Parallel Computing

Announcements

- Midterm has been graded; will be distributed after class along with solutions.
- SCPD students: Midterms have been sent to the SCPD office and should be sent back to you soon.

Announcements

- Assignment 6 due right now.
- Assignment 7 (**Pathfinder**) out, due next Tuesday at 11:30AM.
  - Play around with graphs and graph algorithms!
  - Learn how to interface with library code.
- **No late submissions will be considered**. This is as late as we're allowed to have the assignment due.

Why Algorithms and Data Structures Matter

Making Things Faster

- **Choose better algorithms and data structures**.
  - Dropping from O(n^2) to O(n log n) for large data sets will make your programs faster.
- **Optimize your code**.
  - Try to reduce the constant factor in the big-O notation.
  - Not recommended unless all else fails.
- **Get a better computer**.
  - Having more memory and processing power can improve performance.
- **New option: Use parallelism.**

How Your Programs Run

Threads of Execution

- When running a program, that program gets a **thread of execution** (or **thread**).
- Each thread runs through code as normal.
- A program can have multiple threads running at the same time, each of which performs different tasks.
- A program that uses multiple threads is called **multithreaded**; writing a multithreaded program or algorithm is called **multithreading**.

Threads in C++

- The newest version of C++ (**C++11**) has libraries that support threading.
- To create a thread:
  - Write the function that you want to execute.
  - Construct an object of type **`thread`** to run that function.
    - Need header **`<thread>`** for this.
  - That function will run in parallel alongside the original program.

How Do Threads Work?

- **Preemption**: The computer runs one thread for a short time, then runs the next thread for a short time, etc.
  - Gives the illusion of everything running concurrently, though only one thread runs at a time.
  - Changing which thread runs is called a **context switch**.
- **Parallelism**: The computer has hardware that lets it run multiple threads at the same time.
  - Multiple different tasks really are running at the same time.
- Not mutually exclusive; can do both (most computers do).
- There are other options, but we'll focus on these today.

Indeterminacy

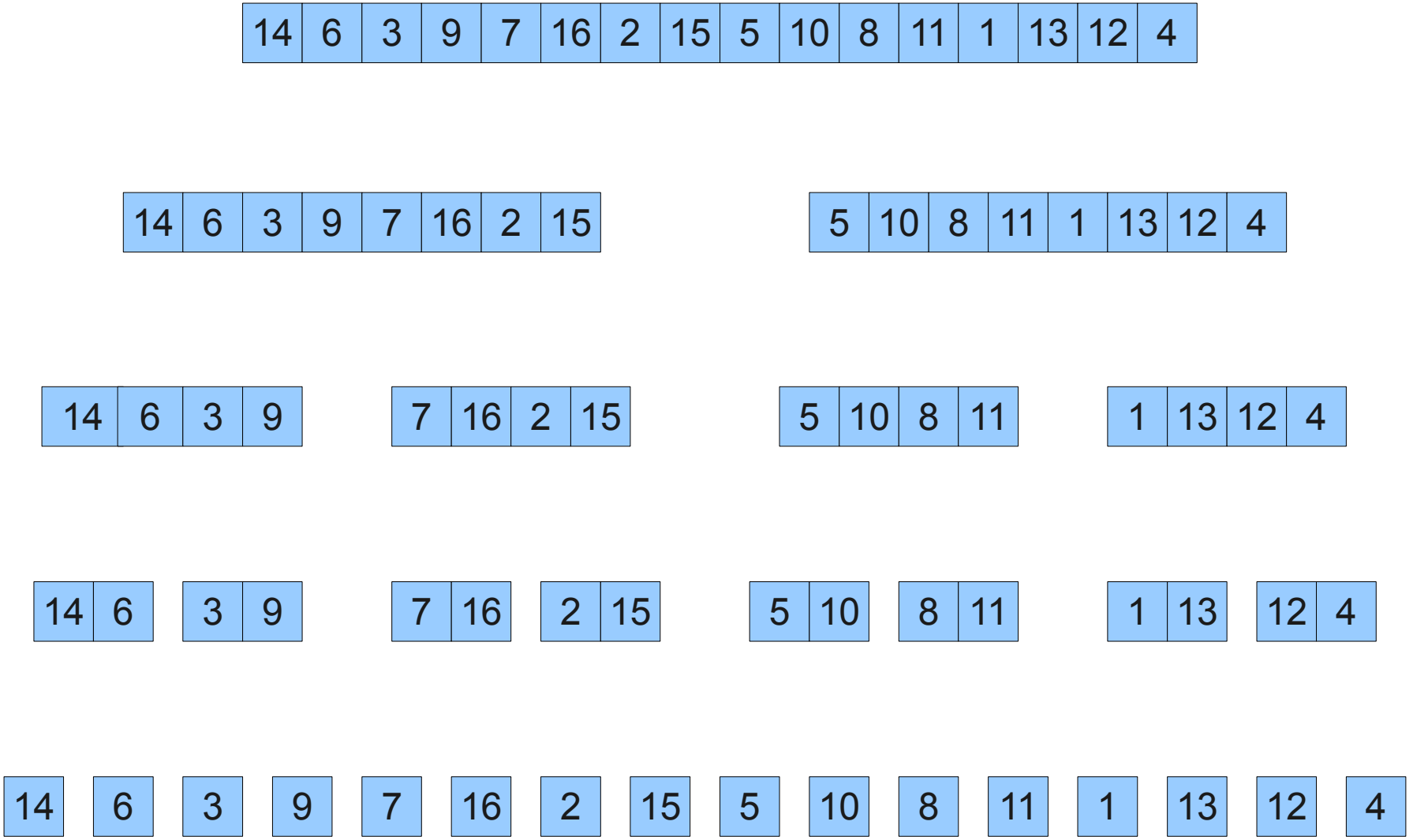
- The order in which different threads execute cannot be controlled.
- Execution order is **indeterminate**.
- Running the same multithreaded program many times can result in different outcomes each time.

Joining a Thread

- When writing a program with multiple threads, we sometimes have to wait for a thread to finish.
- One thread **joins** a second thread if it waits for the second thread to terminate before continuing.
- In C++, you can join a thread with the `.join()` member function:

