Real-World Scheduling

Linux Scheduling

- Policies
  - SCHED_FIFO
    - "real time"
    - infinite time quantum
  - SCHED_RR
    - "real time"
    - adjustable time quantum
  - SCHED_OTHER
    - "normal" scheduler
    - parameterized allocation of processor time

Linux Scheduler Evolution

- Old scheduler
  - very simple
  - poor scaling
- O(1) scheduler
  - introduced in 2.5
  - less simple
  - better scaling
- Completely fair scheduler (CFS)
  - even better
  - simpler in concept
  - much less so in implementation
  - based on stride scheduling

Old Scheduler

- Four per-process scheduling variables
  - *policy*: which one
  - *rt_priority*: real-time priority
    - 0 for SCHED_OTHER
    - 1 – 99 for others
  - *priority*: time-slice parameter ("nice" value)
  - *counter*: records processor consumption

Old Scheduler: Time Slicing

- Clock "ticks" HZ times per second
  - interrupt/tick
- Per-process *counter*
  - current process's is decremented by one each tick
  - time slice over when counter reaches 0

Old Scheduler: Throughput

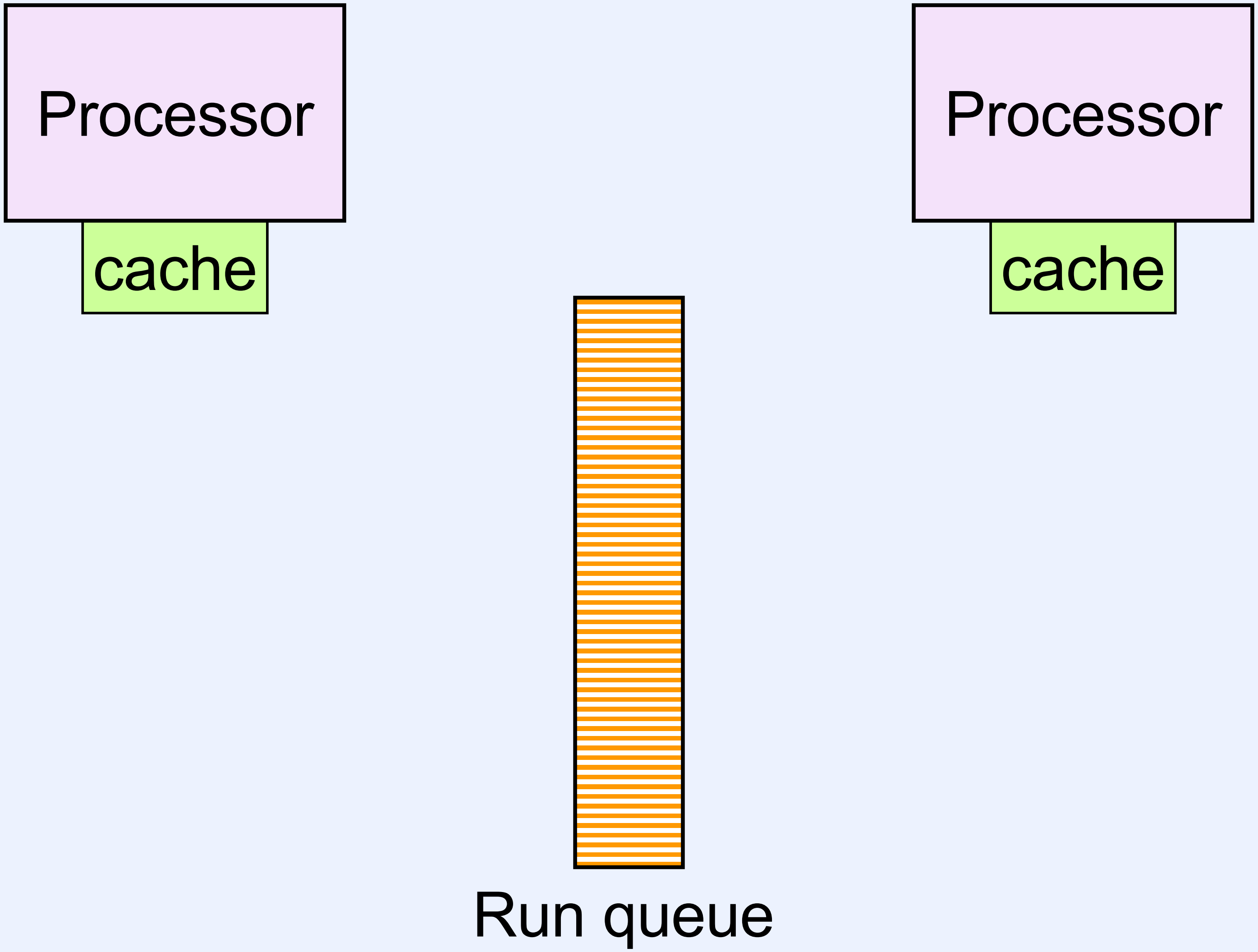
- Scheduling cycle
  - length, in "ticks," is sum of priorities
  - each process gets *priority* ticks/cycle
    - *counter* set to *priority*
    - cycle over when *counter*s for runnable processes are all 0
  - sleeping processes get "boost" at wakeup
    - at beginning of each cycle, for each process:

      counter = counter/2 + priority

Old Scheduler: Who's Next?

