Towards Sustainable IoT Nodes

Green Days at Lyon

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Plan

IoT devices are mostly powered by batteries → millions of batteries replaced each year

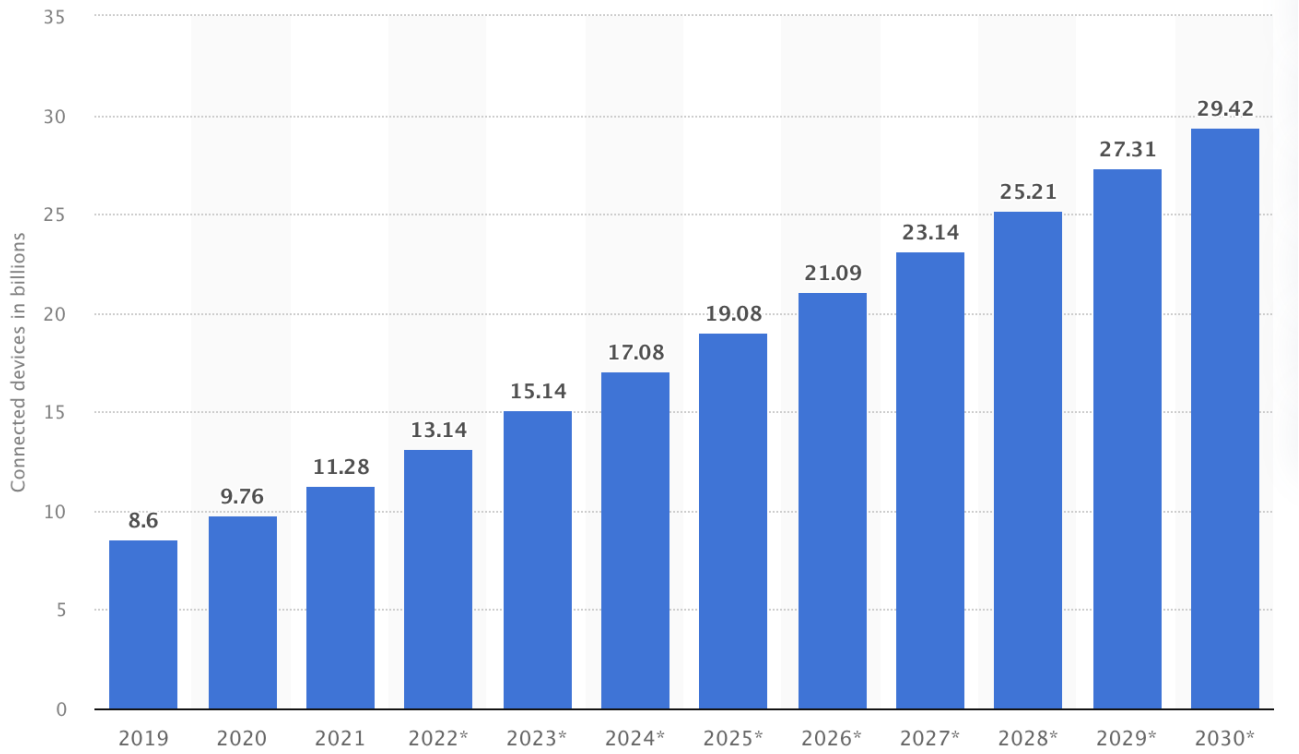
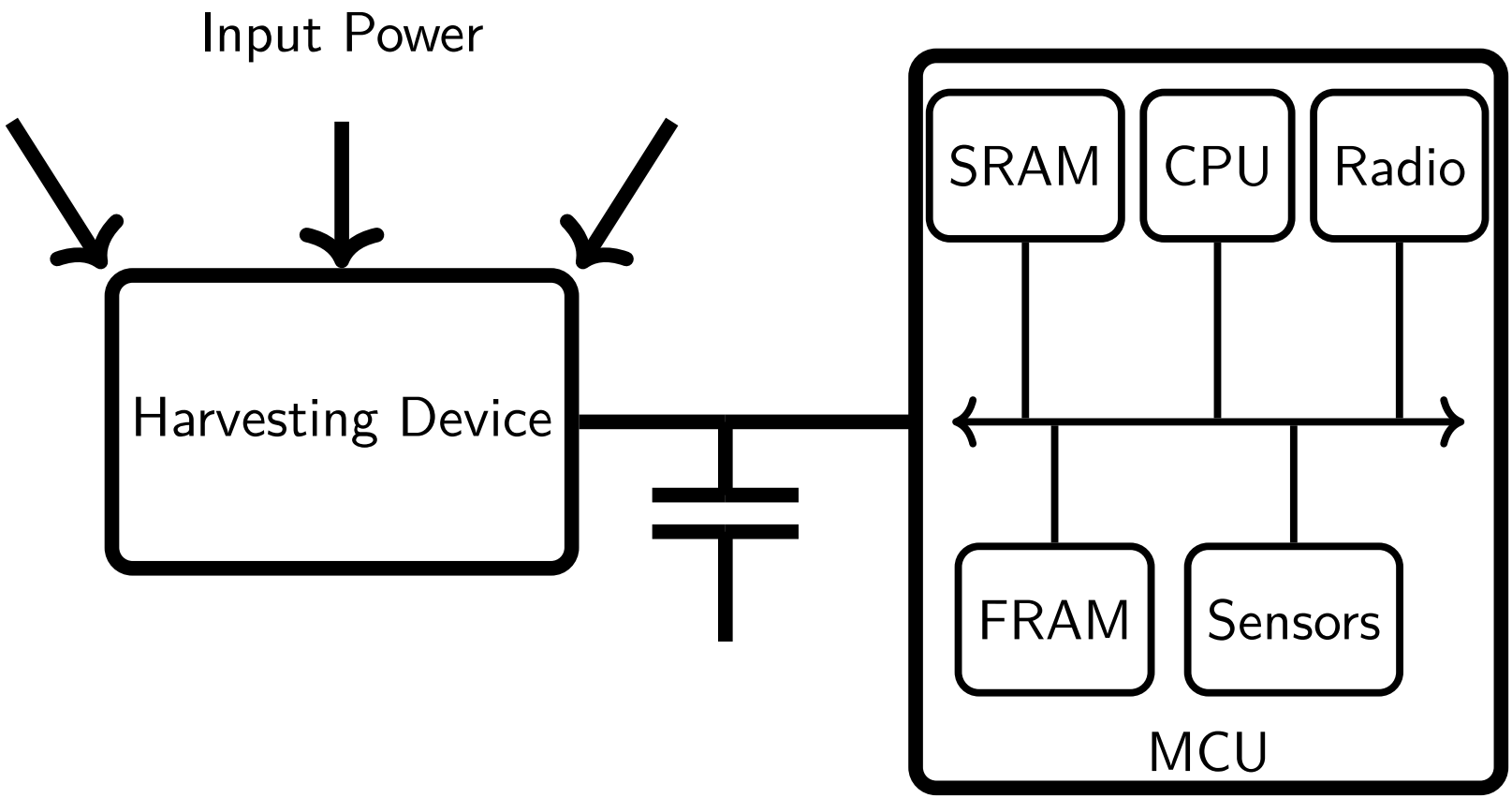


