Using Lock Servers to Scale Real-Time Locking Protocols:
Chasing Ever-Increasing Core Counts

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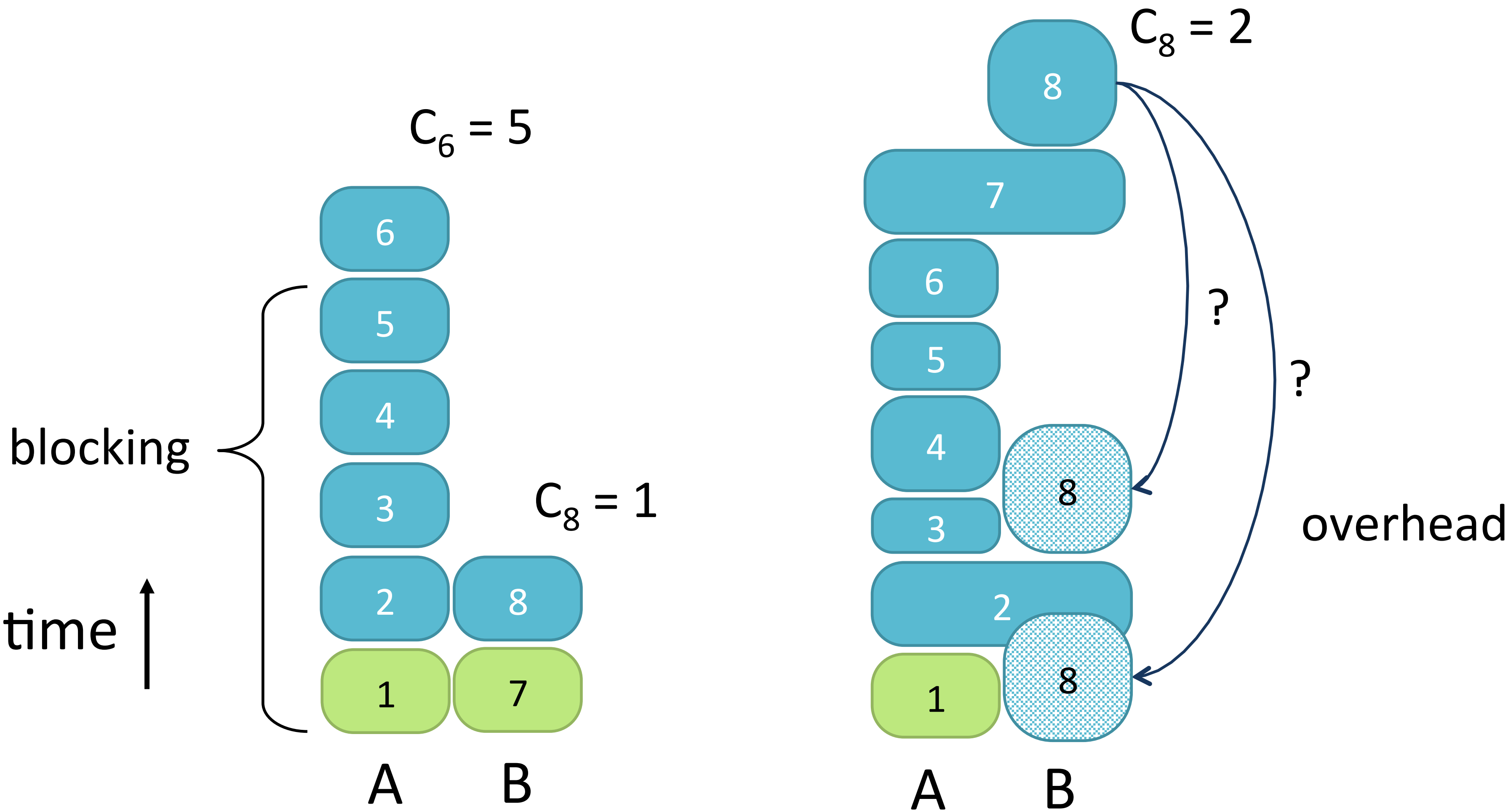
Contention-Sensitive Access



Using Lock Servers to Scale Real-Time Locking Protocols:

Chasing Ever-Increasing Core Counts

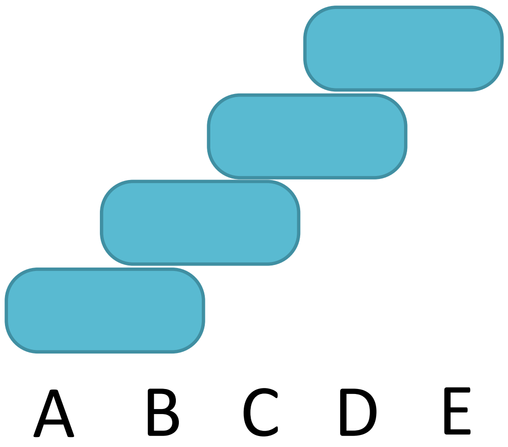
Challenge: Blocking Chains

\# of processors:

m=4

Processing capacity lost:

75%



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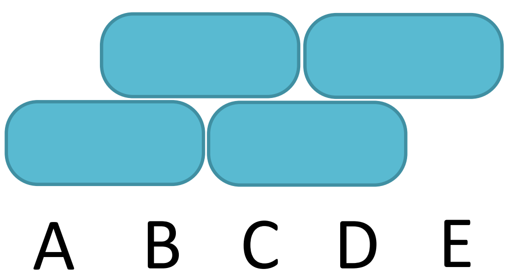
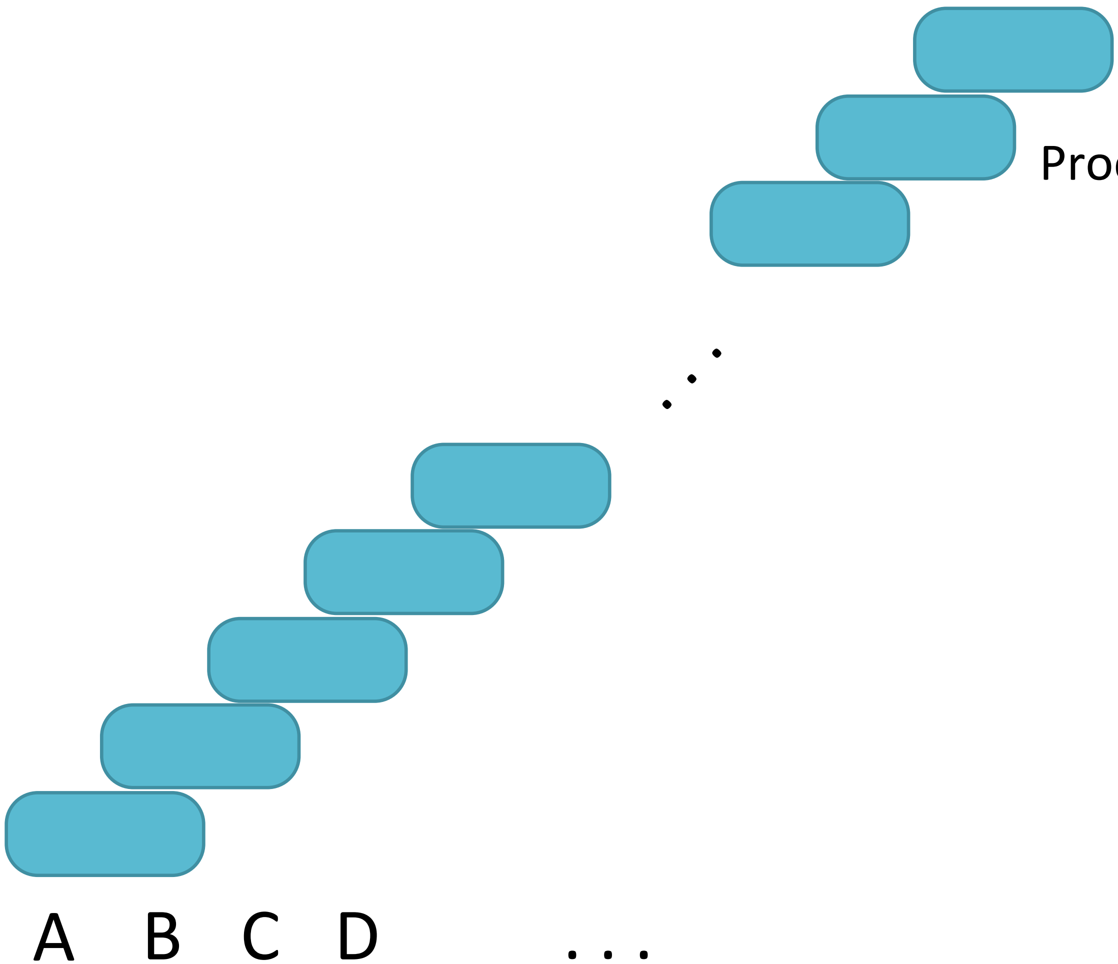


Challenge: Blocking Chains



# of processors:

m=32

Processing capacity lost:

97%

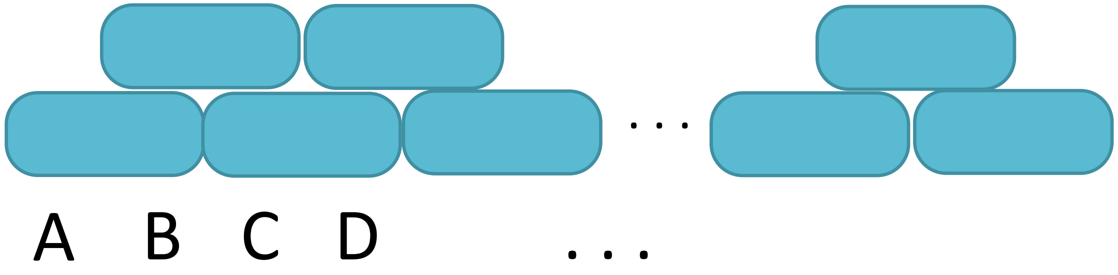
Challenge: Blocking Chains

of processors:

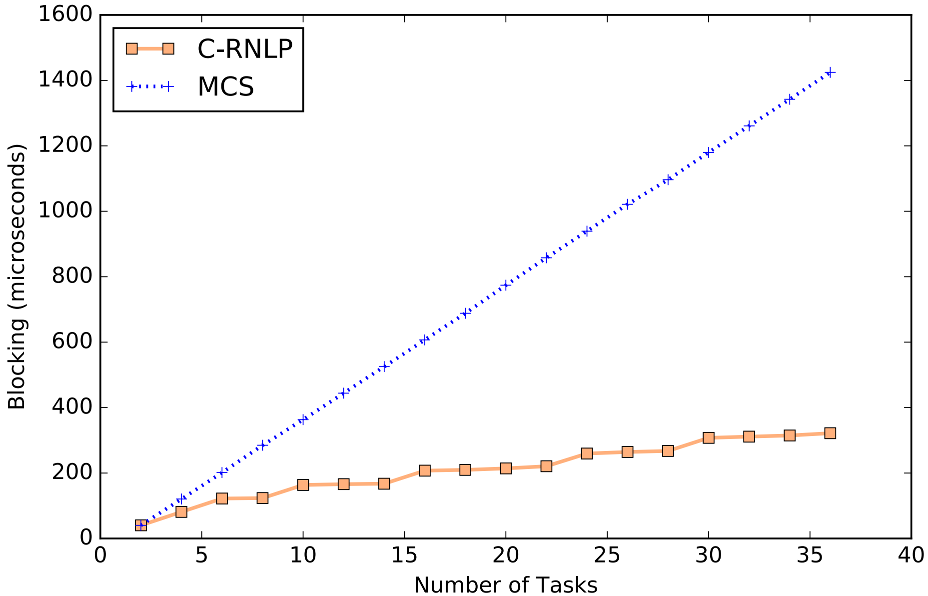
m=32

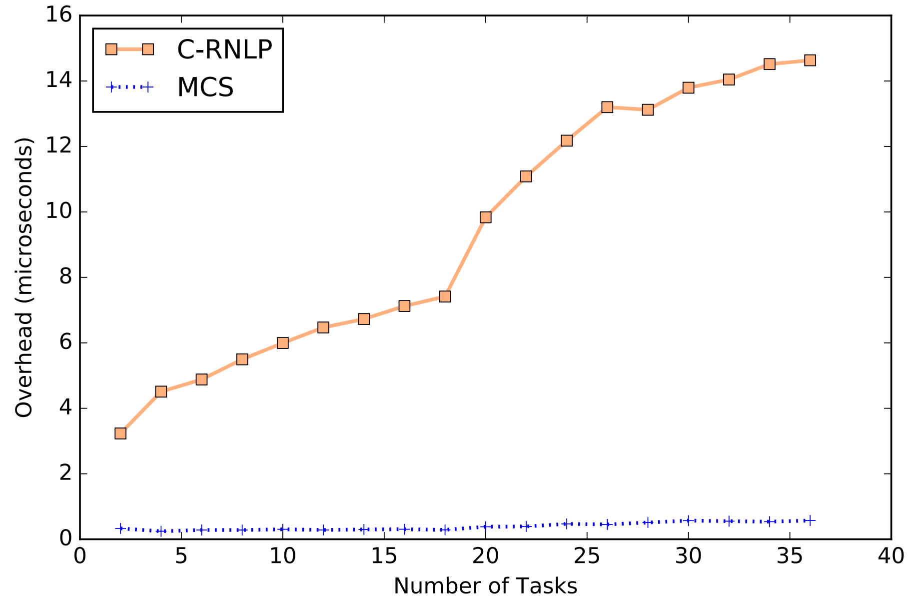
Processing capacity lost:

97%



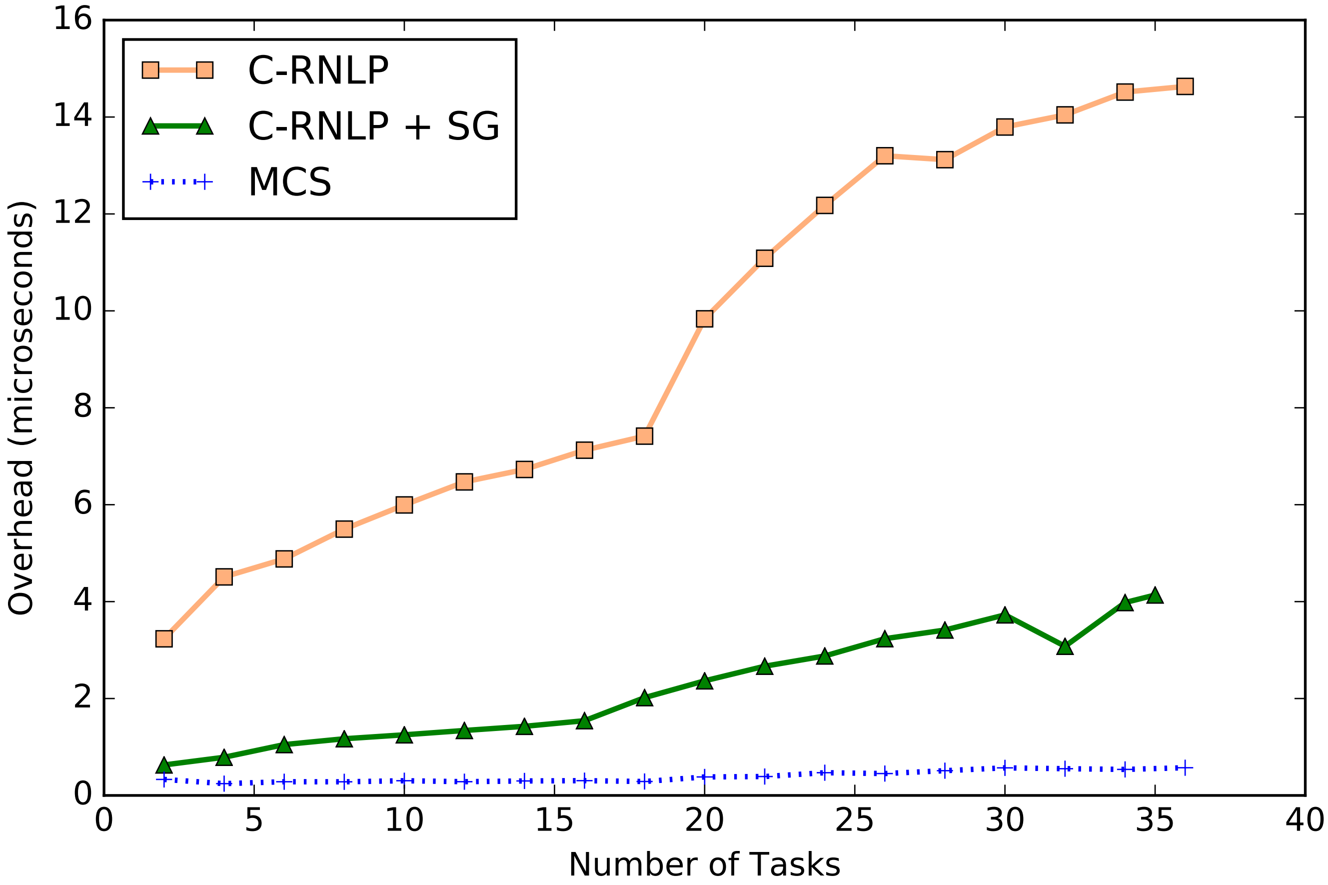
Cost of low blocking: high overhead





C-RNLP: C. Jarrett, B. Ward, and J. Anderson. A contention-sensitive fine-grained locking protocol for multiprocessor real-time systems. *RTNS 2015*.

MCS: J. Mellor-Crummey and M. Scott. Algorithms for scalable synchronization of shared-memory multiprocessors. *Transactions on Computer Systems*, 9(1), 1991.



Proposed Solution: Lock Servers

Four lock server paradigms

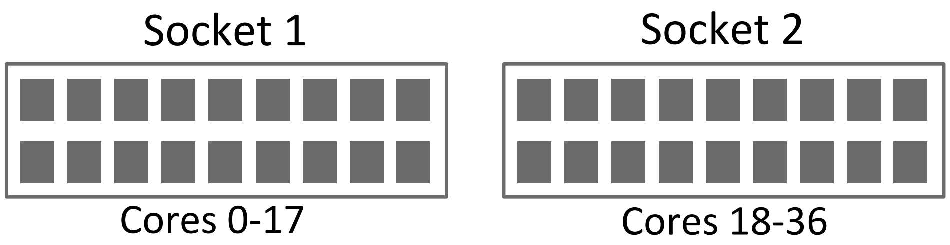
- Implementation
- Evaluation

Lock server coordination protocol

Contributions

Platform Description

dual-socket,
18-cores-per-socket
Intel Xeon E5-2699



L1 Data | L1 Instr.

L2 (shared between two cores)

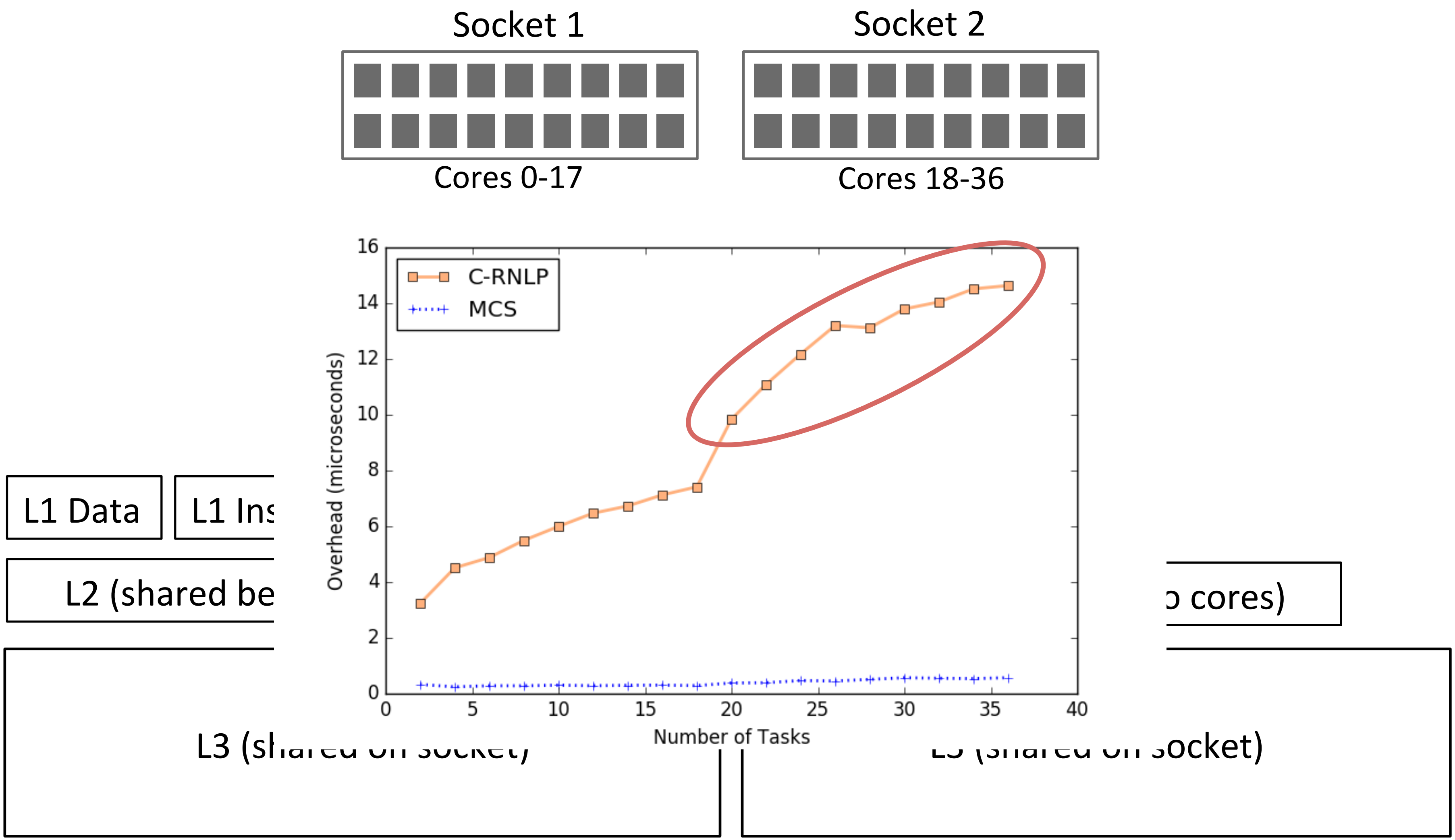
L3 (shared on socket)

L1 Data | L1 Instr.

