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SOFTWARE RELIABILITY GROUP

COM SYS Communication and Distributed Systems

RWTH AACHEN UNIVERSITY

A Deterministic Memory Allocator for Dynamic Symbolic Execution

Daniel Schemmel, Julian Büning, Frank Busse, Martin Nowack, Cristian Cadar

Dynamic Symbolic Execution

```
int x = input();
if (x == 0) {
    abort();
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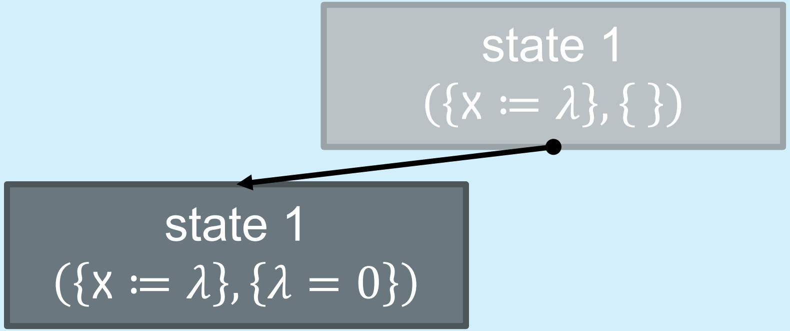

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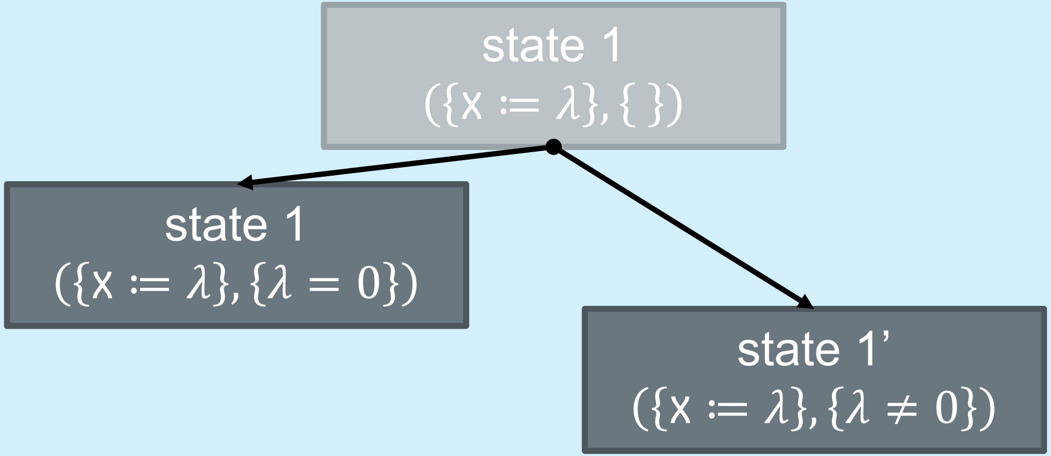

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state 1’
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Address Translation in KLEE

- What is the address of `x`?

