INF5071 – Performance in Distributed Systems

Server Resources:

Server Examples, Resources and CPU Scheduling

September 10, 2010

Motivation

- In a distributed system, the performance of every single machine is important
  - poor performance of one single node might be sufficient to "kill" the system (not better than the weakest)

- Managing the server side machines are challenging
  - a large number of concurrent clients
  - shared, limited amount of resources
  - strict bandwidth and latency requirements

- We will see examples where simple, small changes improve performance
  - decrease the required number of machines
  - increase the number of concurrent clients
  - improve resource utilization
  - enable timely delivery of data

Overview

- Server examples
- Resources, real-time, “continuous” media streams, …
- (CPU) Scheduling
- Next time, memory and storage

Server Examples

(Video) Server Product Examples

1) Real server, VXtreme, Starlight, Netscape Media Server,
MS MediaServer, Apple Darwin, Move Networks, MS Smooth Streaming …

user level server
standard OS
all standard HW

RTSP
RTP
HTTP

2) IBM Mediastreamer,
Oracle Video Cartridge, N-Cube,…

user level layer
scalable, RT-aware OS, RT OS, or OS derivation
custom/special HW

DSM CC, private
ATM, analog, …

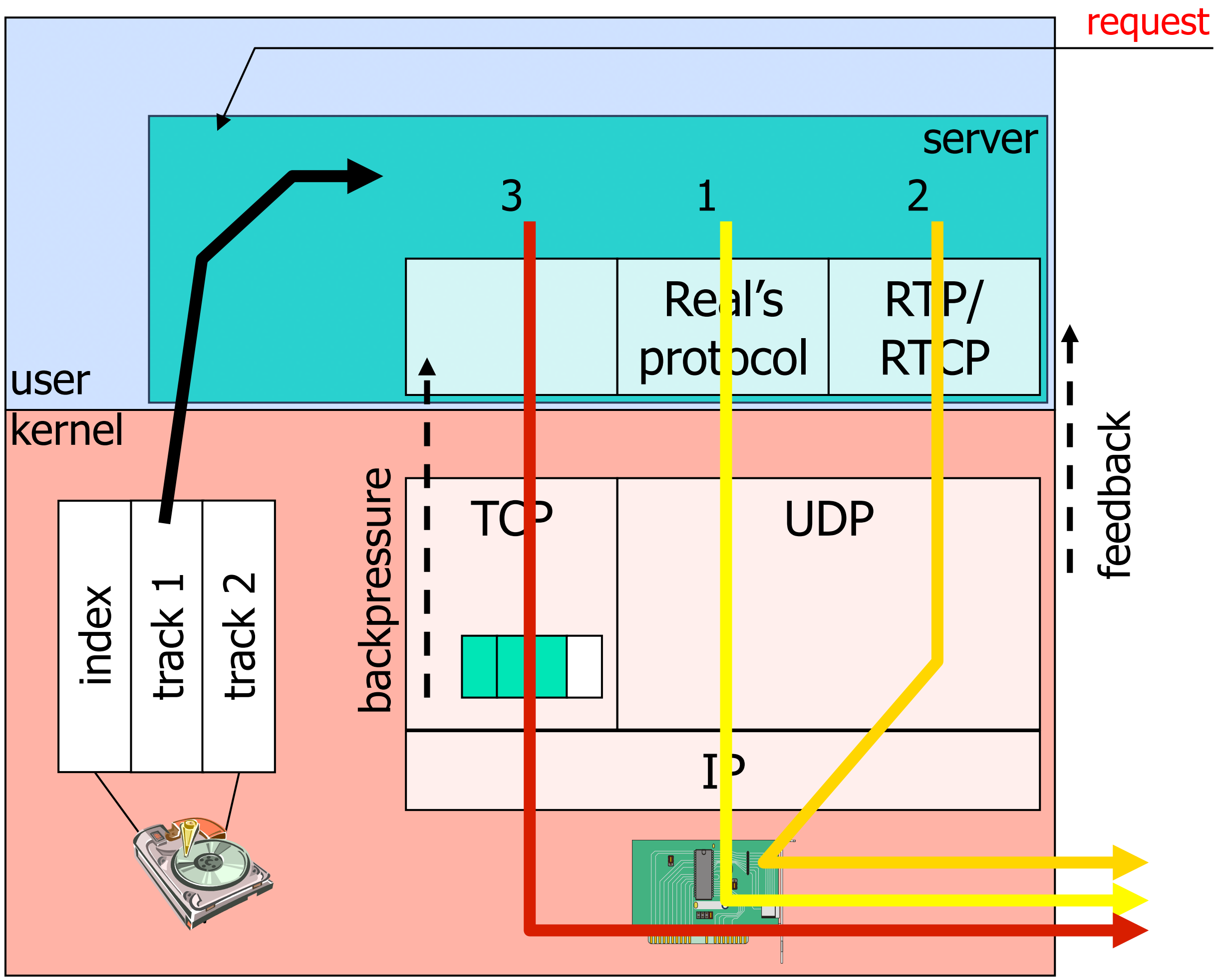
3) SGI/Kassena Media Base,
SUN Media Center,
IBM VideoCharger, …

user level server		
MM FS	standard OS	RT extensions
selected standard HW		

RTSP
RTP

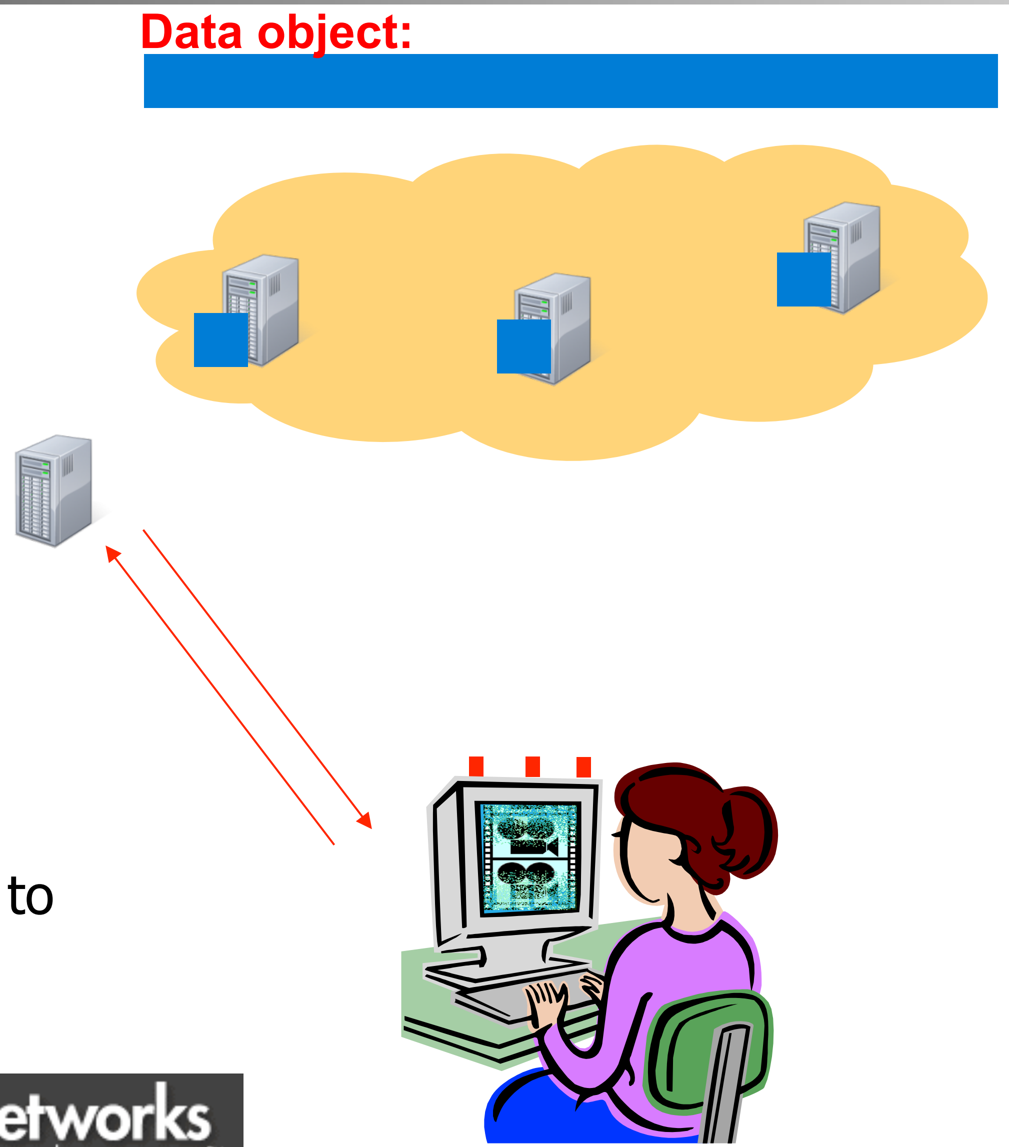
Real Server

- User space implementation
  - one control server
  - several protocols
  - several versions of data in same file
  - adapts to resources
- Several formats, e.g.,
  - Real's own
  - MPEG-2 version with "stream thinning" (dropped with REAL ①)
  - MPEG4, QT, …
- Does not support
  - Quality-of-Service
  - load leveling



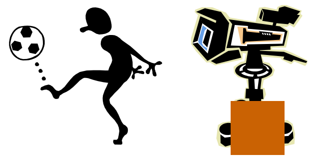
Torrent-like HTTP streaming

- For load-balancing and scaling multiple servers, taking the best from several worlds….
- Downloads segments
- Tracker manages information about segment locations
- The user contacts the tracker for segment locations
- Users send **HTTP GET requests** to download **video segments**

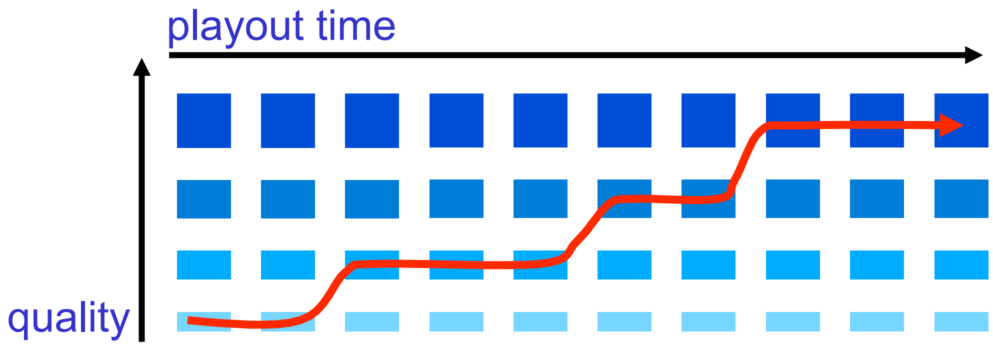


Torrent-like HTTP streaming

- Move use
  2 second segments
  - coded in on2`s VP7 (but other formats could be used)
  - a 2-hour move contains 3600 segments



- To support adaptation to available resources, each segment is coded in many quality levels



IBM VideoCharger

"IBM® Content Manager VideoCharger delivers high-quality audio and video streams over corporate intranet or the Internet.

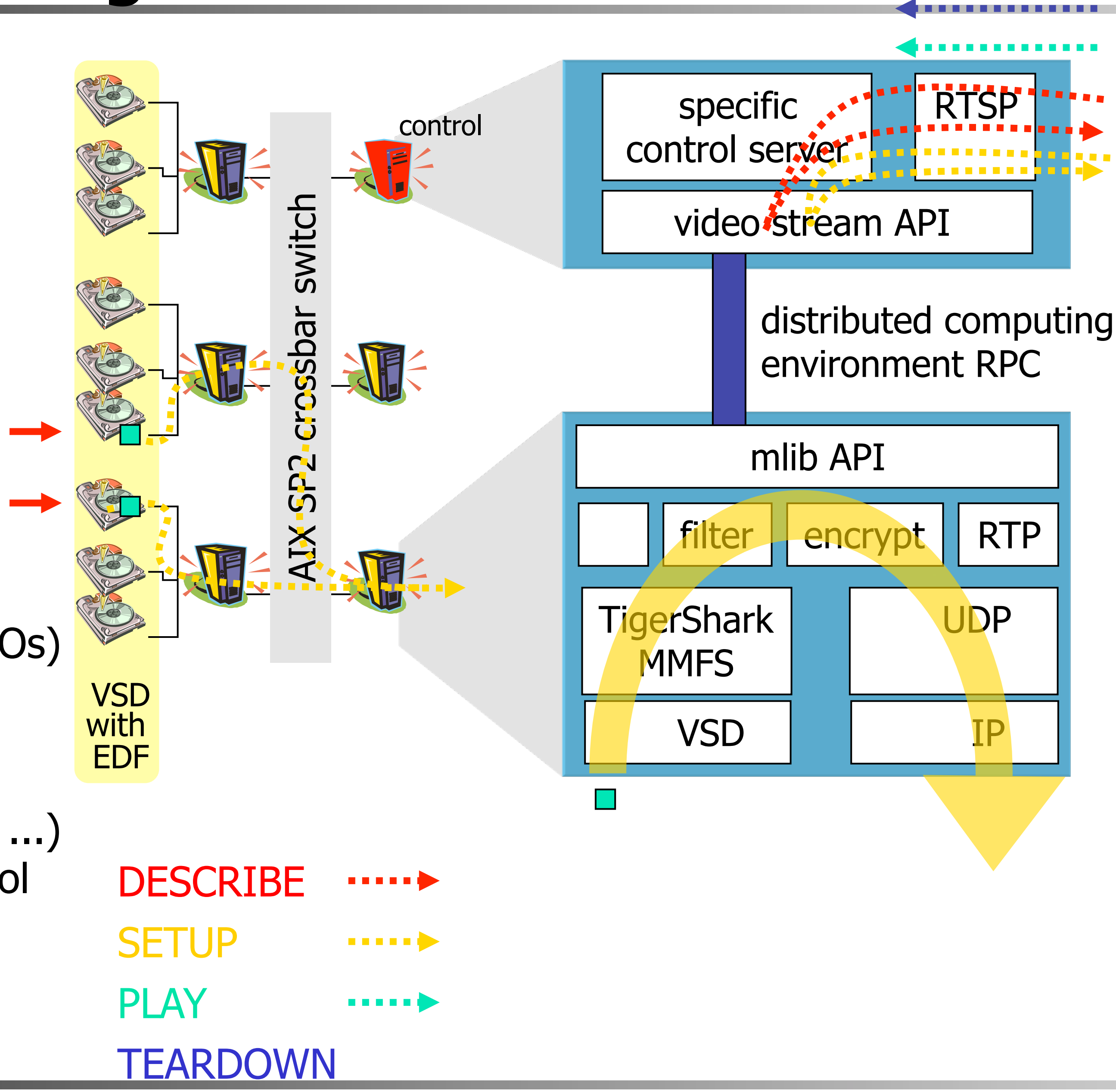
It provides users the latest standard formats, including MPEG-4 and Apple QuickTime 6, and does not require that the file be downloaded or saved before being played.

