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PROBABILISTIC SCHEDULING

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DESKTOP REAL-TIME

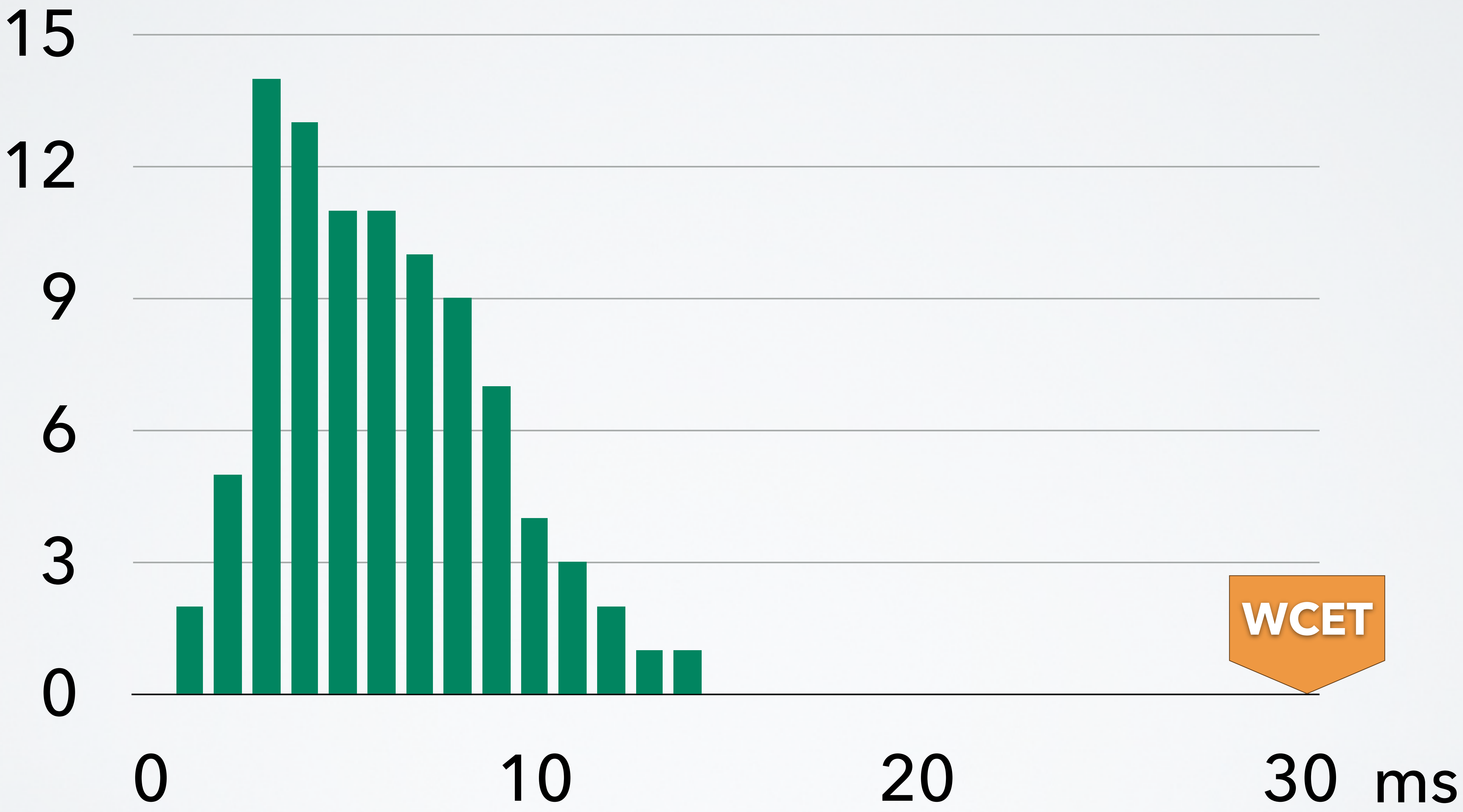
PROBLEM

- 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 scheme

MOTIVATION

- 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

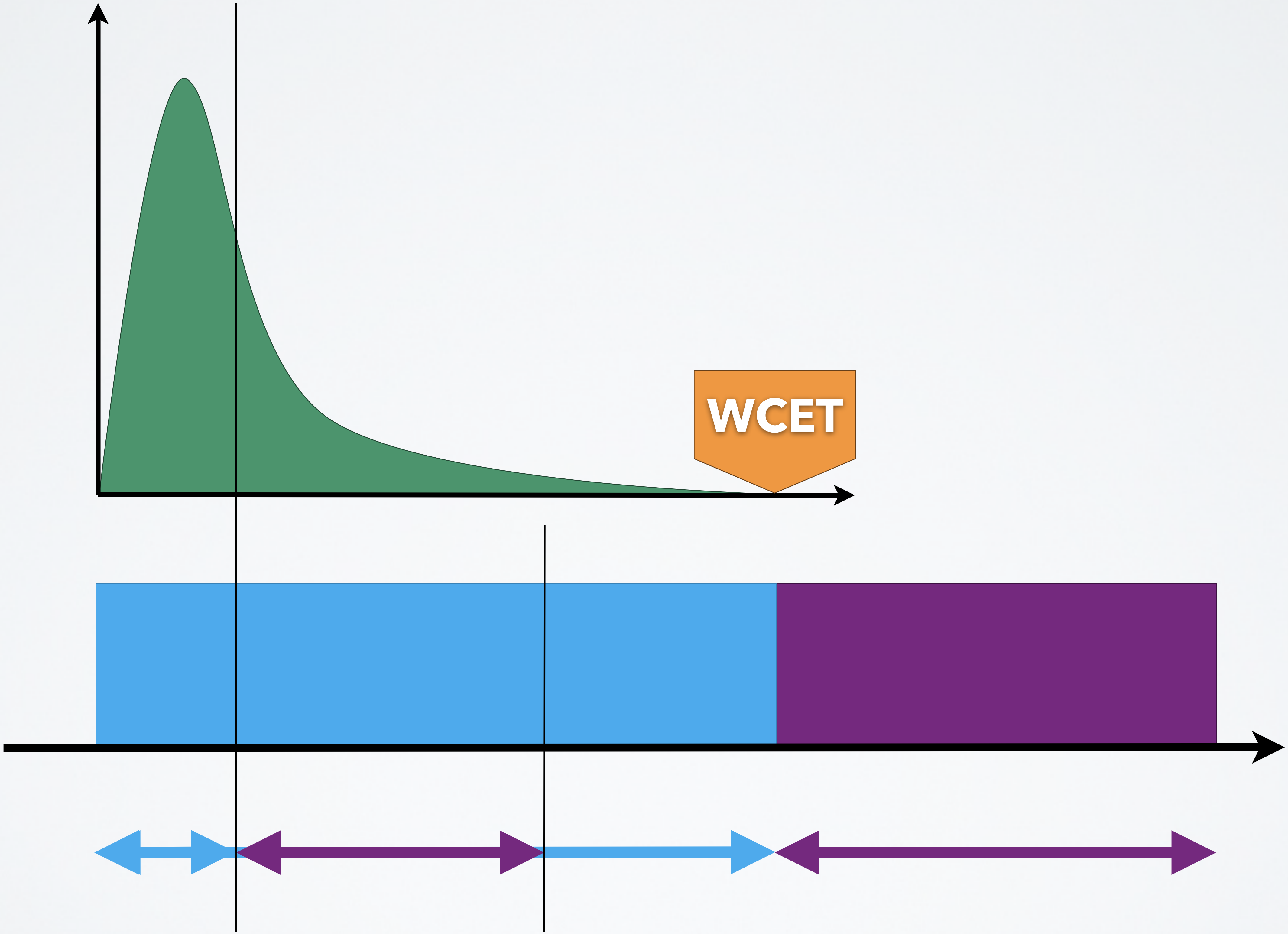
H.264 DECODING



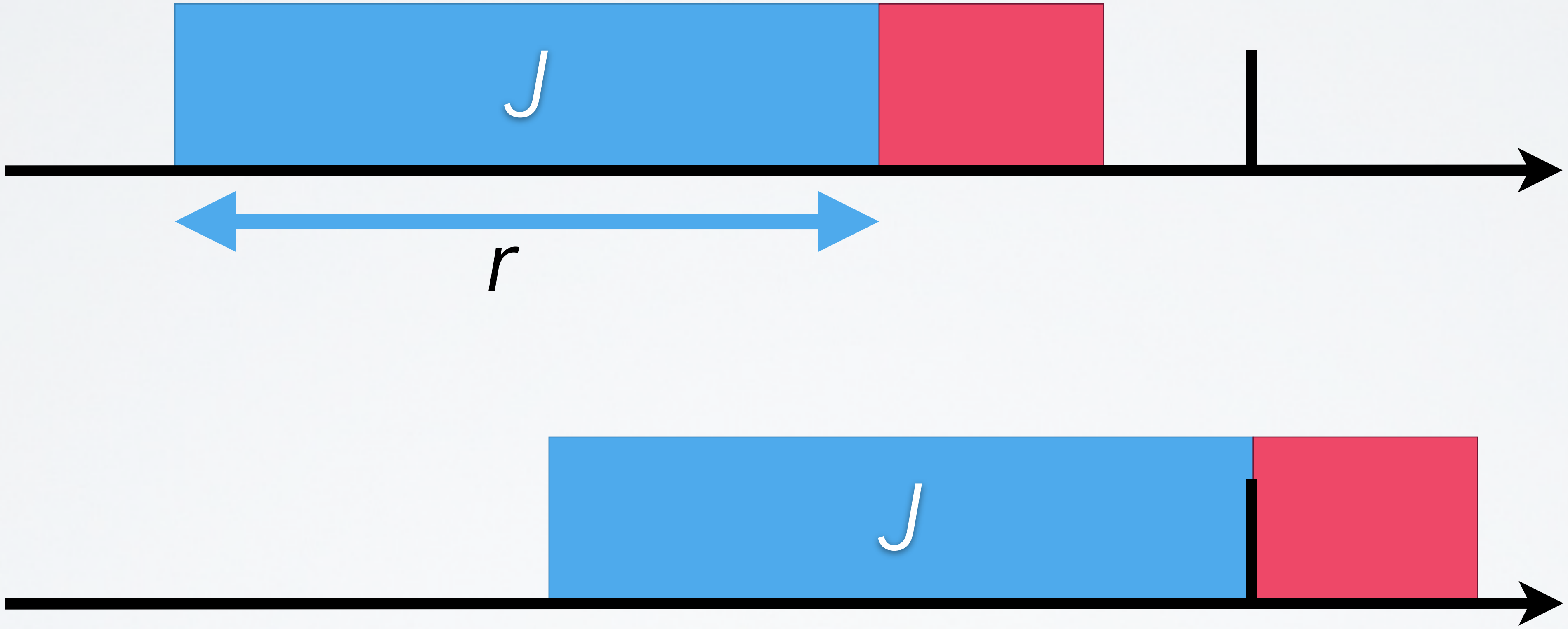
KEY IDEA

- guarantees even slightly below 100% of WCET can dramatically reduce resource allocation
