



**TECHNISCHE  
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# REAL-TIME

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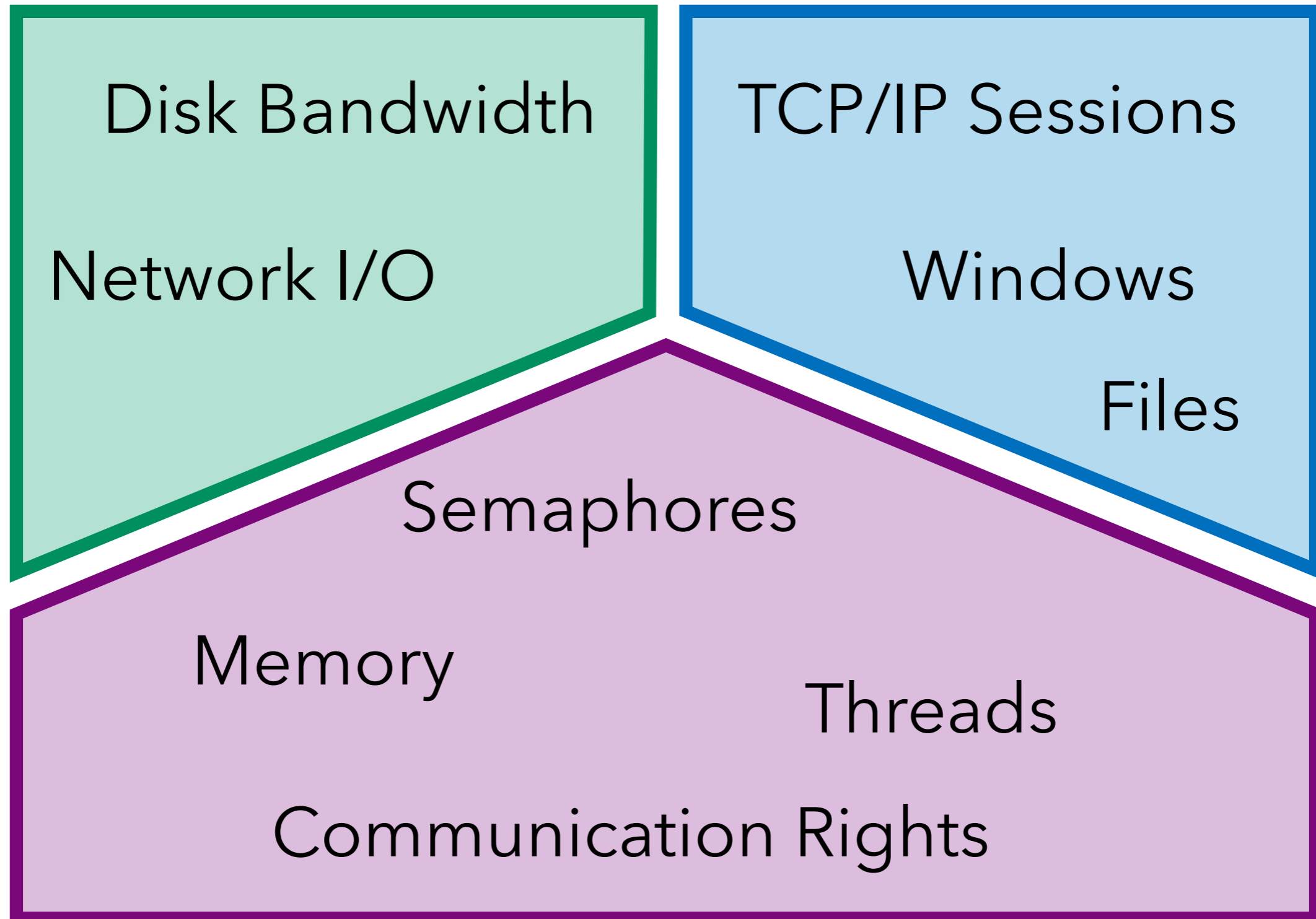
# OVERVIEW

- talked about in-kernel building blocks:
  - threads
  - memory
  - IPC
- drivers enable access to a wide range of non-kernel resources
- need to manage resources

**Applications**

**System Services**

**Basic Abstractions**



## Memory

discrete, limited

hidden in the system

managed by pager

page-granular partitions

all pages are of equal value

active policy decisions,  
passive enforcement

hierarchical management

## Time

continuous, infinite

user-perceivable

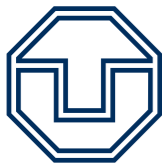
managed by scheduler

arbitrary granularity

value depends on workload

active policy decisions,  
active enforcement

Fiasco: flattened in-kernel view



# REAL-TIME

- a real-time system denotes a system, whose correctness depends on the timely delivery of results
- “it matters, when a result is produced”
- real-time denotes a predictable relation between system progress and wall-clock time



