Battery-Free Game Boy

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Environmental Sustainability of Electronic Devices

Problems of batteries in an electronic everyday life:

- ecological expensive raw materials
- energy-intensive production
- difficult recycling
- hazardous materials

Solution for Small Devices

Leaving behind batteries where possible

(phones, watches, etc.)

- no ecological disadvantages of batteries
- powered only using green energy (sun, heat, motion)

ENGAGE: a Battery-Free Gaming Console

Jasper de Winkel et al: Battery-free Game Boy

- deeply interactive, intermittent system
- handheld gaming relevant today (Nintendo Switch)
- 8 bit Game Boy one of the most influential consoles to exist (118 million devices sold)

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Concept and Challenges

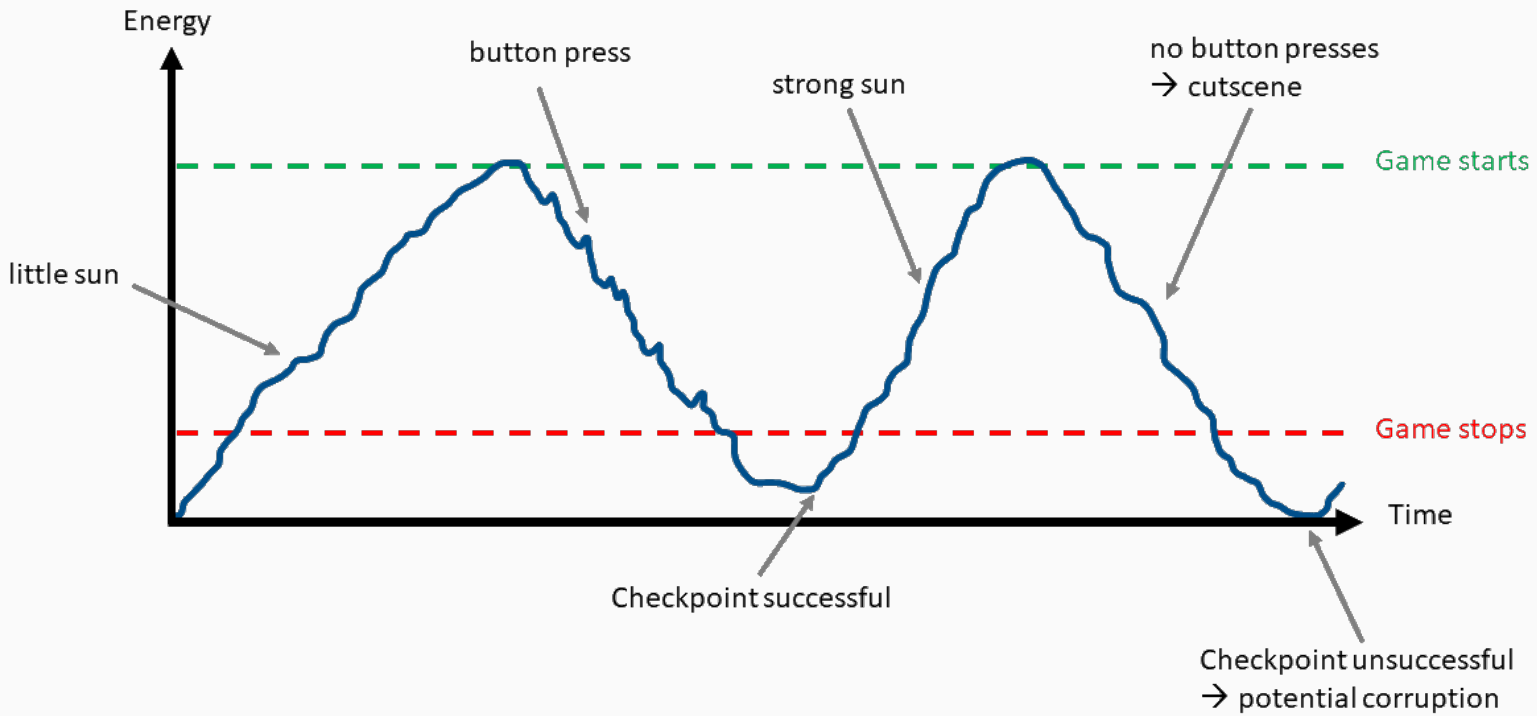
Challenges

multiple things will pose a Challenge

- constant power outages
- game independence
- high system requirements
- expensive checkpointing

–> Resulting device needs a reliable energy source and high energy efficiency

Phases


Energy
button press
strong sun
no button presses
→ cutscene
Game starts
little sun
Game stops
Time
Checkpoint successful
Checkpoint unsuccessful
→ potential corruption

Energy Supply

Types of Power Sources

motion
–> mechanical switches

heat
–> Seebeck generator

light
–> solar panels

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Energy Optimization Measures

Other things tweaked to improve the battery independence

- modern, energy-efficient MCU, Memory and Display
- excessive button holding disabled
- no sound outlet

–> non-trivial compromises

Memory Management

Differential Checkpointing

While Playing, the content of the Memory changes a lot

–> However: some parts change frequently, others barley

–> Why constantly copy Memory that has not changed?