***thread*`.join();`**

Getting Faster with Threads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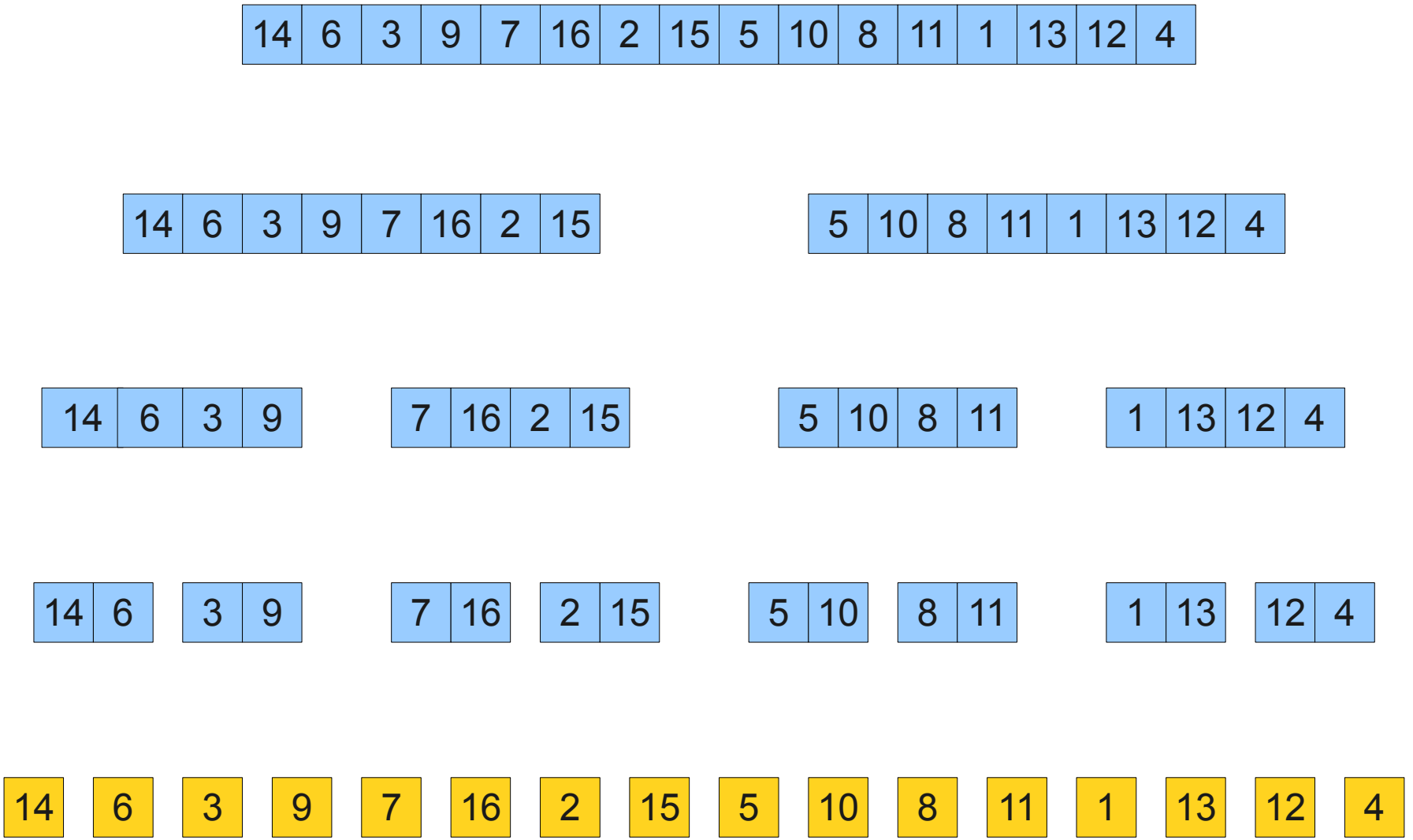
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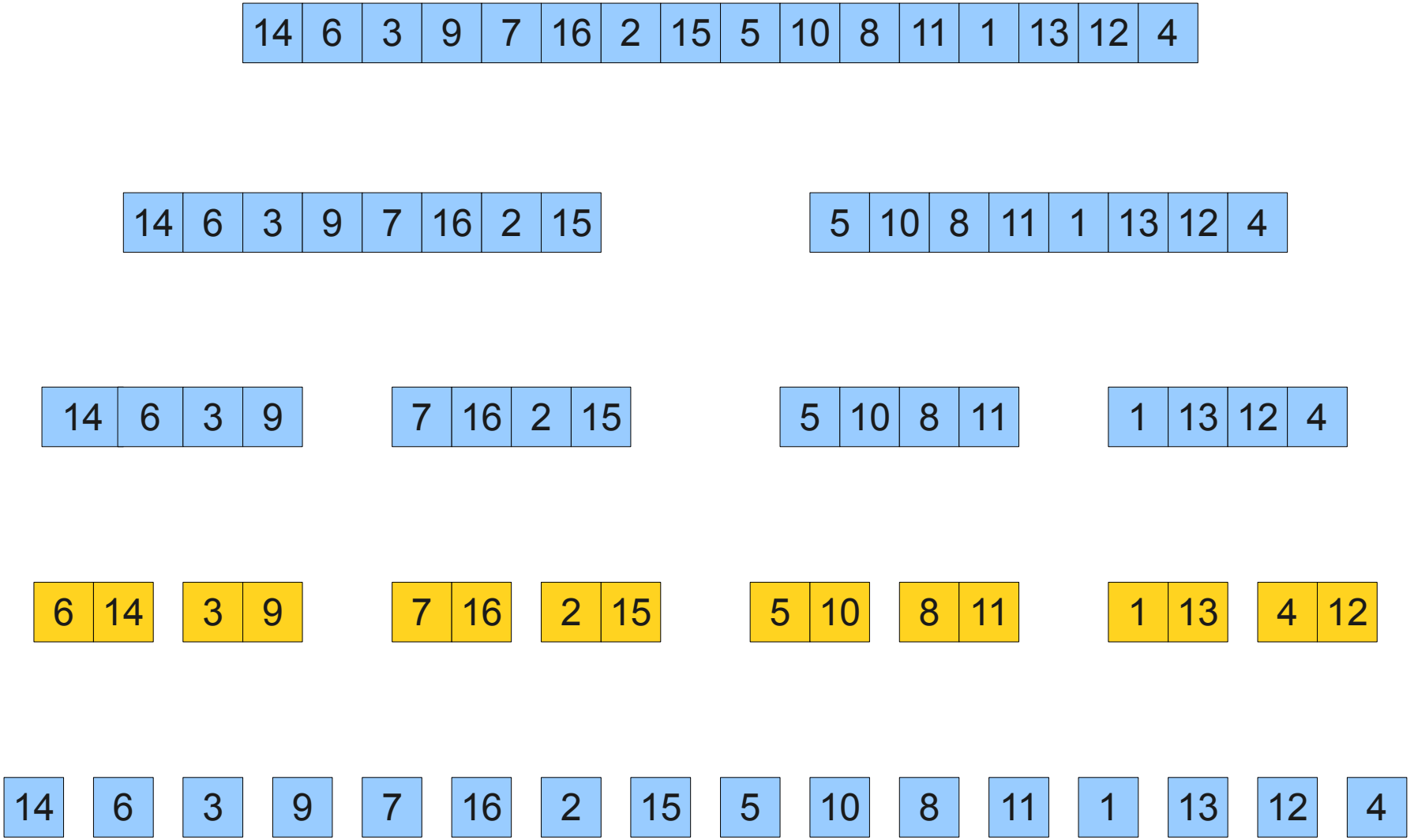
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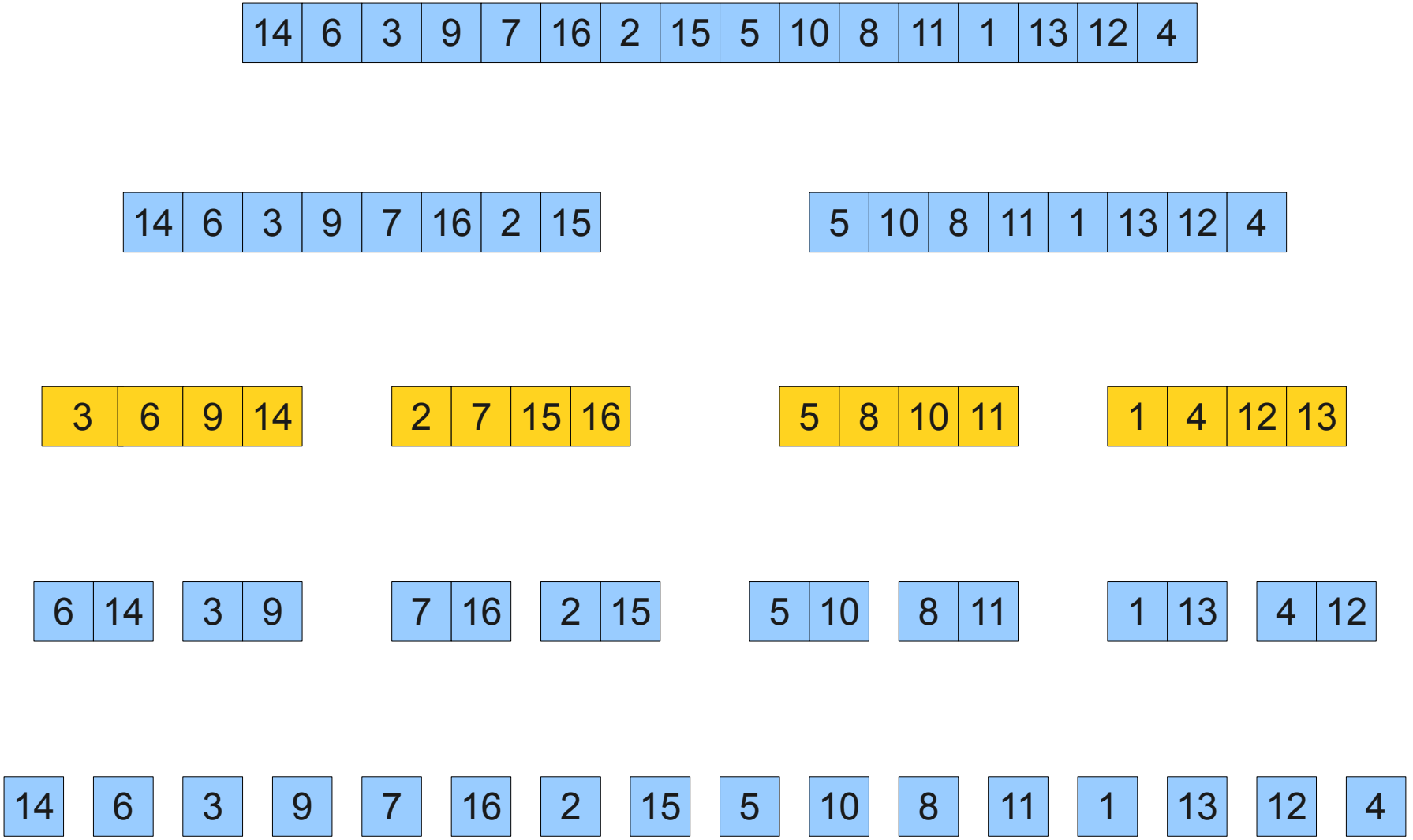
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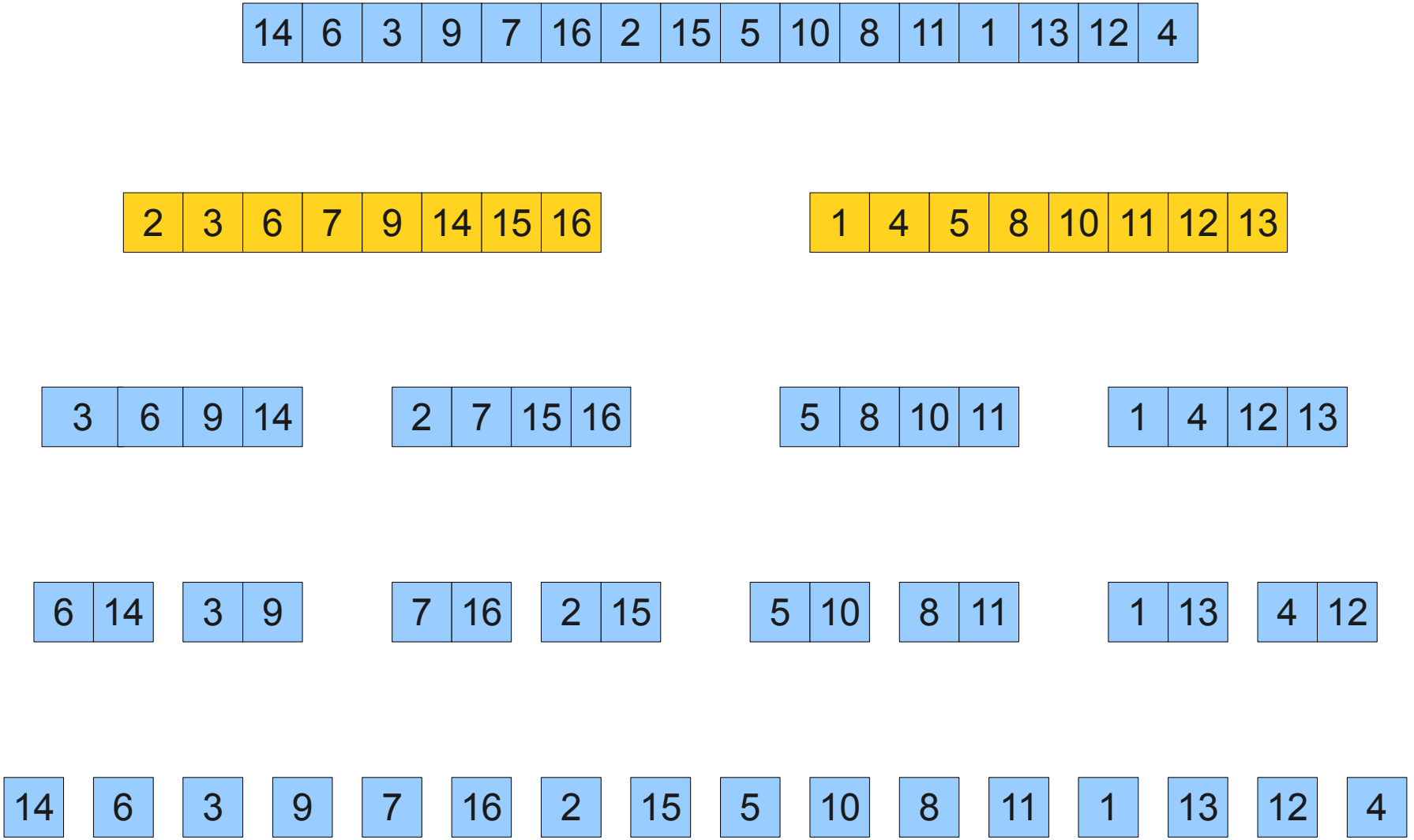
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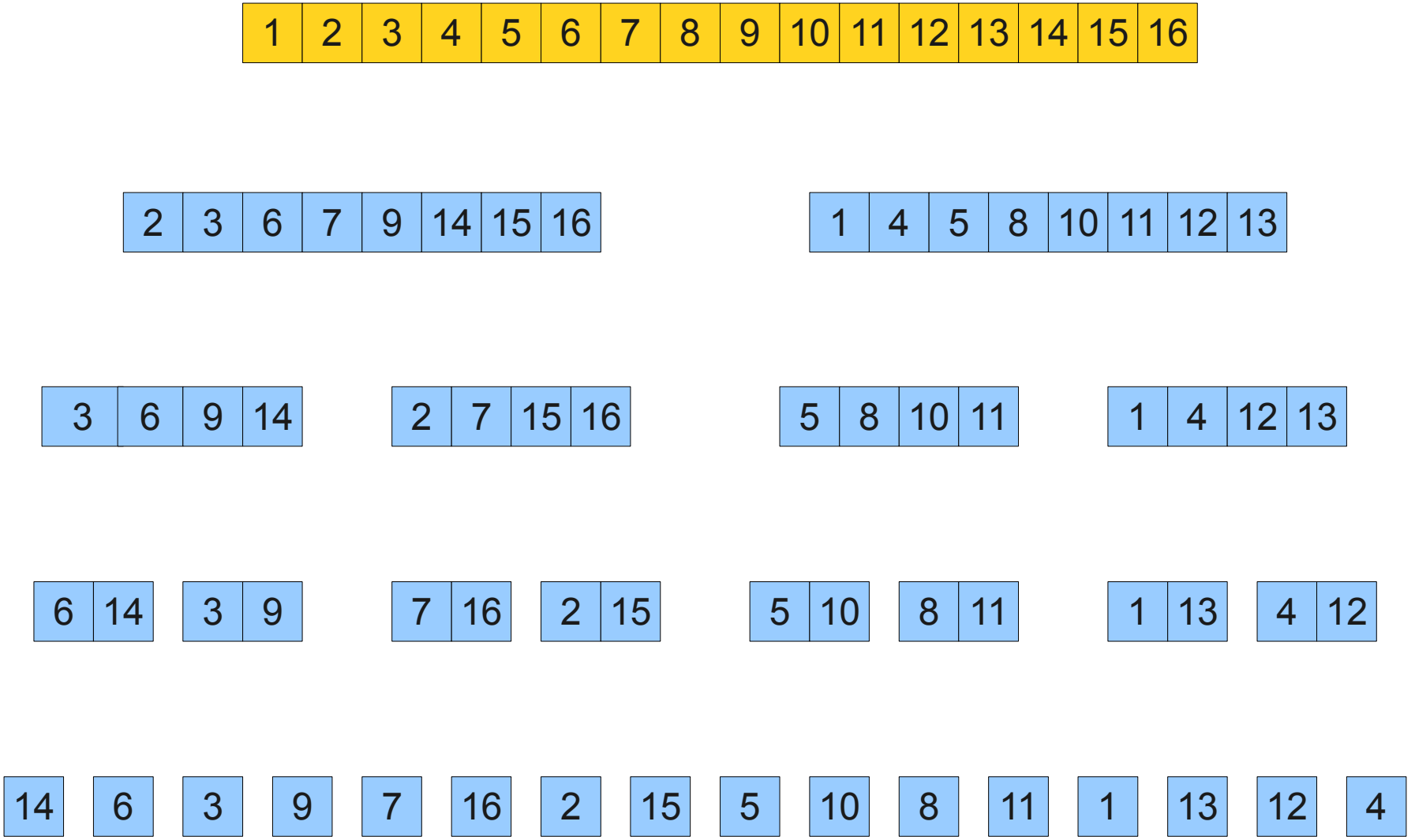
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Parallel Merge Sort

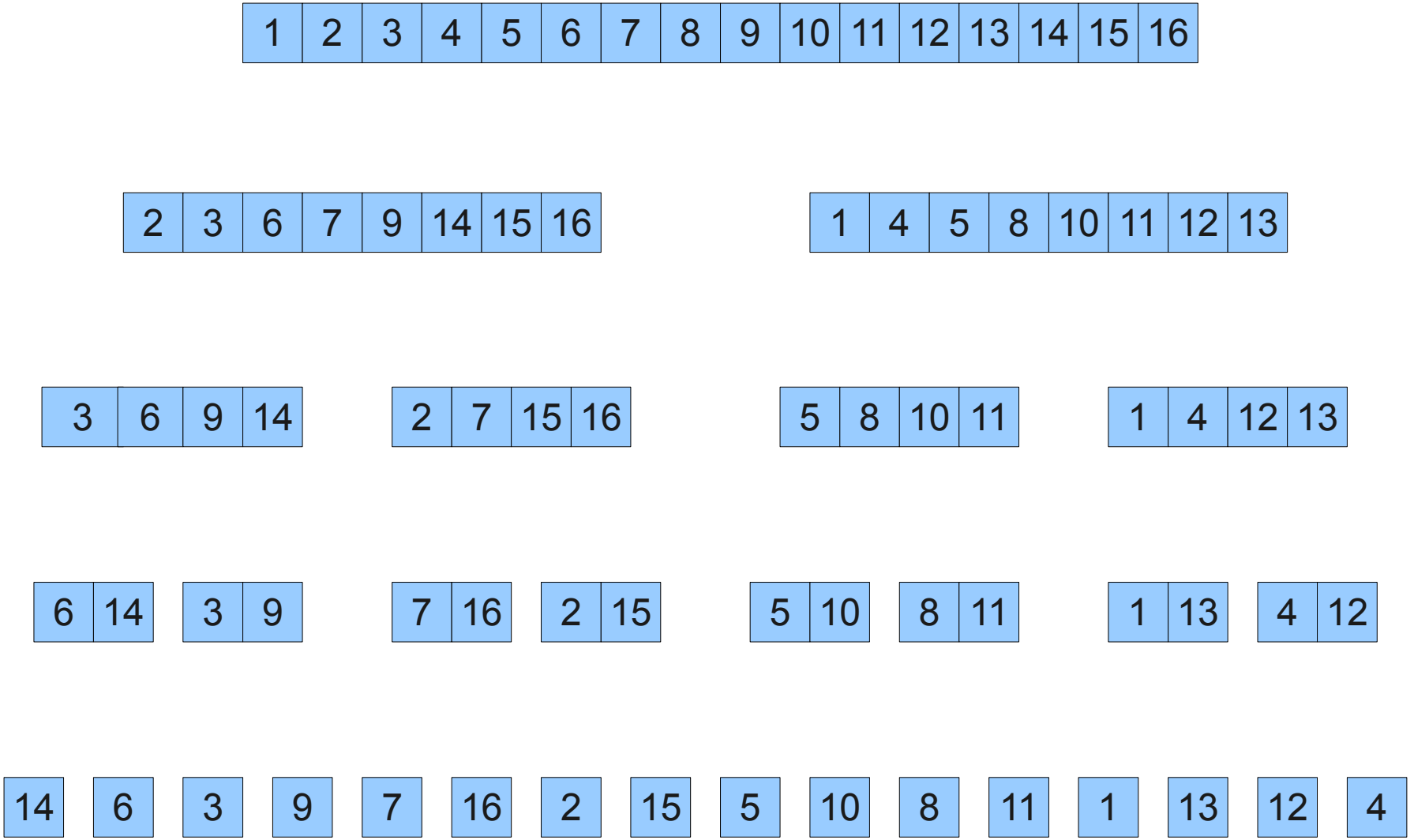
- **Idea**: Parallelize merge sort to sort numbers even faster than before!
- Same algorithm as before, but with multiple threads:
  - Create one thread for each half of the array.
  - Have each thread sort its half independently.
  - Wait for those threads to finish.
  - Merge the subarrays back together.
- Assuming we have multiple cores on the machine, this ends up being much faster.

Let's Code it Up!

What Went Wrong?