- **Run queue searched beginning to end**
  - new arrivals go to front
  - SCHED_RR processes go to end at completion of time slices
- **Next running process is first process with highest "goodness"**
  - 1000 + *rt_priority* for SCHED_FIFO and SCHED_RR processes
  - *counter* for SCHED_OTHER processes

Diagram



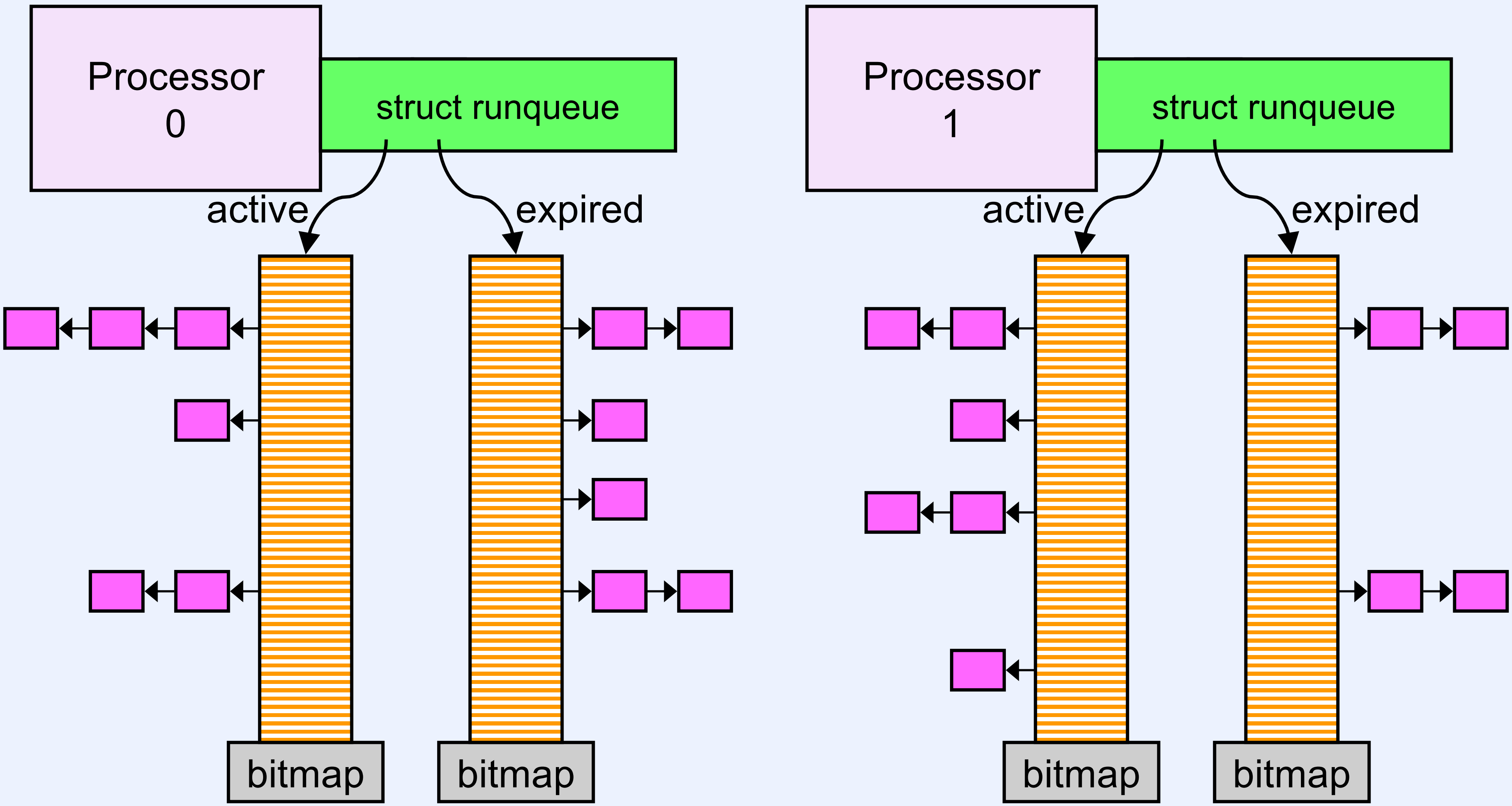
Old Scheduler: Problems

- O(n) execution
- Poor interactive performance with heavy loads
- SMP contention for run-queue lock
- SMP affinity
  - cache “footprint”

O(1) Scheduler

- All concerns of old scheduler plus:
  - efficient, scalable execution
  - identify and favor interactive processes
  - good SMP performance
    - minimal lock overhead
    - processor affinity