Figure 1 – Number of IoT devices [*Source : Statistica 2023*]

Batteryless Architecture



Use-case example : The *Mithræum of Circus Maximus*[1]

Context

- UNESCO archaeological site
- Temperature, humidity and vibration need to be monitored
- Intermittent computing techniques enable batteryless devices

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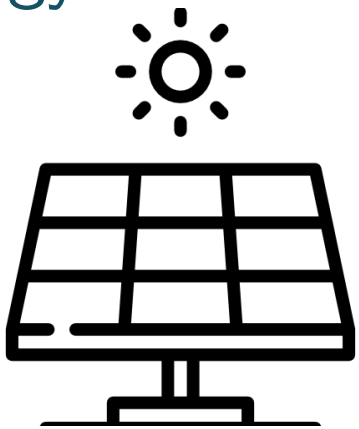
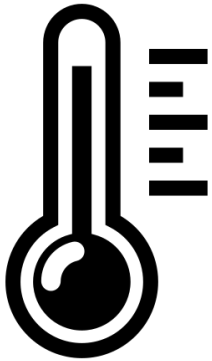
Battery sensing limits :

- Battery sensors require regular maintenance
- Restricted access to the site

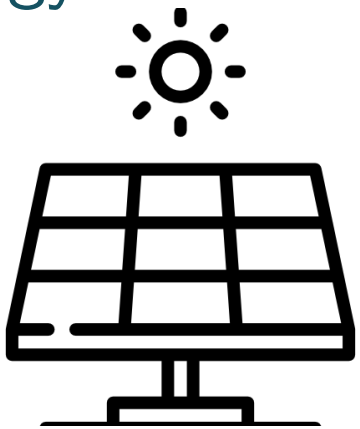
Plan

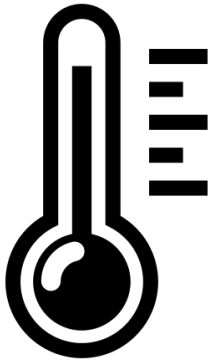
Energy harvesting





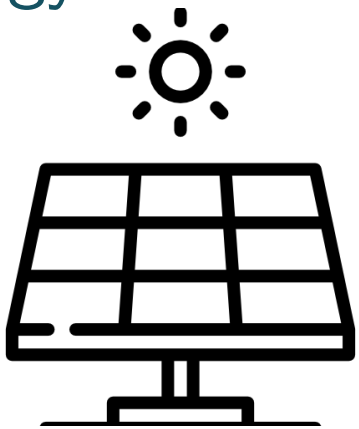
Energy harvesting

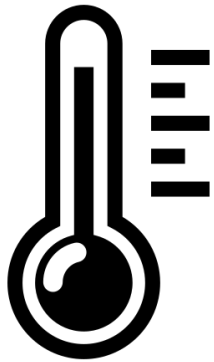




- Maintenance-free
- Reduced environnemental footprint (no battery needed)

