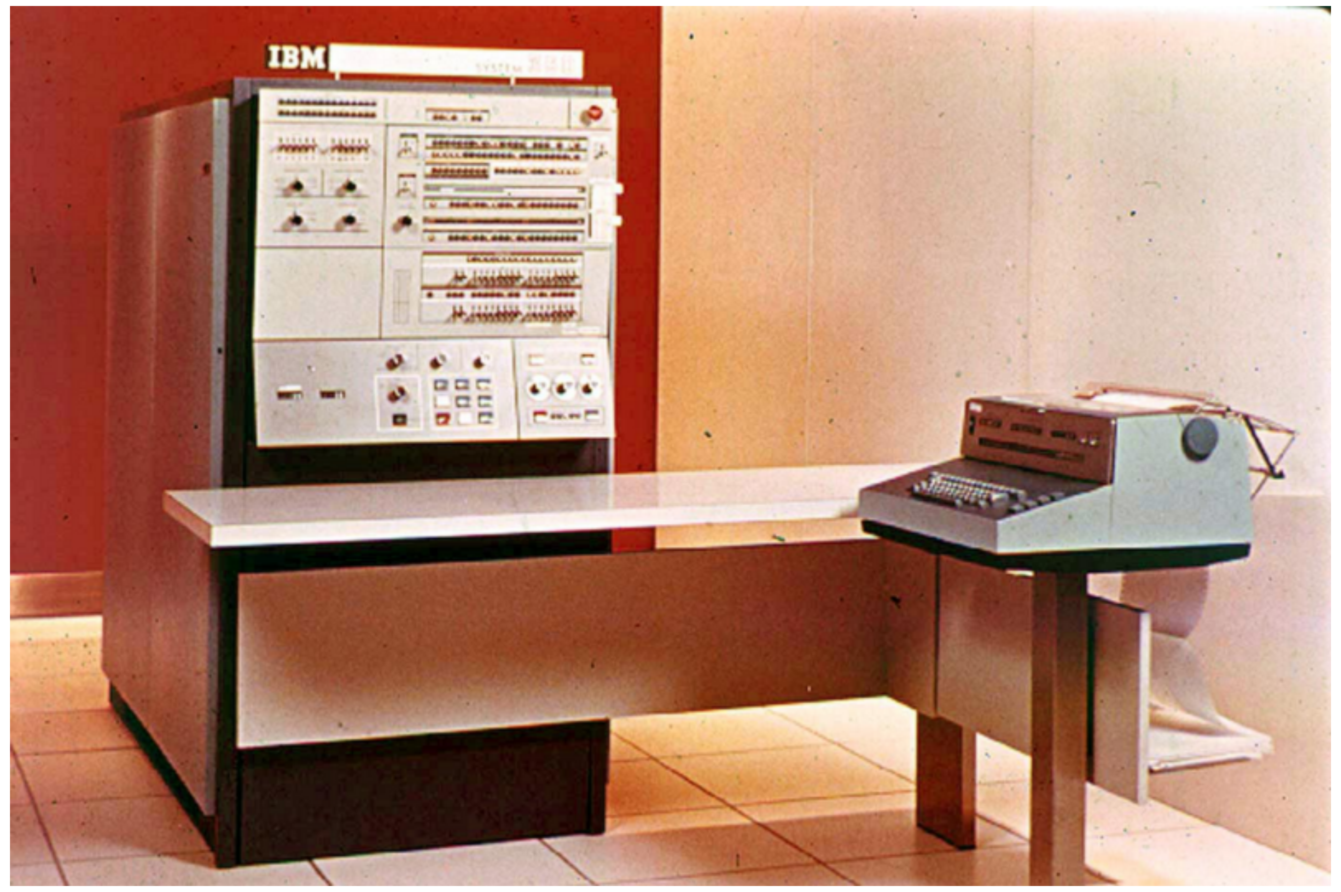
Review

- Running a program requires the code & stack segments in memory.
- Context = memory address space + stack pointer + instruction pointer
  - A CPU is in the context of a program if its instruction pointer and stack pointer registers point to the code & stack segments of the program.
- Context-switch means switching the context of a CPU to different programs by modifying its stack pointer and instruction pointer.

Big picture of context-switch



- The initial goal of operating systems is multi-tasking.
  - A naive way of multi-tasking is batch processing.
  - The concept of context-switch enables time-sharing multi-tasking.
    - There are different implementations of context-switch: user-level threads, kernel-level threads, processes

* Images from https://about.sourcegraph.com/blog/the-ibm-system-360-the-first-modular-general-purpose-computer/

Implementation comparison

		Switching stack pointer?	Switching instruction pointer?	Switching memory address space?	Switching kernel/user mode?
4411 P1	User-level Threads	Yes	No	No	No
Beyond 4411 P1	Kernel-level Threads	Yes	Yes	No	Yes
	Processes	Yes	Yes	Yes	Yes

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Context-switch solves the problem of time-sharing multi-tasking.

Processes and threads implement the concept of context-switch.

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Next problem: how do different processes/threads communicate?

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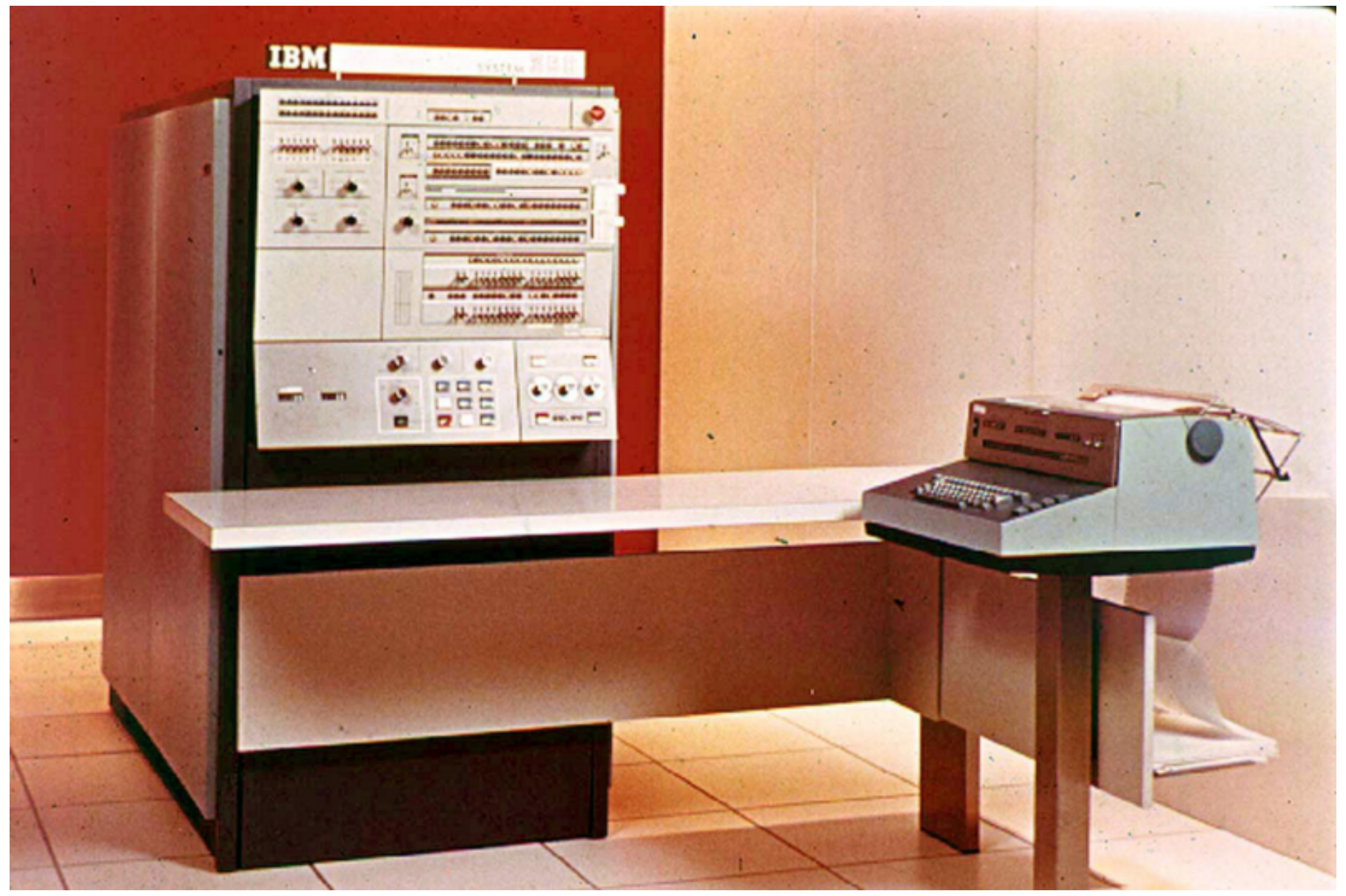
- For example, say there are 3 threads running my zoom together: one for user interface, one for microphone and one for camera.
  - When I click the “mute” button, the user interface thread should tell the microphone thread to stop recording.
  - The camera thread should continuously transfer video data to the user interface thread.

Interprocess communication (IPC)

- The terminology of this problem is IPC which is extensively studied in the operating systems literature. Performance is the key!
    - If IPC has poor performance, the camera thread cannot transfer video data to the user interface thread in time, leading to poor experience.
- Note: we will use the general term IPC to represent both communications among processes and communications among threads.