Corruptible vs Incorruptible Checkpointing

Power outages can lead to incomplete checkpoints!

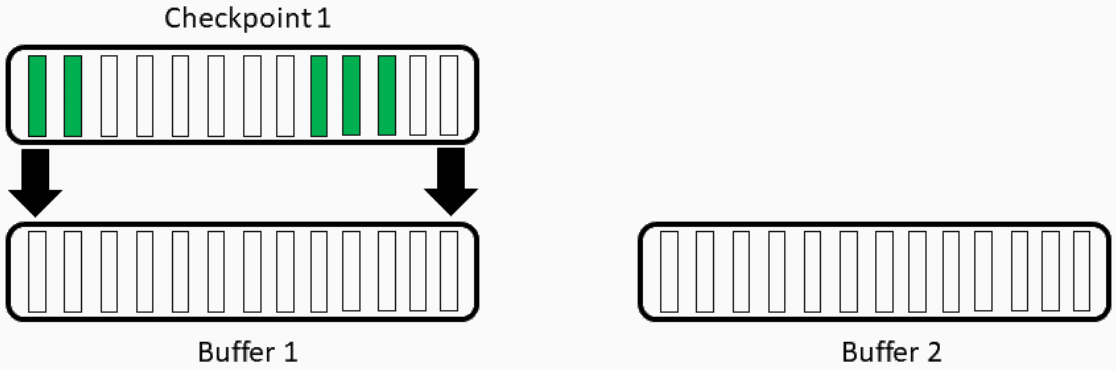
Corrupted save would mean starting over –> has to be avoided

Types of Checkpointing

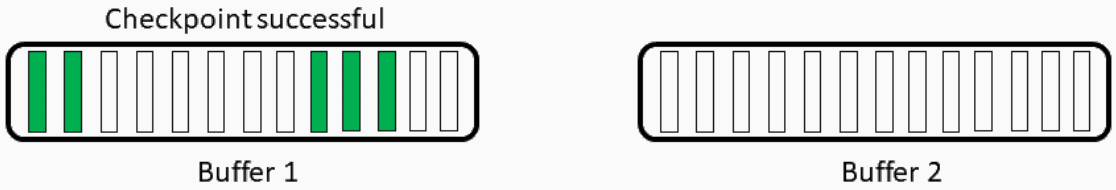
Buffer type	corruptible	differential	space requirement
diff. single	yes	yes	1x emulated memory
non-diff. double	no	no	2x emulated memory
diff. double	yes	yes	2x emulated memory
MPatch	no	yes	varying

Problem of Differential Double Buffering

Problem of Differential Double Buffering



Problem of Differential Double Buffering



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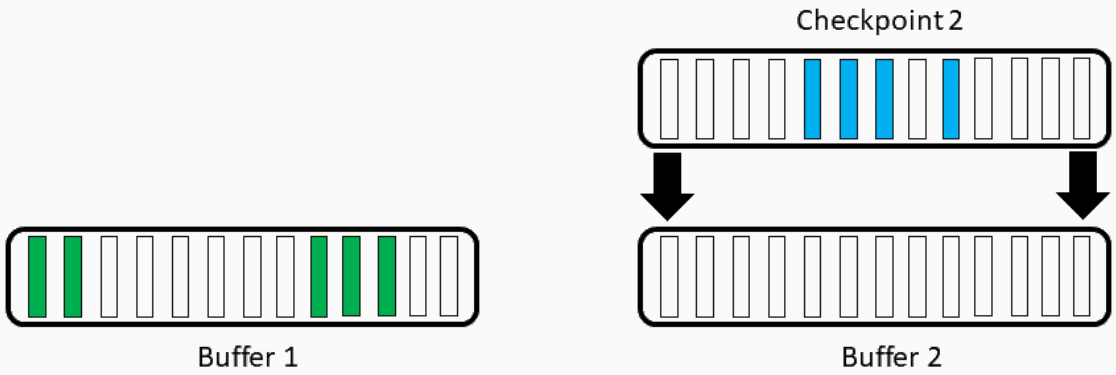

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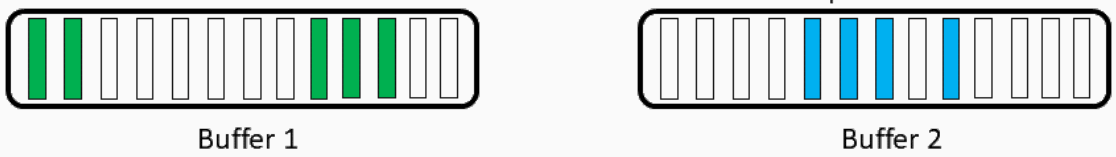