Effective 07/15/09,
IBM **withdrew** Content Manager VideoCharger from marketing."

http://www-01.ibm.com/software/data/videocharger/

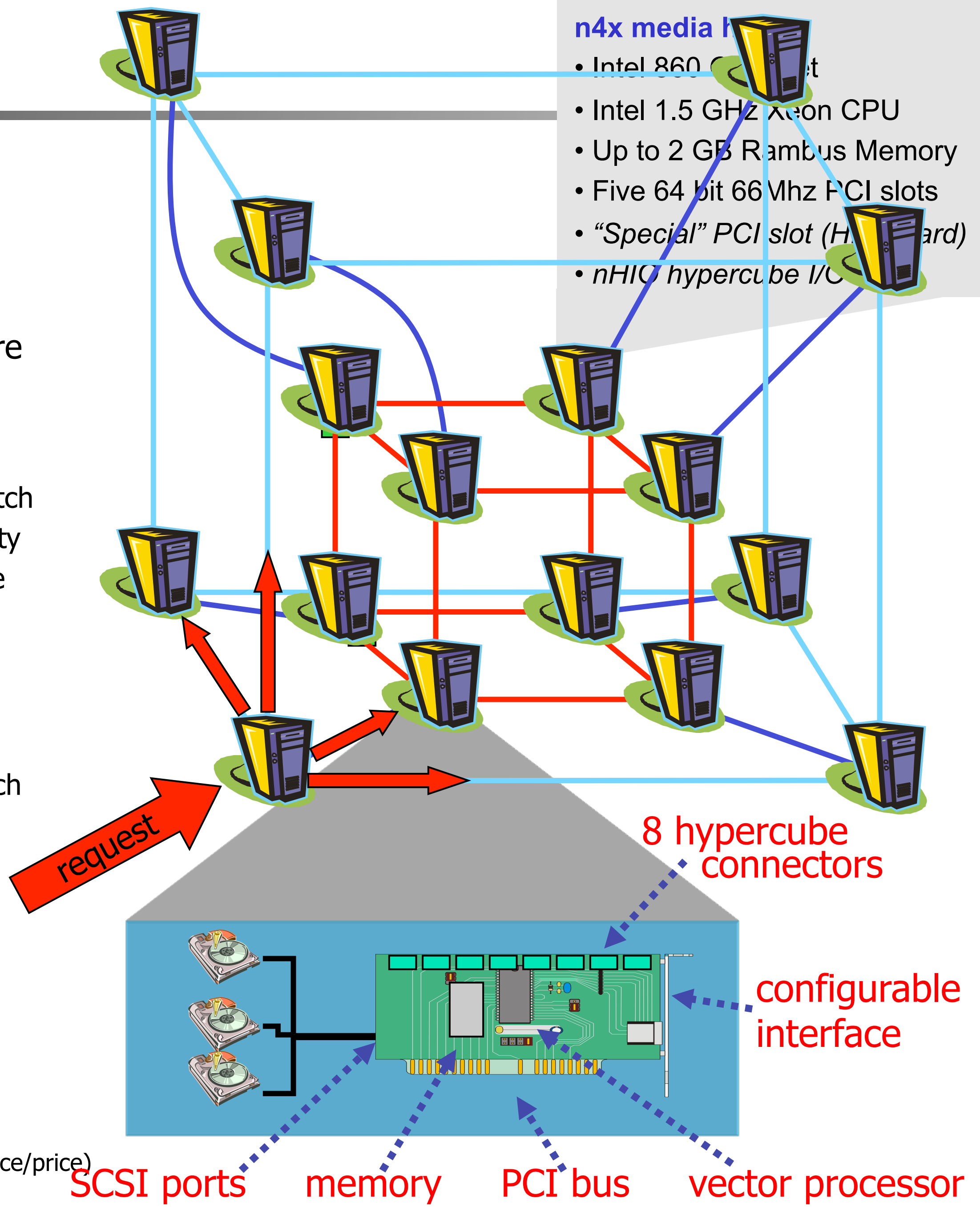
IBM VideoCharger

- May consist of one machine only, or …
- … several Advanced Interactive eXecutive (AIX) machines
- Servers
  - control
  - data
- Lightly modified existing components
  - OS AIX4/5L
  - virtual shared disks (guaranteed disk I/Os)
- Special components
  - TigerShark MMFS (buffers, data rate, prefetching, codec, ...)
  - stream filters, control server, APIs, …



nCUBE

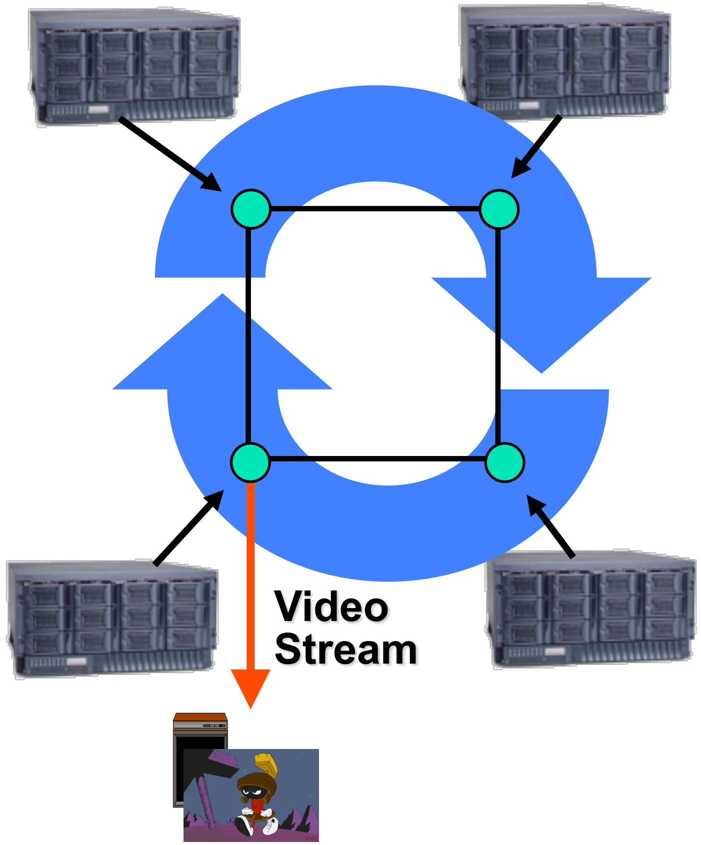
- Original research from Cal Tech/Intel ('83)
- Bought by C-COR in Jan. 05 (~90M$)
- One server scales from 1 to 256 machines, 2^n, $n \in [0, 8]$, using a *hypercube* architecture
- Why a hypercube?
  - video streaming is a switching problem
  - hypercube is a high performance scalable switch
  - no content replication and true linear scalability
  - integrated adaptive routing provides resilience
- Highlights
  - scales from 5,000 to 500,000 clients
  - exceeds 60,000 simultaneous streams
  - 6,600 simultaneous streams at 2 - 4 Mbps each (26 streams per machine if n = 8)
- Special components
  - boards with integrated components
  - TRANSIT operating system
  - n4 HAVOC (1999)
    - Hypercube And Vector Operations Controller
    - ASIC-based hypercube technology
  - n4x nHIO (2002)
    - nCUBE Hypercube I/O controller (8X performance/price)



nCUBE: Naturally load-balanced

- Disks connected to All MediaHubs
  - Each title striped across all MediaHUBs
  - Streaming Hub reads content from all disks in the video server
- Automatic load balancing
  - Immune to content usage pattern
  - Same load if same or different title
  - Each stream's load spread over all nodes
- RAID Sets distributed across MediaHubs
  - Immune to a MediaHUB failure
  - Increasing reliability
- Only 1 copy of each title ever needed
  - Lots of room for expanded content, network-based PVR or HDTV content

Content striped across all disks in the n4x server

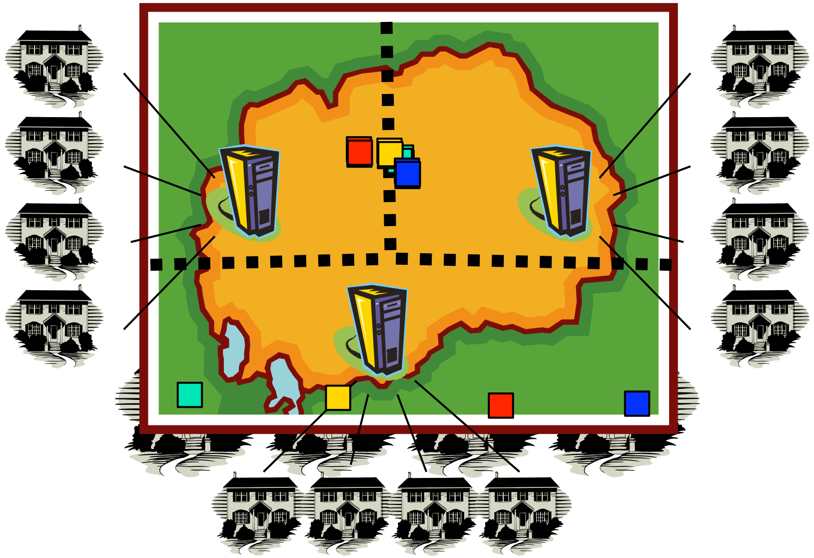


Small Video Server Comparison

Real, Move,…	VideoCharger	nCUBE
standard HW	selected HW	special HW
each machine its own storage, or NFS	shared disk access, replication for load leveling and fault tolerance	shared disk access, no replication
single OS image	cluster machines using switch	cluster machines using wired cube
user space server	user space server and loadable kernel modules	server in both kernel and user space
available and frequently used	still available, but withdrawn from marketing june 2009	????

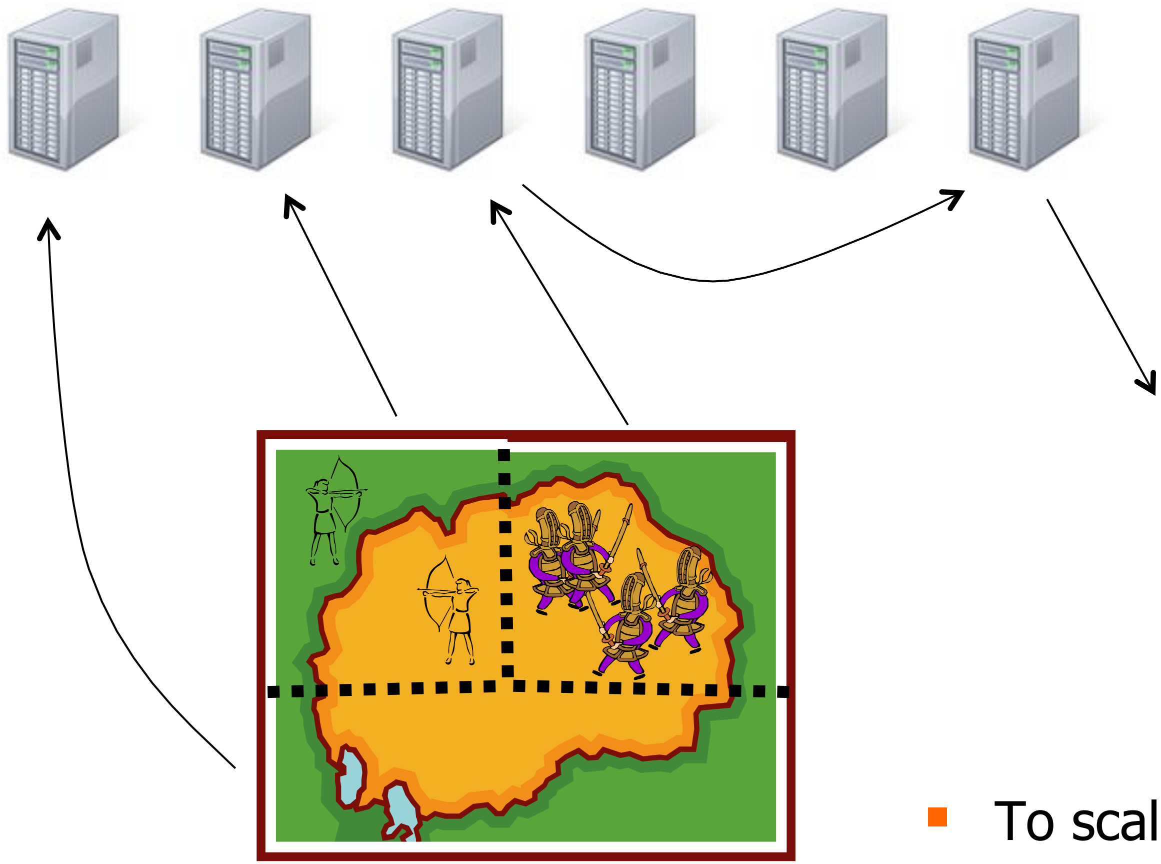
Funcom's Anarchy Online

- World-wide **massive multiplayer online roleplaying game**
  - client-server
    - point-to-point TCP connections



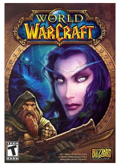
    - virtual world divided into many regions
    - one or more regions are managed by one machine