Resource Limitations

- Like all resources on the computer (memory, disk space, power, etc.), the number of threads is limited.
- We must limit how many threads we use.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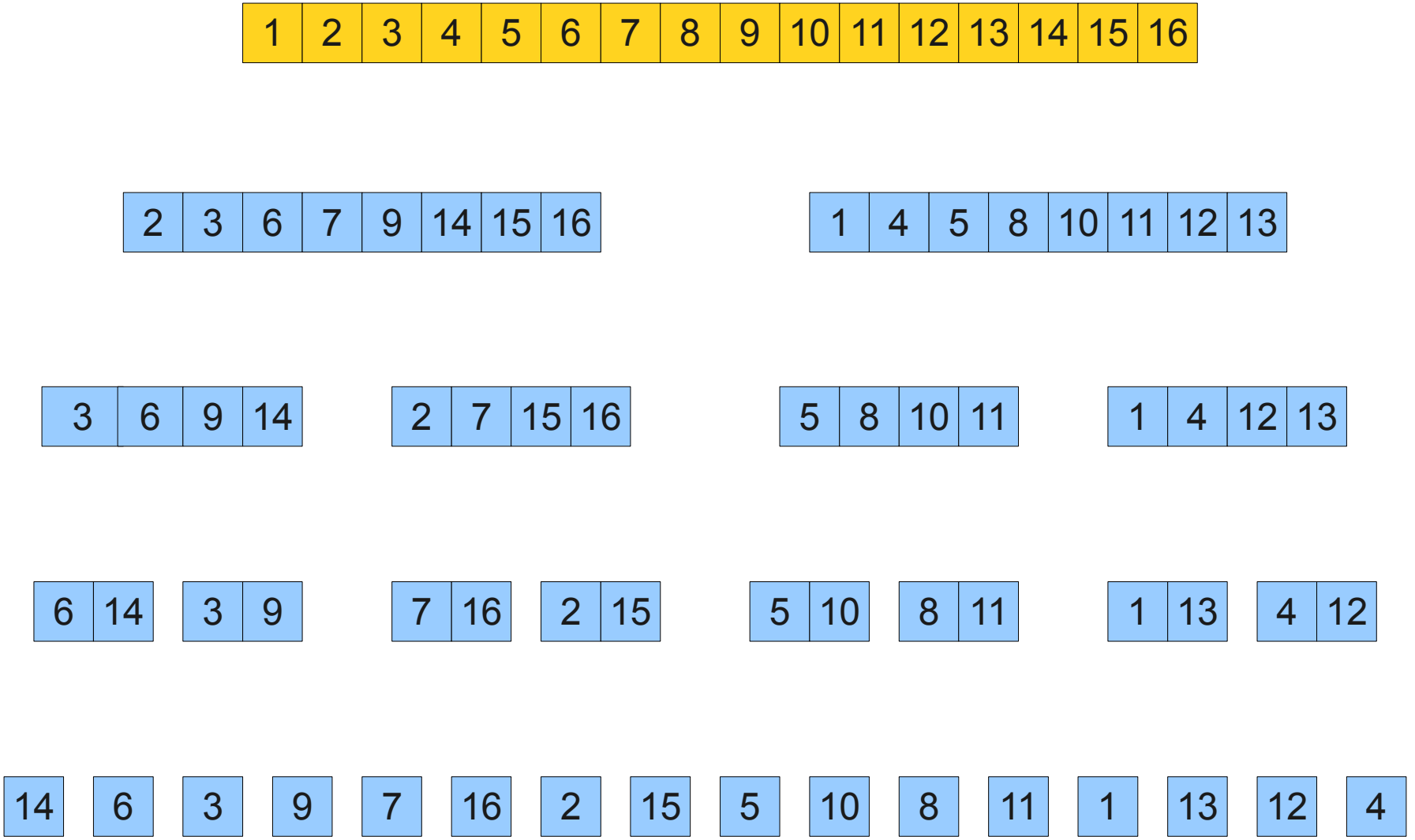
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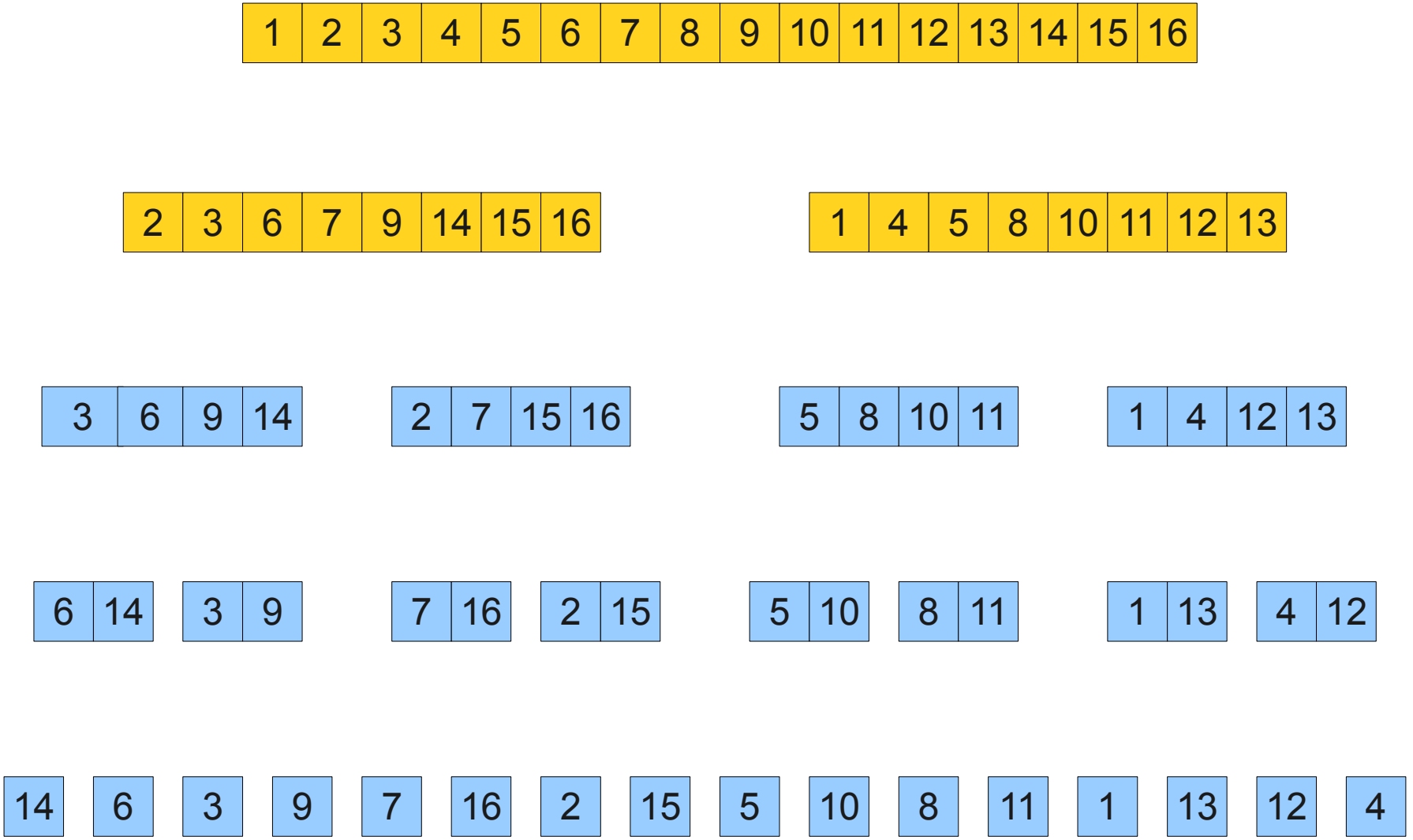
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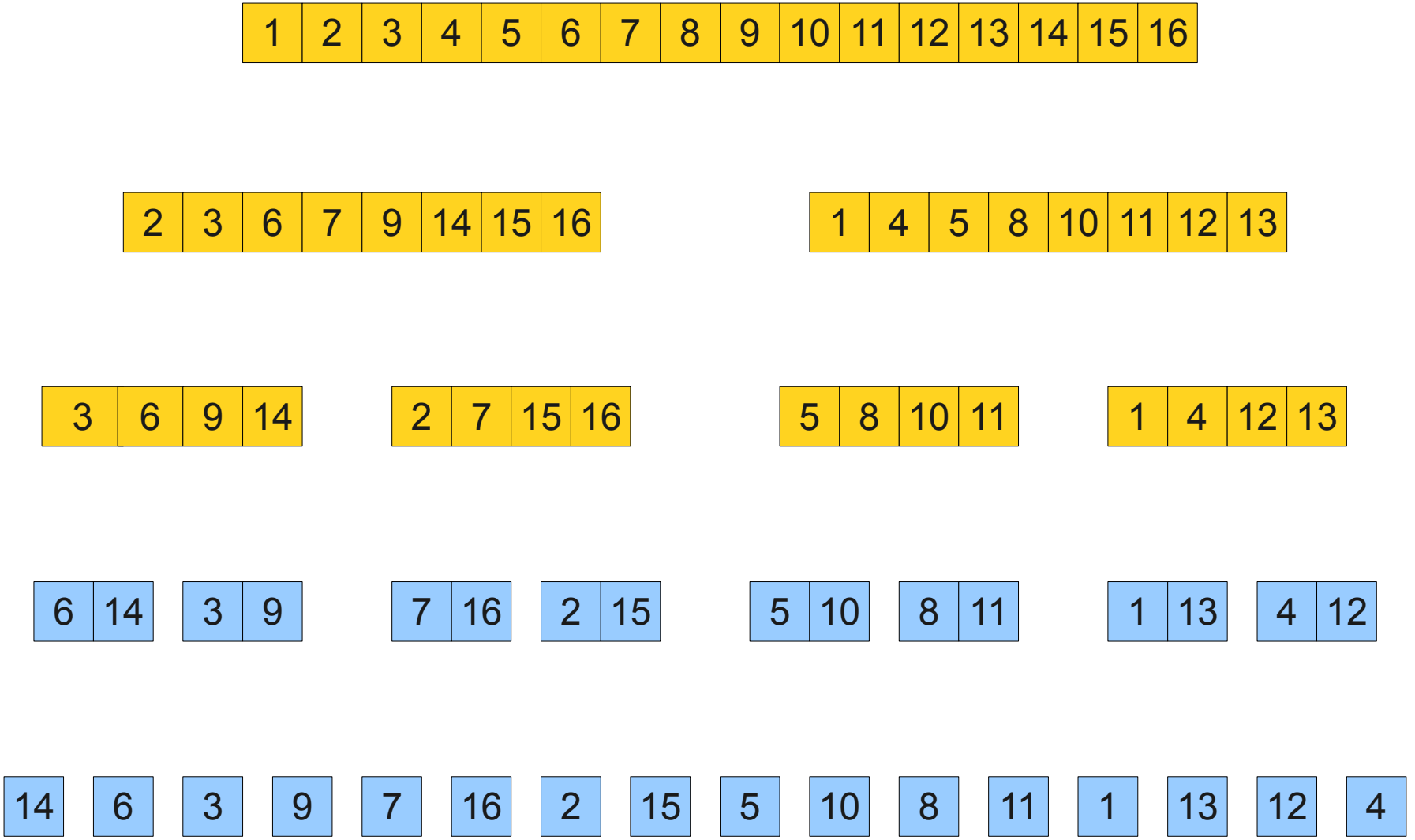
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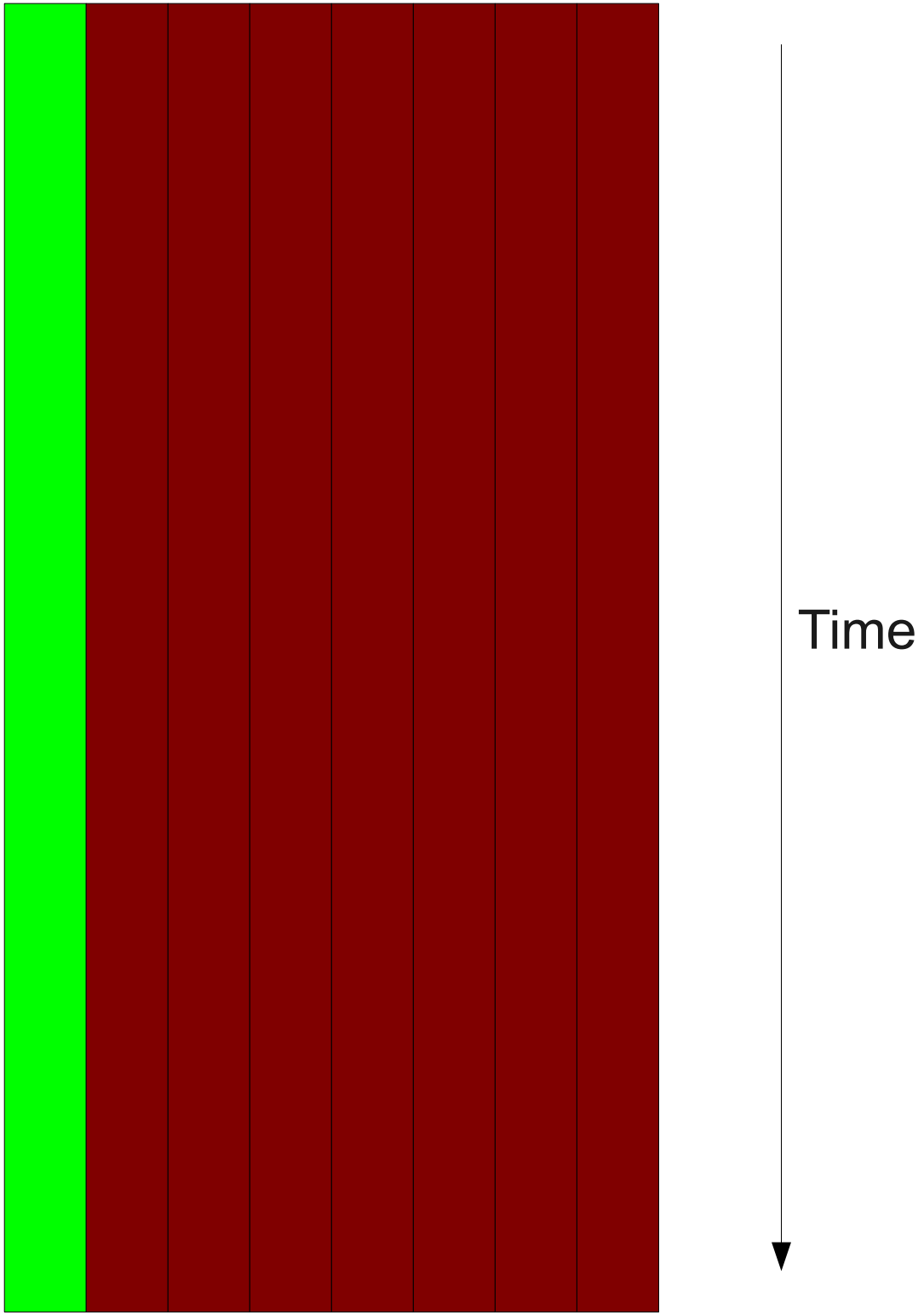
