Université de Liège

Want More Unikernels? Inflate Them!

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Dilemma

Virtual Machines (VMs)

- ✓ Strong isolation
- ✗ Heavyweight
  – Degrade performance

Containers

- ✗ Poor isolation
  – A lot of exploits
- ✓ Lightweight
  – Share underlying kernel

DILEMMA

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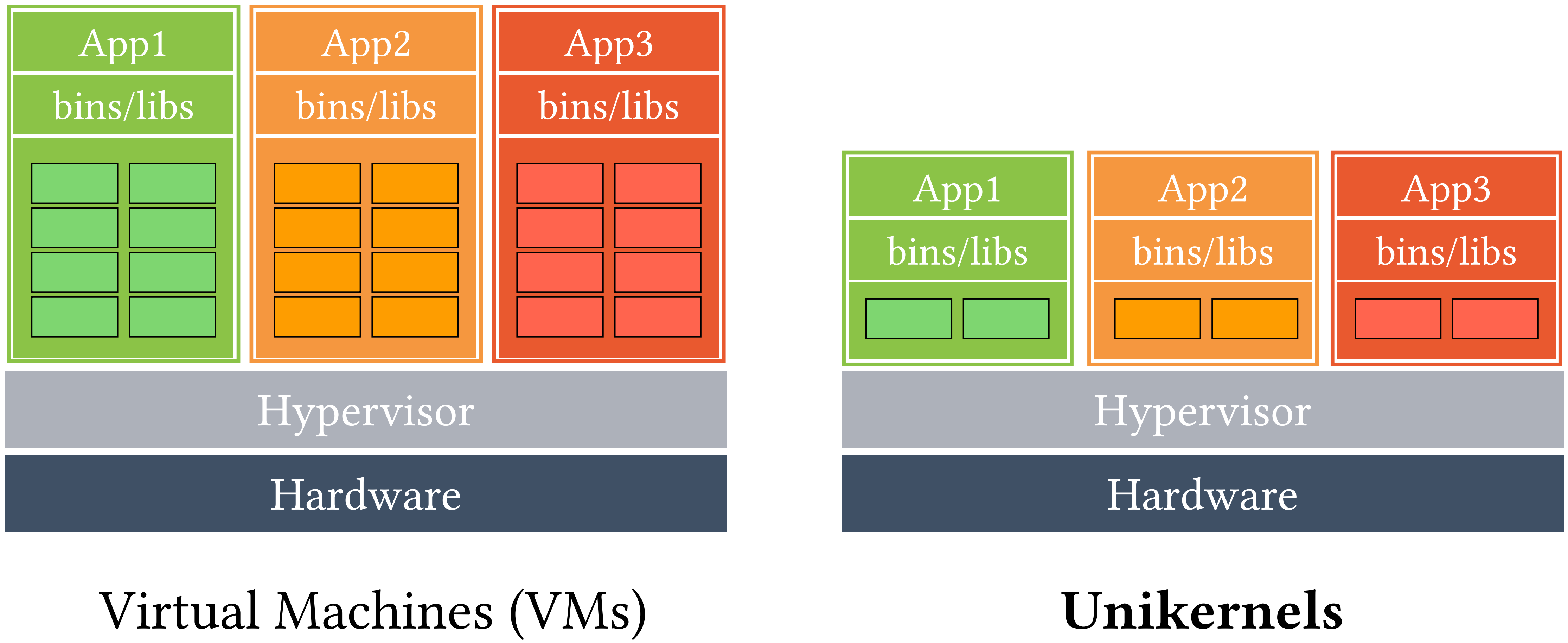
Solution → **Unikernels**

