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DRESDEN

# Hard Real-Time Multiprocessor Scheduling

## (Part II)

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TECHNISCHE
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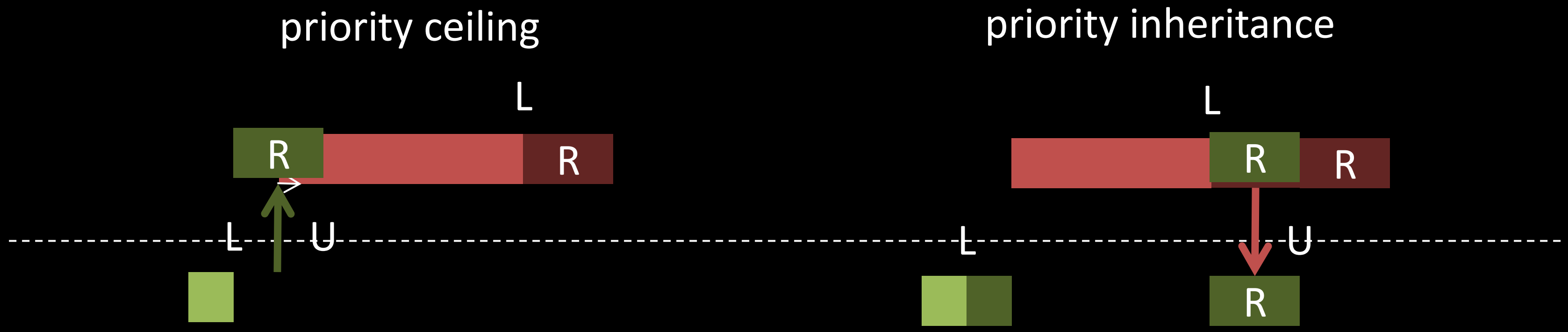
DRESDEN

# Lessons Learned from UP

two concepts to counteract priority inversion

- priority inheritance
- priority ceiling



# Locking Protocols

[Brandenburg ’10,

Brandenburg ‘13]

- Where to execute the critical section?

  local vs. remote

- How to order conflicting critical sections?

  FIFO vs. priorities

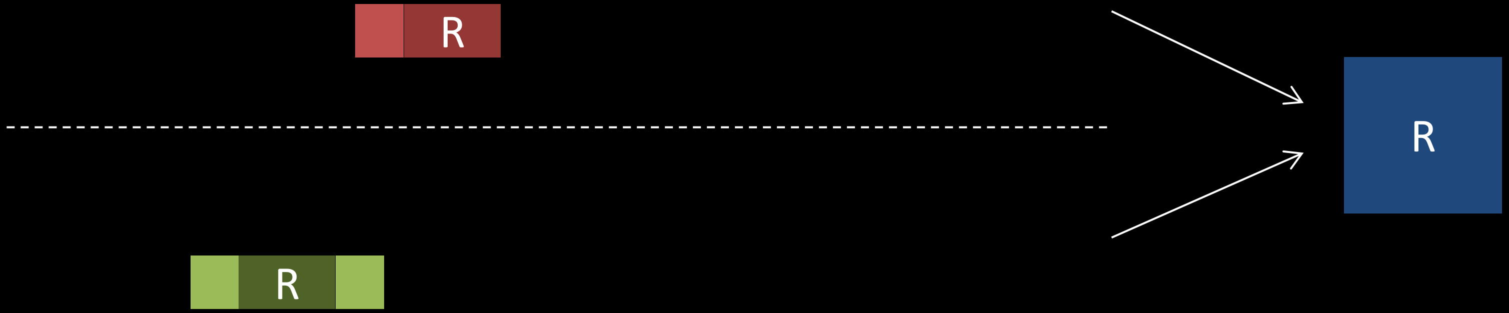
- How unrelated tasks affect the lock holders?
- Whether and how unrelated tasks are affected?

# Where to execute?

[Brandenburg ’10,

Brandenburg ‘13]

local vs. remote



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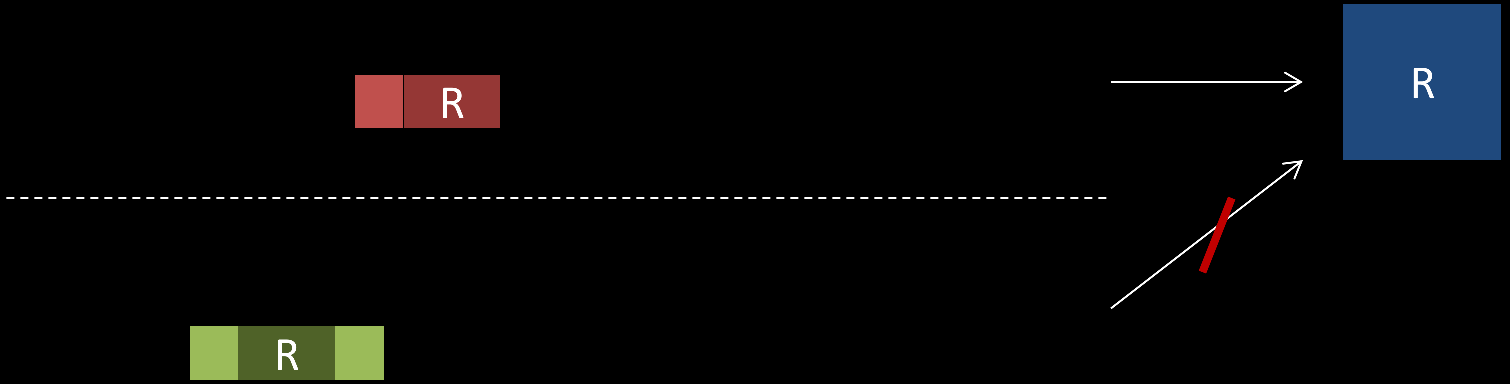