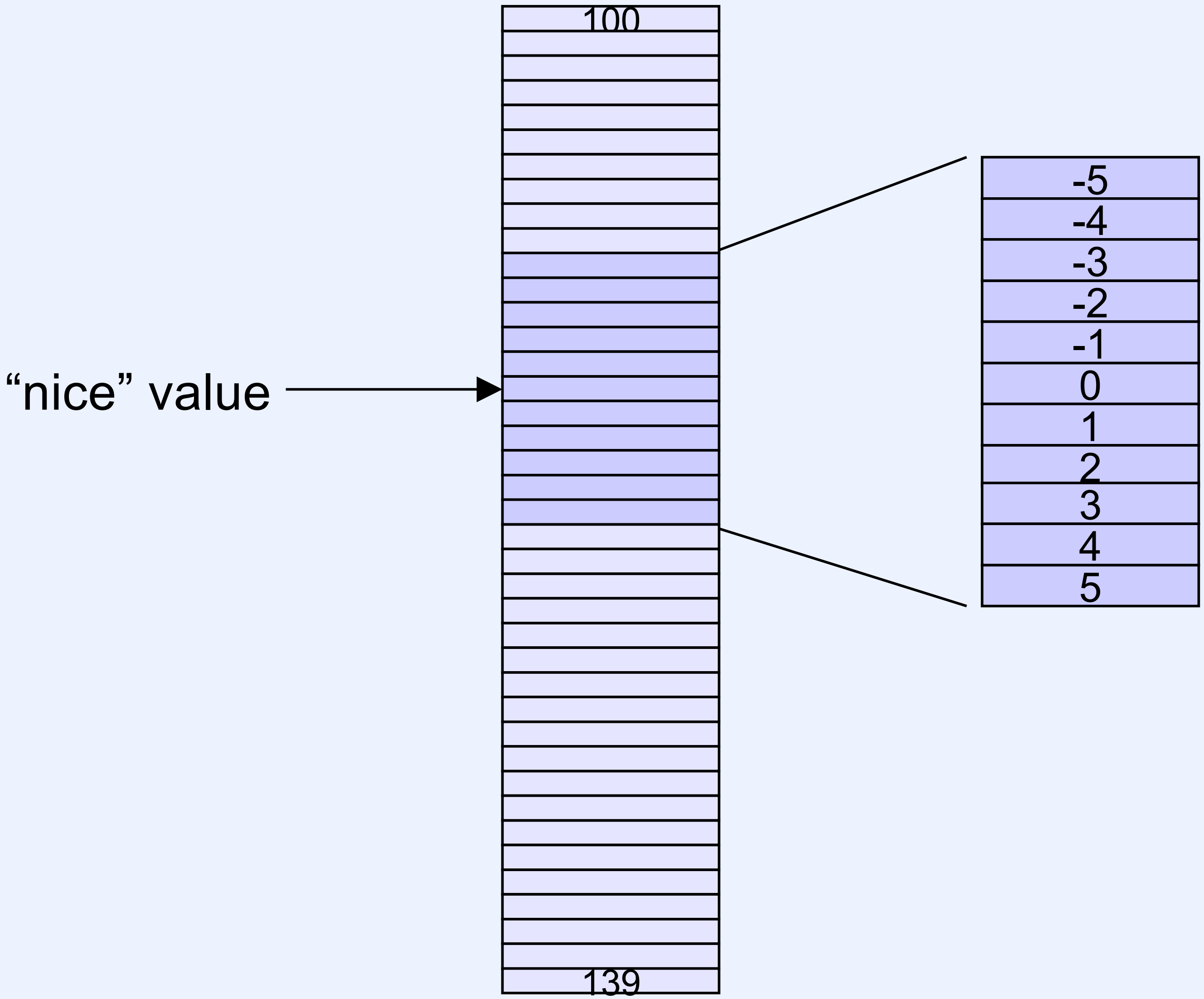
O(1) Scheduler: Data Structures



O(1) Scheduler: Queues

- Two queues per processor
  - active: processes with remaining time slice
  - expired: processes with no more time slice
  - each queue is an array of lists of processes of the same priority
    - bitmap indicates which priorities have processes
  - processors scheduled from private queues
    - infrequent lock contention
    - good affinity

O(1) Scheduler: Priorities



O(1) Scheduler: Actions

- Process switch
  - pick best priority from active queue
    - if empty, switch active and expired
  - new process's time slice is function of its priority
- Wake up
  - priority is boosted or dropped depending on sleep time
  - interactive processes are defined as those who priority is above a certain threshold
- Time-slice expiration
  - interactive processes rejoin active queue
    - unless processes have been on expired queue too long

