The RT Patch

What needs to be done to get it into Mainline?

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RT Patch, What is it?

- Goal: to make a deterministic operating system
- How?
  - Highest priority task responds immediately
  - Control of interrupts
  - Increase preemption areas
  - Prevent unbounded latency

Control of interrupts

- **Interrupt handlers are threads**
  - **Except for timer interrupts (something must control scheduling)**
- **Prioritize interrupt handlers (just like threads)**
- **Interrupts can be preempted**

Increase preemption areas

- Do not disable interrupts
- Do not disable preemption
  - Both prevent a task from being scheduled
- Most places disable preemption or interrupts with spin_lock()s
- PREEMPT_RT converts spin_locks into a sleepable mutex
  - They do not disable preemption nor interrupts.
  - Even spin_lock_irq() does not disable interrupts.

PREEMPT_RT what's in the patch?

- **Version I wrote this for: v4.0.5-rt4**
- **350 patches!**
- **415 files changed, 11713 insertions(+), 1927 deletions(-)**

```
 4.3% arch/x86/
 6.3% arch/
10.0% drivers/misc/
 4.0% drivers/
15.8% include/linux/
 9.1% kernel/locking/
 6.0% kernel/sched/
 5.3% kernel/time/
10.5% kernel/trace/
16.0% kernel/
 3.4% mm/
```

History of the RT patch

- **Started in 2004 by Ingo Molnar**
- **Maintained by Thomas Gleixner**
- **Responsible for:**

High resolution timers
Generic interrupts
mutex code
Priority inheritance futexes
lockdep
RT scheduler
ftrace / latency tracers
Conversions of semaphores to completions
SMP stability!

How does the RT patch make Linux RT?

- Add high resolution timers
- Add interrupts as threads
- Add priority inheritance
- Turn spin locks into sleeping locks

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How does the RT patch make Linux RT?

- Add high resolution timers
- Add interrupts as threads
- Add priority inheritance
- **Turn spin locks into sleeping locks**
  - **Spin locks have lots of side effects**
  - **These side effects are depended on**

Spin lock side effects

- **Disables preemption**
- **Some disable interrupts**
- **Some disable softirqs**
- **Disables migration**

Spin lock side effects

- **Disables preemption**
- **Some disable interrupts**
- **Some disable softirqs**
- **Disables migration**
  - This is the easy one
  - rt_mutex (what spin locks are converted to) disable migration
  - Solves accessing per cpu variables
  - May prevent RT tasks from migrating if preempted by higher priority task

Spinning lock or sleeping lock?

- **When a lock is converted to an rt_mutex**
  - **It's all or nothing!**
  - **Every use case of the lock is the same (sleep or spin)**
  - **Sleeping locks can not be taken when preempt/irq is disabled**
    - **May use trylock()**
  - **Sleeping locks can not be taken in hard interrupts**
    - **May NOT use trylock()!!!**

Taking sleeping lock in interrupt

- **Sleeping locks have priority inheritance**
- **Priority inheritance detects deadlocks**
- **Sleeping locks can be interrupted by interrupt**

Taking sleeping lock in interrupt

```
    CPU0                        CPU1
                              lock(A)
lock(A) <block>
  <interrupt>
      trylock(B)

                              lock(B) <block>
```

Looks to be ABBA deadlock, but it is not.

Wait queues

- **Wait queues can be complex**
  - **wake_up()**
  - **wake_up_nr()**
  - **wake_up_all()**
  - **wake_up_interruptible()**
  - **wake_up_interruptible_nr()**
  - **wake_up_interruptible_all()**
  - **wake_up_interruptible_sync()**

Wait queues

- **Wait queues can be long**
  - **Holds locks for long periods of time**
  - **Must be rt_mutex such that we can preempt**
  - **There's critical sections that use wait queues**
- **What to do?**

Simple wait queues

- **Uses raw spin locks**
- **90% of cases don't need the complexity**
- **Wake up one type only (interruptible or non-interruptible)**
- **Wake all can still be an issue**
  - **Still need to avoid holding a raw lock for a long time**
- **Currently trying to get simple wait queues in**
  - **Need to solve the wake all issue**

The trylock deadlock

- **When you need to take a lock in reverse order**
- **Works fine when you can't preempt**

```
again:
   spin_lock(&a);
   if (!spin_trylock(&b)) {
      spin_unlock(&a);
      goto again;
   }
```

The trylock deadlock

- **But when you can preempt, it's an issue!**
- **If Task-Y is an RT task > prio than Task-X it will loop forever.**

```
<Task-X>
spin_lock(&b);
<preempt => schedule Task-Y>
again:
   spin_lock(&a);
   if (!spin_trylock(&b)) {
      spin_unlock(&a);
      goto again;
   }
```

The trylock deadlock

- **One solution (great when applicable)**

```
again:
   spin_lock(&a);
   if (!spin_trylock(&b)) {
      spin_unlock(&a);
      spin_lock(&b);
      spin_unlock(&b);
      goto again;
   }
```

The trylock deadlock

- **But not always applicable**

```
fs/dcache.c:
dput() {
    repeat:
        if (fast_dput(dentry)) {
            return;
        } /* has dentry->lock */
    [...]
    dentry = dentry_kill(dentry);
    if (dentry) goto repeat;

dentry_kill() {
    if (!spin_trylock(&inode->i_lock))
        goto failed;
    if (!spin_trylock(&parent->i_lock)) {
        spin_unlock(&inode->i_lock);
        goto failed;
```

The trylock deadlock

You've heard of “cpu_relax()”?

The trylock deadlock

cpu_chill()

```
failed:
   spin_unlock(&dentry->lock);
   cpu_chill();
   return dentry;
```

The trylock deadlock

- **cpu_chill()**
- **A hack!**
  - **!PREEMPT_RT(), it is equivalent to cpu_relax()**
  - **otherwise**

```
static inline void cpu_chill(void)
{
        msleep(1);
}
```

per cpu variables

- **In mainline, just need to disable preemption**
  - That is bad for PREEMPT_RT
- **Disabling migration is not enough**
  - get_cpu() / put_cpu()
  - get_cpu_light() / put_cpu_light() when it is enough
- **Need to add locking**
  - local_lock()
  - local_spin_lock()
  - get_locked_var()
  - put_locked_var()

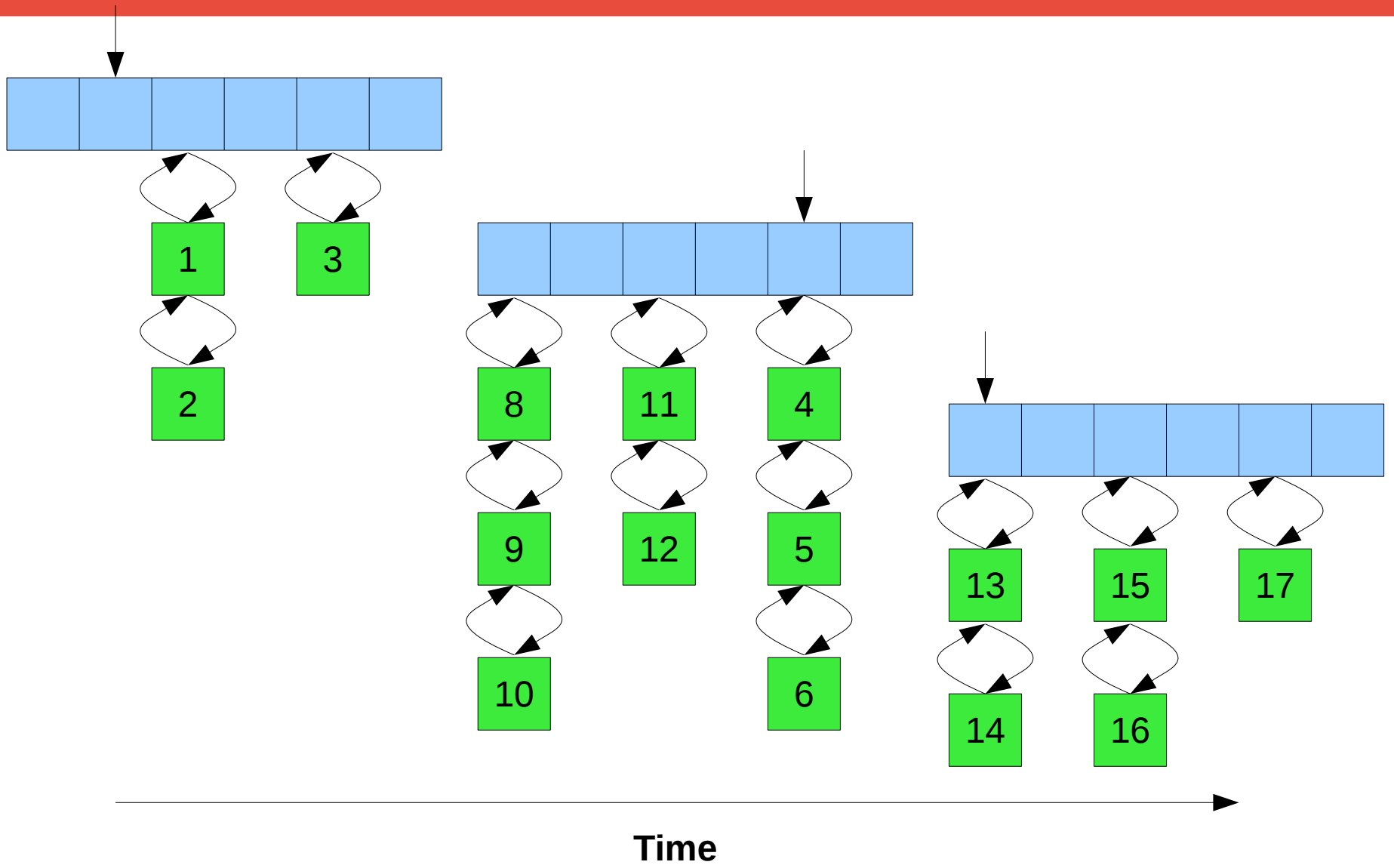
Local locks

- **preempt_disable -> local_lock(lvar)**
- **local_irq_disable -> local_lock_irq(lvar)**
- **local_irq_save -> local_lock_irqsave(lvar)**
- **get_cpu -> local_lock_cpu(lvar)**
- **get_cpu_var -> get_locked_var(lvar, var)**
- **spin_lock_irq() -> local_spin_lock_irq(lvar, lock)**
  - **Used when a per cpu variable is protected by the preemption or irq disabling of a spin lock**

The Timer Wheel

- **Fast add and remove**
  - O(1)
- **Great for timeouts**
  - Network timers
    - Hardly trigger (most likely removed)
- **But has a “cascade” effect**
  - moves one list to the next for individual events
  - 5 levels, first 256 entries, 64 entries for the rest

The Timer Wheel



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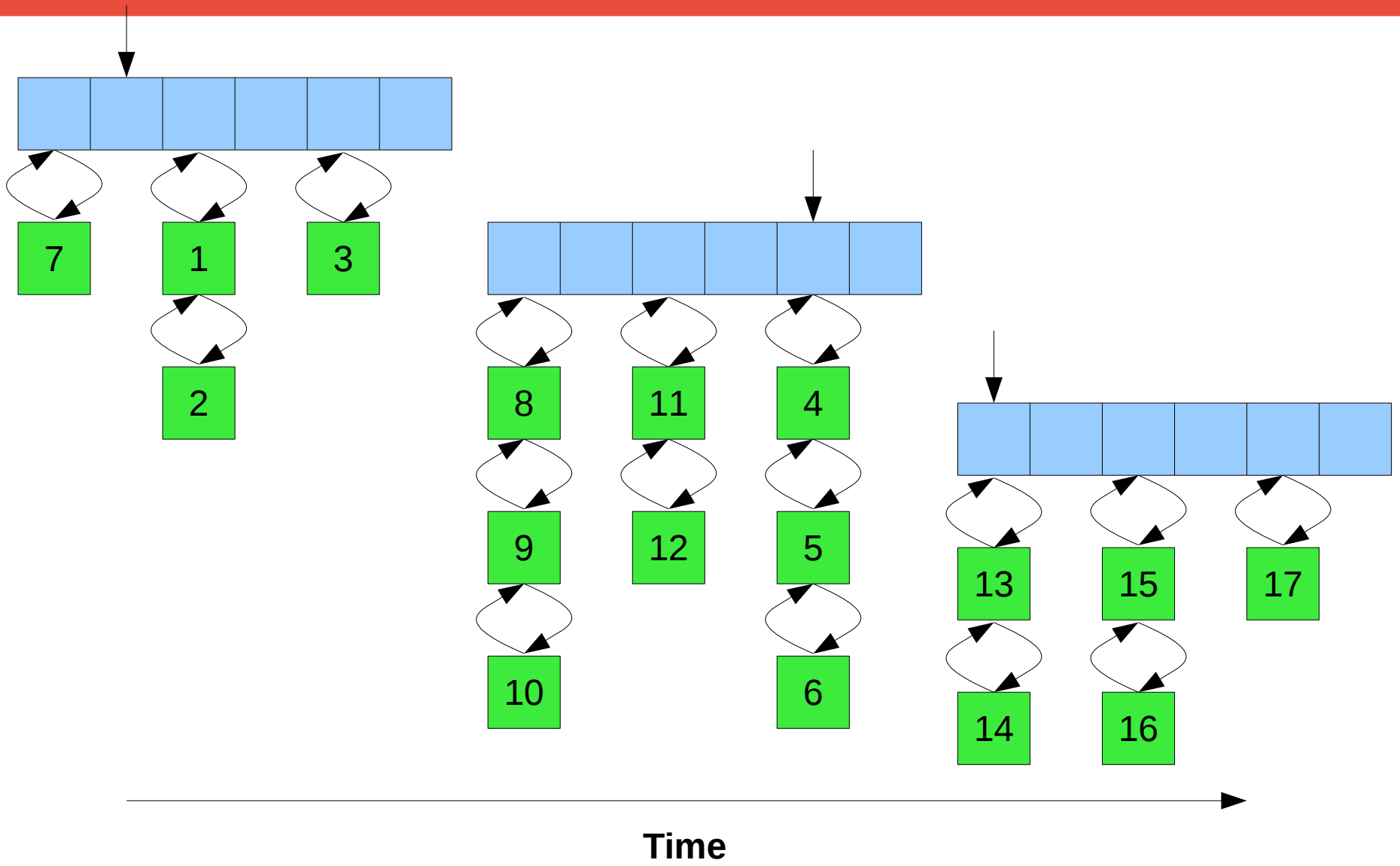

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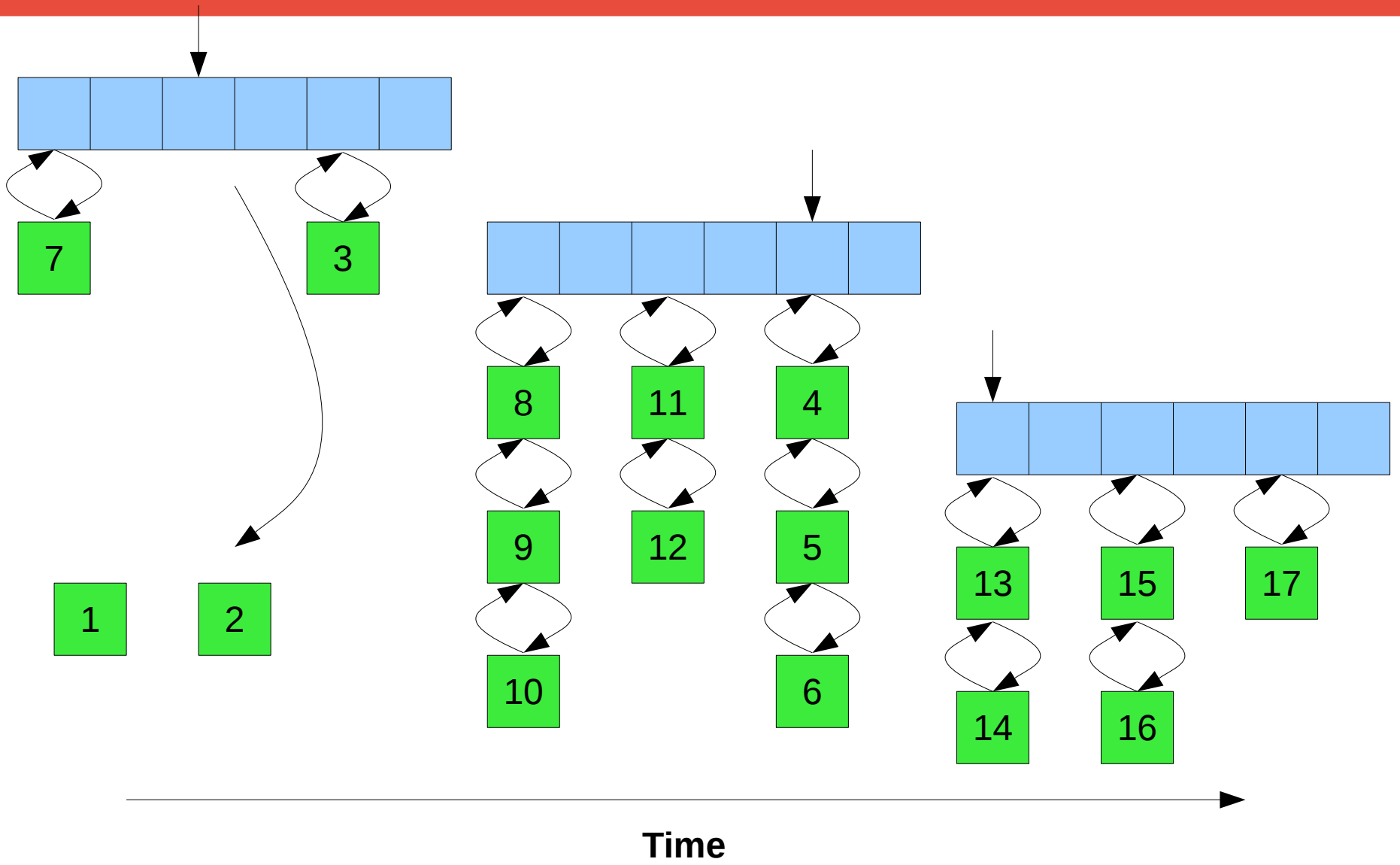

