6.1800 Spring 2025

Lecture #15: Reliability

building reliable systems from unreliable components

Katrina LaCurts | lacurts@mit.edu | 6.1800 2025

you have an exam on Thursday

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there are a lot of things you can use to study, all on the website

- lecture outlines, slides
- recitation notes
- practice exams

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the exam is open book but not open Internet. you will turn your network devices off during the exam. download everything you might need ahead of time.

6.1800 in the news

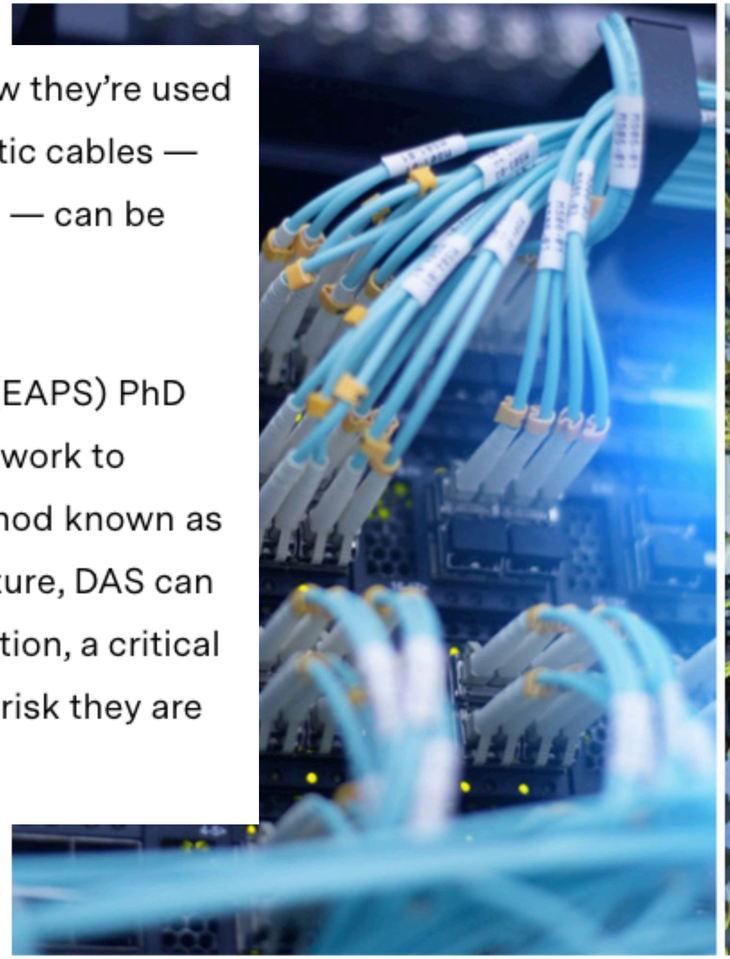
How telecommunications cables can image the ground beneath us

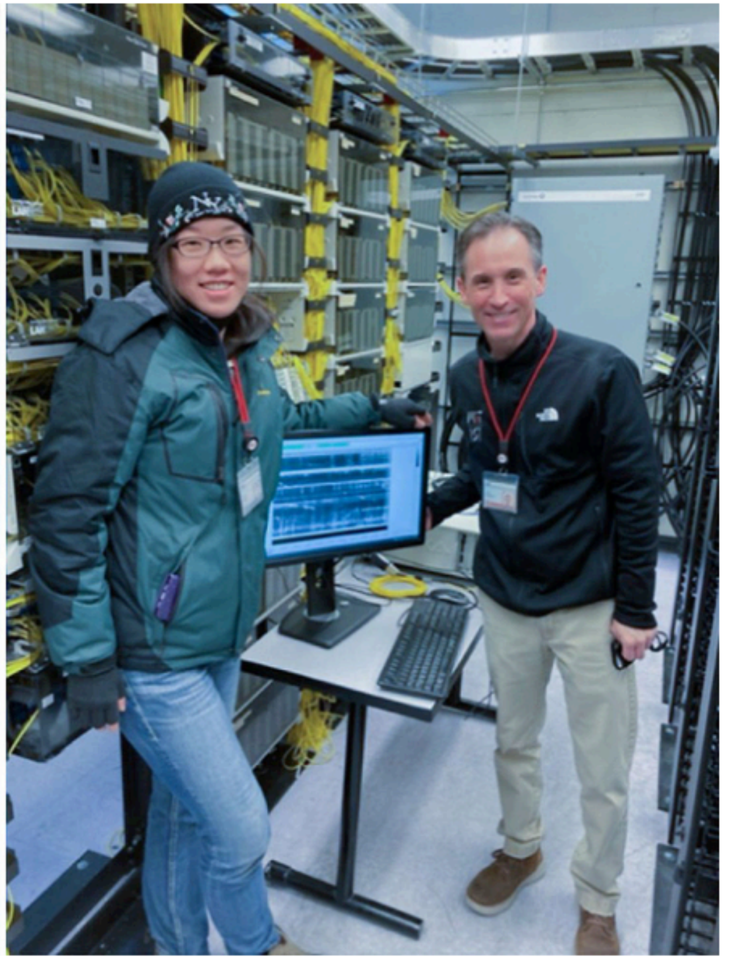
By making use of MIT's existing fiber optic infrastructure, PhD student Hilary Chang imaged the ground underneath campus, a method that can be used to characterize seismic hazards.

Paige Colley | EAPS
February 4, 2025

When people think about fiber optic cables, its usually about how they're used for telecommunications and accessing the internet. But fiber optic cables — strands of glass or plastic that allow for the transmission of light — can be used for another purpose: imaging the ground beneath our feet.

MIT Department of Earth, Atmospheric and Planetary Sciences (EAPS) PhD student Hilary Chang recently used the MIT fiber optic cable network to successfully image the ground underneath campus using a method known as distributed acoustic sensing (DAS). By using existing infrastructure, DAS can be an efficient and effective way to understand ground composition, a critical component for assessing the seismic hazard of areas, or how at risk they are from earthquake damage.





https://news.mit.edu/2025/how-telecommunications-cables-can-image-ground-beneath-us-0204

6.1800 in the news

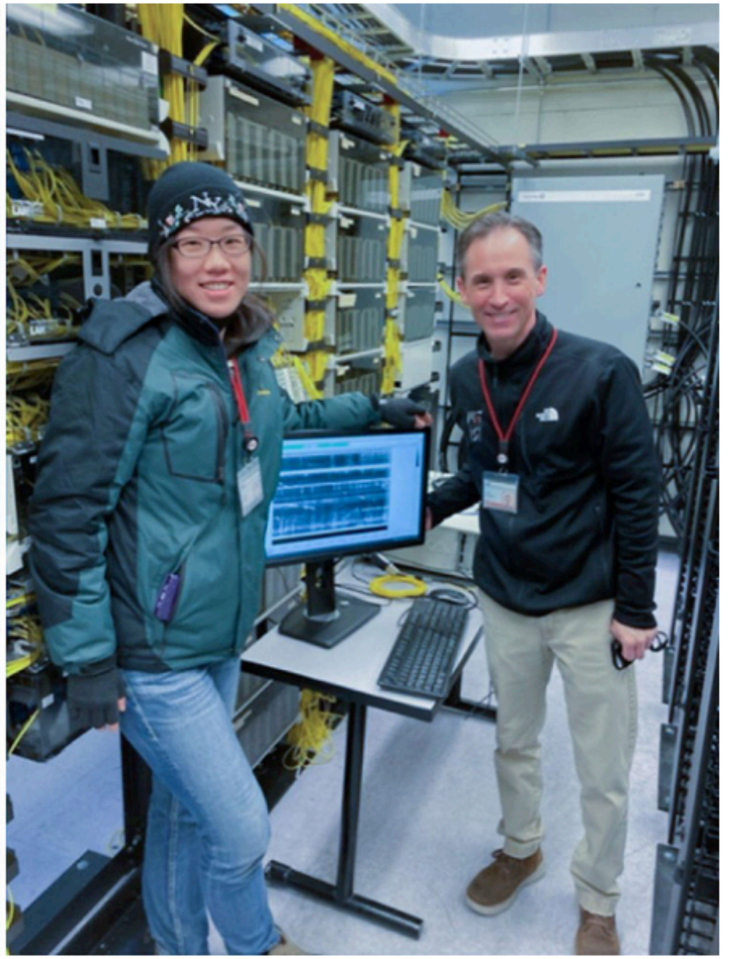
How telecommunications cables can image the ground beneath us

By making use of MIT's existing fiber optic infrastructure, PhD student Hilary Chang imaged the ground underneath campus, a method that can be used to characterize seismic hazards.

The MIT campus fiber optic system, installed from 2000 to 2003, services internal data transport between labs and buildings as well as external transport, such as the campus internet (MITNet). There are three major cable hubs on campus from which lines branch out into buildings and underground, much like a spiderweb.

