Architecting for Intermittence

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Arm Research Summit 2019

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Everything is Computing…

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…Computing is Everything

long lifetime

quick response

advanced capability

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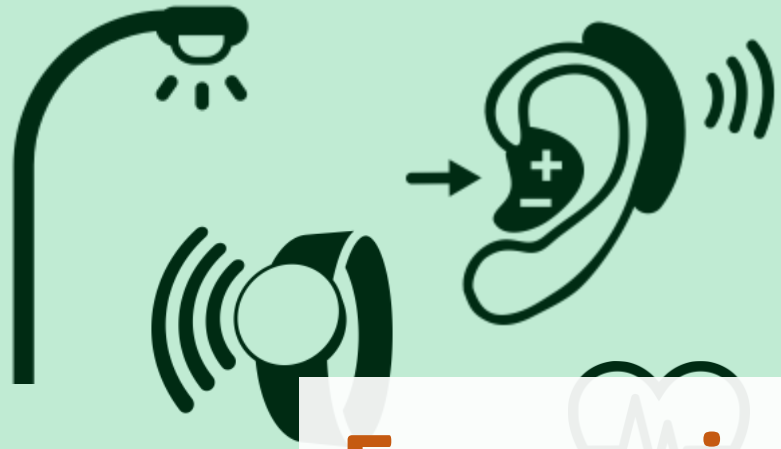
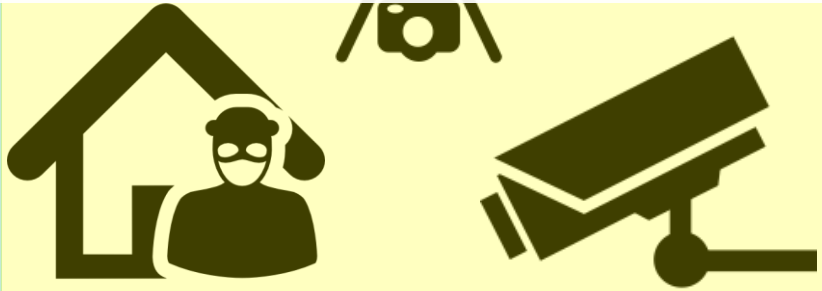
…Computing is Everything



Energy is the common denominator



long lifetime

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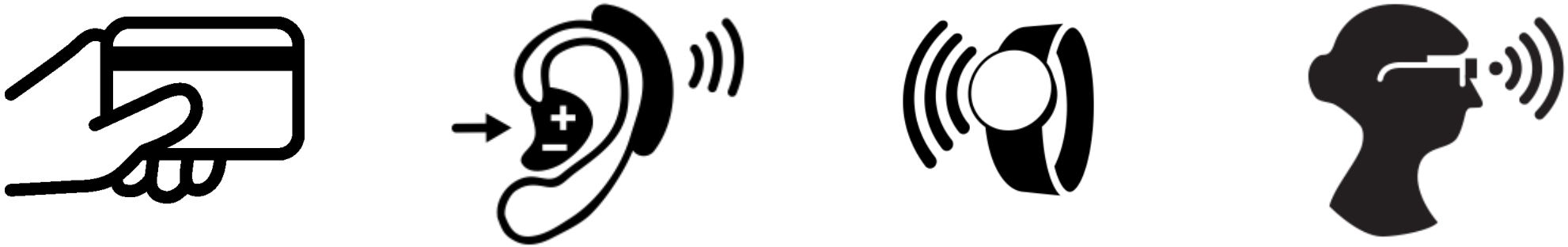
Energy-Harvesting Devices

RF
Motion (Human)
Light (Indoor)
Thermal (Human)
Motion (Mechanical)
Thermal (Industrial)
Light (Outdoor)

µW
mW
W



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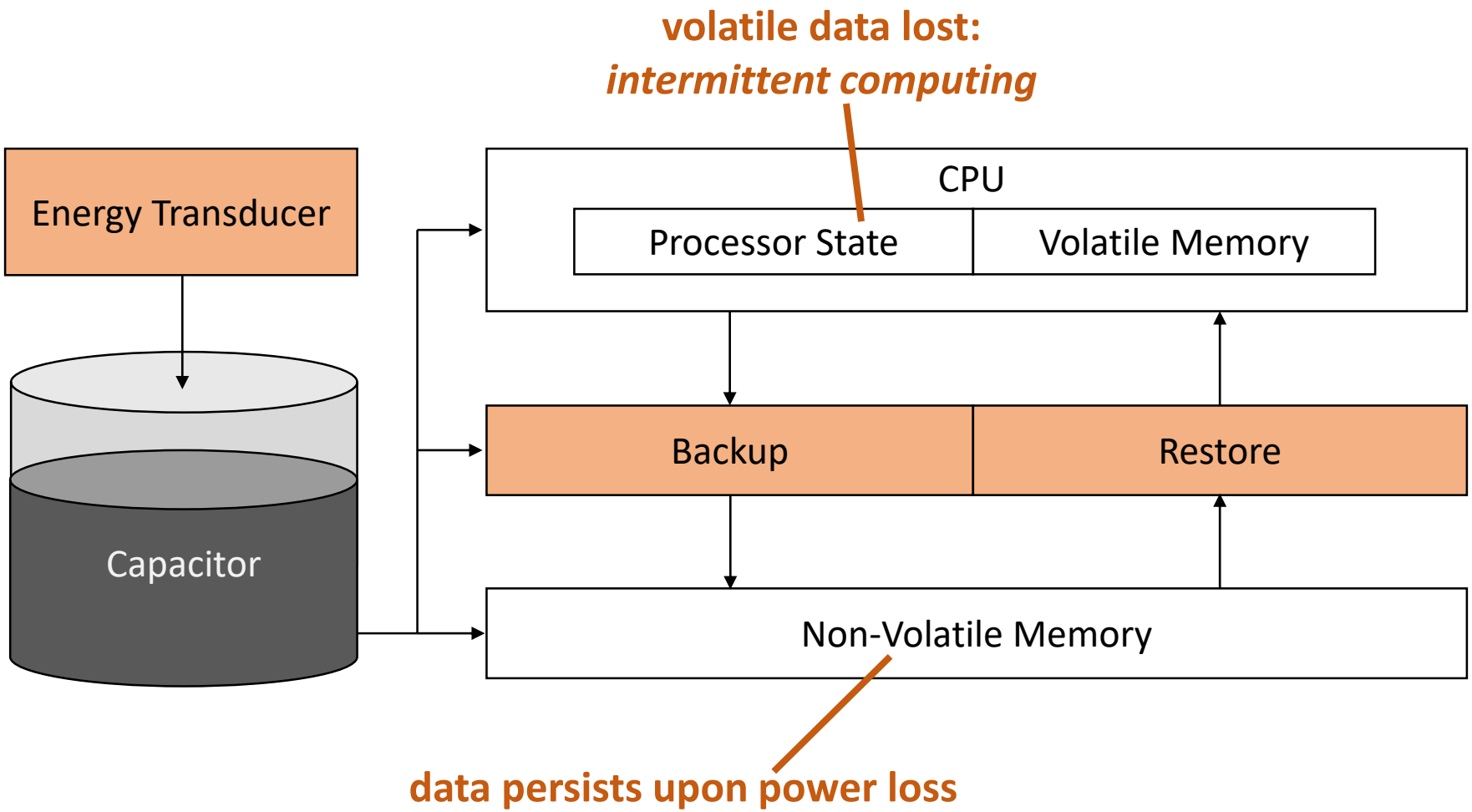
Intermittent Computing



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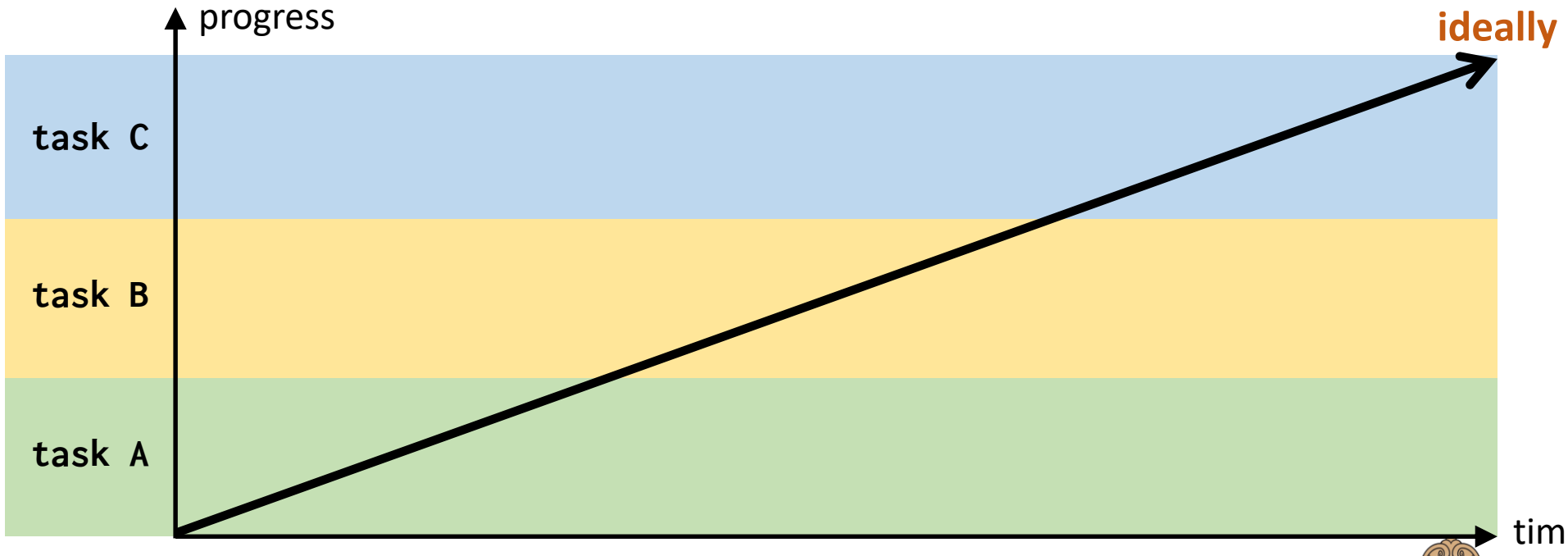

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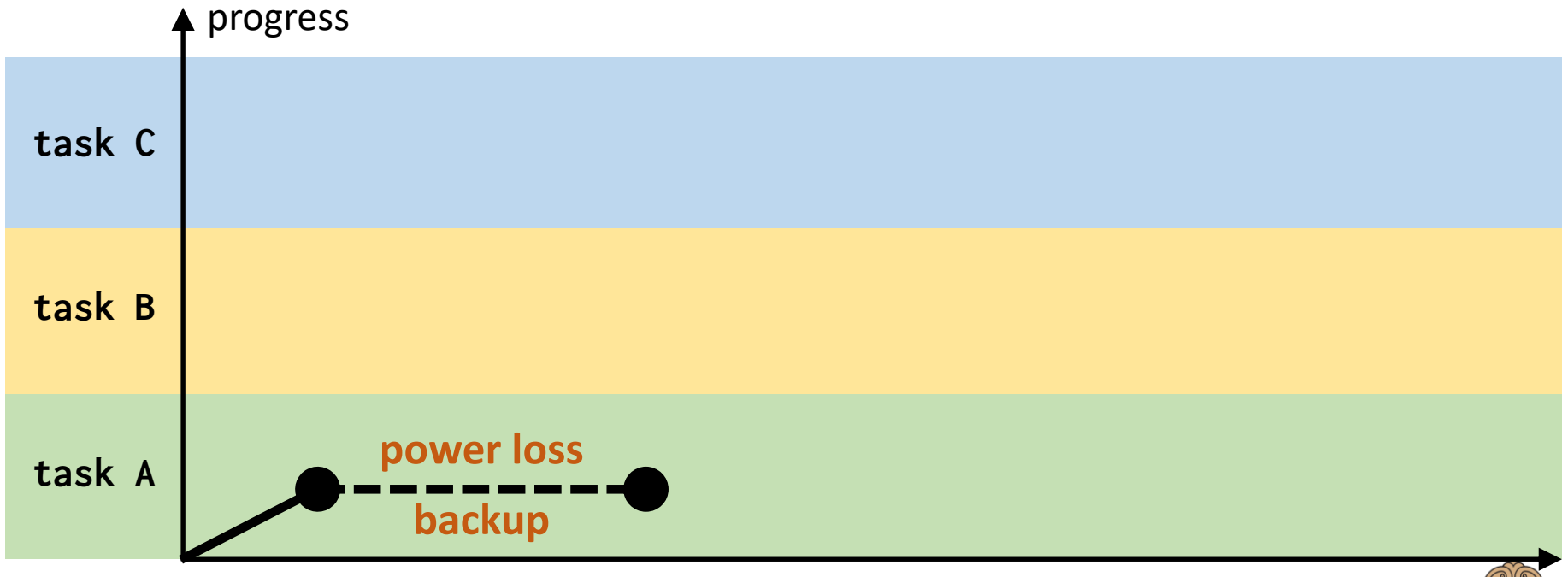

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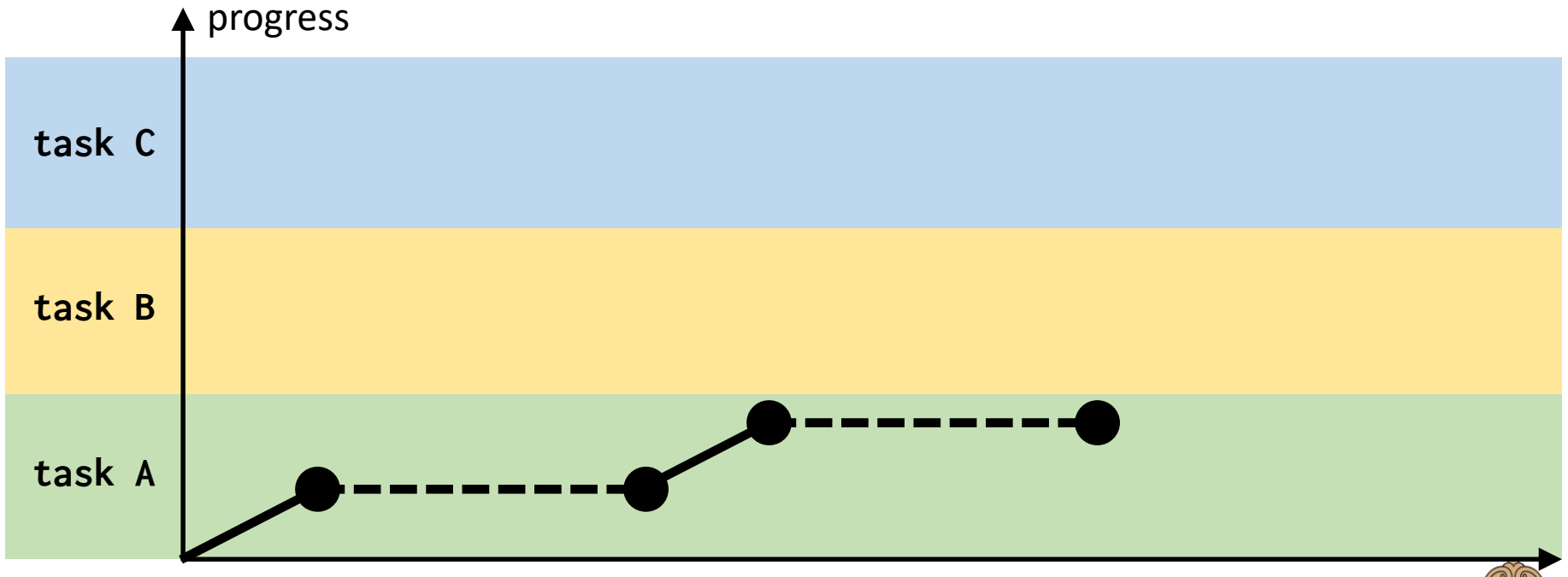