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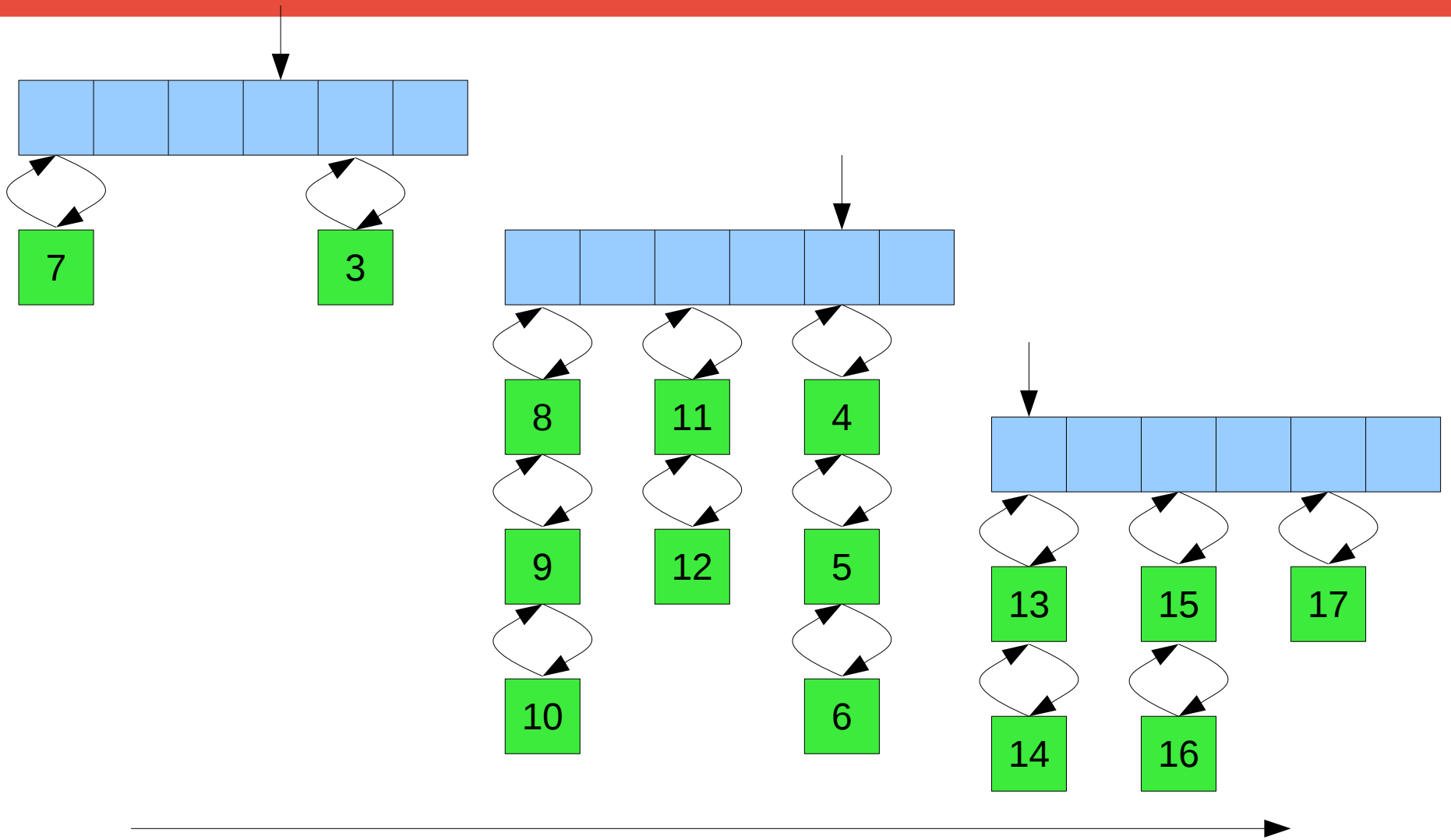

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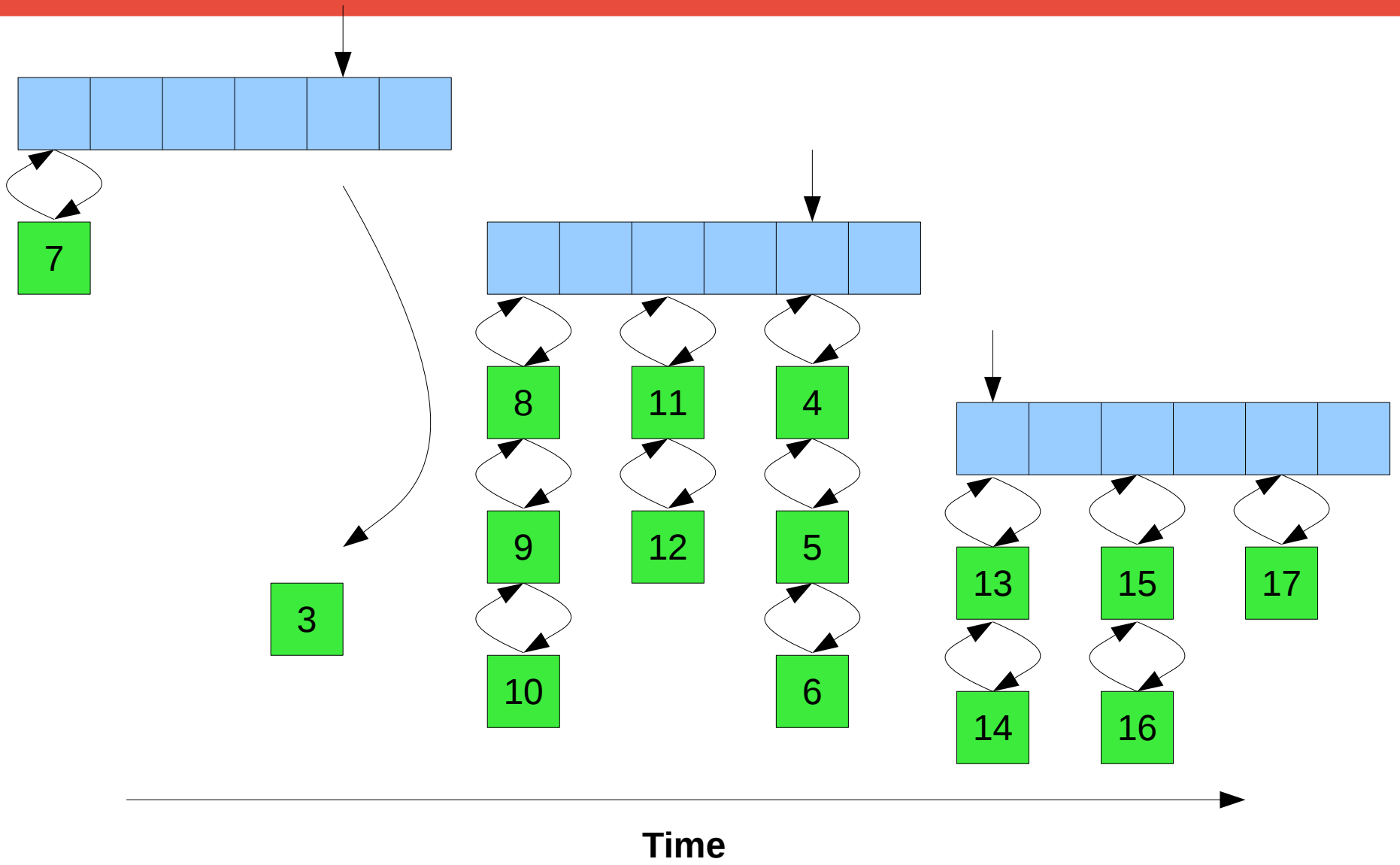

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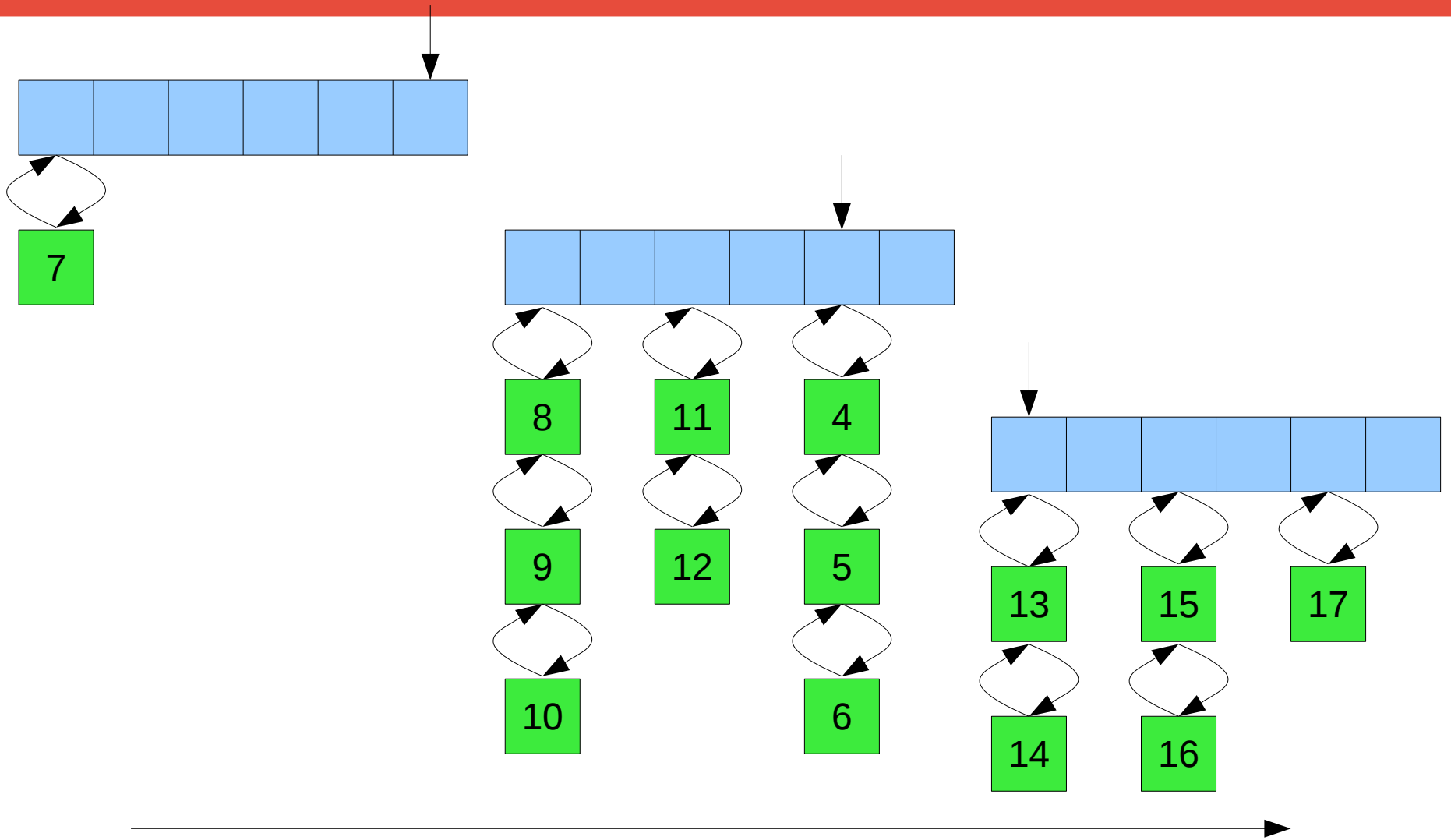

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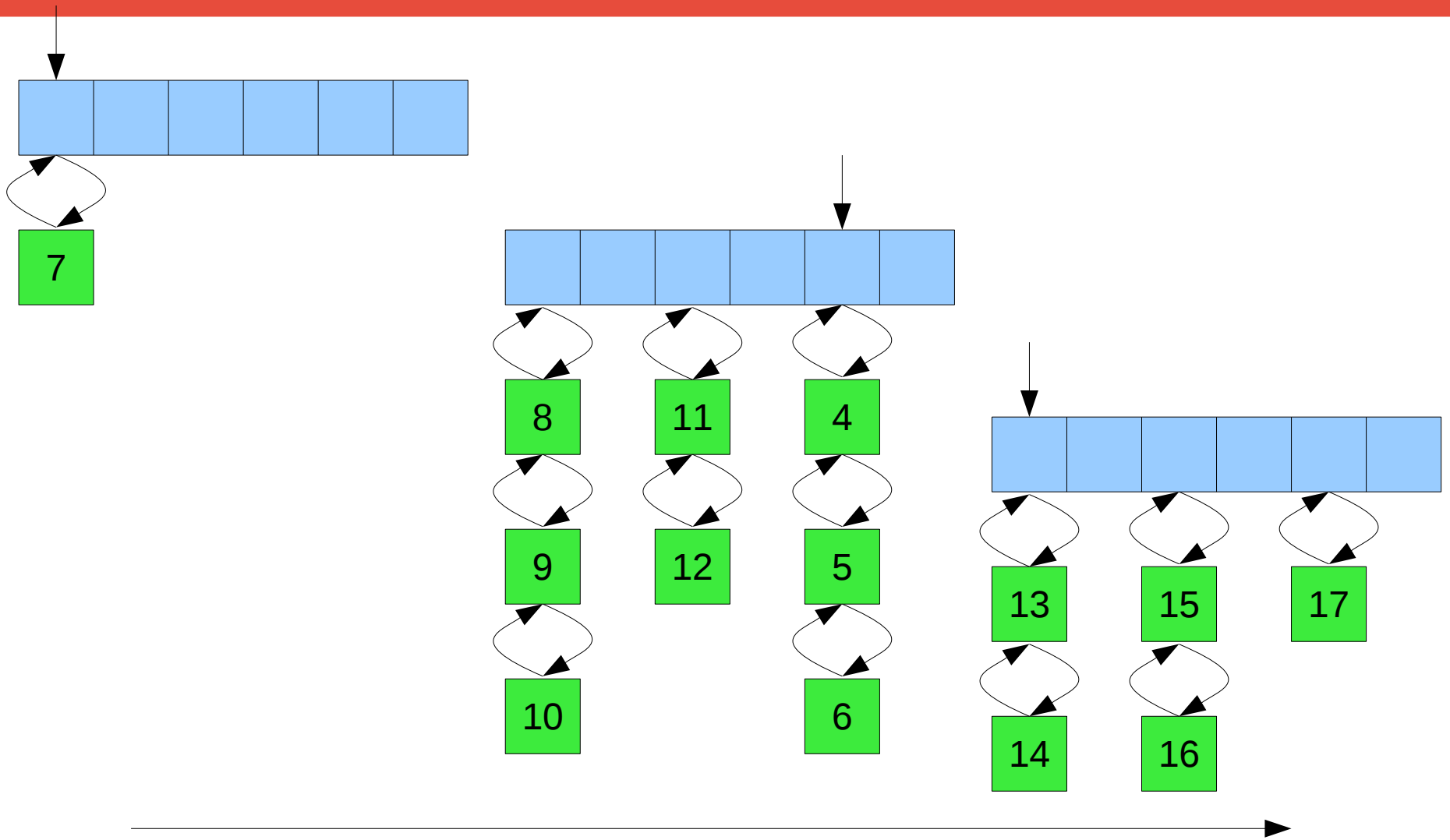

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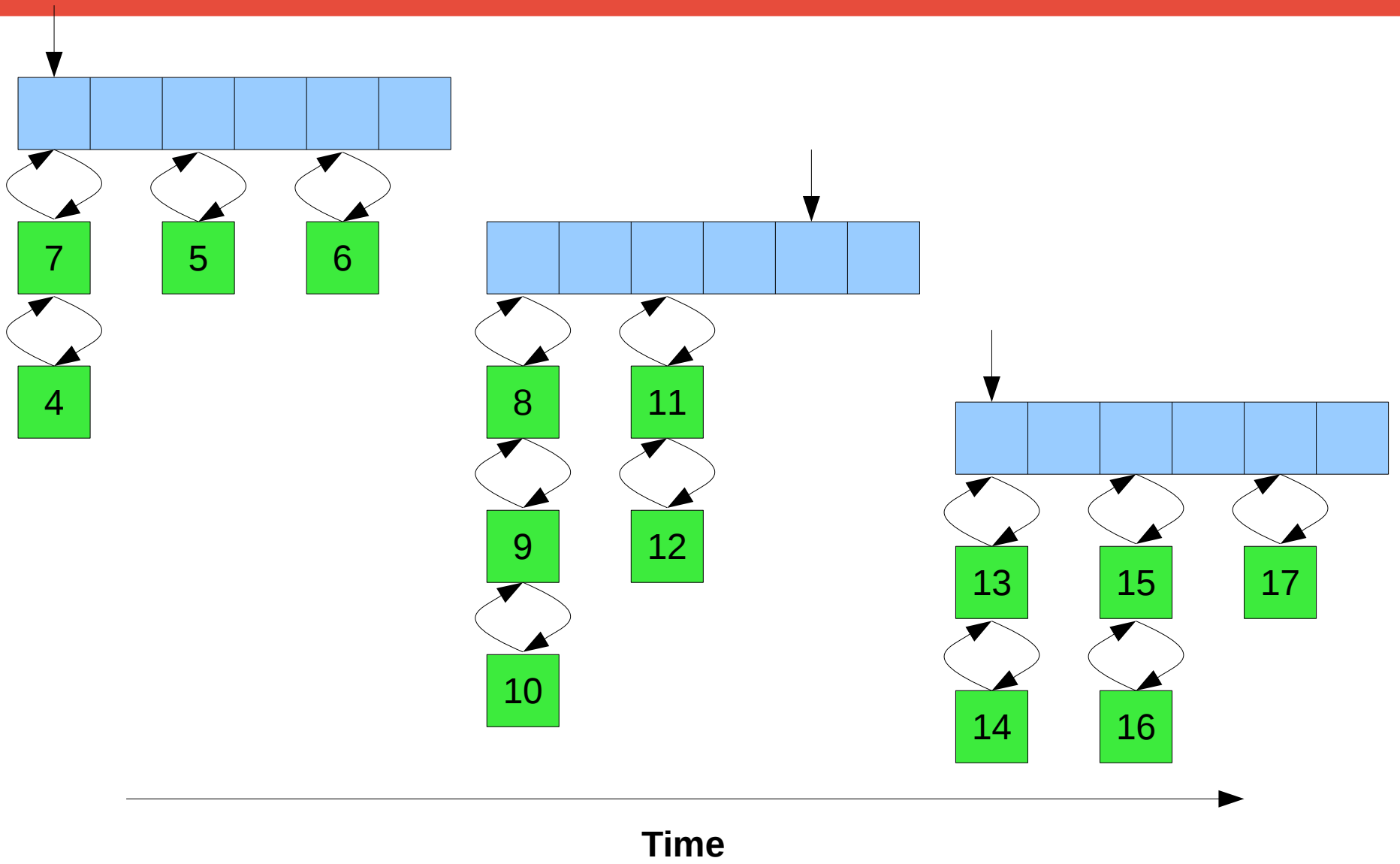