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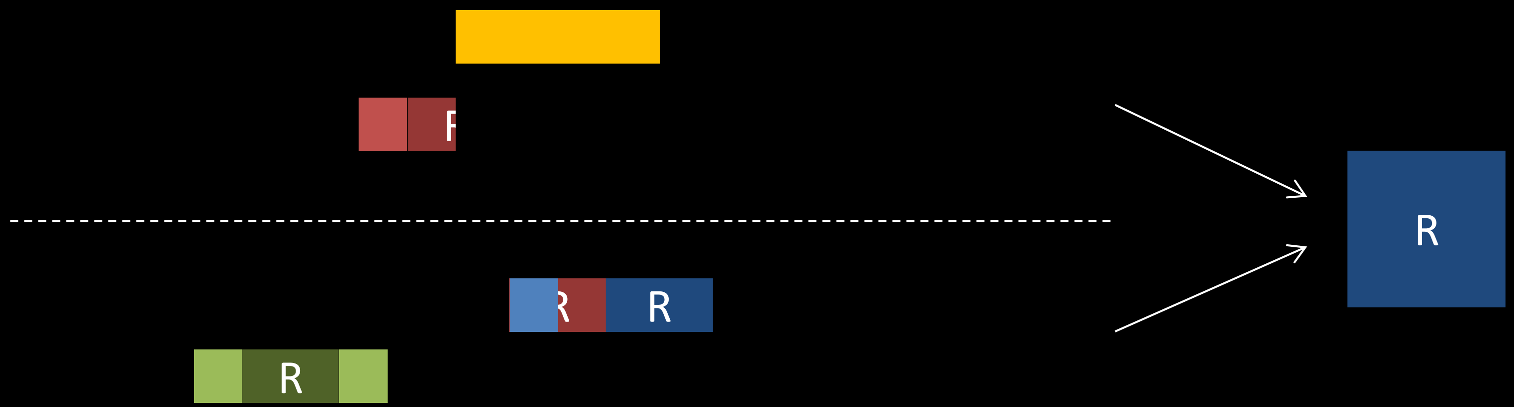
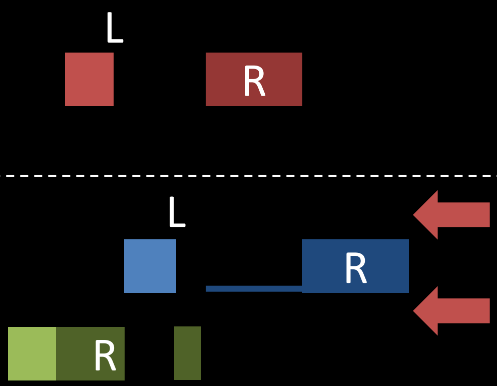


# How to order conflicts?

[Brandenburg ’10,

Brandenburg ‘13]

FIFO vs. priorities



FIFO: O(n)
Priorities: O(higher prioritized on other CPUs)

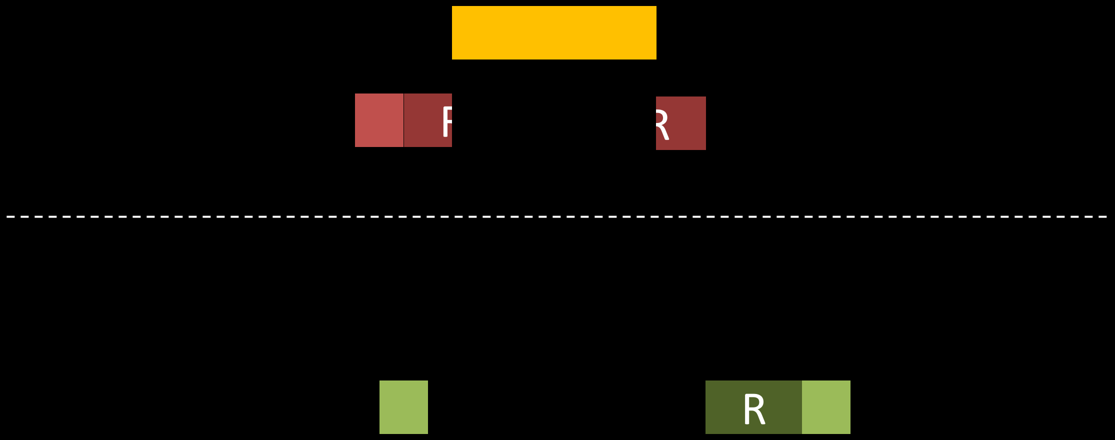
O(1) ?     O(m) ?

# Unrelated tasks affect the lock

[Brandenburg ’10,

Brandenburg ‘13]

Block local vs. remote



$$\sum_{\tau_j \in H(i)} C_j$$

# Unrelated tasks affect the lock

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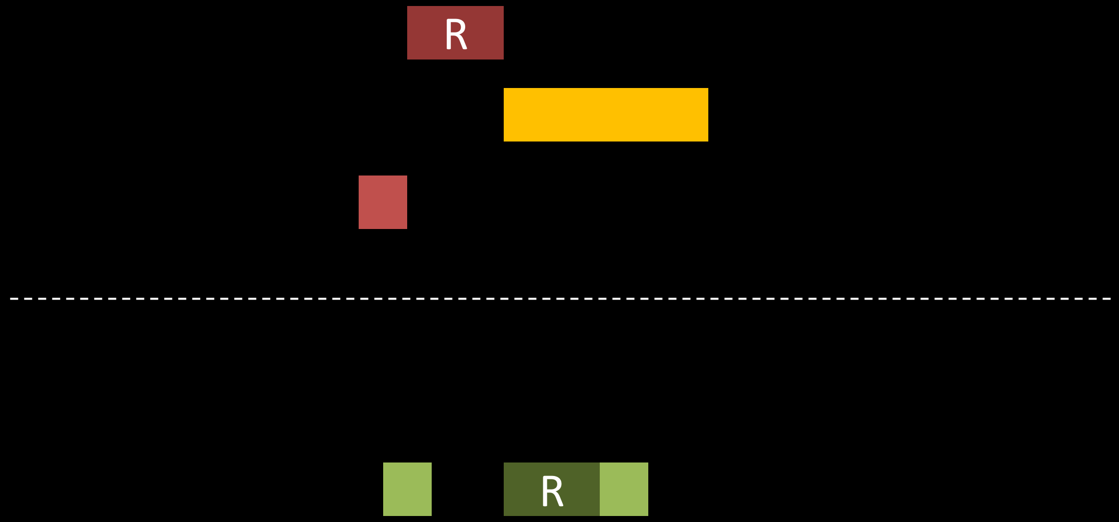

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# How unrelated threads are affected