Unikernels



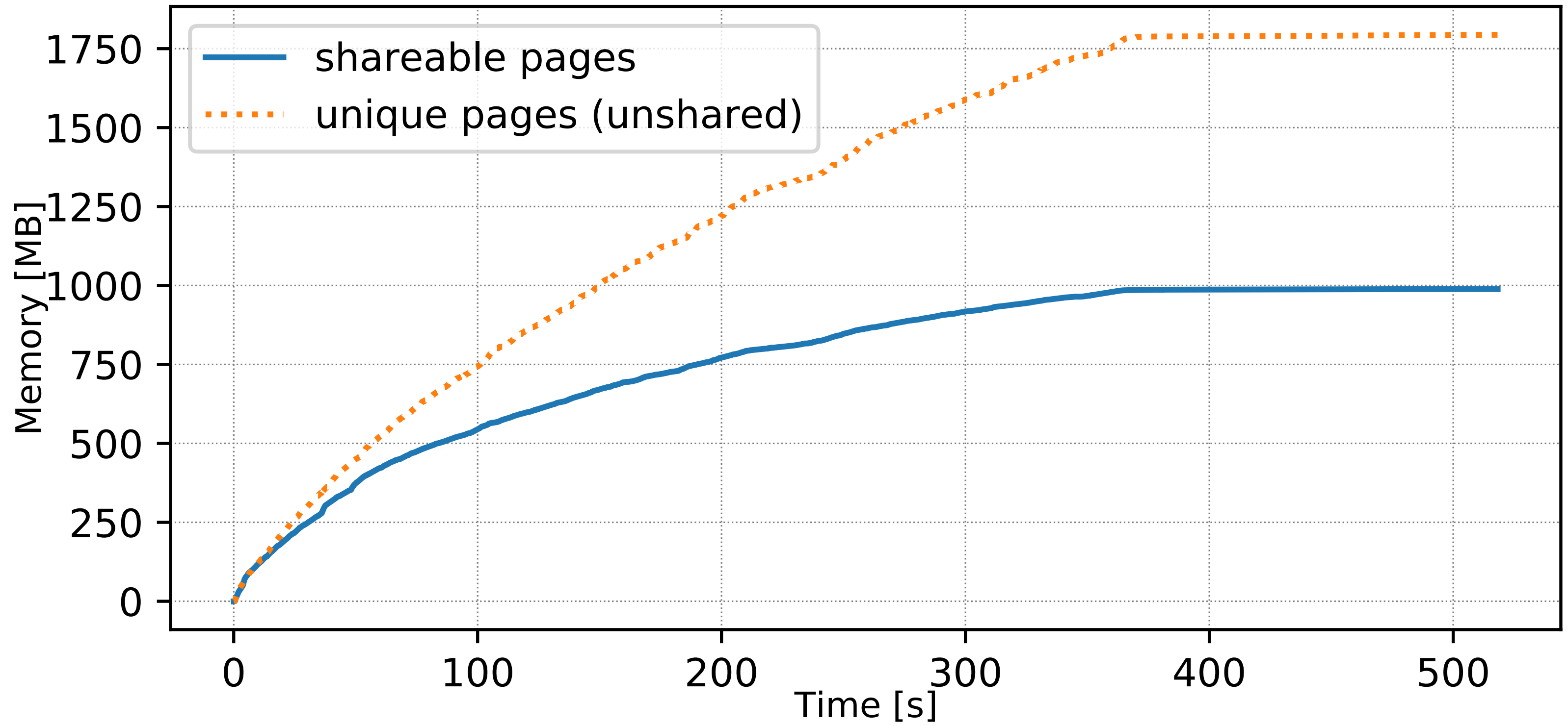
Unikernels are purpose-built:

- Thin kernel layer (only the necessary features that the application needs).
- Essential functions are placed into micro-libs (µlibs) with well-defined behaviour.

Unikernels Gains

- Fast instantiation, destruction and migration times:
  - Hundred of milliseconds.
- Small per-instance memory footprint:
  - Few MBs or even KBs.
- High performance:
  - 10-40 Gbps throughput.
- Reduced attack surface.
  - Less components
- High density:
  - Thousand of instances on a single host $\longrightarrow$ Can we do better ?