engine control in a car

break-by-wire

avionics

railway control

**focused  
catastrophic failures**

set-top box media player

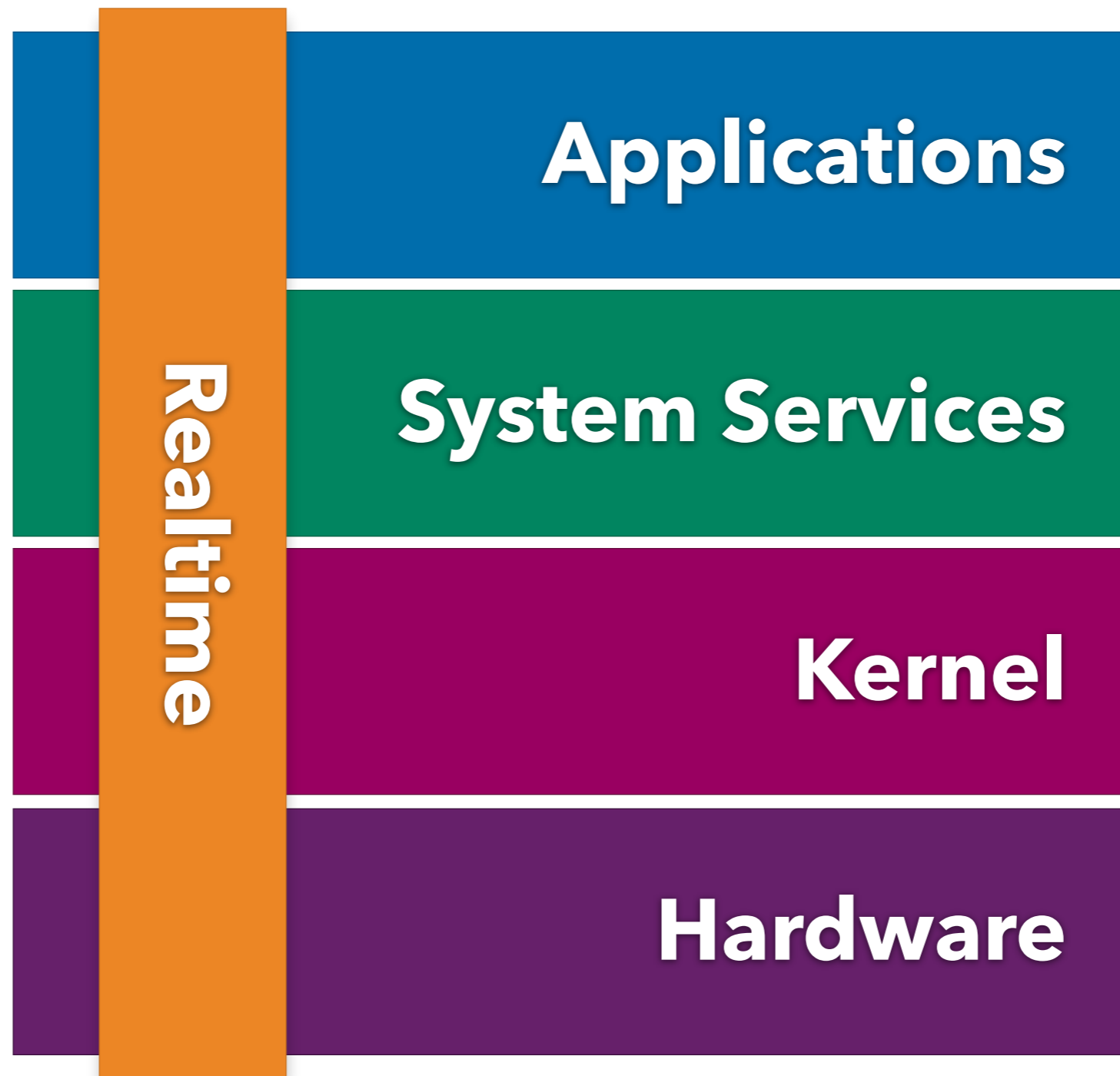
mobile stack in your cell phone

**benign failures  
complex**

- ① Predictability
- ② Guarantees
- ③ Enforcement

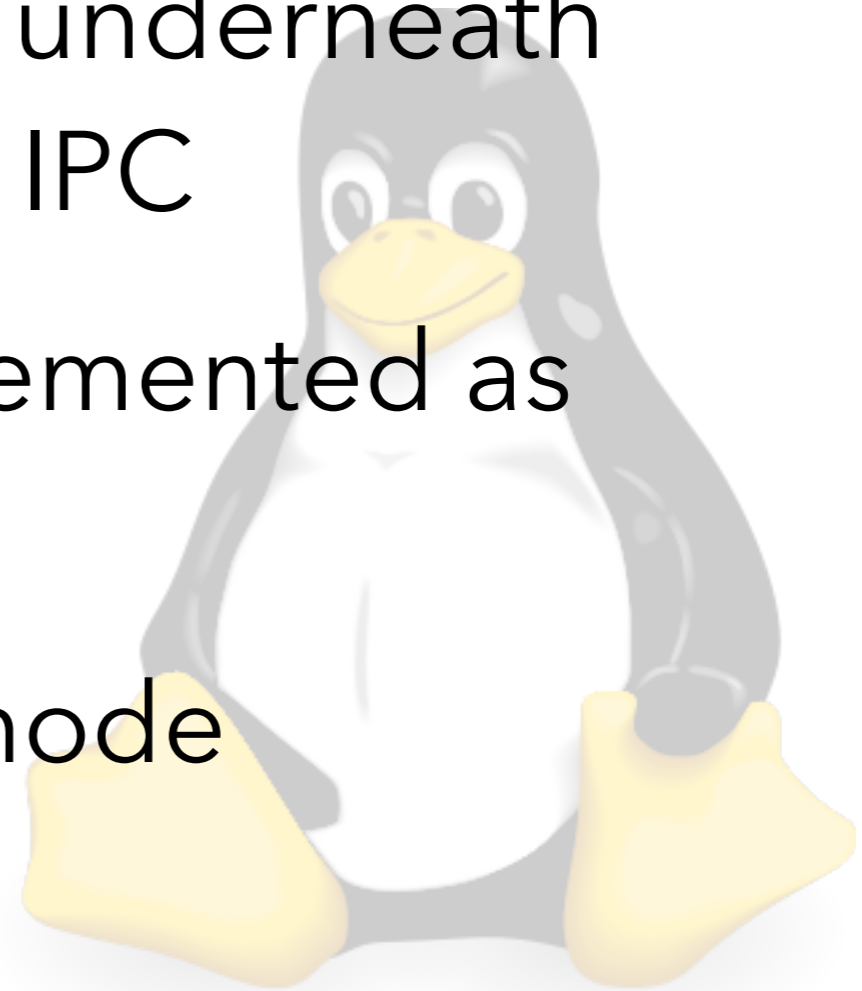
# PREDICTABILITY

- gap between worst and average case
  - memory caches, disk caches, TLBs