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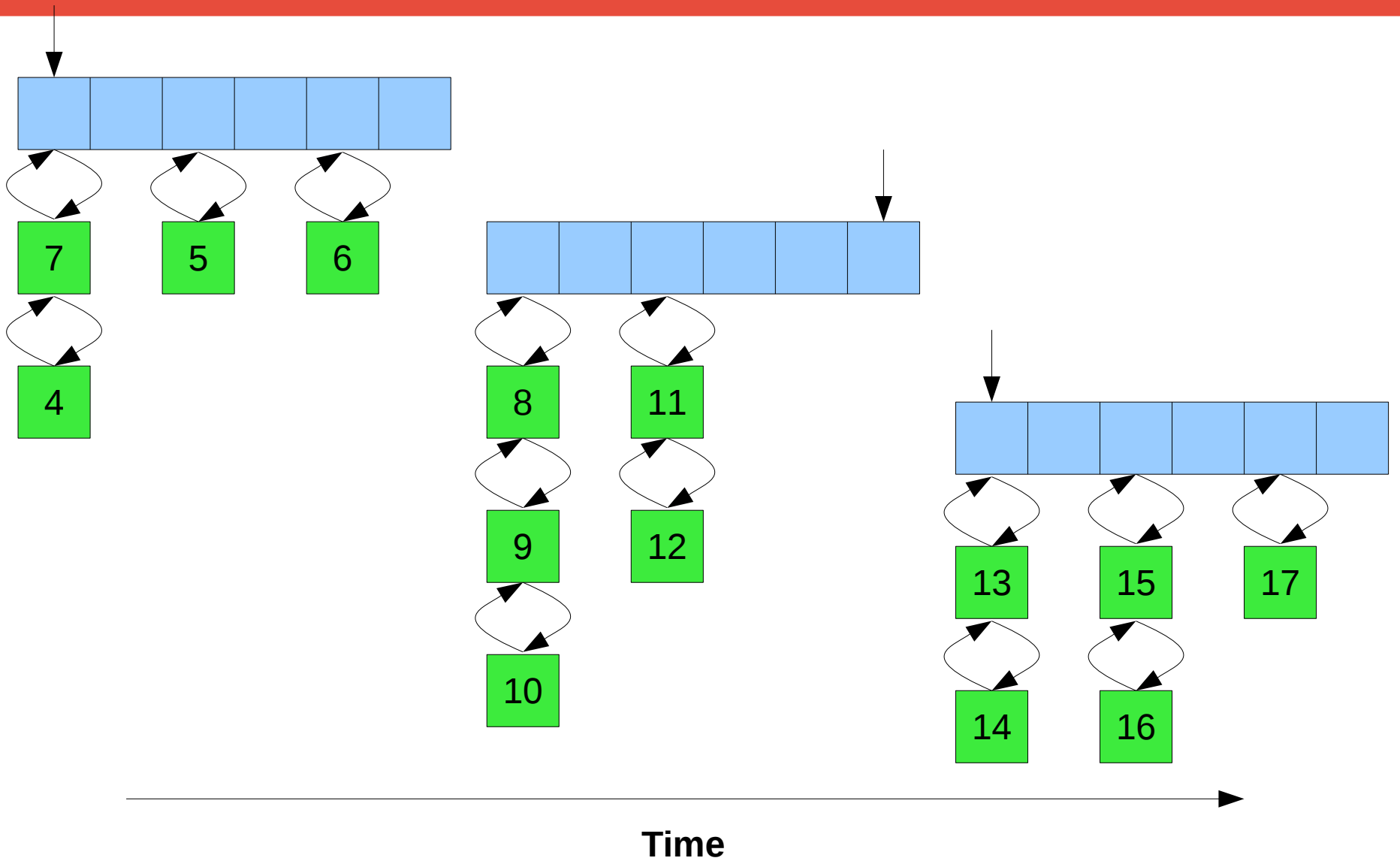

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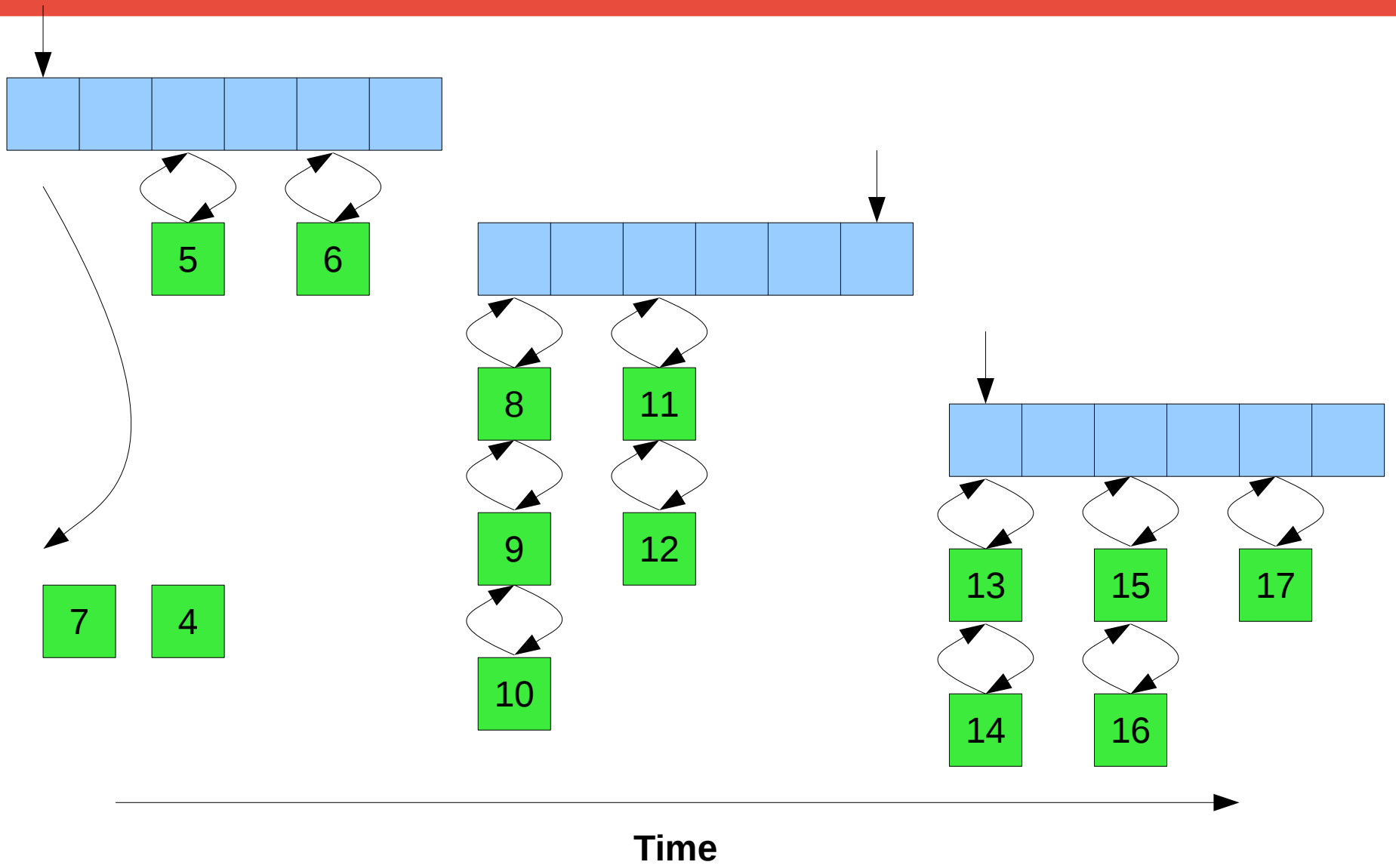

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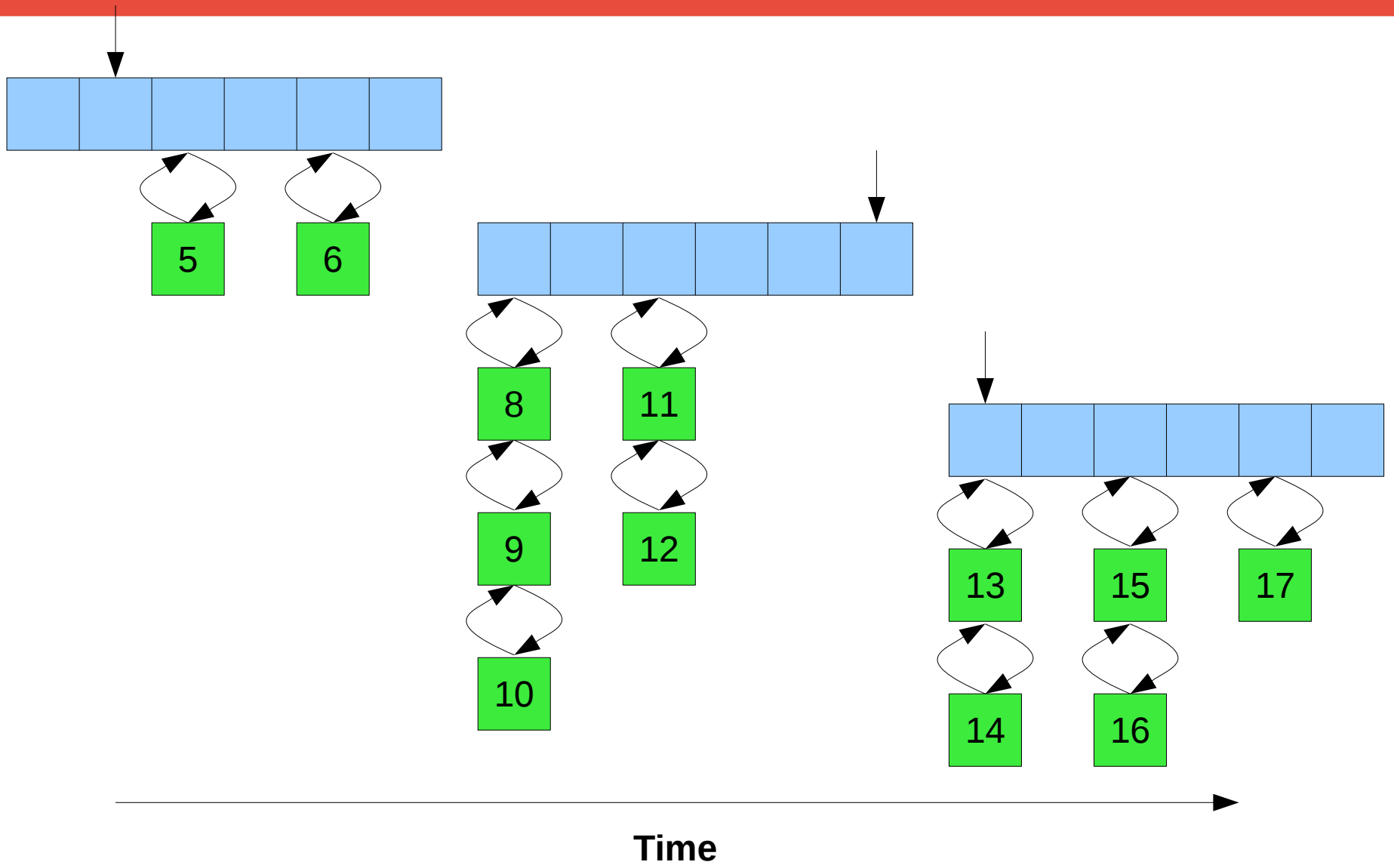

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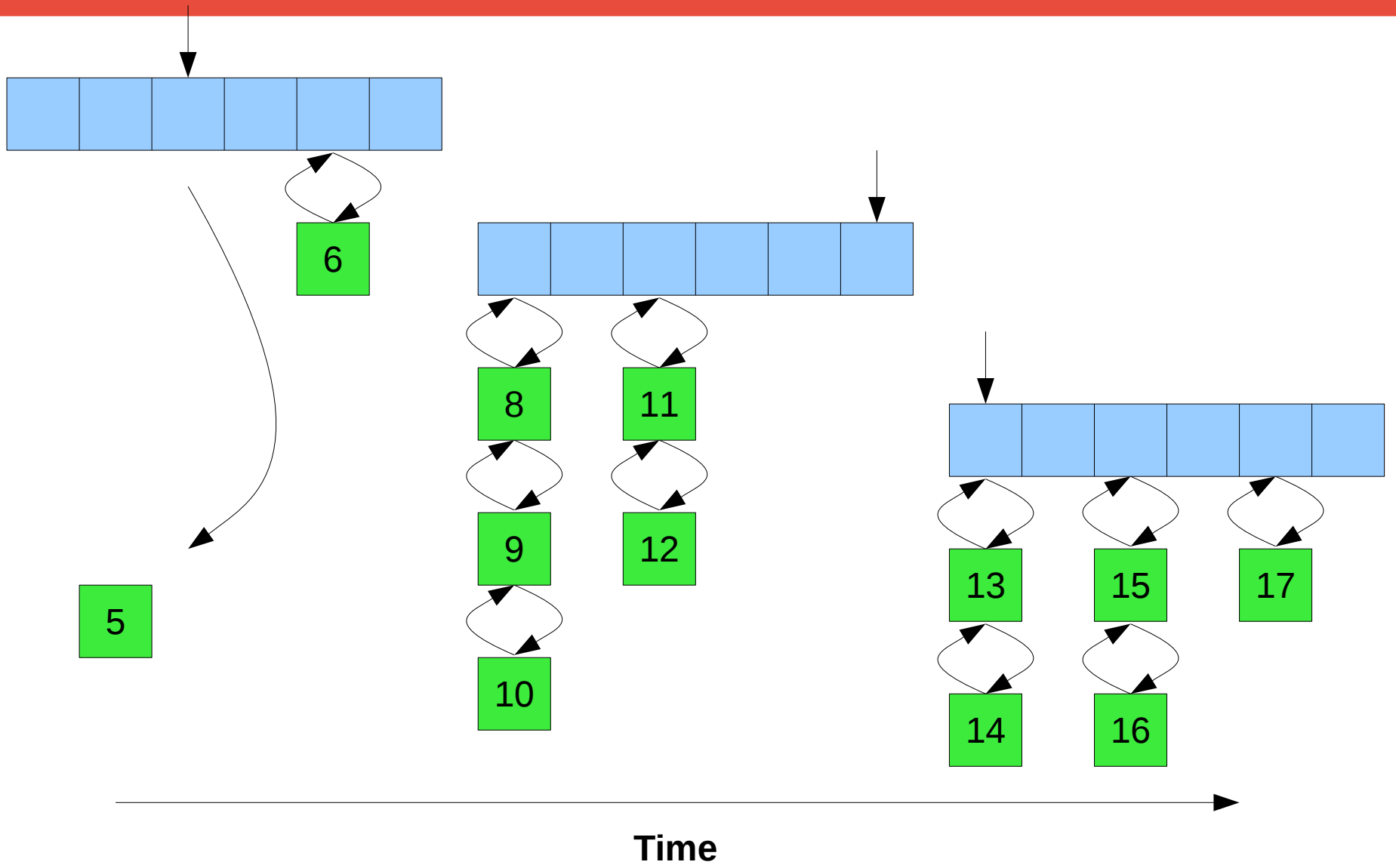

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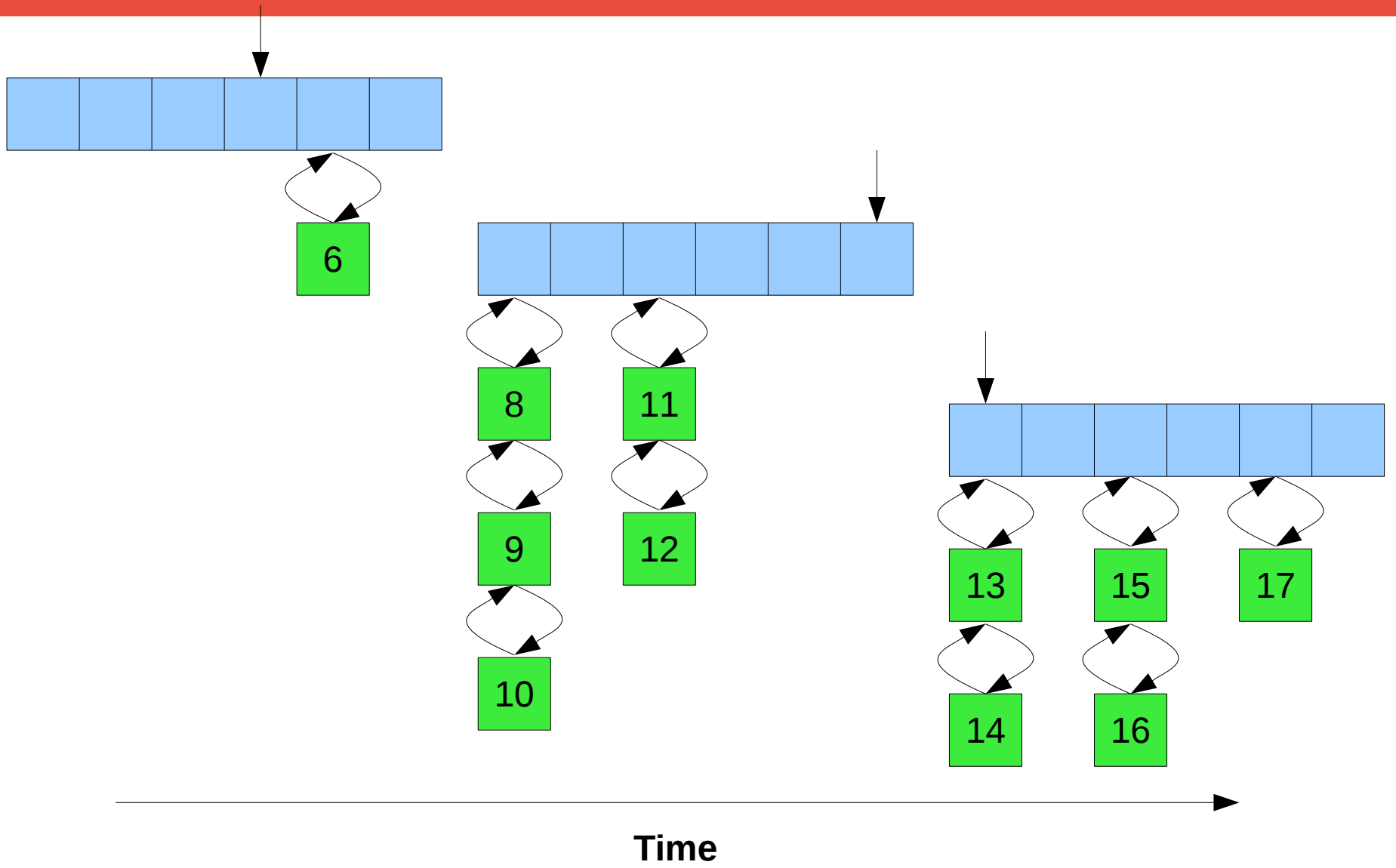