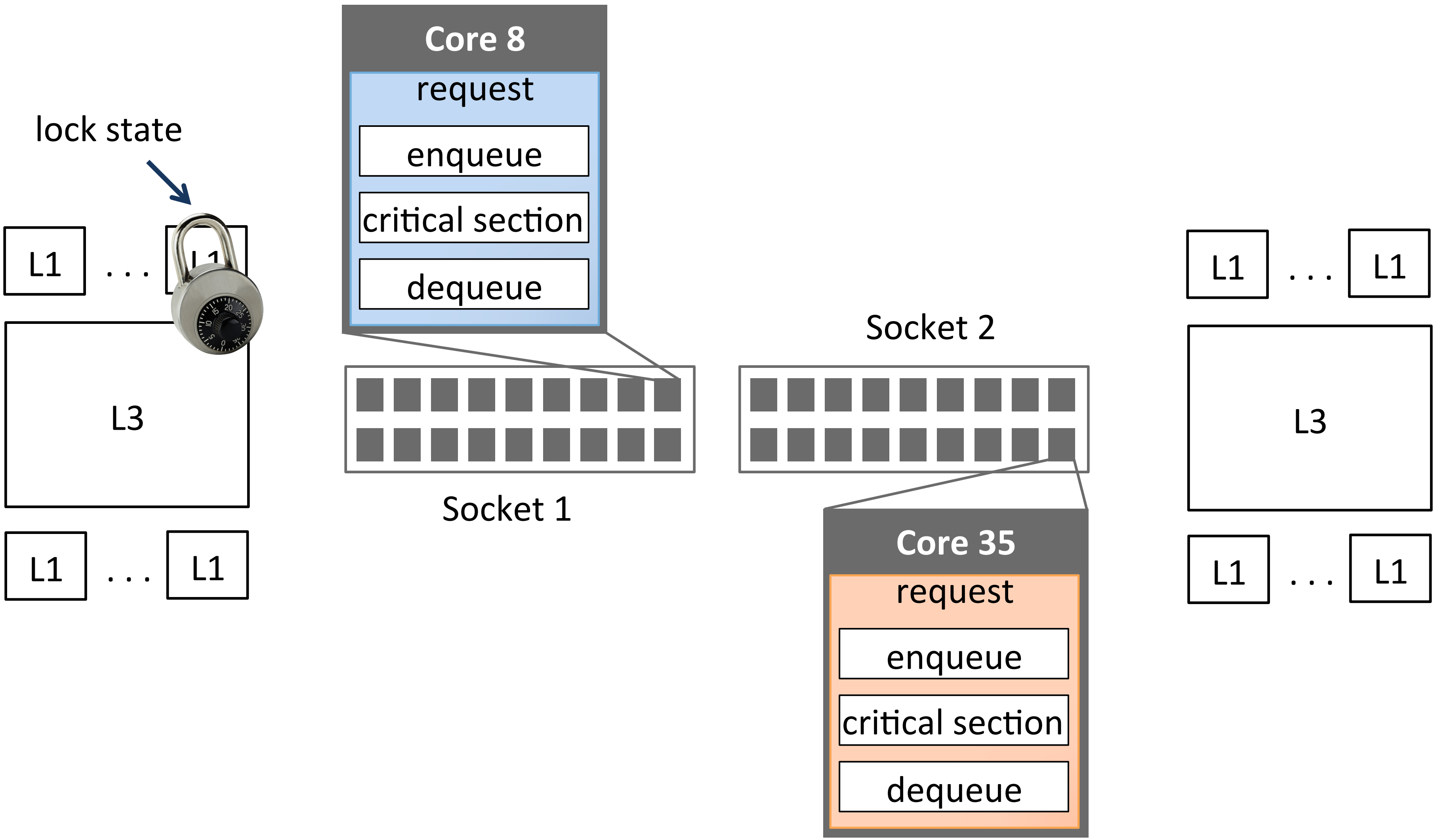
L2 (shared between two cores)

L3 (shared on socket)

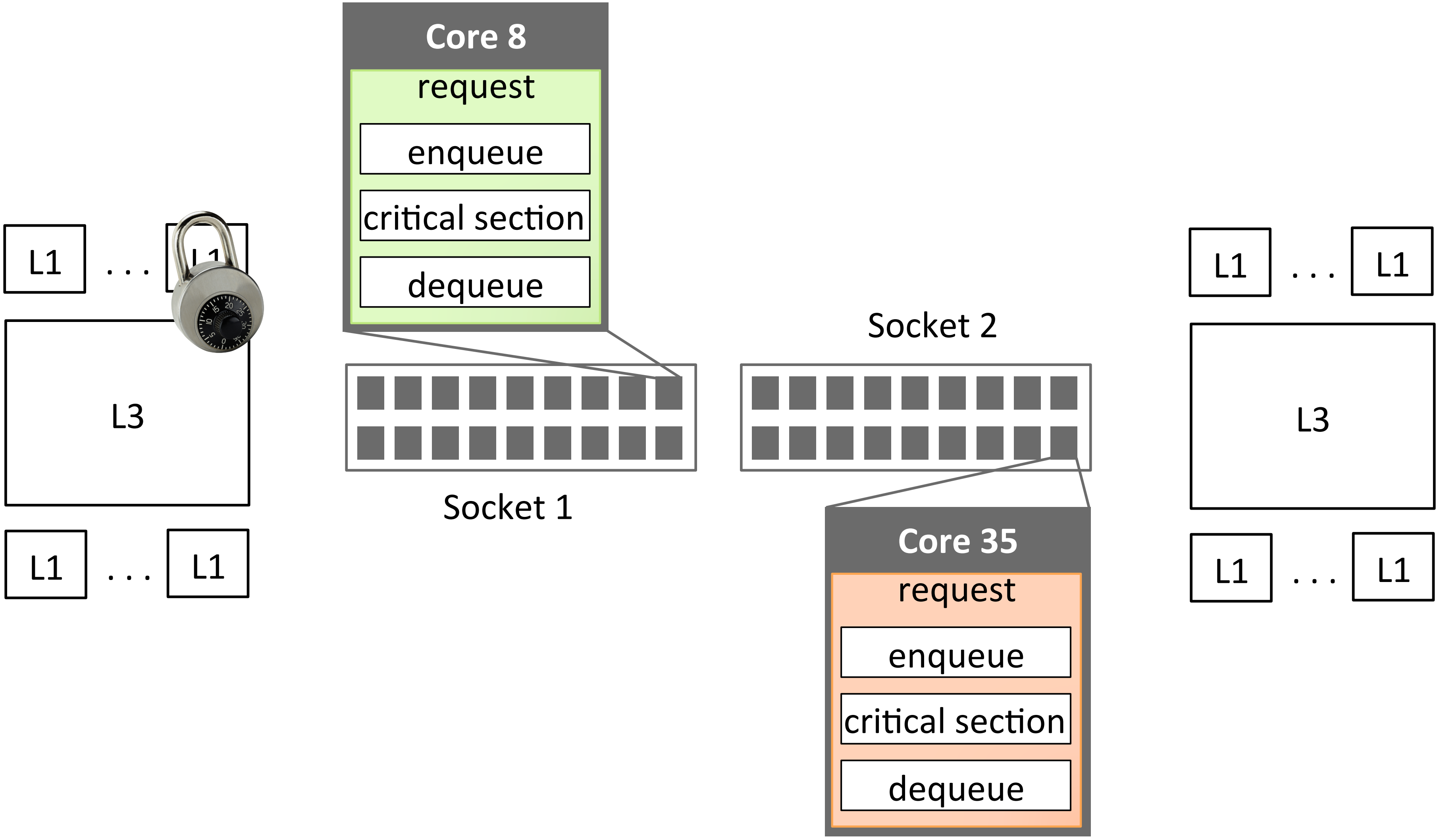
Platform Description



Standard C-RNLP



Standard C-RNLP



The Idea

Remote Core Locking

- used to reduce critical-section lengths [1]

We developed: lock servers

- used to reduce overhead

Lock server: a process dedicated to performing lock and unlock functions

[1] J. Lozi, F. David, G. Thomas, J. Lawall, and G. Muller. Remote core locking: migrating critical-section execution to improve the performance of multithreaded applications. *USENIX ATC 2012*.

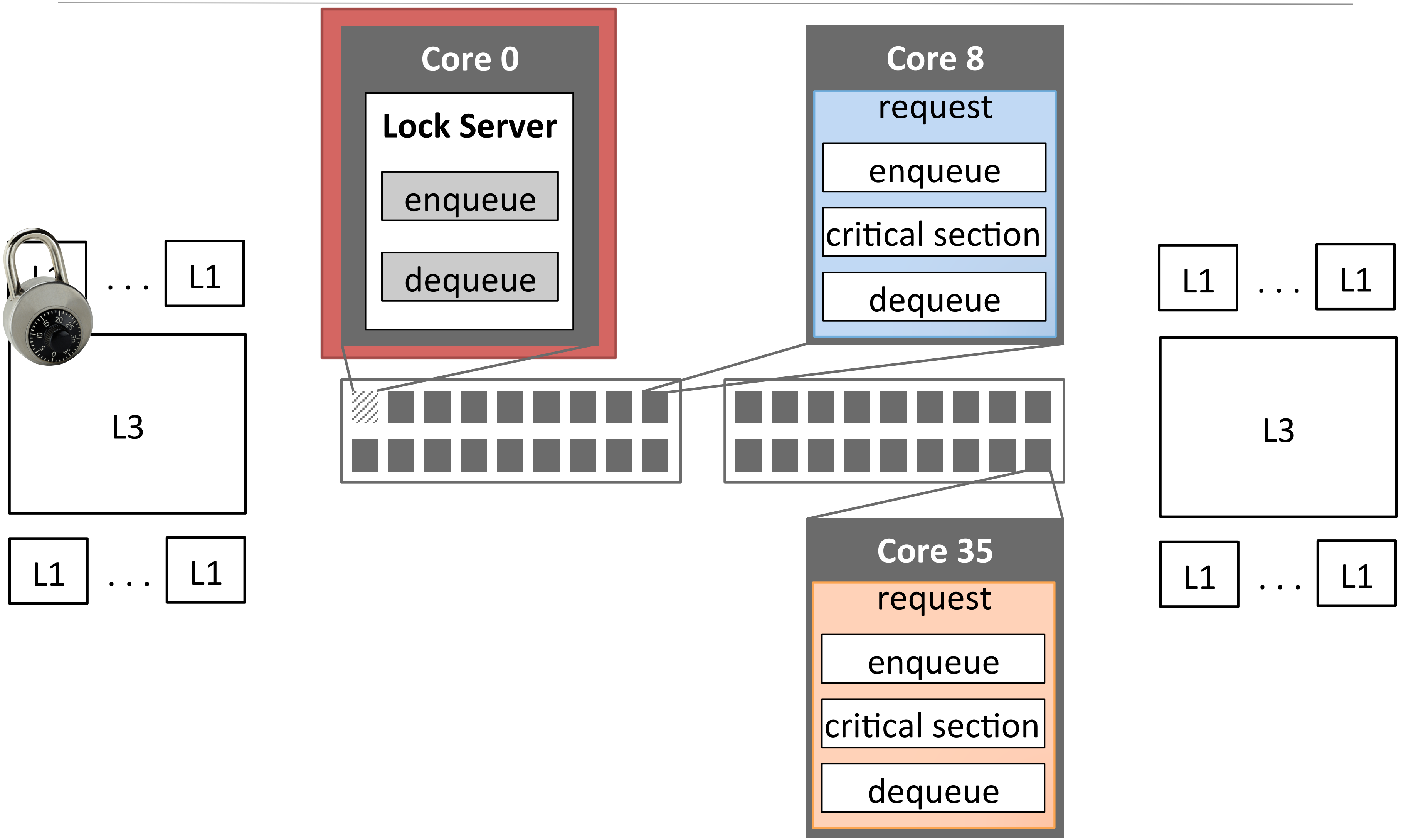
Lock Server Paradigms

locality

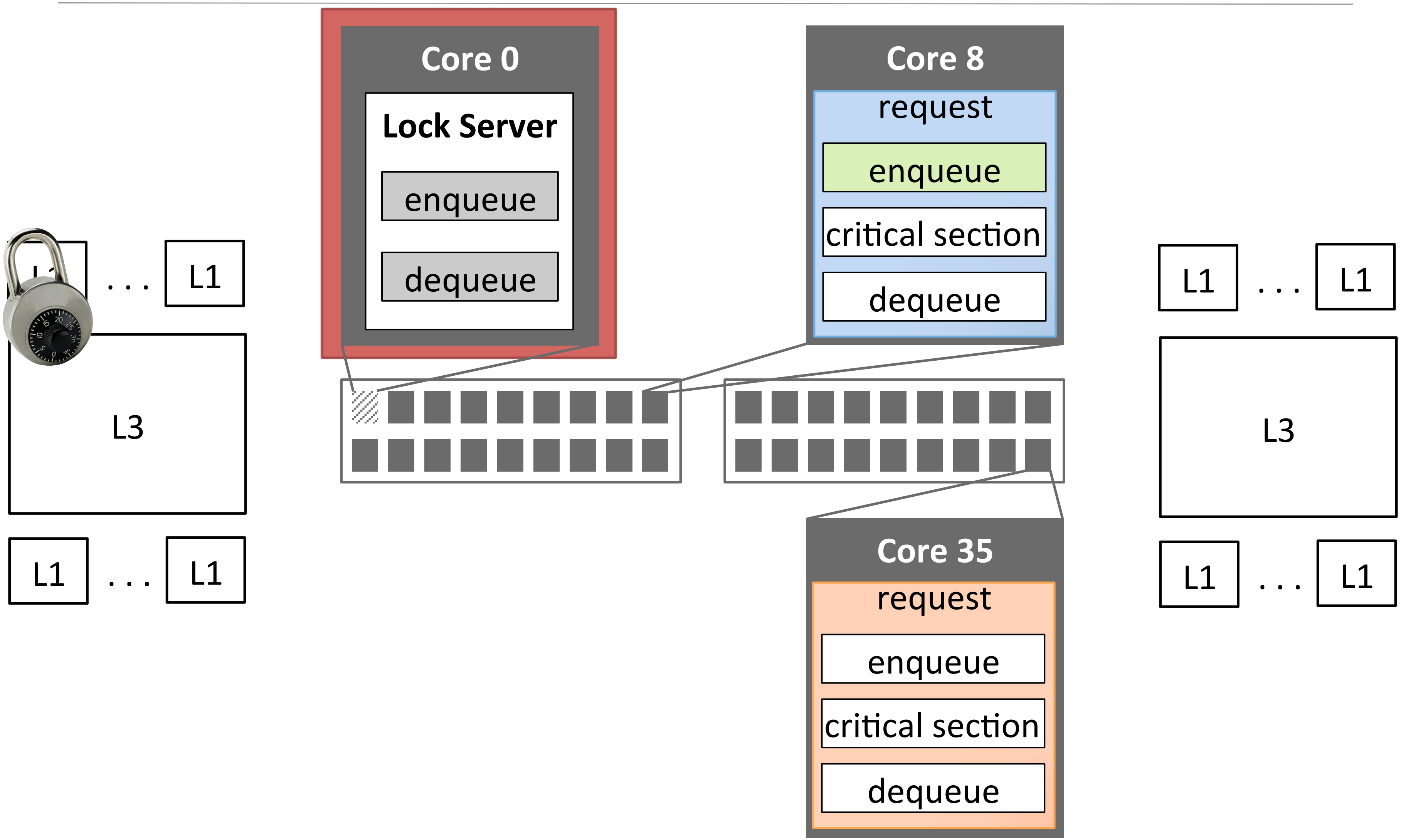
mobility

	Global	Local
Static	#1	
Floating		

Paradigm #1: Static Global



Paradigm #1: Static Global



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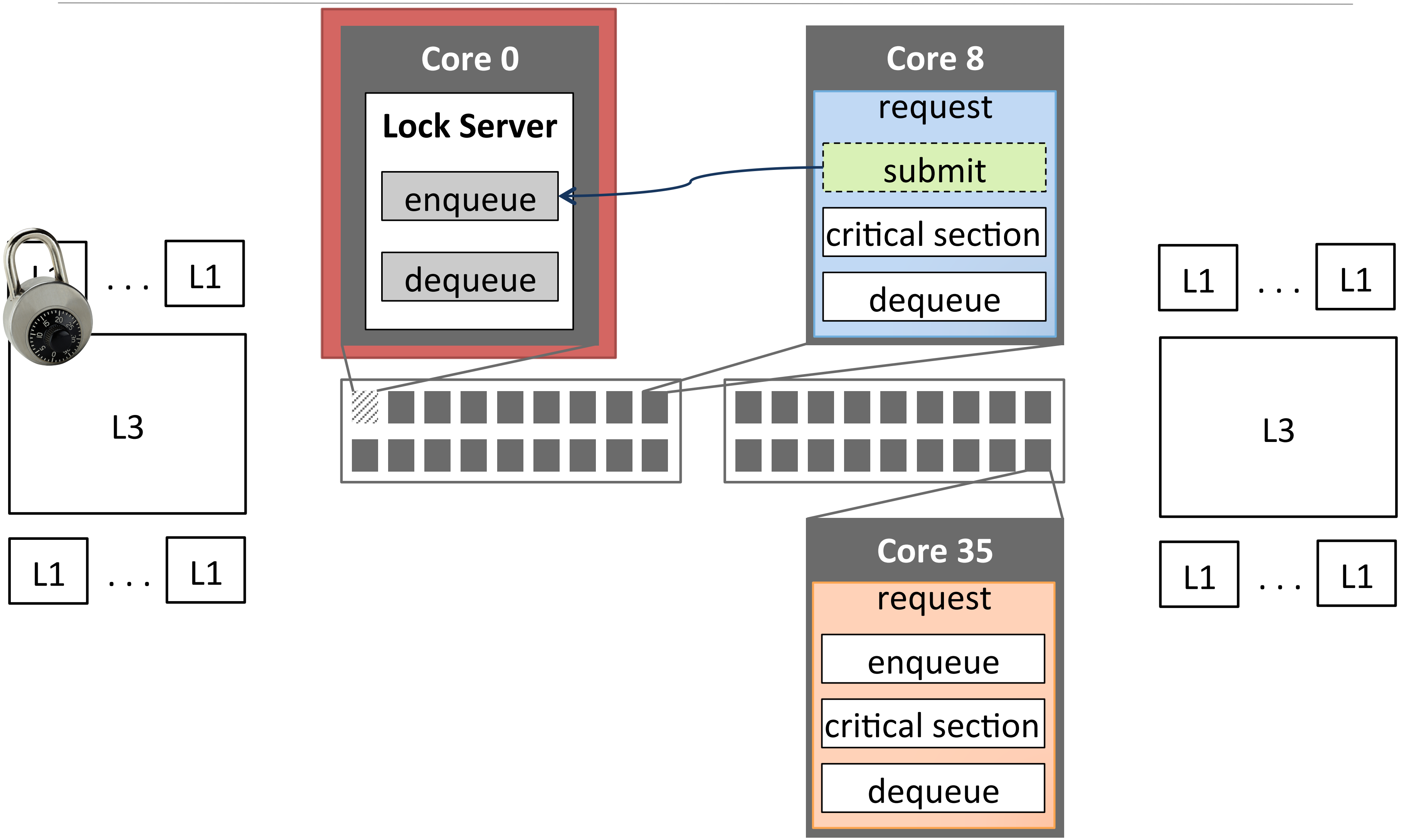

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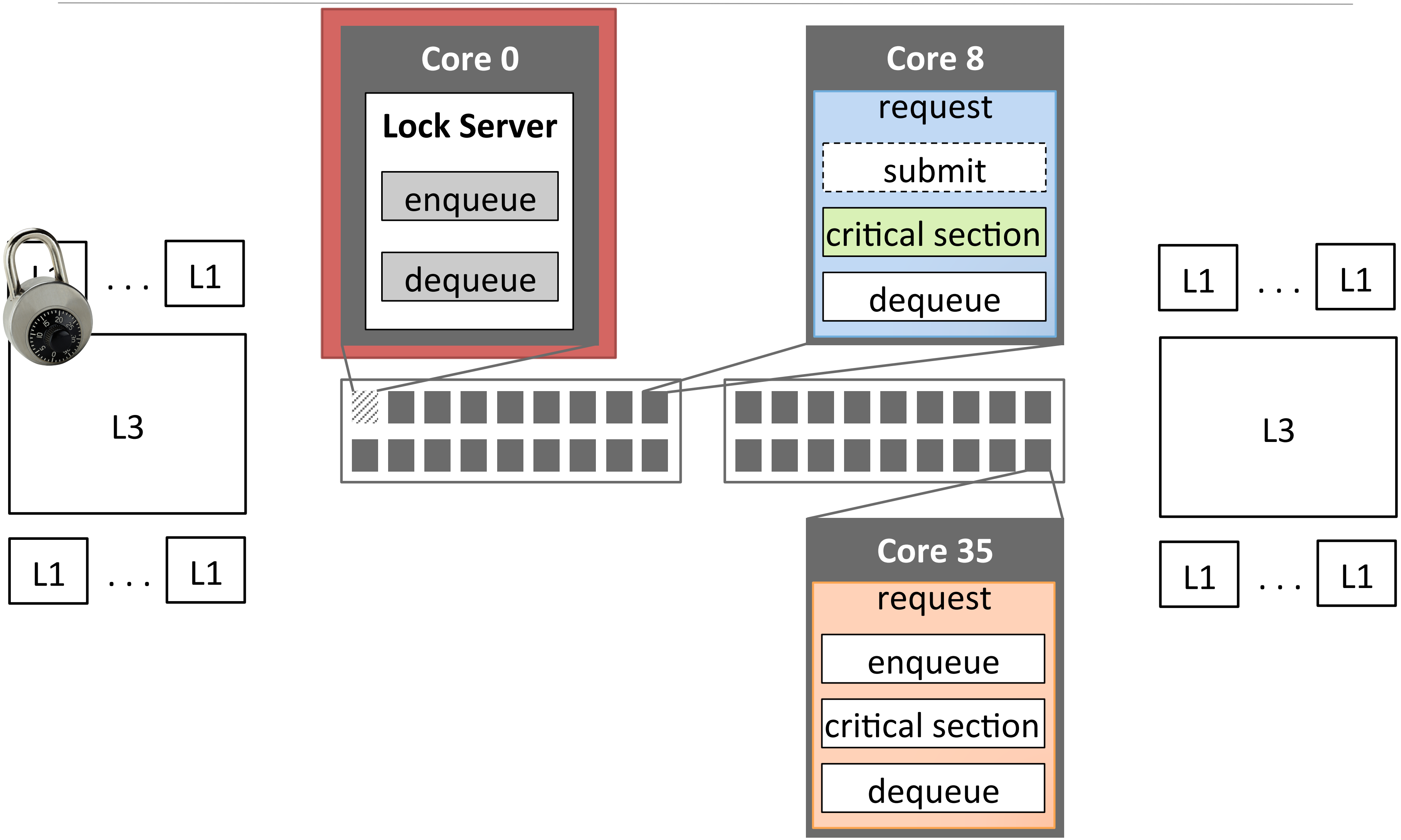

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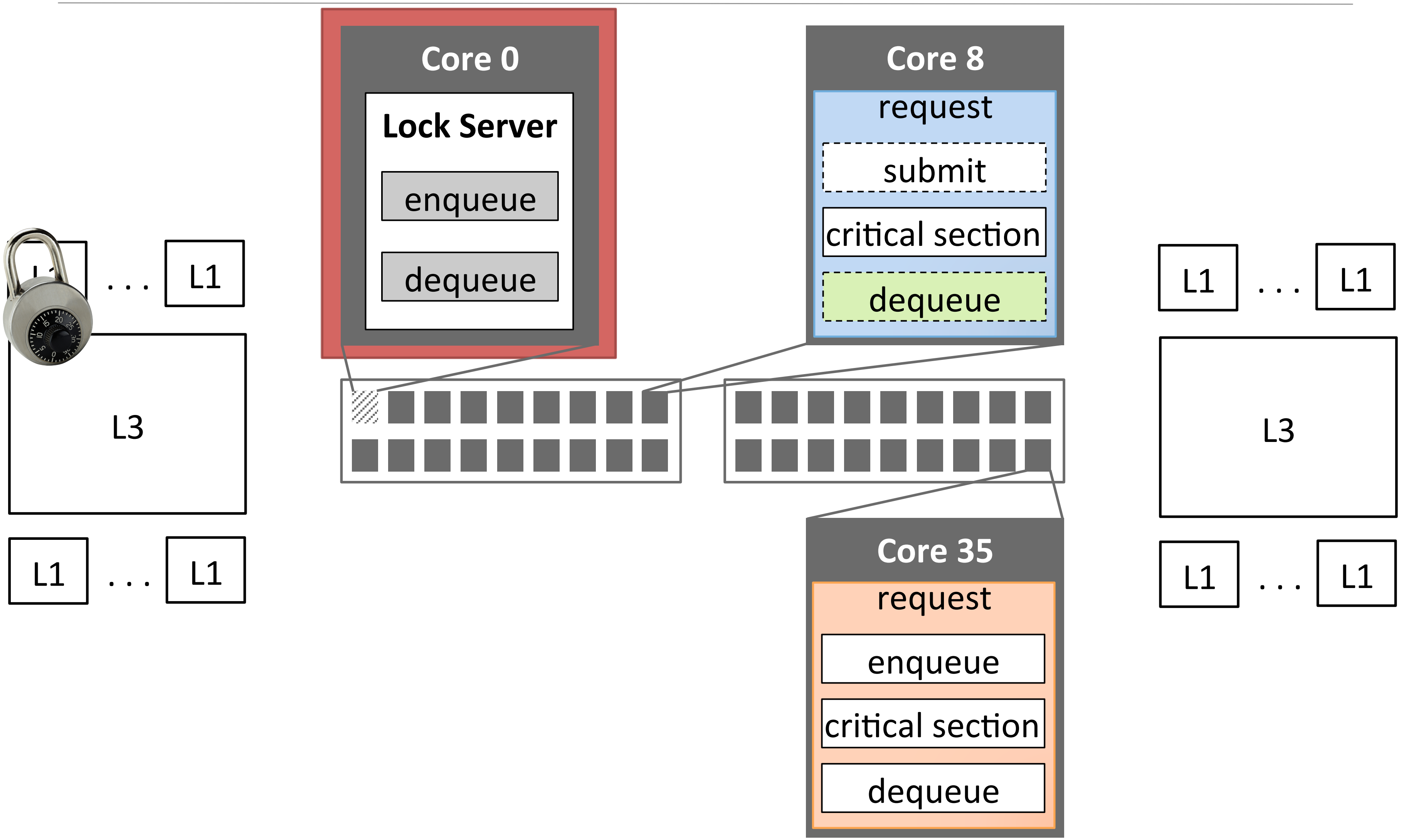