- “smart” hardware
  - system management mode
  - disk request reordering
- cross-talk from resource sharing
  - servers showing  $O(n)$  behavior
  - SMP
- external influences: interrupts

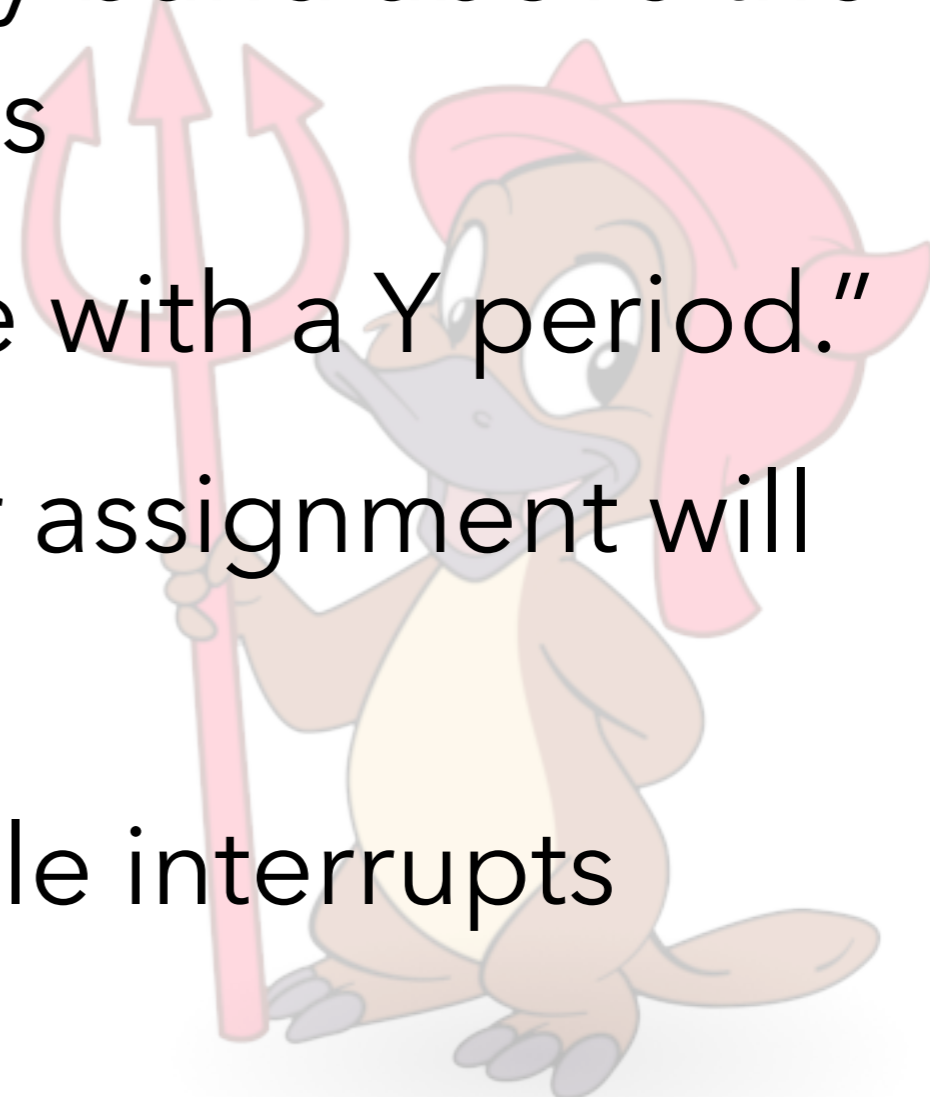


- small real-time executives tailor-made for specific applications
- fixed workload known a priori
- pre-calculated time-driven schedule
- used on small embedded controllers
- benign hardware