- slack reclaiming: unused reservations will be used by others at runtime
- use probabilistic planning to model the actual execution
- quality q: fraction of deadlines to be met

KEY IDEA



RESERVATION



$$\mathbf{P}(J \text{ does not run longer than } r \wedge \\ J \text{ is completed until its relative deadline}) \geq q$$

RESERVATION

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

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

- to fully understand this: see QRMS paper
- good for microkernel: reservation can be calculated by a userland service
- kernel only needs to support static priorities

BREAKPOINT

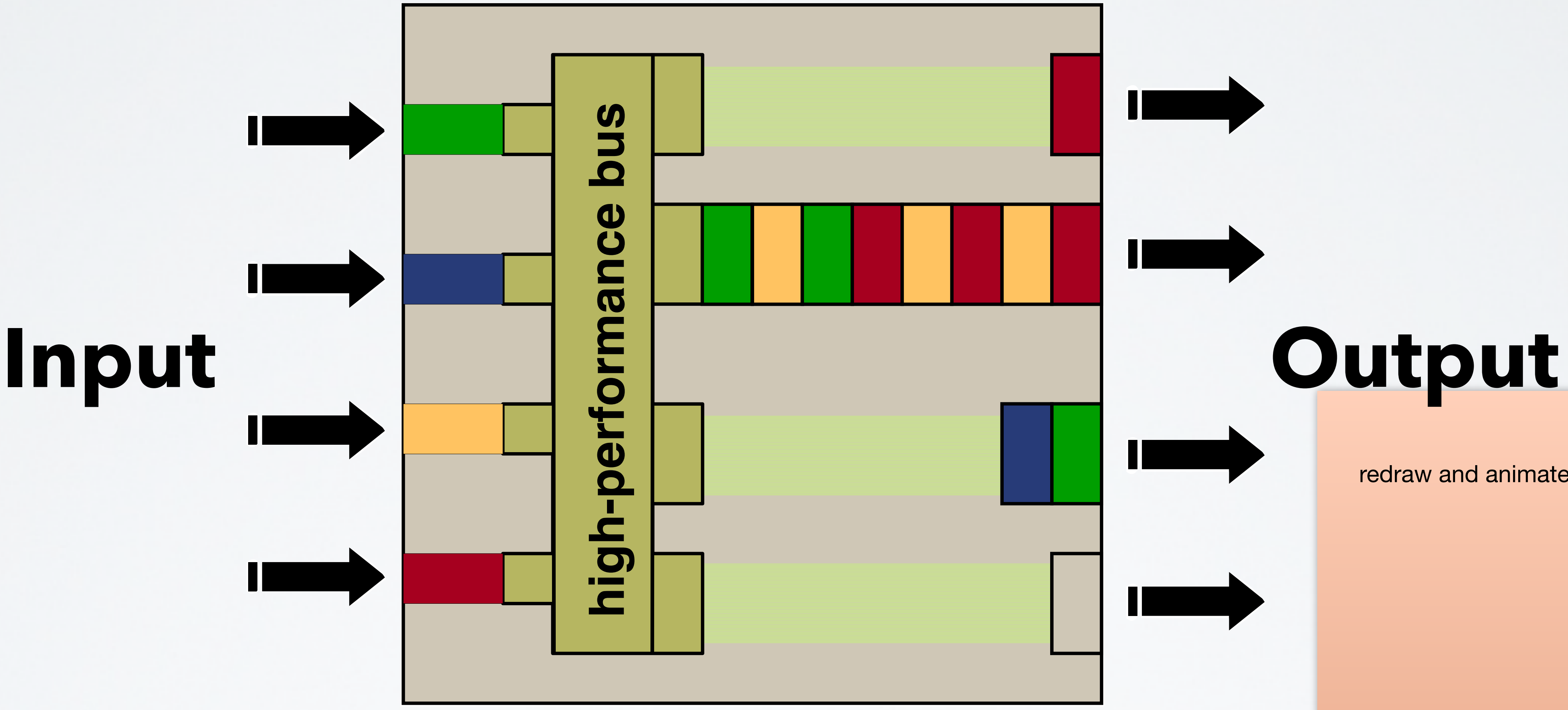
- often research only deals with generic management concepts we just discussed
- drilling down is required for usable systems
- coming up next:
  specific resources in DROPS (aka TUD:OS)
- for each resource we…
  - outline the real-time guarantee
  - sketch an idea for reservation

