A Hardware Approach for Detecting, Tolerating and Exposing High Level Atomicity Violations.

Lois Orosa
João Lourenço

Euro-TM Short Term Scientific Mission
Departamento de informática
Faculdade de Ciências e Tecnologia
Universidade Nova de Lisboa

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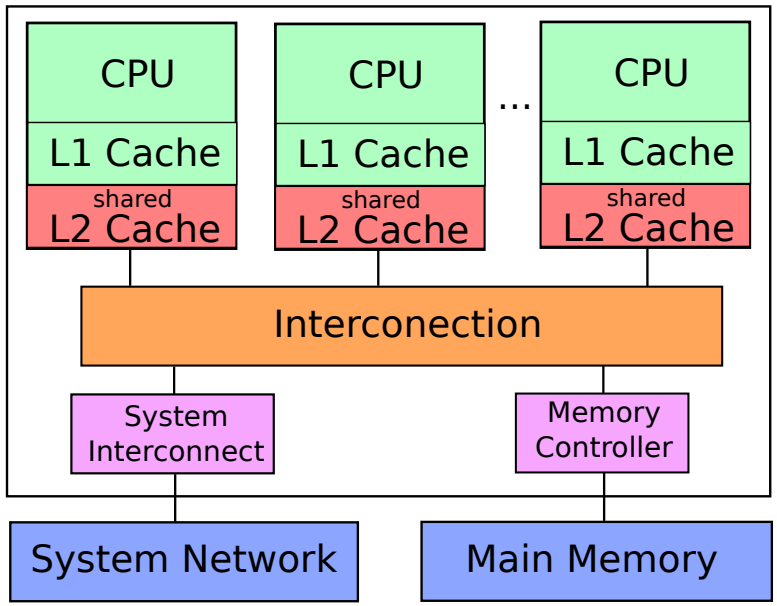
Introduction - Parallel Programming



- Multicore processors are mainstream (Intel, AMD, IBM, etc.)
- Shared memory model (more intuitive than message passing)
- Difficult to program and debug
- Synchronization mechanisms can lead to concurrent bugs

Introduction - Concurrent Bugs

- Concurrent bugs are difficult to detect and reproduce
- It takes long time to debug them
- Several types:
  - Dealocks, Livelocks ...
  - Data Races
  - Order violations
  - Asymmetric (or low level) data races
  - High Level Atomicity Violations
- Other Tools (Deterministic replay, tools for code analisys, etc.)
- Hardware and Software approaches

Introduction - High Level Atomicity Violations (HLAV)

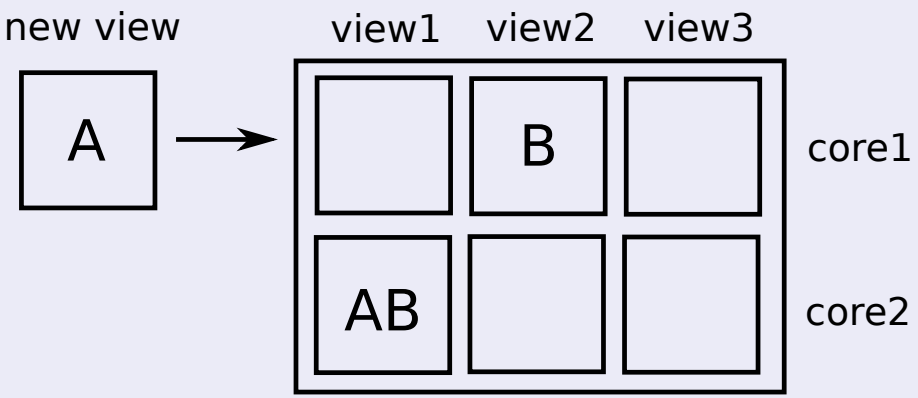
- All shared variables are protected by synchronization mechanisms (no data races).
- If one thread accesses data together in the atomic section and another thread accesses the same data separately in different atomic sections, a HLAV is reported

```
1  atomic void getA() {
2     return pair.a;
3  }
4  atomic void getB() {
5     return pair.b;
6  }
7  atomic void setPair (int a, int b) {
8     pair.a=a;
9     pair.b=b;
10 }
11 boolean areEqual(){
12    int a = getA();
13    int b = getB();
14    return a==b;
15 }
```

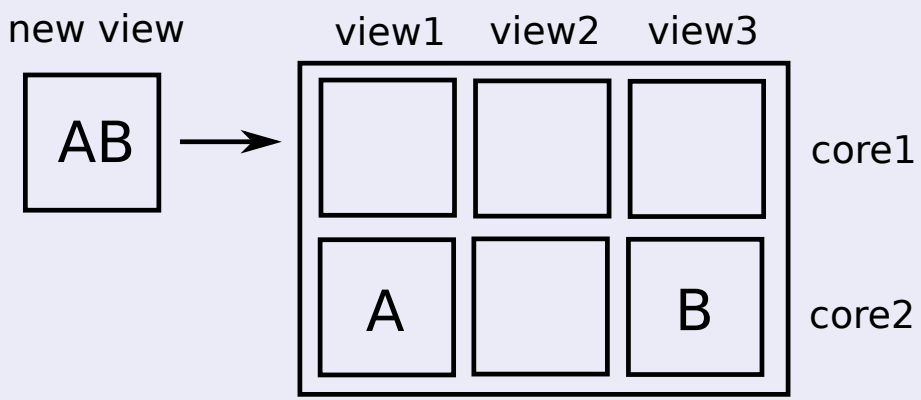
Introduction - High Level Atomicity Violations (II)

- View: addresses of memory locations accessed in an atomic region
- Maximal view: is not a subset of any views of that thread/core

real HLAV



potential HLAV



HLAV: definition

There is an HLAV if the intersections of two views of one thread with the maximal view of another thread do not form an inclusion chain.

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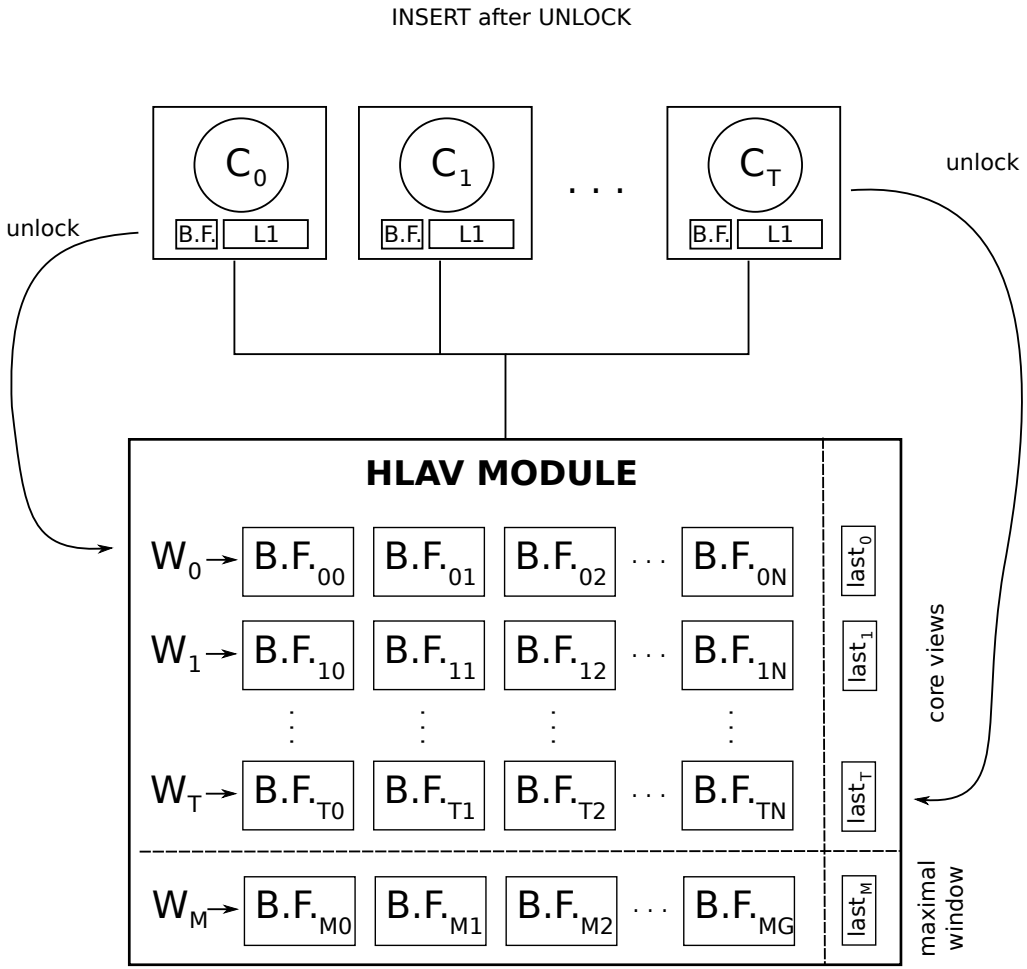
Idea - Module of Bloom filters



- Windows of *N* views per core
- The new view replaces the older view in the window
- Maximal window to maintain maximal views from all cores

Idea - Description

In each core

- Collection of the addresses accessed in the atomic sections.
- Additional Bloom filter per core.
- At unlocks, the core sends the content of the Bloom filter to the module.

Module

- Receives the views of all cores.
- Core windows keep the last views of the cores
- Maximal window keeps the maximal views of all cores
  - Also maintains additional information from cores that can have a HLAV with this maximal view

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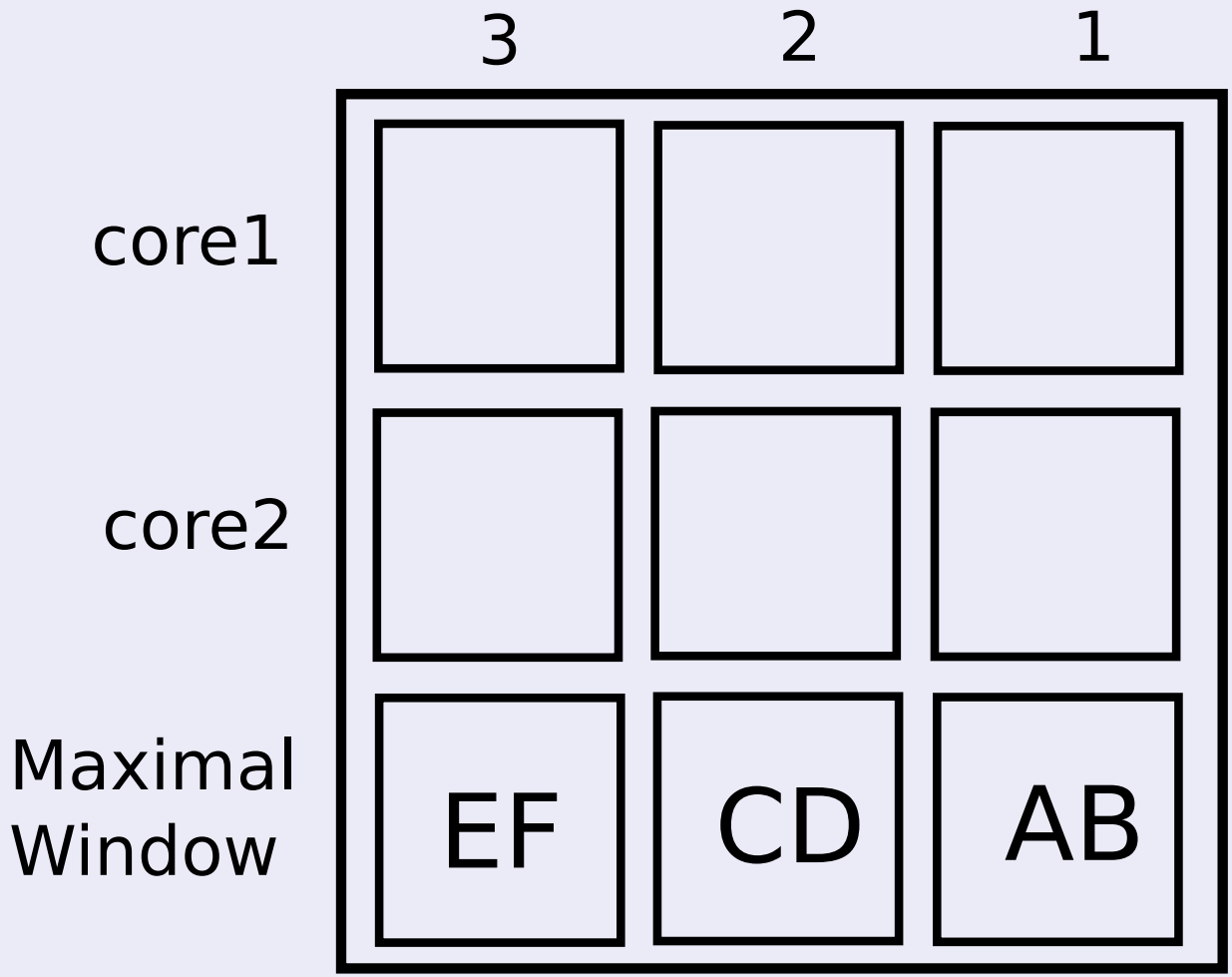
Idea - Detecting HLAVs (I)

New View

1. If a view is maximal, is inserted in the maximal window
2. If the intersection of the new view with a MV is subset of that MV, the new view is set as possible causative of a HLAV
3. If (2) and if there is another view in the same window that the new view that also matches (2), and this 2 views do not form a chain, HLAV is detected

Idea - Detecting HLAVs (II)

Example



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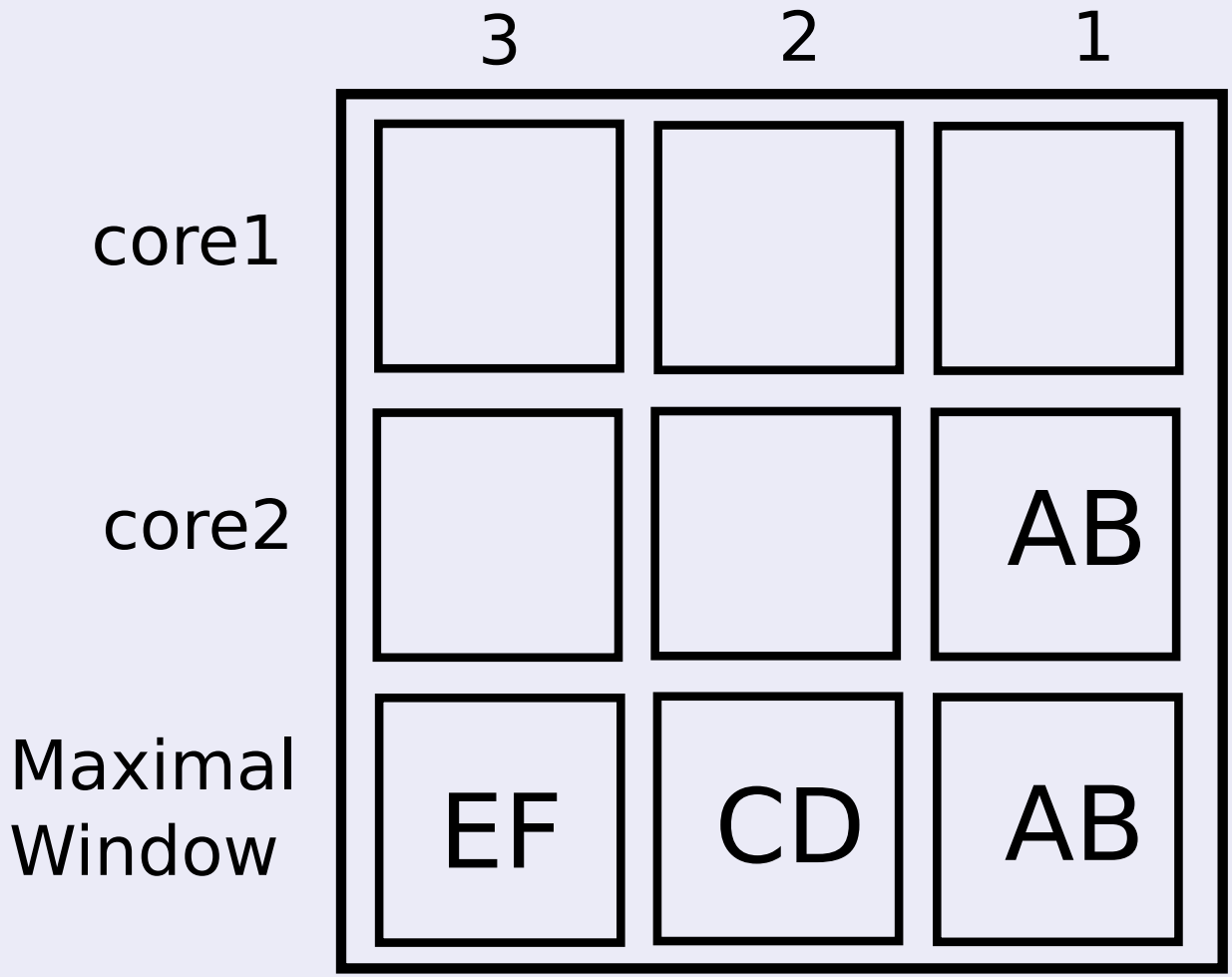