Historical representatives



- IBM 360 is a representative of time-sharing multi-tasking with context-switch.
- 1960s

- AT&T UNIX System V is a representative of interprocess communication (IPC).
- 1980s

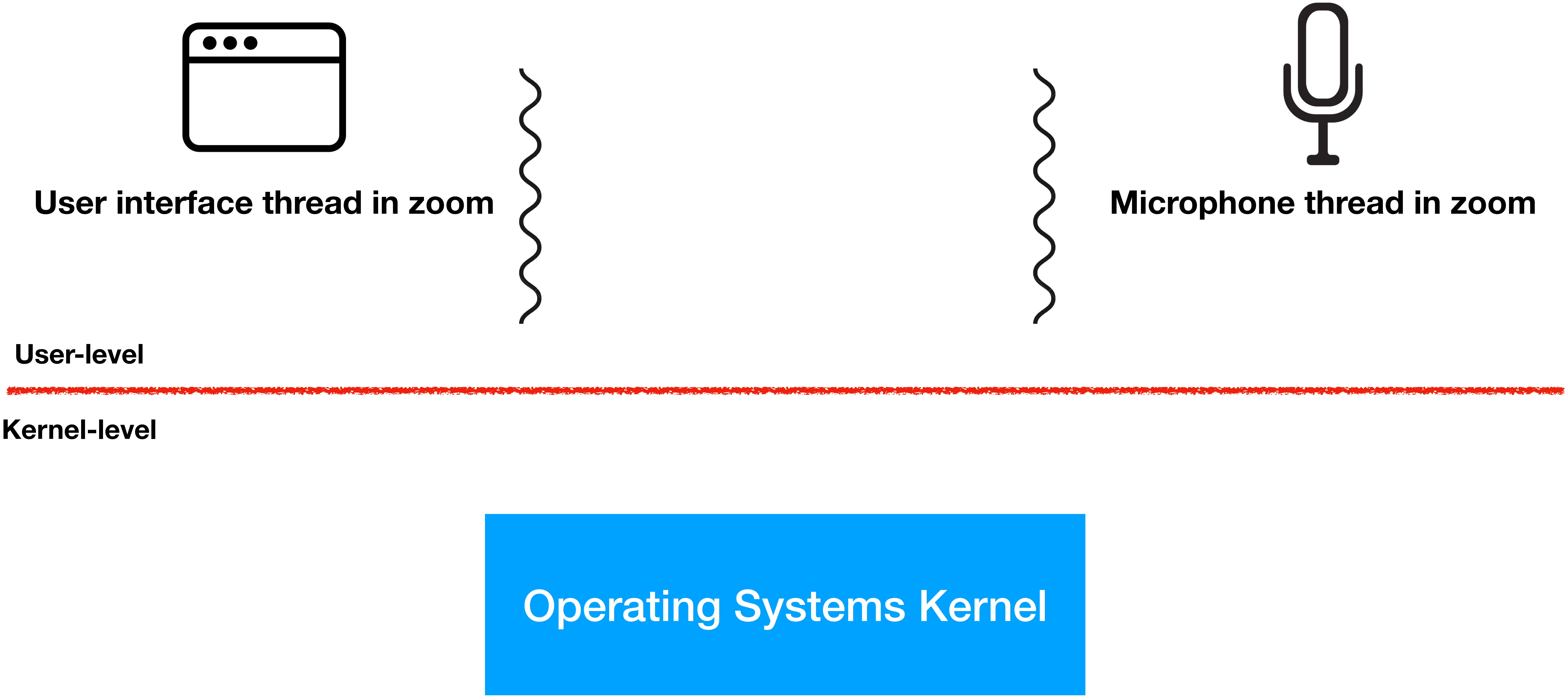
UNIX System V IPC

`System V IPC is the name given to three interprocess communication mechanisms that are widely available on UNIX systems: message queues, semaphore, and shared memory.`