NETWORK

REAL-TIME

- guaranteed timely communication service
  - lower bound for bandwidth
  - upper bound for latency and jitter
- networks in embedded systems
  - field busses
  - collapsed network stacks
  - bus topology, single broadcast domain
  - example: CAN bus

ETHERNET



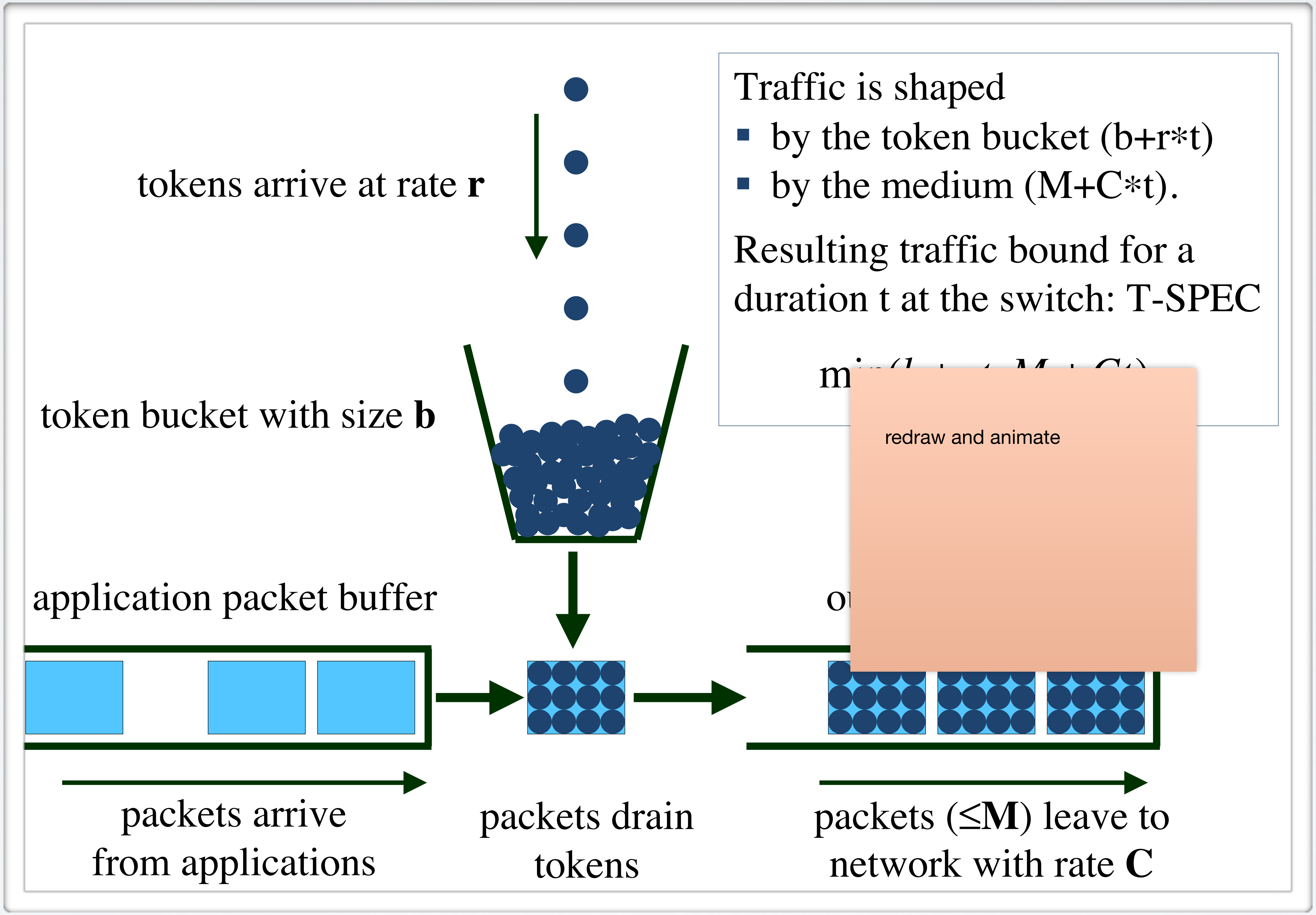
redraw and animate

- switches use buffers on output ports
- delay bound depends on traffic to output
- if queues overflow, frames are dropped

IDEA

- traffic on output ports depends on inbound traffic
- inbound traffic depends on the computers sending to the switch
- shaping the traffic sent by computers helps
  - bounds incoming traffic at the switch
  - bounds the queue length in the switch
  - prevents dropped packets
