Taking a Virtual Machine Towards Many-Cores

Kenneth Lundin , Ericsson

RELEASE

RELEASE

- EU FP7 STREP research project
- October 2011 – September 2013
- Partners:
  - Heriot Watt University (UK)
  - Uppsala University (Sweden)
  - University of Kent (UK)
  - ICCS (Greece)
  - Ericsson AB (Sweden)
  - Erlang Solutions (UK/Sweden)
  - EDF (France)

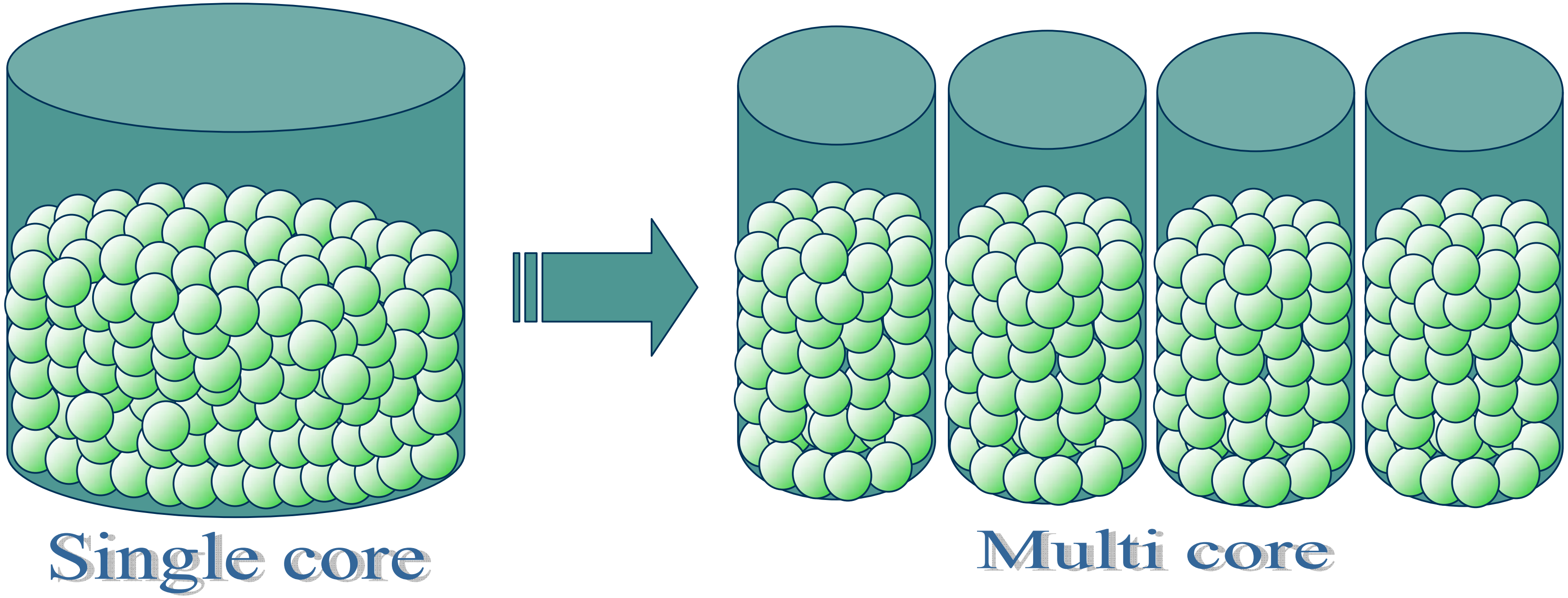
Goals

- *Scale Erlang's concurrency-oriented programming paradigm to build reliable general-purpose software, such as server-based systems, on massively parallel machines (100 000 cores).*
  - Language primitives for scalable distribution
  - **Virtual machine extensions and improvements**
  - Tools for parallelizing/refactoring existing code
  - Tools for profiling and testing for errors
  - Scalable virtualization infrastructure
  - Porting Erlang/OTP on the Blue Gene

www.release-project.eu

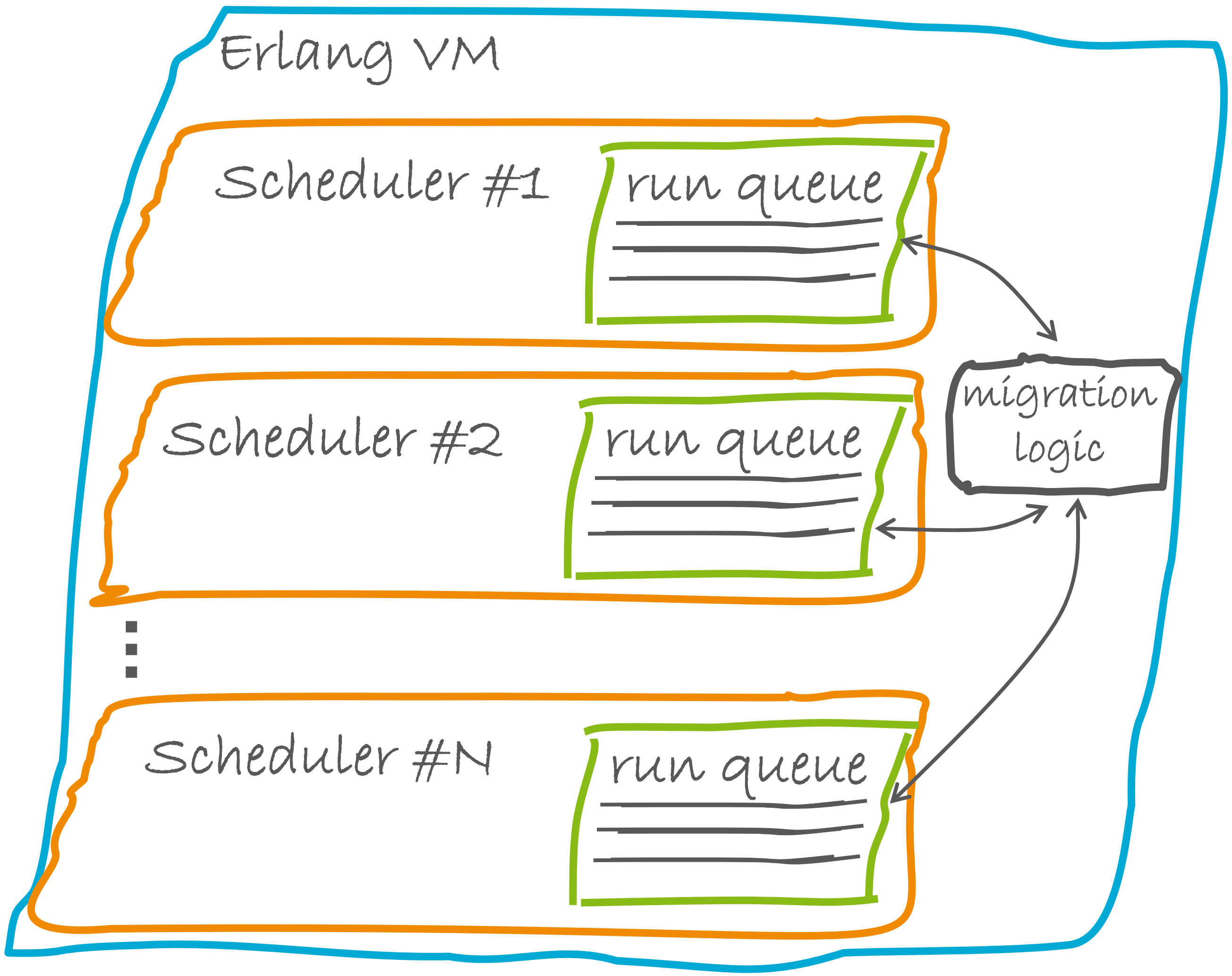
Perfect program for using multicore

- A lot of small units of execution
- The parallel mindset has created applications just waiting to be spread over several physical cores



Multiple run-queues

Erlang SMP VM (since R13B)

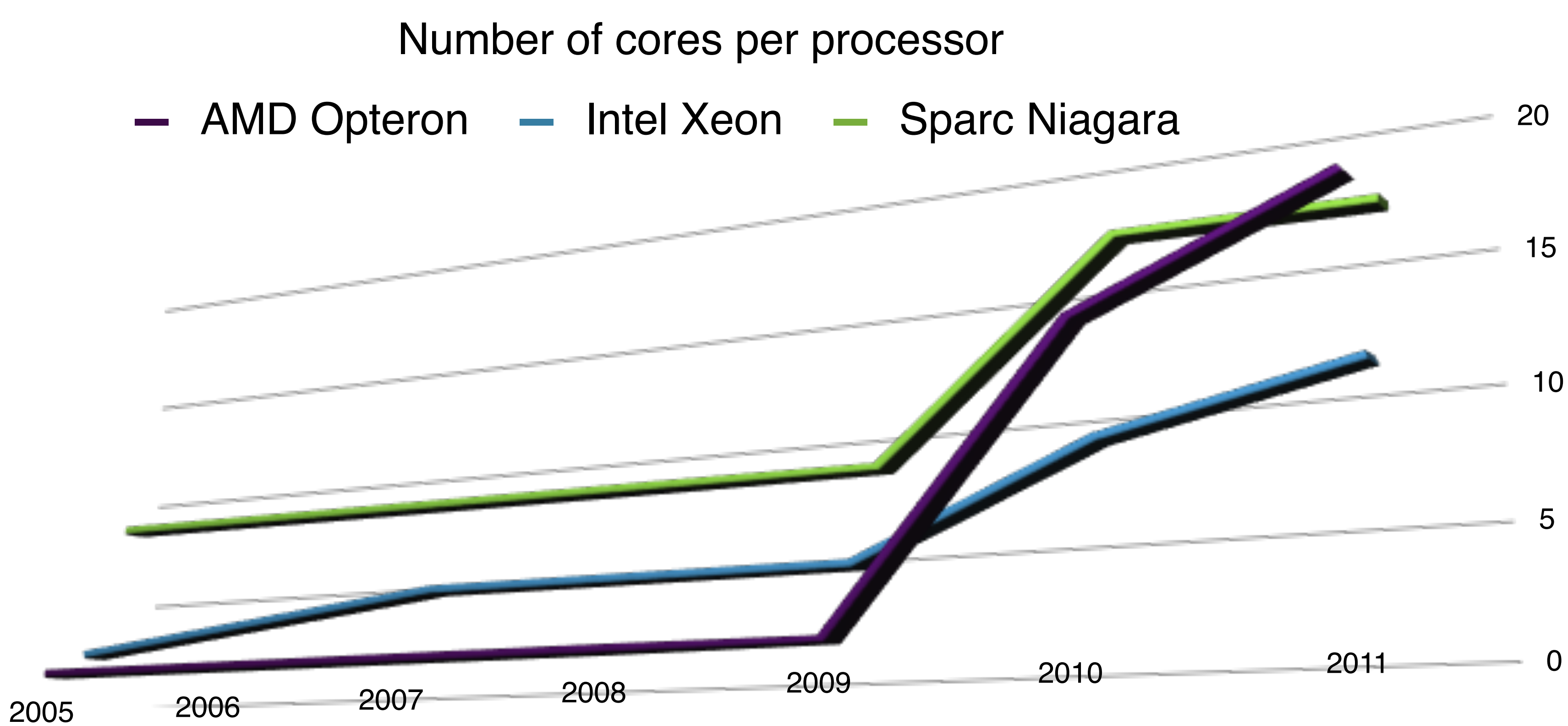


TAKING A VIRTUAL MACHINE TOWARDS MANY-CORES

RICKARD GREEN - *rickard@erlang.org*

PATRIK NYBLOM - *pan@erlang.org*

WHAT WE ALL KNOW BY NOW



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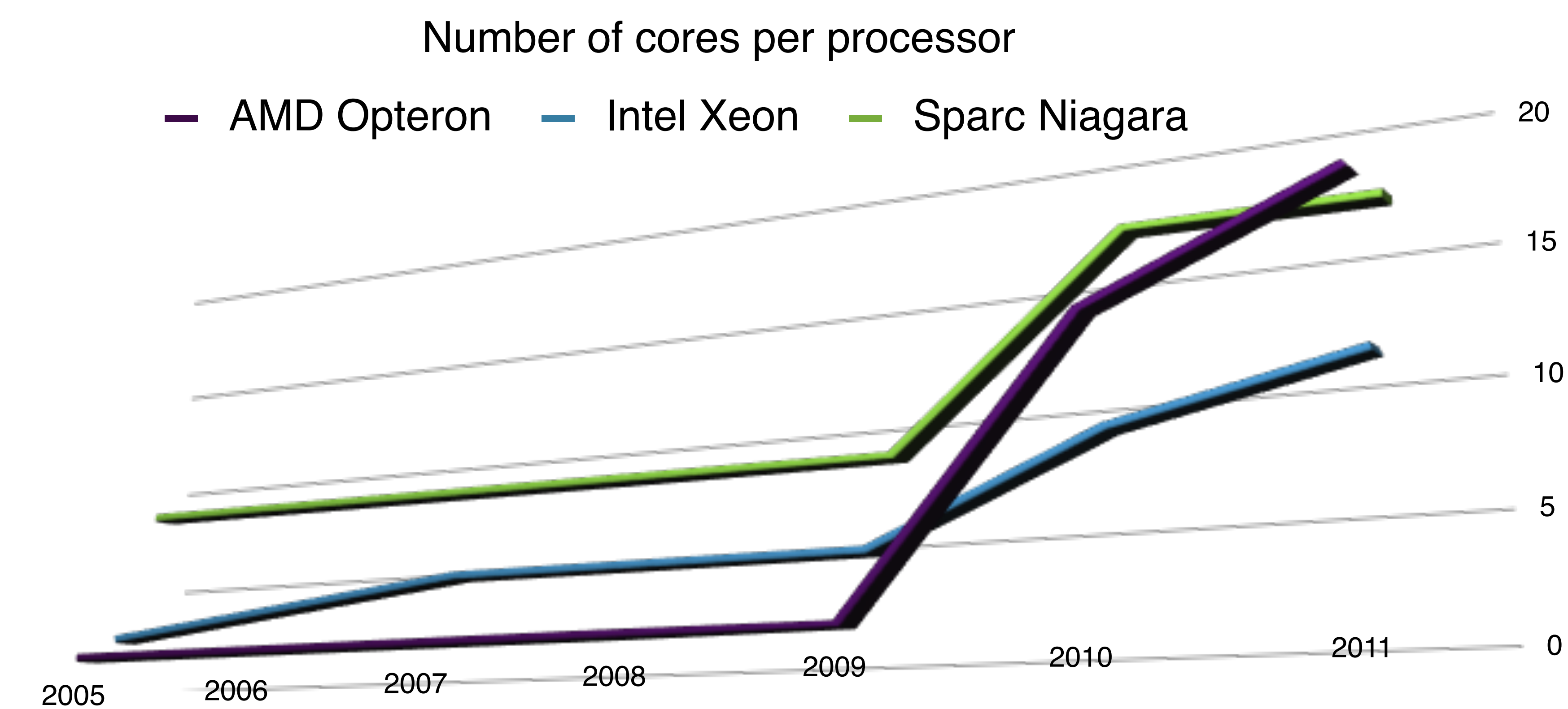

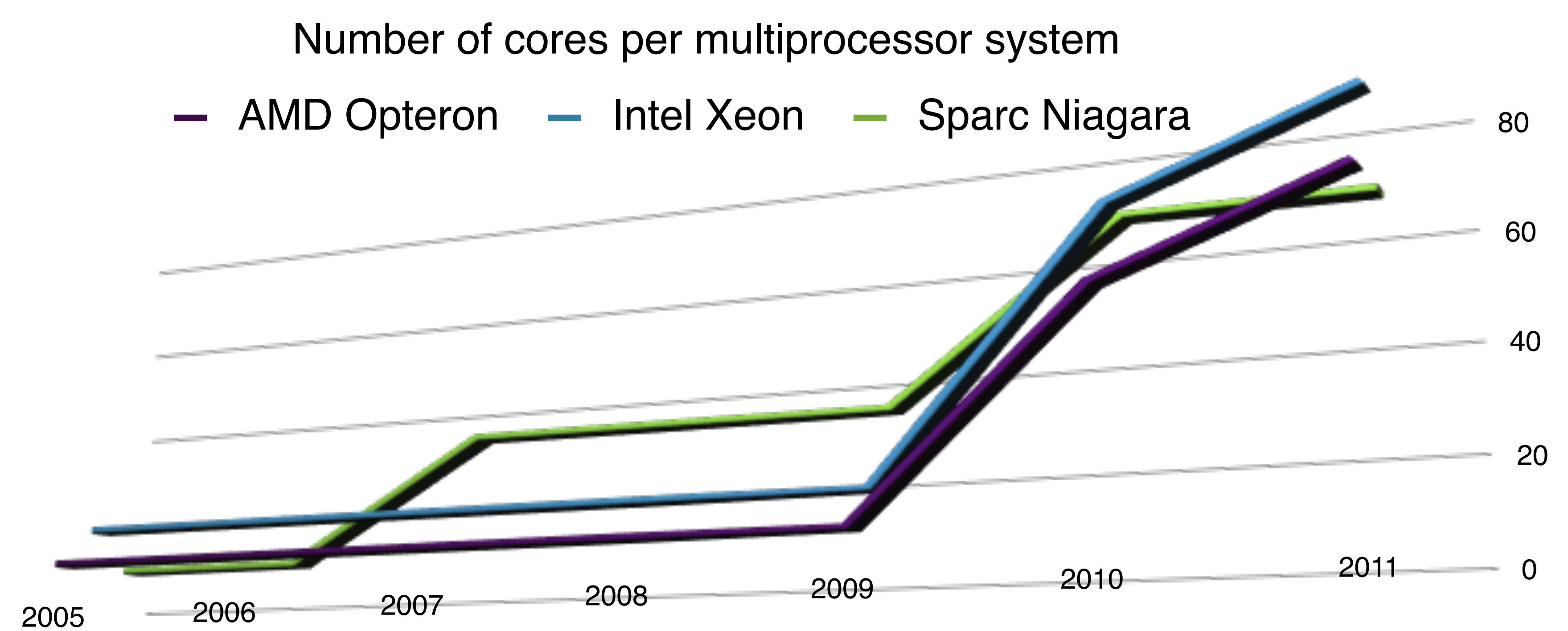

ERLANG

Resource Contention

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- High level algorithms
  - Server
  - ...

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- Software synchronization mechanisms
  - Locks
    - Lock type
    - Lock implementation
  - Lock free data structures
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- Hardware
  - Processor communication
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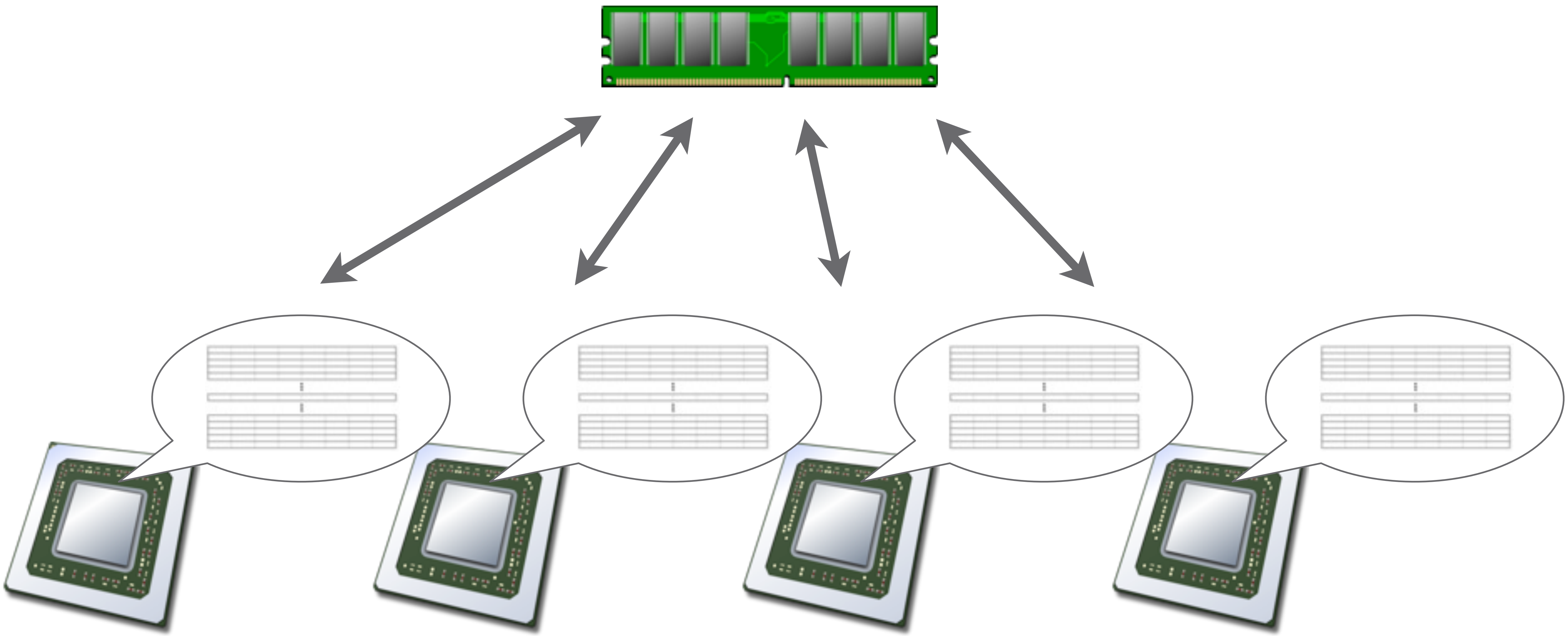
Awareness

SHARED MEMORY MULTIPROCESSOR SYSTEM



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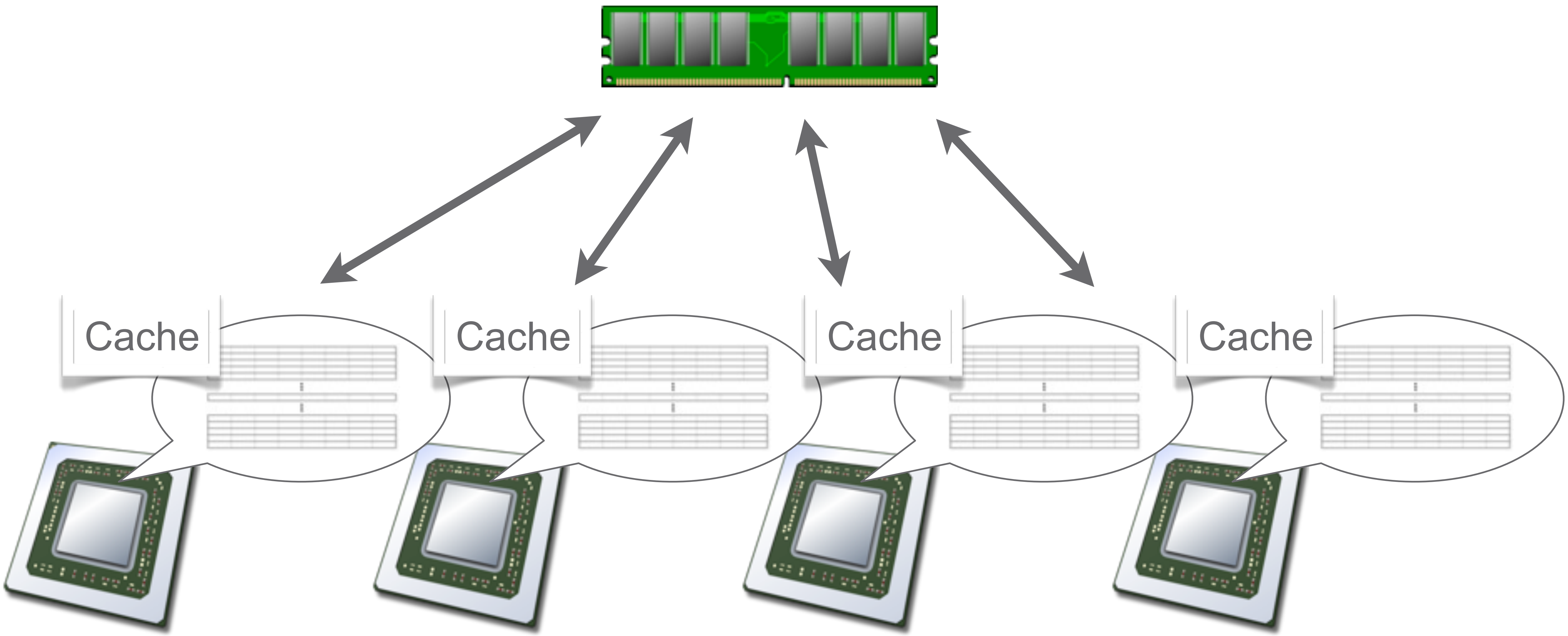

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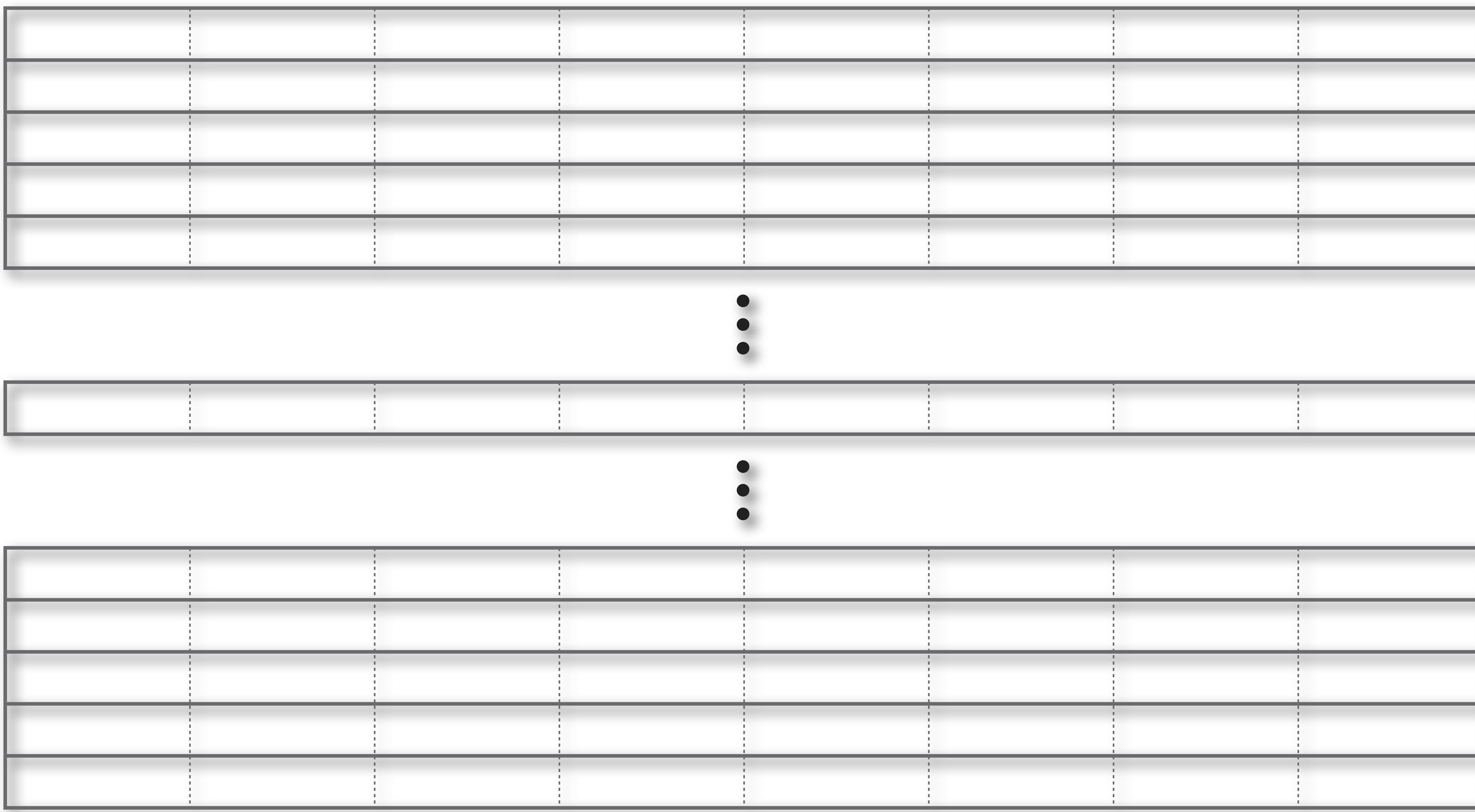