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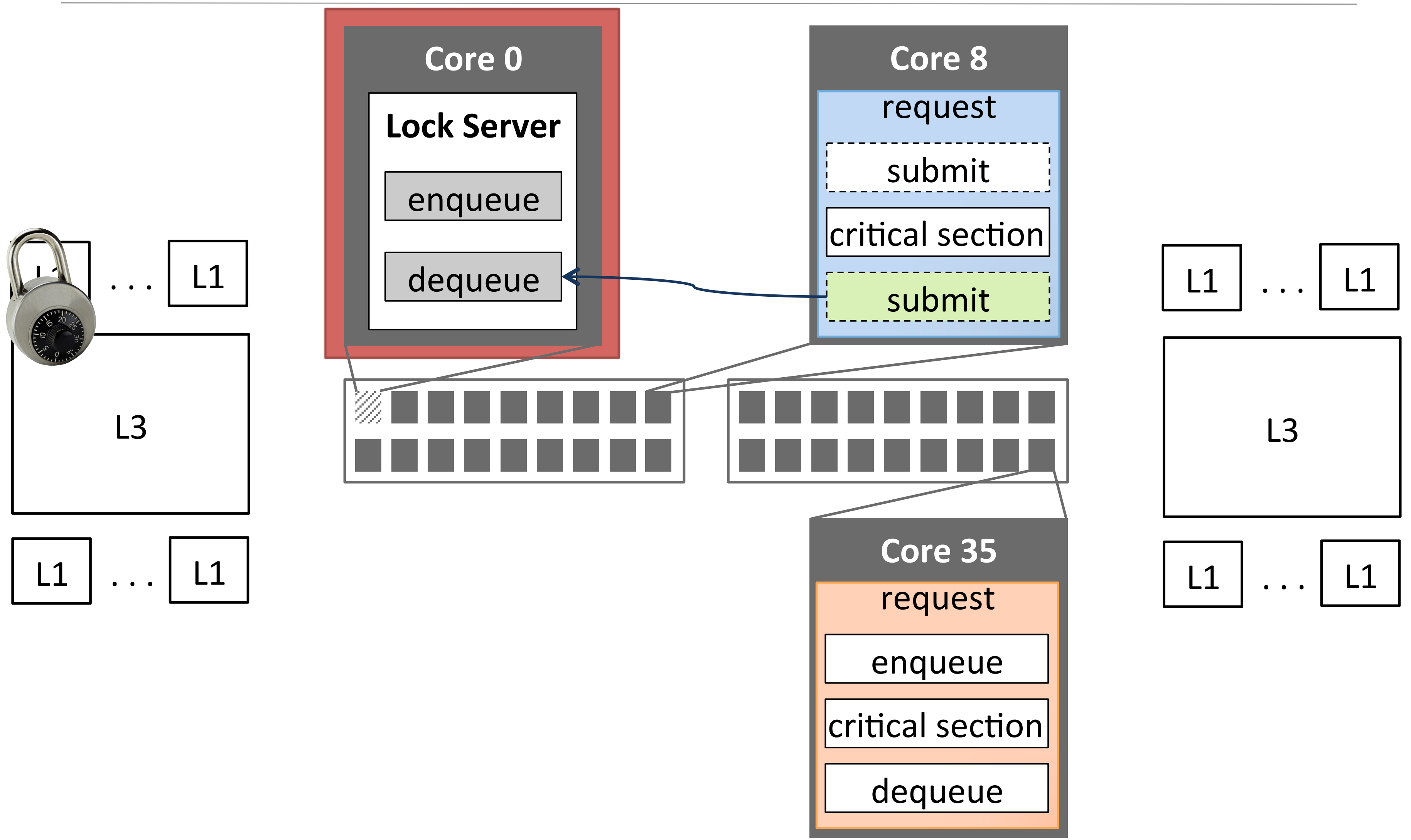

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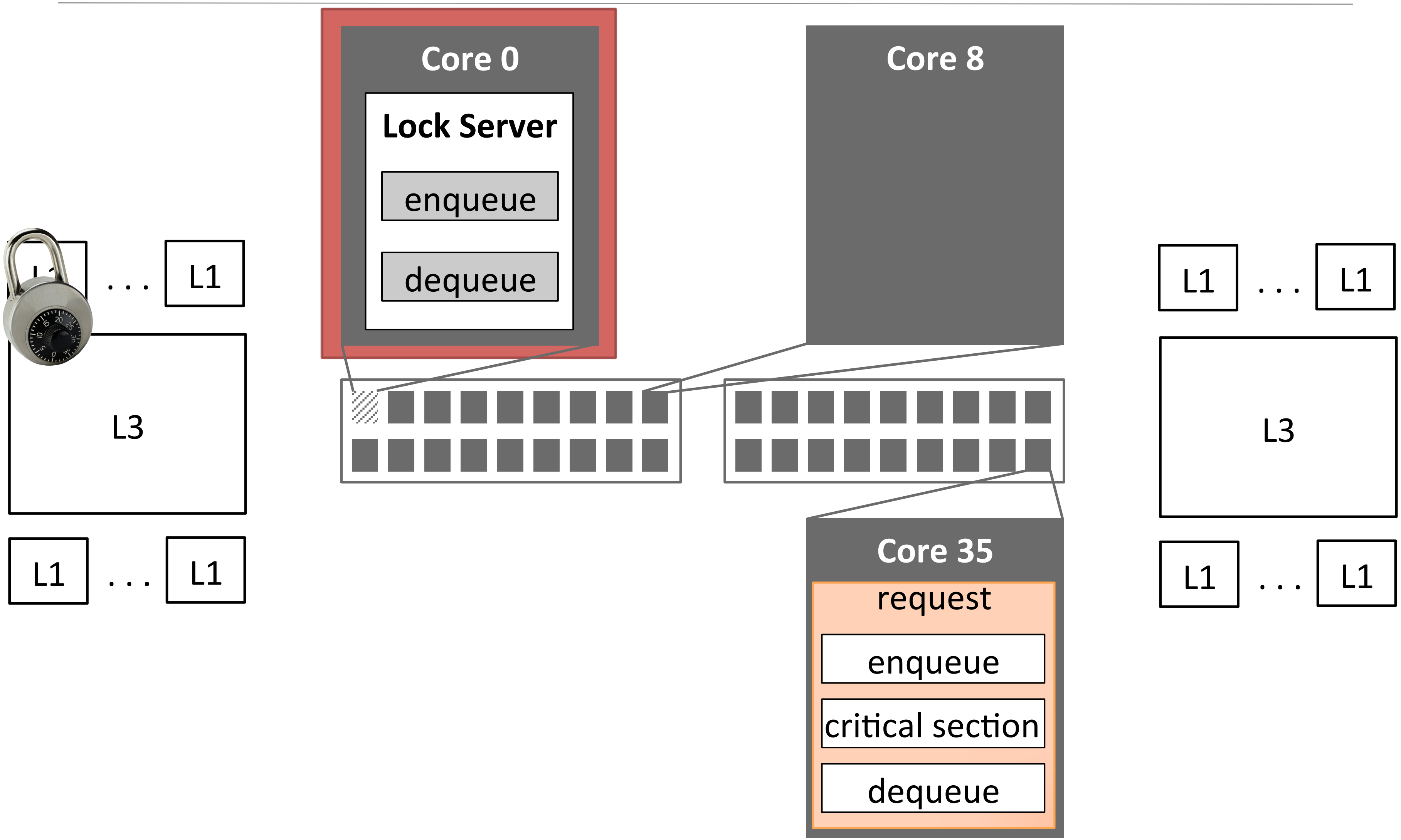

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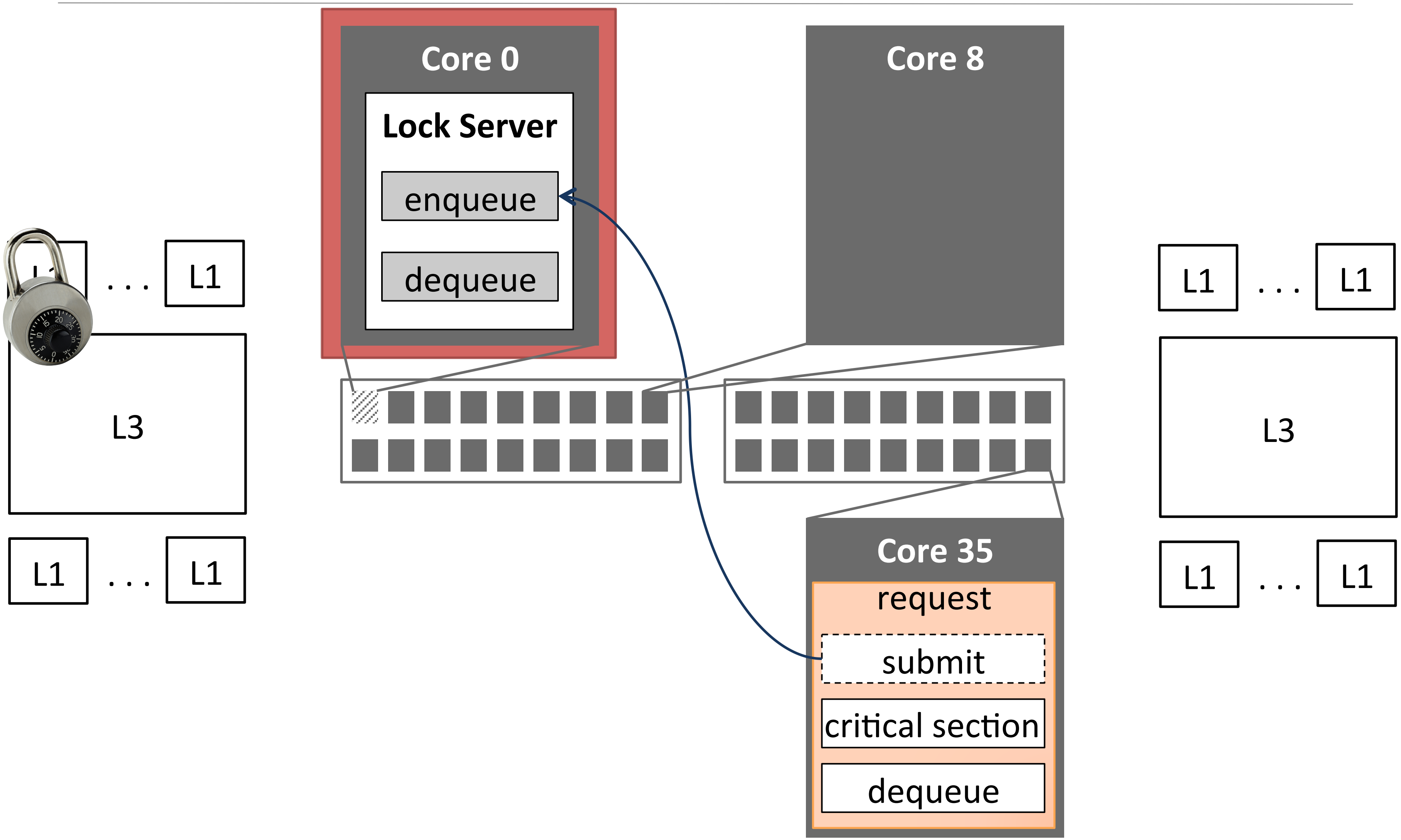

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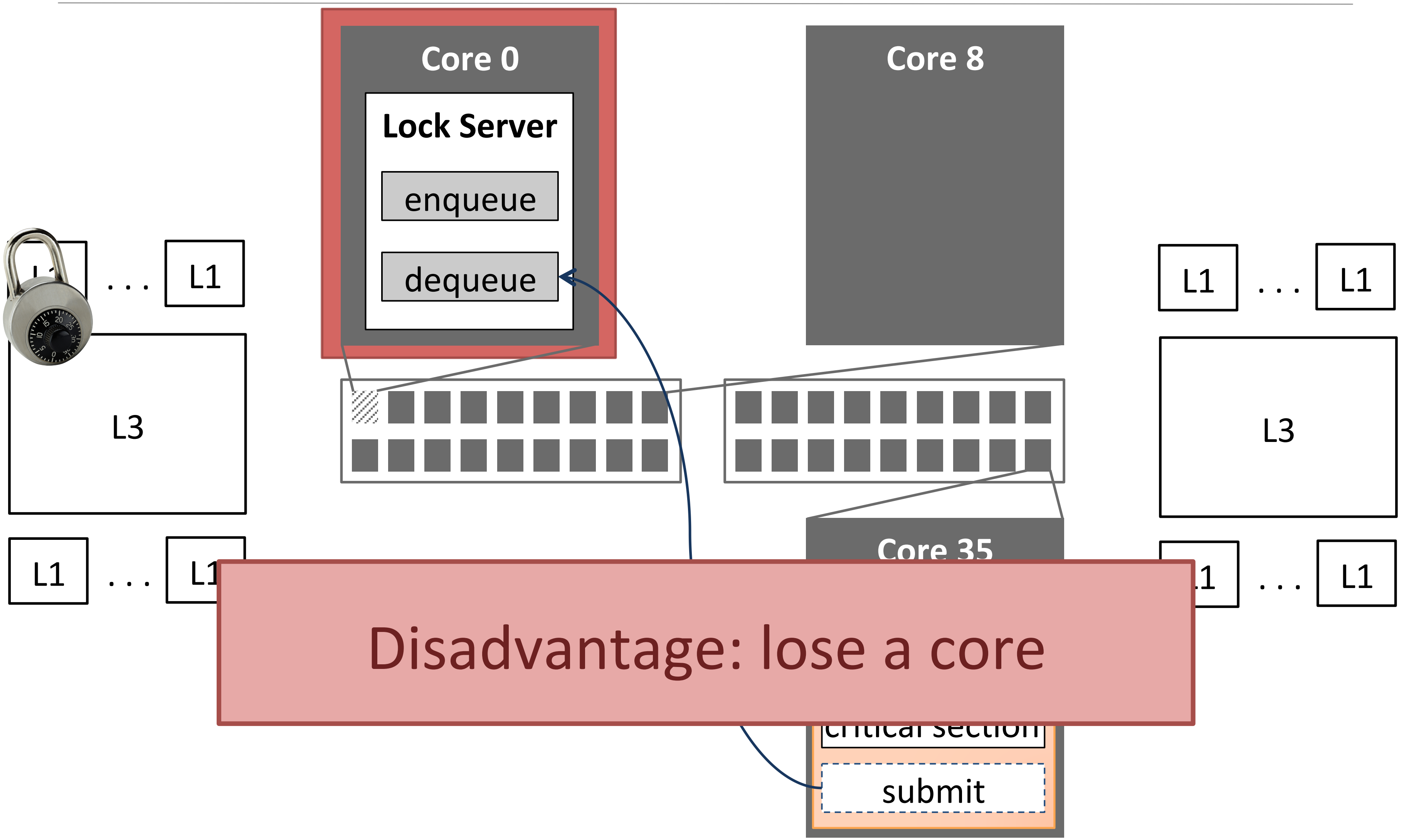


Disadvantage: lose a core

Lock Server Paradigms

locality

mobility

	Global	**Local**
Static	#1	
Floating	#2	

Lock Server Paradigms

locality

mobility

	Global	**Local**
Static	- Lose 1 core + L1 cache affinity	
Floating	#2	

Lock Server Paradigms

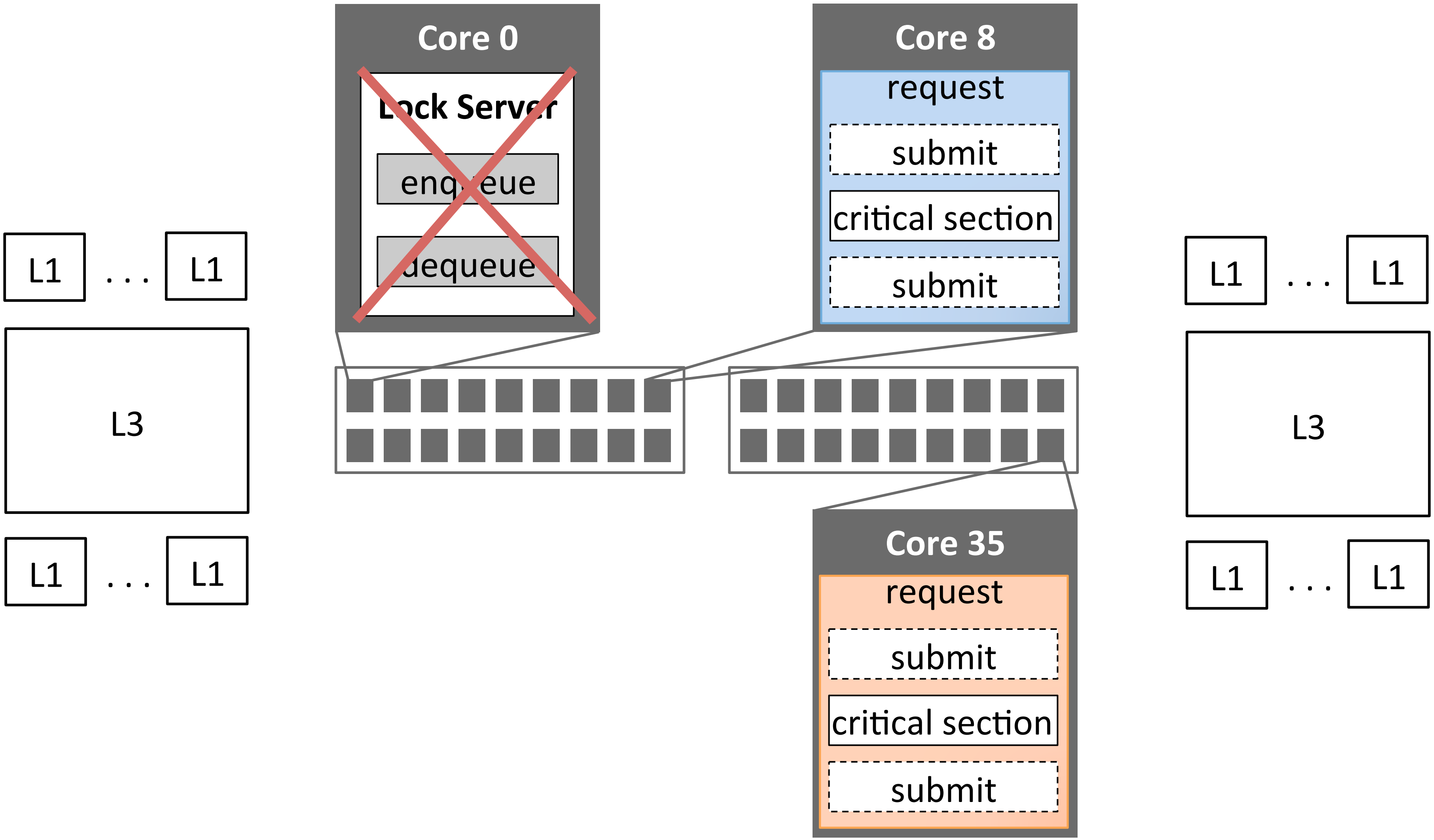
locality

	Global	**Local**
Floating	#2	

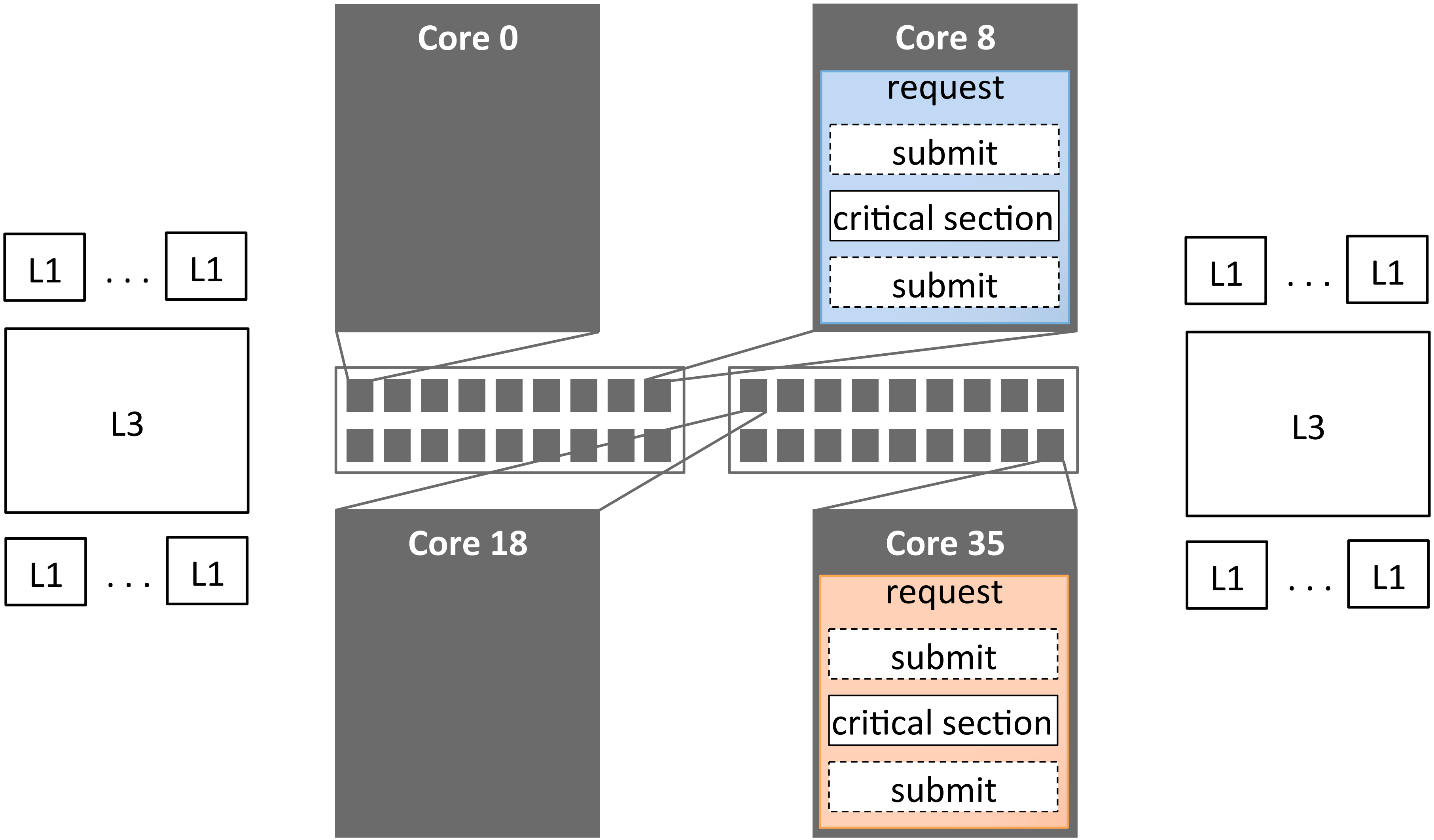
mobility

Key insight: blocked requests are busy-waiting, using CPU

Paradigm #2: Floating Global



Paradigm #2: Floating Global



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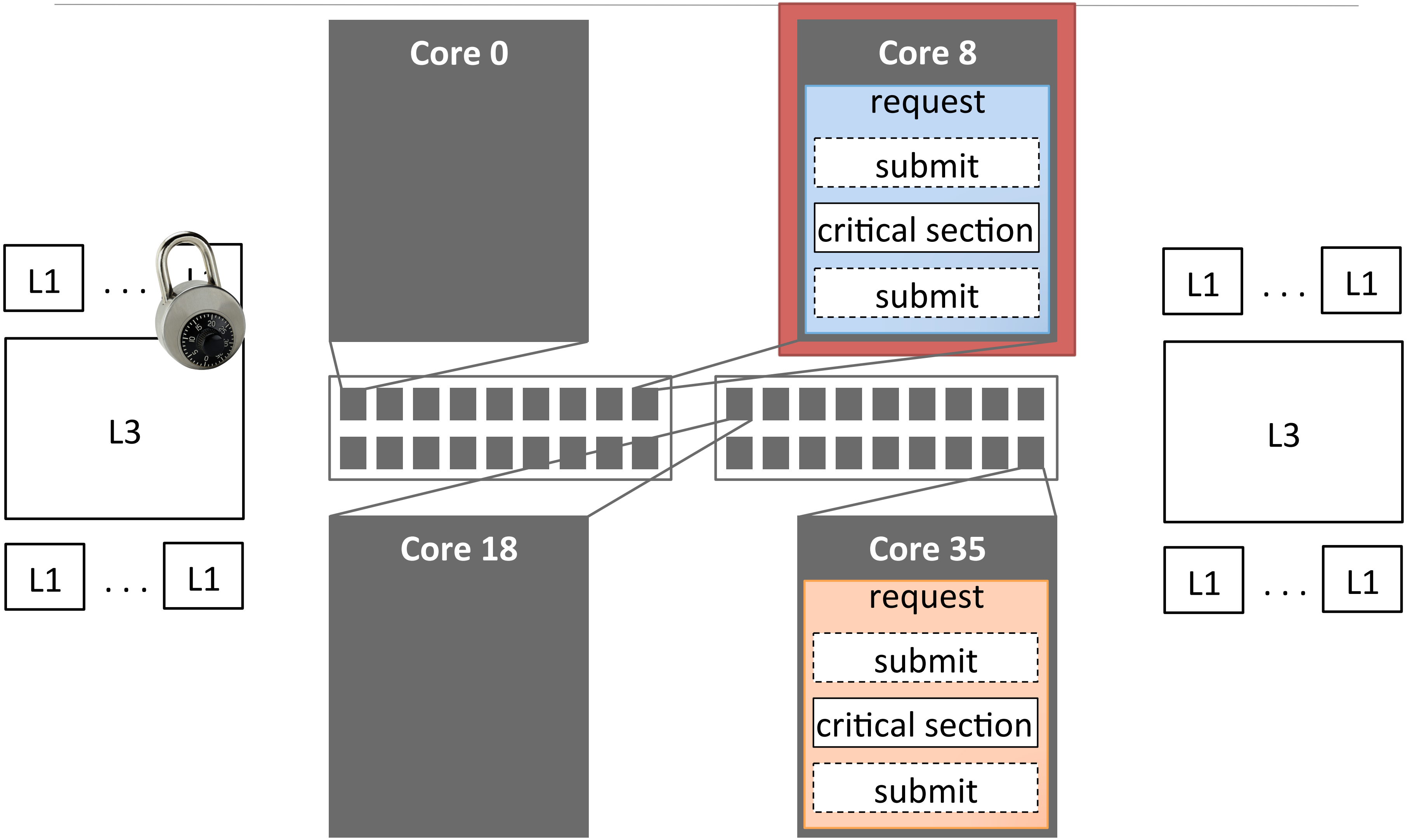