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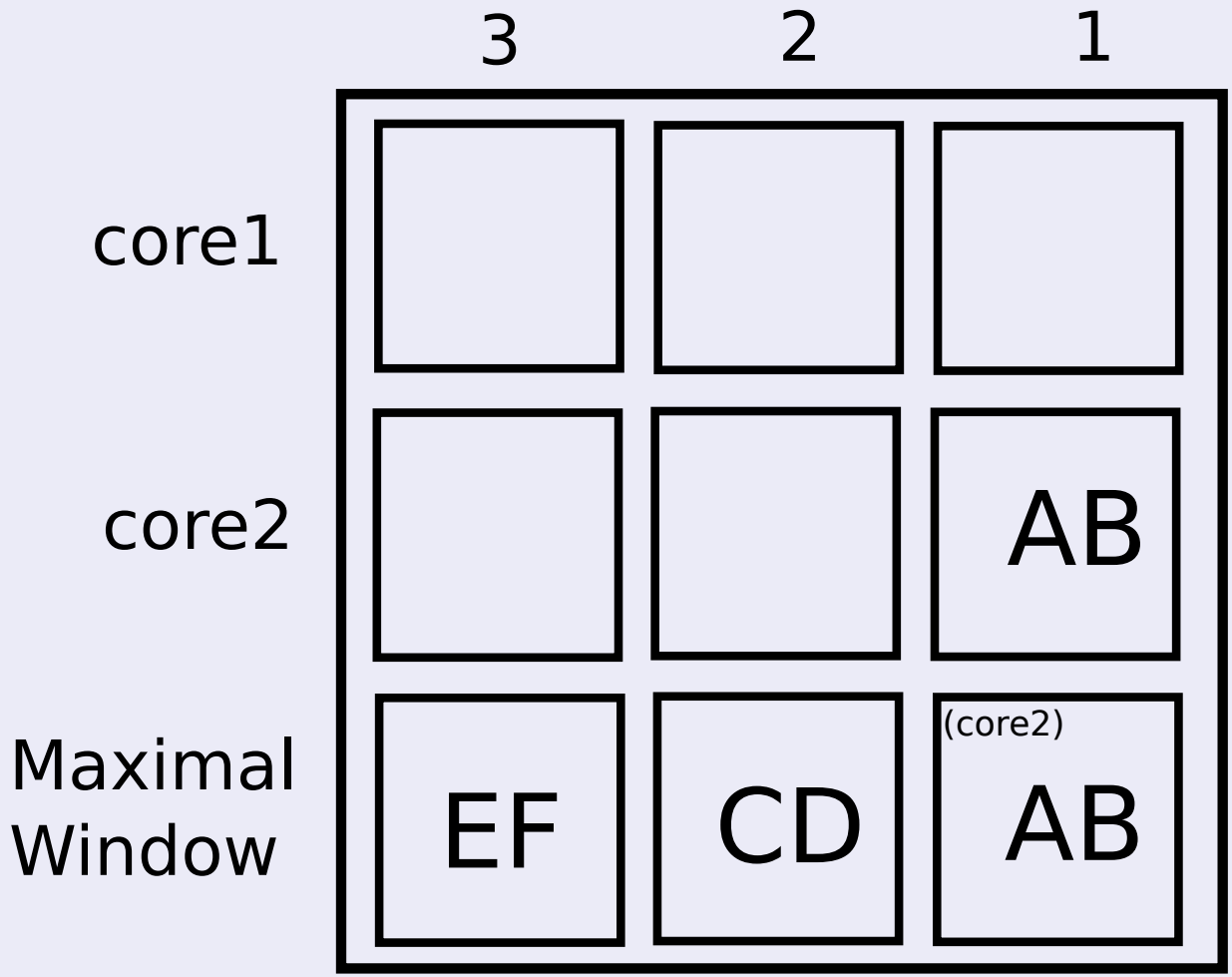

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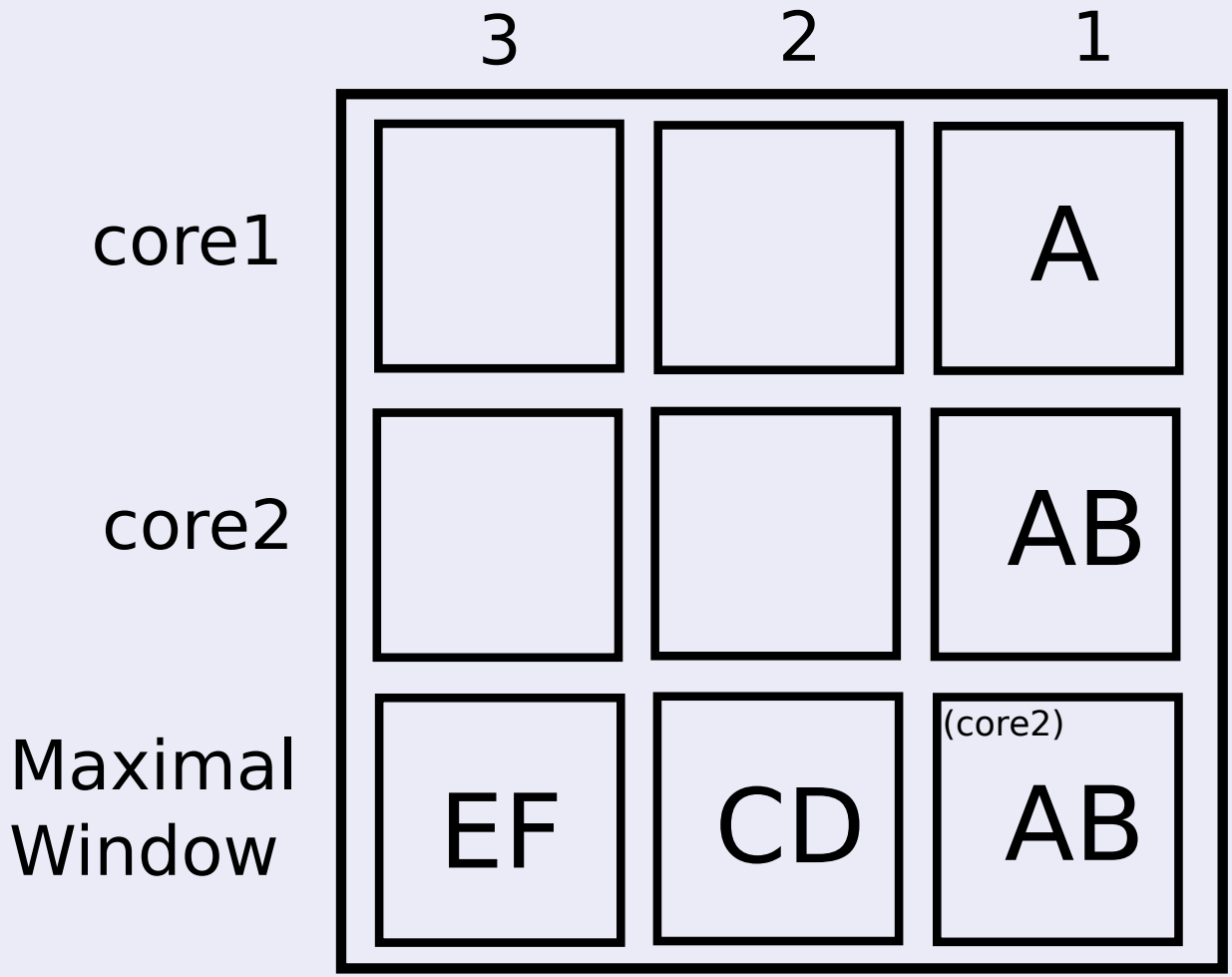

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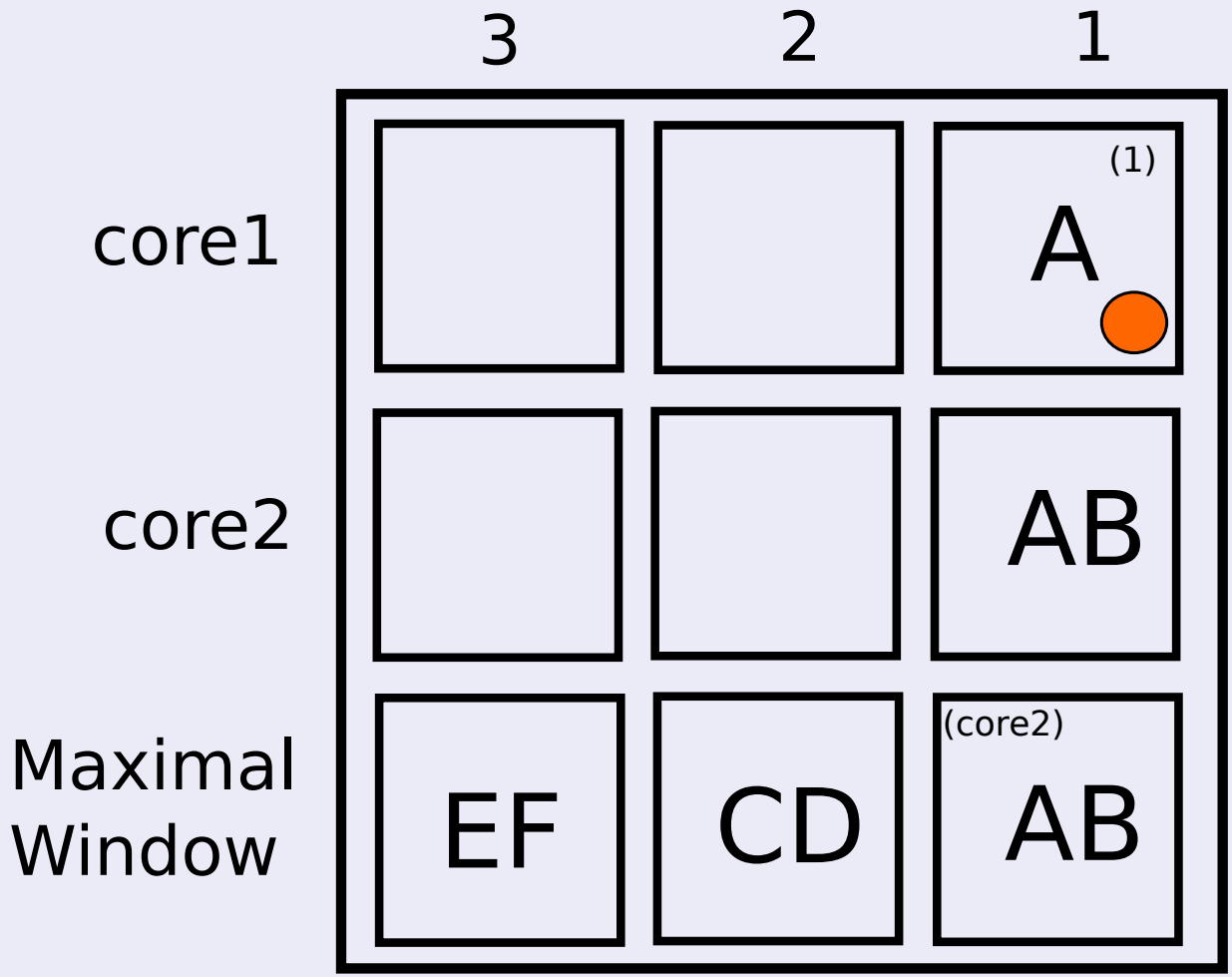

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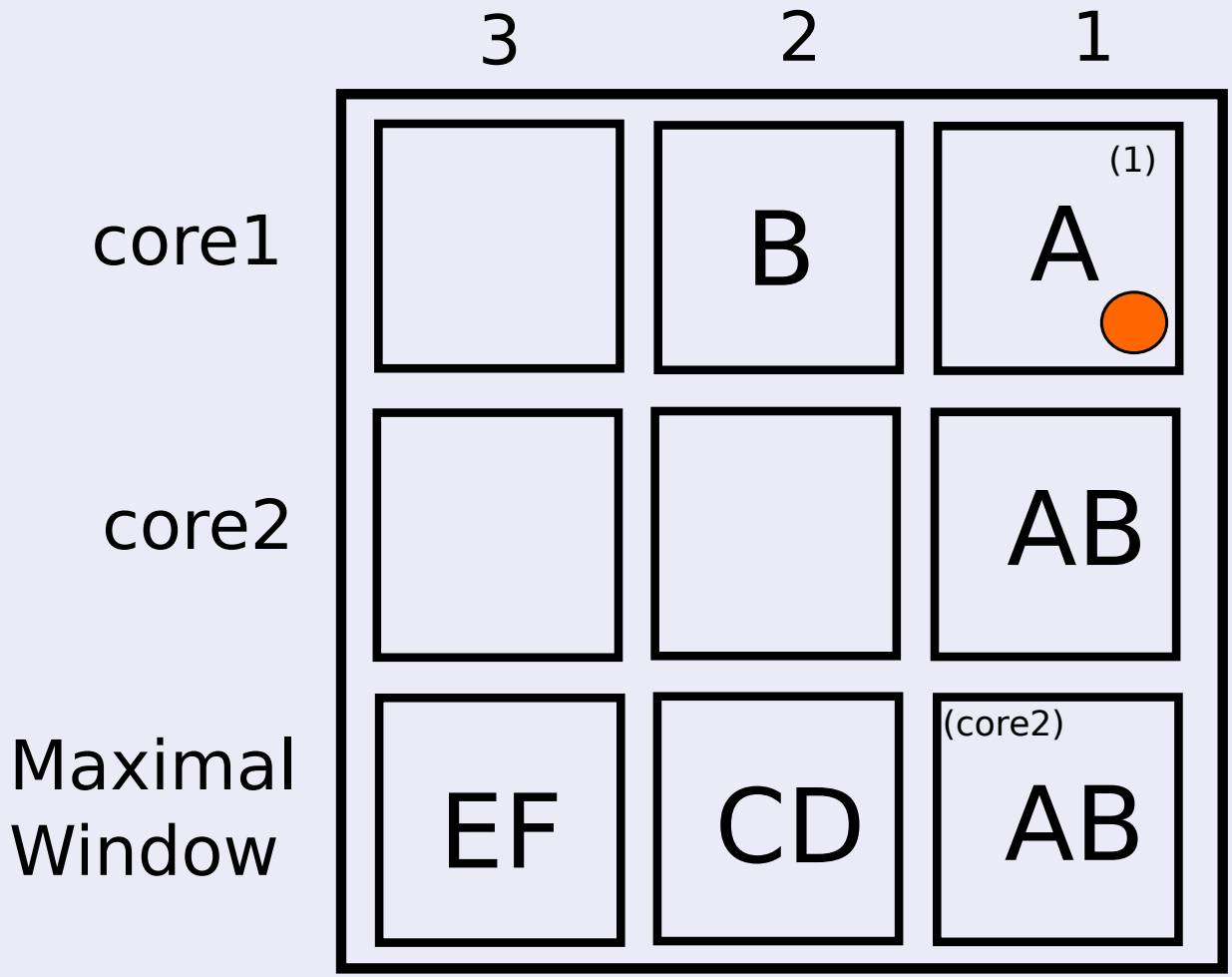