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KLEE Process

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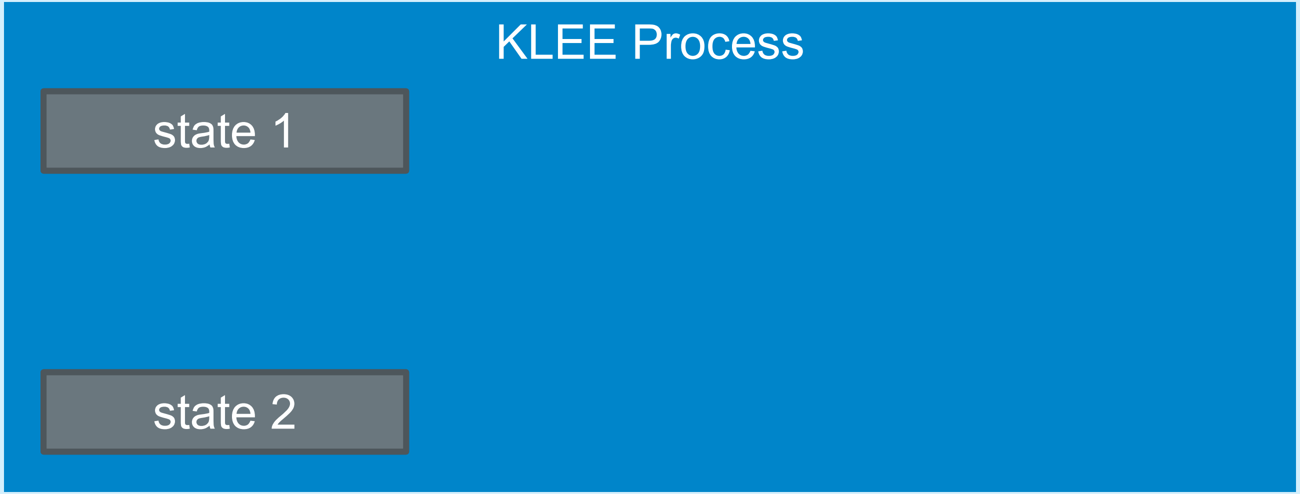

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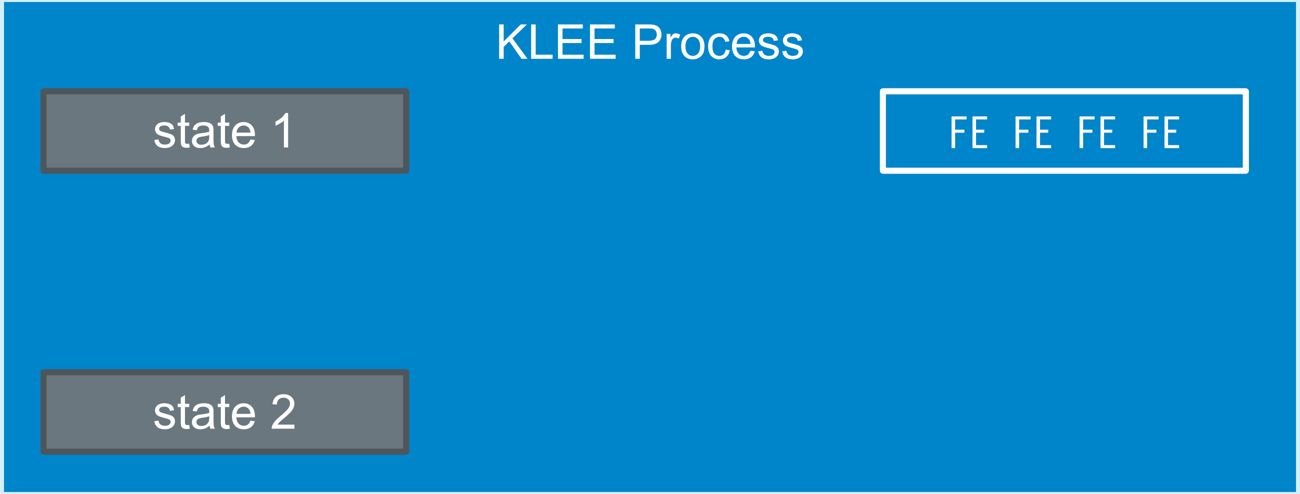

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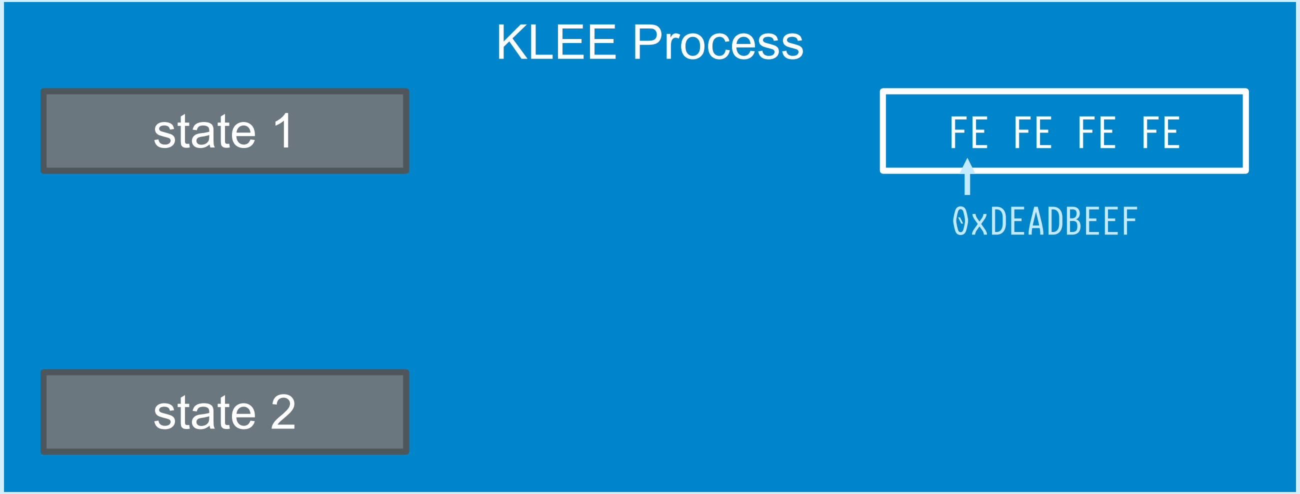

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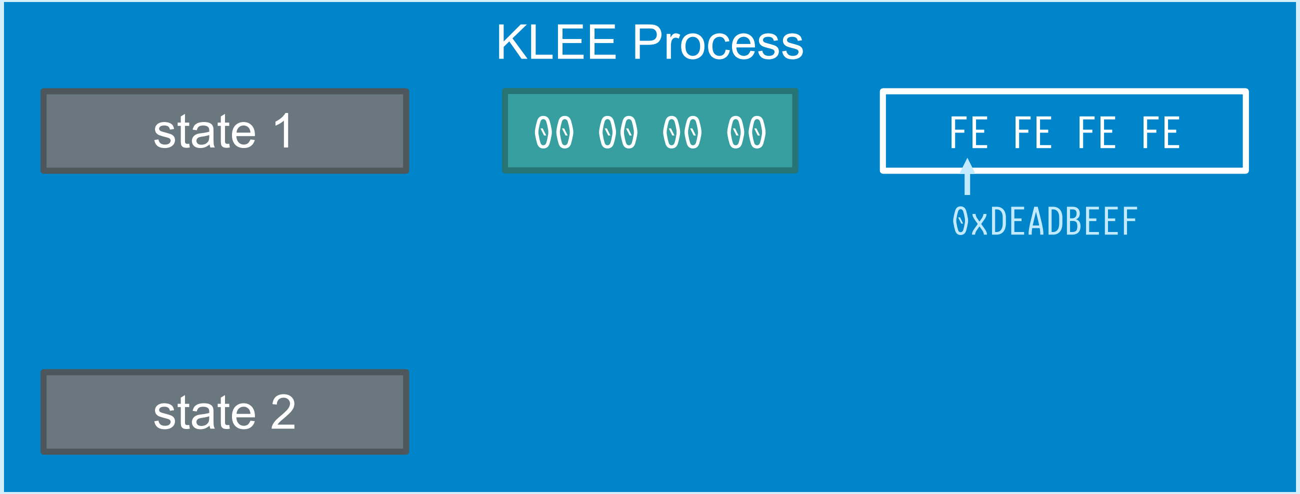

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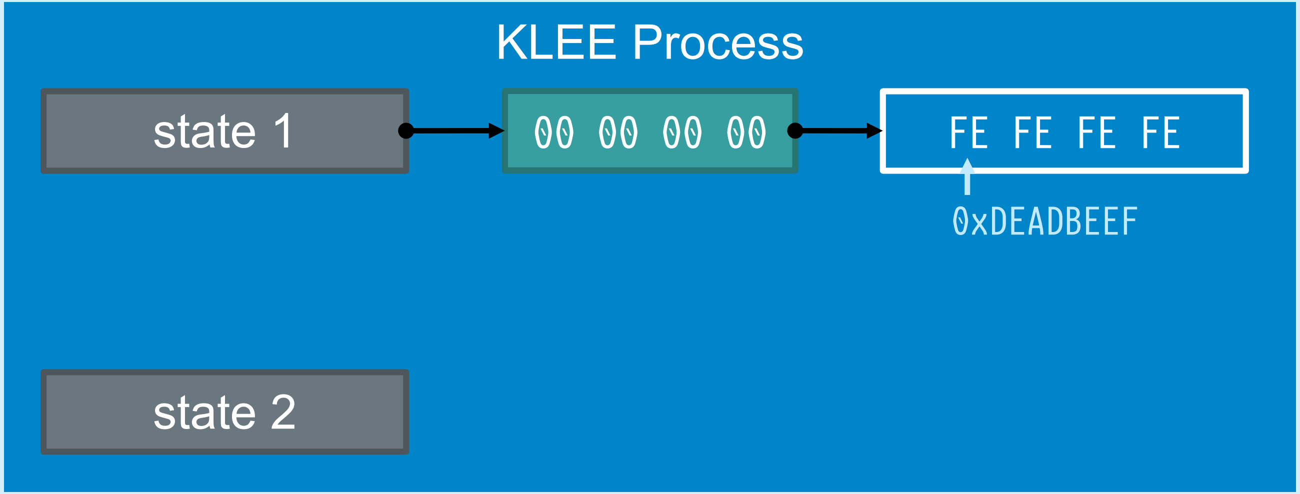

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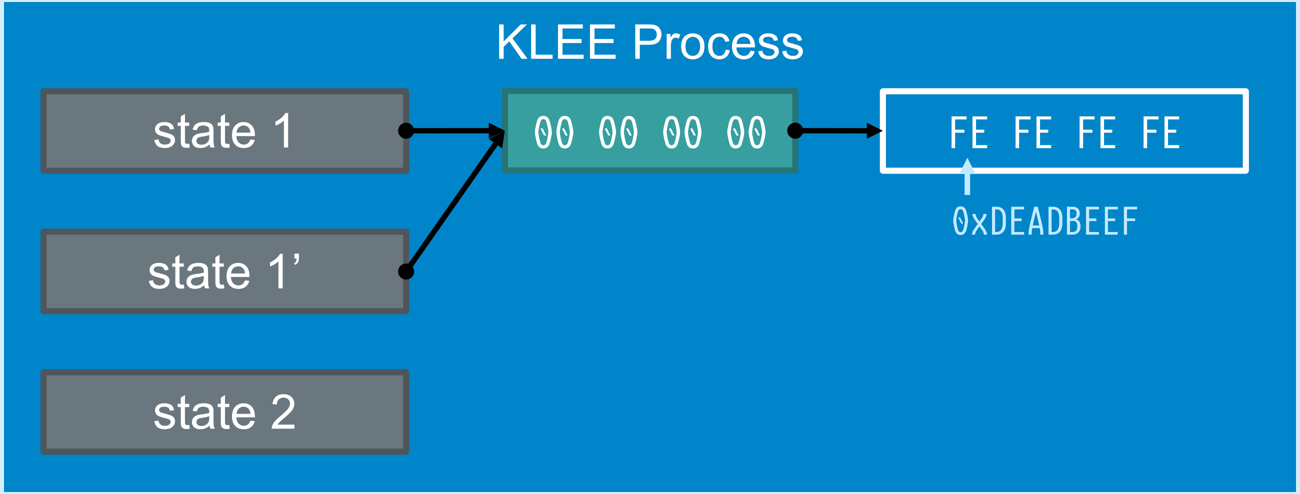

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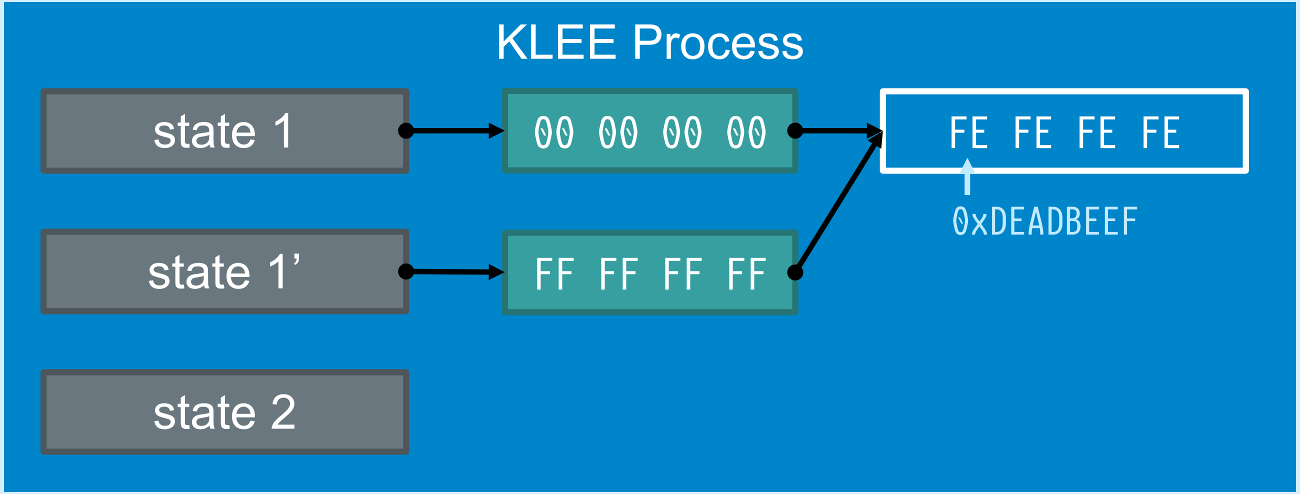

