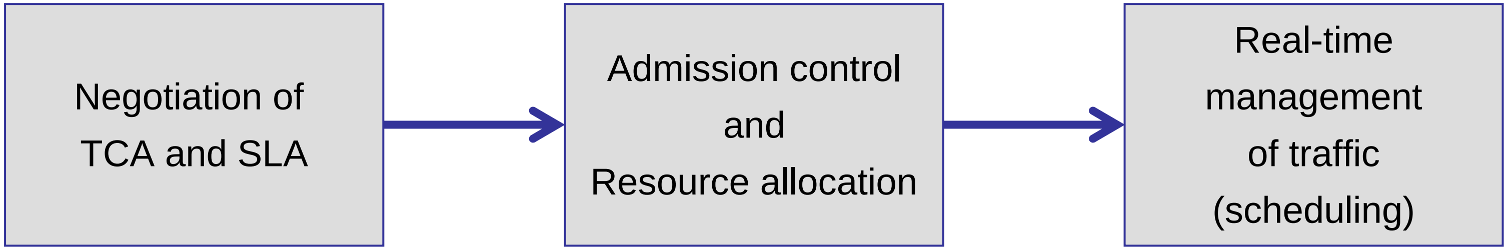
# Traffic contract

- A traffic contract between a provider and a customer includer a TCA and a SLA
- The TCA specifies the traffic profile
- The SLA specifies the QoS requirements
  - a delay threshold
  - the maximum fraction of packets that may exceed the delay threshold
    - If the fraction of packets is zero, the service is GUARANTEED while if the fraction of packets is greater than zero, the service is STATISTICAL
  - a maximum fraction of packets that can be lost

# Guaranteeing QoS

- When a request is issued by the customer, a traffic contract (TCA + SLA) is established
- Admission control checks if this traffic contract can be fulfilled, without affecting the SLA of already established contracts
- If this is possible, resources are allocated for this contract
- The connection becomes active and the real-time management of traffic starts
    - Scheduling at each network node
    - Regulation at the network ingress
    - Active queue management in nodes