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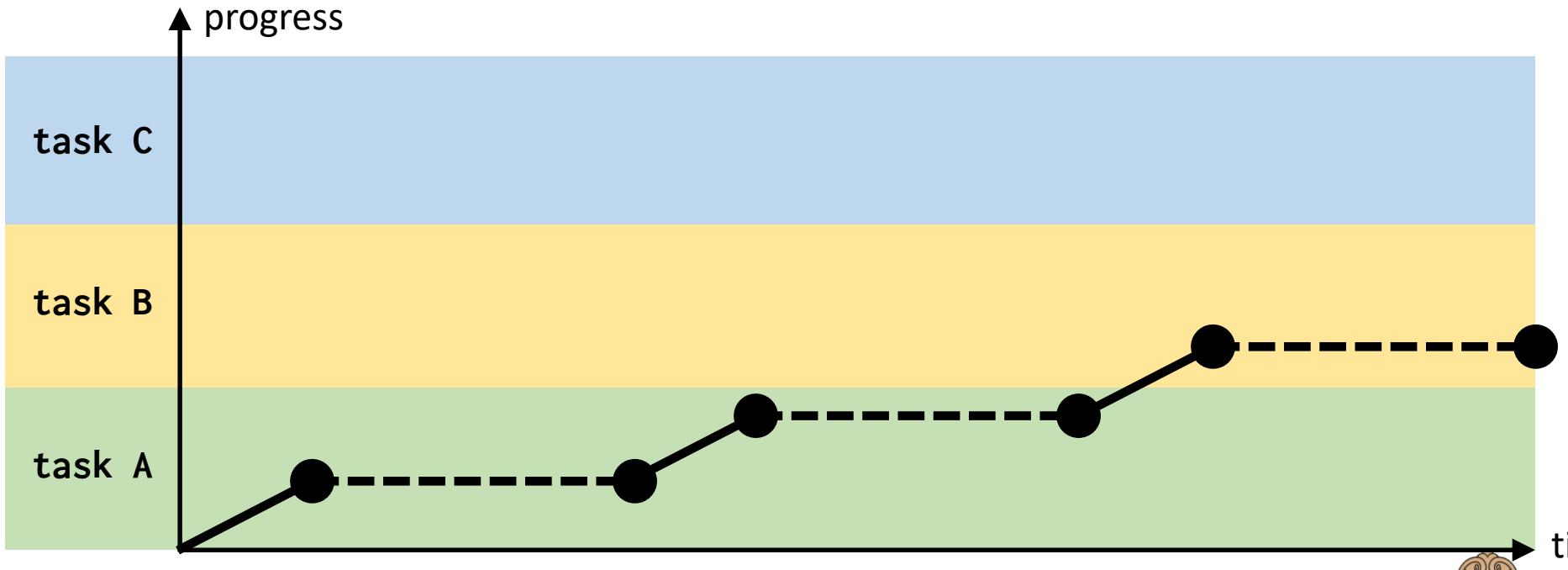
Intermittent Computing

Computation may stop at any point in the program and cannot resume until the device has harvested sufficient energy

- **Power losses and backup overheads greatly impede forward progress**



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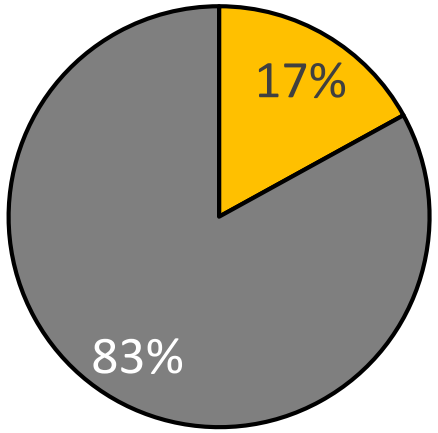
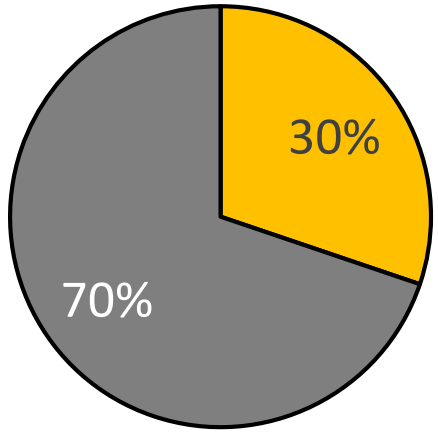
The Necessary Burden of Backups

Clank [ISCA'17]



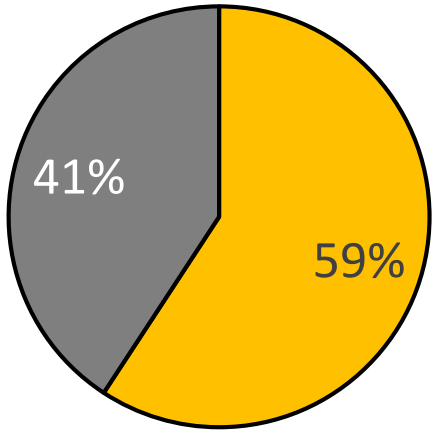
compute backup-restore

DINO [PLDI'15]



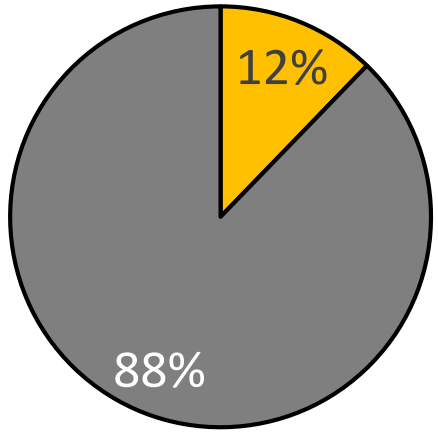
compute backup-restore

Mementos [ASPLOS'11]



compute backup-restore

NVP [HPCA'15]



compute backup-restore

Architecting for Intermittence?

Design Tools:

- EH Model [MICRO'18]

Design Paradigms:

- Computational Skimming [HPCA'19]

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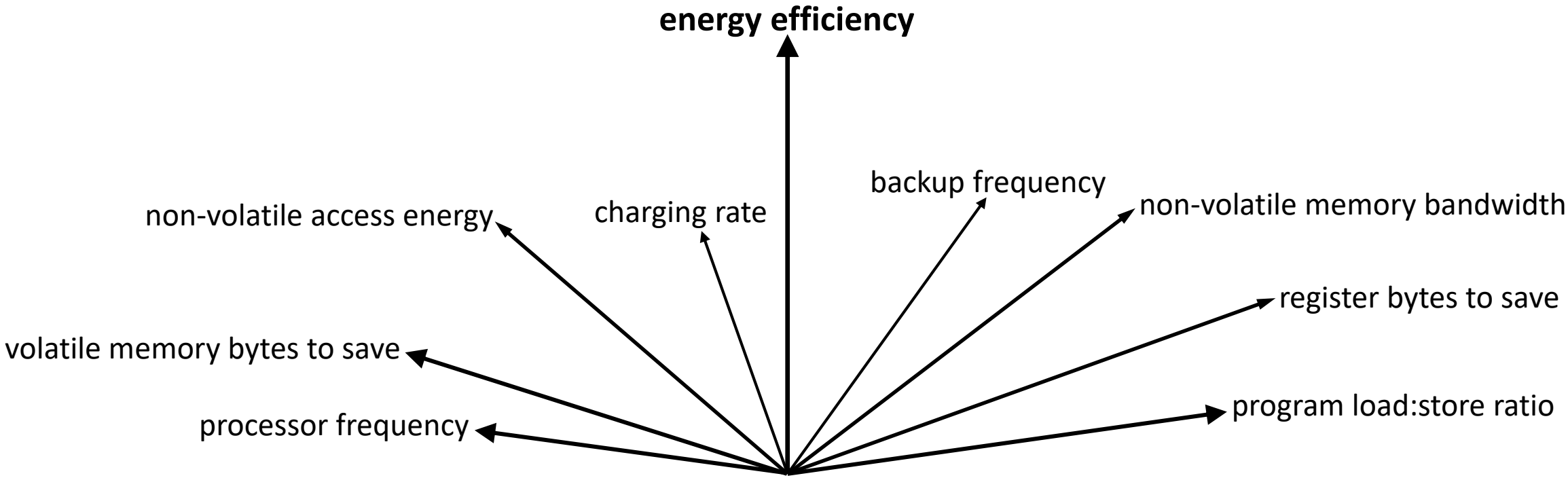
Design Space of Intermittent Systems



And many more design axes…

- e.g., SW vs. HW backups, volatile vs. non-volatile registers, dirty vs. non-dirty data

The EH Model

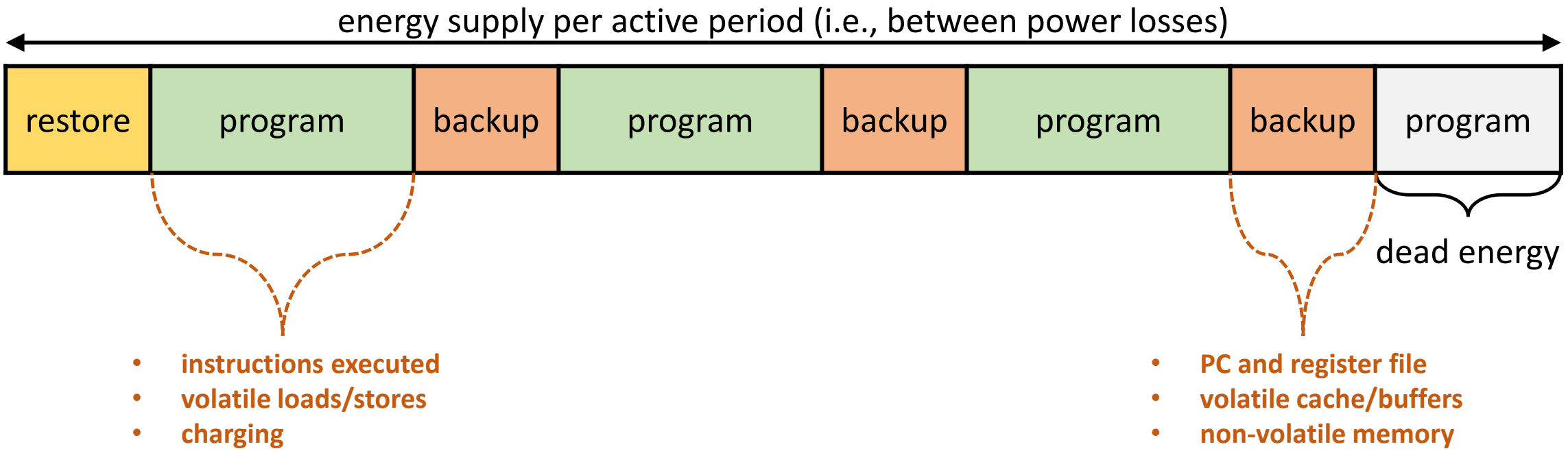
Analytical model for rapid design space exploration of arbitrary intermittent IoT systems [MICRO'18]:

- Estimates **forward progress**: % harvested energy spent on useful work
- Models significant factors that affect energy consumption:
  - Dead cycles: instructions executed that are not saved prior to power loss
  - Charging rate and capacitor size
  - Architectural state (e.g., register file) and application state (e.g., volatile data) per backup
  - Non-volatile memory latency and energy per access
  - Backup frequency; multi-backup vs. single-backup systems

The EH Model

Multi-backup systems:

- e.g., Clank [ISCA'17], Alpaca [OOPSLA'17], Mementos [ASPLOS'11]



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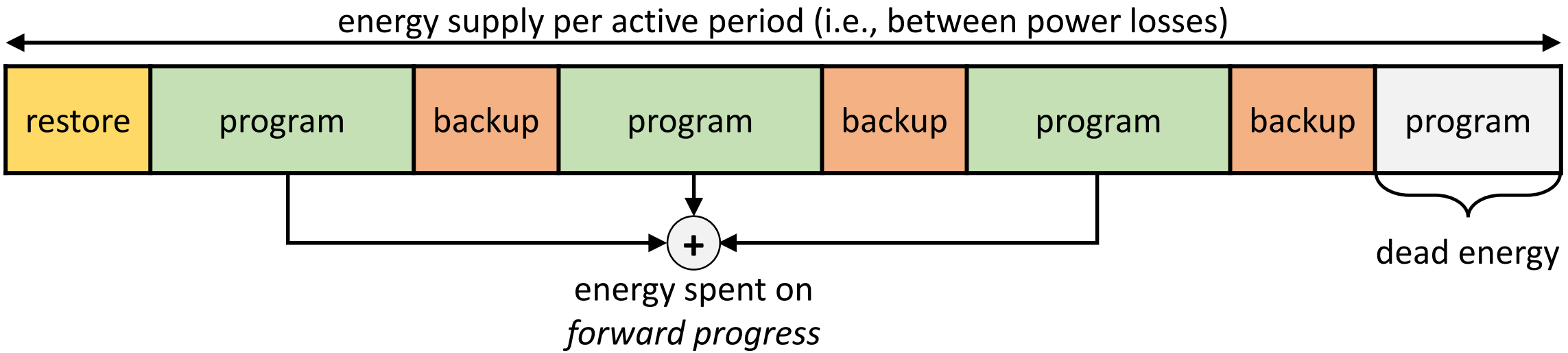
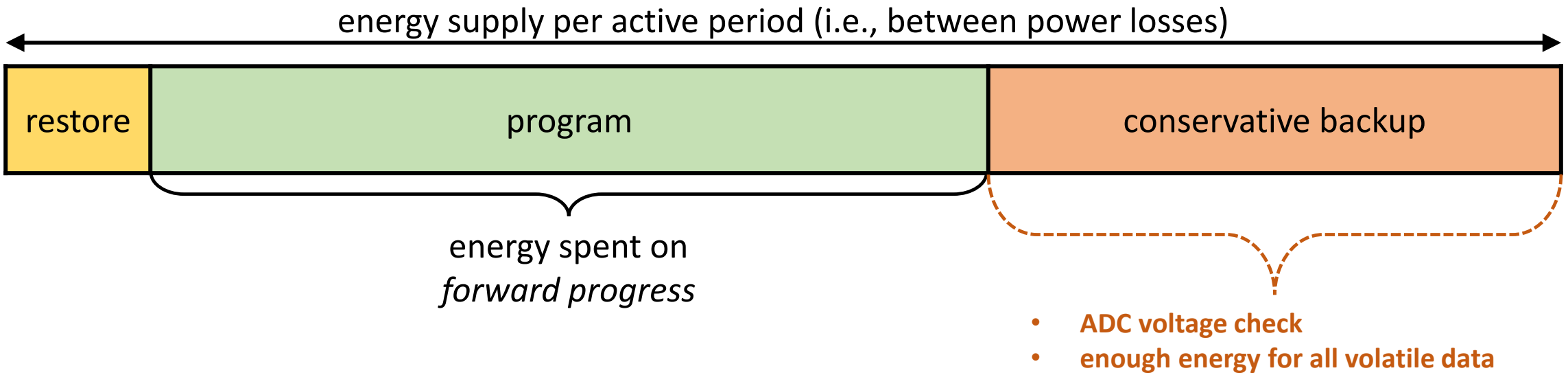


The EH Model

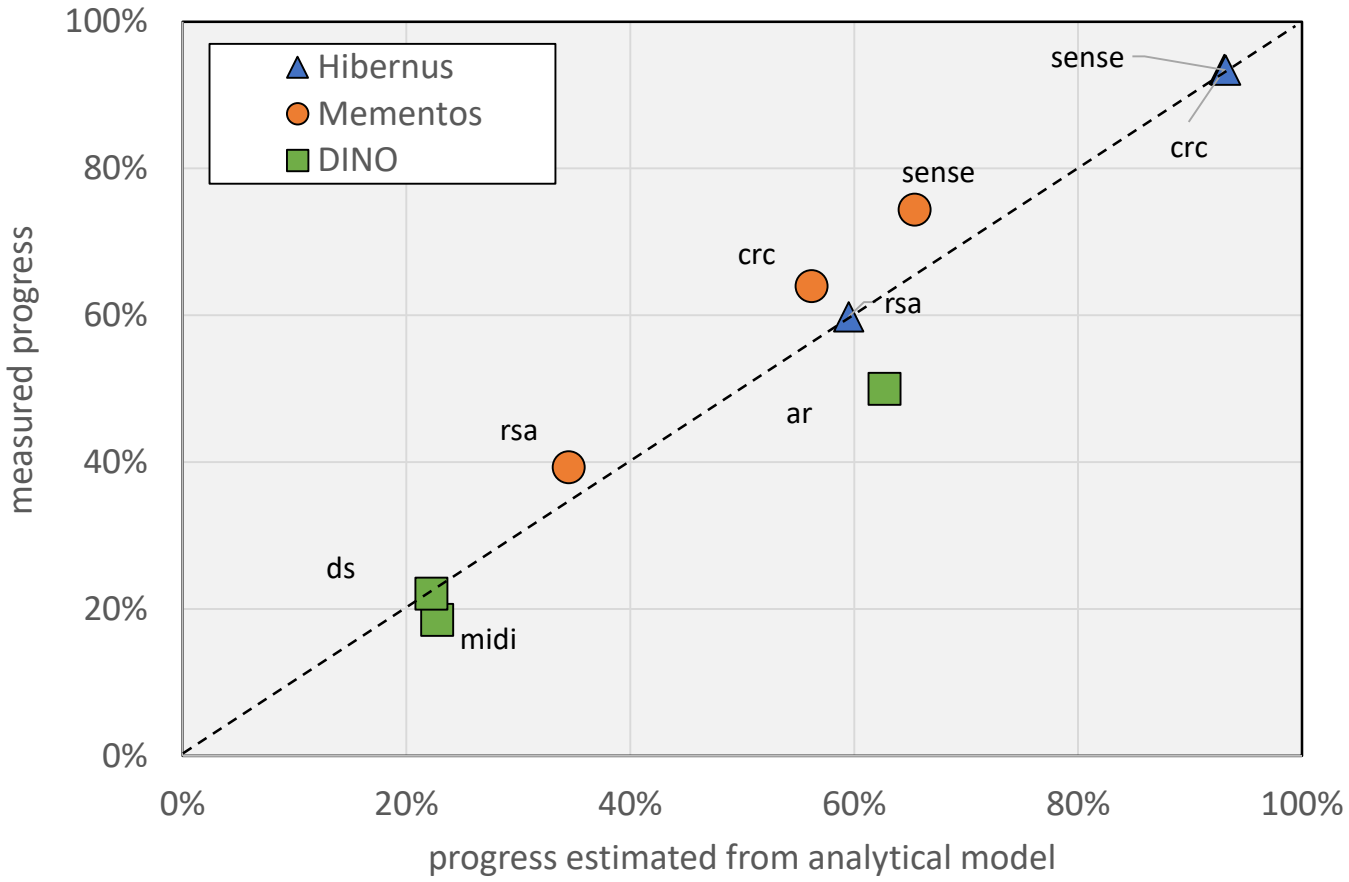
Single-backup systems:

- e.g., Hibernus [IEEE TCAD'16], NVP [HPCA'15], QuickRecall [VLSID'14]



The EH Model

Evaluation on MSP430 LaunchPad:



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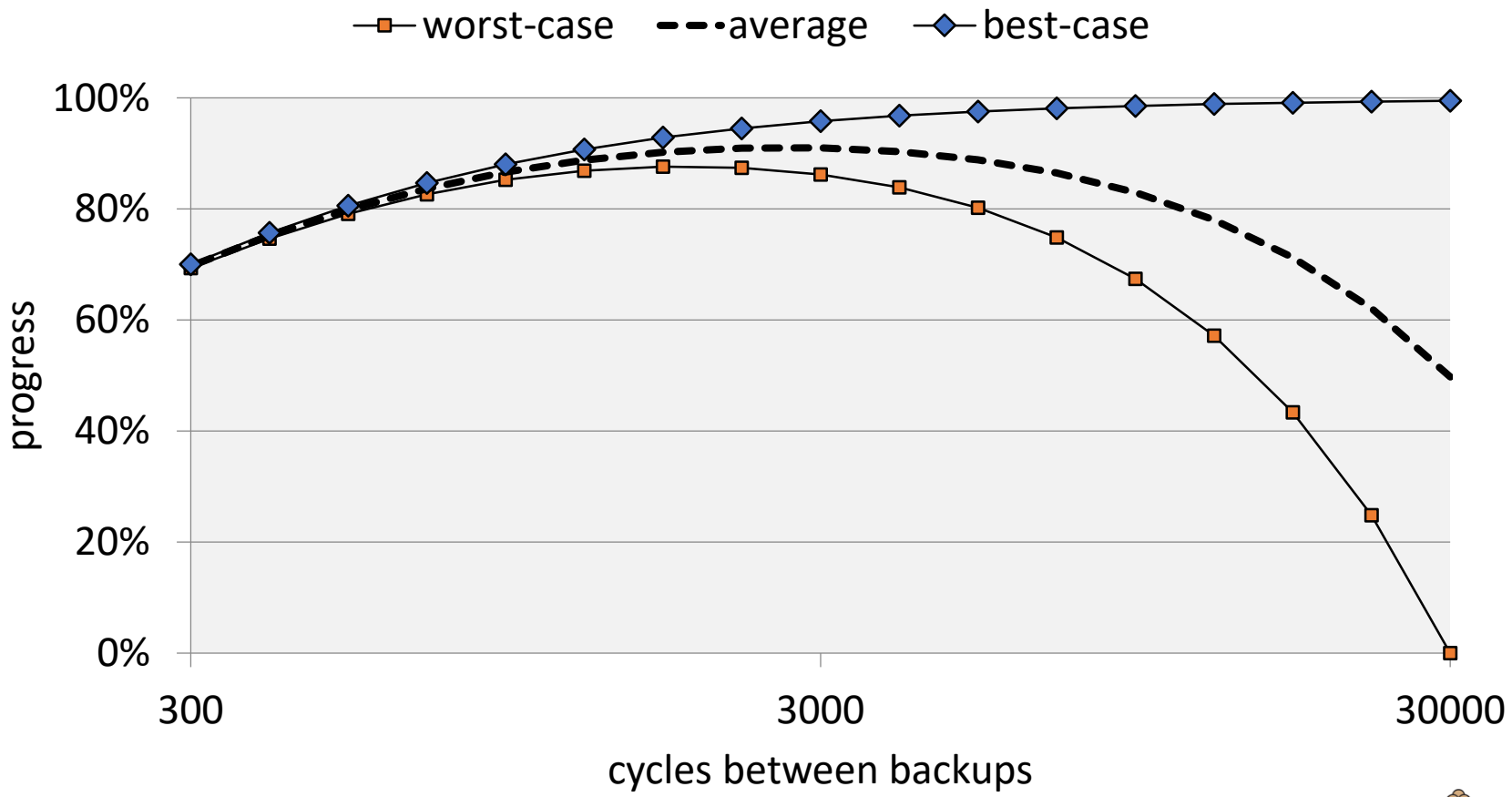
The EH Model – Analytical Explorations

e.g., Mementos [ASPLOS'11]:



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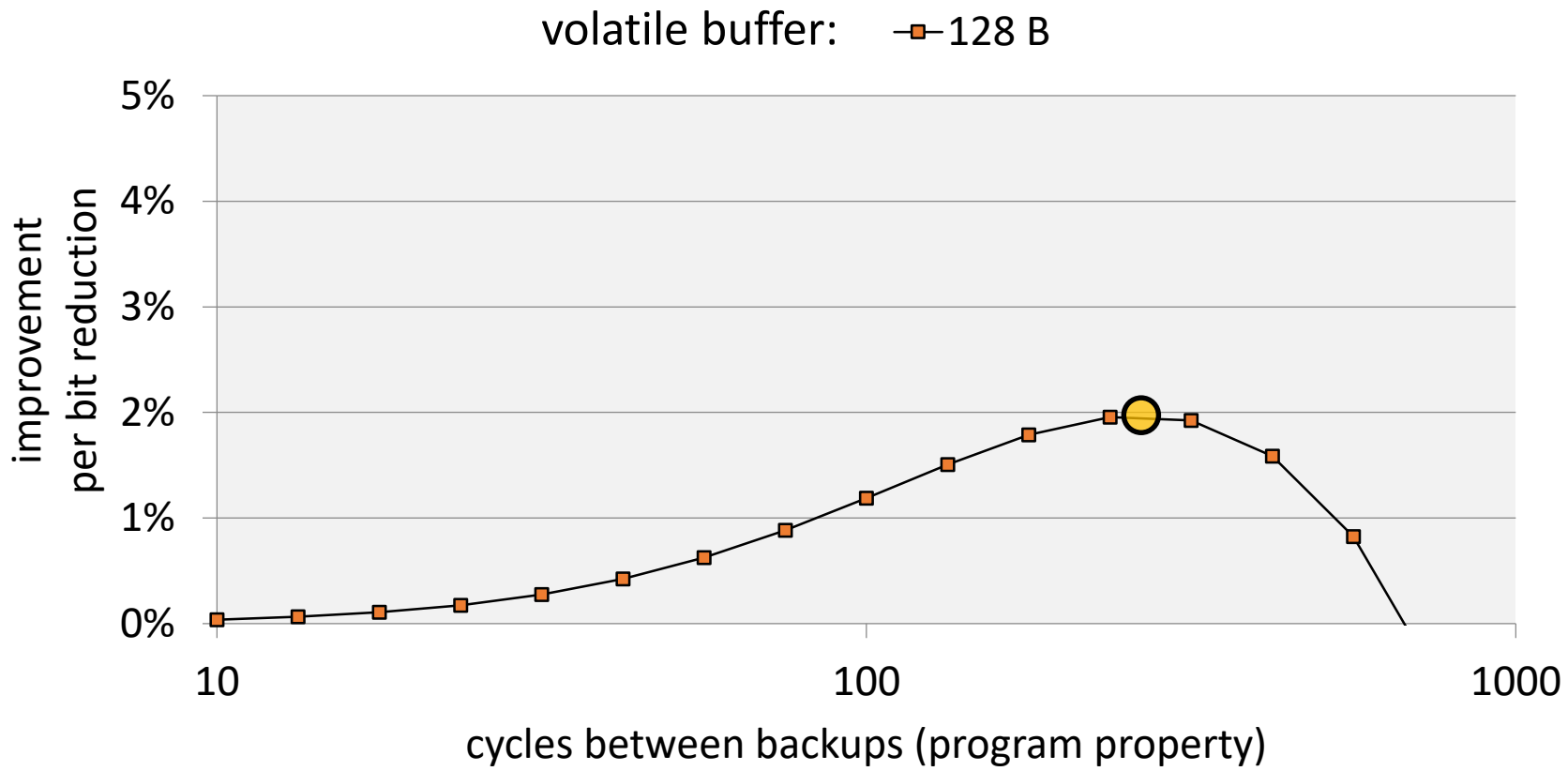
The EH Model – Analytical Explorations

e.g., Reduced-precision image recognition on Clank [ISCA'17]:



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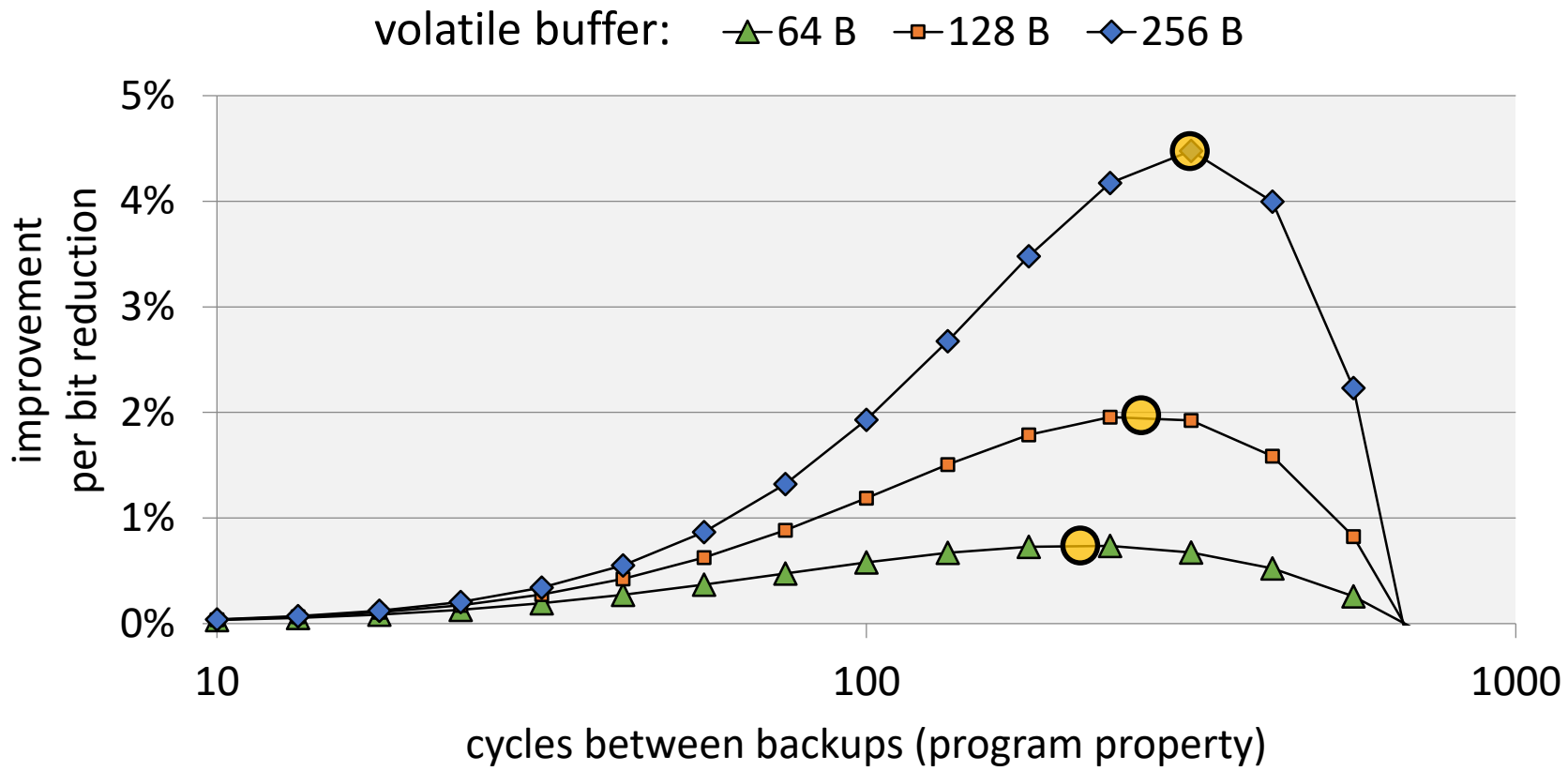

The EH Model – Analytical Explorations

More case studies and explorations [MICRO'18]:

- Saving architectural vs. application state
- The benefits of store-major locality
- Controlling backups via write-after-read dependences

Architecting for Intermittence?

Design Tools:

- EH Model [MICRO'18]

Design Paradigms:

- **Computational Skimming [HPCA'19]**

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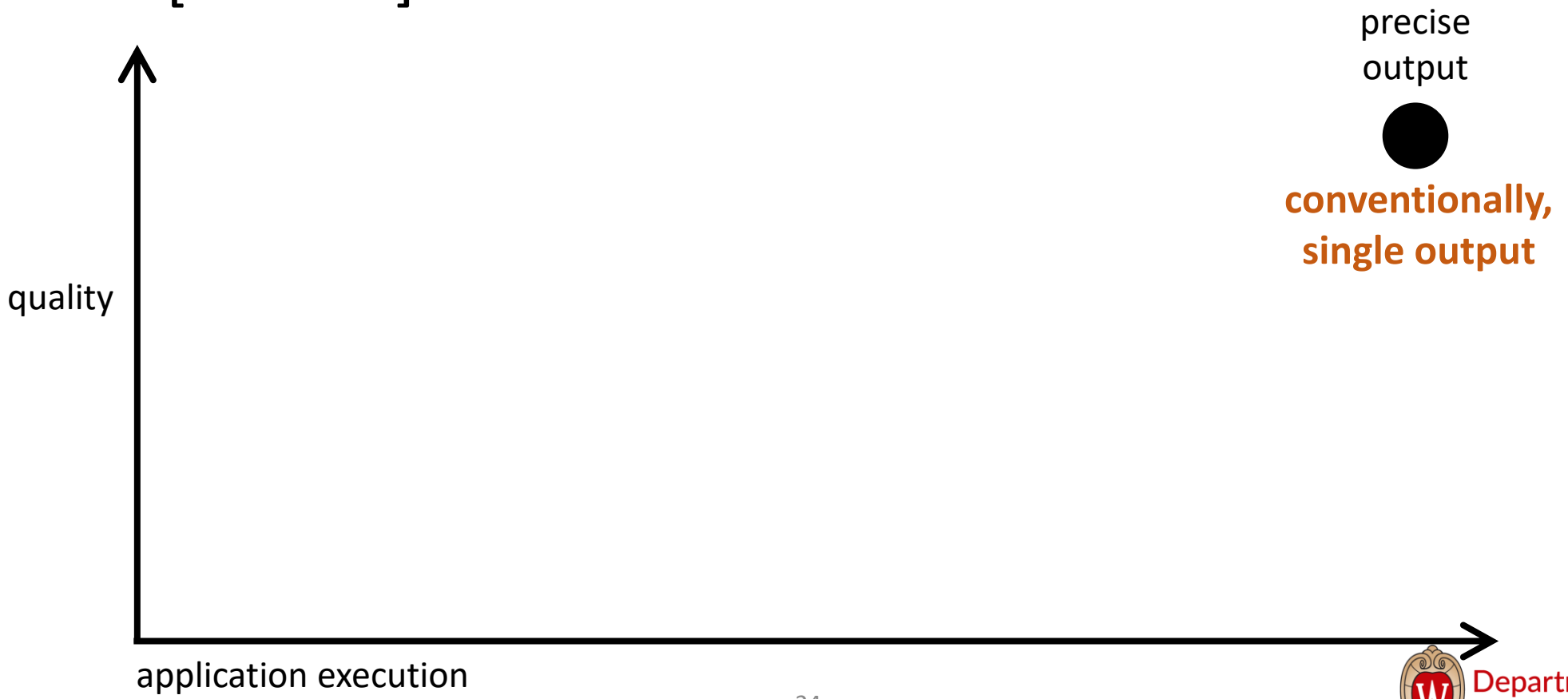
The Anytime Automaton Model