- network calculus for shaping parameters

TOKEN BUCKET


tokens arrive at rate **r**
token bucket with size **b**
application packet buffer
ou
packets arrive
from applications
packets drain
tokens
packets (≤**M**) leave to
network with rate **C**

Traffic is shaped

- by the token bucket (b+r*t)
- by the medium (M+C*t).

Resulting traffic bound for a duration t at the switch: T-SPEC

$$\min(b + rt, M + Ct)$$

redraw and animate

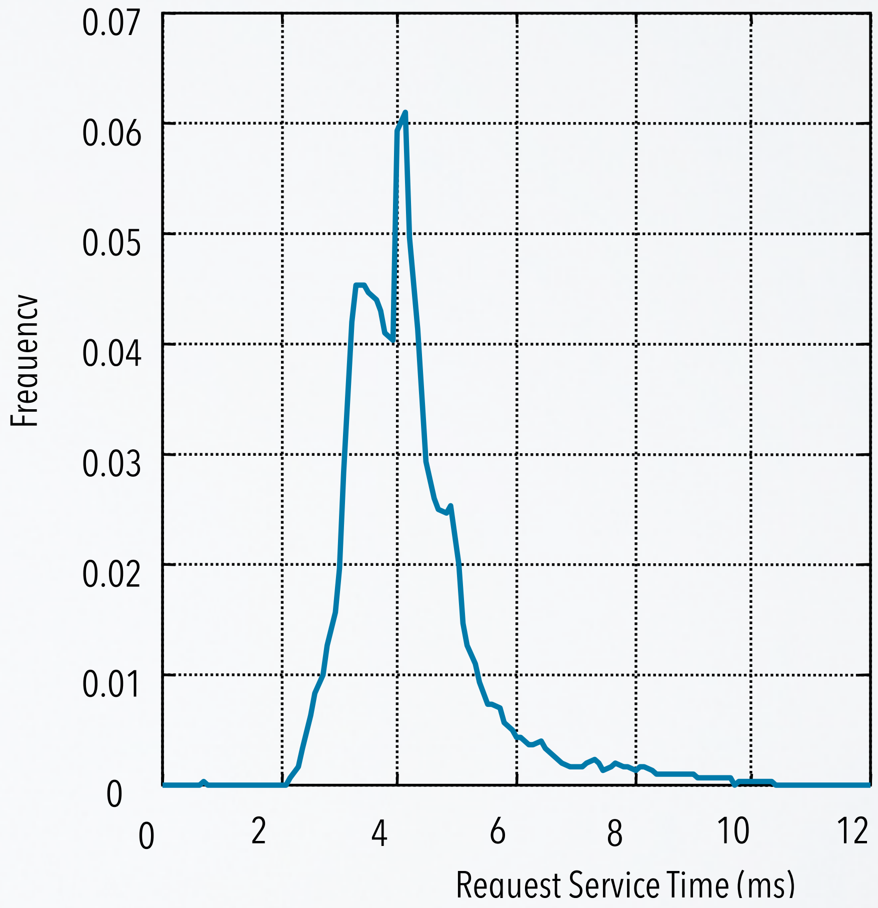
RESULTS

- switch is a shared medium
- all nodes must cooperate for this to work
- worst-case delays ≤ 1ms
- network utilization > 90%
- no node synchronization required
- predictable packet transmission on off-the-shelf switched ethernet
- hard real-time capable