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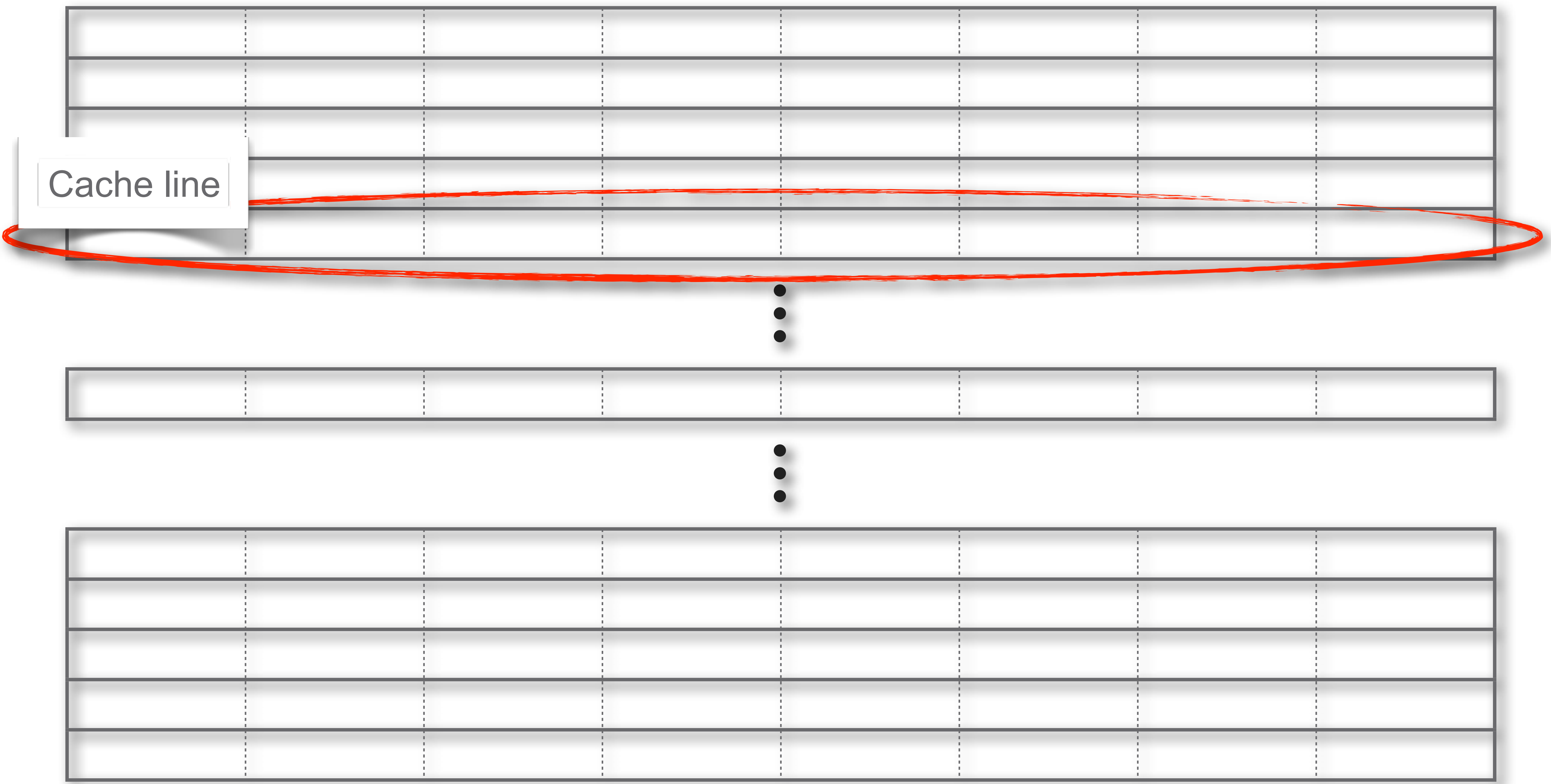

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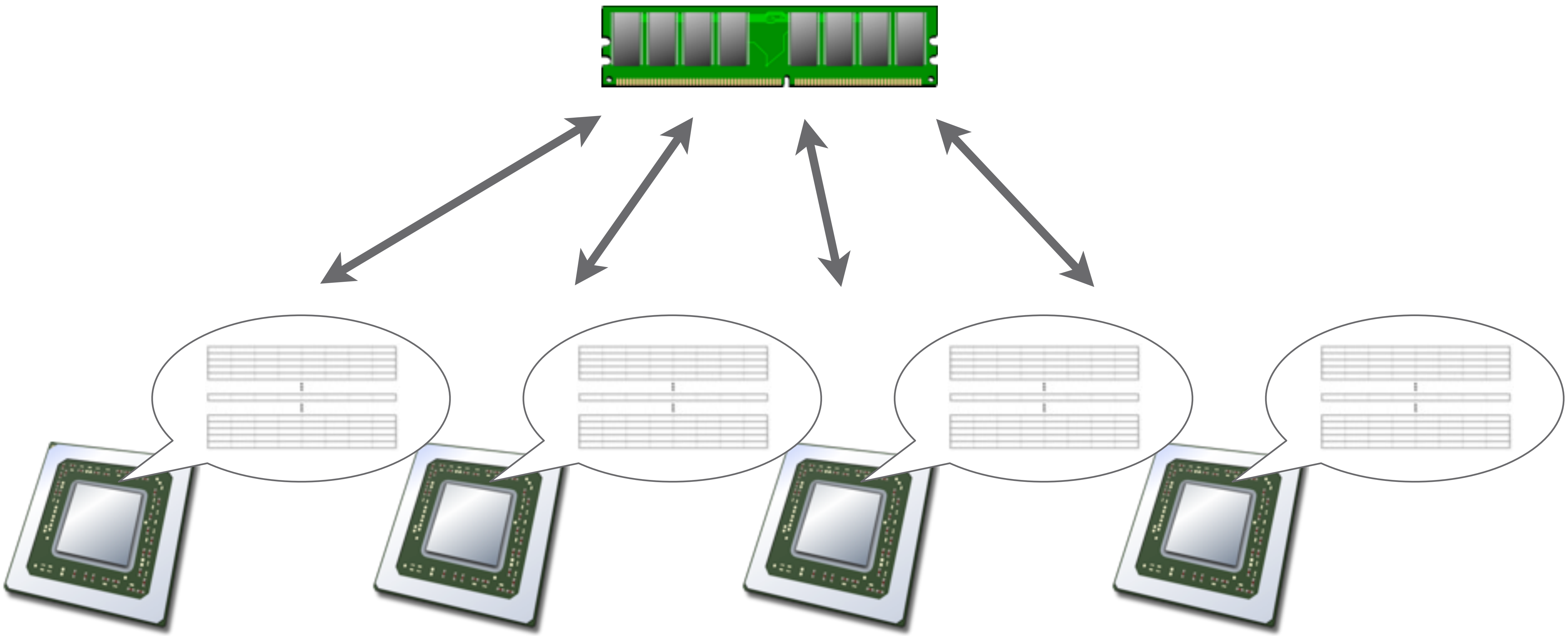

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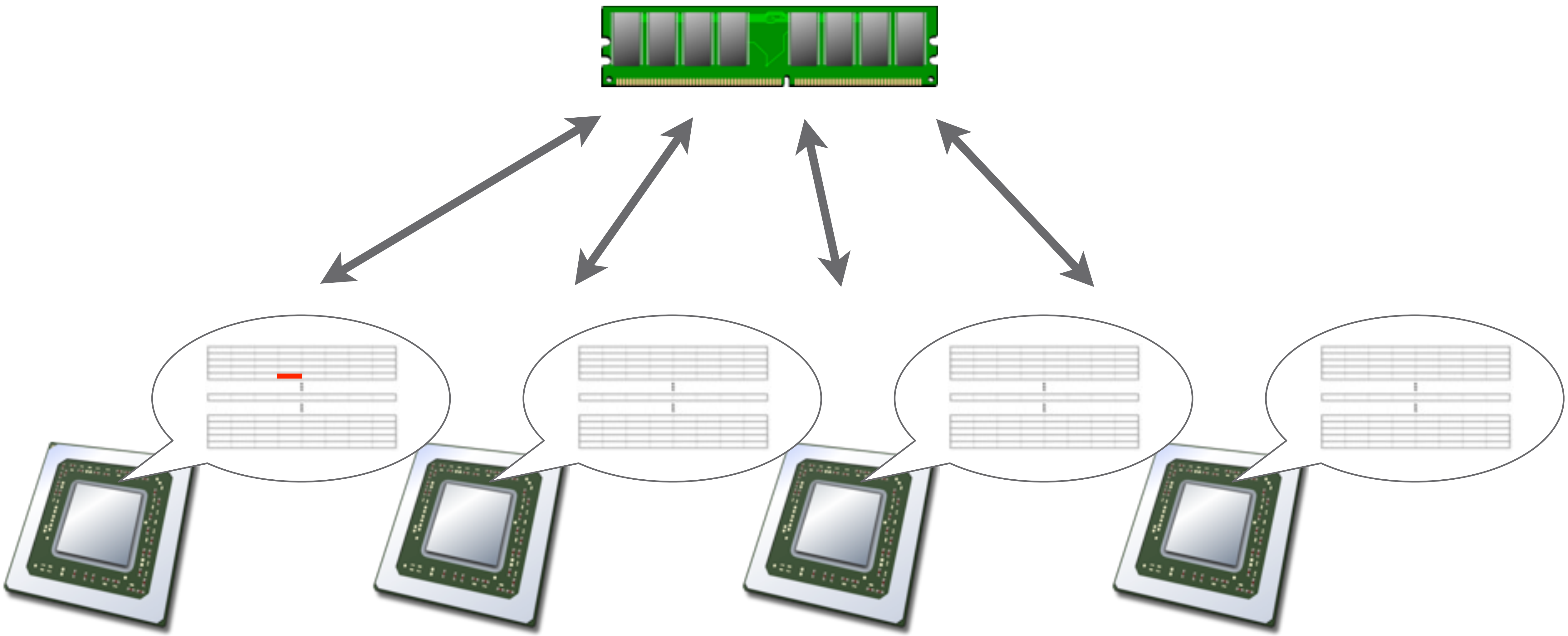

ERLANG

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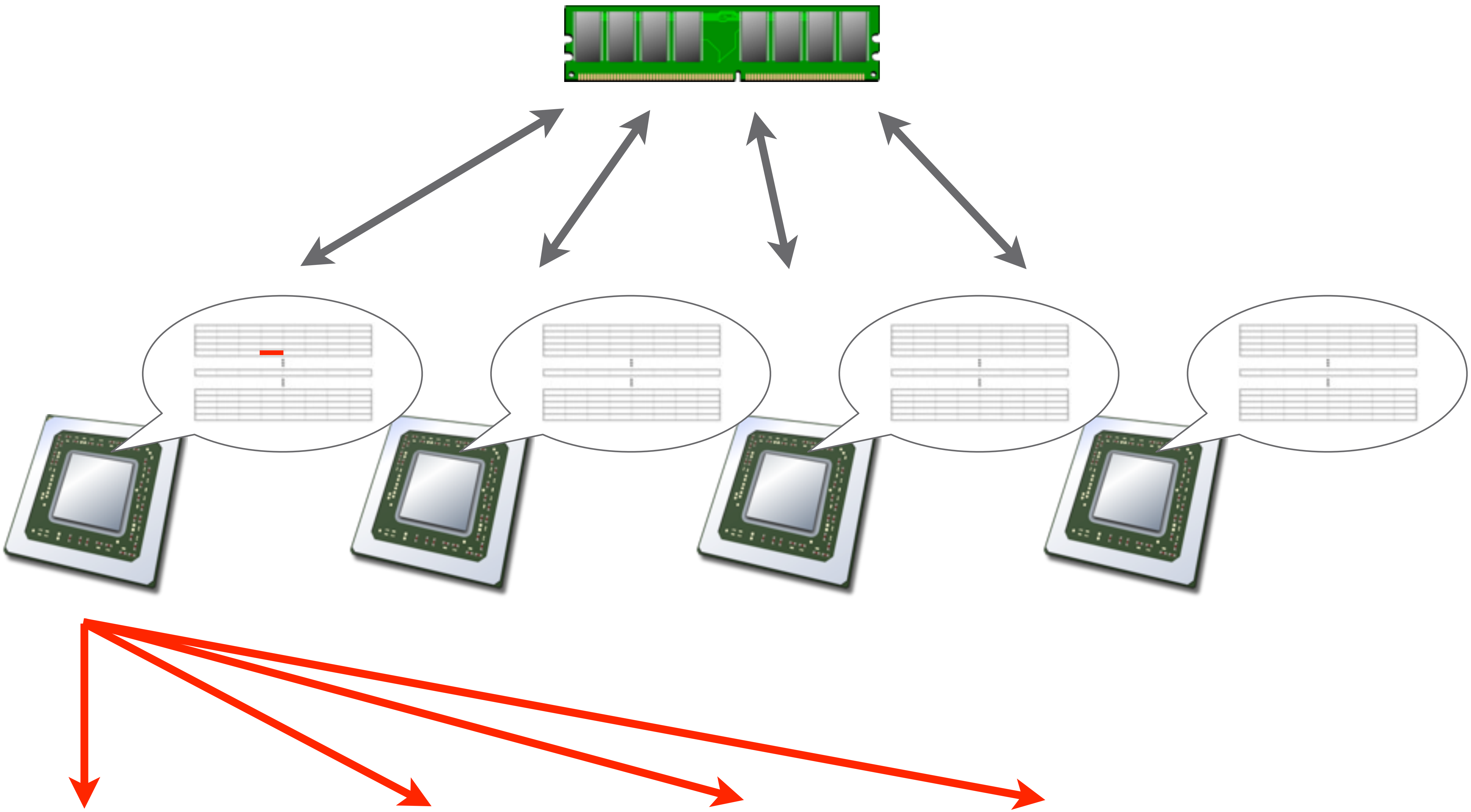

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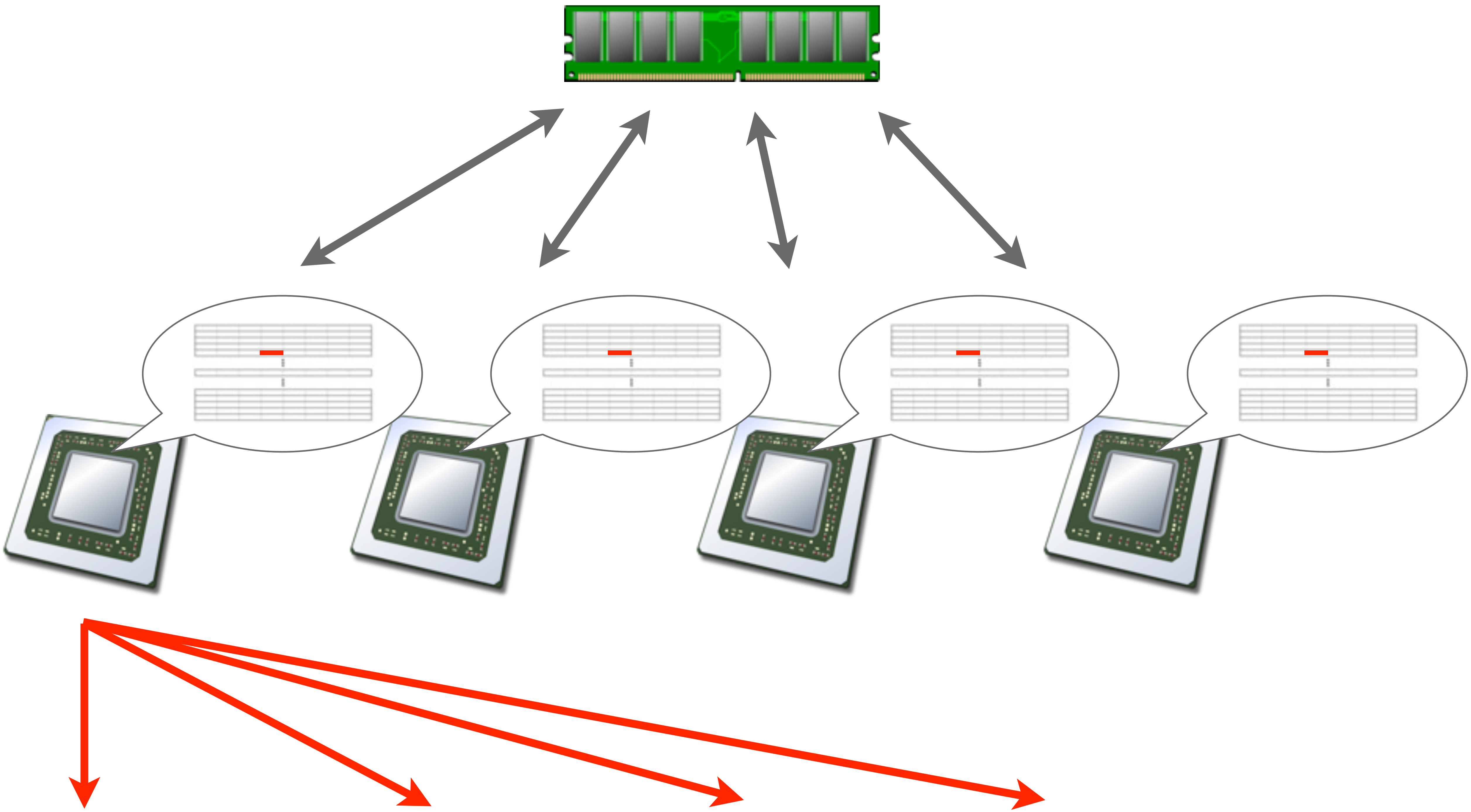

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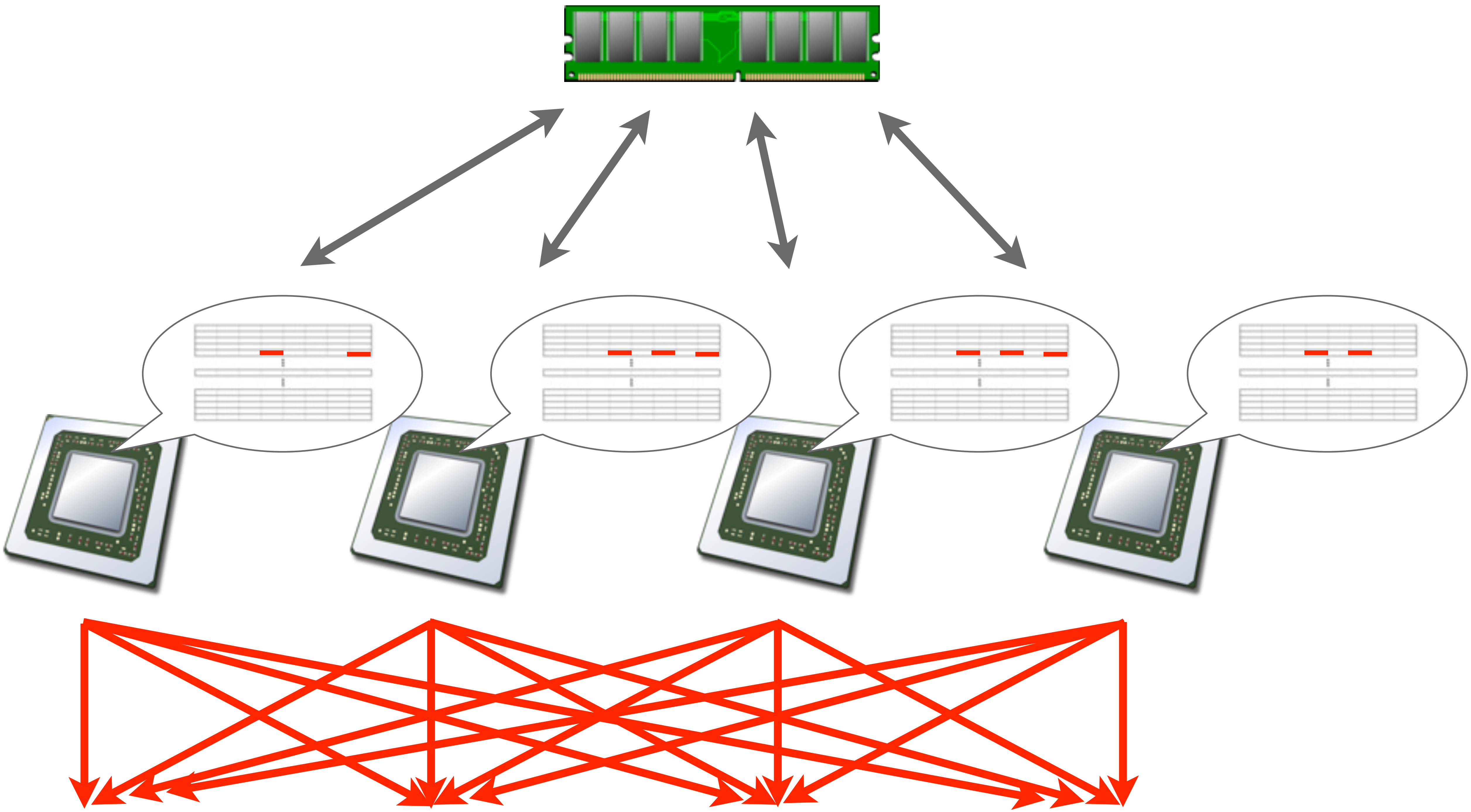

TABLE ELEMENT LOOKUP

- Read-lock table
- Lookup element
- Increment element reference count
- Read-unlock table
- Operate on element
- Decrease element reference count
  - Release if reference count reached zero

- Deletion of element
  - Remove from table
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  - Add number of schedulers to element reference count
  - Decrement reference count once for lost table reference
  - Schedule “confirm deletion jobs” on all schedulers
  - Each scheduler decrease reference count and release if it reached zero

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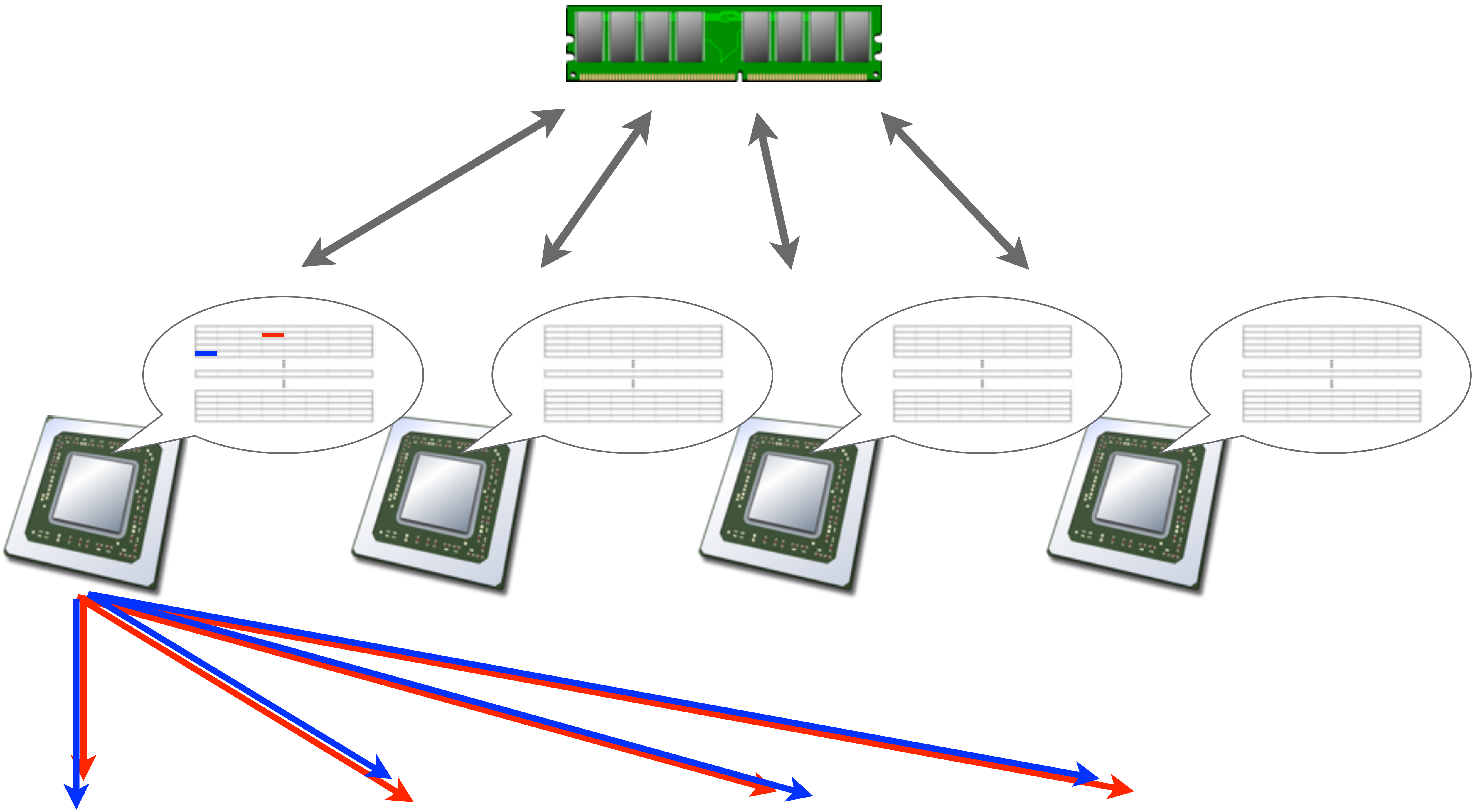
ORDER OF MEMORY OPERATIONS



ORDER OF MEMORY OPERATIONS

c1 = c2 = 1

Thread 1	Thread 2
Store(c1, 0)	Store(c2, 0)
r1 = Load(c2)	r2 = Load(c1)

r1	r2

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ERLANG

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Thread 1	Thread 2
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r1	r2
0	0
0	1
1	0
1	1

ORDER OF MEMORY OPERATIONS

c1 = c2 = 1

Thread 1	Thread 2
Store(c1, 0) MemoryBarrier r1 = Load(c2)	Store(c2, 0) MemoryBarrier r2 = Load(c1)

r1	r2
0	0
0	1
1	0

HARDWARE MEMORY BARRIERS

- Hardware architectures
  - Very different ordering guarantees
    - x86 - quite strict
    - ...
    - alpha - very relaxed
  - Hardware memory barriers
    - Tools for enforcing ordering
    - Expensive
    - Architecture dependent
    - Sometimes lightweight versions exist

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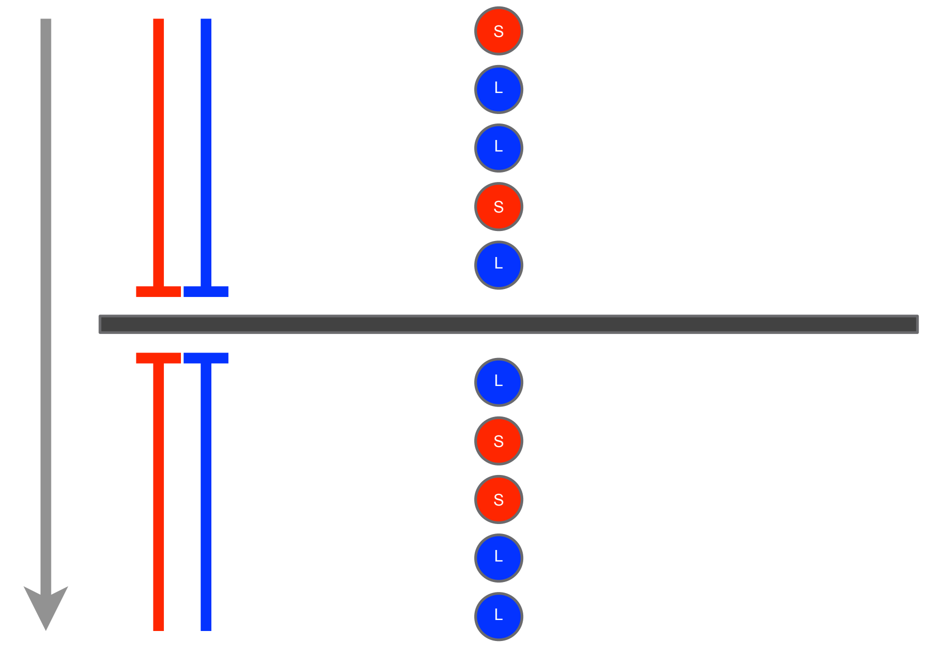