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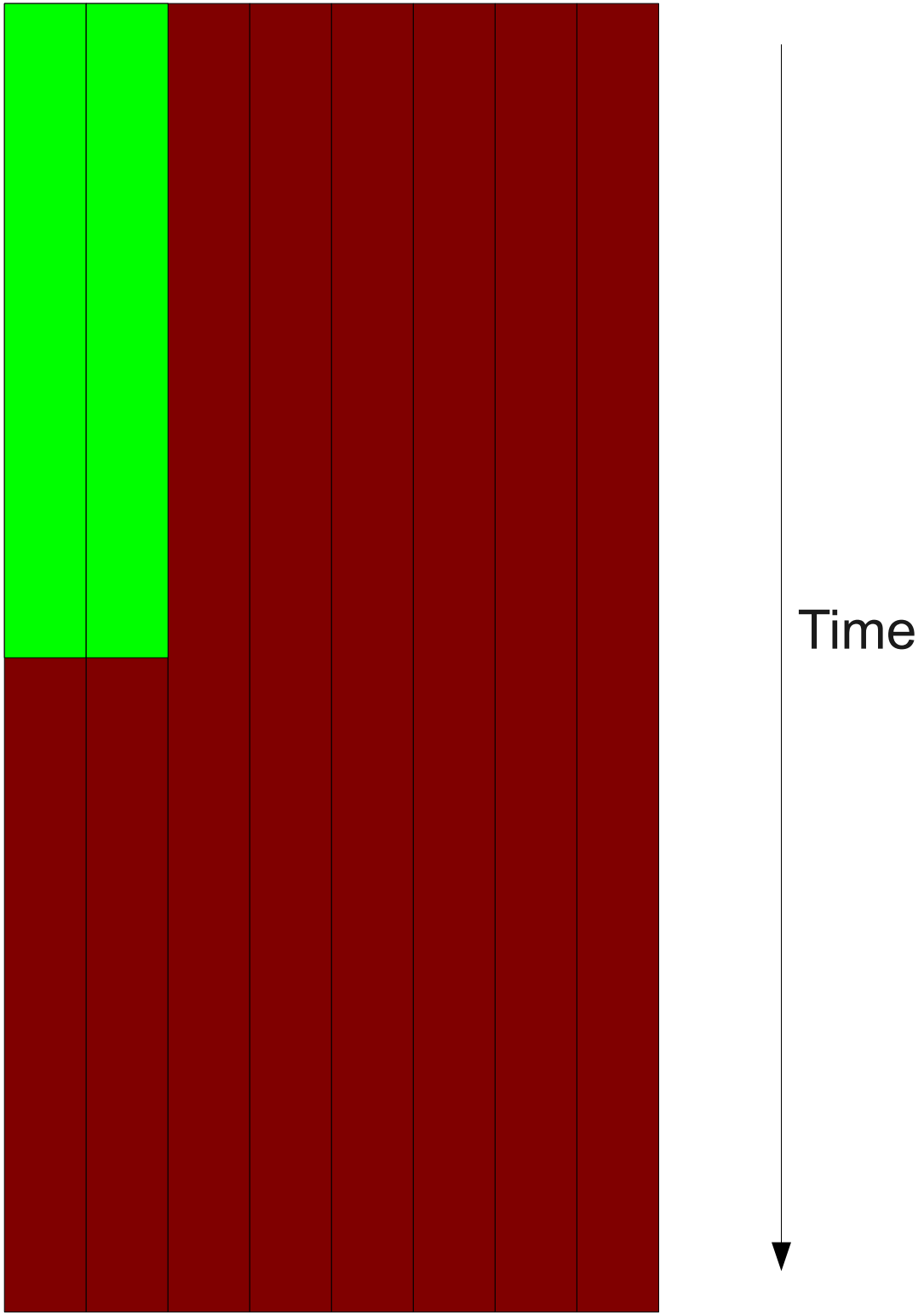
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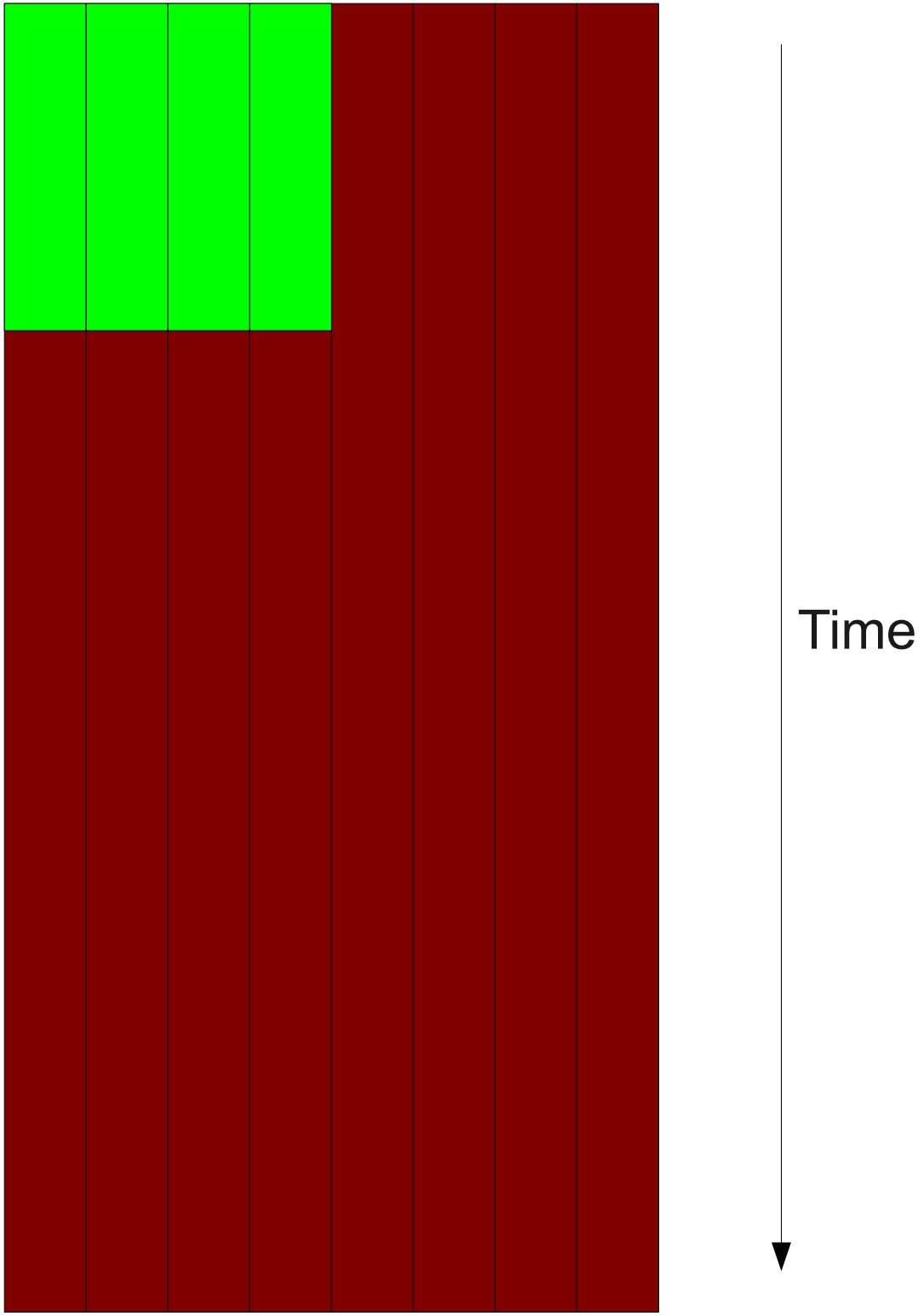
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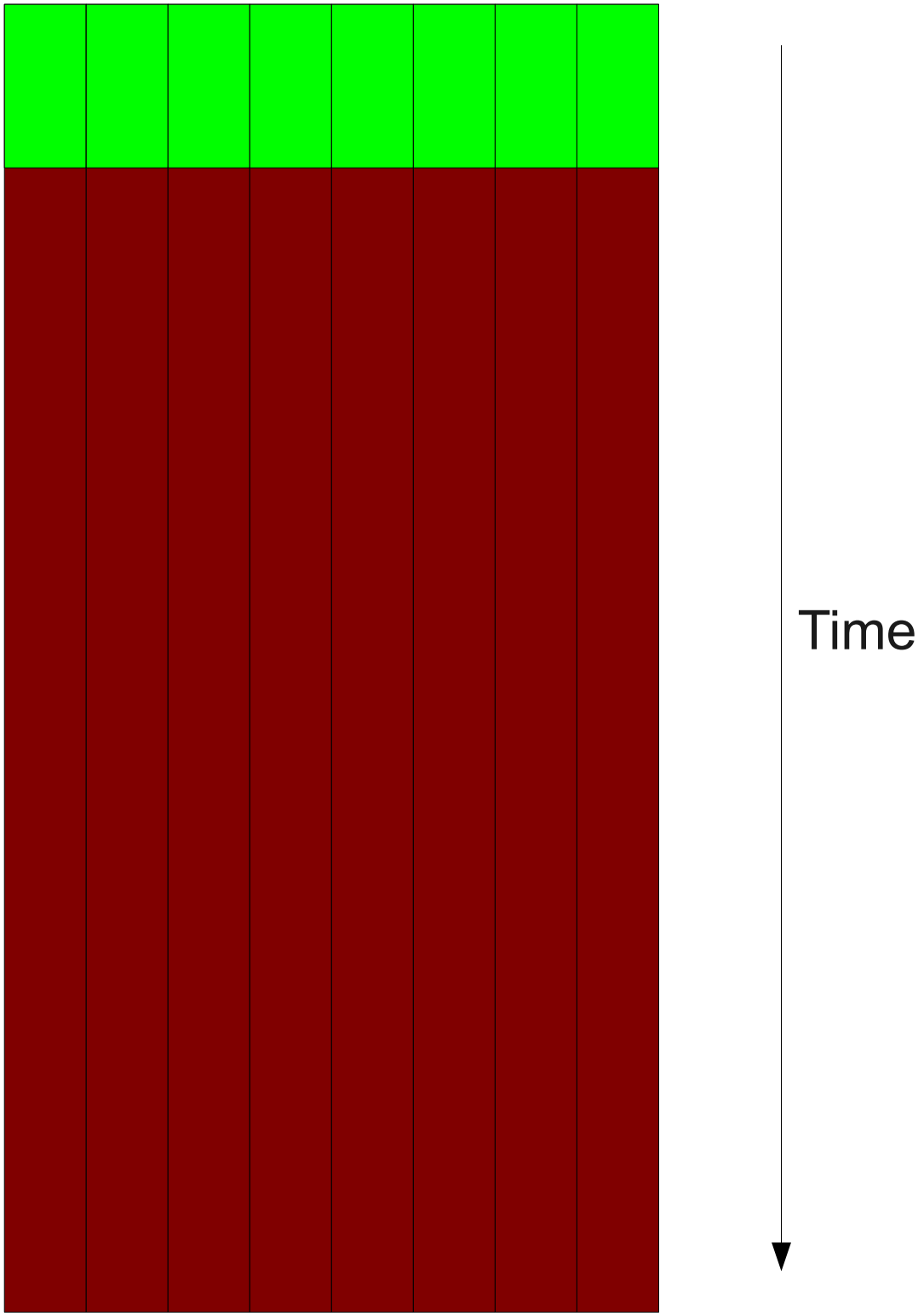
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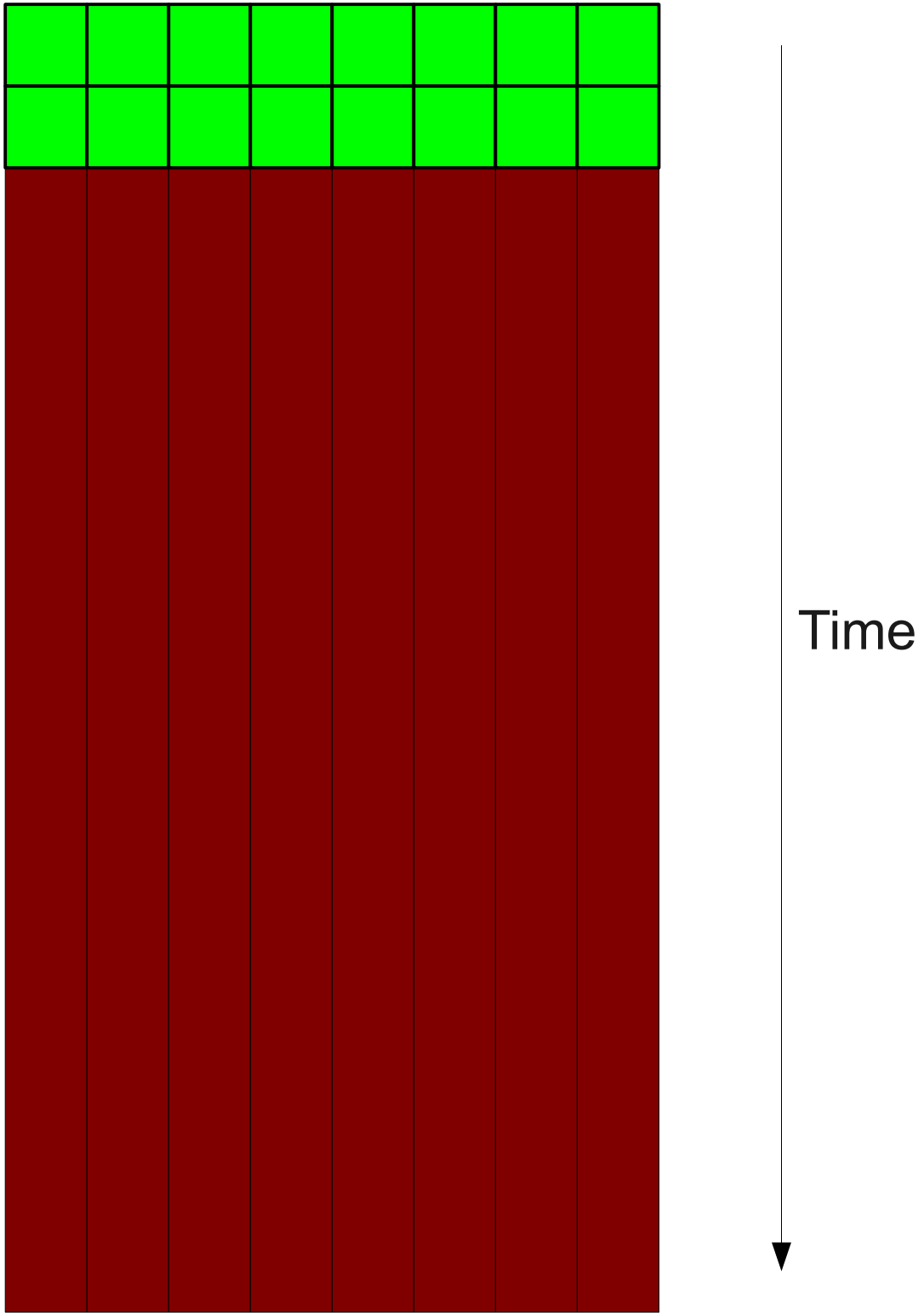
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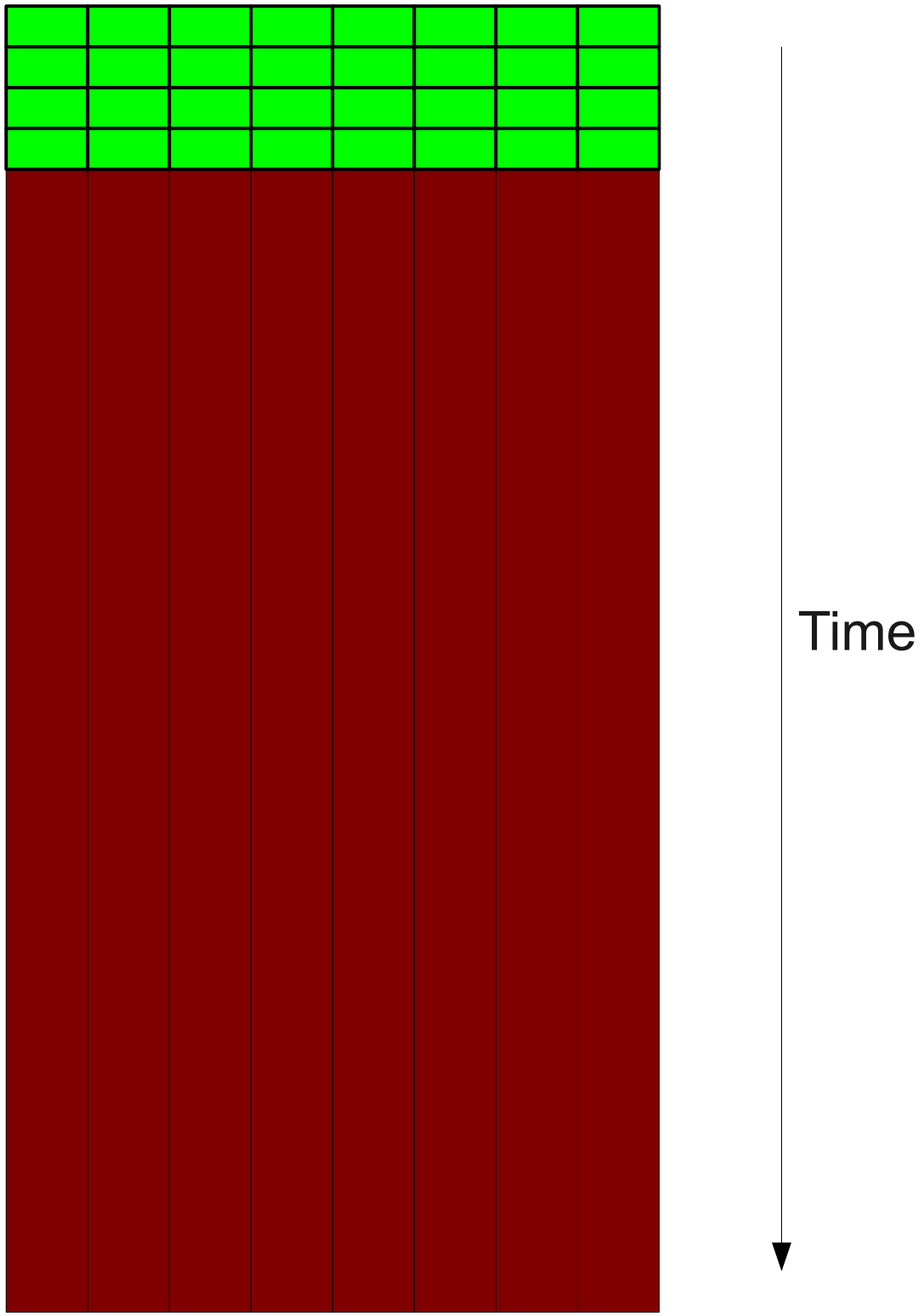
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The Hardware Limit