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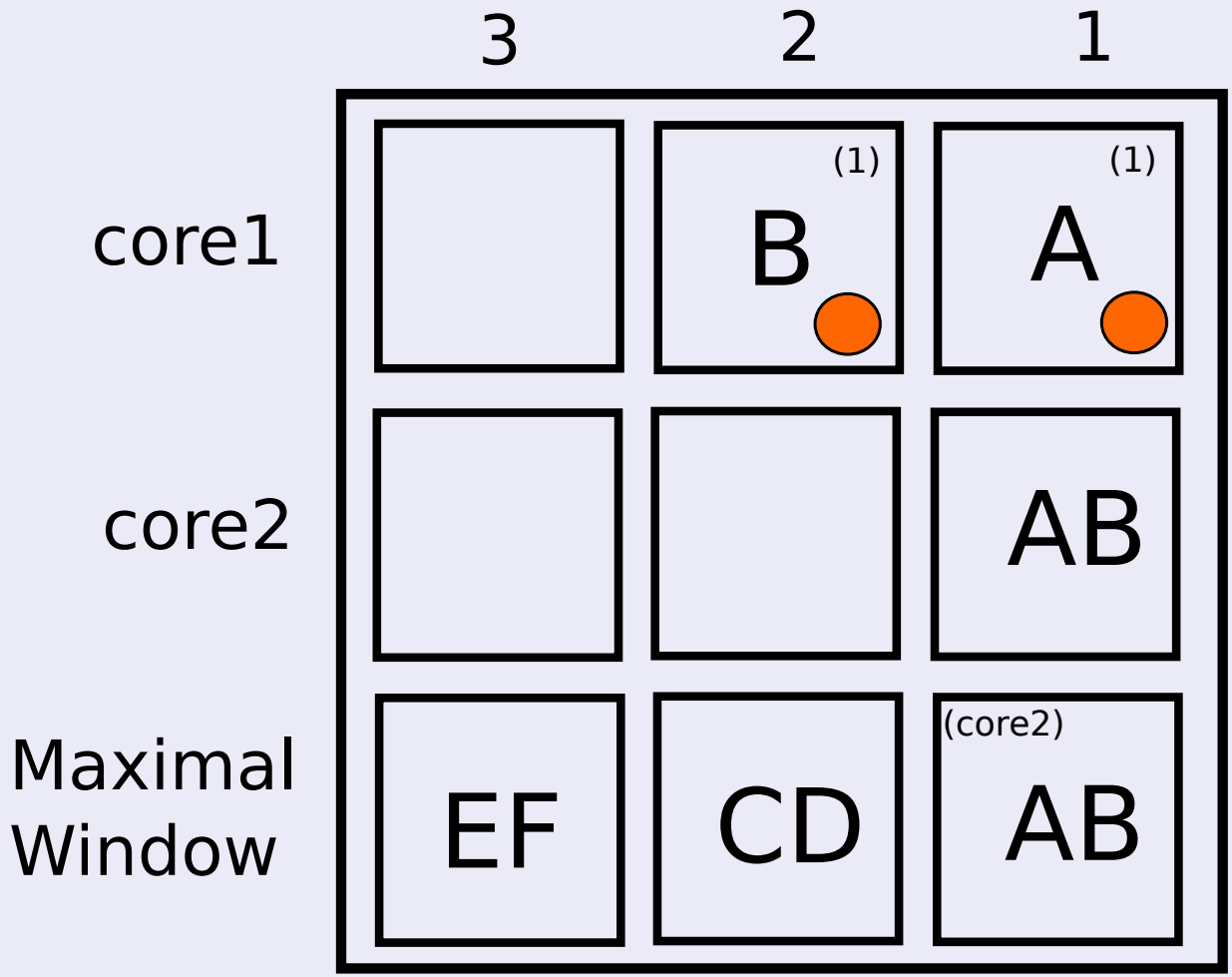

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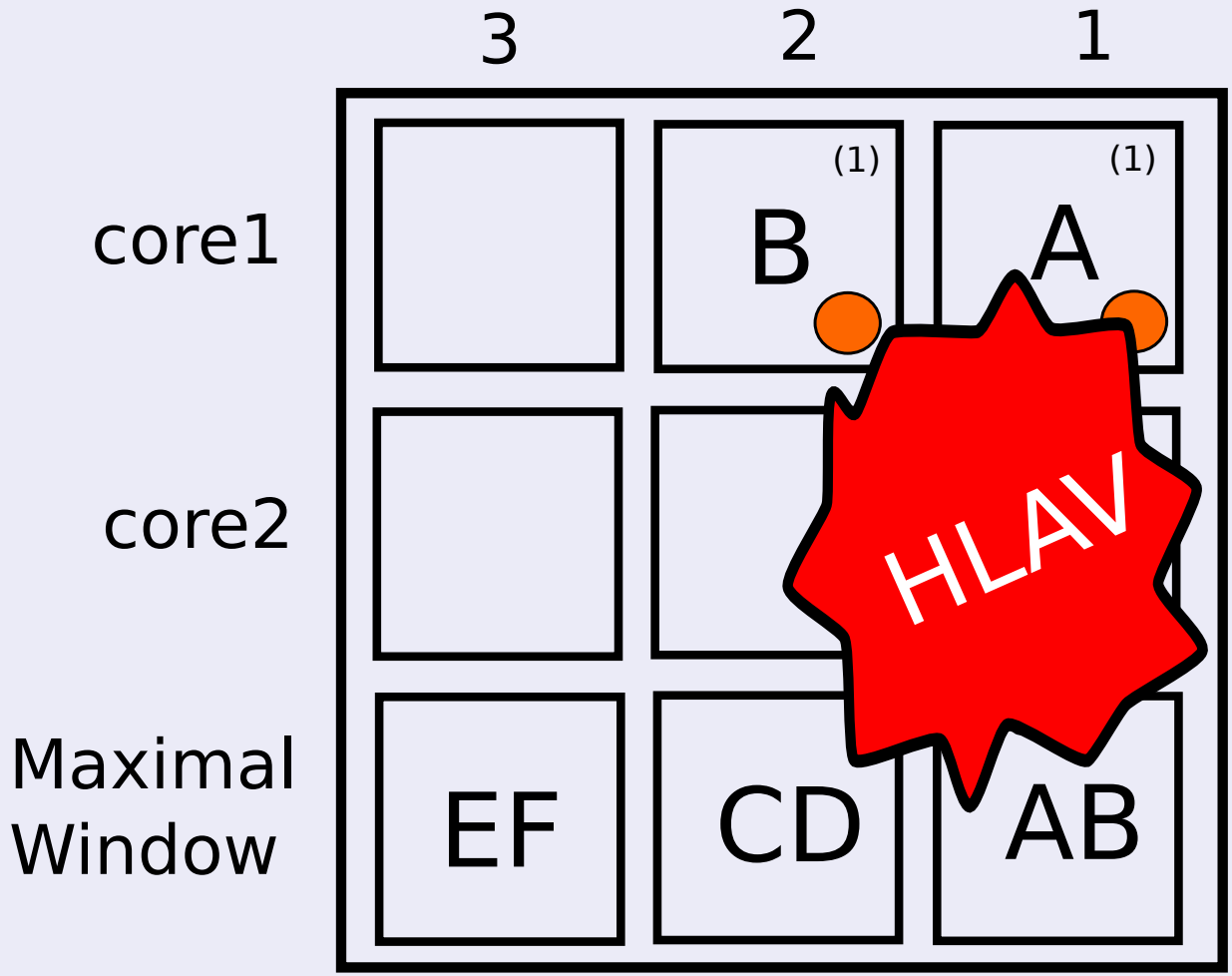

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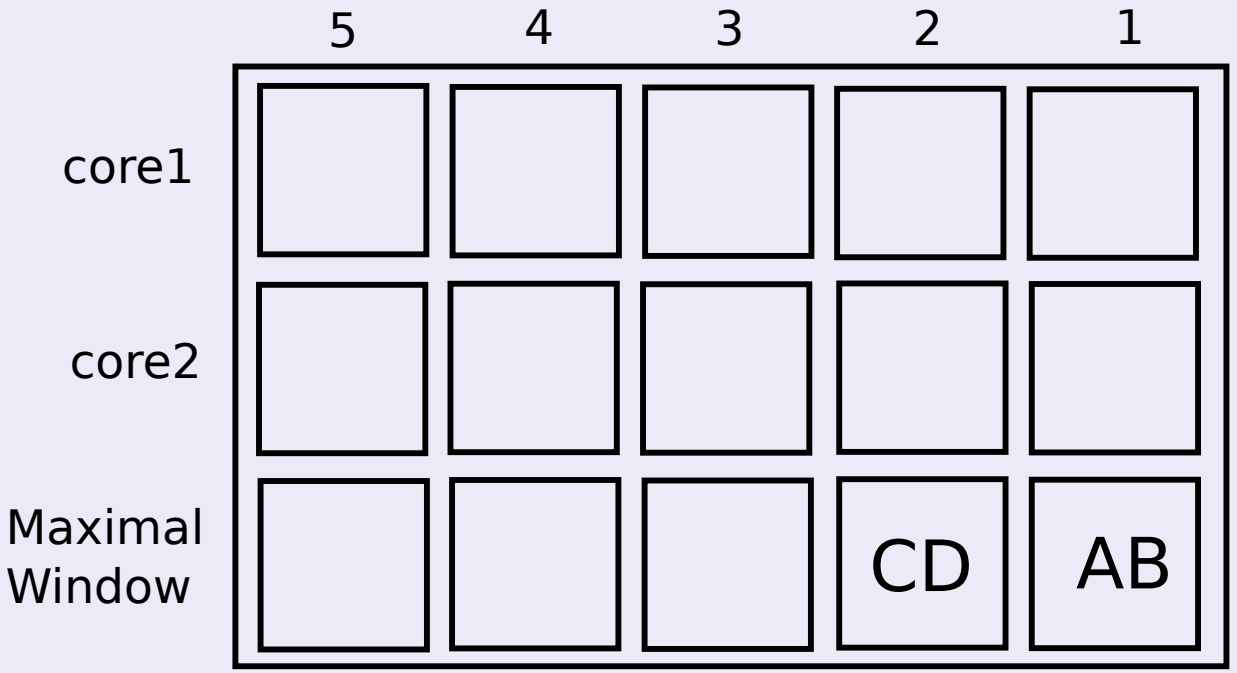
Idea - Exposing HLAVs (I)

- Tries to become the potential HLAVs into real HLAVs
- Forces the interleving by stalling cores
- Timeout to avoid deadlocks
- Minimal hardware additions to support this feature
- Practical in the debugging process

Idea - Exposing HLAVs (II)

Example



Idea - Exposing HLAVs (II)

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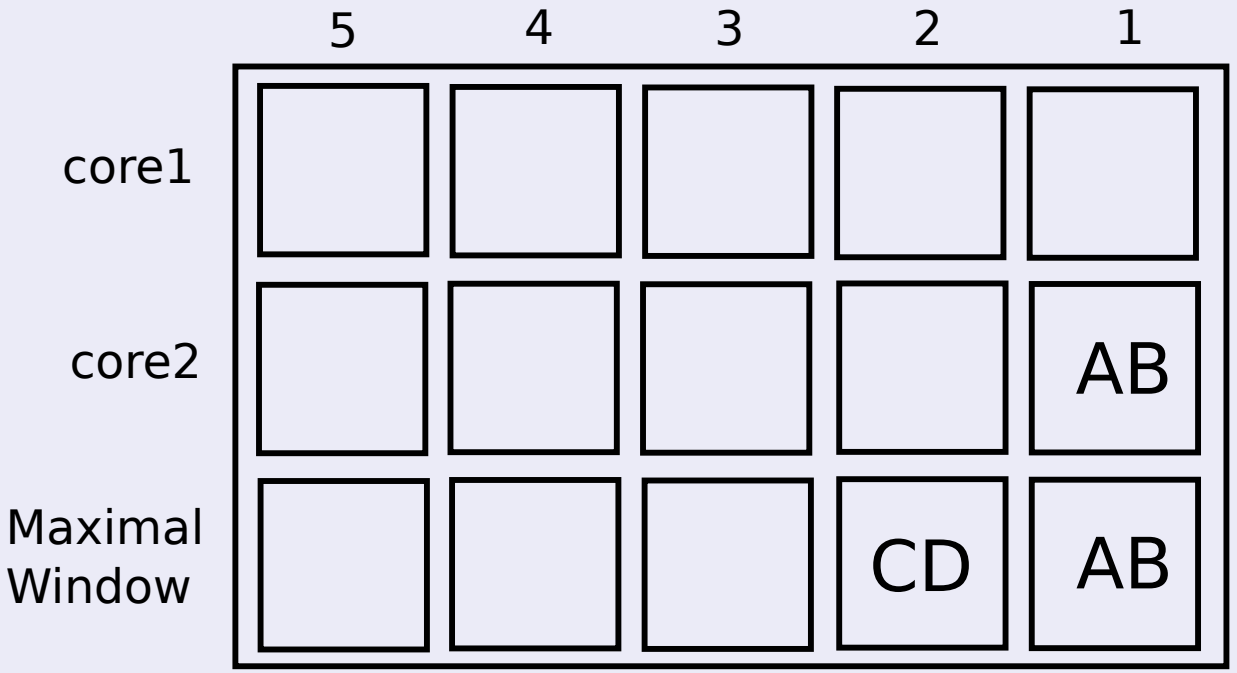

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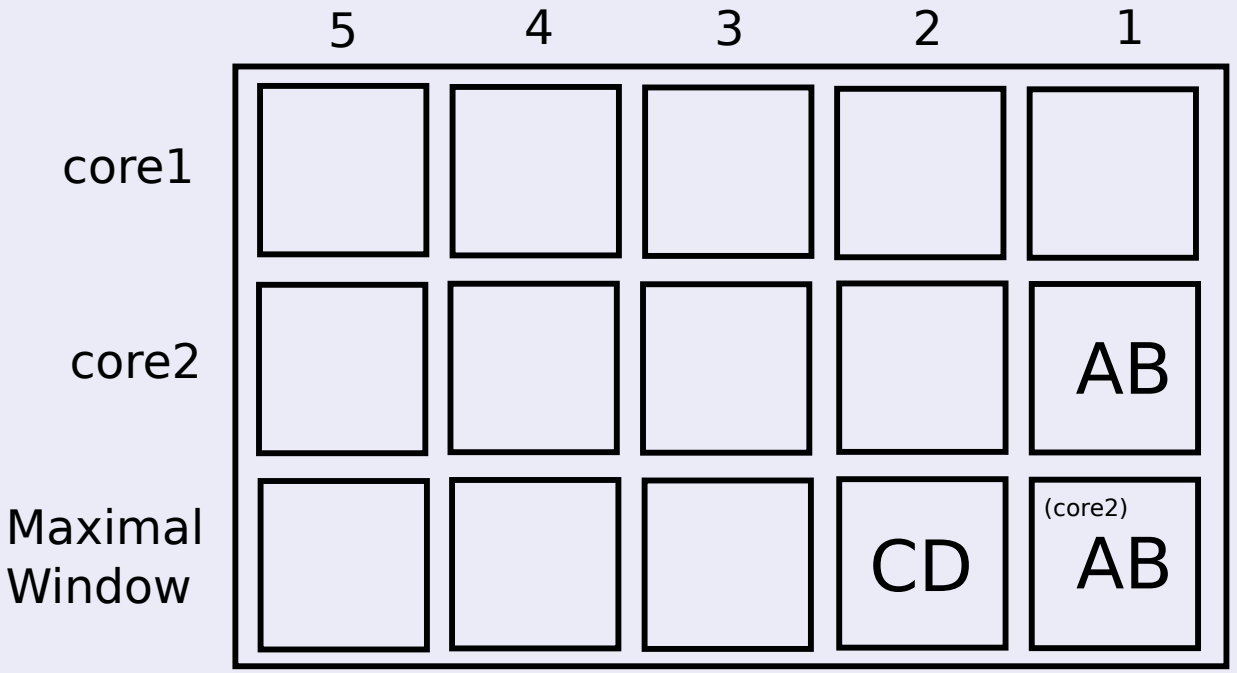