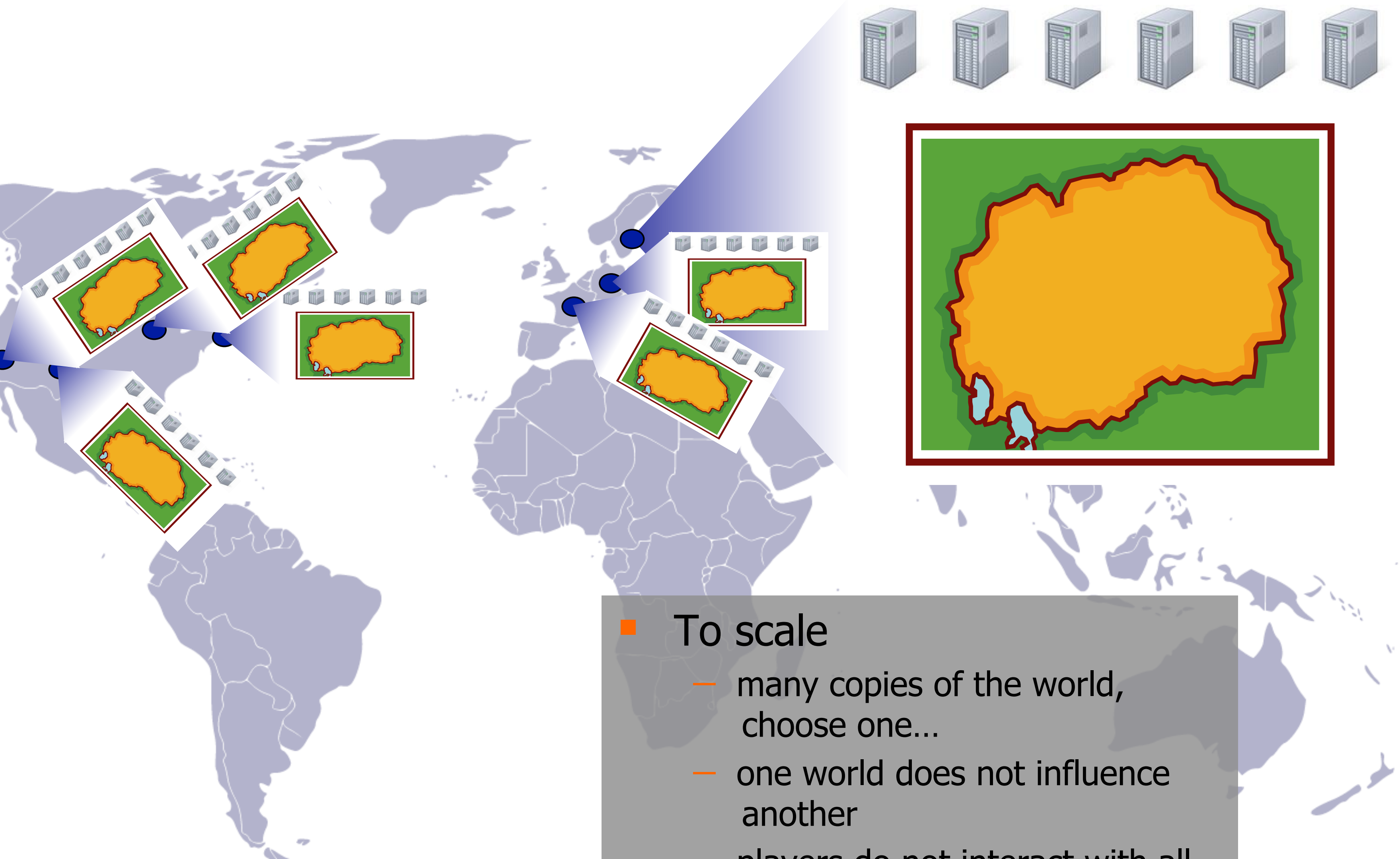
Funcom's Anarchy Online



- To scale, a new instance of a region may be created
  - players do not interact with all other players – only a subset
  - dynamic region-of-interest

Blizzard: World of Warcraft



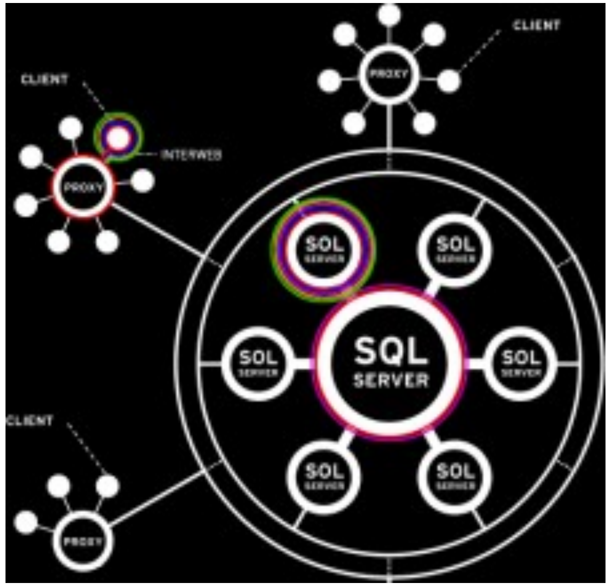


- To scale
  - many copies of the world, choose one…
  - one world does not influence another
  - players do not interact with all other players – only a subset

EVE online

- One SINGLE, SHARED world
- Client-server model with proxies

- 300.000 users, 56.000 concurrent
  - 150.000 *database* entries per day
  - 400.000 random I/O per second



☺ everyone in the same (virtual) location can interact

☹ large lags in popular areas

☹ have had player limitations in popular areas

☹ couple incidents of memory problems

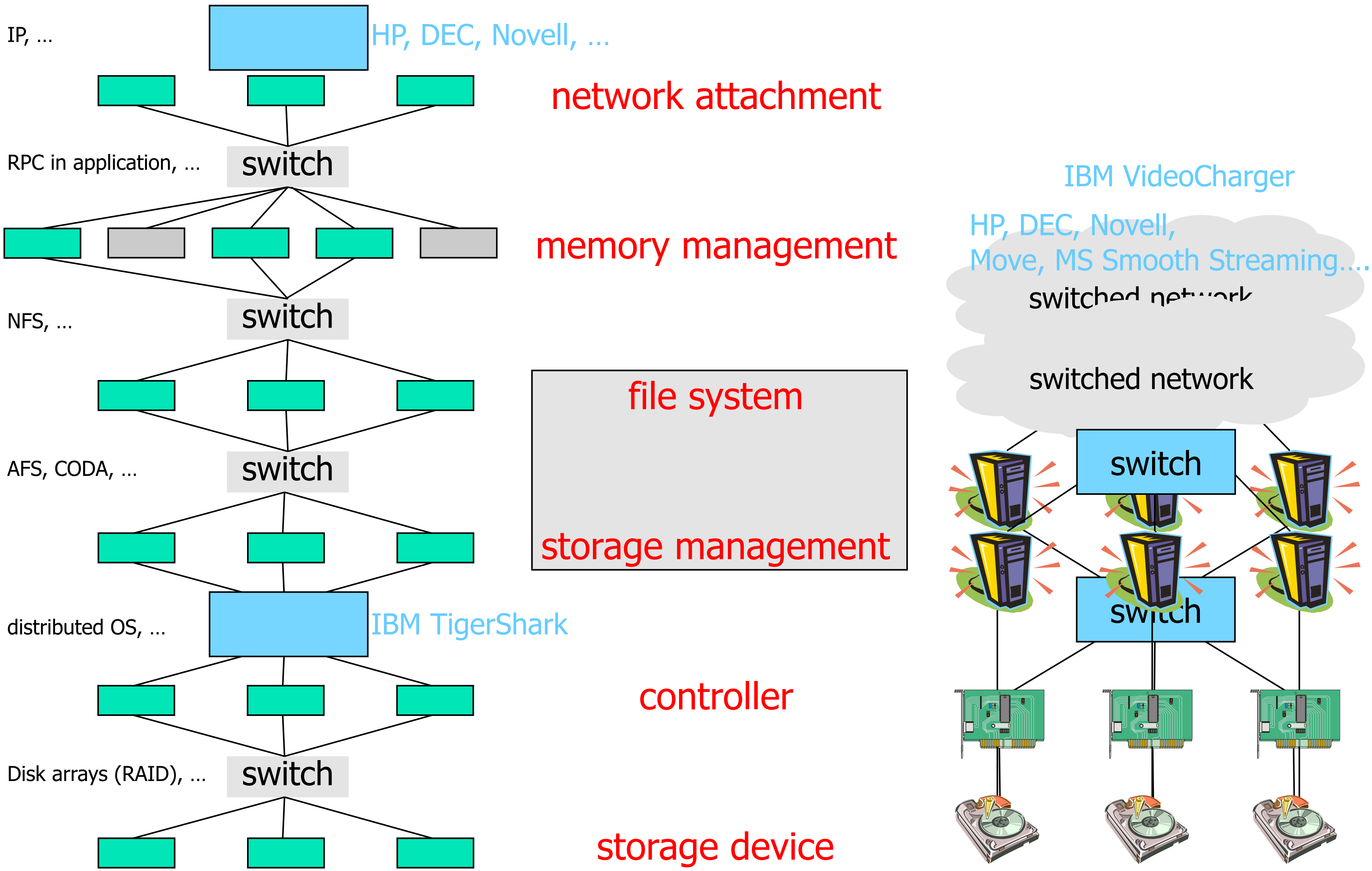
Small Comparison: Video vs. Games

Video	Games
Many users, lots of hardware	
few (VCR) interactions	highly interactive
replication possible	replication changes user perception
high bandwidth per stream	hardly any bandwidth per stream
Bottleneck: I/O bandwidth	Bottleneck: computation
Hardware: special or standard	Hardware: standard
OS: special or standard	OS: standard

Server Structures

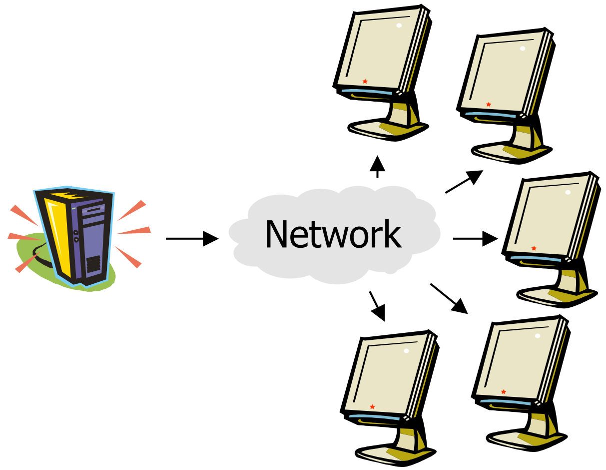
(Video) Server Components & Switches

[Tetzlaff & Flynn 94]

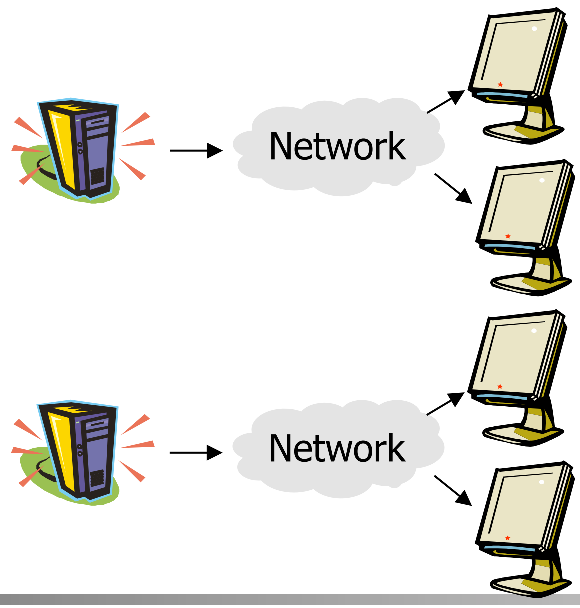


Server Topology – I

- Single server
  - easy to implement
  - scales poorly

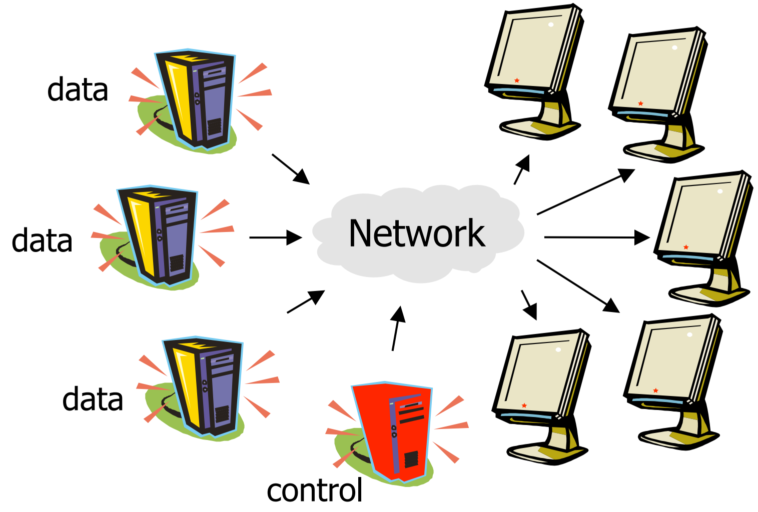


- Partitioned server
  - users divided into groups
  - *content* : assumes equal groups
  - *location* : store all data on all servers
  - load imbalance

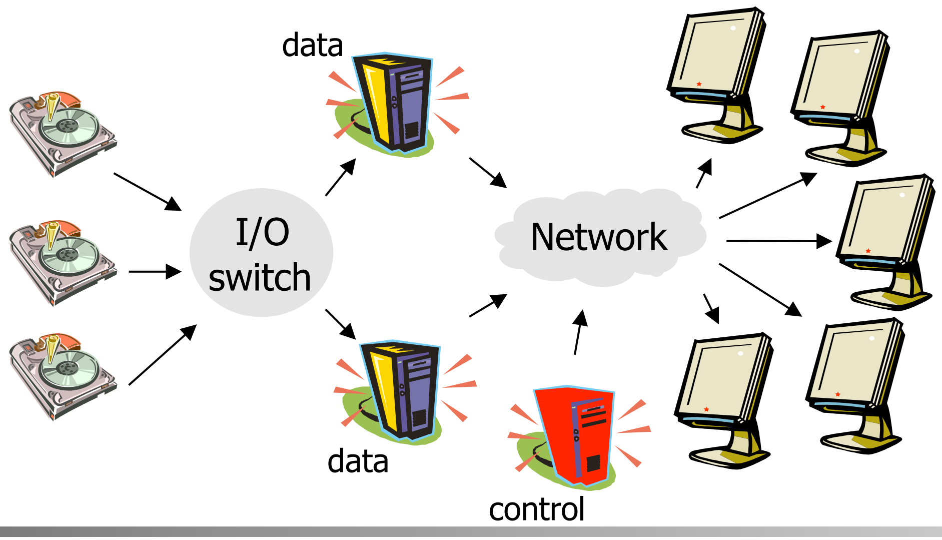


Server Topology – II

- Externally switched servers
  - use network to make server pool
  - manages load imbalance (control server directs requests)
  - still data replication problems
  - (control server doesn't need to be a physical box - distributed process)
  - include also P2P and hierarchical structure