The network allocates a certain number of strands per building, some of which are "dark fibers," or cables that are not actively transporting information. Each campus fiber hub has redundant backbone cables between them so that, in the event of a failure, network transmission can switch to the dark fibers without loss of network services.

DAS can use existing telecommunication cables and ambient wavefields to extract information about the materials they pass through, making it a valuable tool for places like cities or the ocean floor, where conventional sensors can't be deployed. Chang, who studies earthquake waveforms and the information we can extract from them, decided to try it out on the MIT campus.



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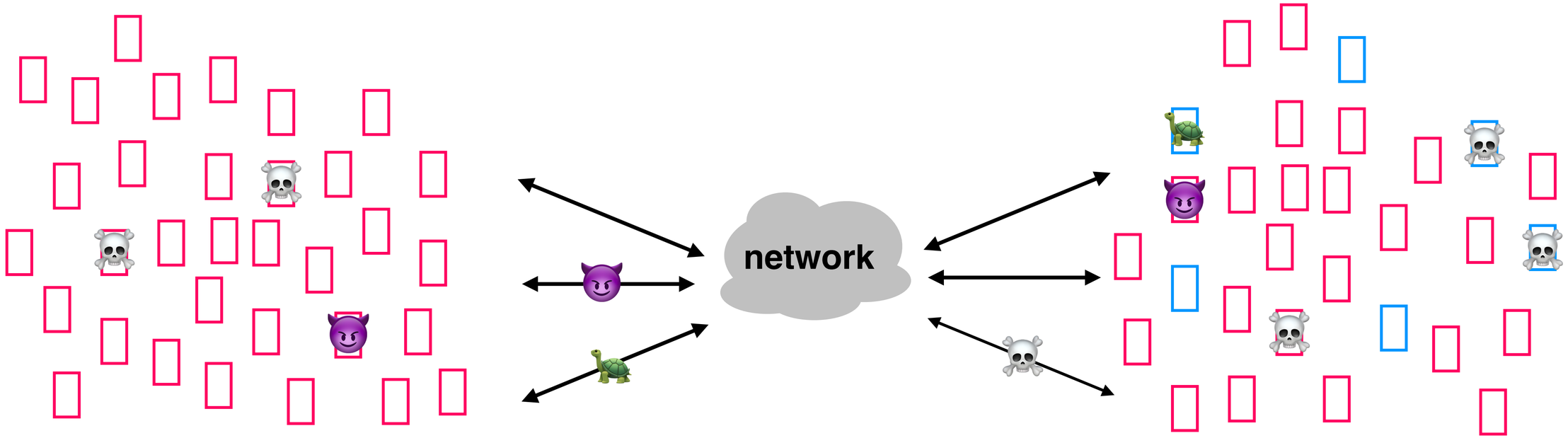
fault-tolerance/reliability: how does our system deal with failures (☠️)? machines crashing, network links breaking, etc.



security: how does our system cope in the face of targeted attacks (😈)?

performance: how do we define our performance requirements, and know if our system is meeting them? what do we do if performance is subpar (🐢)?

who is impacted by our design and implementation choices?
who makes those choices?

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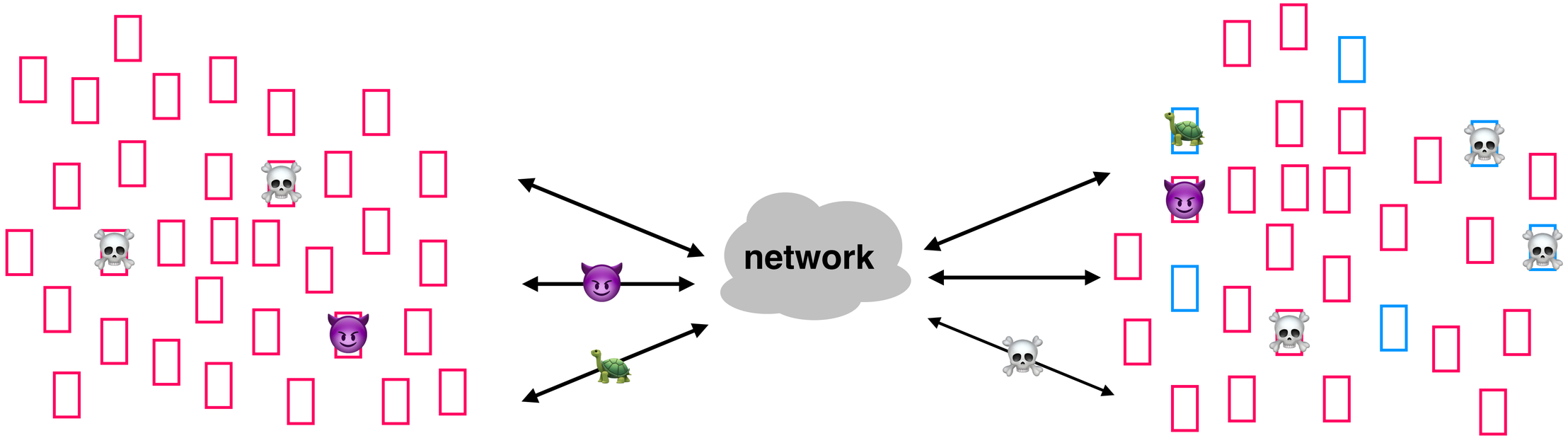

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how to build reliable systems

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how to measure success

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today we'll focus on handling disk failure

we want to make the disk as reliable as possible so that we don't lose data; we especially don't want to lose data when the machine fails (which is what will start happening in the next lecture)

2.12.1 Annualized Failure Rate (AFR) and Mean Time Between Failures (MTBF)

The product shall achieve an Annualized Failure Rate - AFR - of 0.73% (Mean Time Between Failures - MTBF - of 1.2 Million hrs) when operated in an environment that ensures the HDA case temperatures do not exceed 40°C. Operation at case temperatures outside the specifications in Section 2.9 may increase the product Annualized Failure Rate (decrease MTBF). AFR and MTBF are population statistics that are not relevant to individual units.

AFR and MTBF specifications are based on the following assumptions for business critical storage system environments:

- 8,760 power-on-hours per year.
- 250 average motor start/stop cycles per year.
- Operations at nominal voltages.
- Systems will provide adequate cooling to ensure the case temperatures do not exceed 40°C. Temperatures outside the specifications in Section 2.9 will increase the product AFR and decrease MTBF.

Nonrecoverable read errors	1 per 10^{15} bits read, max
Annualized Failure Rate (AFR)	0.73% (nominal power, 40°C case temperature)

https://www.seagate.com/staticfiles/support/disc/manuals/NL35%20Series%20&%20BC%20ES%20Series/Barracuda%20ES.2%20Series/100468393f.pdf

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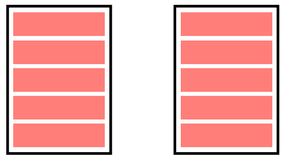
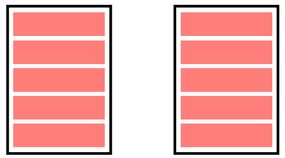
RAID 1