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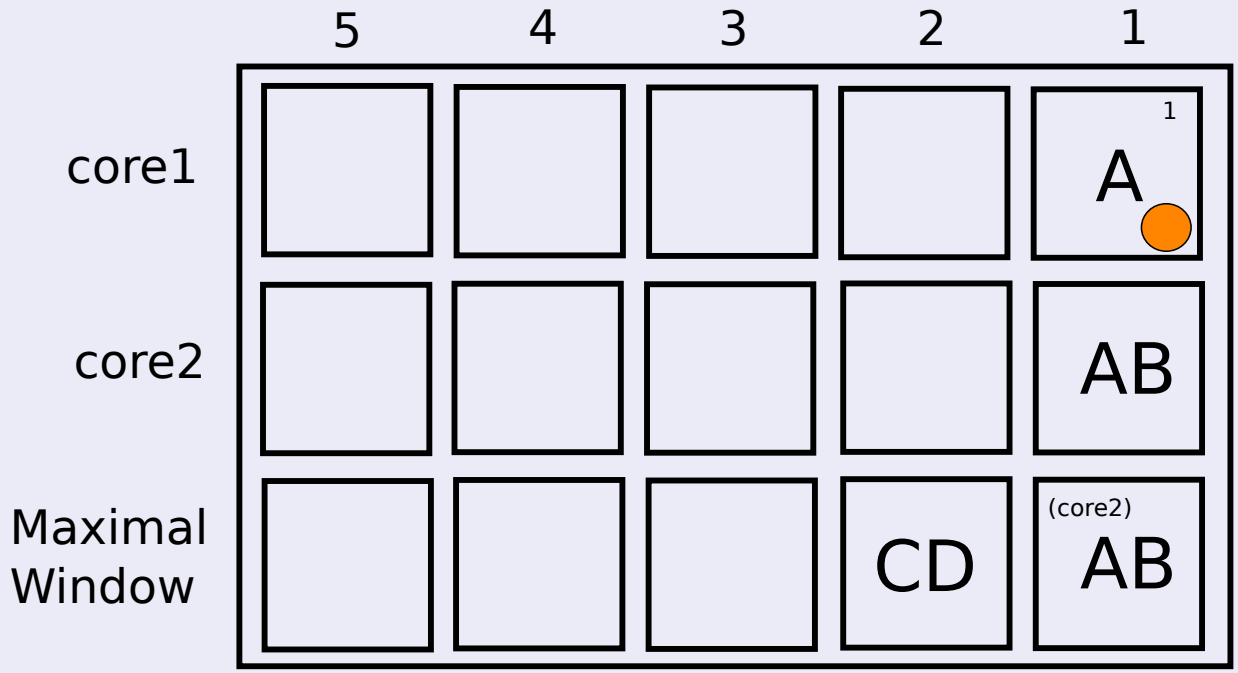

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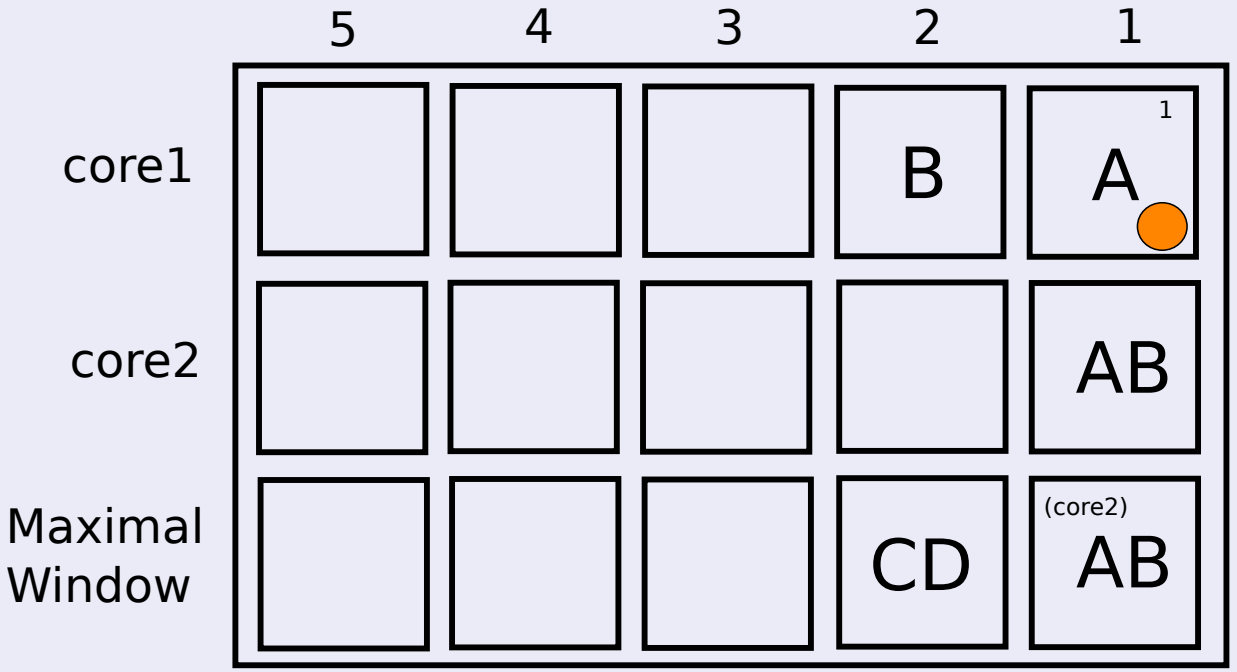

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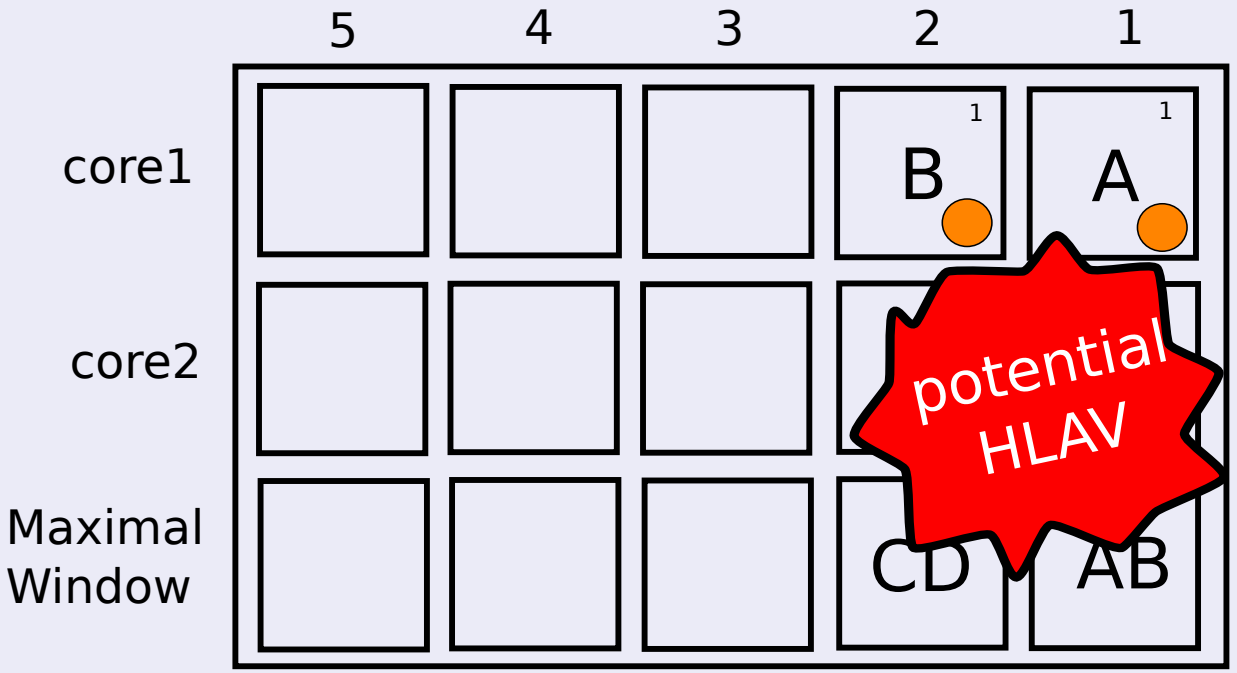

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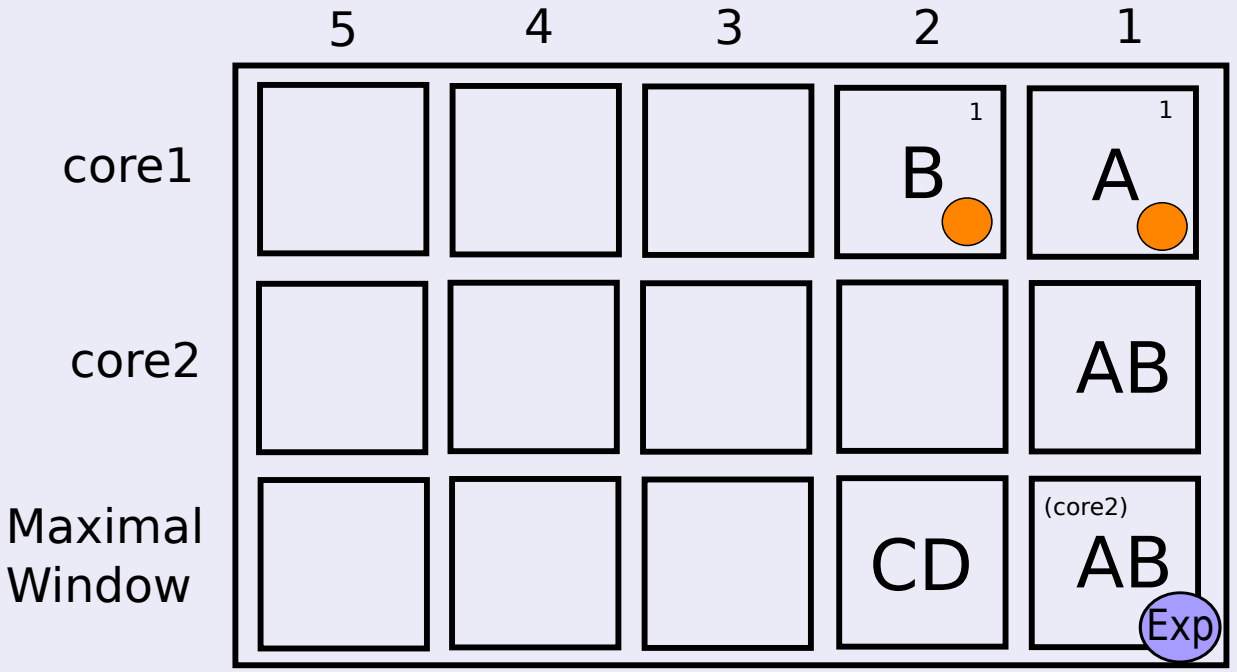

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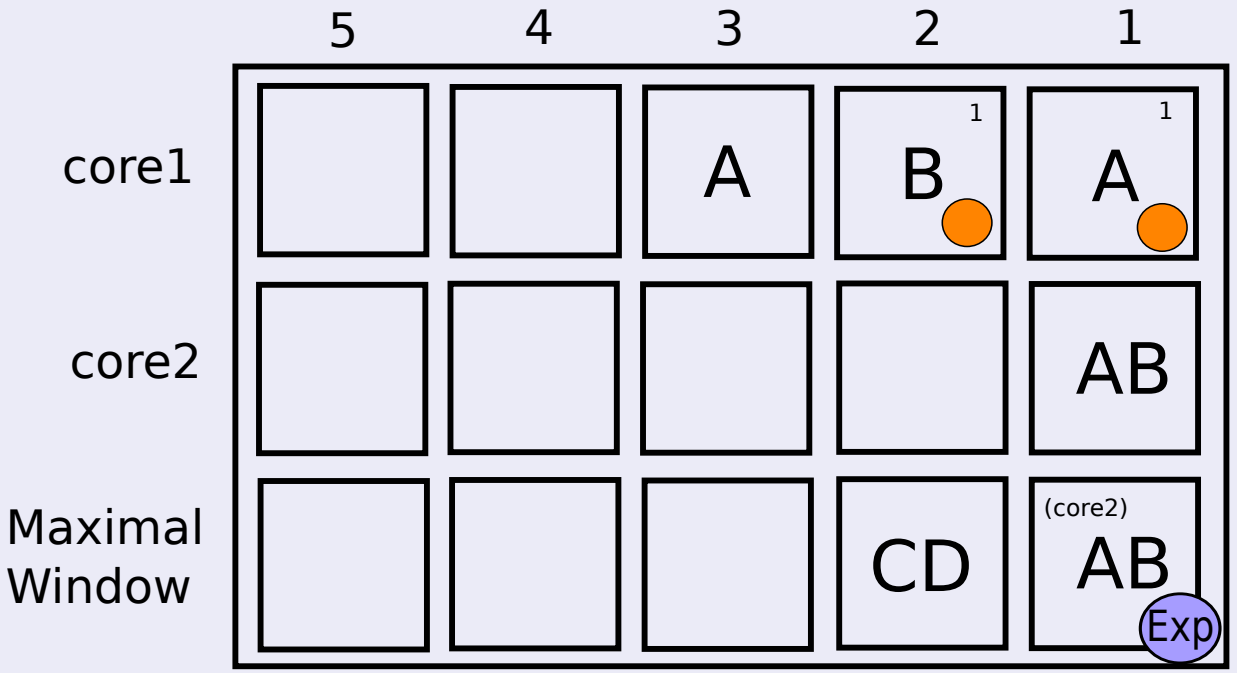

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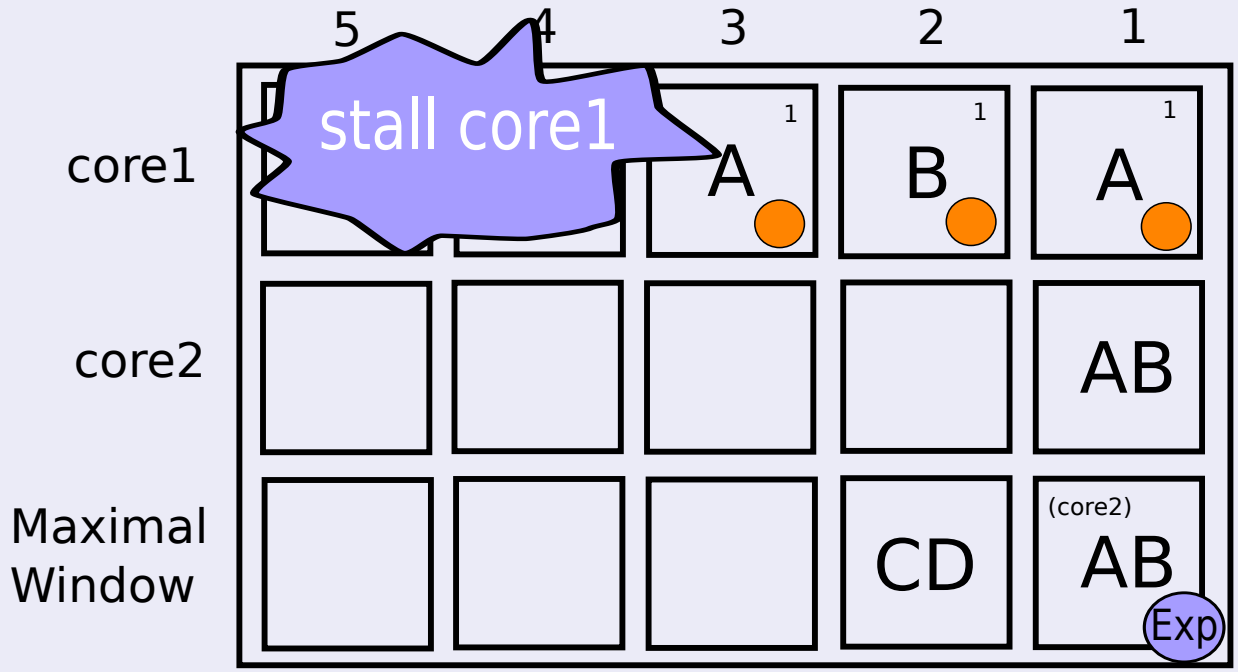