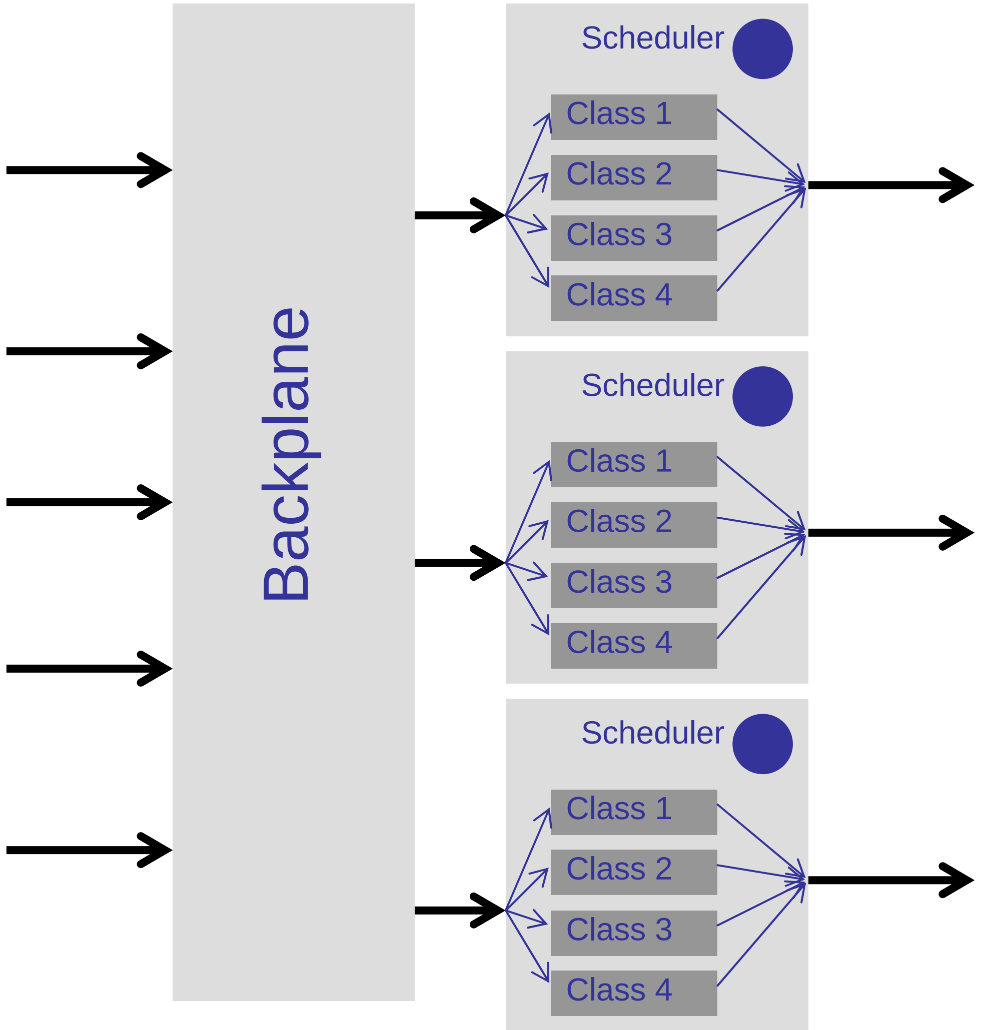


# Admission control

- The admission control function accepts or denies user requests
- A request is accepted only if it
  - is possible to do it fulfilling the requested and
  - Accepting the new request does not degrade the SLA of already accepted requests
- For example, admitting a VoIP flow can be done only if delay can be granted
- After all, it is in the nature of the telephone service to block requests if resources are not available
- Admission control is strictly related to the real-time management of traffic(scheduling)
- In fact, it is possible to determine if the SLA can be met only if the scheduling policy implemented by nodes is known, as well as the amount of available resources in each node