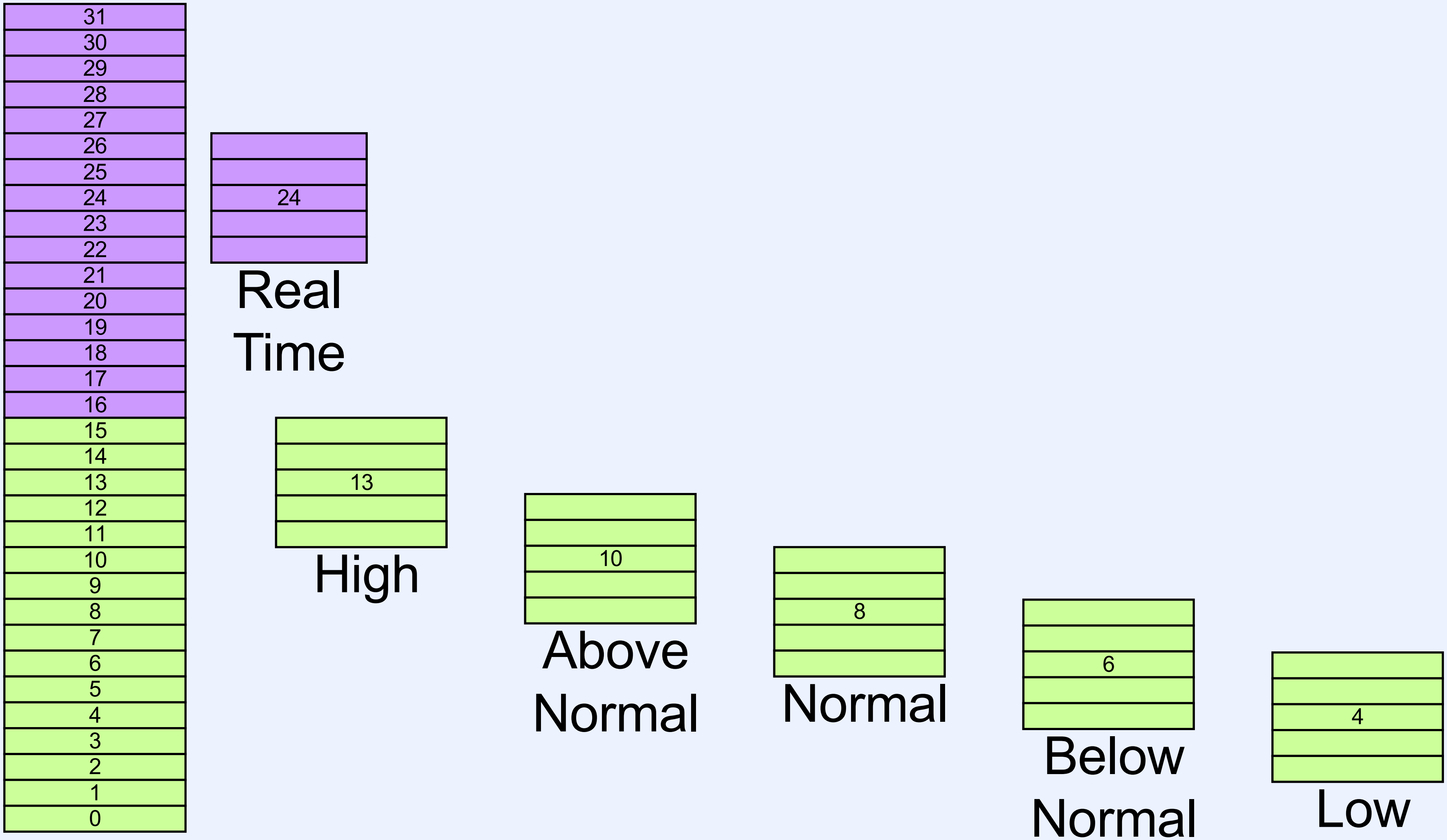
O(1) Scheduler: Load Balancing

- Processors with empty queues steal from busiest processor
  - checked every millisecond
- Processors with relatively small queues also steal from busiest processor
  - checked every 250 milliseconds

Scheduling in Windows

- Handling “normal” interactive and compute-bound threads
- Real-time threads
- Multiple processors

Priorities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Real Time
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High
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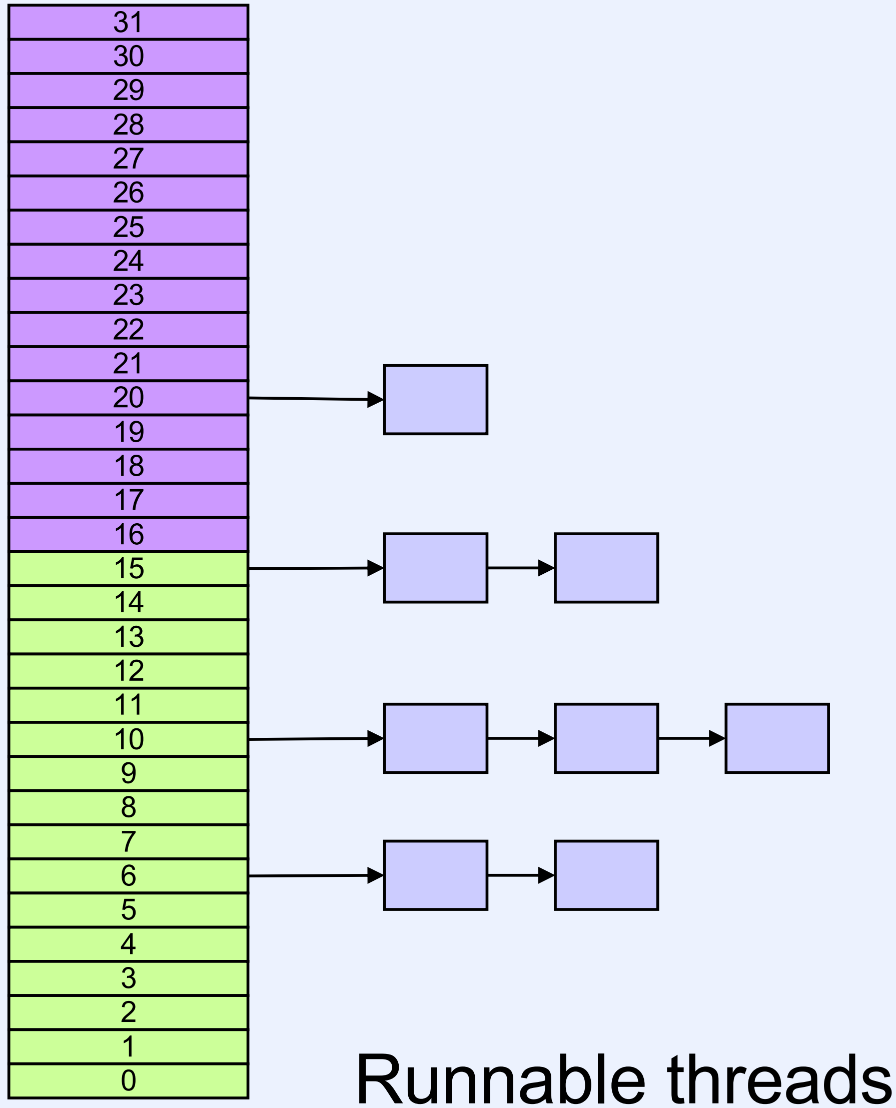
Above Normal
8
Normal
6
Below Normal
4
Low