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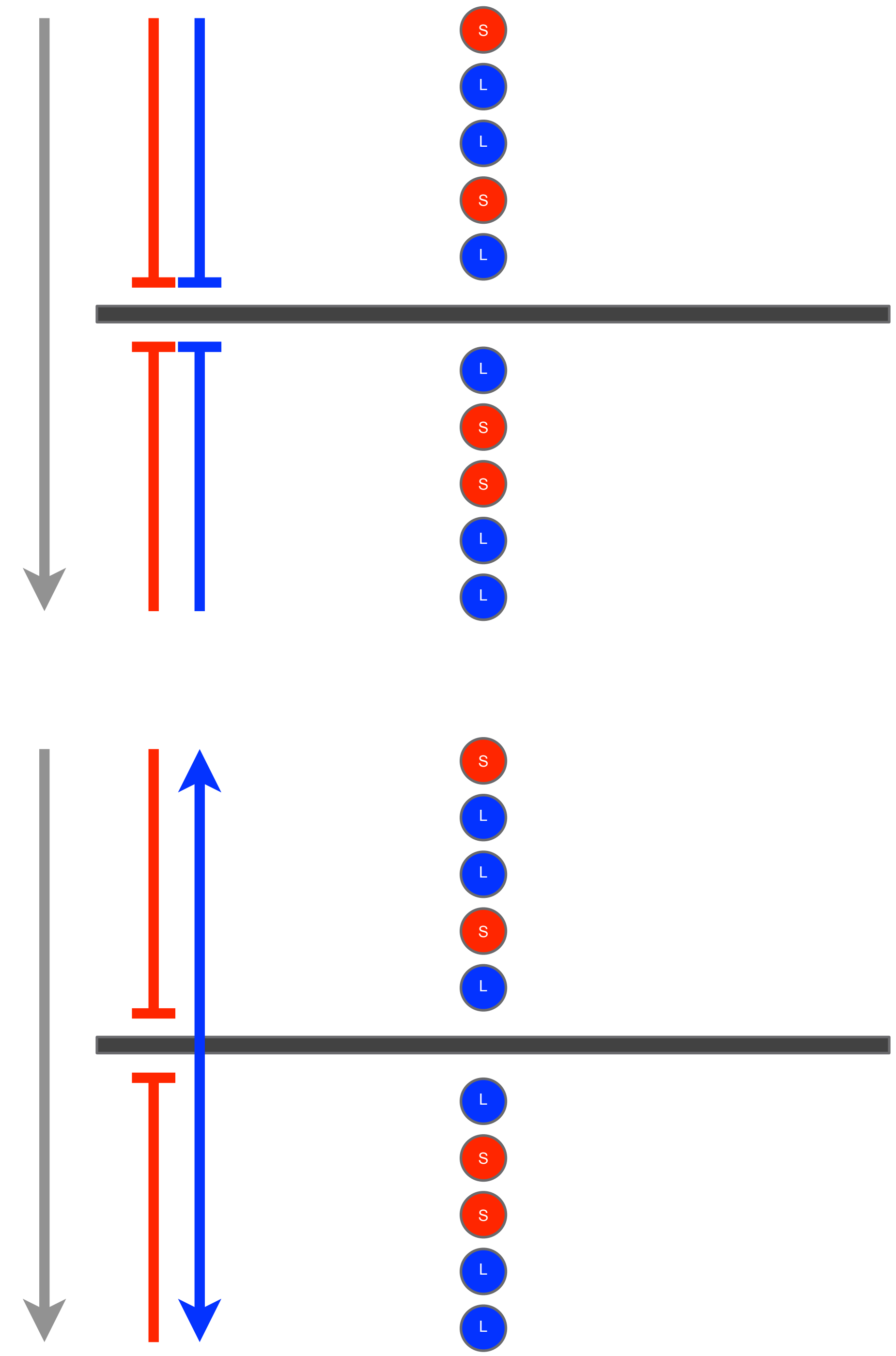

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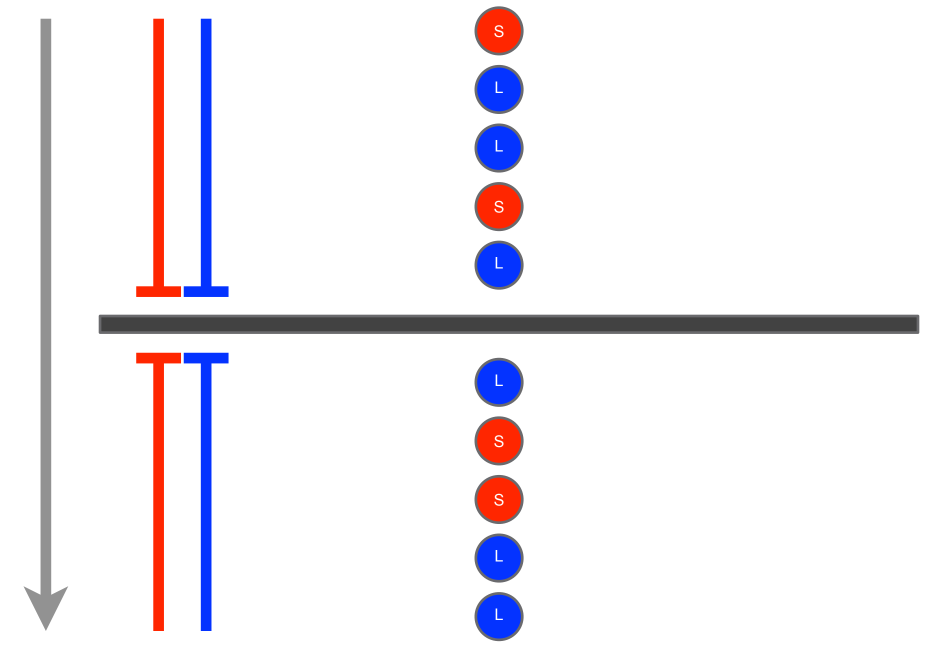

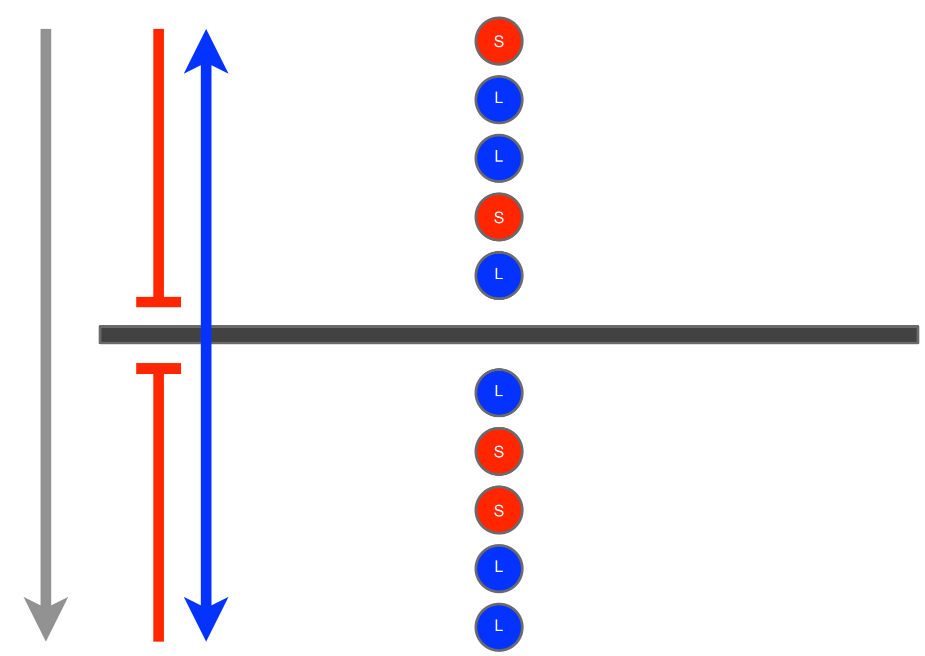

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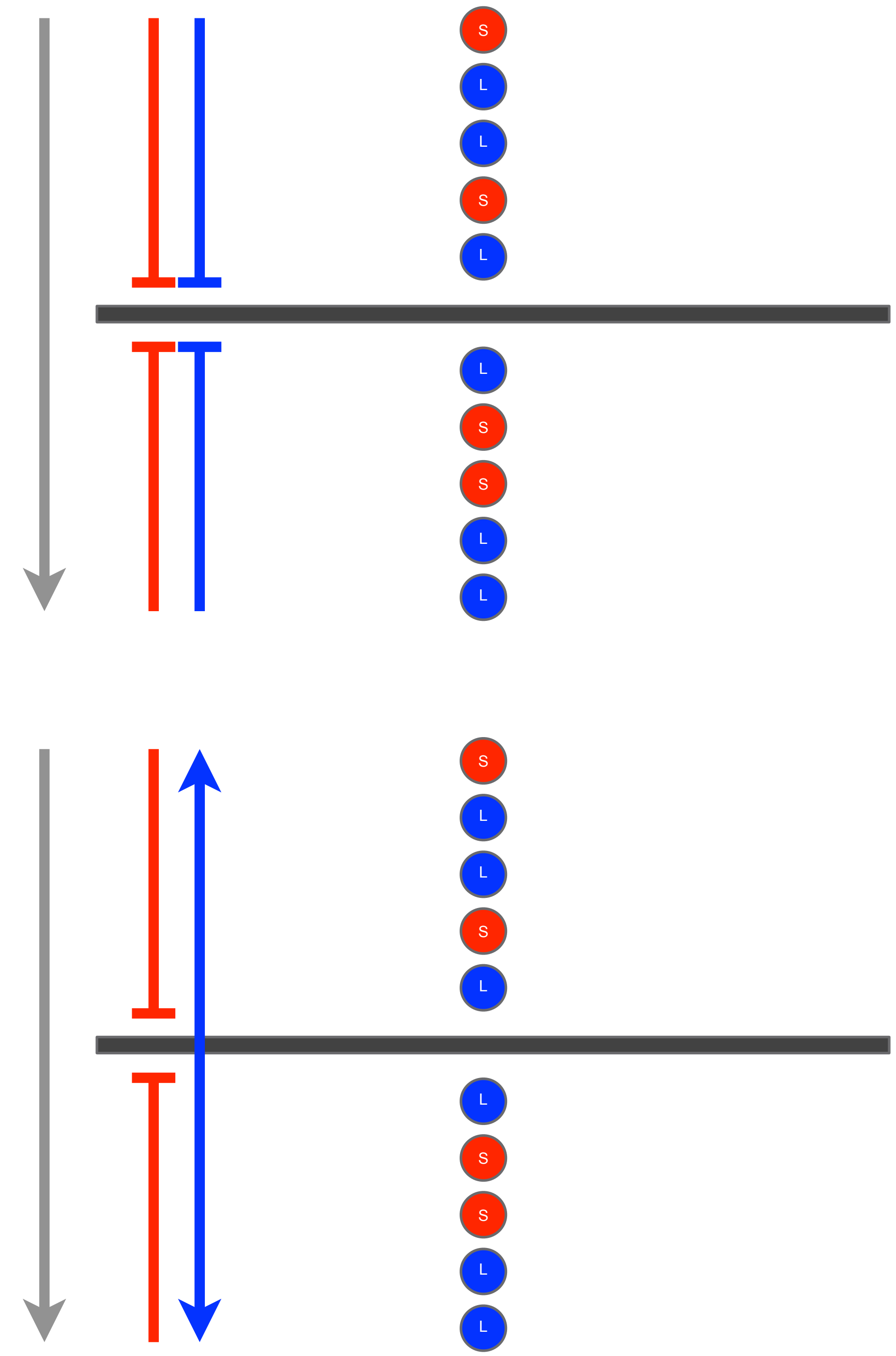

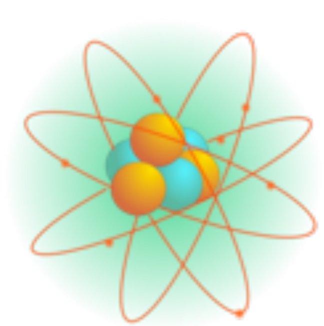

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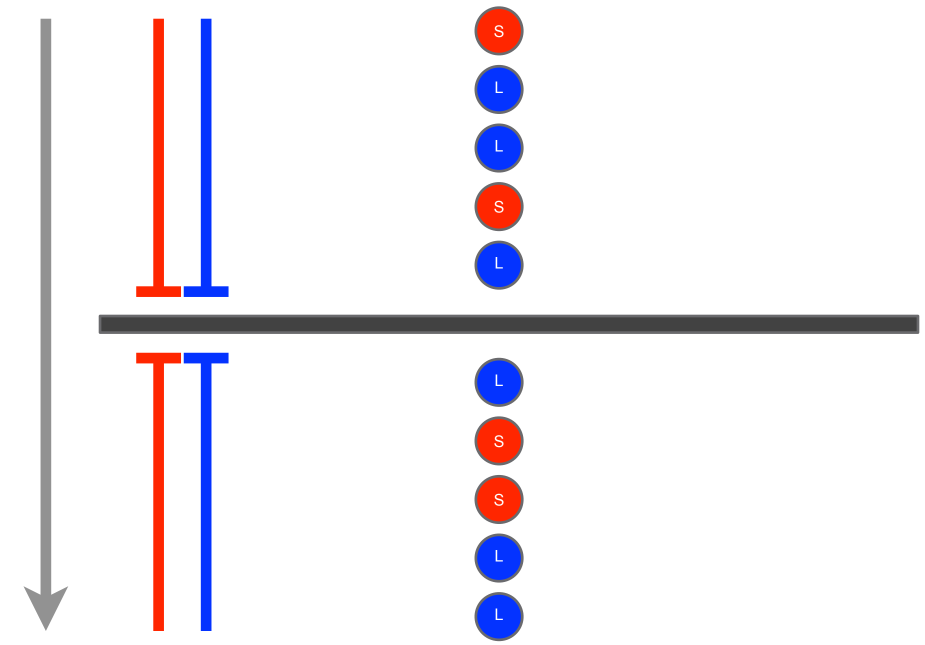

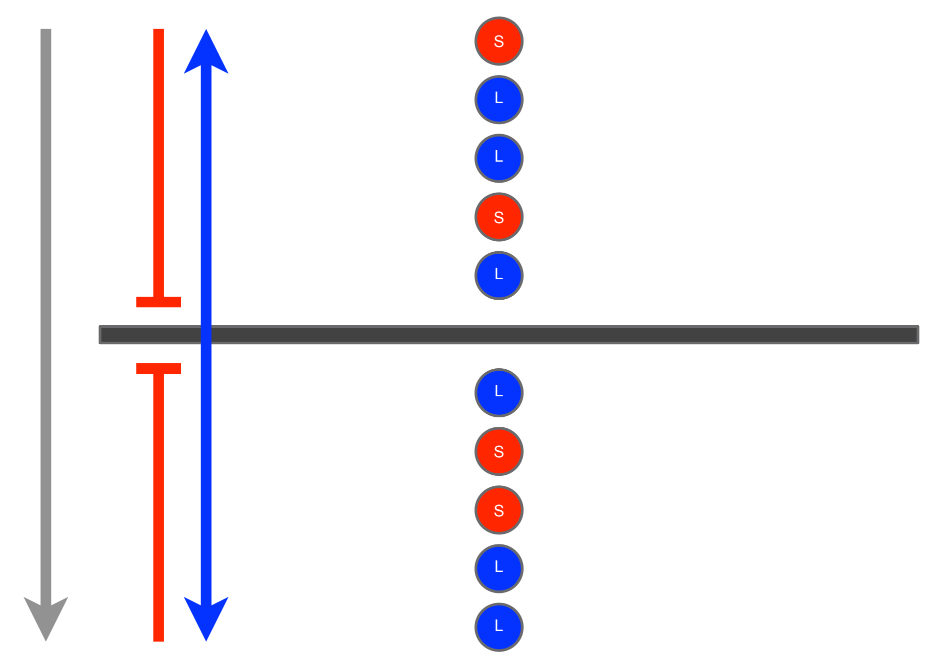

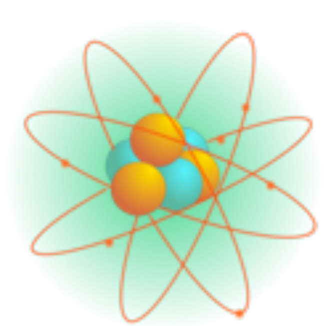

OLD ATOMIC API

Word size

ethr_atomic_init()
ethr_atomic_set()
ethr_atomic_read()
ethr_atomic_inc()
ethr_atomic_dec()
ethr_atomic_add()
ethr_atomic_inc_read_mb()
ethr_atomic_dec_read_mb()
ethr_atomic_add_read_mb()
ethr_atomic_read_bor_mb()
ethr_atomic_read_band_mb()
ethr_atomic_xchg_mb()
ethr_atomic_cmpxchg_mb()

ATOMIC API R15

32-bit

ethr_atomic32_init()
ethr_atomic32_set()
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ethr_atomic_xchg_wb()
ethr_atomic_cmpxchg_wb()

Double word size

ethr_dw_atomic_init()
ethr_dw_atomic_set()
ethr_dw_atomic_read()
ethr_dw_atomic_cmpxchg()
ethr_dw_atomic_init_mb()
ethr_dw_atomic_set_mb()
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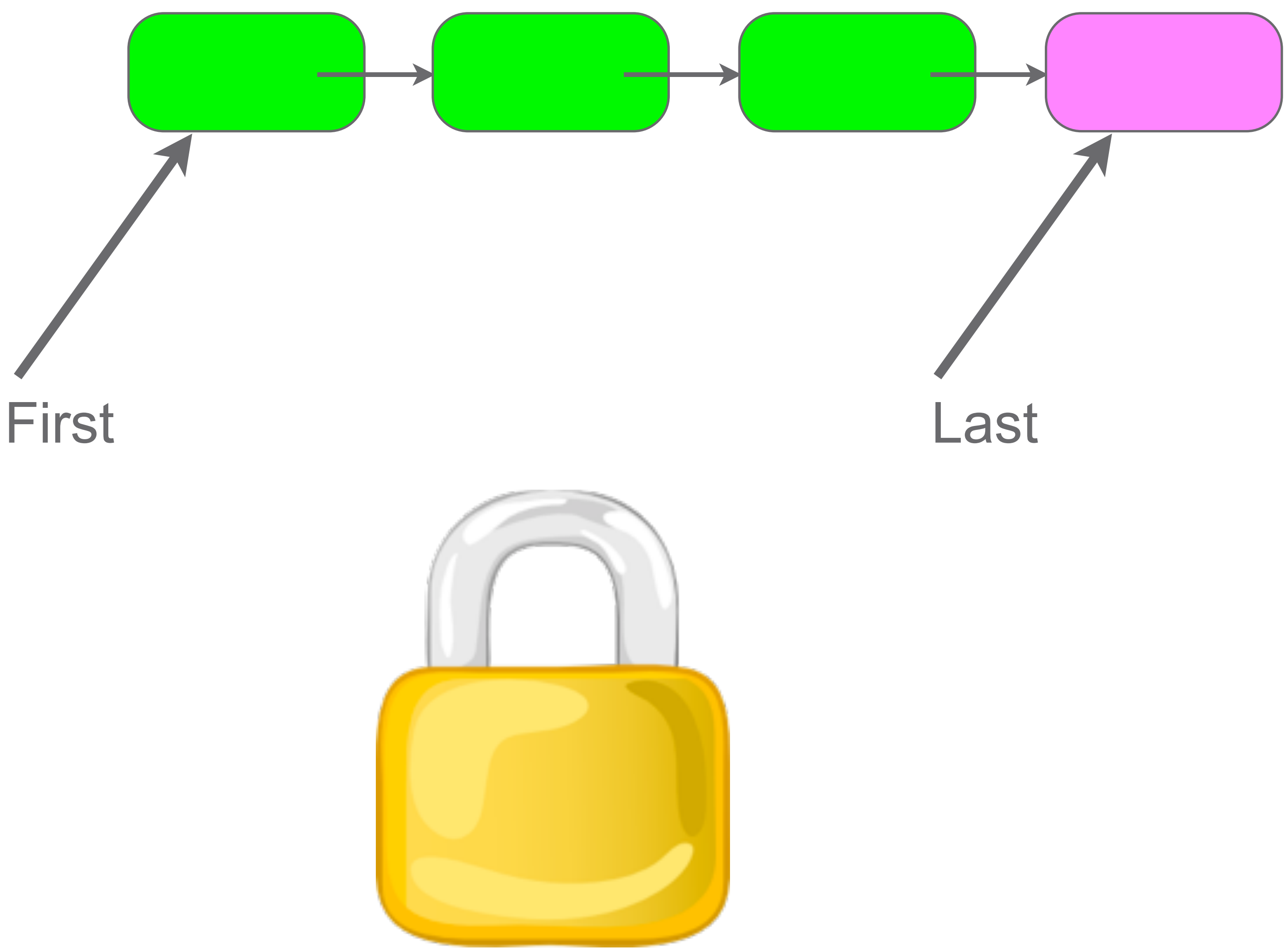
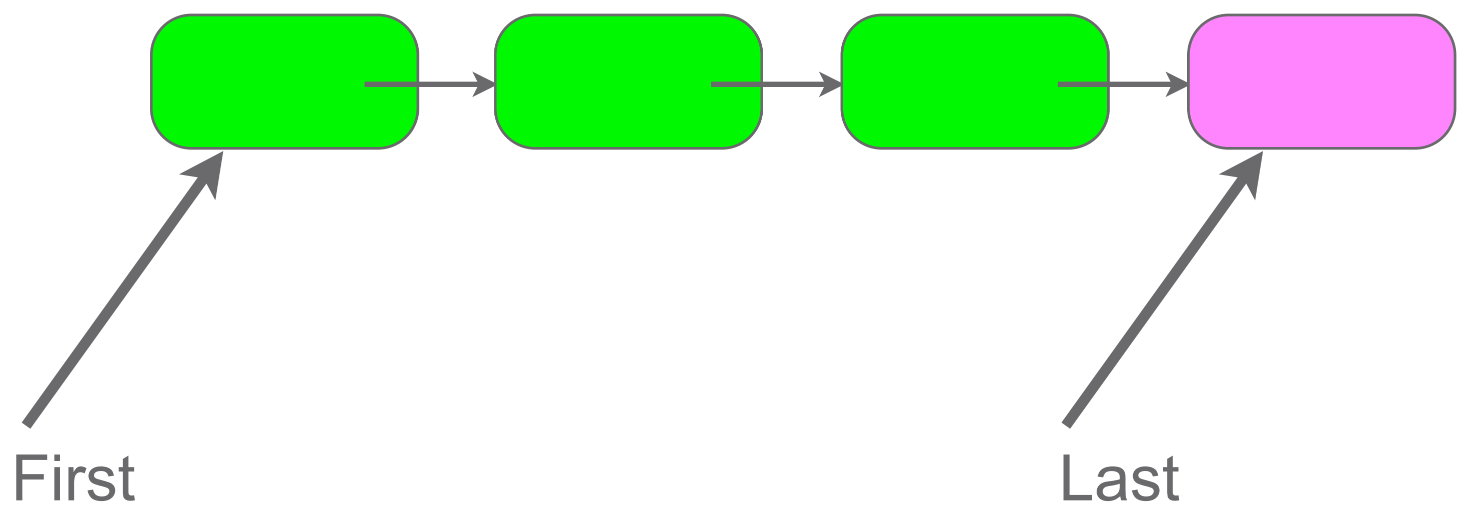
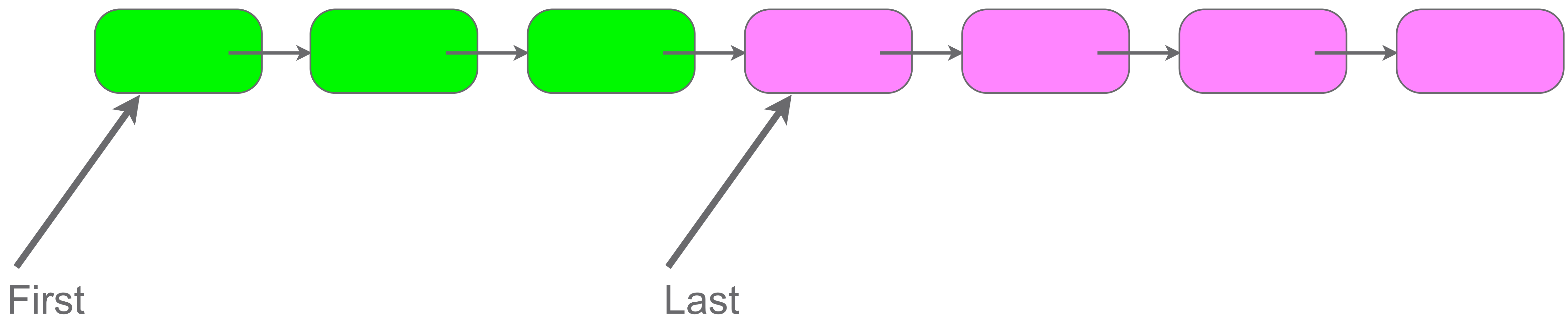
LOCKED QUEUE



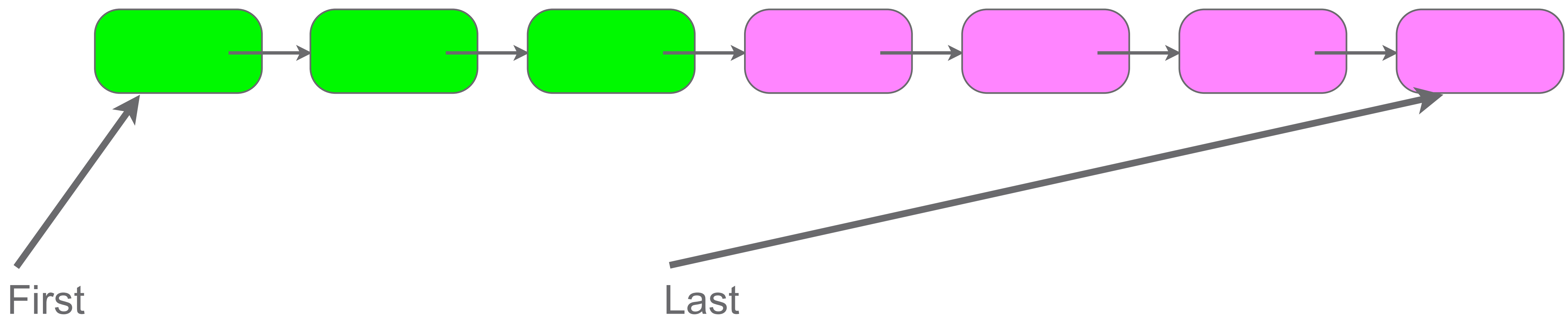
LOCK FREE QUEUE



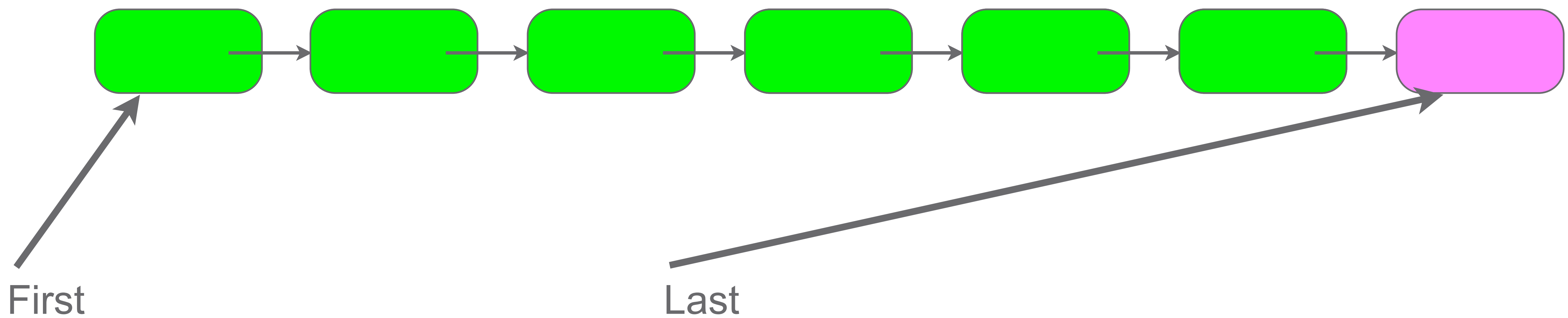
LOCK FREE QUEUE



LOCK FREE QUEUE



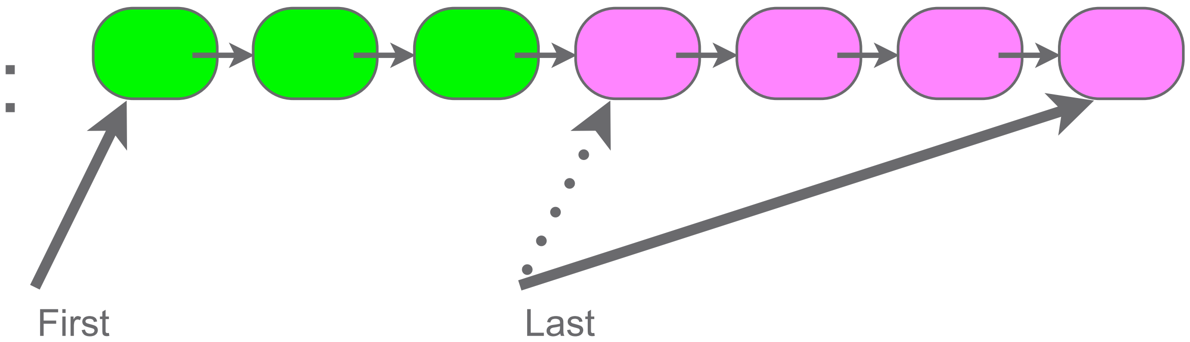
LOCK FREE QUEUE



THREAD PROGRESS

› We want a mechanism that can be used in order to determine when all "interesting" threads
  › have at least once returned to the event loop code
  › have at least once executed a full memory barrier
  › will see all modifications I have made