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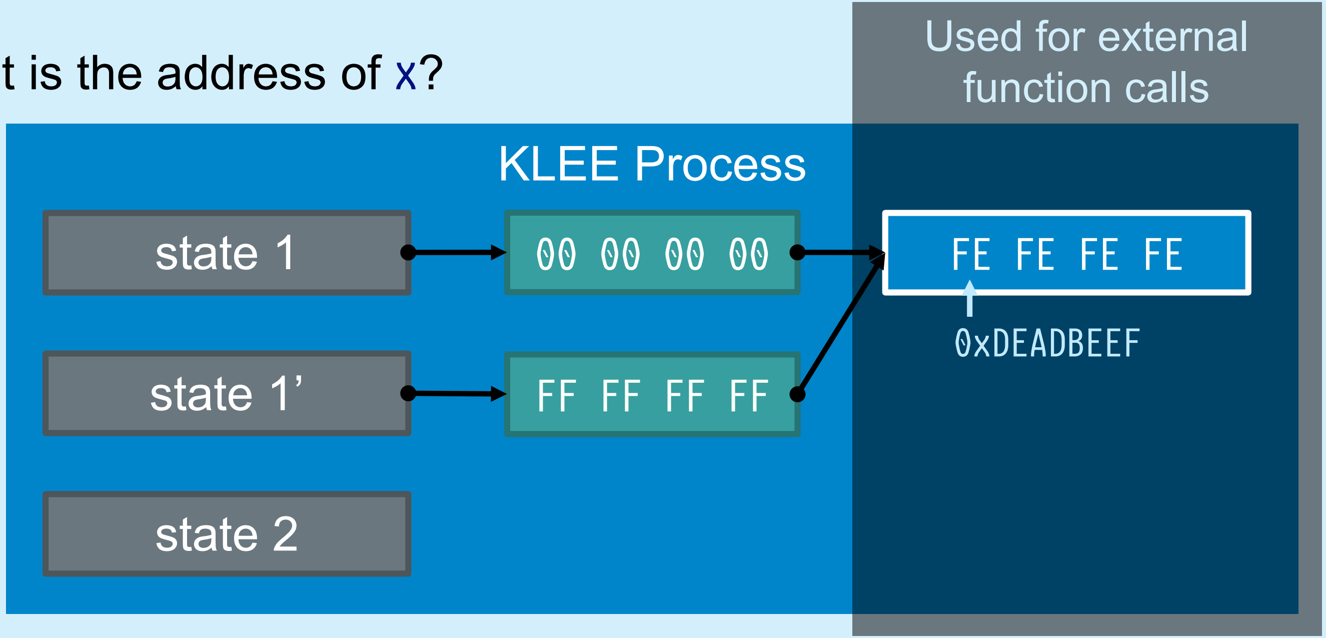

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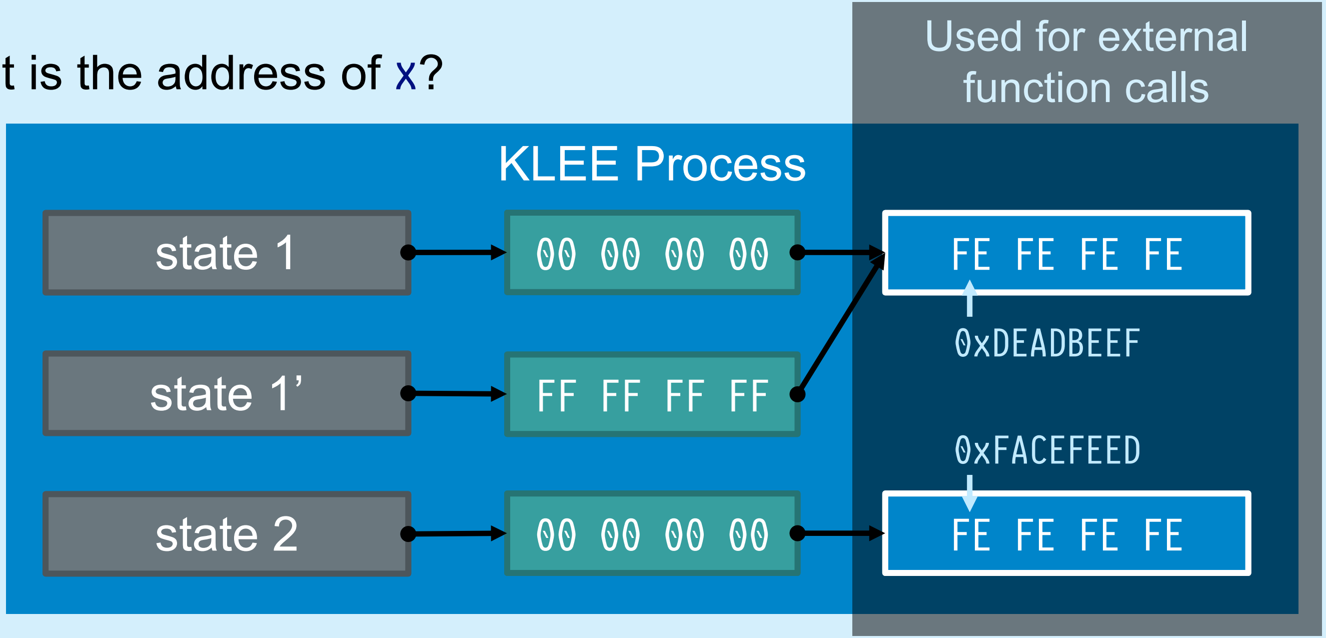

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The Need for Deterministic Memory Allocation

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  - MoKLEE [Running symbolic execution forever. Busse et al. ISSTA 2020]

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  6. Stability (minor changes should not snowball)

General Architecture

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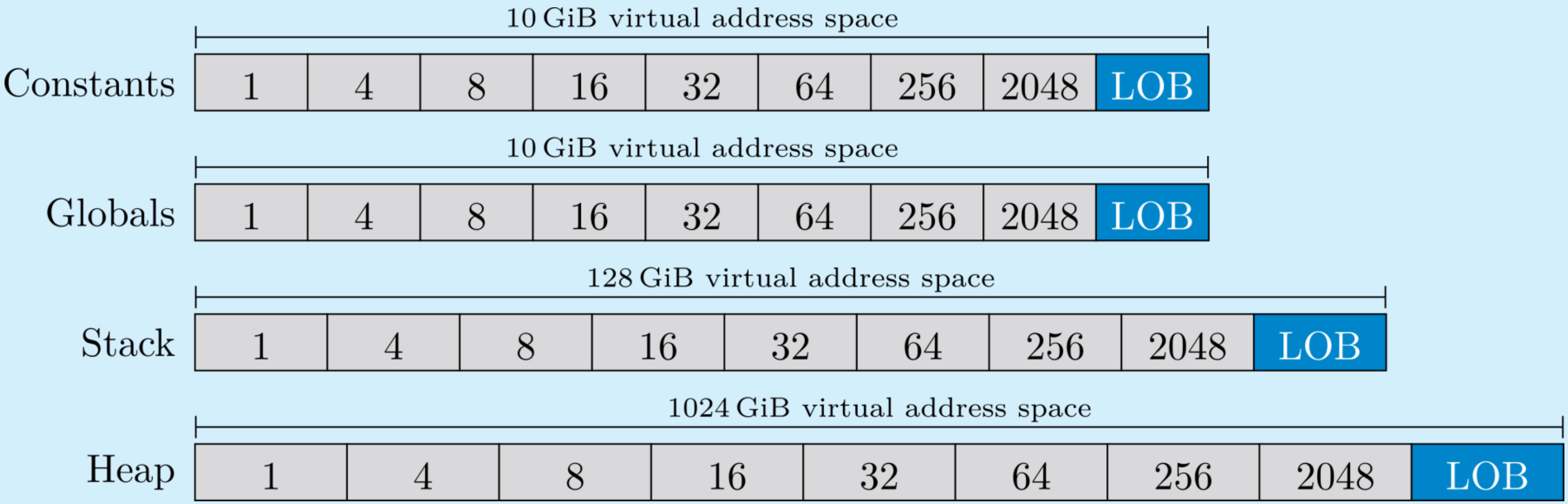
  - Multiple allocators, especially to disconnect stack and heap
  - Binned allocations