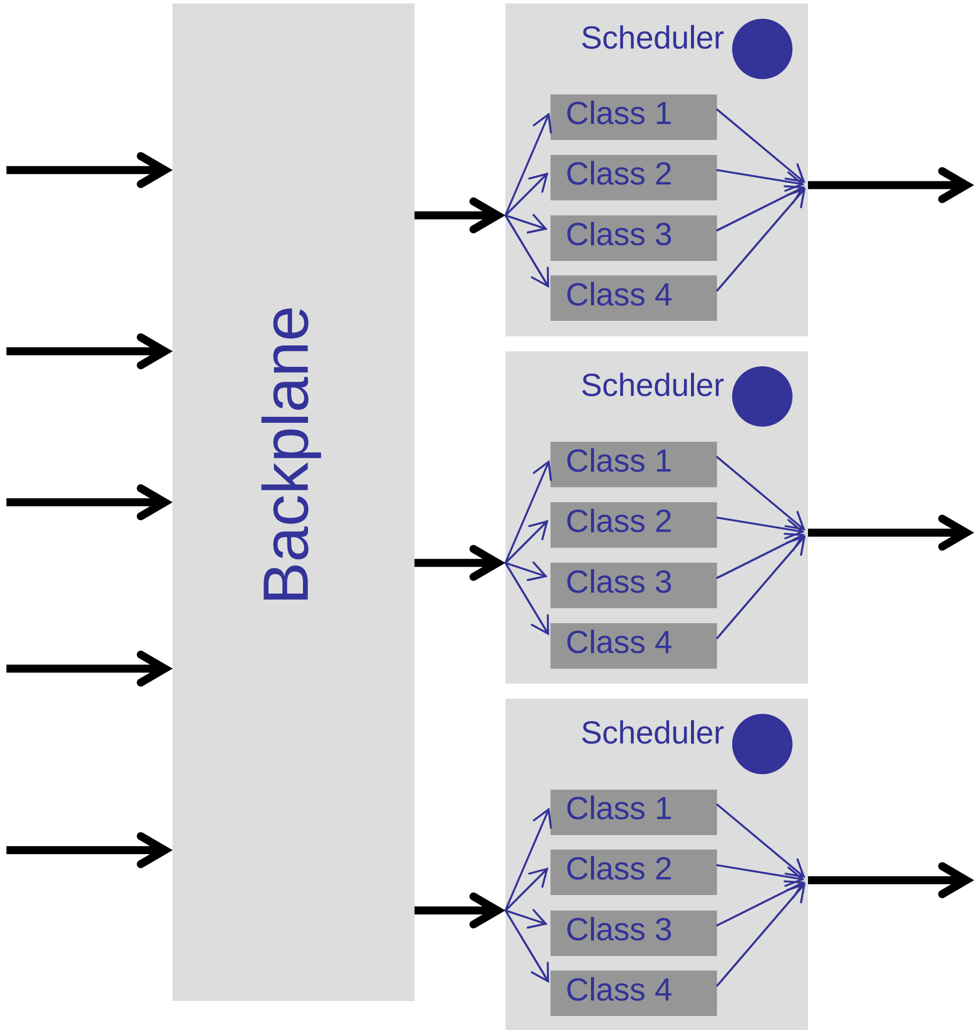
# Scheduling

- In a network node, each output link is managed by a scheduler
- The scheduler organizes the transmission of packets, by choosing on a per-packet base which service calss is to be served
- In particular, as soon as the transmission of a packet is over, the scheduler selects, according to a suitable algorithm, which service class is to be served next
- In some architectures, scheduling is based on service classes, i.e., traffic flows are aggregated into service categories and, in the scheduler, all packets belonging to the same service category are stored in the same buffer