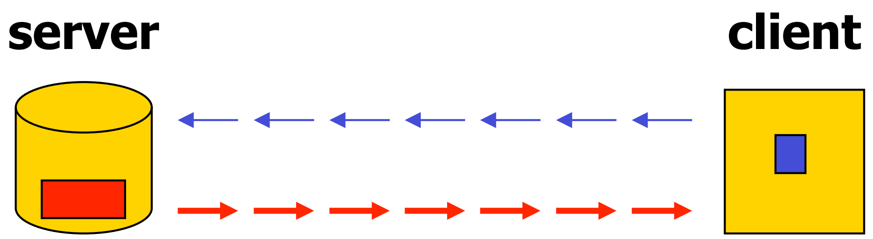


- "Fully" switched server
  - server pool
  - storage device pool
  - additional hardware costs
  - e.g., Oracle, Intel, IBM

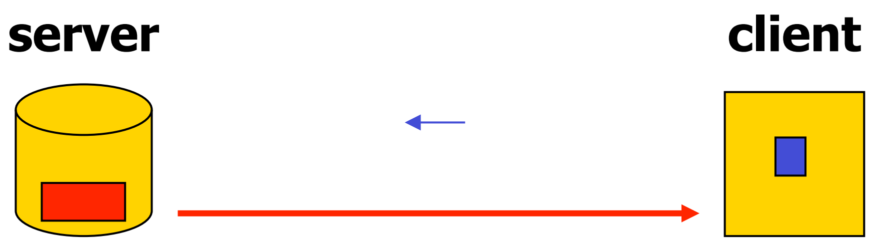


Data Retrieval

- Pull model:
  - client sends several requests
  - deliver only small part of data
  - fine-grained client control
  - favors high interactivity
  - suited for editing, searching, etc.



- Push model
  - client sends *one* request
  - streaming delivery
  - favors capacity planning
  - suited for retrieval, download, playback, etc.



Resources and Real-Time

Resources

- Resource:
  "A resource is a system entity required by a task for manipulating data"
  [Steimetz & Nahrstedt 95]

- Characteristics:
  - active: provides a service,
    e.g., CPU, disk or network adapter
  - passive: system capabilities required by active resources,
    e.g., memory

  - exclusive: only one process at a time can use it,
    e.g., CPU
  - shared: can be used by several concurrent processed,
    e.g., memory

Deadlines and Real-Time

- Deadline:
  "A deadline represents the latest acceptable time for the presentation of the processing result"

  - Hard deadlines:
    - must never be violated → system failure

  - Soft deadlines:
    - in some cases, the deadline might be missed, but …
      - not too frequently
      - not by much time
    - result still may have some (but decreasing) value

- Real-time process:
  "A process which delivers the results of the processing in a given time-span"

- Real-time system:
  "A system in which the correctness of a computation depends not only on obtaining the result, but also upon providing the result on time"

Admission and Reservation

- To prevent overload, admission may be performed:
  - schedulability test:
    - "are there enough resources available for a new stream?"
    - "can we find a schedule for the new task without disturbing the existing workload?"
    - a task is allowed if the utilization remains < 1

  ⇨ yes – allow new task, allocate/reserve resources

  ⇨ no – reject

- Resource reservation is analogous to booking (asking for resources)
  - pessimistic
    - avoid resource conflicts making worst-case reservations
    - potentially under-utilized resources
    - guaranteed QoS
  - optimistic
    - reserve according to average load
    - high utilization
    - overload may occur
  - "perfect"
    - must have detailed knowledge about resource requirements of all processes
    - too expensive to make/takes much time

Real-Time Support

- The operating system manages **local** resources (CPU, memory, disk, network card, busses, ...)

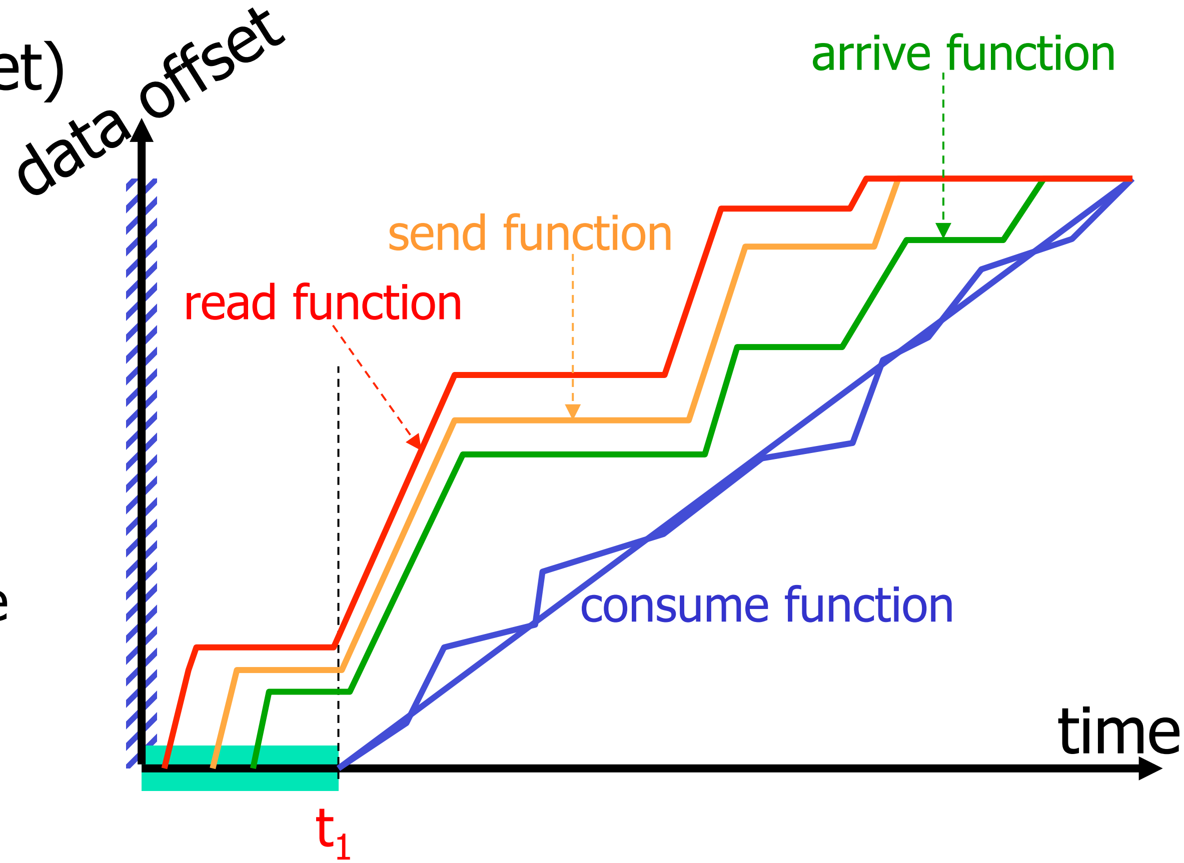
- In a real-time scenario, support is needed for
  - timely processing
  - high-rate, timely I/O

- This means support for proper …
  - *scheduling* – high priorities for time-restrictive tasks
  - *timer support* – clock with fine granularity and event scheduling with high accuracy
  - *kernel preemption* – avoid long periods where low priority processes cannot be interrupted
  - *efficient memory management* – prevent code and data for real-time programs from being paged out (replacement)
  - *fast switching* – both interrupts and context switches should be fast

Timeliness

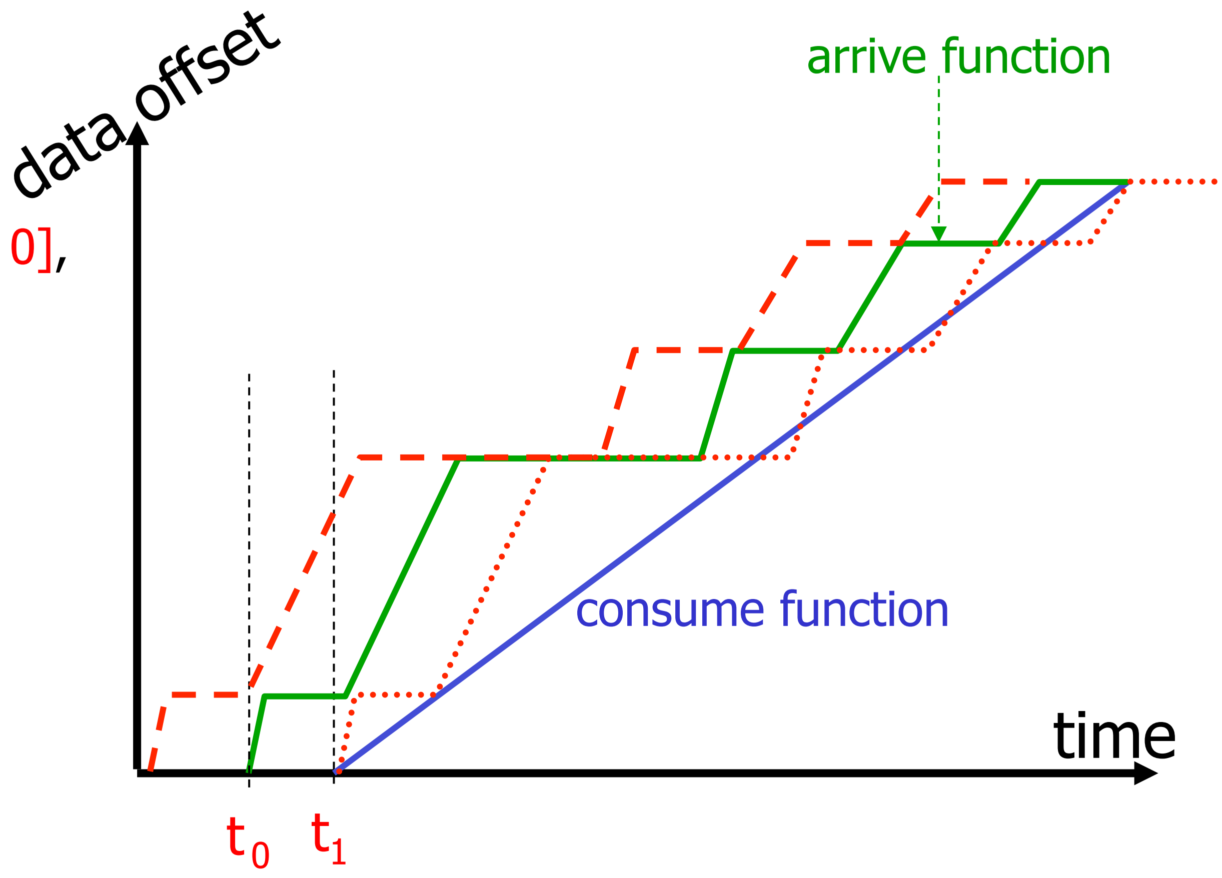
Timeliness: Streaming

- Start presenting data (e.g., video playout) at t_1
- Consumed bytes (offset)
  - variable rate
  - constant rate
- Must start retrieving data earlier
  - Data must arrive before consumption time
  - Data must be sent before arrival time
  - Data must be read from disk before sending time



Timeliness: Streaming

- Need buffers to hold data between the functions, e.g., client $B(t) = A(t) - C(t)$, i.e., $\forall\, t : A(t) \geq C(t)$
- Latest start of data arrival is given by $\min[B(t,t_0,t_1)\ ;\ \forall\, t\ B(t,t_0,t_1) \geq 0]$, i.e., the buffer must at all times **t** have more data to consume