Uniprocessor Windows



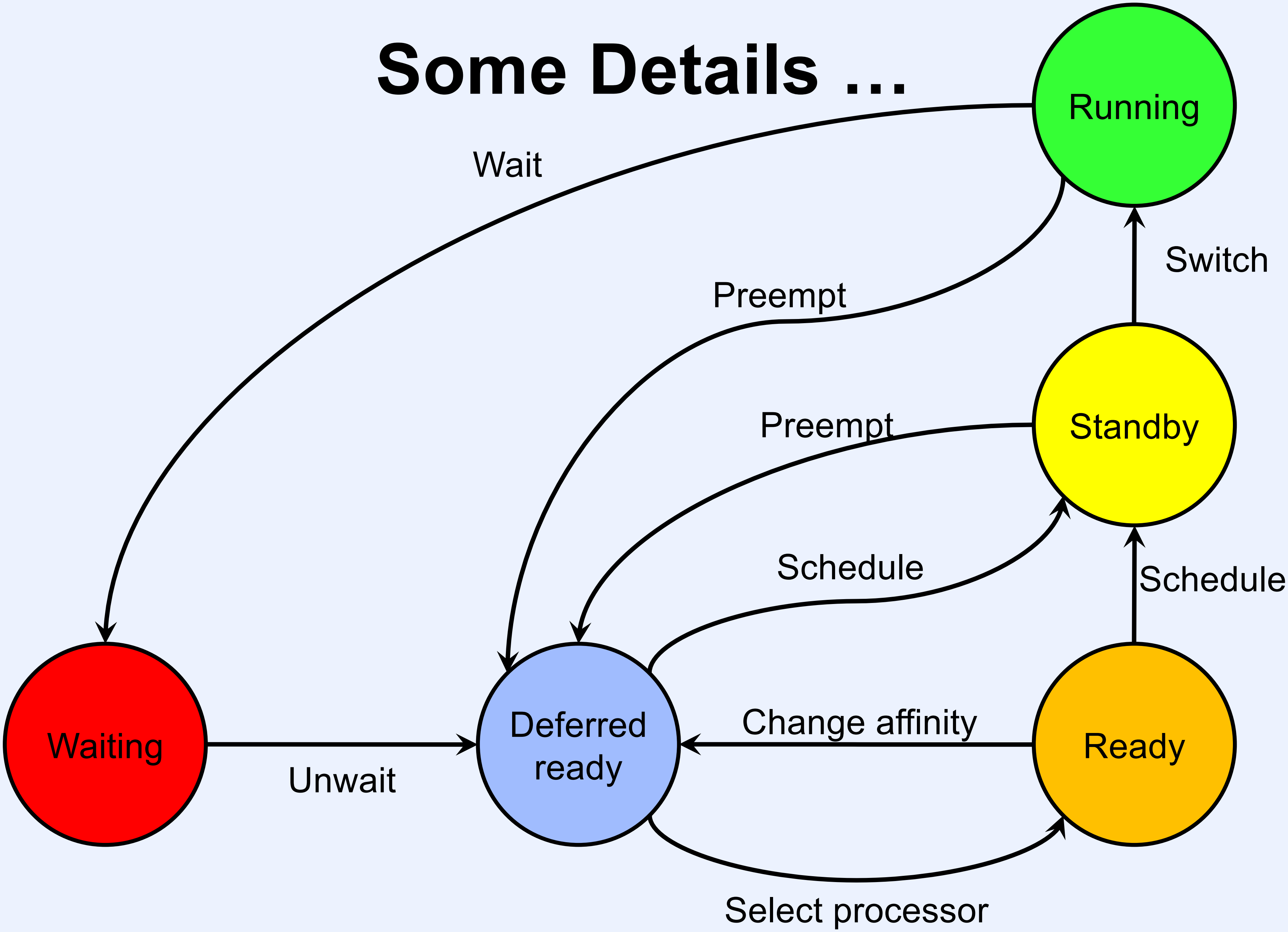
Improving Real Time

- Multimedia applications need 80% of processor time
- Make sure normal applications get at least 20%
- How?
- Windows solution: MMCSS
  - multimedia class scheduler service
  - dynamically manage multimedia threads
    - run at real-time priority 80% of time
    - run at normal priority 20% of time