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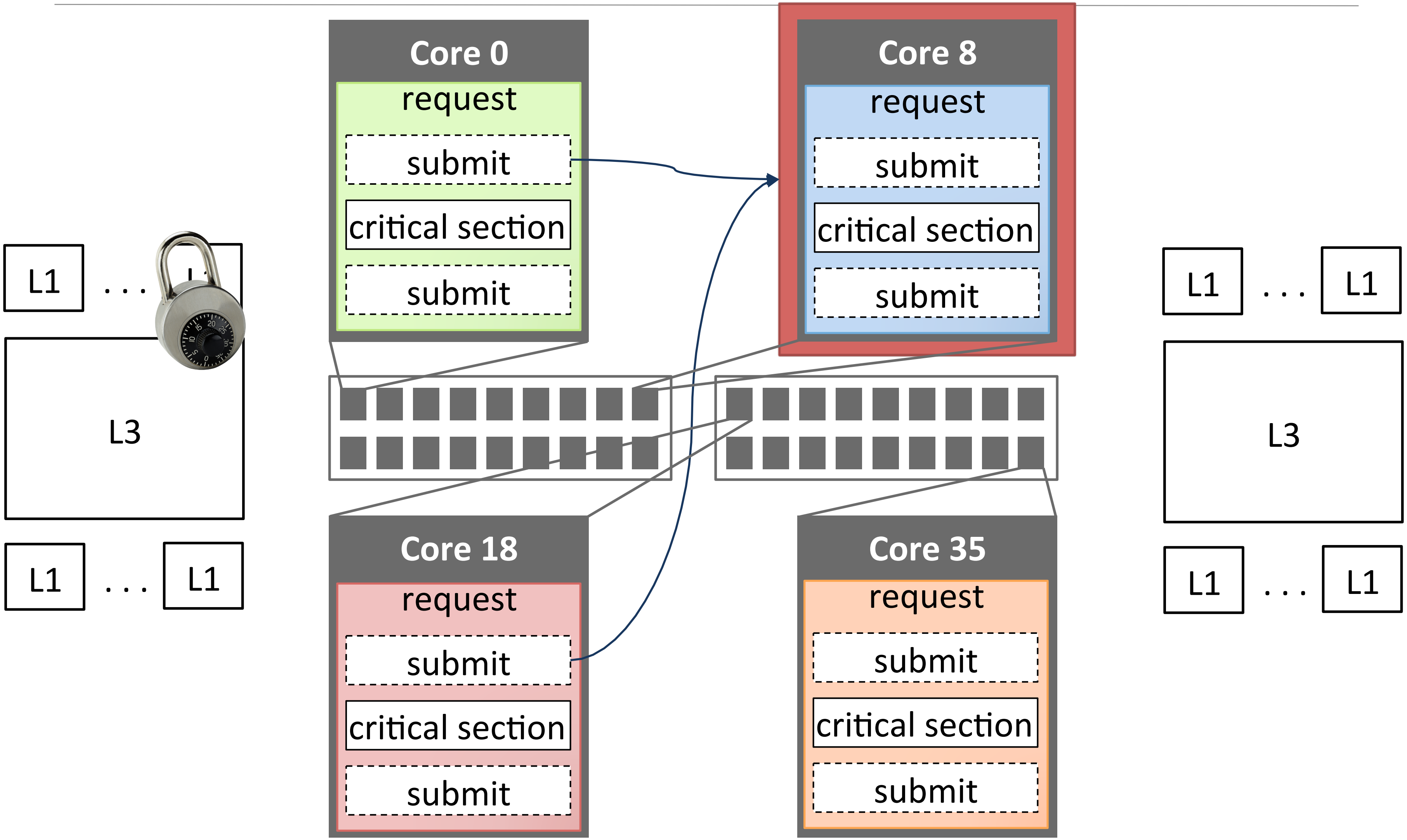

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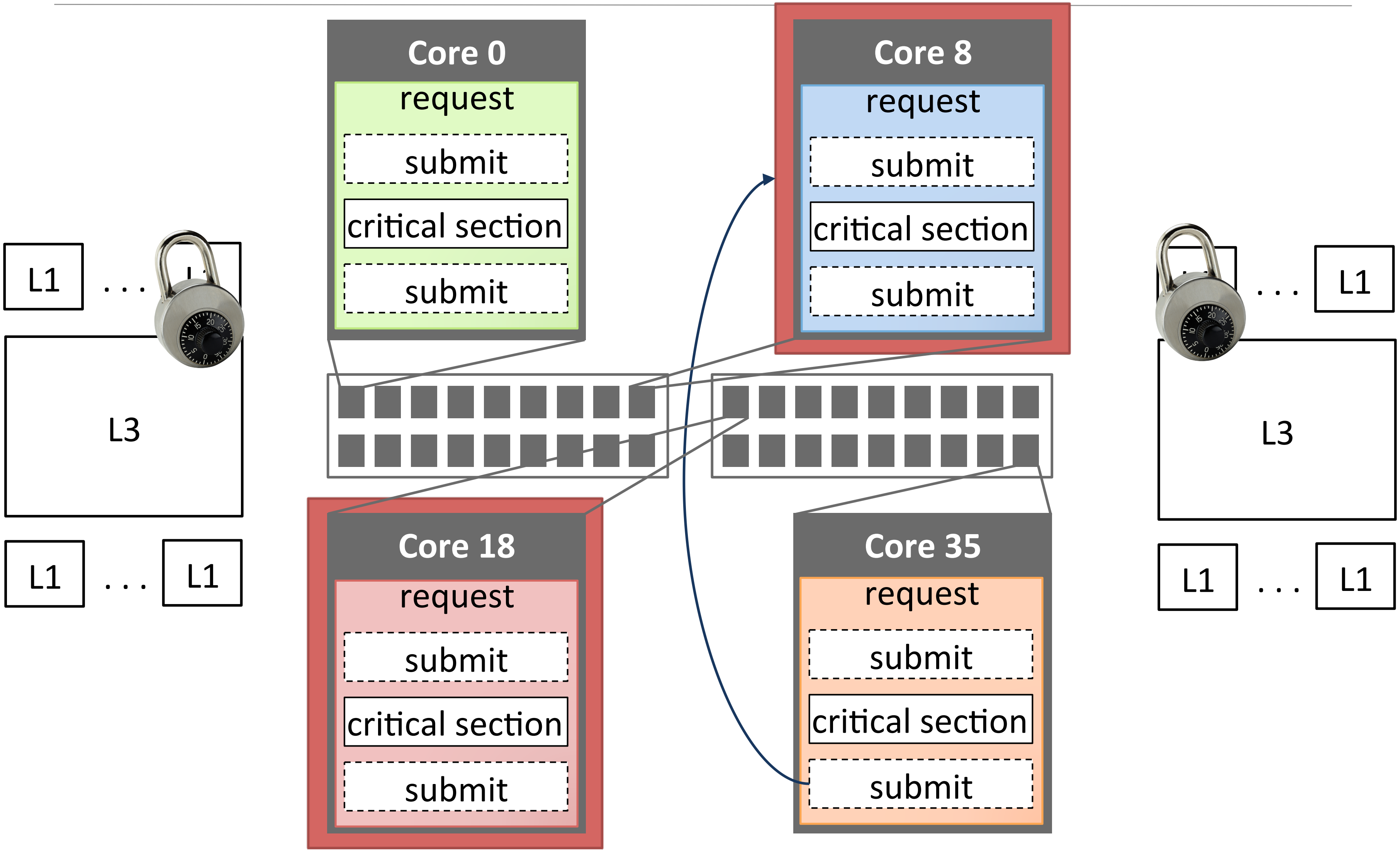

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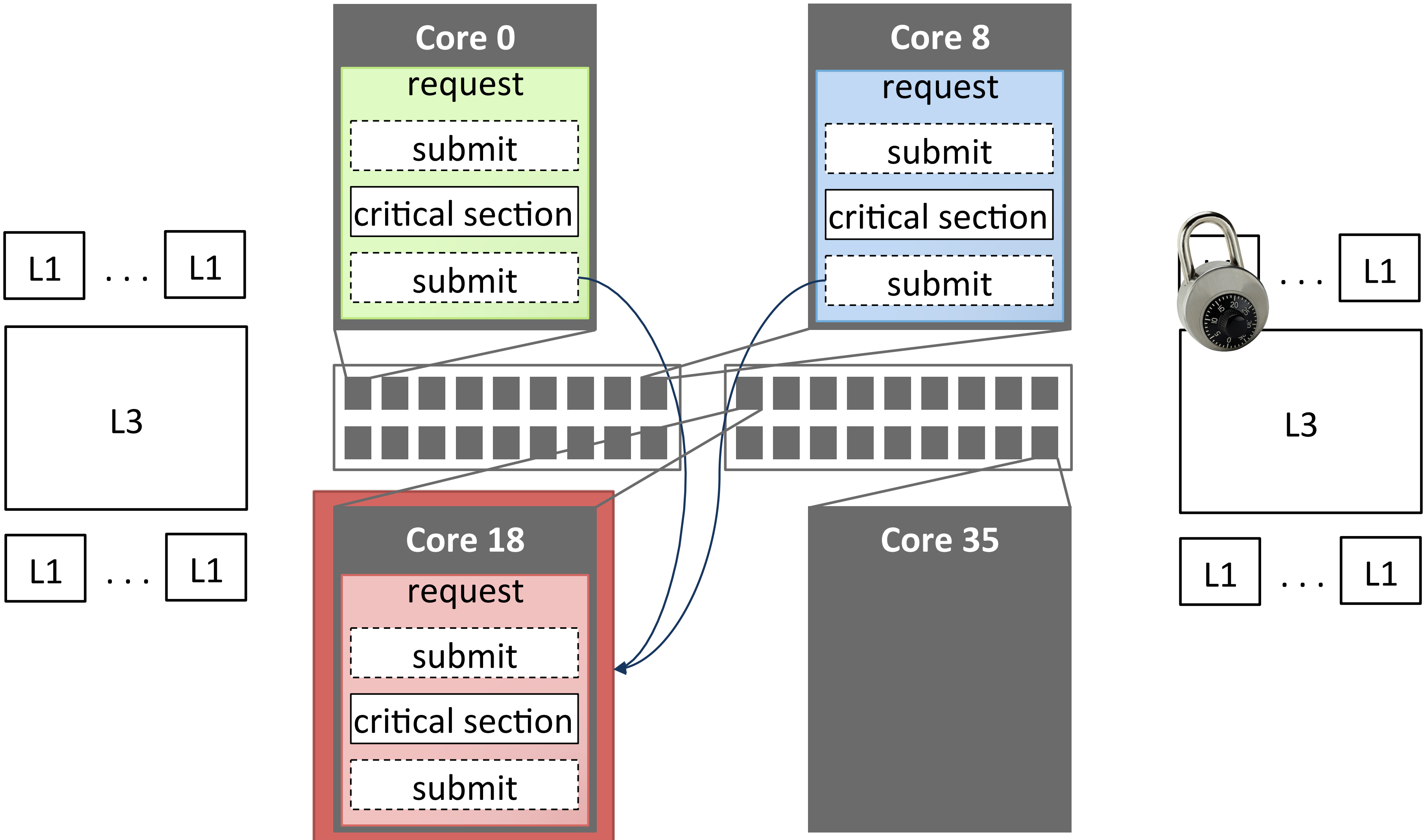


Lock Server Paradigms

locality

mobility	Global	Local
Static	- Lose 1 core + L1 cache affinity	
Floating	#2	

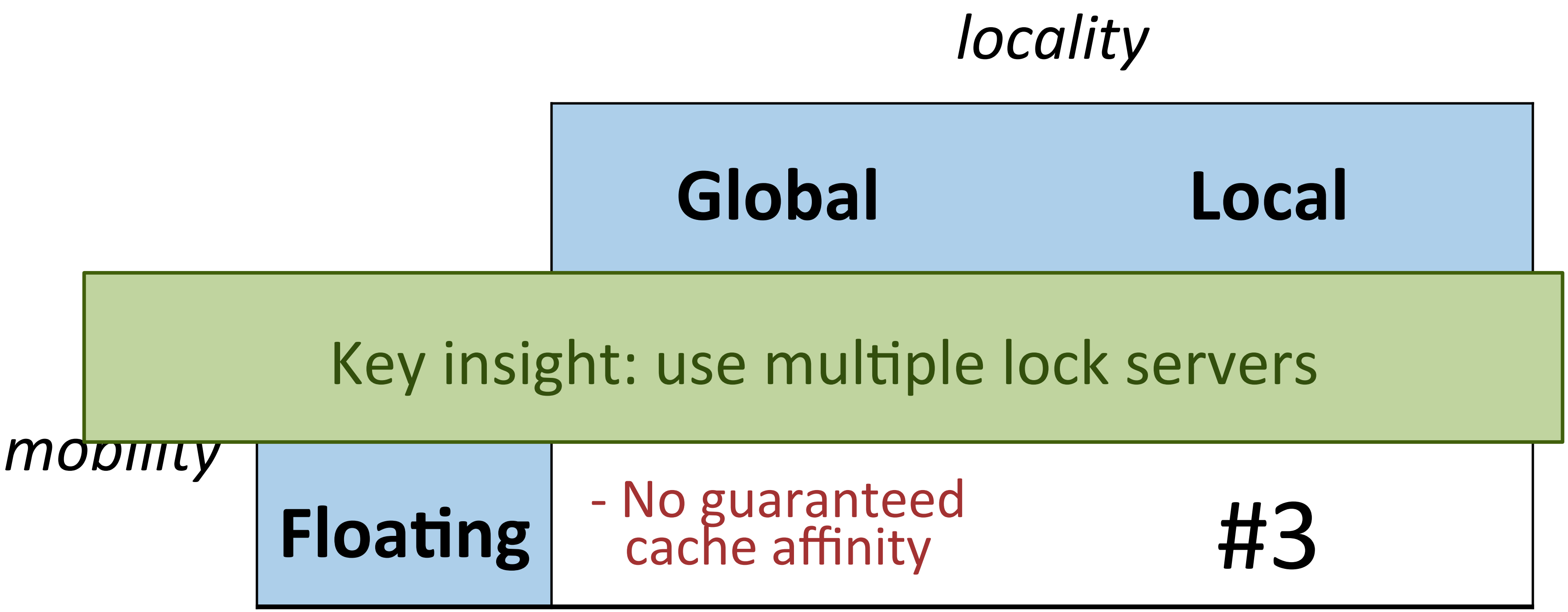
Lock Server Paradigms

locality

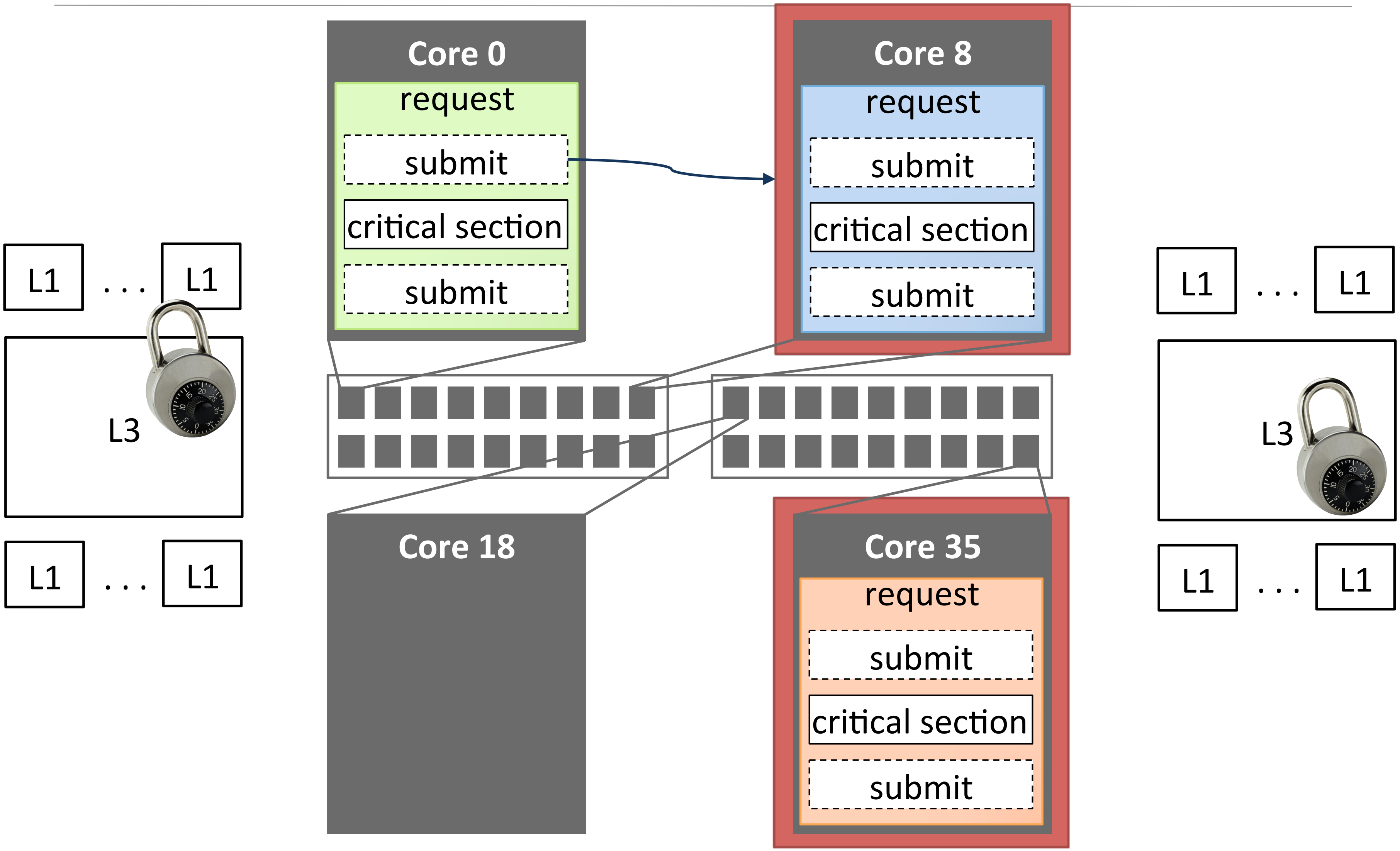
mobility

	Global	**Local**
Static	- Lose 1 core + L1 cache affinity	
Floating	- No guaranteed cache affinity	#3

