https://hao-ai-lab.github.io/dsc204a-f25/

DSC 204A: Scalable Data Systems
Fall 2025

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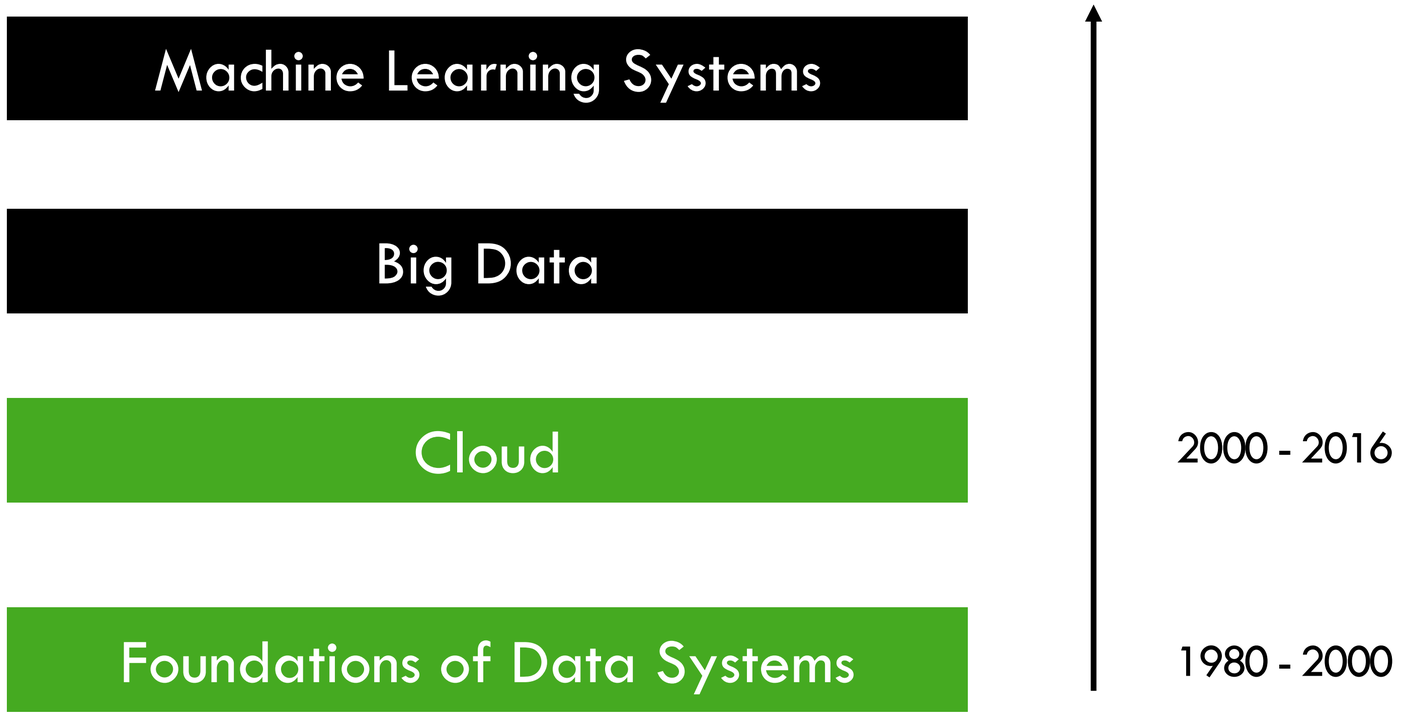
Where We Are


Machine Learning Systems
Big Data
Cloud
Foundations of Data Systems
2000 - 2016
1980 - 2000

Logistics

- BoQ Survey completion rate: 107%
  - All of you will get 1 bonus point
- Overall Feedback
  - Want more advanced stuff, less basics
  - Want to learn ML/LLM Systems (Many expect >= 30% content on it)
  - Want me to lecture slower
- Waitlisted Students:
  - Please get in touch with me/TA to get enrolled (there should be room now)

Evolution of Cloud Infrastructure

- Data Center: Physical space from which a cloud is operated
- 3 generations of data centers/clouds:
  - Cloud 1.0 (Past)
  - Cloud 2.0 (Current)
  - Cloud 3.0 (Ongoing Research)

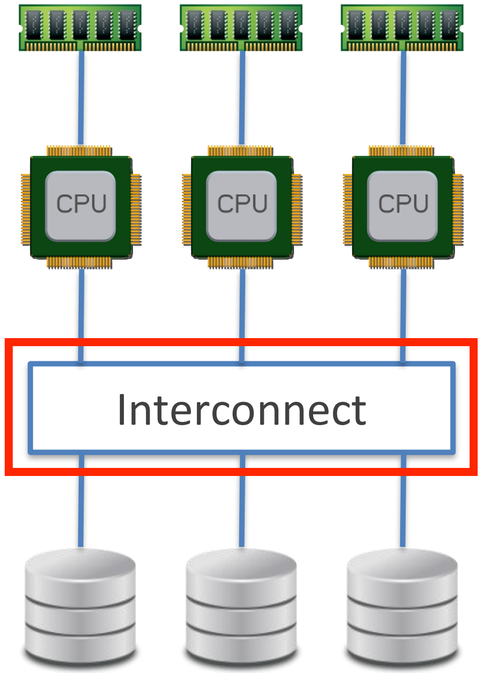
Cloud 1.0 (Past)

- Networked servers;
- User rents servers (time-sliced access) needed for data/software

Cloud 2.0 (Current)

- “Virtualization” of networked servers;
- User rents amount of resource capacity (e.g., memory, disk);
- Cloud provider has a lot more flexibility on provisioning (multi-tenancy, load balancing, more elasticity, etc.)

Parallelism in the Cloud



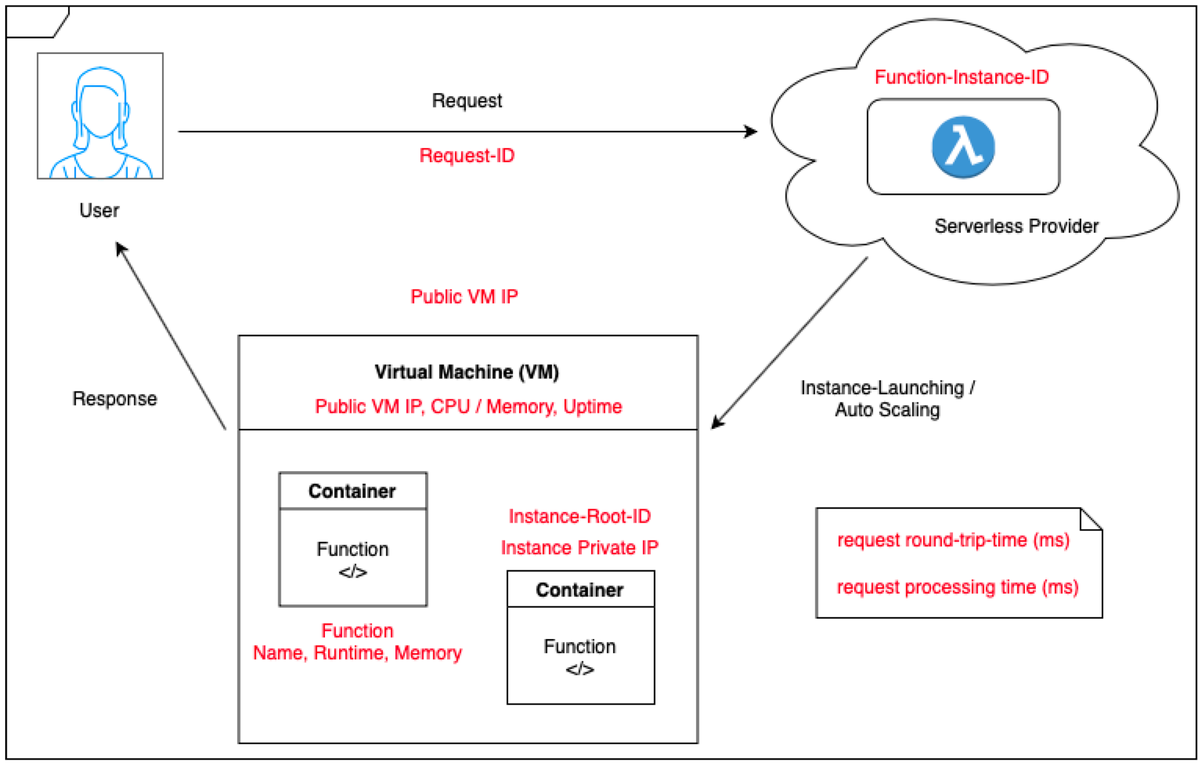
Shared-Disk Parallelism

Modern networks in data centers have become much faster: 100GbE to even TbE!

- Decoupling of compute+memory from storage is common in cloud
  - *Hybrids* of shared-disk parallelism + shared-nothing parallelism
  - E.g, store datasets on S3 and read as needed to local EBS

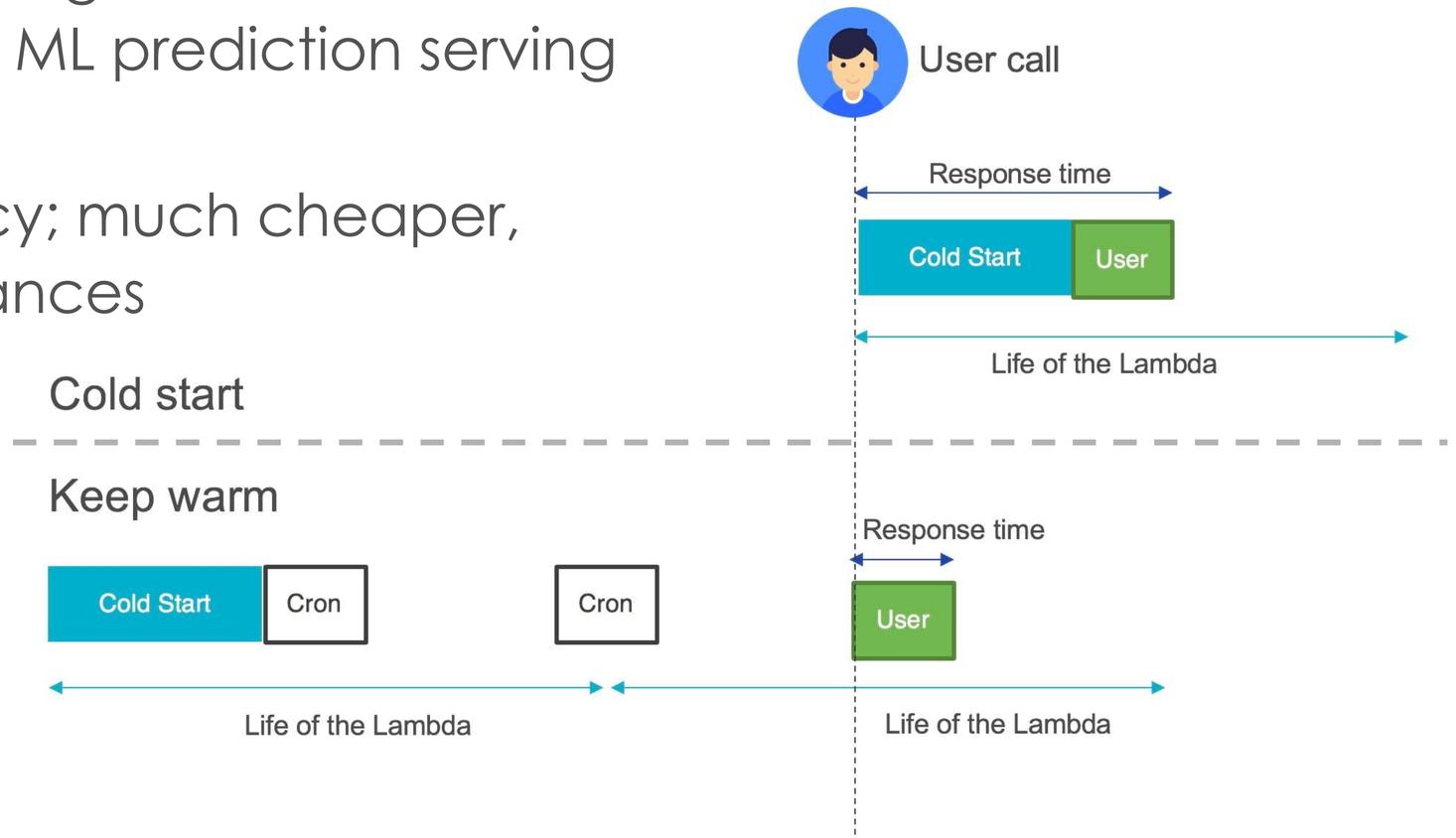
Cloud 3.0 (Ongoing Research)

- Full resource disaggregation! That is, compute, memory, storage, etc. are all network-attached and elastically added/removed
- User gives a program (function) to run and specifies CPU and DRAM needed
- Cloud provider abstracts away all resource provisioning entirely
- Aka *Function-as-a-Service* (FaaS)



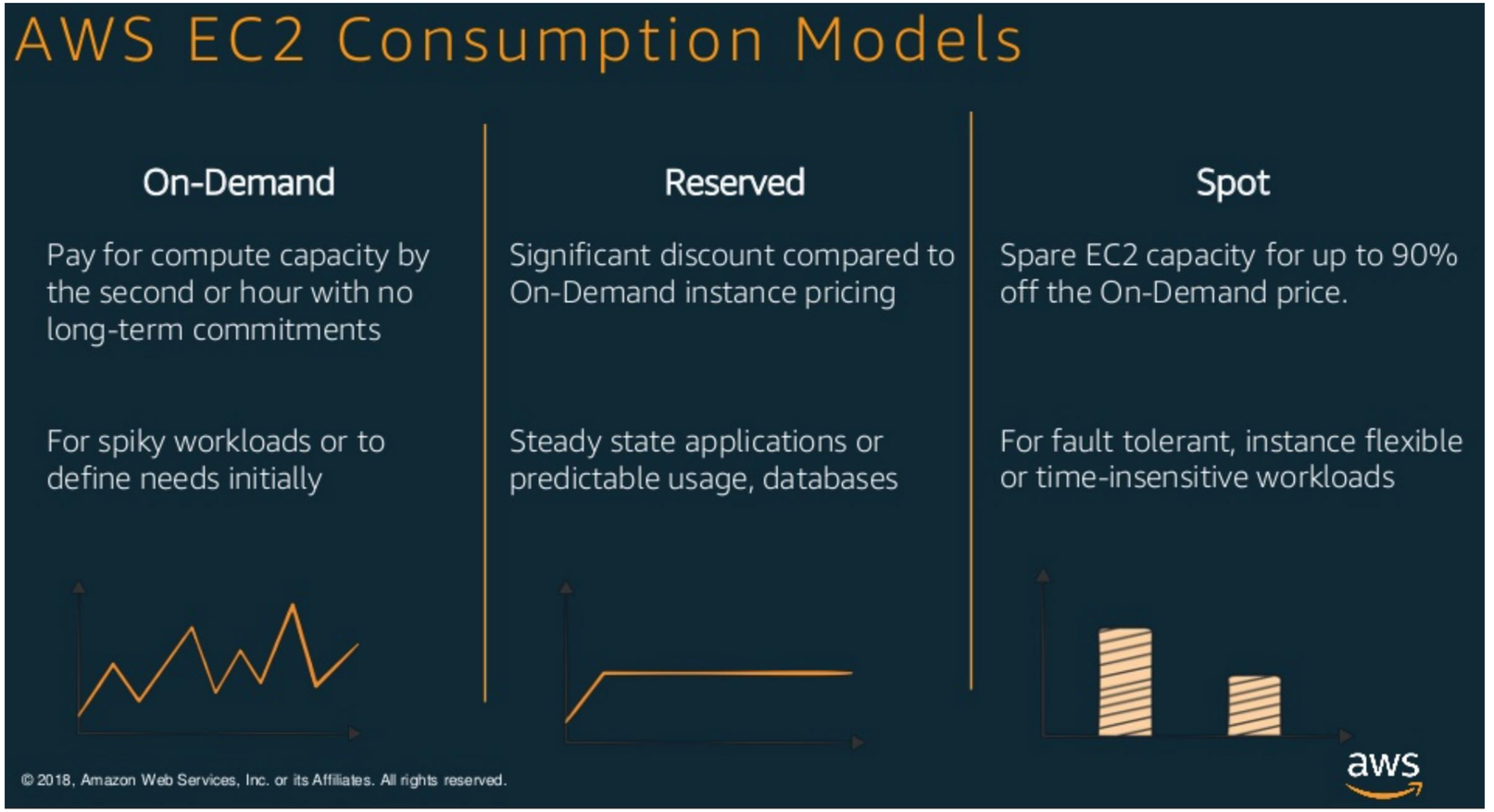
Cloud 3.0 (Ongoing Research)

- "Serverless" and disaggregated resources all connected to fast networks
- Serverless paradigm gaining traction for some applications, e.g., online ML prediction serving on websites
- Higher resource efficiency; much cheaper, often by 10x vs Spot instances



New Cloud Renting Paradigms

- Cloud 2.0's flexibility enables radically different paradigms
- AWS example below; Azure and GCP have similar gradations



https://www.slideshare.net/AWSUsersGroupBengalu/amazon-ec2-spot-instances

More on Spot vs On-Demand

	Spot Instances	On-Demand Instances
Launch time	Can only be launched immediately if the Spot Request is active and capacity is available.	Can only be launched immediately if you make a manual launch request and capacity is available.
Available capacity	If capacity is not available, the Spot Request continues to automatically make the launch request until capacity becomes available.	If capacity is not available when you make a launch request, you get an insufficient capacity error (ICE).
Hourly price	The hourly price for Spot Instances varies based on demand.	The hourly price for On-Demand Instances is static.
Rebalance recommendation	The signal that Amazon EC2 emits for a running Spot Instance when the instance is at an elevated risk of interruption.	You determine when an On-Demand Instance is interrupted (stopped, hibernated, or terminated).
Instance interruption	You can stop and start an Amazon EBS-backed Spot Instance. In addition, the Amazon EC2 Spot service can interrupt an individual Spot Instance if capacity is no longer available, the Spot price exceeds your maximum price, or demand for Spot Instances increases.	You determine when an On-Demand Instance is interrupted (stopped, hibernated, or terminated).

https://docs.aws.amazon.com/AWSEC2/latest/UserGuide/using-spot-instances.html

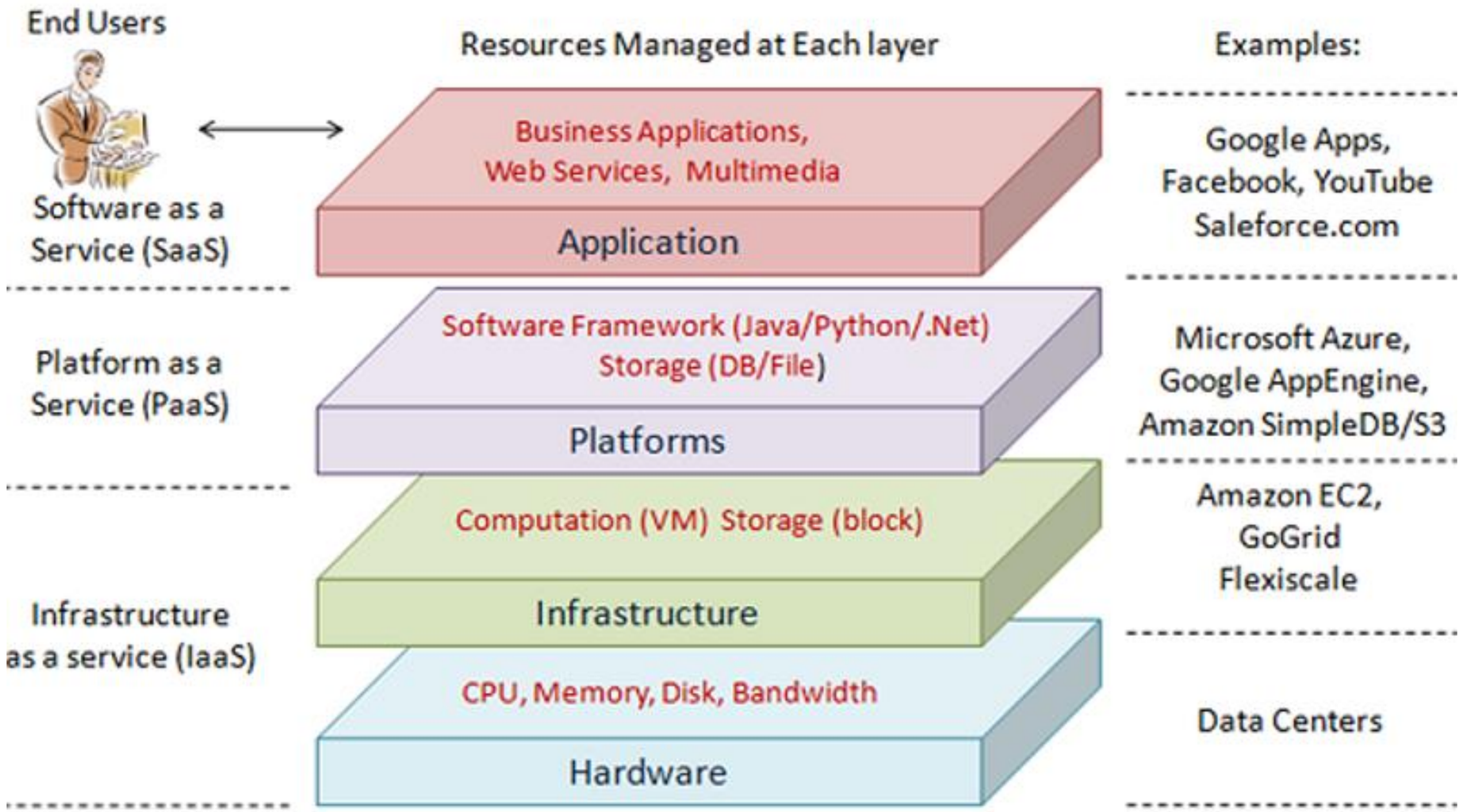
Advantage and disadvantage

- Cloud 1.0:
  - +: Simple, Perfect isolation,
  - - : Expensive.
- Cloud 2.0:
  - +: Cheaper than Cloud 1.0.
  - - : Some resource waste
- Cloud 3.0:
  - +: Cheapest
  - - : Cold-start issues, Security & Privacy, Hard to manage.

Recap: Cloud Computing v.s. on-premise clusters

- Compute, storage, memory, networking, etc. are virtualized and exist on *remote servers*; *rented* by application users
- Main pros of cloud vs on-premise clusters:
  - **Manageability**: Managing hardware is not user's problem
  - **Pay-as-you-go**: Fine-grained pricing economics based on actual usage (granularity: seconds to years!)
  - **Elasticity**: Can dynamically add or reduce capacity based on actual workload's demand
- Infrastructure-as-a-Service (IaaS); Platform-as-a-Service (PaaS); Software-as-a-Service (SaaS)

Cloud Computing is a Huge Ecosystem



https://benchpartner.com/layered-model-of-cloud-computing

Examples of AWS Cloud Services

- IaaS: Infra-
  - Compute: EC2, ECS, Fargate, Lambda
  - Storage: S3, EBS, EFS, Glacier
  - Networking: CloudFront, VPC
- PaaS: Platform-
  - Database/Analytics Systems: Aurora, Redshift, Neptune, ElastiCache, DynamoDB, Timestream, EMR, Athena
  - Blockchain: QLDB; IoT: Greengrass
- SaaS: Software-
  - ML/AI: SageMaker, Elastic Inference, Lex, Polly, Translate, Transcribe, Textract, Rekognition, Ground Truth
  - Business Apps: Chime, WorkDocs, WorkMail

However: we are at a transition point, again.

Profit chain

OpenAI

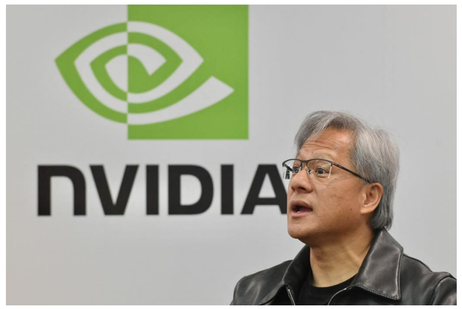
Google DeepMind

Meta

Microsoft

aws

Google Cloud



New Trends in the Deep Learning Era

- New trends:
  - Reservation takes precedence than on-demand/spot
  - GPU vertical cloud
  - Community cloud

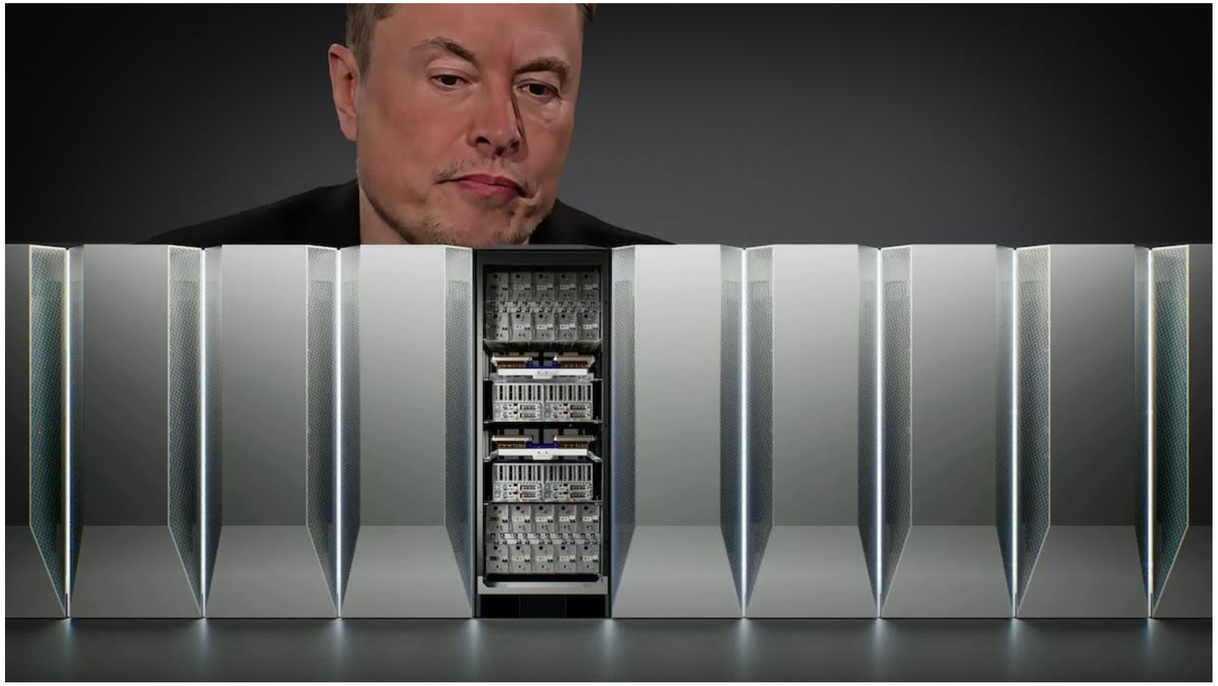
LAST UPDATED: 1 WEEK AGO

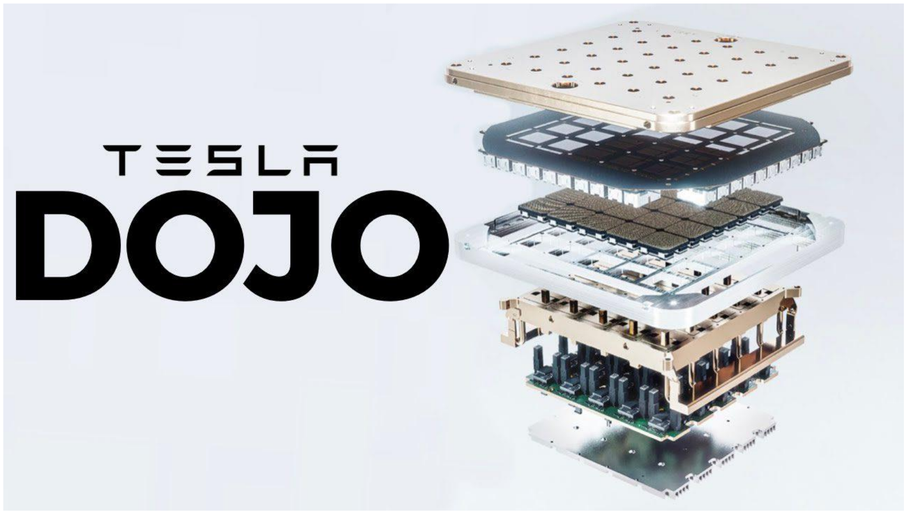
Provider	A100 40GB	A100 80GB	H100
Lambda Labs	**Unavailable**	**Unavailable**	**Unavailable**
FluidStack	**Unavailable**	**Unavailable**	**Unavailable**
Runpod	**Unavailable**	$1.59/hour ✅	$3.39/hour ✅

However

There is a trend of building on-premise super computers again

FAILED





But More are Coming!