Running a large number of unikernels

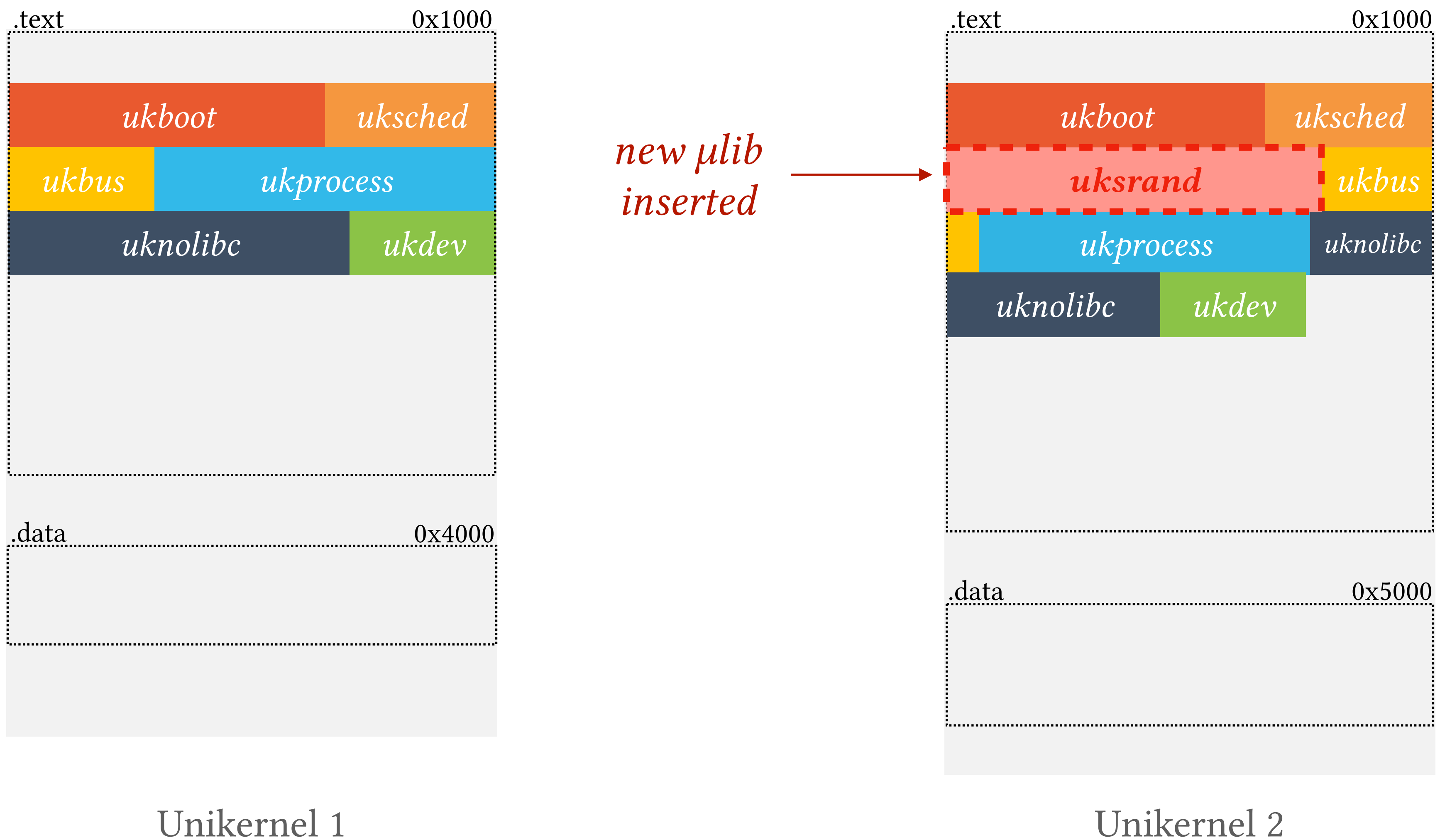


Evolution of unshared and shareable (i.e. having at least one copy) pages when running 1000 different FaaS unikernels (with ASLR) on a single physical server.

- We investigated by running a large number of unikernels on a same physical server and we relied on a memory deduplication scanner (UKSM*).
- Unique pages are much more frequent than shared pages.
- Specialisation? Need further investigation to understand the reason.

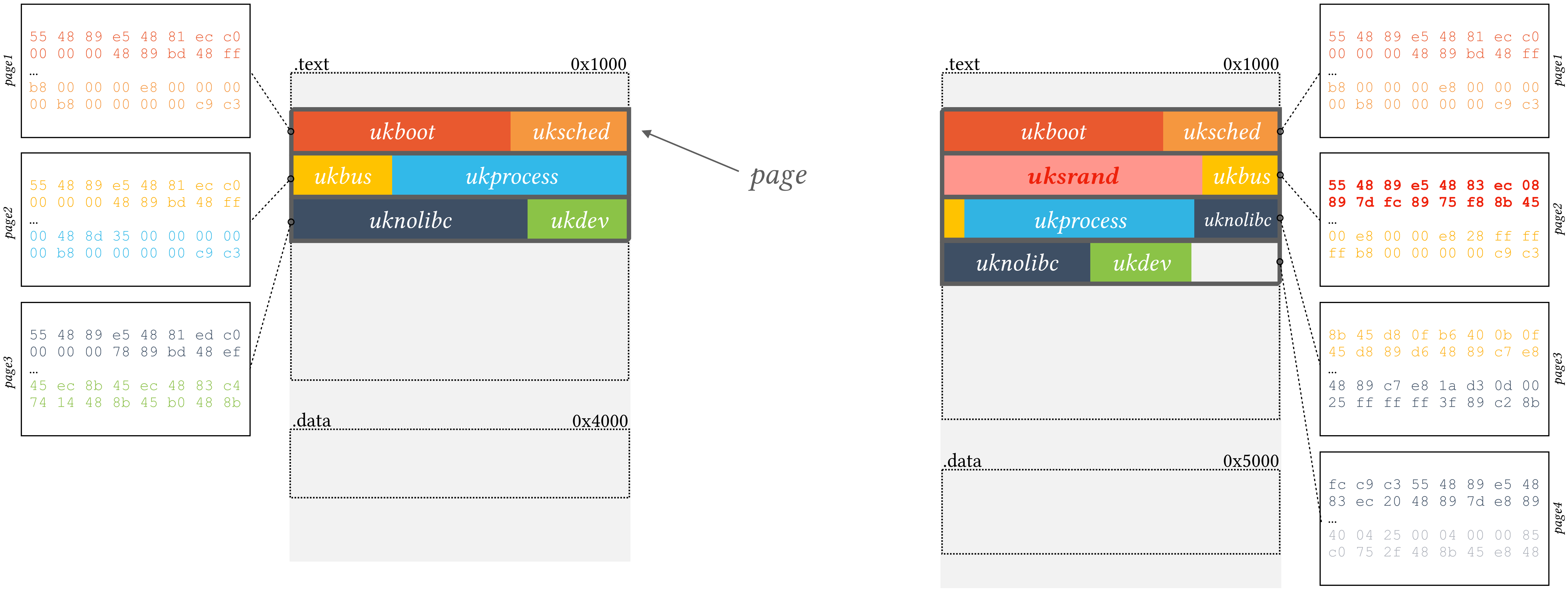
*Ultra Kernel Same-Page Merging

Memory deduplication with unikernels: Overview



- Having several instances will result into different µlibs configurations.
- The underlying build system does not have a global overview of the µlibs: Each unikernel is built in an individual way.
- All µlibs are compacted: resulting unikernel consumes as little memory and disk space as possible.