mirroring

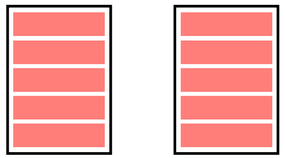


RAID 1
mirroring

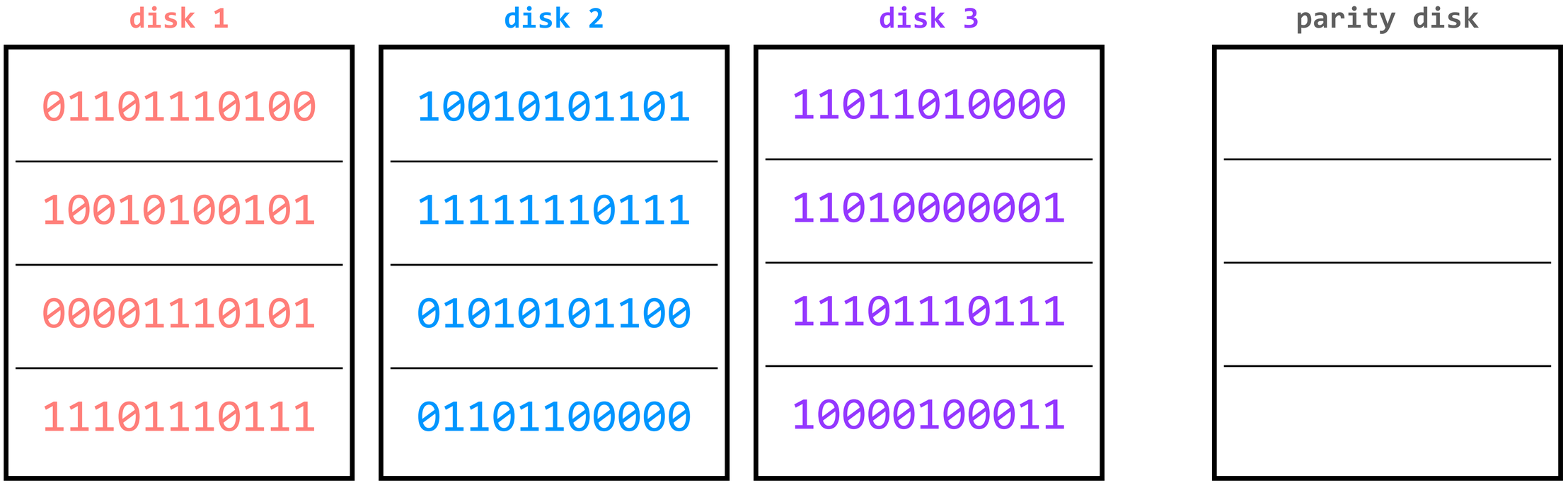


+ can recover from single-disk failure

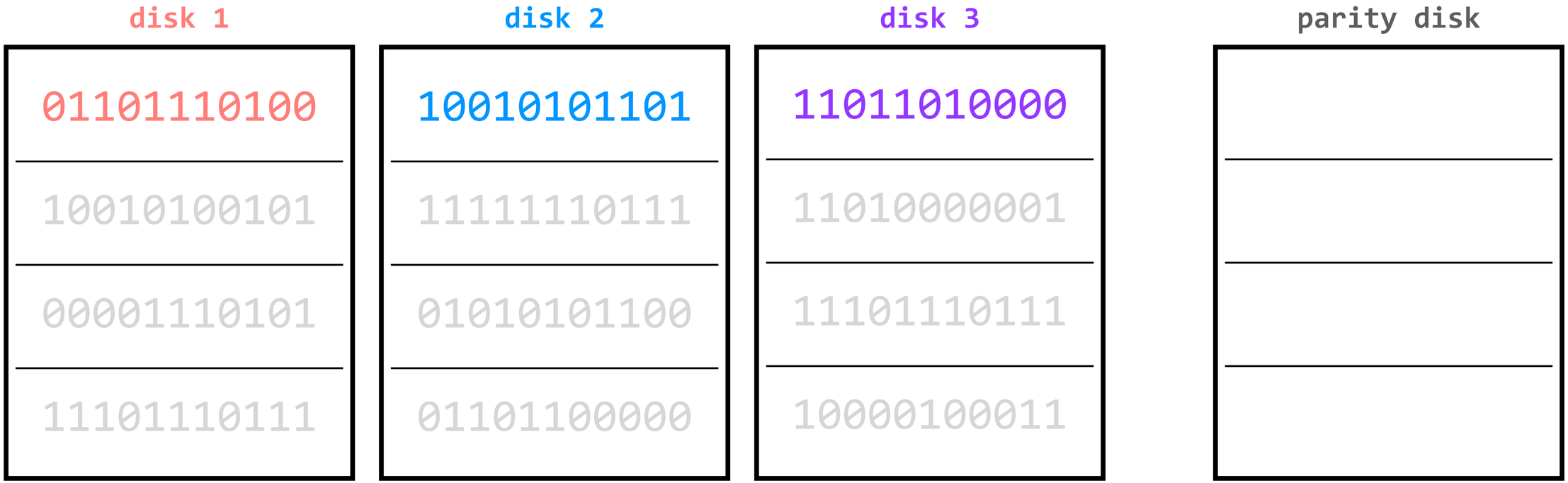
RAID 1
mirroring



+ can recover from single-disk failure
- requires 2N disks


disk 1
01101110100
10010100101
00001110101
11101110111
disk 2
10010101101
11111110111
01010101100
01101100000
disk 3
11011010000
11010000001
11101110111
10000100011
parity disk

xor sector 1 from each disk to get sector 1 on the parity disk



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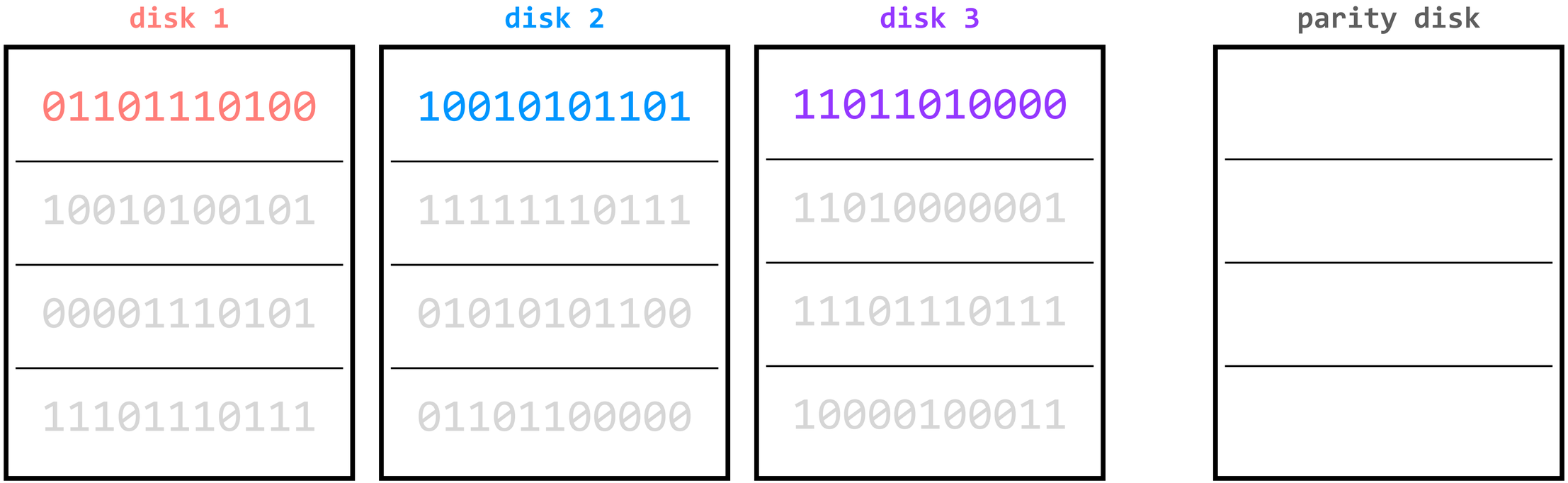

$$
\begin{array}{r}
01101110100 \\
10010101101 \\
\oplus\ 11011010000 \\
\hline
\end{array}
$$

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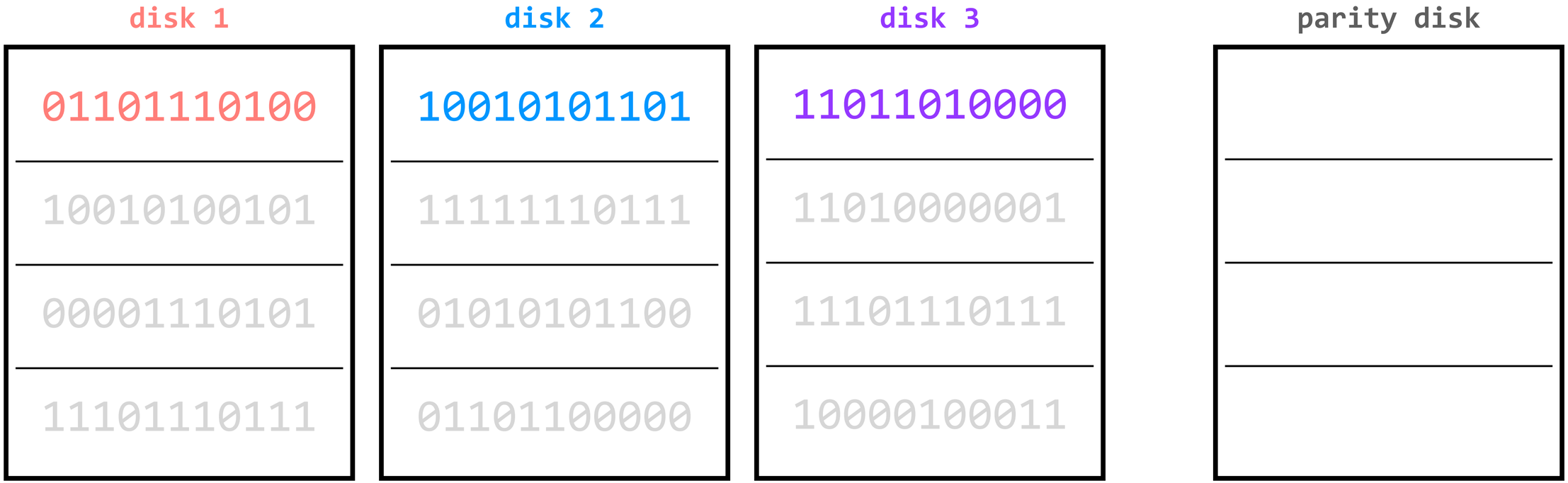


```
  01101110100
  10010101101
⊕ 11011010000
-------------
  00100001001
```