[Brandenburg ’10,

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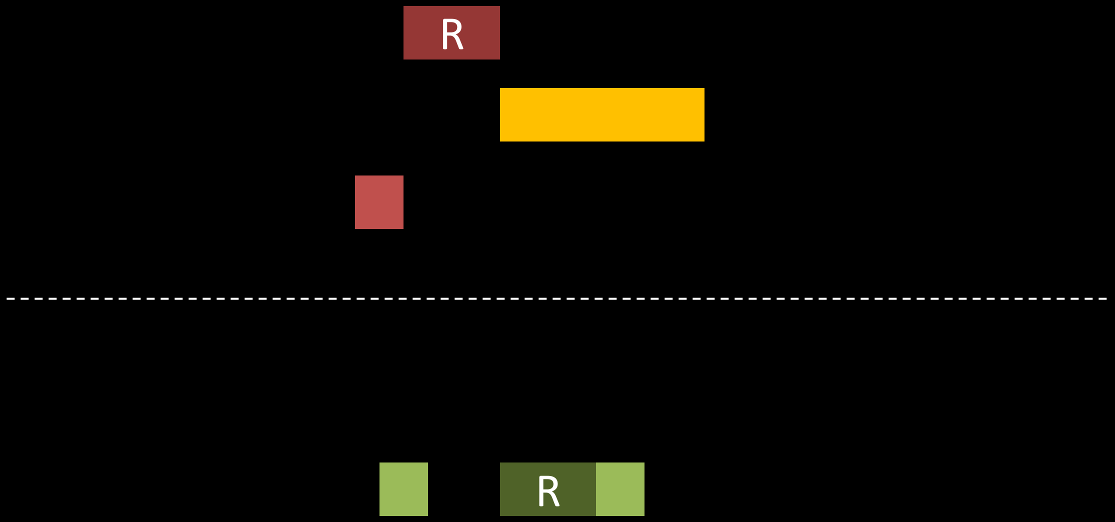
Block local vs. remote



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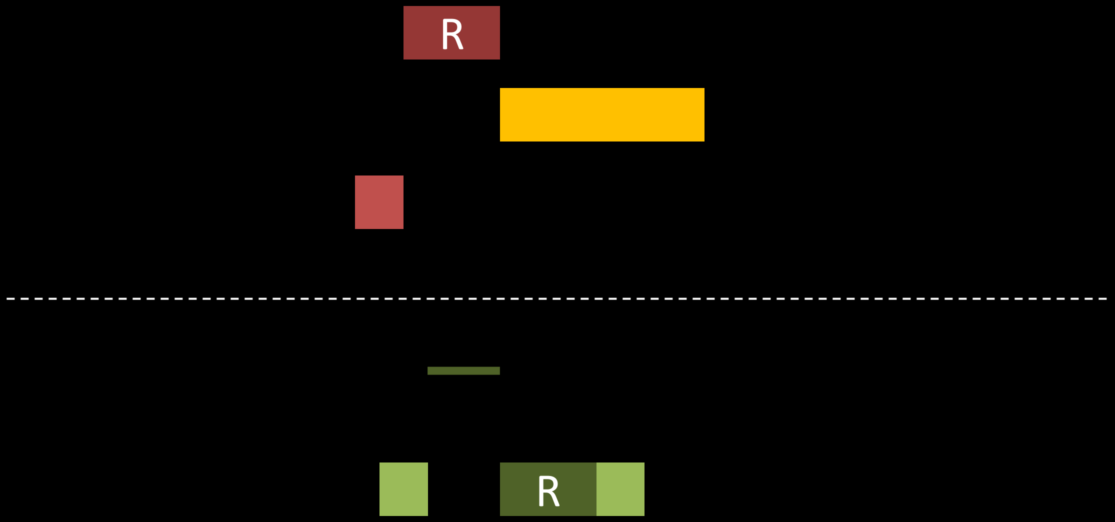