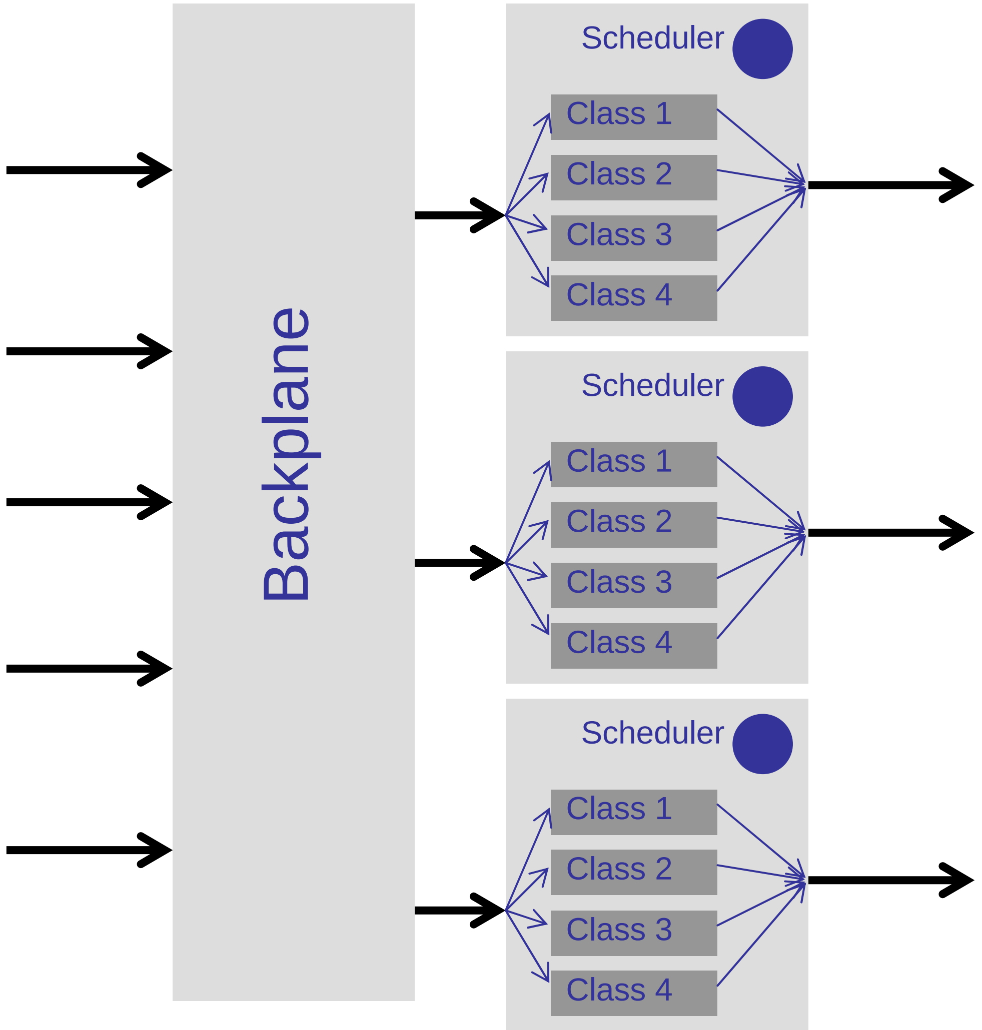
# Scheduling

- In other architectures, buffering and service occur on a per-flow basis
- That is, there is a buffer for each individual flow and the service of each individual flow is differentiated
- In this way, it is possible to obtain a very fine differentiation of service
- However, this presents scalability issues, as the schedulers of a core network node may have to manage several thousands of individual flows
- There is an upper limit of flows that can be meneged on an architecture differentiating the service of individual flows