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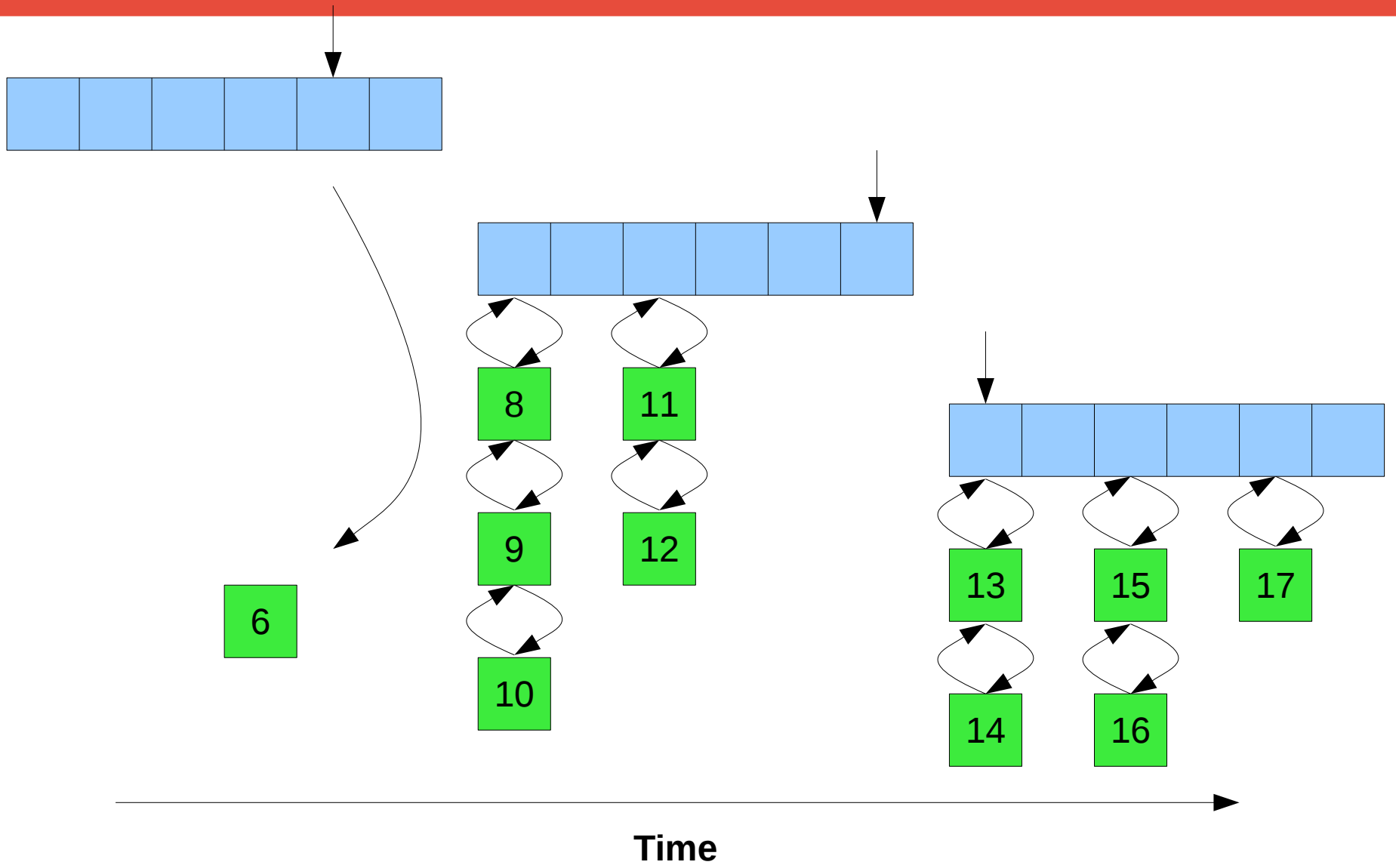

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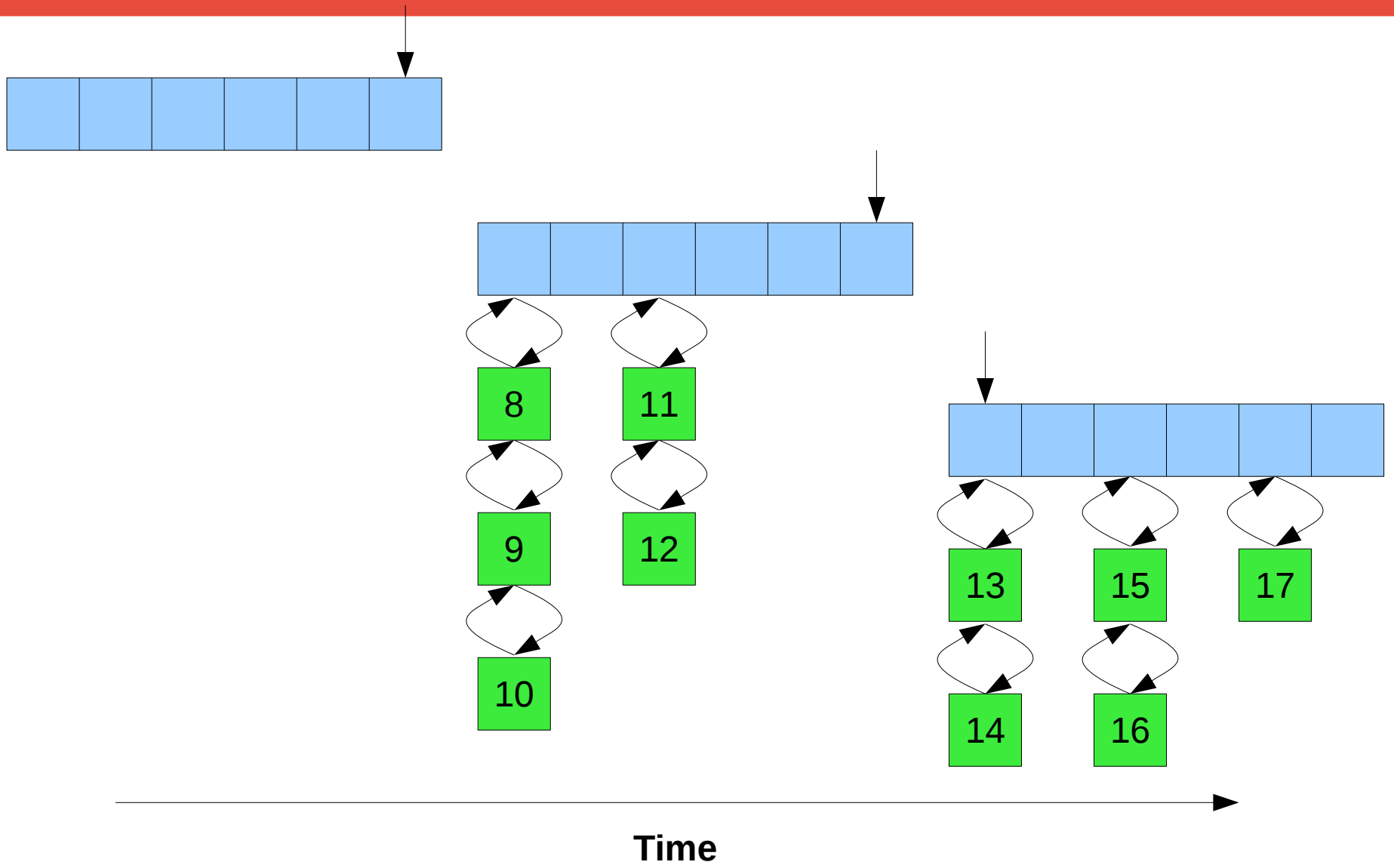

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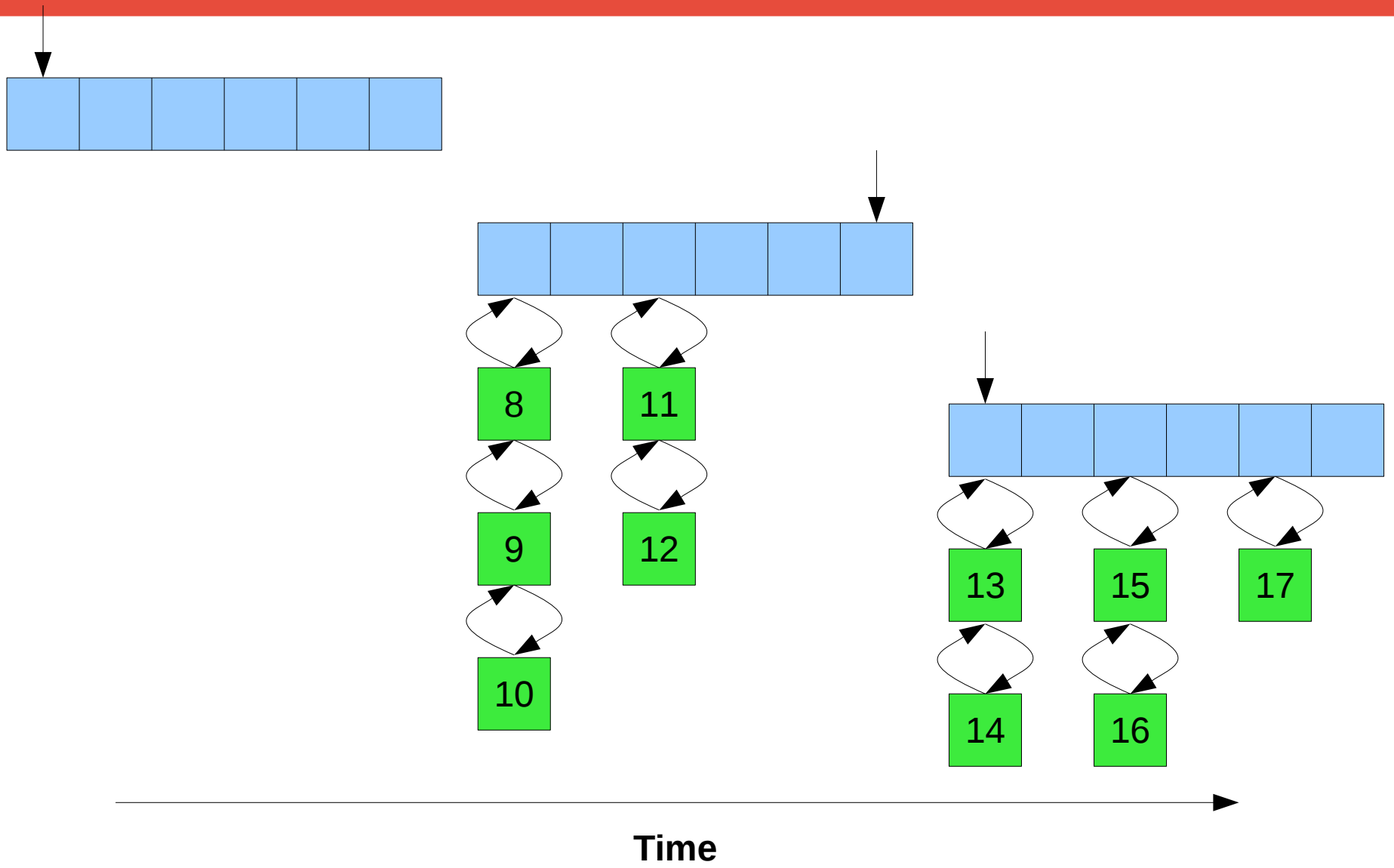

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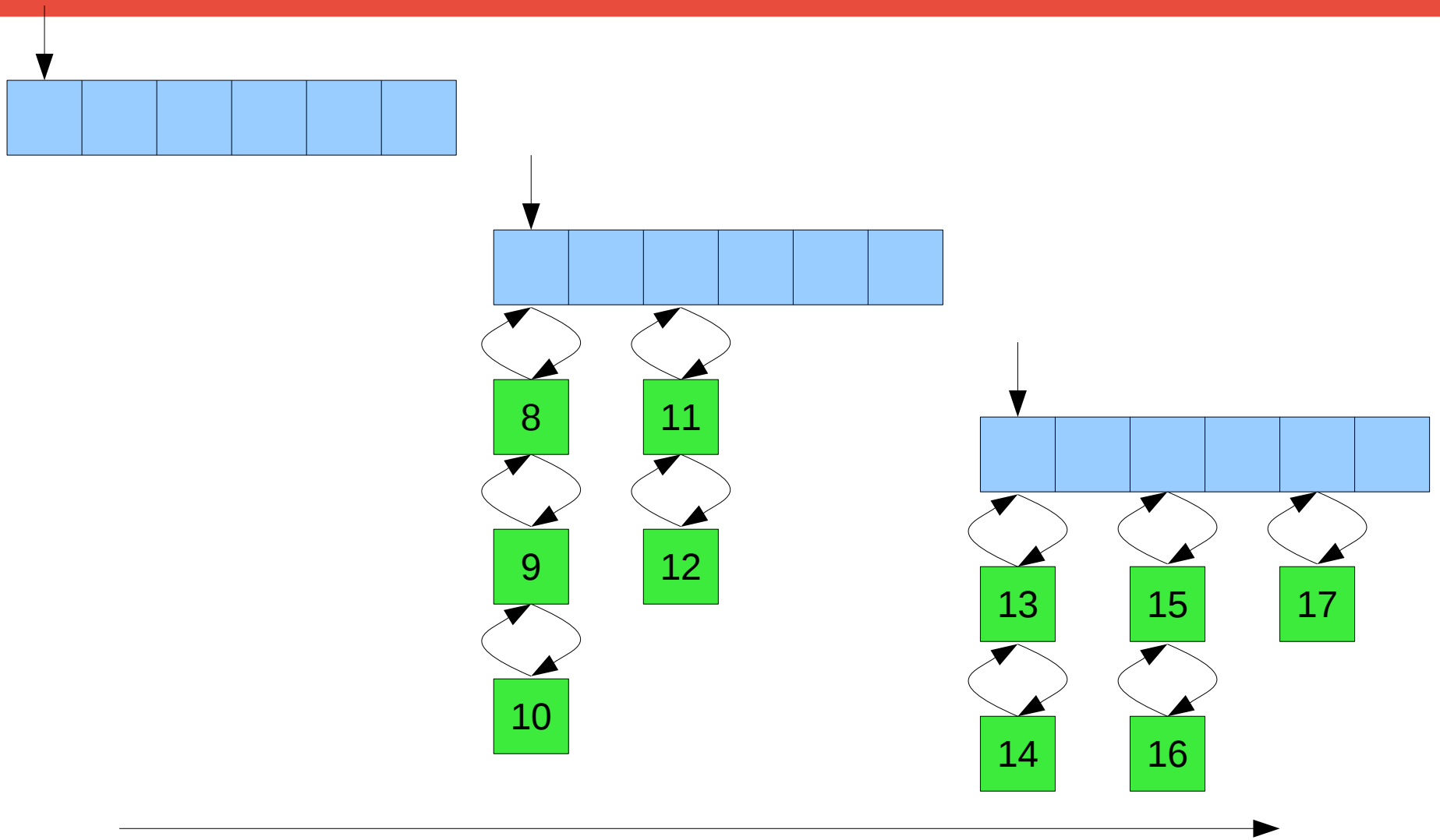

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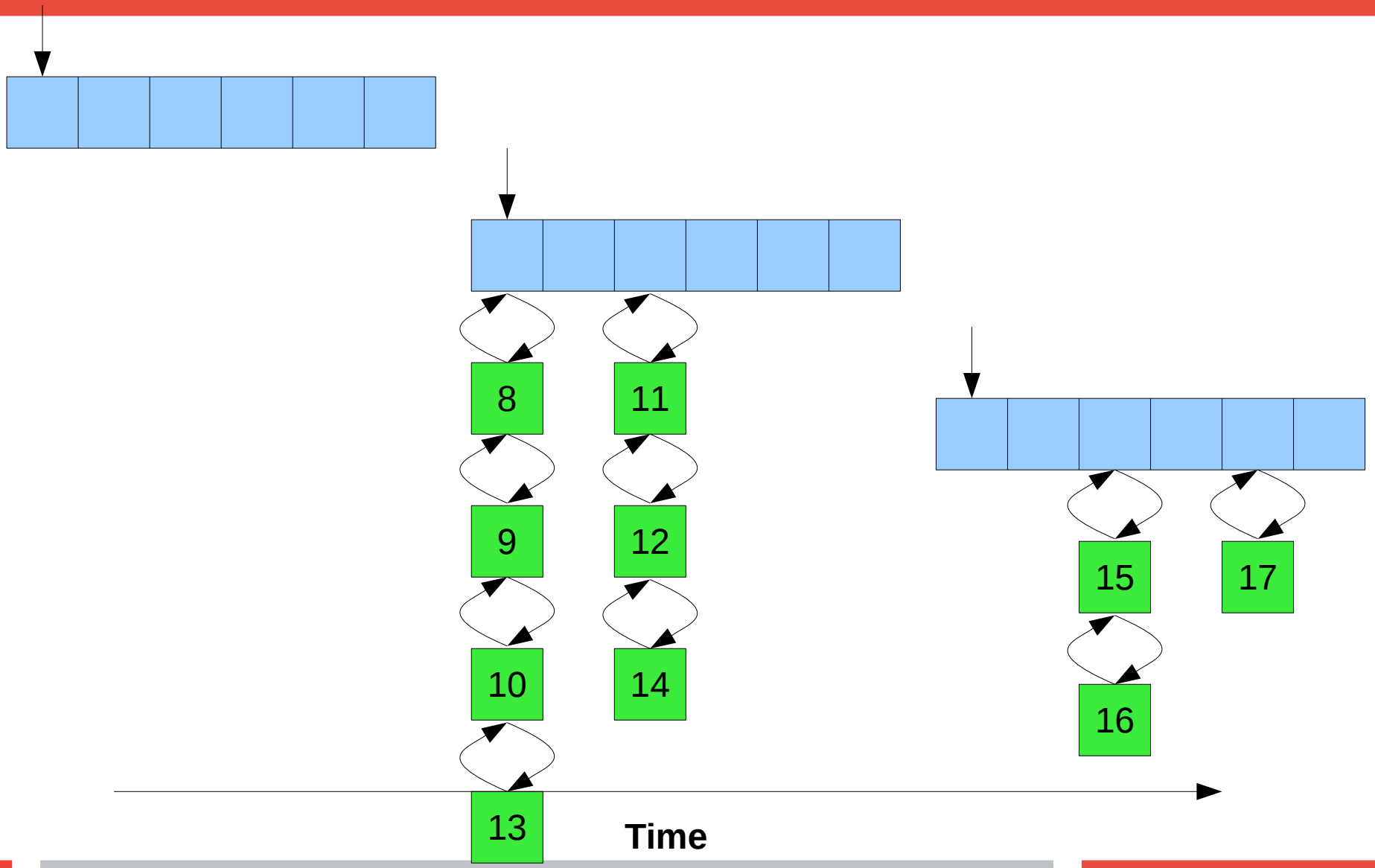