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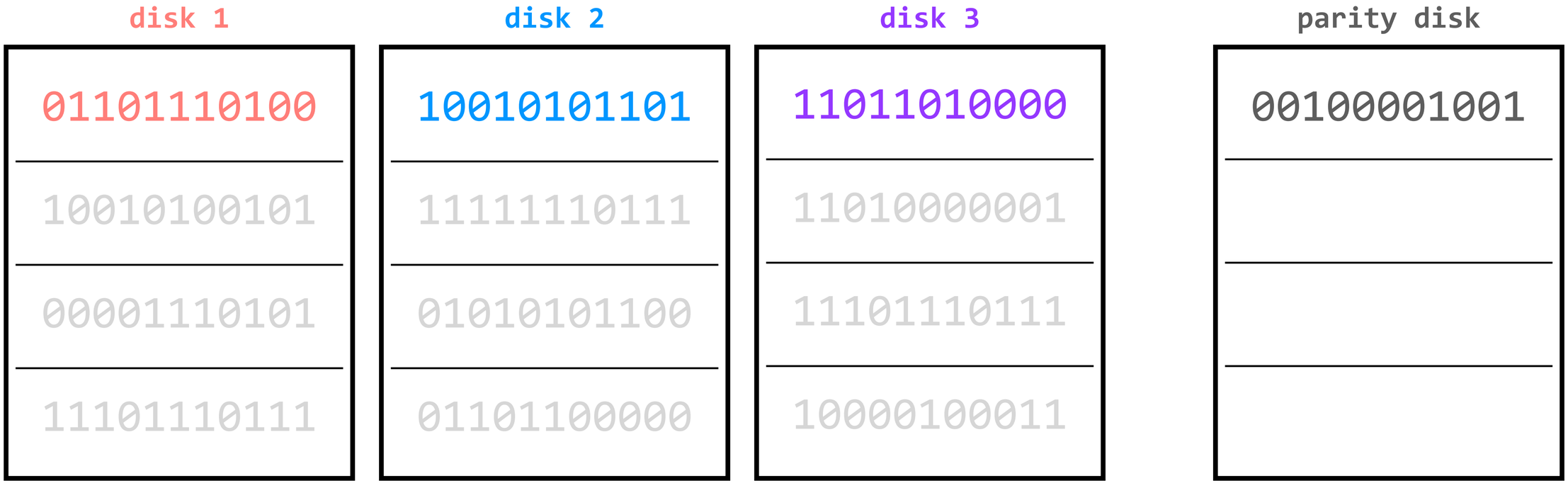
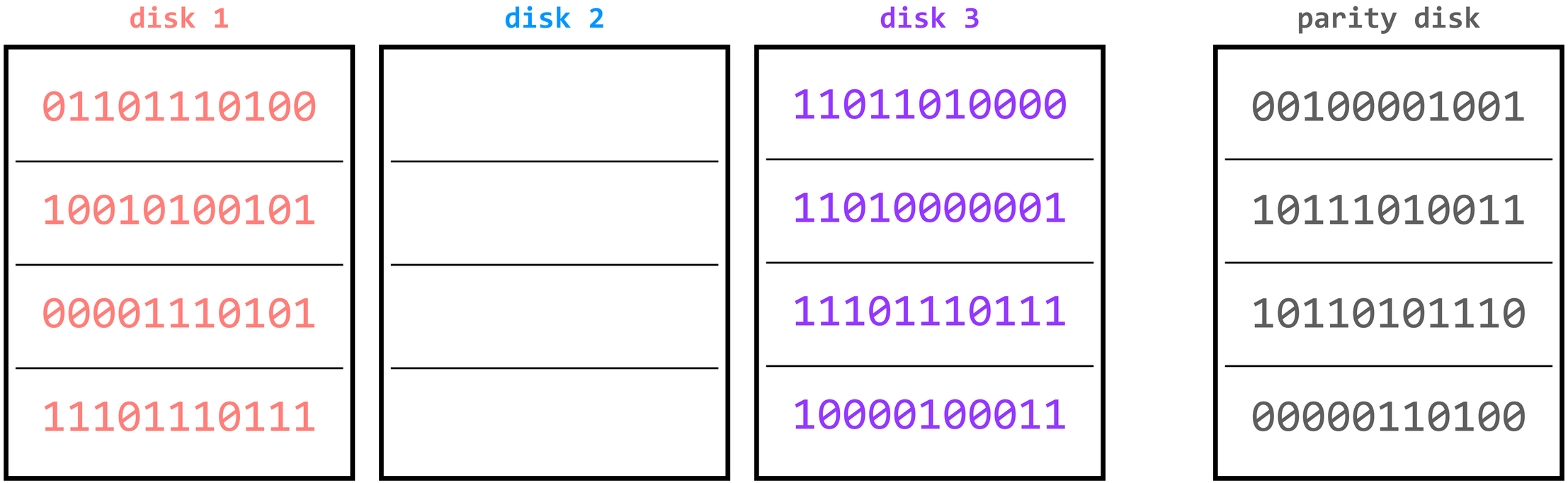


xor sector *i* from each disk to get sector *i* on the parity disk

disk 1	disk 2	disk 3	parity disk
01101110100	10010101101	11011010000	00100001001
10010100101	11111110111	11010000001	10111010011
00001110101	01010101100	11101110111	10110101110
11101110111	01101100000	10000100011	00000110100

suppose disk 2 fails, and after recovery, all data has been lost



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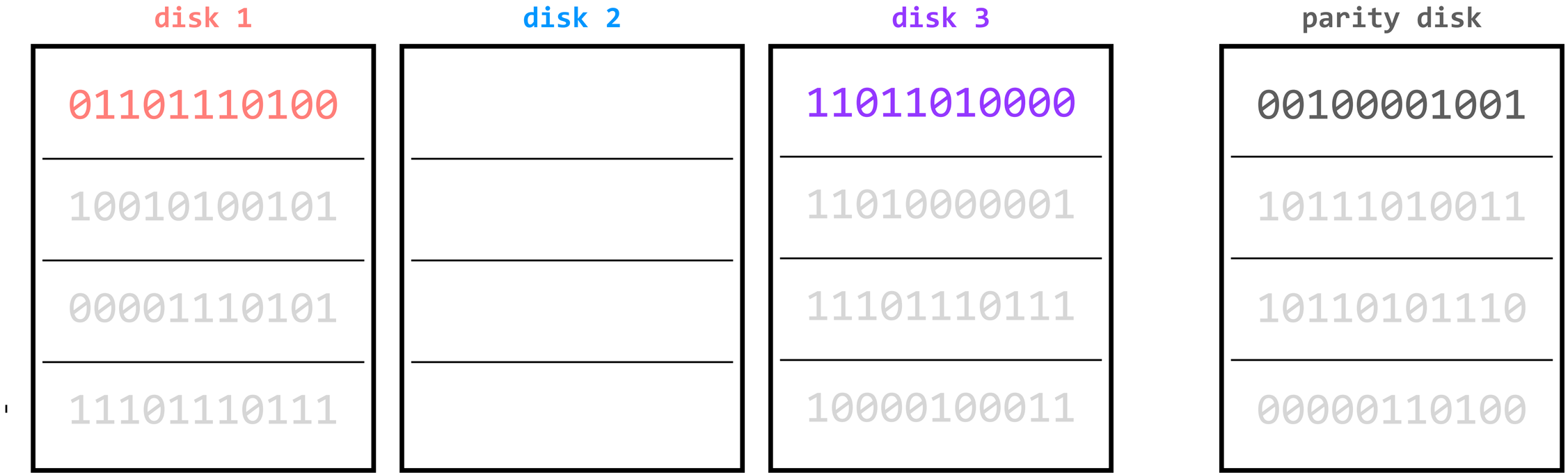