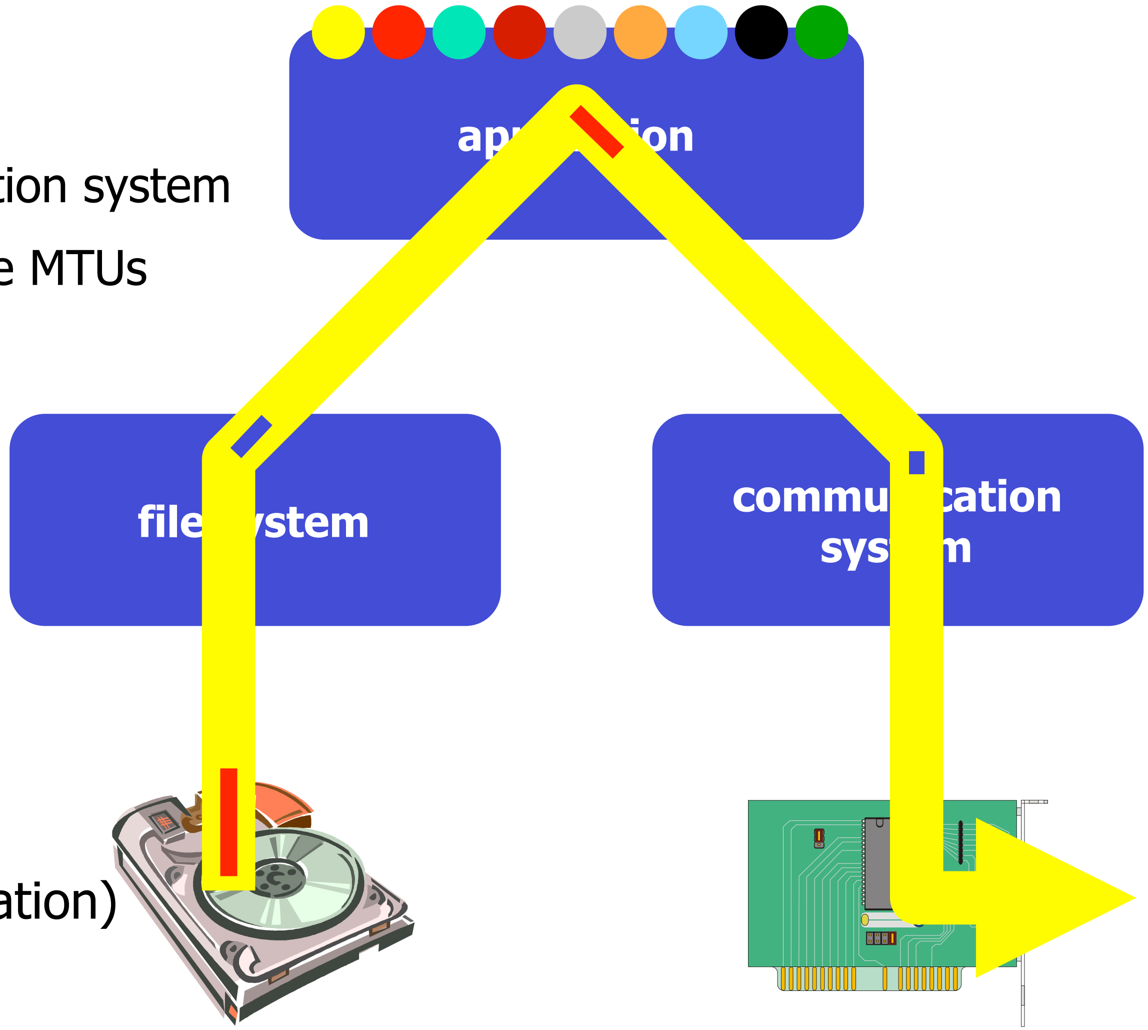
Timeliness: Streaming

- "Continuous Media" and "continuous streams" are ILLUSIONS
  - retrieve data in blocks from disk
  - transfer blocks from file system to application
  - send packets to communication system
  - split packets into appropriate MTUs
  - ... (intermediate nodes)
  - ... (client)

  ➔ different optimal sizes

  - pseudo-parallel processes (run in time slices)

  ☞ need for scheduling
  (to have timing and appropriate resource allocation)



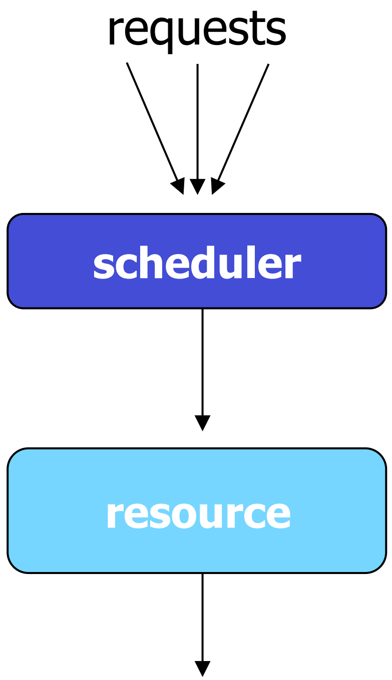
(CPU) Scheduling

Scheduling

- A task is a schedulable entity
  (a process/thread executing a job, e.g.,
  a packet through the communication
  system or a disk request through the file system)

- In a multi-tasking system, several tasks may wish to use a resource simultaneously

- A scheduler decides which task that may use the resource, i.e., determines order by which requests are serviced, using a scheduling algorithm



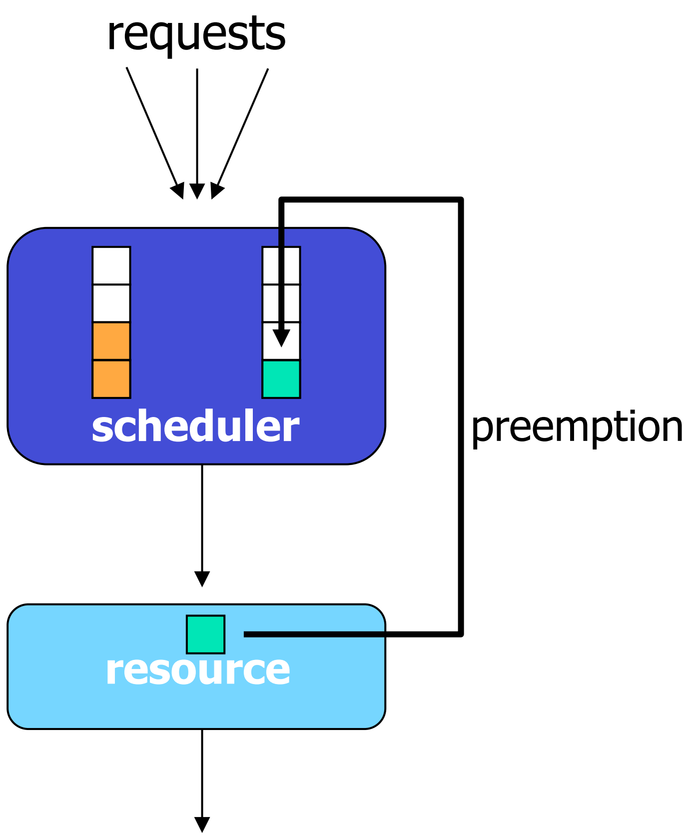
- Each active (CPU, disk, NIC) resource needs a scheduler
  (passive resources are also "scheduled", but in a slightly different way)

Scheduling

- Scheduling algorithm classification:
  - dynamic
    - makes scheduling decisions at *run-time*
    - flexible to adapt
    - considers only actual task requests and execution time parameters
    - large run-time overhead finding a schedule
  - static
    - makes scheduling decisions at *off-line* (also called pre-run-time)
    - generates a dispatching table for run-time dispatcher at compile time
    - needs complete knowledge of task before compiling
    - small run-time overhead
  - preemptive
    - currently executing tasks may be interrupted (preempted) by higher priority processes
    - the preempted process continues later at the same state
    - potential frequent contexts switching
    - (almost!?) useless for disk and network cards
  - non-preemptive
    - running tasks will be allowed to finish its time-slot (higher priority processes must wait)
    - reasonable for short tasks like sending a packet (used by disk and network cards)
    - less frequent switches

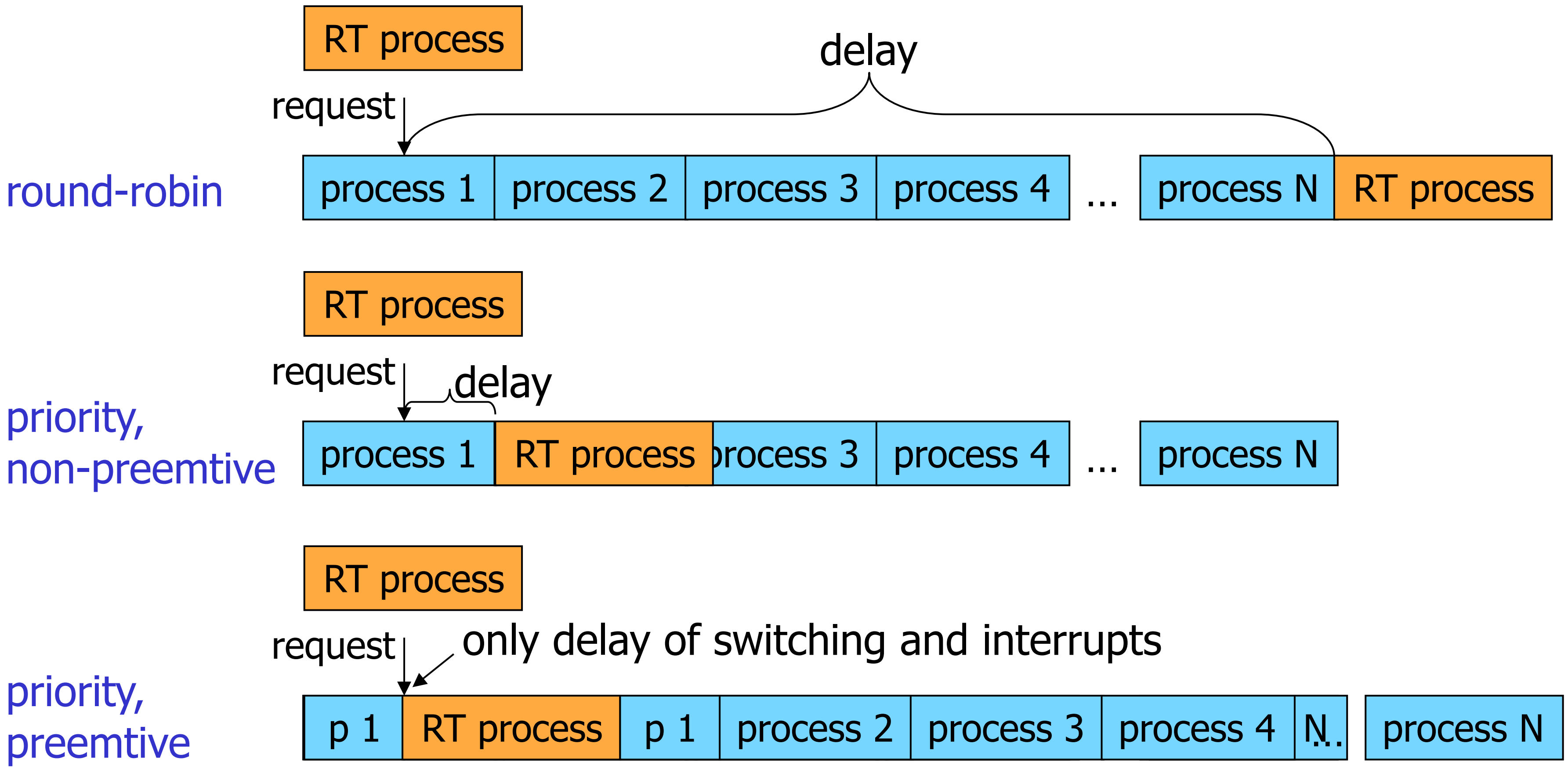
Scheduling

- Preemption:
  - tasks waits for processing
  - scheduler assigns priorities
  - task with highest priority will be scheduled first
  - preempt current execution if a higher priority (more urgent) task arrives
  - real-time and best effort priorities (real-time processes have higher priority - if exists, they will run)
  - to kinds of preemption:
    - preemption points
      - predictable overhead
      - simplified scheduler accounting
    - immediate preemption
      - needed for hard real-time systems
      - needs special timers and fast interrupt and context switch handling



Scheduling

- Scheduling is difficult and takes time – RT vs NRT example:



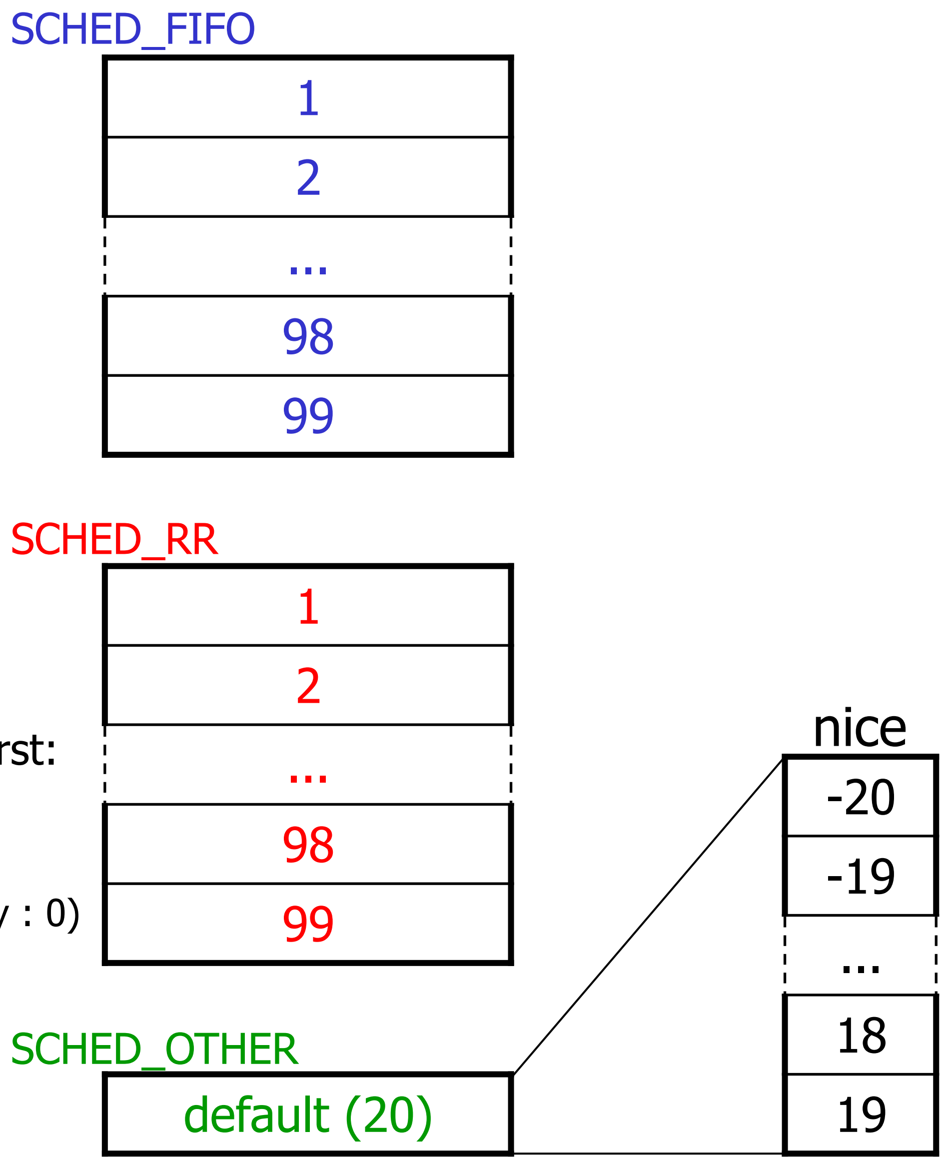
Scheduling in Linux

- Preemptive kernel
- Threads and processes used to be equal, but Linux uses (in 2.6) thread scheduling

- SCHED_FIFO
  - may run forever, no timeslices
  - may use it's own scheduling algorithm
- SCHED_RR
  - each priority in RR
  - timeslices of 10 ms (quantums)
- SCHED_OTHER
  - ordinary user processes
  - uses "nice"-values: 1≤ priority≤40
  - timeslices of 10 ms (quantums)

- Threads with highest *goodness* are selected first:
  - realtime (FIFO and RR):
    goodness = 1000 + priority
  - timesharing (OTHER):
    goodness = (quantum > 0 ? quantum + priority : 0)

- *Quantums* are reset when no ready process has quantums left (end of *epoch*):
  quantum = (quantum/2) + priority



Scheduling in Linux

http://kerneltrap.org/node/8059

- The 2.6.23 kernel used the new *Completely Fair Scheduler (CFS)*
  - address unfairness in desktop and server workloads
  - uses ns granularity, does not rely on jiffies or HZ details
  - uses extensible hierarchical scheduling classes
    - SCHED_FAIR (SCHED_NORMAL) – the CFS desktop scheduler – replace SCHED_OTHER
      - no run-queues, a tree-based timeline of future tasks
    - SCHED_BATCH – similar to SCHED_OTHER, but always assumes CPU intensive workloads (actually new from 2.6.16)
    - sched_rt replaces SCHED_RR and SCHED_FIFO
      - uses 100 run-queues

Real-Time Scheduling

- Resource reservation
  - QoS can be guaranteed
  - relies on knowledge of tasks
  - no fairness
  - origin: time sharing operating systems
  - e.g., earliest deadline first (EDF) and rate monotonic (RM)
    (AQUA, HeiTS, RT Upcalls, ...)