- Multithreading decreases the time required to finish sorting, but doesn't decrease the total work required.
- Once all cores are working, further subdividing the task does not give any performance increase.
- Launching and joining threads adds extra work; too much subdivision can cause a *decrease* in performance.

Race Conditions

Race Condition

- A **race condition** (or **data race**) is an error in a program where the outcome of the program differs based on the timing of the threads.
- In our code, if multiple threads all read **`isSpartacus`** as **`true`** before the first thread to read it sets it to **`false`**, every thread thinks it's Spartacus.

Having Threads Coordinate

Mutexes

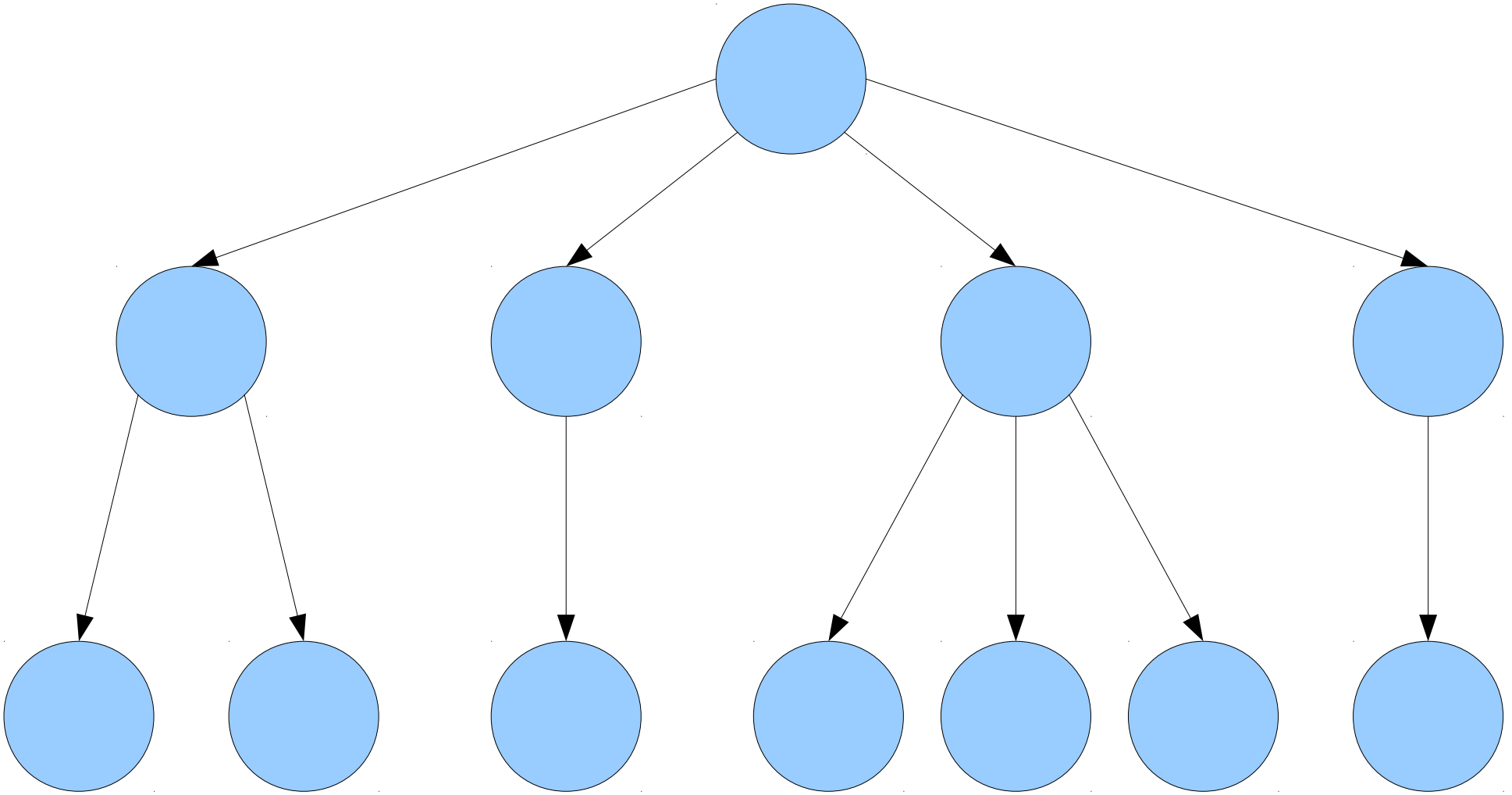
- A **mutex** (from **mut**ual **ex**clusion) is a variable designed to let threads coordinate with one another.
- A thread can try to lock the mutex.
  - If the mutex is unlocked, then the thread locks the mutex and continues as usual until it unlocks it.
  - If the mutex is already locked, the thread pauses until the mutex is unlocked, then locks the mutex.

Threads are Hard

- Coordinating multiple threads can be extremely difficult.
- Take CS110, CS140, or CS149 on details on how to do this.

Getting Faster with Threads

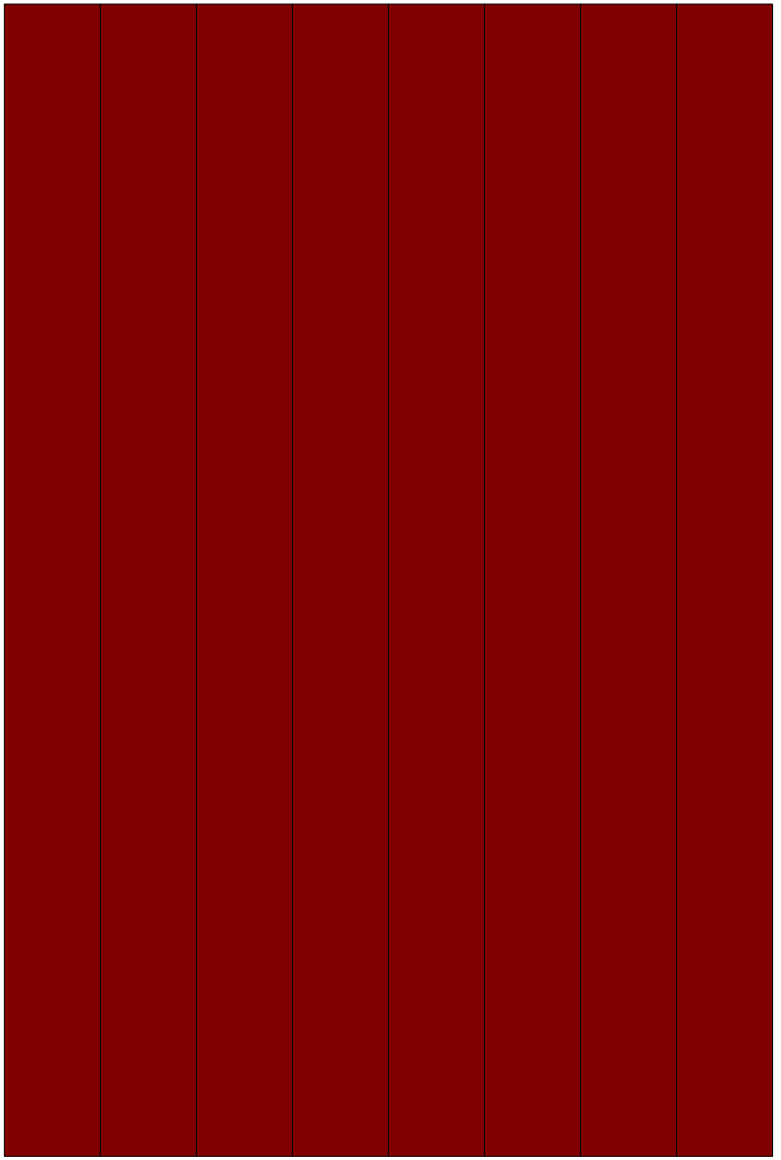
Downloading Wikipedia



Downloading Wikipedia

- You can think of downloading all of Wikipedia as a graph search problem.
- Given some set of starting articles, do a DFS or BFS of the Wikipedia graph one page at a time.
- How fast is this?

Network Latency



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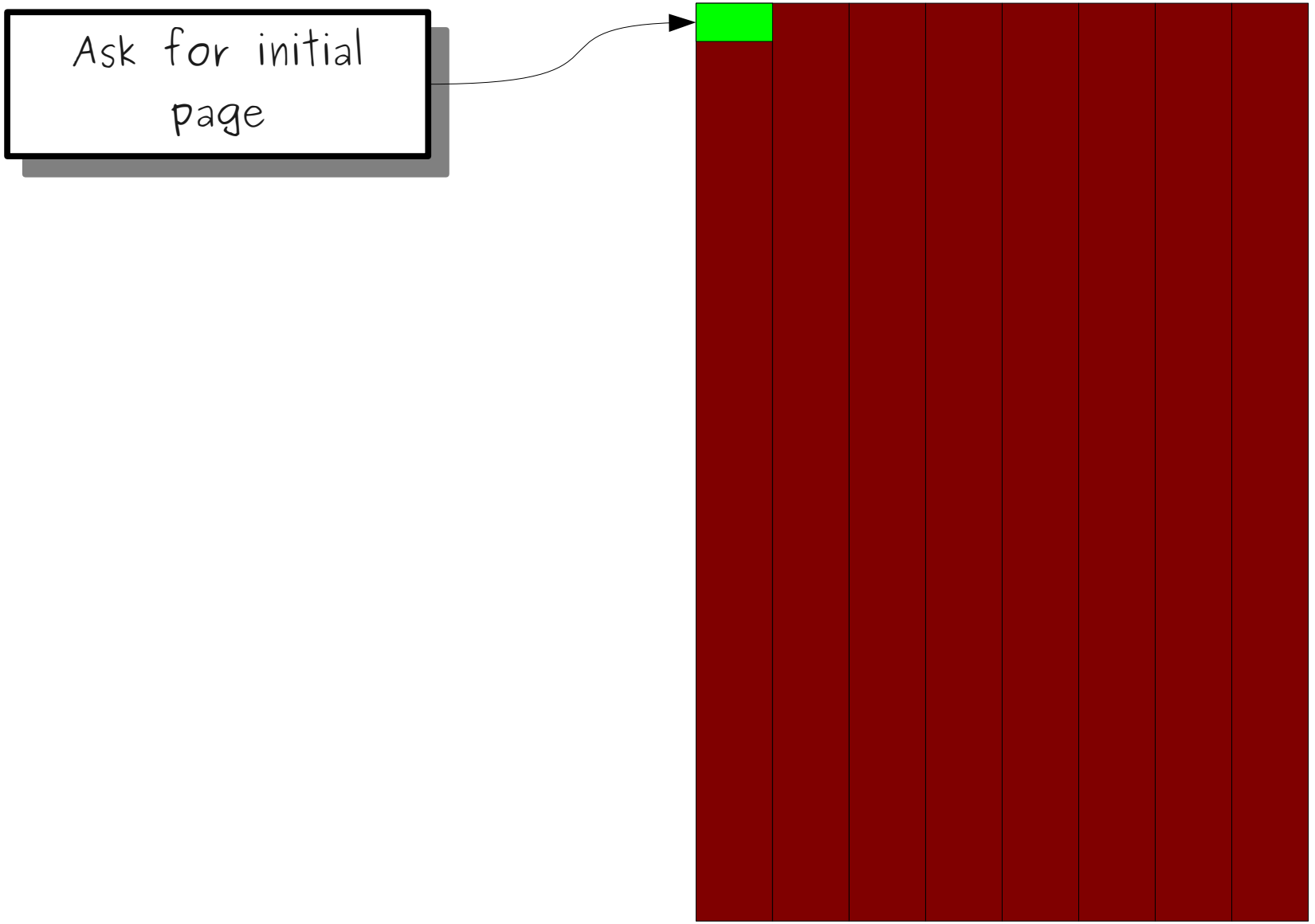