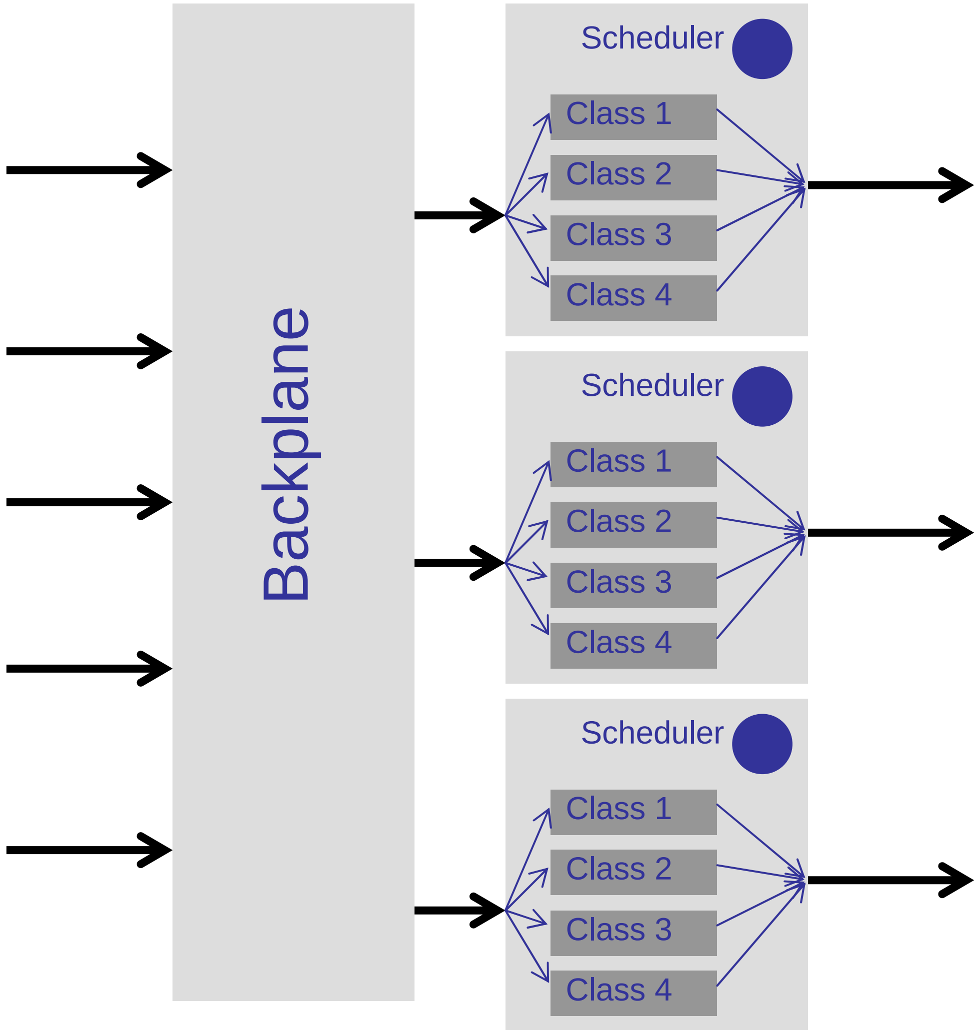
# Scheduling

- Managing service classes instead of individual flows eliminates the scalability issue
- The number of service classes is much smaller than the number of flows that a scheduler sustains
- For example, 10,000 VoIP flows would fit in one service class inside a class-based scheduler
- To the contrary, a per-flow based scheduler would have to istantiate 10,000 buffers and it would have to select among 10,000 flows for the transmission of each packet