General-purpose computation model for quality-proportional execution [ISCA'16]:



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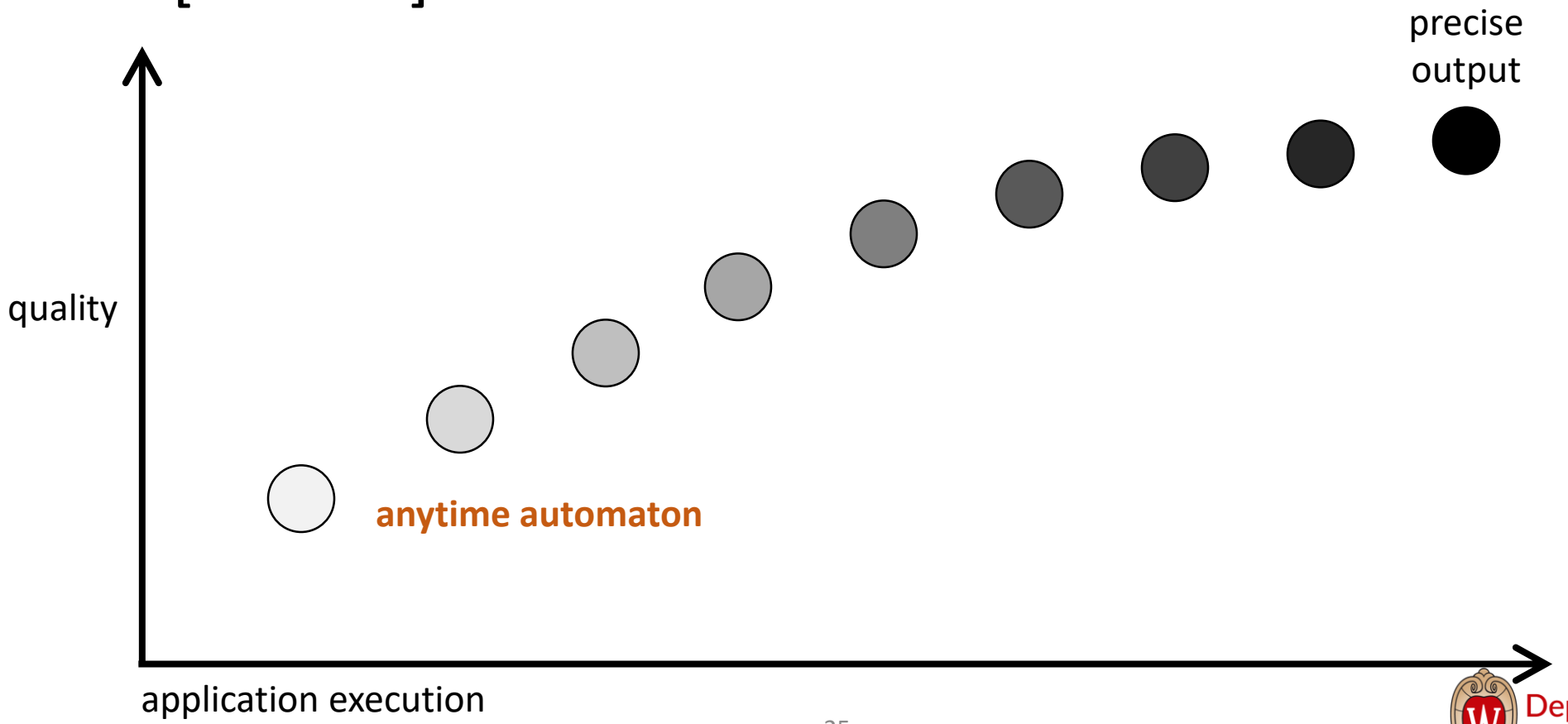

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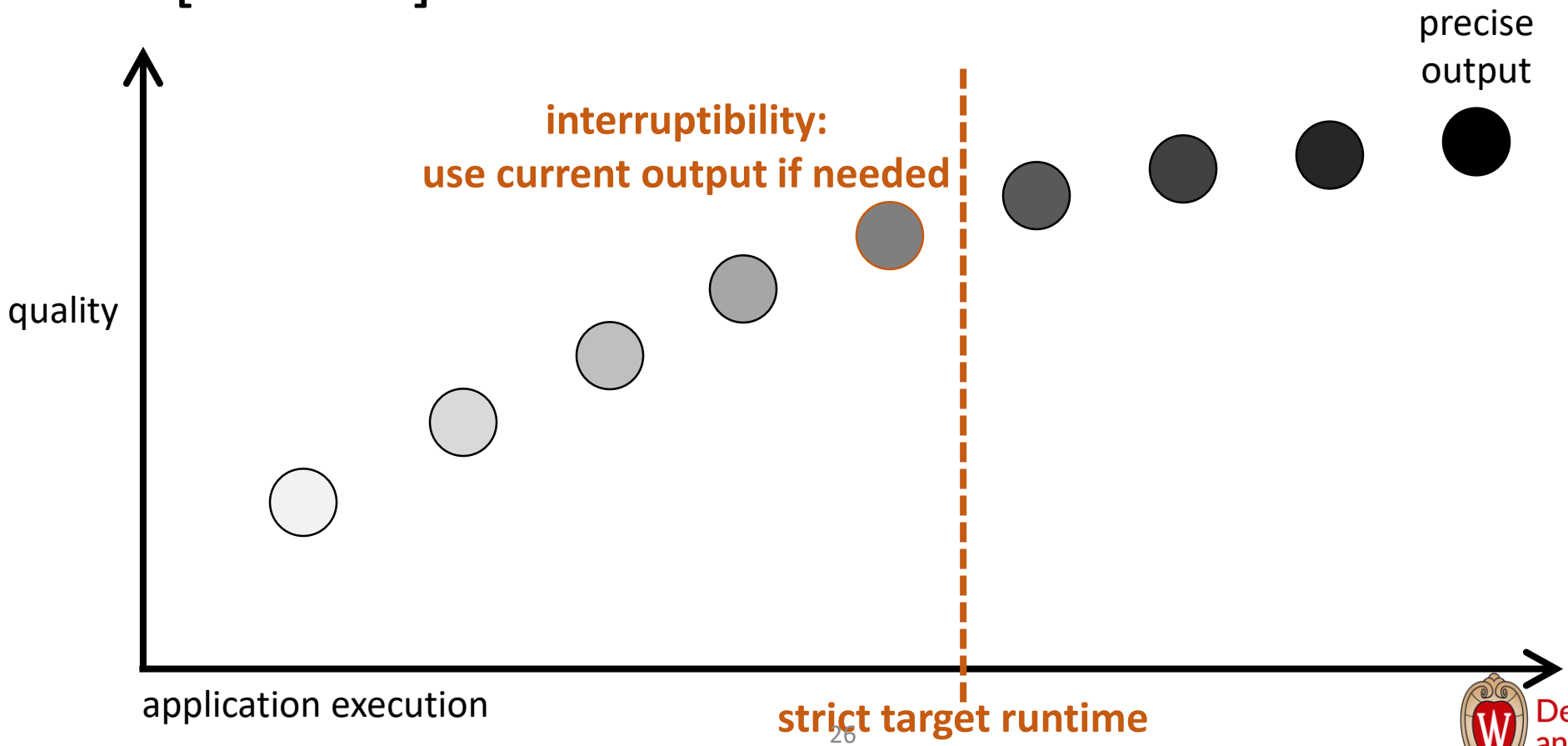

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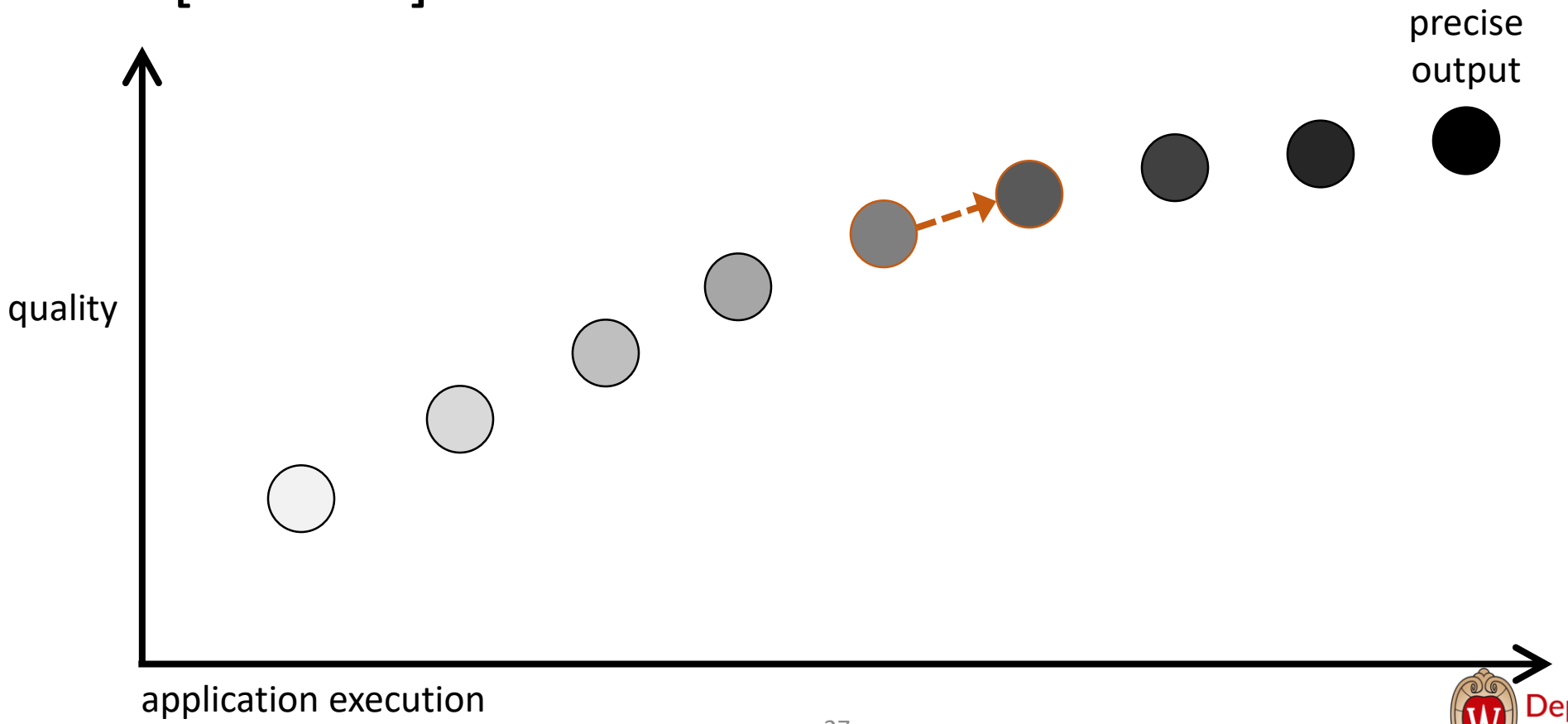

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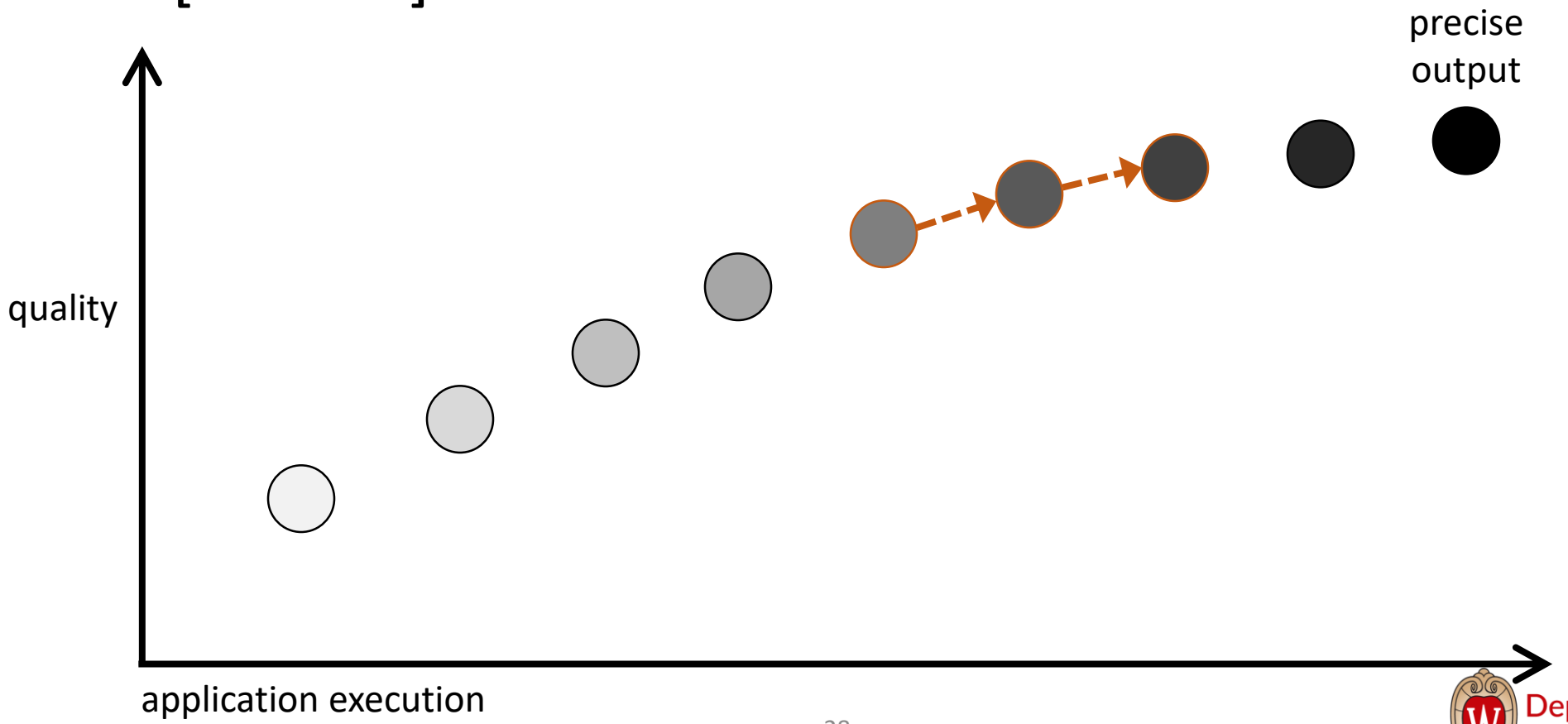