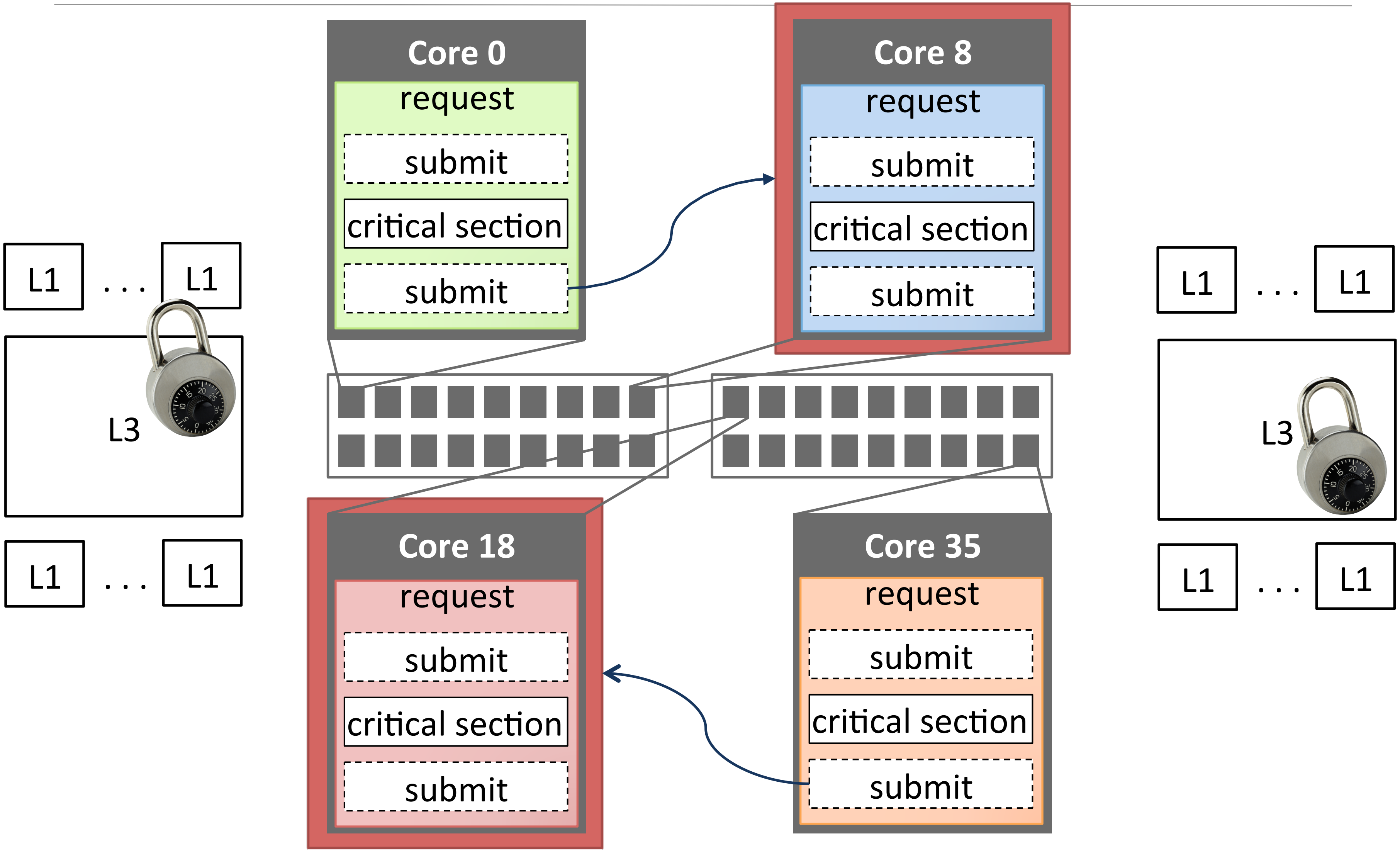
Lock Server Paradigms



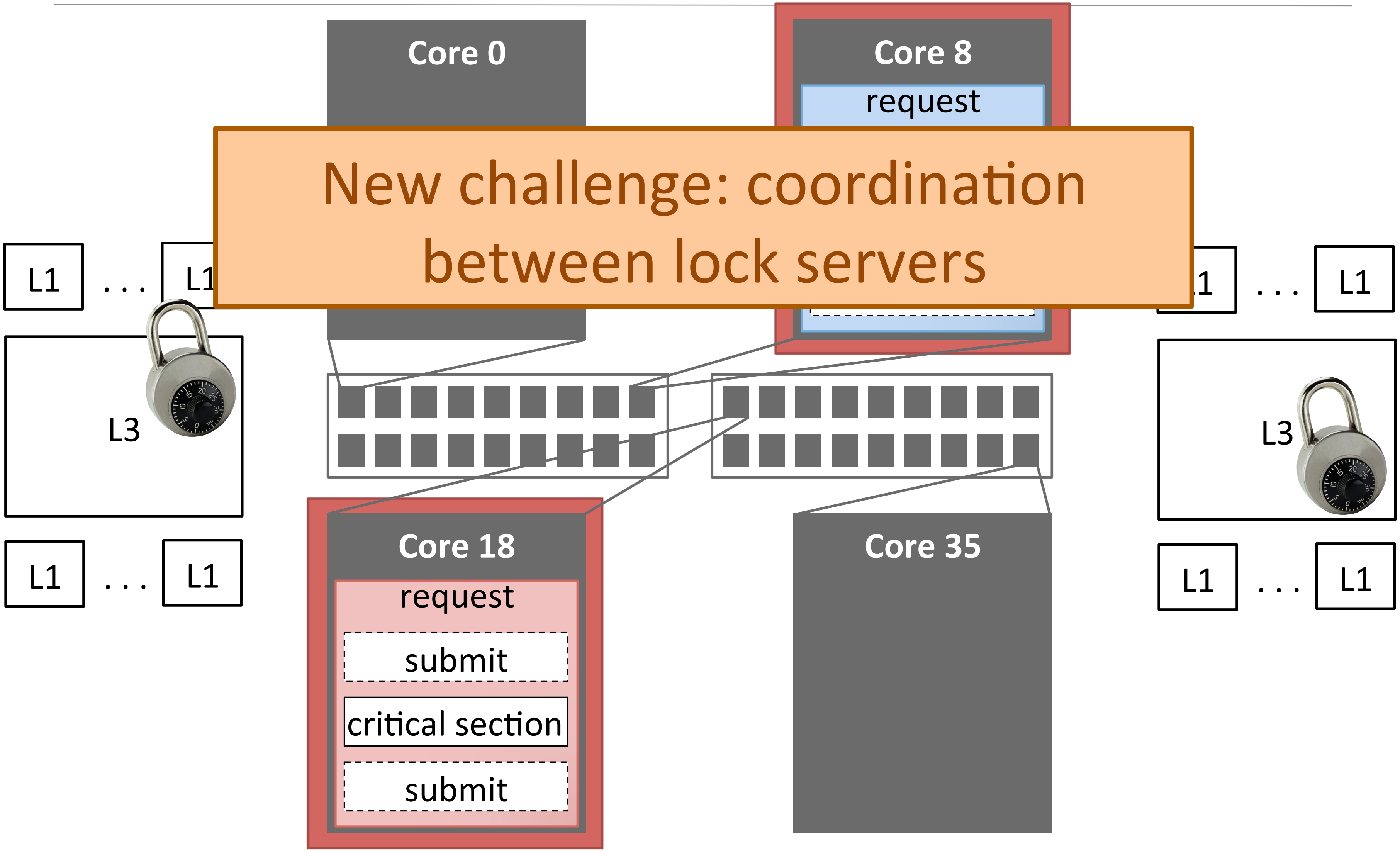
Paradigm #3: Floating Local



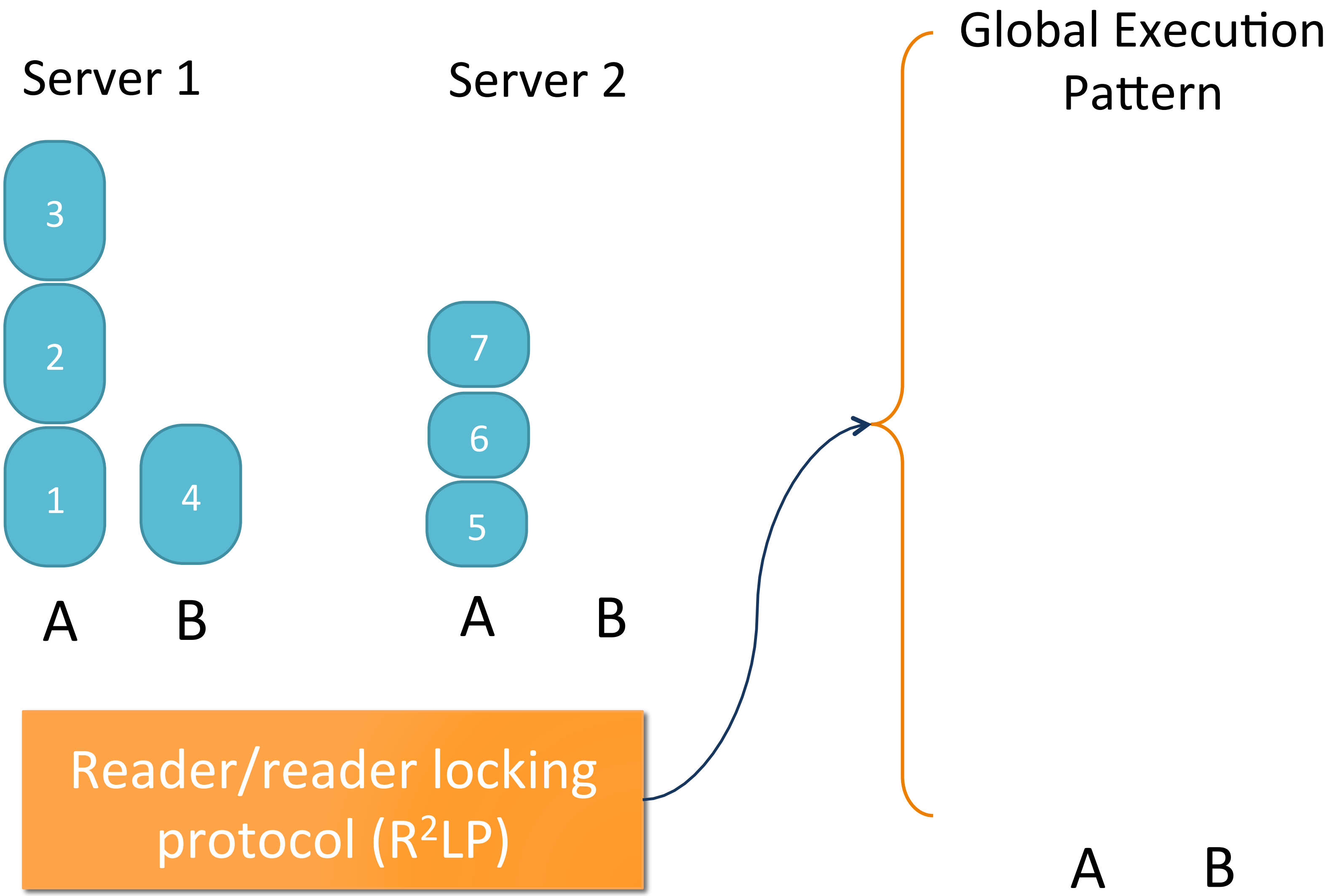
Paradigm #3: Floating Local



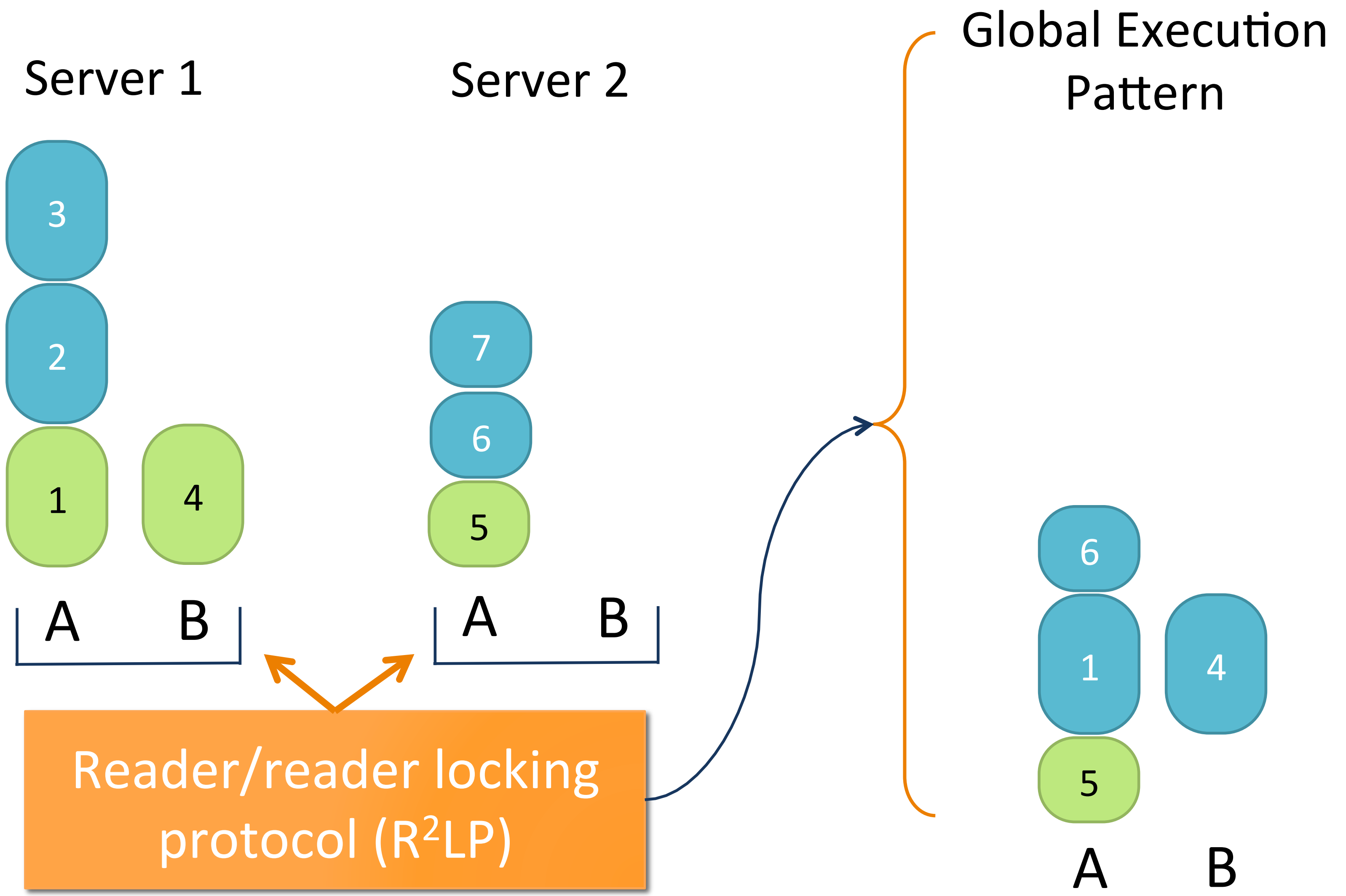
Paradigm #3: Floating Local



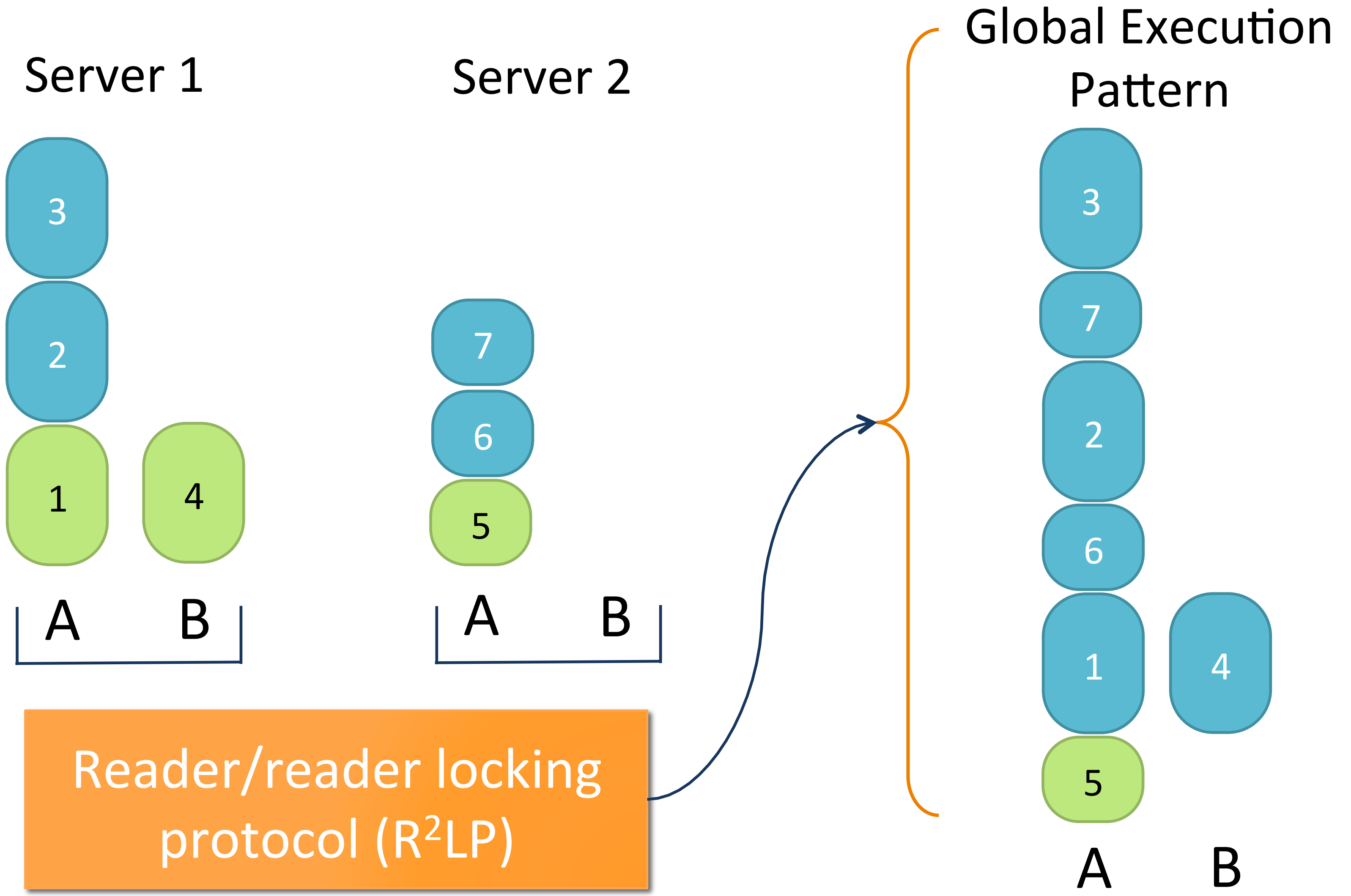
Lock Server Coordination



Lock Server Coordination

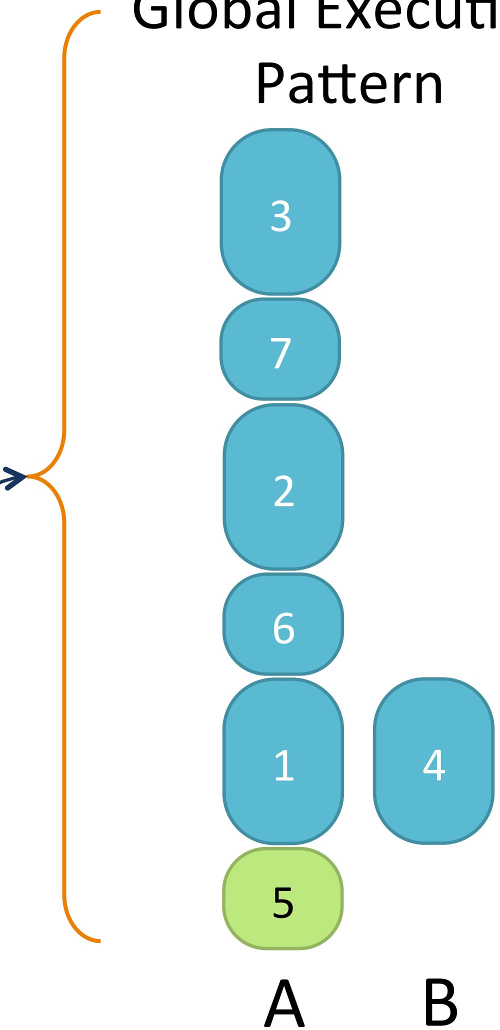


Lock Server Coordination



Lock Server Coordination

Global Execution Pattern



Original C-RNLP bound:

$(c_i + 1)L_{MAX}$

Reader/reader locking protocol (R^2LP)

Lock Server Coordination

Original C-RNLP bound:

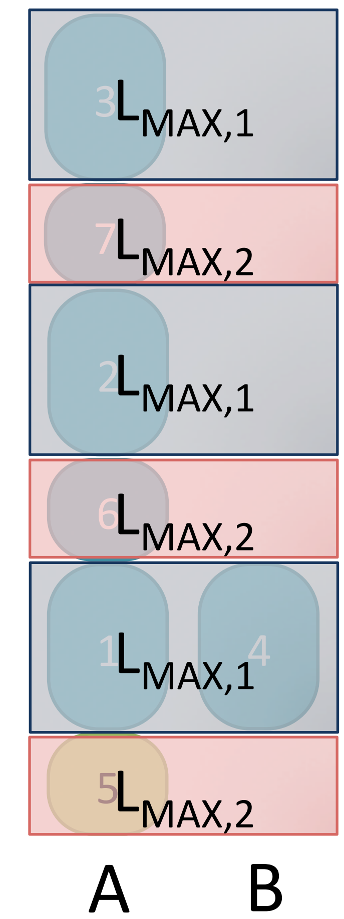
$$(c_i + 1)L_{MAX}$$

Two-server C-RNLP bound with R^2LP:

$$(c_{i,s} + 1)(L_{MAX,1} + L_{MAX,2})$$

Reader/reader locking protocol (R^2LP)

Global Execution Pattern



Lock Server Paradigms

locality / *mobility*

	Global	**Local**
Static	- Lose 1 core + L1 cache affinity	
Floating	- No guaranteed cache affinity	+ L3 cache affinity

Lock Server Paradigms

locality

mobility

	Global	**Local**
Static	- Lose 1 core + L1 cache affinity	- Lose multiple cores + L1 cache affinity
Floating	- No guaranteed cache affinity	+ L3 cache affinity

coordination with R^2LP, additional blocking considerations

Experimental Evaluation

Measured **overhead** and **blocking**

One task per core issuing 10,000 random requests

64 resources, each task requests 4 of these, critical-section lengths = 40μs

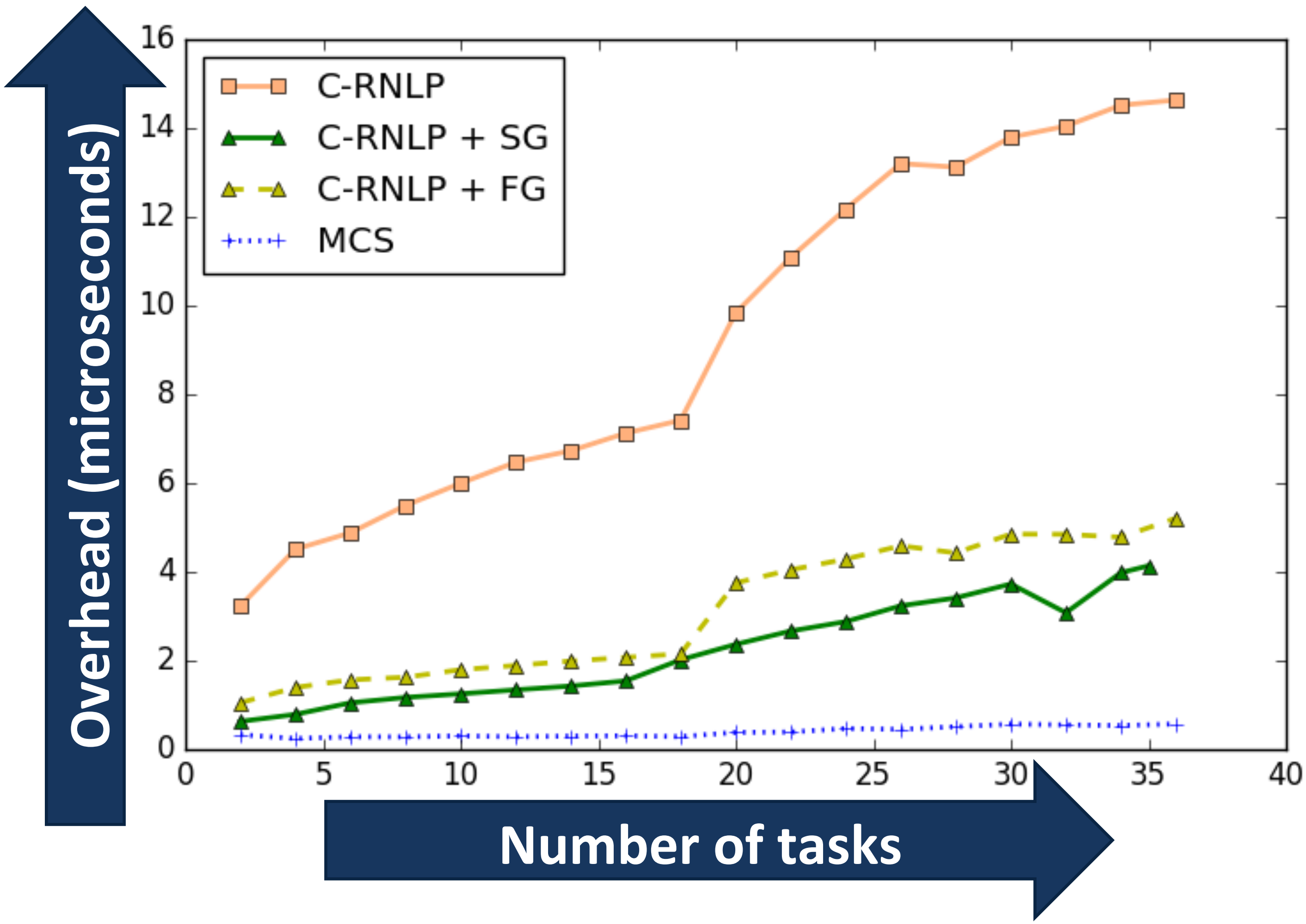
Experimental Evaluation

By how much can a lock server paradigm reduce worst-case overhead?

How do **overhead** and **blocking** differ between static and floating lock servers?

	Global	Local
Static	- Lose 1 core + L1 cache affinity	- Lose multiple cores + L1 cache affinity
Floating	- No guaranteed cache affinity	+ L3 cache affinity

Experimental Results



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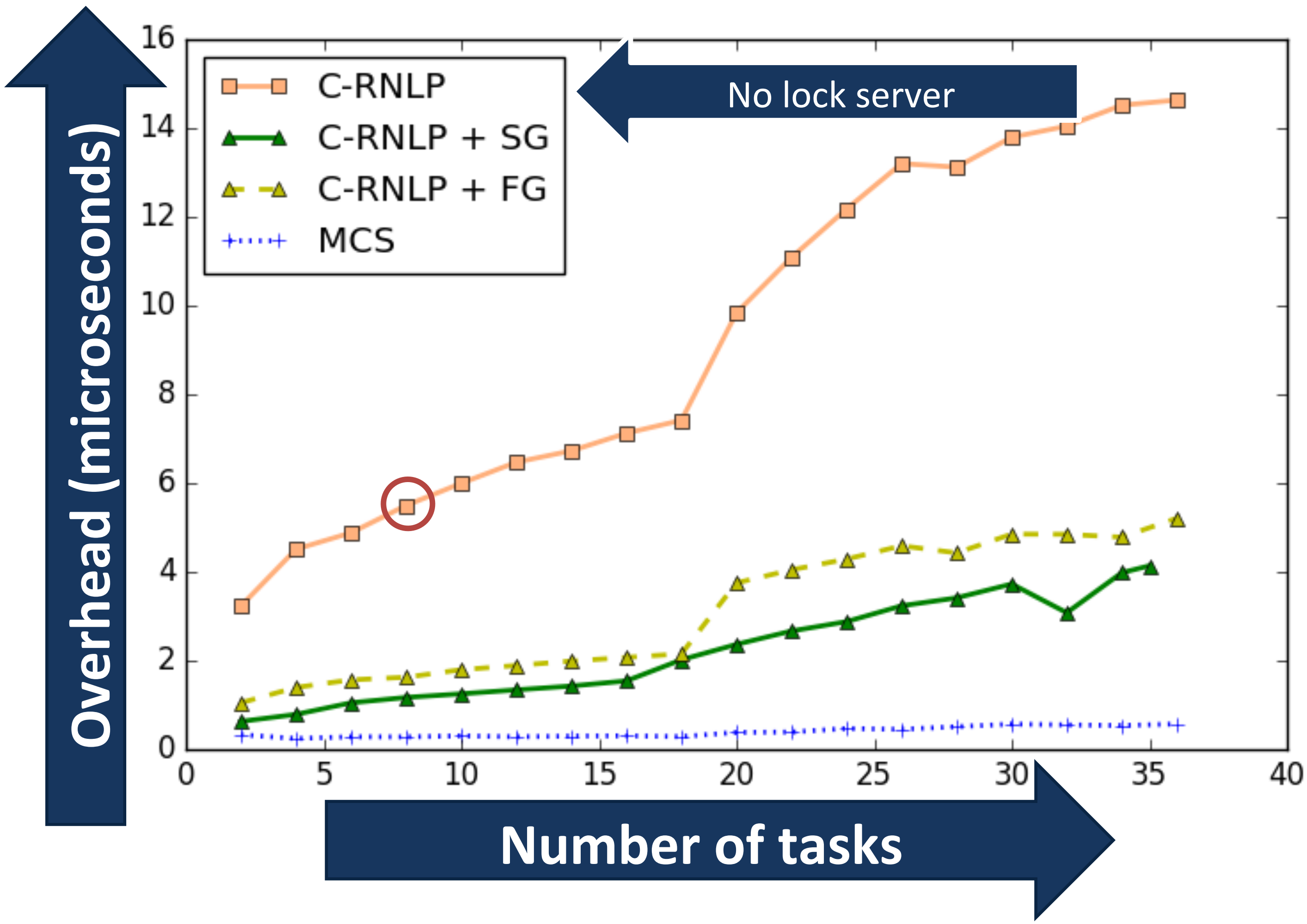