xor sector 1 from the remaining disks to recover sector 1 on the failed disk

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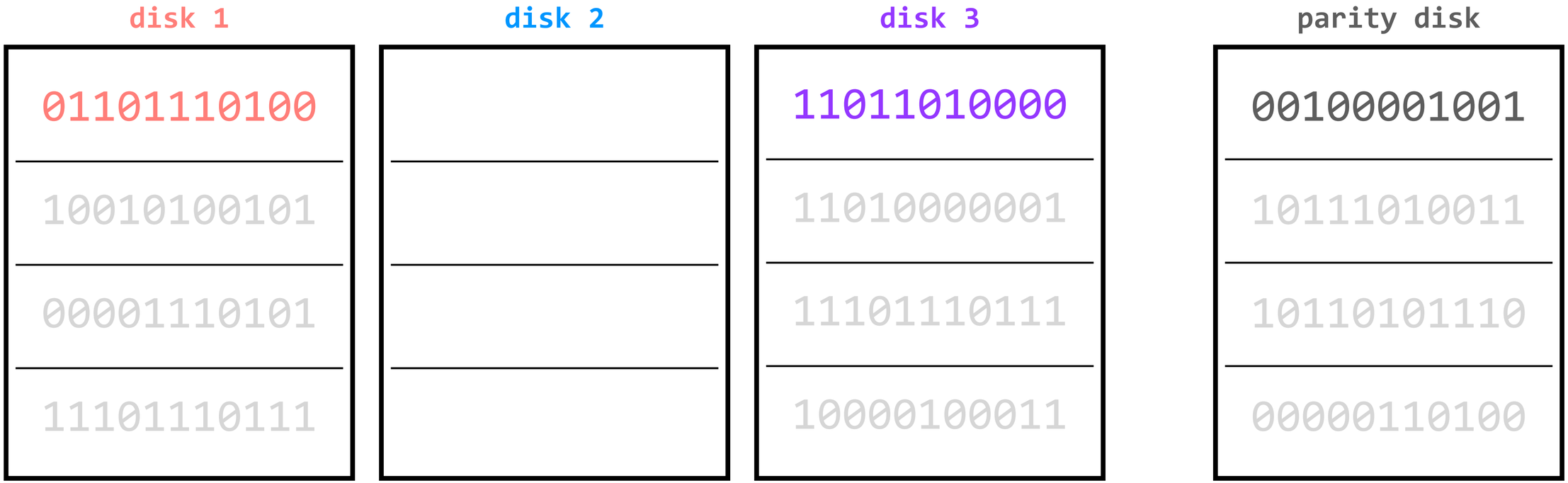

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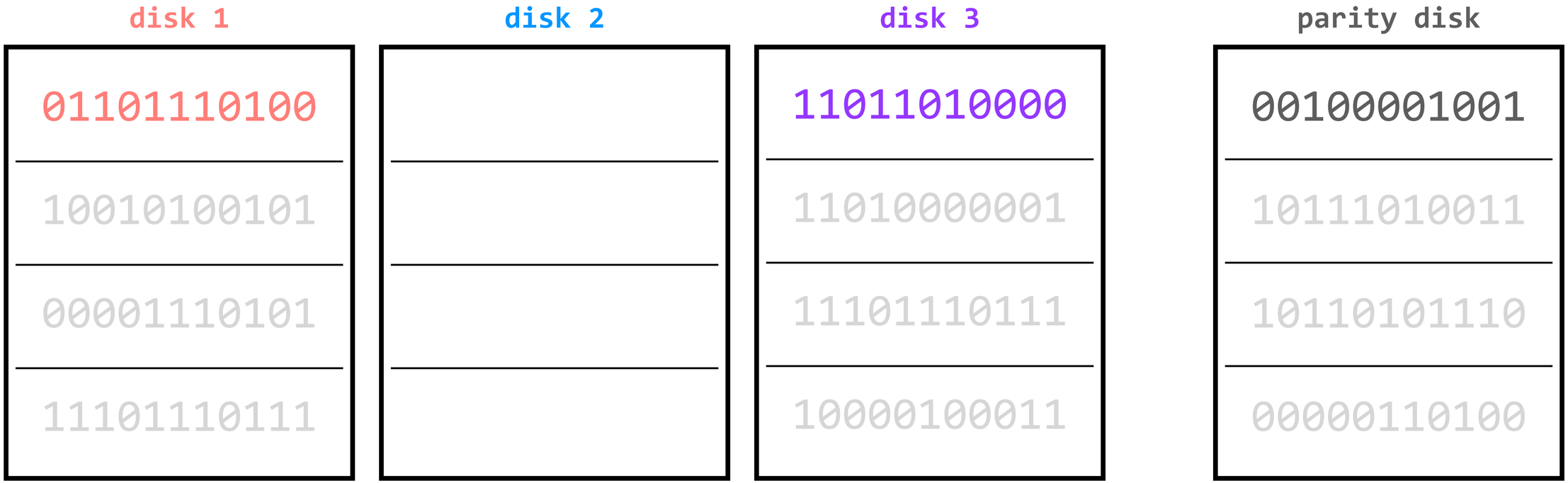

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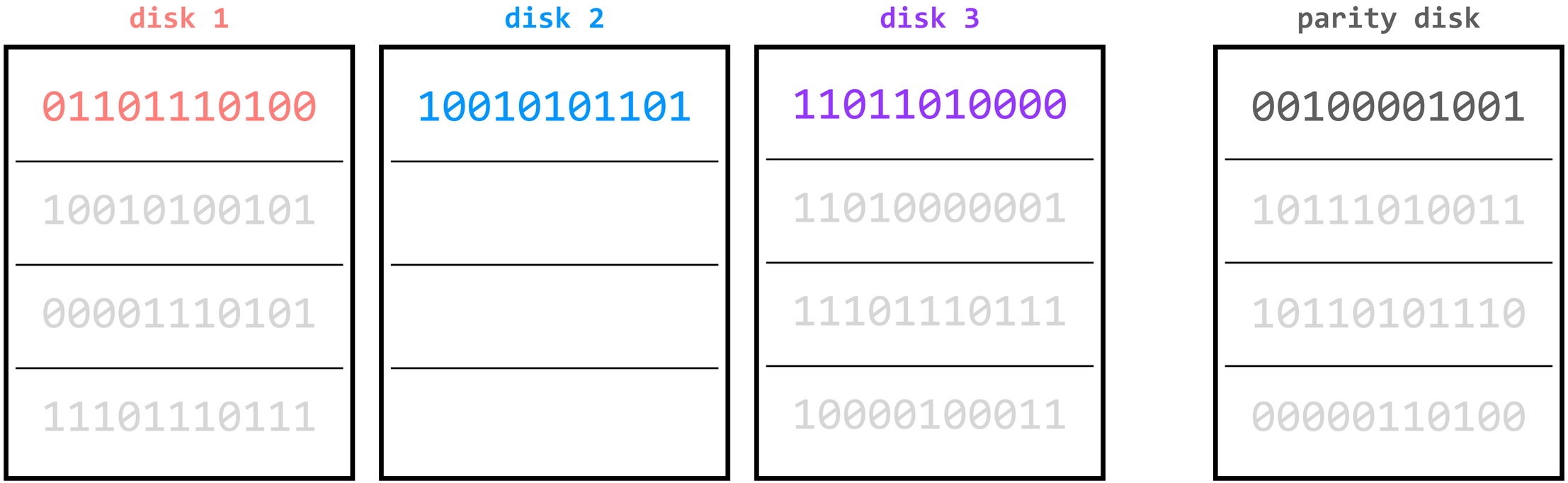

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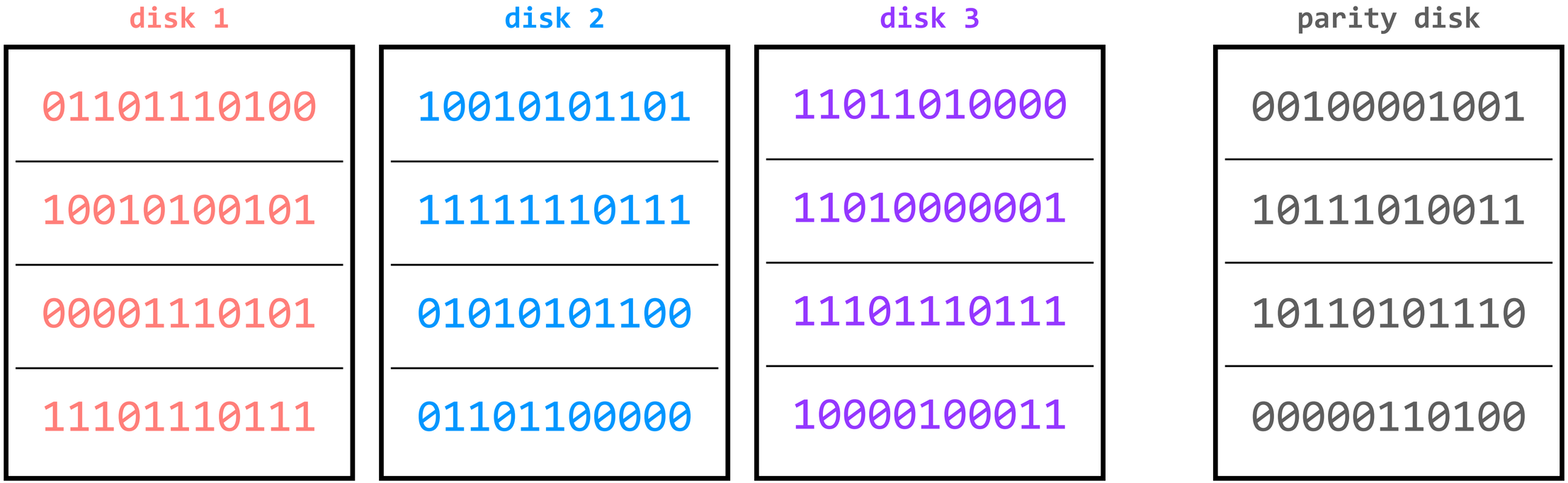