$$\sum_{\tau_j \in H(i)} C_j$$

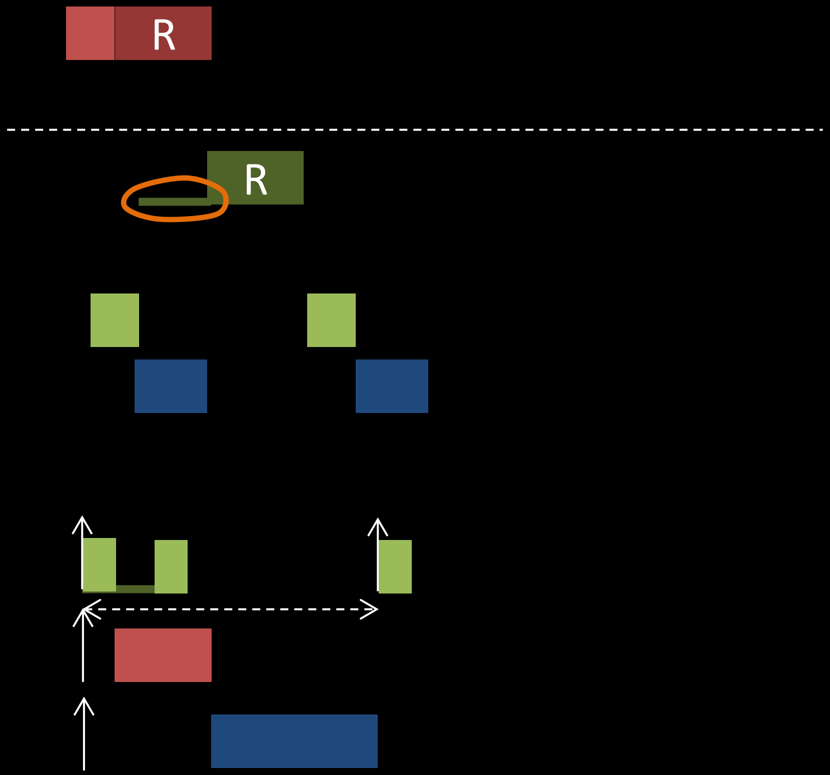
# RT-Locking Terminology

schedulability analysis

- suspension-aware
- suspension-oblivious

blocking

- priority-inversion blocking
- deferral blocking



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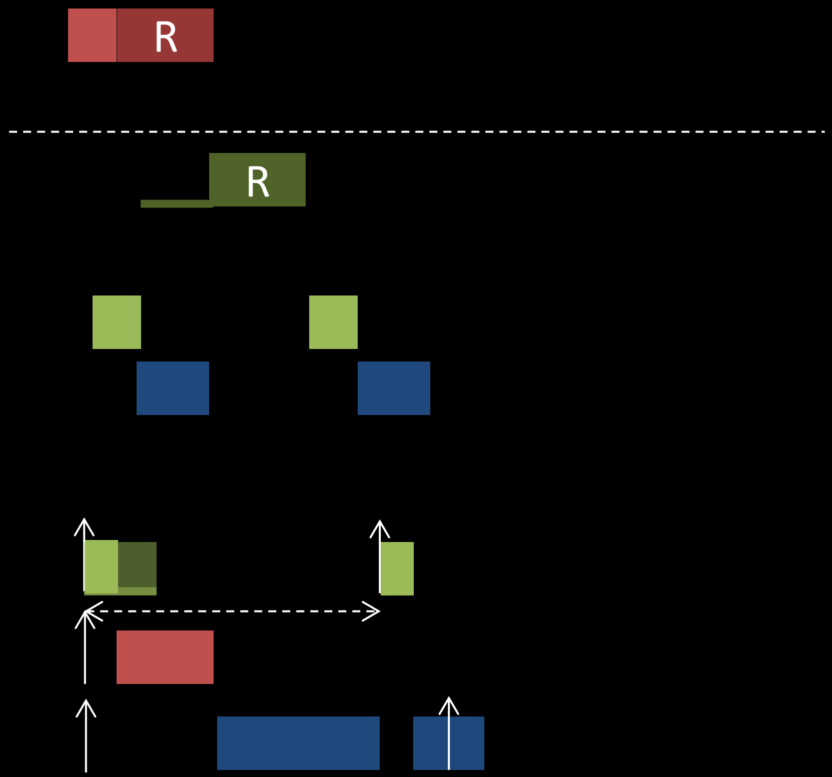
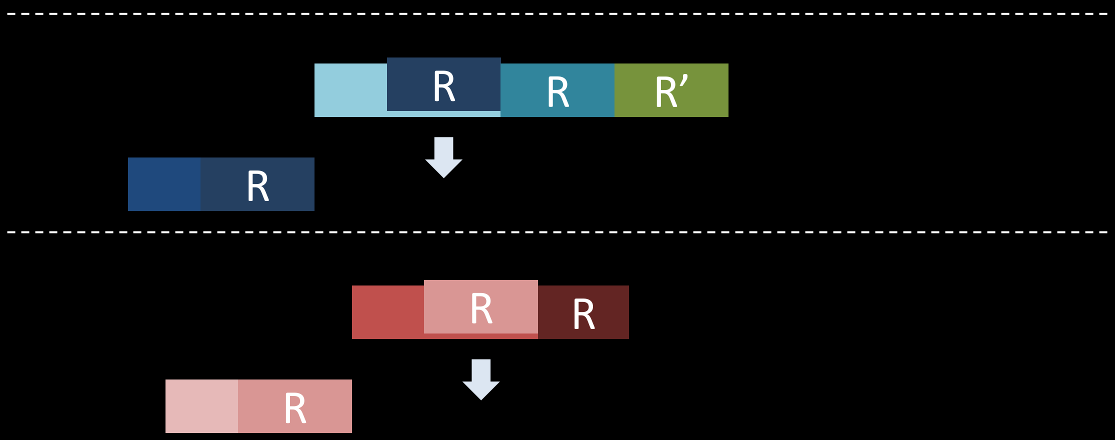


# Reuse UP Protocols?

Distributed Priority-Ceiling Protocol (DPCP) [Rajkuma, Sha, Lehocky ‘88]



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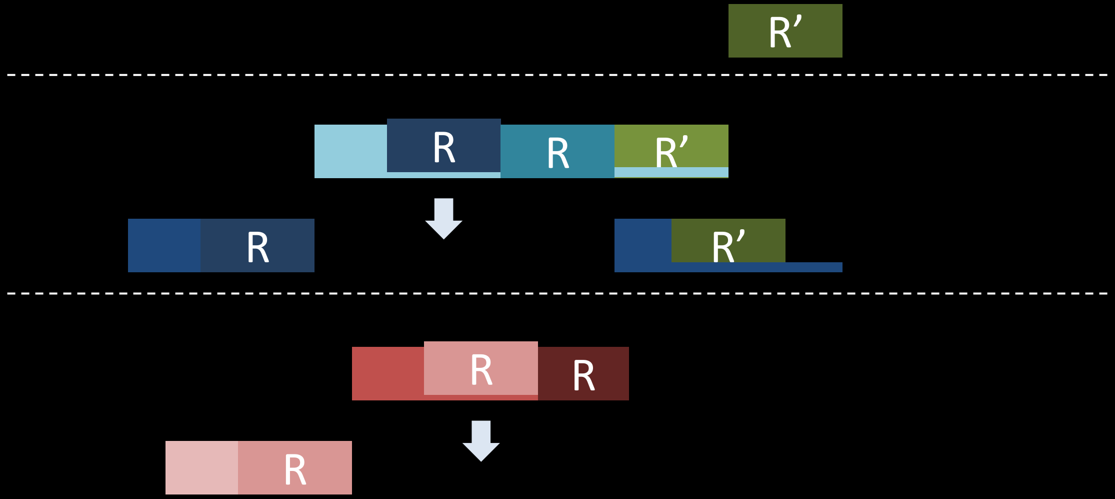
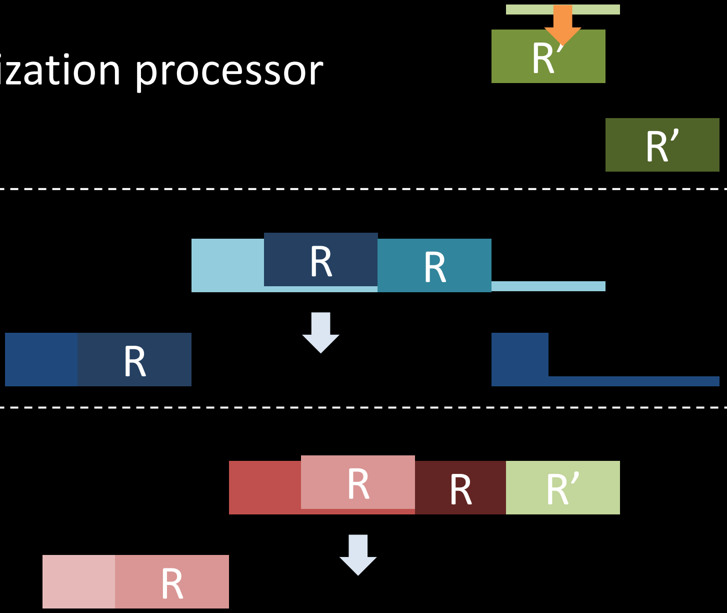


# Reuse UP Protocols?

Distributed Priority-Ceiling Protocol (DPCP) [Rajkuma, Sha, Lehocky '88]

synchronization processor

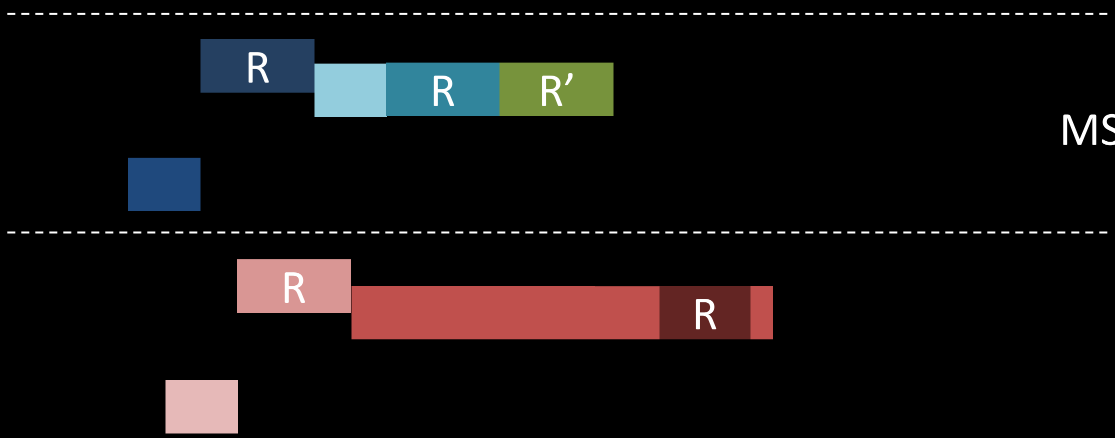


DPCP = $\text{BPCP}^{m+1}$

# Reuse UP Protocols?

Multiprocessor Stack Resource Protocol (MSRP) [Gai, Lipari, Natale ‘01]