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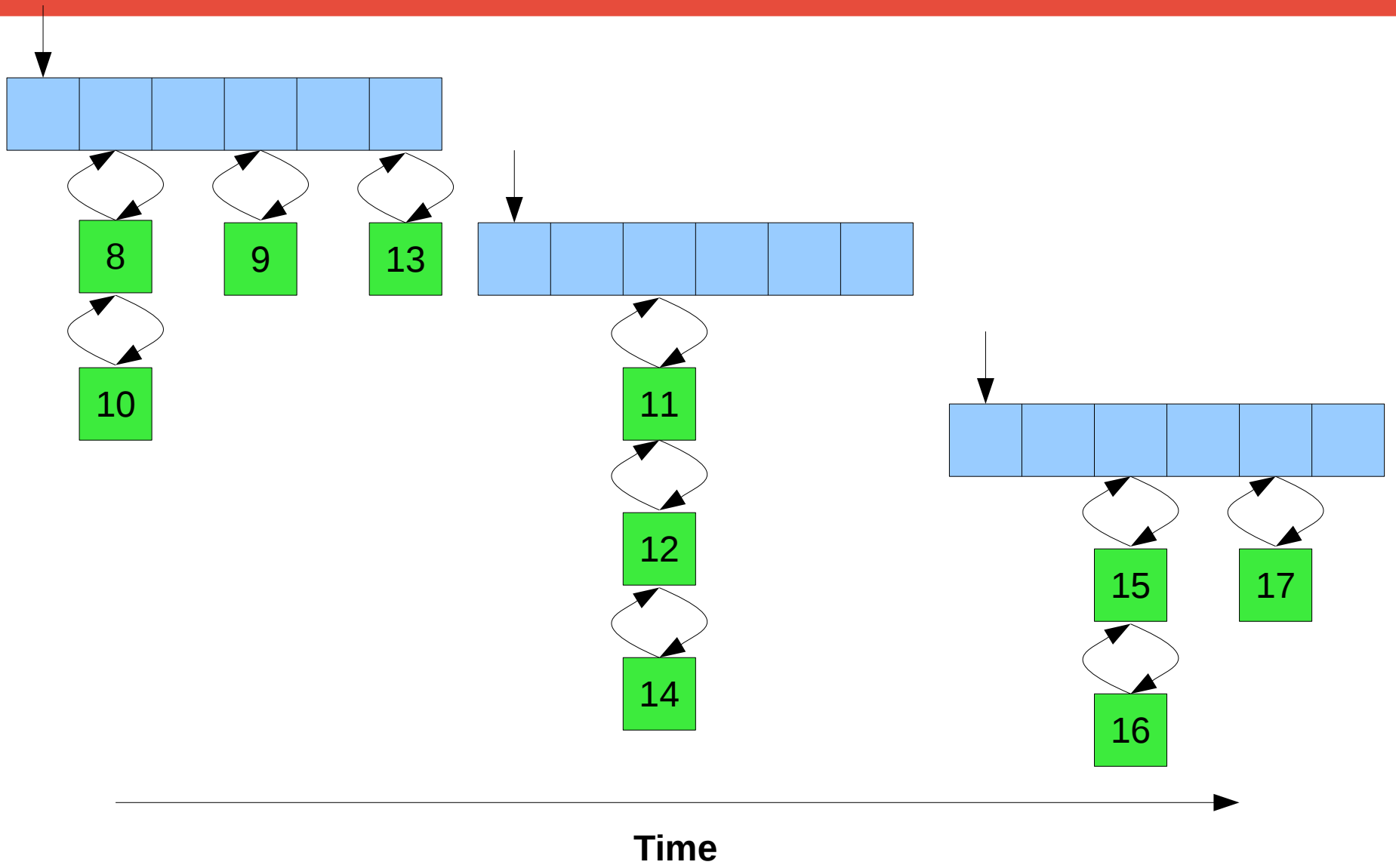


The New Timer Wheel

Remove the cascade effect

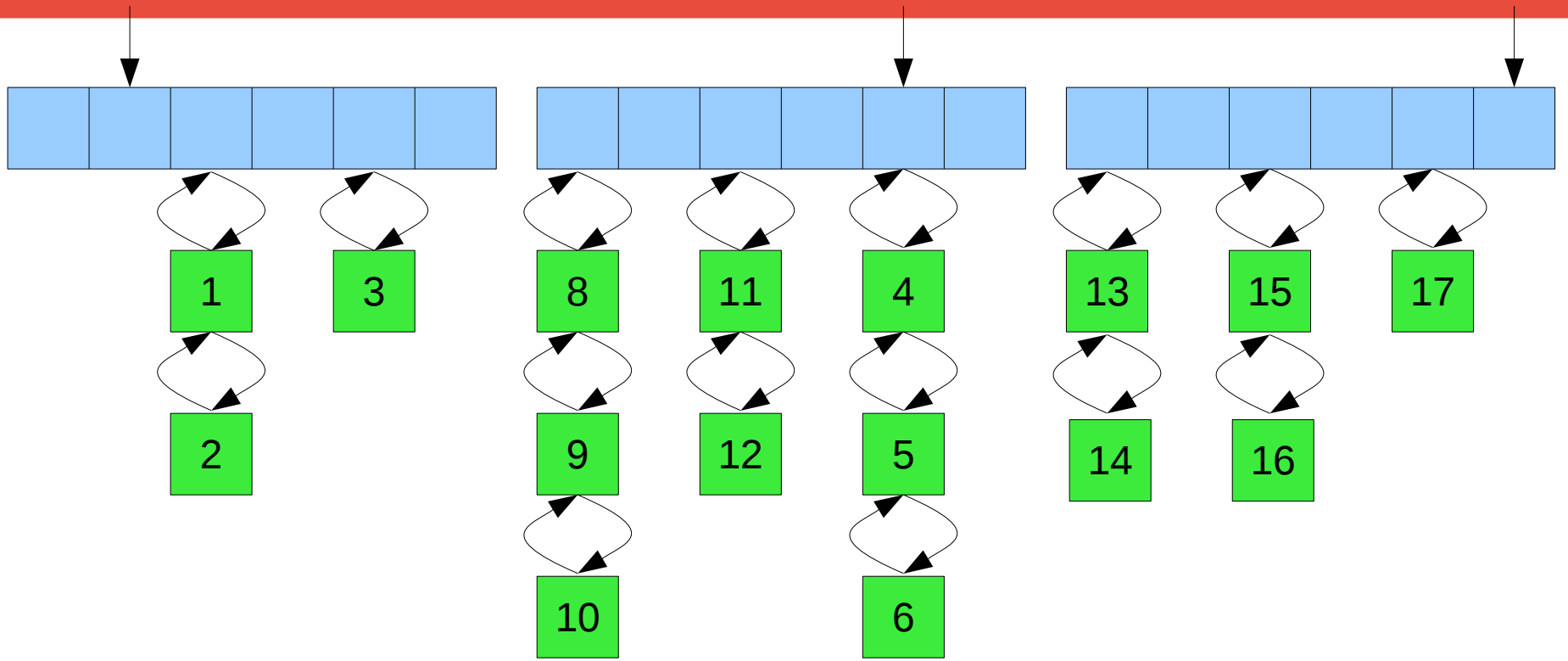
Farther out the timer, the less granularity

More levels (8 instead of 5)

Each level contains 32 entries

```
HZ 1000
Level Offset  Granularity              Range
 0     0            1 ms                0 ms -         31 ms
 1    32            8 ms               32 ms -        255 ms
 2    64           64 ms              256 ms -       2047 ms (256ms - ~2s)
 3    96          512 ms             2048 ms -      16383 ms (~2s - ~16s)
 4   128         4096 ms (~4s)      16384 ms -     131071 ms (~16s - ~2m)
 5   160        32768 ms (~32s)    131072 ms -    1048575 ms (~2m - ~17m
 6   192       262144 ms (~4m)    1048576 ms -    8388607 ms (~17m - ~2h)
 7   224      2097152 ms (~34m)   8388608 ms -   67108863 ms (~2h - ~18h)
```

The New Timer Wheel



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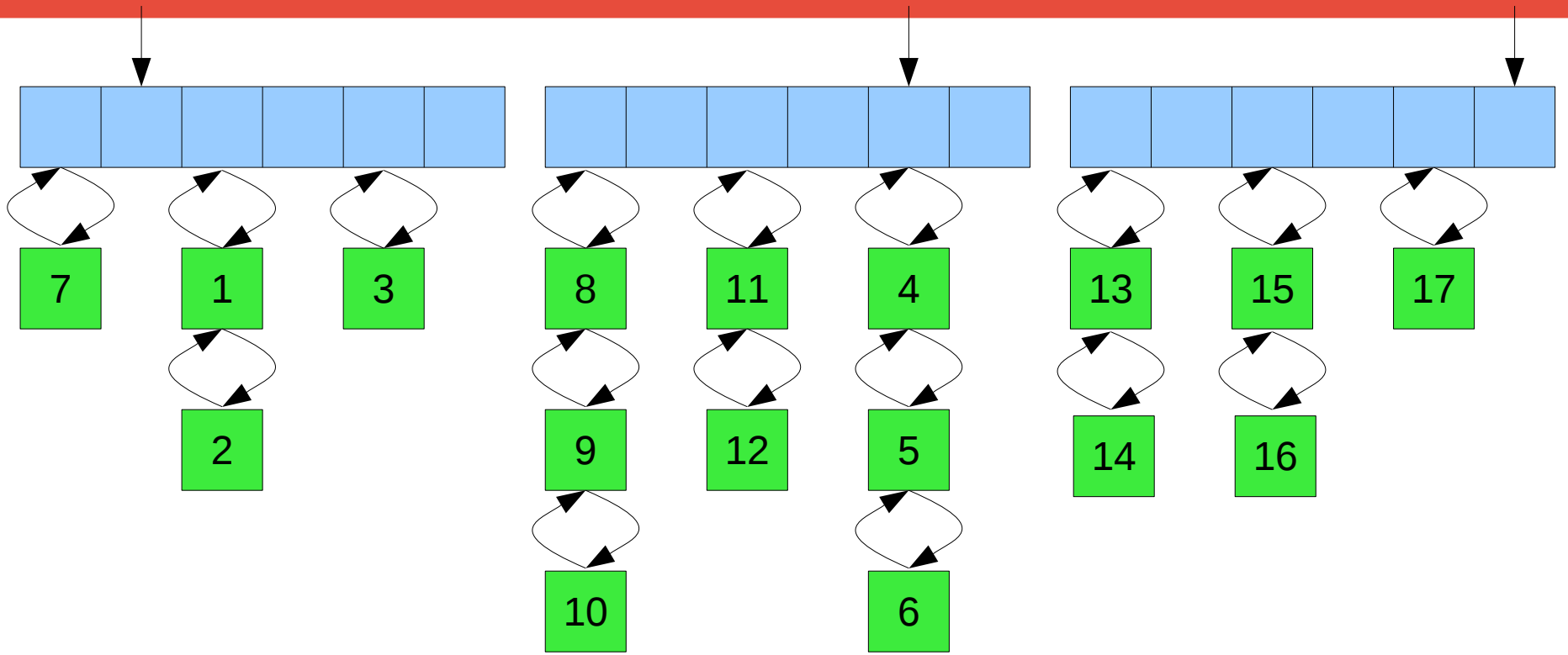

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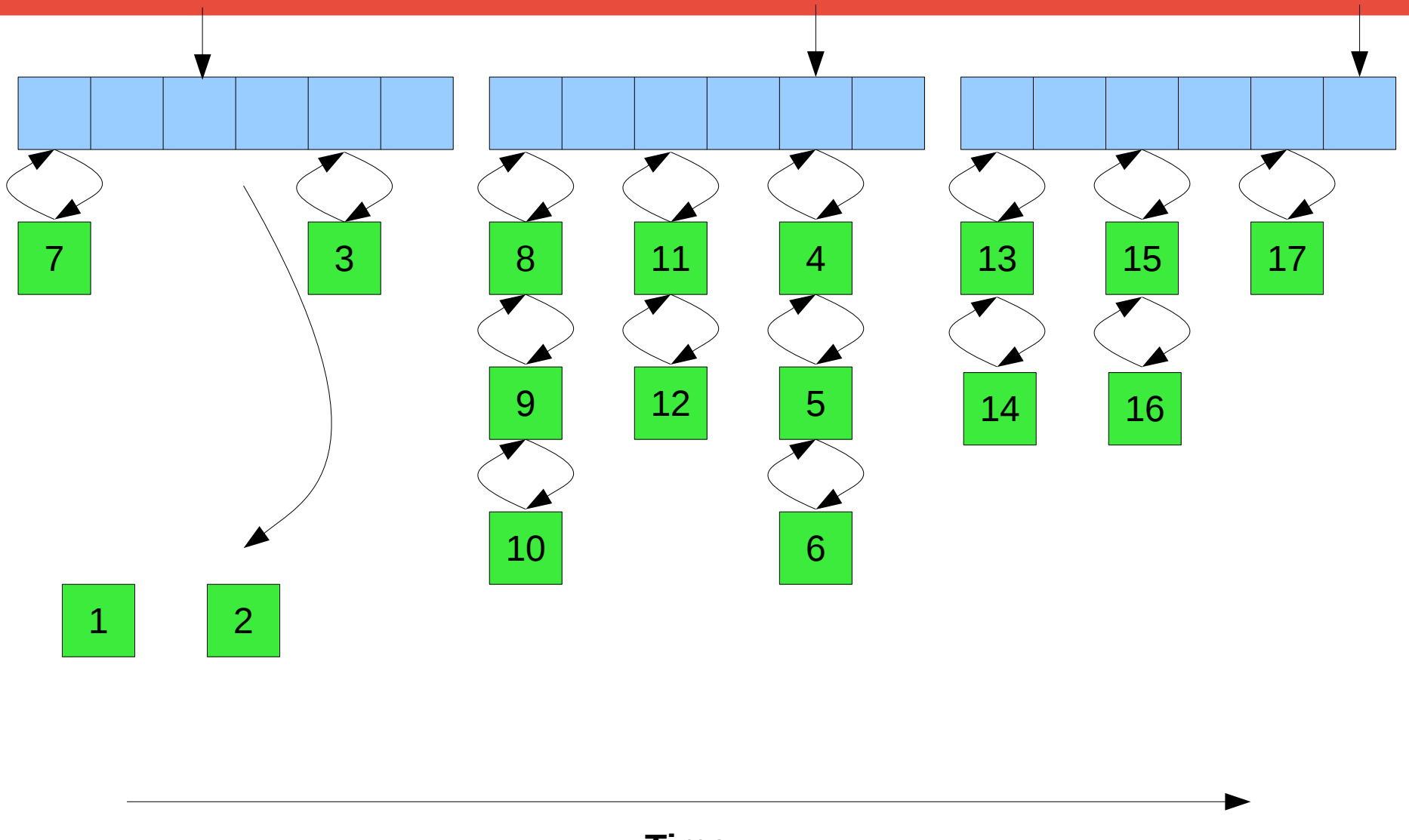

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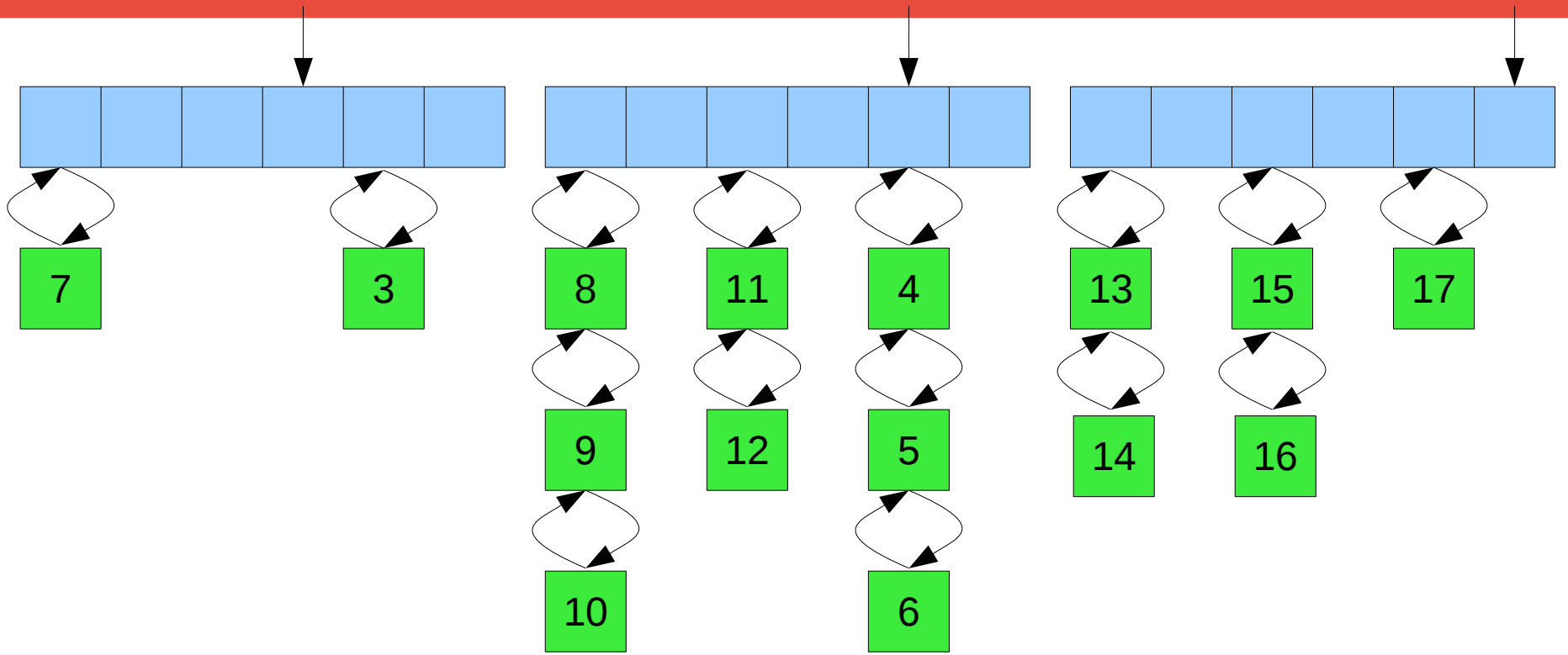