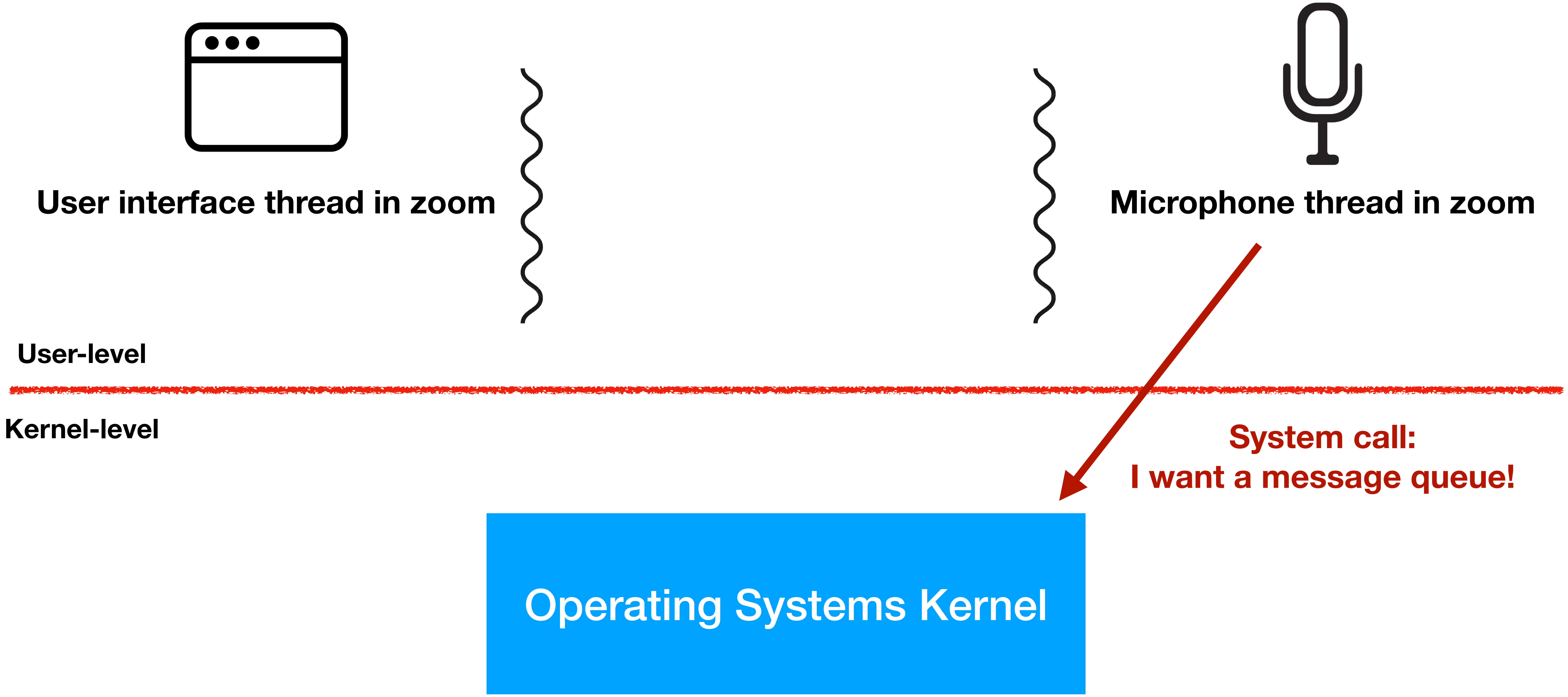
what you need to implement in 4411 P1

https://man7.org/linux/man-pages/man7/svipc.7.html

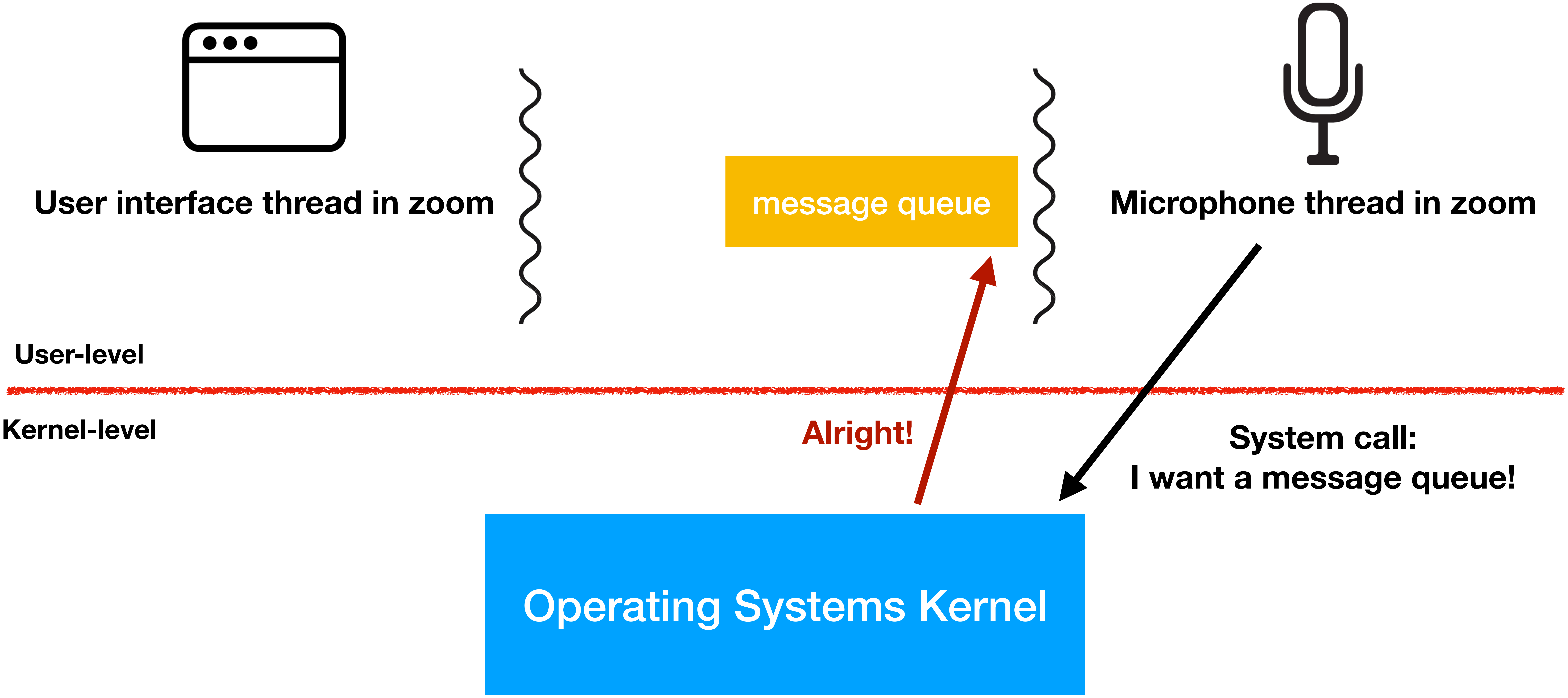
Message queue example



Message queue example



Message queue example



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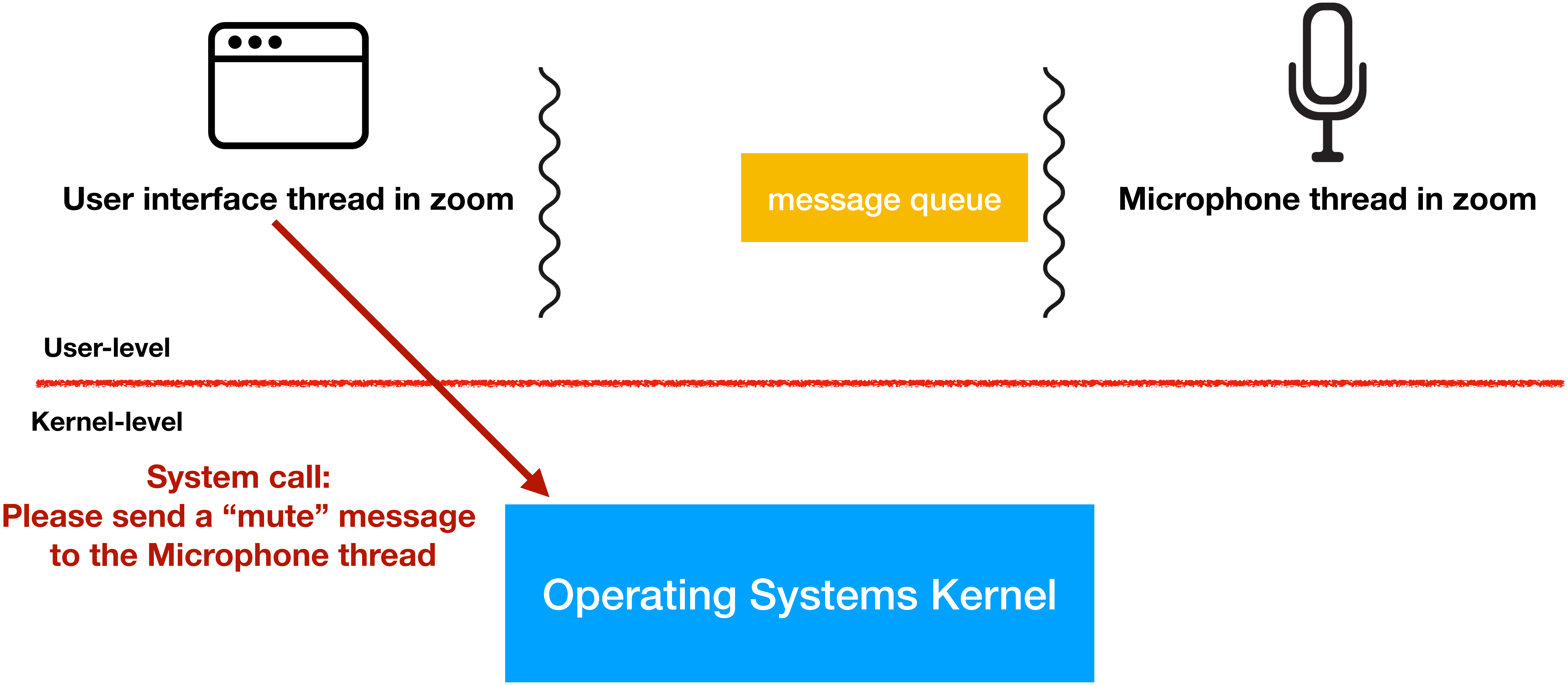

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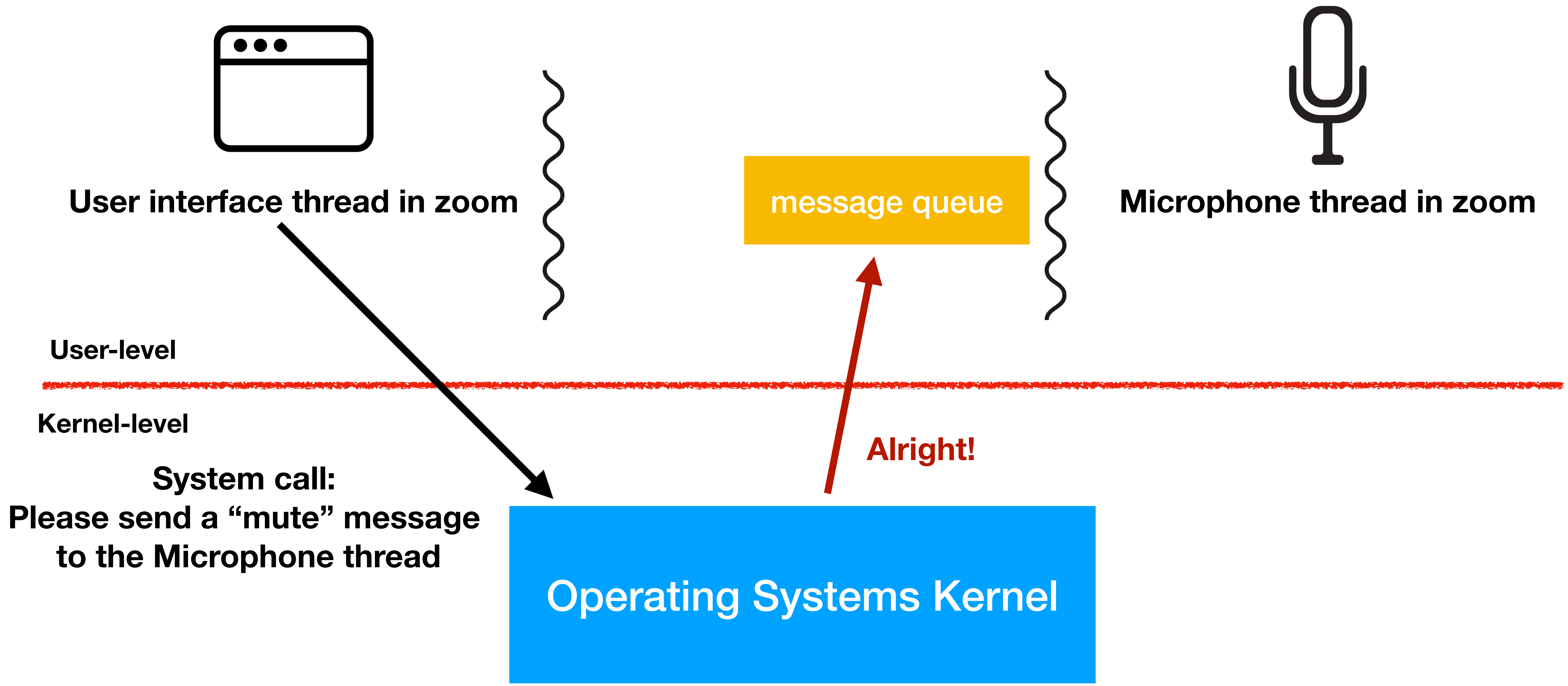