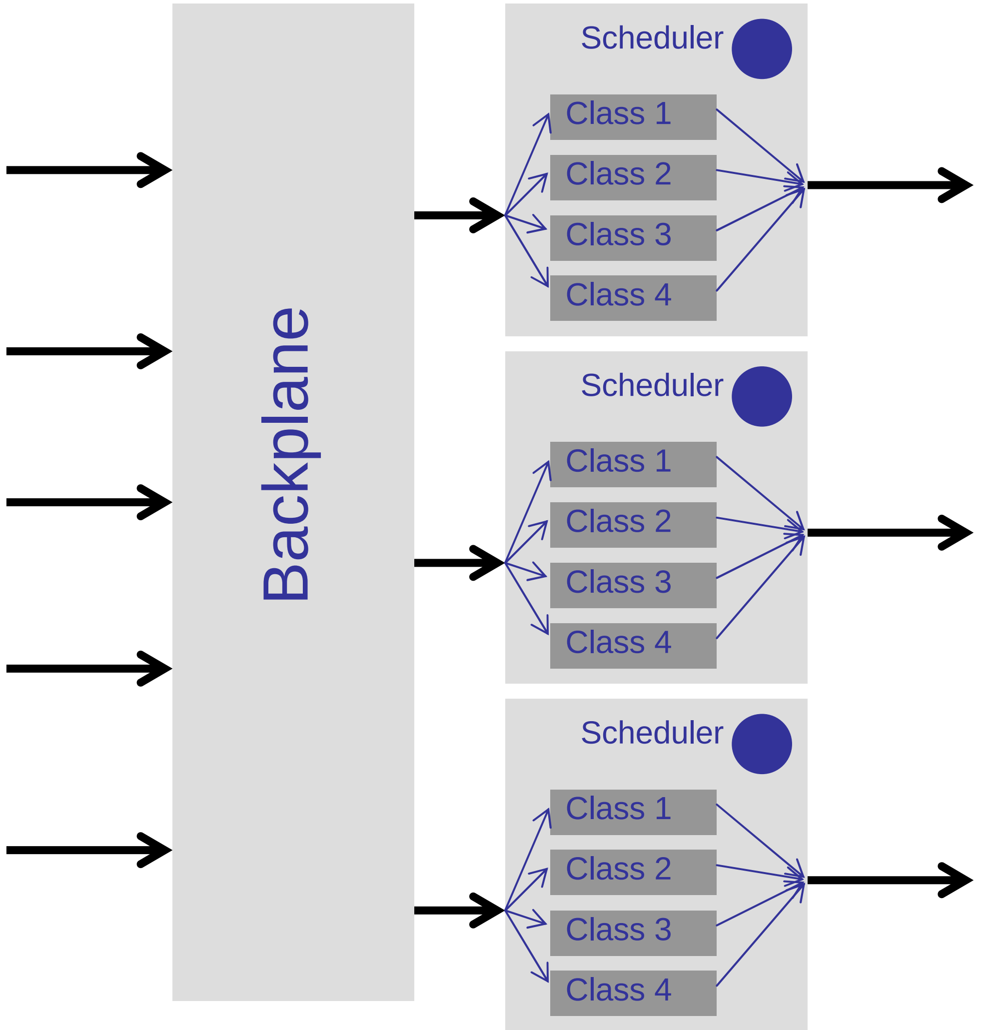
# Scheduling

- Scheduling can be a complex function
- The amount of resources needed to meet the SLA of all service classes sharing a link depends on
  - The compound TCA of each service class
  - The SLA of each service class
  - The scheduling policy (algorithm)
- Connection admission control can be performed properly only if all these items are known



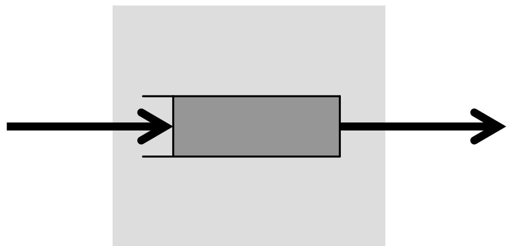
# Scheduling

- Given the compound TCA of a service class on a link's scheduler, referred to as TCAi
- Given the SLA of that service class, referred to as SLAi
- The total link's capacity *C* consumed by the service classes sharing that link is a function (indeed complex) of the TCAs and SLAs and of the scheduling policy
  - *C = f((TCA1, SLA1), (TCA2, SLA2), (TCA3, SLA3), (TCA4, SLA4),policy)*



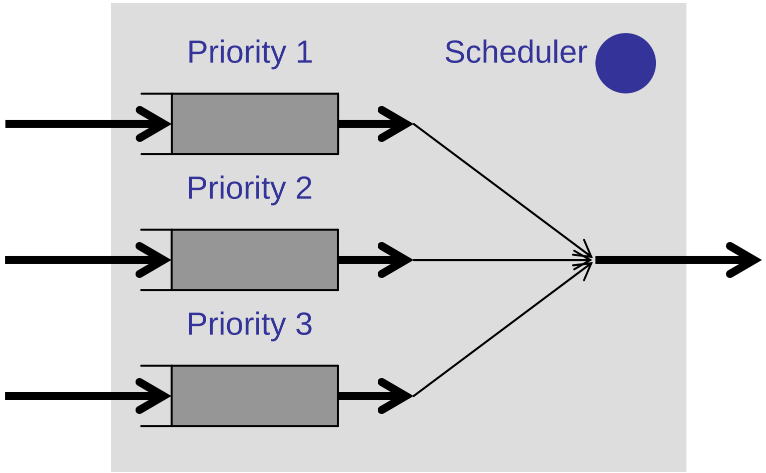
# FIFO scheduler

- The FIFO (First-In First-out) scheduler is the simplest
- However, it is the less useful to offer differentiated QoS
- All packets, independently on their service class, are stored in the same buffer and they are served in the same order of their arrivals
- Clearly, only one SLA can be offer to all flows
- In order to meets all SLAs concurrently, the most stringent SLA must be guaranteed
- This is clearly very inefficent
- As a matter of fact, the FIFO scheduler can be used only for Best-Effort networks