MEMORY DEDUPLICATION WITH UNIKERNELS: ISSUE 1

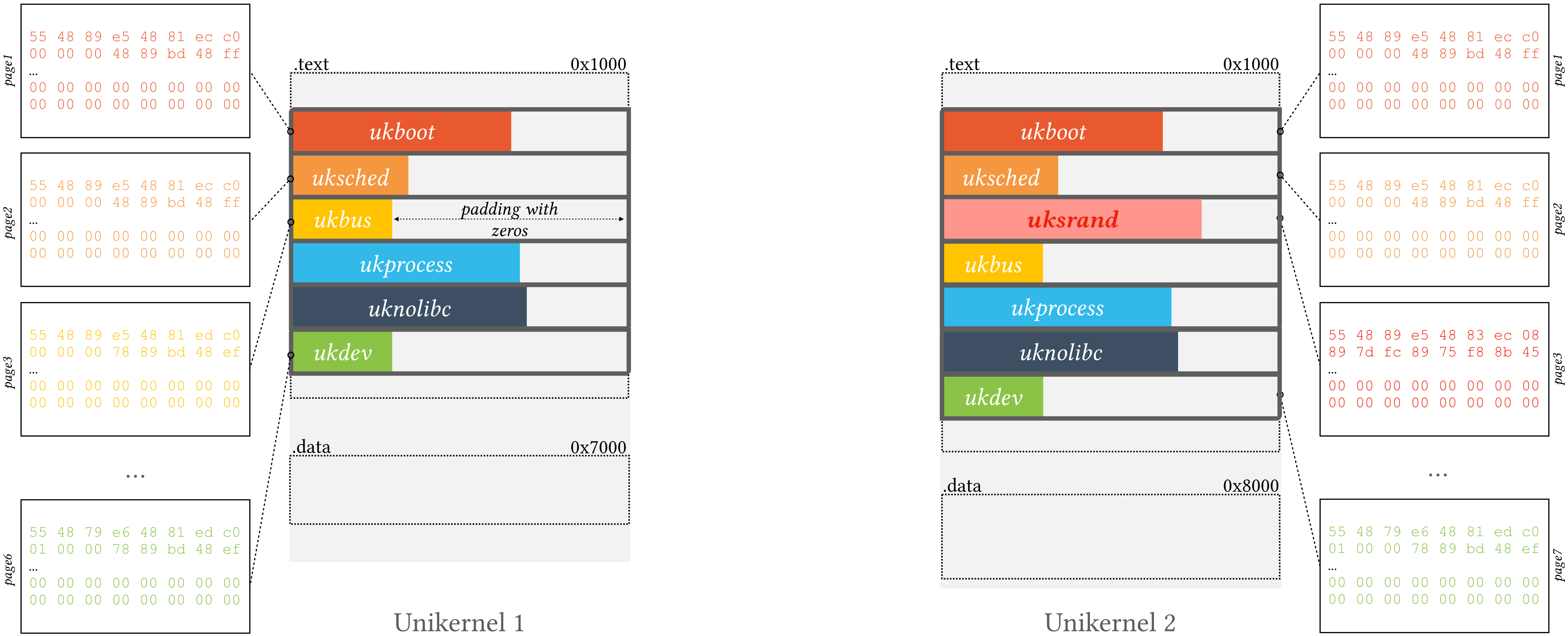


Unikernel 1 Unikernel 2

If a new µlib ‘*uksrand*’ is inserted between other µlibs:

- µlibs’ code will be split across different pages.
- It reduces memory sharing since pages are different.

Memory deduplication with unikernels: A first solution?