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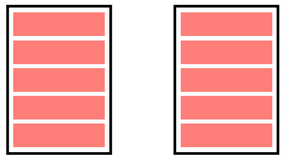
RAID 1

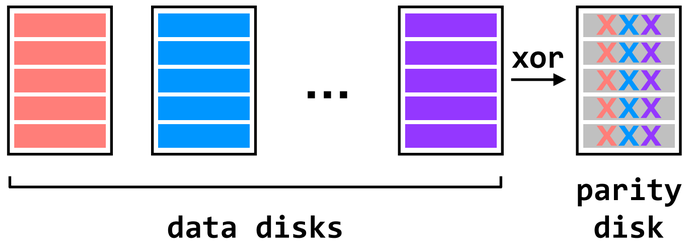
mirroring



+ can recover from single-disk failure
- requires 2N disks

RAID 4

dedicated parity disk



sector i of the parity disk is the xor of sector i from all data disks

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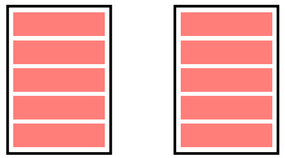
mirroring



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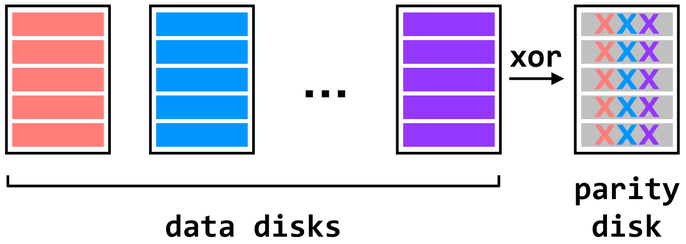

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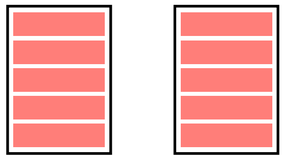

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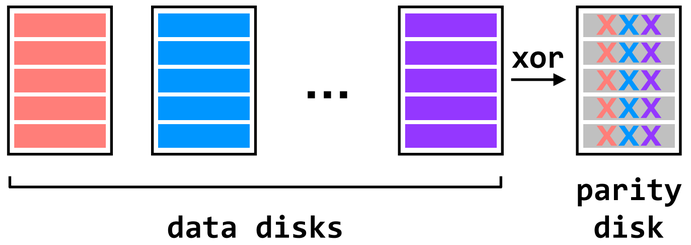
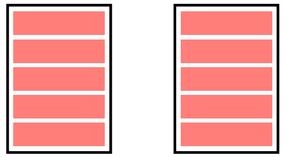


sector i of the parity disk is the xor of sector i from all data disks

+ can recover from single-disk failure
+ requires N+1 disks

RAID 1

mirroring



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RAID 4

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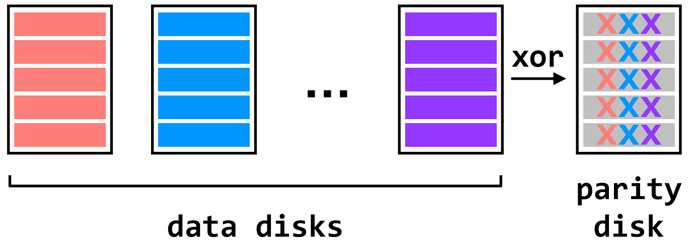

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+ can recover from single-disk failure
+ requires N+1 disks
+ performance benefits if you stripe a single file across multiple data disks

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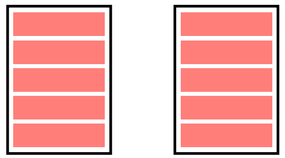

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- requires 2N disks

RAID 4
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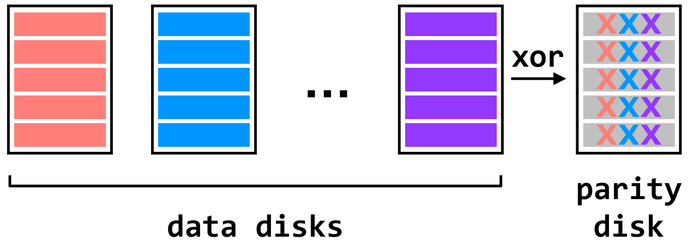

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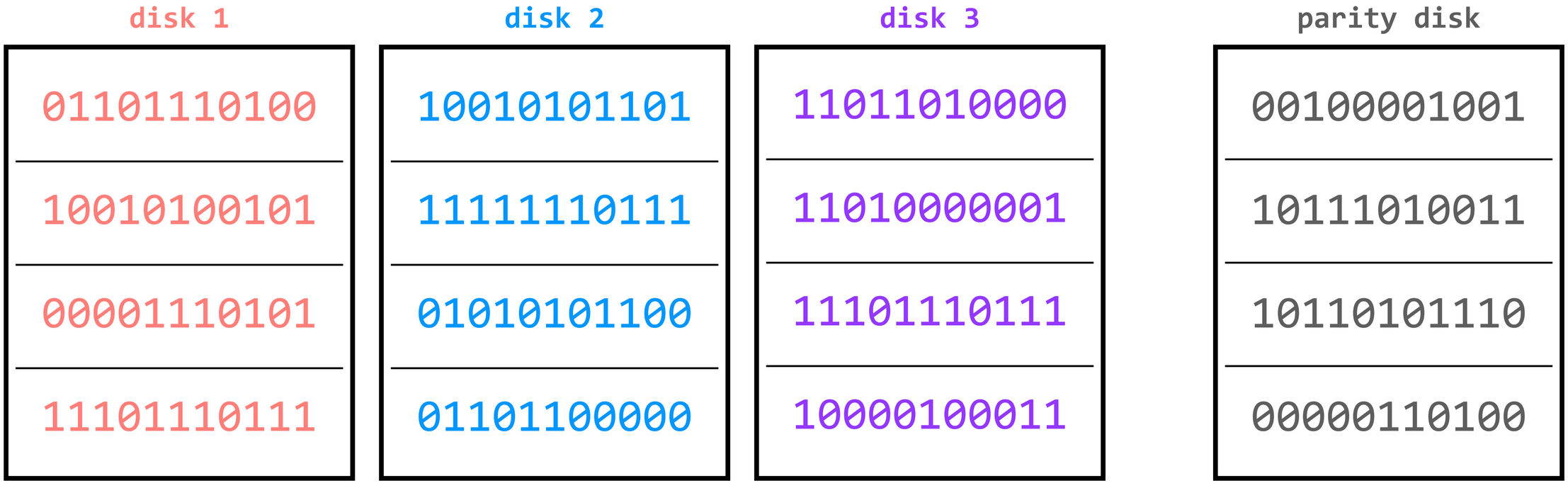
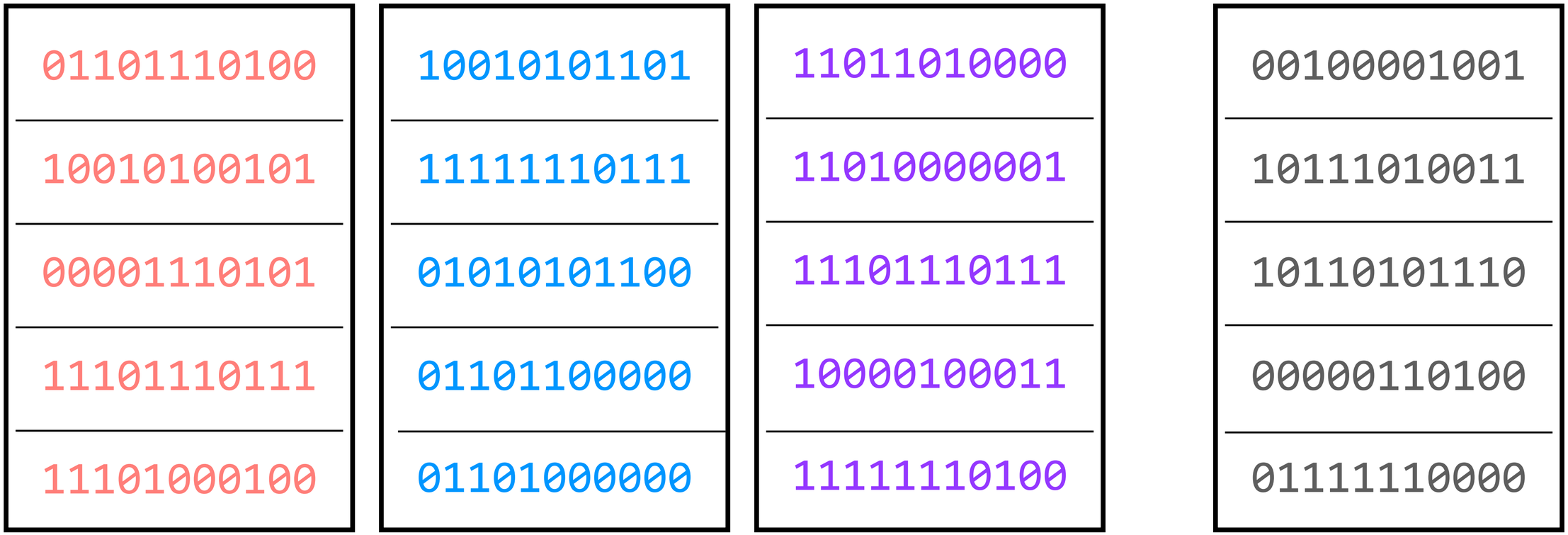
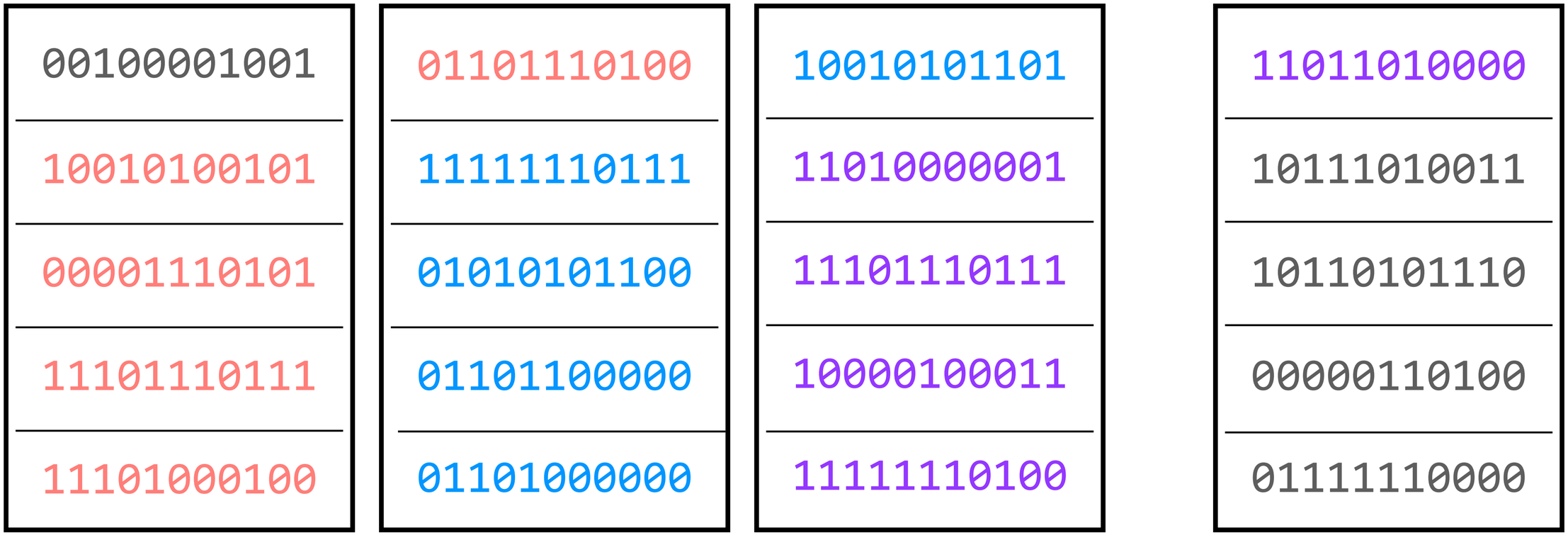
+ can recover from single-disk failure
+ requires N+1 disks
+ performance benefits if you stripe a single file across multiple data disks
- all writes go to the parity disk