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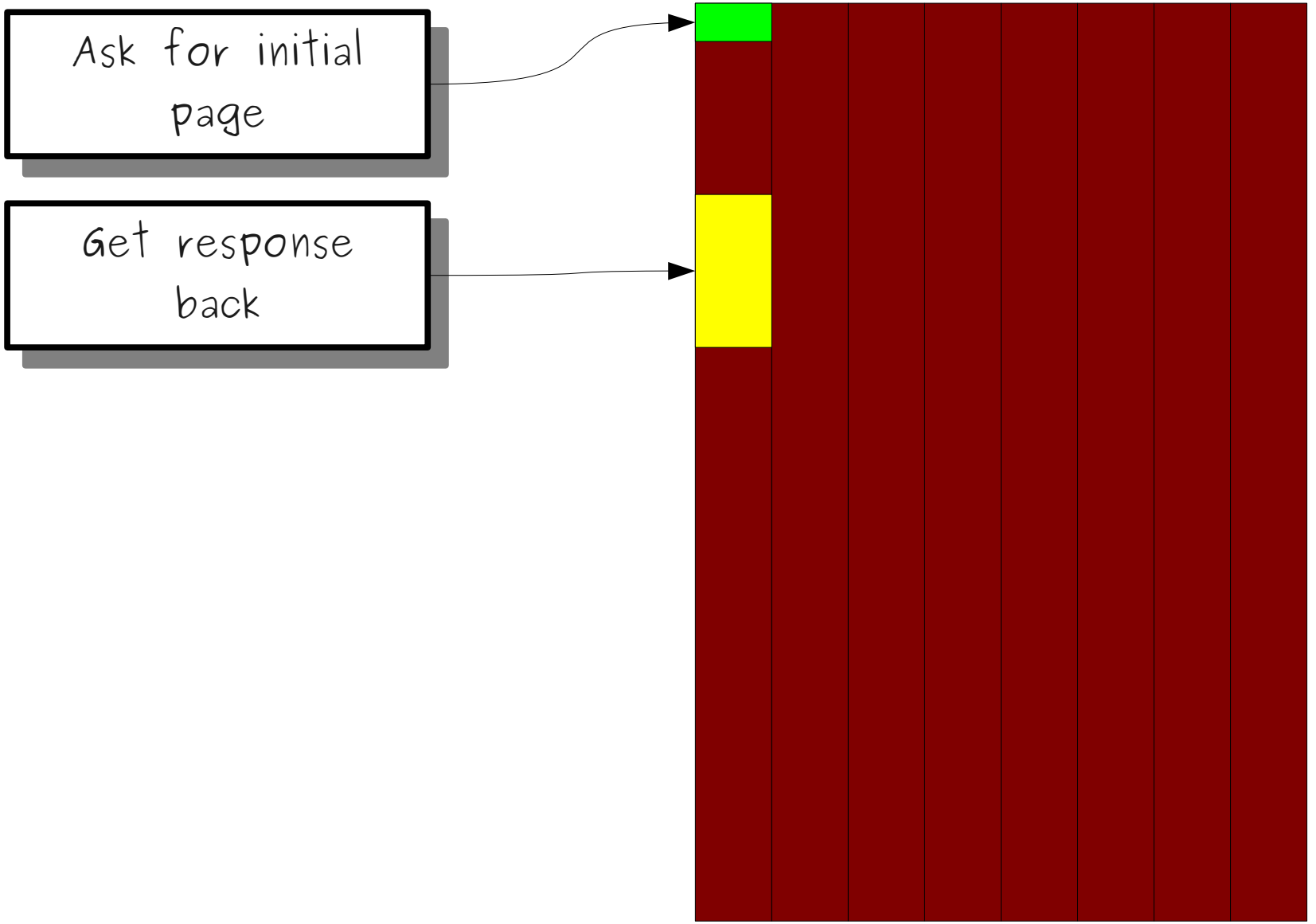

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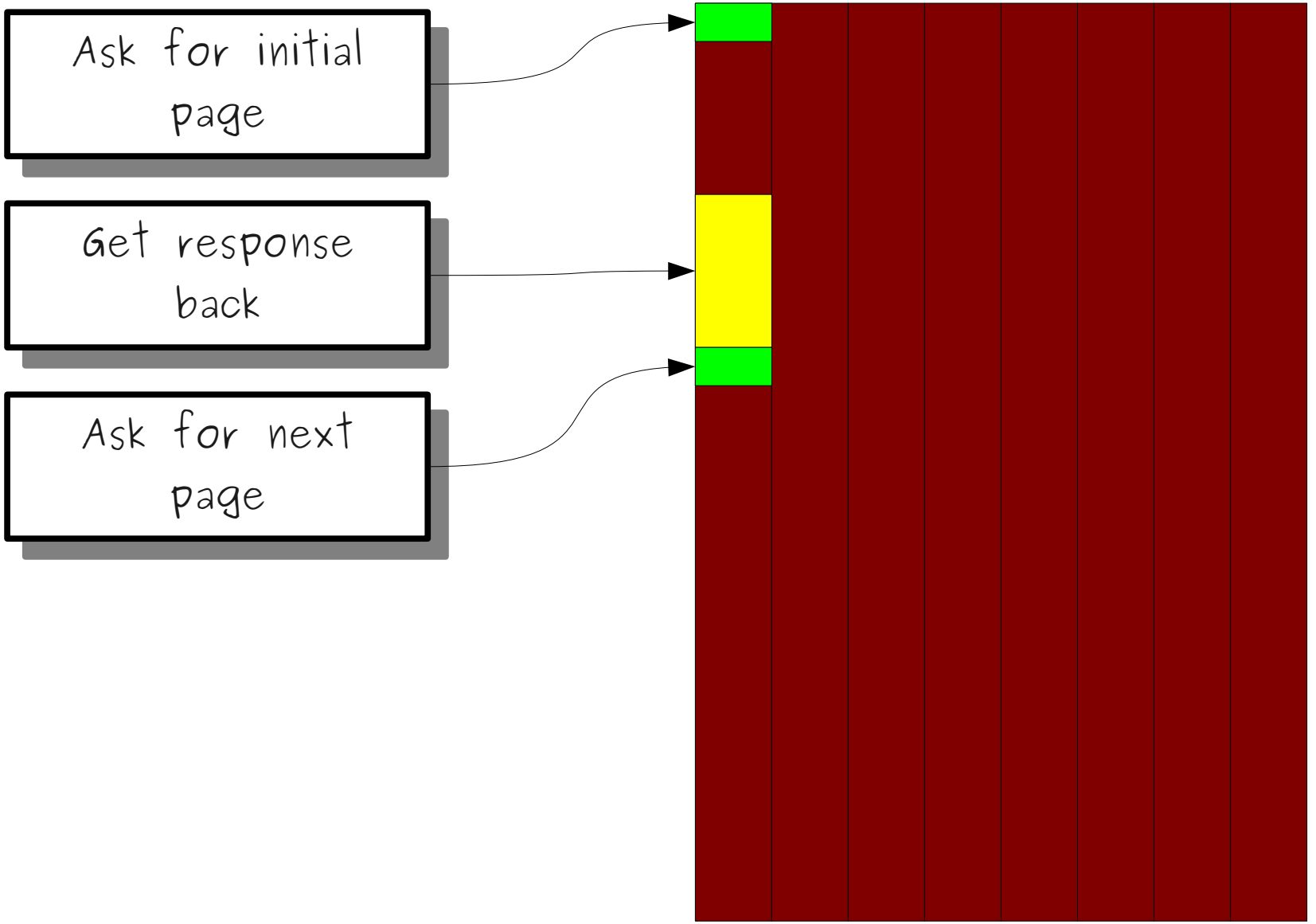

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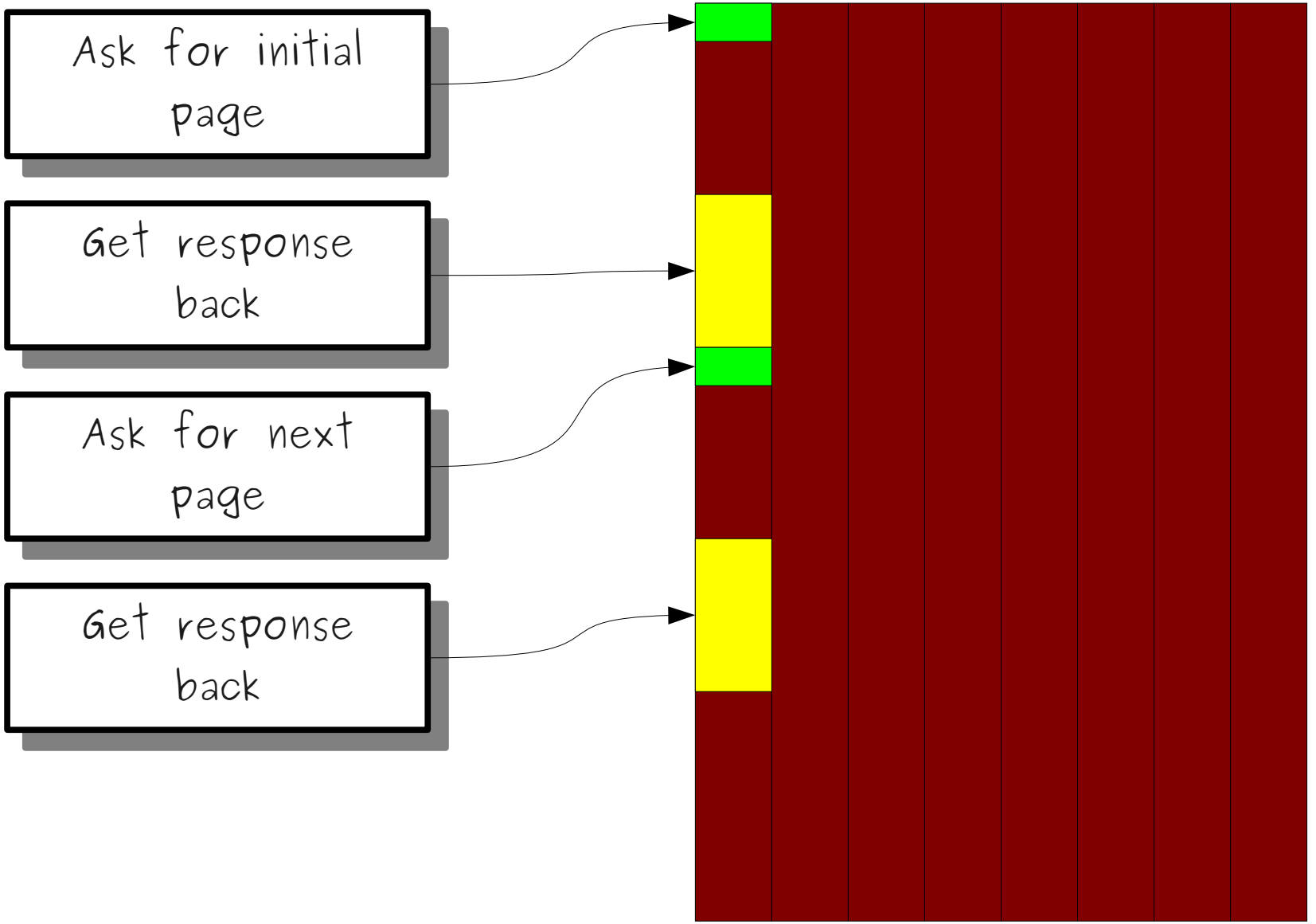

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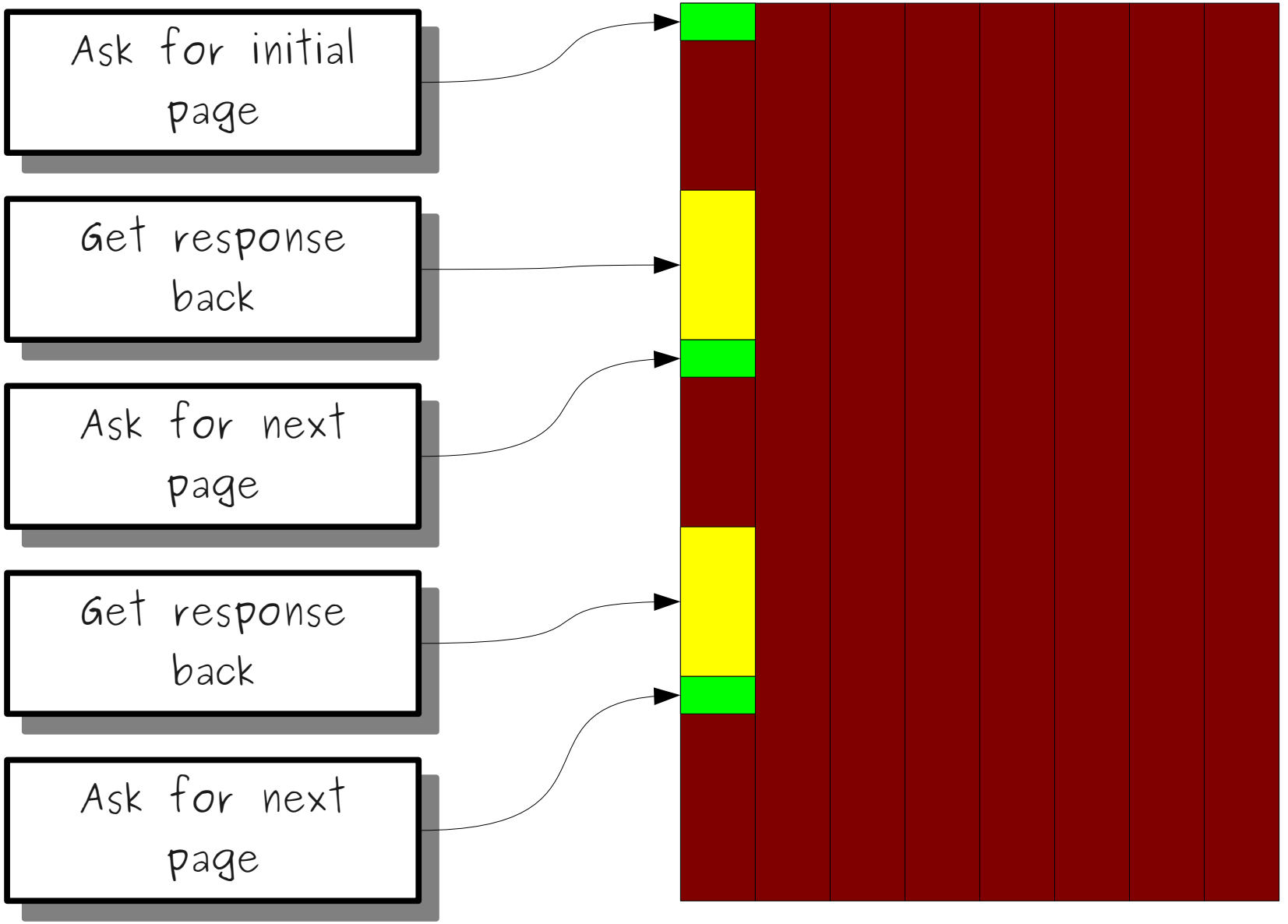