January 21, 2025 Company

Announcing The Stargate Project

Zuckerberg says Meta will build data center the size of Manhattan in latest AI push

CEO says company plans to spend hundreds of billions on developing artificial intelligence products

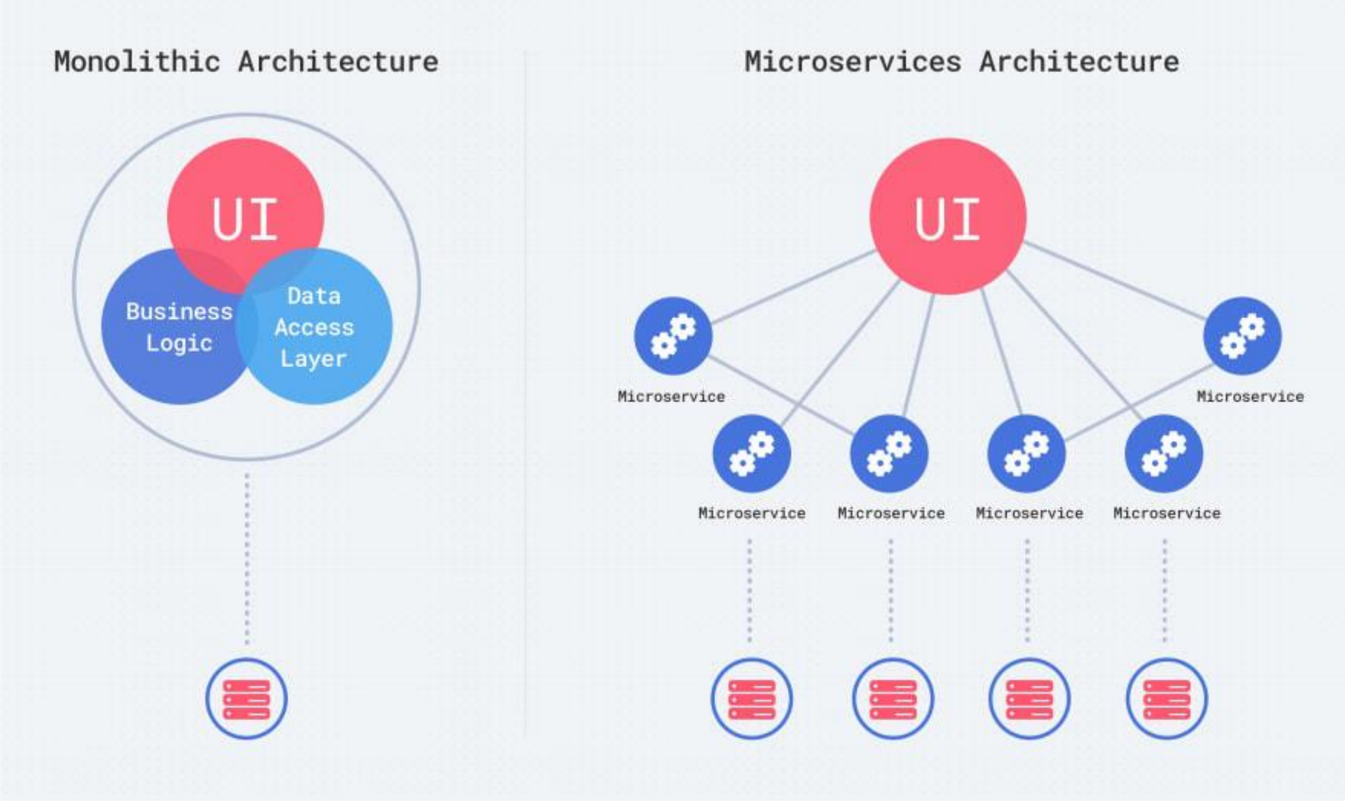
Meta Founder and CEO Mark Zuckerberg speaks at LlamaCon 2025, an AI developer conference, in Menlo Park, California, on 29 April 2025. Photograph: Jeff Chiu/AP

Open Question after class

Google has pioneered and created many distributed systems and technologies that shape today's cloud computing, but why Amazon (and even Microsoft) wins over Google Cloud (GCP) on Cloud computing market shares?

Instructor‘s Take: Amazon’s Micro-services vs. Cloud 3.0

- Microservice architecture correlates well with today’s cloud trend: resources and services are more and more **disaggregated.**

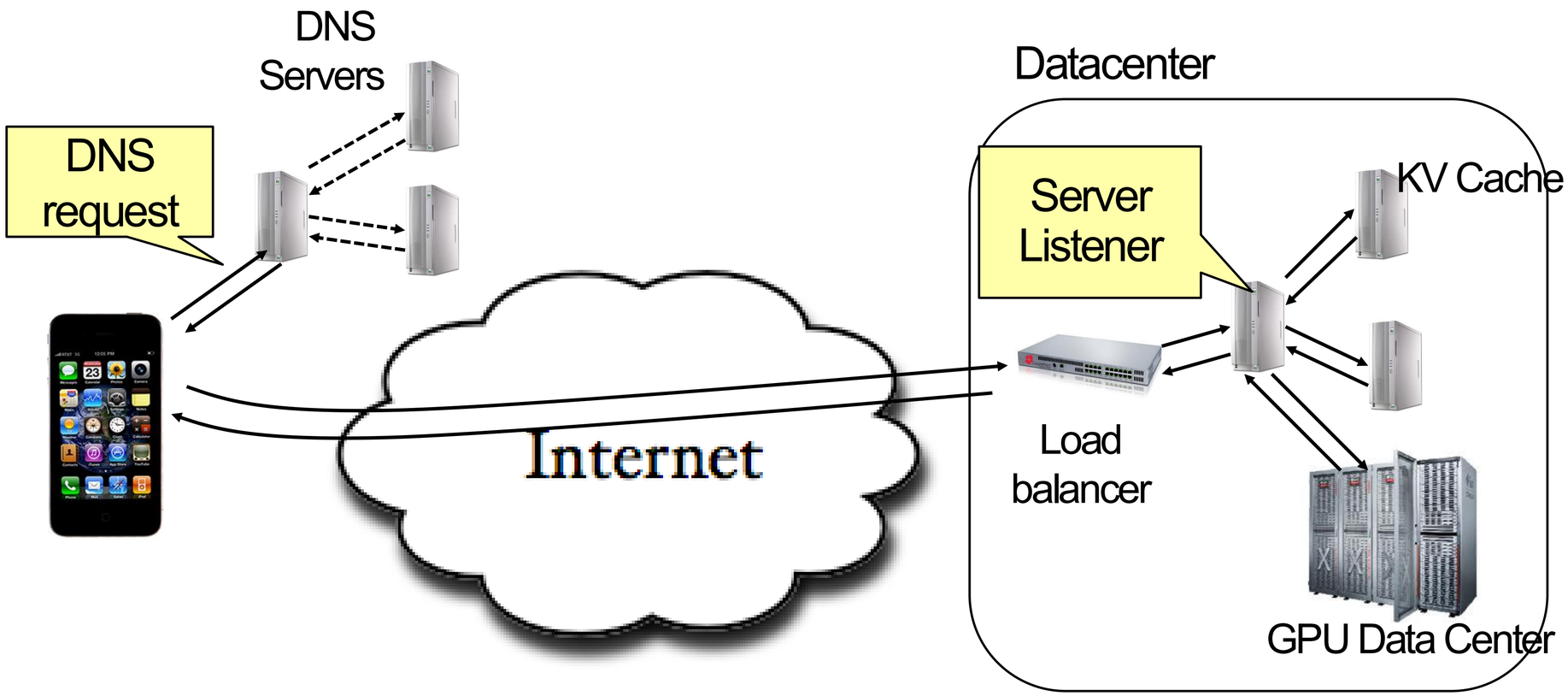


Part 2: Cloud Computing and Distributed Systems

- Intro to Cloud Compute
- **Networking Basics**
- Collective Communication

Example: What's in a ChatGPT Query?

- Complex interaction of multiple components in multiple administrative domains

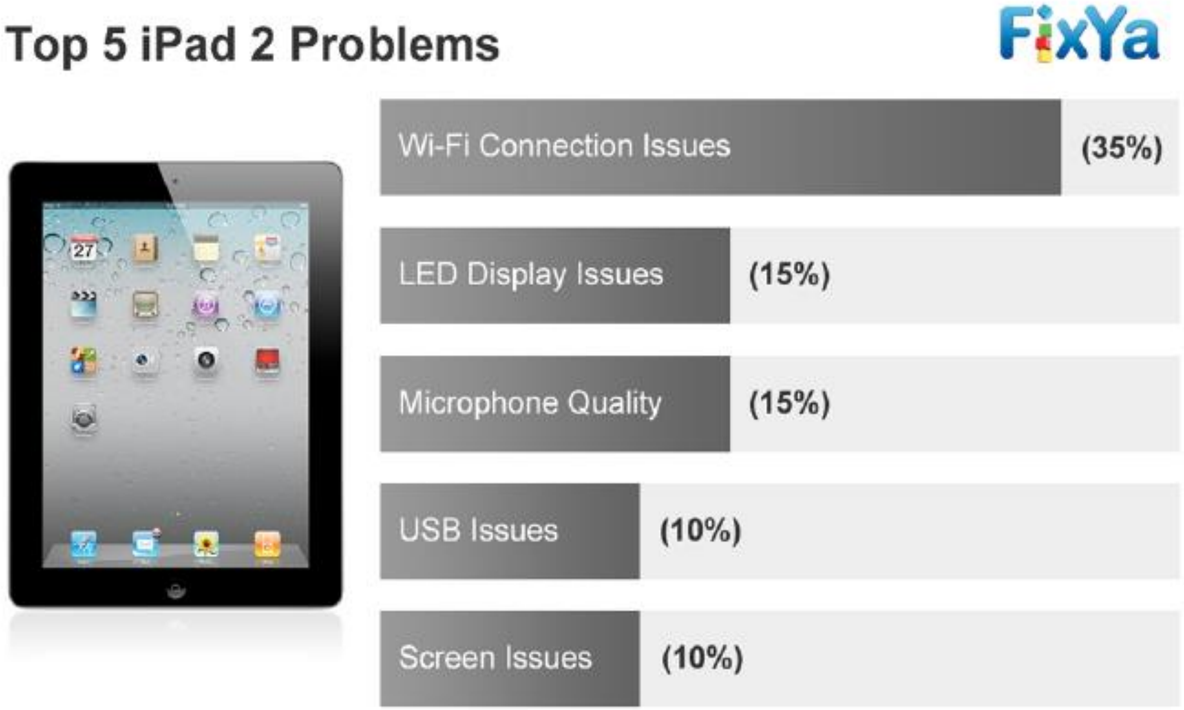


Why is Networking Important?

- Virtually all apps you use comm
  - Many times main functionalit services, Amazon, Facebook

- Thus, connectivity is key service
  - Many times, connectivity issu
  - A data center is down -> net

- Some of the hottest opportuniti
  - Datacenter networking
  - OSes for Software Defined Networks (SDNs)
  - Networking for GPU Data Centers

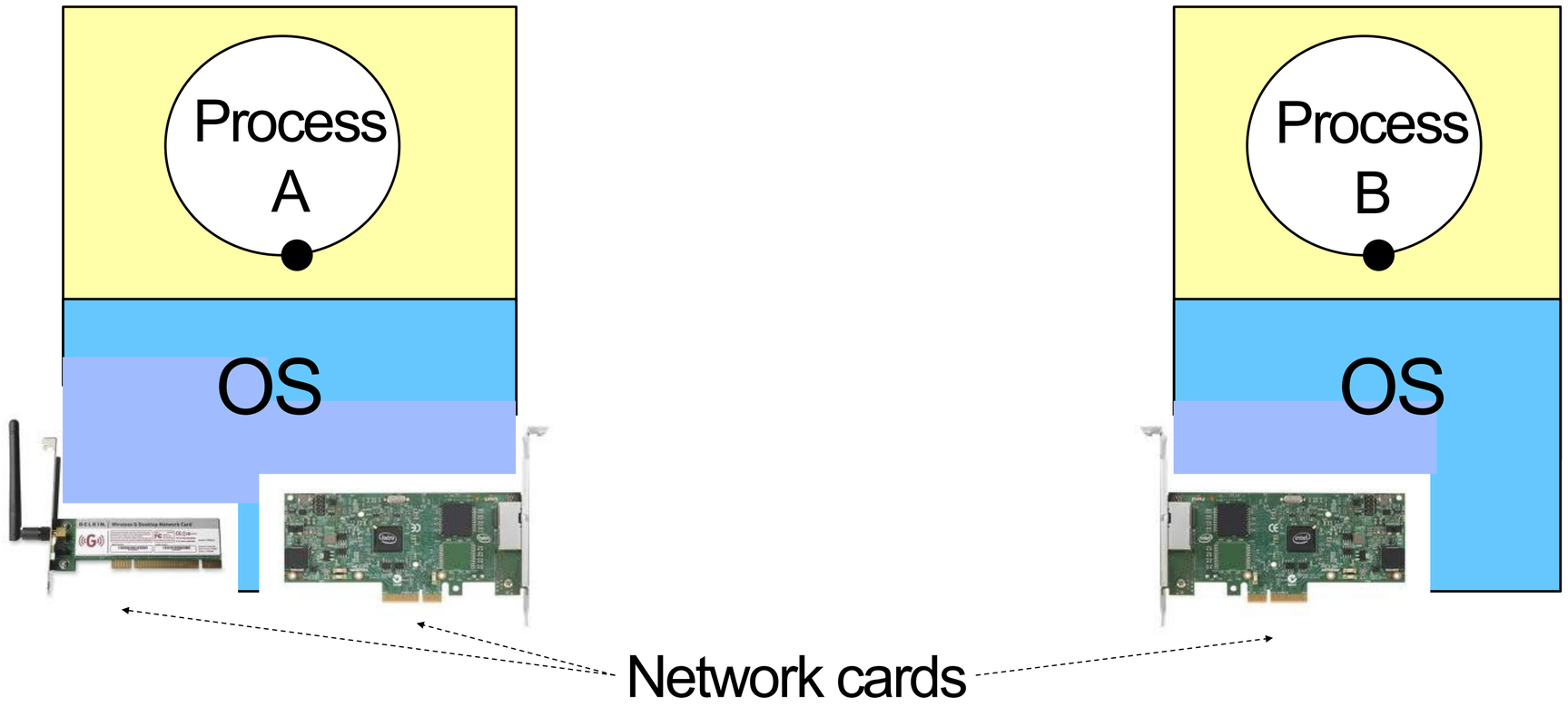


Networking

- Network Basics
- Collective Communication

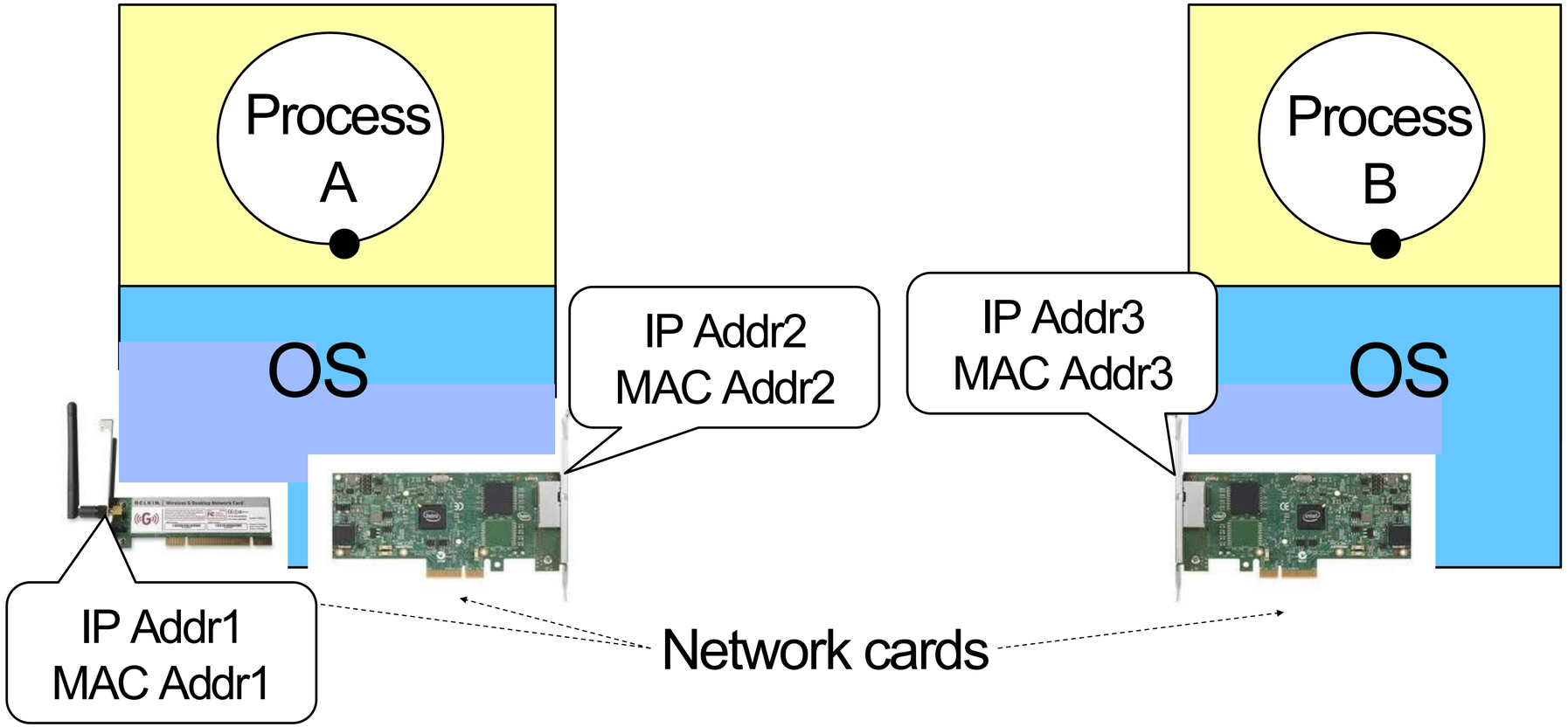
Network Hardware

- **Network (interface) card/controller**: hardware that physically connects a computer to the network



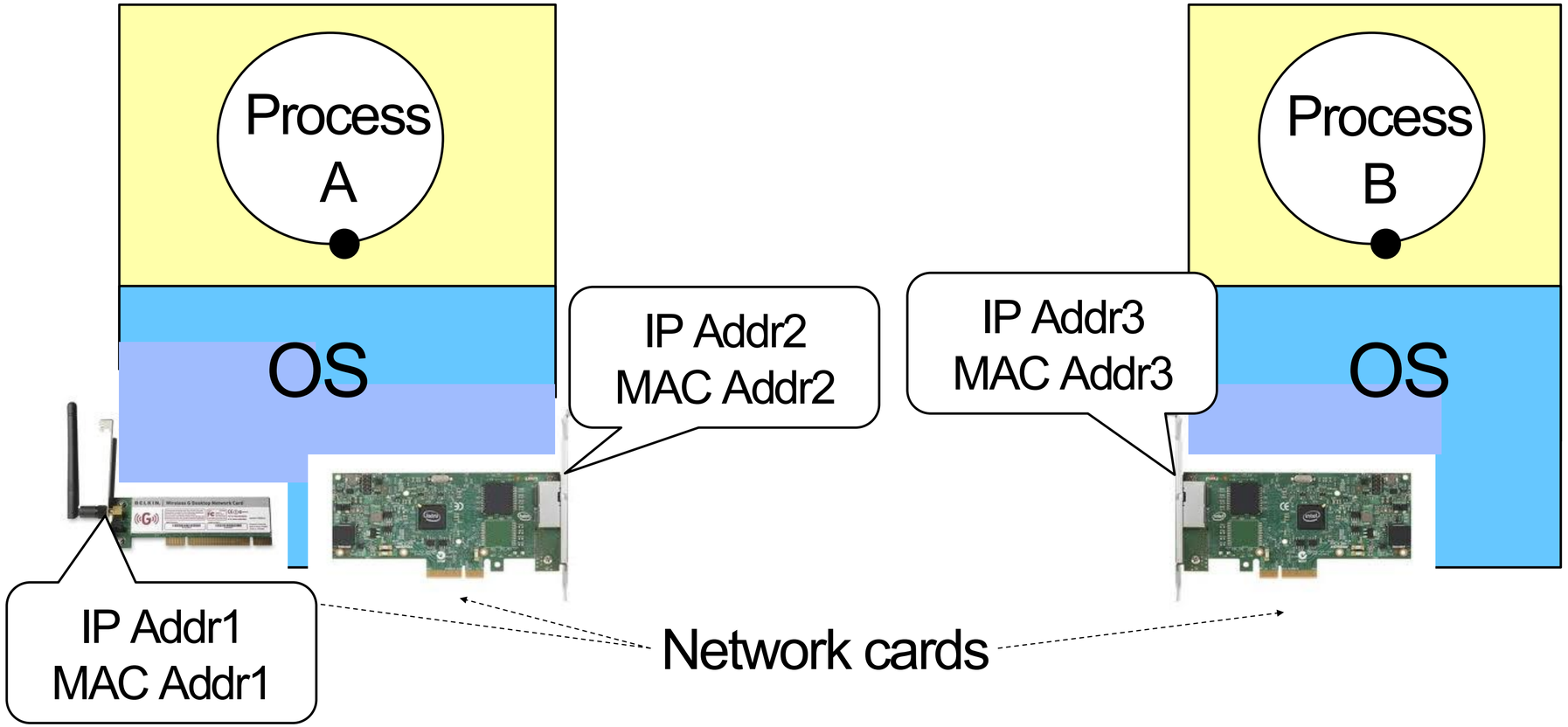
Network Addresses

- Typically, each network card is associated two addresses:
  - Media Access Control (MAC), or physical, address
  - IP (network) address; can be shared by network cards on same host



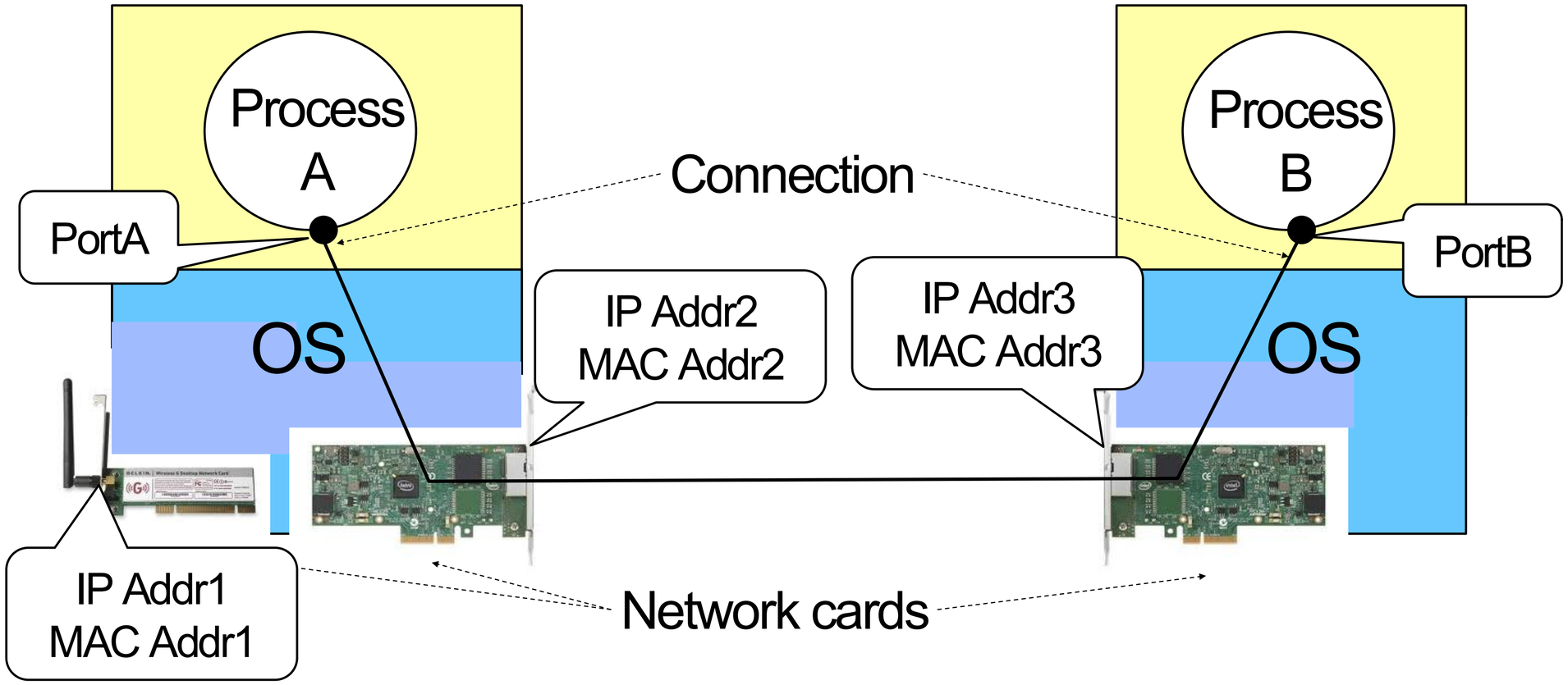
Network Addresses (cont'd)

- **MAC address**: 48-bit unique identifier assigned by card vendor
- **IP Address**: 32-bit (or 128-bit for IPv6) address assigned by network administrator or dynamically when computer connects to network



Network Identifier (cont'd)

- **Connection**: communication channel between two processes
- Each endpoint is identified by a **port number**



Common Port Numbers

Application	Port number
Wake-on-LAN	9
FTP data	20
FTP control	21
SSH	22
Telnet	23
DNS	53
HTTP	80
SNMP	161
…	…

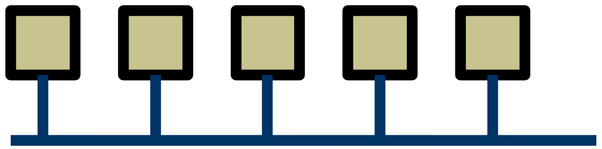
Abstract Network

- Electrical questions
  - Voltage, frequency, …
  - Wired or wireless?

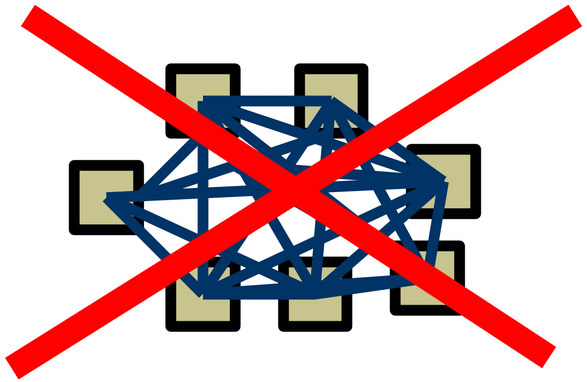
- Link-layer issues: How to send data?
  - When to talk – can either side talk at once?
  - What to say – low-level format?

Basic Building Block: Links

- … But what if we want more hosts?



One wire

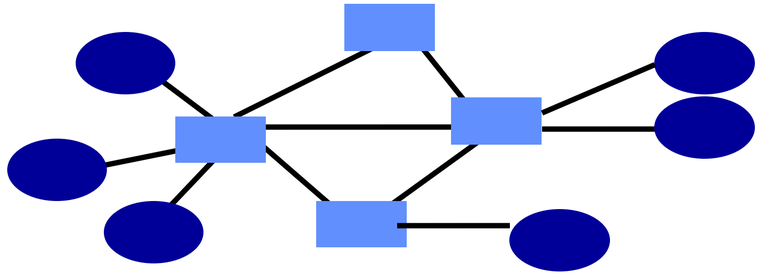


Wires for everybody!

- Scalability?!

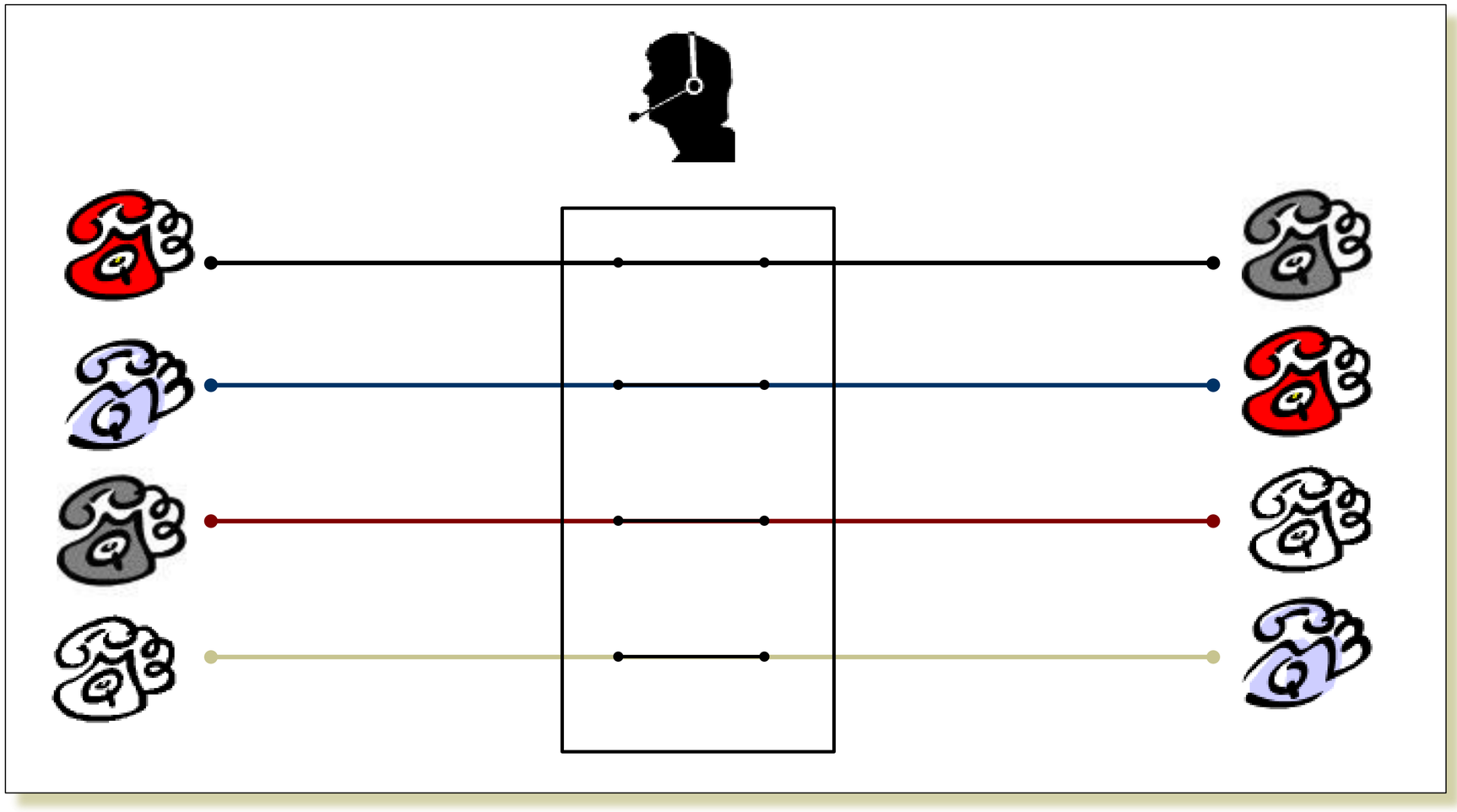
Idea: Multiplexing

- Need to share network resources



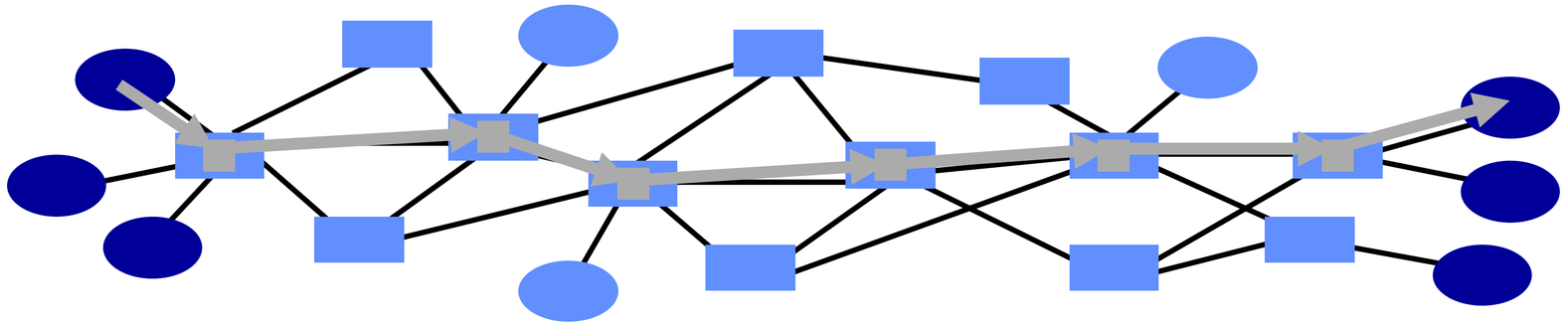
- How? Switched network
  - Party “A” gets resources sometimes
  - Party “B” gets them sometimes
- Interior nodes act as “Switches”
- What mechanisms to share resources?