synchronization processor



MSRP = $\text{MSRP}^{m+1}$

# Björn Brandenburg

Improved Analysis and Evaluation of Real-Time Semaphore Protocols for Partitioned Fixed Priority Scheduling ‘13

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| | MPCP<br>[Rajkumar ‘90,<br>Lakshmanan ’09] | FMLP<br>[Brandenburg ’11] | DPCP<br>[Rajkumar ’88] | DFLP<br>[Brandenburg ’11] |
|---|---|---|---|---|
| wait queue | priority | FIFO | priority | FIFO |
| protocol type | shared mem.<br>(local) | shared mem.<br>(local) | distributed<br>(sync. CPU) | distributed<br>(sync. CPU) |
| asymptotically optimal (wrt. maximal blocking) | No | Yes | No | Yes |

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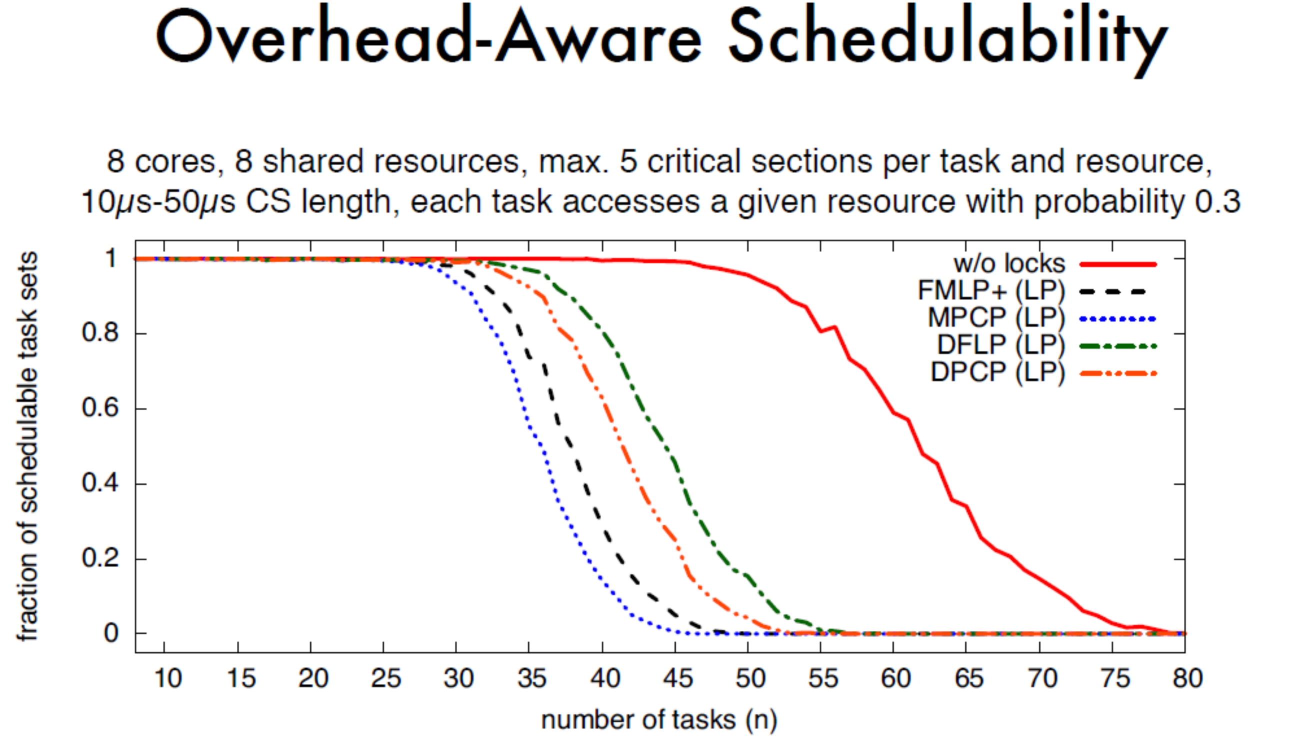
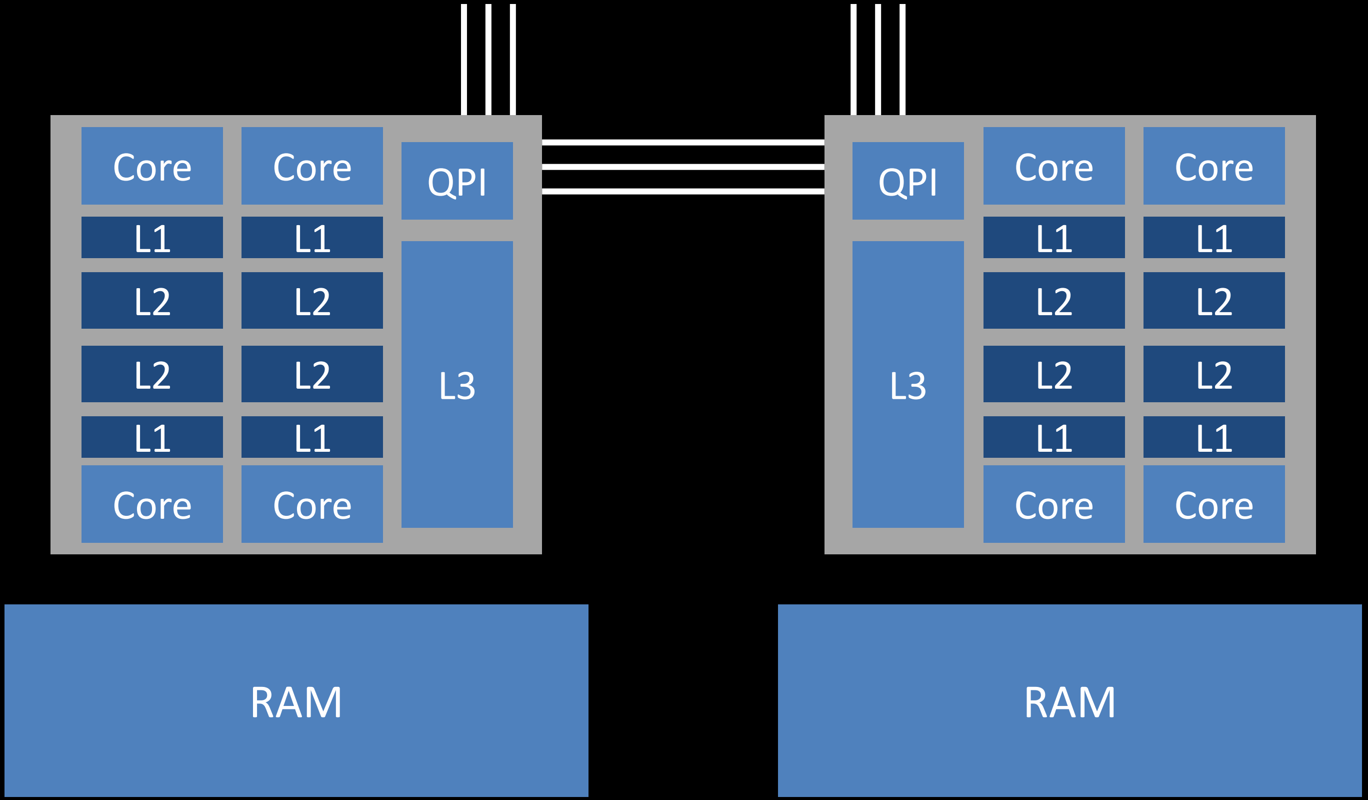