› Interesting threads are "managed":



– We know about all of them
– They do not hang
– They will always return to a certain point
– Typically - the schedulers and a few other threads

› The mechanism is called Thread Progress in the VM code

› Unmanaged threads need to be taken care of by other means

THREAD PROGRESS

- We want a mechanism that can be used in order to determine when all “interesting” threads
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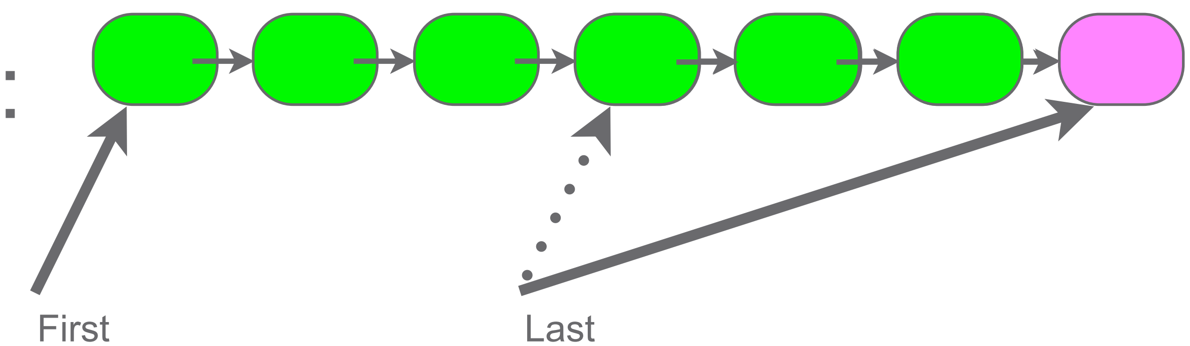
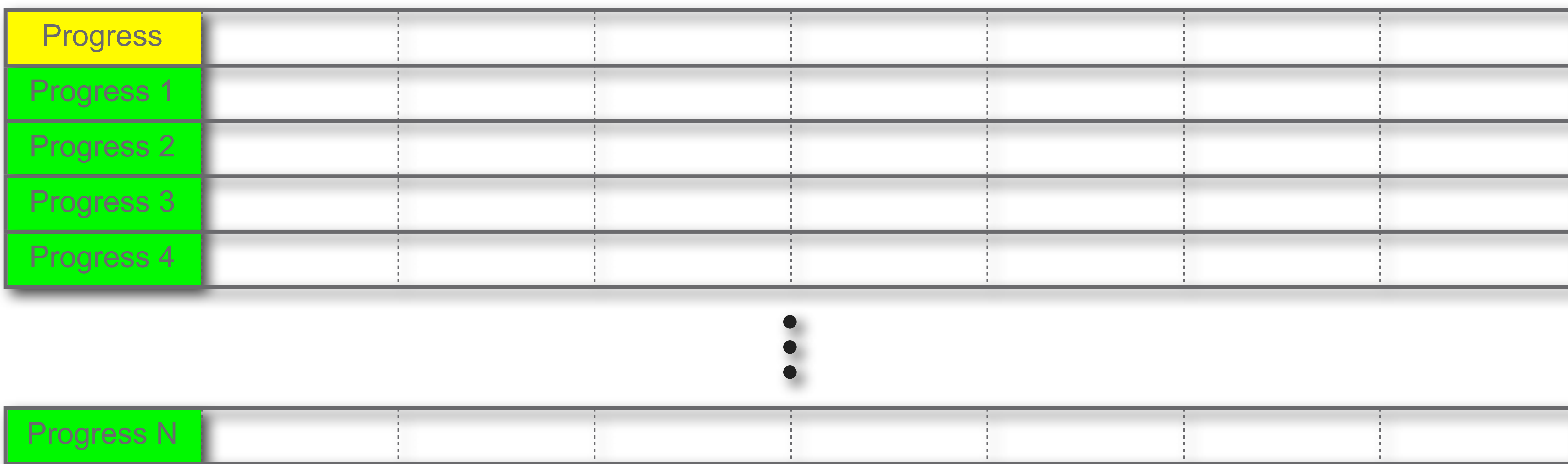


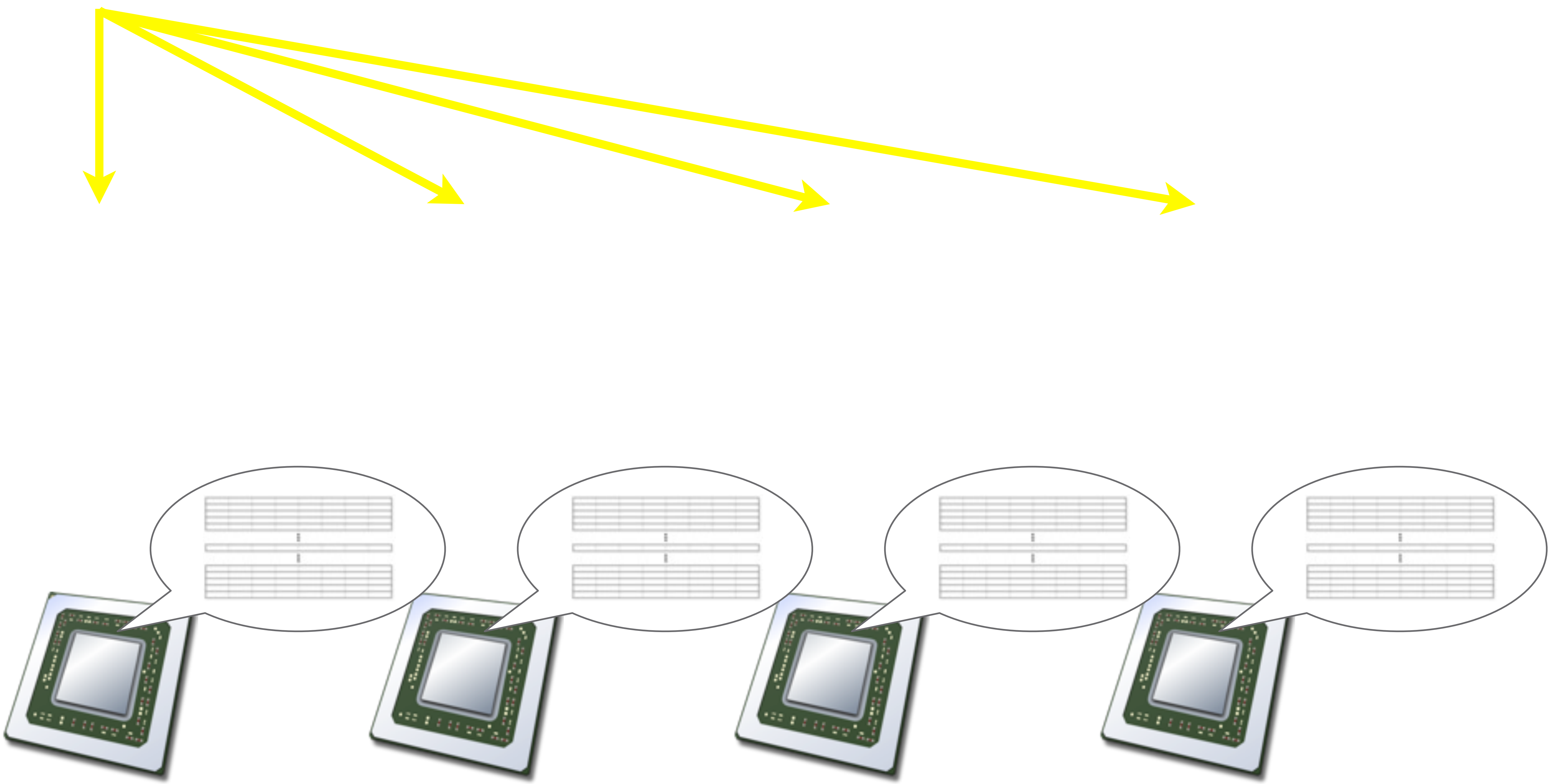
- The mechanism is called Thread Progress in the VM code
- Unmanaged threads need to be taken care of by other means

THREAD PROGRESS

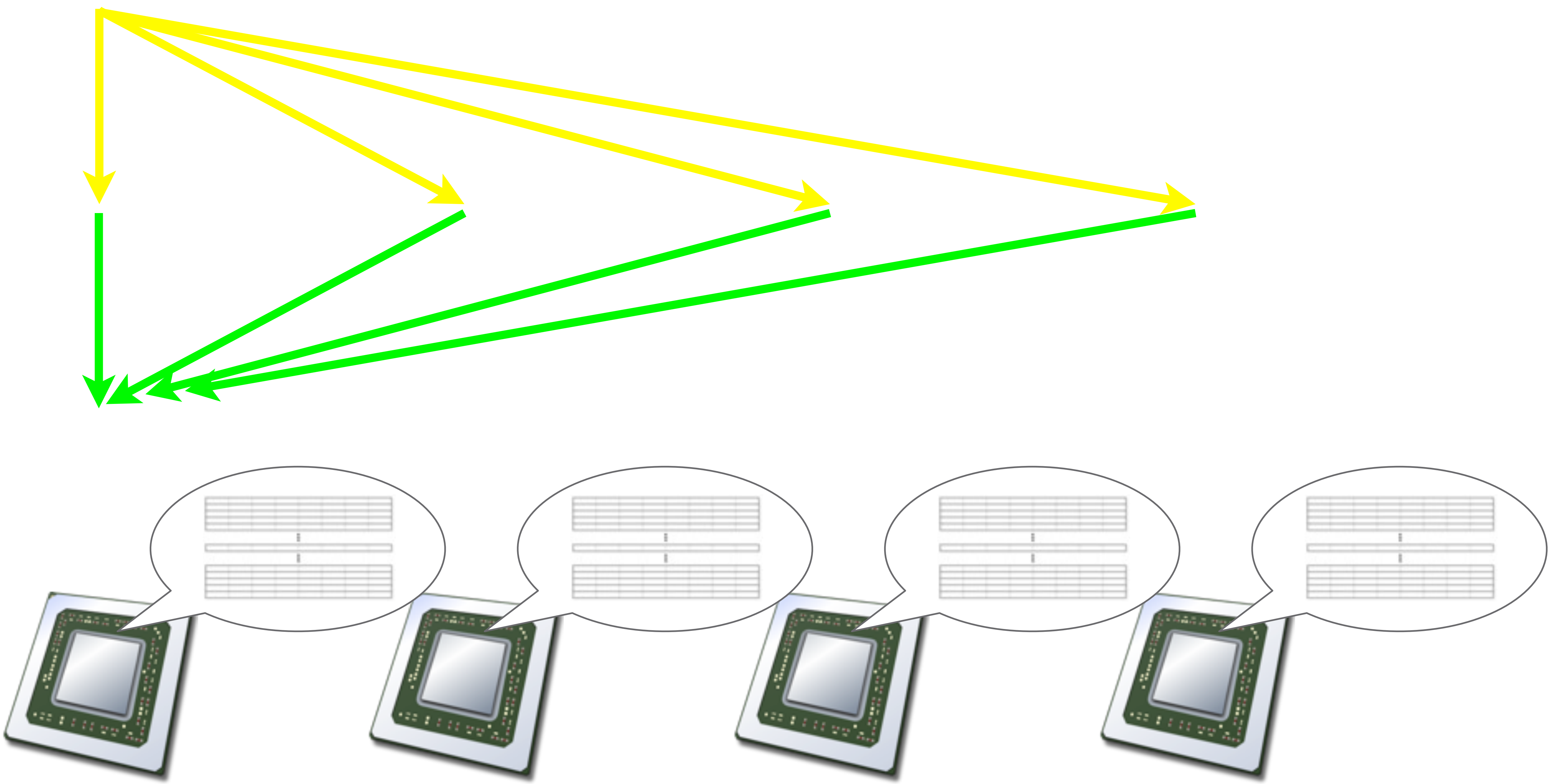
- Master thread coordinates
- Thread progress communicated via thread specific cache lines