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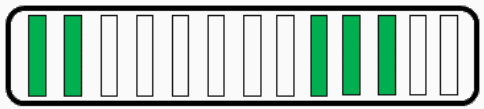
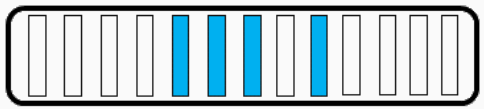
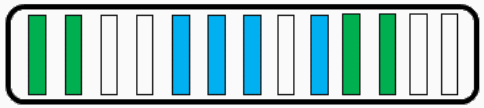


Buffer 1

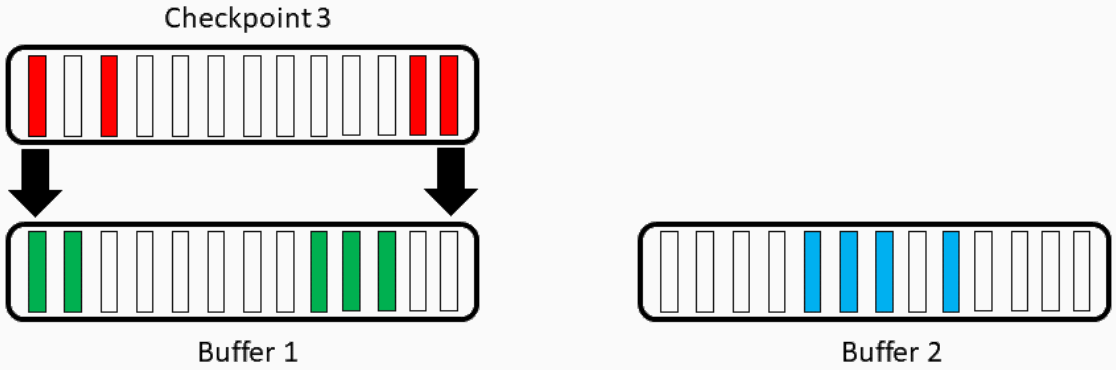


Buffer 2



Restoration needs
both buffers

Problem of Differential Double Buffering



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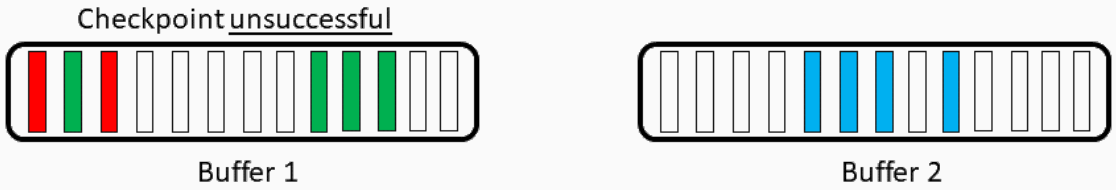

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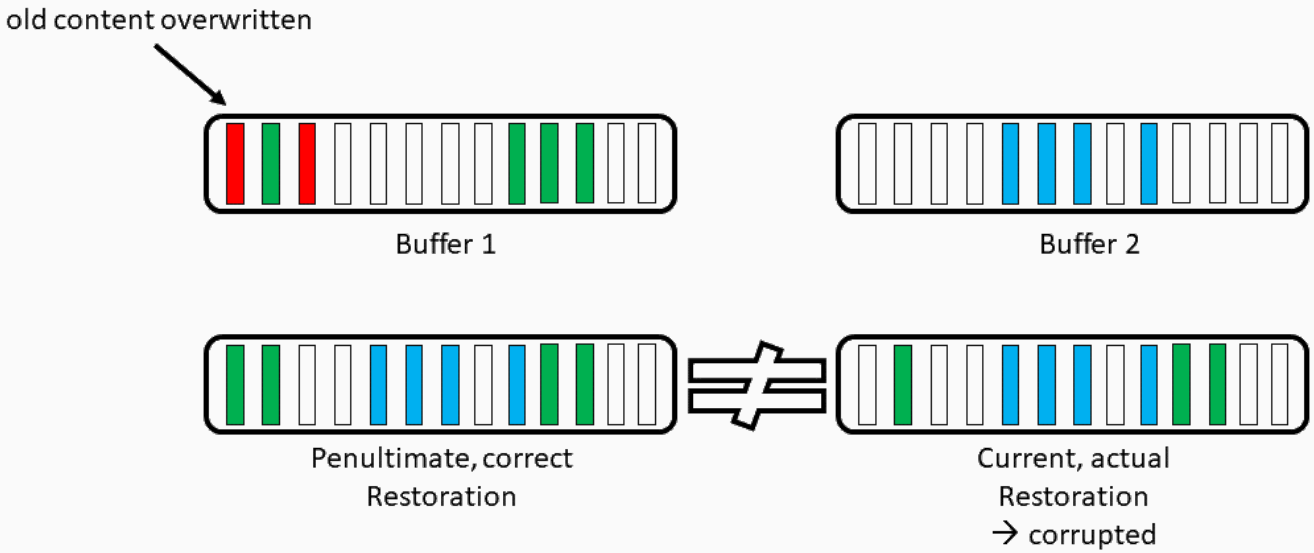
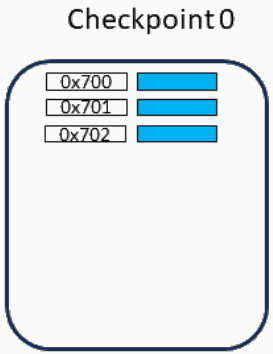