Memory Layout for KDAlloc



10 GiB virtual address space

Constants: 1 | 4 | 8 | 16 | 32 | 64 | 256 | 2048 | LOB

10 GiB virtual address space

Globals: 1 | 4 | 8 | 16 | 32 | 64 | 256 | 2048 | LOB

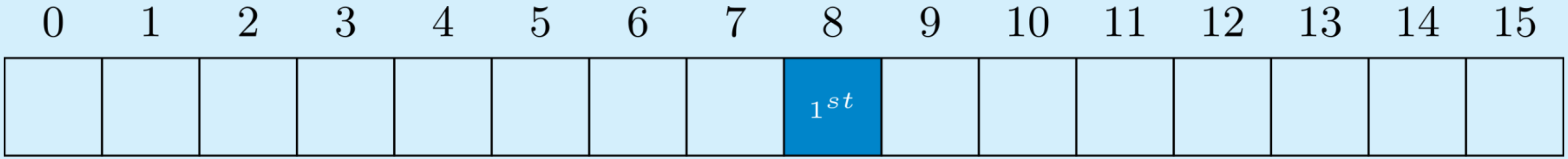
128 GiB virtual address space

Stack: 1 | 4 | 8 | 16 | 32 | 64 | 256 | 2048 | LOB

1024 GiB virtual address space

Heap: 1 | 4 | 8 | 16 | 32 | 64 | 256 | 2048 | LOB

Slot Allocator for Sized Bins: Spatially Distanced



0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
								1^{st}							

Slot Allocator for Sized Bins: Spatially Distanced

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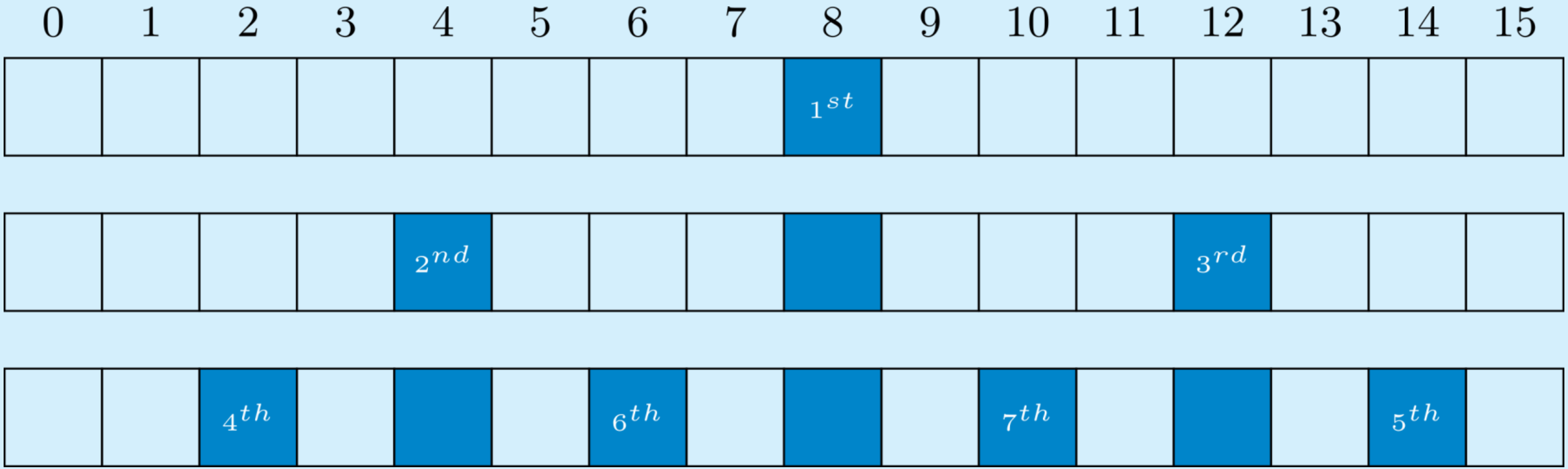
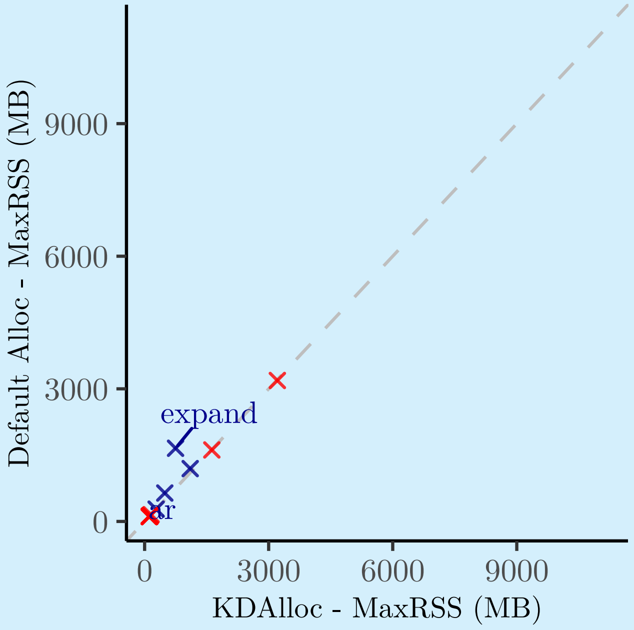