In the Old Days…Circuit Switching



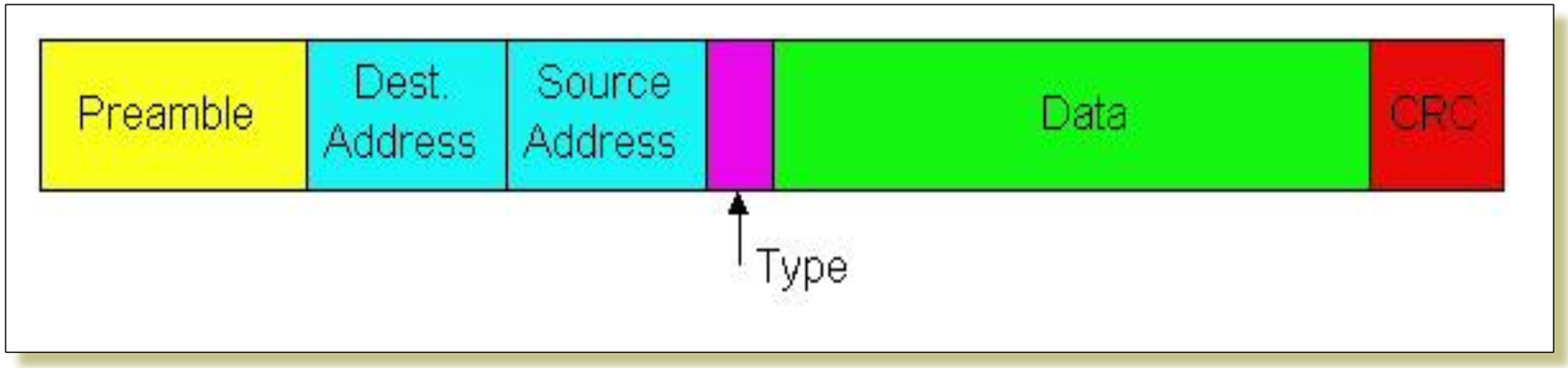
Packet Switching

- Source sends information as self-contained packets that have an address.
  - Source may have to break up single message in multiple packets
- Each packet travels independently to the destination host.
  - Switches use the address in the packet to determine how to forward the packets
  - Store and forward
- Analogy: a letter in surface mail.

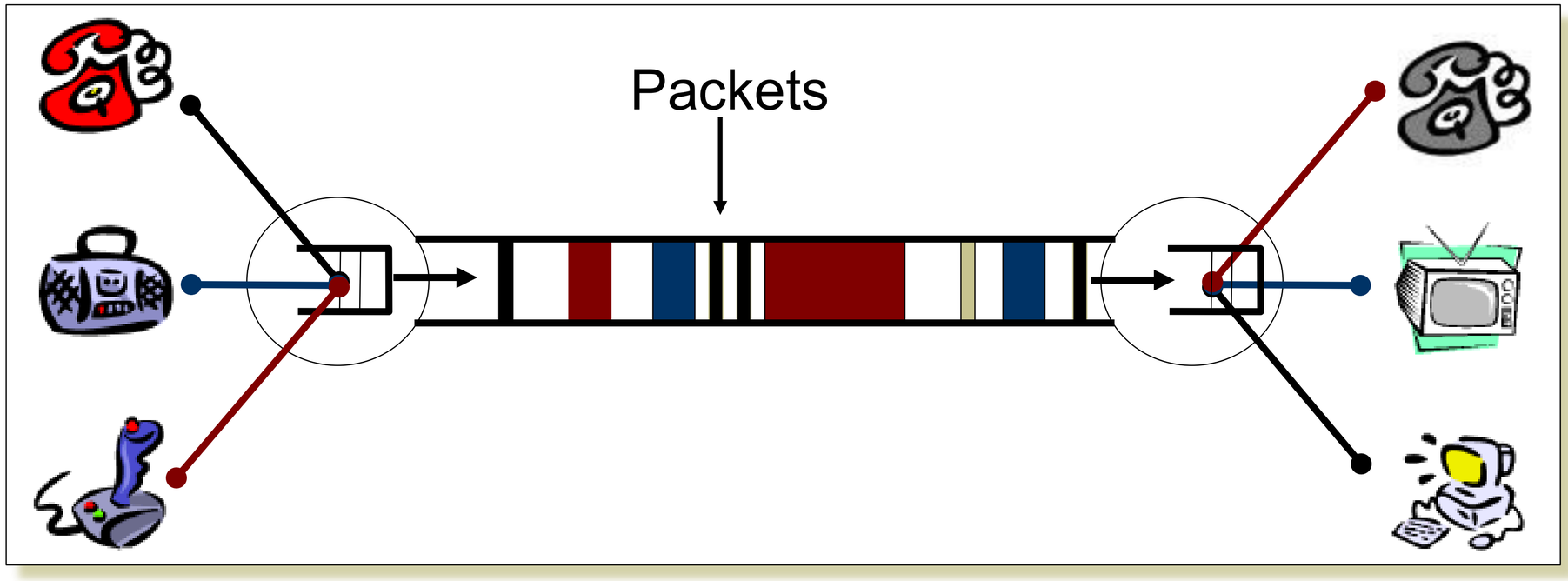


Example: Ethernet Packet

- Sending adapter encapsulates IP datagram (or other network layer protocol packet) in Ethernet frame



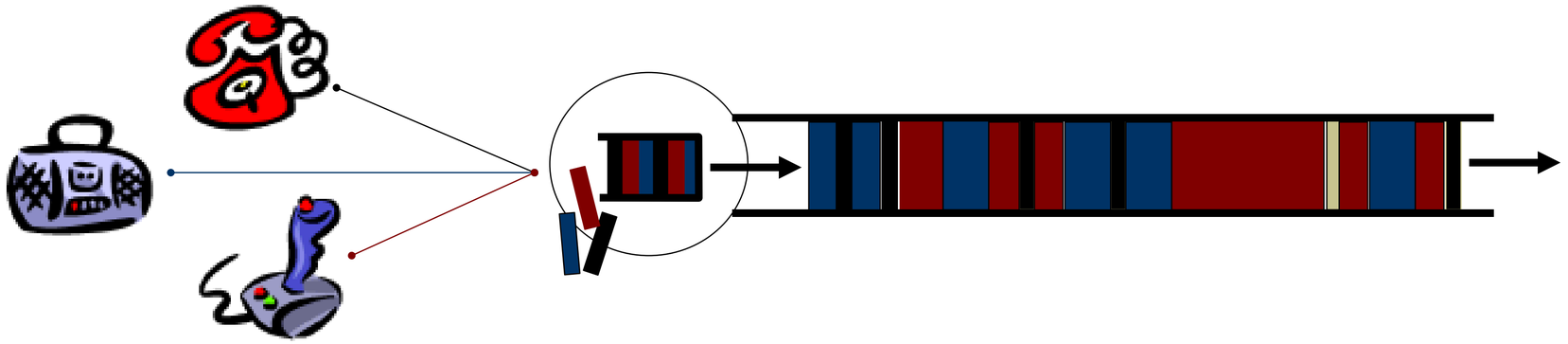
Packet Switching



- Switches arbitrate between inputs
- Can send from *any* input that's ready
  - Links never idle when traffic to send
  - (Efficiency!)

What if Network is Overloaded?

Problem: Network Overload



Solution: Buffering and Congestion Control

- Short bursts: buffer
- What if buffer overflows?
  - Packets dropped
  - Sender adjusts rate until load = resources → "congestion control"

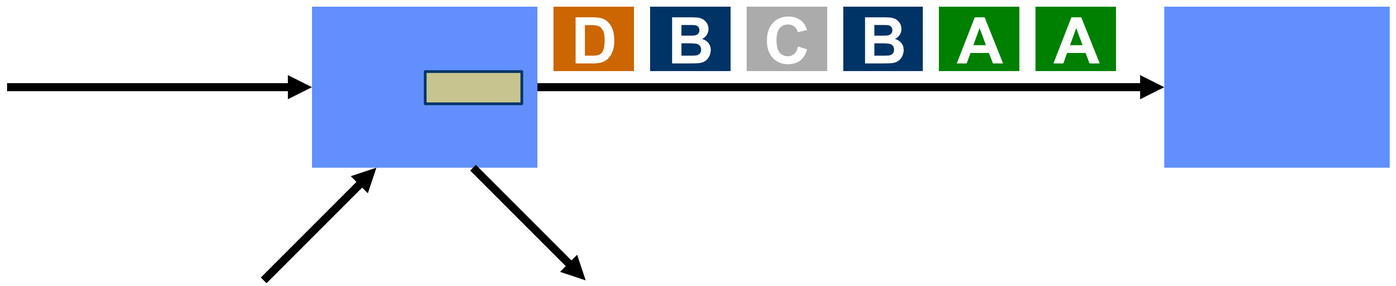
Characterizing Network Communication

- Latency - how long does it take for the first bit to reach destination
- Capacity - how many bits/sec can we push through? (often termed “bandwidth”)
- Jitter - how much variation in latency?
- Loss / Reliability - can the channel drop packets?
- Reordering

Packet Delay

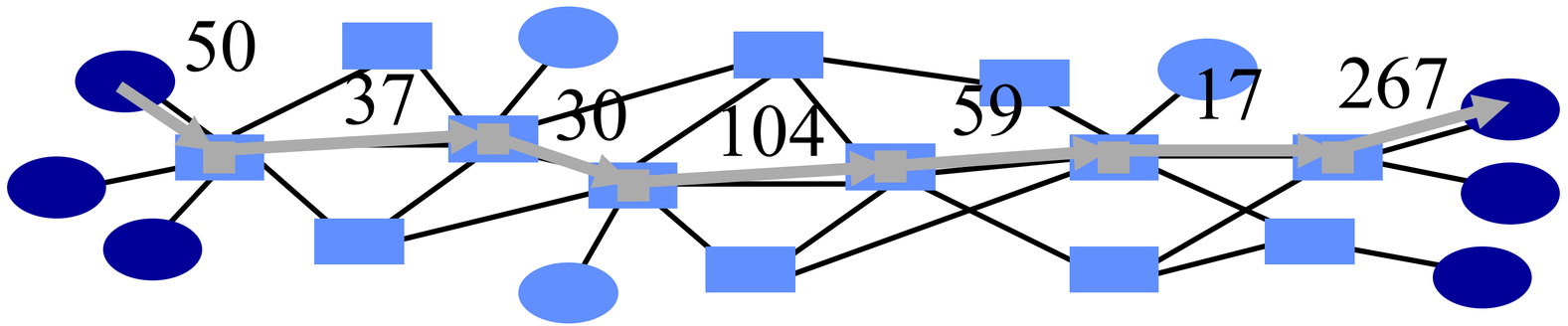
- Sum of a number of different delay components:

- Propagation delay on each link.
  - Proportional to the length of the link
- Transmission delay on each link.
  - Proportional to the packet size and 1/link speed
- Processing delay on each router.
  - Depends on the speed of the router
- Queuing delay on each router.
  - Depends on the traffic load and queue size



Throughput

- When streaming packets, the network works like a pipeline.
  - All links forward different packets in parallel
- Throughput is determined by the slowest stage.
  - Called the bottleneck link
- Does not really matter why the link is slow.
  - Low link bandwidth
  - Many users sharing the link bandwidth



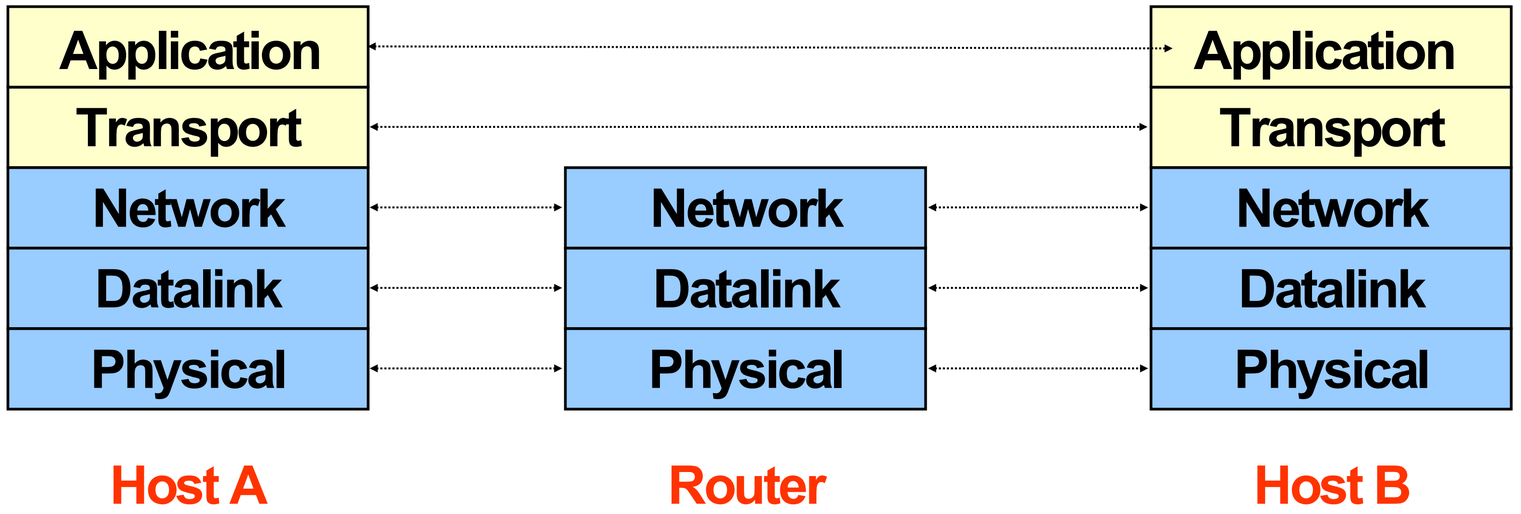
Some simple calculations (mbps/kbps)

- Cross country latency
  - Distance/speed = 5 * 10^6m / 2x10^8m/s = 25 * 10^-3 s = 25ms
  - 50ms RTT
- Link speed (capacity) 100Mbps
- Packet size = 1250 bytes = 10 kbits
  - Packet size on networks usually = 1500 bytes across wide area or 9000 bytes in local area
- 1 packet takes
  - 10k/100M = .1 ms to transmit
  - 25ms to reach there
  - ACKs are small → so 0ms to transmit
  - 25ms to get back
- Effective bandwidth = 10kbits/50.1ms = 200kbits/sec

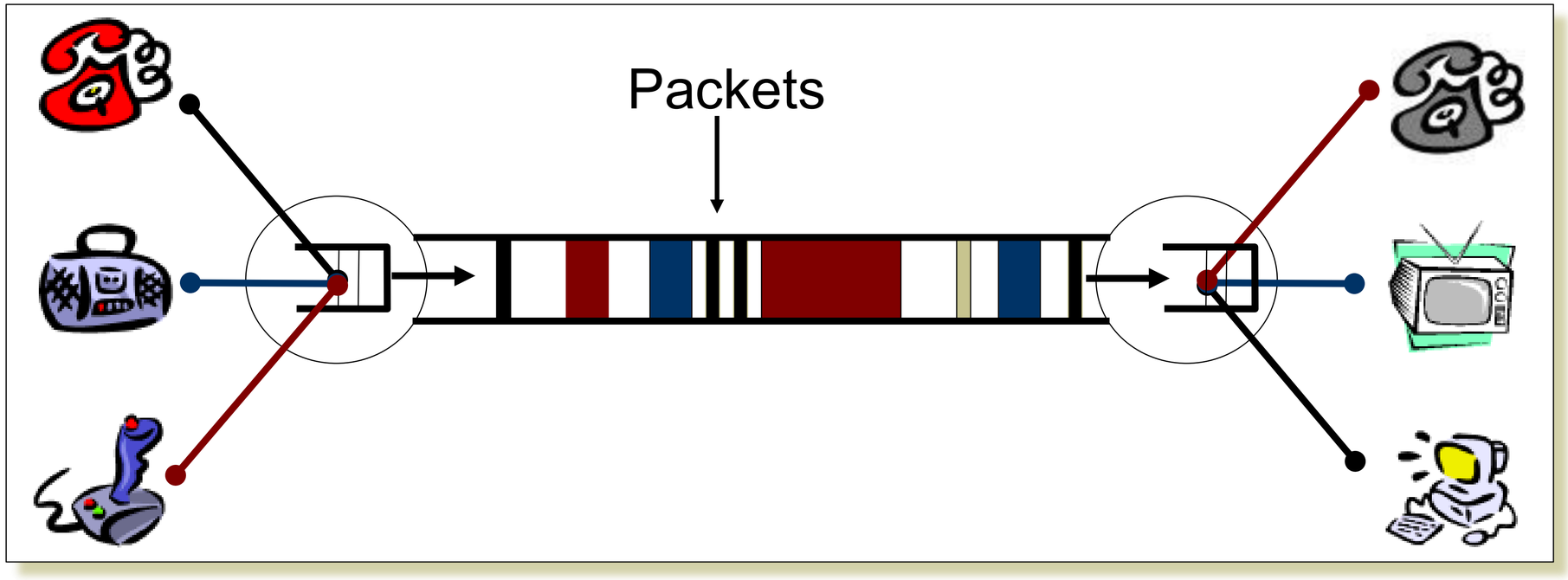
https://www.quora.com/Which-is-faster-the-speed-of-electric-current-through-a-copper-wire-or-the-speed-of-l

Layers

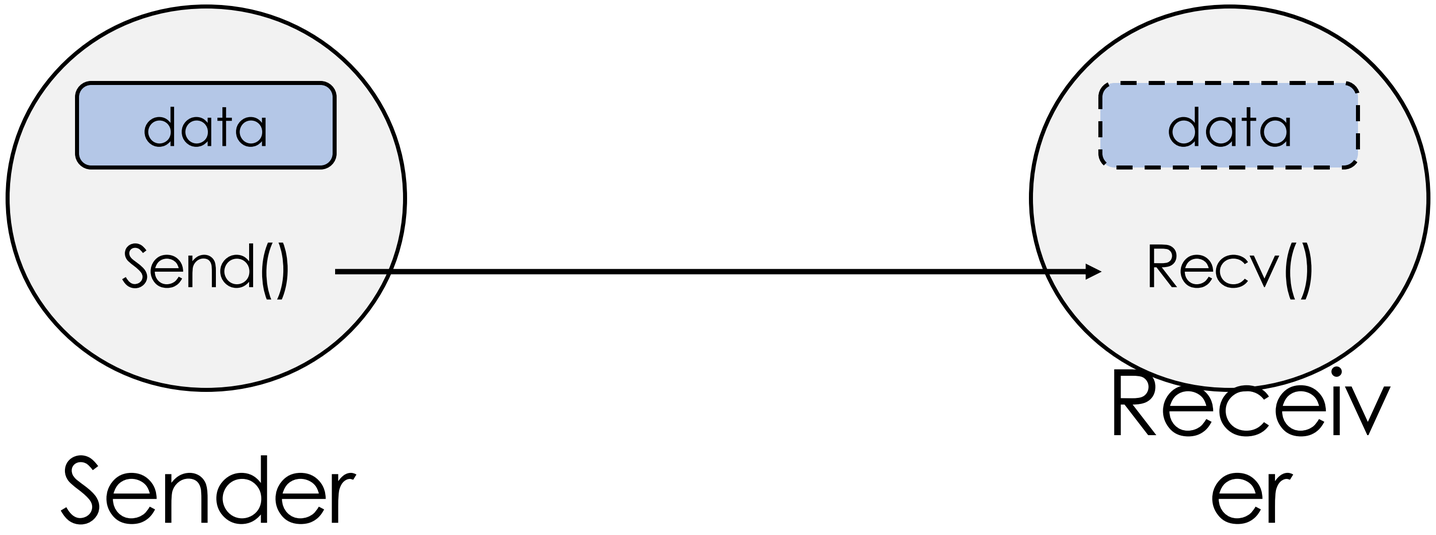
- Lower three layers implemented everywhere
- Top two layers implemented only at hosts
- Logically, layers interacts with peer's corresponding layer



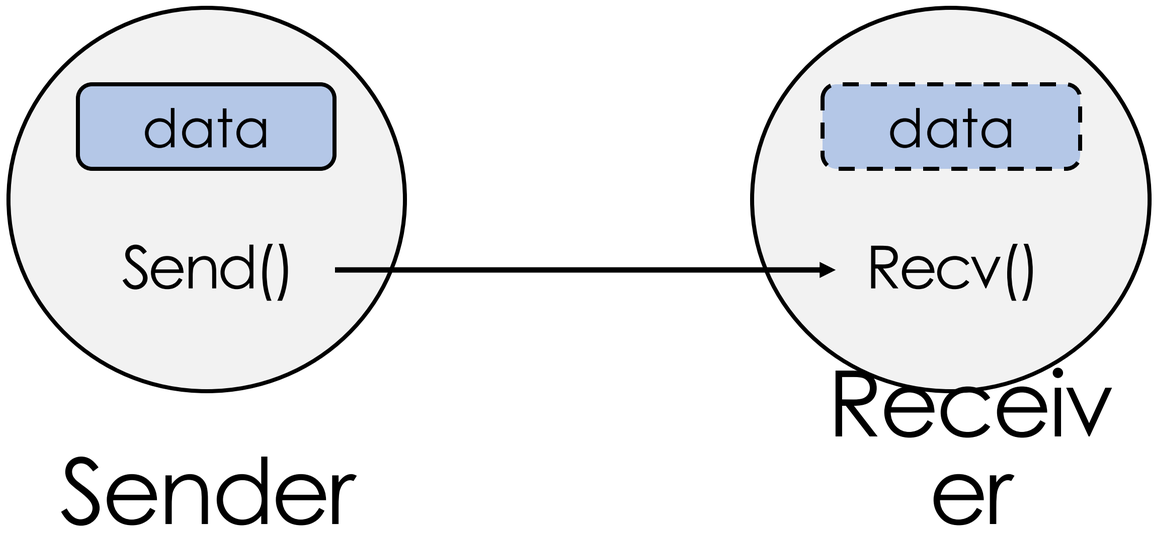
Communication



Communication: Point-to-point communication



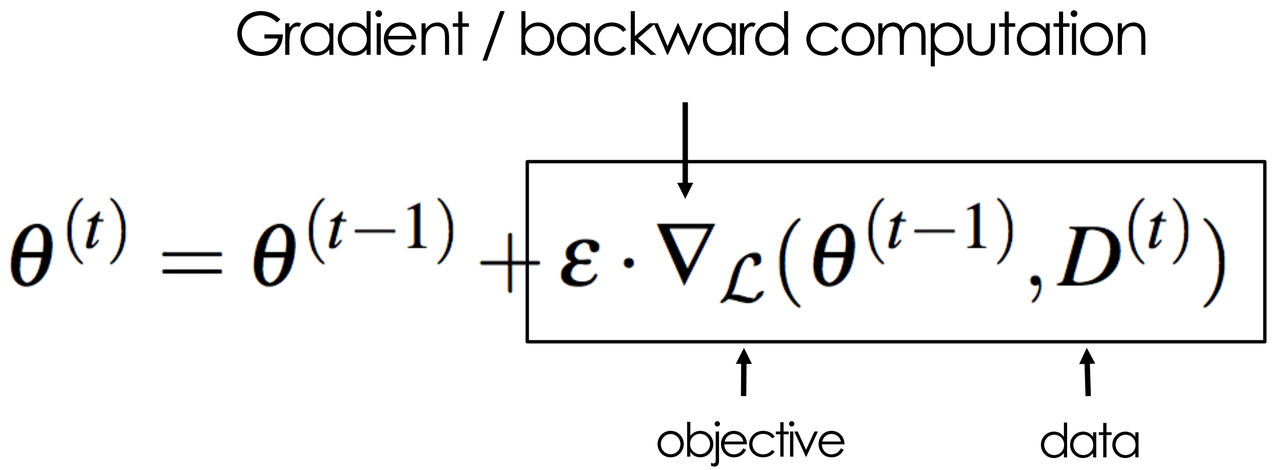
Program P2P communication: Very Simple in Ray




```python
def send(array: np.array):
    # Running on sender processs
    ref = ray.put(array)
    return ref

def receive(ref):
    # Running on receiver process
    array = ray.get(ref)
    print(array)
```

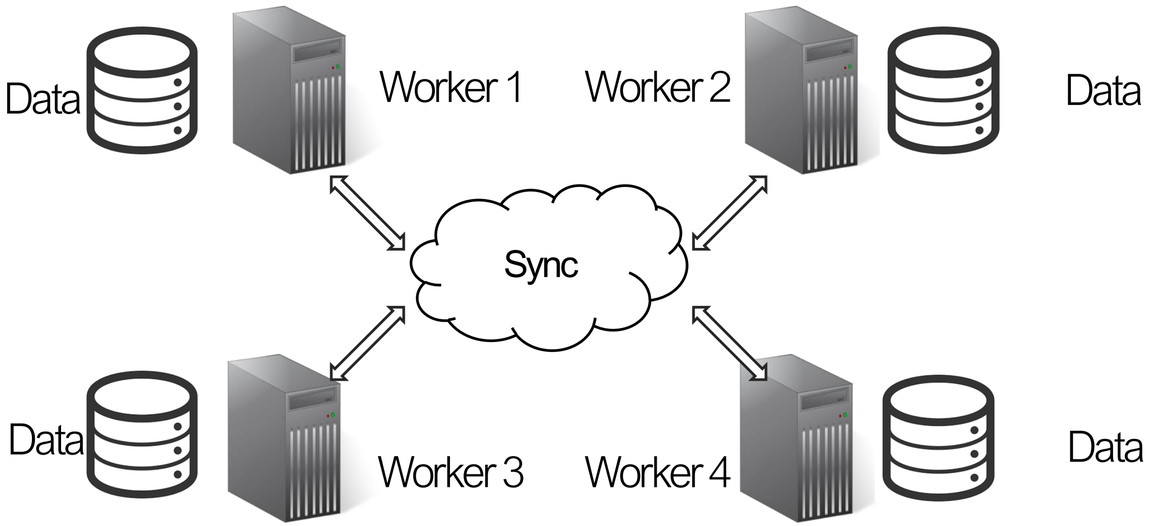
Case study: Gradient update in DL



What If Data is super Big?

What if Data is Super Big?