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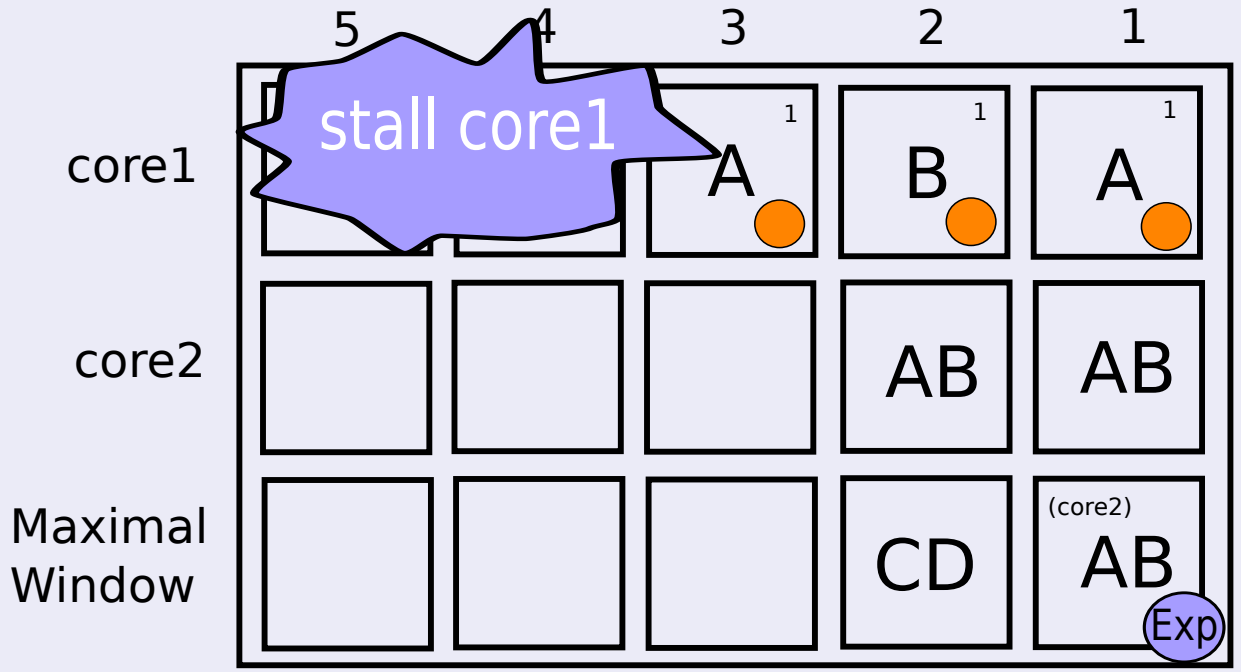

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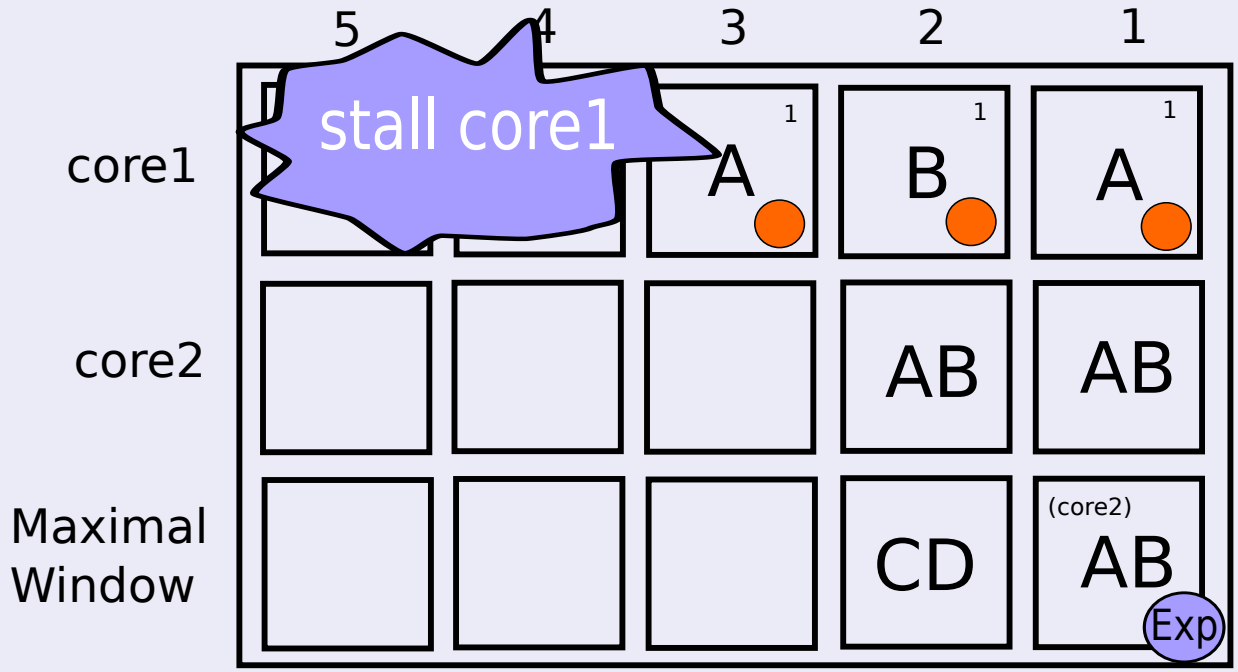

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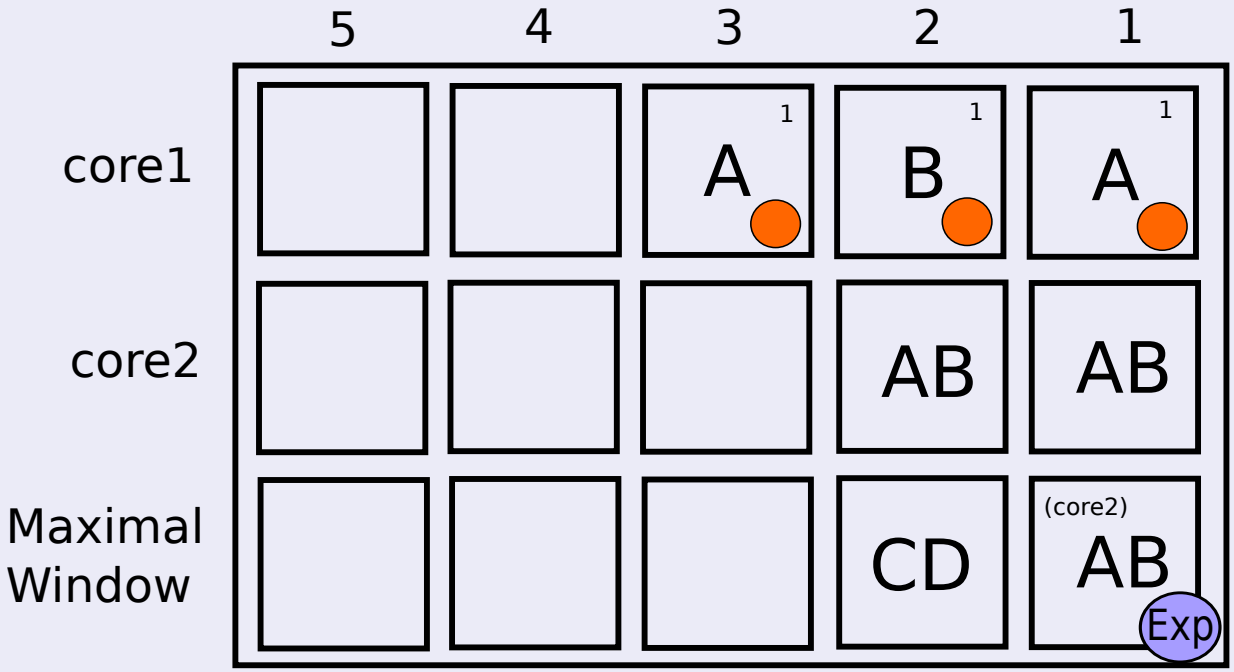

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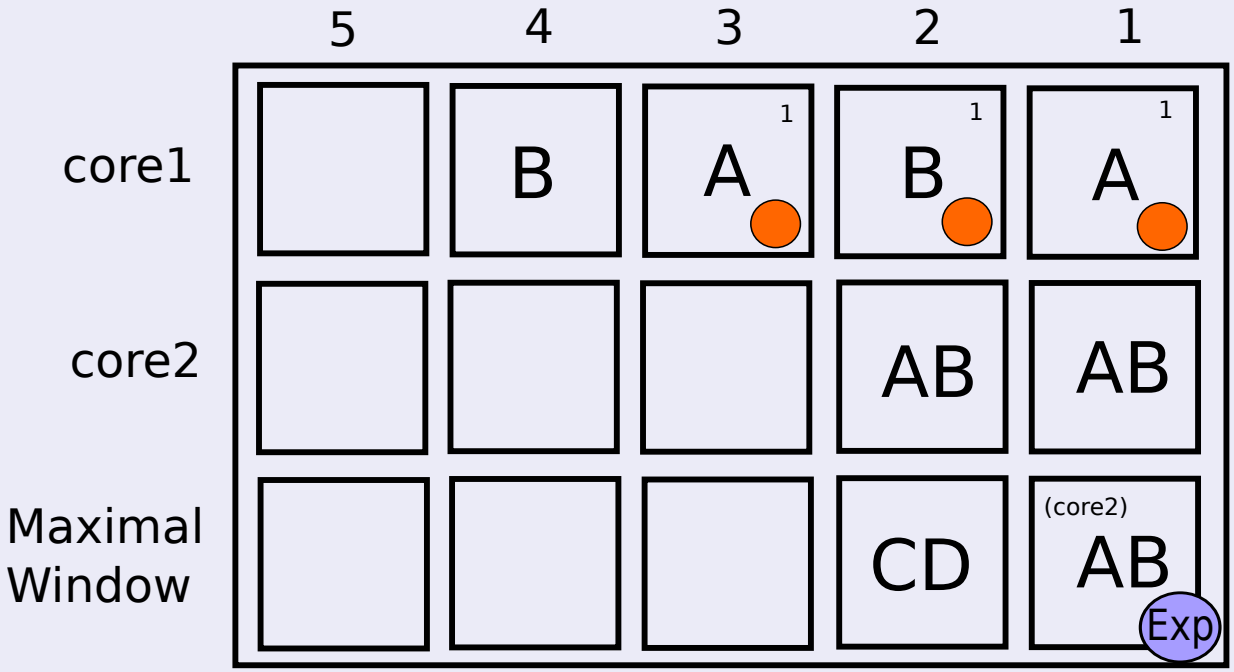

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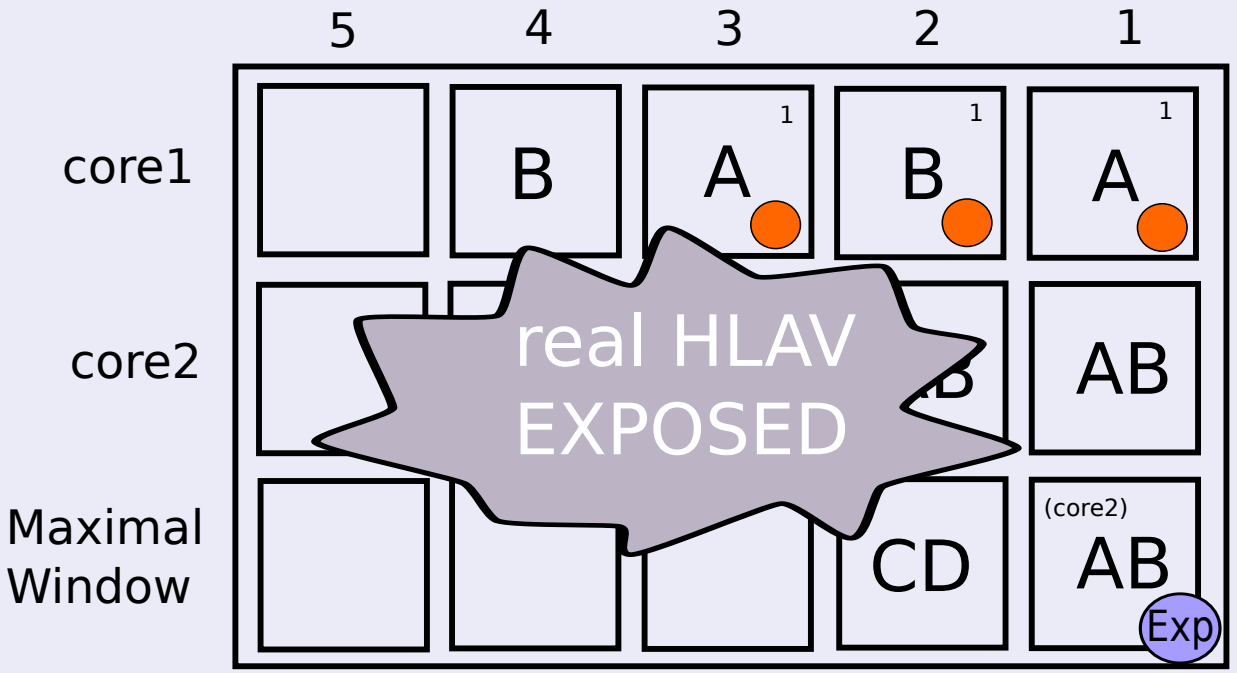

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Idea - Tolerating HLAVs (I)

General Idea

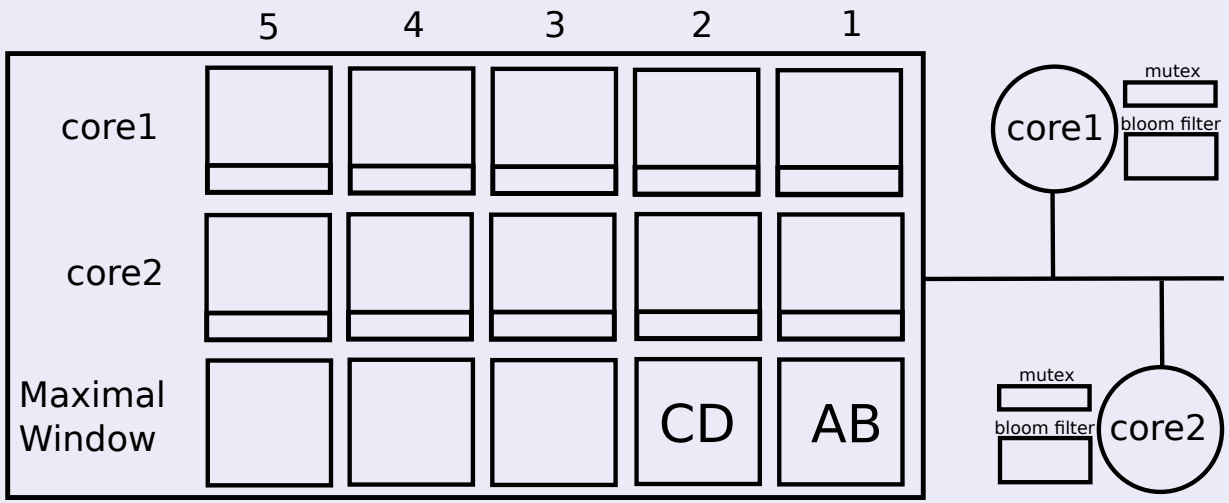
- Useful in production runs
- Tries to avoid real HLAVs
- Uses information based on previous potential HLAV
- Uses transactions to protect regions that are suspect to be buggy

Additions

- Lock addresses are tracked, and used by the module
- Cores have a list of suspicious locks (to start Tx)
- The views in the module could be now in speculative state

Idea - Tolerating HLAVs (II)