Energy harvesting





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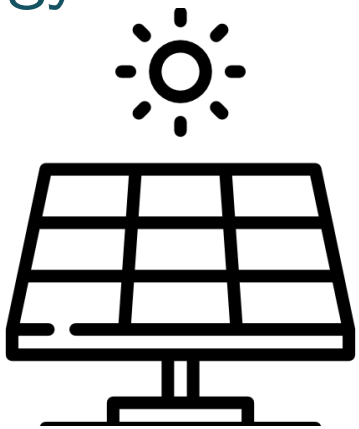
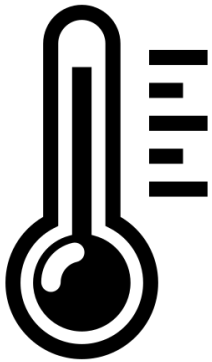
- Scarce energy
- Variable energy

Energy harvesting





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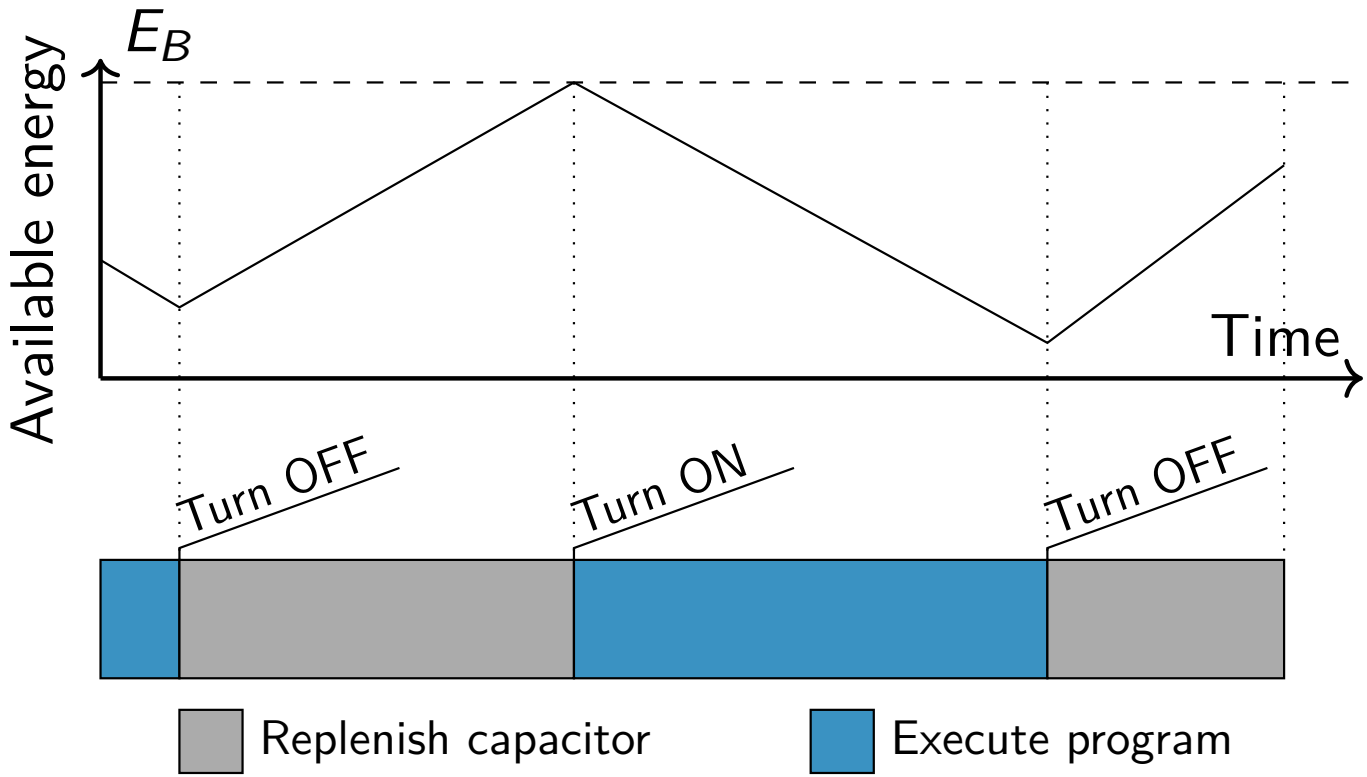
- Reduced environnemental footprint (no battery needed)