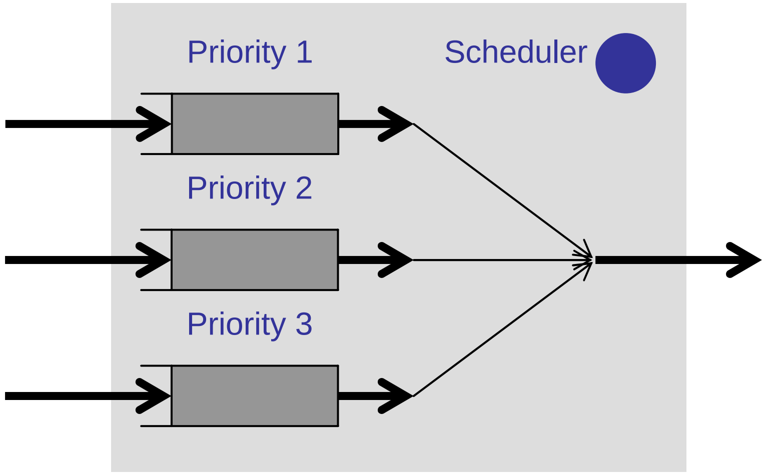
# The strict priority scheduler

- The strict priority (SP) scheduler is simple but effective
- The SP scheduler, when it has to select the next packet to be served, at first examines the highest priority queue (priority 1)
- If the queue stores at least one packet, a packet is fetched from the queue and served
- If the priority-1 queue is empty, the scheduler examined the priority-2 queue and, if a packet is present, it is served
- The priority-3 queue is served only if the other queues are empty



# The strict priority scheduler

- For example, with the strict priority scheduler
  - traffic with stringent QoS requirements can be assigned to the highest priority level
  - Best_Effort traffic can be assigned to the lowest priority level
  - Traffic with intermediate QoS requirements can be served within the second priority level



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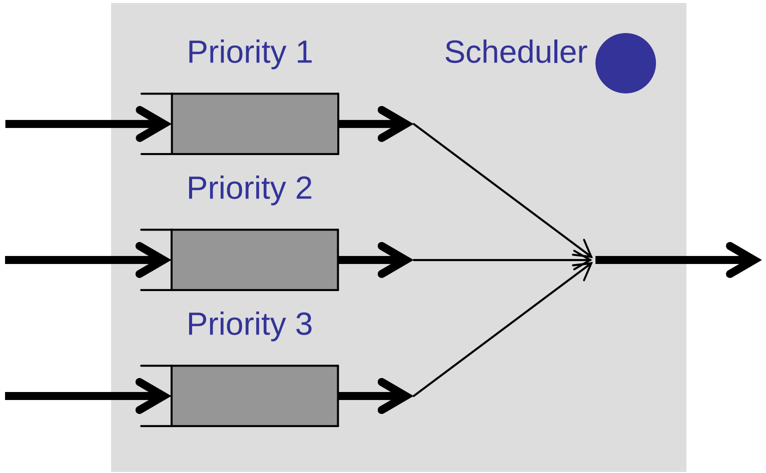
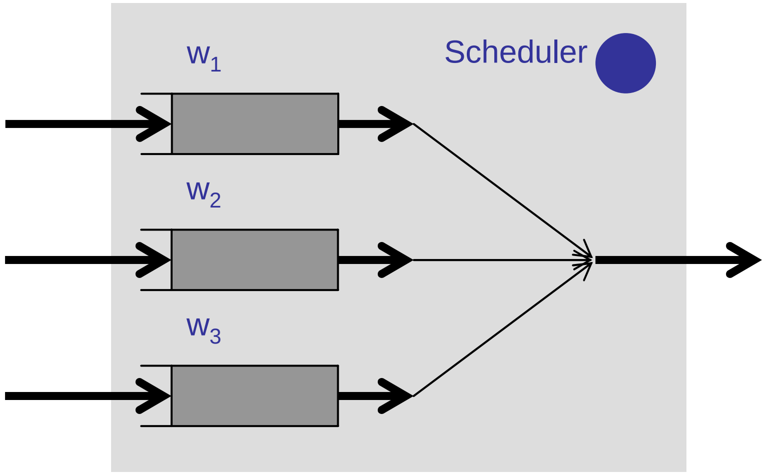