- full Linux kernel and real-time processes run side-by-side
- small real-time executive underneath supports scheduling and IPC
- real-time processes implemented as kernel modules
- all of this runs in kernel mode
- no isolation



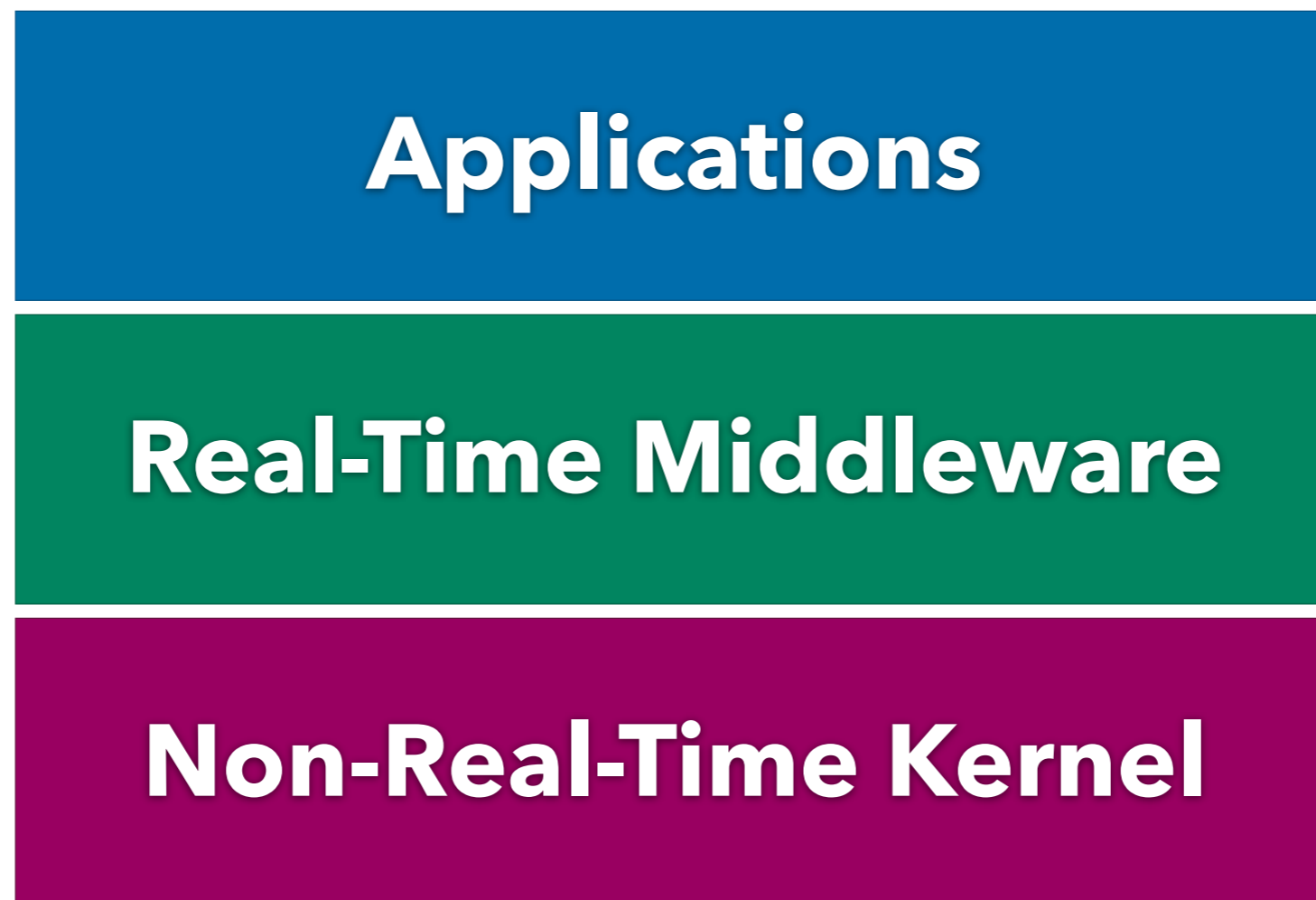
- the kernel used in macOS and iOS
- offers a real-time priority band above the priority of kernel threads
- interface: "I need X time with a Y period."
- threads exceeding their assignment will be demoted
- all drivers need to handle interrupts correctly