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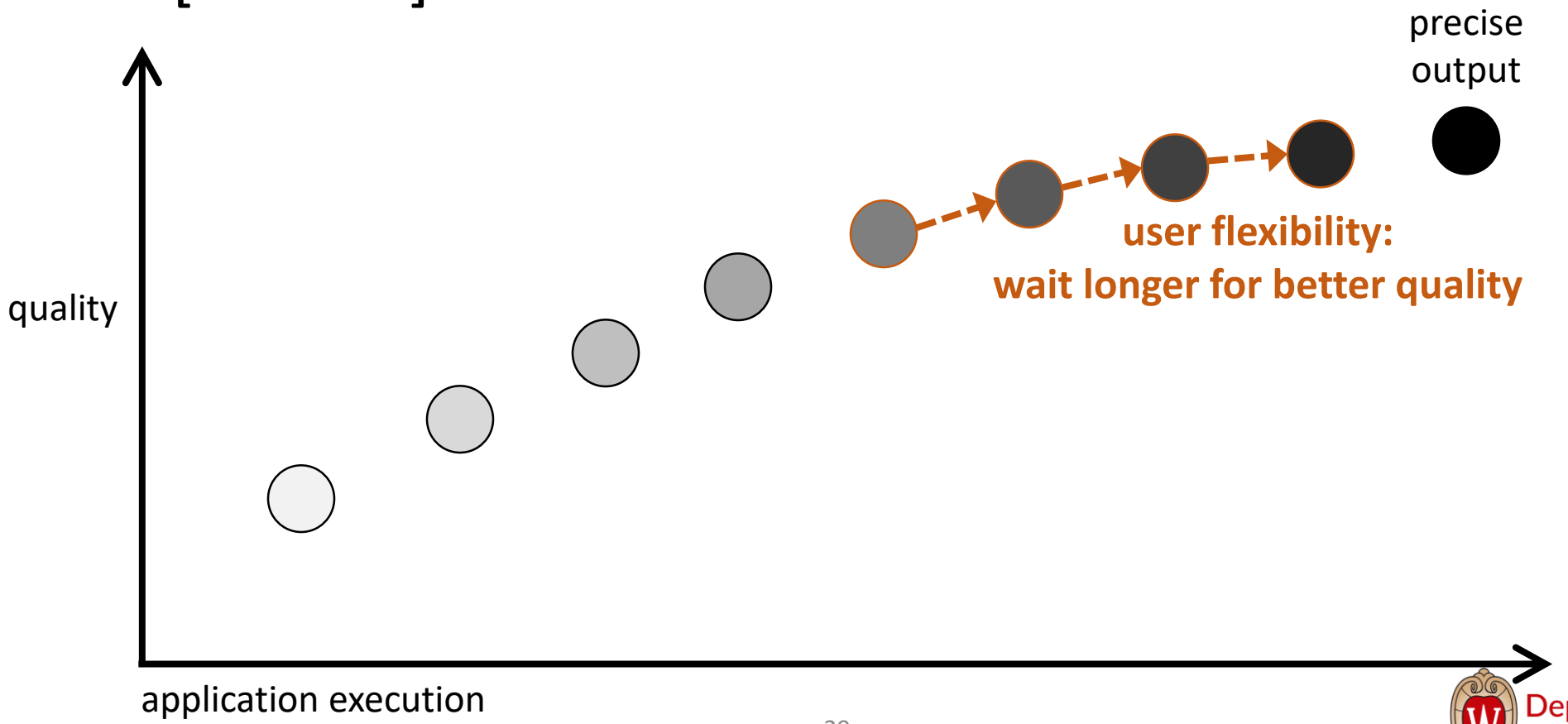

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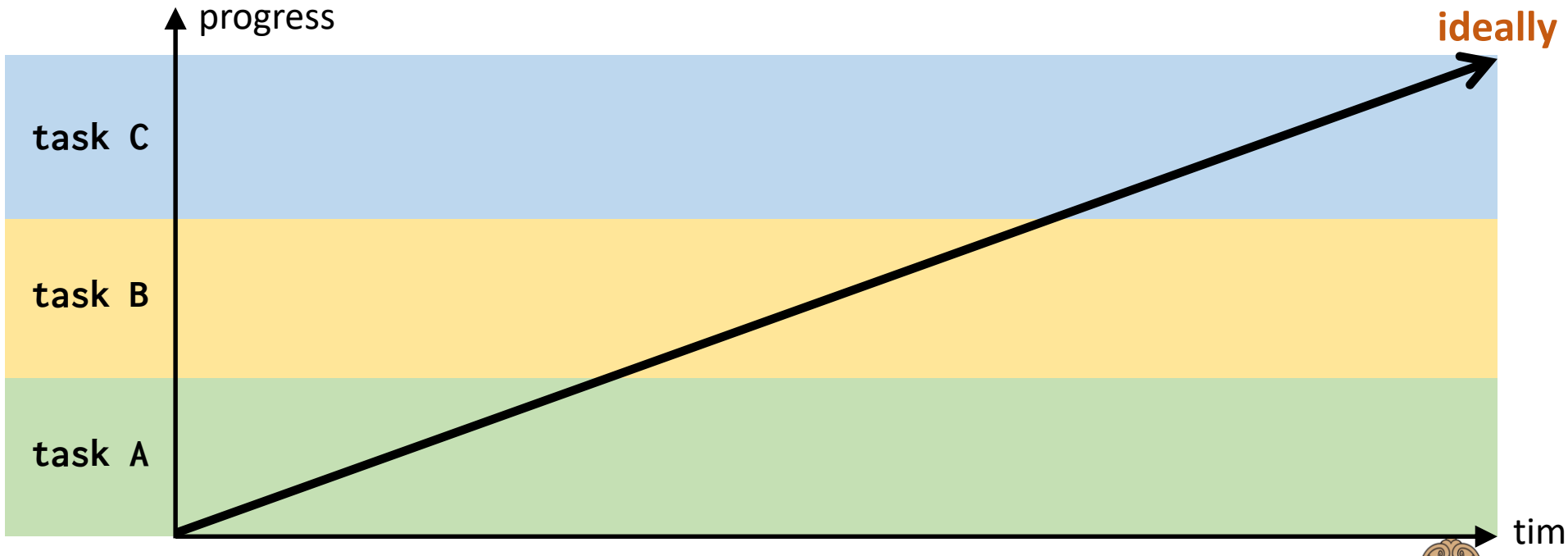

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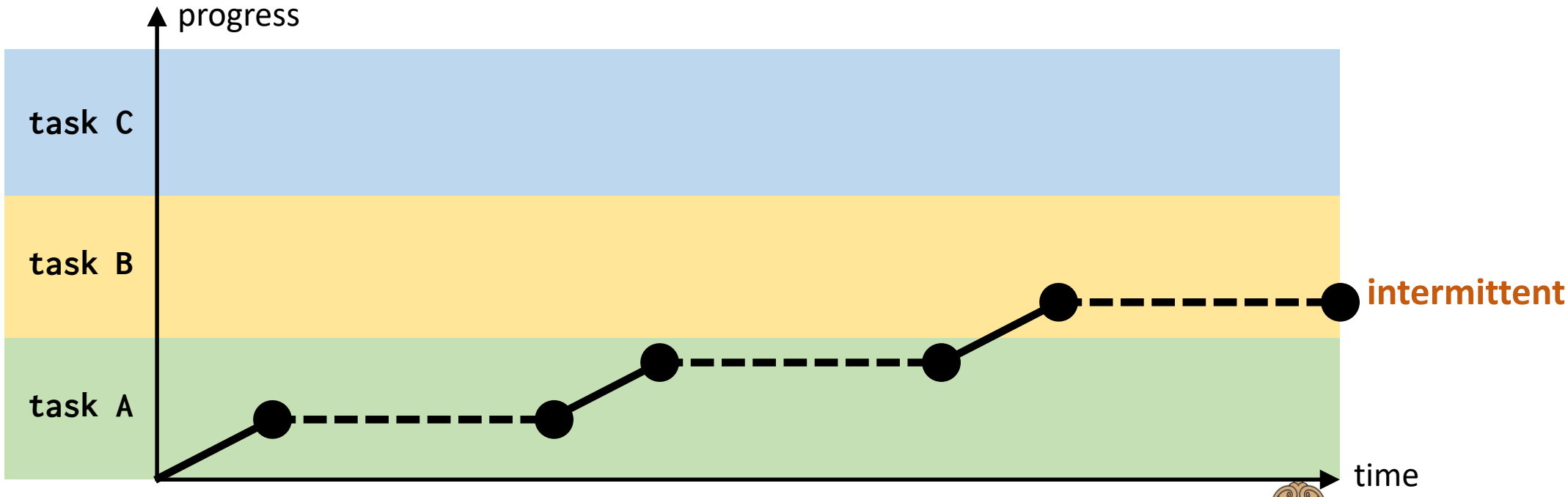

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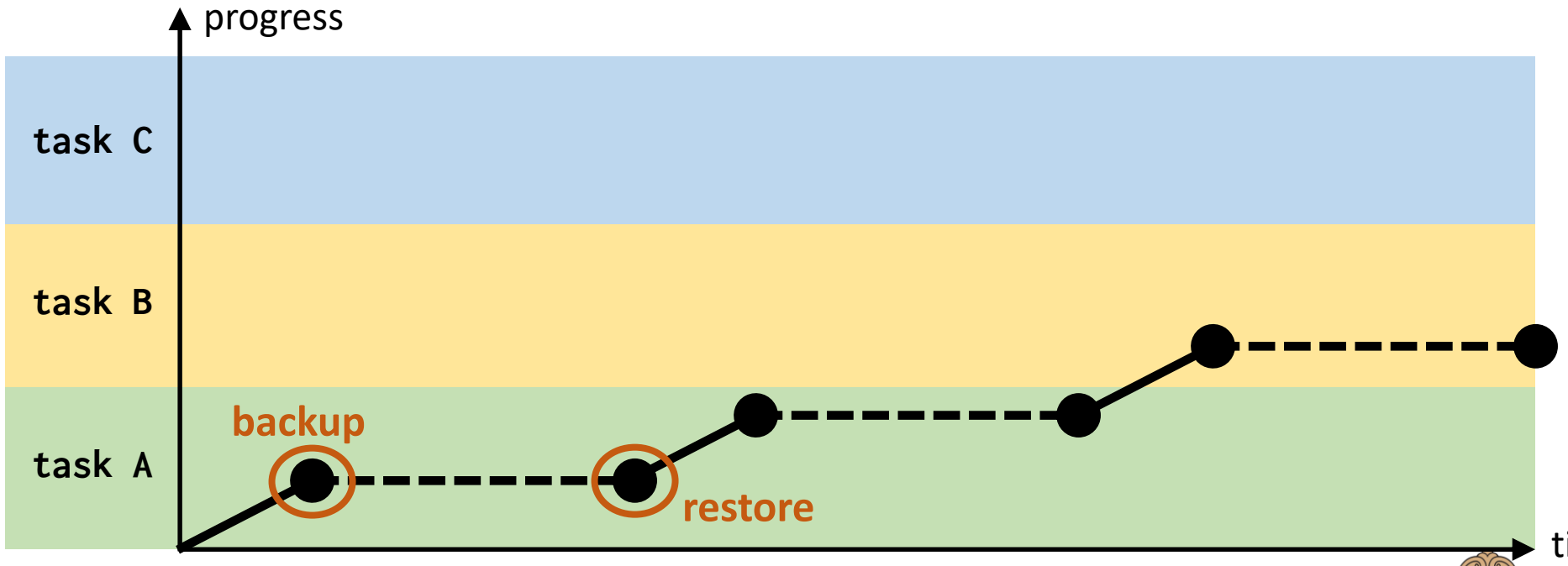
Computational Skimming

Insight: Decouple backup from restore point via anytime model



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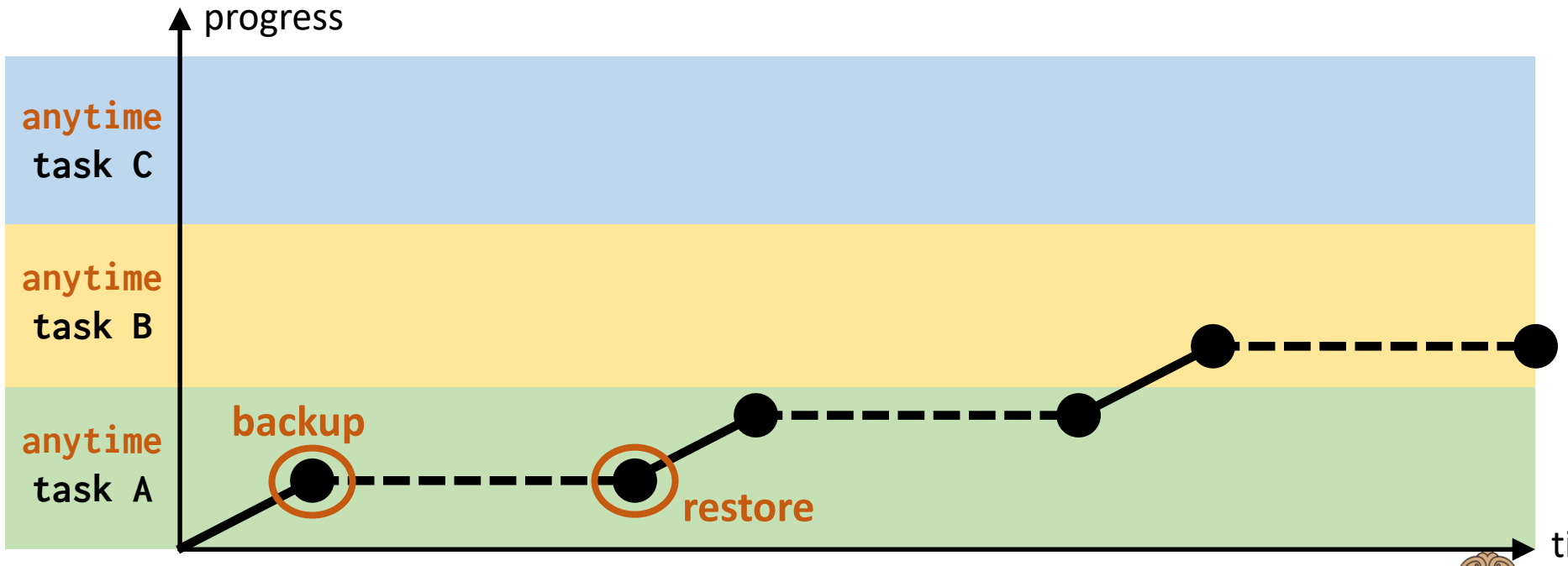

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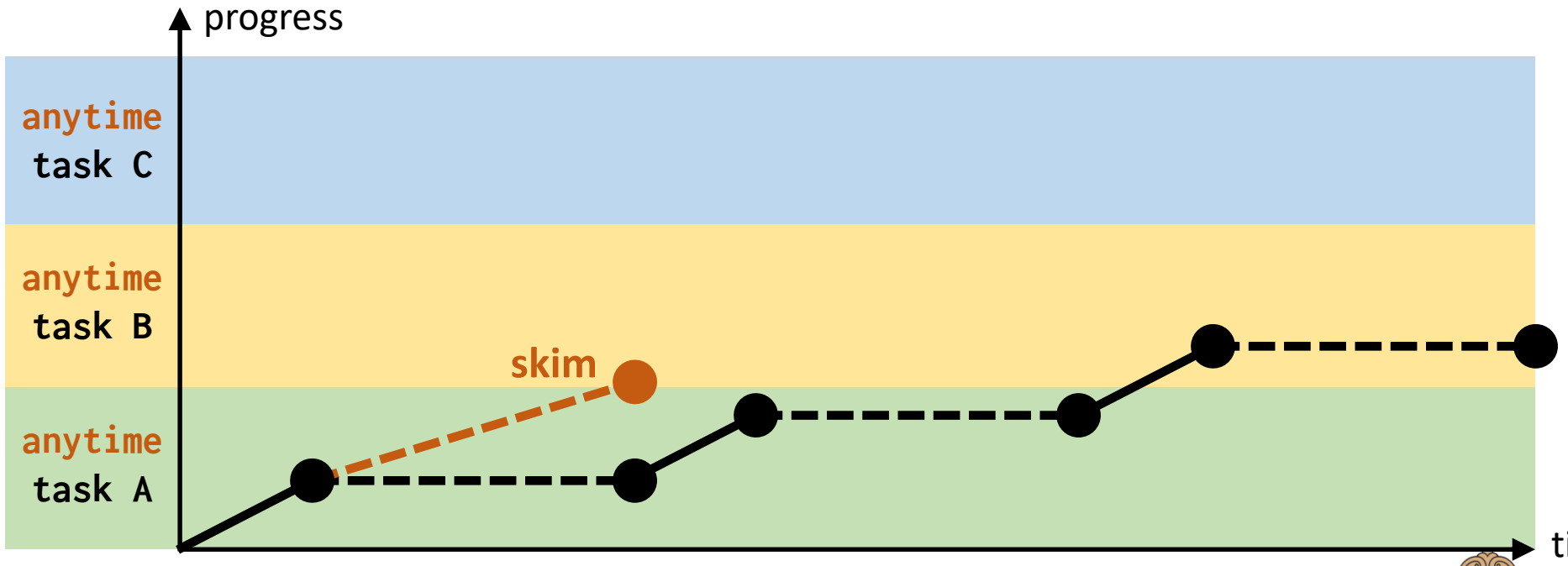