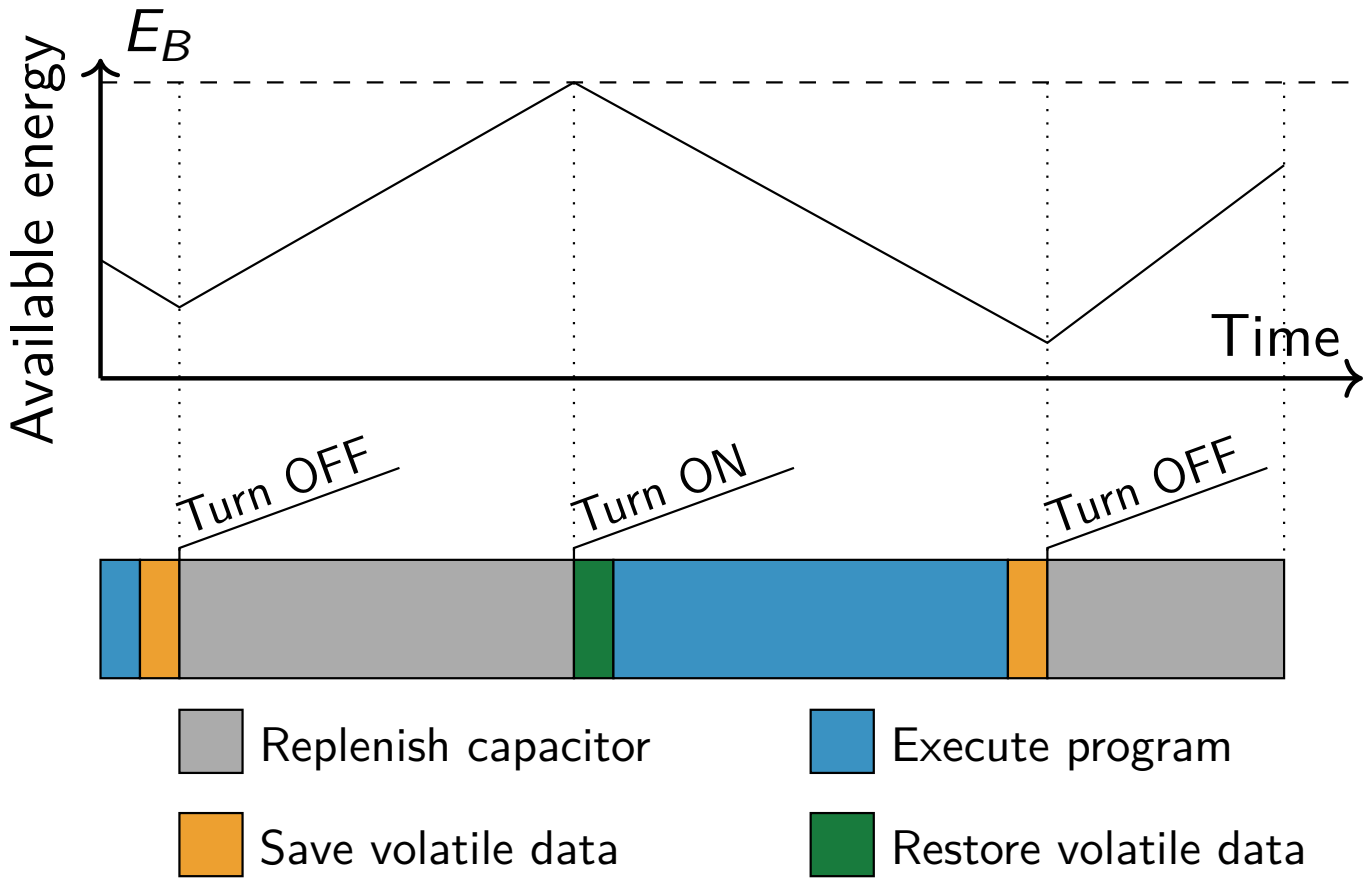
- Scarce energy
- Variable energy

Not enough energy to power the platform continuously

Intermittent Computing



Intermittent Computing



Checkpointing

Save checkpoint here ?

```
1  int sum = 0;
2  for(int i=offset;i<SIZE; i++)
3    sum += array
4  /* ..... */
5  class = f(sum);
```

Save checkpoint here ?

Save checkpoint here ?