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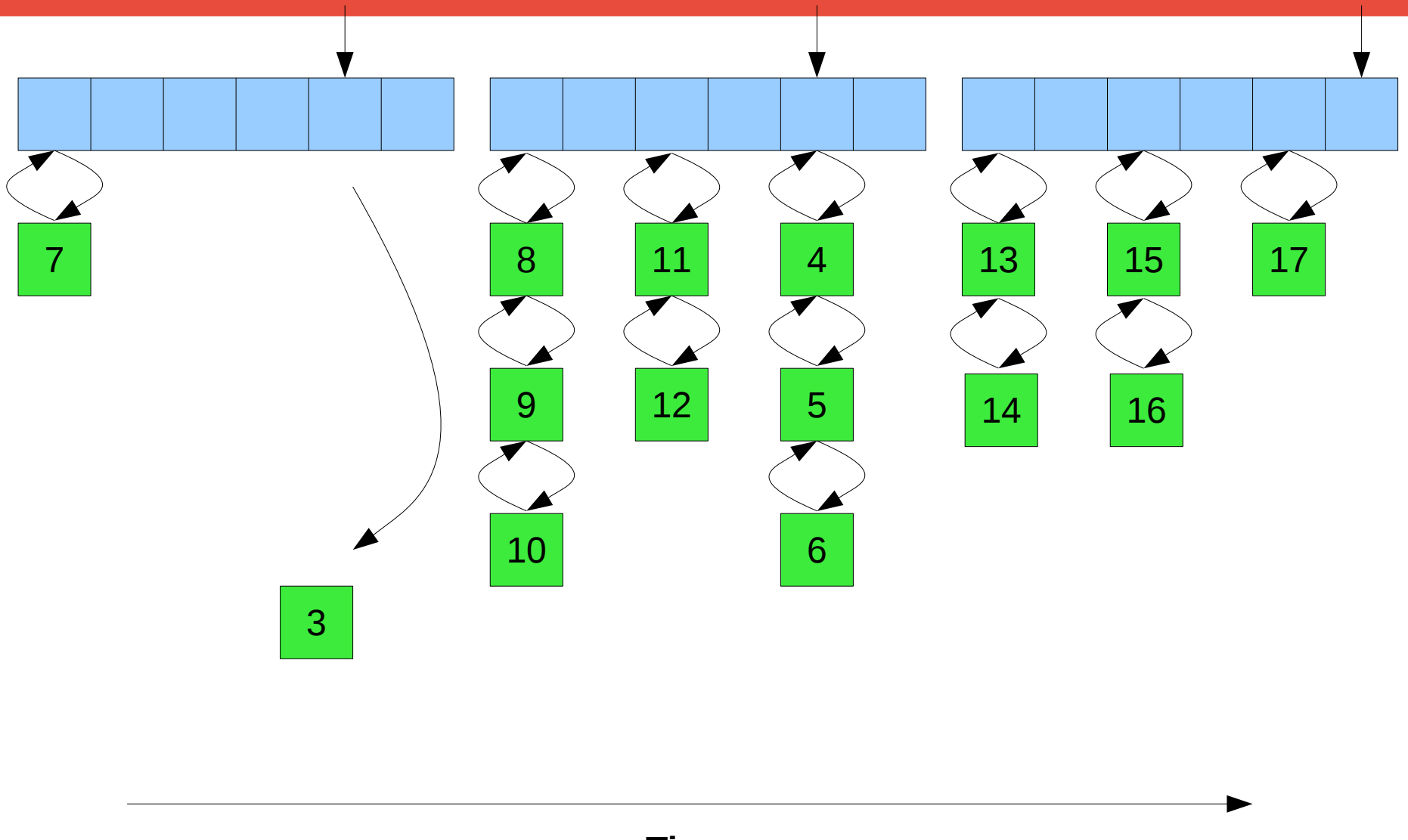

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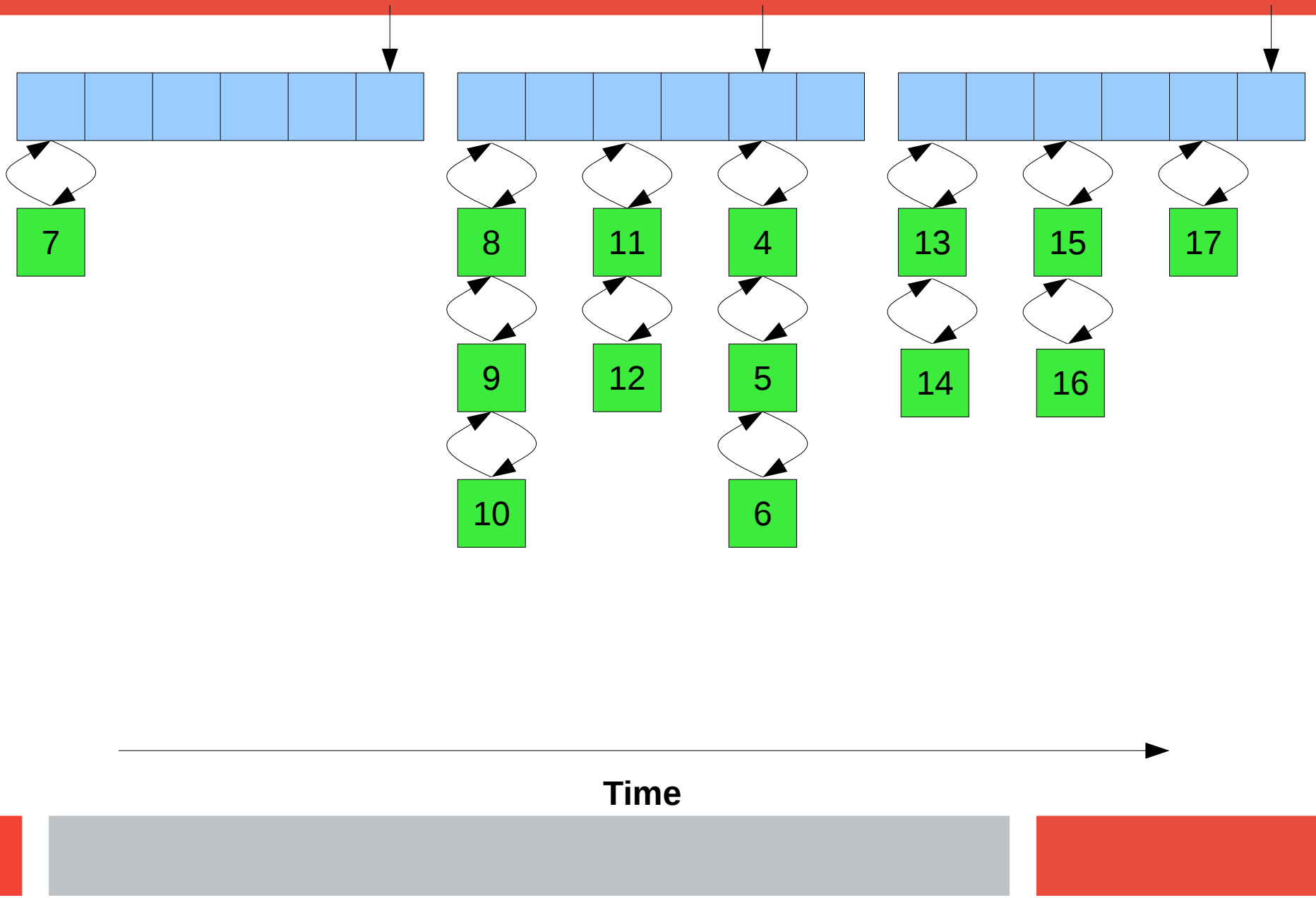

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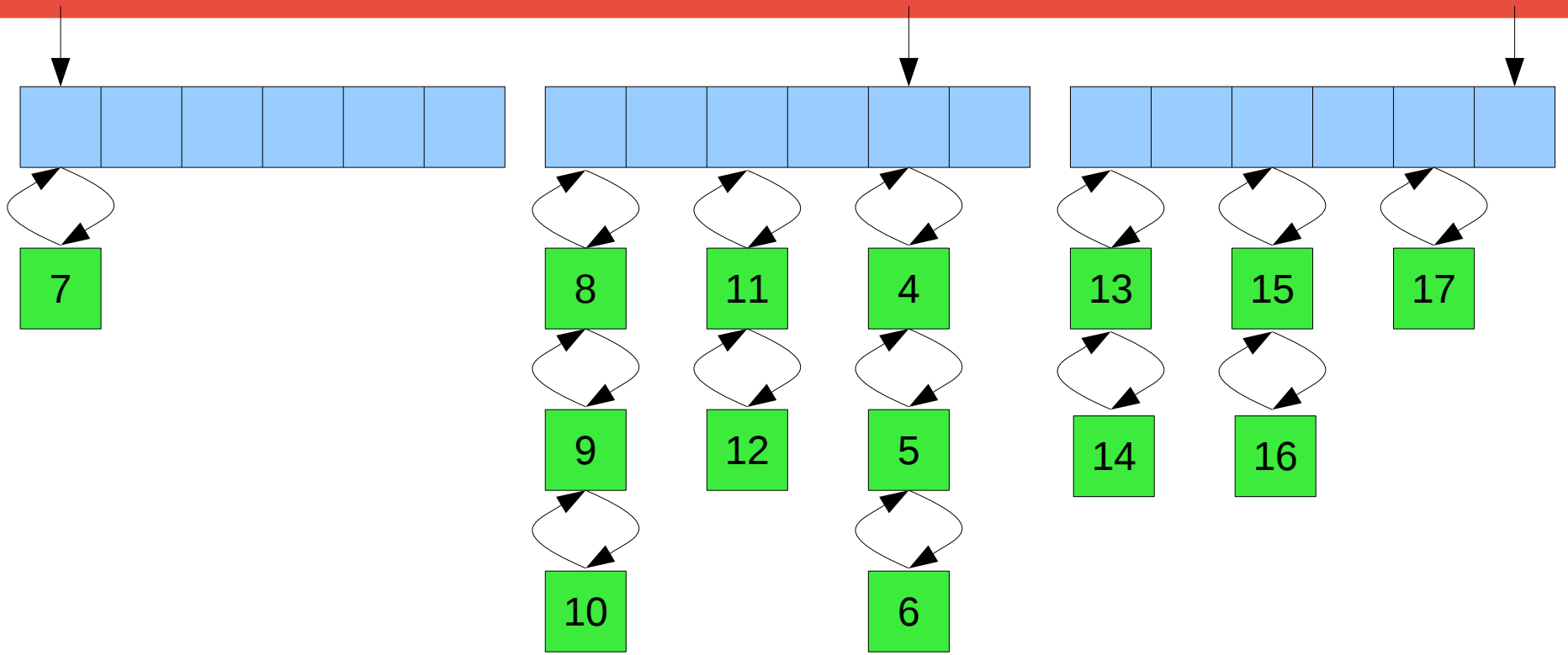

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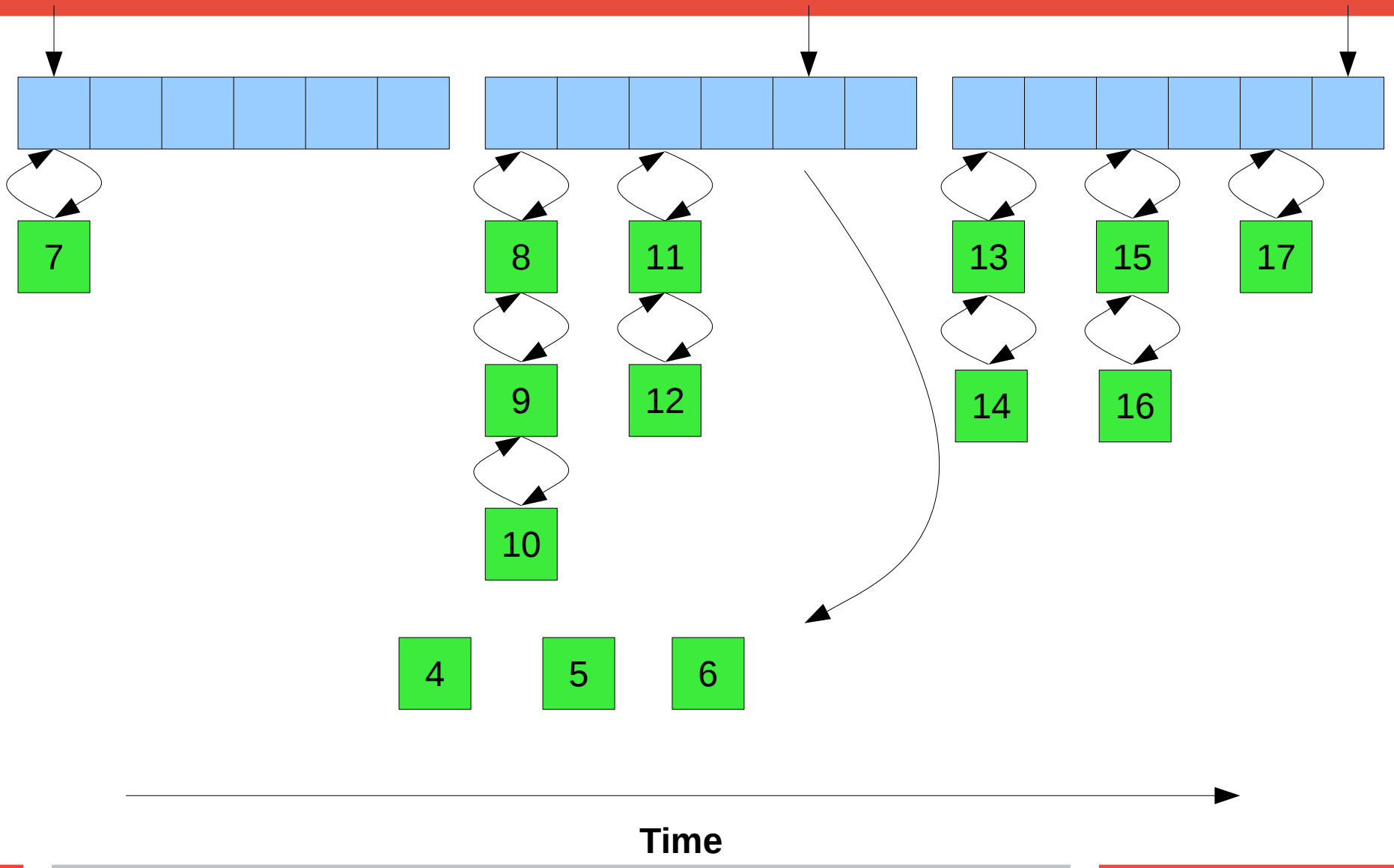

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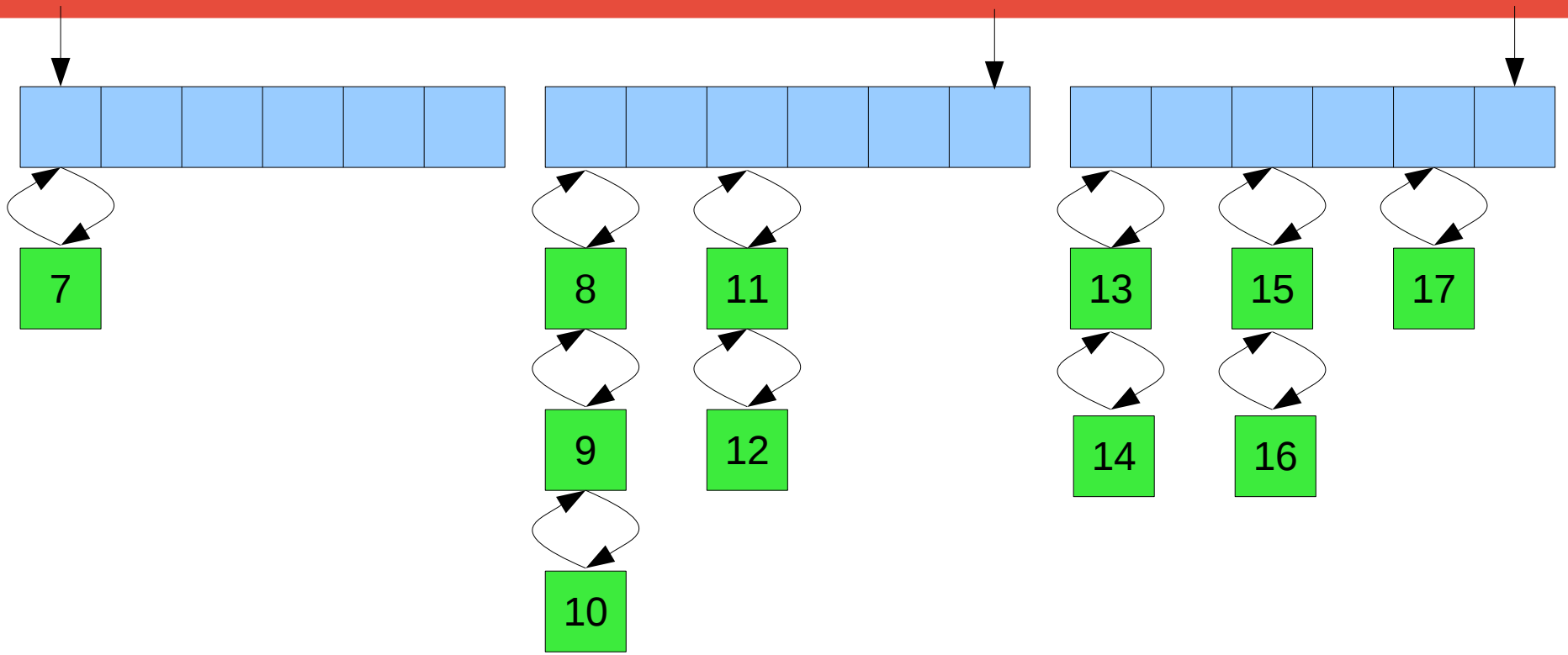