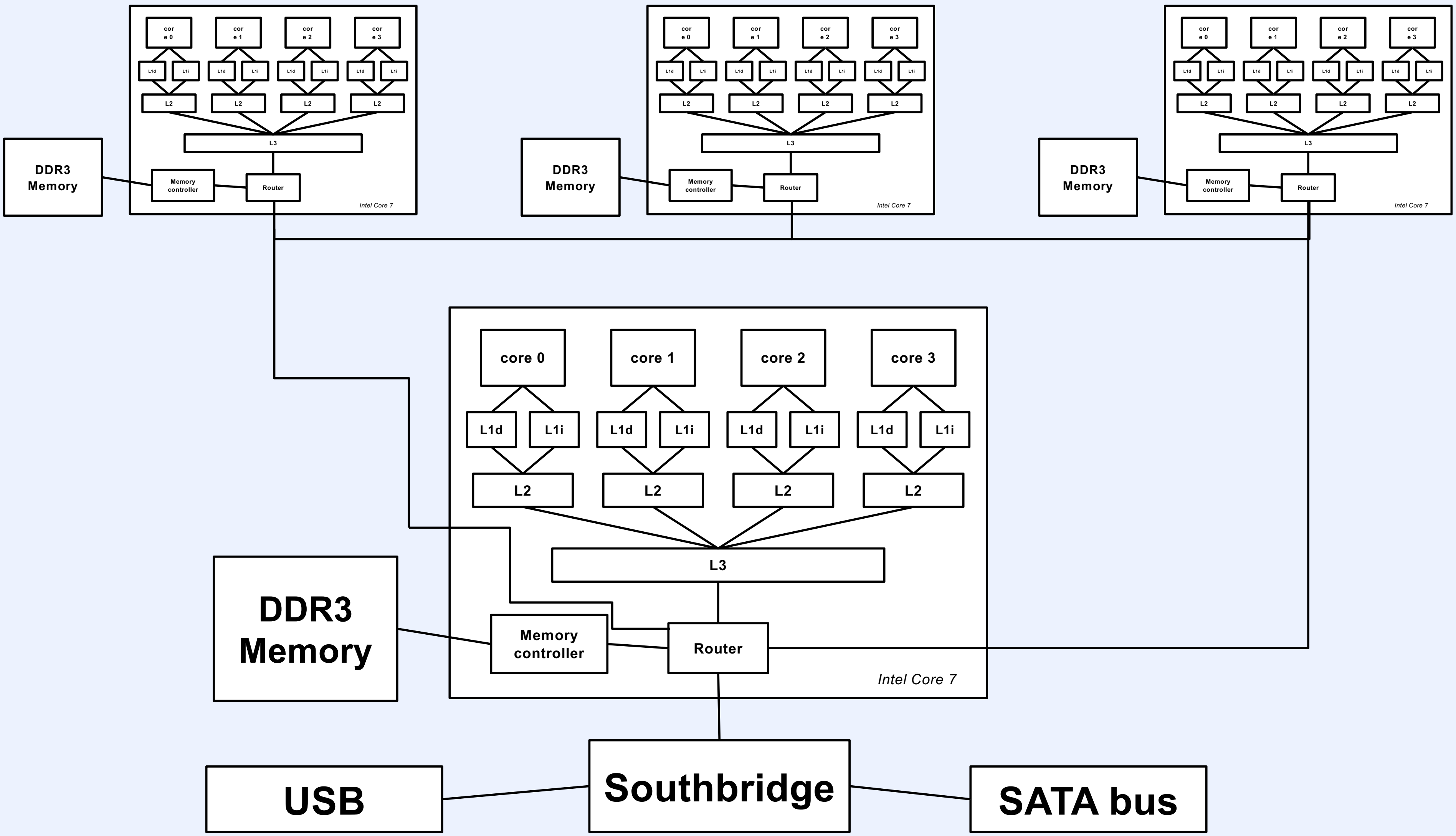
Which Processor?

- Newly created thread assigned *ideal processor*
  - randomly chosen
- May also set *affinity mask*
  - may be scheduled only on processors in mask
- Scheduling decision:
  - if idle processors available
    - first preference: ideal processor
    - second preference: most recent processor
  - otherwise
    - joins run queue of ideal processor