Example



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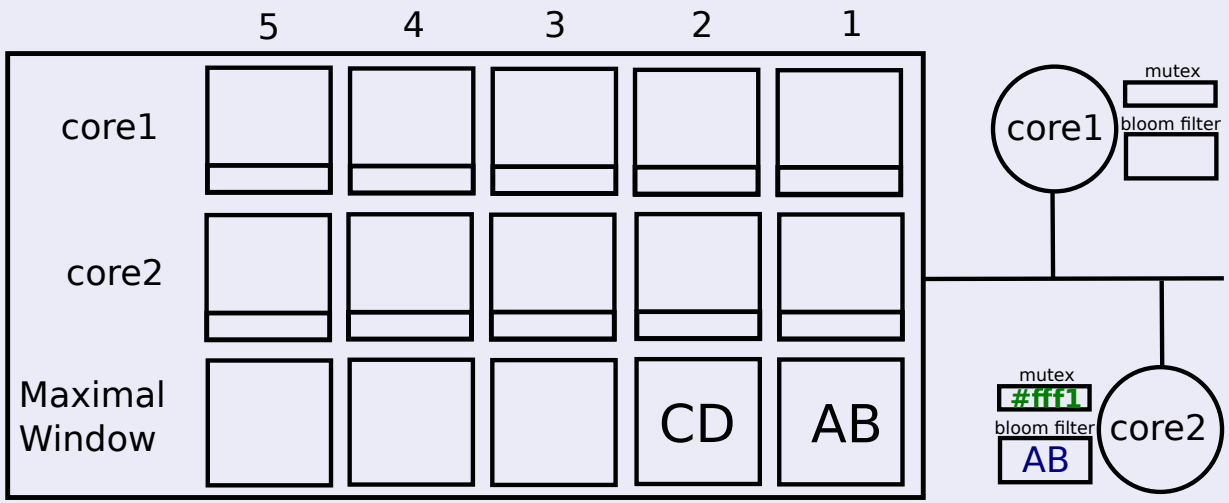

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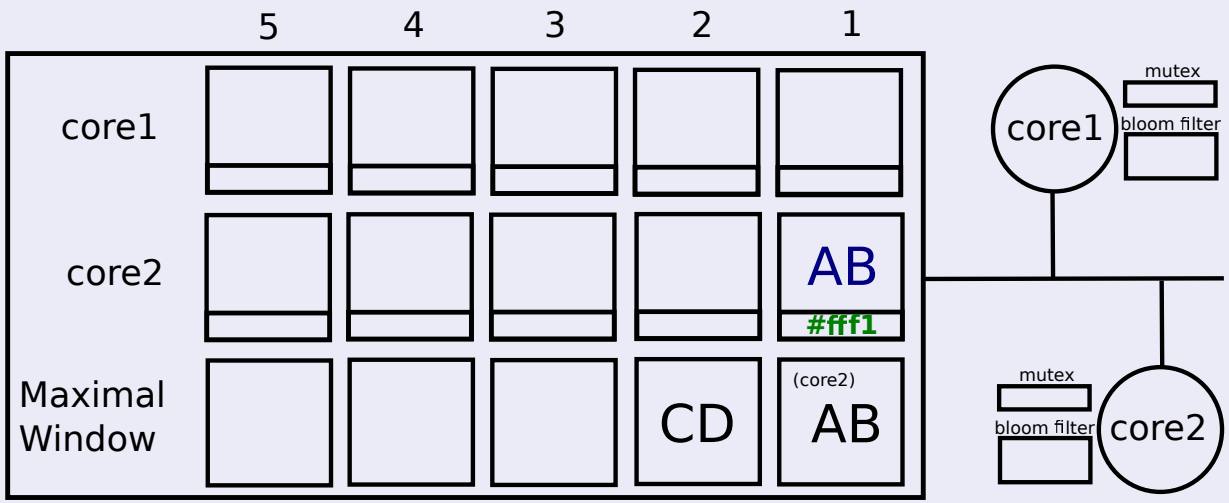

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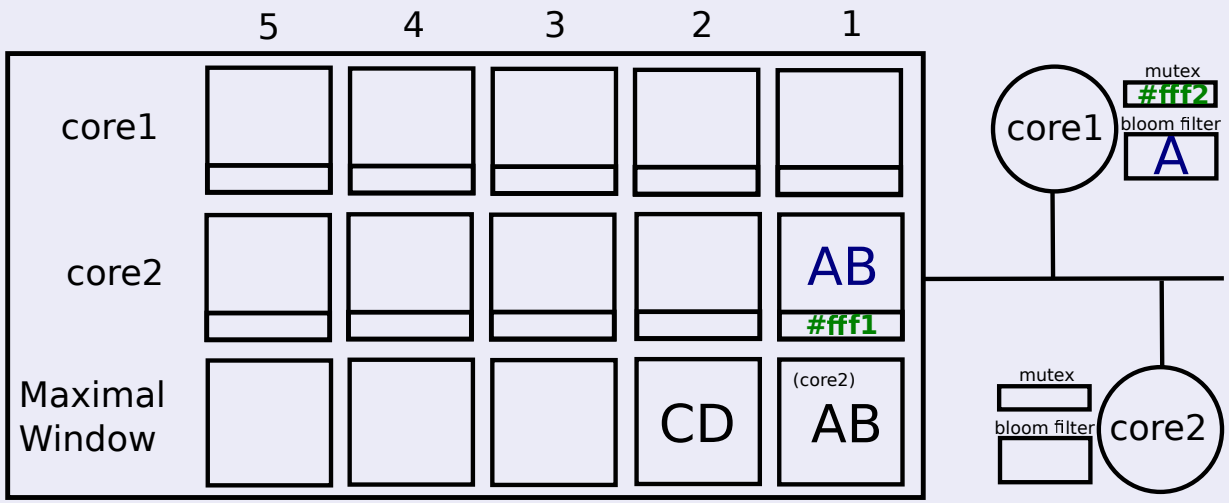

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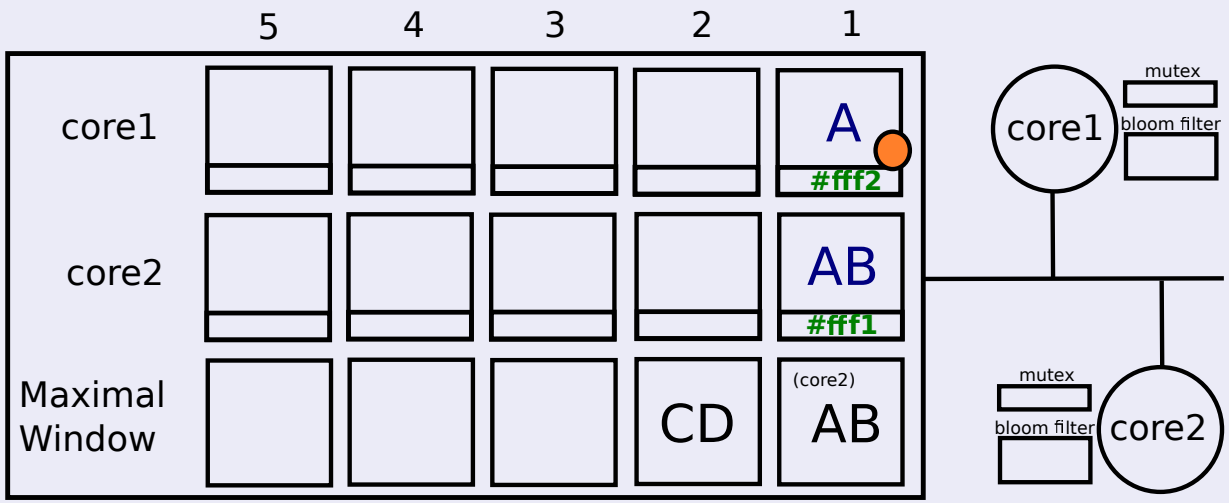

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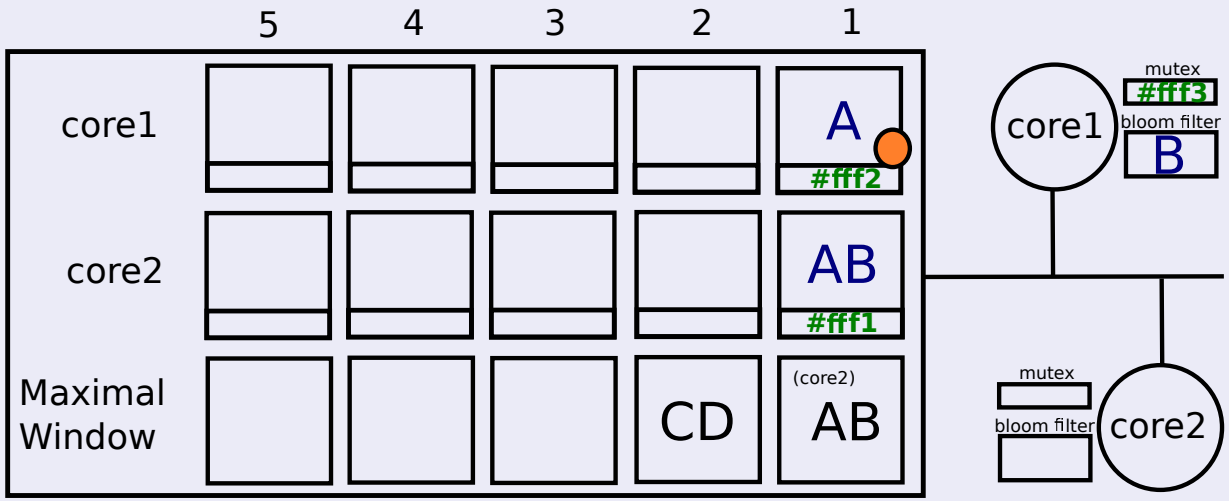

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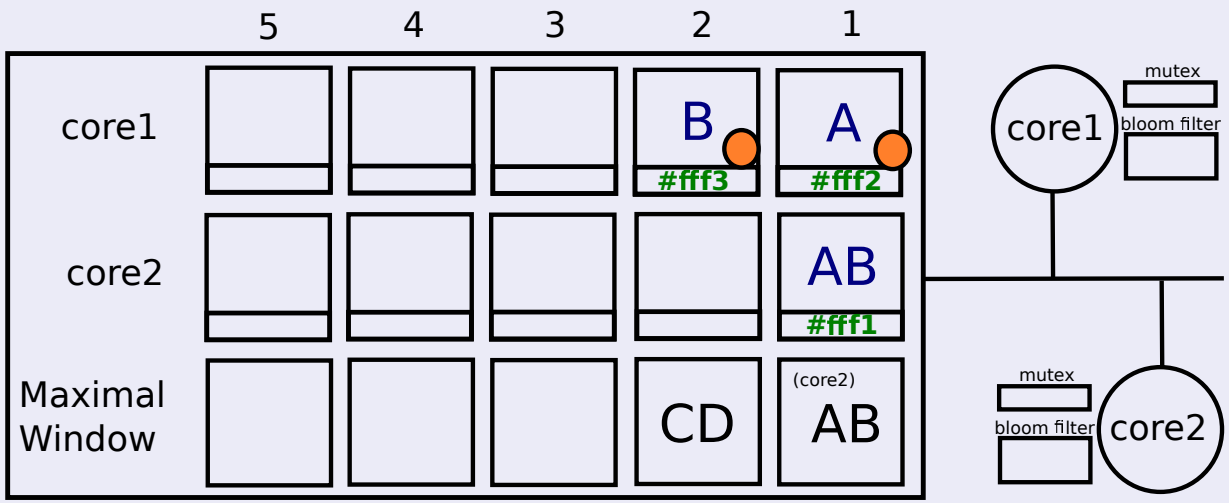

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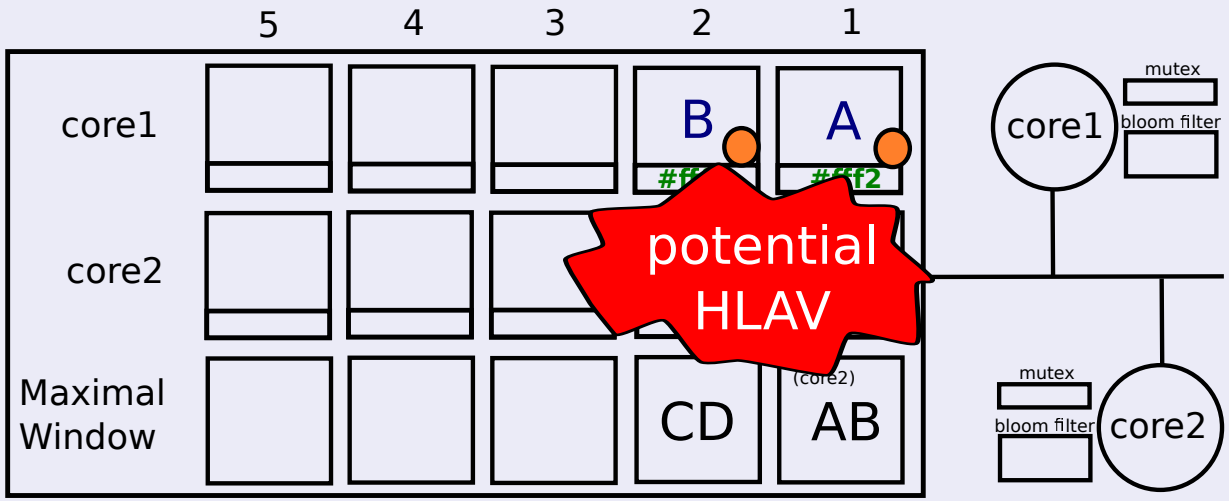

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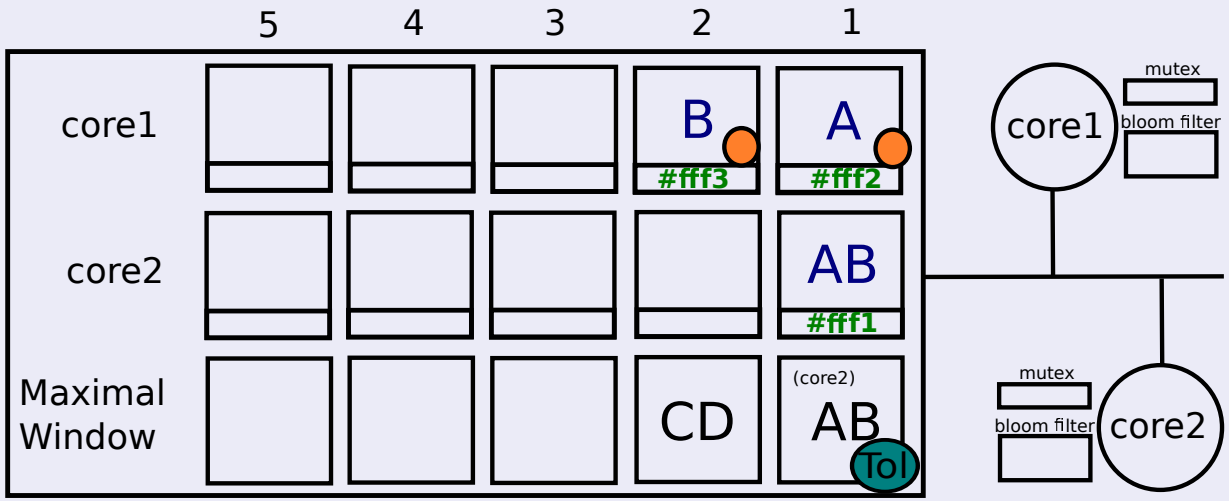

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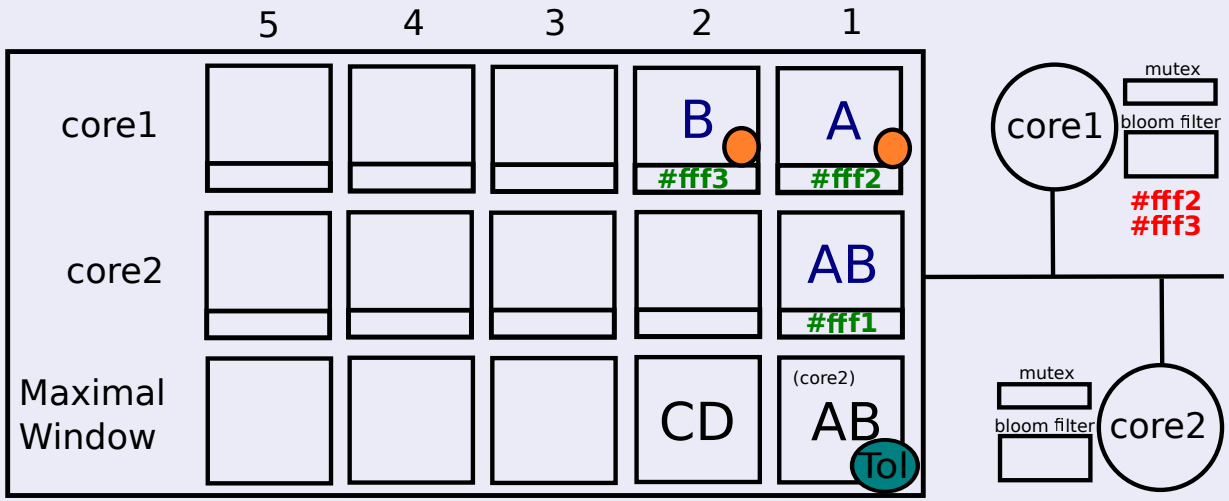

