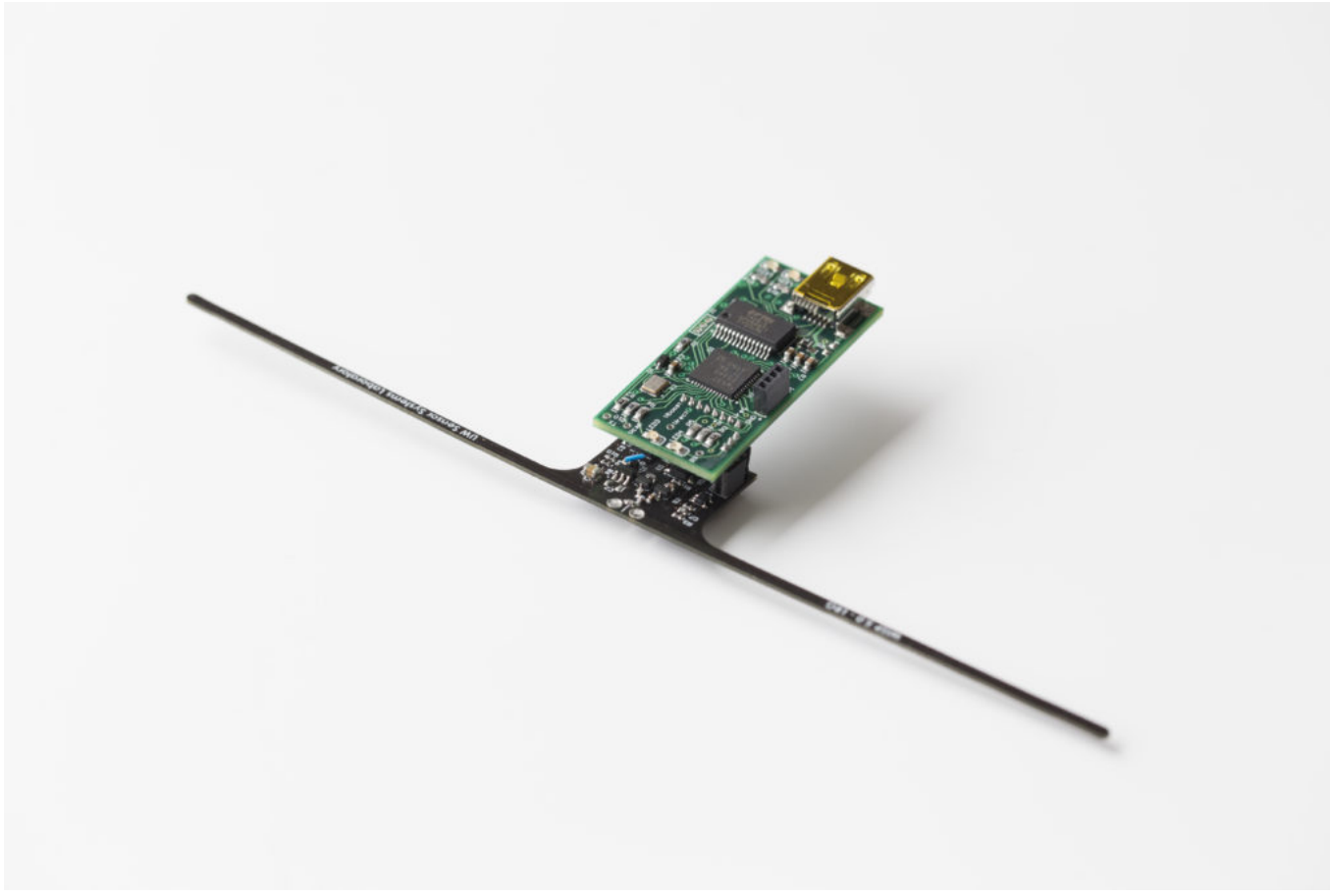
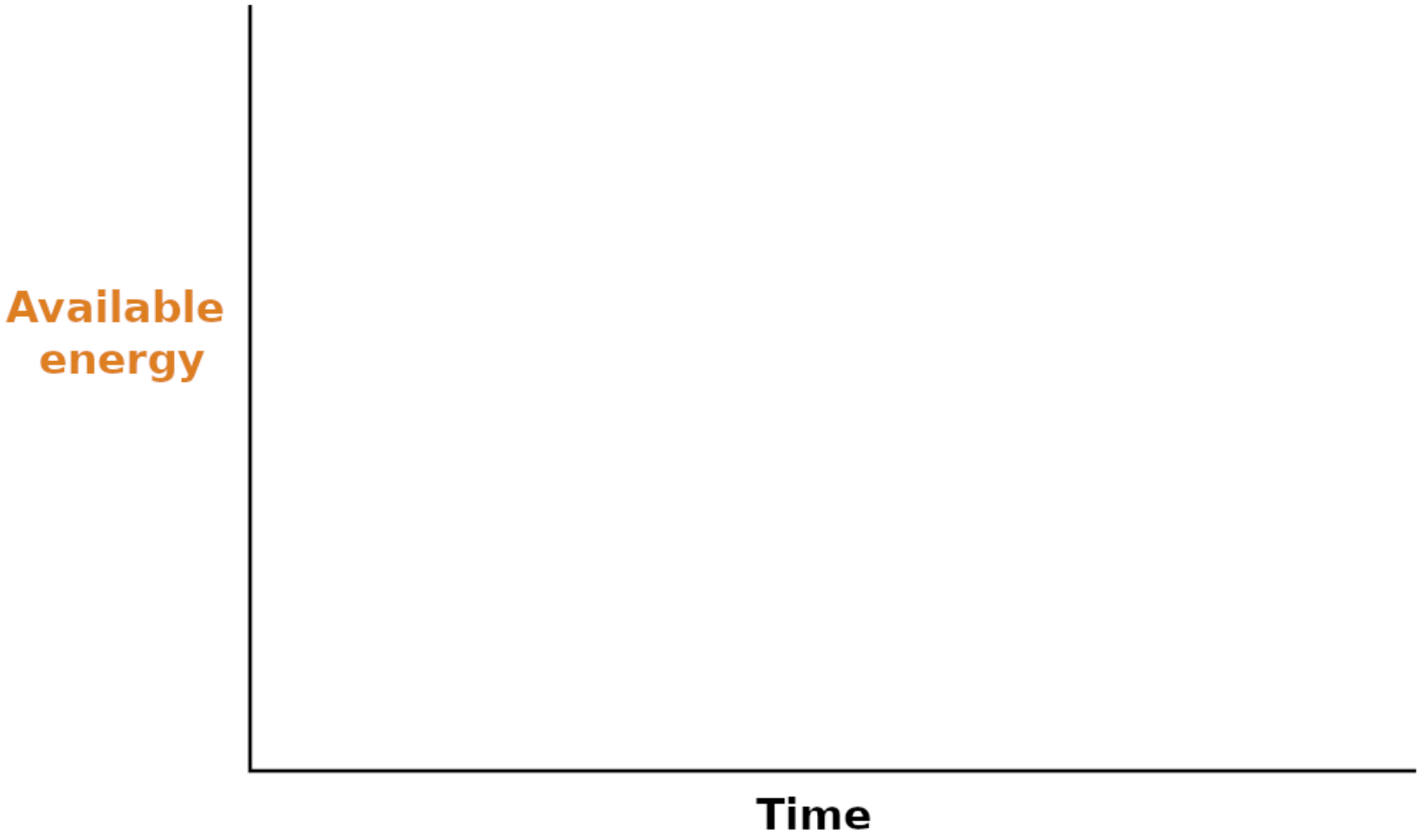
Adaptive Dynamic Checkpointing for Safe Efficient Intermittent Computing