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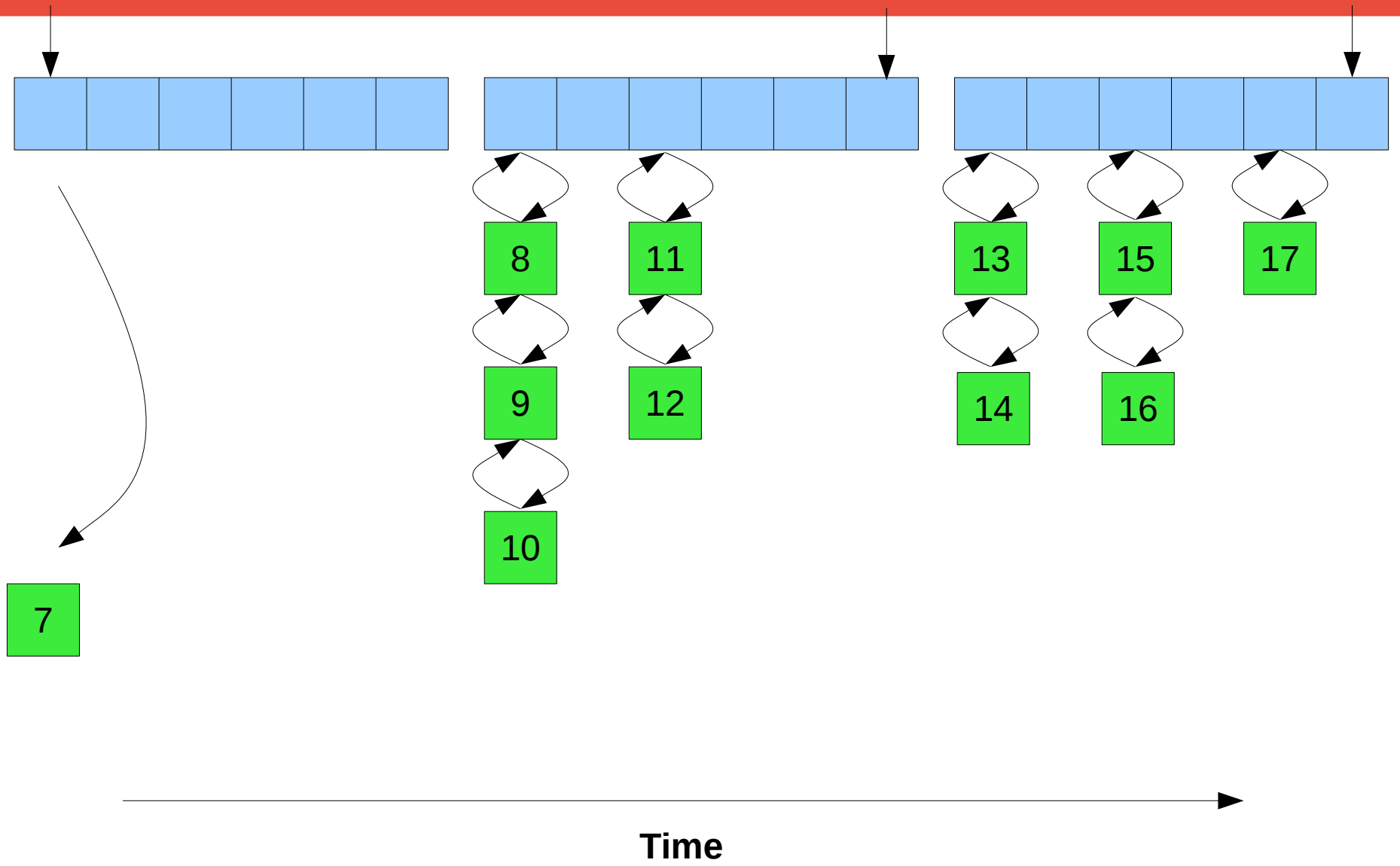

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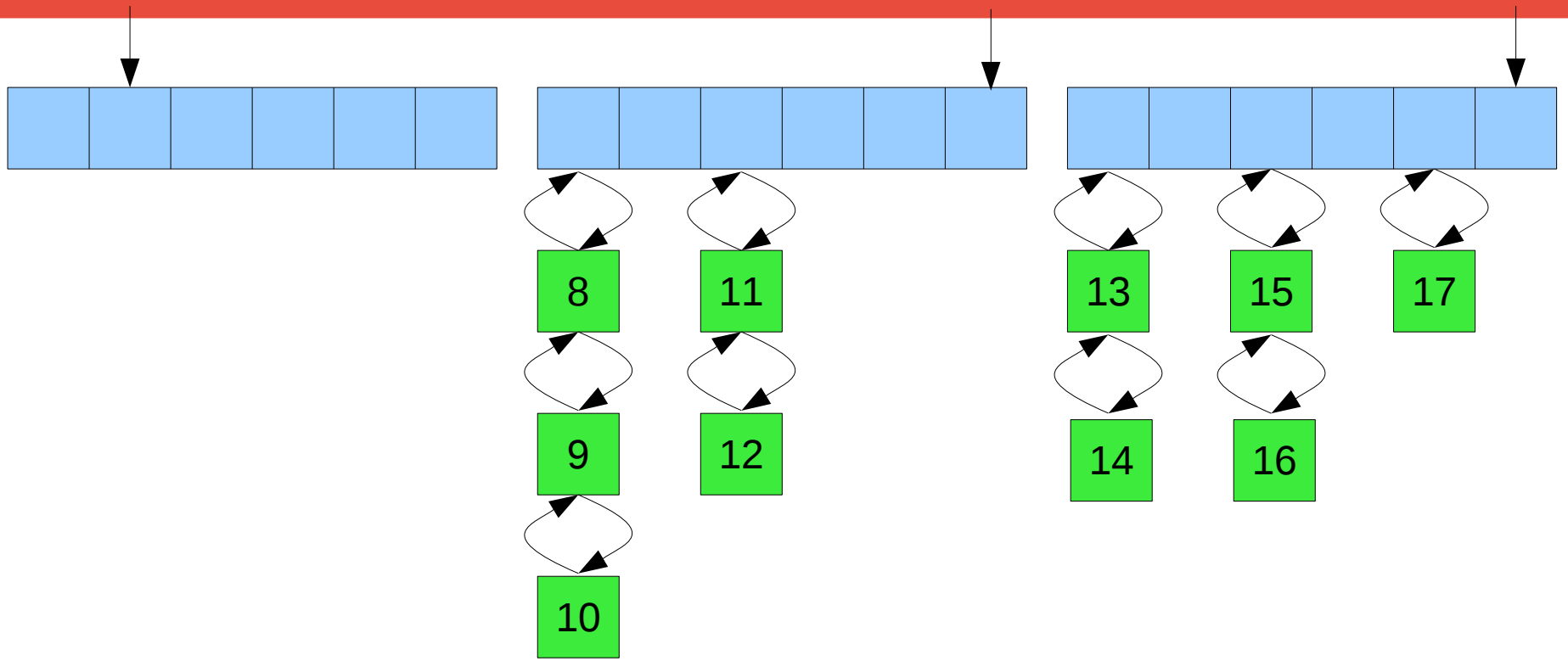

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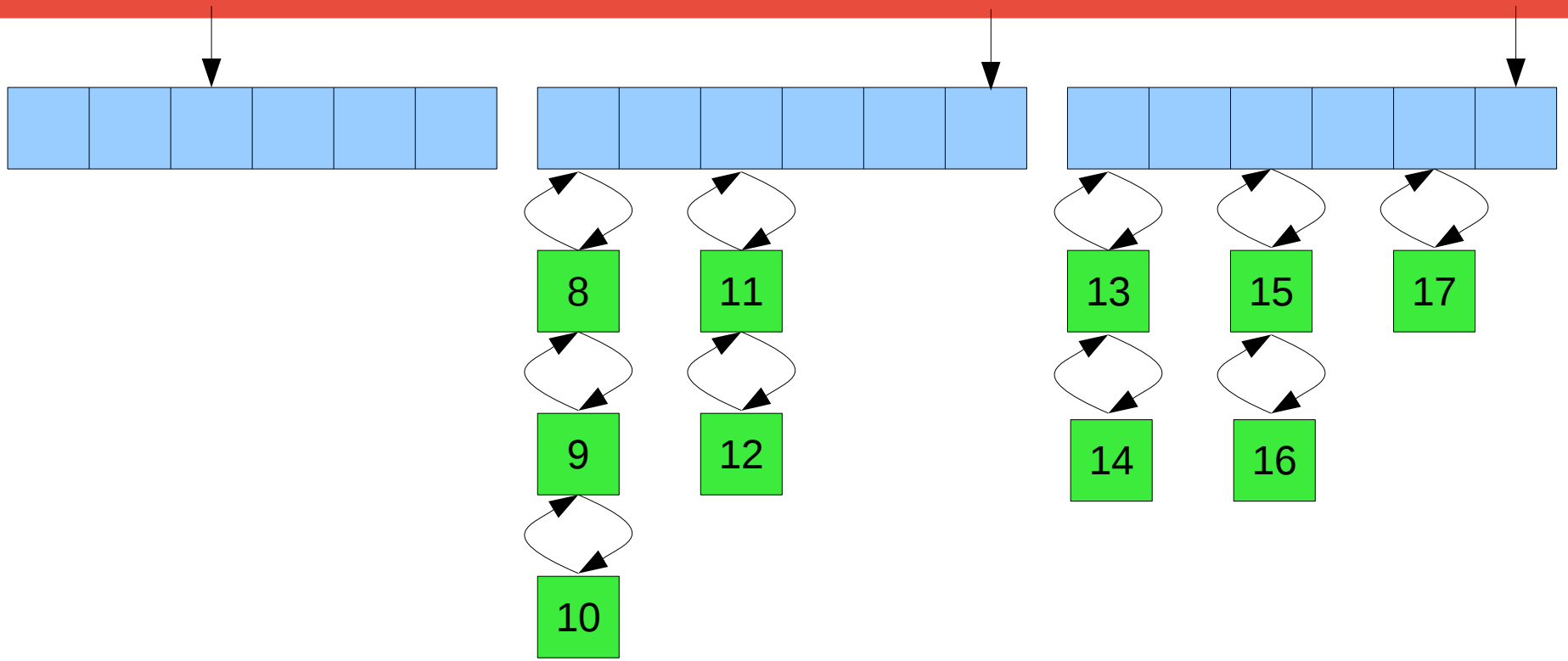

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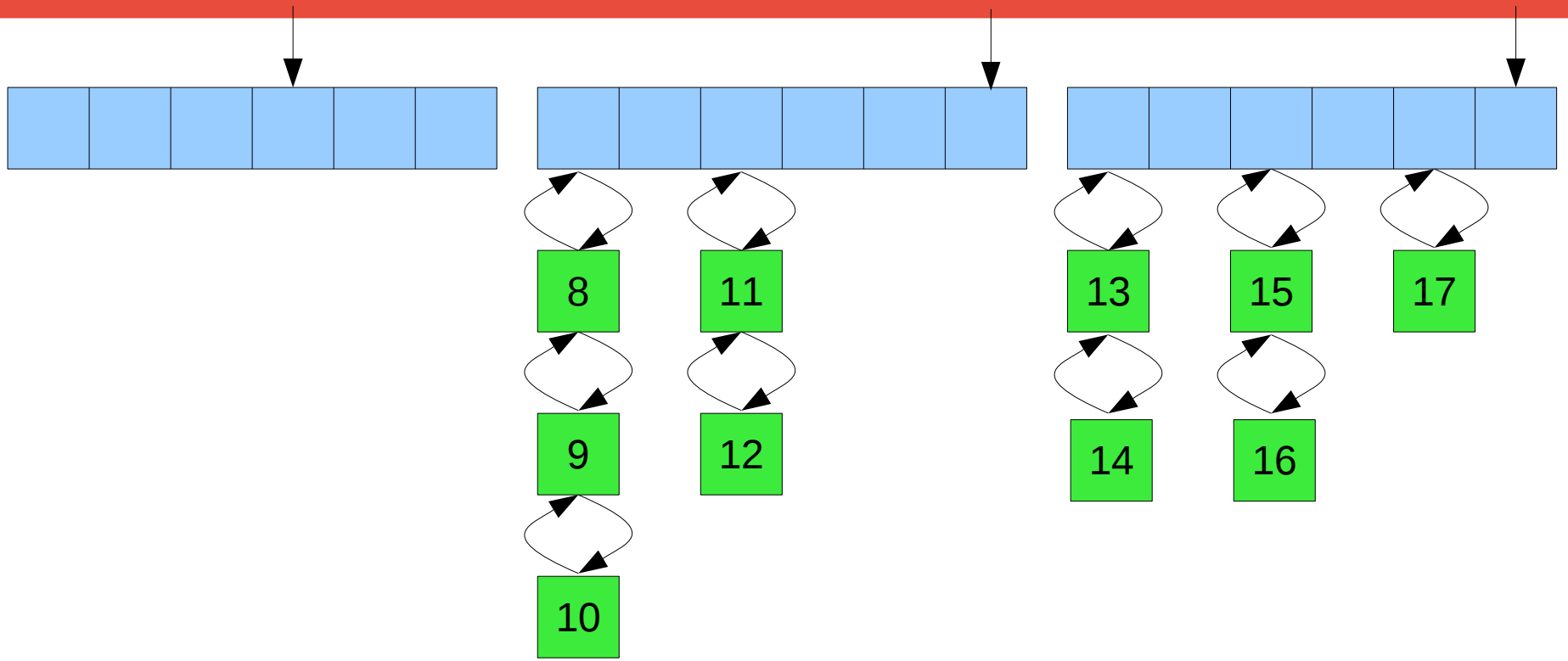

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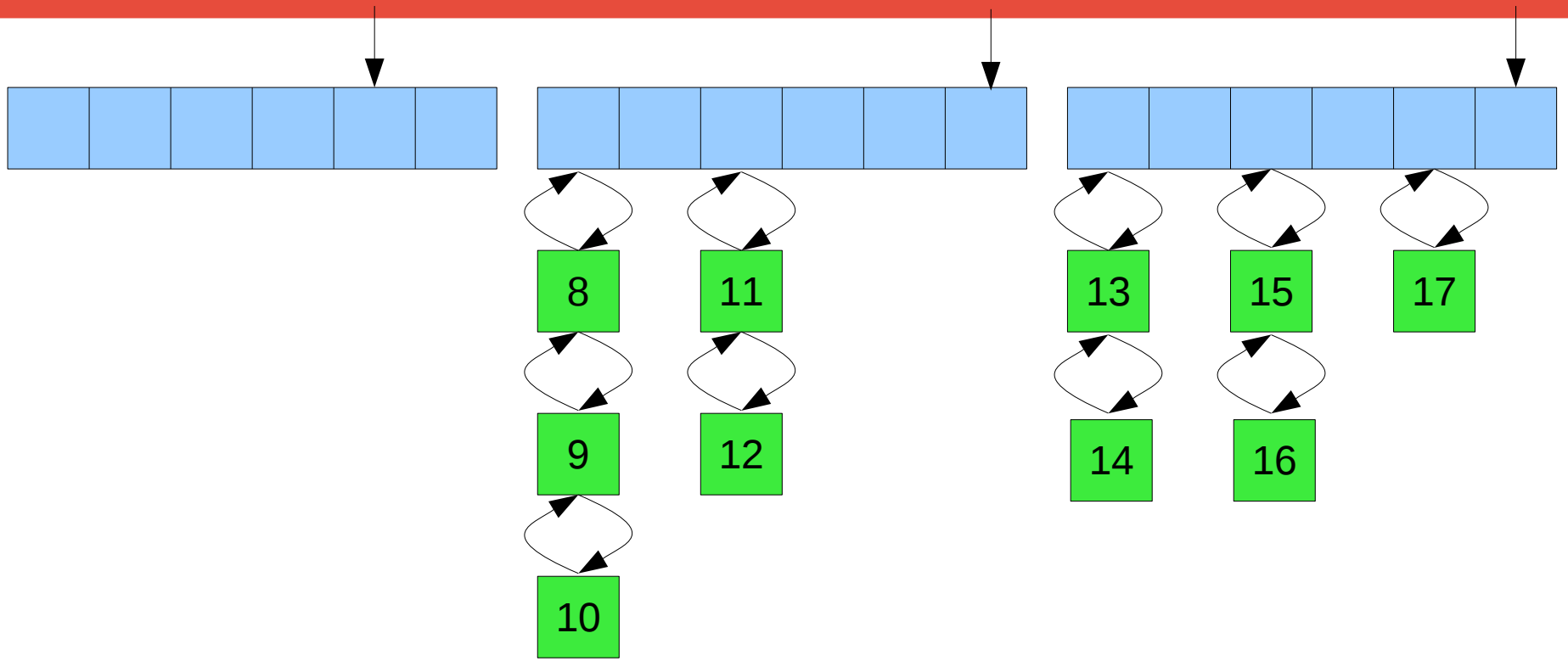

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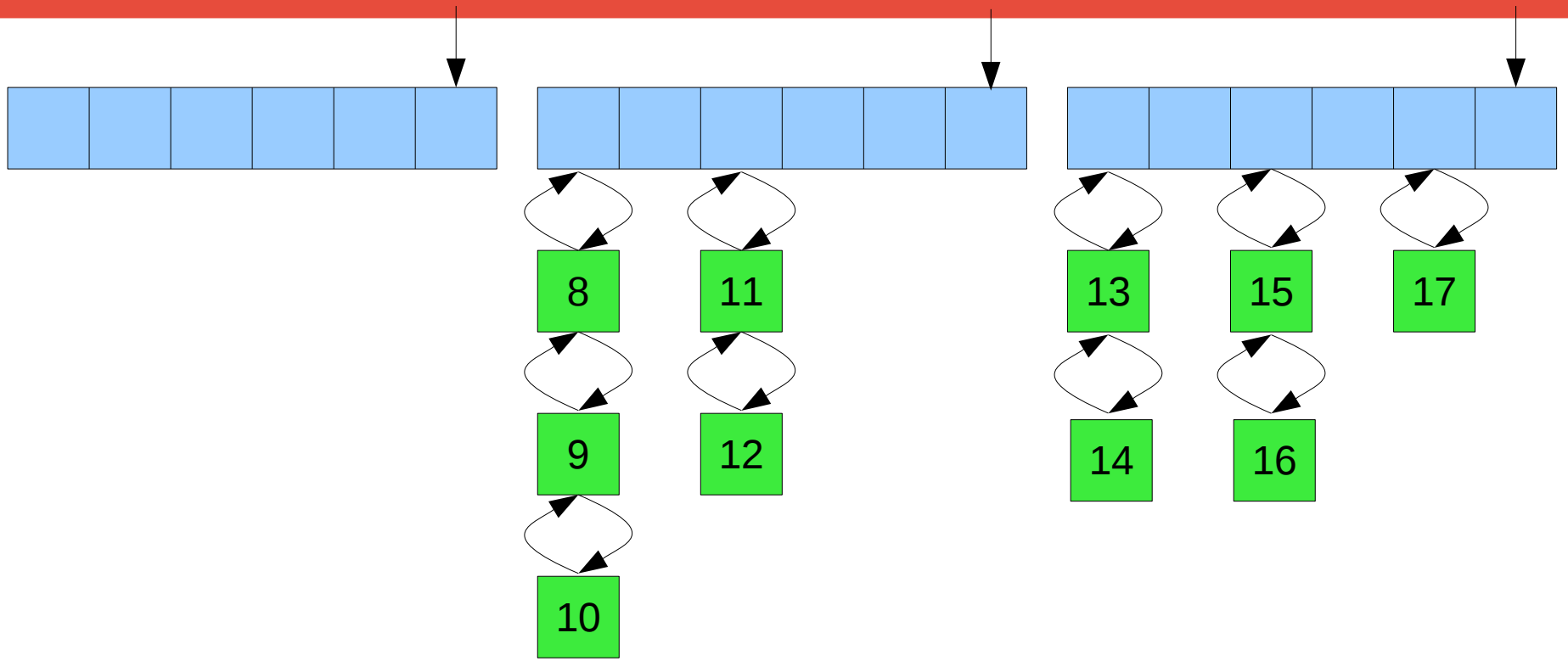