Big Data



Case study: Gradient update

Gradient / backward computation

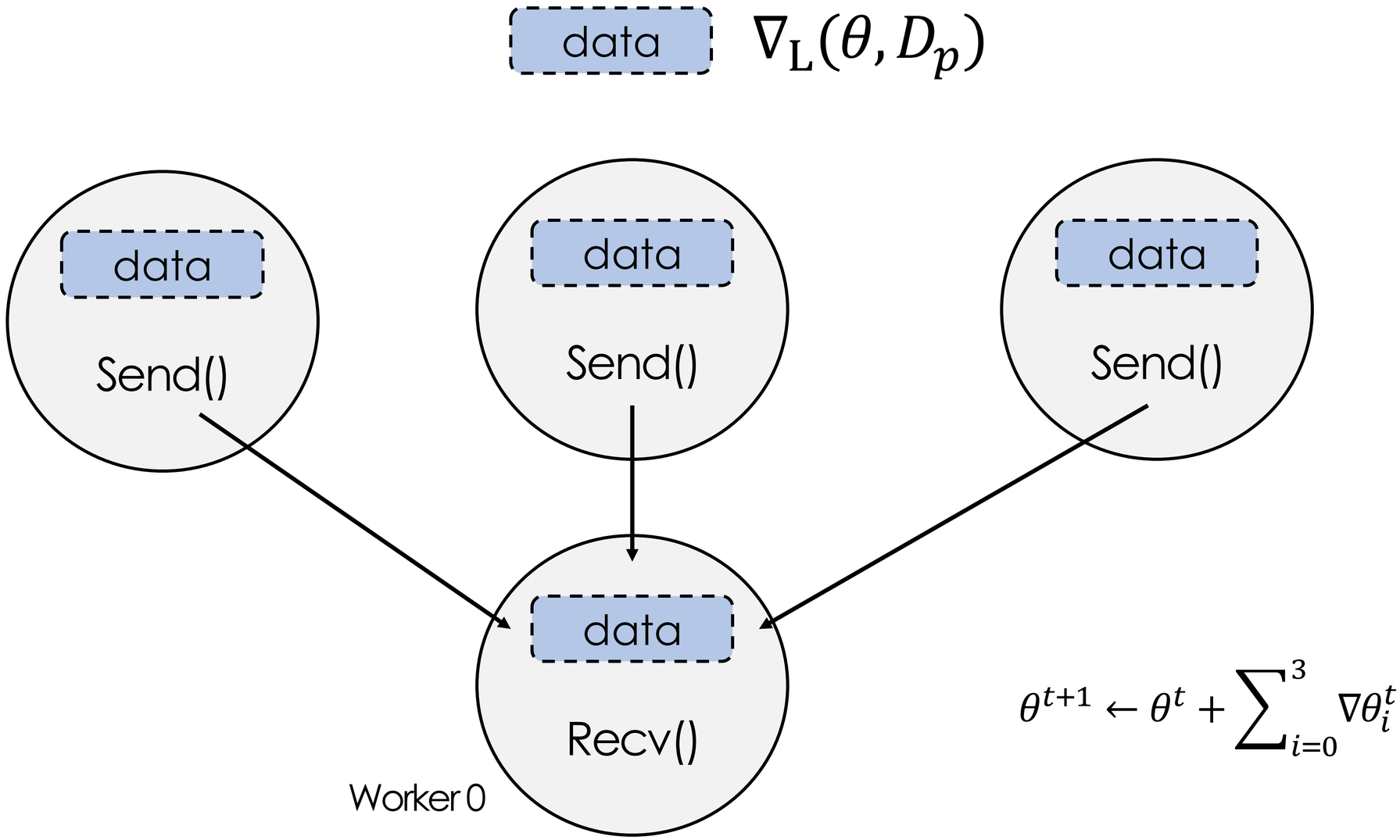
$$\theta^{(t)} = \theta^{(t-1)} + \boxed{\varepsilon \cdot \nabla_{\mathcal{L}}(\theta^{(t-1)}, D^{(t)})}$$

objective data

$$\theta^{(t+1)} = \theta^{(t)} + \varepsilon \sum_{p=1}^{P} \nabla_{\mathcal{L}}(\theta^{(t)}, D_p^{(t)})$$

How to perform this sum?

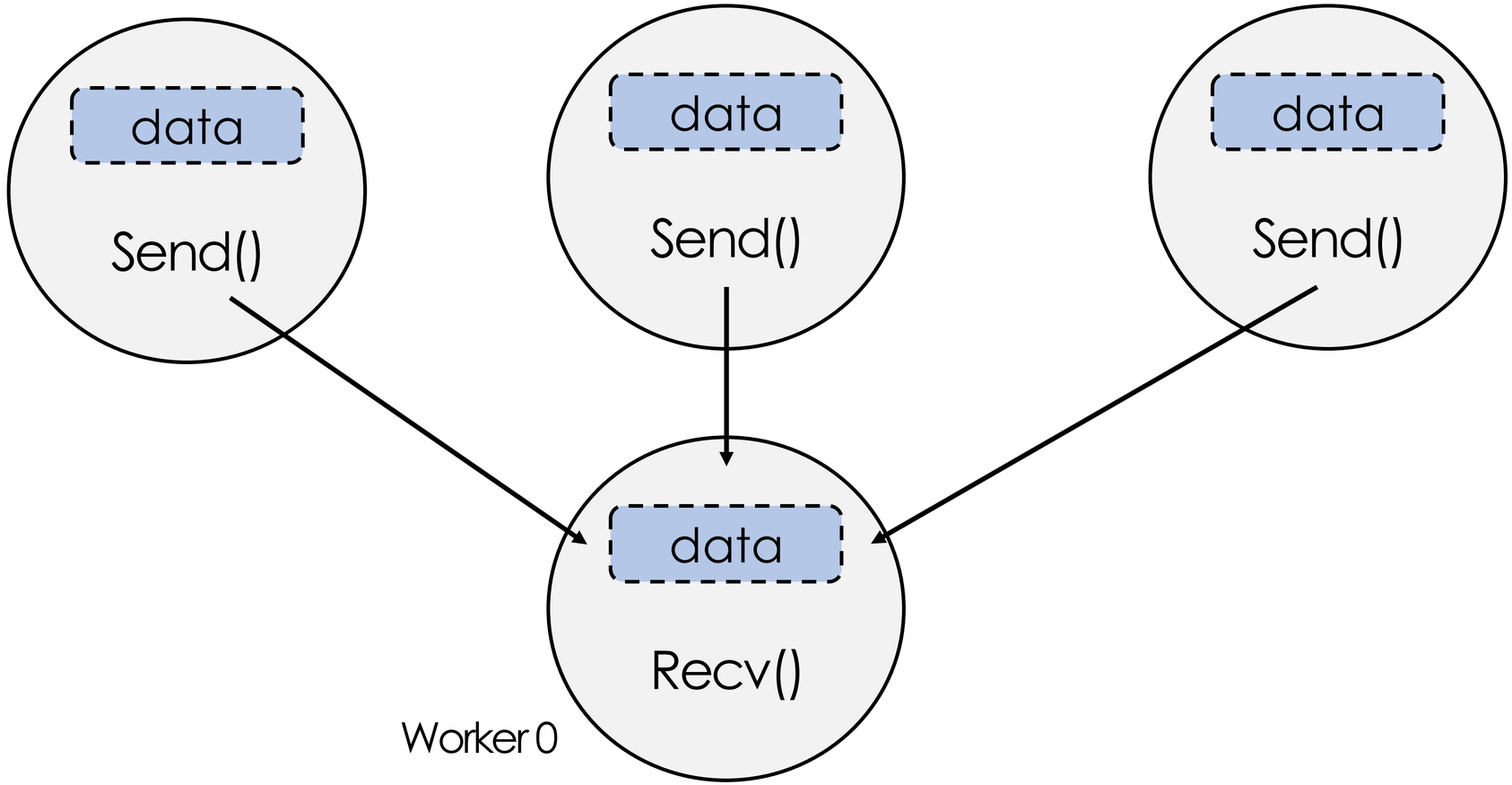
Collective Primitive: Reduce



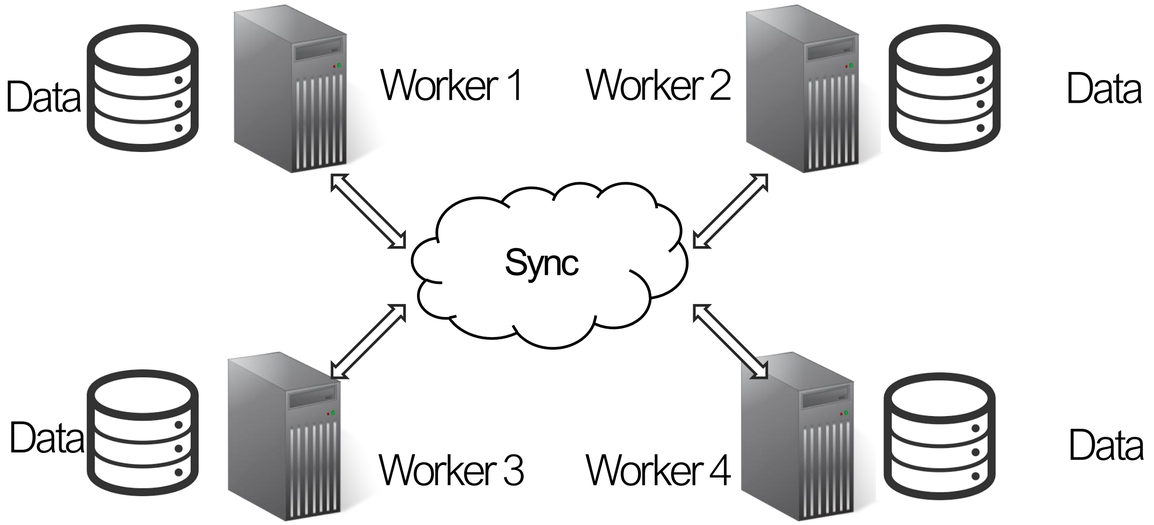
Program This? Will be in PA2!

Analyze Performance

- Message over networks: 3*N.
- Can we do better?



Not Yet Finished: Synchronization

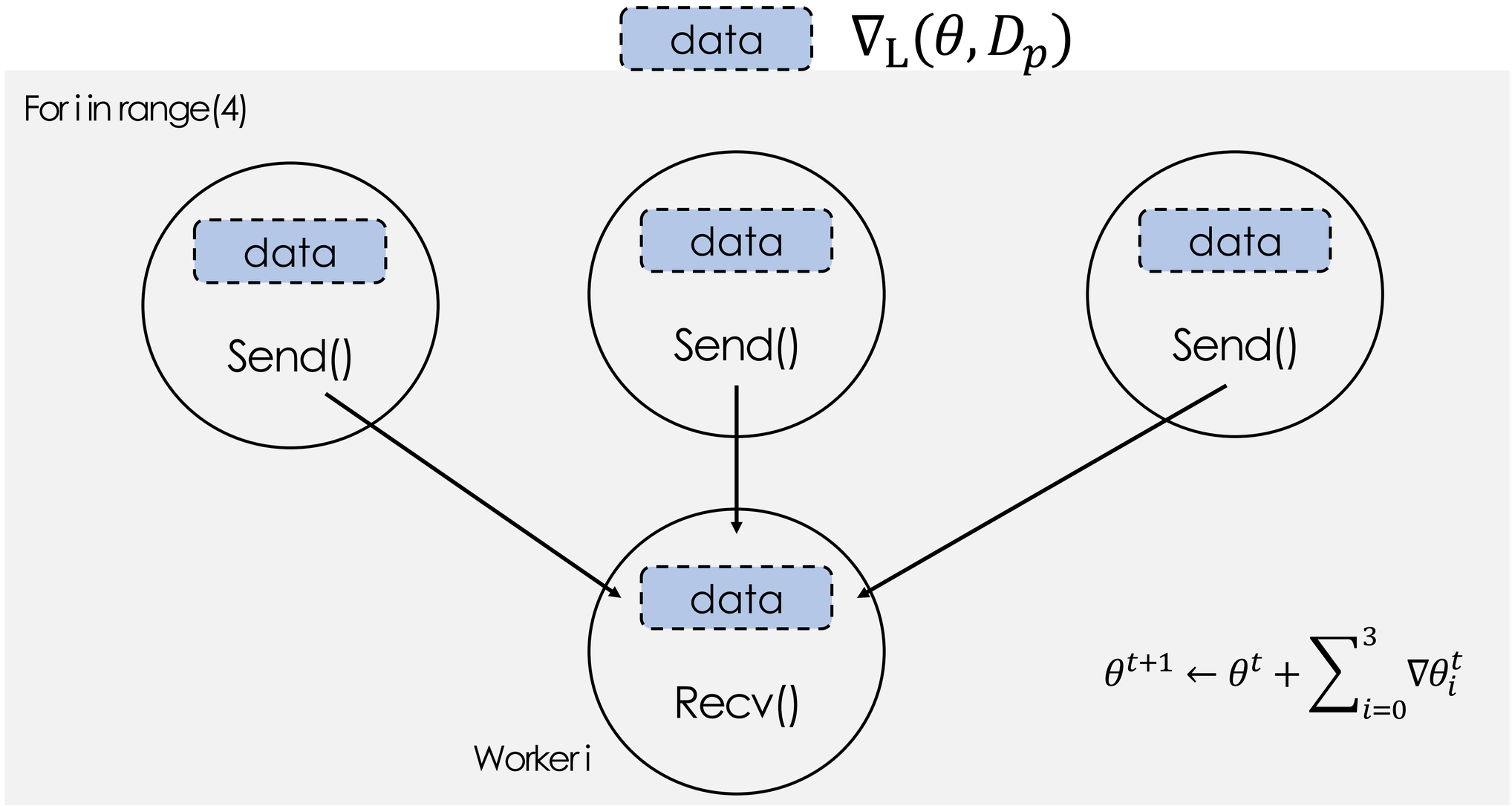


For each worker

$$\theta^{(t+1)} = \theta^{(t)} + \varepsilon \sum_{p=1}^{P} \nabla_{\mathcal{L}}(\theta^{(t)}, D_p^{(t)})$$

How to perform this sum?

Problem: We need **All-**Reduce



Program This? Will be in PA2!

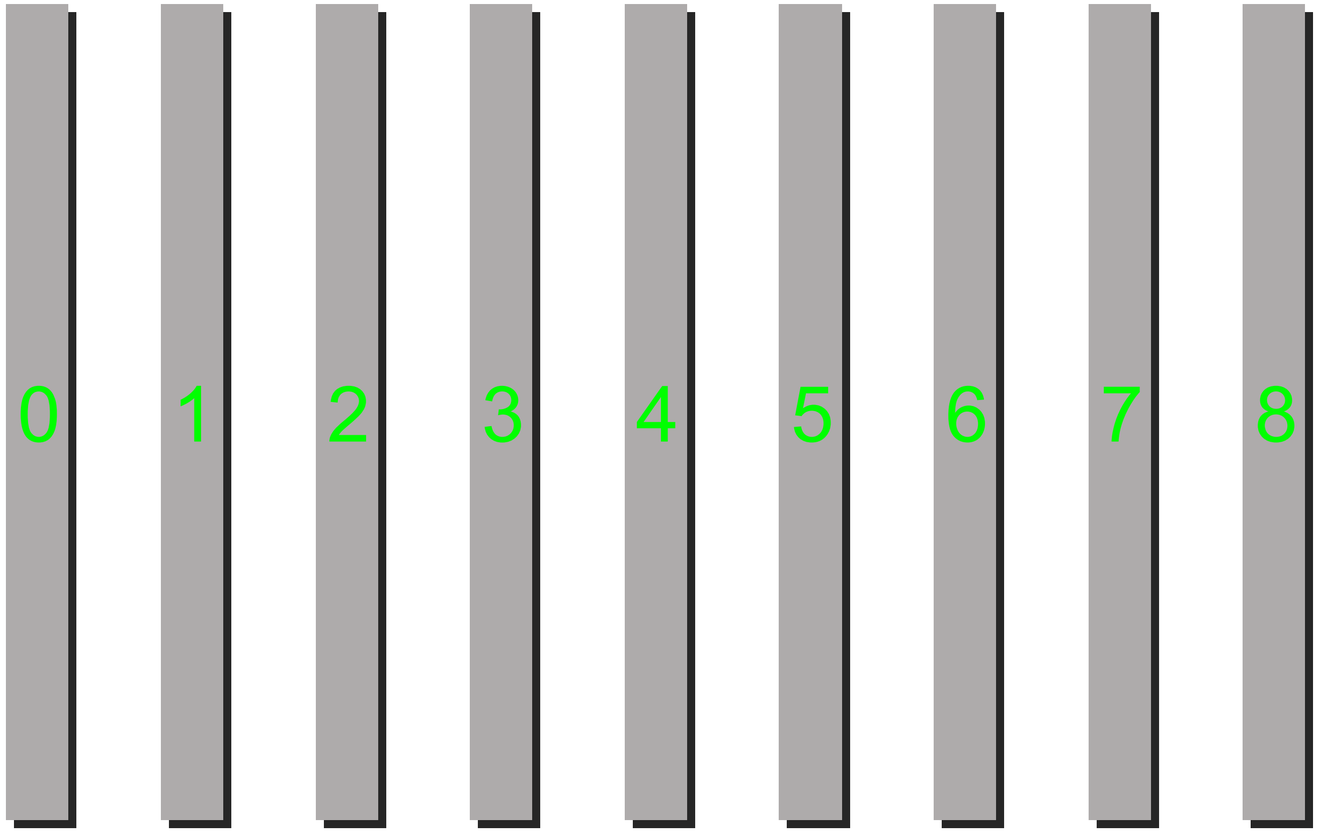
Performance

- Message size over networks:
  - Sum: 3N
  - Send Sum back: 3N
  - = 6N
- Can we do better?
  - Hint: we cannot do better than 3N

Why Collective Communication?

- Programming Convenience
  - Use a set of well-defined communication primitives to express complex communication patterns
- Performance
  - Since they are well defined and well structured, we can optimize them to the extreme
- ML Systems 🧡 Collective communication

Make it Formal



- A 1D **Mesh** of workers (or devices, or nodes)

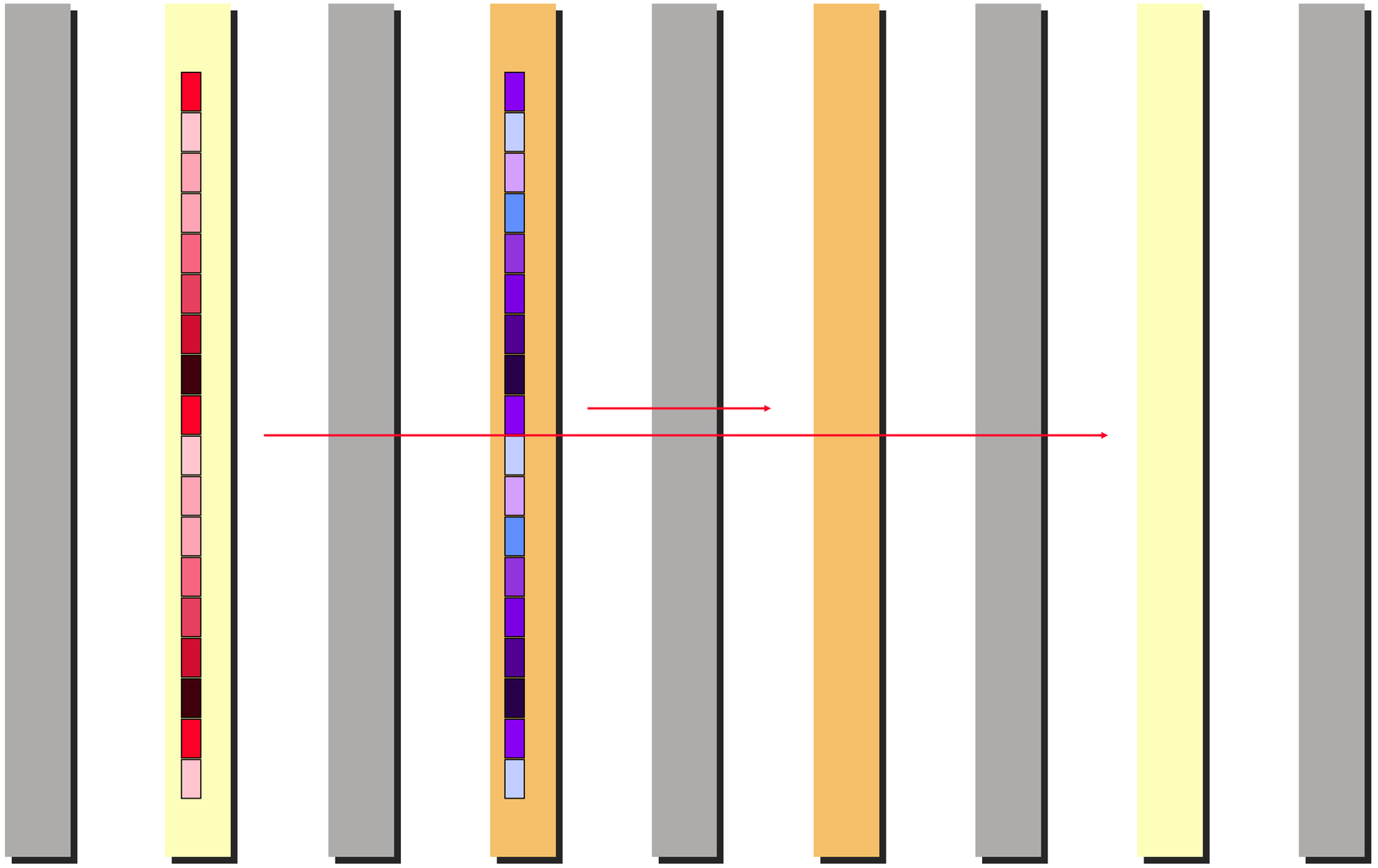
Model of Parallel Computation

- a node can send directly to any other node (maybe not true)
- a node can simultaneously receive and send
- cost of communication
  - sending a message of length *n* between any two nodes

$$\alpha + n\,\beta$$

  - if a message encounters a link that simultaneously accommodates *M* messages, the cost becomes

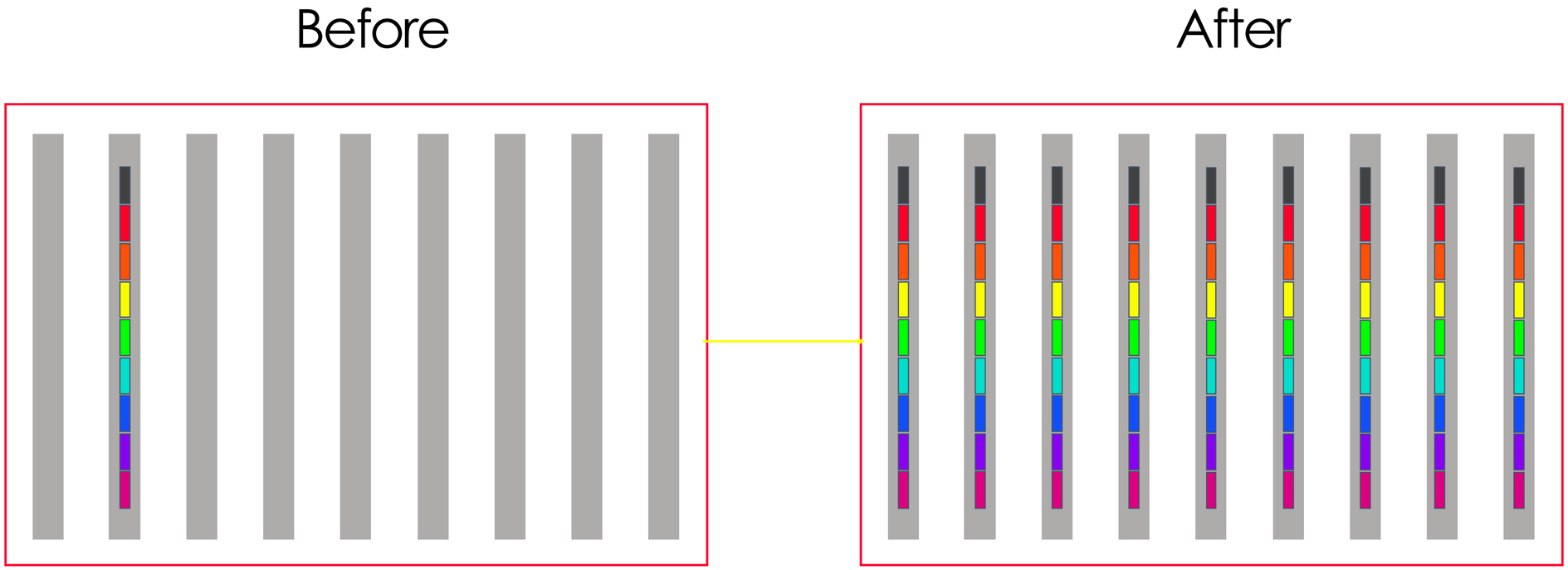
$$\alpha + Mn\,\beta$$



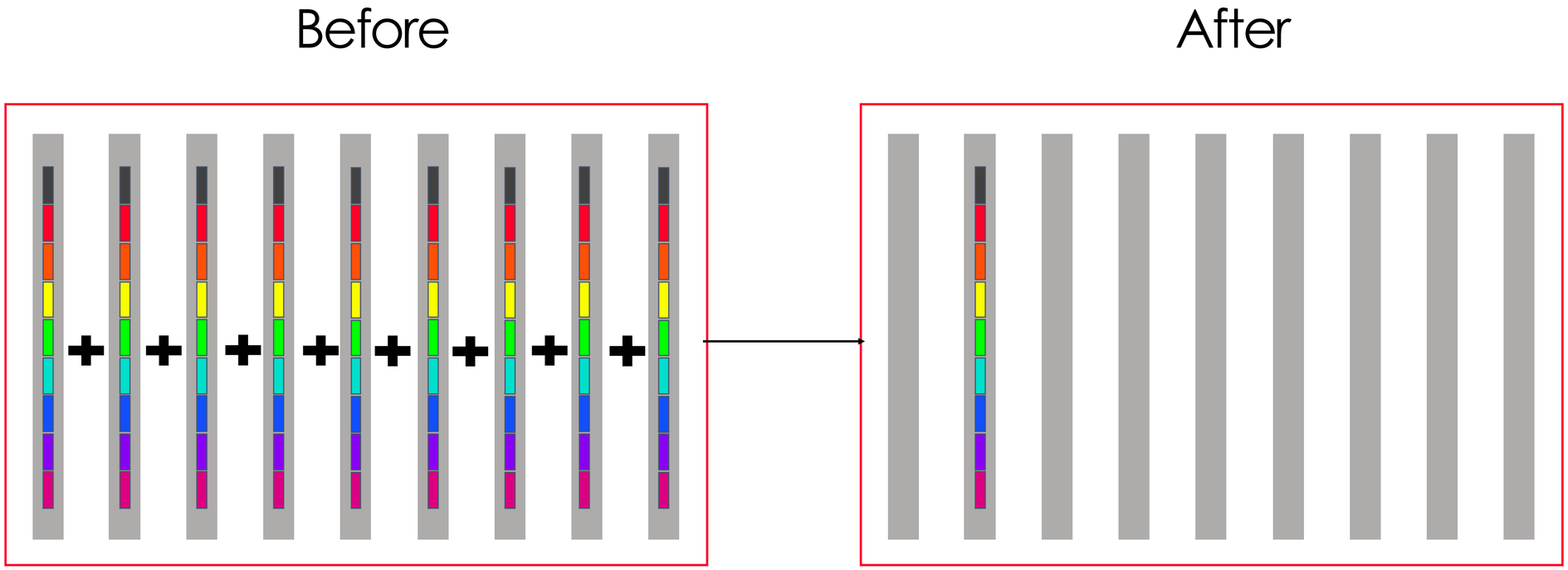
Collective Communications

- Broadcast
- Reduce(-to-one)
- Scatter
- Gather
- Allgather
- Reduce-scatter
- Allreduce

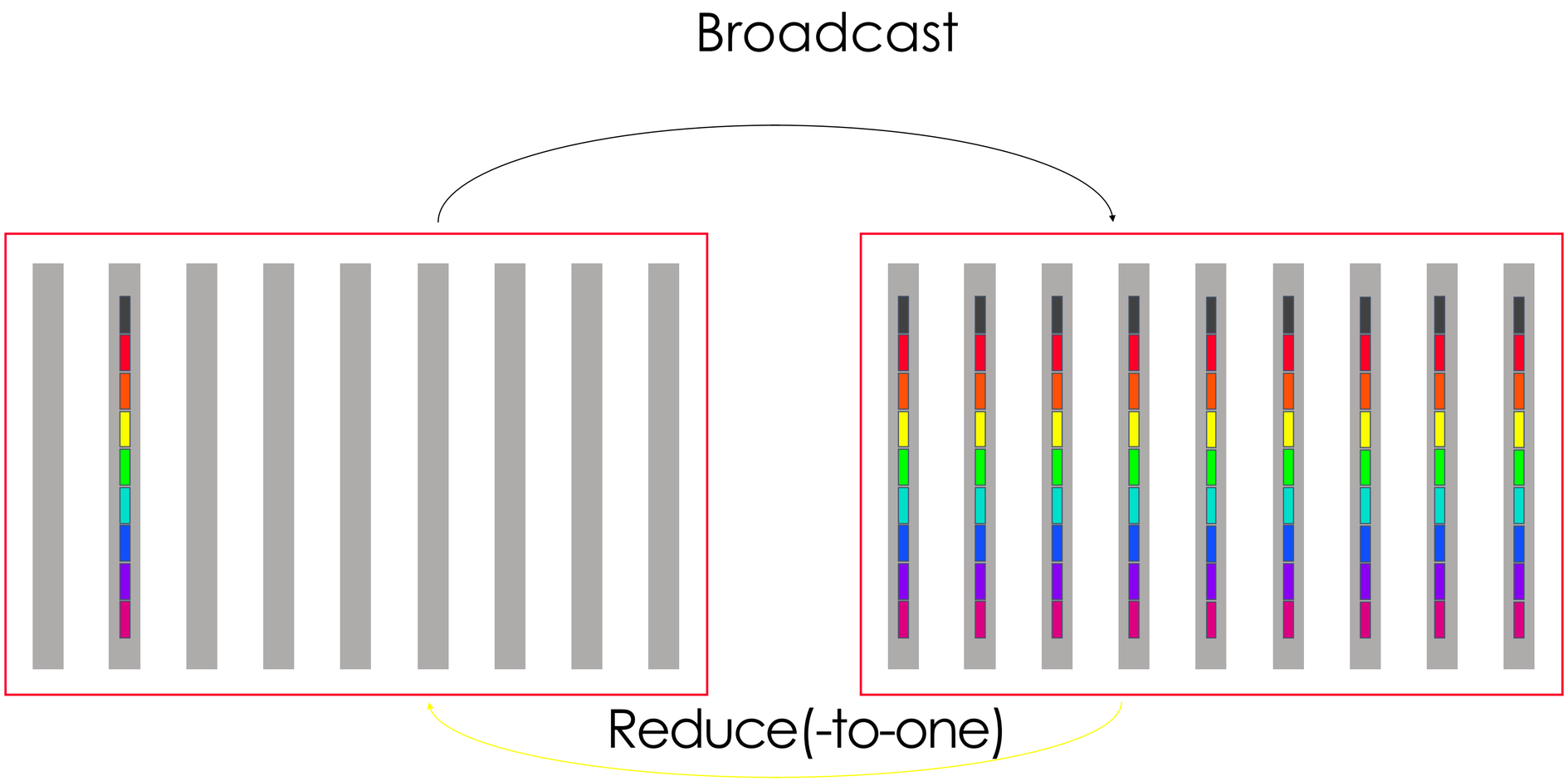
Broadcast



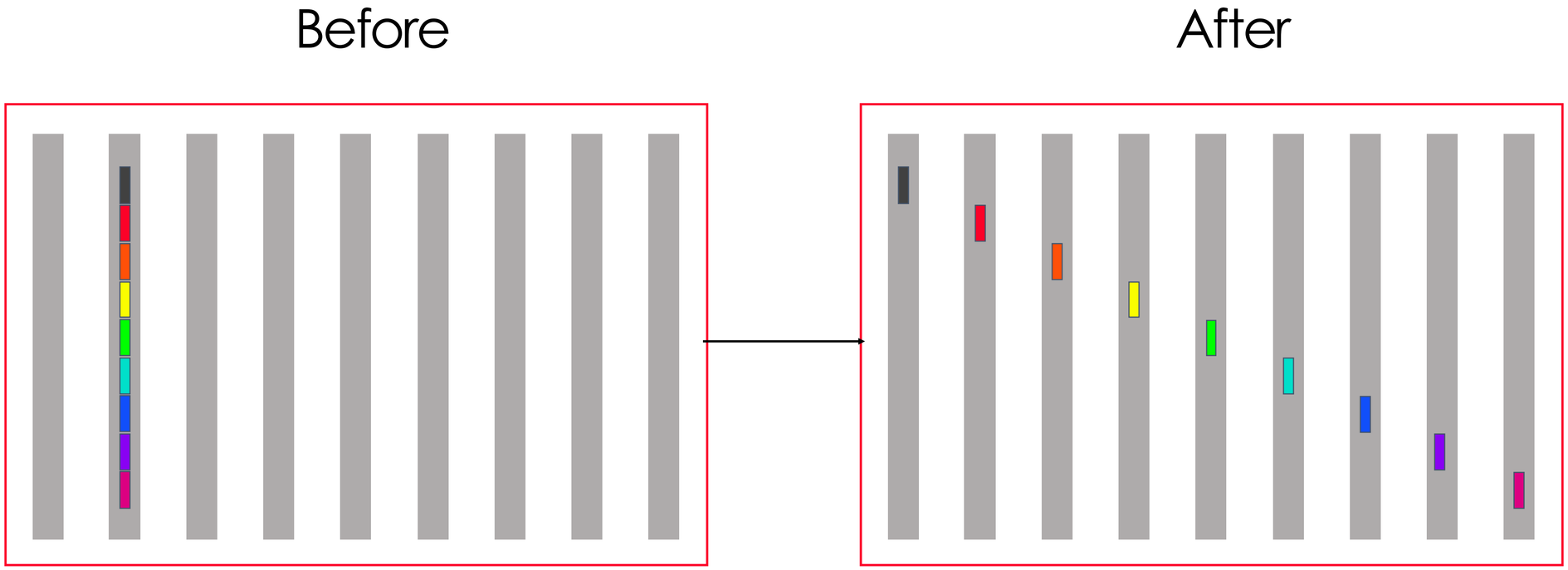
Reduce(-to-one)