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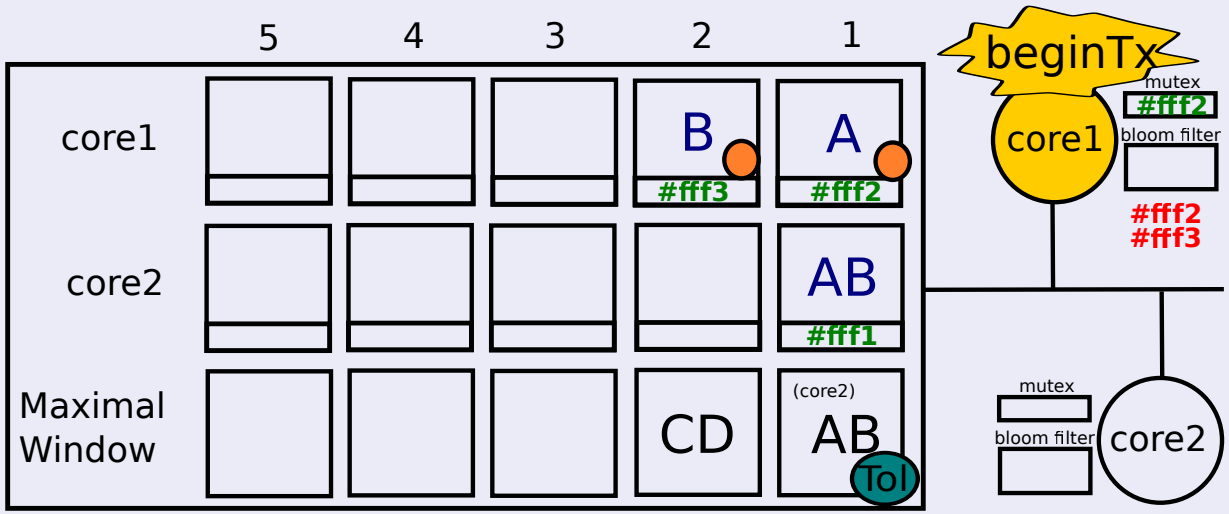

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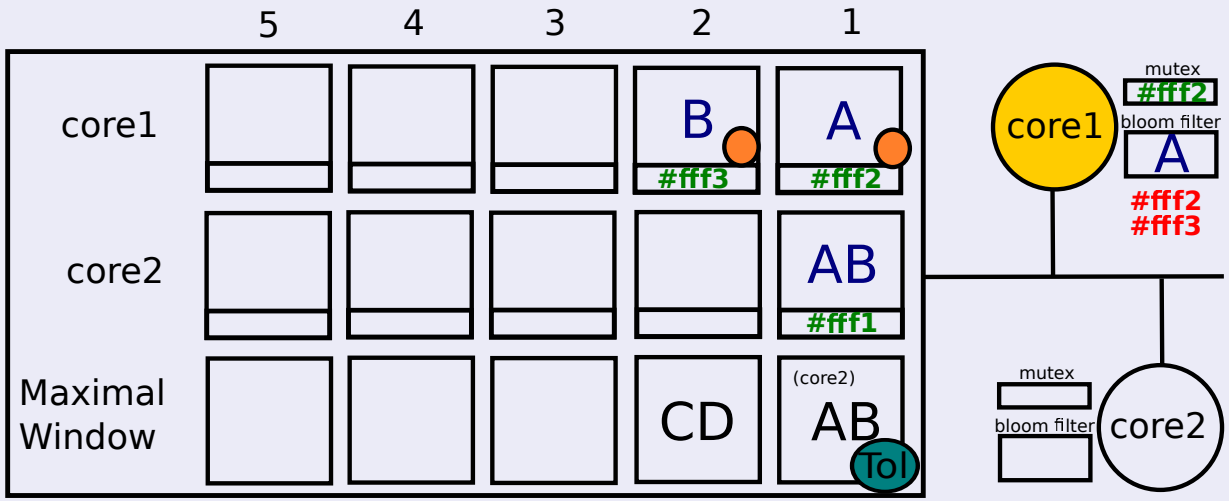

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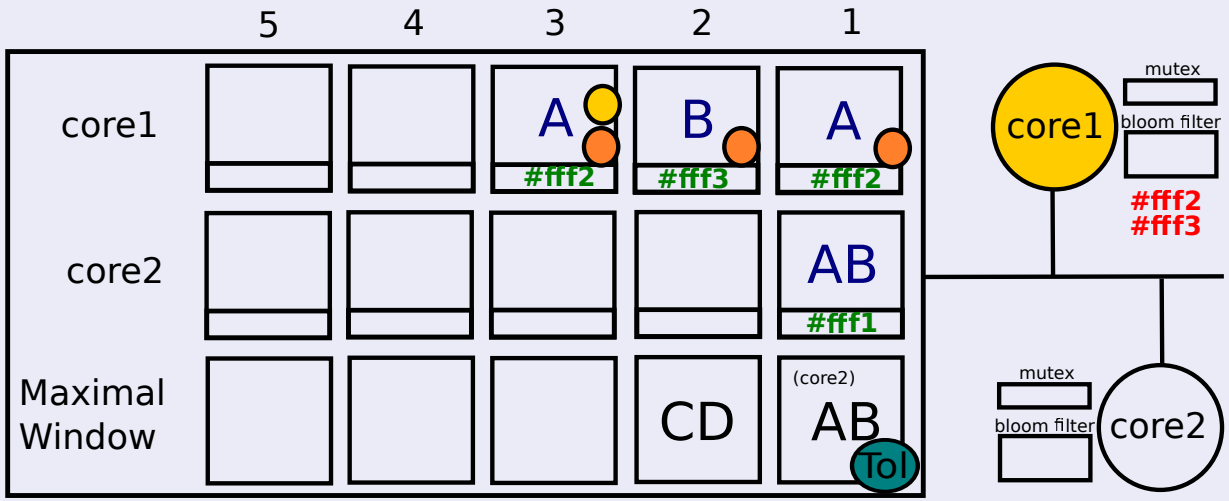

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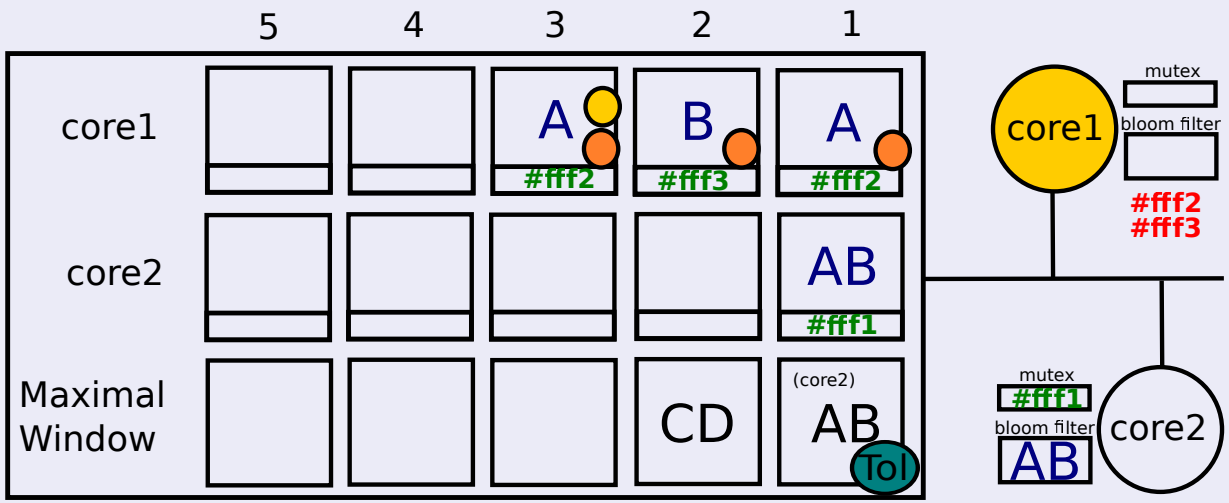

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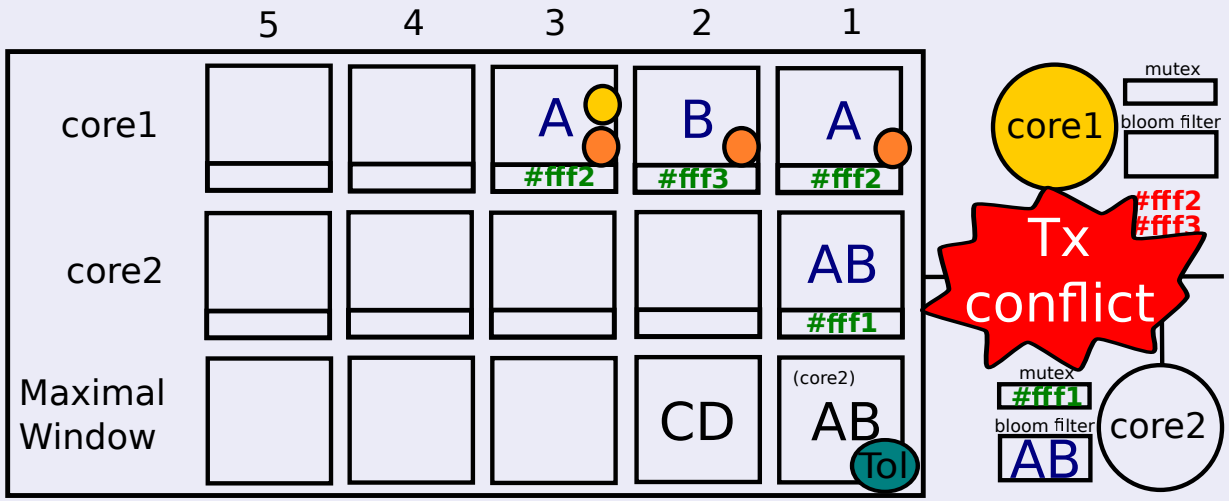

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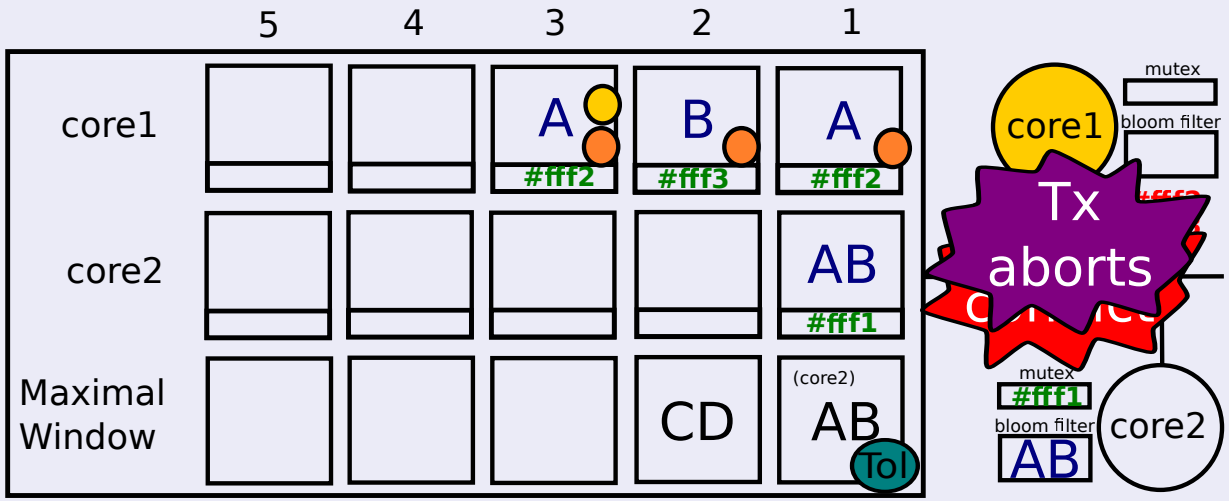

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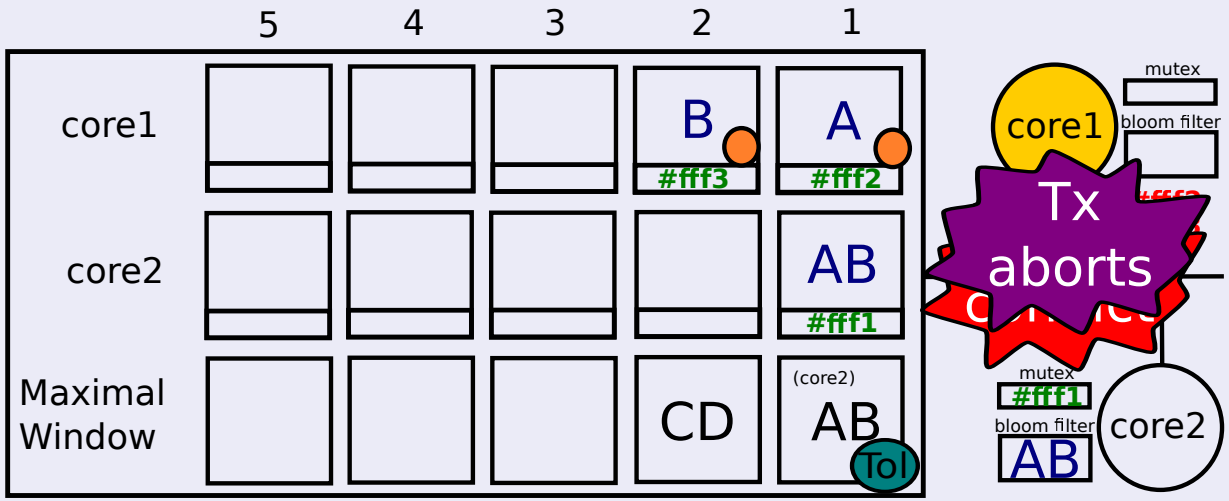

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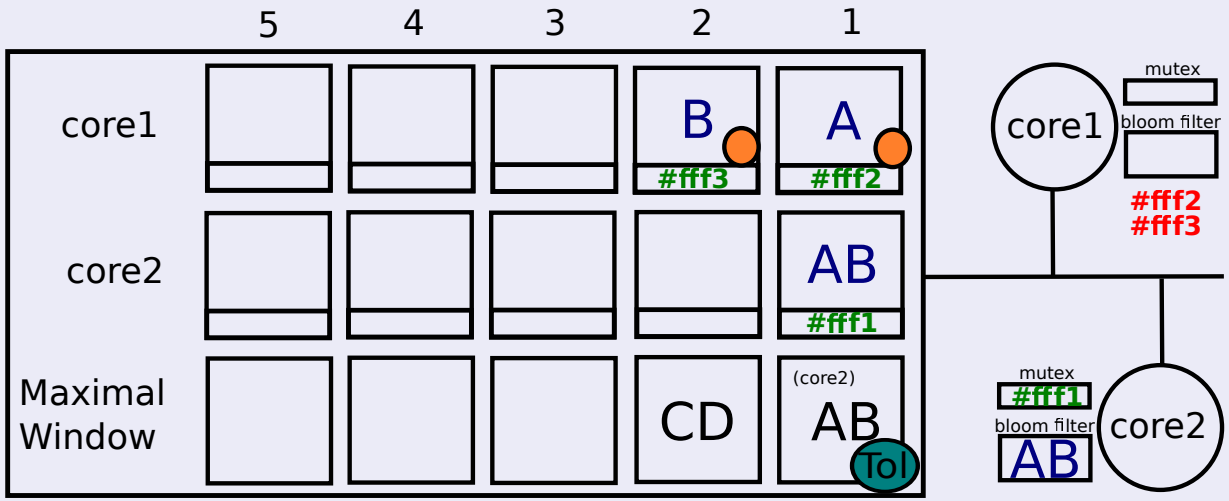