Solution: MPatch

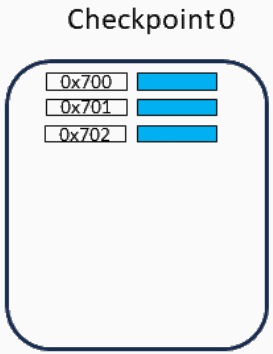
Checkpointing



N = 0

Solution: MPatch

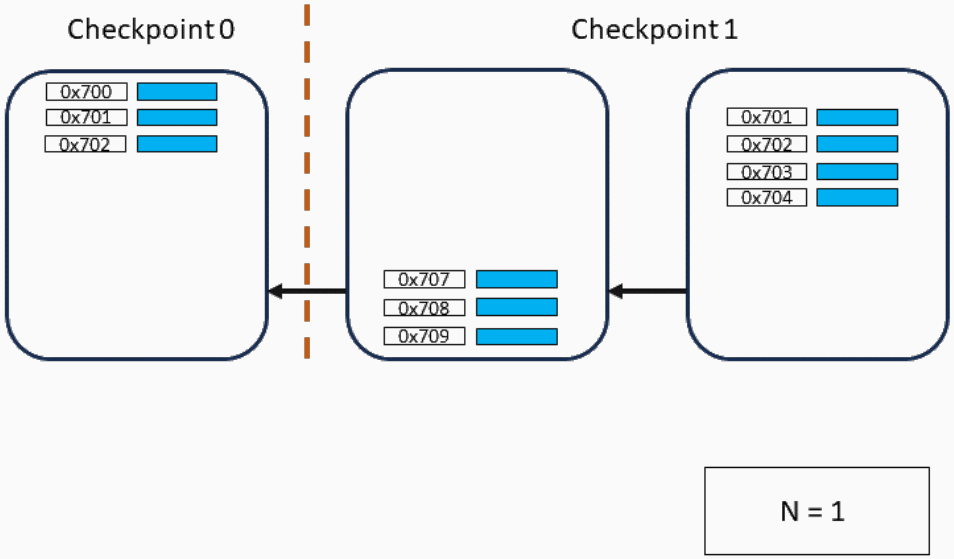
Checkpointing



N = 1