- static thread priorities
- $O(1)$  complexity for most system calls
- fully preemptible in kernel mode
  - bounded interrupt latency
- lock-free synchronization
  - uses atomic operations
- wait-free synchronization
  - locking with helping instead of blocking

- “real-time” architecture for those afraid of touching the OS
- example: Real-Time Java



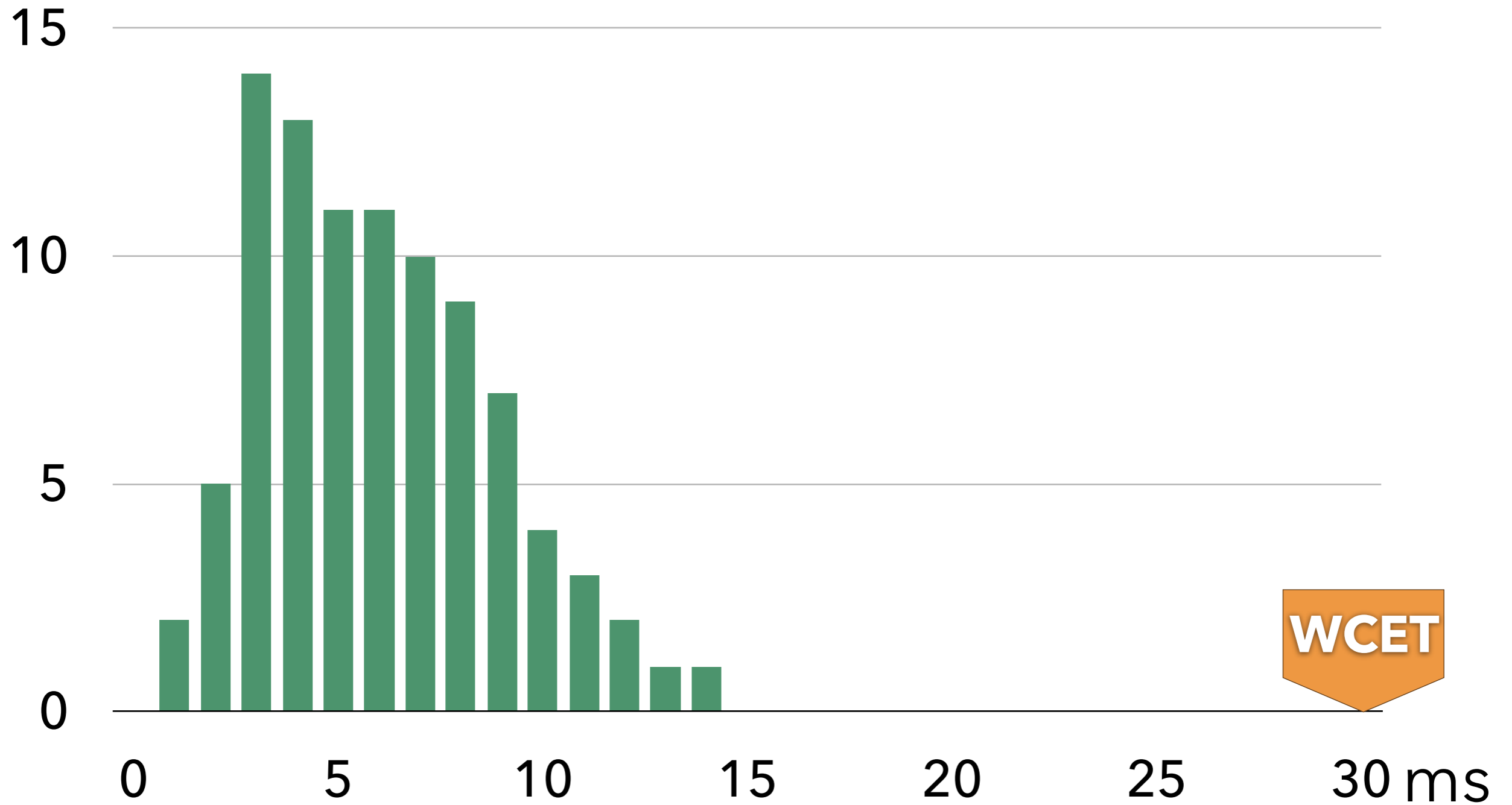
- a real-time kernel alone is not enough
- microkernel solution: temporal isolation
  - eliminates cross-talk through system calls
  - interrupt handling controlled by scheduler
- user-level servers as resource managers
  - implement real-time views on specific resources
- **real-time is not only about CPU**

# GUARANTEES

- worst case execution time (WCET) largely exceeds average case
- offering guarantees for the worst case will waste lots of resources
- missing some deadlines can be tolerated with the firm and soft real-time flavors

- desktop real-time
- there are no hard real-time applications on desktops
- there is a lot of firm and soft real-time
  - low-latency audio processing
  - smooth video playback
  - desktop effects
  - user interface responsiveness