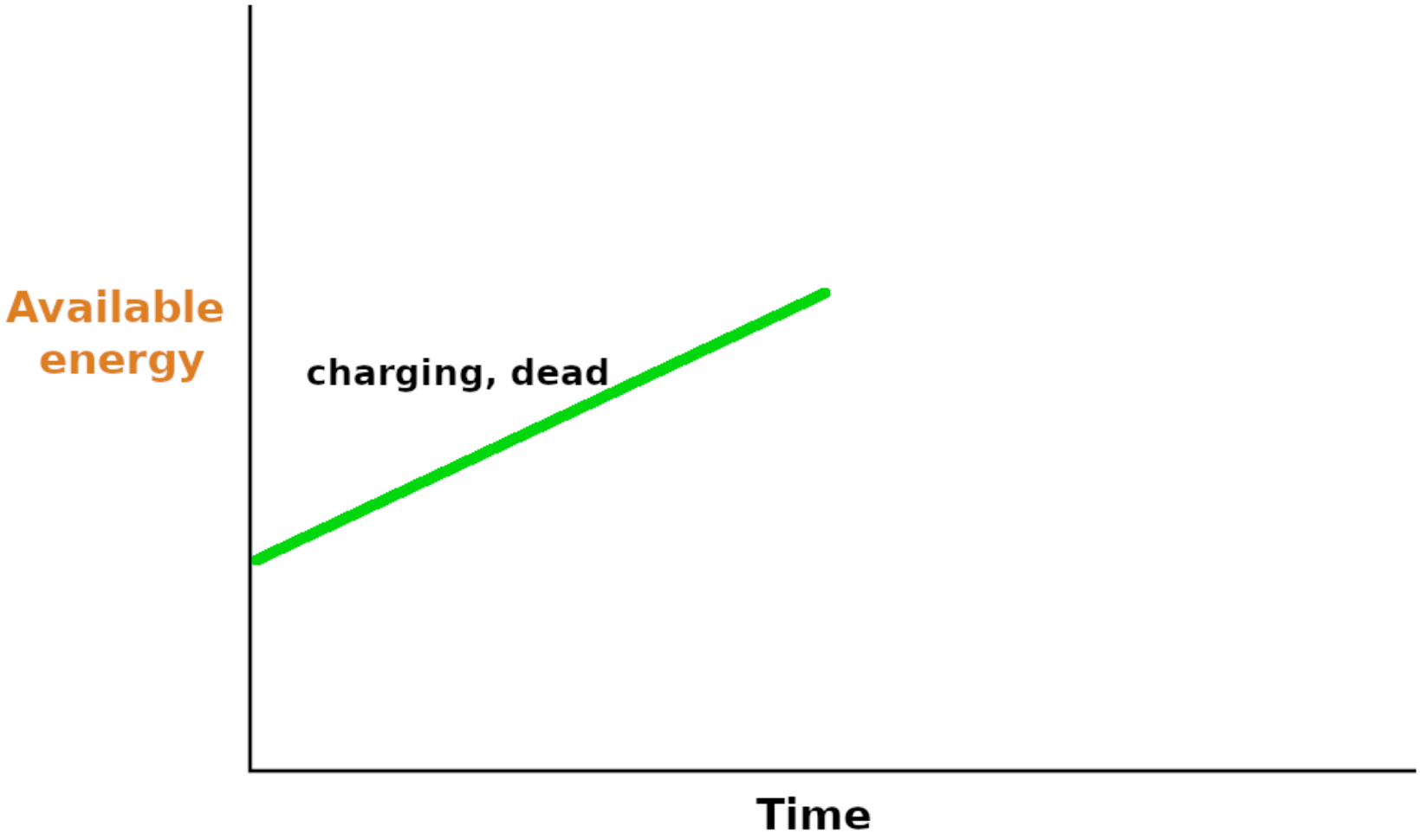
Kiwan Maeng Brandon Lucia

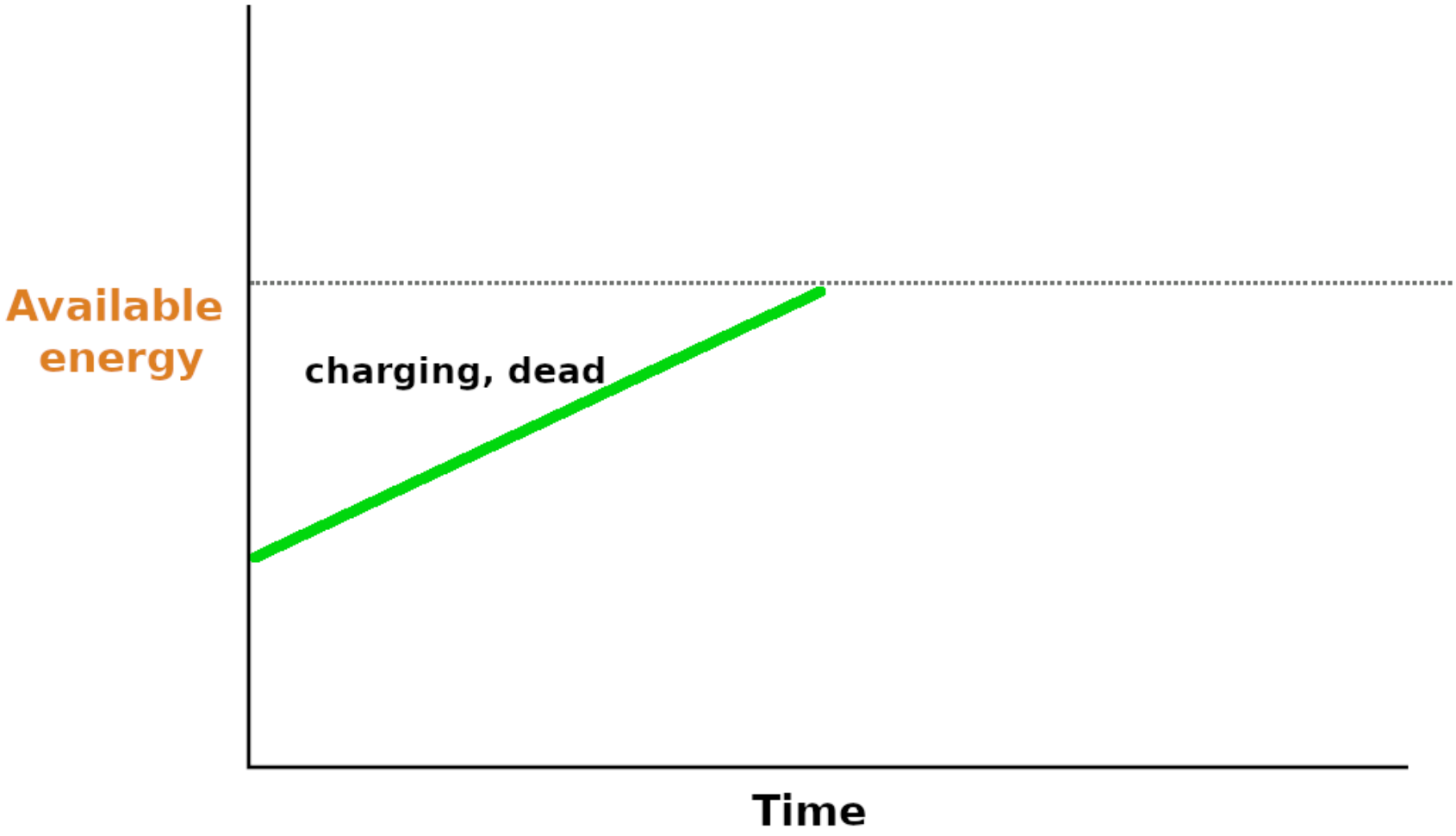
Energy-Harvesting Devices

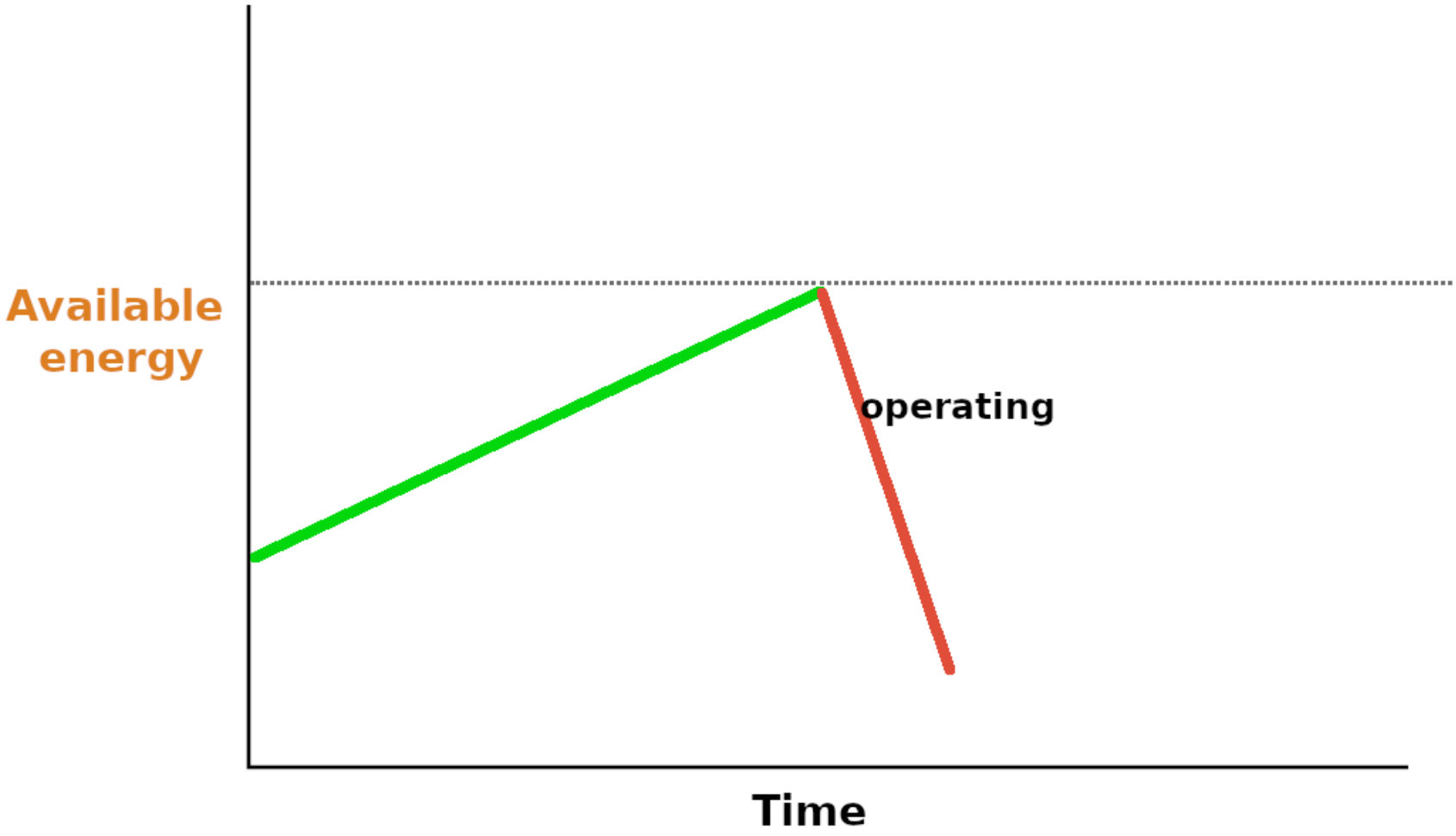


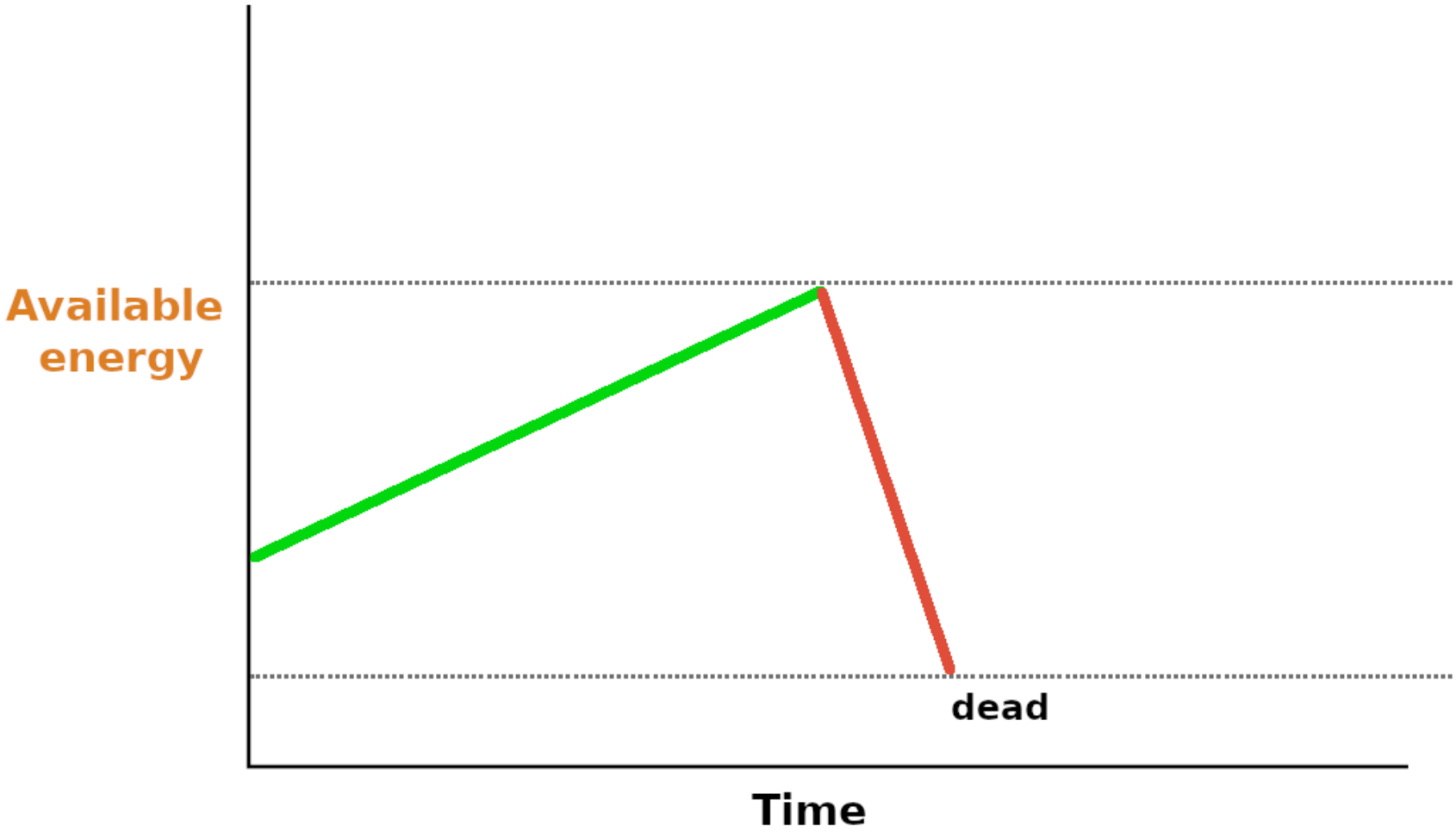
Intermittent Computing

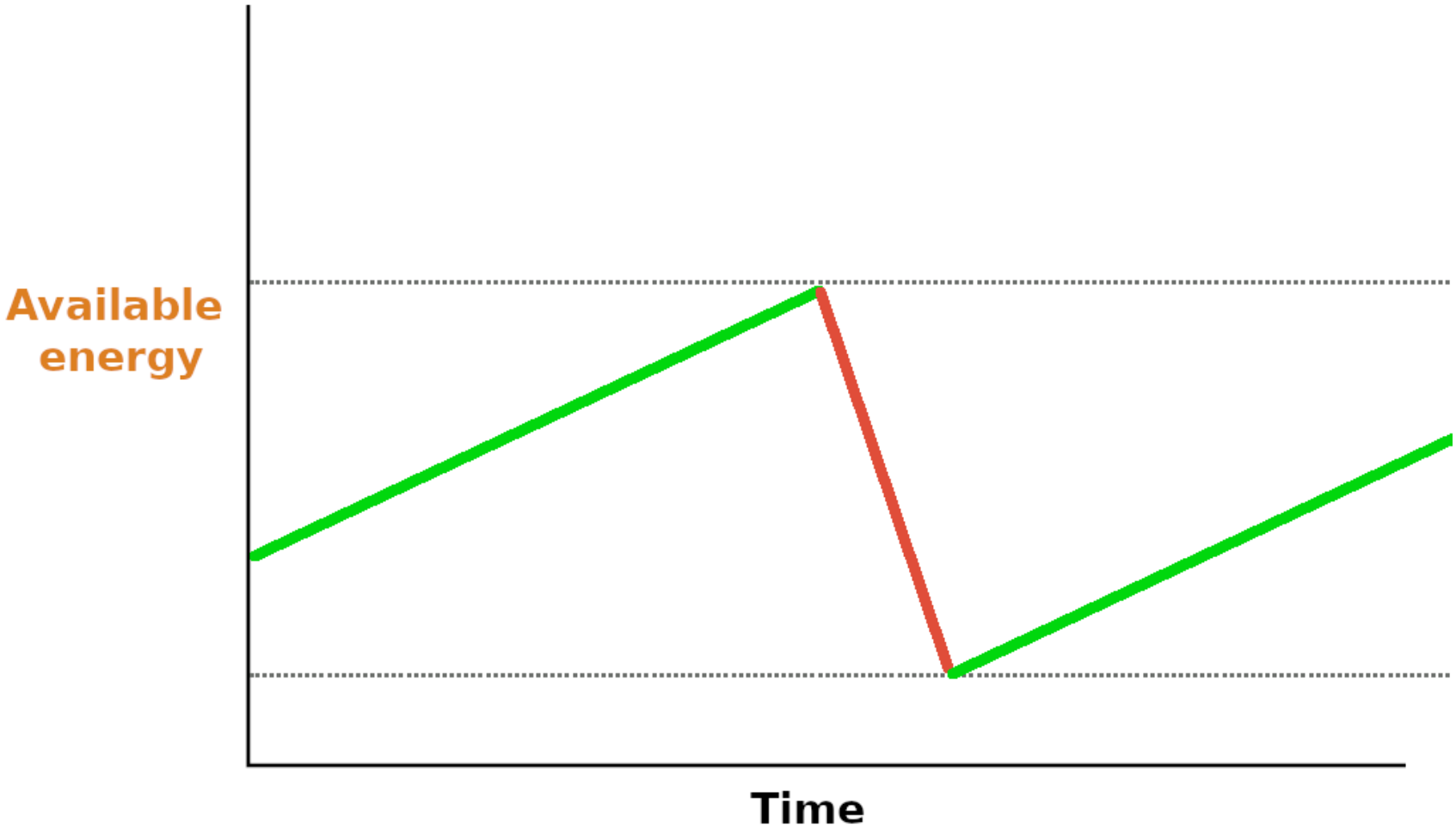

Available energy
Time


Available energy
charging, dead
Time


Available energy
charging, dead
Time


Available energy
operating
Time


Available energy
dead
Time


Available energy
Time

Prior Work

- General idea: periodically save state to non-volatile memory

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- Two main approaches:

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  - Automatic checkpointing

Alpaca

Alpaca - explicit tasks

Problems:

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- Programmability overhead
- Not obvious how to estimate energy use of code
- Not portable

Ratchet

Ratchet - automatic checkpointing

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Problems:

- High execution overhead
  - Ratchet inserts checkpoints between every Write-After-Read dependency
- No task atomicity
- Might be hard to solve/pin-point non-termination issues

Let's solve all of these!

Chinchilla

Correct, **H**ardware-agnostic **IN**termittent **CH**eckpointing **I**nstrumentation **L**ayer with **L**ow-overhead **A**dapation

Strategy:

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- dynamically deactivate unnecessary ones at run-time

This should give us:

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- Tends towards minimal runtime overhead
- Portable to systems with different energy buffers

Approach

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- Start a timer
- Execute checkpointing code only if timer passed a threshold
  - We start with a high threshold
- At next reboot, if we hadn't hit a checkpoint, halve the timer threshold

- Once we find an interval that works, increase threshold to median of new and old threholds

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- Binary search for an optimal interval!