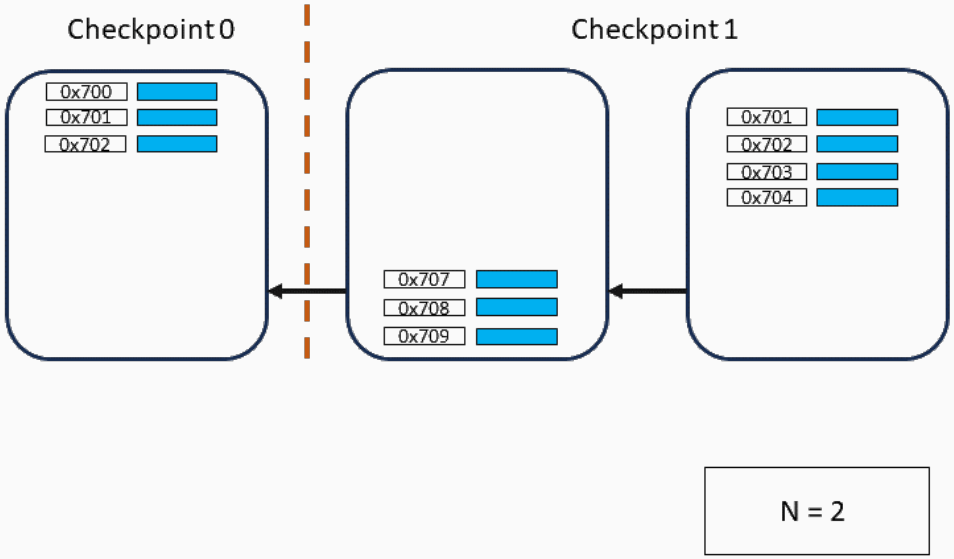
Solution: MPatch

Checkpointing



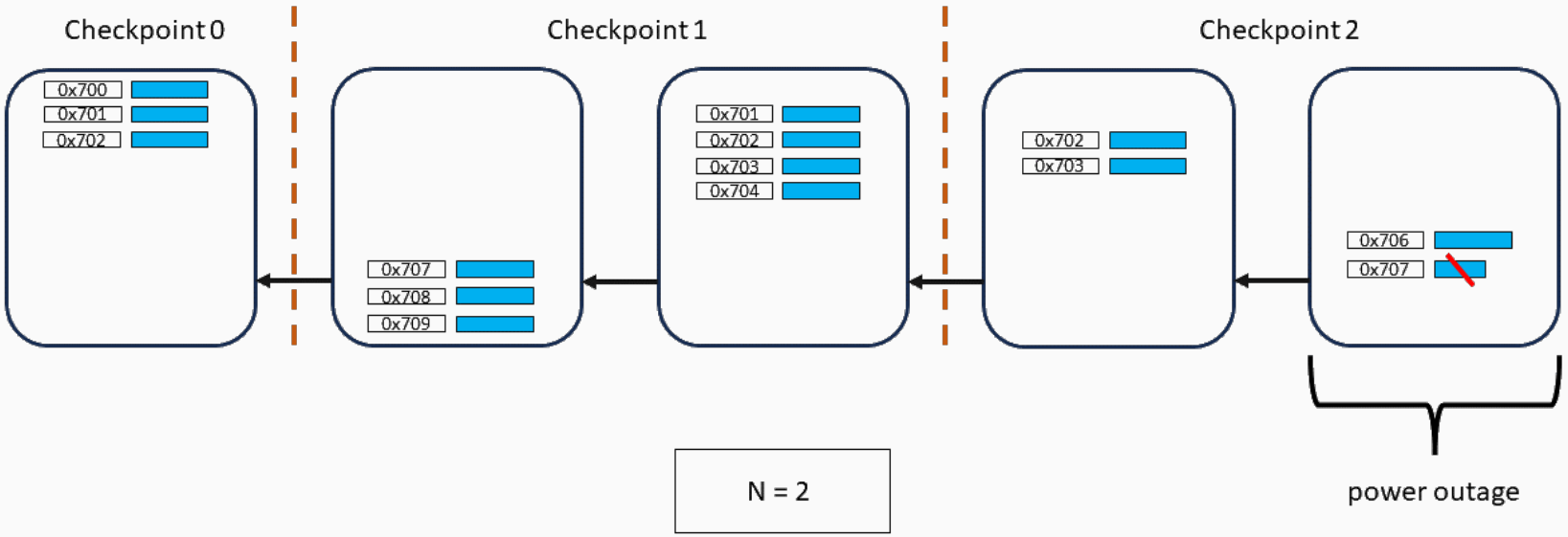
Solution: MPatch

Checkpointing



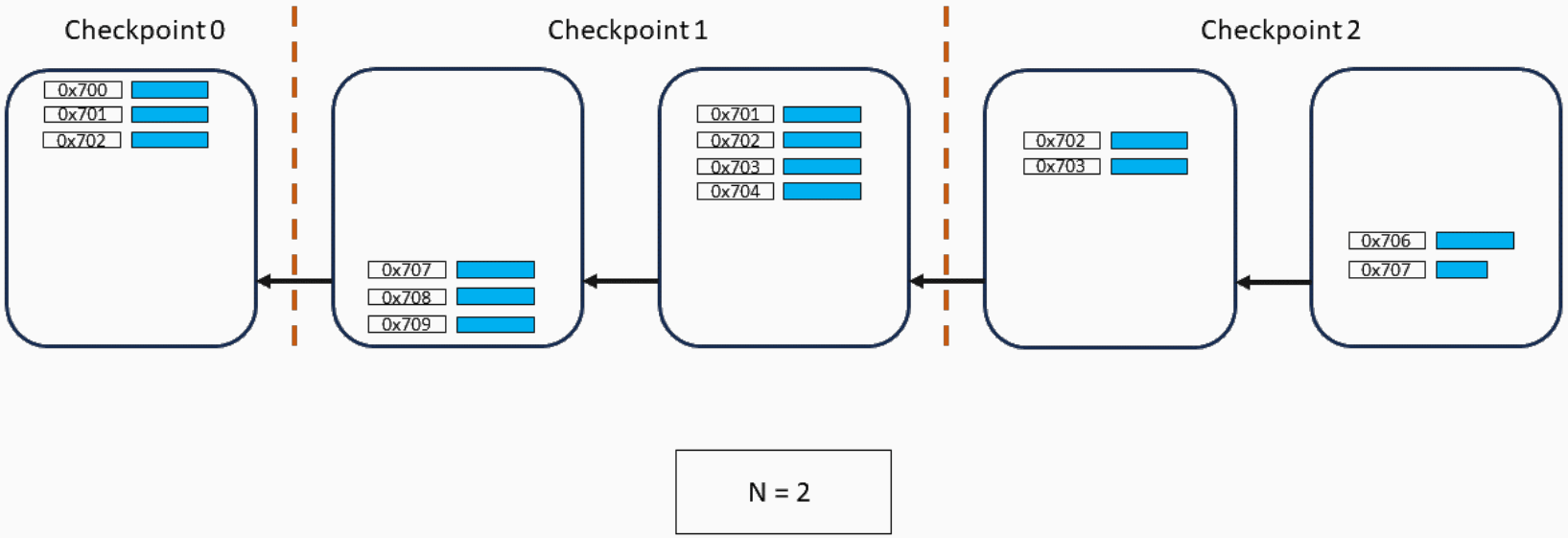