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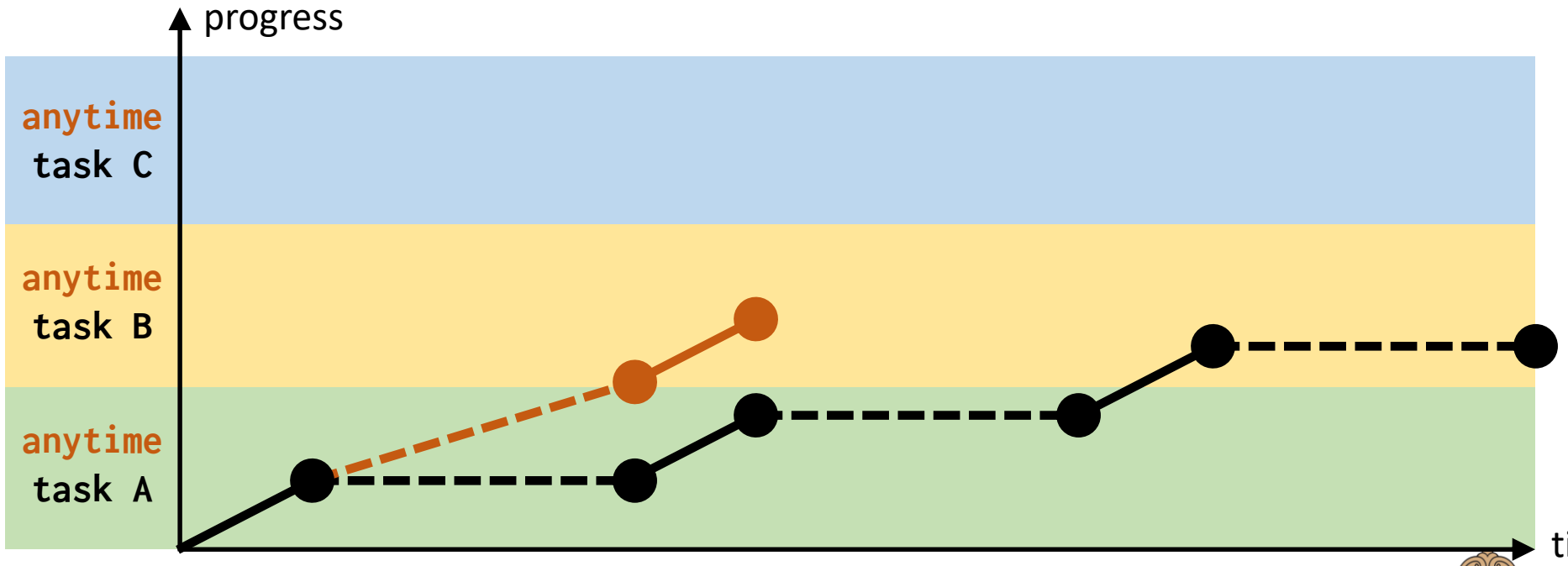

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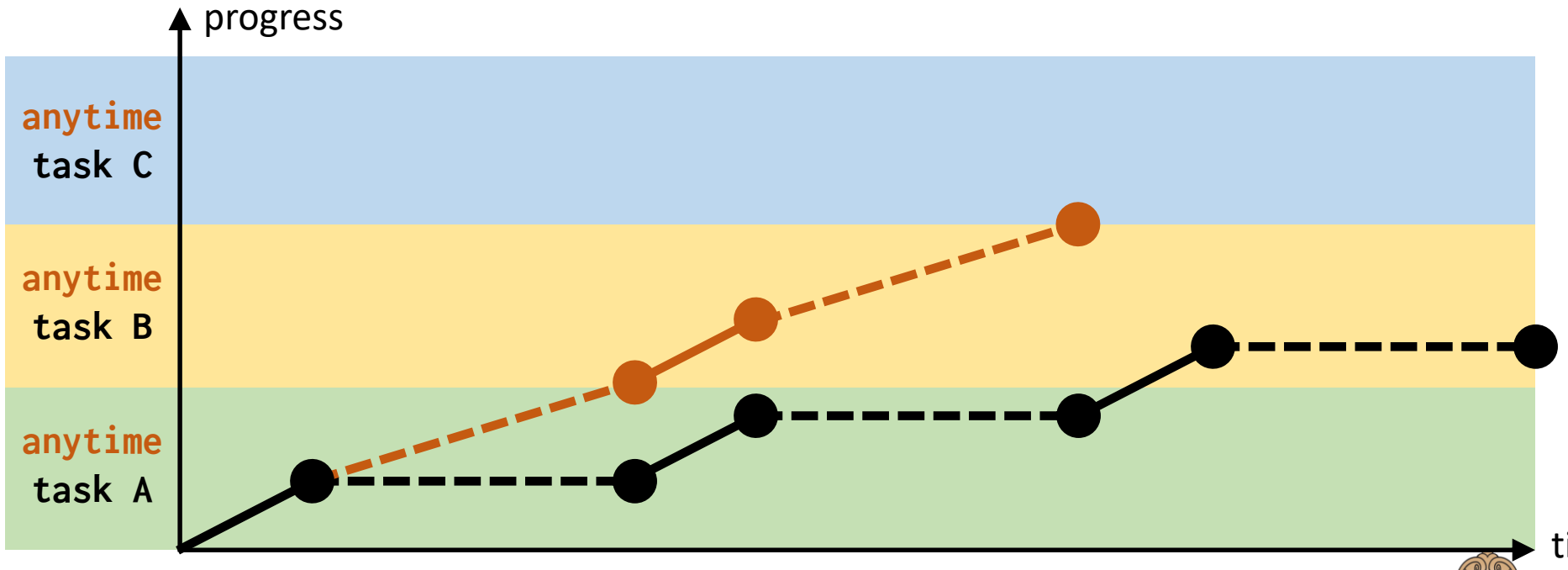

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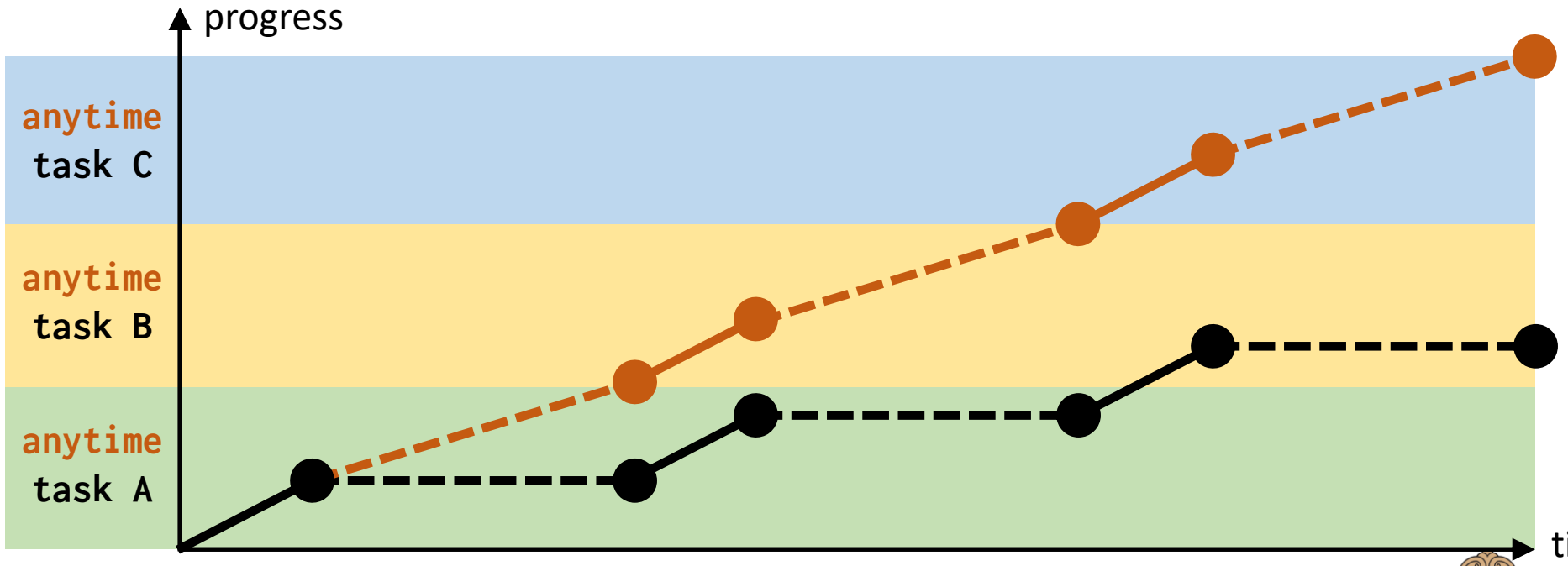
Computational Skimming

Insight: Decouple backup from restore point via anytime model

Computational Skimming: Quality of program output scales with how much energy we can afford



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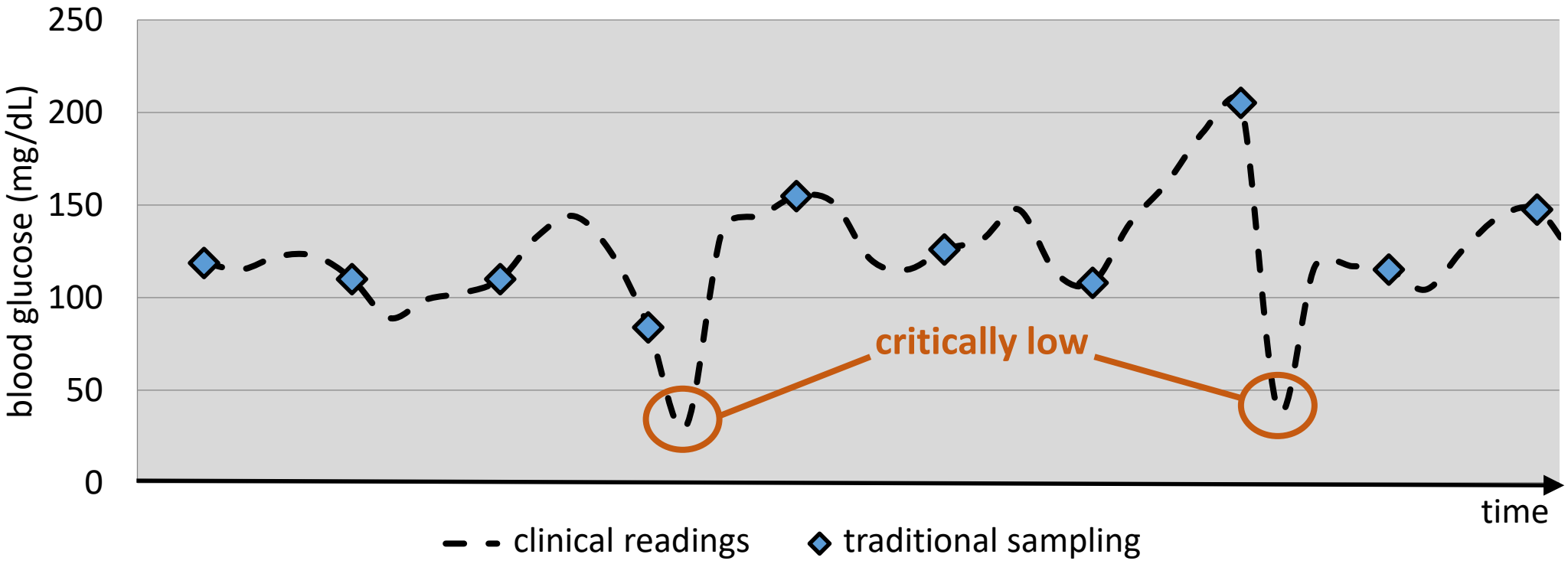
Computational Skimming

e.g., Blood glucose monitoring:



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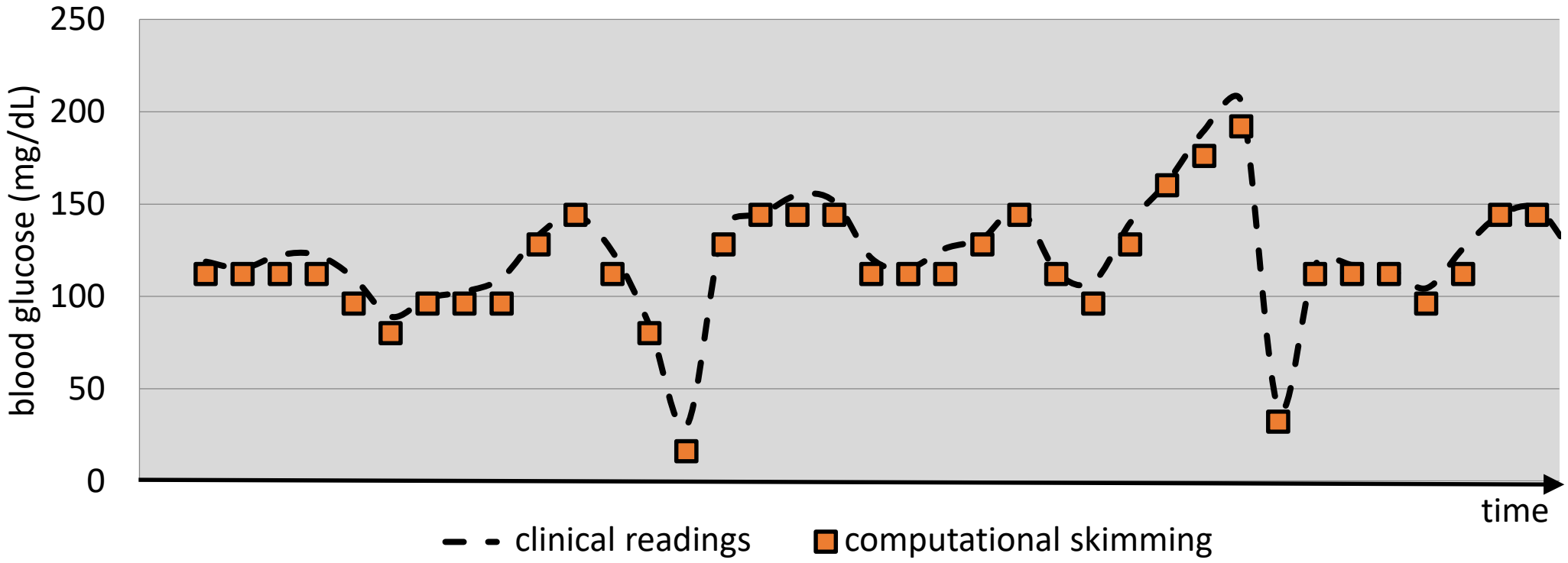

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Computational Skimming – What's Next

What's Next processor architecture for computational skimming, designed from baseline ARM M0+ [HPCA'19]:

- Anytime subword pipelining
- Anytime subword vectorization
- Subword memoization

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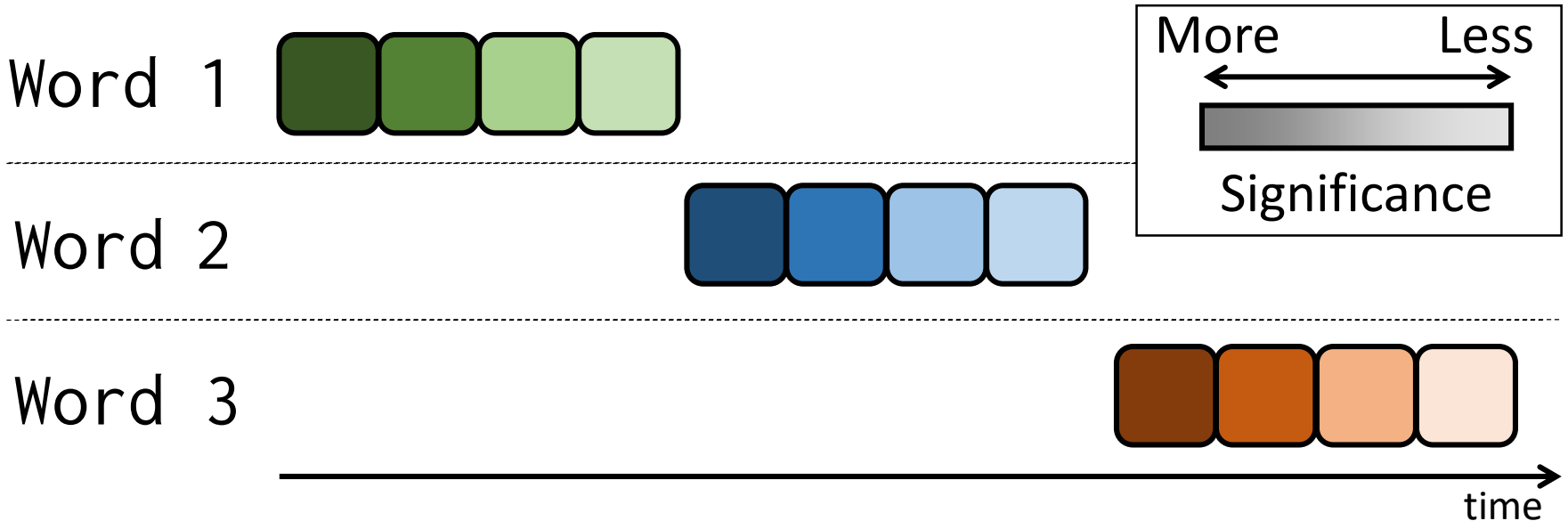
Computational Skimming – Anytime Pipelining