- Saving too often => High overhead
- Not saving before power failure => No progress

Contributions

- Resurrect : An Energy Consumption Aware Runtime
- Eloise : A joint checkpoint placement and memory allocation technique

Plan

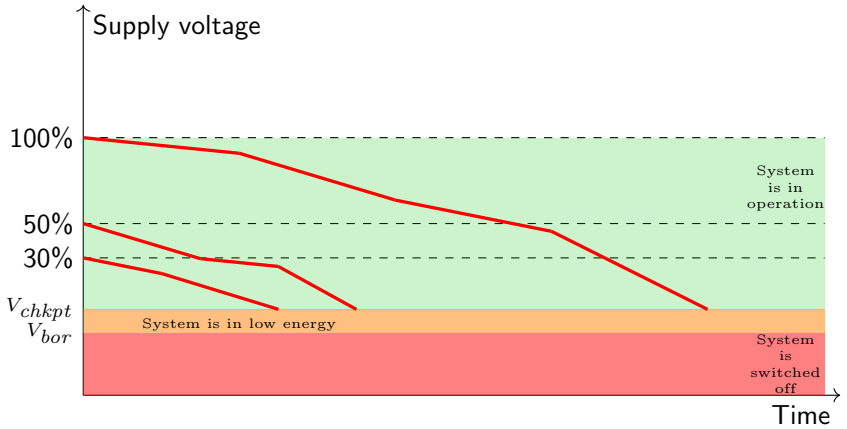
Resurrect

Resurrect
An Energy Consumption Aware Runtime

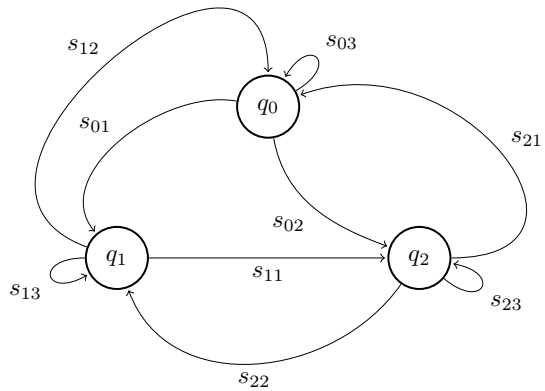
- *Power failure immunity* execution model : run code only when energy level is high enough to complete
- Optimal schedule computed offline based on worst-case energy consumption
- Runtime adaptation of schedule to account for actual execution parameters and harvested energy

Offline Schedule Computation [2]

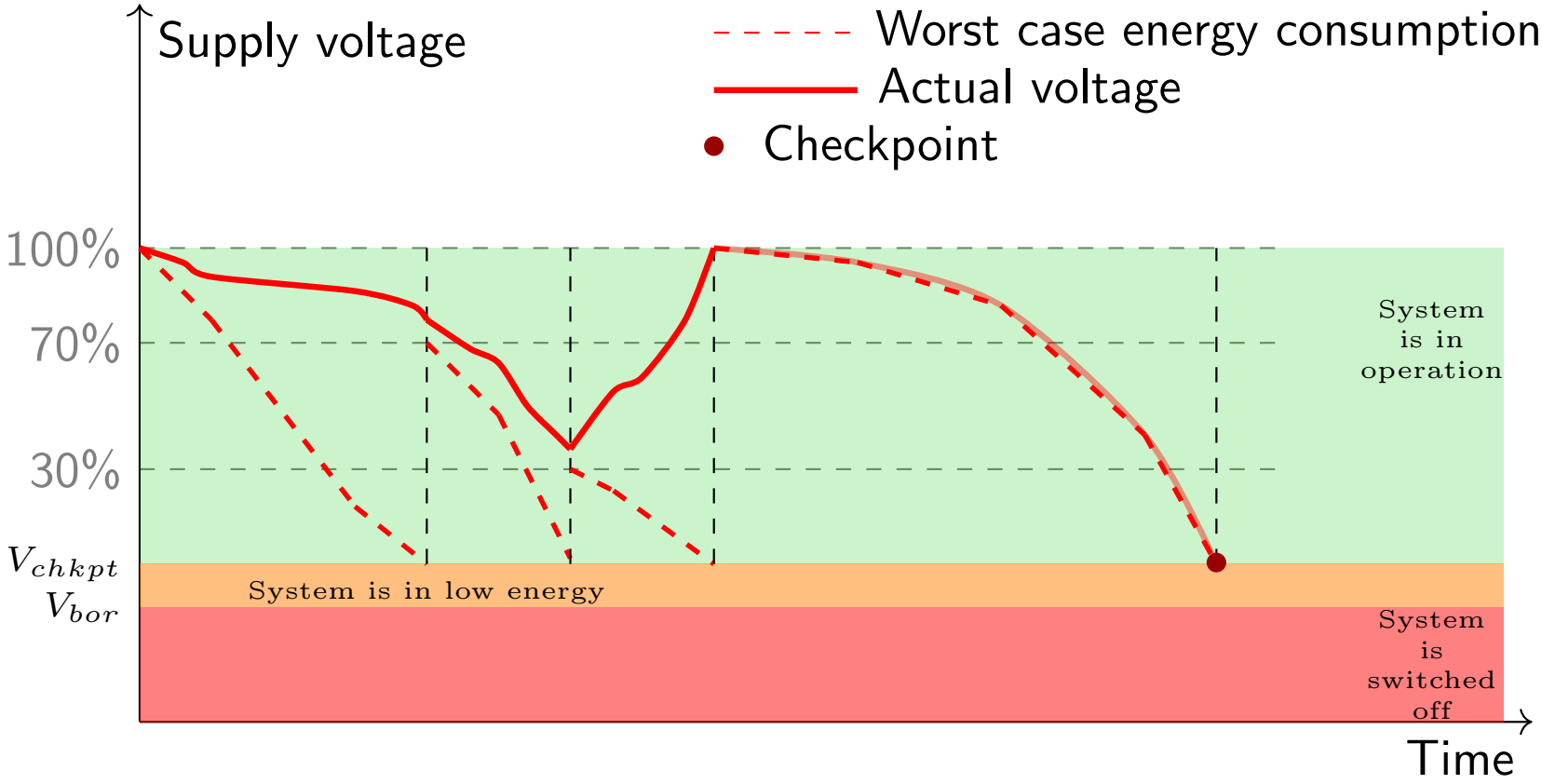
- Goal : maximize forward progress under energy consumption constraint
- Worst-case based approach : worst-case energy consumption per task, no harvesting
- Schedule computation as an optimization problem in time Petri nets with costs and rewards