Solution: MPatch

Checkpointing



Solution: MPatch

Restoring



Solution: MPatch

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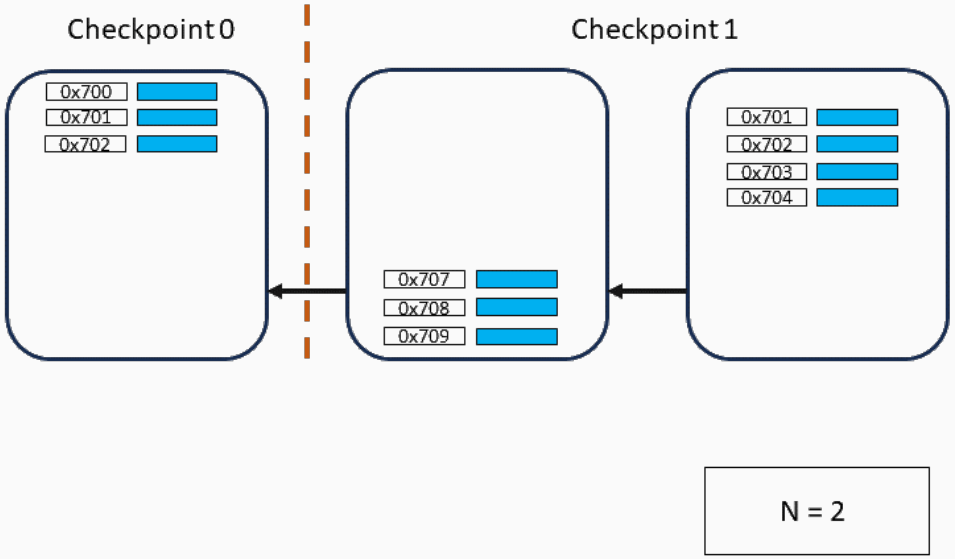