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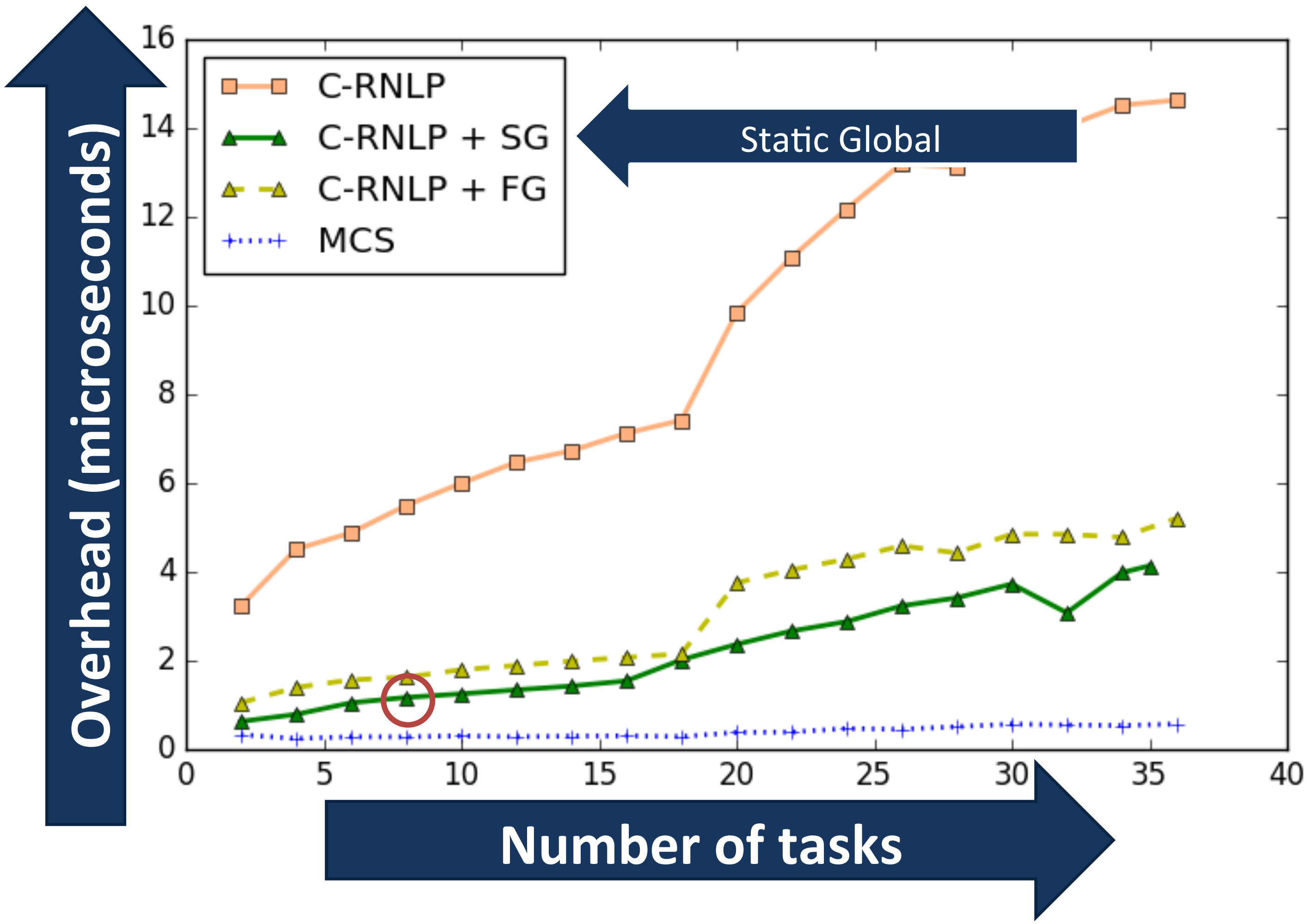
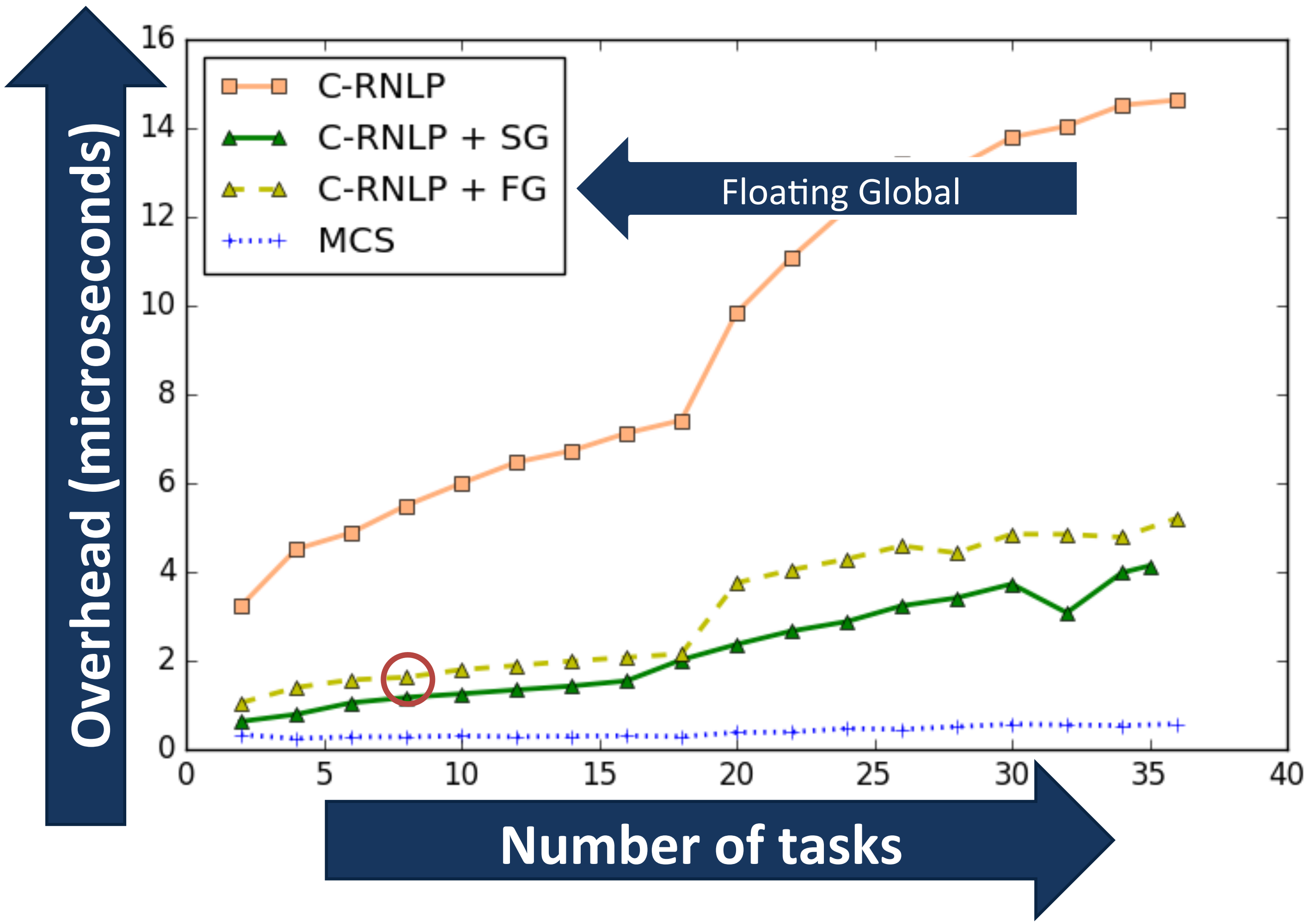
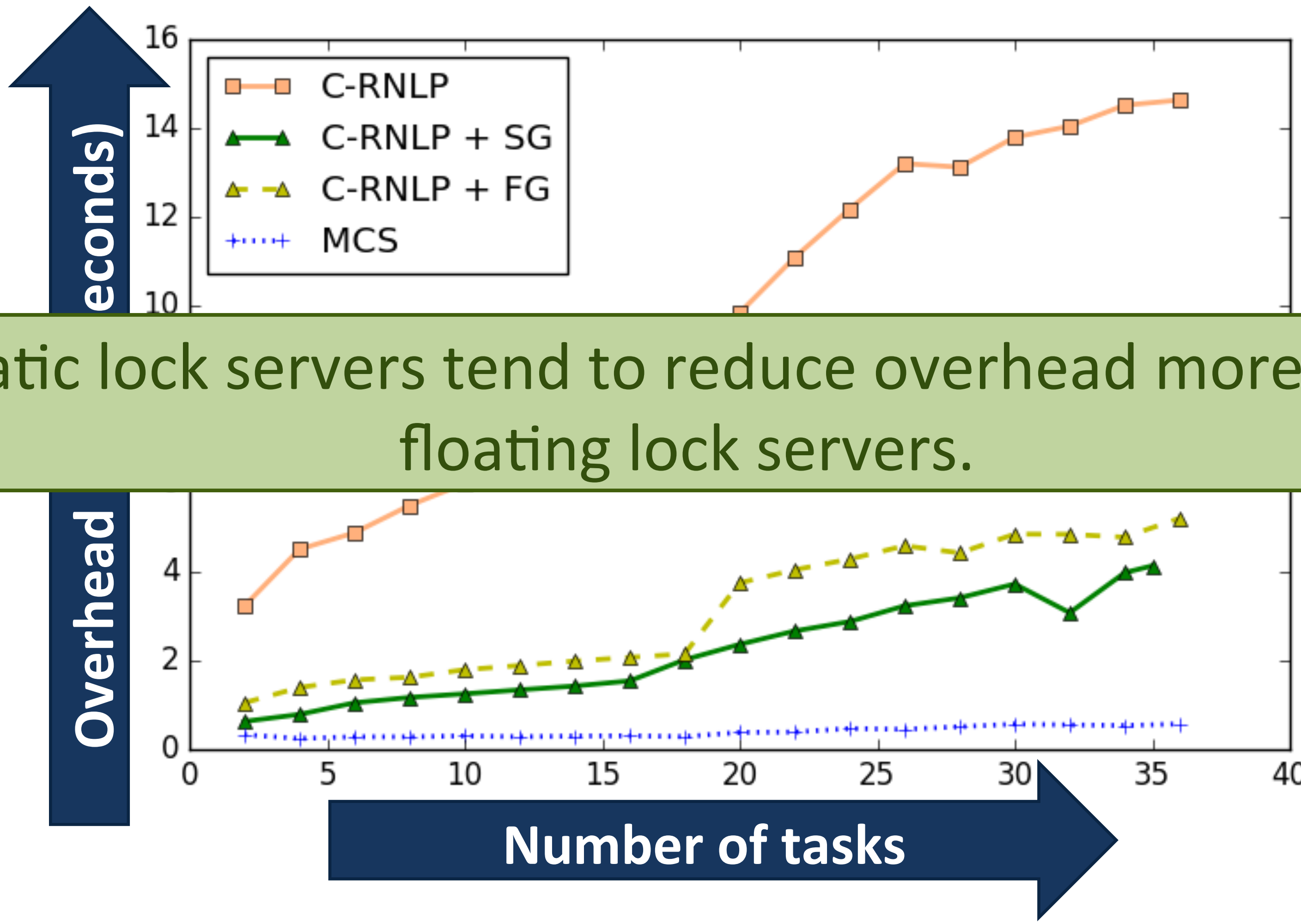


Experimental Results

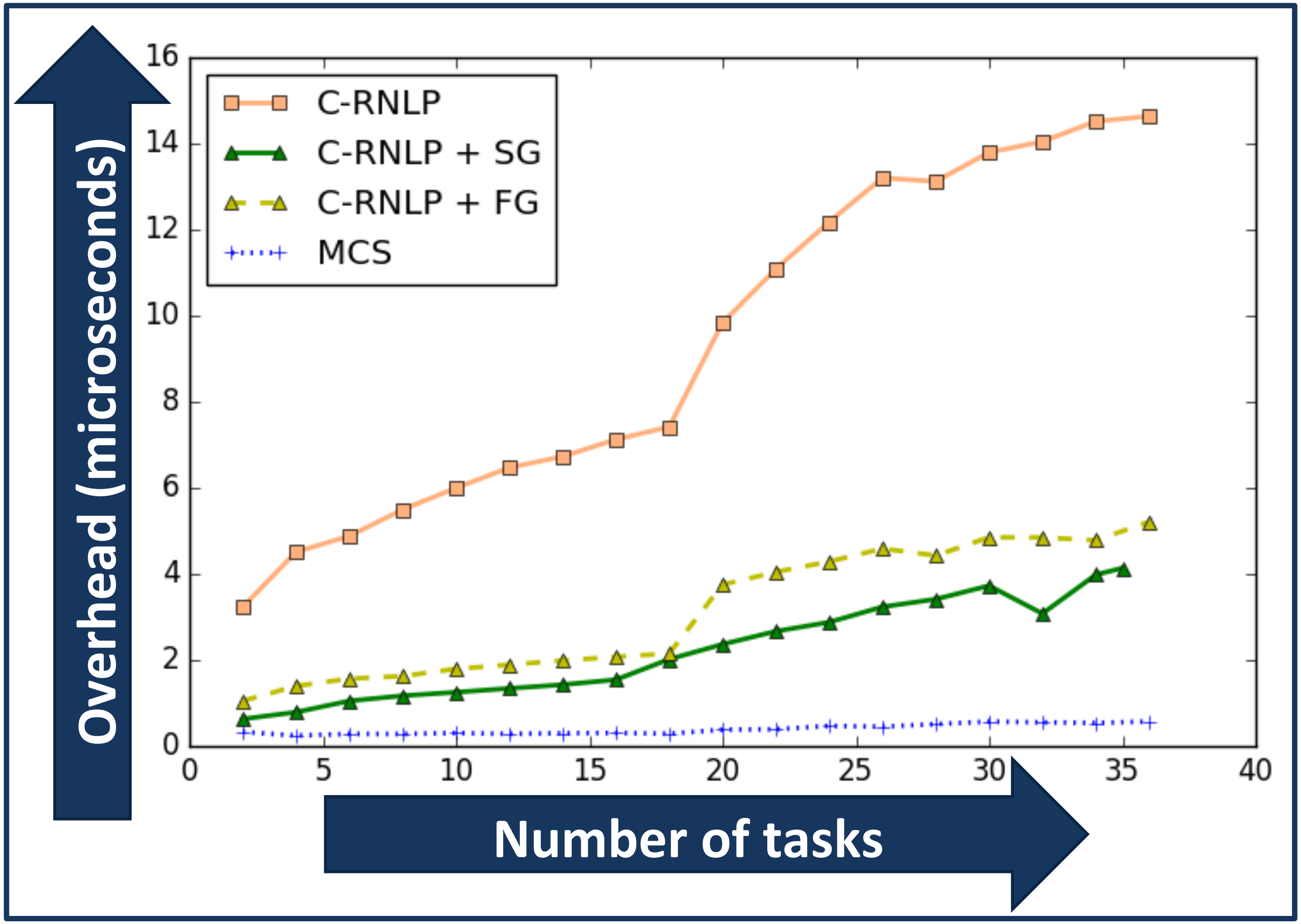


Experimental Results

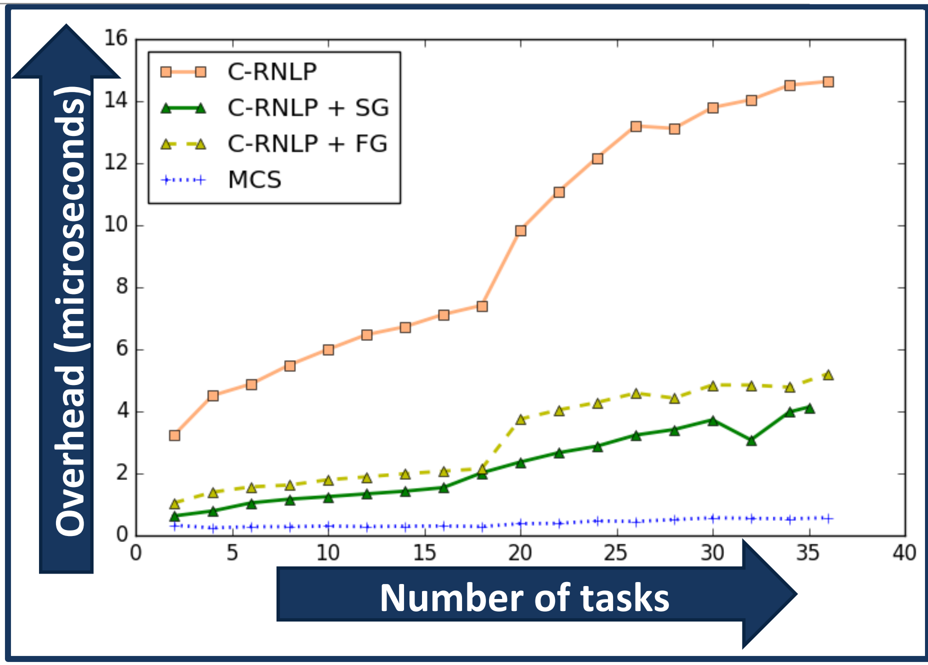


Static lock servers tend to reduce overhead more than floating lock servers.

Experimental Results



Experimental Results



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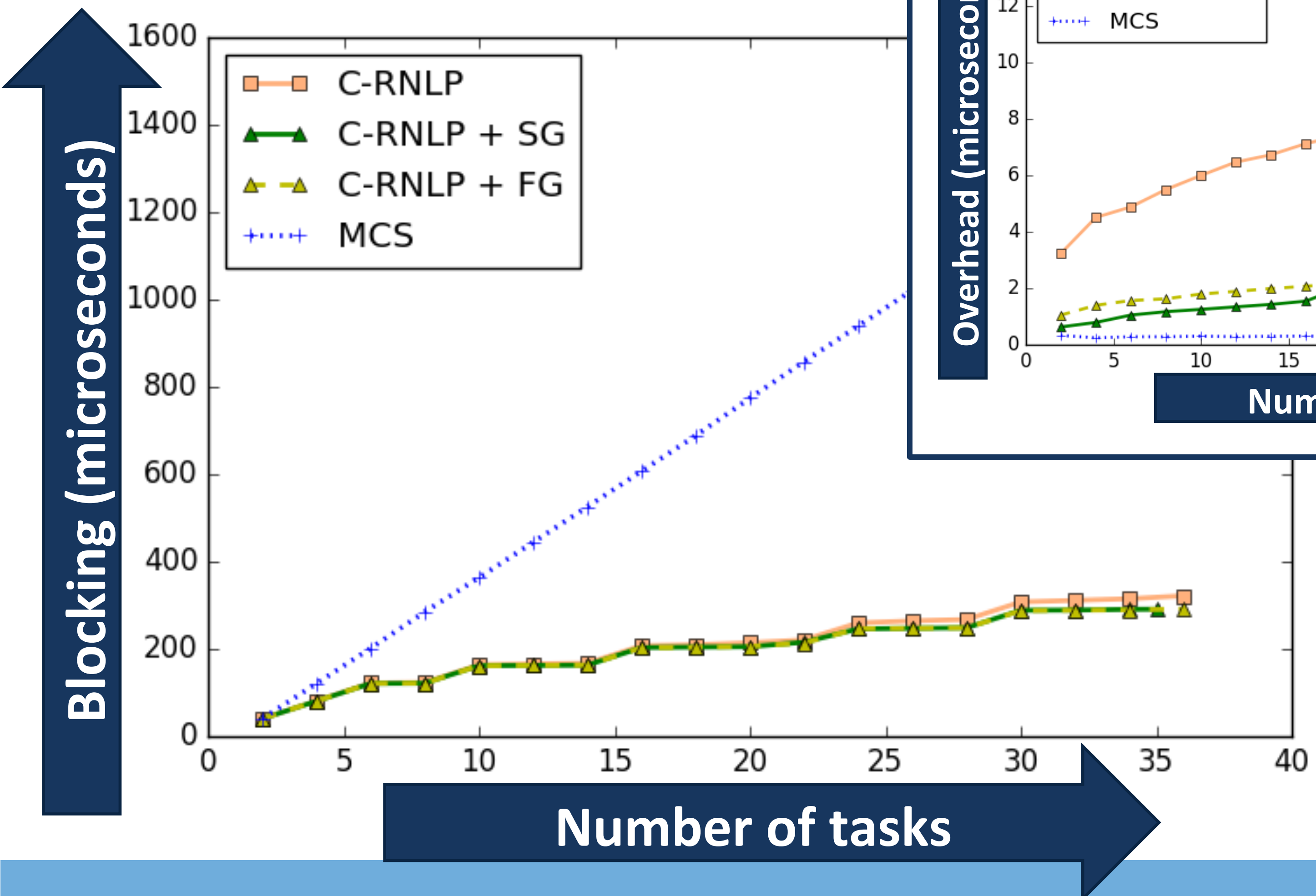
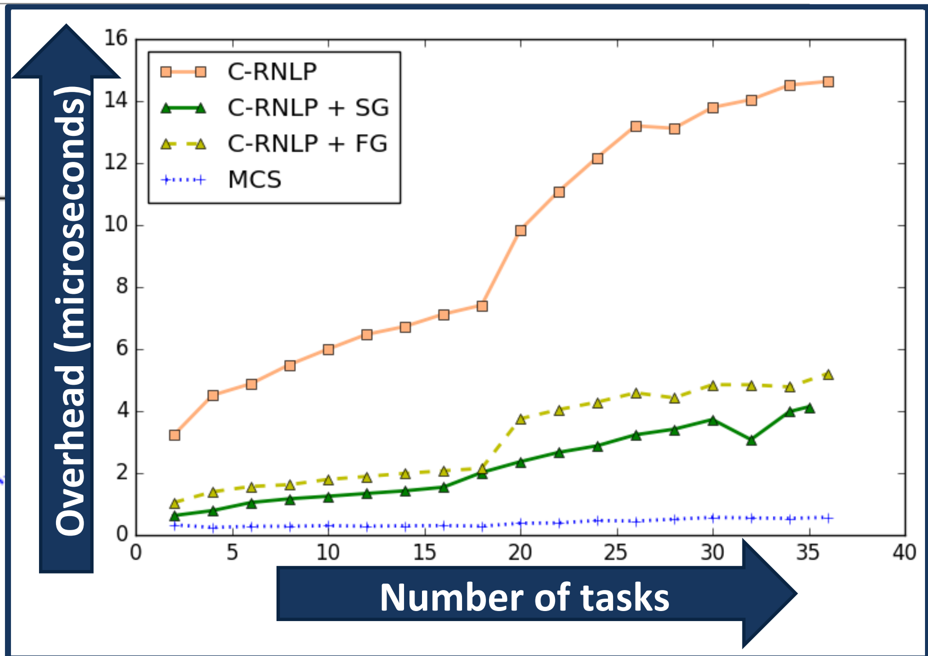
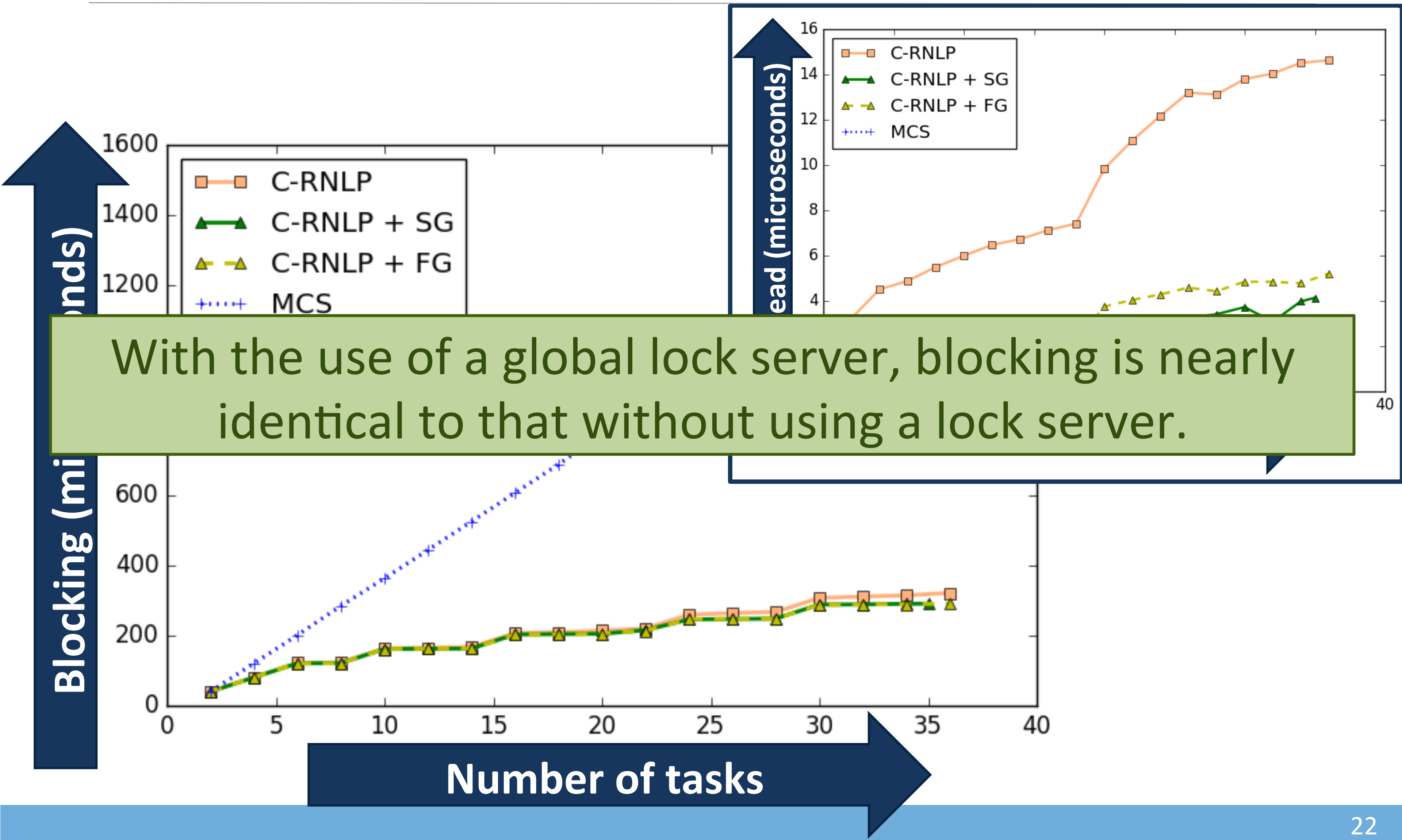