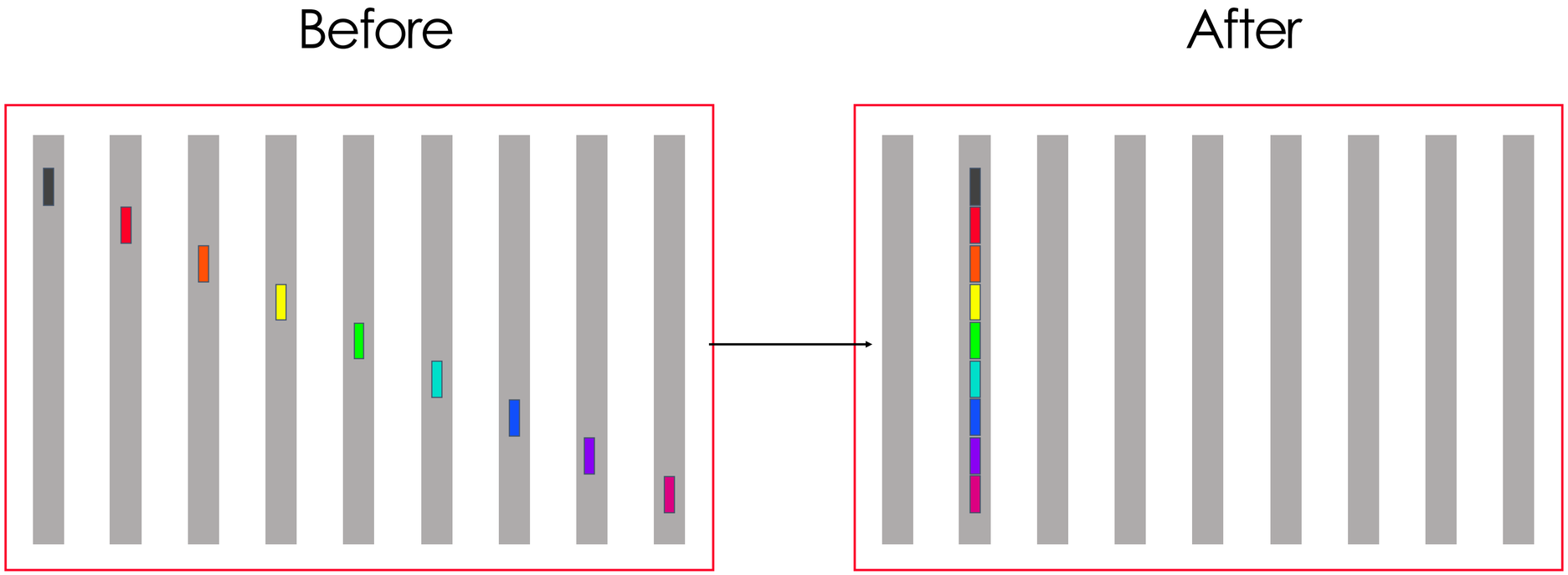
Broadcast/Reduce(-to-one)



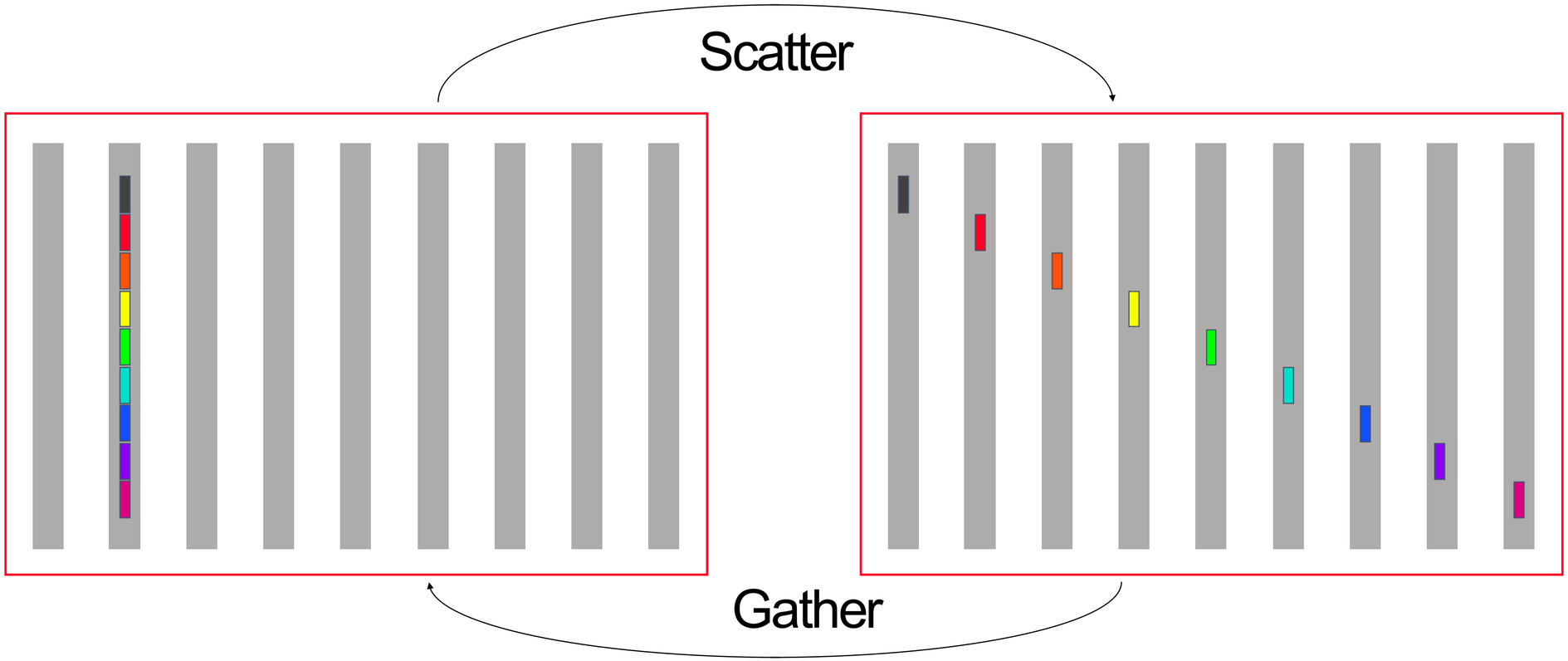
Scatter



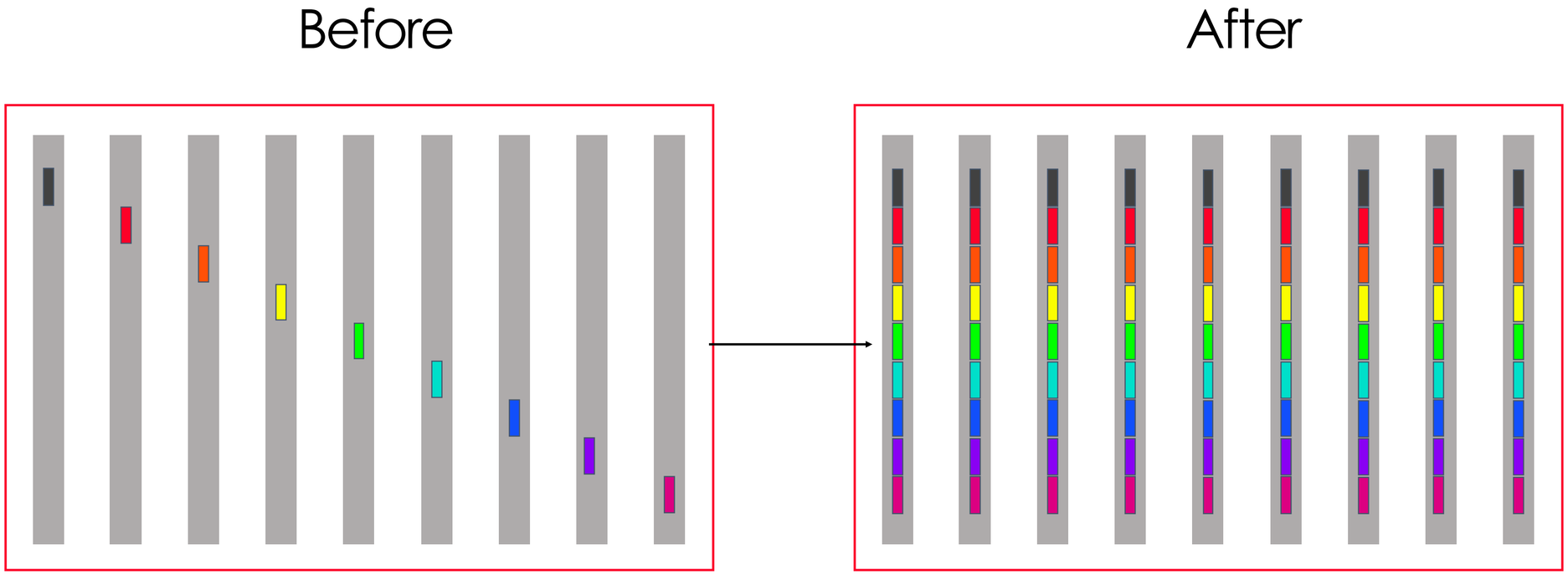
Gather



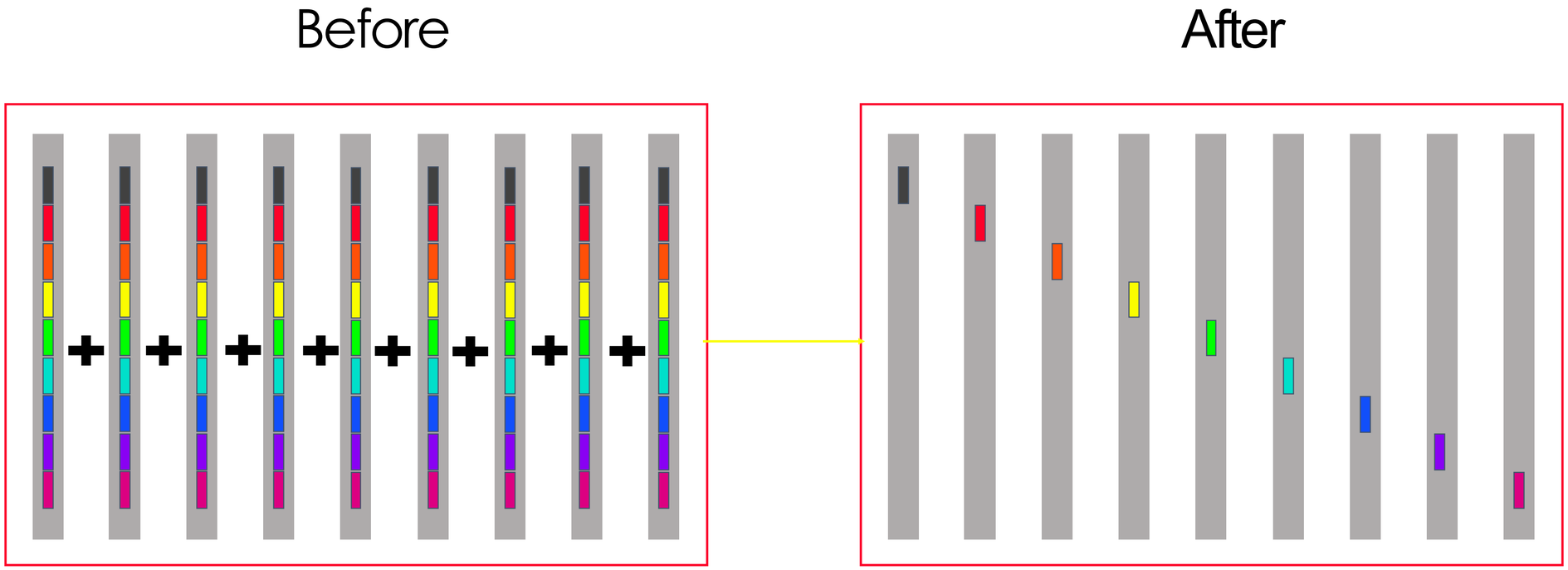
Scatter/Gather



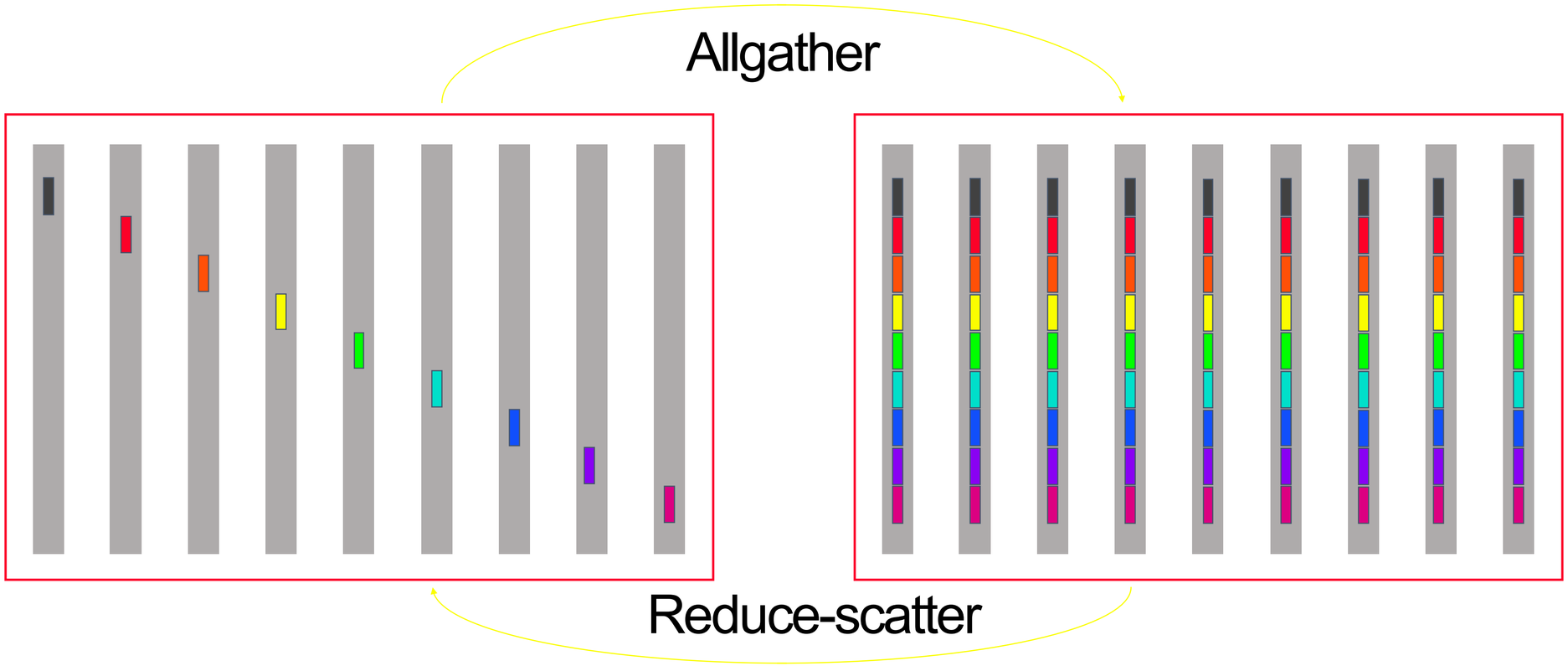
Allgather



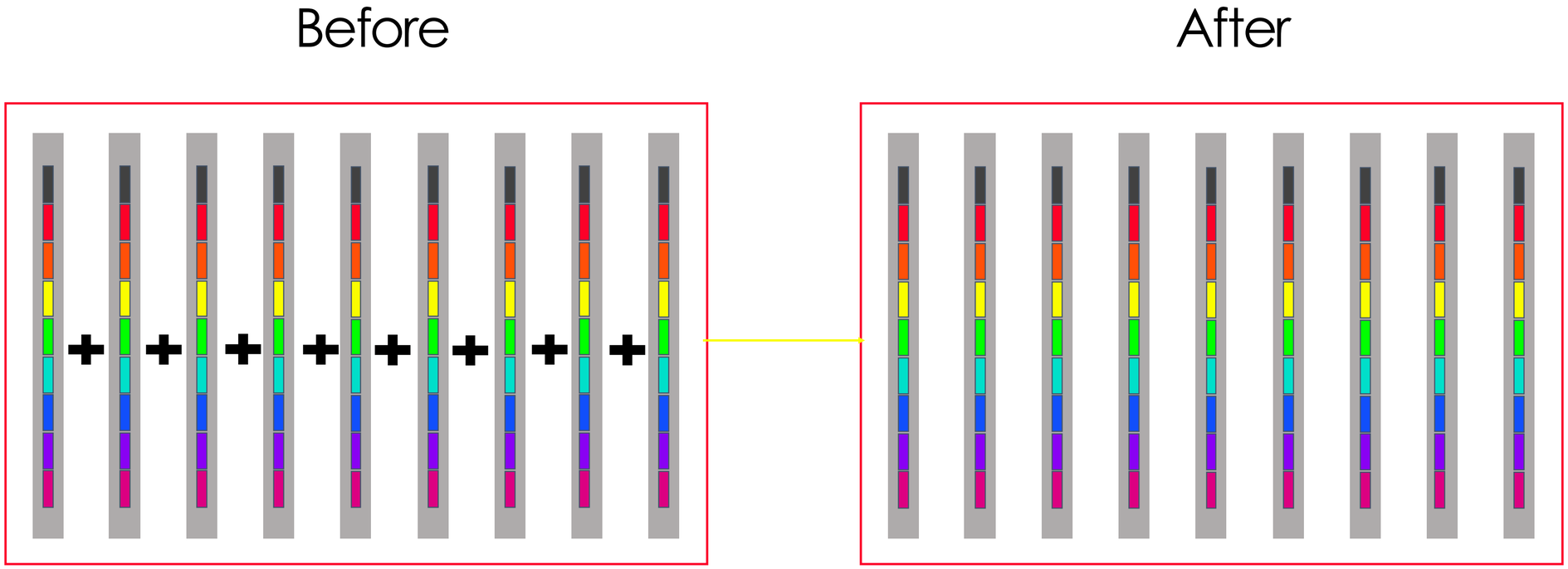
Reduce-scatter



Allgather/Reduce-scatter



Allreduce



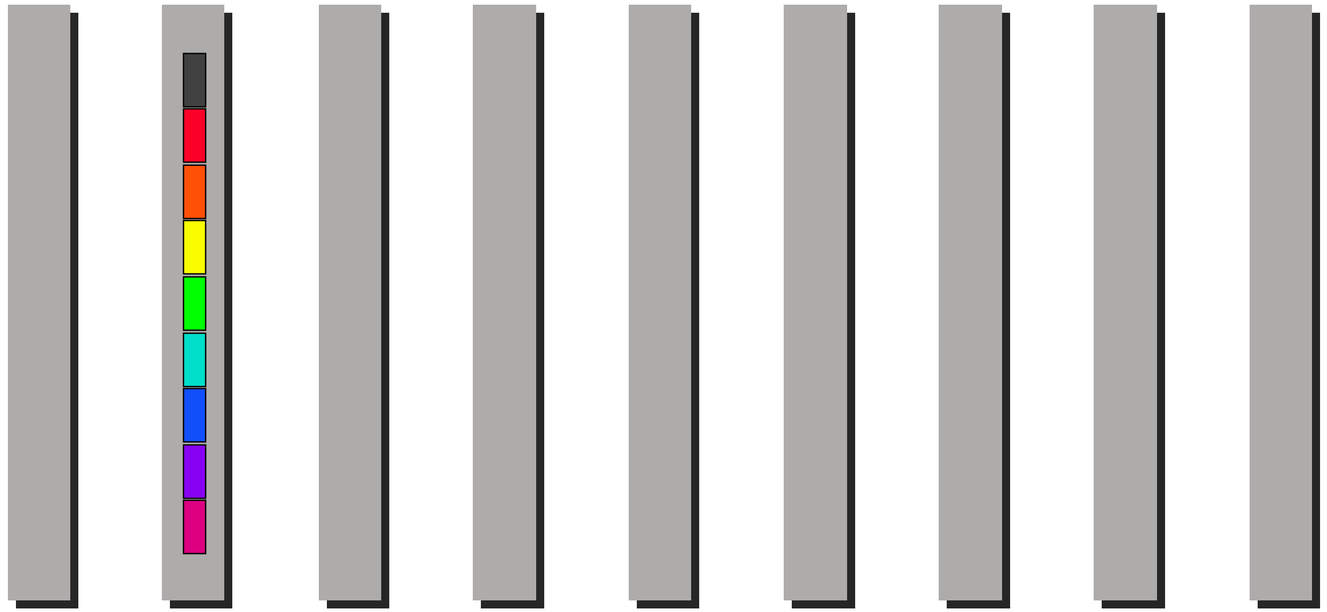
Two Family of Mainstream Algorithms/Implementations

- Small message: Minimum Spanning Tree algorithm
  - Emphasize **low latency**

- Large Message: Ring algorithm
  - Emphasize **bandwidth utilization**

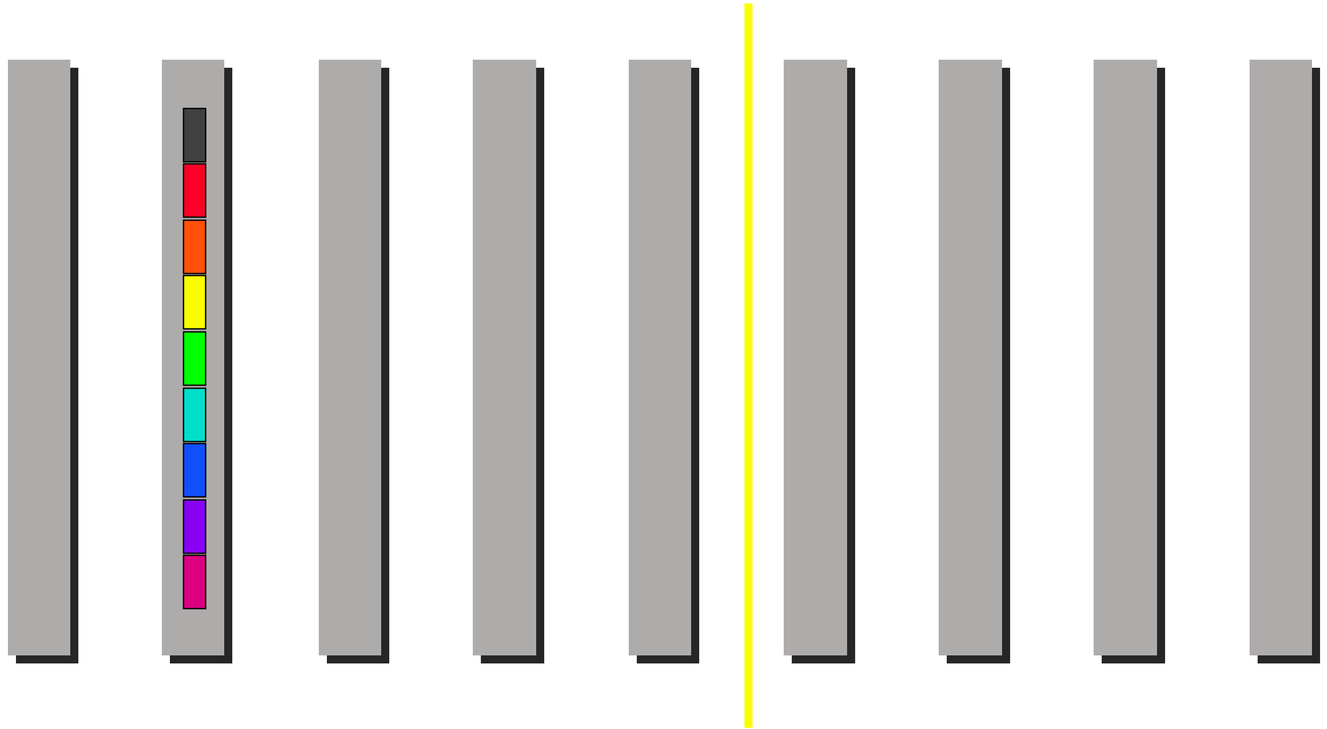
- There are 50+ different algorithms developed in the past 50 years by a community called “High-performance computing”
  - Last year Turing award