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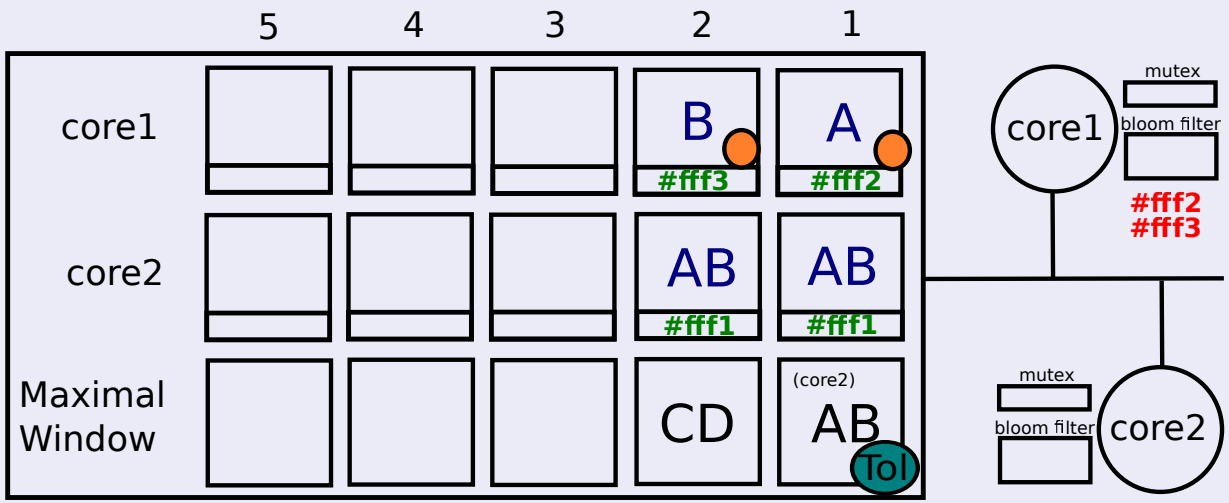

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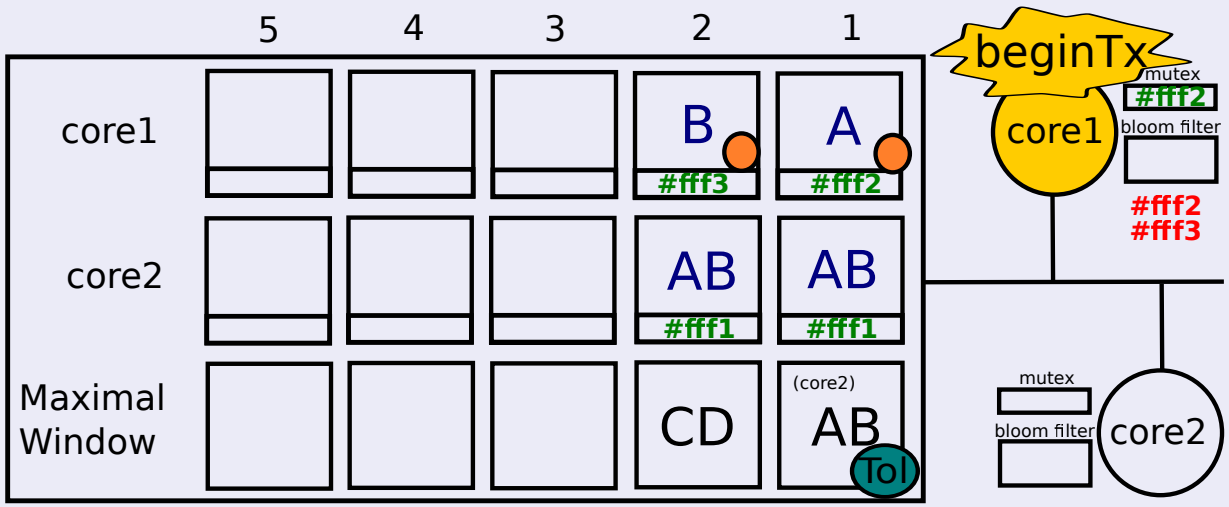

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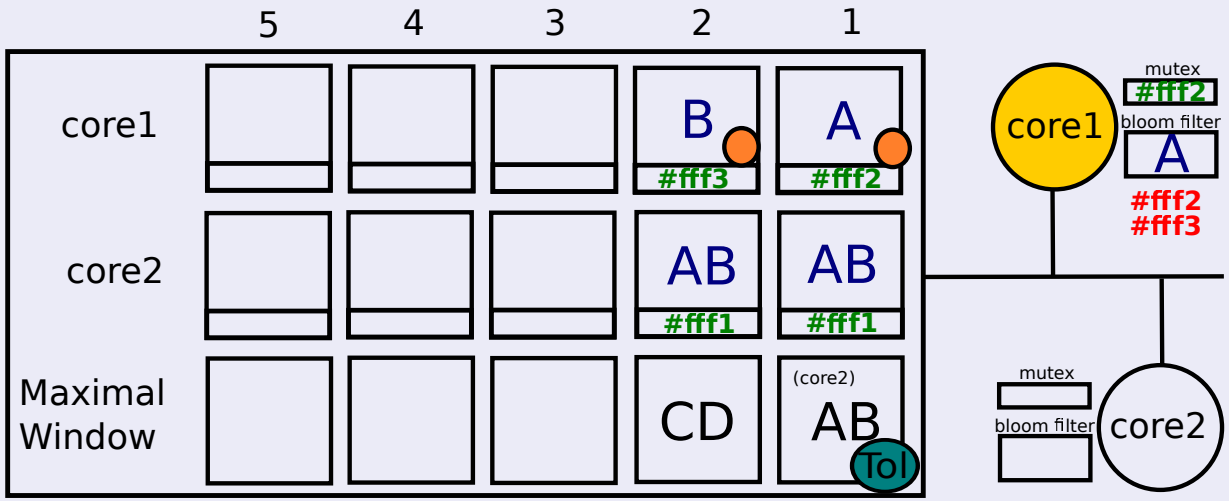

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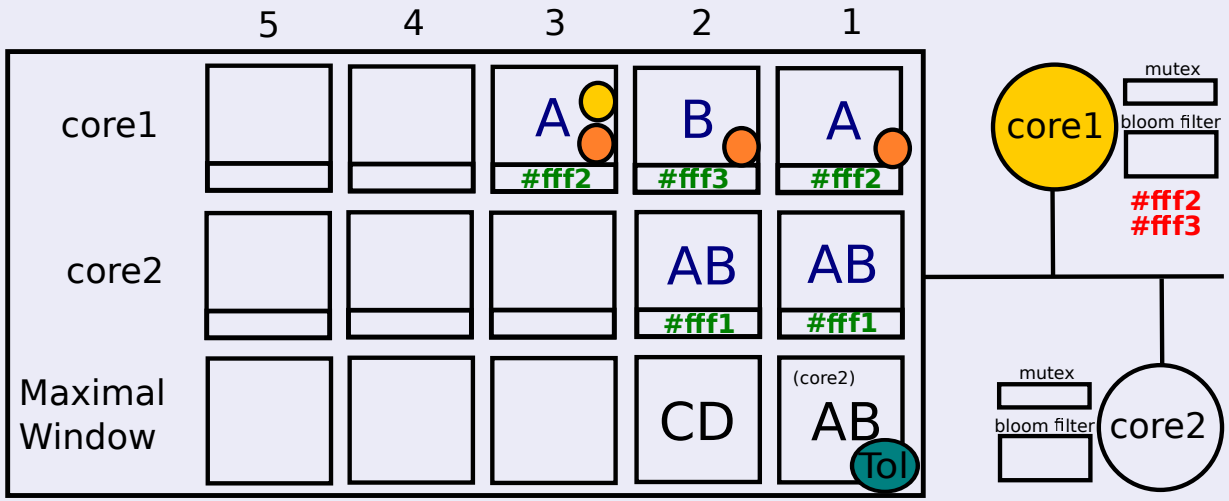
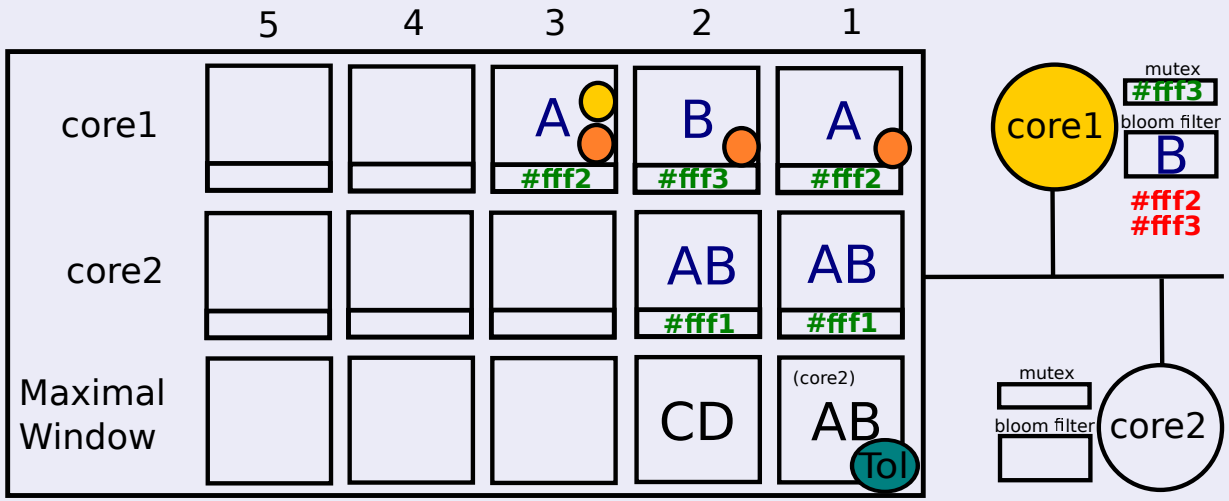


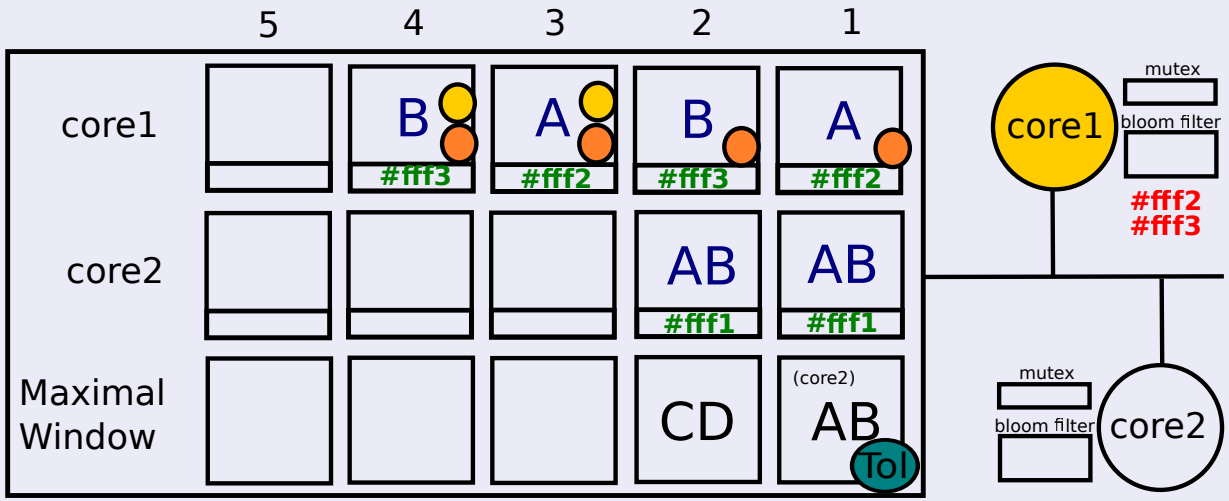
Idea - Tolerating HLAVs (II)

Example



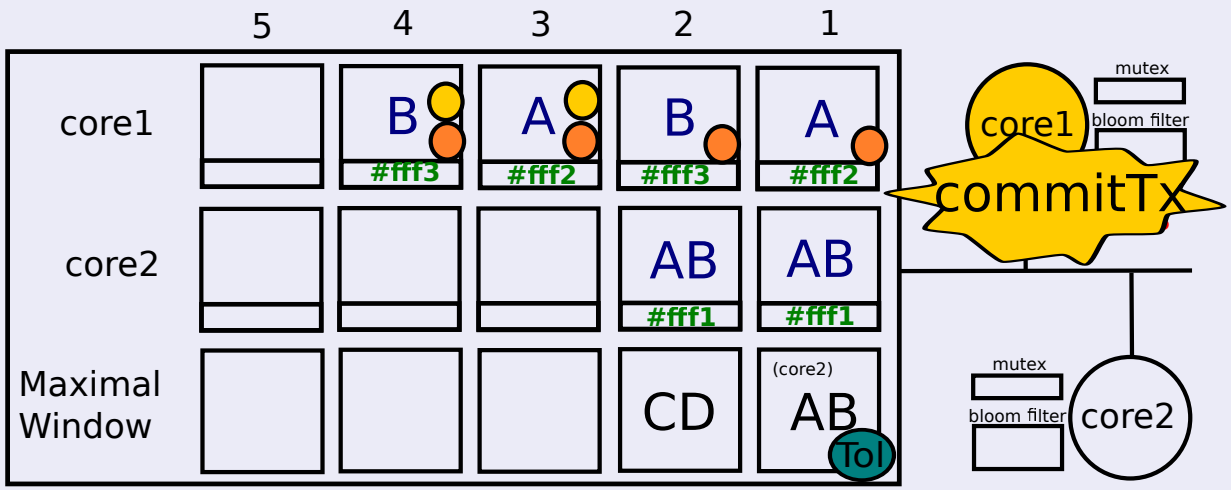
Idea - Tolerating HLAVs (II)

Example



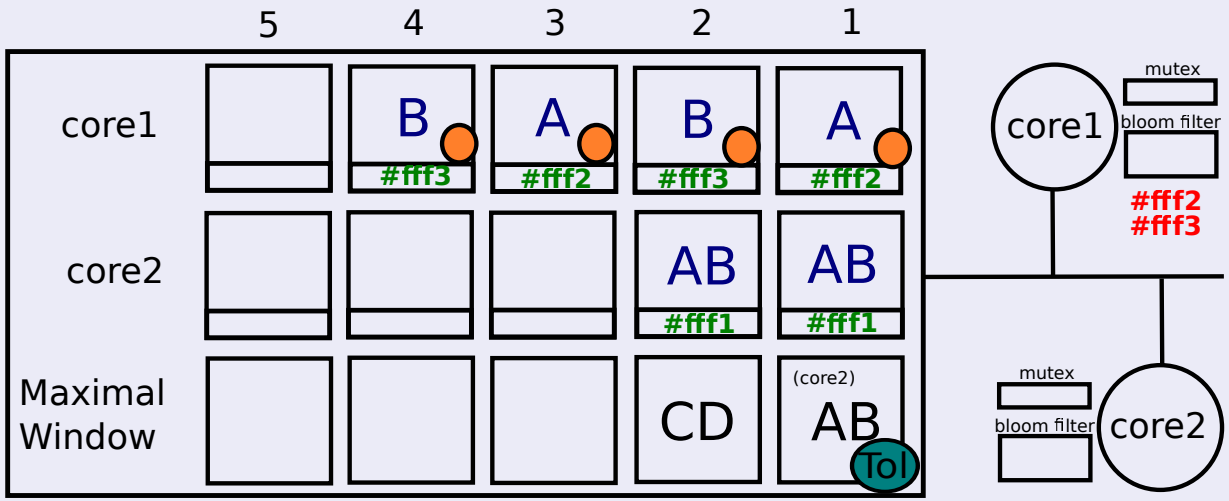
Idea - Tolerating HLAVs (II)

Example



Idea - Tolerating HLAVs (II)

Example



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Conclusions

- First hardware approach addressing the detection of HLAVs
- The module Exposes bugs
- The module Tolerates bugs in production runs
- Very low performance overhead

Questions

Thank you very much!

Questions?