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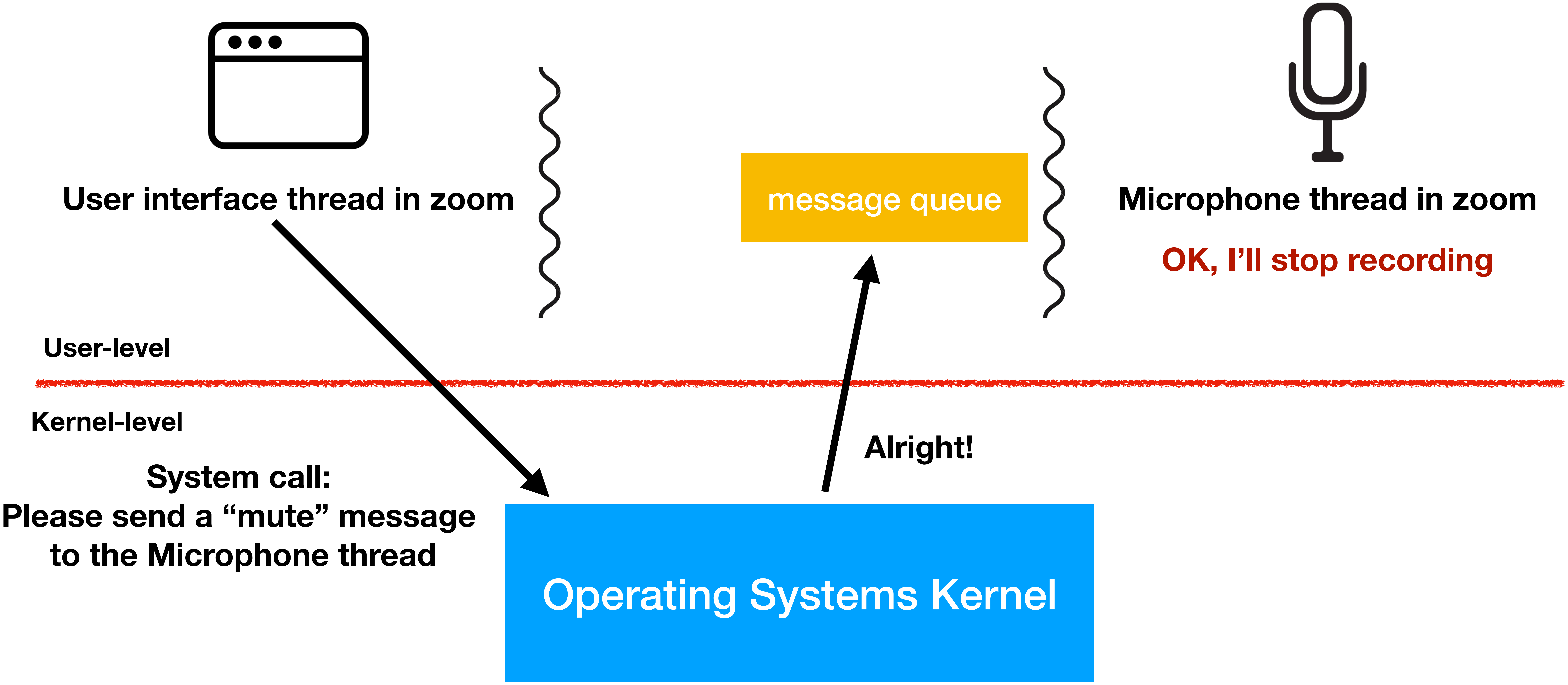
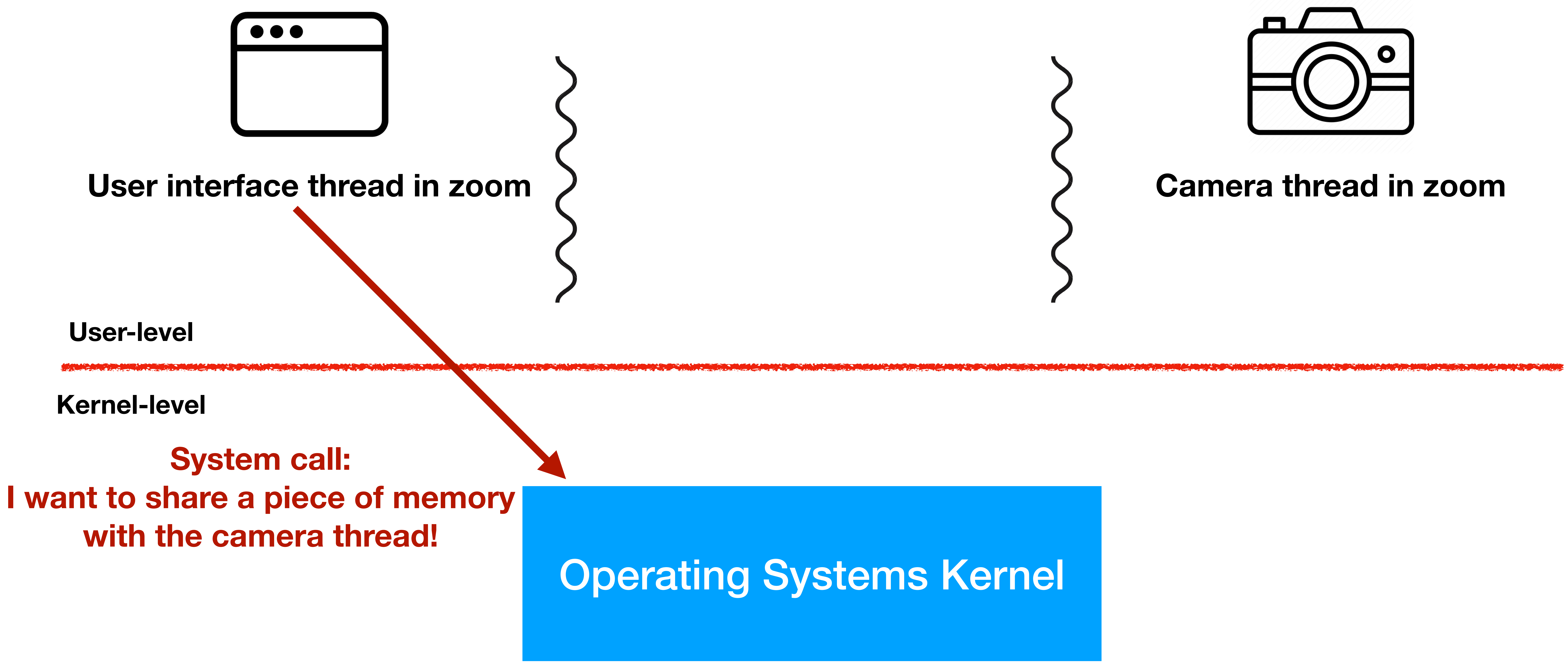


Shared memory example



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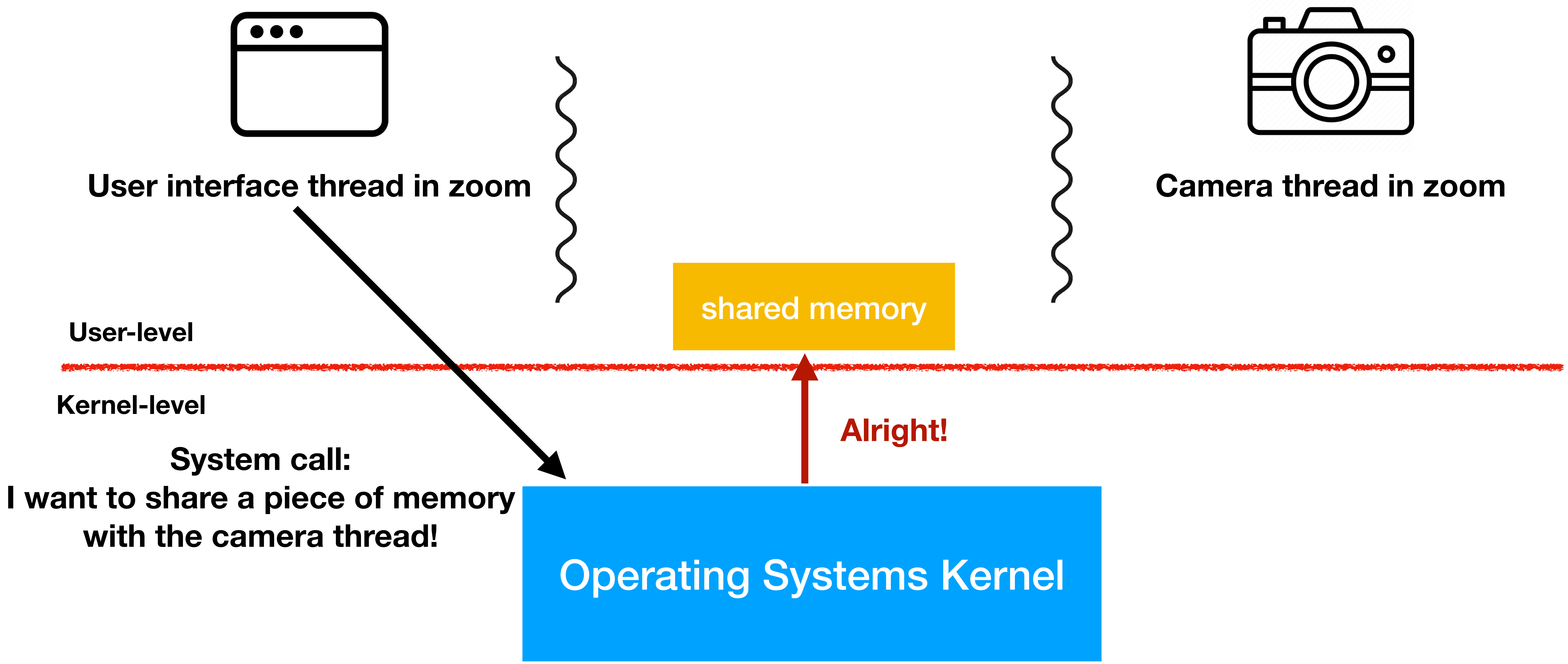