General principles



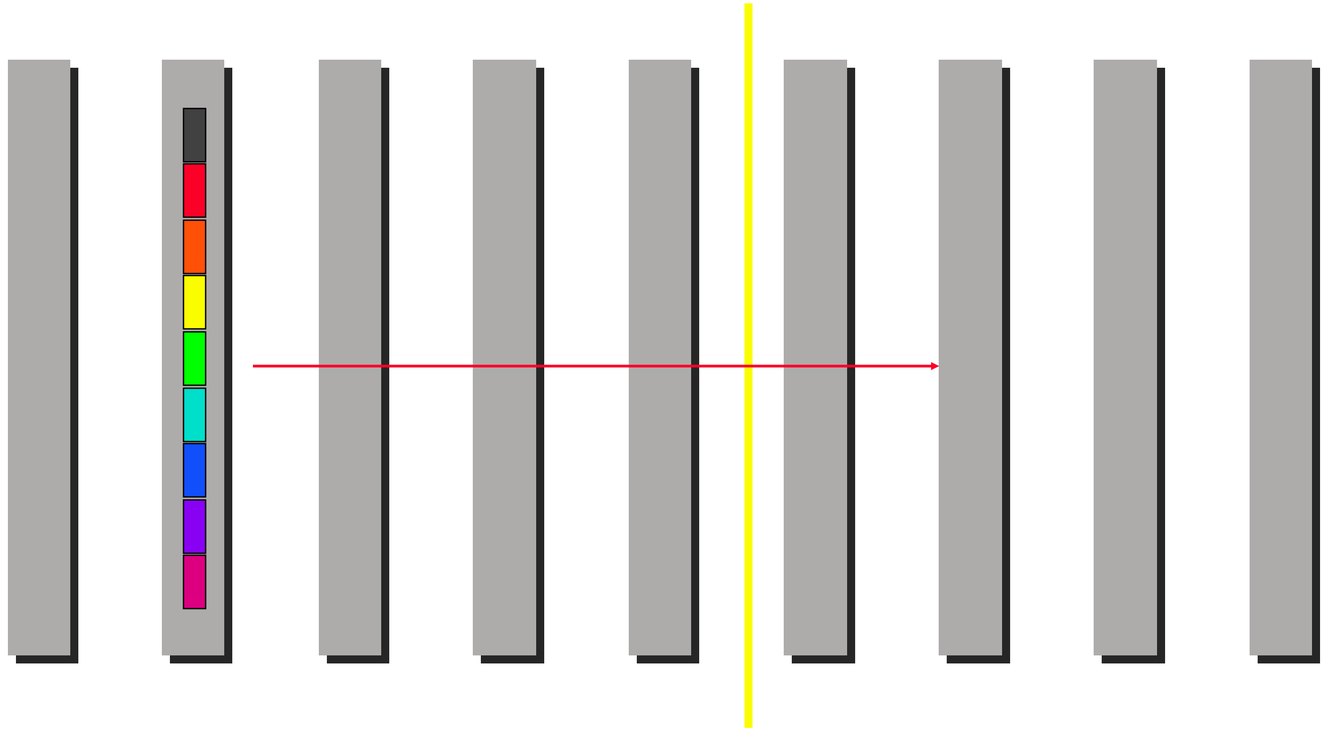
- message starts on one processor

General principles



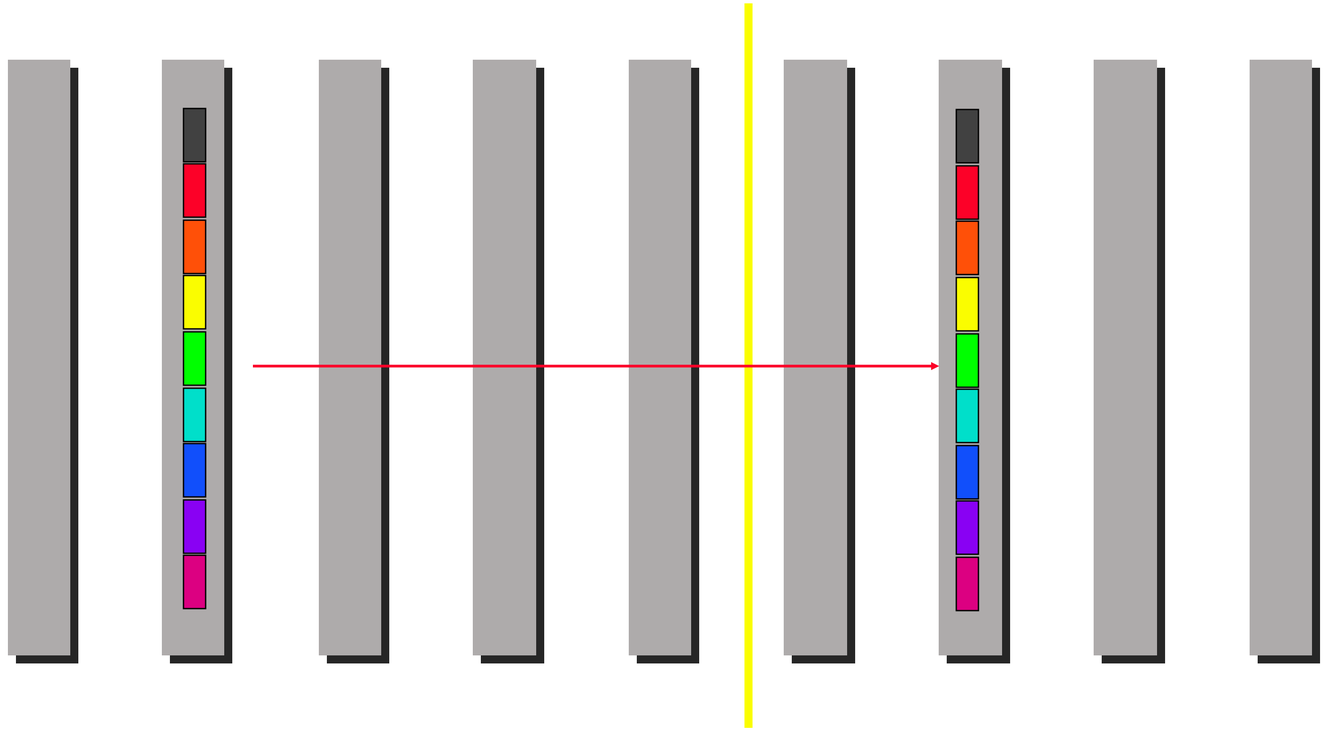
- divide logical linear array in half

General principles



- send message to the half of the network that does not contain the current node (root) that holds the message

General principles



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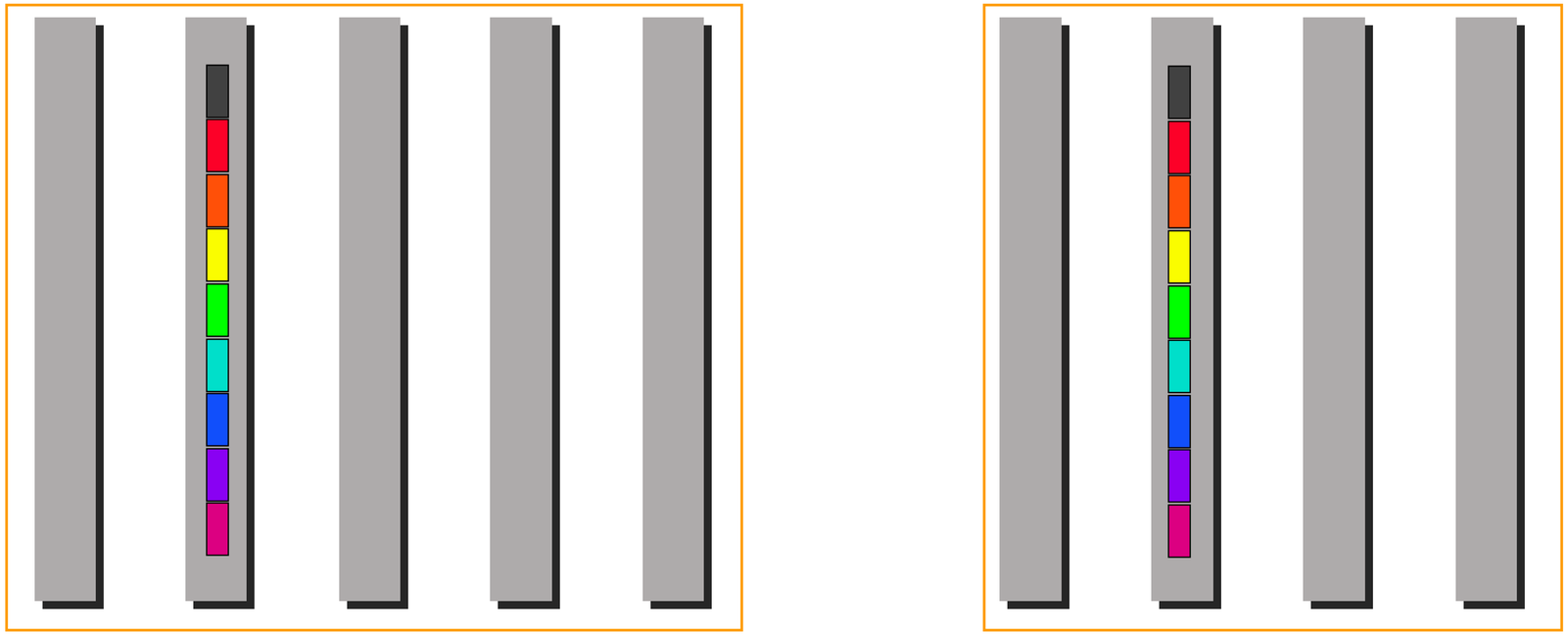
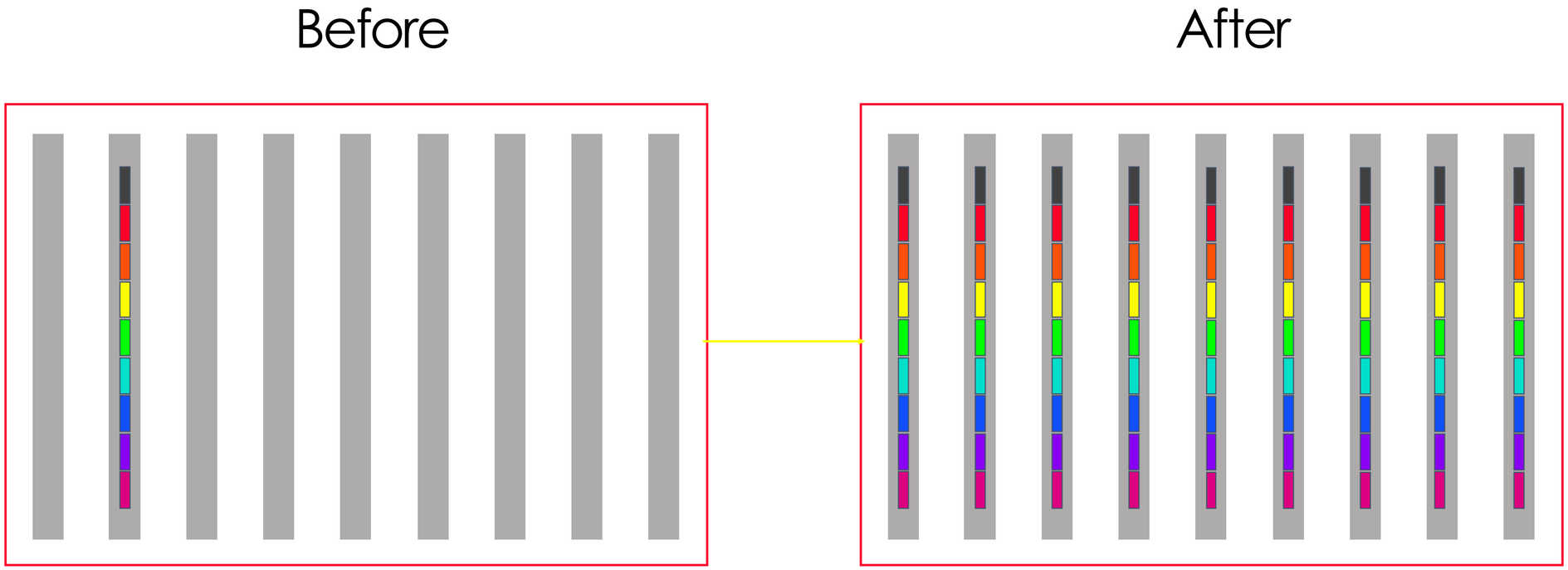
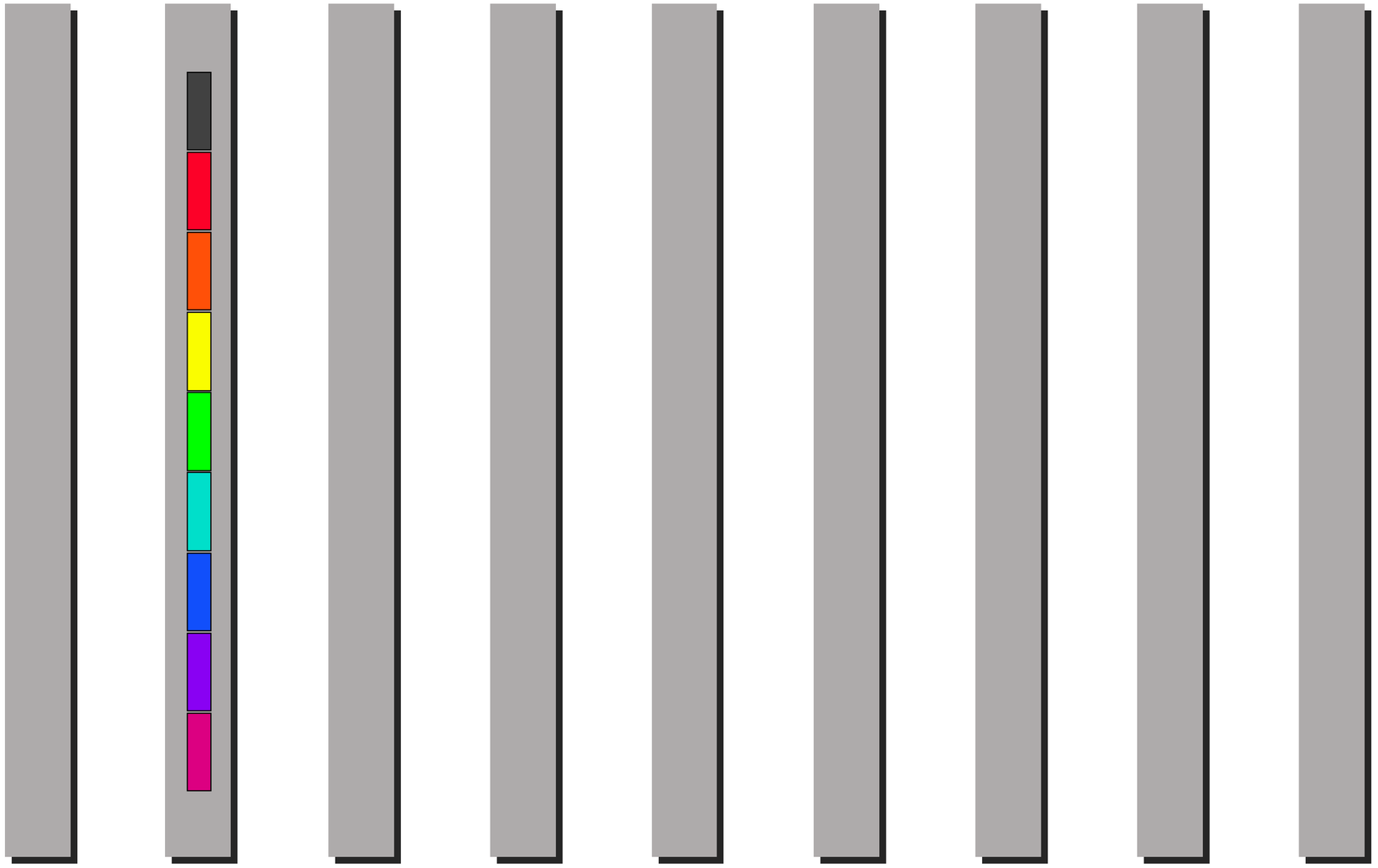
General principles

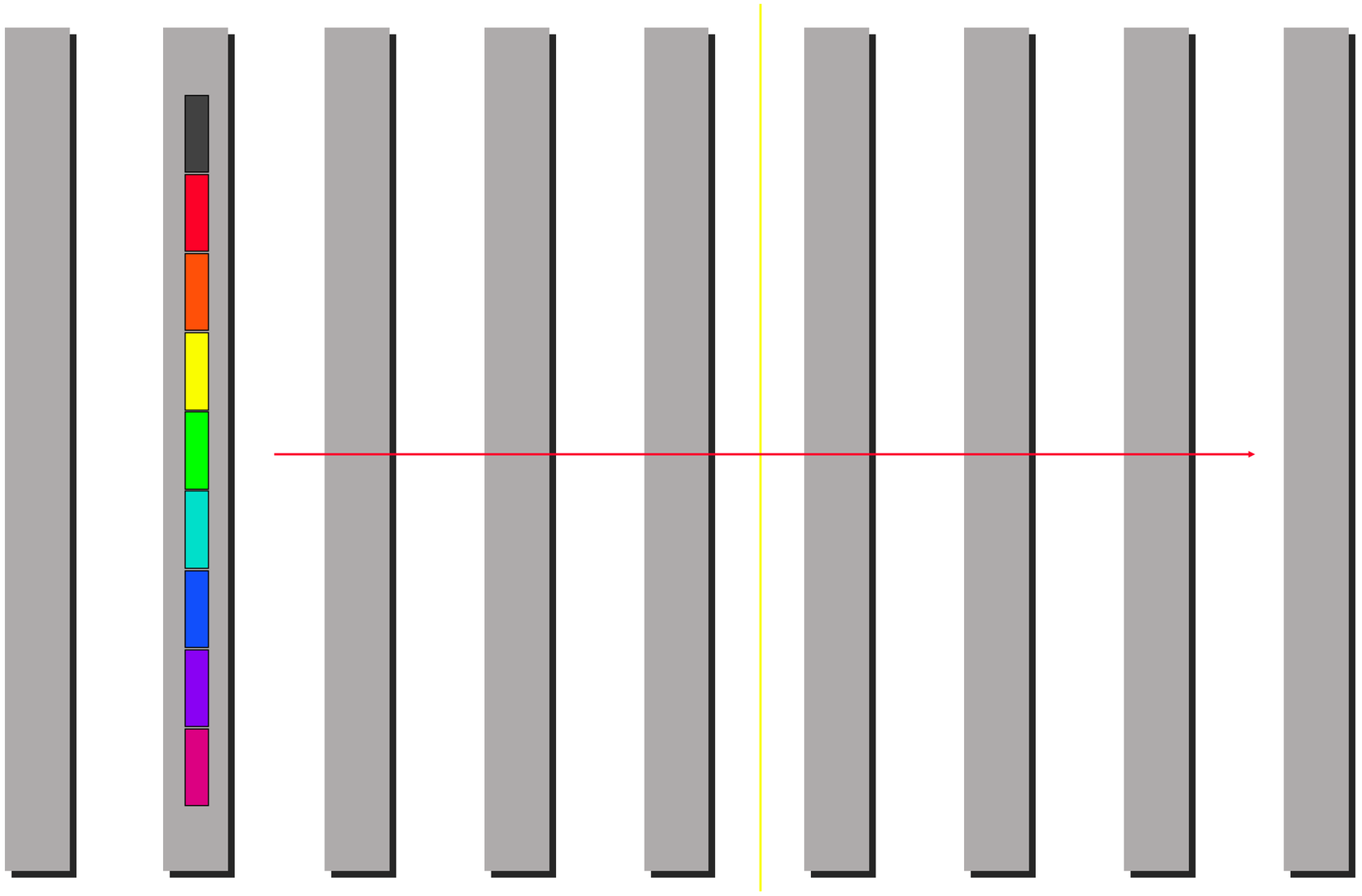


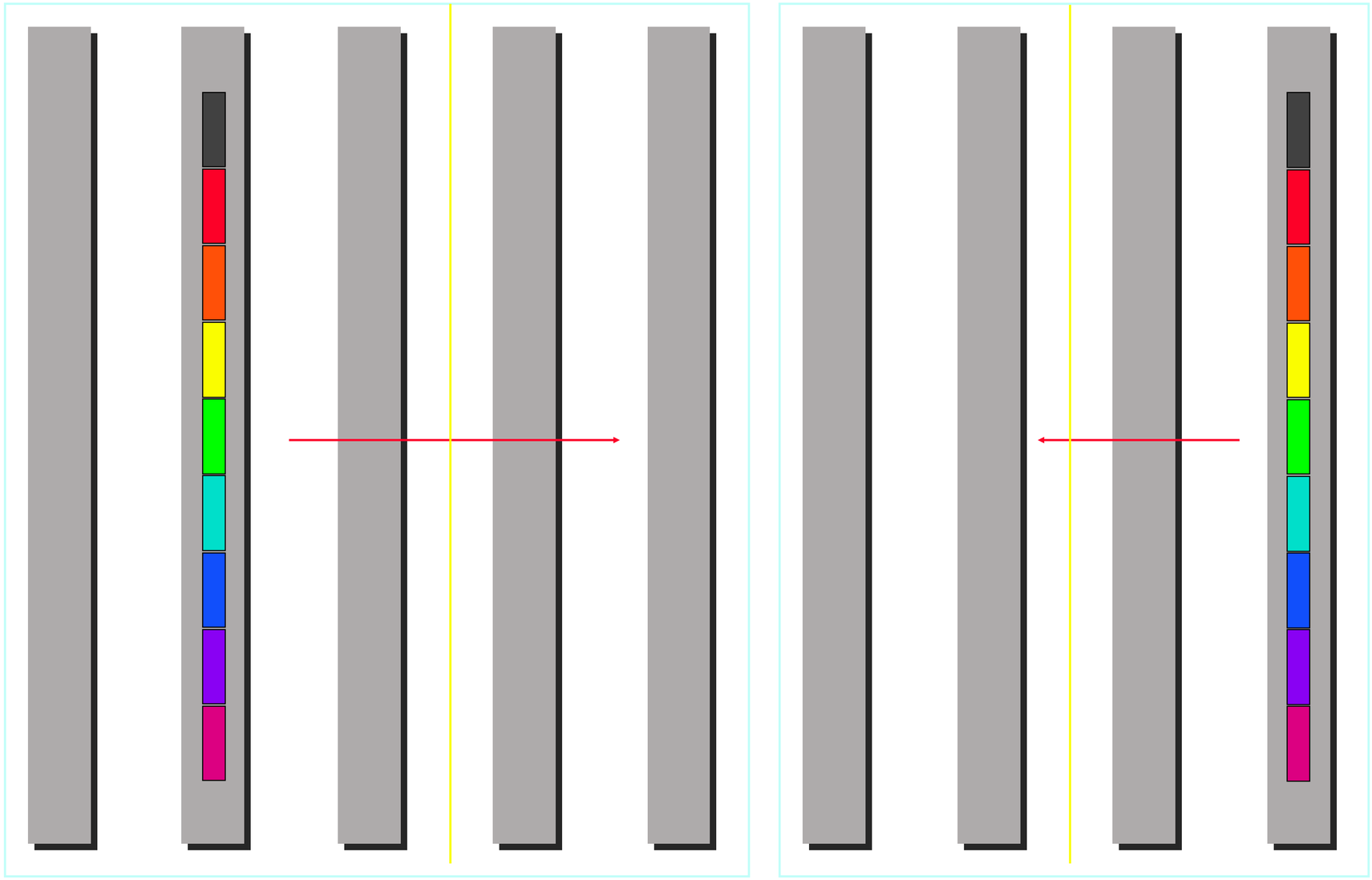
- continue recursively in each of the two halves