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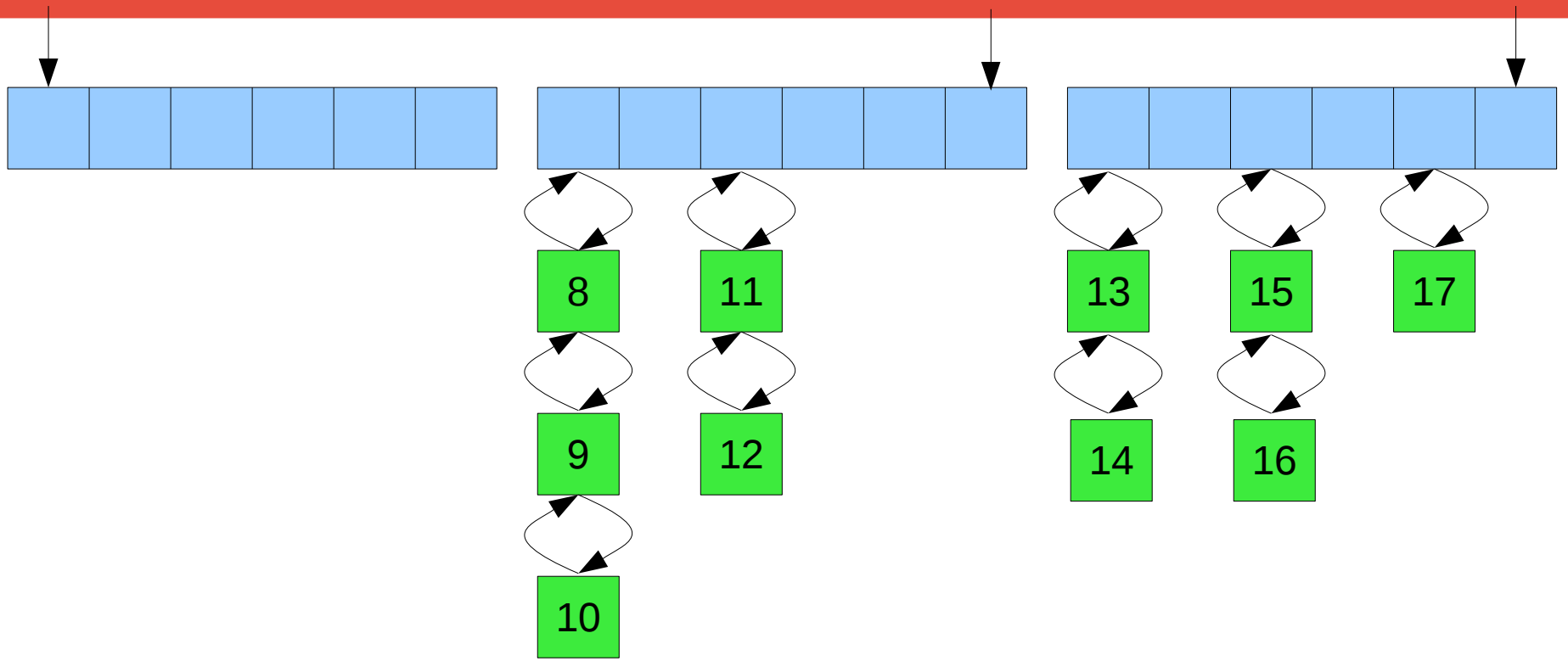

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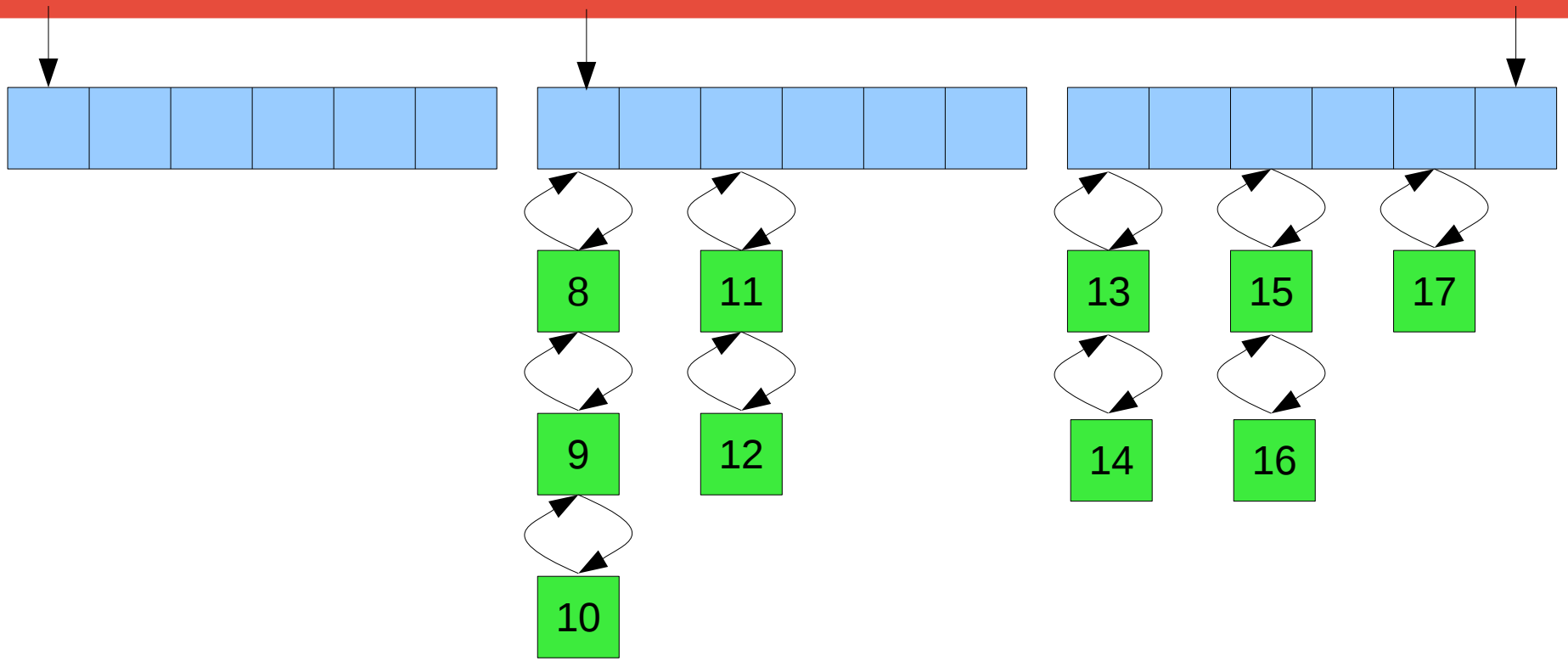

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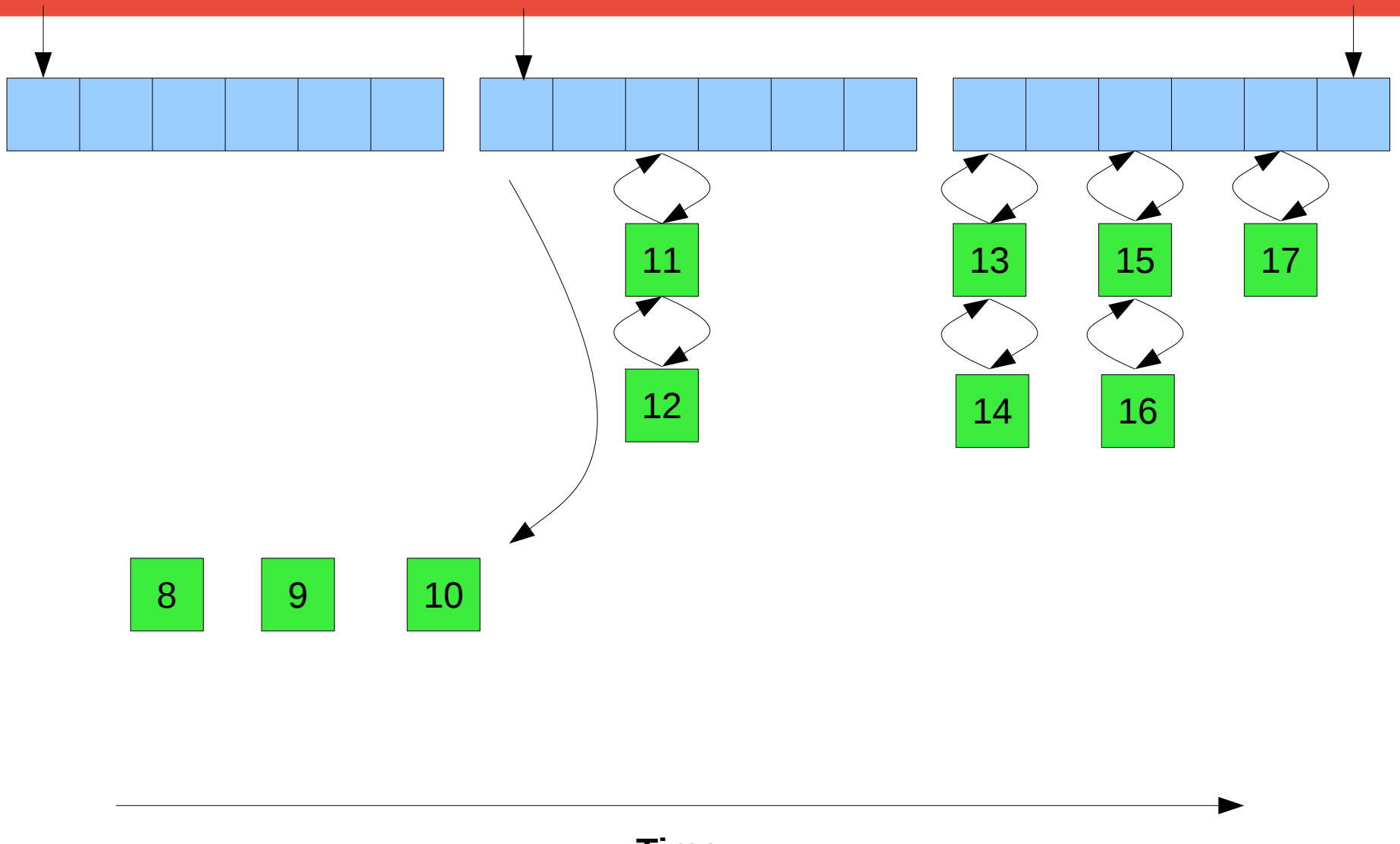

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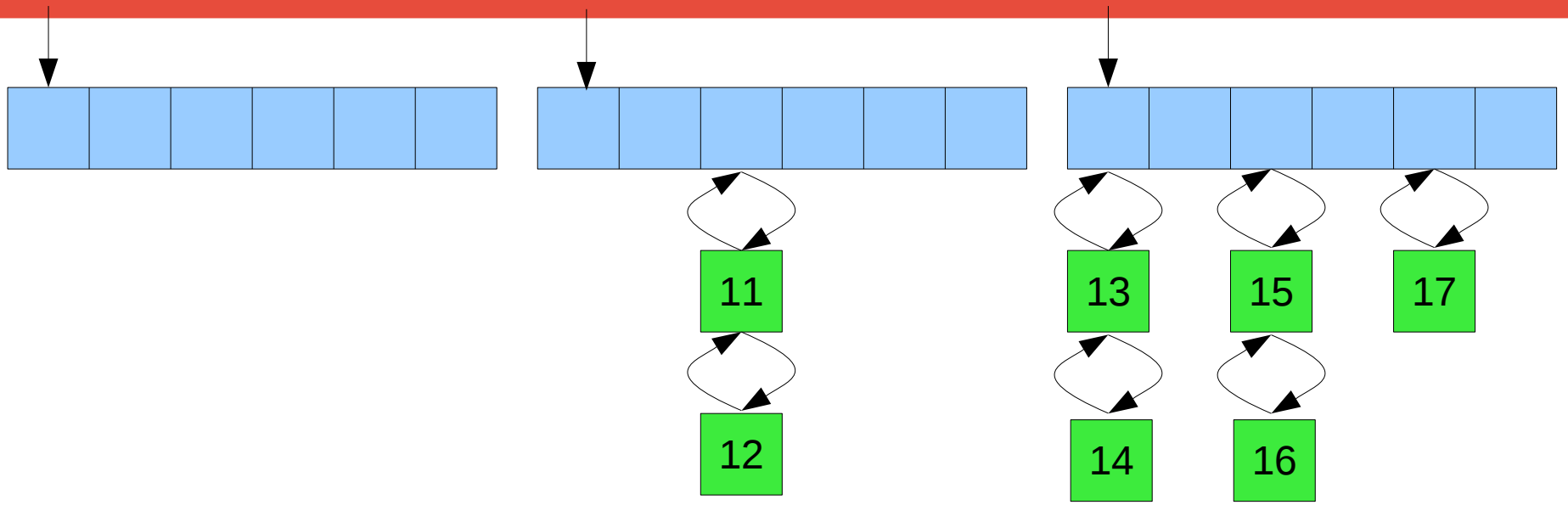

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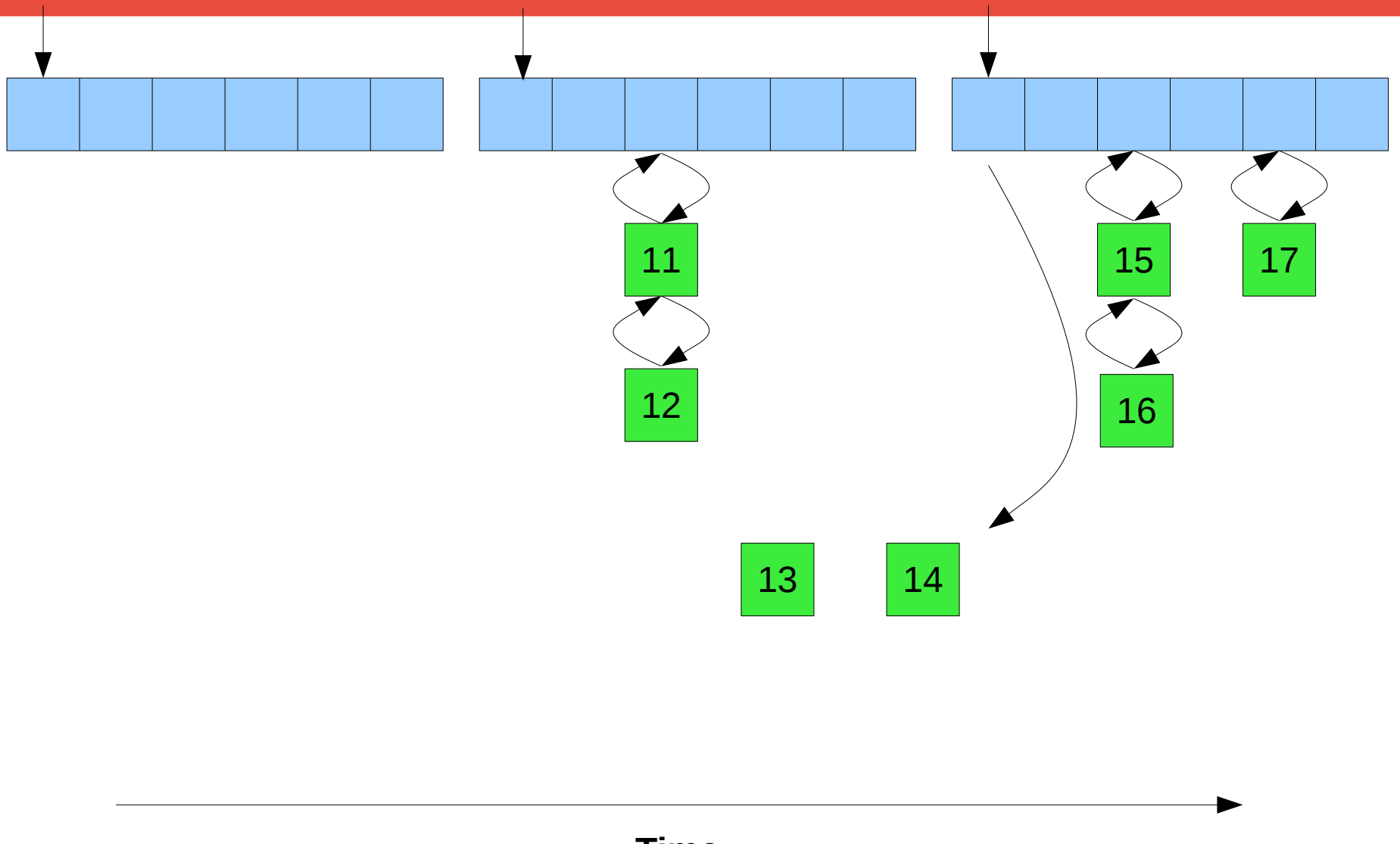

Softirqs

- Runs after a hard interrupt
- In interrupt context, but with interrupts enabled
- Runs on the CPU they were enabled on
- local_bh_disable() stops them (and disables preemption)

Softirqs

- **In PREEMPT RT, all (most really) interrupts are threads**
- **Making softirqs theads has a problem**
  - **What prio should they be?**
  - **Low and high prio tasks may use them**
- **Running after interrupts can have issues as interrupts and softirqs have different CPU affinities**

Softirqs

- Run by whoever called for them at their prio
- If local_bh_disable() set, run raised softirqs in local_bh_enable()
- Run directly when softirq is raised if bh is not disabled.
- Works for tasks as well as interrupt threads
- Hard interrupts must not call softirqs

CPU Hot Plug

- **Now must handle tasks with migration disabled**
- **Notifiers!**
  - **Called at each stage of bringing CPU up or down**
  - **May have issues with sleeping spin locks**
- **Bringing a CPU online can be just as bad**
  - **There may be cases with notifiers called with interrupts disabled**

Questions?