Long-latency operations (e.g., mul):

- Conventional



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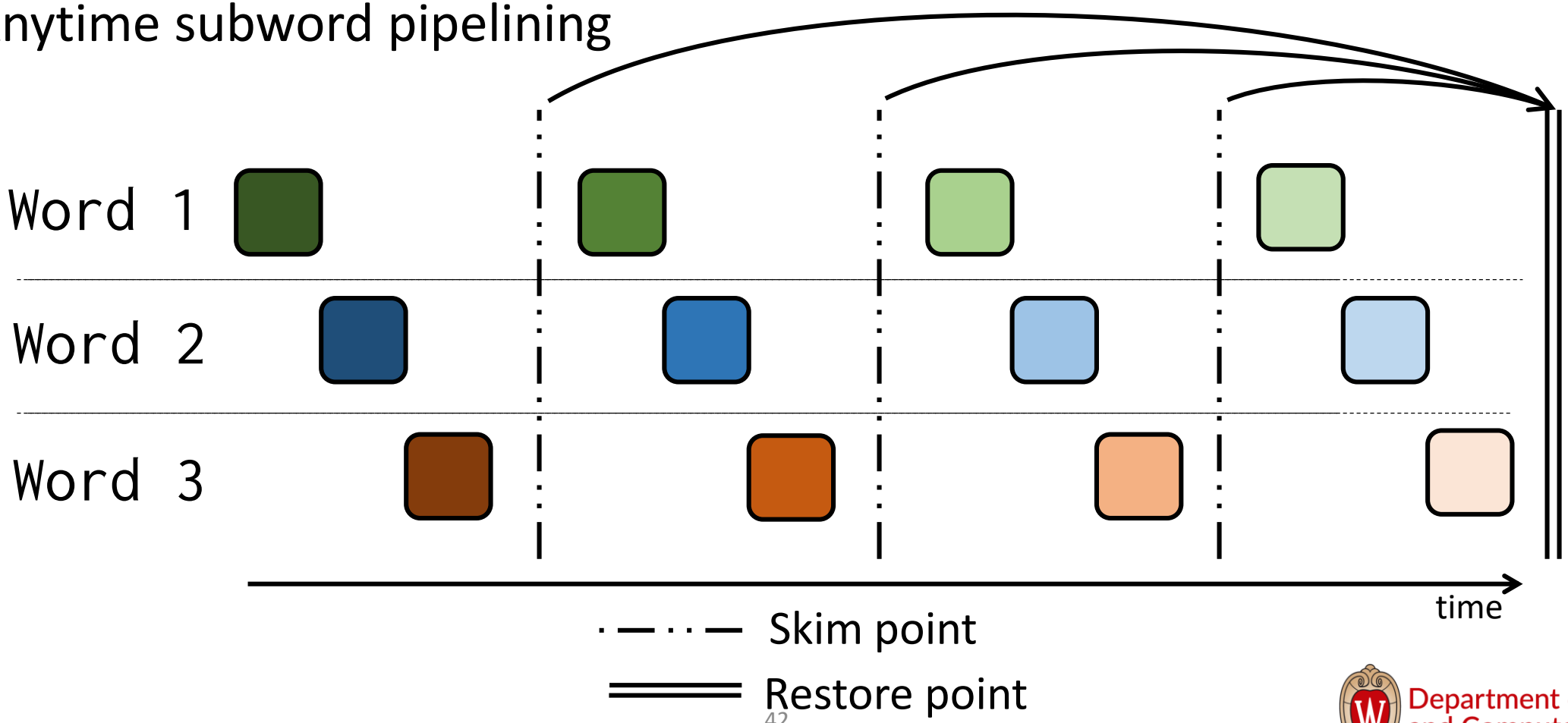

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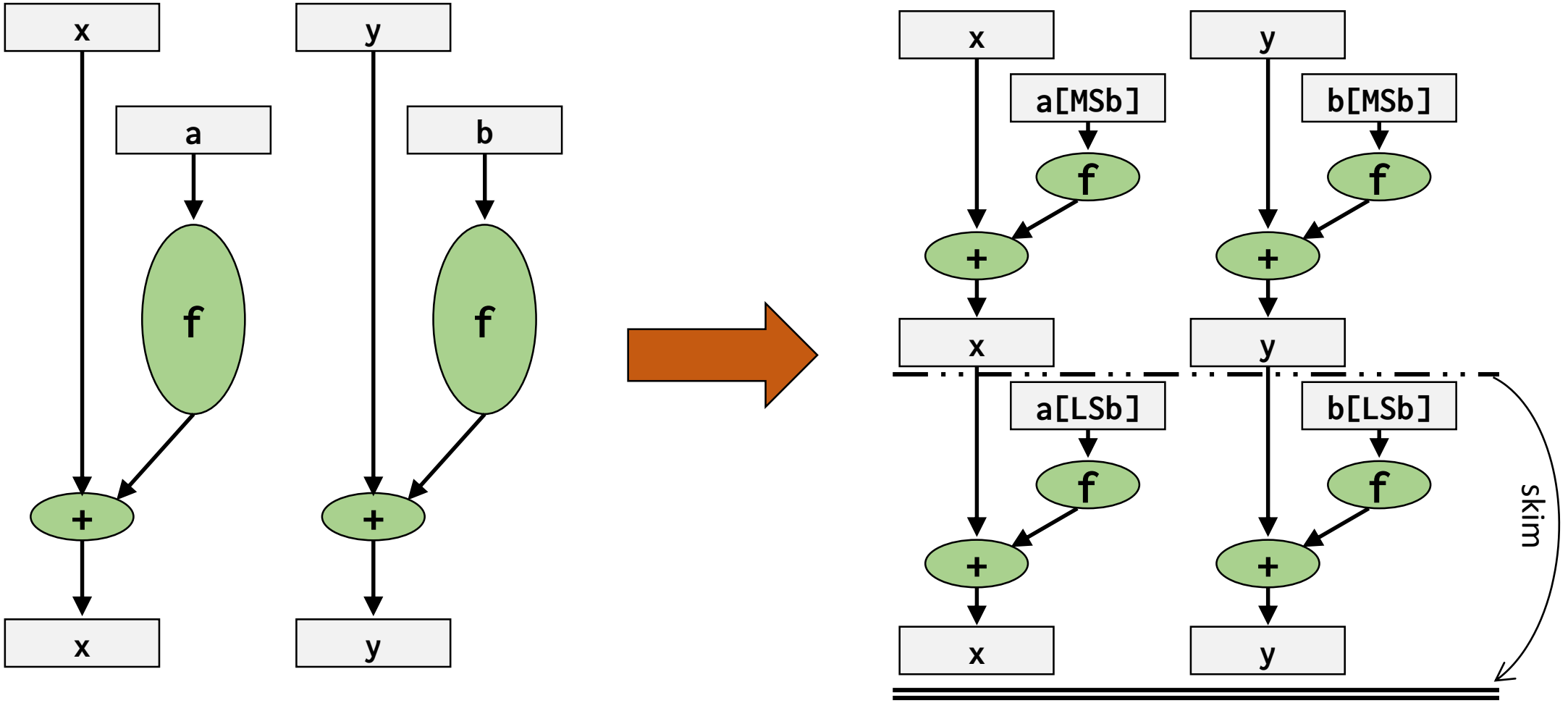
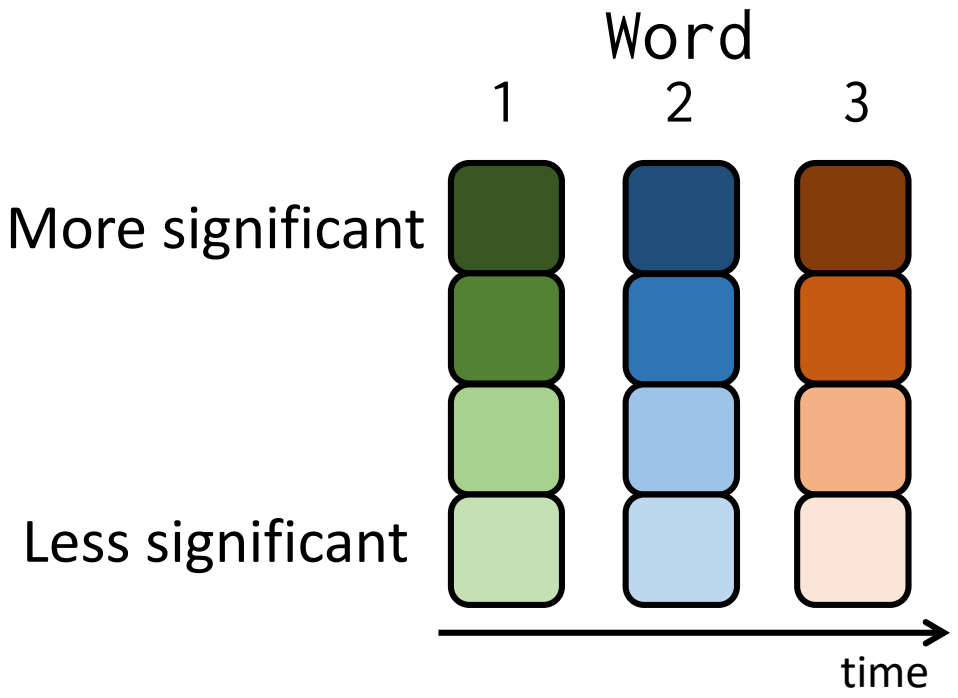


Computational Skimming – Anytime Vectorization

Short-latency operations (e.g., add):

- Conventional



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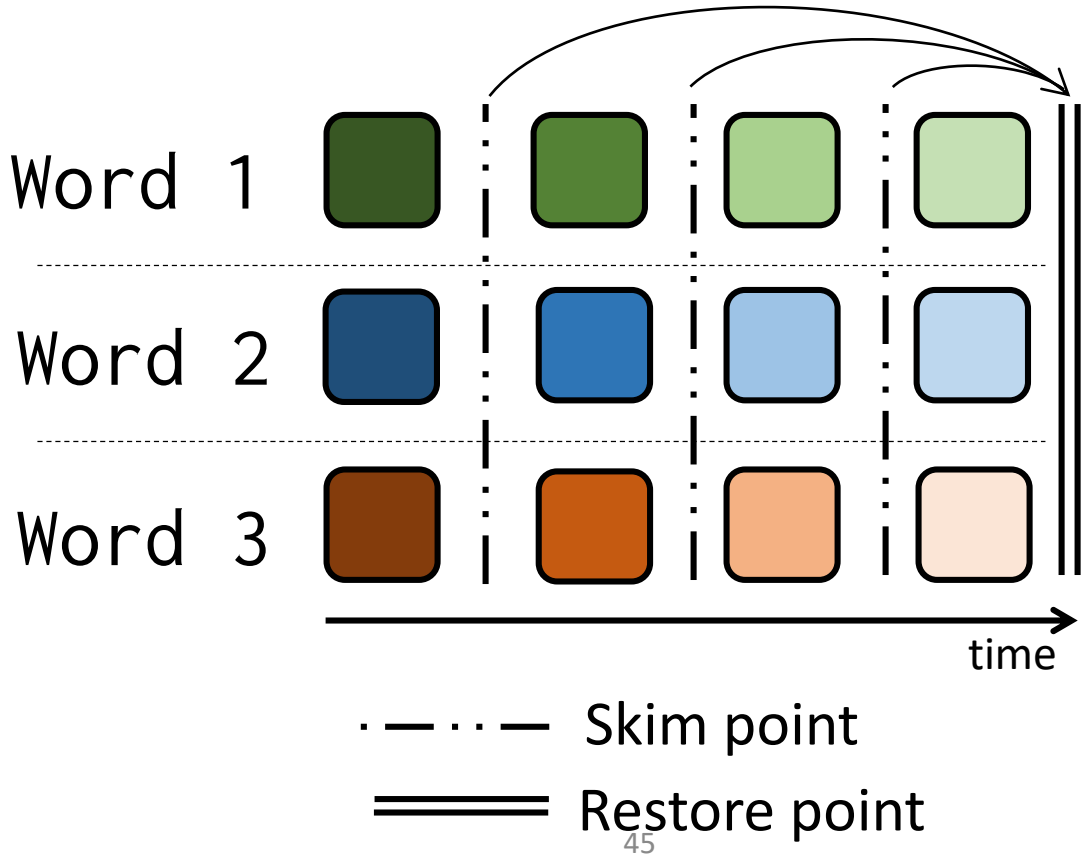
- Anytime subword vectorization



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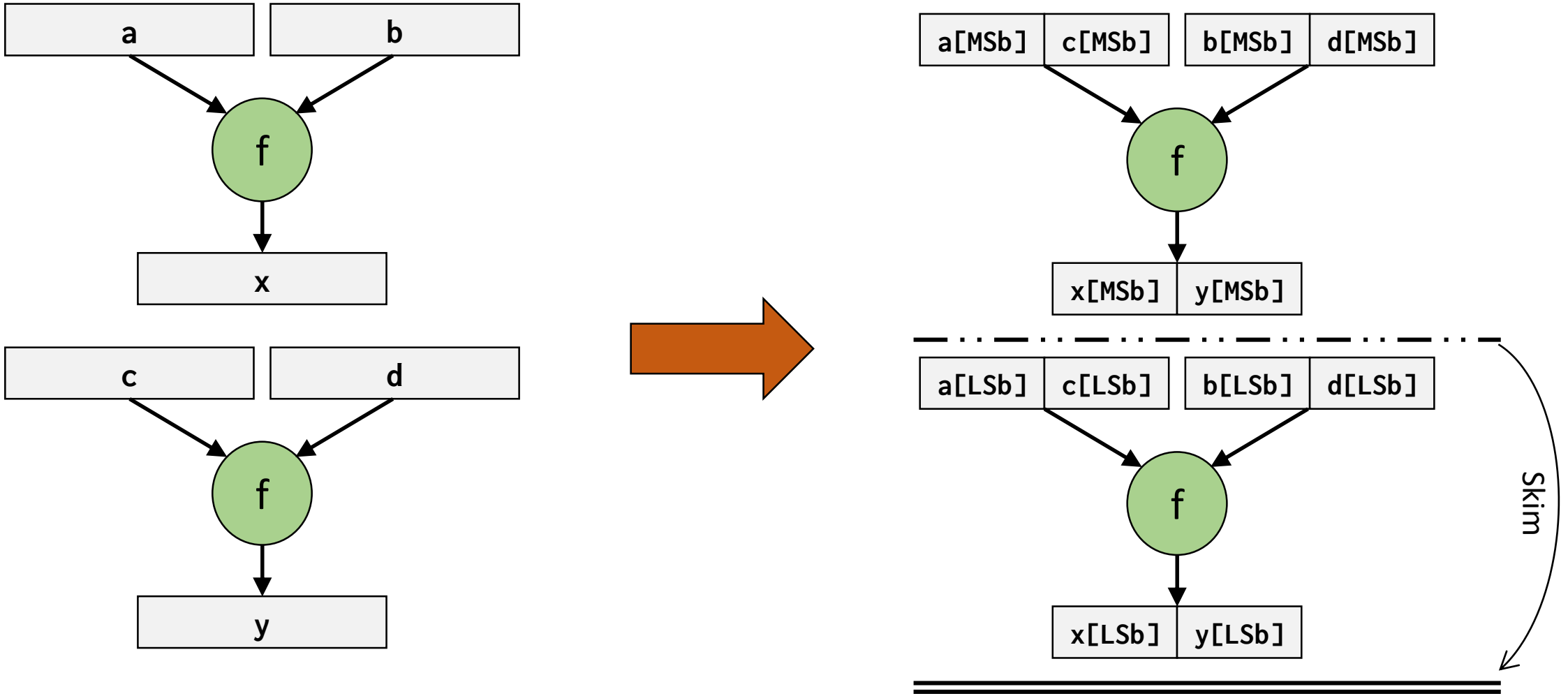
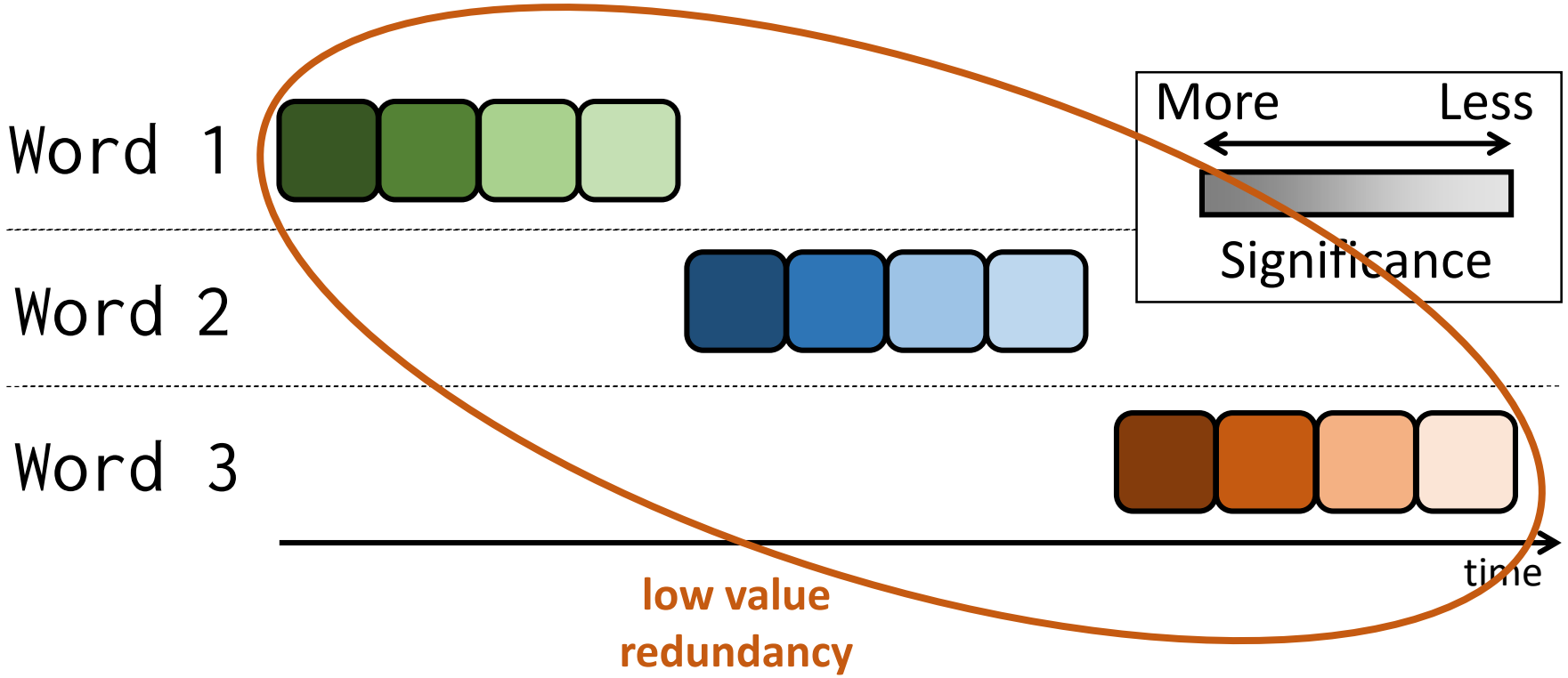