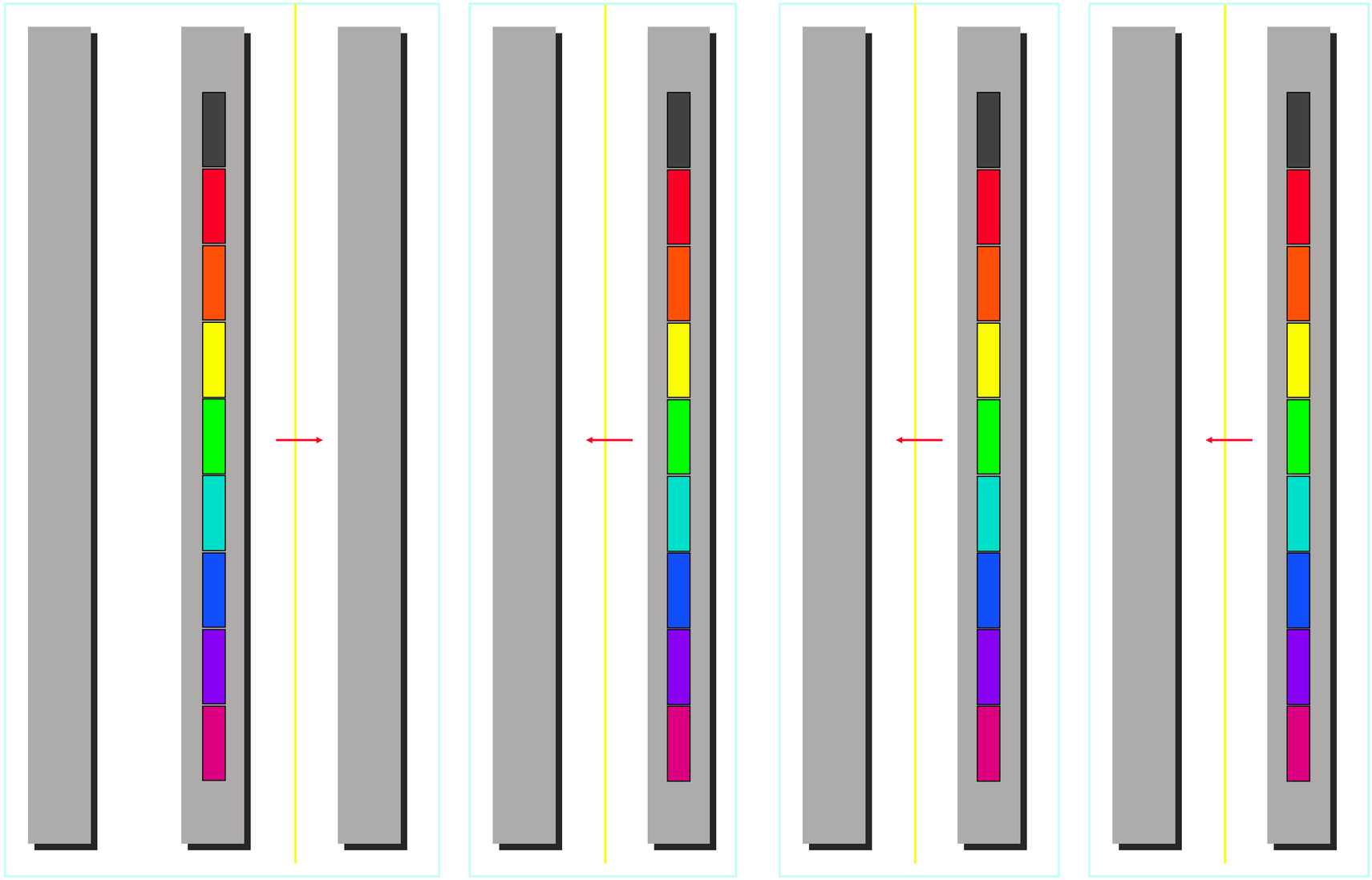
Broadcast

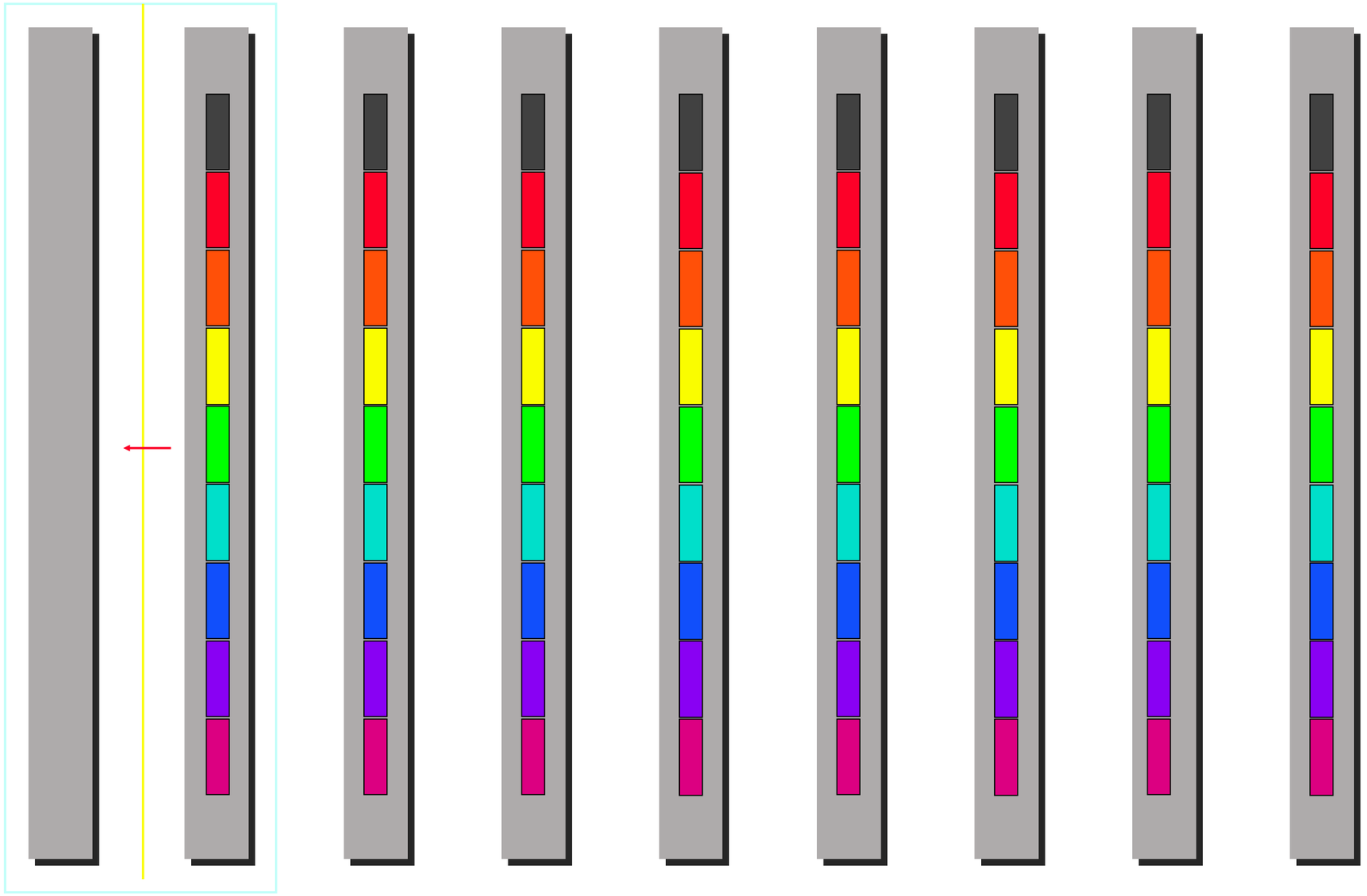


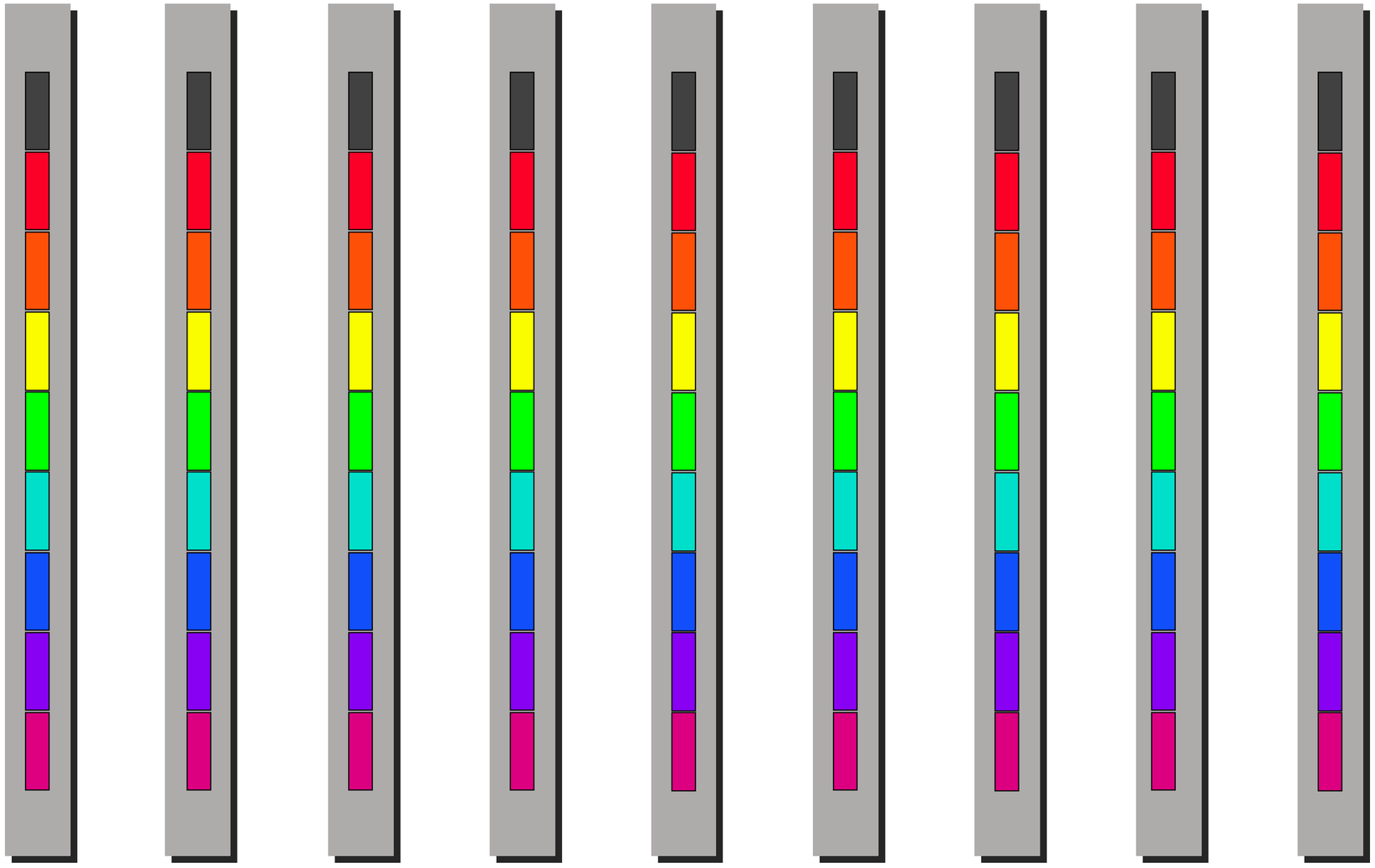








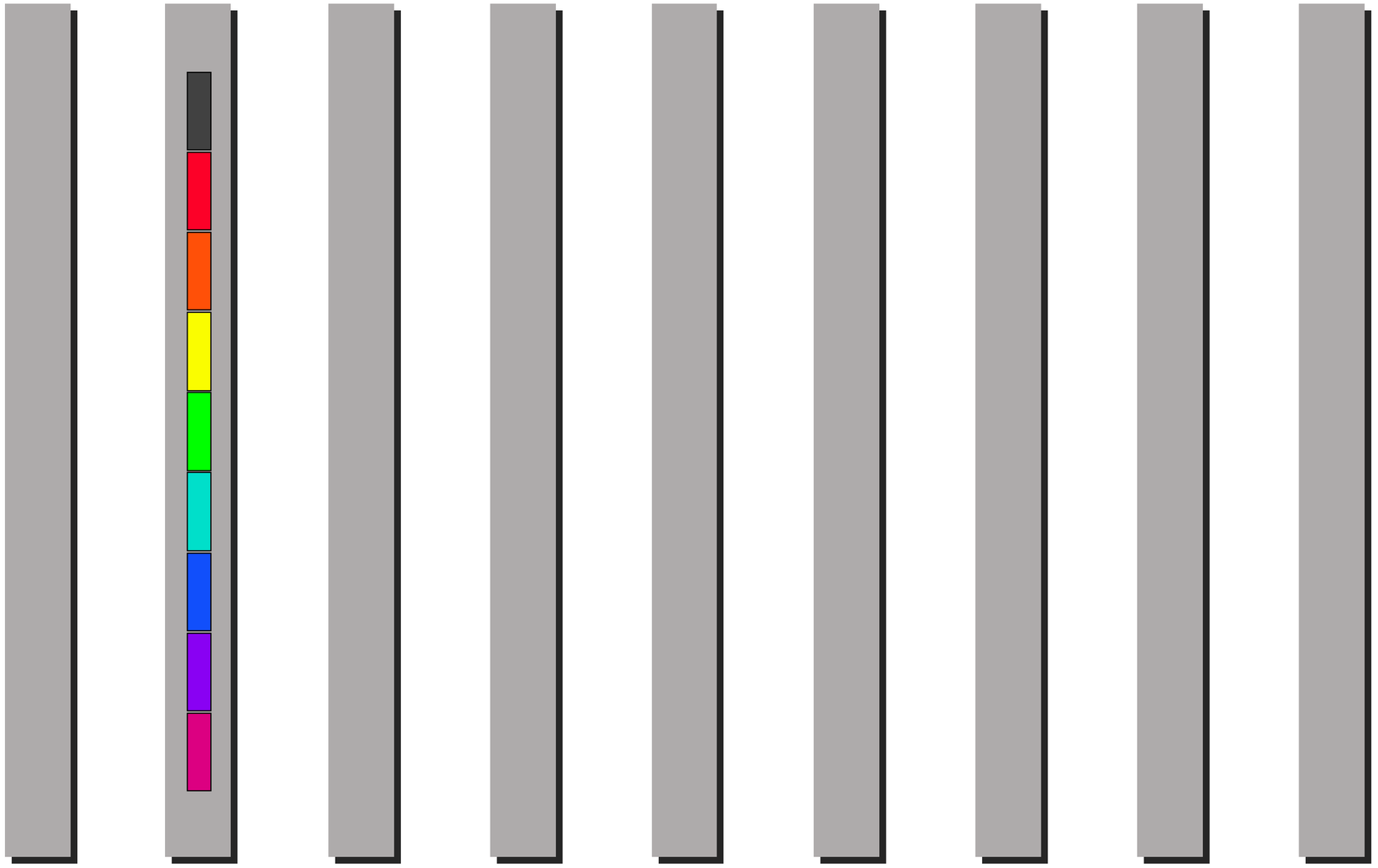


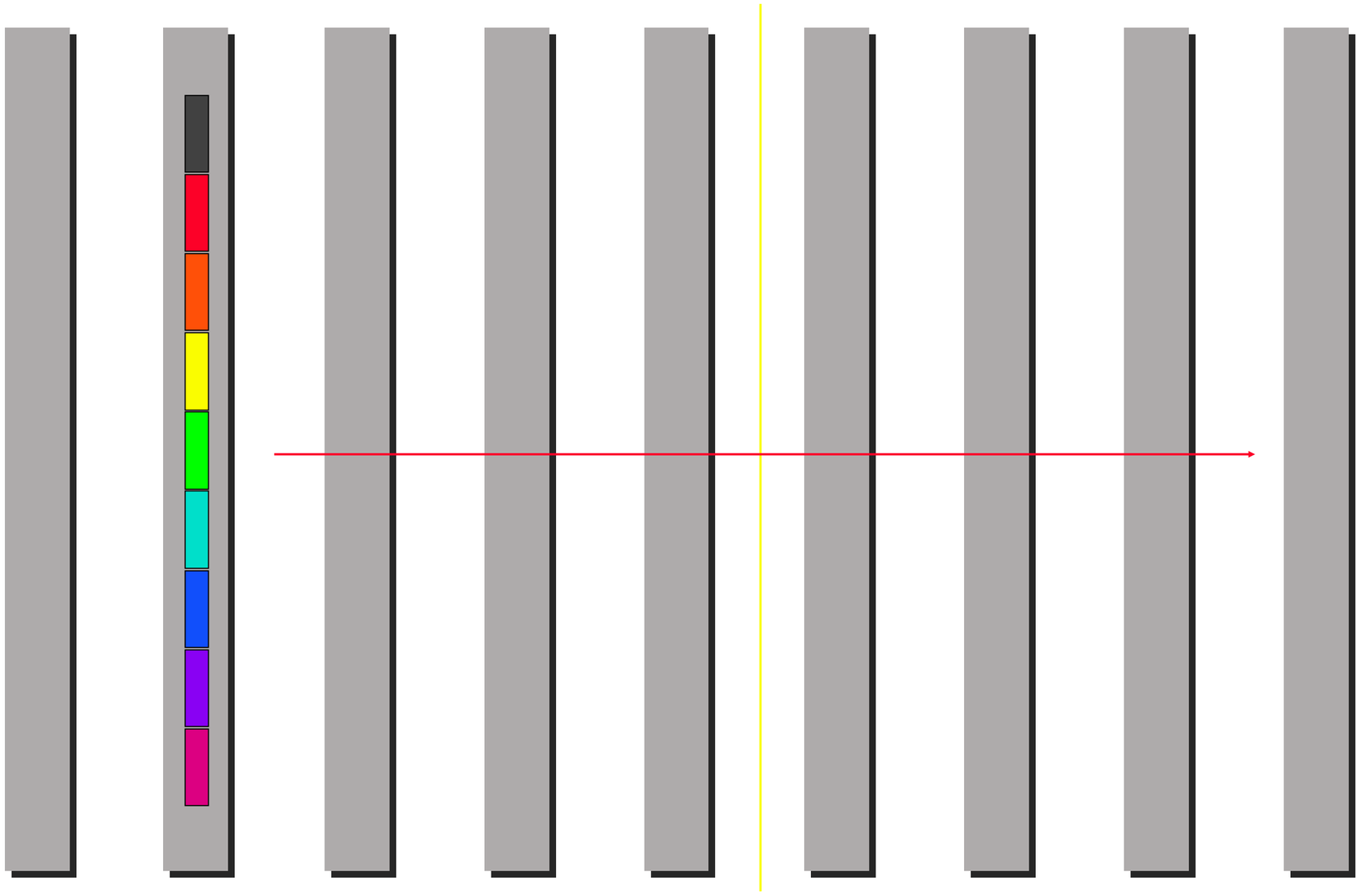


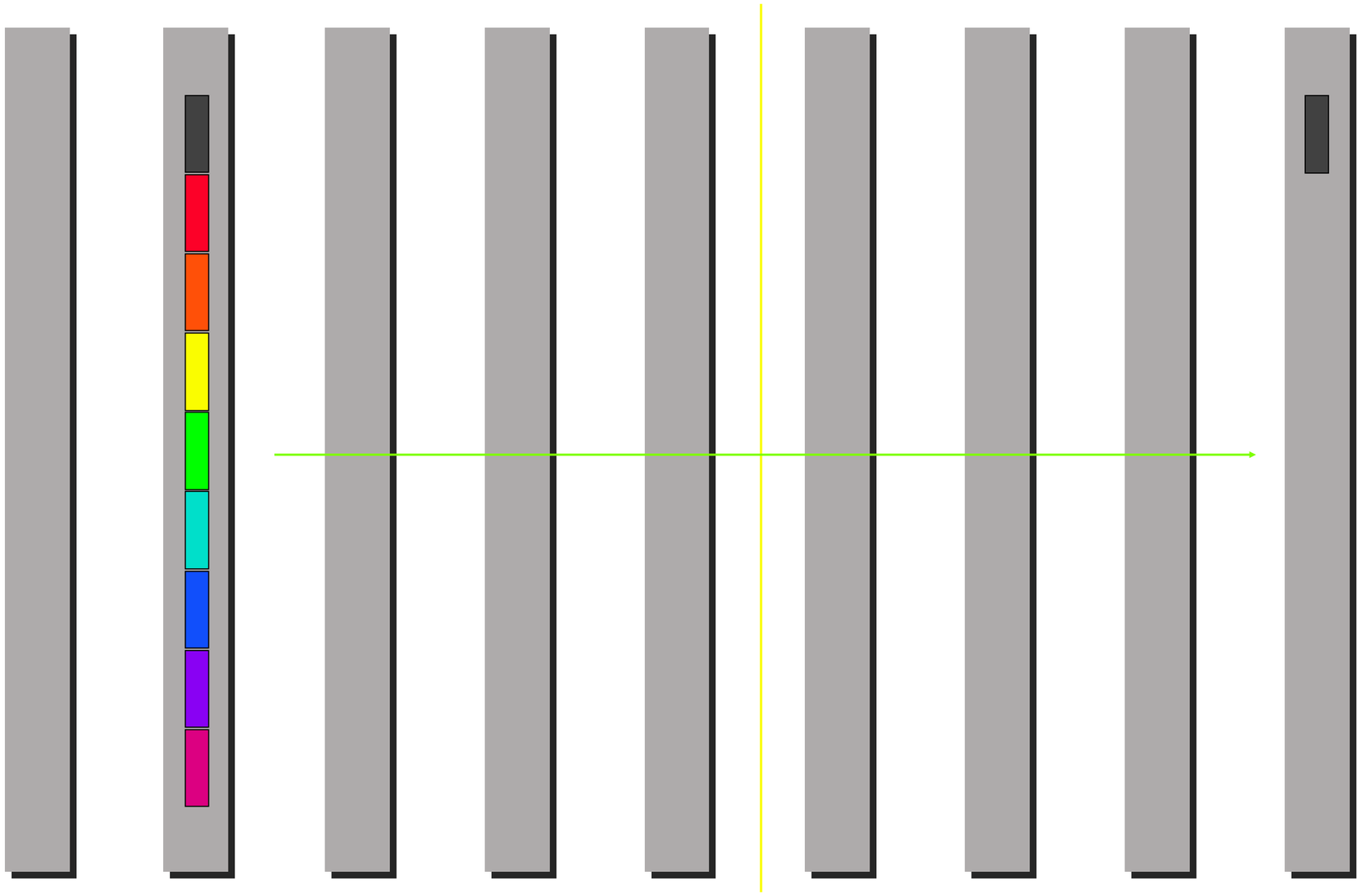
Let us view this more closely

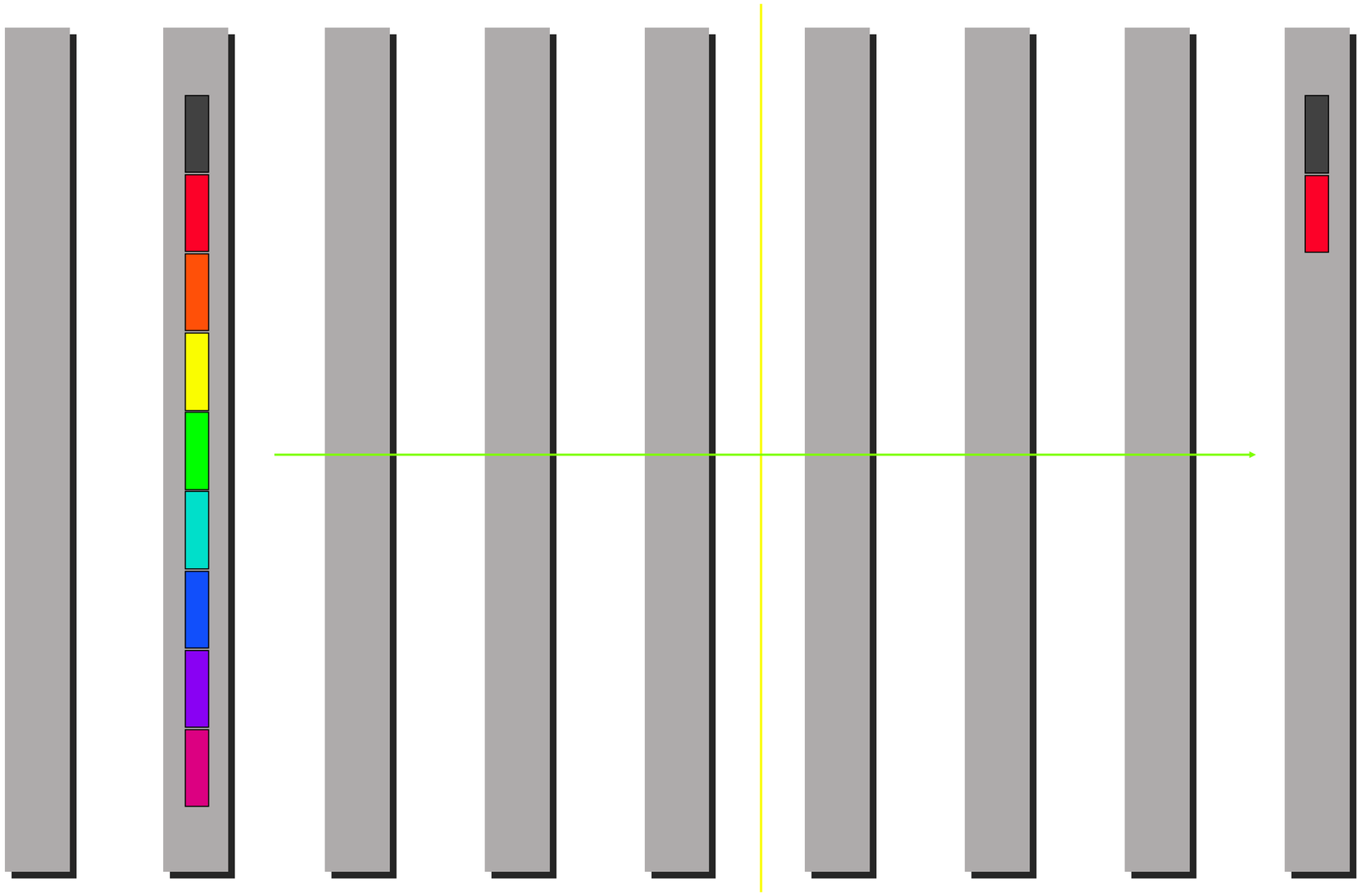
- Red arrows indicate startup of communication (leading to latency, α)

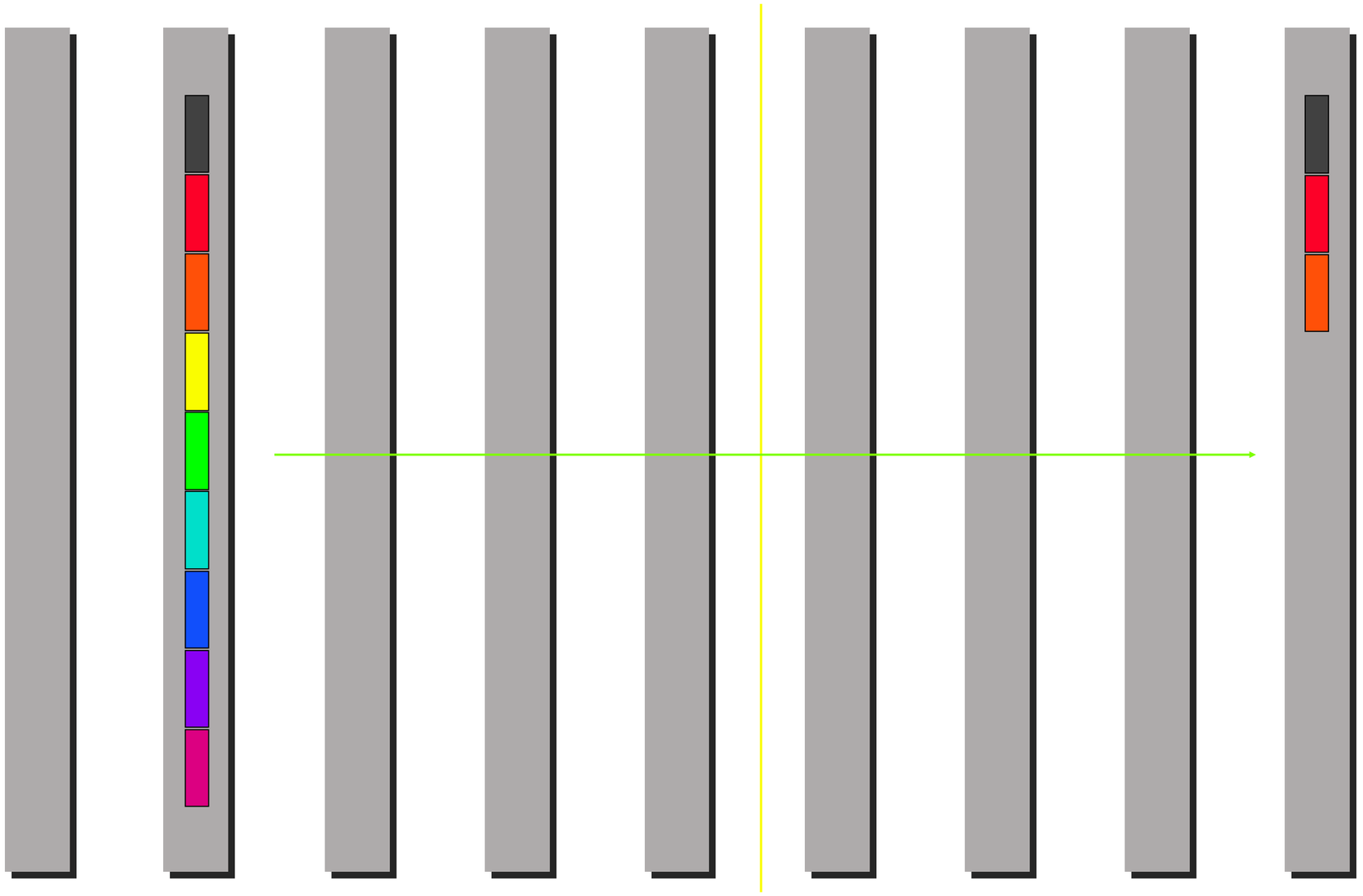
- Green arrows indicate packets in transit (leading to a bandwidth related cost proportional to β and the length of the packet