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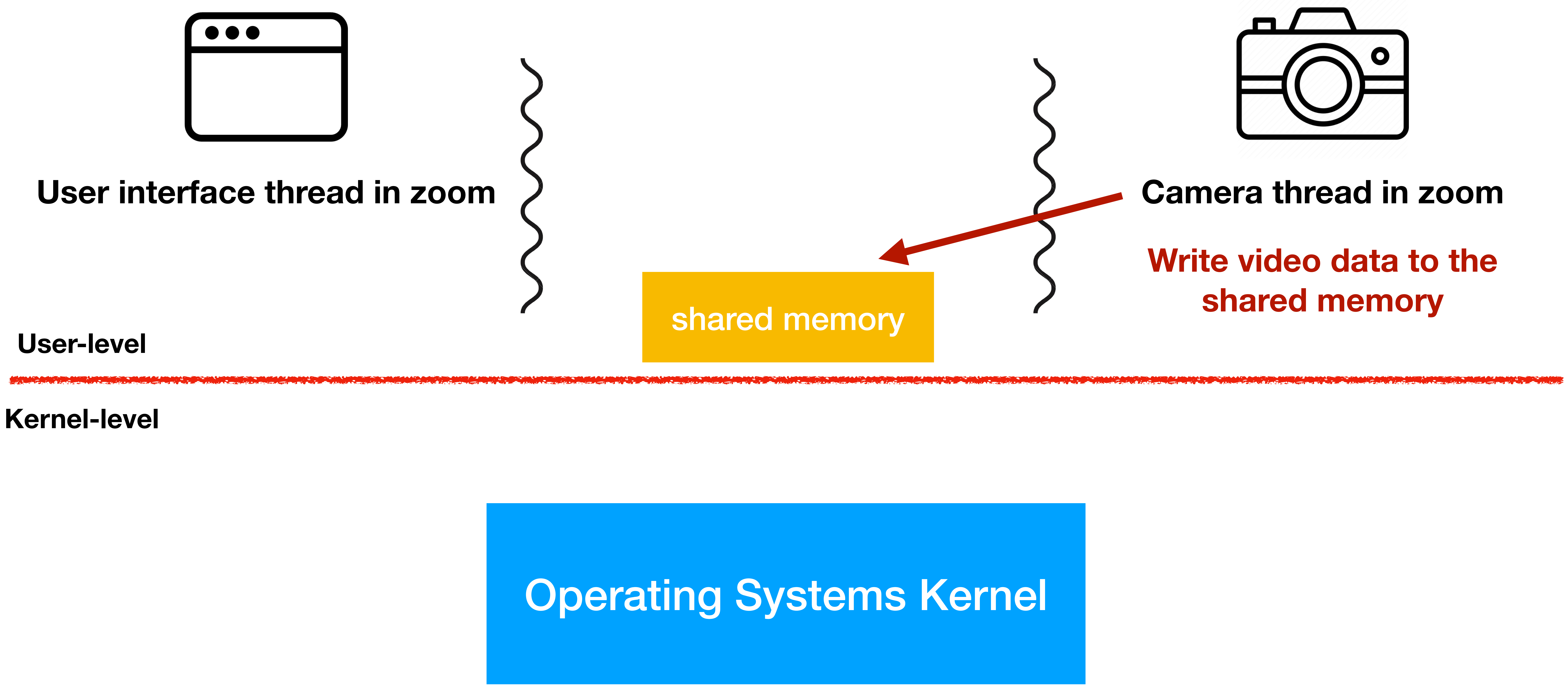

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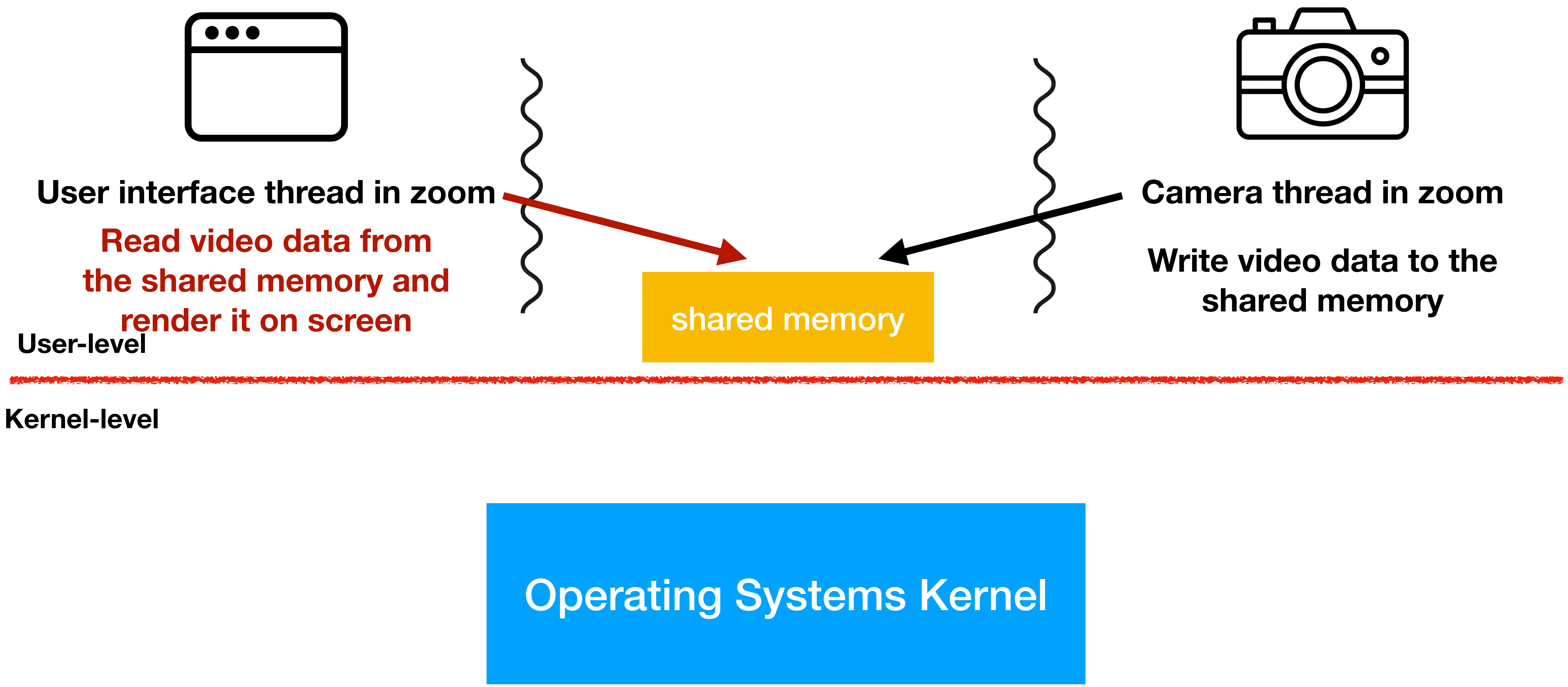

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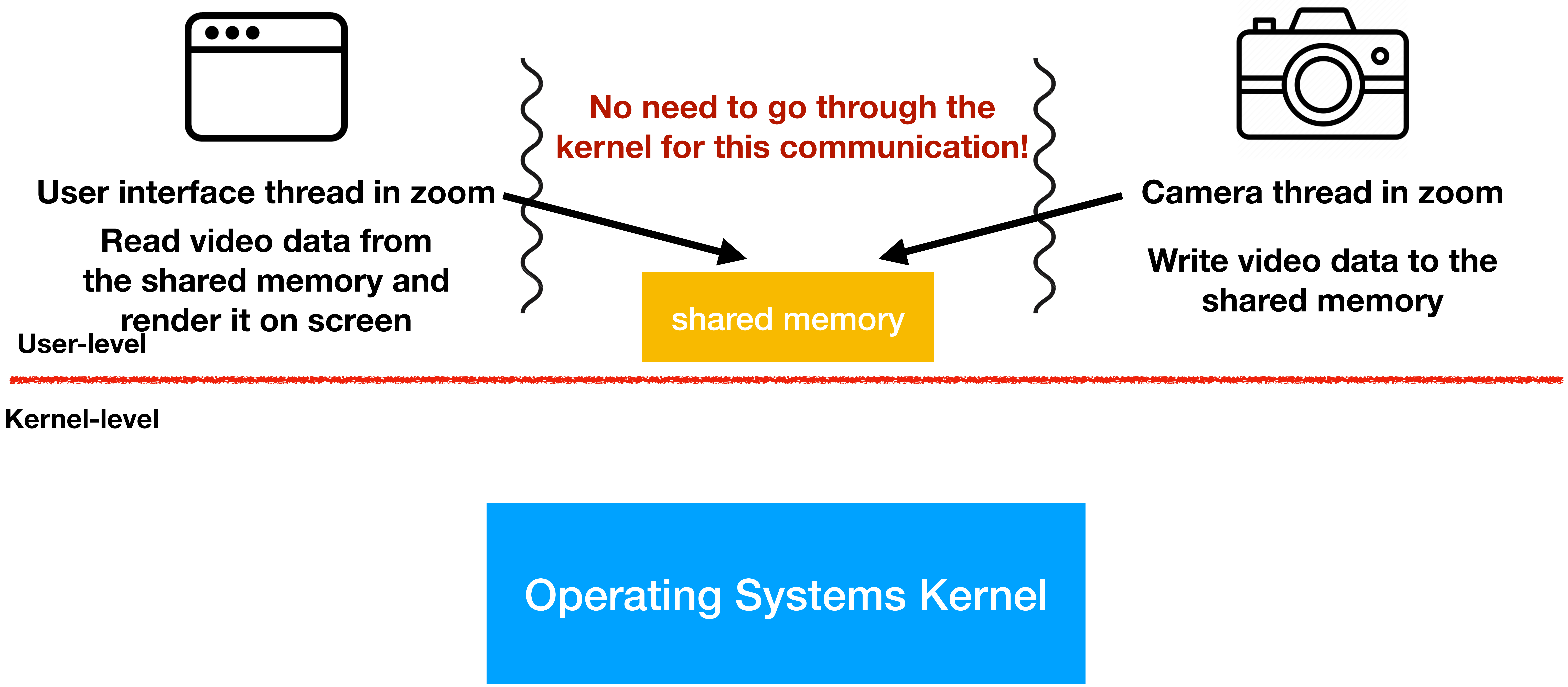


Lesson: shared memory has better performance than message queues because communications get around the kernel.