# H.264 DECODING



$$r'_i = \min(r \in \mathbb{R} \mid \frac{1}{m_i} \sum_{k=1}^{m_i} \mathbf{P}(X_i + k \cdot Y_i \leq r) \geq q_i)$$

$$r_i = \max(r'_i, w_i) \quad i = 1, \dots, n$$

- to fully understand this (or not):  
real-time systems lecture (defunct)
- good for microkernel: reservation can be  
calculated by a userland service
- kernel just needs to support static priorities

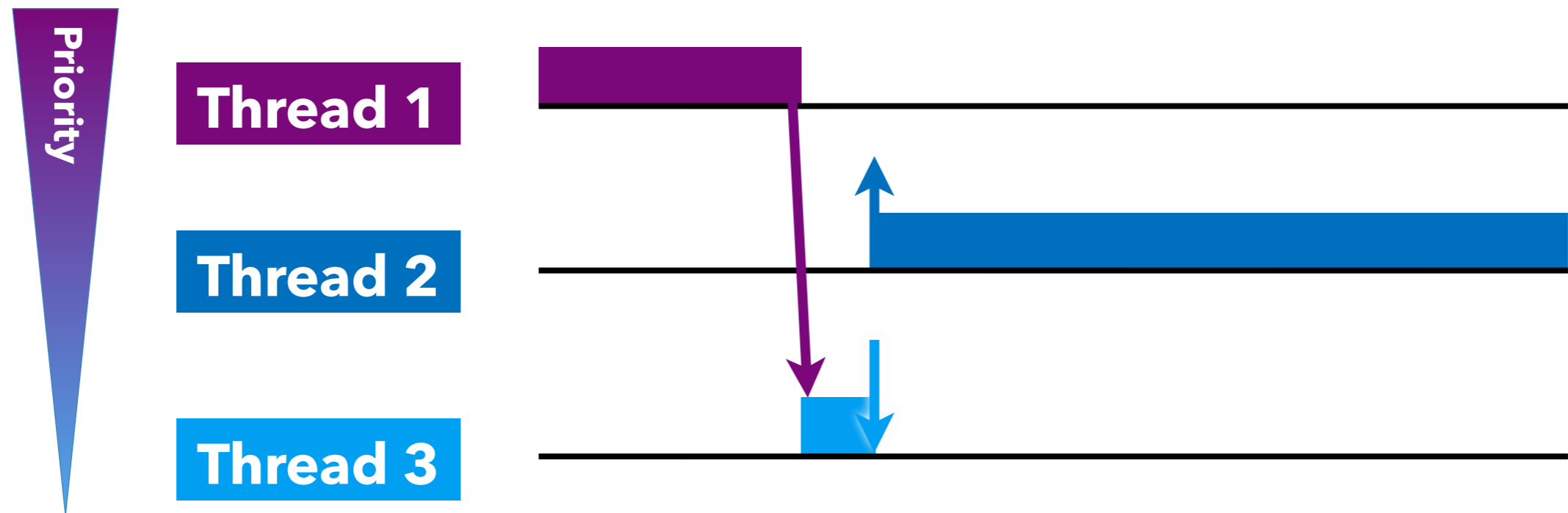


- **scheduling = admission + enforcement**
- admission = scheduling analysis
  - verifies the feasibility of client requests
  - formal task model
  - calculates task parameters
  - can reject requests
- enforcement
  - executing the schedule
  - preempt when reservation expires

# ENFORCEMENT

- executed at specific events
- enforces task parameters by preemption
  - e.g. on deadline overrun
- picks the next thread
  - static priorities (e.g. RMS, DMS)
  - dynamic priorities (e.g. EDF)
- seems simple...

- high priority thread calls low priority service, medium priority thread interferes:



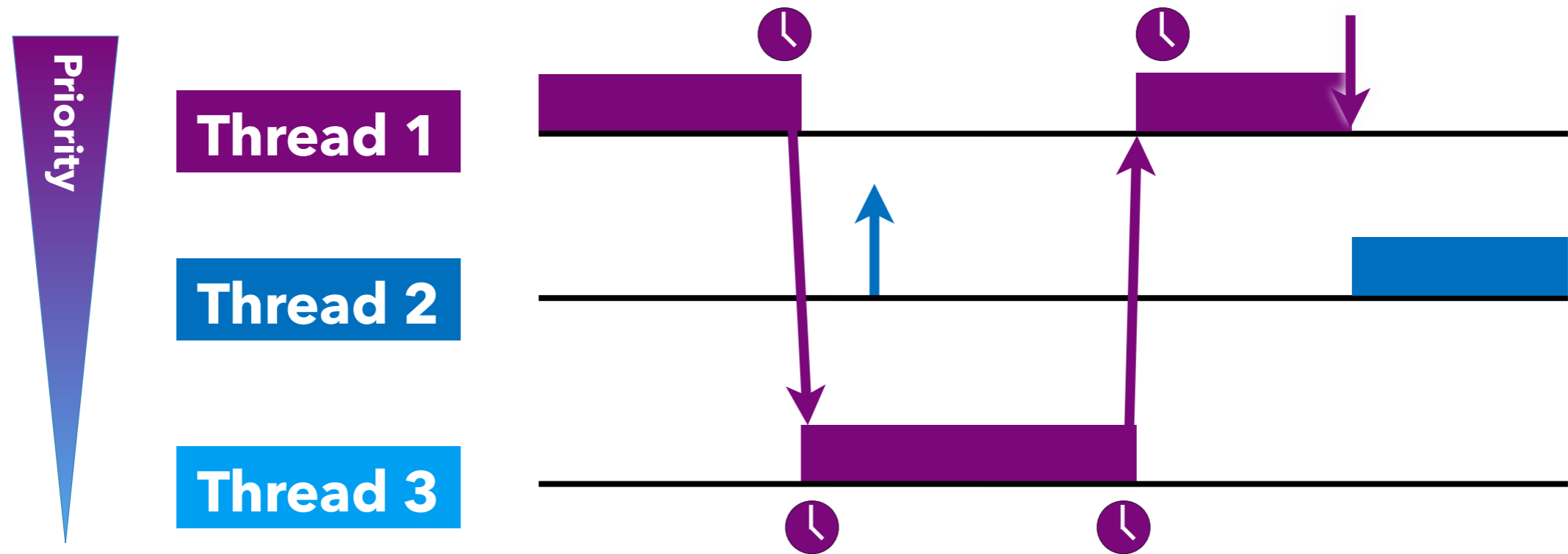
1 waits for 3 ✓

3 waits for 2 ✓

= 1 waits for 2 ✗

## Priority Inversion

- priority inheritance, priority ceiling
- nice mechanism for this in Fiasco, NOVA:  
timeslice donation
- split thread control block
  - execution context: holds CPU state
  - scheduling context: time and priority
- on IPC-caused thread switch, only the execution context is switched



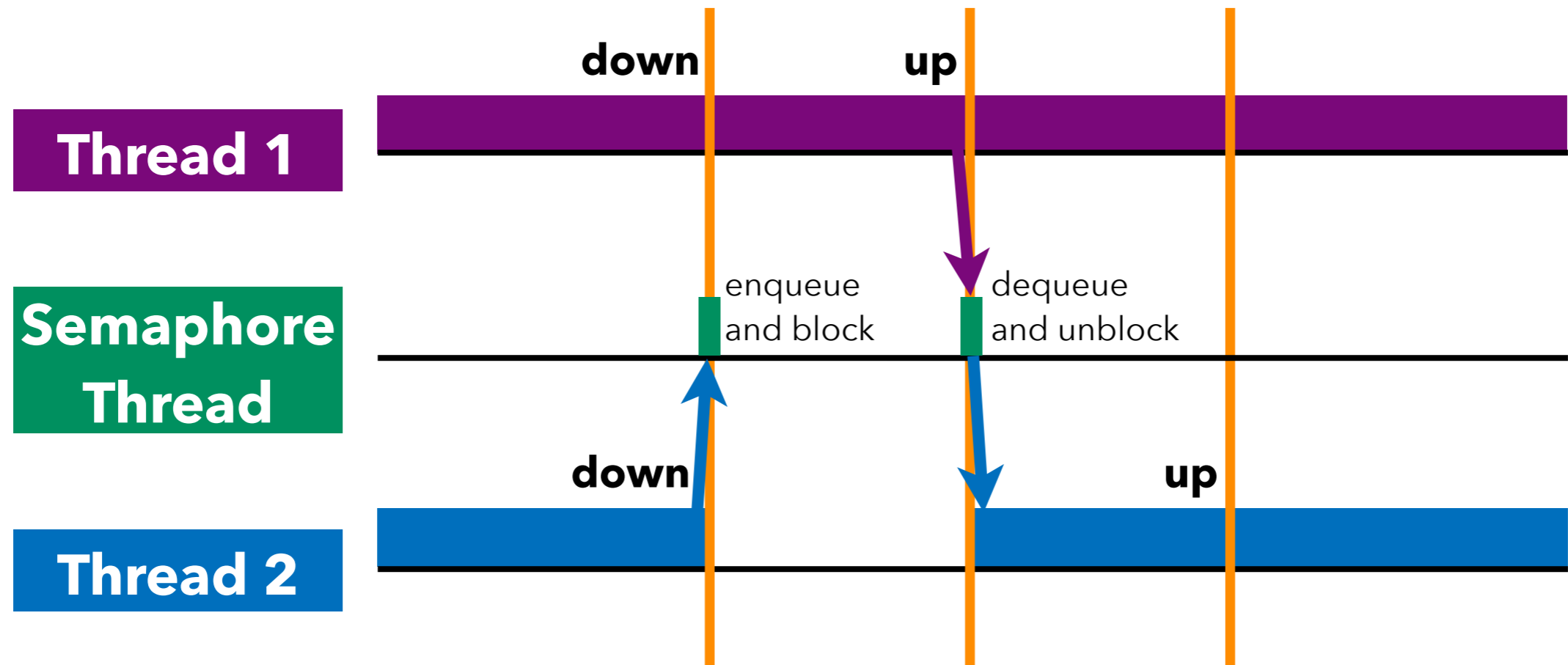
- IPC receiver runs on the sender's scheduling context
- priority inversion problem solved with priority inheritance