HARD DISK

REAL-TIME

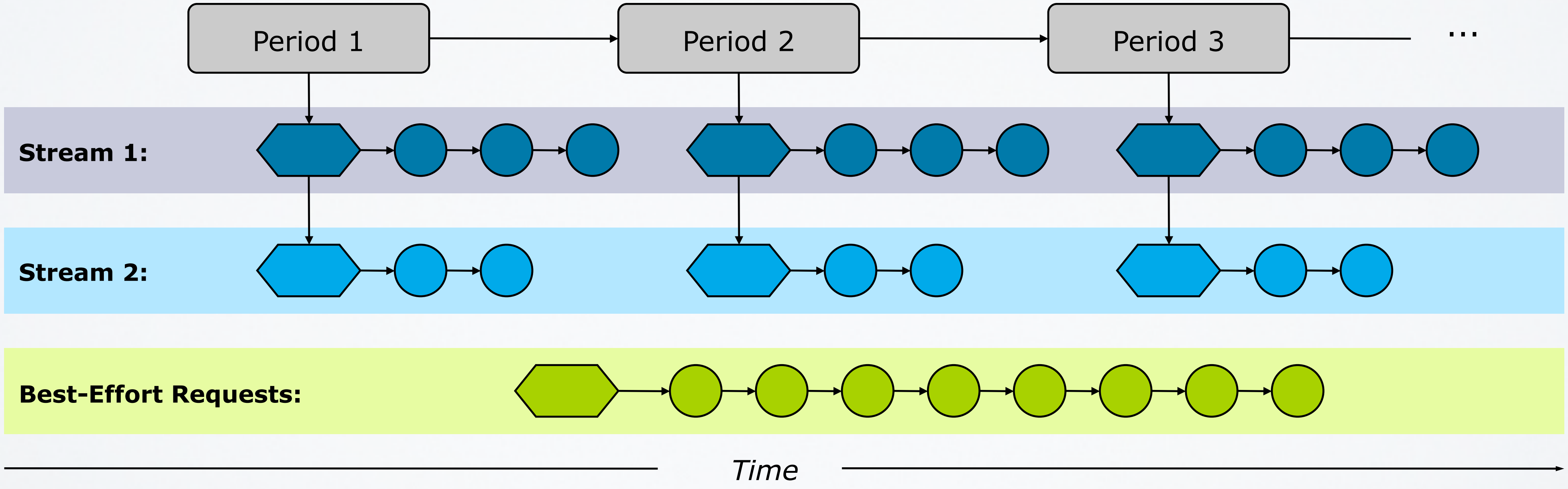
- guaranteed bandwidth of data streams read from / written to disk
- execution times of disk requests vary
  - disk head position
  - rotational delay
- poor ratio between worst and average case
  - average: 4ms
  - worst: 30ms



IDEA

- quality-based probabilistic scheduling
- map disk bandwidth to the periodic execution of disk requests
  - constant number per period
  - fixed request size

redraw



SCHEDULING

- quality parameter: fraction of requests processed on time
- admission control calculates reservation time for each stream
- disk scheduler enforces reservation
    - requests are only executed as long as the reservation is not depleted
    - problem: disk requests cannot be aborted, admission math must deal with this

OPTIMIZE

- scheduler picks requests according to remaining reservation and quality
- not good for disk utilization
- existing non-real-time disk schedulers are much better
  - elevator
  - SATF: shortest access time first

OPTIMIZE

- solution: two level scheduling using Dynamic Active Subset
- first level selects set of disk requests
  - that can be executed in any order
  - while still meeting all guarantees
- this set is then handed to the second level scheduler
  - can execute disk requests in any order
  - any non-real-time scheduler works