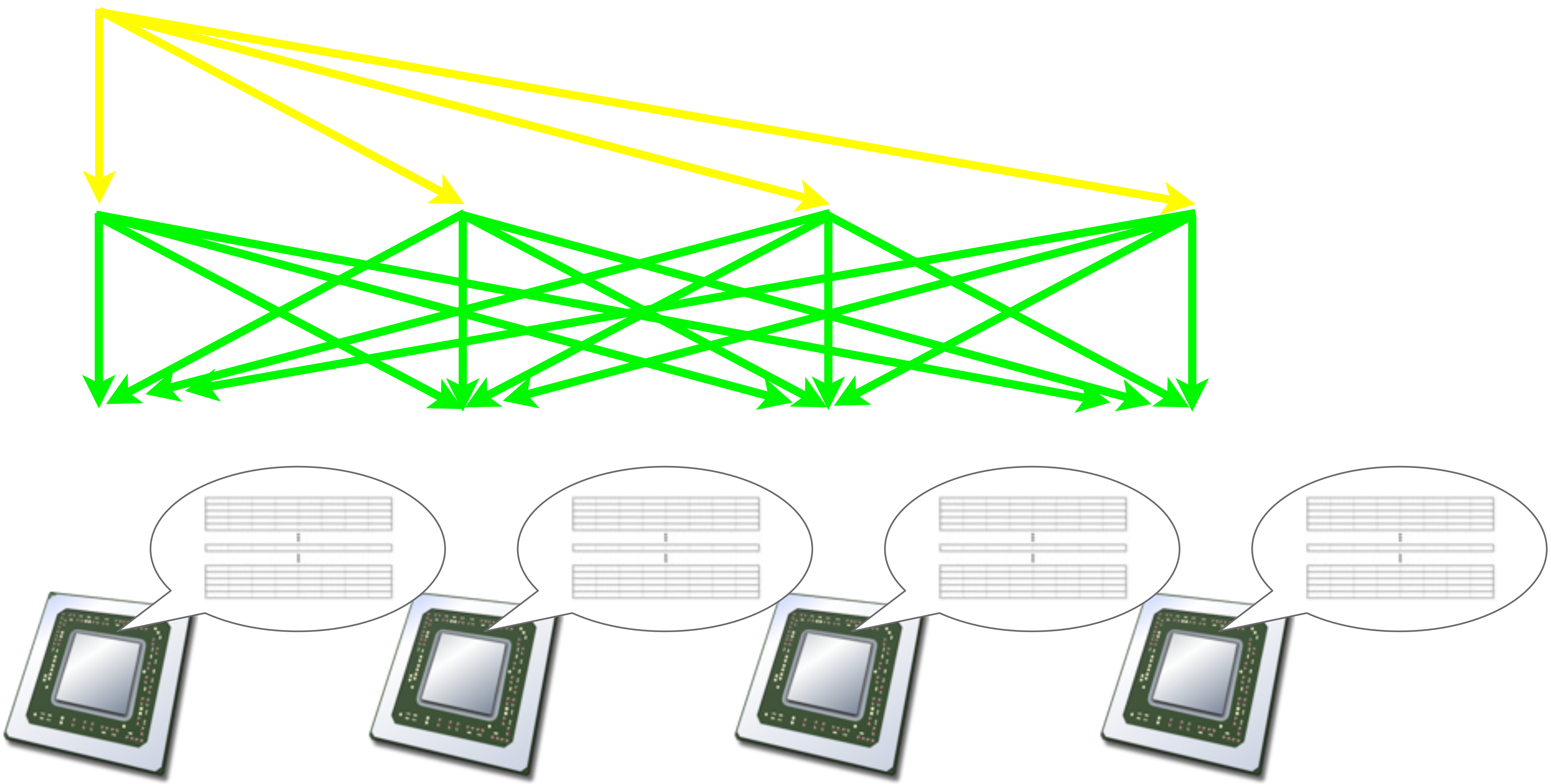
THREAD PROGRESS



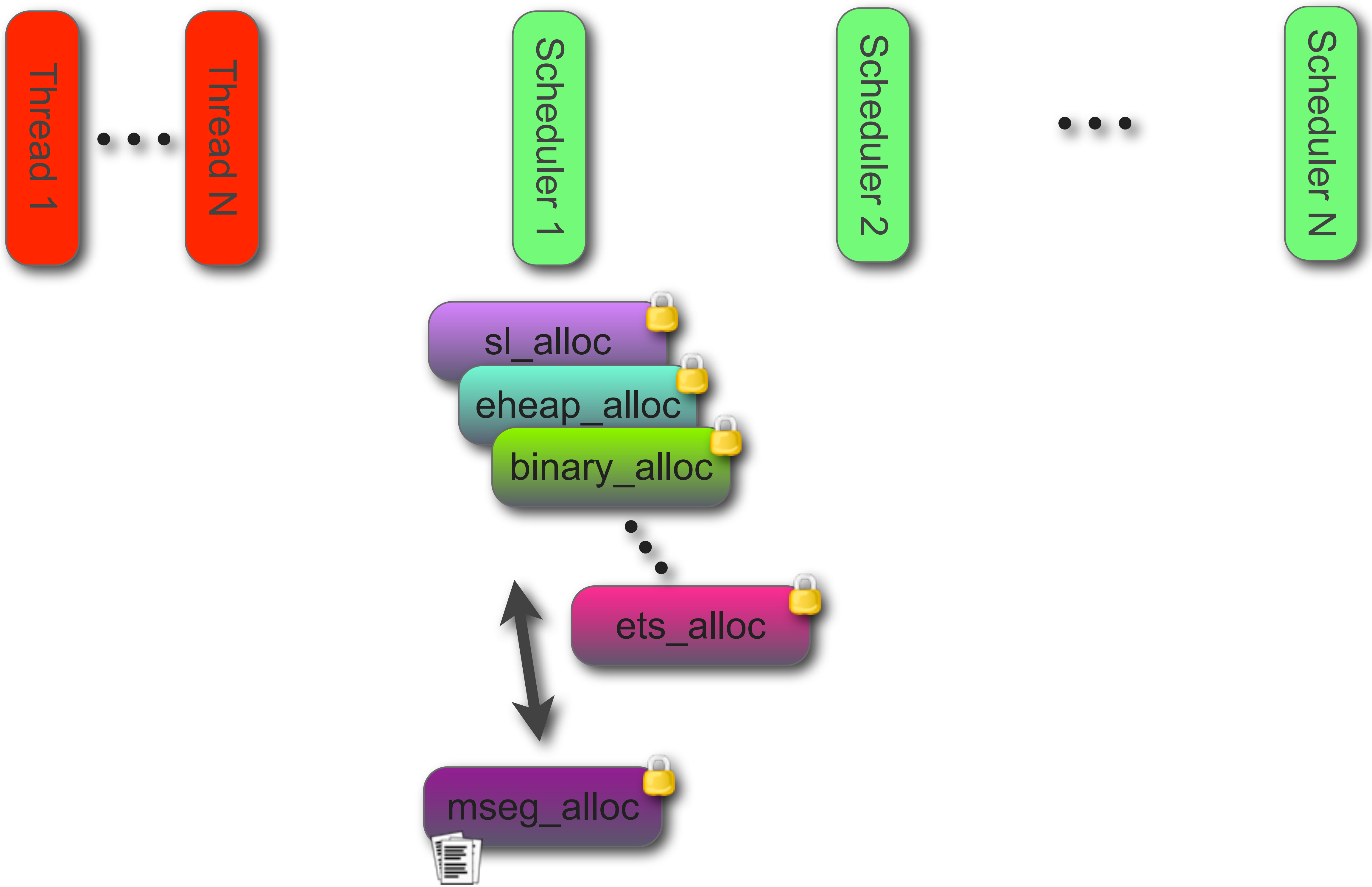
THREAD PROGRESS



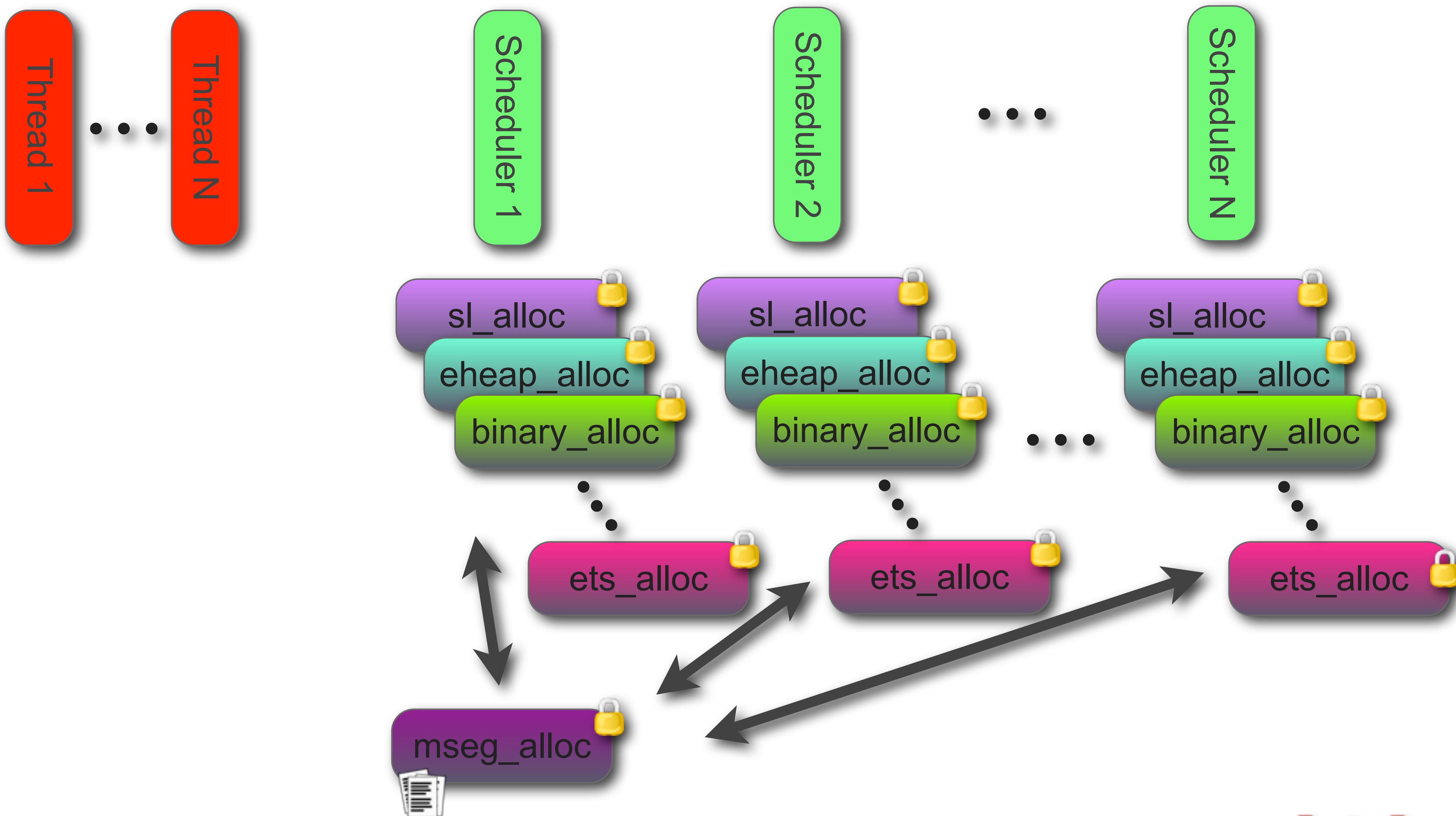
THREAD PROGRESS



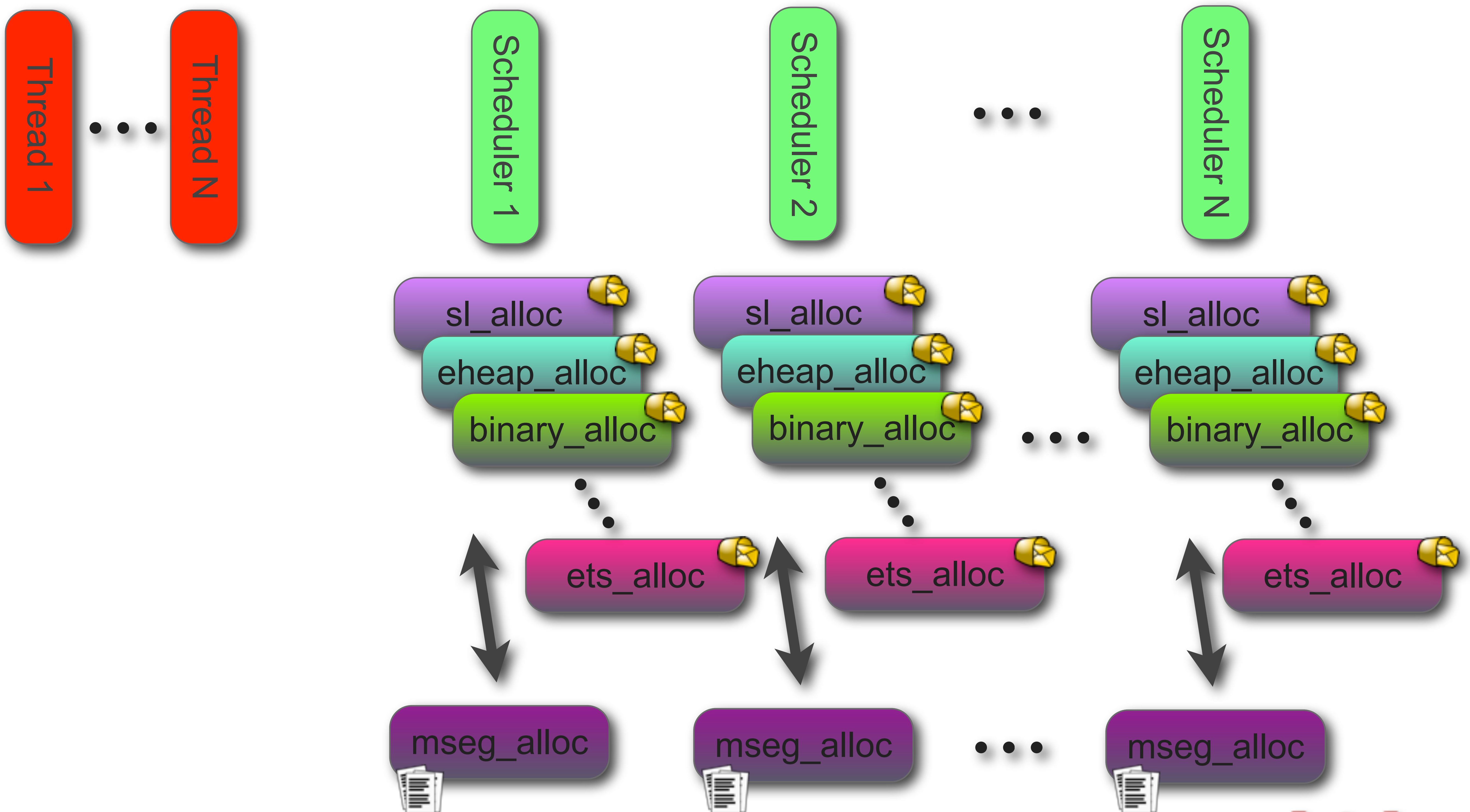
MEMORY ALLOCATORS R11B



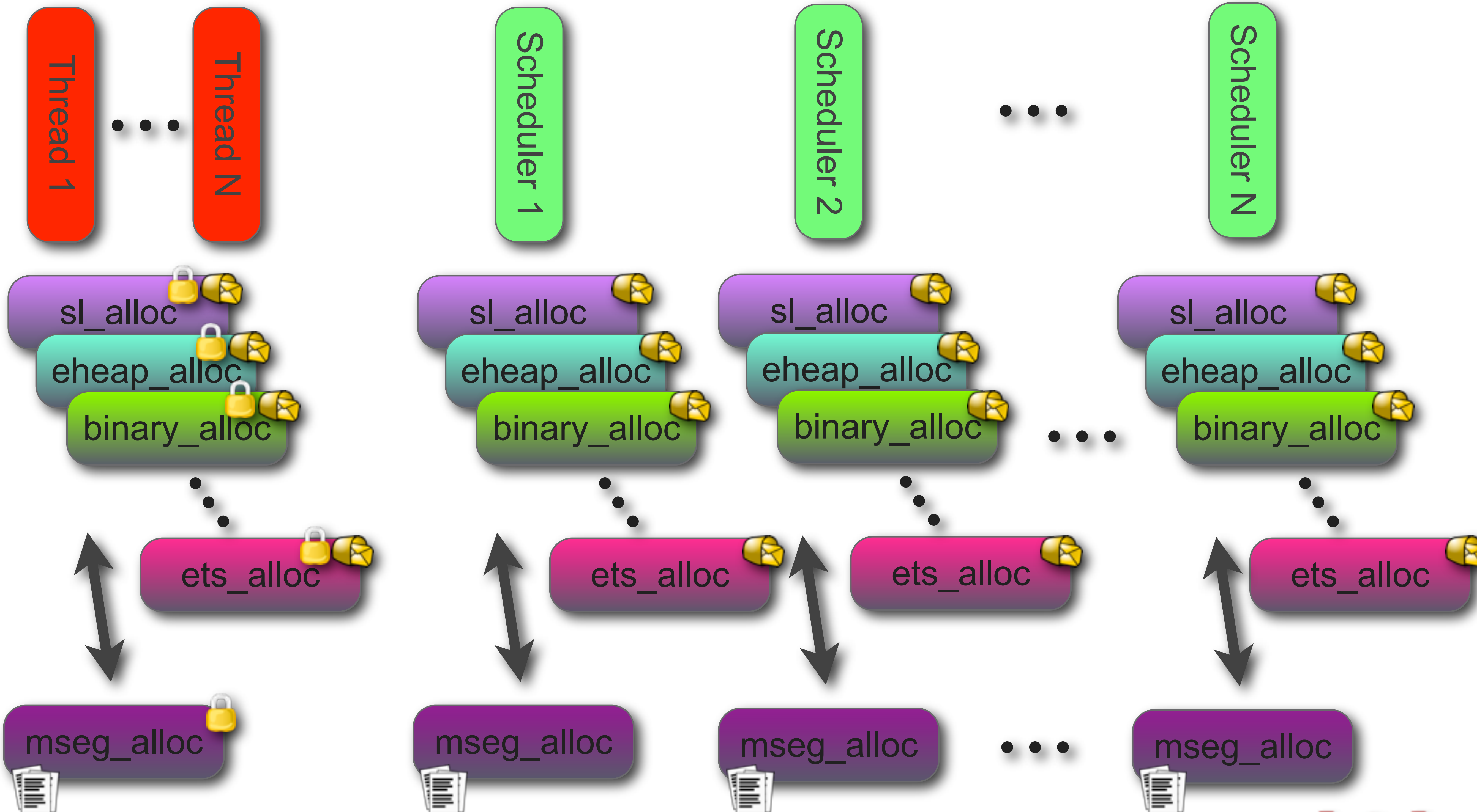
MEMORY ALLOCATORS R12B-1



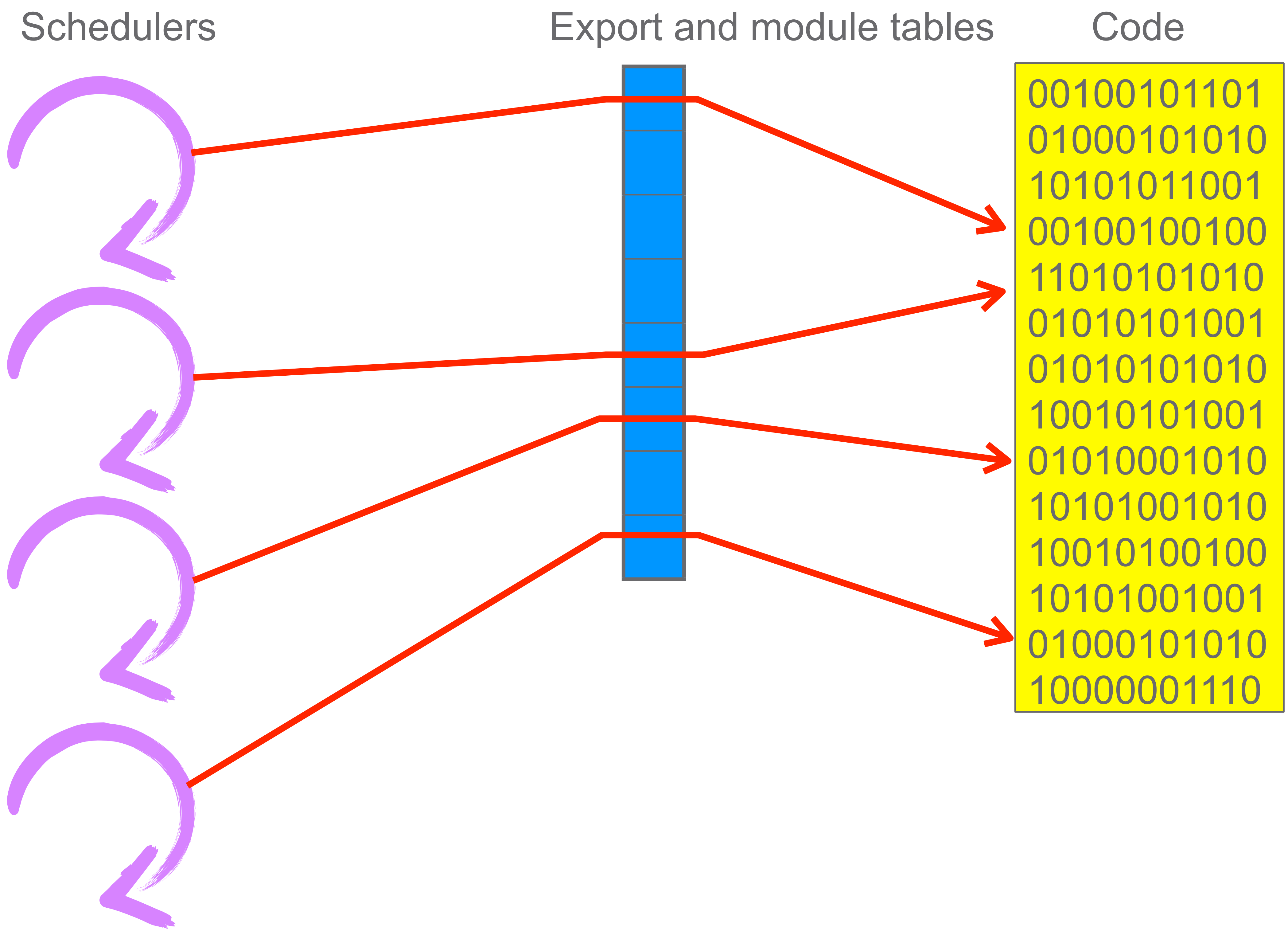
MEMORY ALLOCATORS R15B



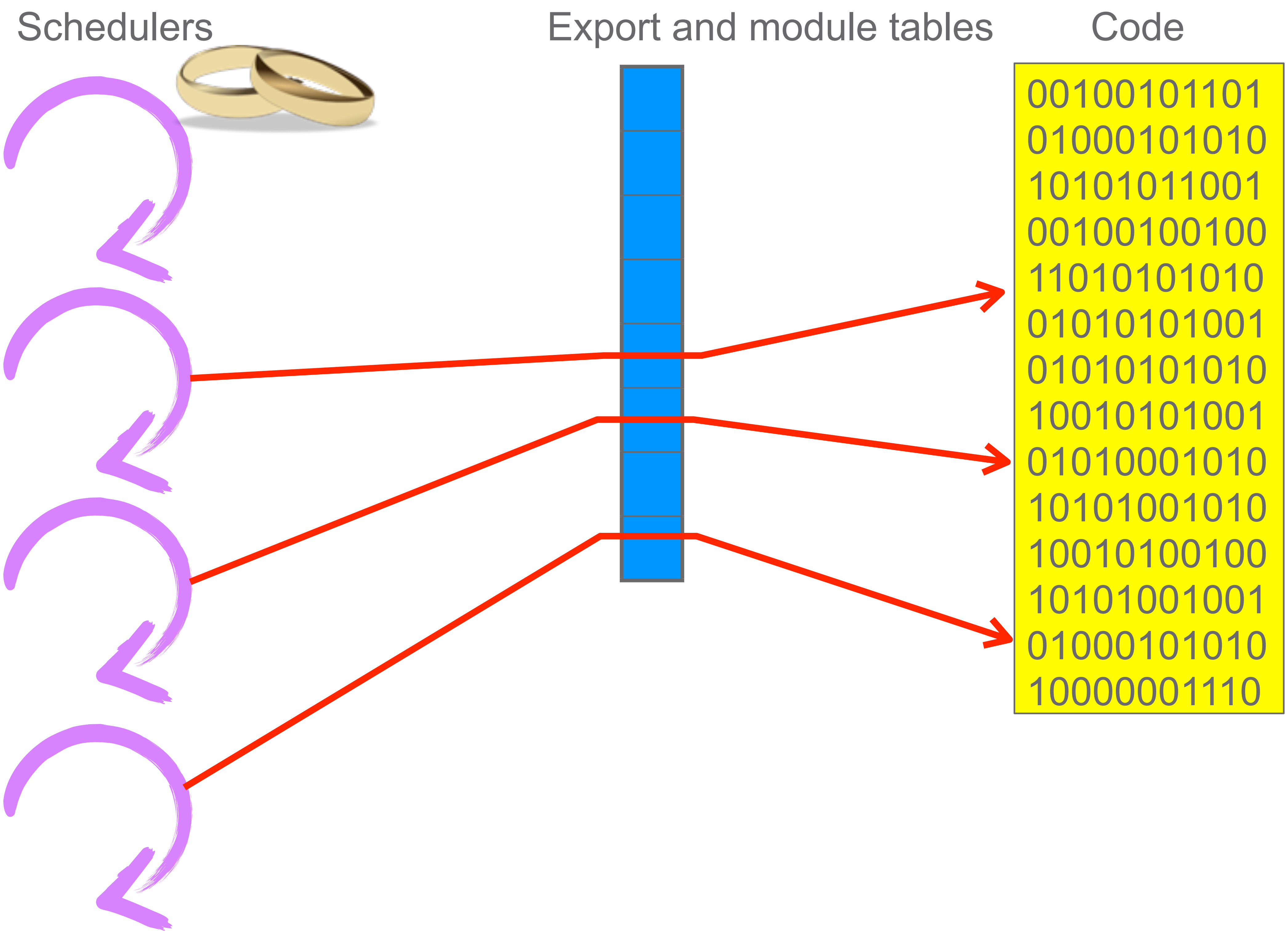
MEMORY ALLOCATORS R15B



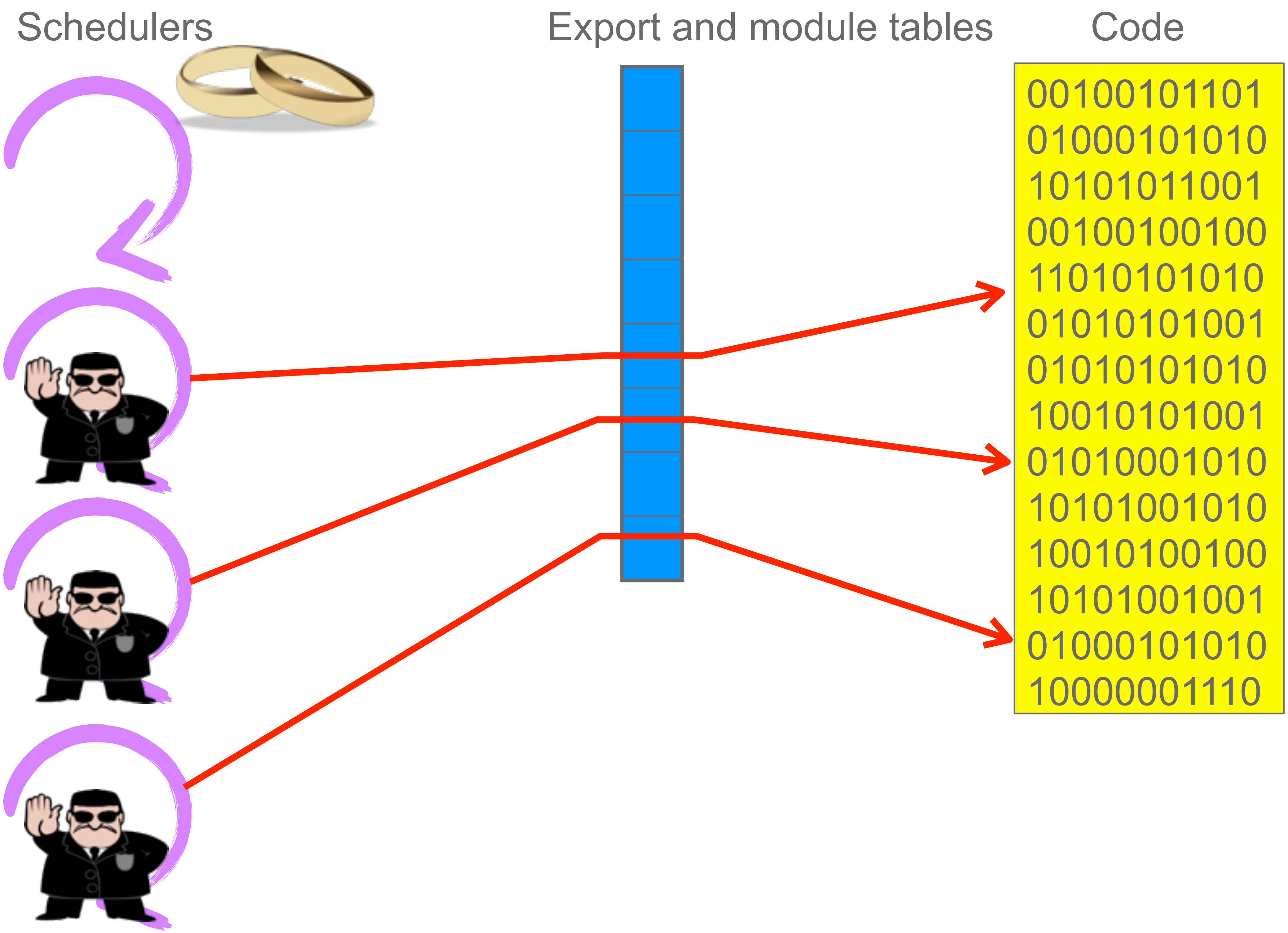
CODE-LOADING R11-R15



CODE-LOADING R11-R15

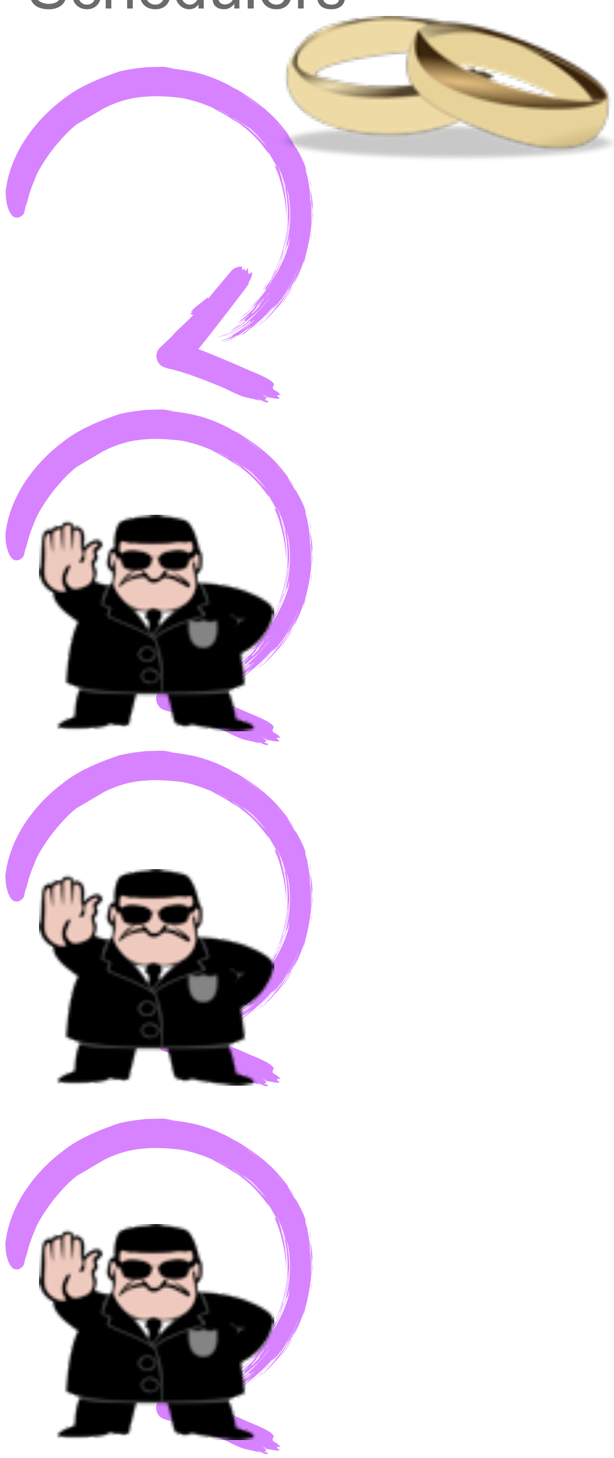


CODE-LOADING R11-R15

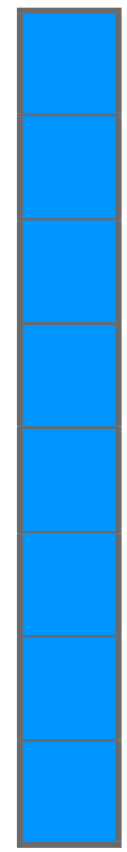


CODE-LOADING R11-R15

Schedulers



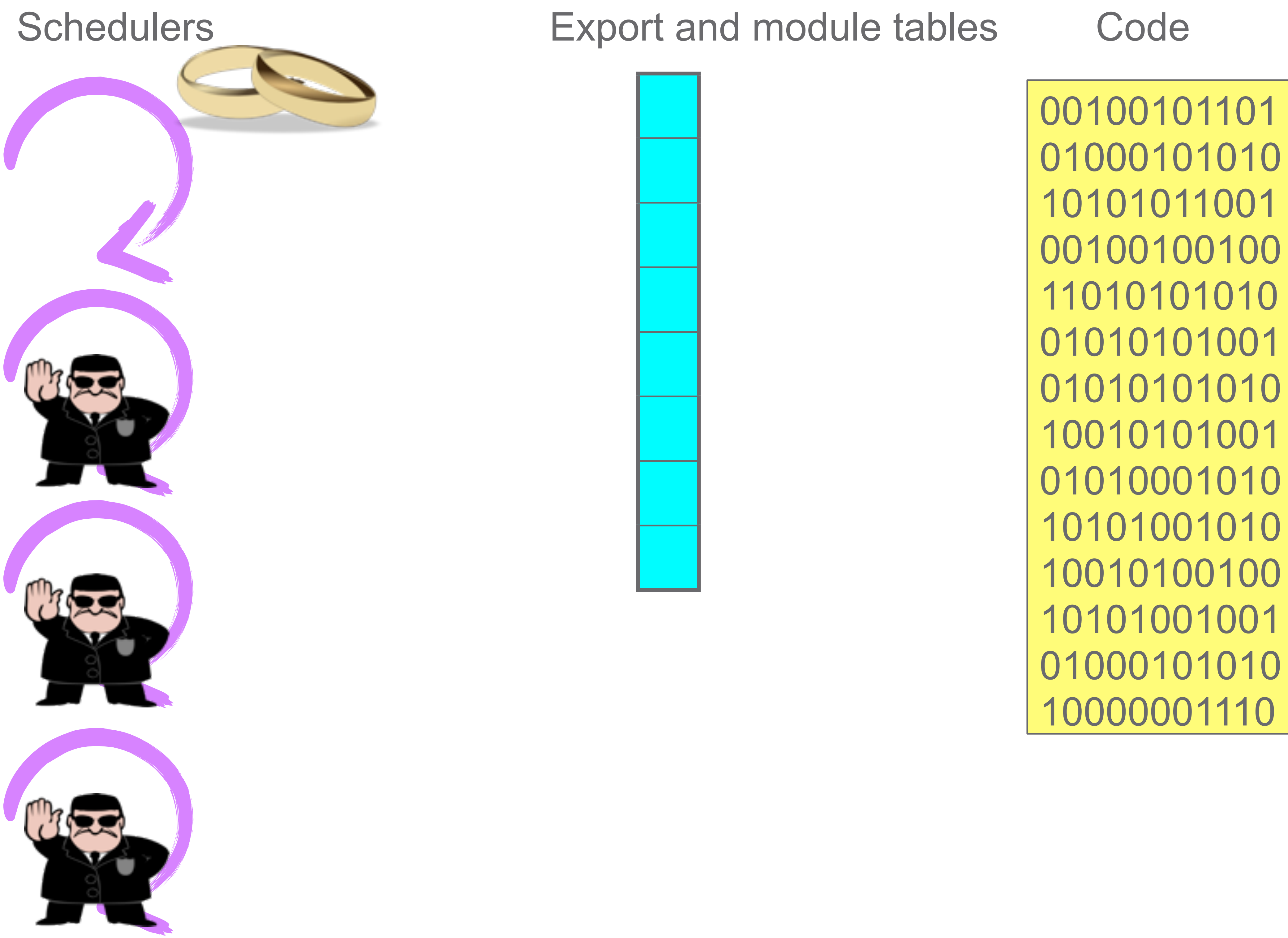
Export and module tables



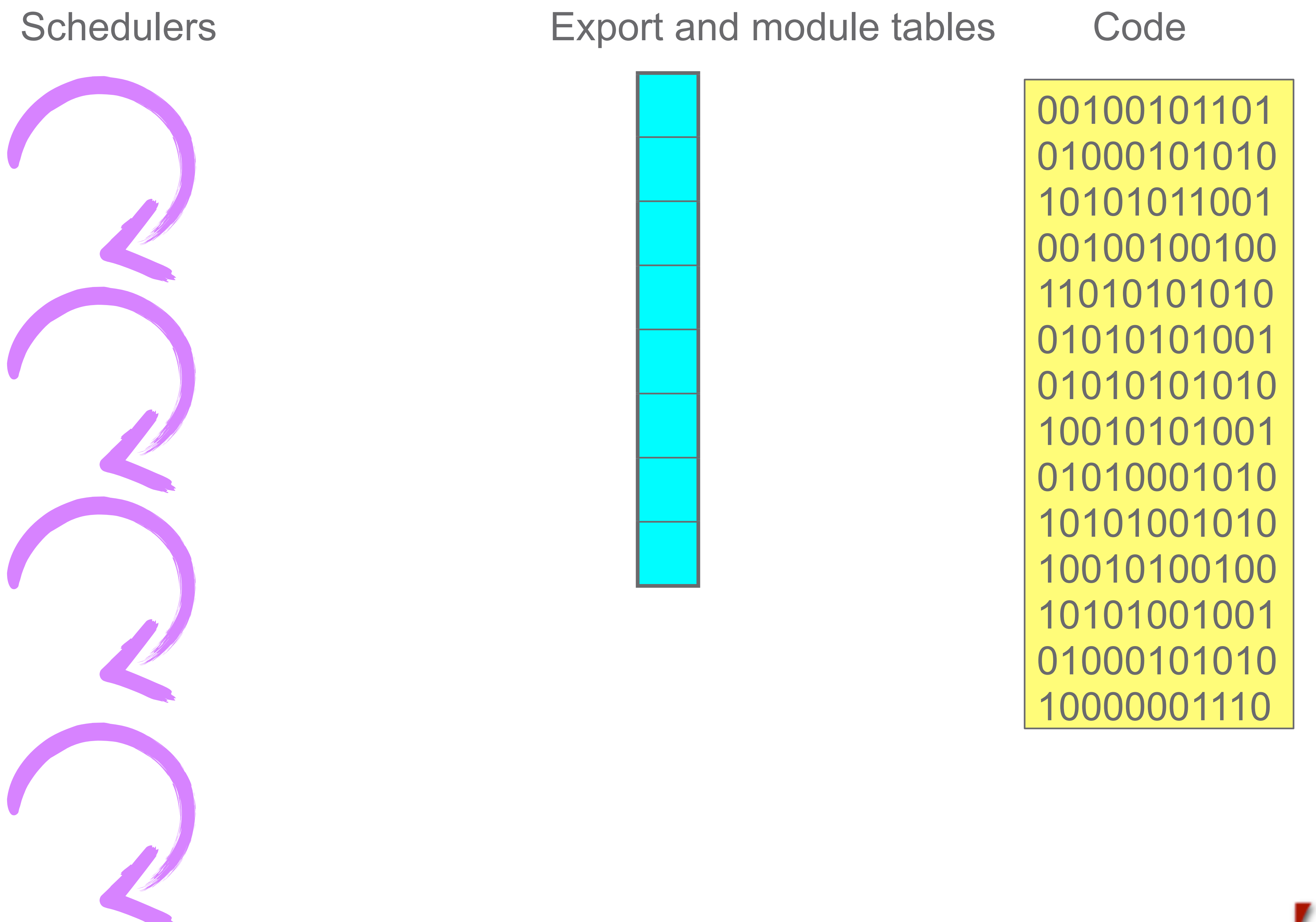
Code

00100101101
01000101010
10101011001
00100100100
11010101010
01010101001
01010101010
10010101001
01010001010
10101001010
10010100100
10101001001
01000101010
10000001110