$s_{01} = t_1$
$s_{02} = t_1 \to t_2$
$s_{03} = t_1 \to t_2 \to t_3$
$s_{11} = t_2$
$s_{12} = t_2 \to t_3$
$s_{13} = t_2 \to t_3 \to t_1$
$s_{21} = t_3$
$s_{22} = t_3 \to t_1$
$s_{23} = t_3 \to t_1 \to t_2$

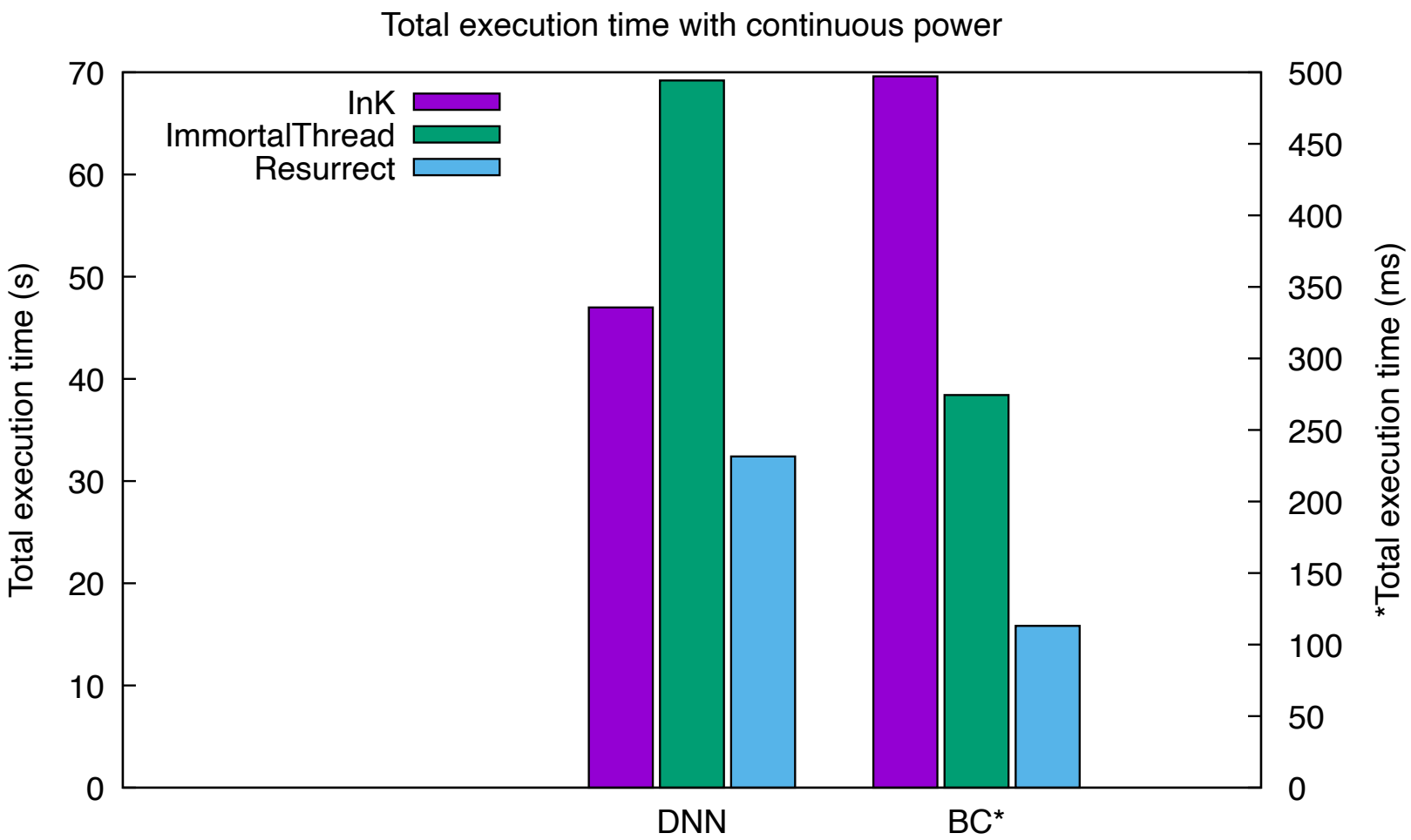


Online Adaption



- Integration of the mixed offline-online scheduling in TrampolineRTOS

Performances



Plan

Eloise

Eloise
Compile-time joint checkpoint placement and memory allocation

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1. Ensure forward progress

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2. Take the most out of the dual memory architecture