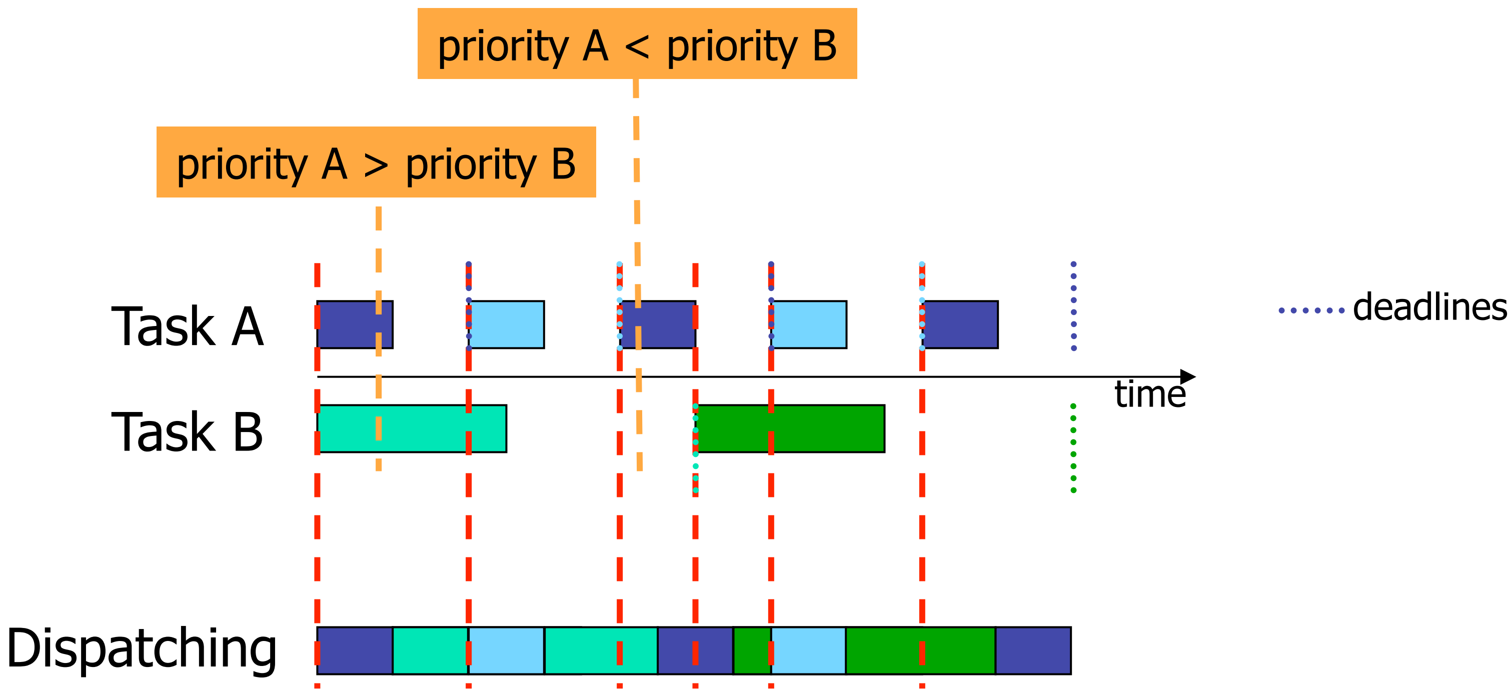
- Proportional share resource allocation
  - no guarantees
  - requirements are specified by a relative share
  - allocation in proportion to competing shares
  - size of a share depends on system state and time
  - origin: packet switched networks
  - e.g., Scheduler for Multimedia And Real-Time (SMART)
    (Lottery, Stride, Move-to-Rear List, ...)

Earliest Deadline First (EDF)

- Preemptive scheduling based on dynamic task priorities
- Task with *closest deadline has highest priority (dynamic)*
  → stream priorities vary with time
- Dispatcher selects the highest priority task
- Optimal: if any task schedule without deadline violations exits, EDF will find it
- Assumptions:
  - requests for all tasks with deadlines are periodic
  - the deadline of a task is equal to the end on its period (starting of next)
  - independent tasks (no precedence)
  - run-time for each task is known and constant
  - context switches can be ignored

Earliest Deadline First (EDF)

- Example:



Rate Monotonic (RM) Scheduling

- Classic algorithm for hard real-time systems with one CPU
[Liu & Layland '73]

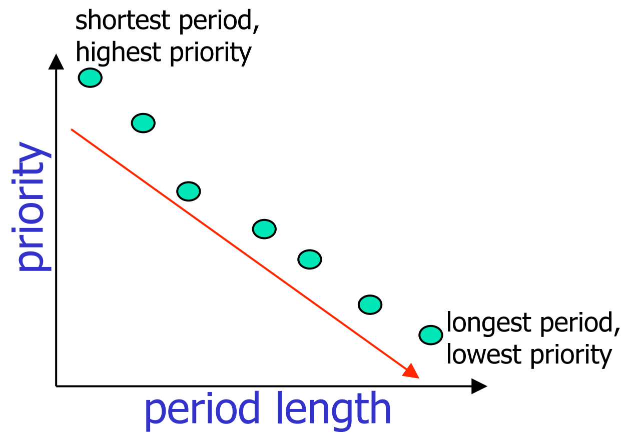
- Pre-emptive scheduling based on *static task priorities*

- Optimal: no other algorithms with *static* task priorities can schedule tasks that cannot be scheduled by RM

- Assumptions:
  - requests for all tasks with deadlines are periodic
  - the deadline of a task is equal to the end on its period (starting of next)
  - independent tasks (no precedence)
  - run-time for each task is known and constant
  - context switches can be ignored
  - *any non-periodic task has no deadline*

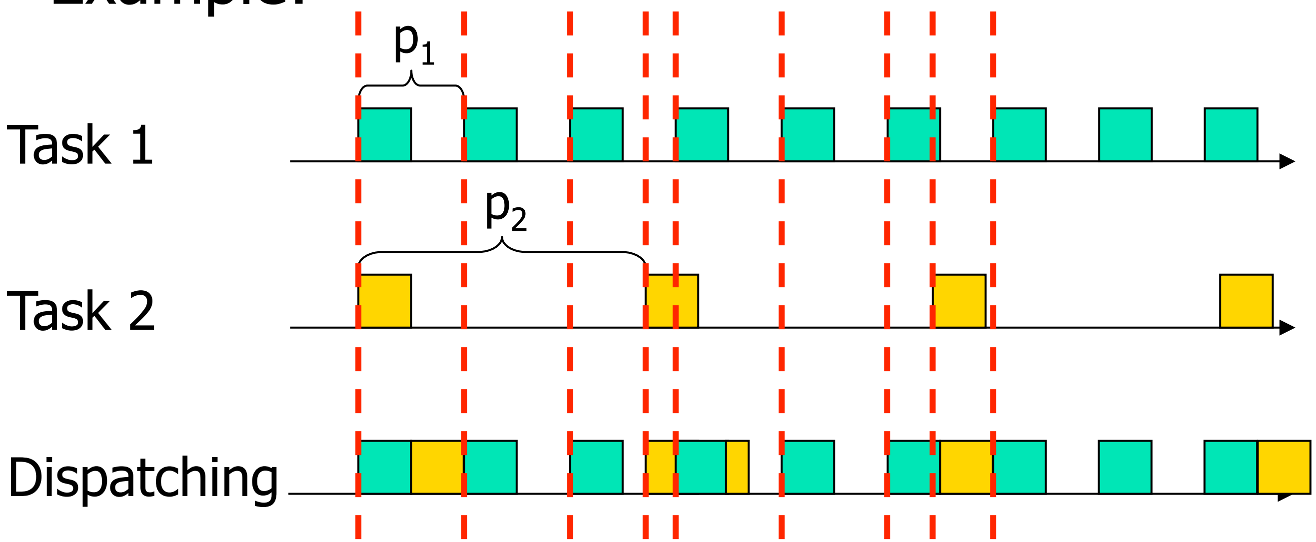
Rate Monotonic (RM) Scheduling

- Process priority based on task periods
  - task with shortest period gets highest *static* priority
  - task with longest period gets lowest *static* priority
  - dispatcher always selects task requests with highest priority



- Example:

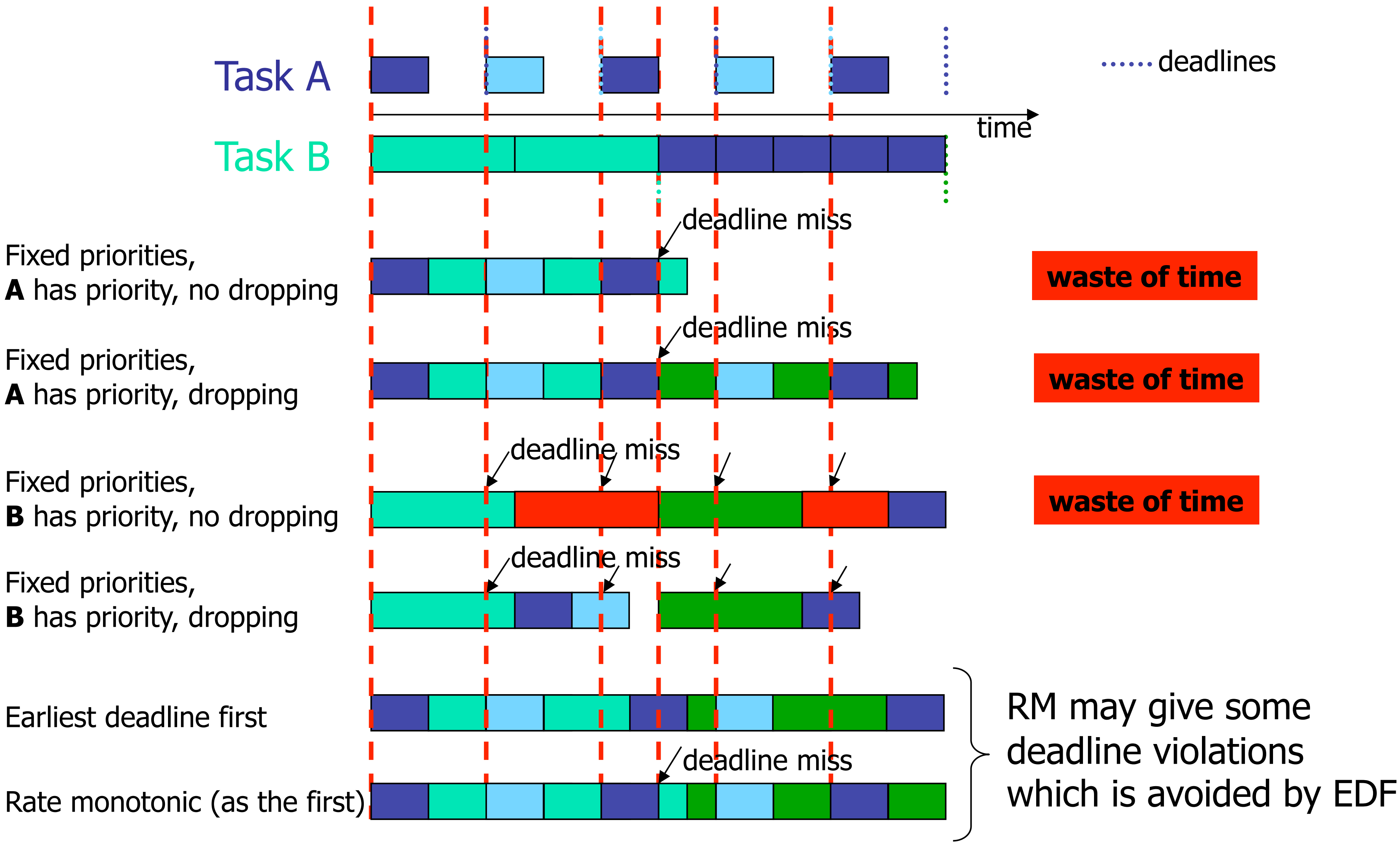
P_i = period for task i



$P_1 < P_2$
→ $Task_1$ highest priority

EDF Versus RM

- It might be impossible to prevent deadline misses in a strict, fixed priority system:



SMART (**S**cheduler for **M**ultimedia **A**nd **R**eal–**T**ime applications)