Further timer adaptation

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  - Means we're close to the actual operating period
- Failure followed by a successful checkpoint - make a small decrement to timer interval
- Many consecutive failures - halve the timer

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- Optimization timer:
  - second timer with slightly higher threshold than checkpoint timer
  - if the optimization timer expires before a power failure, make small increment to checkpoint timer

Instrumentation Implementation

Checkpoints

- Checkpoints added between each basic block

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  - easily identifiable

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  - easy to measure block energy cost
  - easy to subdivide if necessary

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- Identify protected variables via liveness analysis
- If `x`'s live-range crosses a checkpoint, it needs to be protected
  - allocated in non-volatile memory
  - consistency between reboots thanks to undo logging
    - log before every potential write to a protected variable that may be the variable's first write since a checkpoint

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- Restores protected variables from log

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- Store them on a non-volatile stack
- For consistency, keep track of top and depth pointer
  - depth is the deepest the stack has popped to since last checkpoint
  - at next checkpoint, need to back up what's between the two pointers

Benchmarks

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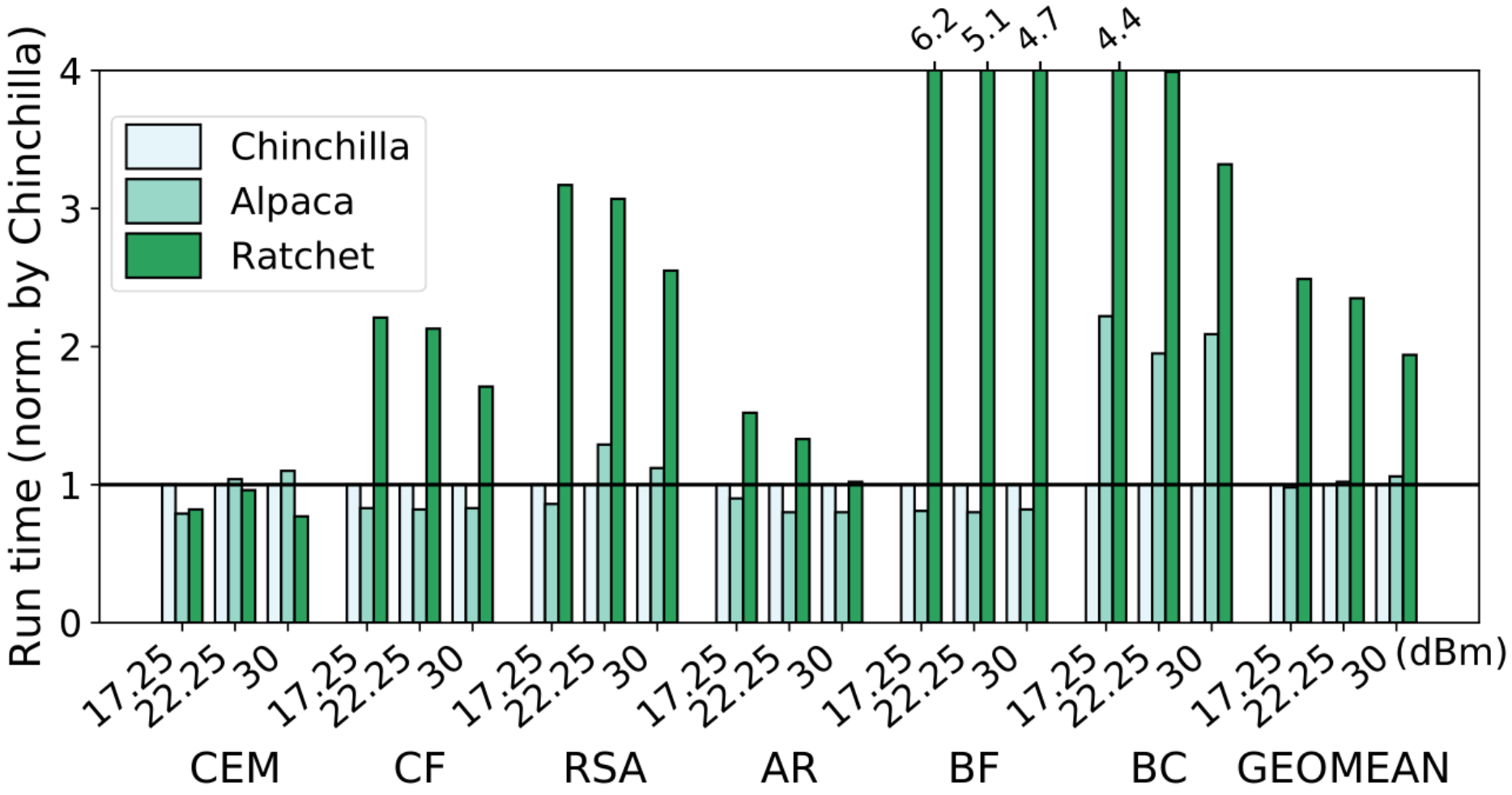
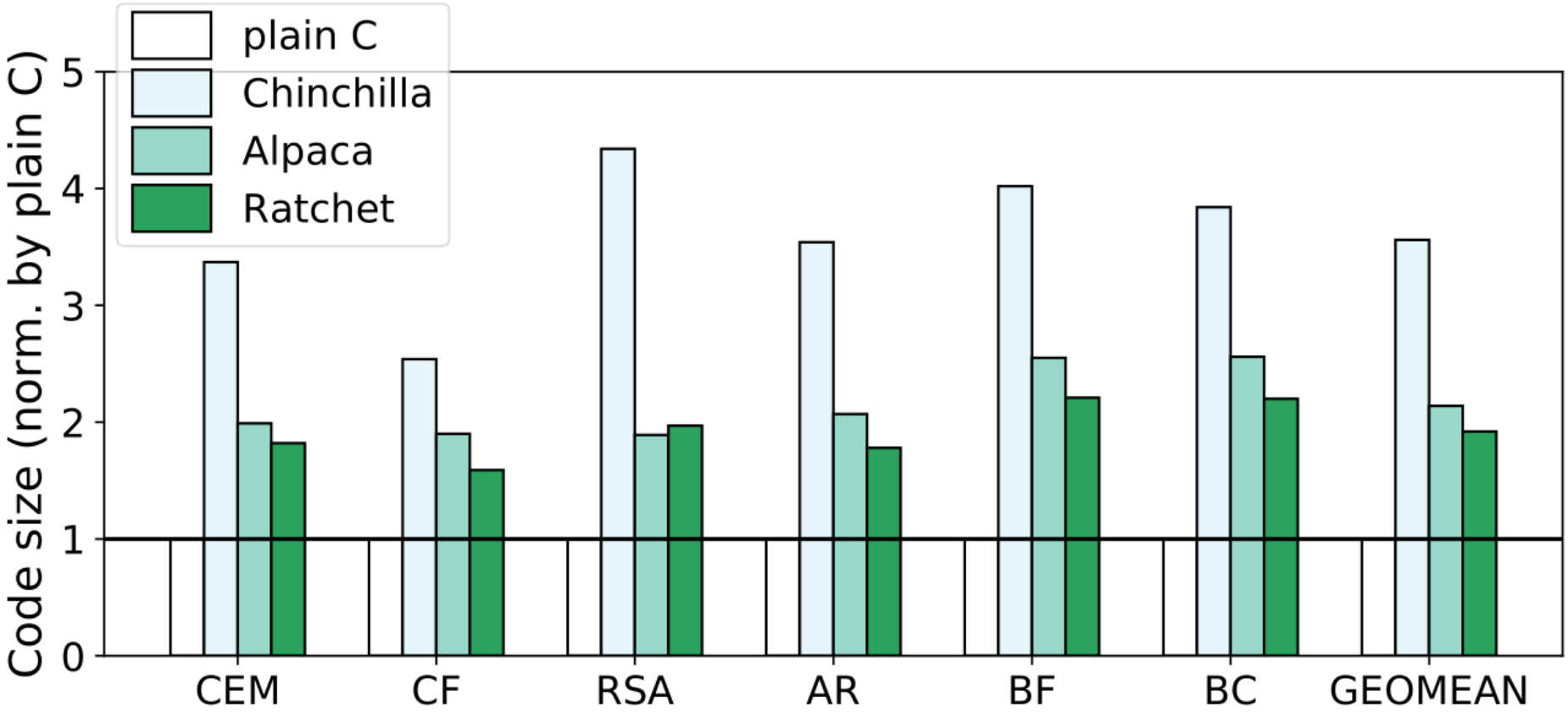
- Average speed-up of 2.25x over Ratchet
- Similar perfomance to Alpaca, 2% speedup on average
- Orders of magnitude less checkpoints than either solution


Run time (norm. by Chinchilla)
0
1
2
3
4
6.2
5.1
4.7
4.4
Chinchilla
Alpaca
Ratchet
17.25
22.25
30
(dBm)
CEM
CF
RSA
AR
BF
BC
GEOMEAN

# Checkpoints	RSA	CEM	BC
Chinchilla	16	30	15
Alpaca	315	1611	710
Ratchet	7643	2319	8907

Chinchilla does end up with larger binary size - cost we pay for performance and reliability.


plain C
Chinchilla
Alpaca
Ratchet
Code size (norm. by plain C)
0
1
2
3
4
5
CEM
CF
RSA
AR
BF
BC
GEOMEAN

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  - Recommended watching: Reliable Intermittent Computing