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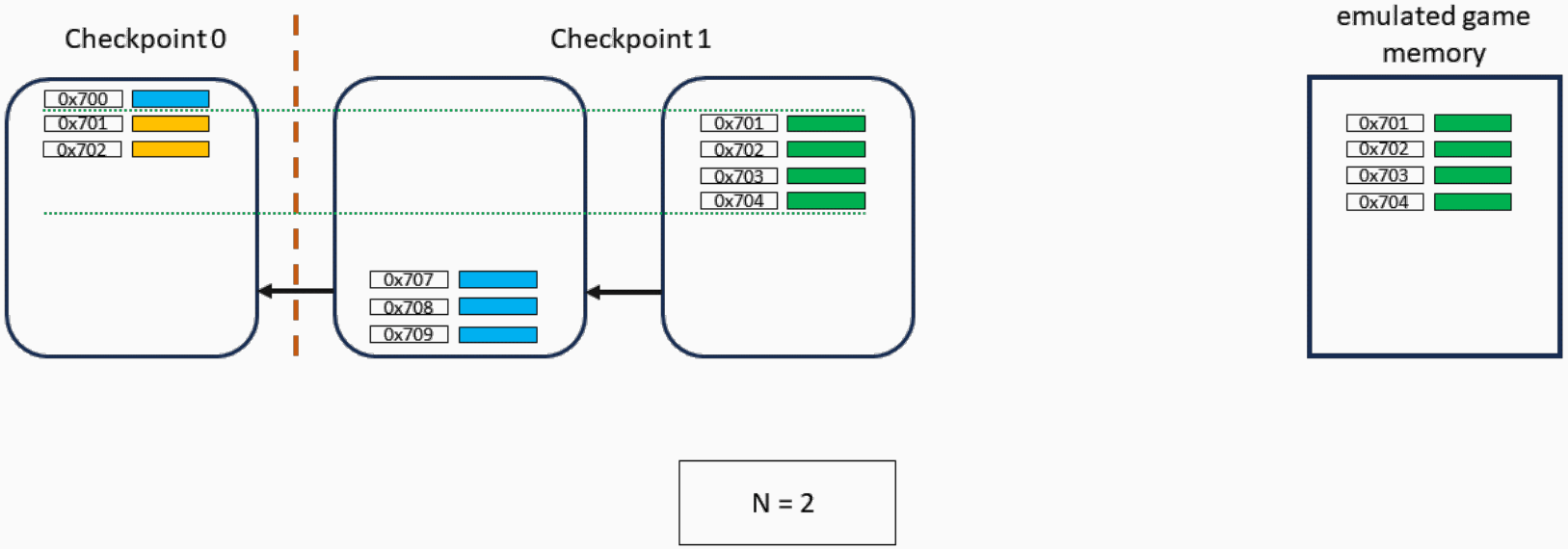
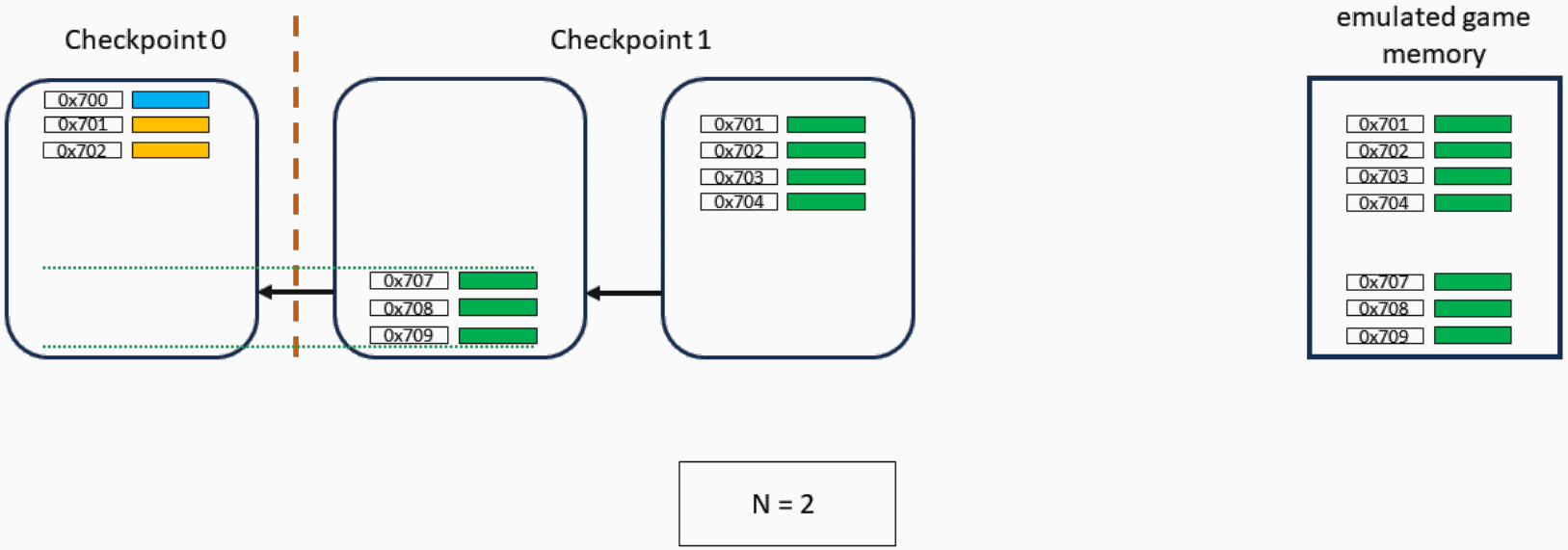