Eloise

Eloise
Compile-time joint checkpoint placement and memory allocation

1. Ensure forward progress
2. Take the most out of the dual memory architecture
3. Reduce overall energy consumption

Checkpoint placement and memory allocation

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Checkpoint placement and memory allocation

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energy consumed
<
energy available ?

Checkpoint placement and memory allocation

Allocation : SRAM or FRAM ?

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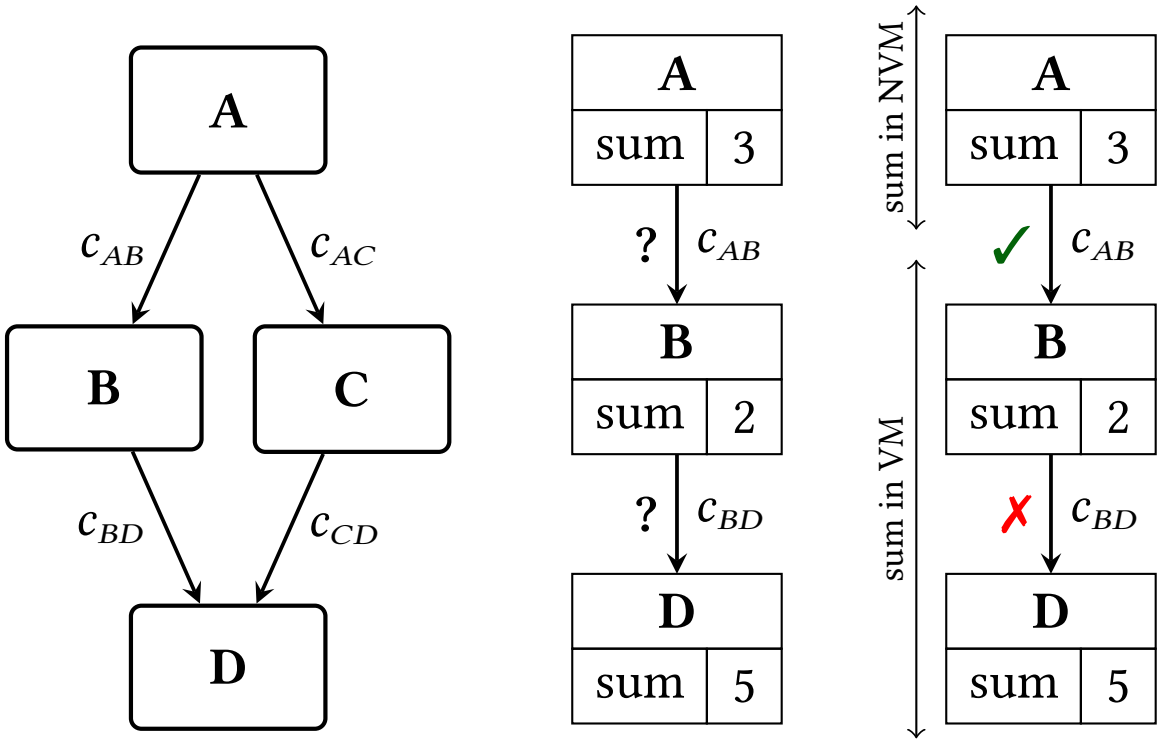
Allocation : SRAM or FRAM ?