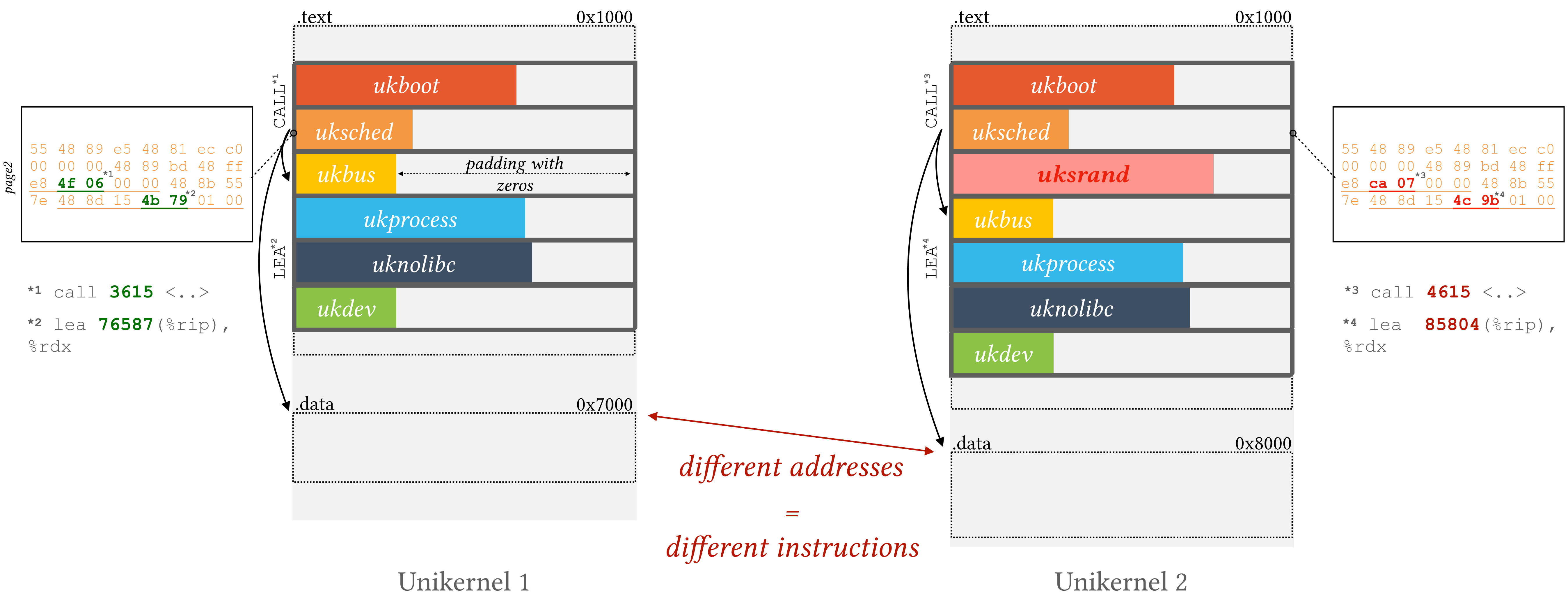


To circumvent this issue:

- Align each µlib to a page boundary address.
- Pad the µlib code with zeros to fill a complete page.

$\rightarrow$ Is it enough?

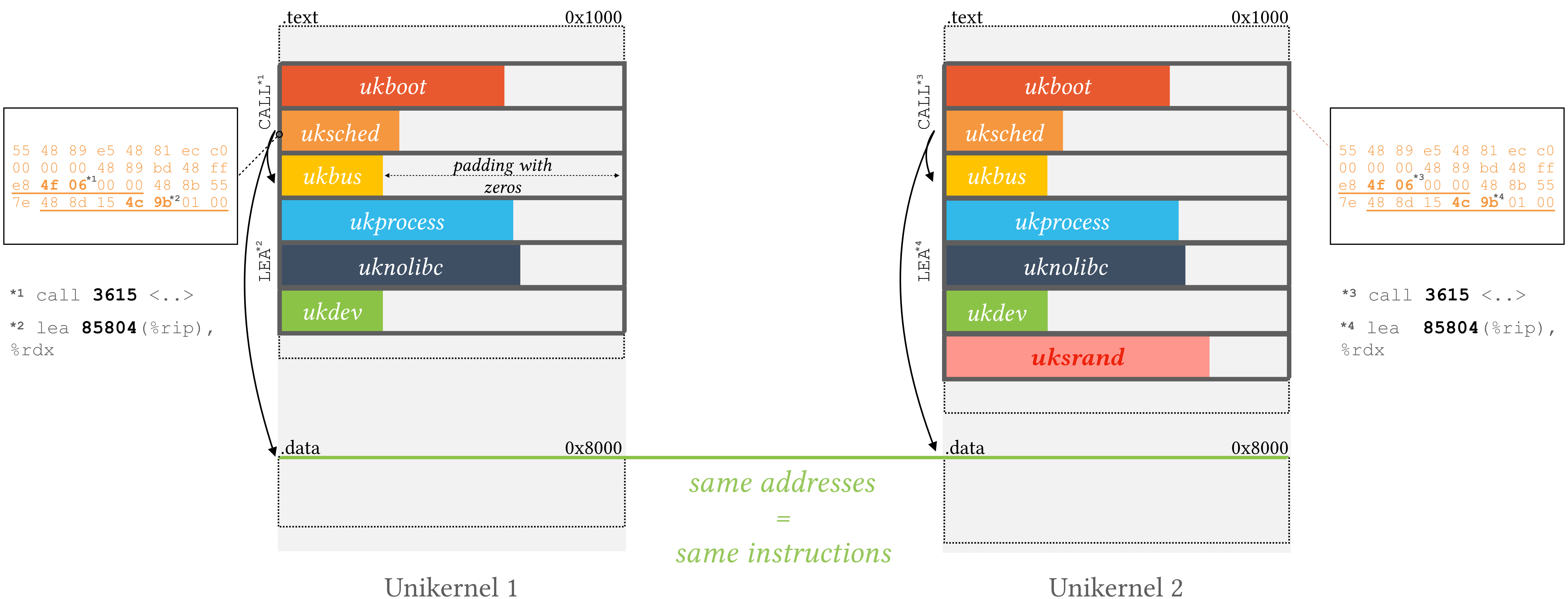
MEMORY DEDUPLICATION WITH UNIKERNELS: ISSUE 2



Some instructions use different addresses in the *.text* section:

- Related to other sections (e.g., *.data*, *.rodata*): `MOV` and `LEA`.
- Related to another part of the *.text* section: `CALL`.

Memory deduplication with unikernels: A Working Solution

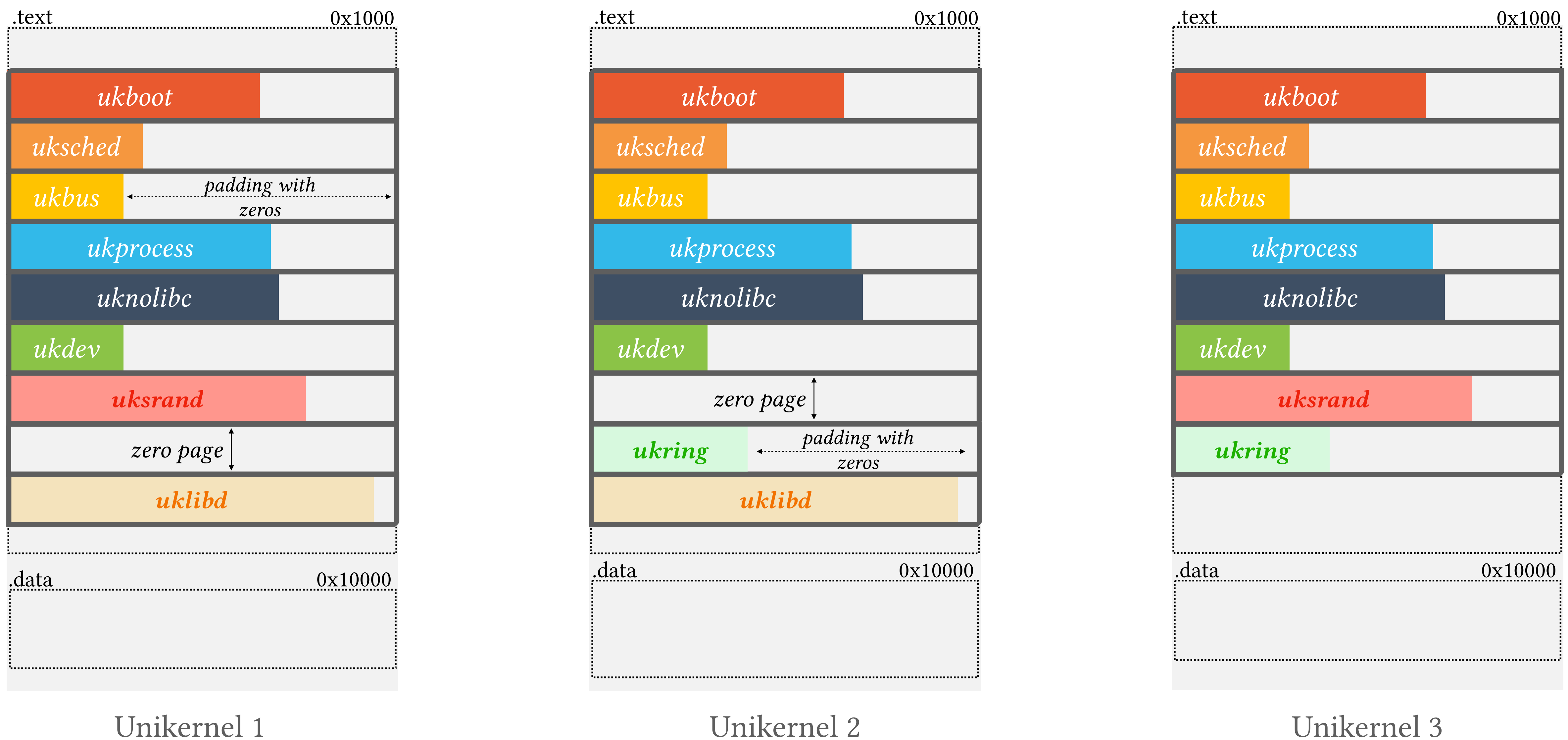


1. Placing µlibs at page boundary addresses.

2. Keep a same µlibs order.

