)
- The RET framework can extend battery life up to 144.4%.
- First work for dealing battery aging in real-time system

Thank You!