disk 1
01101110100
10010100101
00001110101
11101110111
disk 2
10010101101
11111110111
01010101100
01101100000
disk 3
11011010000
11010000001
11101110111
10000100011
parity disk
00100001001
10111010011
10110101110
00000110100



we’re adding a fifth sector to each disk to better illustrate how to spread out the parity sectors



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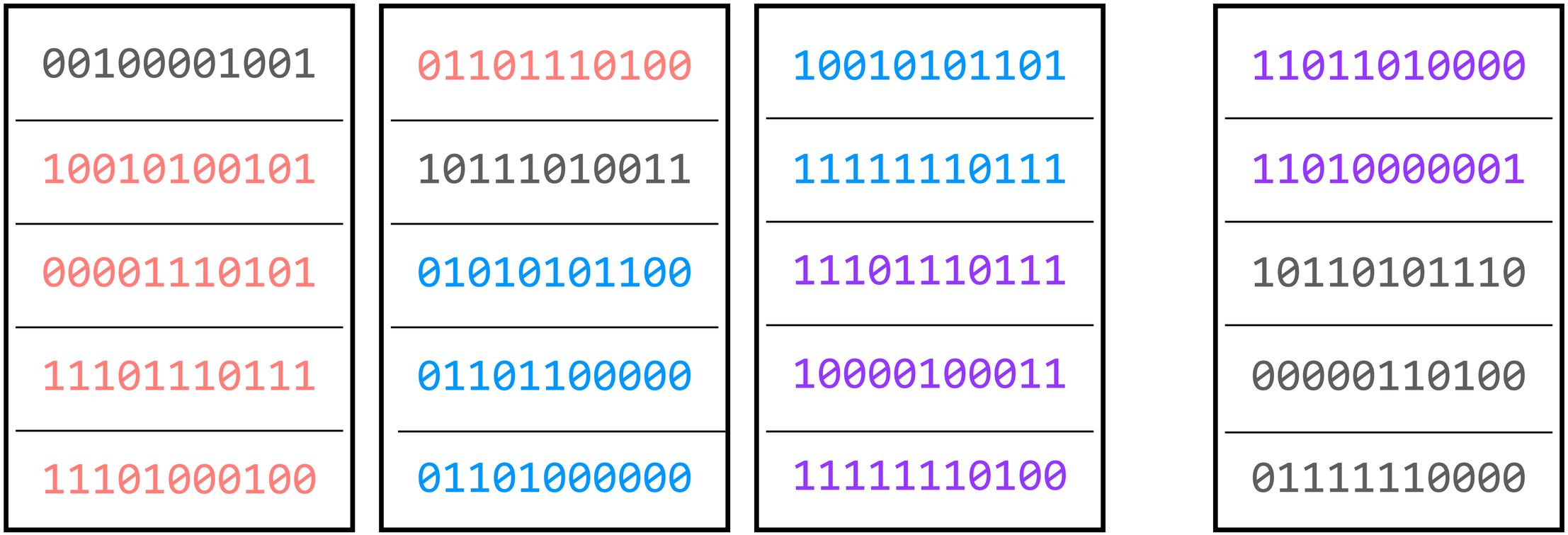

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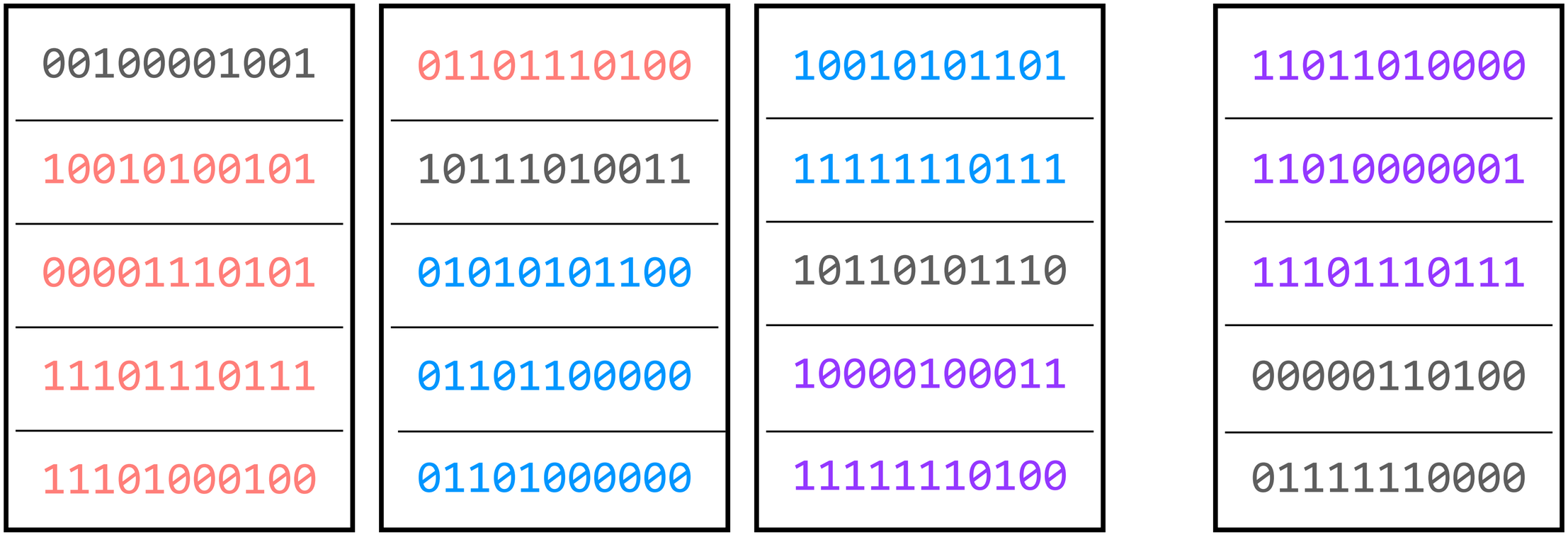