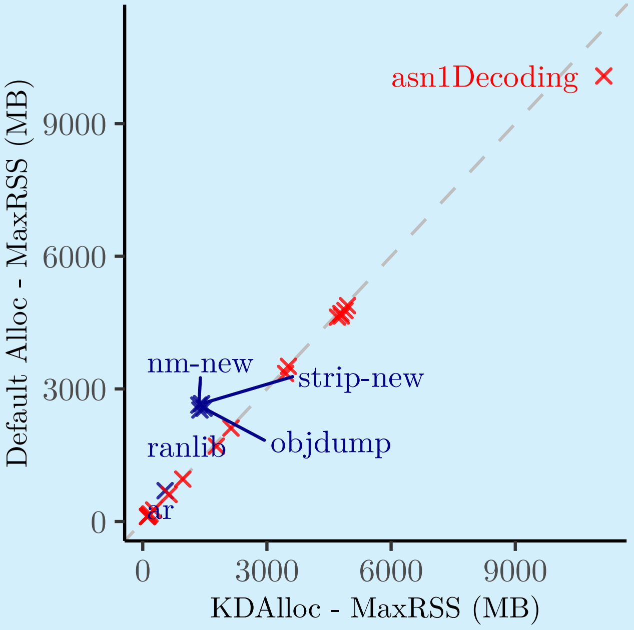


Memory Consumption

DFS

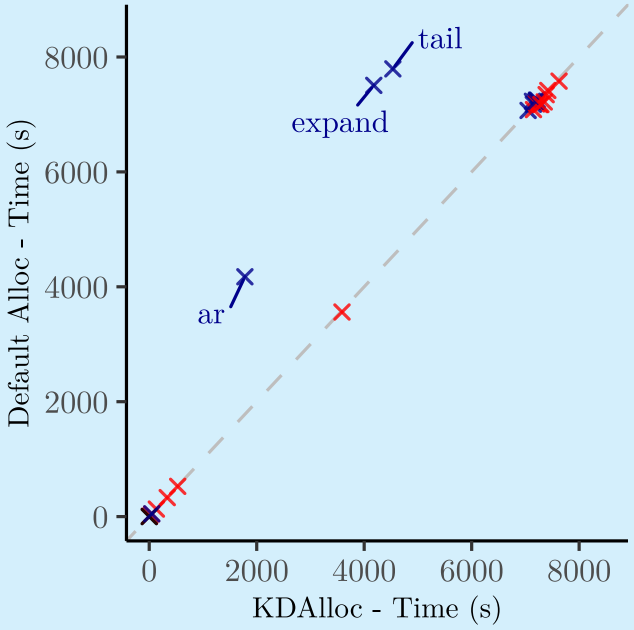


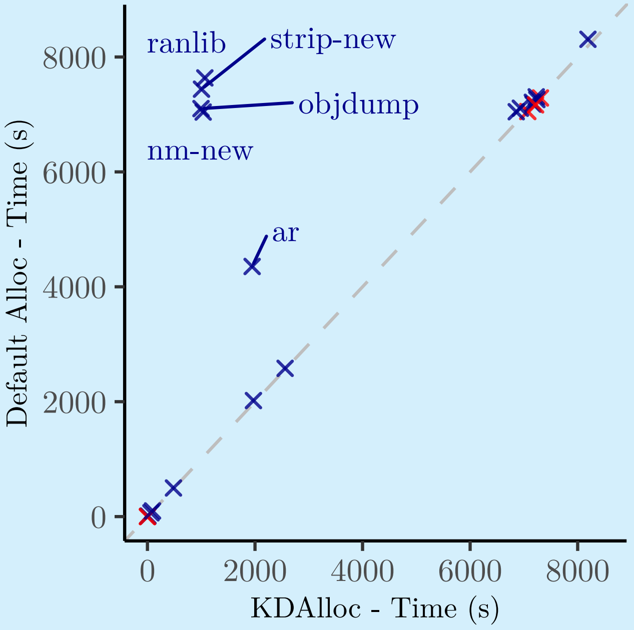


RndCov

Performance

DFS





RNDCOV

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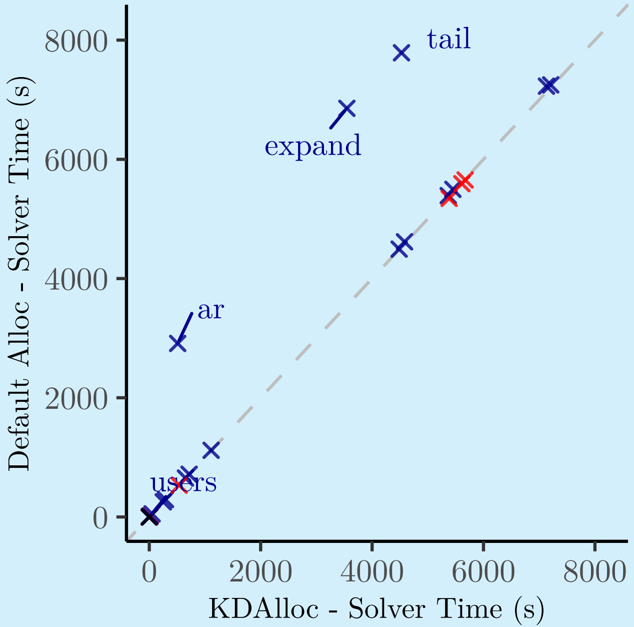
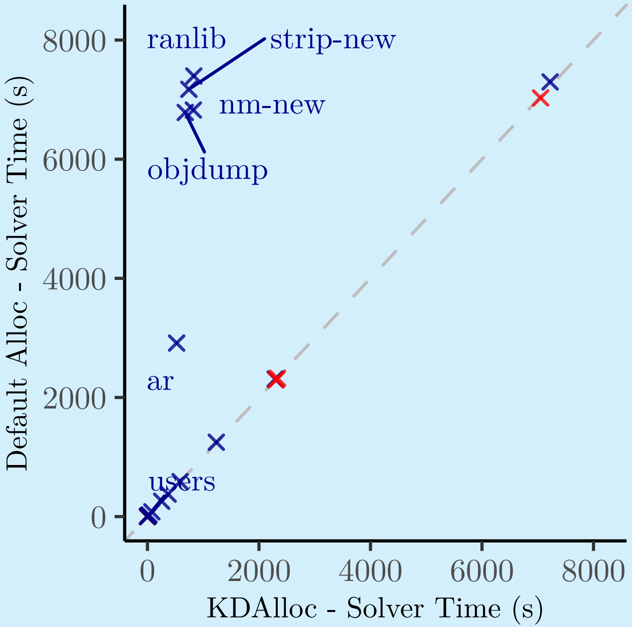
Solver Time

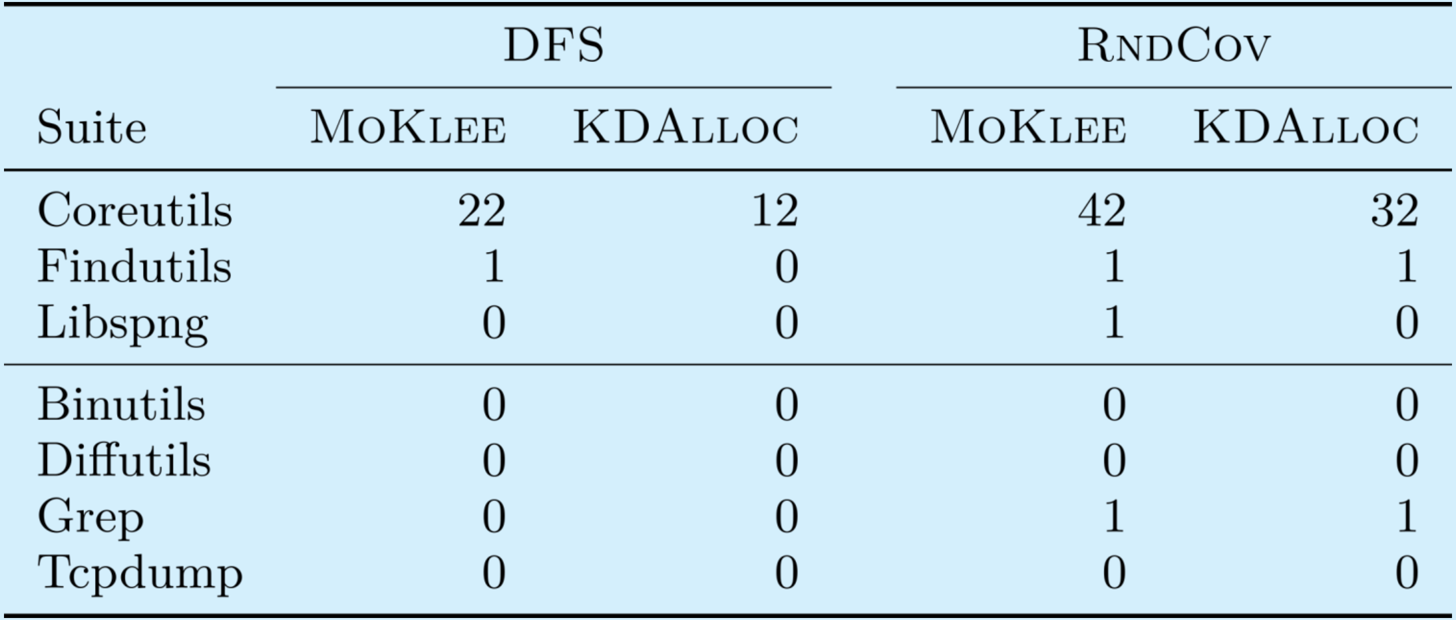
DFS





RndCov

MoKlee: Fewer Diverging Locations



	DFS		RndCov	
Suite	MoKlee	KDAlloc	MoKlee	KDAlloc
Coreutils	22	12	42	32
Findutils	1	0	1	1
Libspng	0	0	1	0
Binutils	0	0	0	0
Diffutils	0	0	0	0
Grep	0	0	1	1
Tcpdump	0	0	0	0

MoKlee: Fewer Divergences in `memmove`

```c
char* s = (char*)dest;
const char* p = (const char*)src;
if (p >= s) {
    while (n) {