Experimental Results



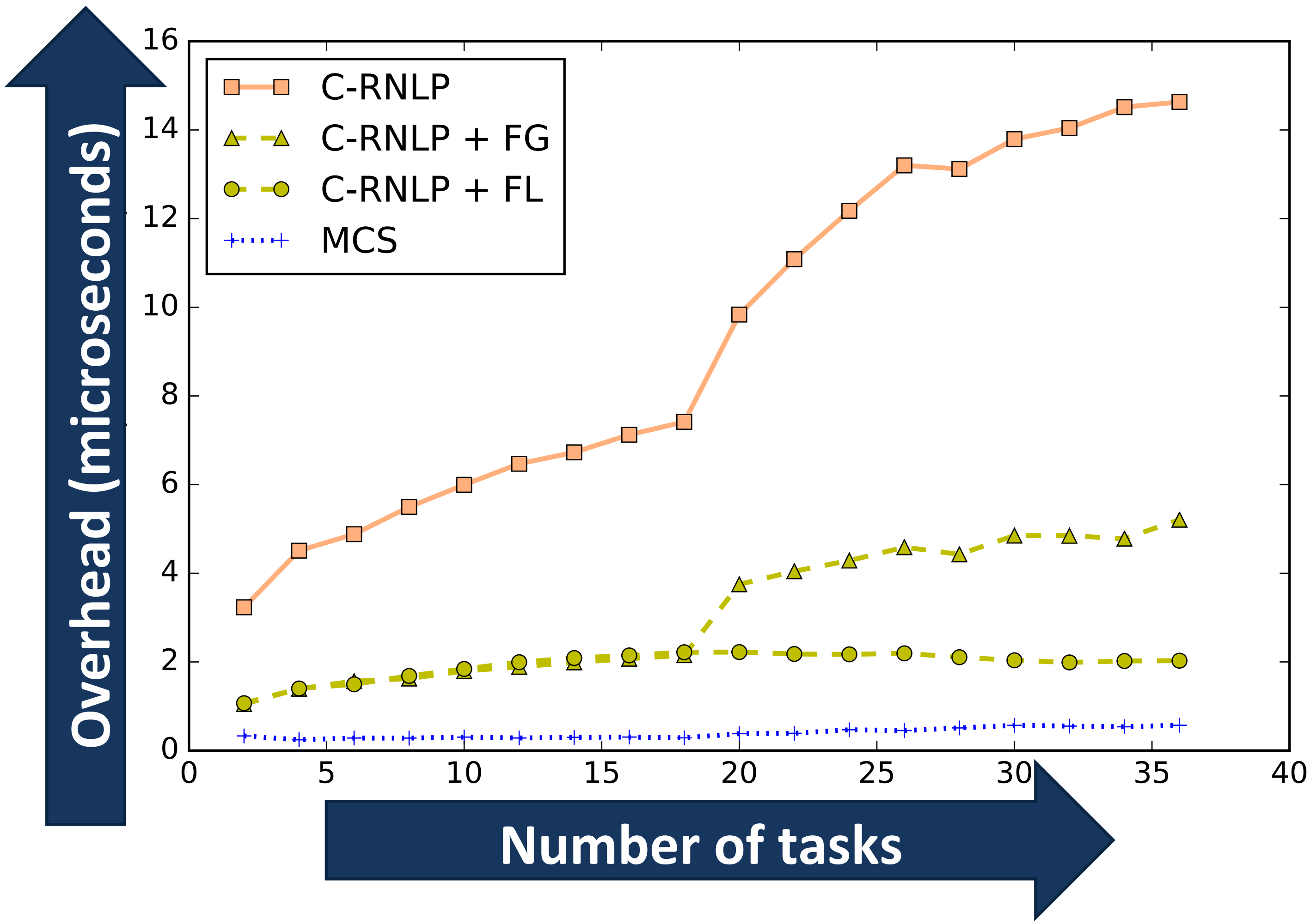
With the use of a global lock server, blocking is nearly identical to that without using a lock server.

Experimental Evaluation

How do **overhead** and **blocking** differ between global and local lock servers?

	Global	**Local**
Static	- Lose 1 core + L1 cache affinity	- Lose multiple cores + L1 cache affinity
Floating	- No guaranteed cache affinity	+ L3 cache affinity

Experimental Results



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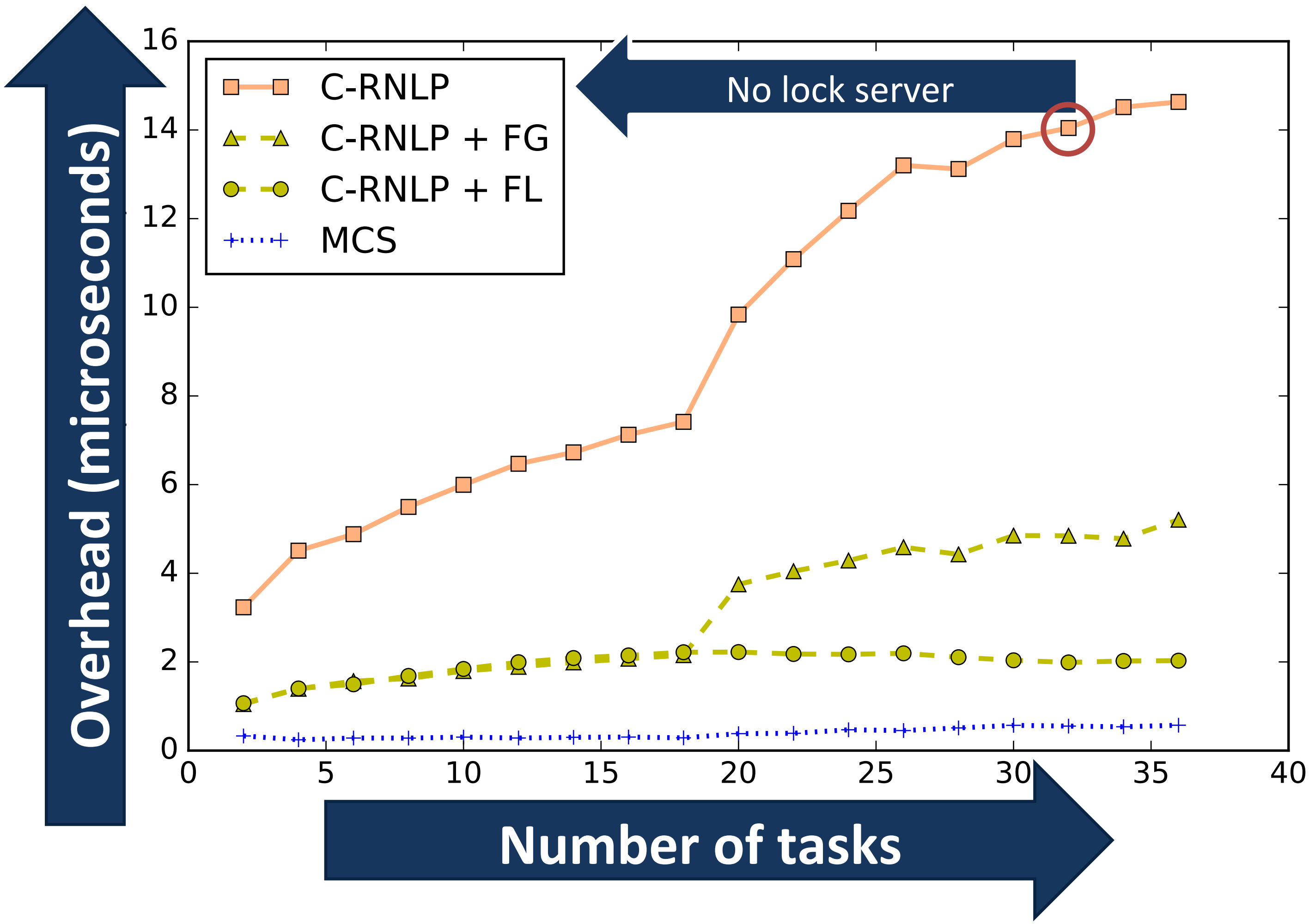

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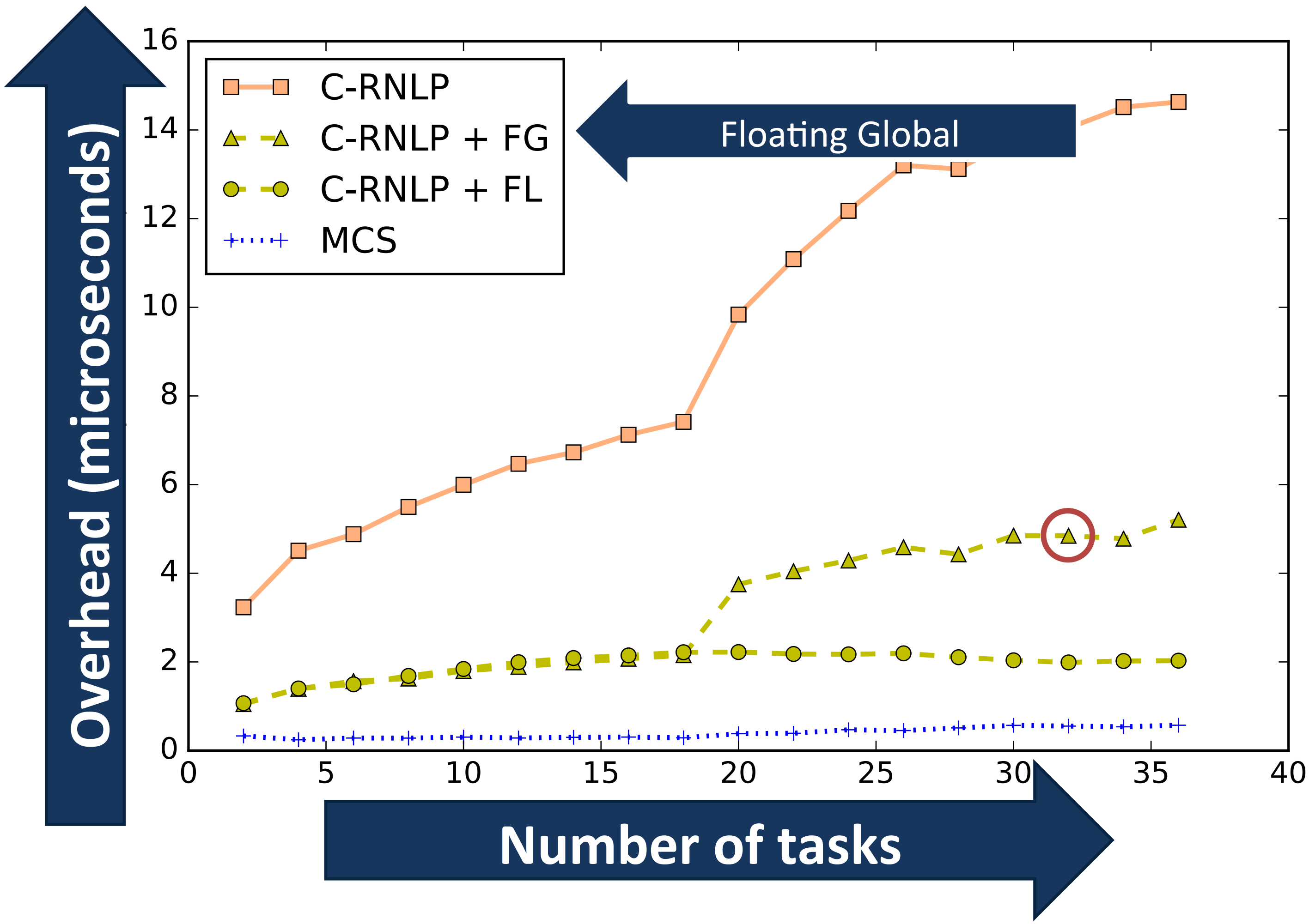

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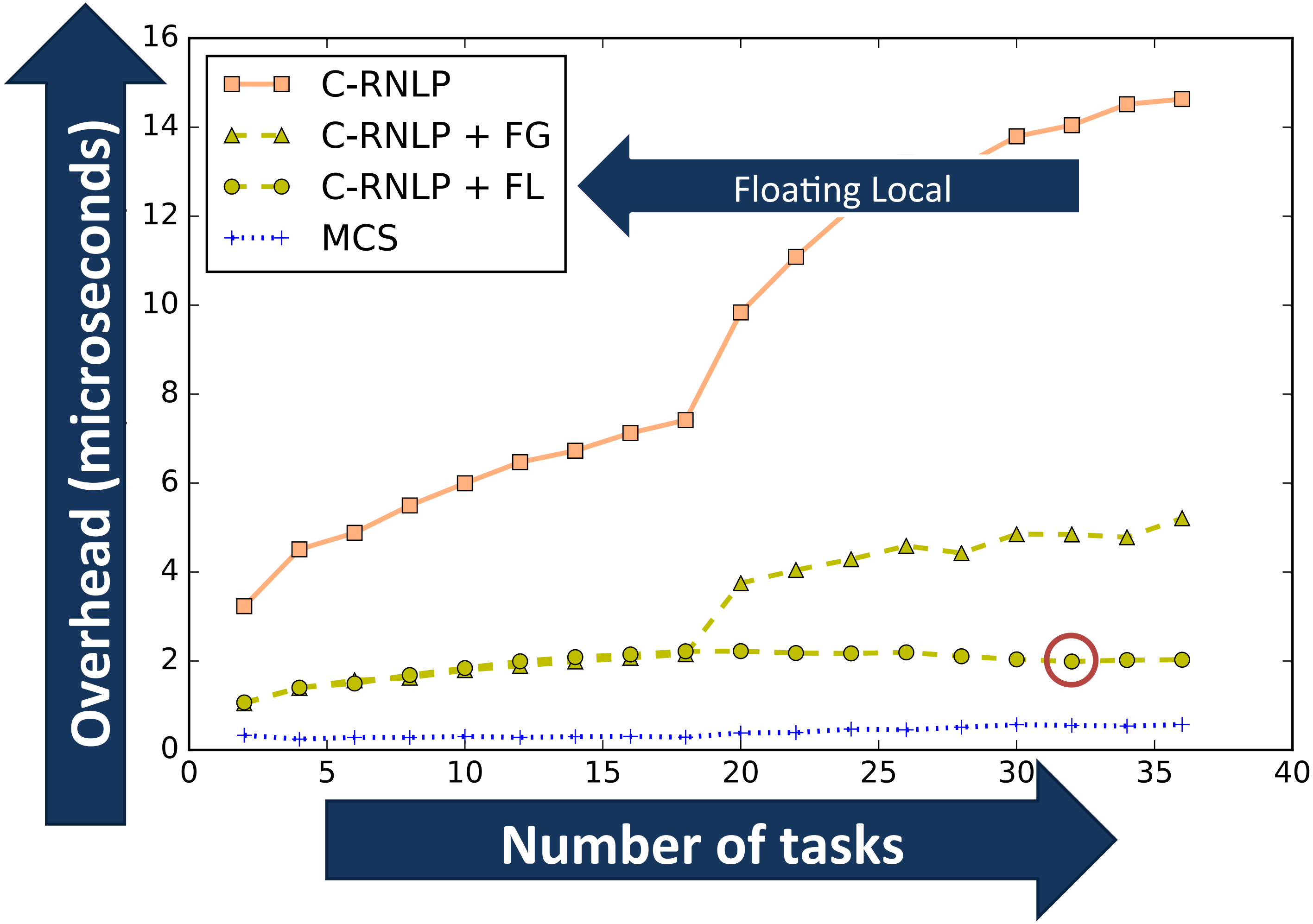

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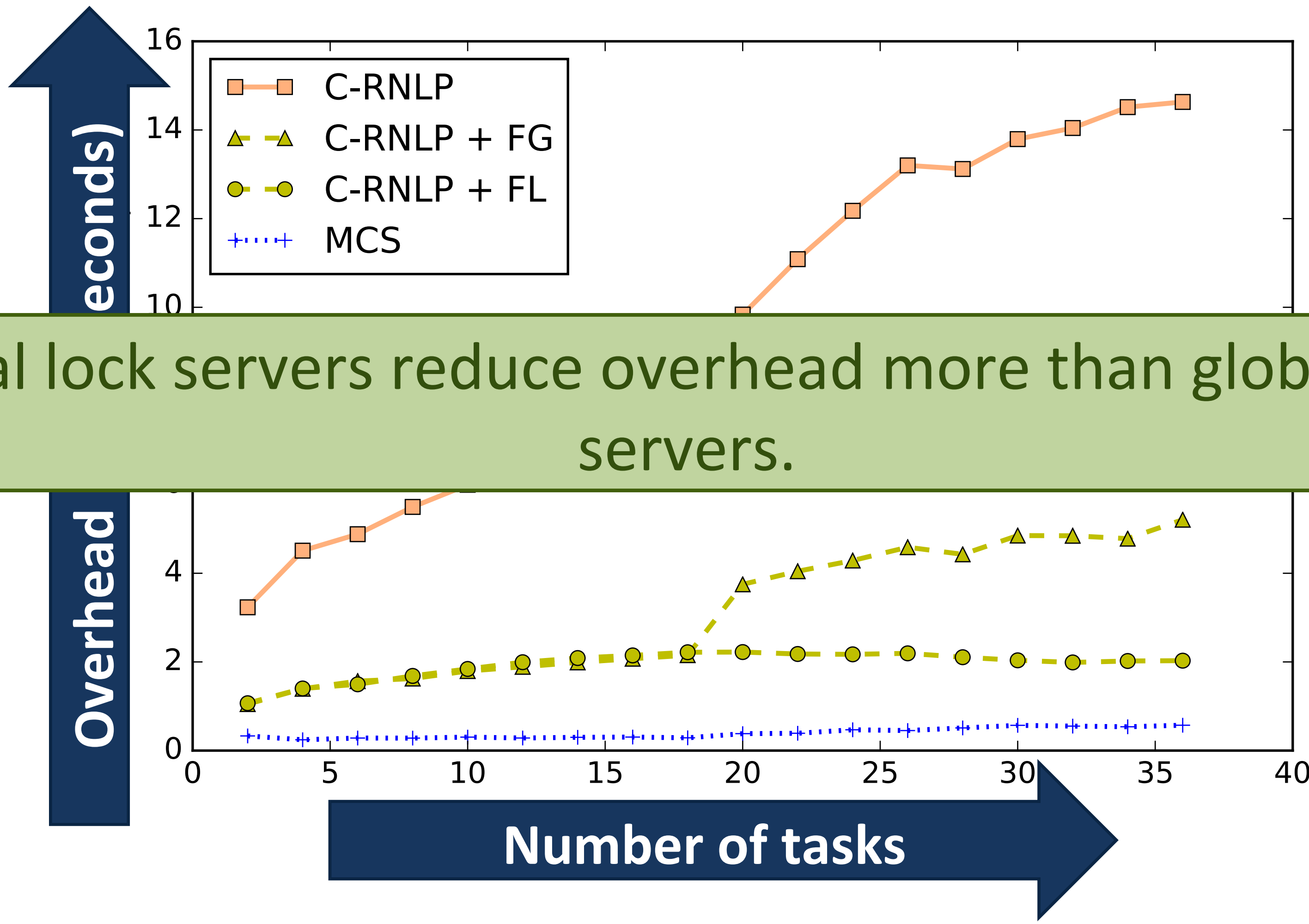
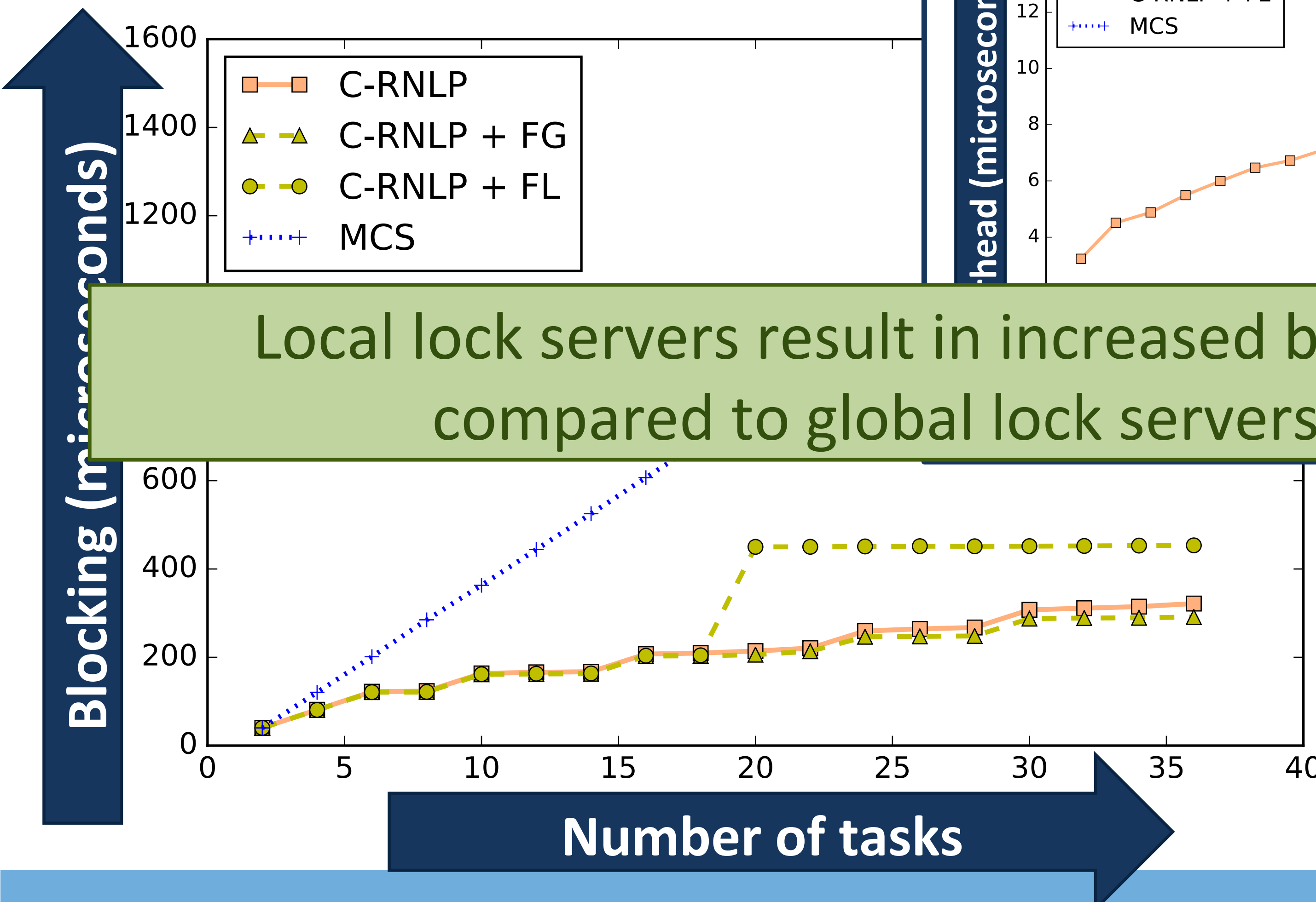
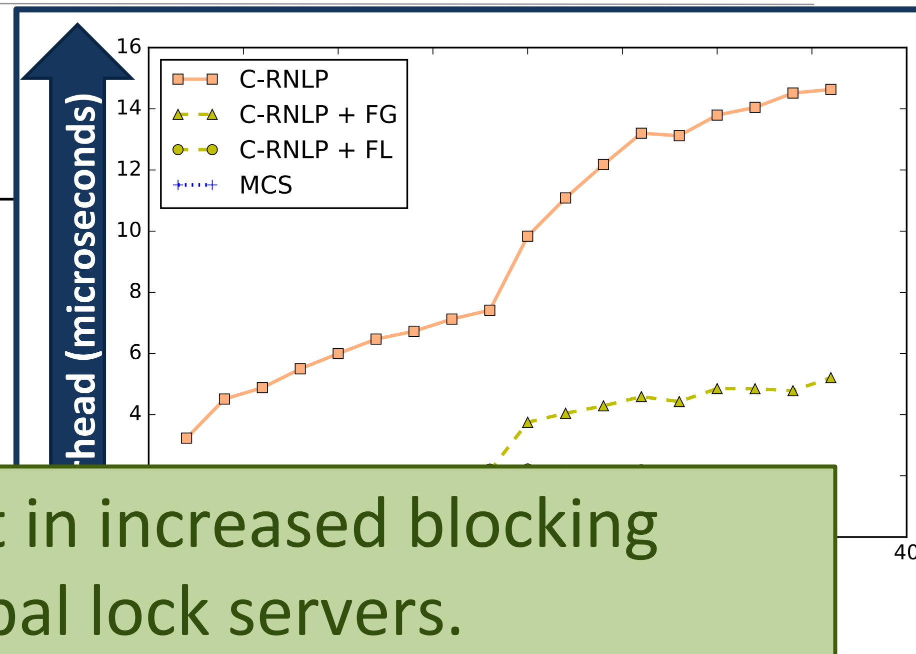


Local lock servers reduce overhead more than global lock servers.