- Designed for multimedia and real-time applications

- Principles
  - priority – high priority tasks should not suffer degradation due to presence of low priority tasks
  - proportional sharing – allocate resources proportionally and distribute unused resources (work conserving)
  - tradeoff immediate fairness – real-time and less competitive processes (short-lived, interactive, I/O-bound, ...) get instantaneous higher shares
  - graceful transitions – adapt smoothly to resource demand changes
  - notification – notify applications of resource changes

SMART (**S**cheduler for **M**ultimedia **A**nd **R**eal–**T**ime applications)

- Tasks have…
  - urgency – an immediate real-time constraint, short deadline (determine when a task will get resources)
  - importance – a priority measure
    - expressed by a tuple:
      `[ priority p , biased virtual finishing time bvft ]`
    - **p** is static: supplied by user or assigned a default value
    - **bvft** is dynamic:
      - virtual finishing time: measure for the degree to which the proportional share has been given
      - bias: bonus for interactive and real-time tasks

- *Best effort schedule* based on urgency and importance
  1. find most important tasks *integrating priorities and weighted fair queuing* – compare tuple:
     $T_1 > T_2 \Leftrightarrow (p_1 > p_2) \vee (p_1 = p_2 \wedge bvft_1 > bvft_2)$
  2. sort each group after urgency (EDF based sorting)
  3. iteratively select task from candidate set as long as schedule is feasible
     (select the task with shortest deadline as long as it does not influence the deadline of tasks with higher importance)

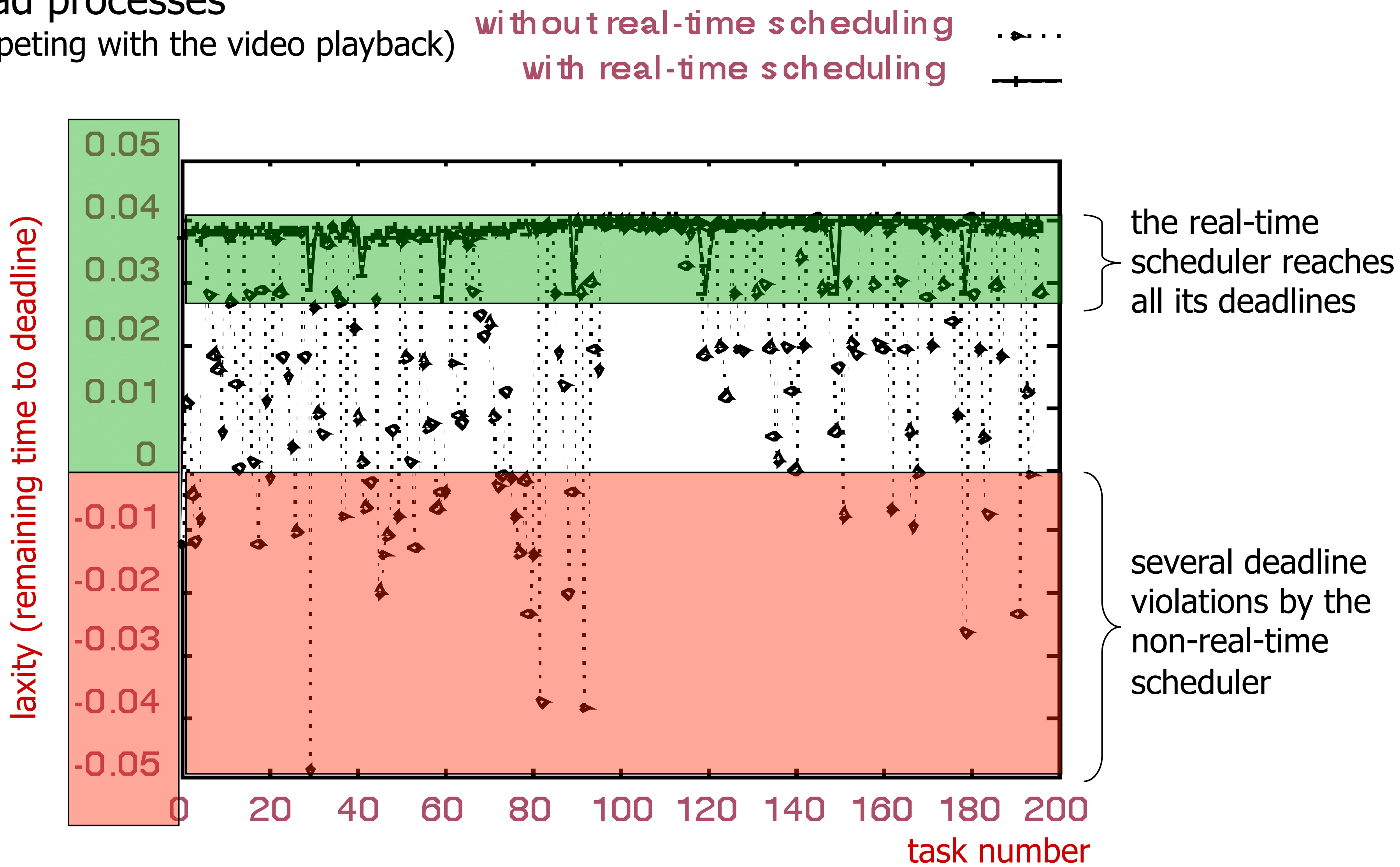
Evaluation of a Real-Time Scheduling

- Tests performed
  - by IBM (1993)
  - executing tasks with and without EDF
  - on an 57 MHz, 32 MB RAM, AIX Power 1

- Video playback program:
  - one real-time process
    - read compressed data
    - decompress data
    - present video frames via X server to user
  - process requires 15 timeslots of 28 ms each per second
    → 42 % of the CPU time

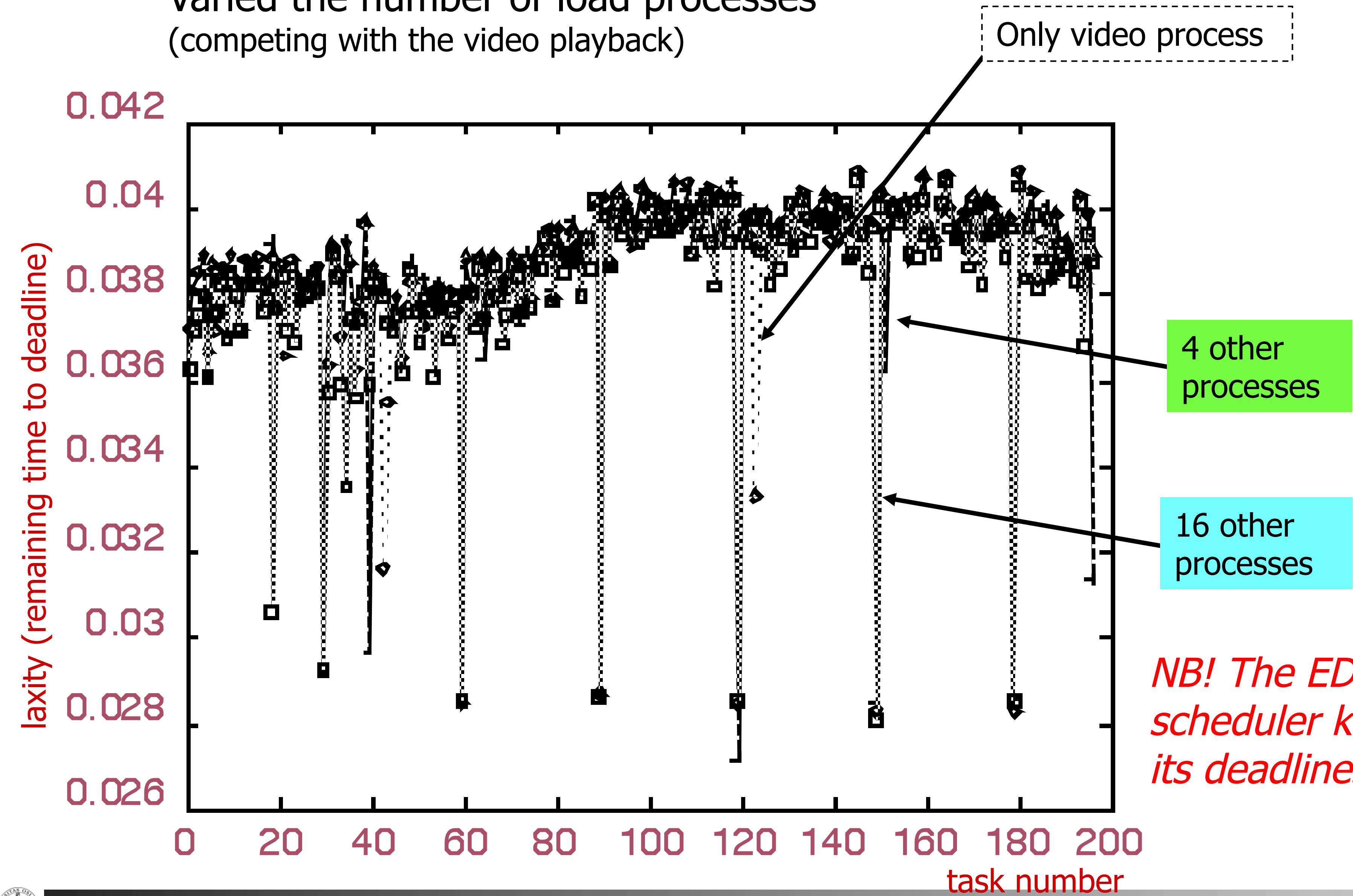
Evaluation of a Real-Time Scheduling

3 load processes
(competing with the video playback)



Evaluation of a Real-Time Scheduling

Varied the number of load processes
(competing with the video playback)



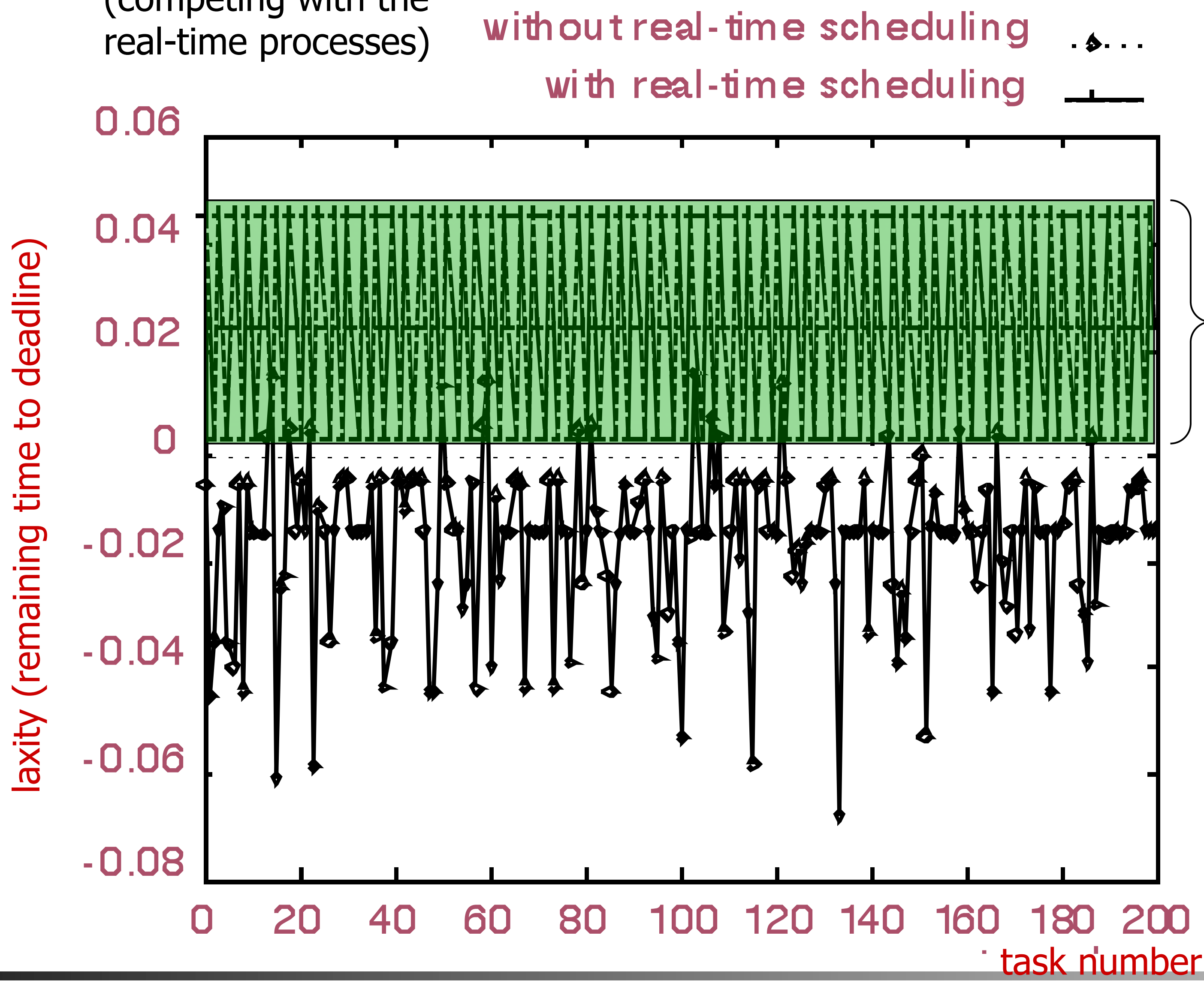
NB! The EDF scheduler kept its deadlines

Evaluation of a Real-Time Scheduling

- Tests again performed
  - by IBM (1993)
  - on an 57 MHz, 32 MB RAM, AIX Power 1
- "Stupid" end system program:
  - 3 real-time processes only requesting CPU cycles
  - each process requires 15 timeslots of 21 ms each per second
    → 31.5 % of the CPU time each
    → 94.5 % of the CPU time required for real-time tasks

Evaluation of a Real-Time Scheduling

1 load process
(competing with the real-time processes)