        *s++ = *p++;
        --n;
    }
} else {
    while (n) {
        --n;
        s[n] = p[n];
    }
}
return dest;
```

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- uClibc’s memmove is sensitive to memory layout

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  - Use-after-free detection is improved (general benefit)
  - Specific benefits for multiple DSE-based techniques

- KDAlloc is becoming part of mainline KLEE!

Guaranteed Use-After-Free Behavior

```
char *mallocfree() {
    char *s = strdup("A");
    free(s);
    char *t = strdup("B");
    return s;
}
```

```
int main(void) {
    char *s = mallocfree();
    puts(s);
    return 0;
}
```

- KDAlloc guarantees detection when quarantine is enabled

Query Structure with KDAlloc

```
(Extract w32 0
    (Add w64 0xFFFFDDBC00000000 (Select w64 C 0x0000000000000000 0x0000224400000000)))
        ↓ Extract(Add): (Extract (Add x y)) → (Add (Extract x) (Extract y))
(Add w32 (Extract w32 0 0xFFFFDDBC00000000)
    (Extract w32 0 (Select w64 C 0x0000000000000000 0x0000224400000000)))
        (Extract w32 0 0xFFFFDDBC00000000) → 0x00000000 and ↓ Extract(Select)
(Add w32 0x00000000
    (Select w32 C (Extract w32 0 0x0000000000000000) (Extract w32 0 0x0000224400000000)))
        (Extract w32 0 0x0000000000000000) → 0x00000000
        (Extract w32 0 0x0000224400000000) → 0x00000000
(Add w32 0x00000000 (Select w32 C 0x00000000 0x00000000))
        (Select w32 C 0x00000000 0x00000000) → 0x00000000
(Add w32 0x00000000 0x00000000) = 0x00000000
```

Query Structure without KDAlloc

```
(Extract w32 0
    (Add w64 0xFFFFAAAAA7290C00 (Select w64 C 0x0000000000000000 0x0000555558D6F400)))
  ↓ Extract(Add): (Extract (Add x y)) → (Add (Extract x) (Extract y))
(Add w32 (Extract w32 0 0xFFFFAAAAA7290C00)
    (Extract w32 0 (Select w64 C 0x0000000000000000 0x0000555558D6F400)))
  (Extract w32 0 0xFFFFAAAAA7290C00) → 0xA7290C00 and ↓ Extract(Select)
(Add w32 0xA7290C00
    (Select w32 C (Extract w32 0 0x0000000000000000) (Extract w32 0 0x0000555558D6F400)))
  (Extract w32 0 0x0000000000000000) → 0x00000000
  (Extract w32 0 0x0000555558D6F400) → 0x58D6F400
(Add w32 0xA7290C00 (Select w32 C 0x00000000 0x58D6F400))
```