GRAPHICS

REAL-TIME

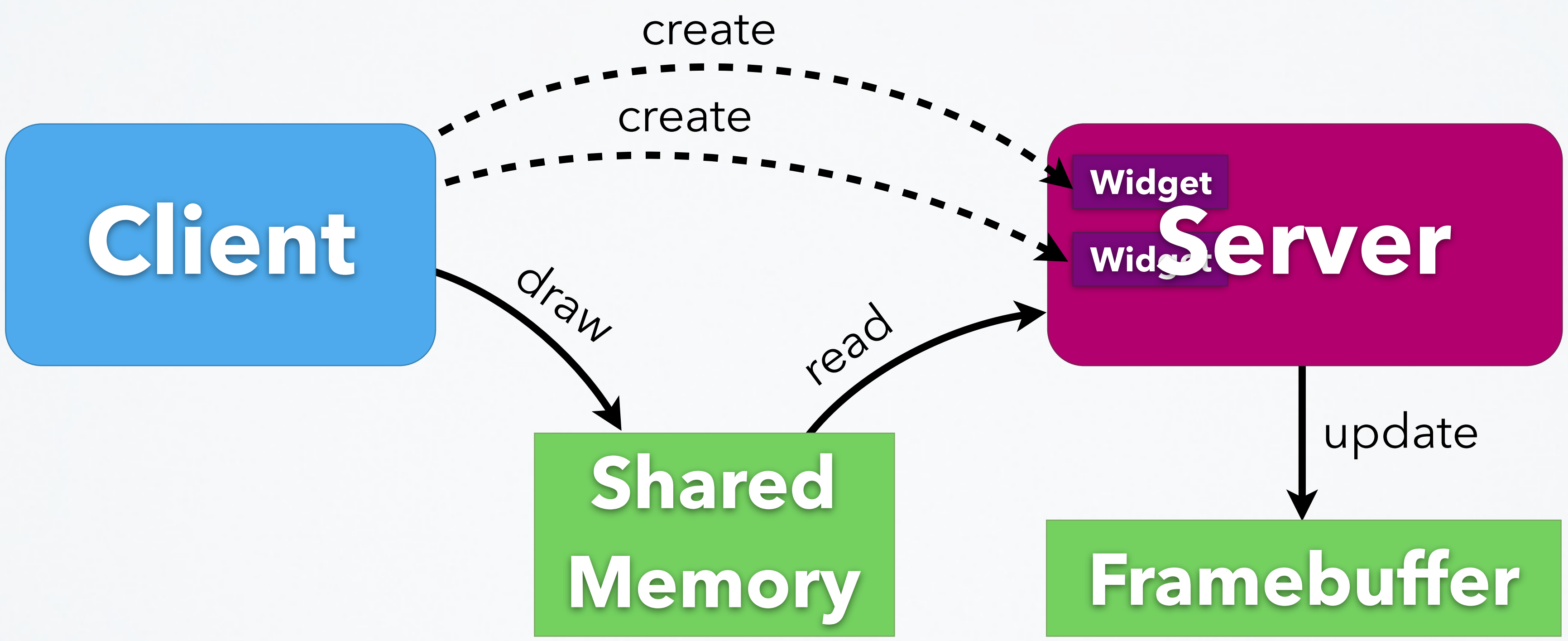
- guaranteed update rates of GUI elements
  - video output, animations
  - periodic jobs
  - known frame rate and drawing time
- support non-real-time applications at the same time
  - unpredictable
  - minimize latency for responsiveness