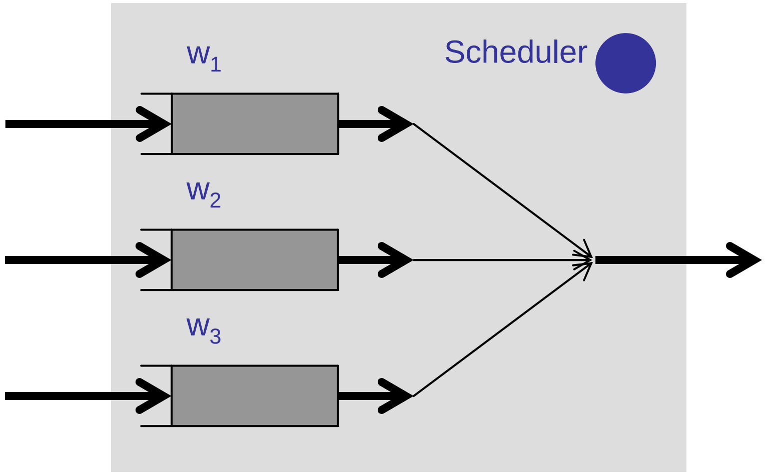
# The General Processor Sharing scheduler

- In the *General Processor Sharing* scheduler (GPS), each service class is assigned a weight, ranging from 0 to 1
- The sum of weigth is 1
  - $w_1 + w_2 + w_3 = 1$
- The *i*th service class receives at least a transmission capacity equal to $w_i C$, where $C$ is the link's capacity
- If a service class is momentarily silent, spare capacity is available
- In this case, the spare capacity is distributed among the non-silent service classes, proportionally to their respective weight



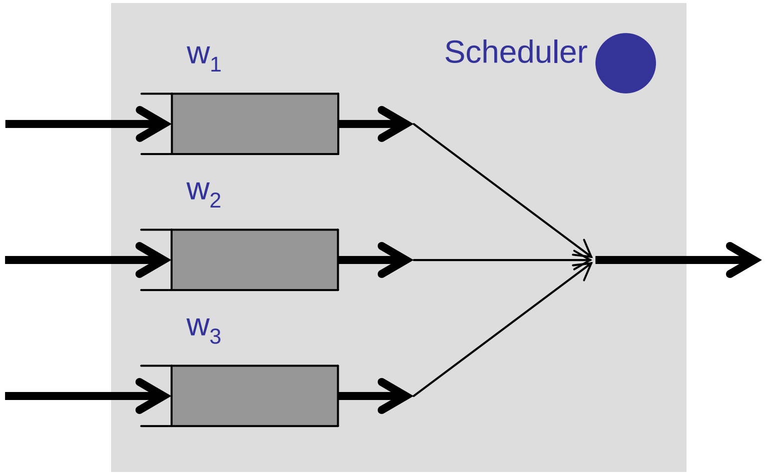
# The General Processor Sharing scheduler

- For example, let $w_1=0.3$, $w_2 = 0.5$, $w_3 = 0.2$
- If service class 3 is silent, the fraction of link's capacity received by service class 1 is equal to
  - $0.3 + 0.2 \times 0.3 / (0.3 + 0.5) = 0.375$
- And the fraction of capacity received by service class 2 is equal to
  - $0.5 + 0.2 \times 0.5 / (0.3 + 0.5) = 0.625$
- When service class 3 returns active, the link's capacity is divided according to the respective weights of service classes



# The General Processor Sharing scheduler

- GPS schedulers are referred to also as rate-based schedulers, as they assign explicitly a rate of service to each service class
- There are several implementations of GPS schedulers, such as the family of weighted fair queueing schedulers



# The Earliest Deadline First scheduler

- In the *Earliest Deadline First* (EDF) scheduler, service class *i* is characterized by its service deadline $d_i$ [seconds]
- At the end of each packet transmission, the scheduler fetches, among the packets waiting for transmission, the packet with the smallest residual time
- This is done by marking each packet on its arrival with the time stamp indicating its arrival time $t_k$
- At time *t*, the residual time of this packet, belonging to service class *i*, is calculated as $t_k + d_i - t$, representing the amount of time left before the packet service deadline expires
- Note that the packet residual time can be negative, indicating that the service deadline has already expired
- Smaller residual time means more urgent need of service: this is the reason why the packet with the smallest residual time is selected for service