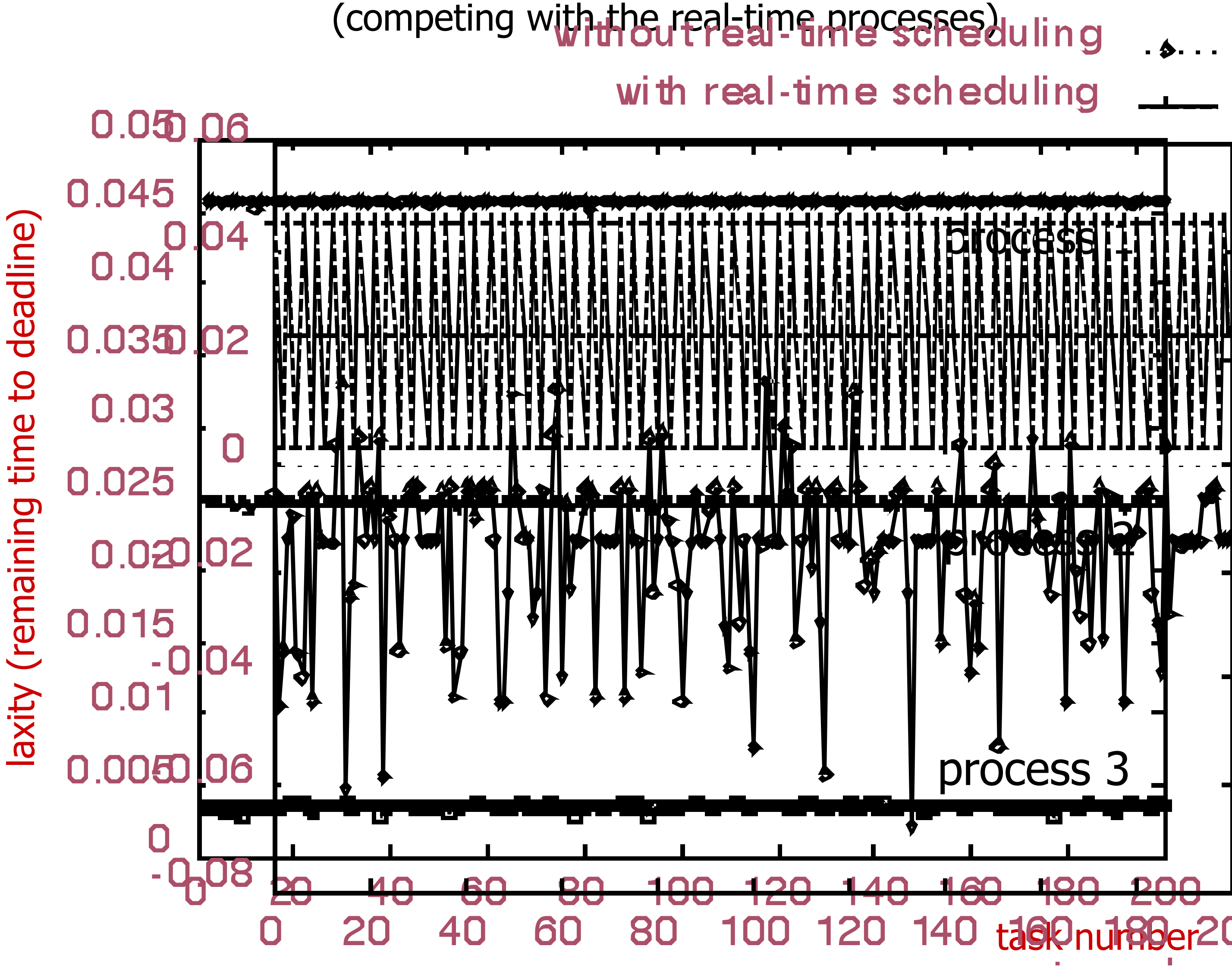


the real-time scheduler reaches all its deadlines

Evaluation of a Real-Time Scheduling

16 load processes

(competing with the real-time processes)

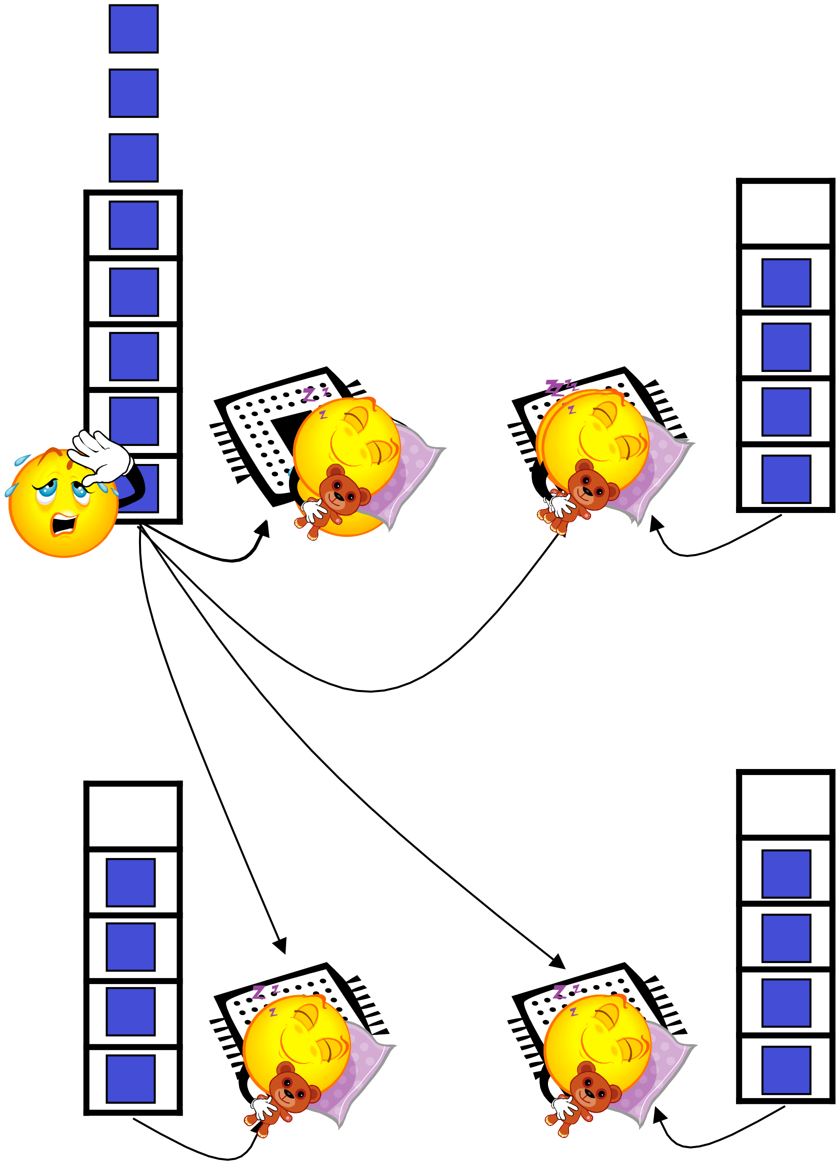


Regardless of other load, the EDF-scheduler reach its deadlines (laxity almost equal as in 1 load process scenario)

NOTE: Processes are scheduled in same order

Multicore

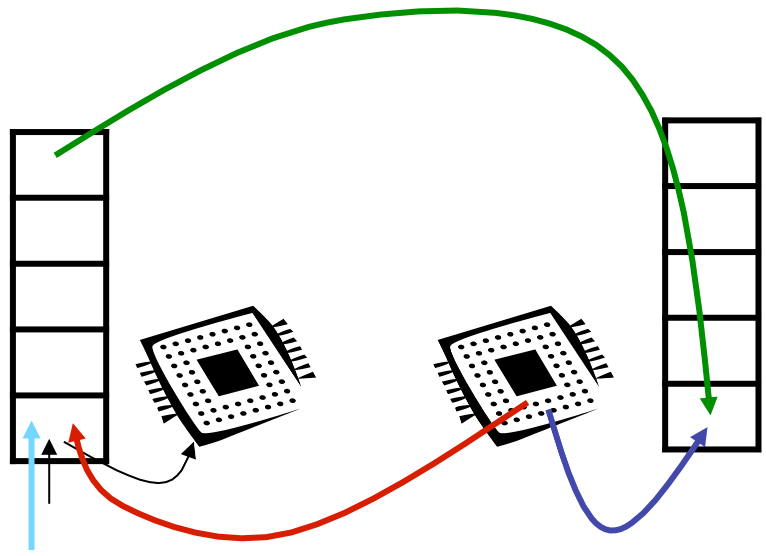
- So far, one single core…
- … multiple cores/CPUs
  - 1 single queue
    - potential bottleneck?
    - locking/contention on the single queue
  - Multiple queues
    - potential bottleneck?
    - load balancing
  - Load balancing
    - Linux checks every 200 ms
    - But where to place a new process?
    - And where to wake up a blocked process?

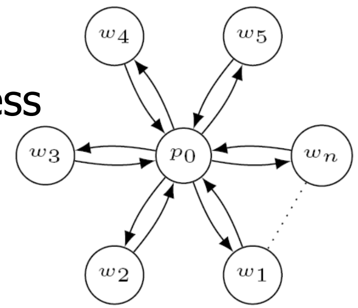


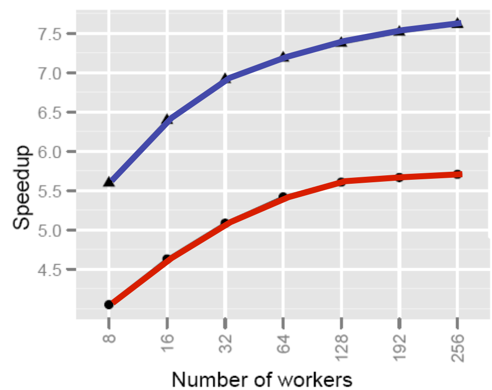
Multicore: Work Stealing

- Scheduling mechanism in the Intel Tread Building Block (TBB) framework
- LIFO queues (insert and remove from beginning of queues)
- One master CPU
  - new processes are placed here
  - awaken processes are placed here
- If own queue is empty, STEAL:
  - select random CPU_x
  - if CPU_x queue not empty
    - steal from the back of the queue
    - place first in own queue
- Importance of process placement?
  - change CPU of where wake up a process
  - scatter-gather workload
    (100 μs work per thread, 12500 iterations, 8 over 1 CPU speedup)

  ⇨ 300.000 more steal attempts per second

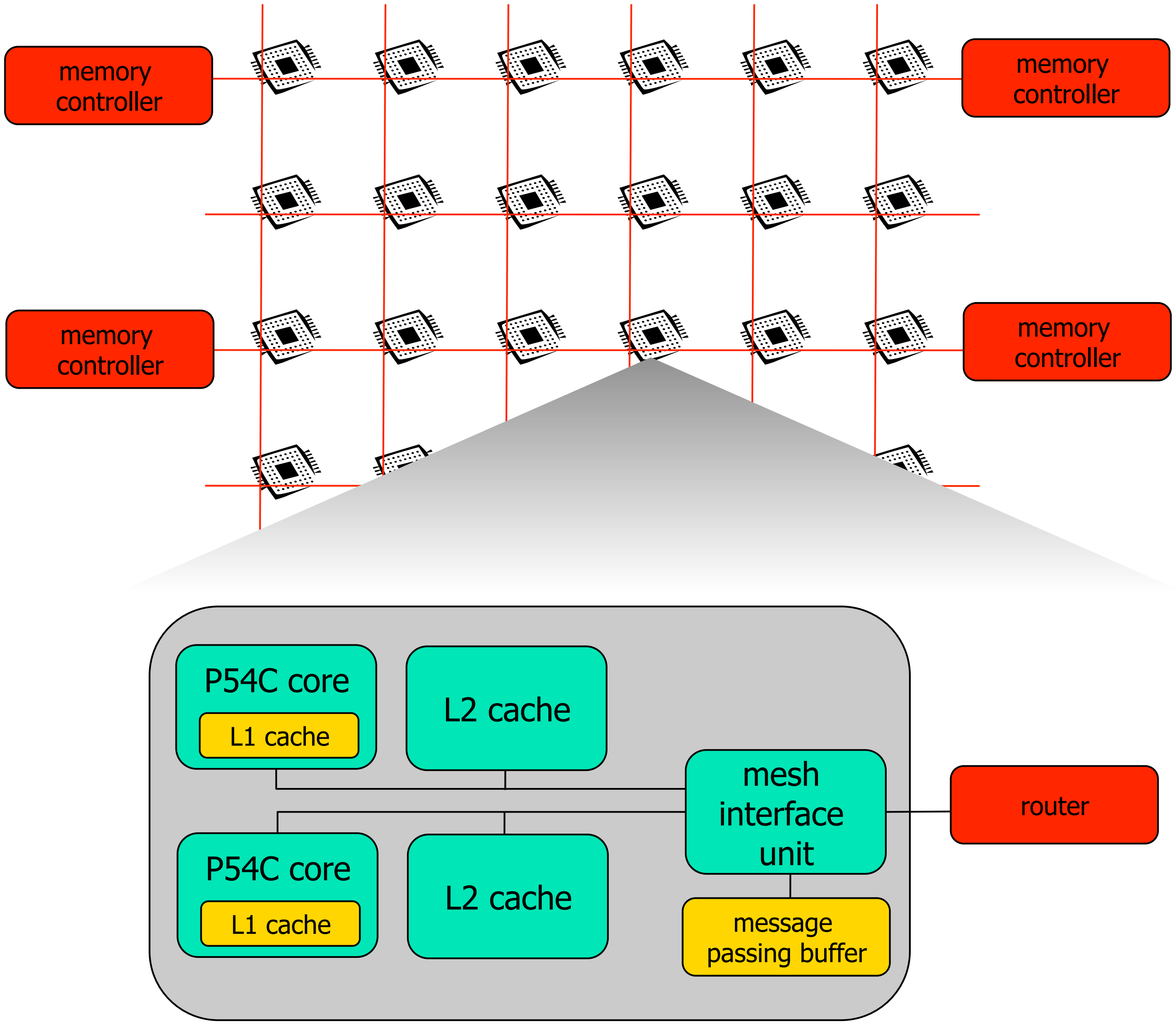






Future Chips: Intel's Single-chip Cloud Computer (SCC)

- What does introduction of such processors mean in terms of scheduling?



Summary

- Resources need to be properly scheduled

- CPU is an important resource
- Many ways to schedule depending on workload

- Hierarchical, multi-queue priority schedulers have existed a long time already, and newer ones usually try to improve upon this idea

- Next week, memory and persistent storage

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