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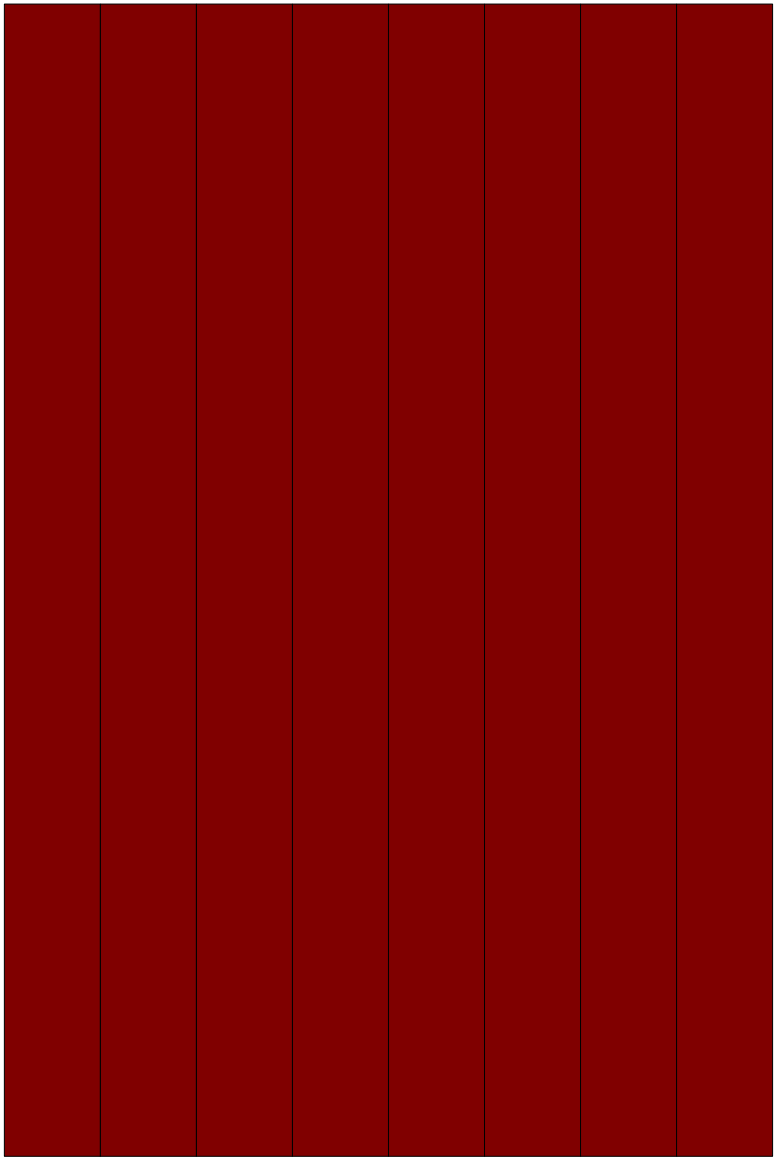

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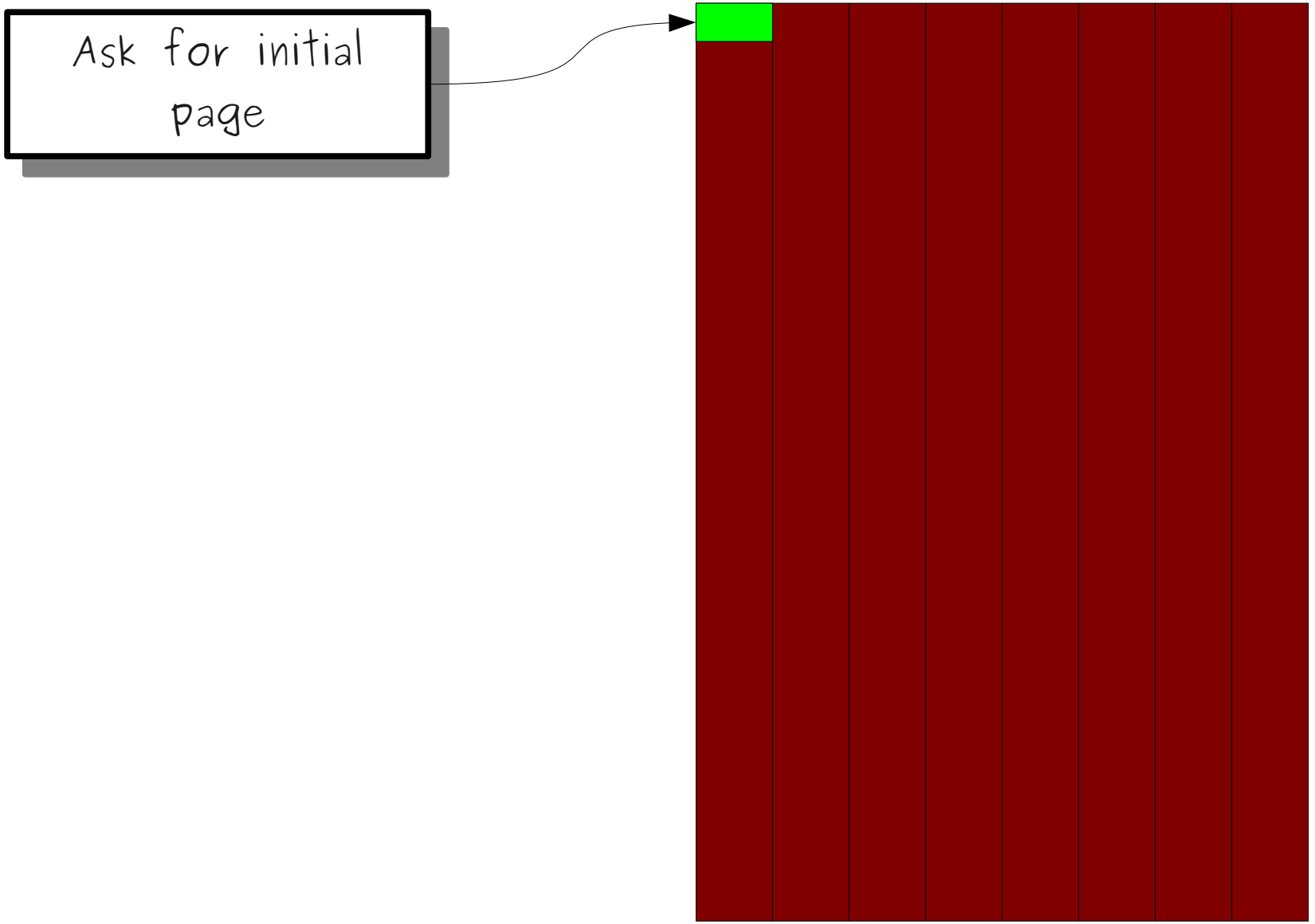

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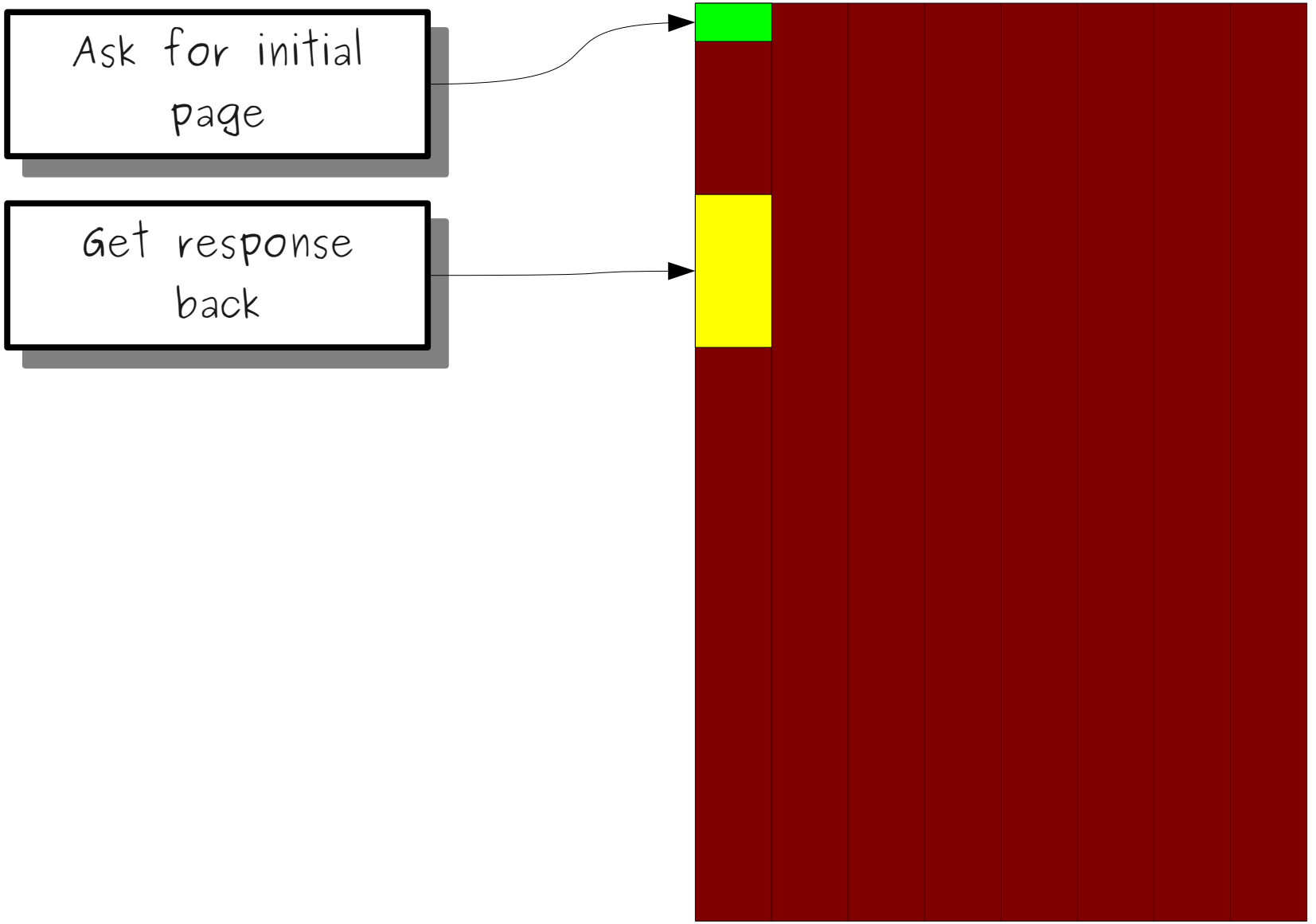

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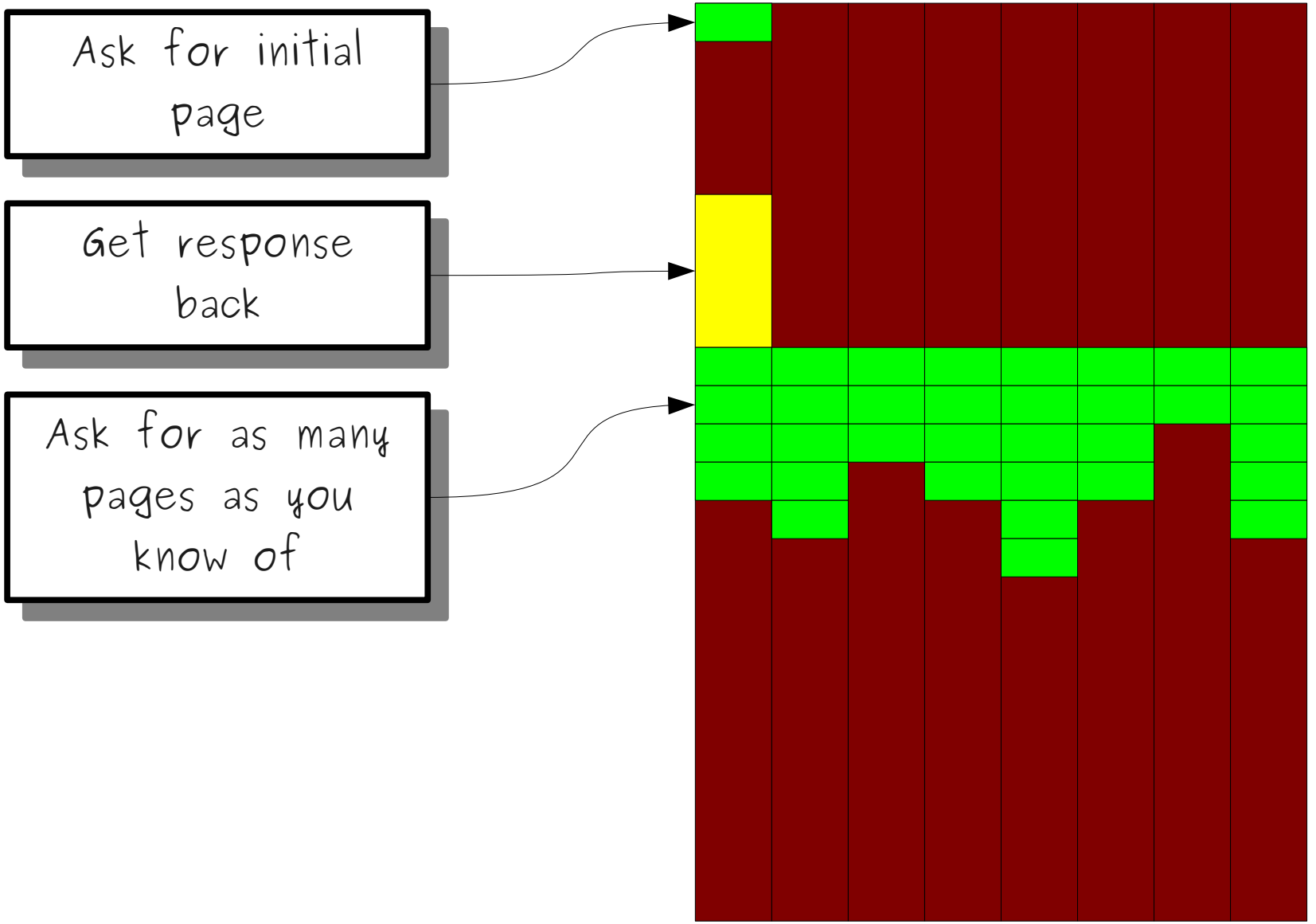