Some Details …



NUMA

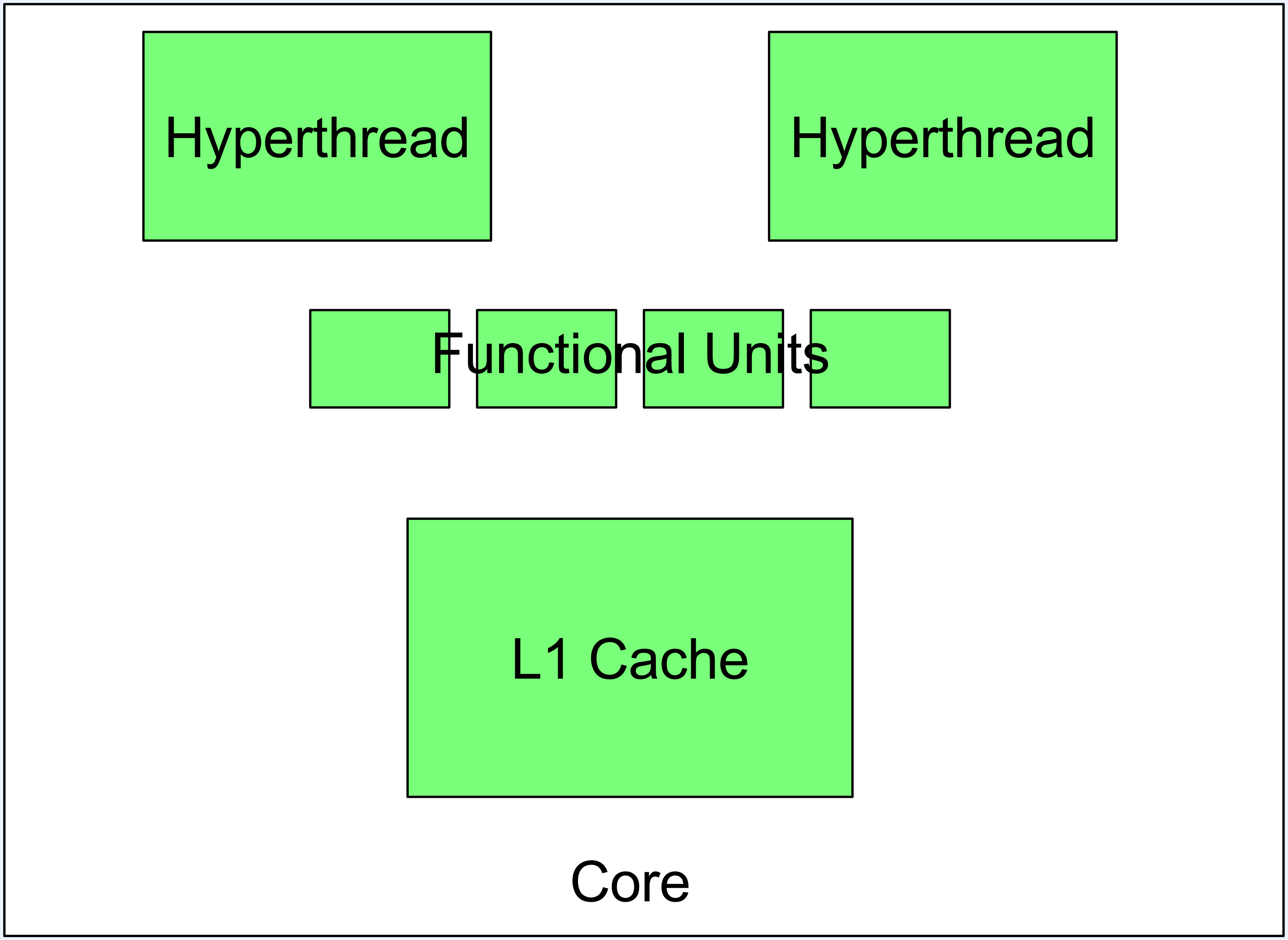


DDR3 Memory
Memory controller
Router
L3
L2
L1d
L1i
core 0
core 1
core 2
core 3
Intel Core 7
Southbridge
USB
SATA bus

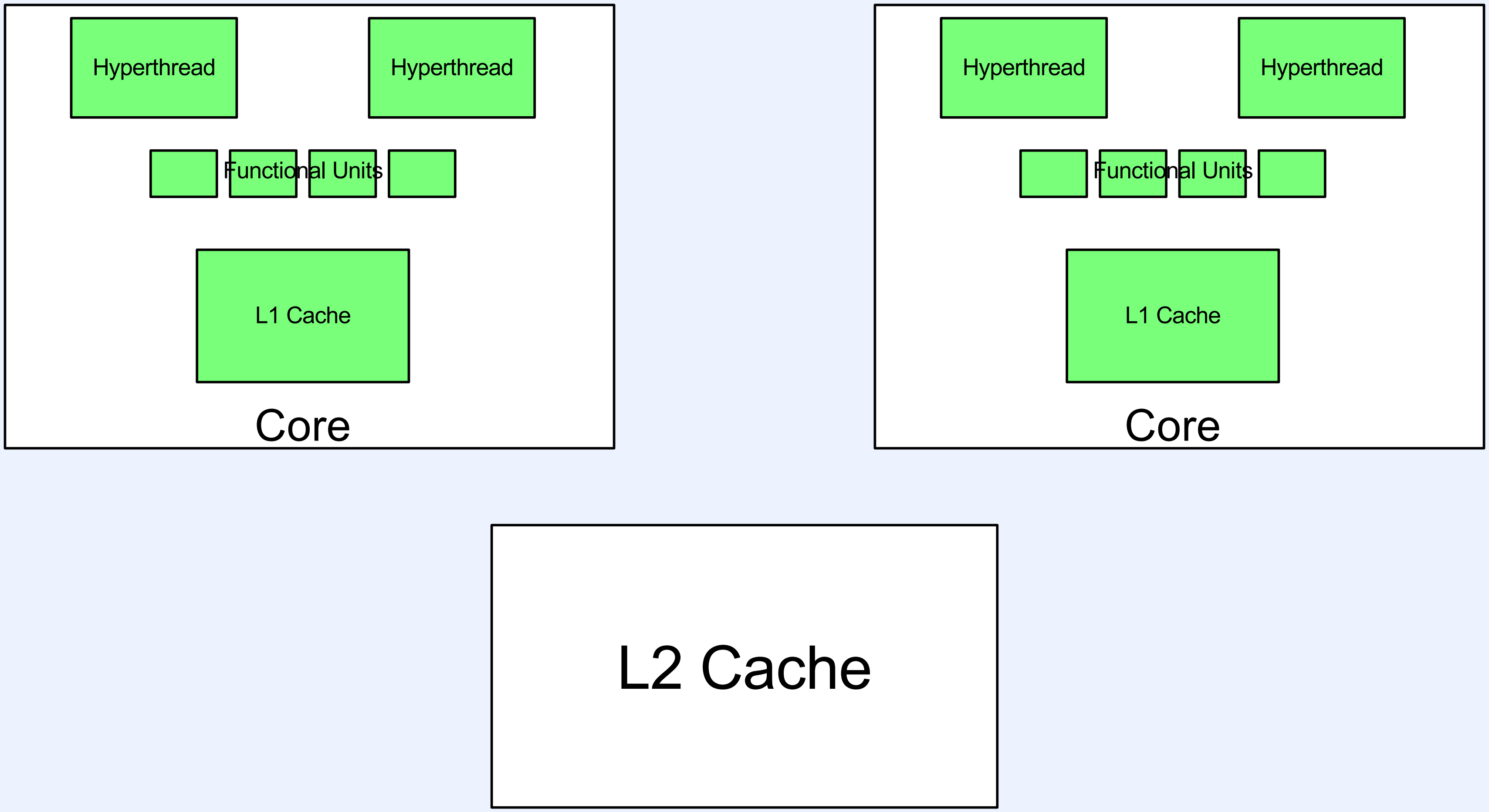
Scheduling Concerns

- Hyperthreads
  - two instruction streams sharing same functional units and same L1 cache
- How long does cache footprint matter?
  - what cache parameters are important?
- When is it a good idea to put a thread on:
  - a different core?
  - a different NUMA node?