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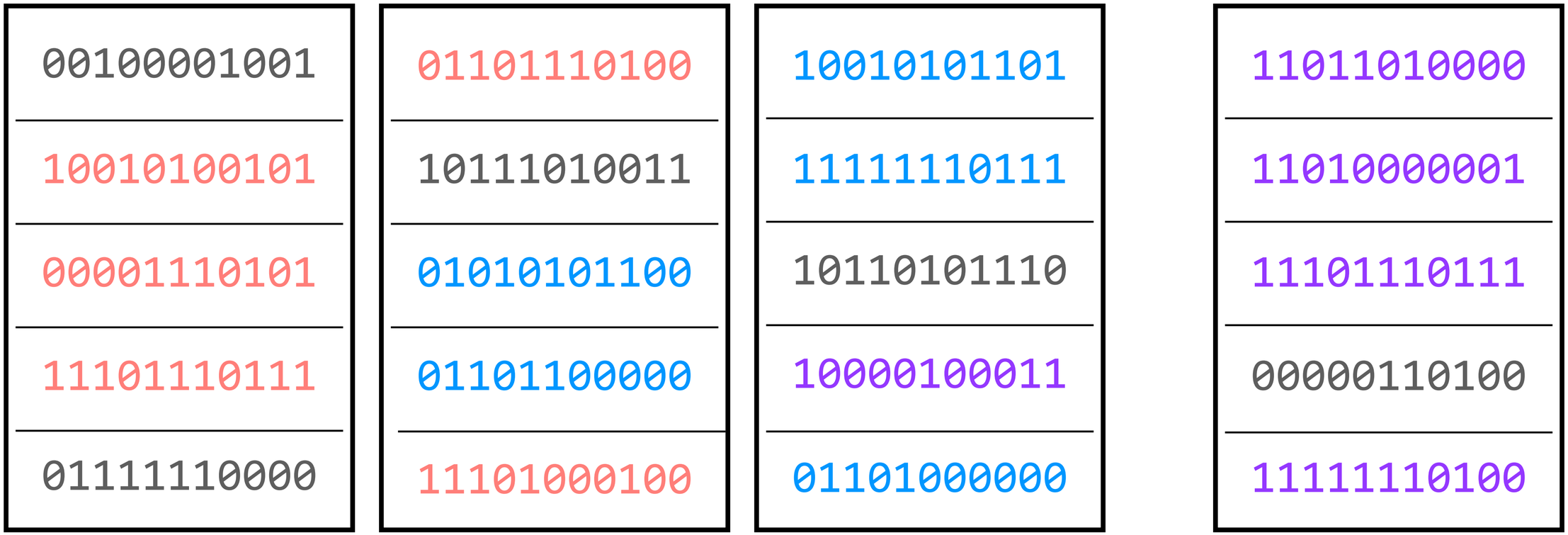

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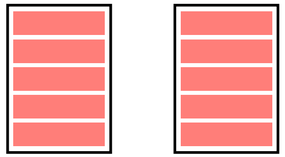
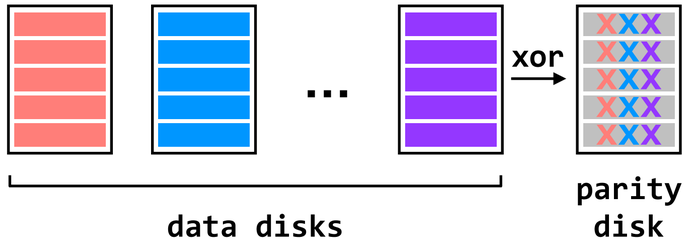
RAID 1
mirroring



+ can recover from single-disk failure
- requires 2N disks

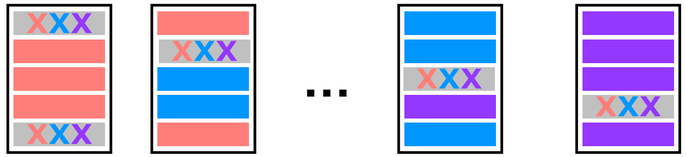
RAID 4
dedicated parity disk



sector i of the parity disk is the xor of sector i from all data disks

+ can recover from single-disk failure
+ requires N+1 disks
+ performance benefits if you stripe a single file across multiple data disks
- all writes go to the parity disk

RAID 5
spread out the parity



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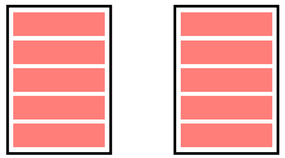
mirroring



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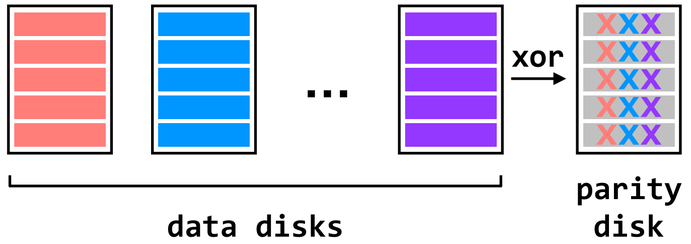

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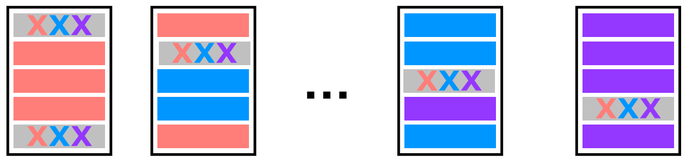

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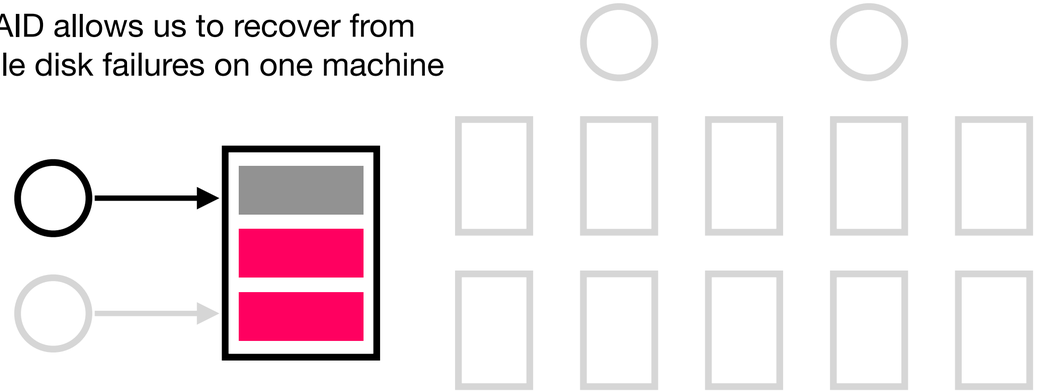

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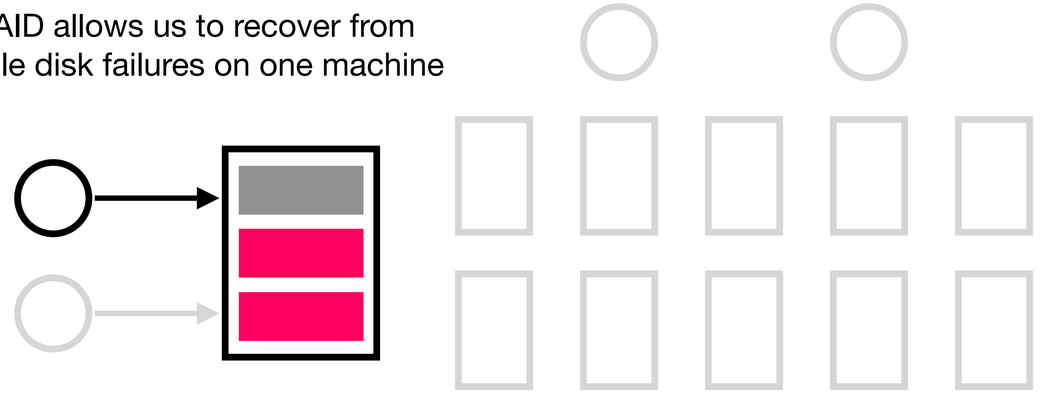

the high-level process of dealing with failures is to identify the faults, detect/contain the faults, and handle the faults. in lecture, we will build a set of abstractions to make that process more manageable

this slide — which we'll start and end on in each lecture — will get more involved as that goes along

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RAID replicates data across disks on a single machine in a smart way. RAID 5 protects against single-disk failures while maintaining good performance.

one can extend the ideas in RAID to protect against multiple disk failures. RAID 6 does this, for example