Experimental Results





Local lock servers result in increased blocking compared to global lock servers.

Experimental Evaluation

Measured **overhead** and **blocking**

One task per core issuing 10,000 random requests

Parameter sweep:

- Number of tasks: {2,4,…,36}
- Total # of resources: {16, 32, 64}
- # resources per request: {1,2,4,6,8,10}
- Critical-section lengths: {1, 20, 40, …, 100} µs

Contributions

Four lock server paradigms

- Implementation
- Evaluation

Lock server coordination protocol

Lock Server Coordination

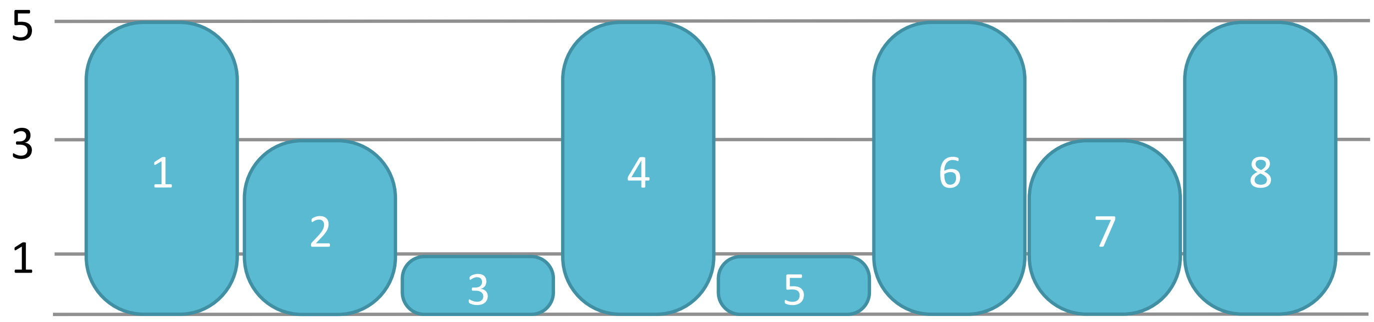
Original C-RNLP bound:

$$(c_i + 1)L_{MAX}$$

Two-server C-RNLP bound with R^2LP:

$$(c_{i,s} + 1)(L_{MAX,1} + L_{MAX,2})$$

C-RNLP bound



$(c_i + 1)L_{MAX} = (7 + 1)(5) = 40$ time units

40 time units

Arbitrary Split

Server 1 Server 2

Blocking

Server 1: (3 + 1)(5 + 5) = 40 — 40 time units

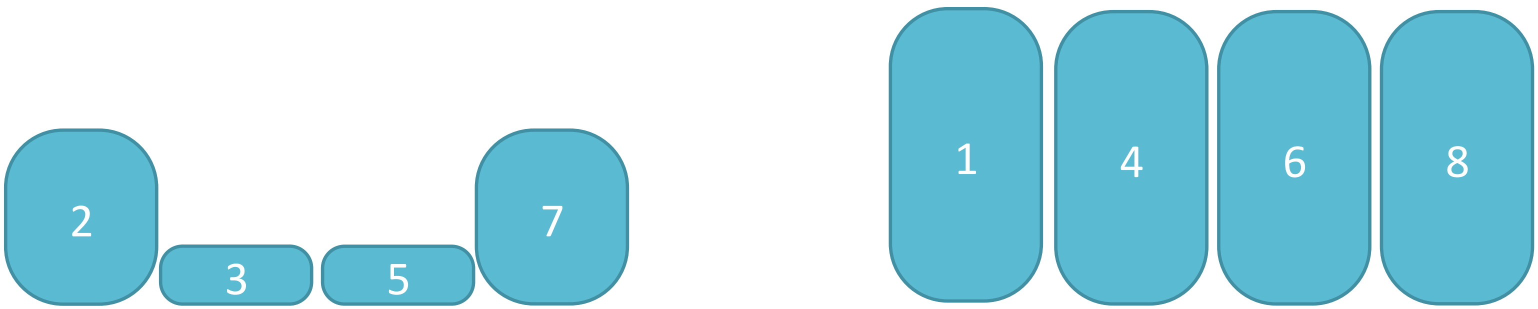
Server 2: (3 + 1)(5 + 5) = 40 — 40 time units

$$(c_{i,s} + 1)(L_{MAX,1} + L_{MAX,2})$$

Even Split by Critical-Section Length

Server 1

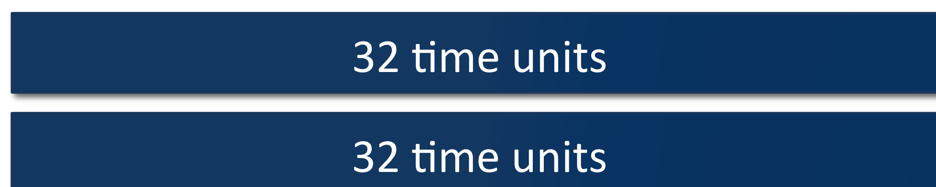
Server 2



Blocking

Server 1: $(3 + 1)(3 + 5) = 32$

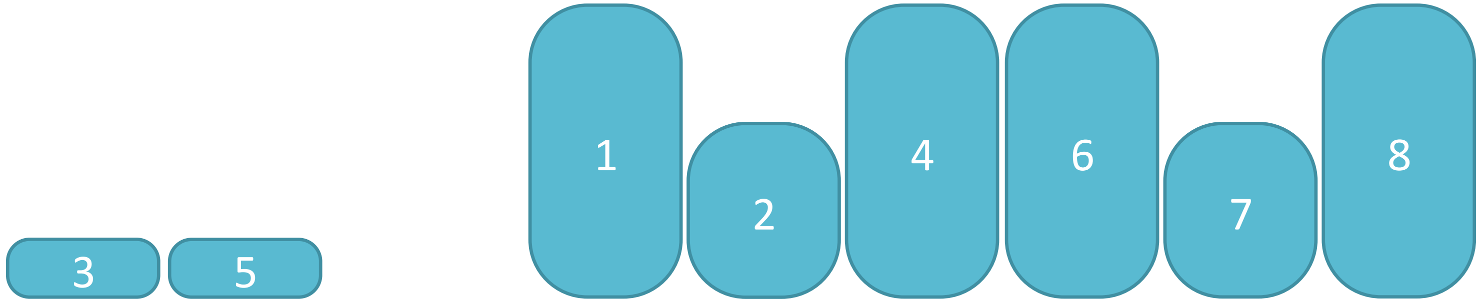
Server 2: $(3 + 1)(3 + 5) = 32$



$$(c_{i,s} + 1)(L_{MAX,1} + L_{MAX,2})$$

Uneven Split by Critical-Section Length

Server 1 Server 2



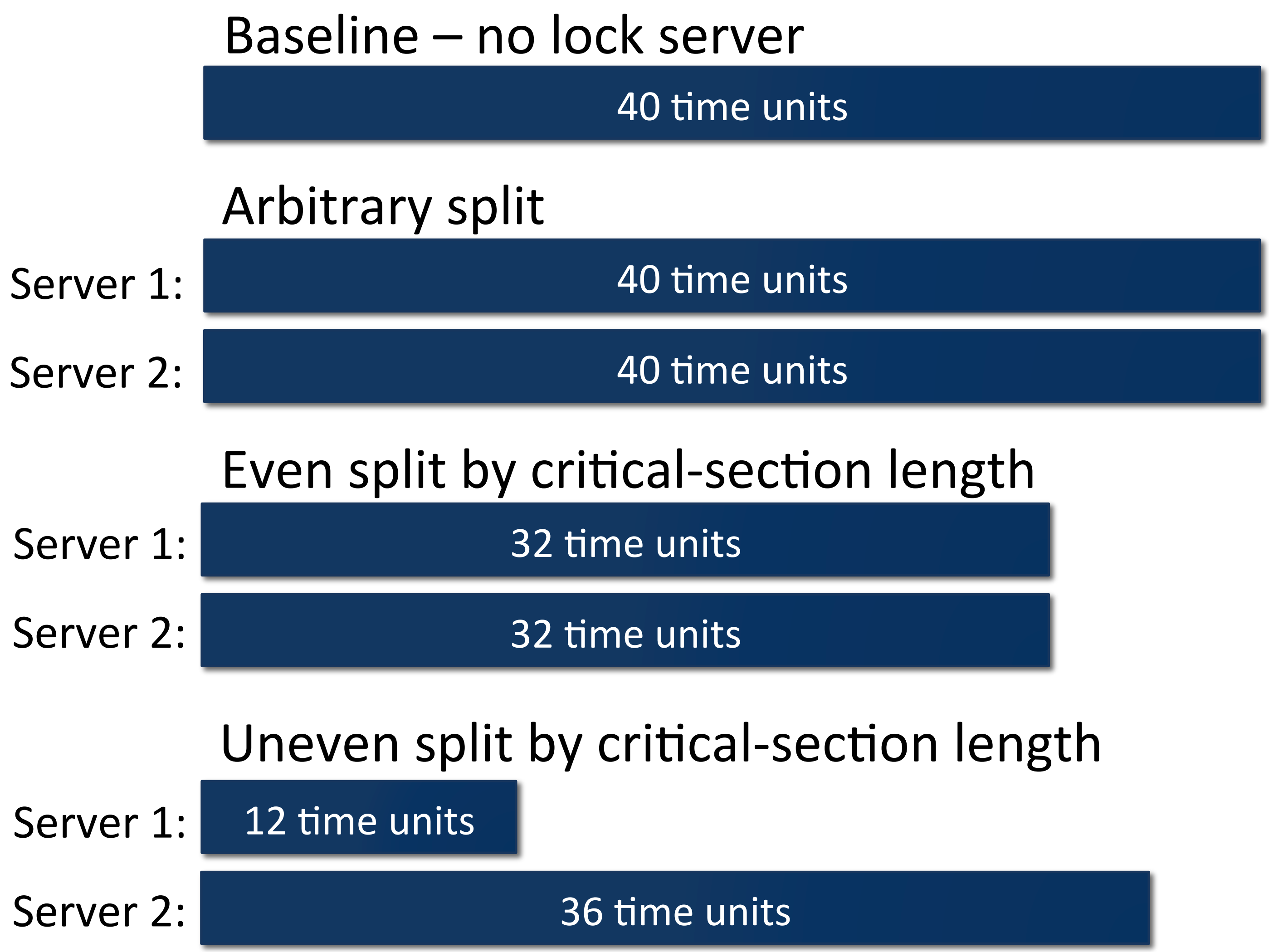
Blocking

Server 1: (1 + 1)(1 + 5) = 12

Server 2: (5 + 1)(1 + 5) = 36

$$(c_{i,s} + 1)(L_{MAX,1} + L_{MAX,2})$$

Blocking Bounds

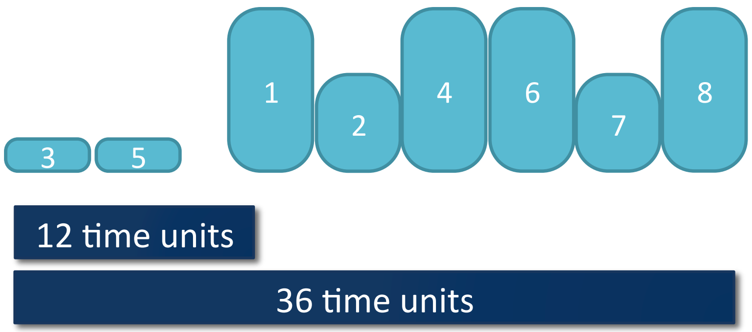


Future Work

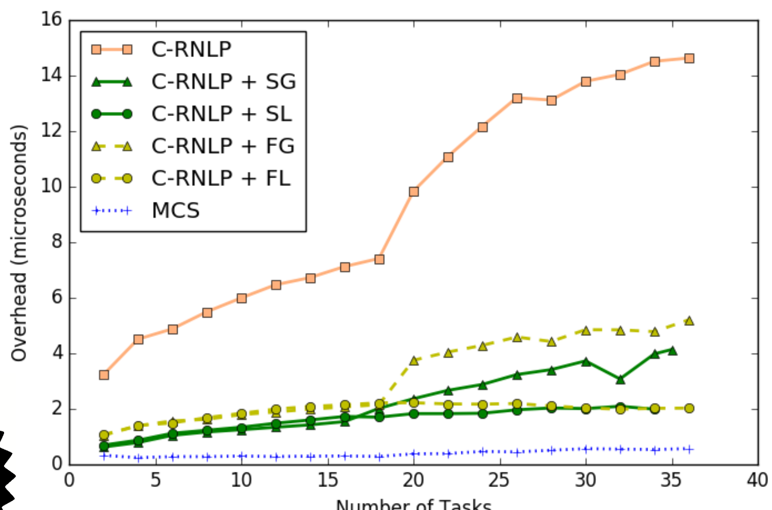
- Choose how to split tasks (based on requests) when using lock servers
- Explore accounting for static servers
  - Set server at highest priority, ensure lock state in cache
  - Use a dedicated IRQ-handling core
  - Treat as a special kind of interrupt
- Conduct a large-scale overhead-aware schedulability study

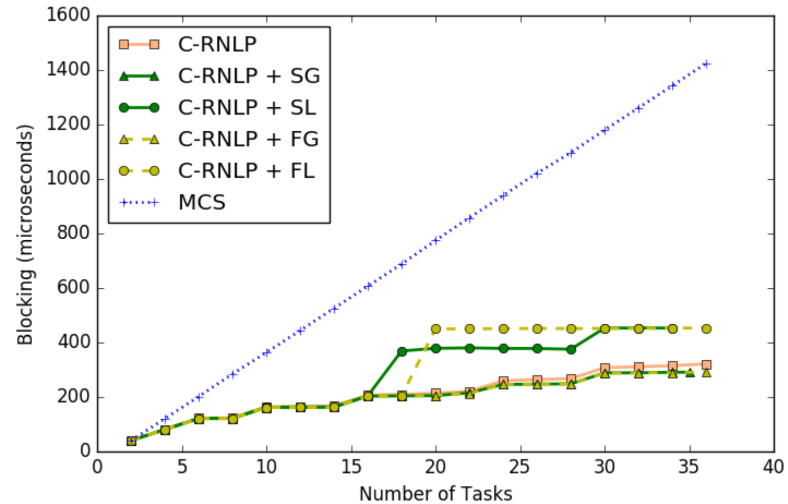
	Global	Local
Static	- Lose 1 core + L1 cache affinity	- Lose multiple cores + L1 cache affinity
Floating	- No guaranteed cache affinity	+ L3 cache affinity

Server Coordination: R^{2}LP



Questions?

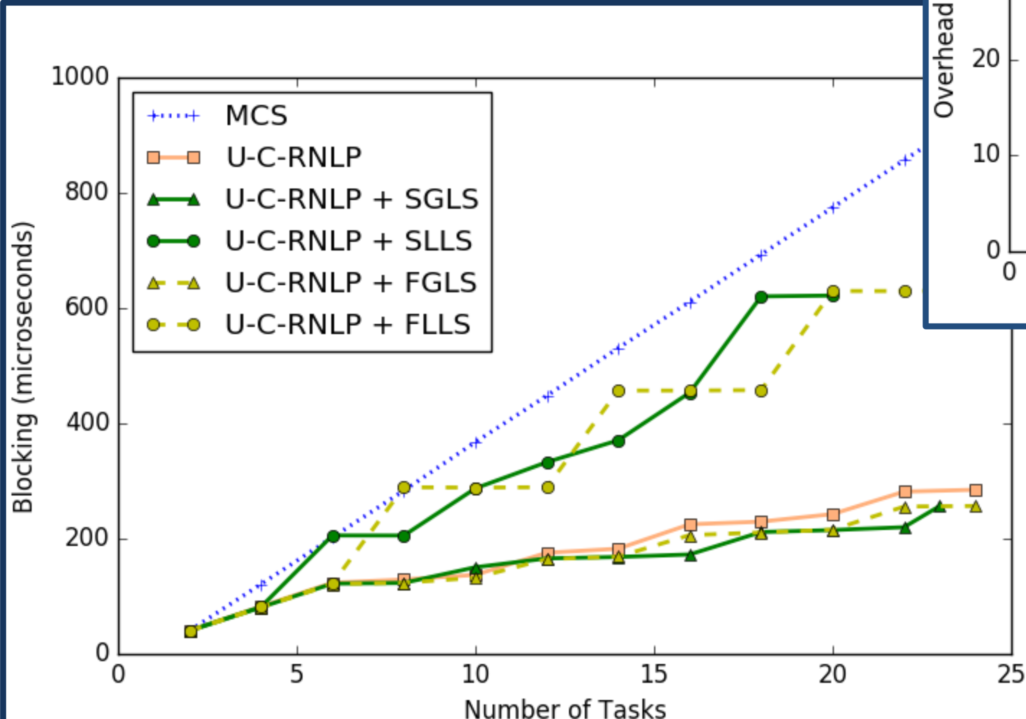


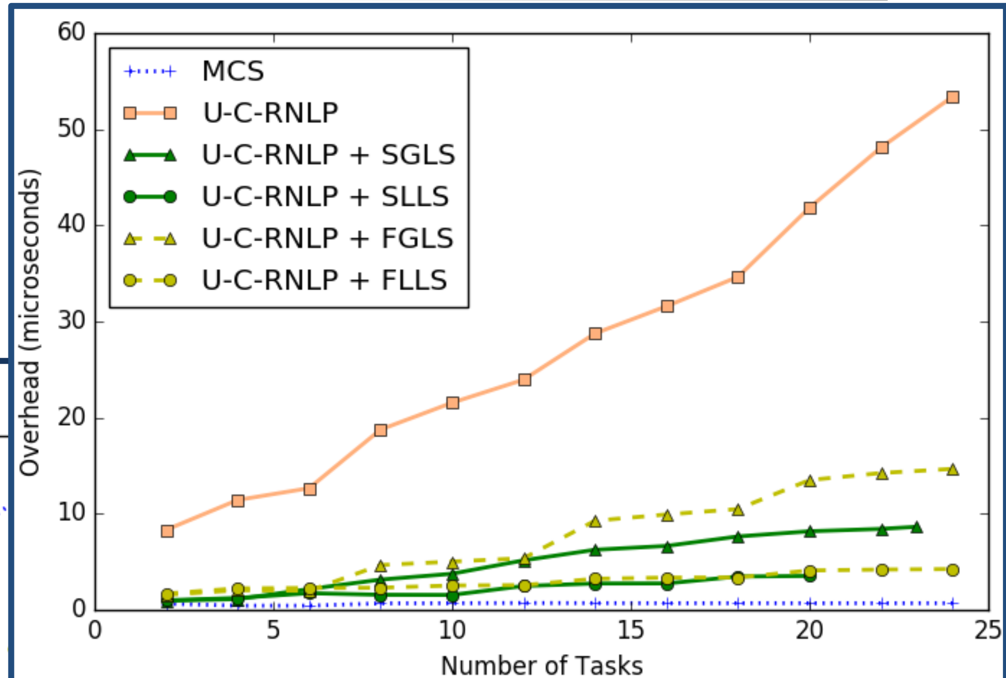


dx.doi.org/10.4230/DARTS.4.2.2

Case Study: Four Sockets

four-socket, 6-cores-per-socket
Intel Xeon L7455





L1 data: 32KB
L1 instruction: 32KB
L2: 3MB
L3: 12MB

Case Study: Profile of Requests

TABLE IV. RUNNABLE AVERAGE EXECUTION TIMES

Period	Average Execution Times in µs		
	Min.	Avg.	Max.
1 ms	0,34	5,00	30,11
2 ms	0,32	4,20	40,69
5 ms	0,36	11,04	83,38
10 ms	0,21	10,09	309,87
20 ms	0,25	8,74	291,42
50 ms	0,29	17,56	92,98
100 ms	0,21	10,53	420,43
200 ms	0,22	2,56	21,95
1000 ms	0,37	0,43	0,46

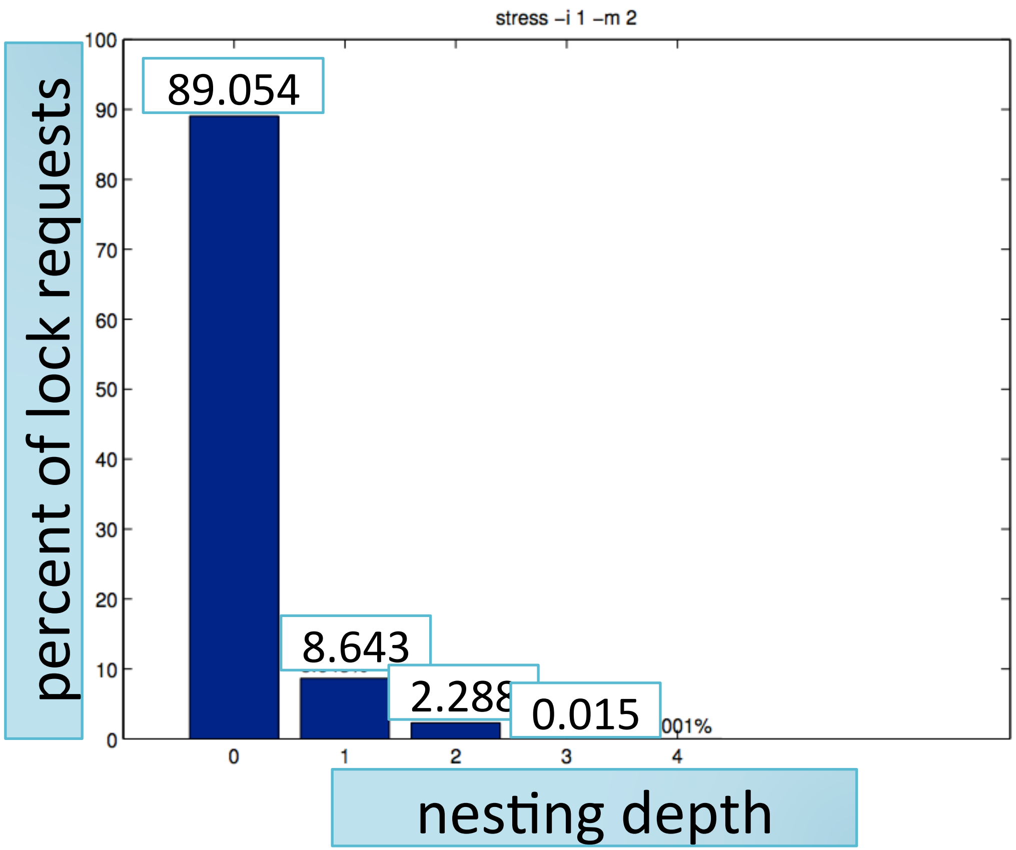
I	II	III	IV	V	VI
<10	10-50	51-100	100-500	501-1000	>1000

TABLE II. INTER-TASK COMMUNICATION

Period	1 ms	2 ms	5 ms	10 ms	20 ms	50 ms	100 ms	200 ms	1000 ms	sync
1 ms				I	I		I			I
2 ms				I	I		I			
5 ms		I	IV	IV	II	II	I			
10 ms	II	II	II	VI	IV	II	IV	II	III	IV
20 ms	I	I	I	IV	VI	II	IV	I	II	IV
50 ms			II	II	II	III	I			
100 ms		I	I	V	IV	II	VI	II	III	IV
200 ms				I	I		I	I	I	
1000 ms				III	II		III	I	IV	I
Angle-sync	I	I	I	IV	IV	I	III	I	I	V

S. Kramer, D. Ziegenbein, and A. Hamann. Real world automotive benchmarks for free. *WATERS 2015.*

Case Study: Nested Requests



B. Brandenburg and J. Anderson. Feather-trace: A lightweight event tracing toolkit. *OSPERT 2007*.

Handling Nested Requests

Non-nested lock request

```
lock(A)
    //critical section
unlock(A)
```

With Dynamic Group Locks (DGLs)

```
lock(A)
    //critical section
unlock(A)
```

Nested lock request

```
lock(A)
    lock(B)
      //critical section
    unlock(B)
unlock(A)
```

```
lock(A,B)
    //critical section
unlock(A,B)
```

Additional Experimental Results

	U-C-RNLP	U-C-RNLP + SGLS	U-C-RNLP + SLLS	U-C-RNLP + FGLS	G-C-RNLP + SGLS
Total Firsts	0	92	0	23	12
Total Seconds	1	26	18	70	4
Total Thirds	68	2	17	20	8
Total	69	120	35	113	24

- **Figure 16** Results of total request time comparison.

Challenge: Blocking Chains

Sequential resource acquisition: critical-section length $O(m^D)$

H. Takada and K. Sakamura. Real-time scalability of nested spin locks. *RTCSA 1995*.

Dynamic group locks: no worst-case critical-section inflation, same asymptotic bounds

B. Ward and J. Anderson. Supporting nested locking in multiprocessor real-time systems. *ECRTS 2012.*