Computational Skimming – Subword Memoization

In conjunction with anytime subword pipelining:

- Conventional



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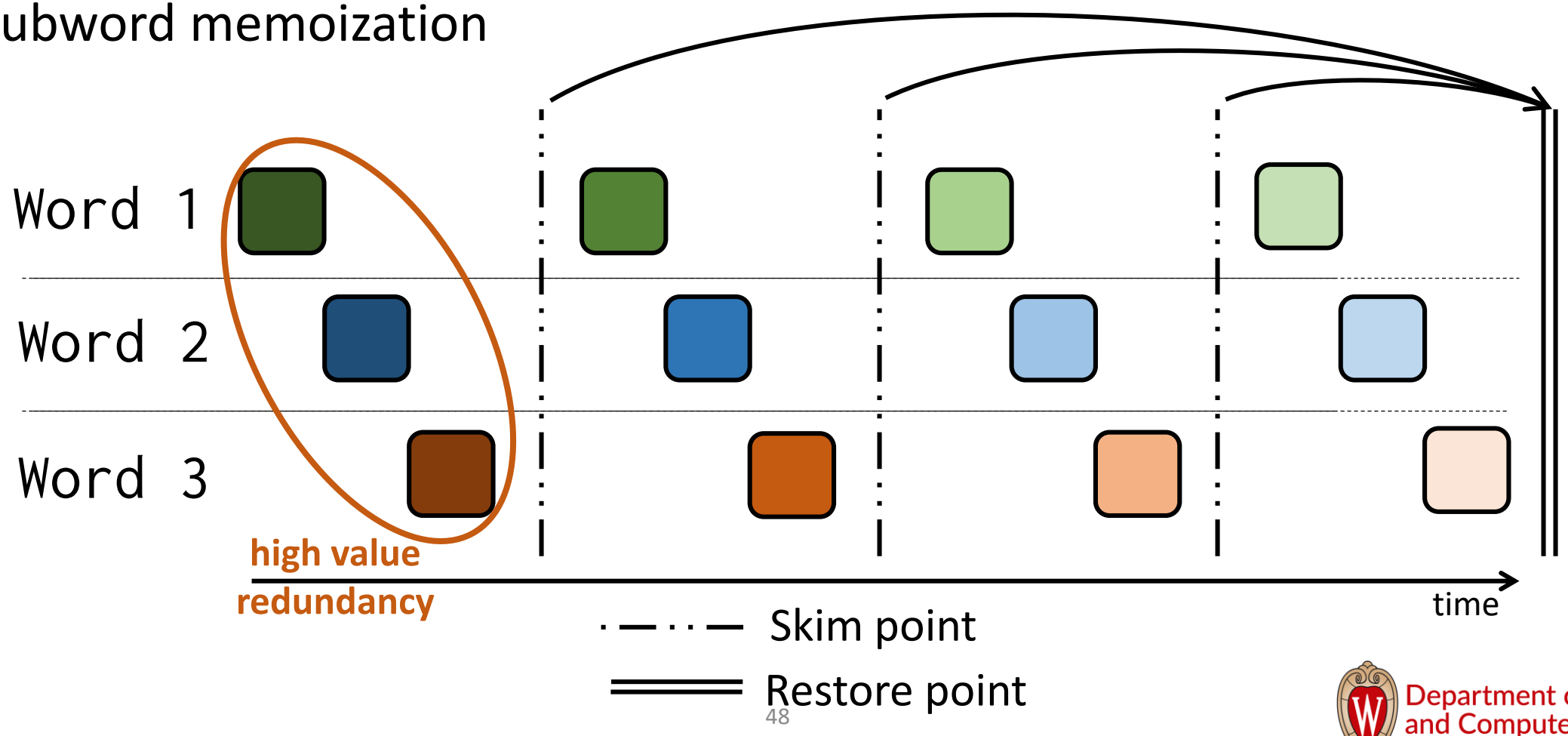
- Subword memoization



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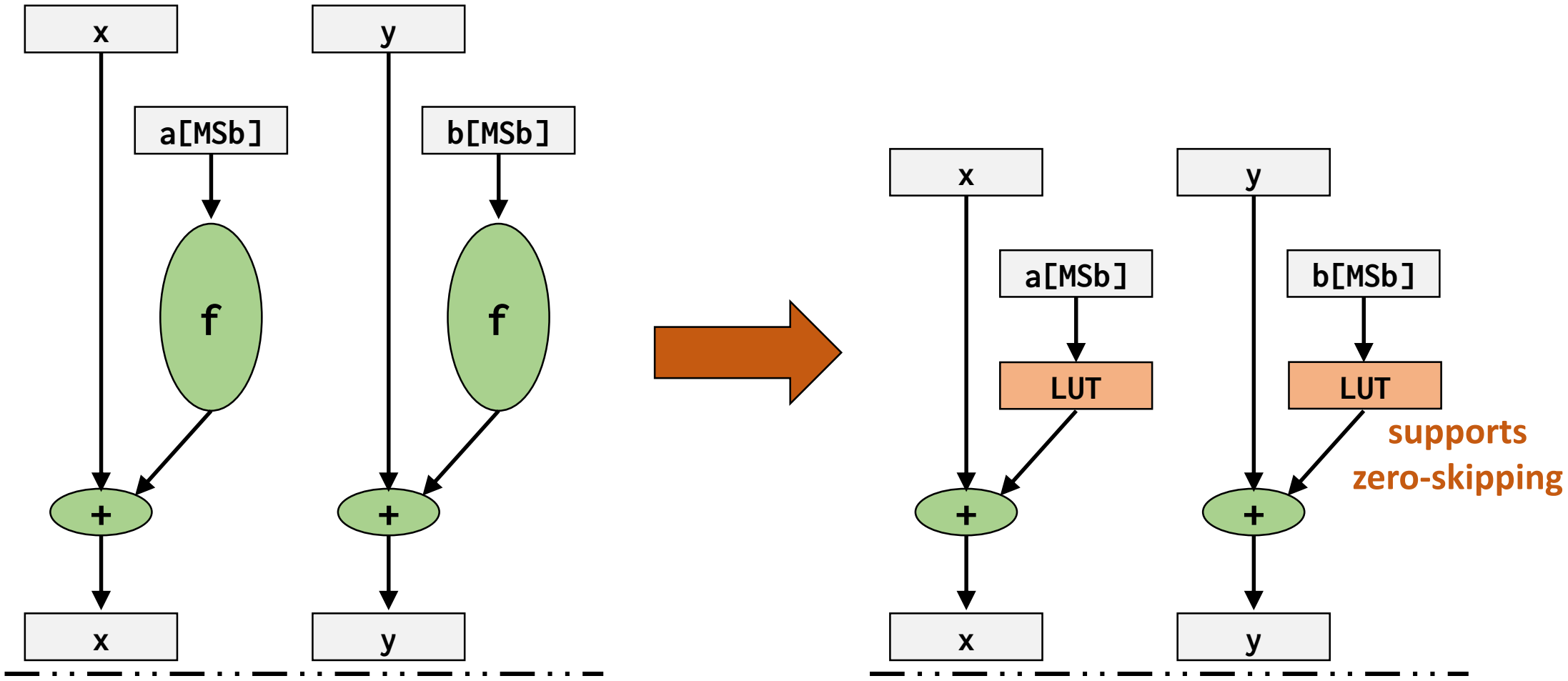
Computational Skimming – Subword Memoization



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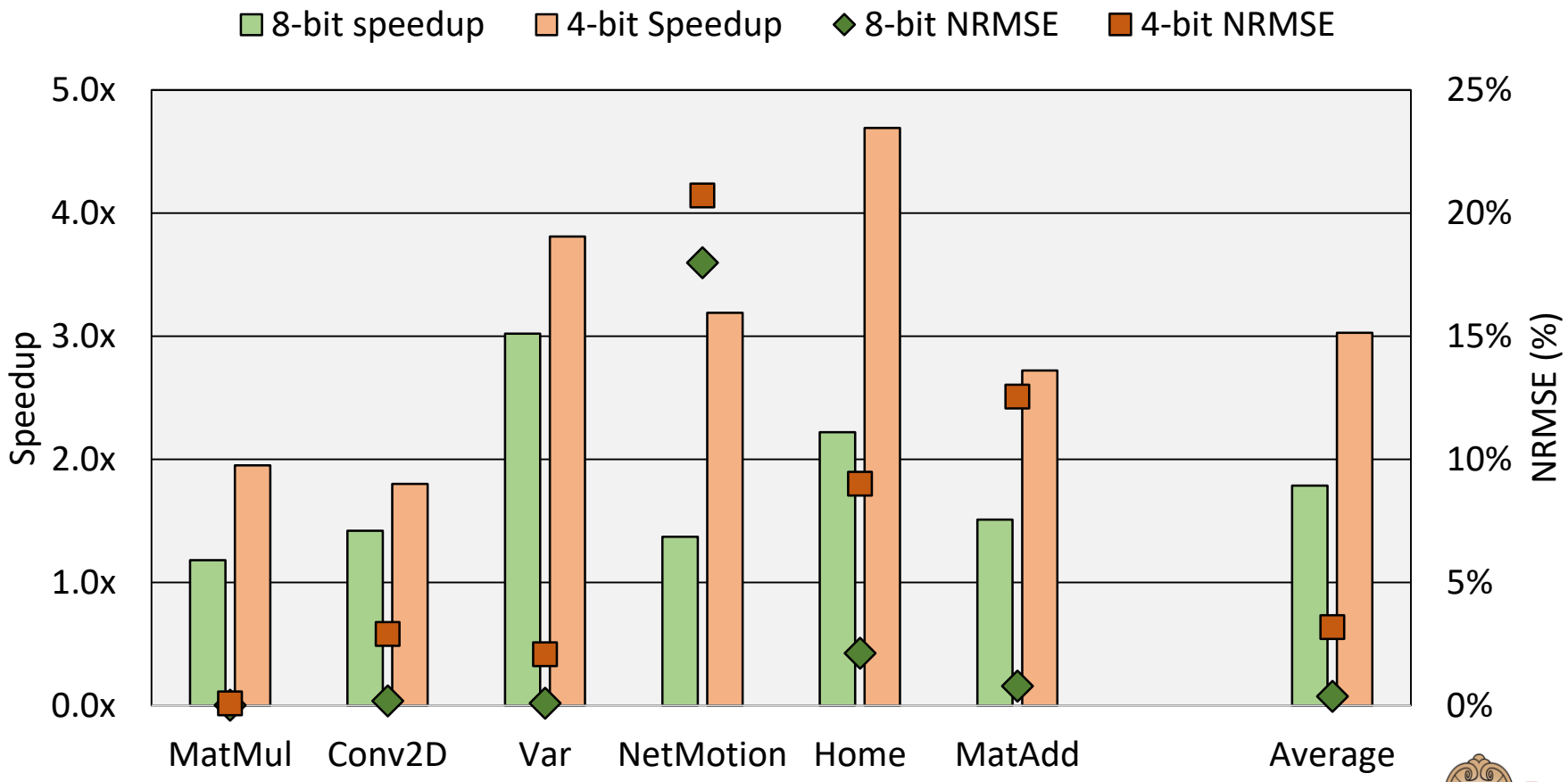
Computational Skimming

What's Next multi-backup system:



Conclusion

Design Tools:

- EH Model [MICRO'18]

Design Paradigms:

- Computational Skimming [HPCA'19]

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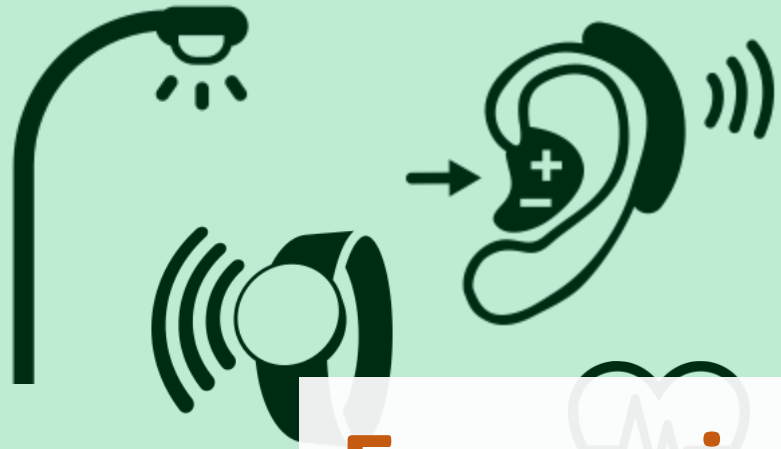
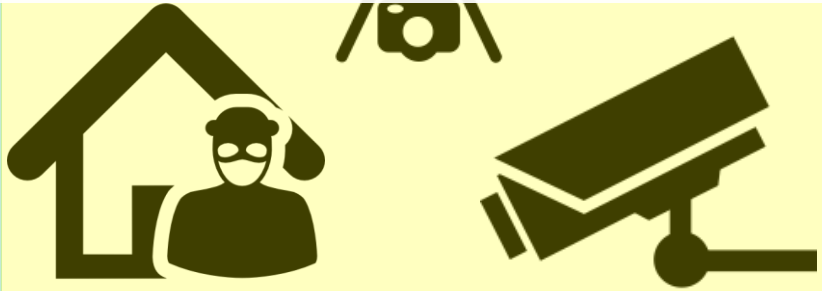
Conclusion



Energy is the common denominator



long lifetime

quick response

advanced capability

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Thank you

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