## Overhead-Aware Schedulability

8 cores, 8 shared resources, max. 5 critical sections per task and resource, 10$\mu$s-50$\mu$s CS length, each task accesses a given resource with probability 0.3

# Caches



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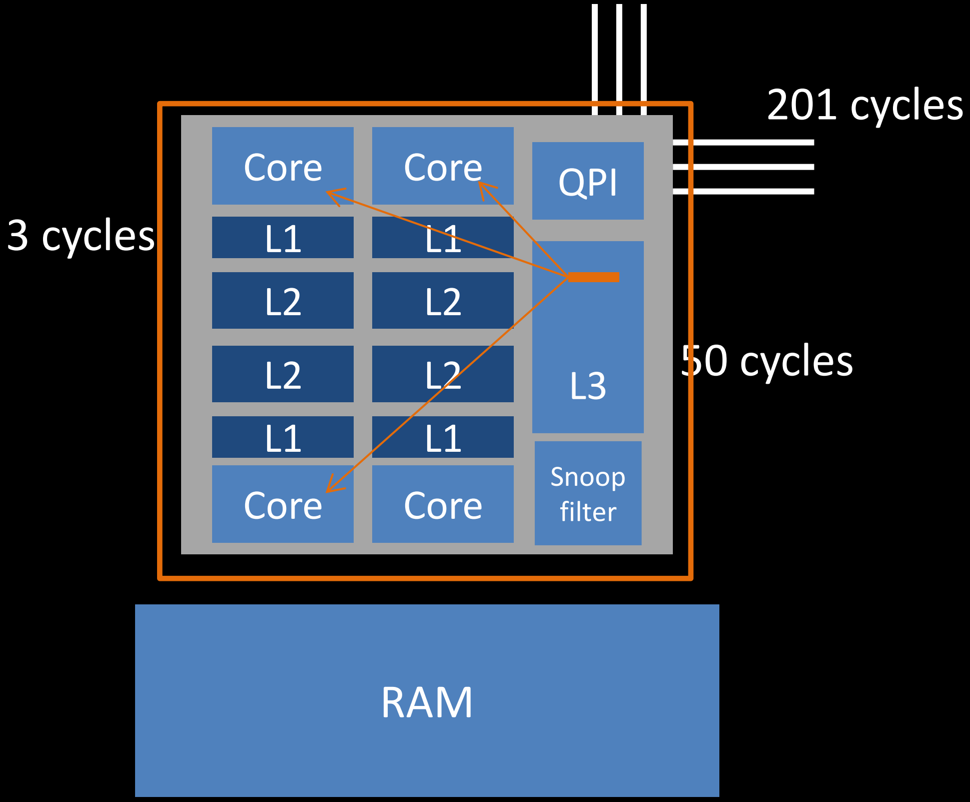


[Corey: OSDI ‘08]

reduce coherent traffic by

keeping track of cached lines

- inclusive L3:

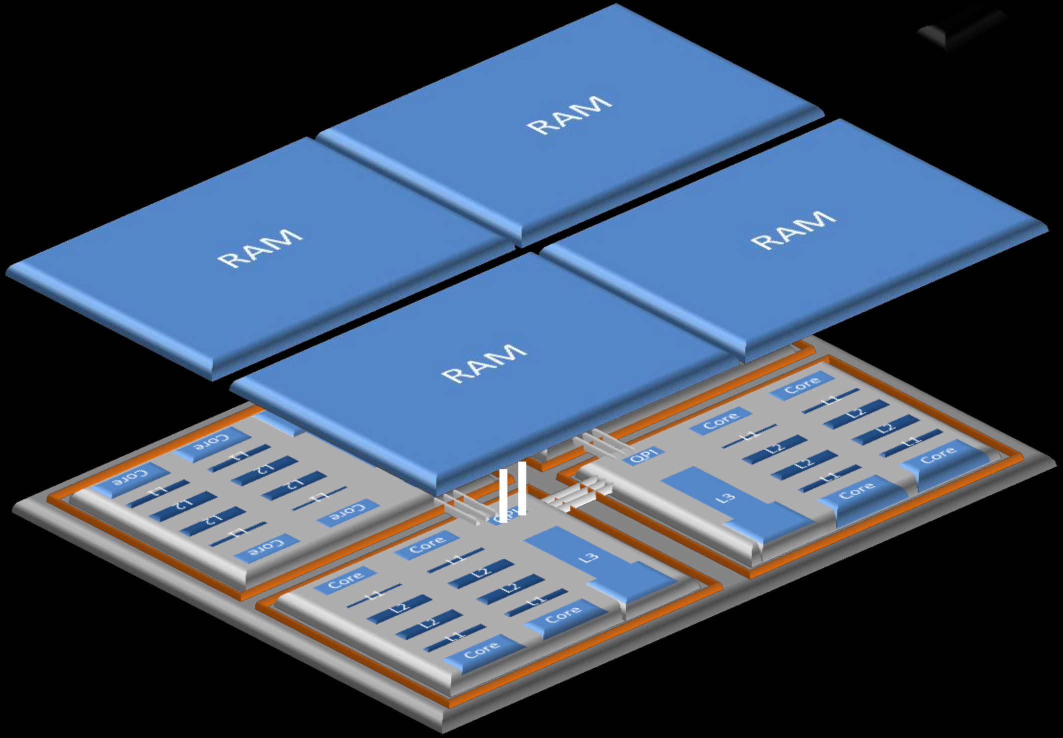
  line ∈ L1, L2 => line ∈ L3

- snoop filter:

  keep address not data

# Caches

[Corey: OSDI '08]



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# RT - Locks for Clusters

Real-Time Resource-Sharing under Clustered Scheduling:
Mutex, Reader-Writer, and k-Exclusion Locks
Björn Brandenburg, Jim Anderson '11

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What if

- every task helps out a little bit when it is released?
- only the n-highest prioritized tasks may acquire locks?