Memory allocation parameters :

- number of accesses
- size
- liveliness

Eloise algorithm



a. Analyzed CFG

b. Path (A, B, D) before analysis

c. Path (A, B, D) after analysis

Basic block

? Potential checkpoint location

✓ Checkpoint location enabled

✗ Checkpoint location disabled

Performance

- ELOISEensure forward progress even in extreme-intermittency setup
- Overall, 51% reduction of the energy consumption

Plan

Conclusion

- Battery-less devices : Low-maintenance sensing with a reduced environnemental impact

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NOP project

- Propose solutions to handle intermittent execution
- Use-case : Bird sound recognition

References I

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In *18th Conference on Embedded Networked Sensor Systems* (2020), SenSys '20.

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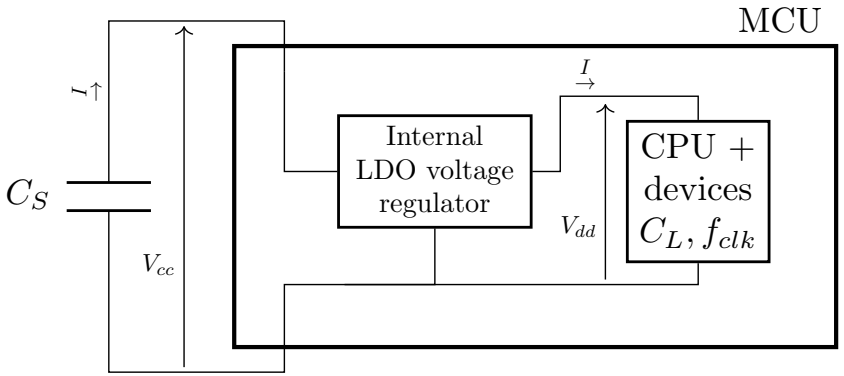
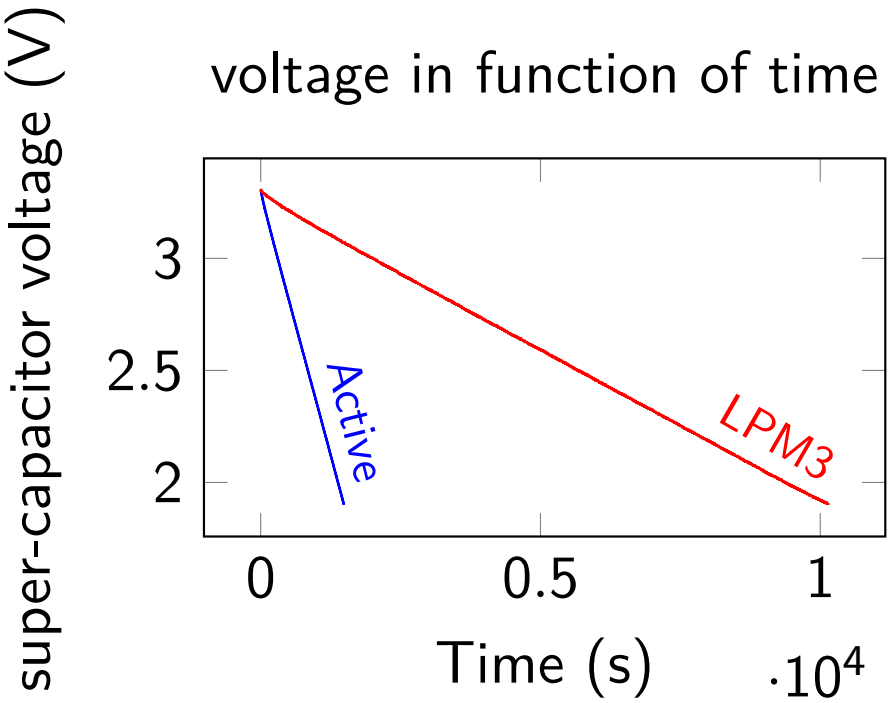
Energy Consumption Model



$$\frac{dV_{cc}}{dt} = \frac{f_{clk} \times C_L \times V_{dd}}{C_S}$$



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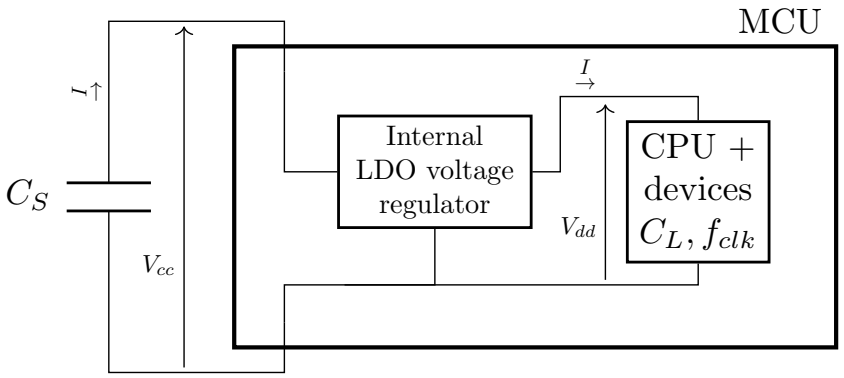

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