TRADITION

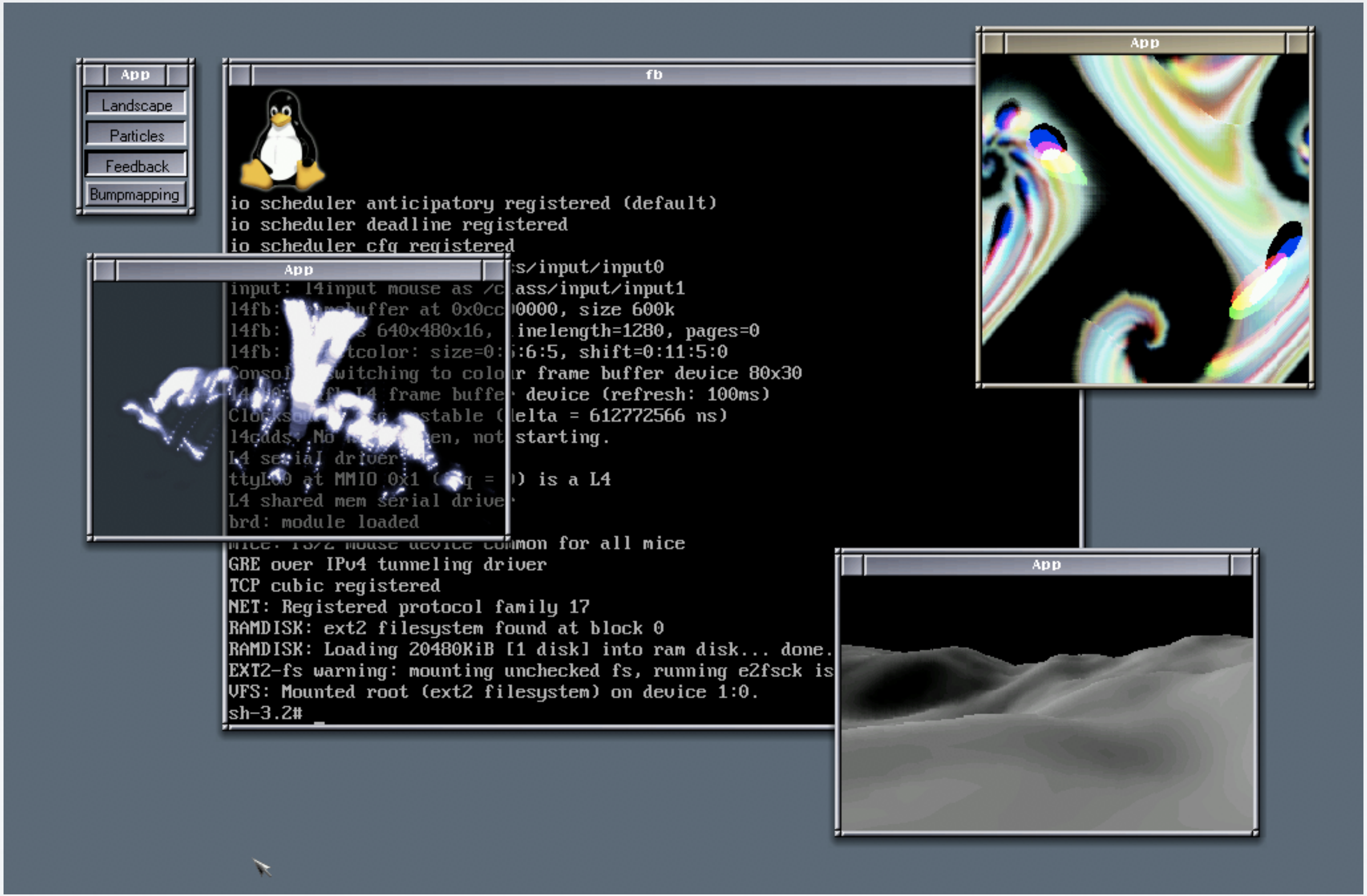
- traditional GUIs implement GUI elements (“widgets”, “controls”) outside the display system
  - as a library in the application
- window system has no global view on objects involved in a redraw
  - cannot predict effects of redraw operations
  - no guarantees

DOPE

- DOpE (Desktop Operating Environment) implements widgets in the window server
  - shared memory buffers for transfer
  - no client interaction for redraw operations



SCREENSHOT



```
io scheduler anticipatory registered (default)
io scheduler deadline registered
io scheduler cfq registered
s/input/input0
input: l4input mouse as /class/input/input1
l4fb: framebuffer at 0x0cc00000, size 600k
l4fb: s 640x480x16, linelength=1280, pages=0
l4fb: tcolor: size=0:5:6:5, shift=0:11:5:0
Console: switching to colour frame buffer device 80x30
l4fb0: l4fb L4 frame buffer device (refresh: 100ms)
Clocksource tsc unstable (delta = 612772566 ns)
l4cdds: No [illegible]en, not starting.
L4 serial driver
ttyLv0 at MMIO 0x1 (irq = 0) is a L4
L4 shared mem serial driver
brd: module loaded
mice: PS/2 mouse device common for all mice
GRE over IPv4 tunneling driver
TCP cubic registered
NET: Registered protocol family 17
RAMDISK: ext2 filesystem found at block 0
RAMDISK: Loading 20480KiB [1 disk] into ram disk... done.
EXT2-fs warning: mounting unchecked fs, running e2fsck is
VFS: Mounted root (ext2 filesystem) on device 1:0.
sh-3.2# _
```

SCHEDULING

- processing time for redraw correlates with pixels to be carried over the bus
- DOpE reserves fixed CPU shares
- reservation is used to locally schedule redraw operations
    - periodic scheduling of real-time redraws
    - remaining time used for non-real-time drawing

SCHEDULING

- split complex non-real-time redraws
- outstanding redraws can be merged
  - maximum queue length for outstanding redraws is bounded by the screen pixels
  - bounded latency for all graphical output, even for non-real-time applications
- guaranteed response time to user input

TRENDS

- bus-bandwidth-scheduling only sufficient for software drawing
- today: compositing window managers
- GPU is becoming an essential co-processor
  - needs to be scheduled (like a CPU?)
  - access must be governed
- current hardware not well suited
  - no paging in graphics memory (no MMU!)

SUMMARY

- probabilistic scheduling
- real-time views for specific devices
  - network
  - disk
  - graphics