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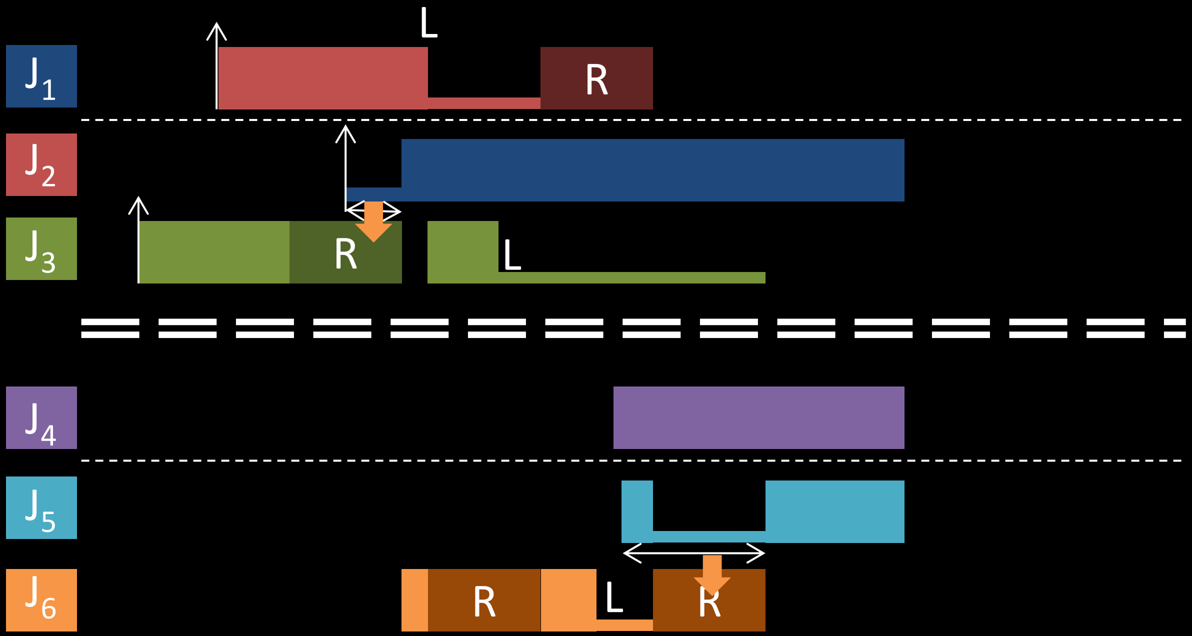

# RT - Locks for Clusters

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D1. $J_i$ may issue a request only if it among the n = |CPU| highest prioritized jobs

D2. When released at time ta, Jd becomes Ji's priority donor if a) $J_i$ was the c = |Cluster| highest-priority pending job released prior to $J_d$, b) $J_d$ has one of the c highest base priorities, and c) $J_i$ has issued a request that is incomplete

D3. $J_i$ inherits $J_d$'s priority

D4. If $J_d$ ceases to be among the c highest-priority jobs in its cluster, the newly released job takes over the donor role

D5. / D6. schedule either $J_i$ or its donor $J_d$

D7. a priority donor may not issue requests ($J_d$ suspends in this case while being a priority donor)

D8. If $J_d$ finishes execution while being a donor, $J_d$ remains the donor but is suspended

D9. $J_d$ stops being a donor if a) $J_i$ completes its request, b) $J_i$ becomes one of the c highest prioritized jobs c) another job takes over being the donor of $J_i$

# Outline

Last Week:

- Terminology and Notations
- Anomalies and Impossibility Results
- Partitioned Scheduling
- Global Scheduling
- Optimal MP Scheduling
- Practical Matters

Today:

- Exercise: UP Resource Protocols
- Resources
  - Caches / Memories
- One More Resource
- Dynamic Tasks
- Peek and Poke into other Bleeding Edge Research

# Caches

A Coordinated Approach for Practical OS-Level Cache Management in Multi-Core Real-Time Systems
Hyoseung Kim, Arvind Kandhalu, Ragunathan (Raj) Rajkumar (ECRTS ’13)

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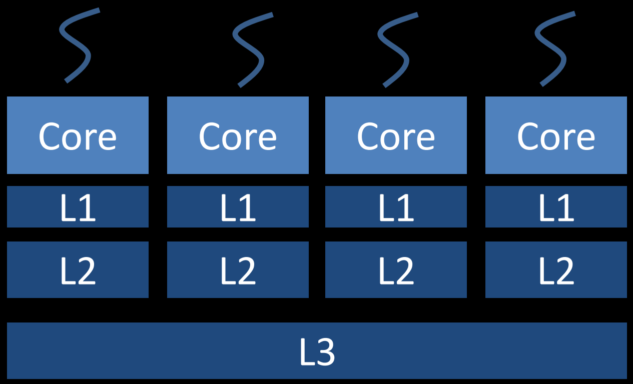
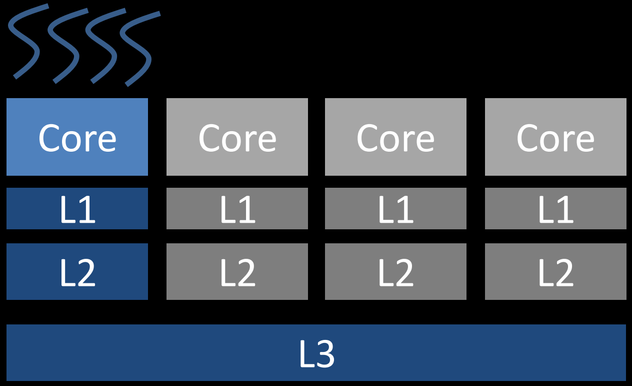