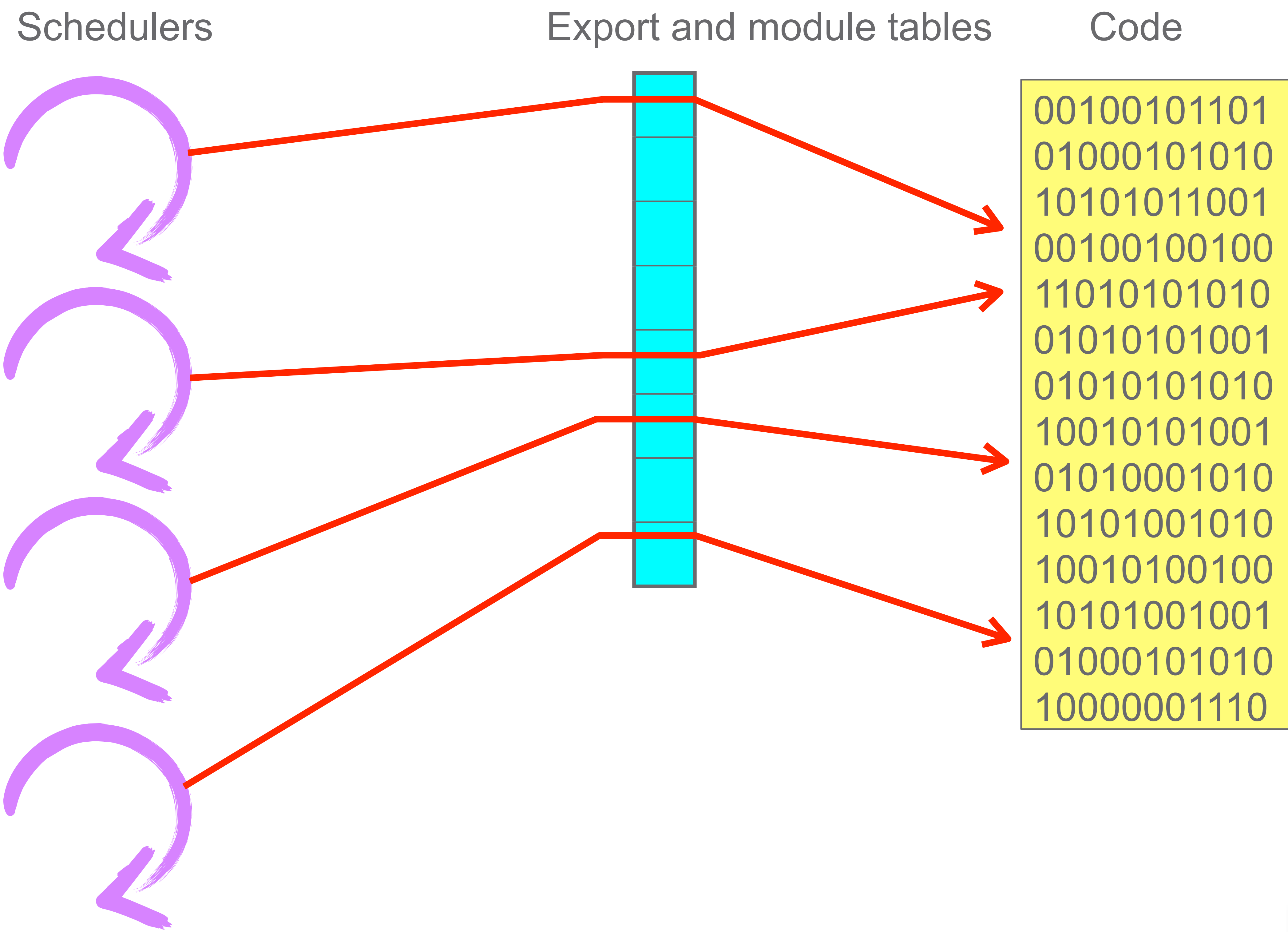
CODE-LOADING R11-R15



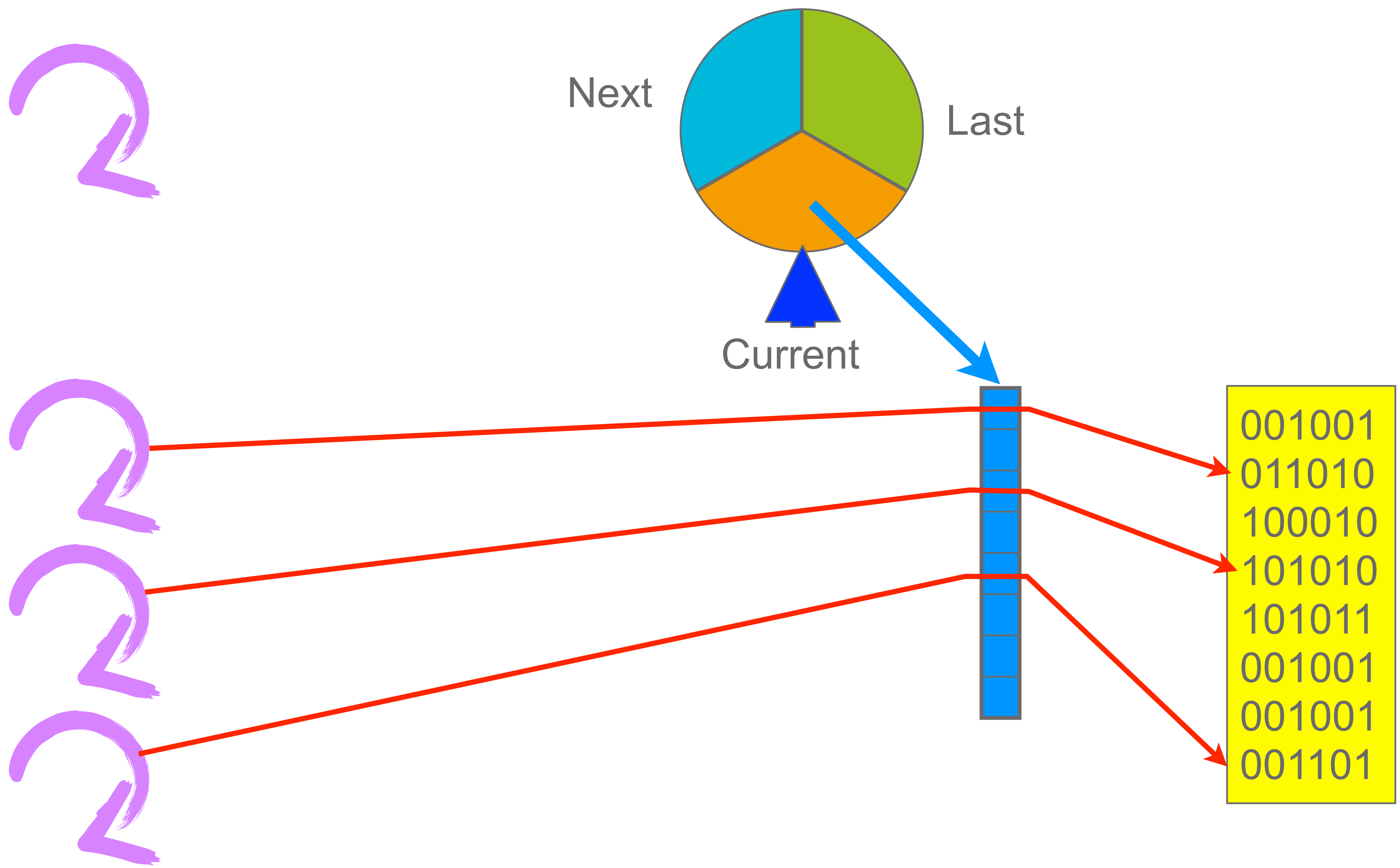
CODE-LOADING R11-R15



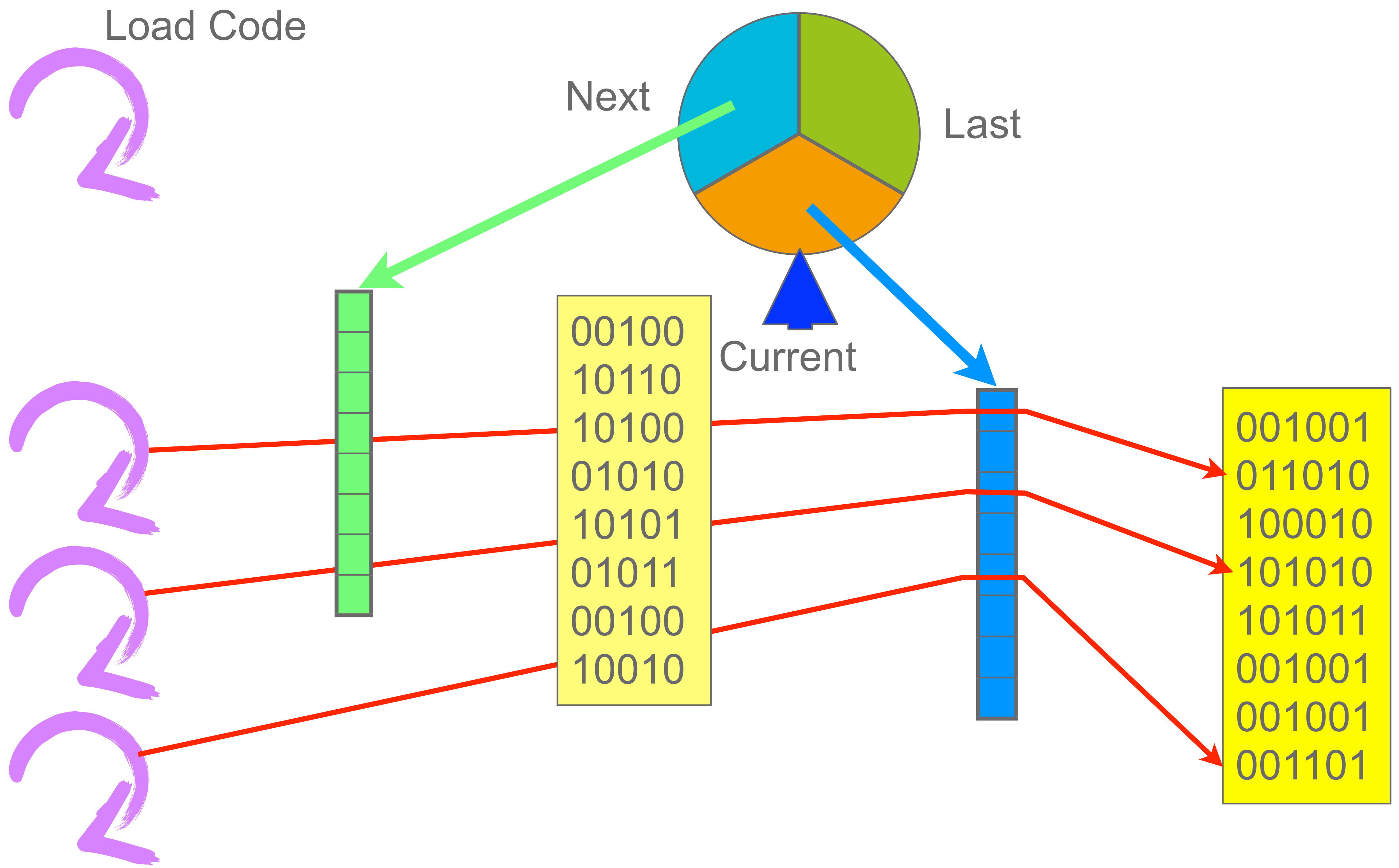
CODE-LOADING R11-R15



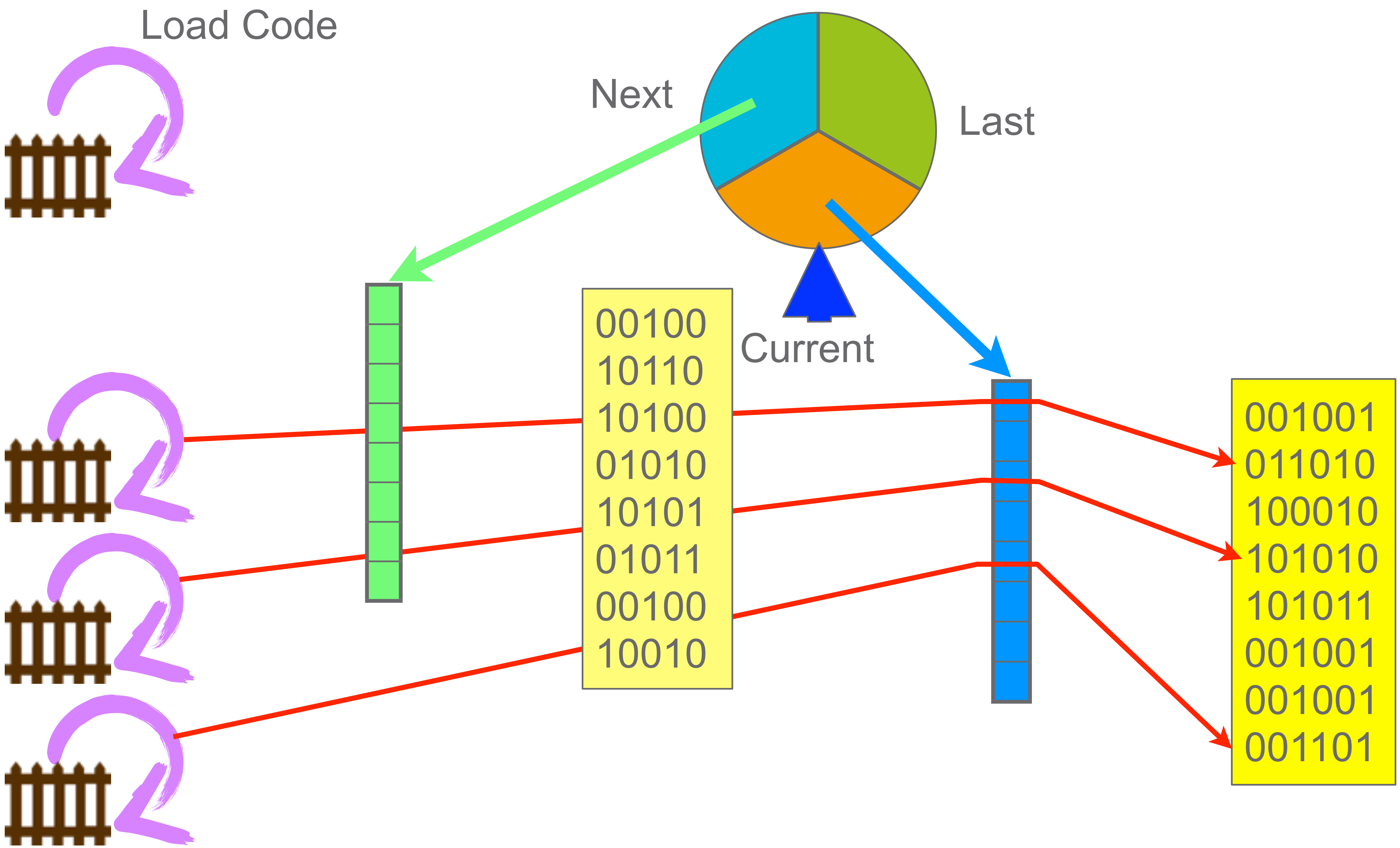
CODE-LOADING R16



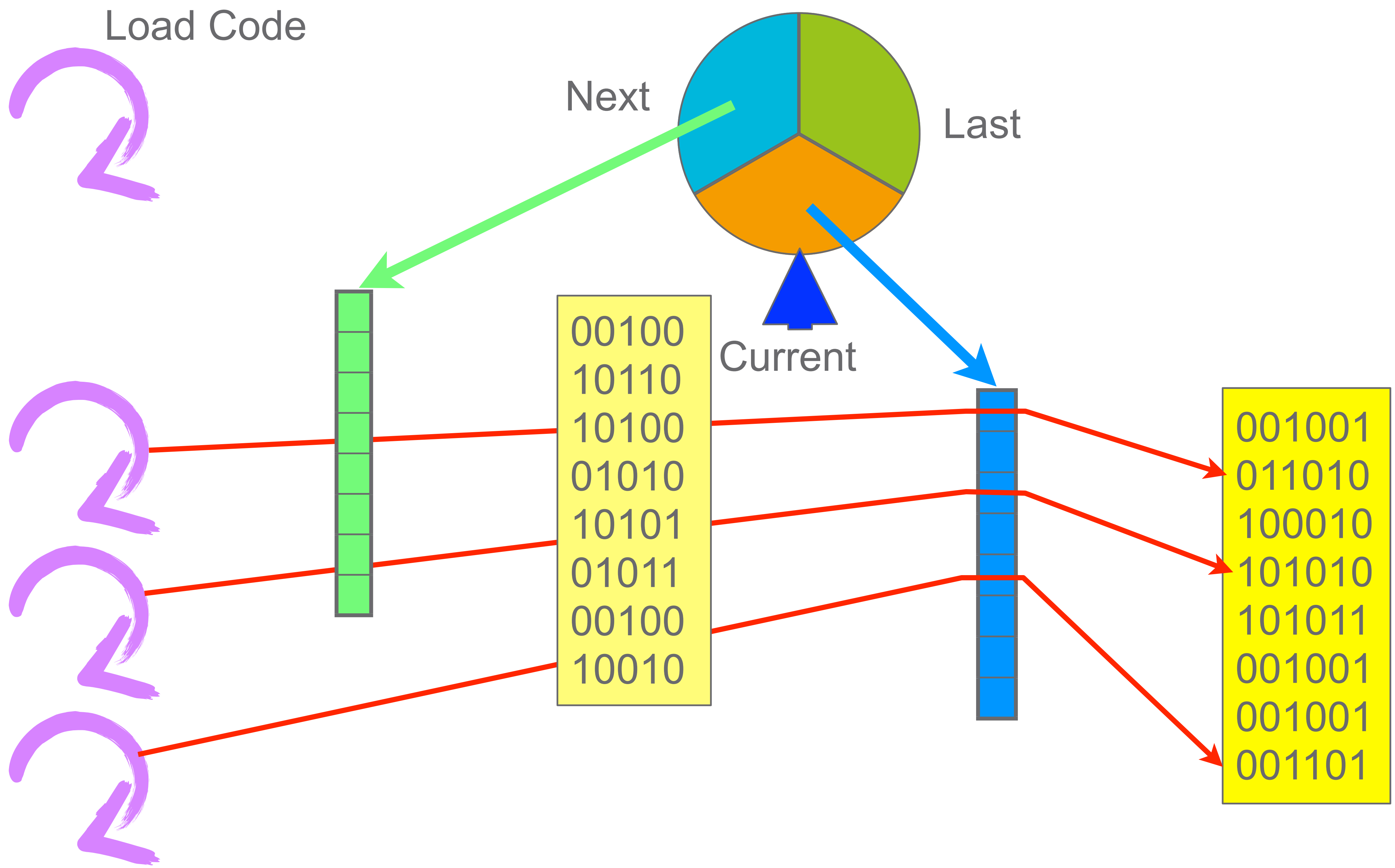
CODE-LOADING R16



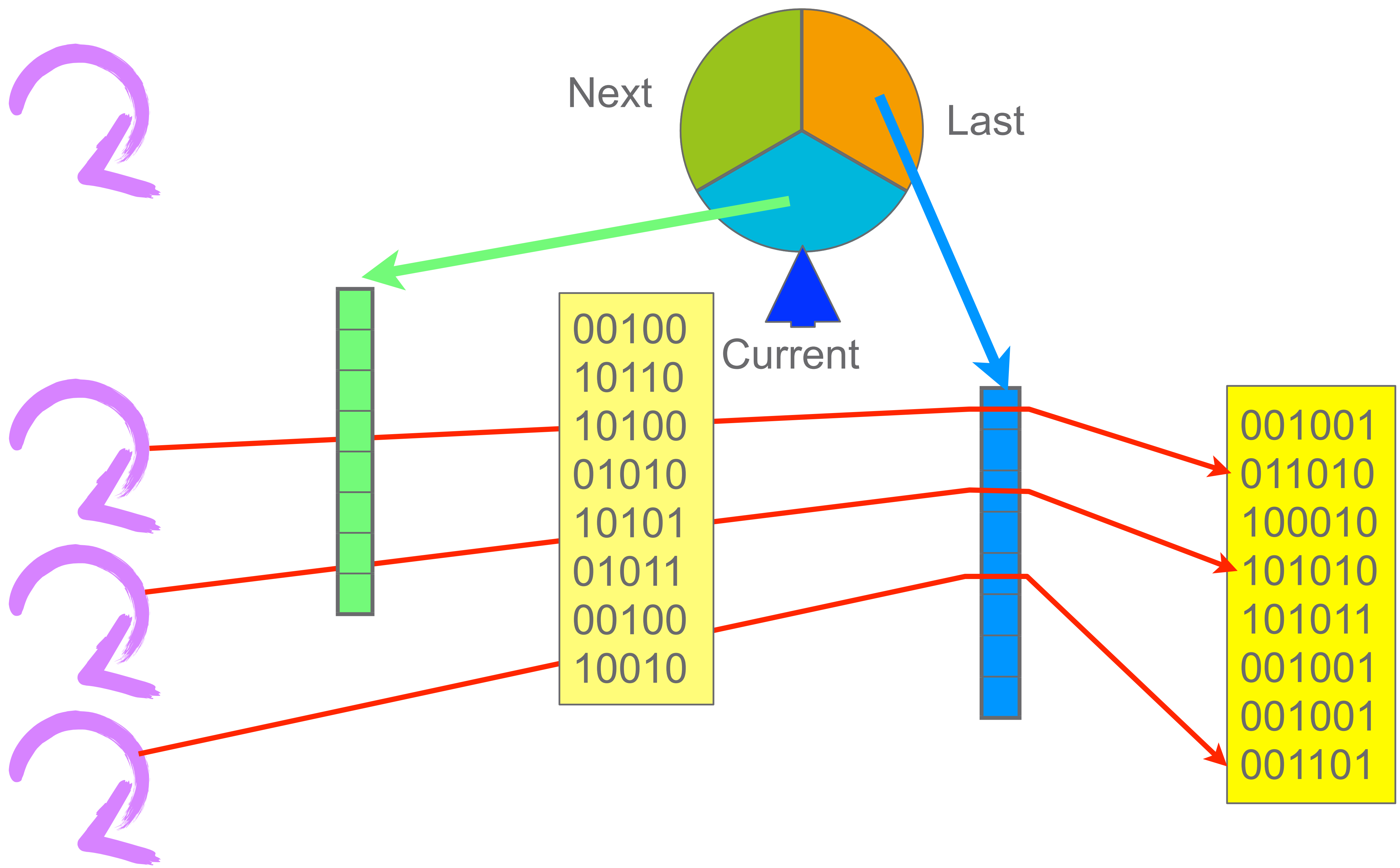
CODE-LOADING R16



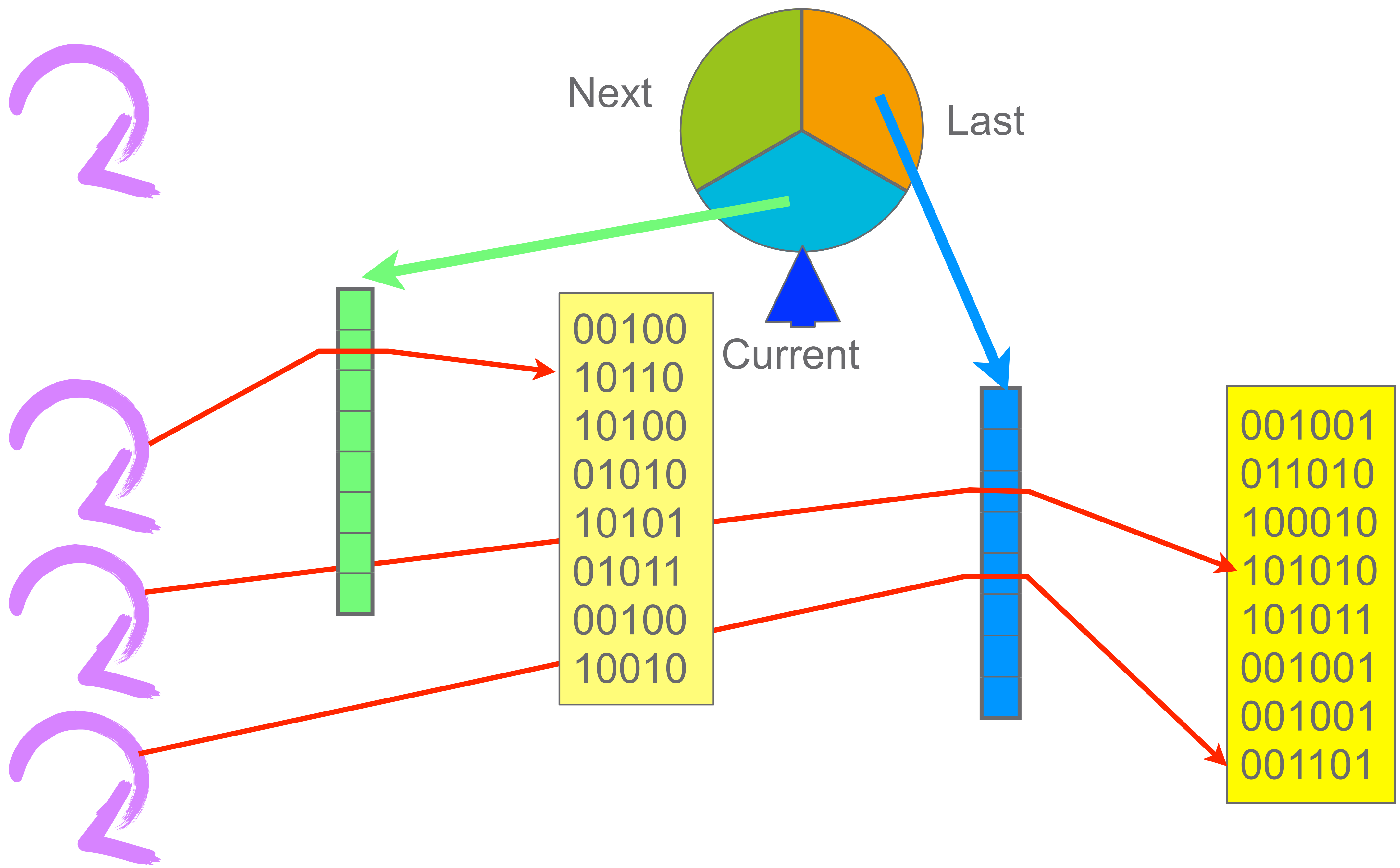
CODE-LOADING R16



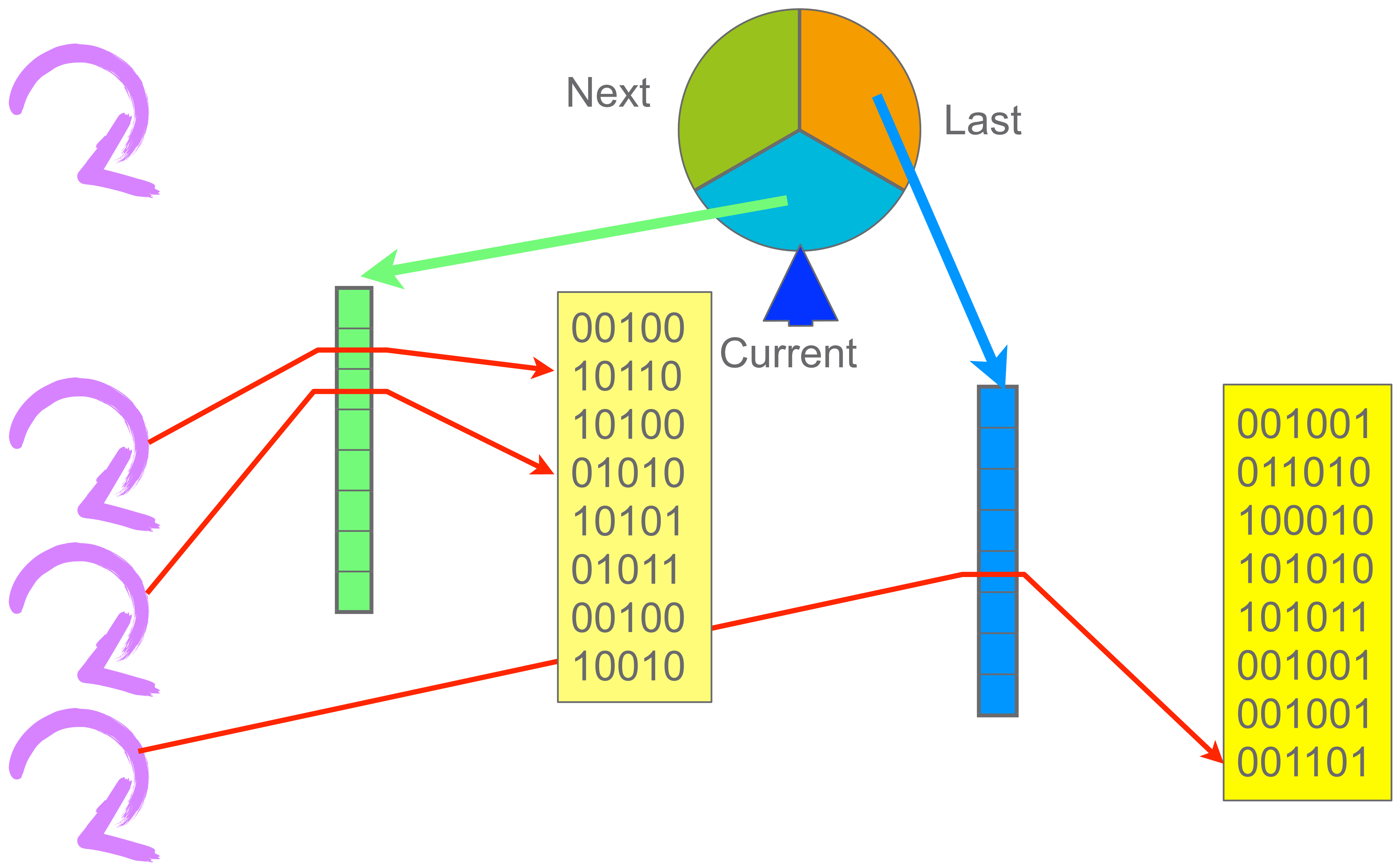
CODE-LOADING R16



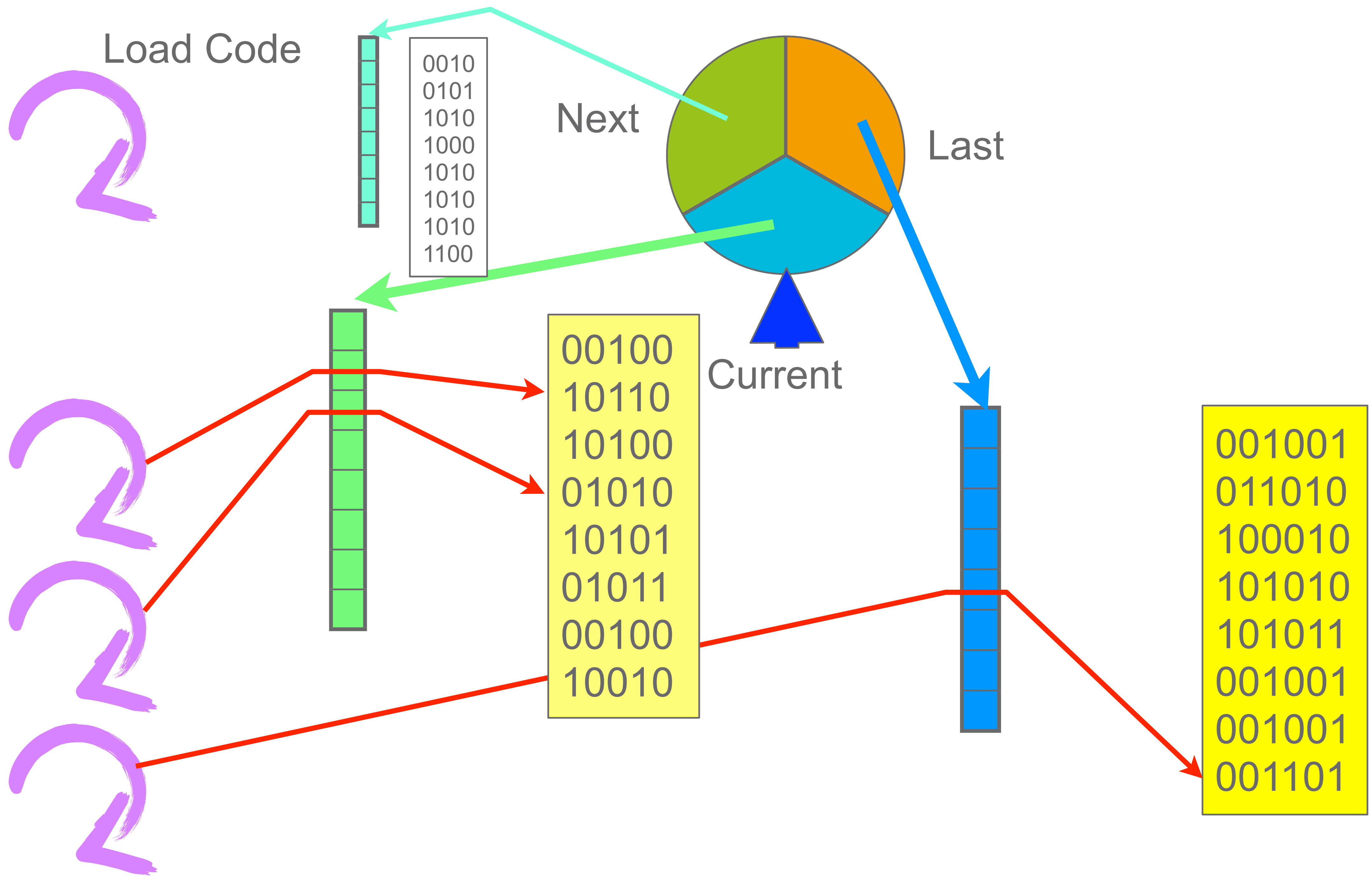
CODE-LOADING R16



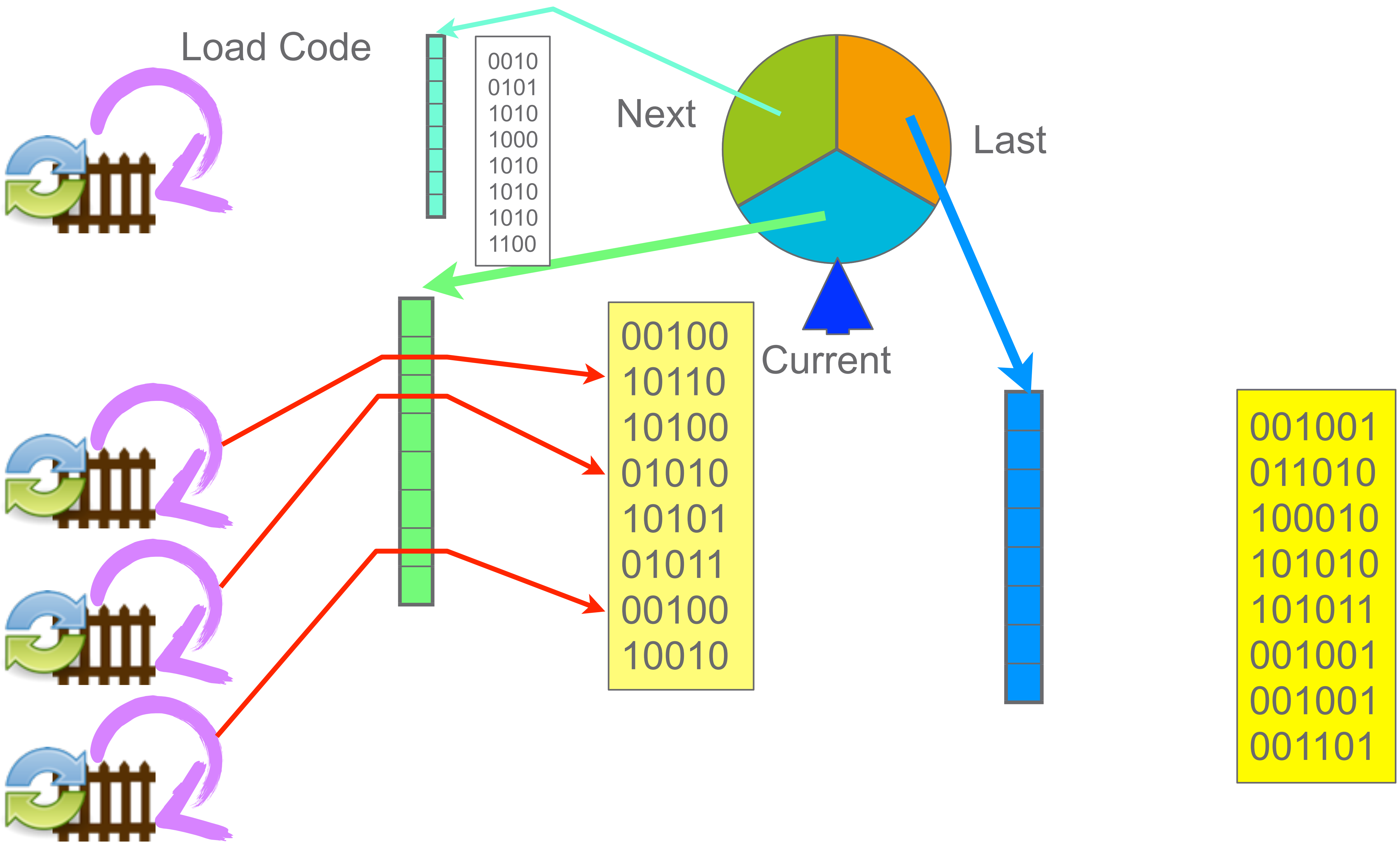
CODE-LOADING R16



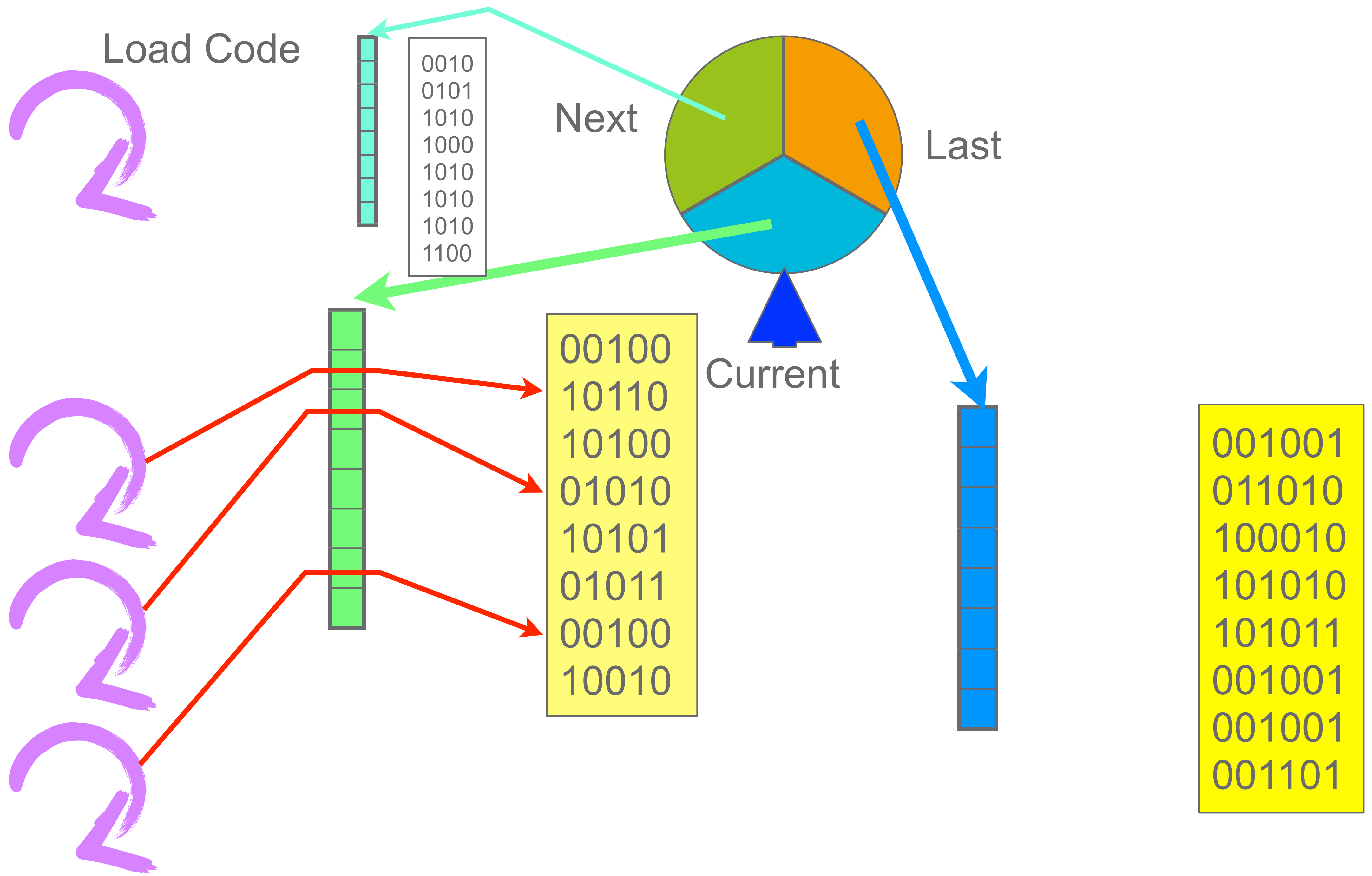