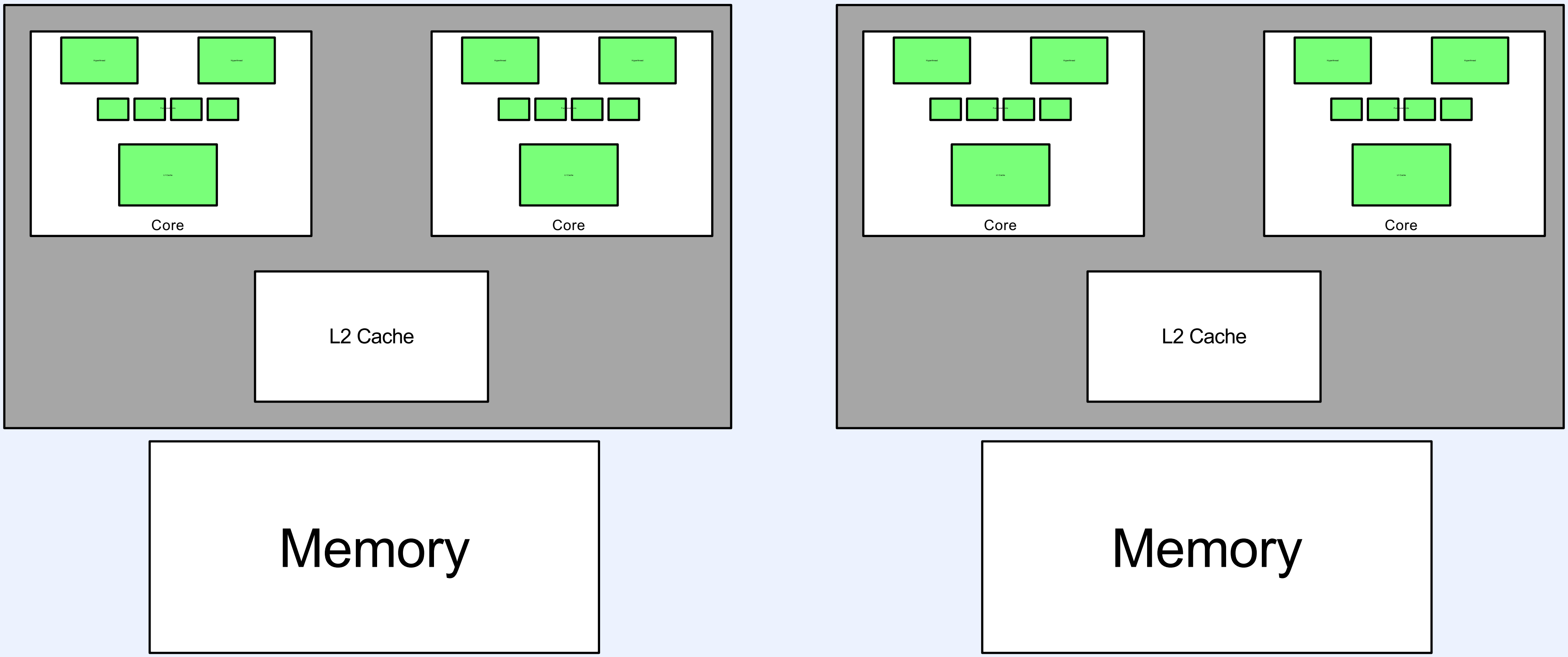
Hyperthreads



Cores


Hyperthread
Hyperthread
Functional Units
L1 Cache
Core
Hyperthread
Hyperthread
Functional Units
L1 Cache
Core
L2 Cache

NUMA Nodes



Quiz 1

We have a system comprised of two NUMA nodes, each with four cores, each with two hyperthreads. The first node has four threads of different processes running on it; the other node is completely idle. One of the threads on the first node calls *pthread_create*.

a) The new thread should be assigned to an idle hyperthread on the first node

b) The new thread should be assigned to a hyperthread on the other node

c) The new thread should be assigned to a hyperthread on the same node and some other thread should move to the other node

Quiz 2

We have a system comprised of two NUMA nodes, each with four cores, each with two hyperthreads. The first node has four threads of different processes running on it; the other node is completely idle. One of the threads on the first node calls *fork*.

a) The new thread should be assigned to an idle hyperthread on the first node

b) The new thread should be assigned to a hyperthread on the other node

c) The new thread should be assigned to a hyperthread on the same node and some other thread should move to the other node

Quiz 3

We have a system comprised of two NUMA nodes, each with four cores, each with two hyperthreads. The first node has four threads of different processes running on it; the other node is completely idle. One of the threads on the first node calls *exec*.

a) The thread should stay where it is

b) The thread should be assigned to a hyperthread on the other node

c) The thread should stay where it is and some other thread should move to the other node