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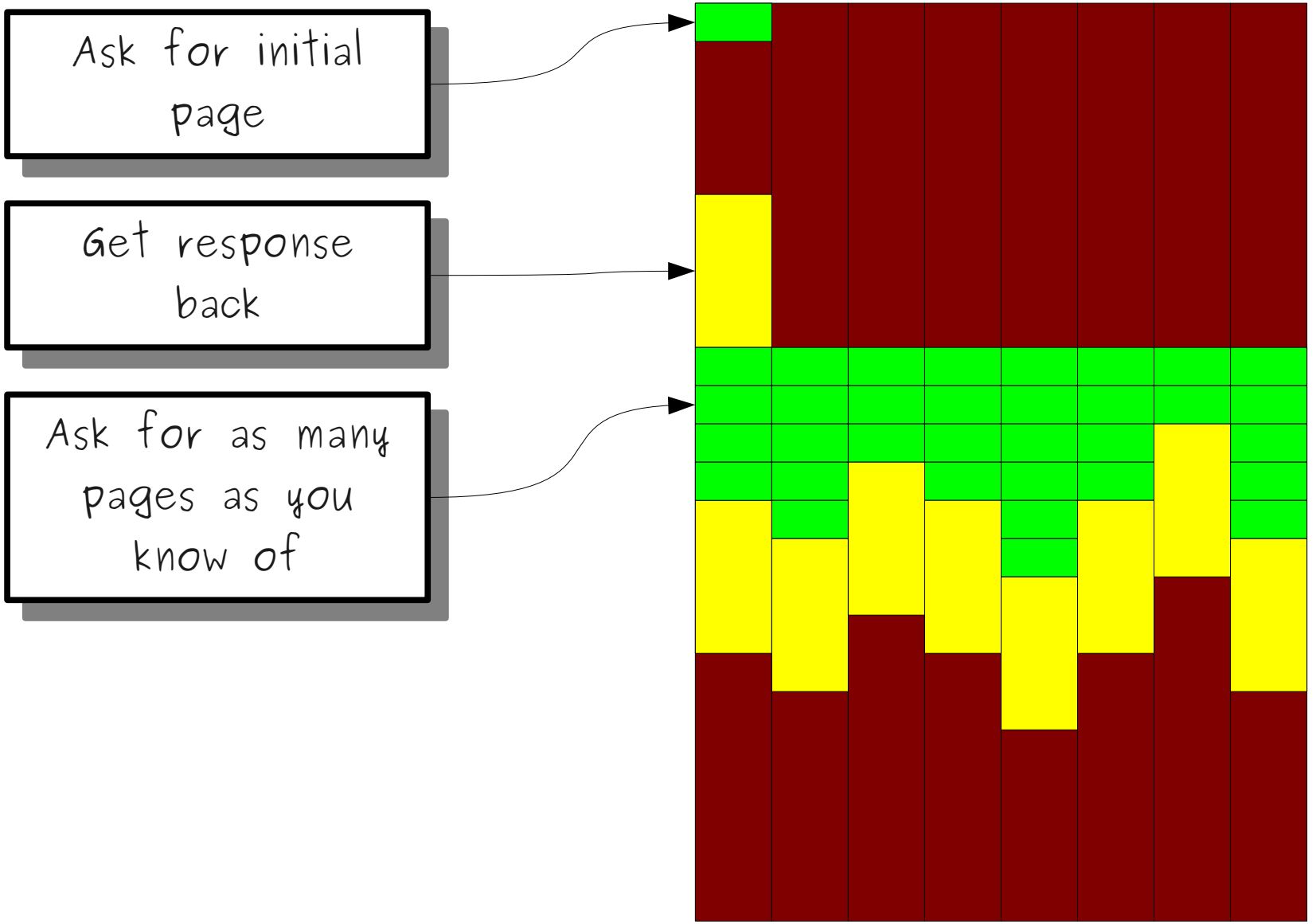

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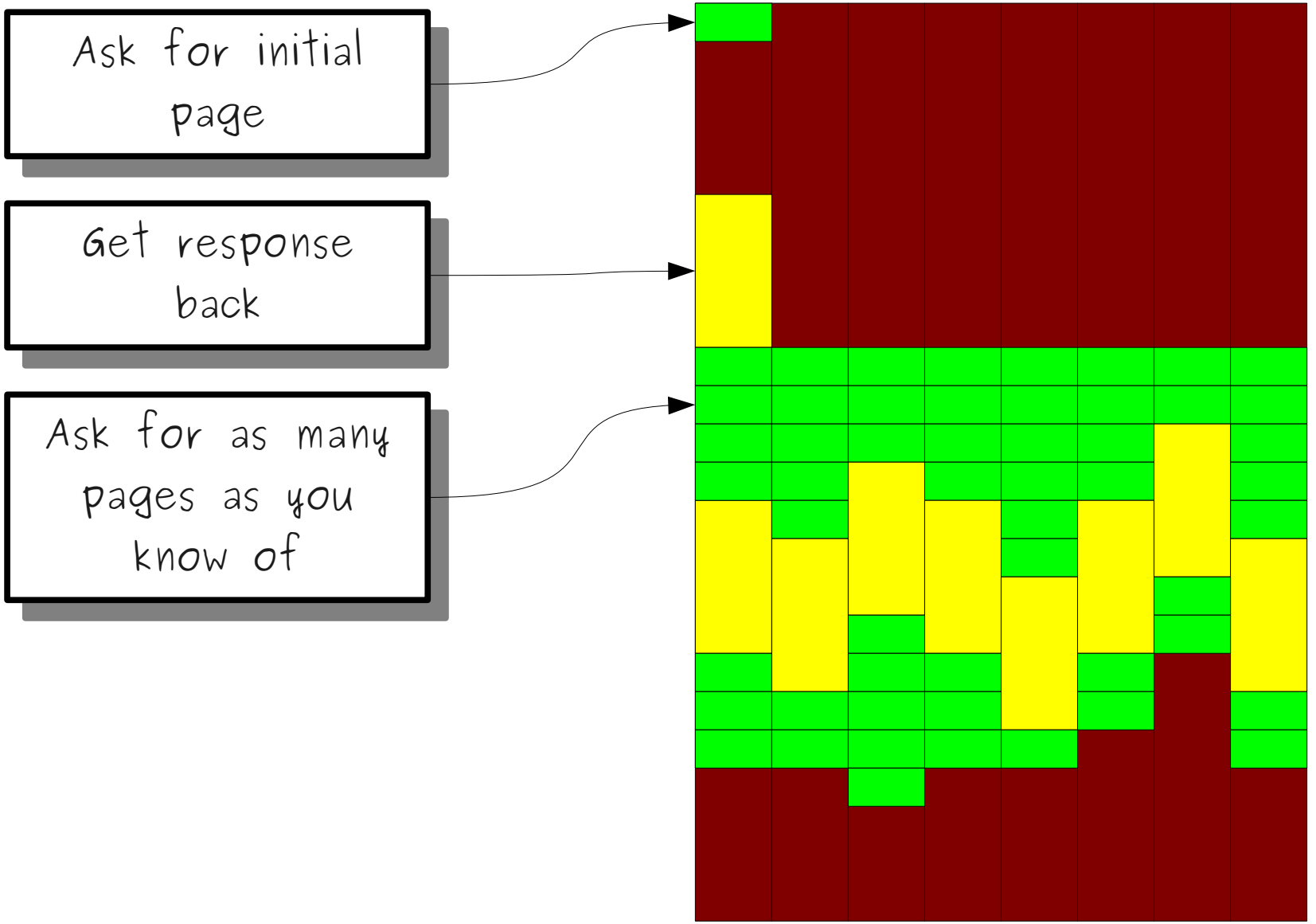

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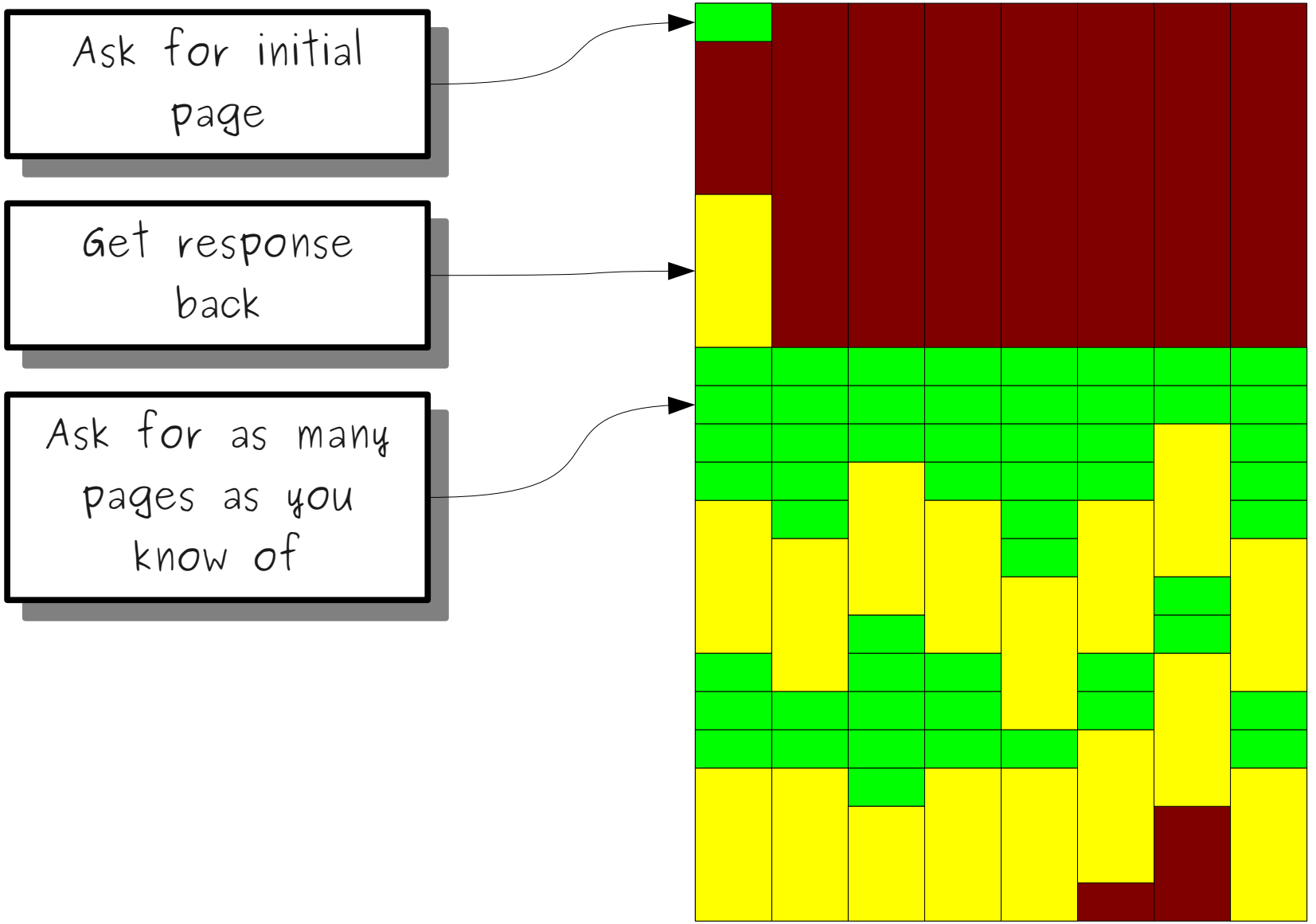

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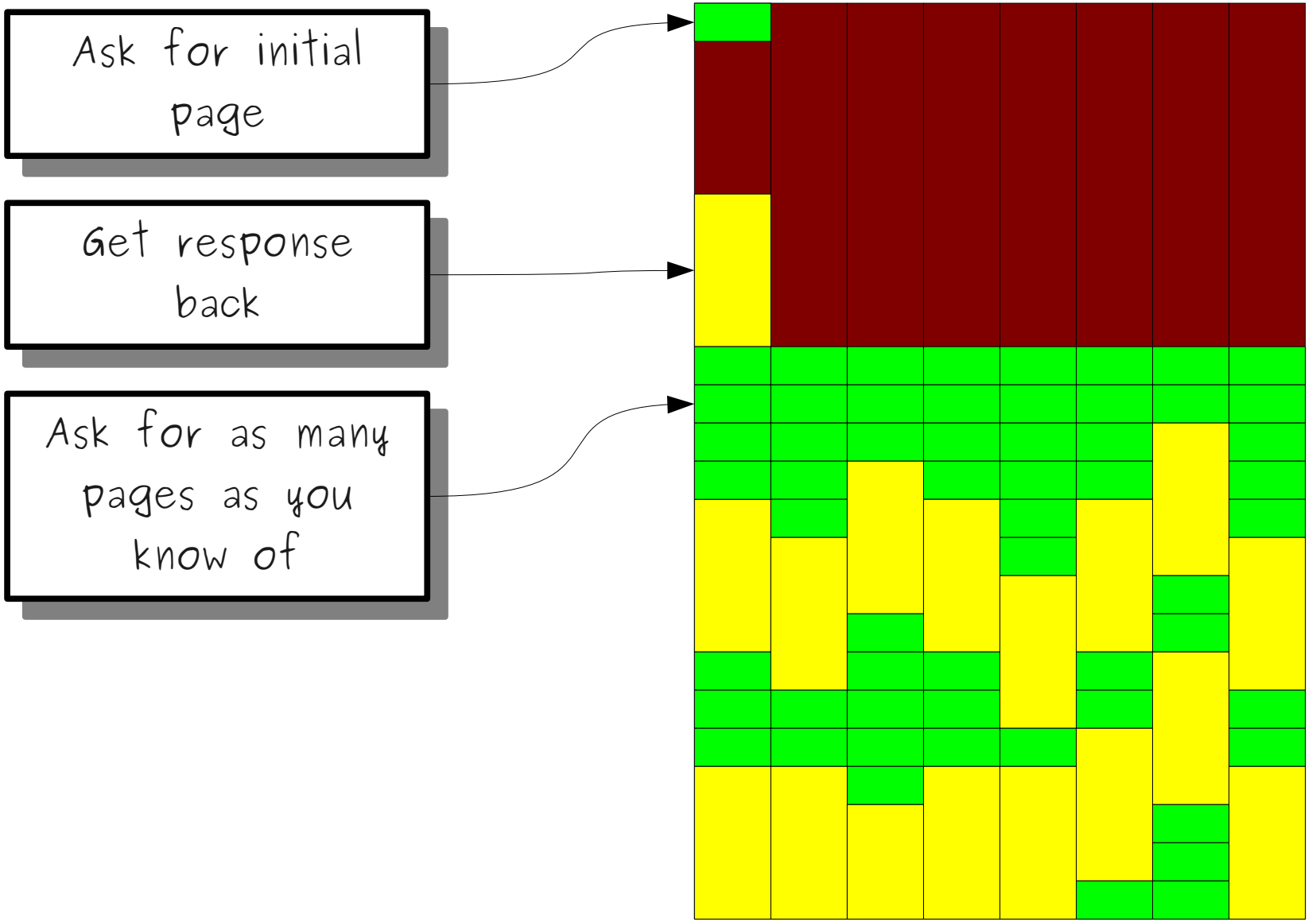

What's Happening?

- Network operations are called **I/O-bound** operations because most of the work done is waiting for I/O operations, not computation.
  - Those tasks are called **CPU-bound**.
- Having a huge number of threads improves efficiency because the computer is always working while waiting for the network.

A Parallelism Sampler

GPU Processing

CPUs and GPUs

- A CPU (**central processing unit**) is the actual hardware that runs your programs.
- A GPU (**graphics processing unit**) is a separate piece of hardware for displaying images on the screen.

CPUs versus GPUs

- A typical CPU has hardware to run between 1 – 8 threads at a time.
  - Each thread can do whatever it wants independently of the others.
- A typical GPU can run hundreds or thousands of threads at a time.
  - Each thread executes the same code as all the others, but processes different data.

GPU Parallelism

- GPUs can be used to parallelize mathematically intense tasks.
- Leads to enormous speedups.

Taking It Further...

Distributing Computing

- A **distributed system** is a system of computers that all work together to solve some large problem.
- Similar to threads – each computer works in parallel with the rest.
- Different from threads – each computer can only access its own memory.

Folding@home DISTRIBUTED COMPUTING

Client statistics by OS

OS Type	Native TFLOPS*	x86 TFLOPS*	Active CPUs	Total CPUs
Windows	218	218	210192	4231570
Mac OS X/PowerPC	2	2	3075	151743
Mac OS X/Intel	79	79	19219	171988
Linux	138	138	51043	706959
ATI GPU	2325	2453	16372	308636
NVIDIA GPU	1072	2262	6745	275700
PLAYSTATION®3	676	1426	23973	[illegible]
Total	4520	6588	337652	8214054

Looking Further

- Interested in parallelism?
- **Writing Parallel Code**:
  - CS110
  - CS149
- **Writing Distributed Systems**:
  - CS244B
- **Implementing Threads**:
  - CS140
  - CS240

Next Time

Where to Go from Here