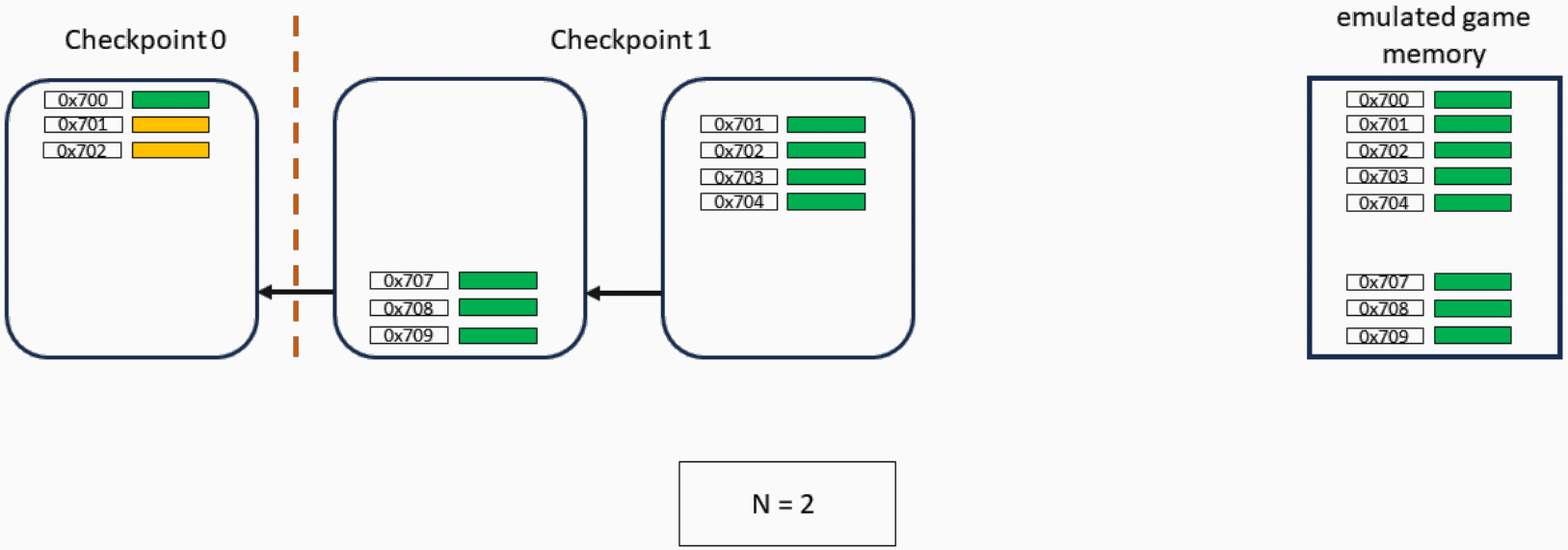
Solution: MPatch

Restoring



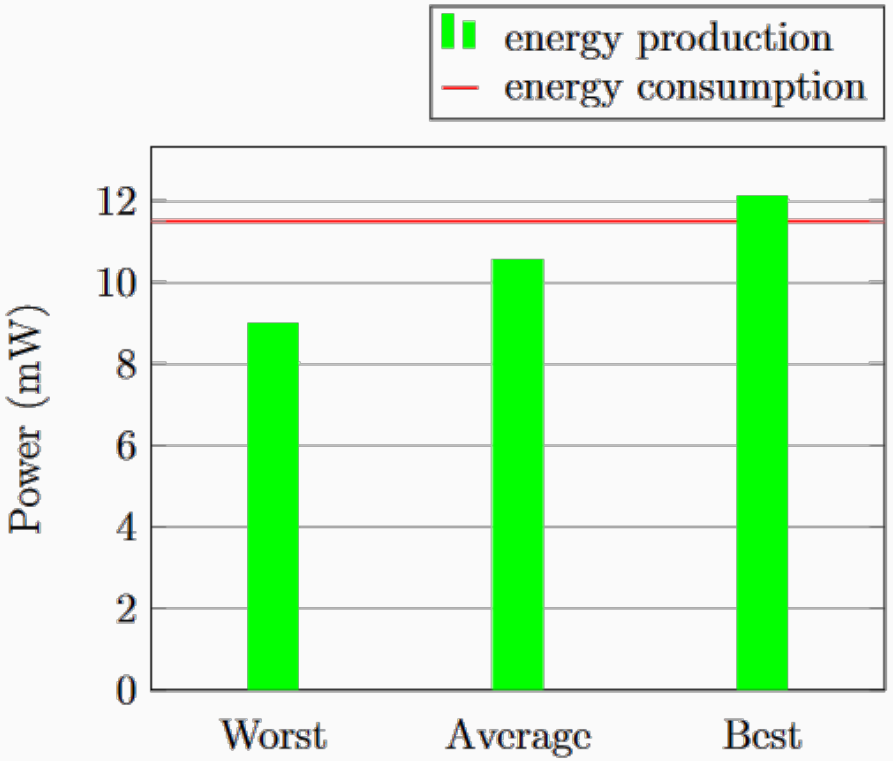
Solution: MPatch

Restoring



Evaluation

Energy Balance



–> power outages happend frequently

MPatch Evaluation

Testing MPatch vs. non-differential double buffering MPatch...

1. needs less time to create a checkpoint and
2. less time to restore a checkpoint

Discussion

Positives

+ working Game Boy emulator
+ superior Checkpointing system (at least for this use case)
+ first step towards interactive intermittent systems

Negatives

- highly dependant on sunlight
- no sound
- little testing of MPatch
- afterall: only a 8-bit Game Boy

Conclusion

Good first step towards interactive intermittent systems with a promising Checkpointing approach

–> questionable, if future of handheld gaming is battery-free

–> environmentally friendly batteries maybe promising?

Questions and Thoughts

Thank you for your attention!

–> Your questions/ thoughts about the battery-free Game Boy