The third IPC mechanism: semaphores

```
System V IPC is the name given to three interprocess
communication mechanisms that are widely available on
UNIX systems: message queues, semaphore, and shared
memory.
```

✅ ✅

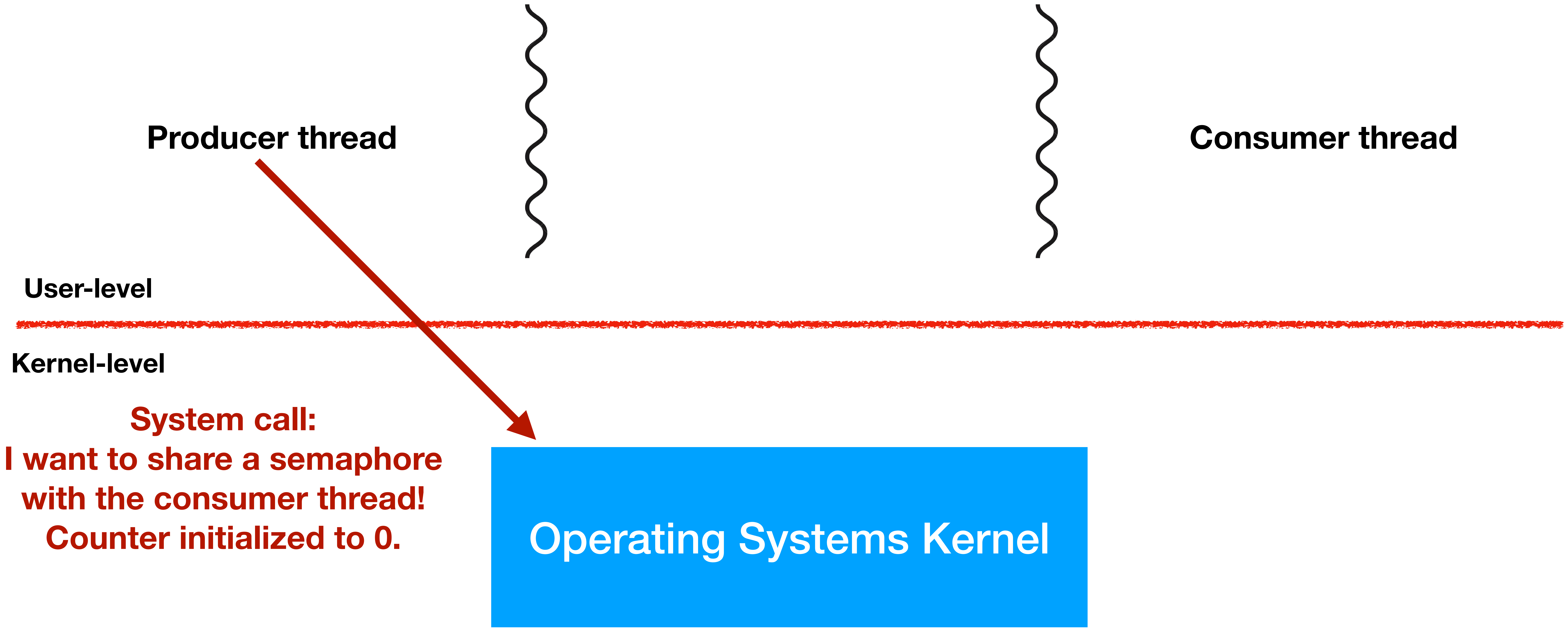
↑ what you need to implement in 4411 P1

https://man7.org/linux/man-pages/man7/svipc.7.html

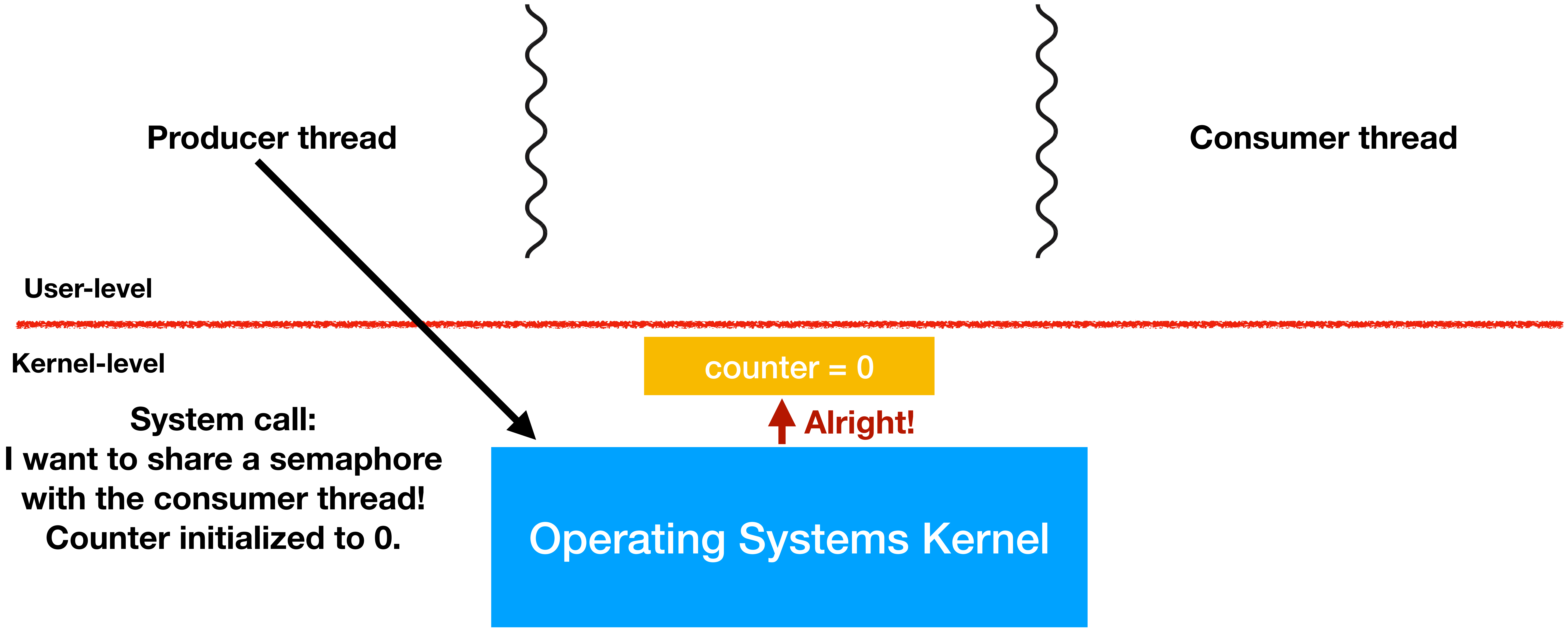
The producer-consumer problem

- There are two types of threads (or processes): producer and consumer.
  - Producer produces some kind of resources (e.g., HTTP web request) and consumer consume the resources (e.g., process the request).
- Goal: consumer should only be scheduled when some resource produced by the producer is available (i.e., has not been consumed).
- The core of semaphore is a counter of such available resources. If counter is greater than 0, a consumer thread will be scheduled.

Producer-consumer example



Producer-consumer example



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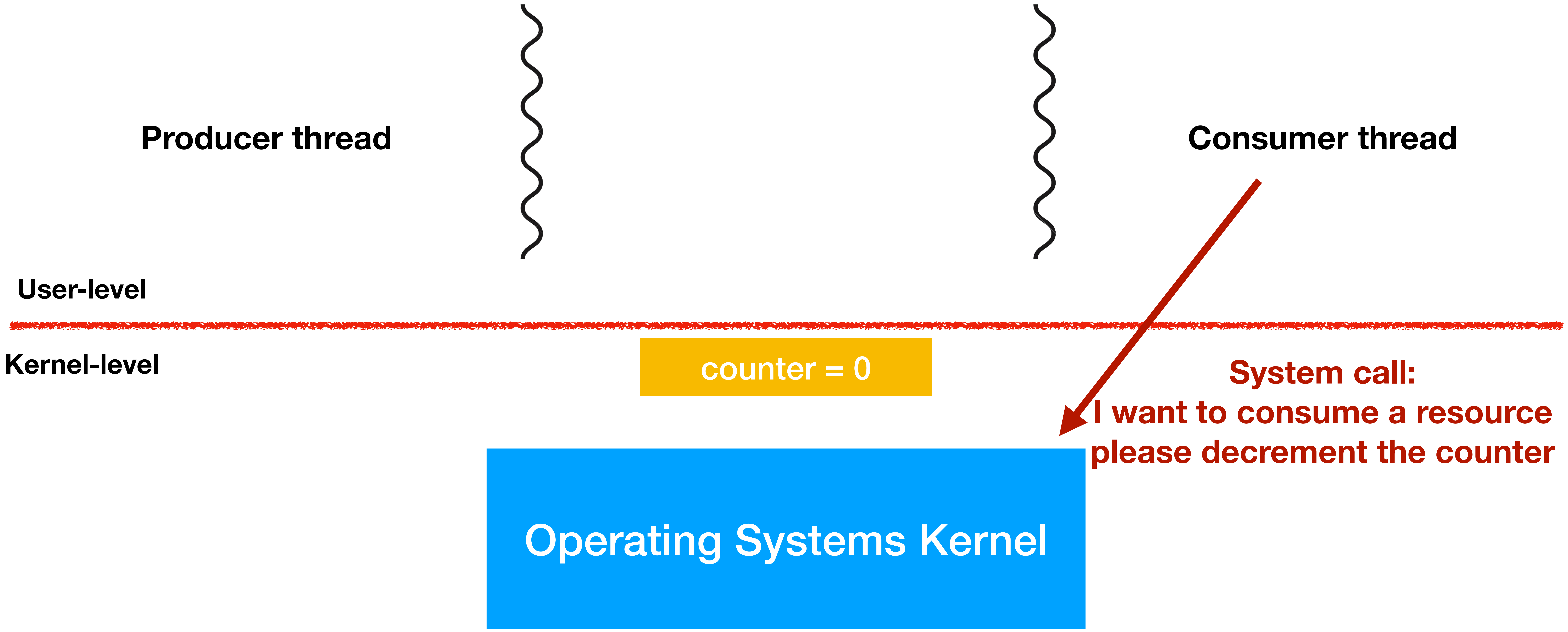