CODE-LOADING R16



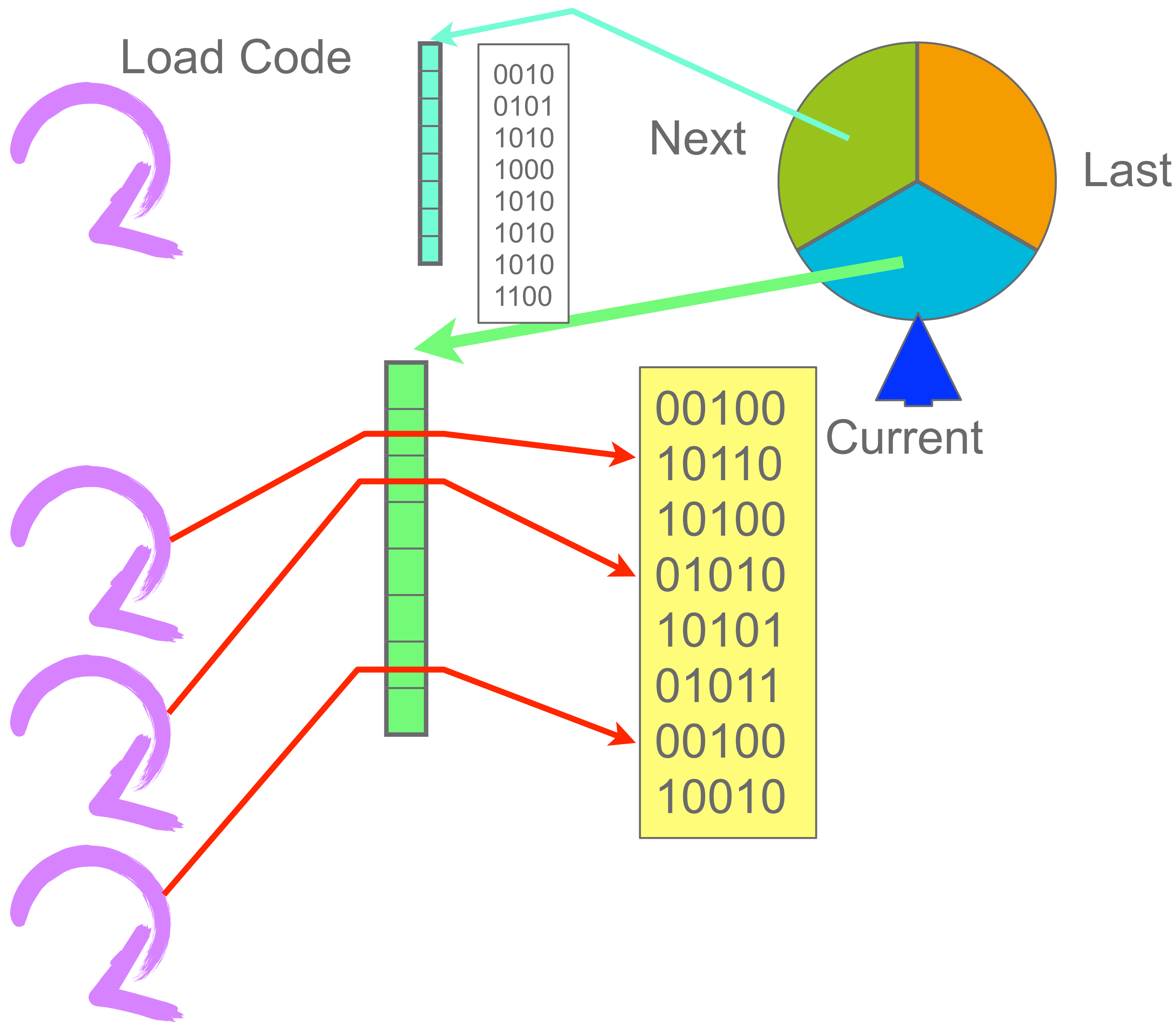
CODE-LOADING R16



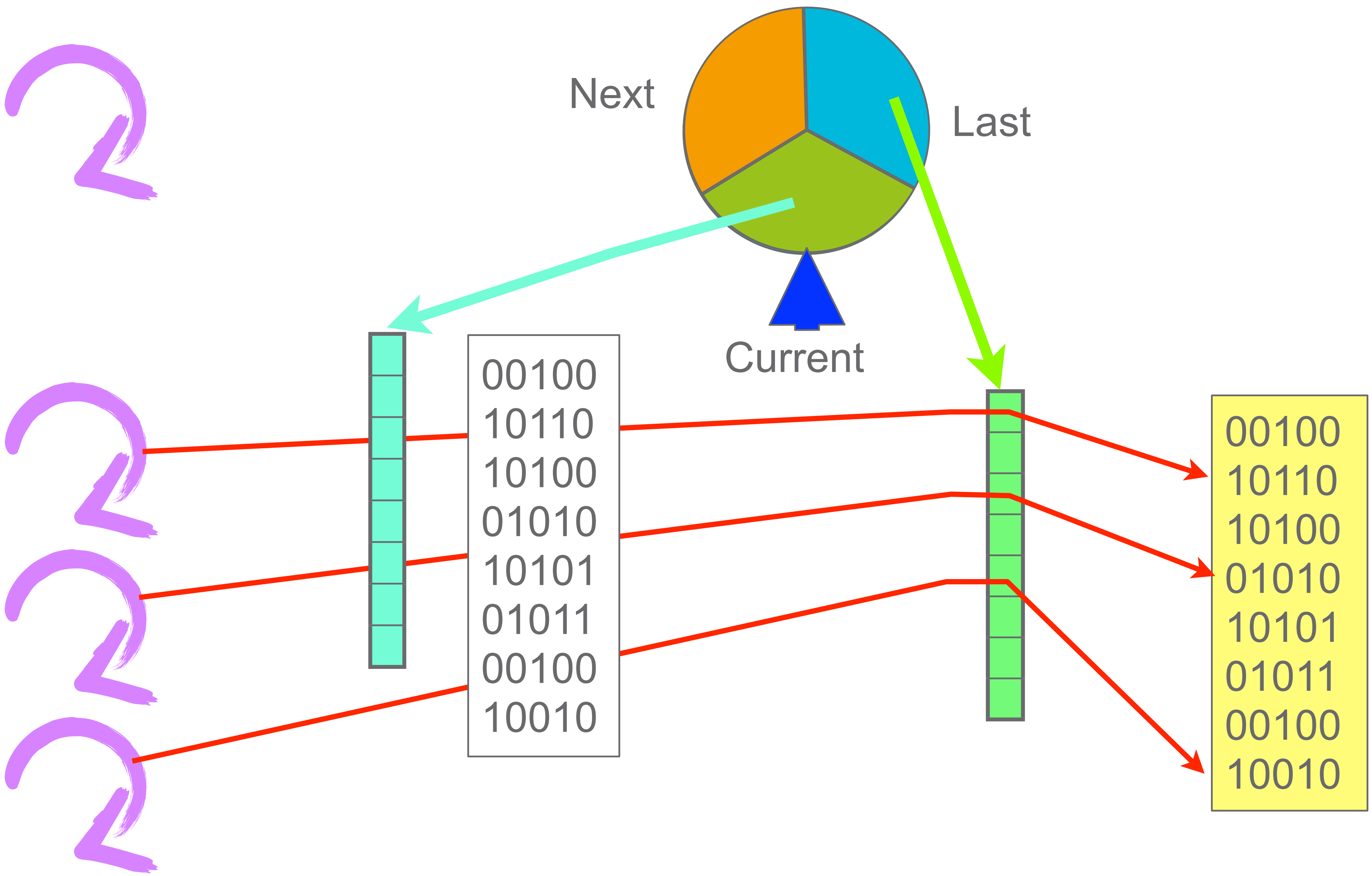
CODE-LOADING R16



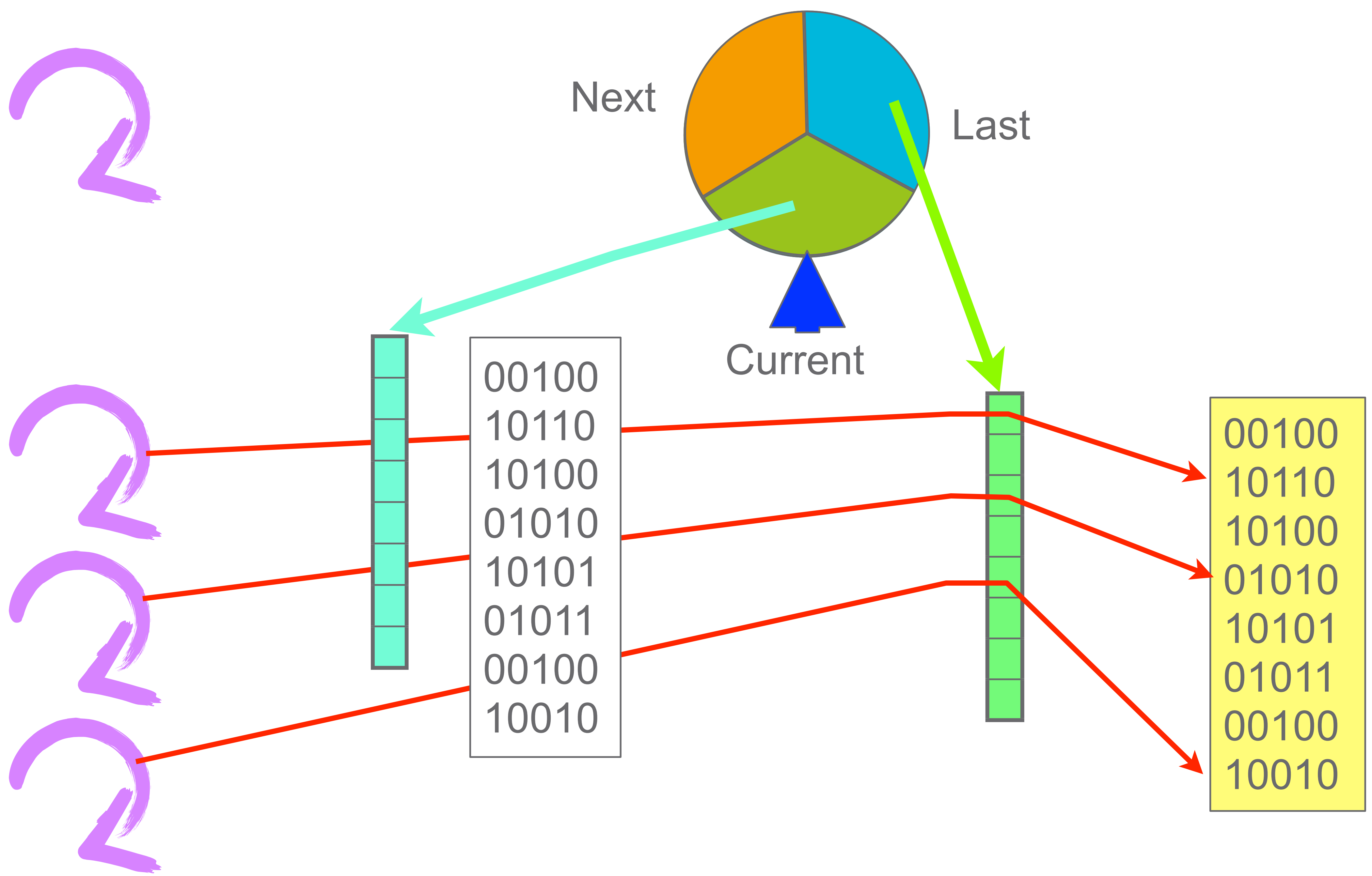
CODE-LOADING R16



CODE-LOADING R16



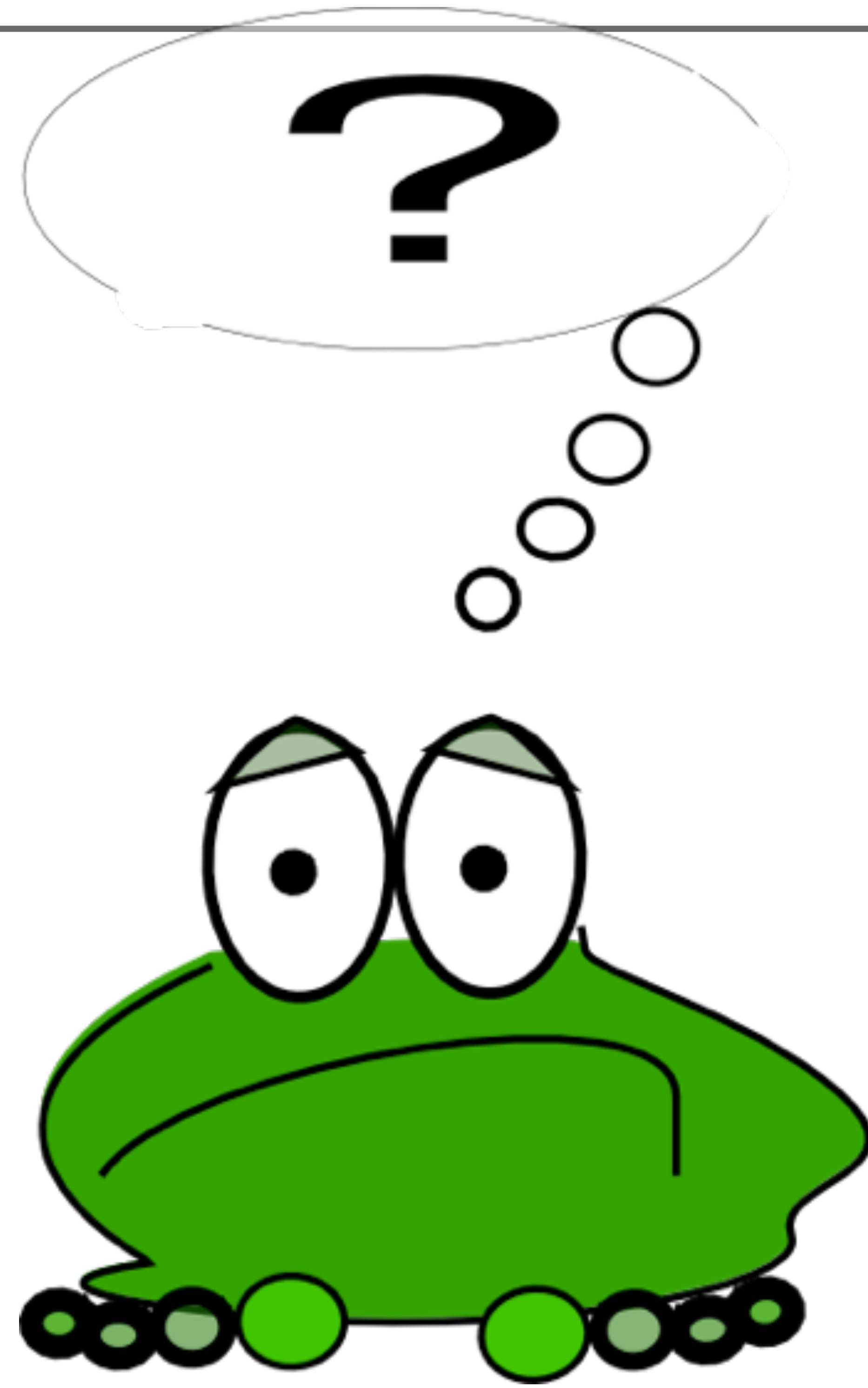
CODE-LOADING R16



RECIPES

- Divide or multiply resources
  - Separate memory
  - Separate cache-lines
- Asynchronously schedule work
  - Delayed dealloc
- Only involve relevant parties
  - Fine-grained synchronization
  - Lock-free queues
  - Reader optimized RW-Locks
- Postpone until possible
  - Thread progress
    - Lock-free queues
    - Code loading
  - Table cleanup

QUESTIONS?