40% slowdown



27% slowdown

PARSEC on i7

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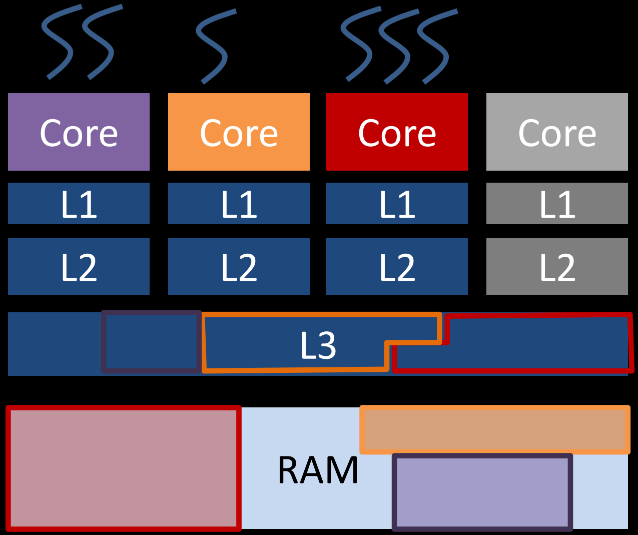

# Dynamic Tasks

Algorithm and complexity for the global scheduling of sporadic tasks on multiprocessors with work-limited parallelism
S. Collette, L. Cucu, J. Goossens [Real-Time and Network Systems, ’07]

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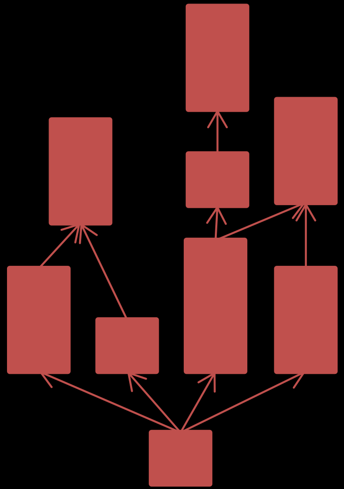
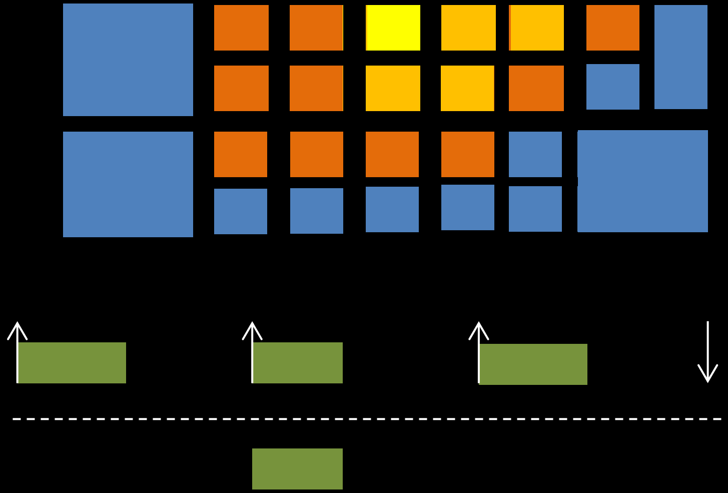


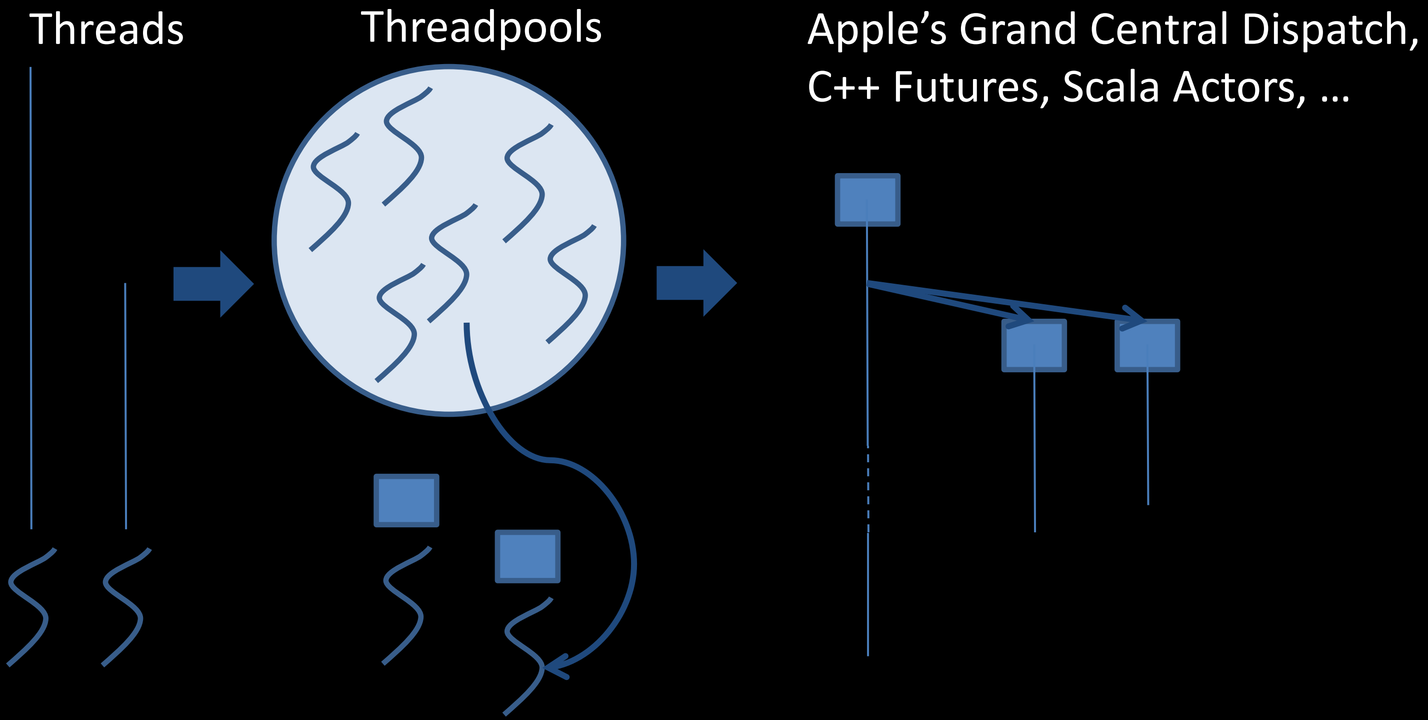


$J_i \overset{\text{def}}{=} (C_i, P_i, \Gamma_i)$

$\Gamma_i \overset{\text{def}}{=} (\gamma_{i,1}, \gamma_{i,2}, \dots, \gamma_{i,m})$

Job $J_i$ with j CPUs completes in $\gamma_{i,j}$ $C_i$

# Dynamic Tasks / Runtime



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