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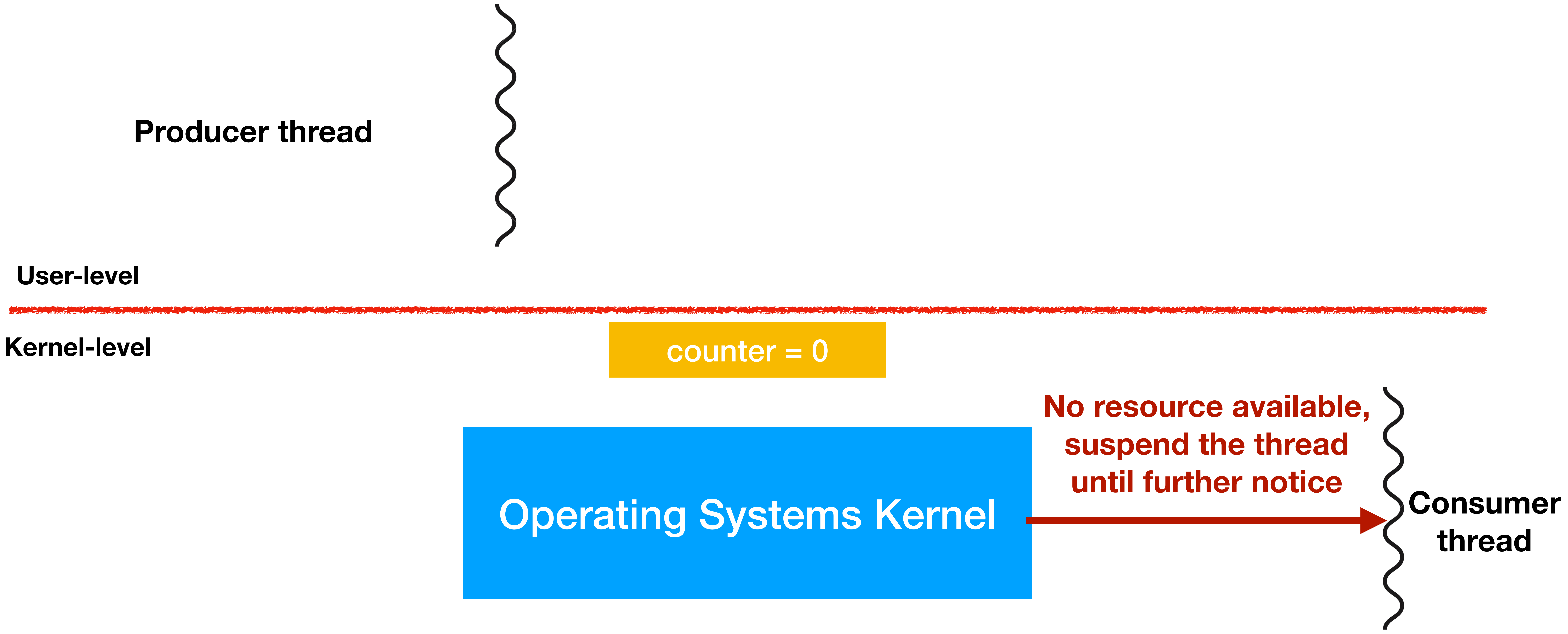

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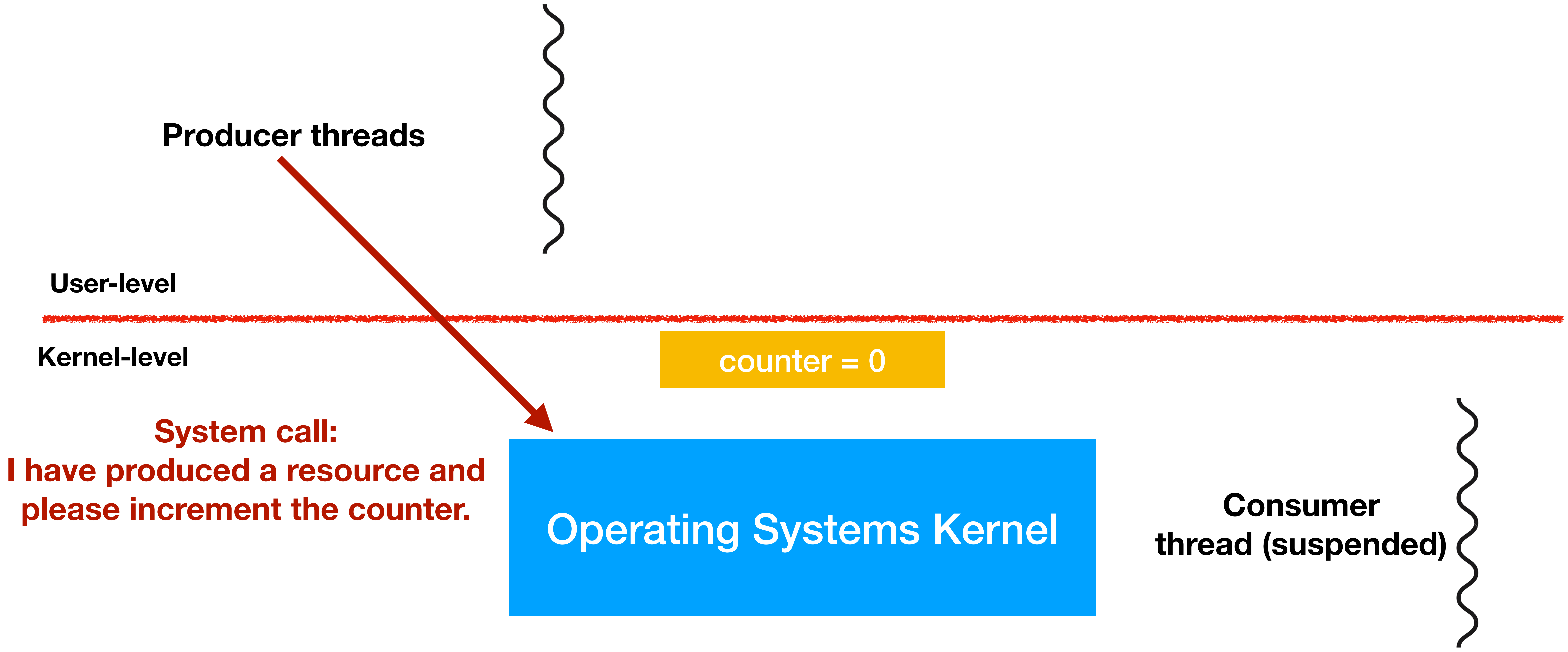