3. Align sections (e.g., *.data*, *.rodata*, …) at same addresses.

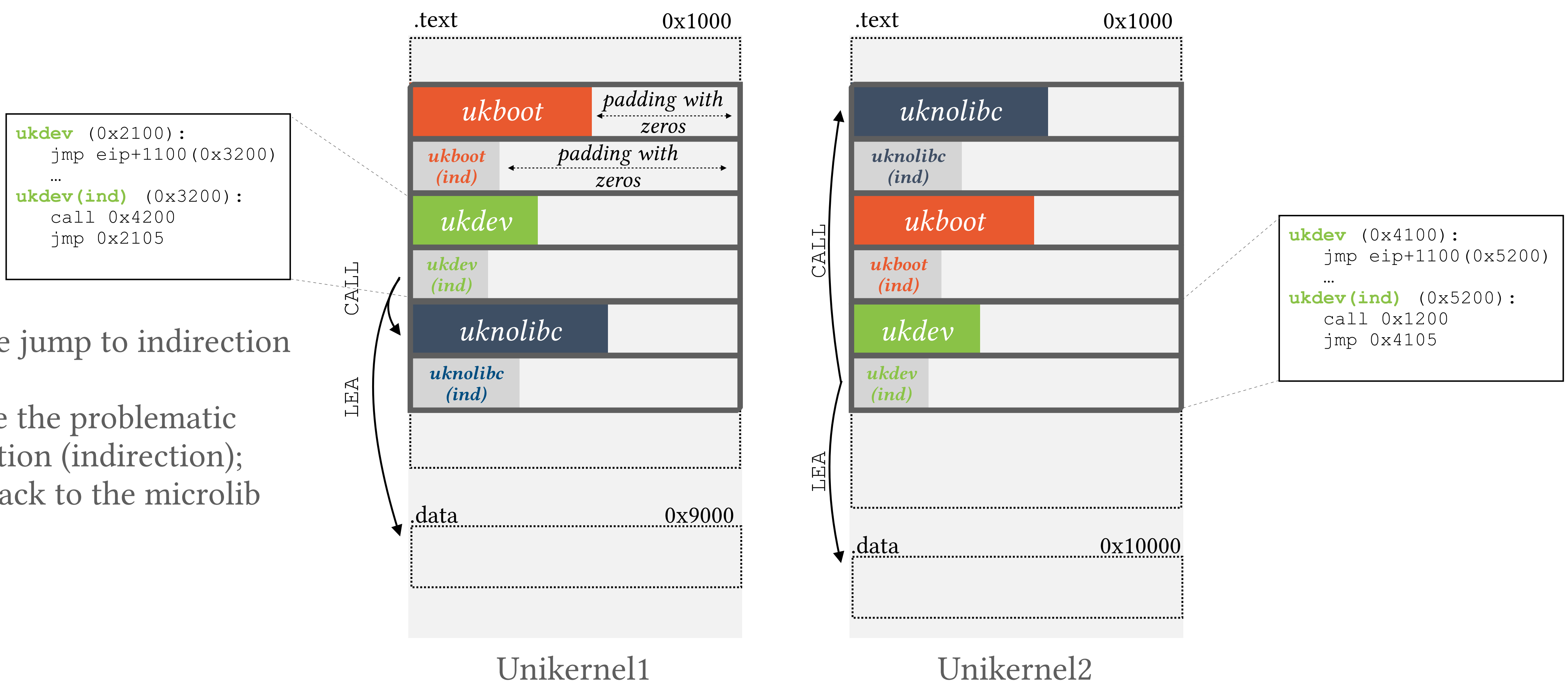
Memory deduplication with unikernels



If there are more than two instances with different µlibs subsets:

- It is necessary to align them to specific addresses.
- This leads to ‘gaps’ of zero pages in the memory virtual space.