ERICSSON

DISTRIBUTION ENCODING/DECODING R11B-R13B

Atom Cache node 1

0	‘$gen_call’
1	‘procs’
2	
3	

Atom Cache node 2

0	‘$gen_call’
1	‘procs’
2	
3	

DISTRIBUTION ENCODING/DECODING R11B-R13B

RemotePid ! {procs,r,us}

Atom Cache node 1

0	‘$gen_call’
1	‘procs’
2	
3	

Atom Cache node 2

0	‘$gen_call’
1	‘procs’
2	
3	

DISTRIBUTION ENCODING/DECODING R11B-R13B

RemotePid ! {procs,r,us}

To external format

Atom Cache node 1

0	'$gen_call'
1	'procs'
2	
3	

Atom Cache node 2

0	'$gen_call'
1	'procs'
2	
3	

DISTRIBUTION ENCODING/DECODING R11B-R13B

RemotePid ! {procs,r,us}

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Atom Cache node 1

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2	
3	

Atom Cache node 2

0	‘$gen_call’
1	‘procs’
2	
3	

DISTRIBUTION ENCODING/DECODING R11B-R13B

RemotePid ! {procs,r,us}

To external format

Tuple 3			

Atom Cache node 1

0	‘$gen_call’
1	‘procs’
2	
3	

Atom Cache node 2

0	‘$gen_call’
1	‘procs’
2	
3	

DISTRIBUTION ENCODING/DECODING R11B-R13B

RemotePid ! {procs,r,us}

To external format

Tuple 3	Cache 1		

Atom Cache node 1

0	'$gen_call'
1	'procs'
2	
3	

Atom Cache node 2

0	'$gen_call'
1	'procs'
2	
3	

DISTRIBUTION ENCODING/DECODING R11B-R13B

RemotePid ! {procs,r,us}

To external format

Tuple 3	Cache 1	Insert 2 ‘r’	

Atom Cache node 1

0	‘$gen_call’
1	‘procs’
2	‘r’
3	

Atom Cache node 2

0	‘$gen_call’
1	‘procs’
2	
3	

DISTRIBUTION ENCODING/DECODING R11B-R13B

RemotePid ! {procs,r,us}

To external format

Tuple 3	Cache 1	Insert 2 ‘r’	Insert 3 ‘us’

Atom Cache node 1

0	‘$gen_call’
1	‘procs’
2	‘r’
3	‘us’

Atom Cache node 2

0	‘$gen_call’
1	‘procs’
2	
3	

DISTRIBUTION ENCODING/DECODING R11B-R13B

RemotePid ! {procs,r,us}

To external format

Tuple 3	Cache 1	Insert 2 ‘r’	Insert 3 ‘us’

Send to network

Atom Cache node 1

0	‘$gen_call’
1	‘procs’
2	‘r’
3	‘us’

Atom Cache node 2

0	‘$gen_call’
1	‘procs’
2	
3	

DISTRIBUTION ENCODING/DECODING R11B-R13B

RemotePid ! {procs,r,us}

Atom Cache node 1

0	'$gen_call'
1	'procs'
2	'r'
3	'us'

To external format

Tuple 3	Cache 1	Insert 2 'r'	Insert 3 'us'

Send to network

Receive from network

Tuple 3	Cache 1	Insert 2 'r'	Insert 3 'us'

Atom Cache node 2

0	'$gen_call'
1	'procs'
2	
3	

DISTRIBUTION ENCODING/DECODING R11B-R13B

RemotePid ! {procs,r,us}

To external format

Tuple 3	Cache 1	Insert 2 ‘r’	Insert 3 ‘us’

Atom Cache node 1

0	‘$gen_call’
1	‘procs’
2	‘r’
3	‘us’

Send to network

Receive from network

Tuple 3	Cache 1	Insert 2 ‘r’	Insert 3 ‘us’

Atom Cache node 2

0	‘$gen_call’
1	‘procs’
2	
3	

ERLANG

DISTRIBUTION ENCODING/DECODING R11B-R13B

RemotePid ! {procs,r,us}

To external format

Tuple 3	Cache 1	Insert 2 ‘r’	Insert 3 ‘us’

Send to network

Atom Cache node 1

0	‘$gen_call’
1	‘procs’
2	‘r’
3	‘us’

Receive from network

Tuple 3	Cache 1	Insert 2 ‘r’	Insert 3 ‘us’

From external format

Atom Cache node 2

0	‘$gen_call’
1	‘procs’
2	‘r’
3	‘us’

ERLANG

DISTRIBUTION ENCODING/DECODING R11B-R13B

RemotePid ! {procs,r,us}

Atom Cache node 1

0	‘$gen_call’
1	‘procs’
2	‘r’
3	‘us’

To external format

Tuple 3	Cache 1	Insert 2 ‘r’	Insert 3 ‘us’

Send to network

Receive from network

Tuple 3	Cache 1	Insert 2 ‘r’	Insert 3 ‘us’

From external format

LocalPid ! {procs,r,us}

Atom Cache node 2

0	‘$gen_call’
1	‘procs’
2	‘r’
3	‘us’

DISTRIBUTION ENCODING R13B01-...

Atom Cache node 1

0	‘$gen_call’
1	‘procs’
2	
3	

DISTRIBUTION ENCODING R13B01-...

Atom Cache node 1

RemotePid ! {procs,r,us}

0	'$gen_call'
1	'procs'
2	
3	

DISTRIBUTION ENCODING R13B01-…

RemotePid ! {procs,r,us}

To external format

Atom Cache node 1

0	‘$gen_call’
1	‘procs’
2	
3	

Tuple 3			

DISTRIBUTION ENCODING R13B01-...

RemotePid ! {procs,r,us}

To external format

Atom Cache node 1

0	'$gen_call'
1	'procs'
2	
3	

procs

Tuple 3	Atom 0		

DISTRIBUTION ENCODING R13B01-...

Atom Cache node 1

0	‘$gen_call’
1	‘procs’
2	
3	

RemotePid ! {procs,r,us}

To external format

procs
r

Tuple 3	Atom 0	Atom 1	

DISTRIBUTION ENCODING R13B01-...

Atom Cache node 1

0	'$gen_call'
1	'procs'
2	
3	

RemotePid ! {procs,r,us}

To external format

procs
r
us

Tuple 3	Atom 0	Atom 1	Atom 2

ERLANG

DISTRIBUTION ENCODING R13B01-…

RemotePid ! {procs,r,us}

To external format

Atom Cache node 1

0	‘$gen_call’
1	‘procs’
2	
3	

Tuple 3	Atom 0	Atom 1	Atom 2

procs
r
us

To port

DISTRIBUTION ENCODING R13B01-...

RemotePid ! {procs,r,us}

To external format

Atom Cache node 1

0	'$gen_call'
1	'procs'
2	
3	

procs	
r	
us	

Tuple 3	Atom 0	Atom 1	Atom 2

To port

DISTRIBUTION ENCODING R13B01-...

RemotePid ! {procs,r,us}

To external format

Atom Cache node 1

0	'$gen_call'
1	'procs'
2	'r'
3	'us'

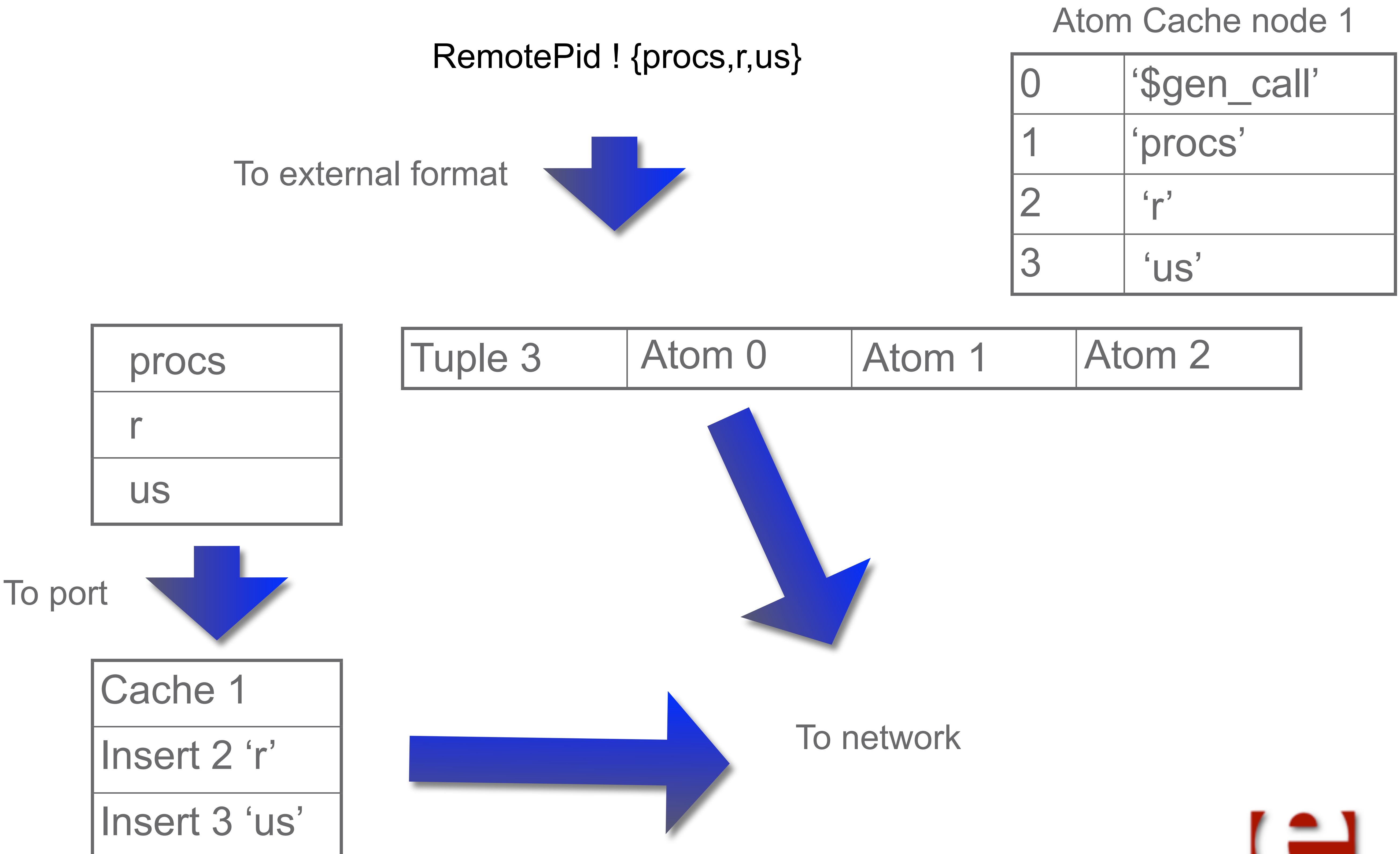
Tuple 3	Atom 0	Atom 1	Atom 2

procs
r
us

To port

Cache 1
Insert 2 'r'
Insert 3 'us'

DISTRIBUTION ENCODING R13B01-...



DISTRIBUTION DECODING R13B01-...

From network

Cache 1	
Insert 2 ‘r’	
Insert 3 ‘us’	

Tuple 3	Atom 0	Atom 1	Atom 2

Atom Cache node 2

0	‘$gen_call’
1	‘procs’
2	
3	

DISTRIBUTION DECODING R13B01-…

From network

Cache 1
Insert 2 ‘r’
Insert 3 ‘us’

Tuple 3	Atom 0	Atom 1	Atom 2

Decode cache instructions

Atom Cache node 2

0	‘$gen_call’
1	‘procs’
2	
3	

DISTRIBUTION DECODING R13B01-...

From network

Cache 1
Insert 2 ‘r’
Insert 3 ‘us’

Tuple 3	Atom 0	Atom 1	Atom 2

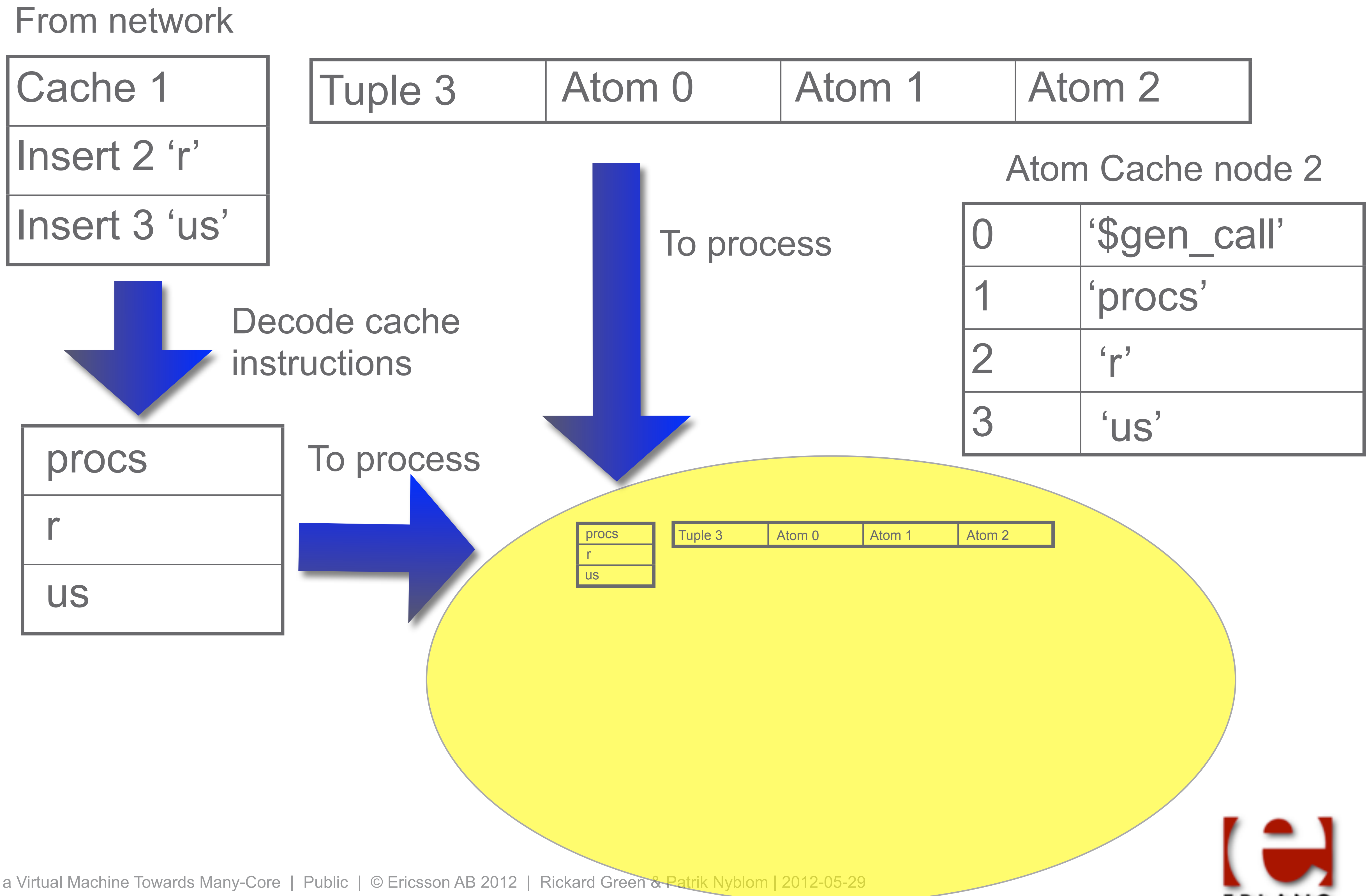
Decode cache instructions

procs
r
us

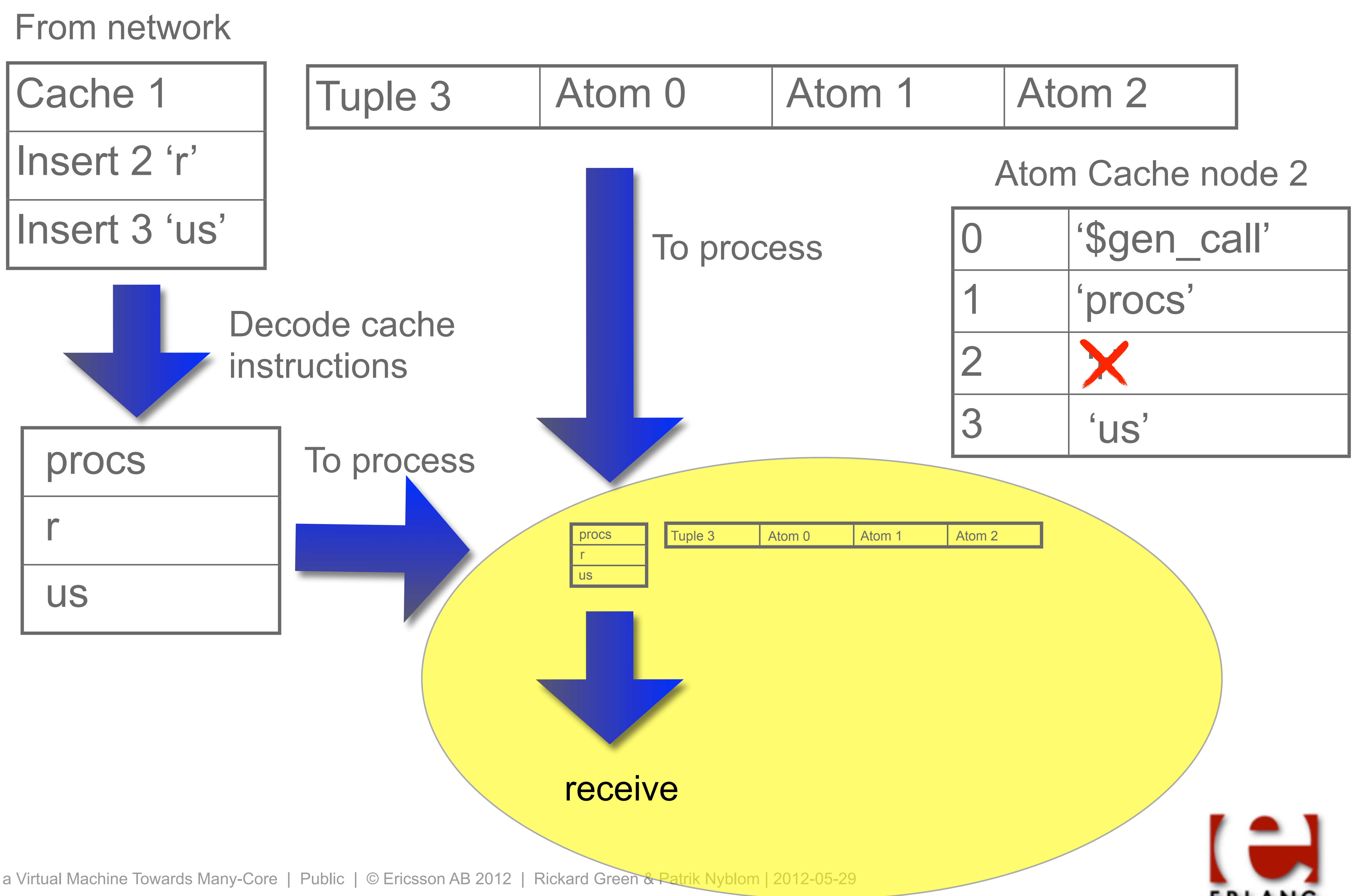
Atom Cache node 2

0	‘$gen_call’
1	‘procs’
2	‘r’
3	‘us’

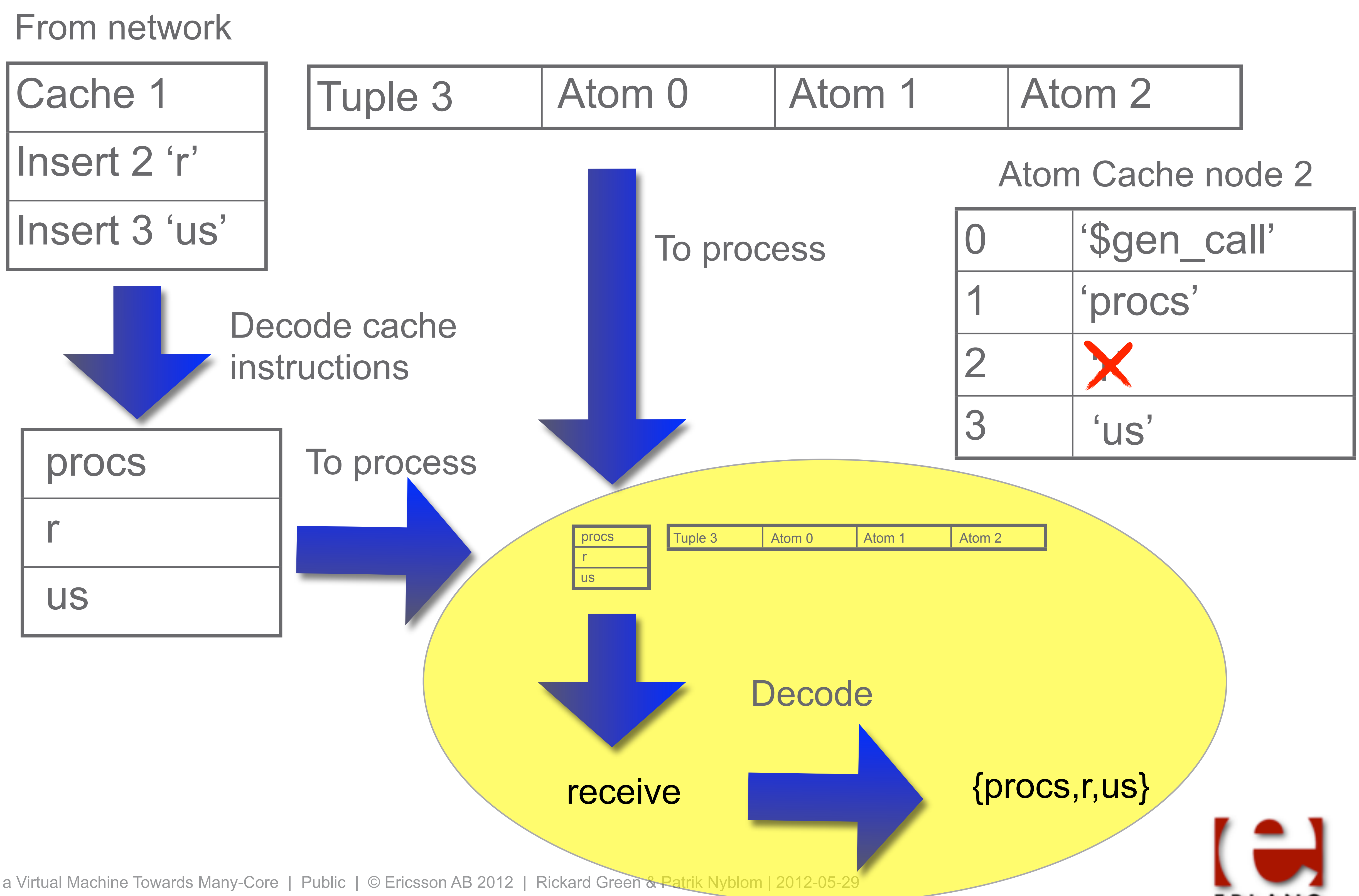
DISTRIBUTION DECODING R13B01-...



DISTRIBUTION DECODING R13B01-...

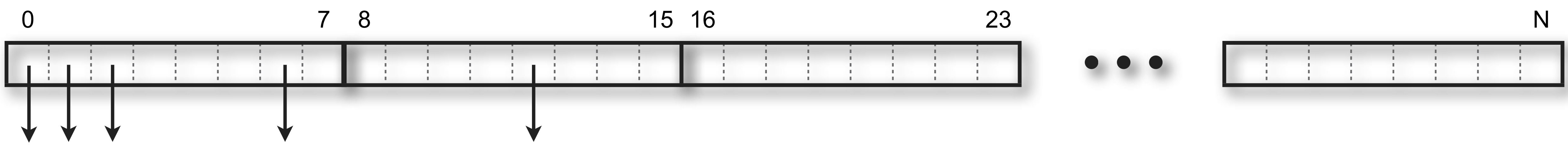


DISTRIBUTION DECODING R13B01-...



PROCESS TABLE R11-R15

Process table

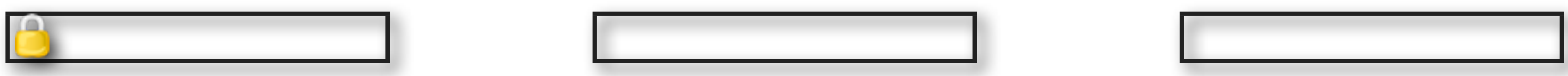



```
PIX = PID rem N
```

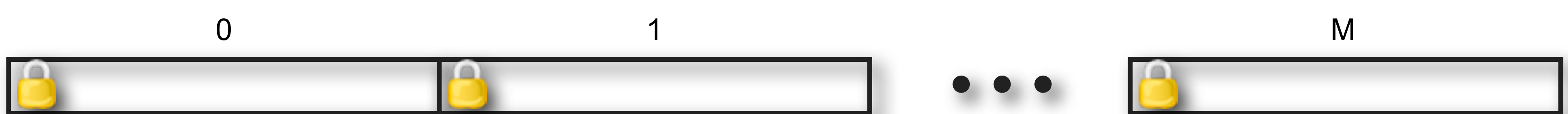
Process table lock

Last pid

Process count



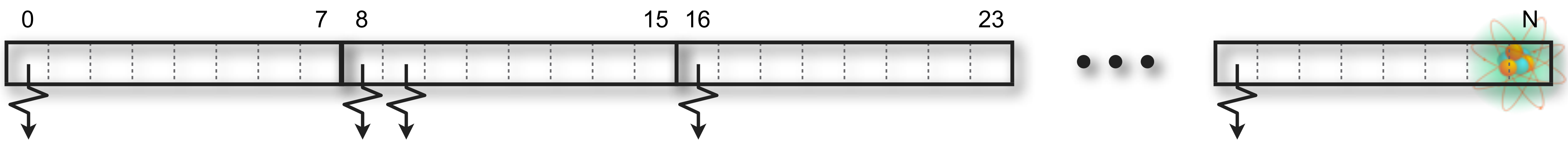
PIX-lock table




```
PIXLIX = PID rem M
```

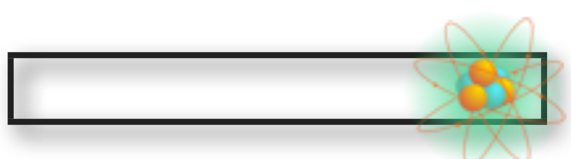
PROCESS TABLE R16

Process table

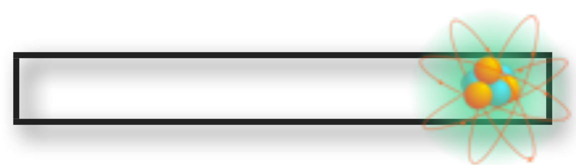



```
SeqPIX = PID rem N,
CacheLineBeginIX = (SeqPIX rem TabCacheLines) * PixPerCacheLine,
PIX = CacheLineBeginIX + SeqPIX div TabCacheLines
```

Last pid

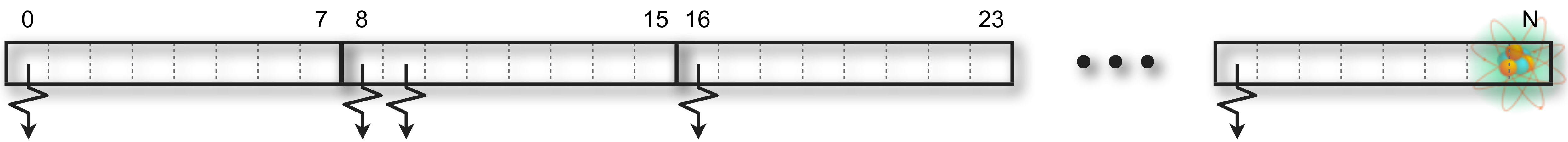


Process count



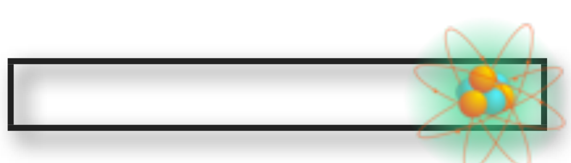
PROCESS TABLE R16

Process table

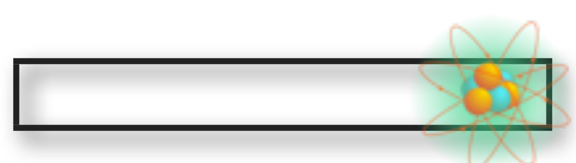



```
SeqPIX = PID rem N,
CacheLineBeginIX = (SeqPIX rem TabCacheLines) * PixPerCacheLine,
PIX = CacheLineBeginIX + SeqPIX div TabCacheLines
```

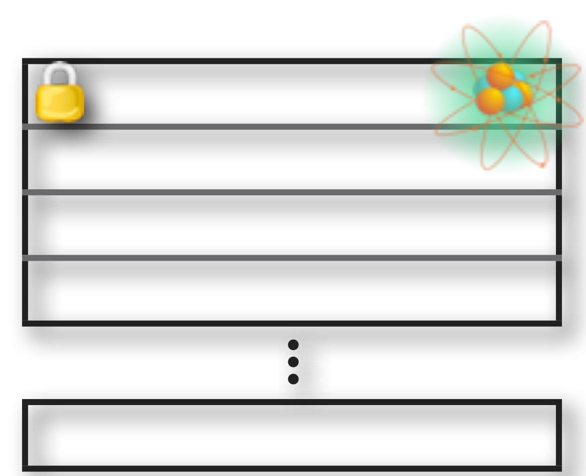
Last pid



Process count



“Inverted” reader optimized RW-Lock



ERTS READER OPTIMIZED RW-LOCKS

- ETS `read_concurrency`
- Misc ERTS internal RW-Locks