- servers run on their clients' time slice
  - when the server executes on behalf of a client, the client pays with its own time
- this allows for servers with no scheduling context
  - server has no time or priority on its own
  - can only execute on client's time
  - relieves scheduler from dealing with servers

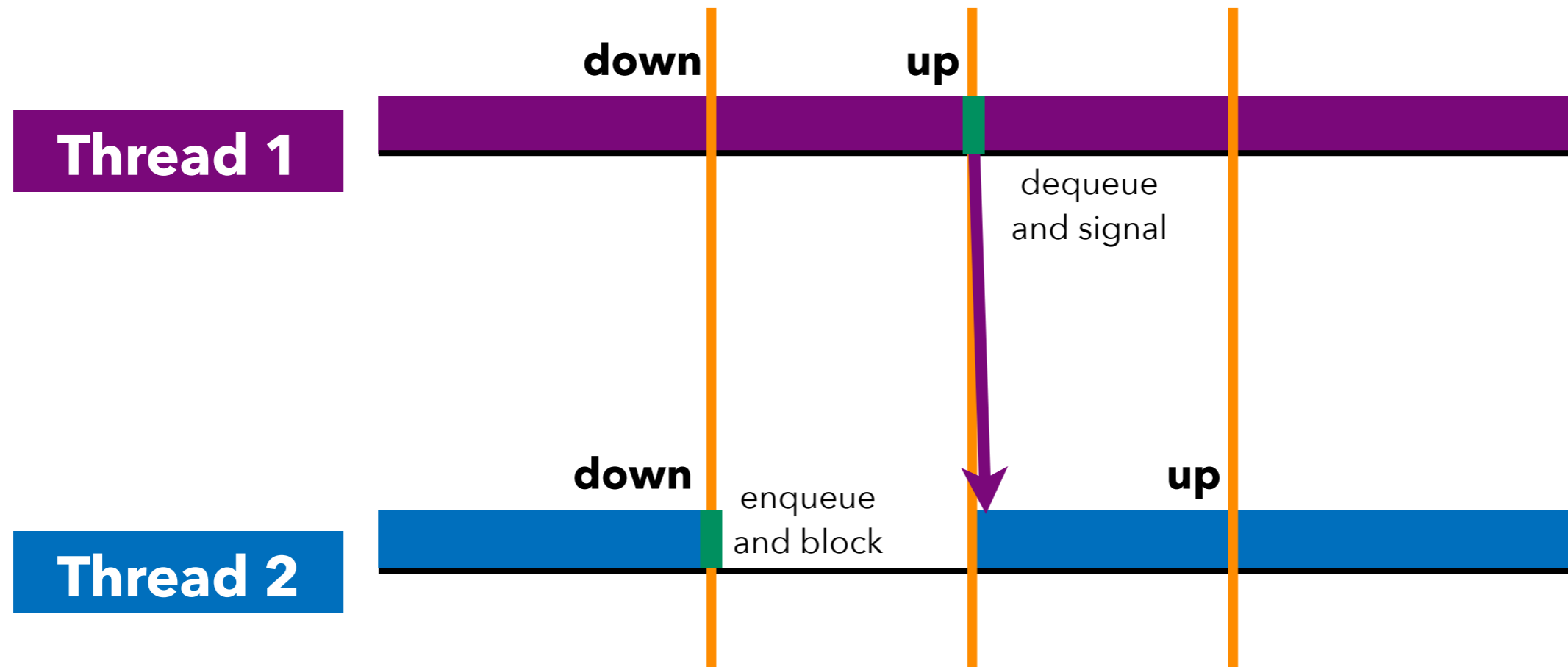
- servers could be malicious, so you need timeouts to get your time back
- now, malicious clients can call the server with a very short timeout
- on what time will the server do cleanup?
- donation does not work across CPUs
  - would thwart admission; one CPU cannot execute on behalf of another
- migrate servers or clients?



# OPTIMIZATION



- IPC only in the contention case
- optimized for low contention
- bad for producer-consumer problems



- reduce from 2 IPCs to one
- how to protect the short critical section?
- spinlocks suffer lockholder preemption

- allow threads to have short periods where they are never preempted
  - like a low cost global system lock
  - like a userland flavor of disabling interrupts
- **delayed preemption**
- threads set "don't preempt" flag in UTCB
  - very low cost
  - not a lock, no lockholder preemption

- unbounded delay
  - kernel honors the delayed preemption flag only for a fixed maximum delay
  - what delay is useful?
- delay affects all threads
  - effect can be limited to a priority band
  - must be included in real-time analysis
- does not work across multiple CPUs

- managing time is necessary
  - we interact with the system based on time
- real-time is a cross-cutting concern
- heavy-math admission in userland,  
simple priorities in the kernel
- priority inheritance by timeslice donation
- synchronisation, delayed preemption
- next week: resource management