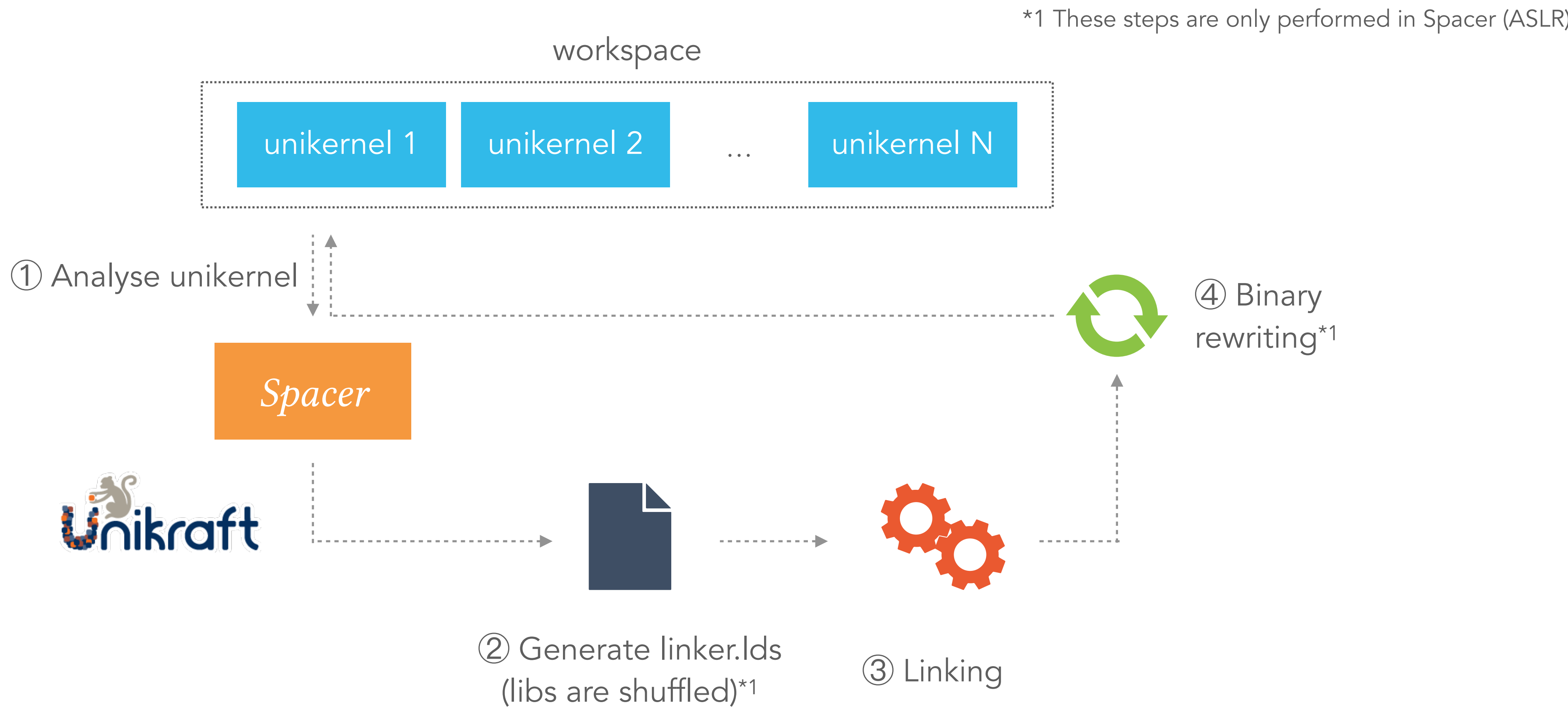
Towards ASLR support



1. Relative jump to indirection table;
2. Execute the problematic instruction (indirection);
3. Jump back to the microlib code.

- Using fixed absolute addresses leads to security issues (no ASLR).
- Create an indirection table per µlib which contains problematic instructions (using addresses from other sections/µlibs). Such instructions are replaced by relative jump to their new position.

Spacer High-Level Architecture



- From our methodology, we derive Spacer, a tool aims to have a global knowledge of all the µlibs used by all unikernels on the same workspace.
- Spacer performs a new linking by associating µlibs with absolute addresses according to a map (by rewriting the linker script).
- For Spacer (ASLR), µlibs are shuffled during the linker file generation. Furthermore, there is one extra step of binary rewriting (move problematic instructions to indirection tables).

Evaluation: methodology

- We compared Spacer with DCE (Dead Code Elimination) and Default configuration.
  - 10 applications ported as unikernels.
  - 1000 FaaS unikernels.
  - On several dimensions: memory consumption, file size and performance.

Evaluation (1)

Memory consumption:

- Without memory deduplication, Spacer and Spacer (ASLR) consume significantly more memory (zero pages and indirection tables).
- With memory deduplication, the benefits of alignment increases as we run more applications. Spacer and Spacer (ASLR) consume less memory than default and DCE.
- Up to a 3x gain compared to DCE.

Heap-intensive applications:

- The gain is less noticeable (e.g., in-memory databases).
- If there are thousands of applications, Spacer still allows to reduce the memory consumed (code and read-only data are shared).
- But if they are only some instances: do not apply Spacer on it.

Evaluation (2)

Elf Size:

- Spacer and Spacer (ASLR) have a slight impact on file size:
  - The inflation of the header string table (ELF section).
  - Indirection tables (problematic instructions).
- Elf files do not have inflation due to zeros, it is only in memory.

Performance:

- Total execution time of short-lived and long-lived unikernels.
- UKSM has a slight impact on scanning and merging pages.
- Spacer performance degradation is minimal: having zero pages and indirection tables introduces a slight overhead.

Conclusion & Future work

- Unikernels are small and have impressive performance, but they show few opportunities for VM page sharing (specialisation).
- We brought a new methodology that rearranges and inflates unikernels by using µlibs alignment.
  - Aligning µlibs may lead up to a big reduction in memory consumption, even when compared to unikernels built with DCE (Dead Code Elimination).
  - Furthermore, the alignment does not introduce significant overhead in terms of ELF size, nor does it impairs application performance.

Future work:

  - *Loader*: A loader that performs deduplication at load time could make µlib pages point directly to the corresponding frames when loading the kernel image into main memory.

Thank you for your attention

Questions?