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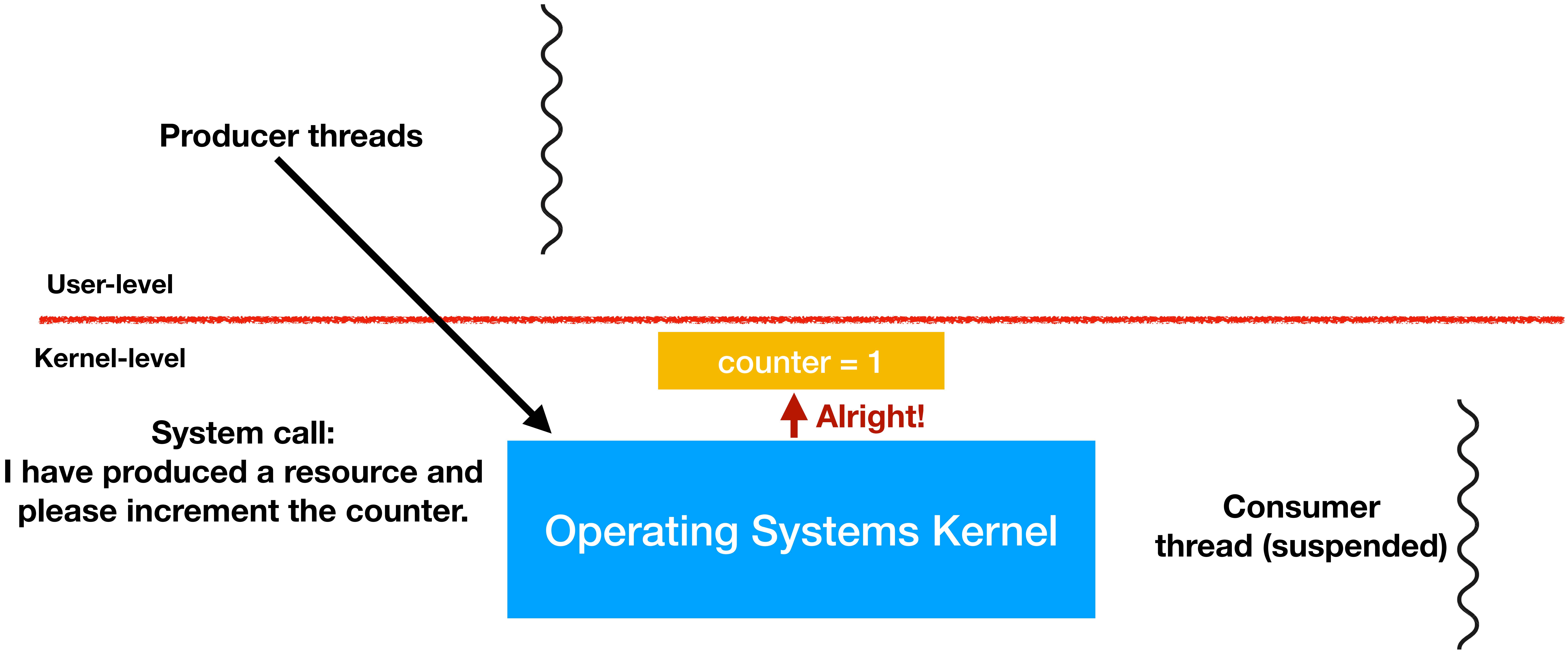

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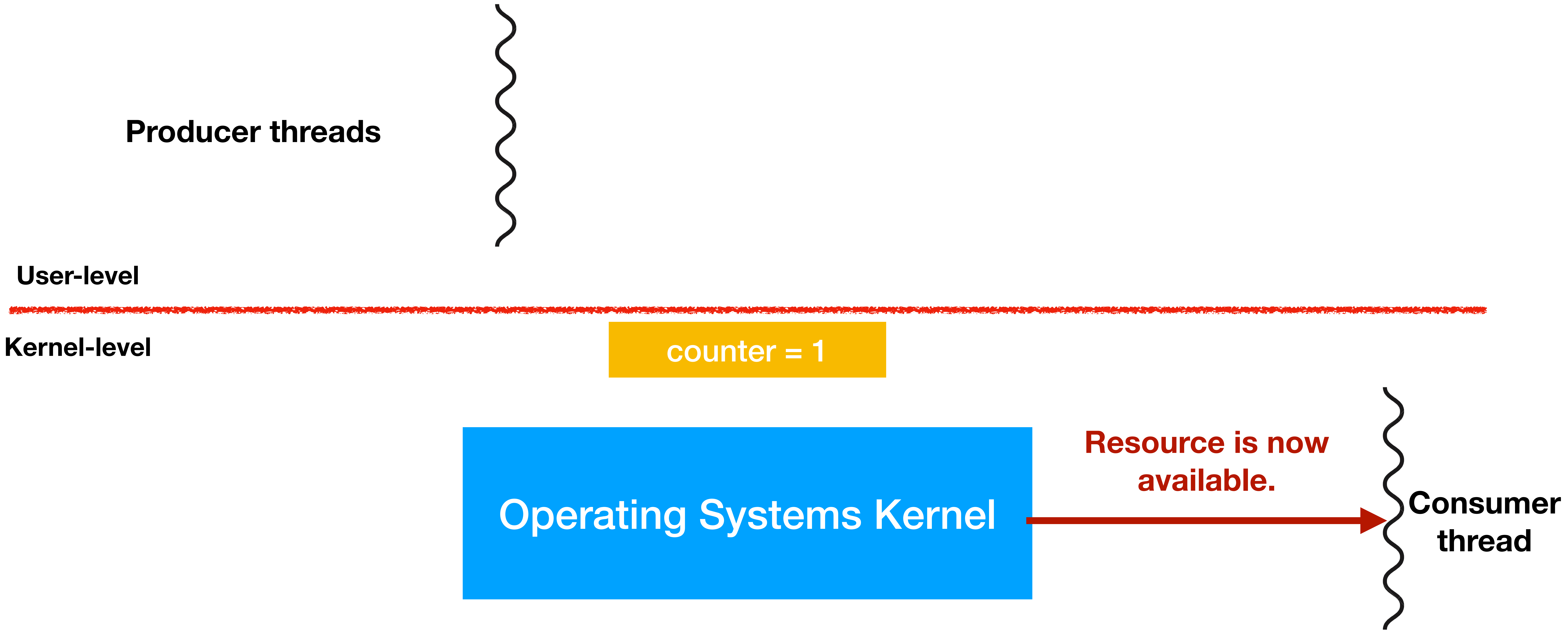

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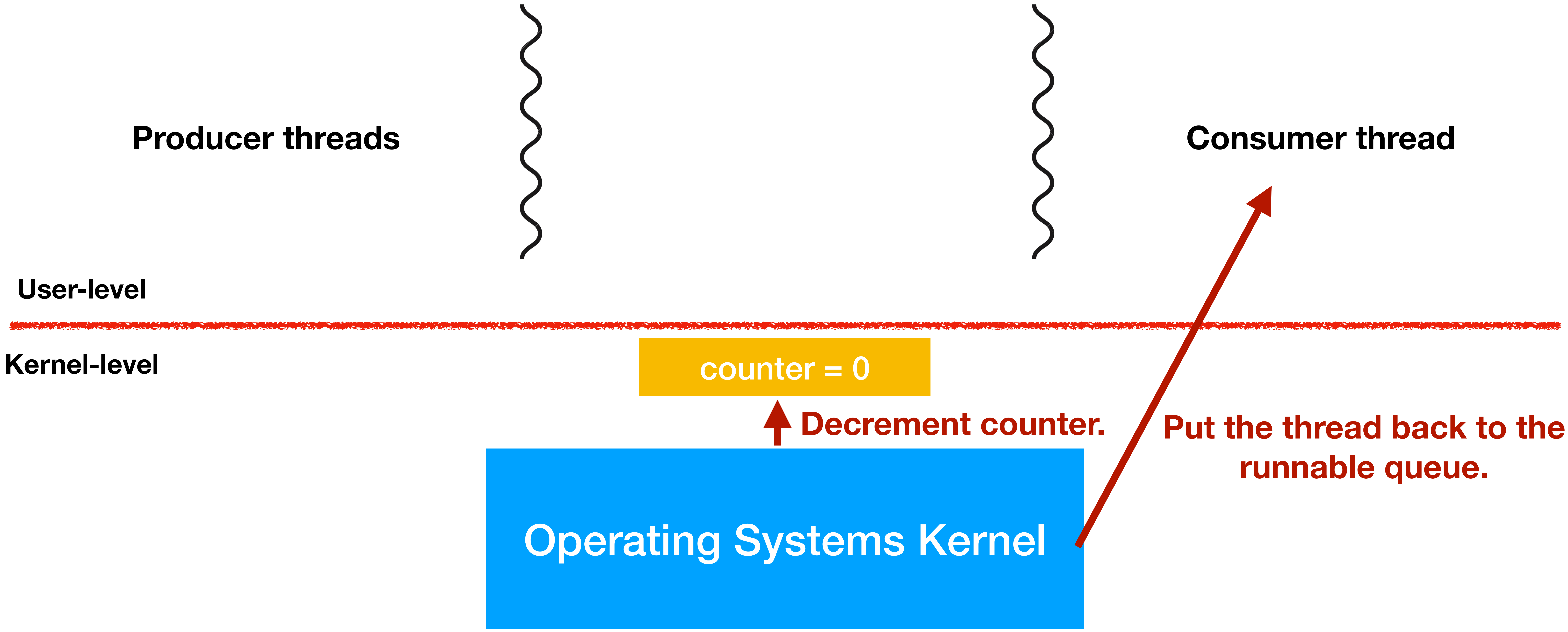

Variants of producer-consumer

- There can be multiple producer threads and consumer threads.
- Bounded buffer: a producer can only produce if the number of available resources (the value of the counter) is not greater to a given number.
- …

Semaphores in P1

```
struct sema {
    // counter
    // queue of threads that are put to sleep
    // feel free to add other fields that you need
};

// initialize a semaphore
void sema_init(struct sema *sema, unsigned int count)

// produce a resource by incrementing the semaphore
void sema_inc(struct sema *sema)

// consume a resource by decrementing the semaphore
void sema_dec(struct sema *sema)
```

Lesson: semaphore is easy to implement, but it is not very useful and one should try to avoid using it.

Refer to “12 Commandments of Synchronization” by Emin Gün Sirer

Homework

- P1: implement semaphores and test your semaphore with producer-consumer and other synchronization problems.
- Read the Linux manual of System V IPC: https://man7.org/linux/man-pages/man7/svipc.7.html
- Next lecture: introduce the concepts of timer interrupt and scheduling for P2.

Concepts in the real-world (Unix/Linux)

- User-level threads
  - `getcontext, setcontext, …`
- Kernel-level threads
  - `pthread_create, pthread_join, …`
- Processes
  - `fork, …`

Concepts in the real-world (Unix/Linux)

- Message queues
  - `msgget, msgsnd, msgrcv, …`
- Semaphores
  - `semget, semop, …`
- Shared memory
  - `shmget, shmdt, …`