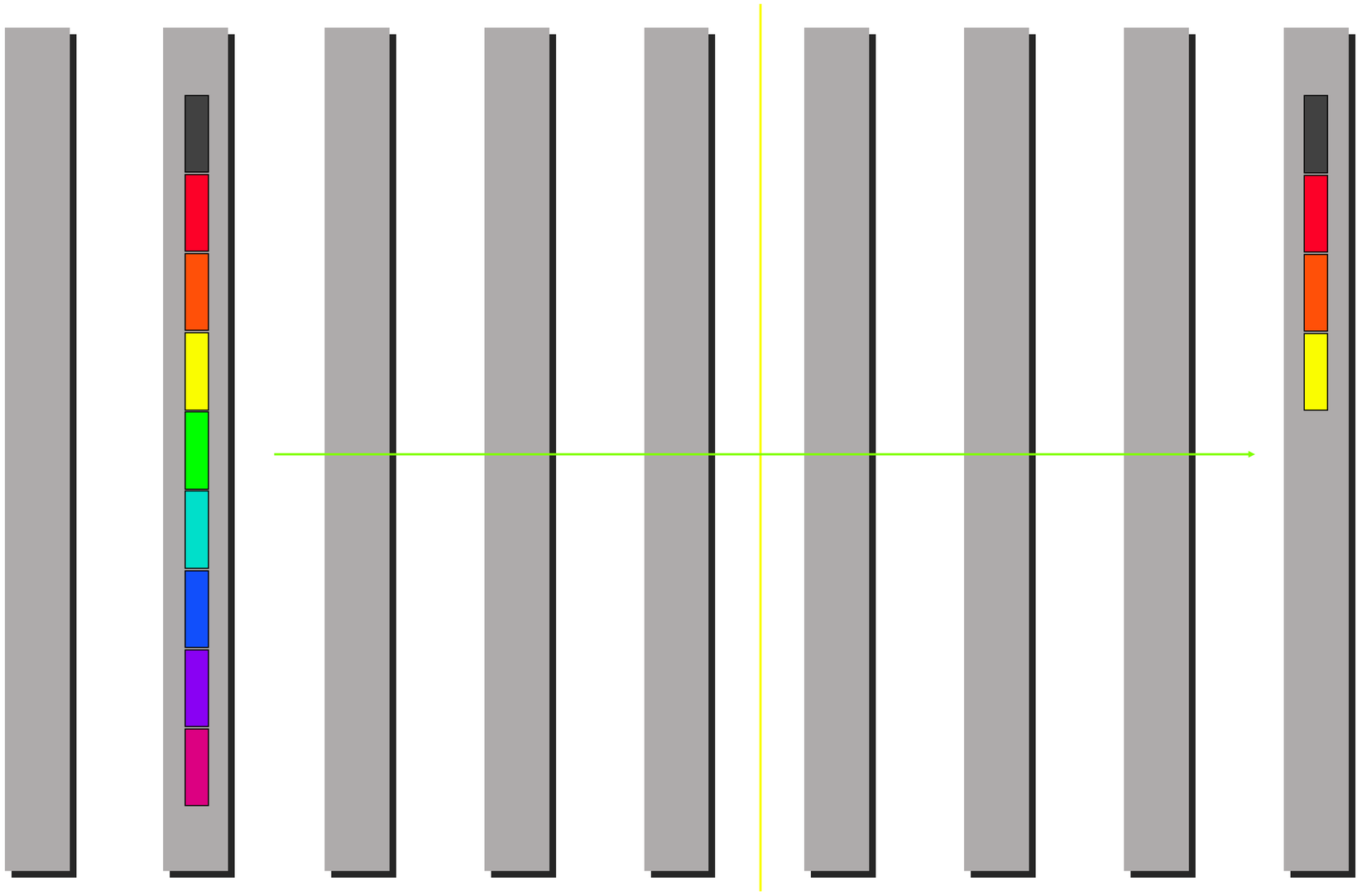


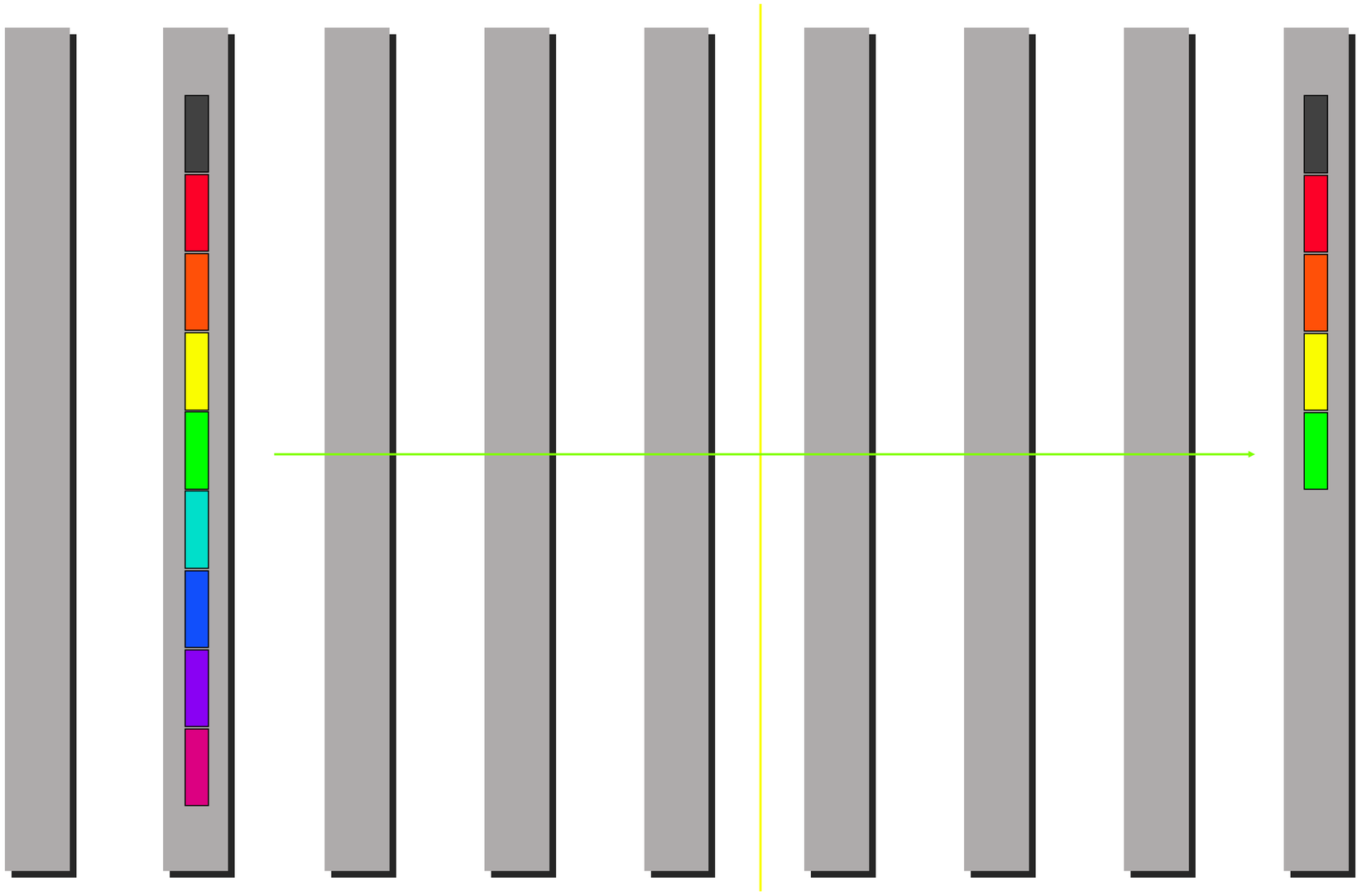


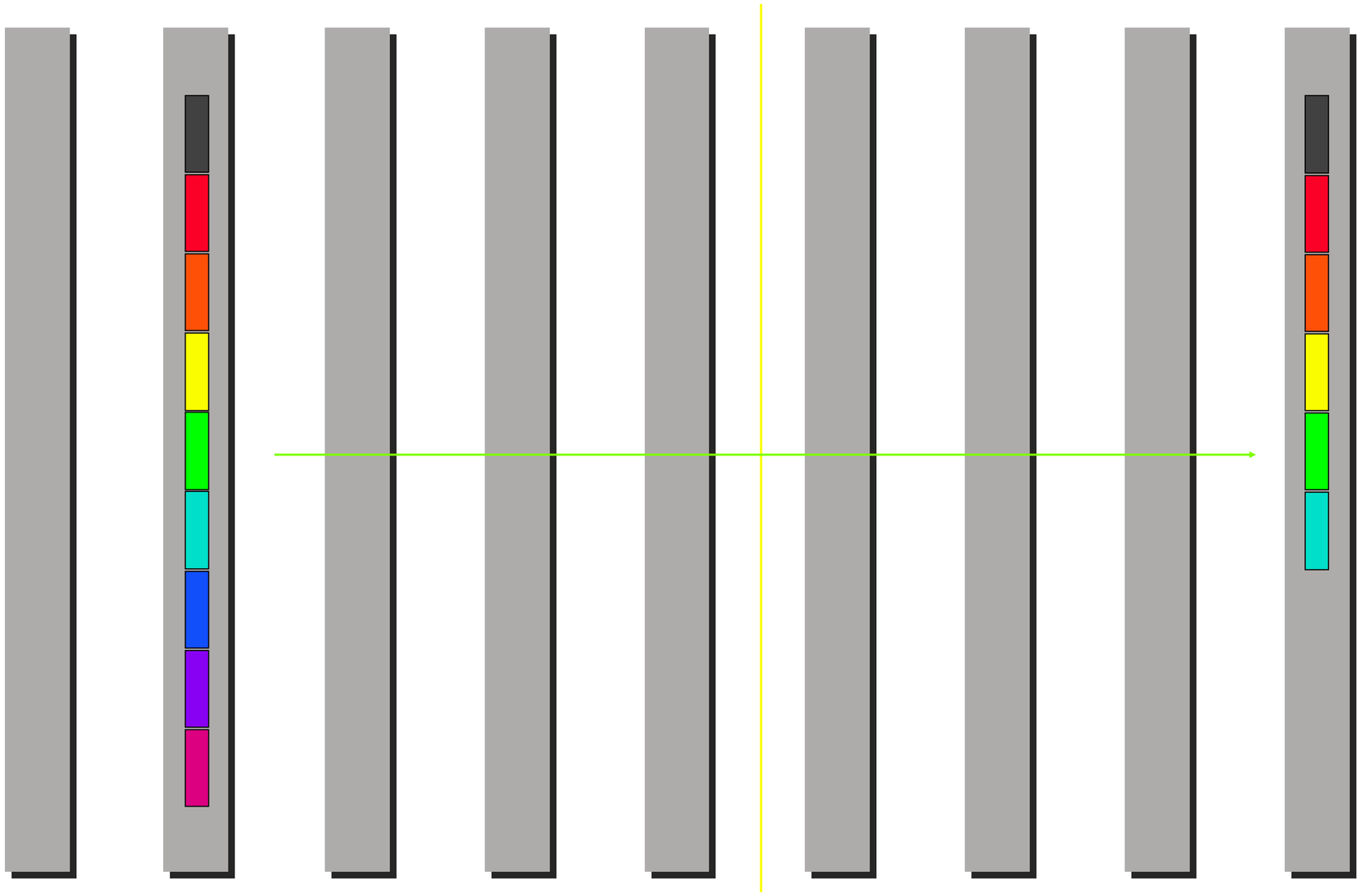


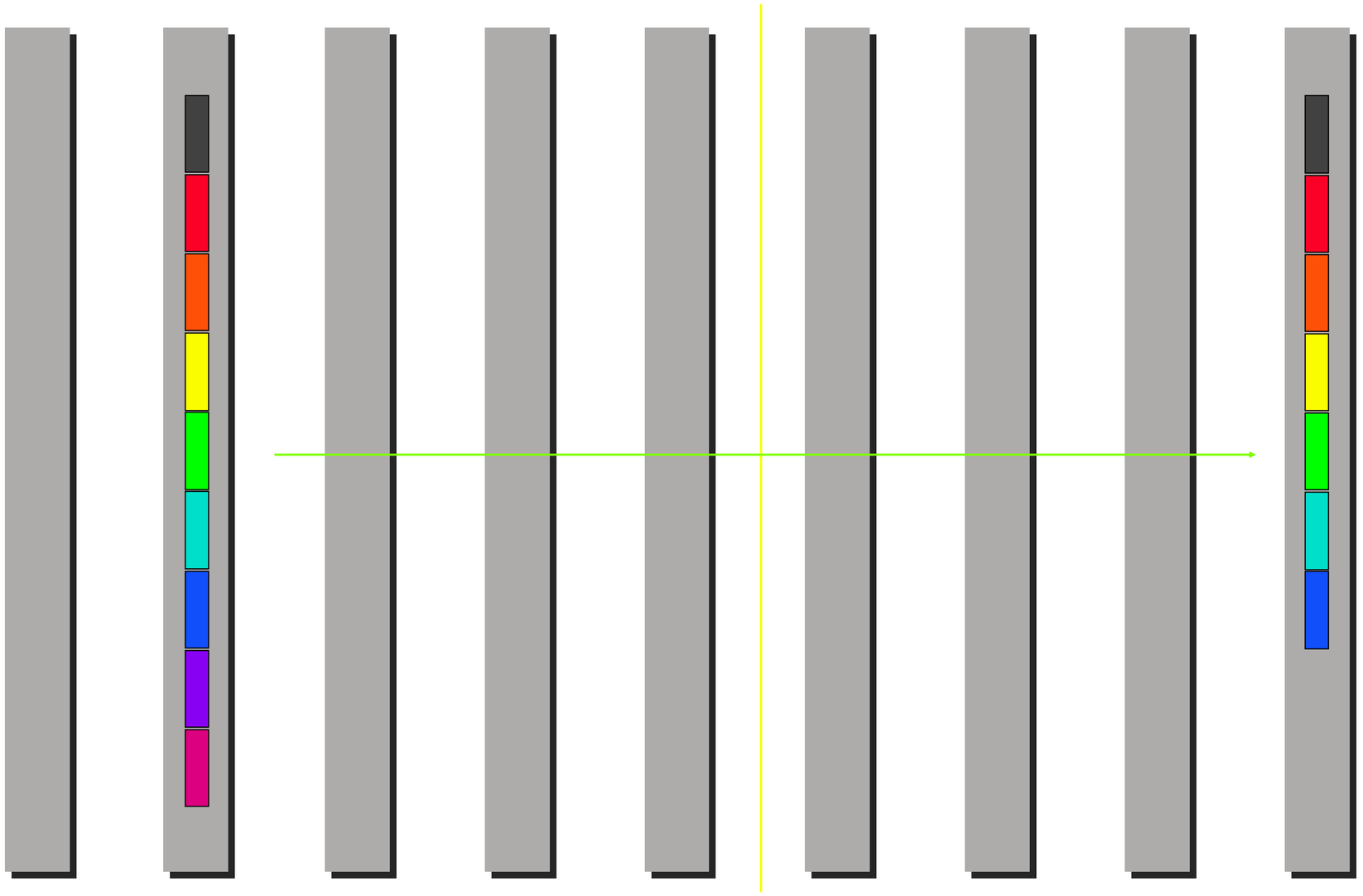


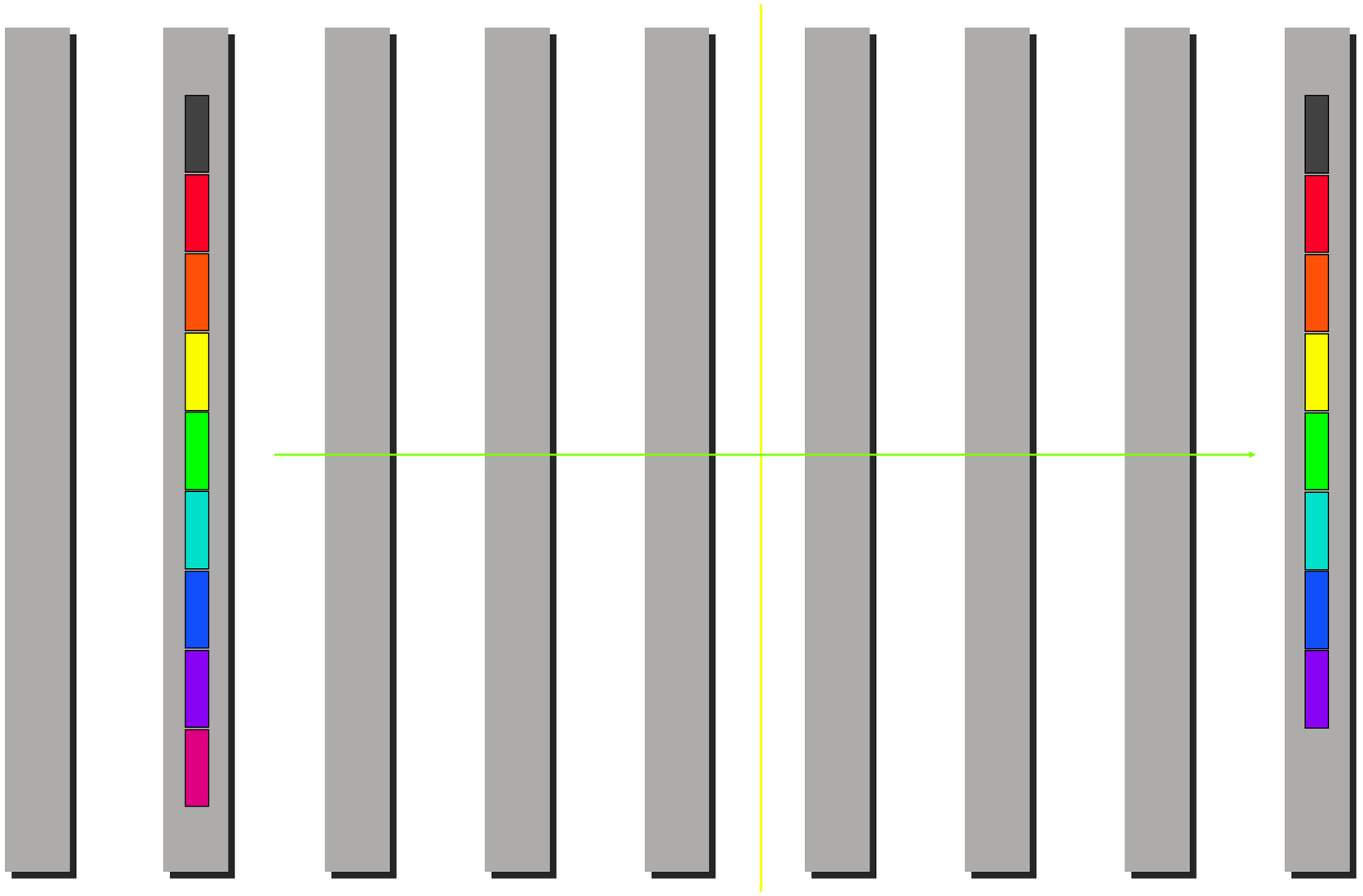


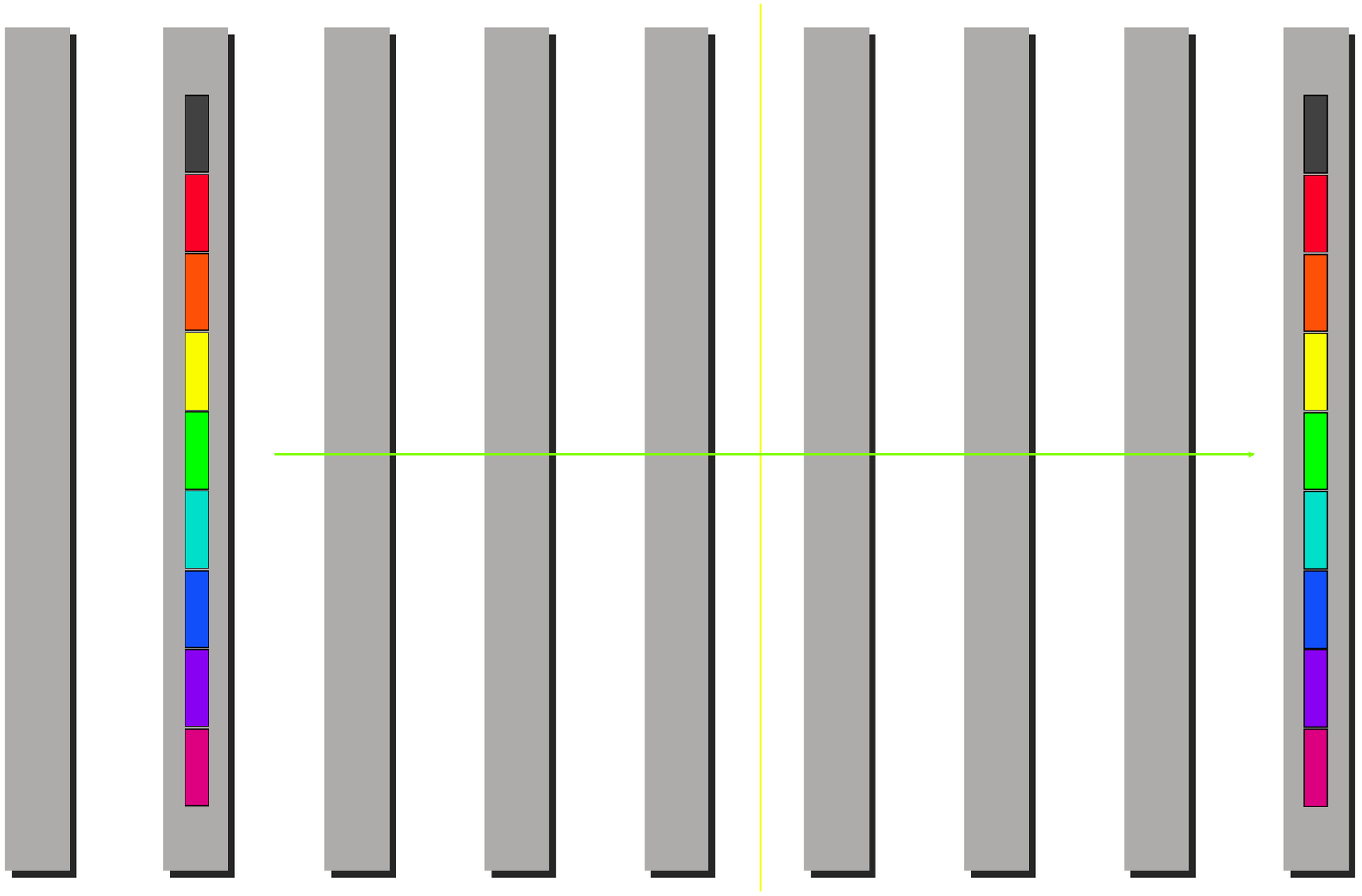


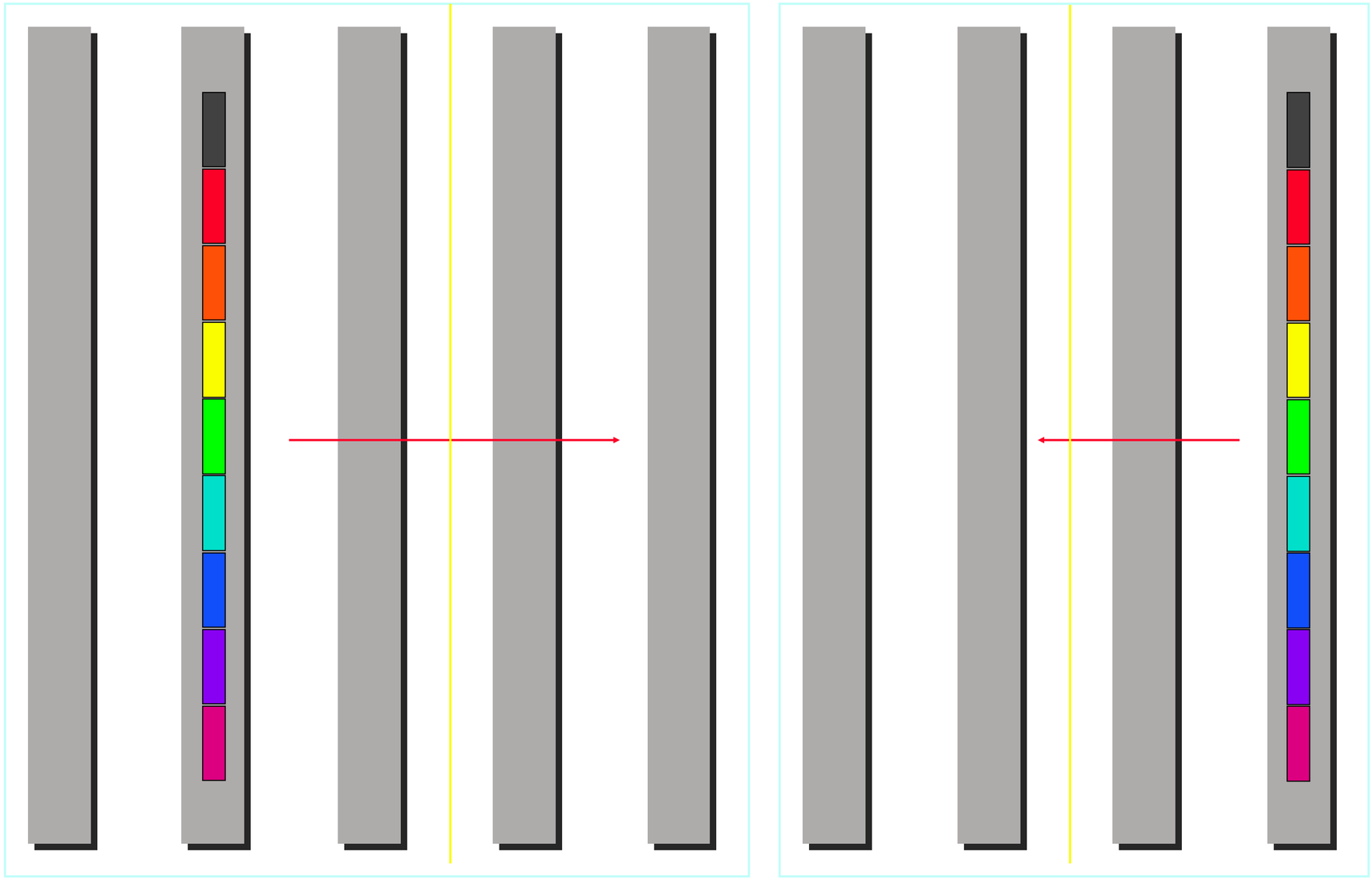


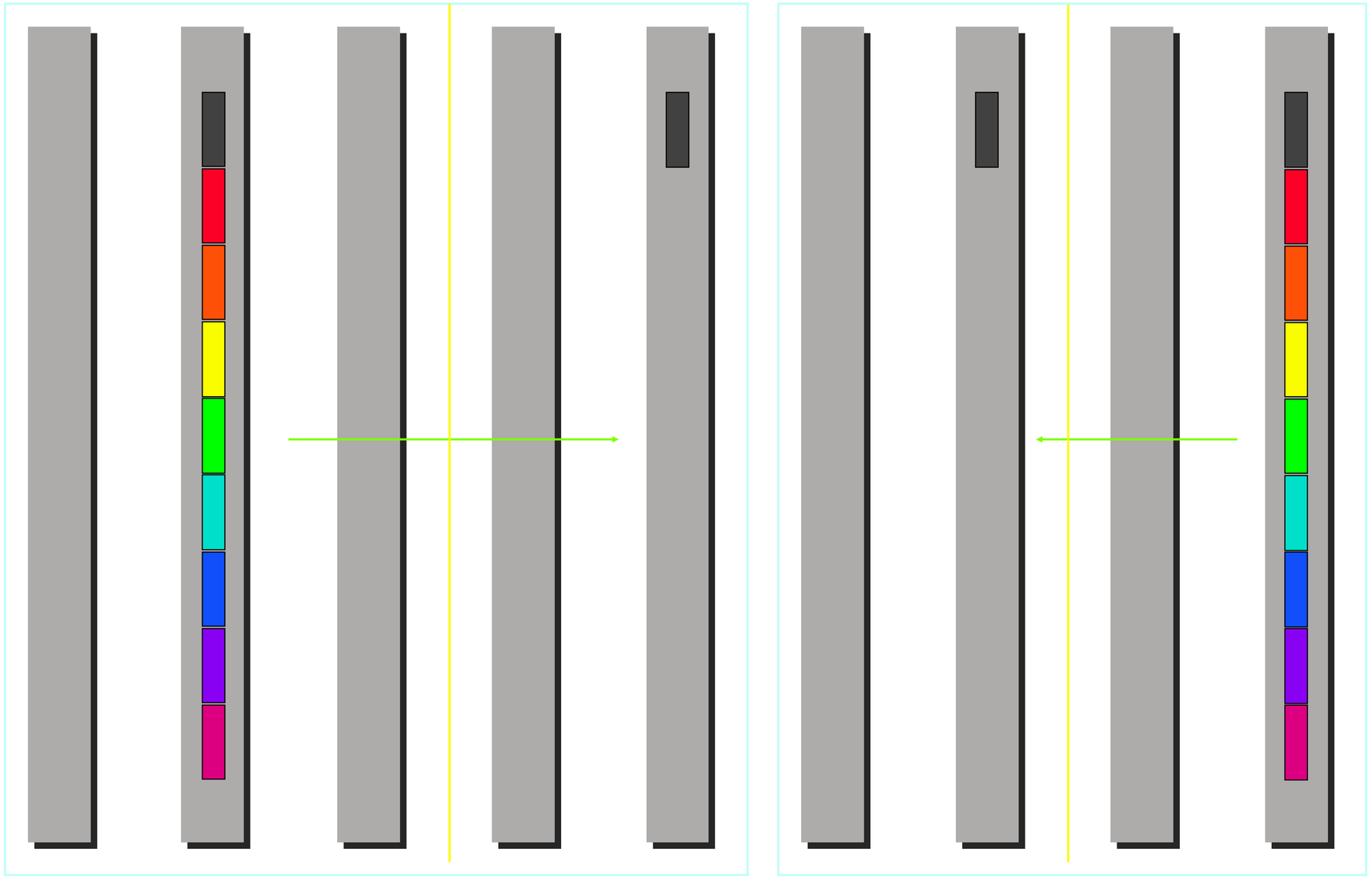


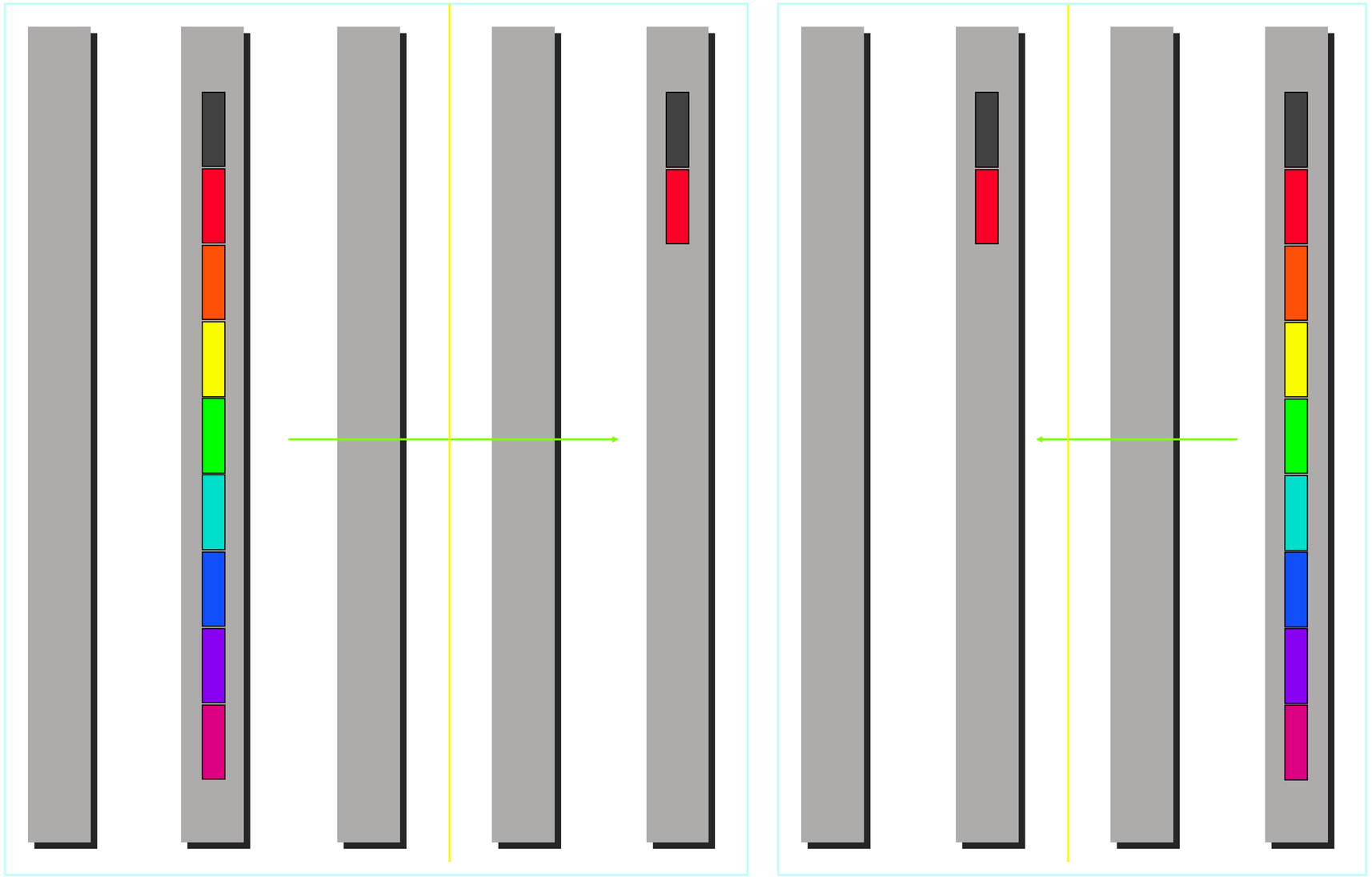


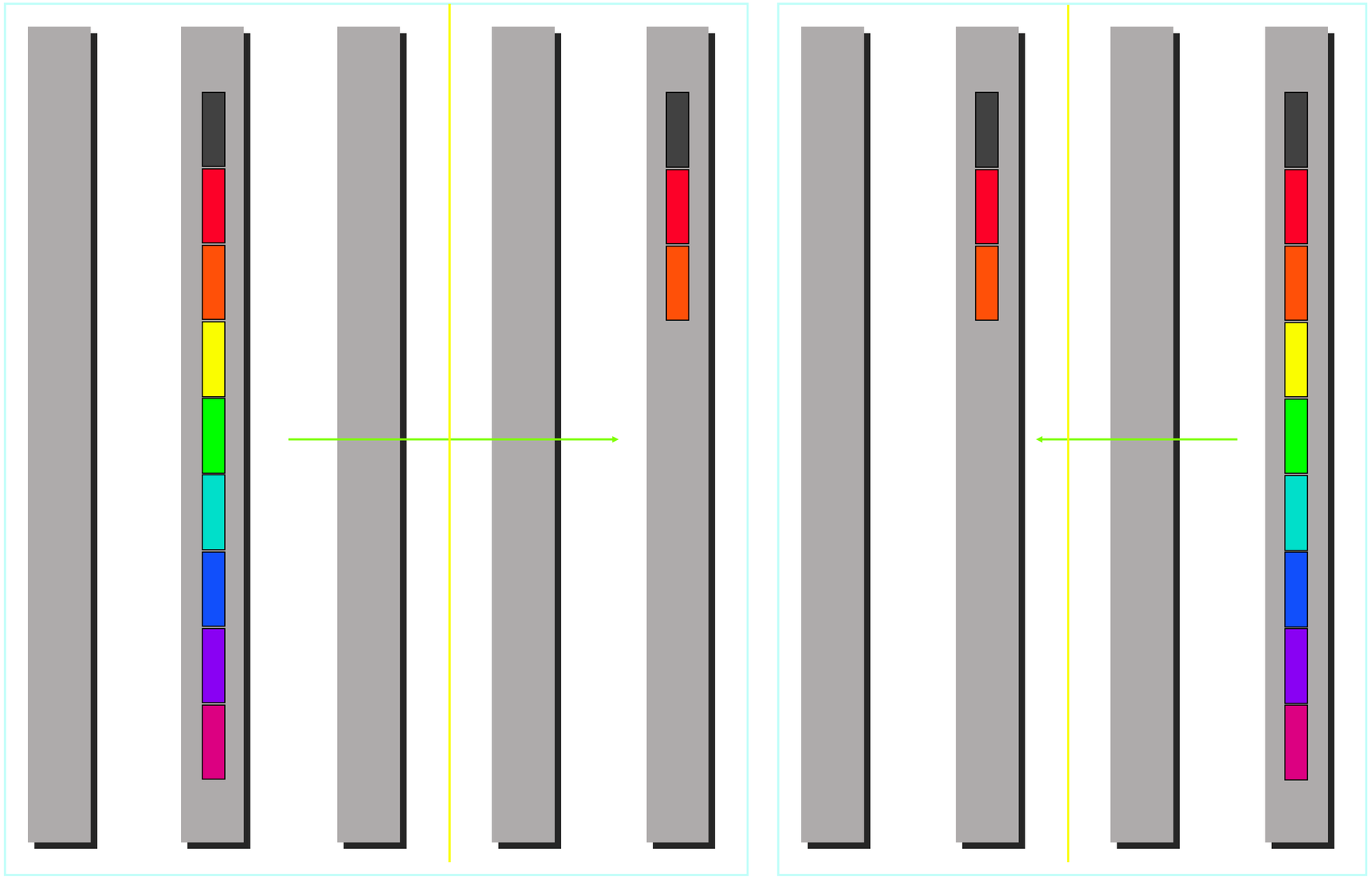


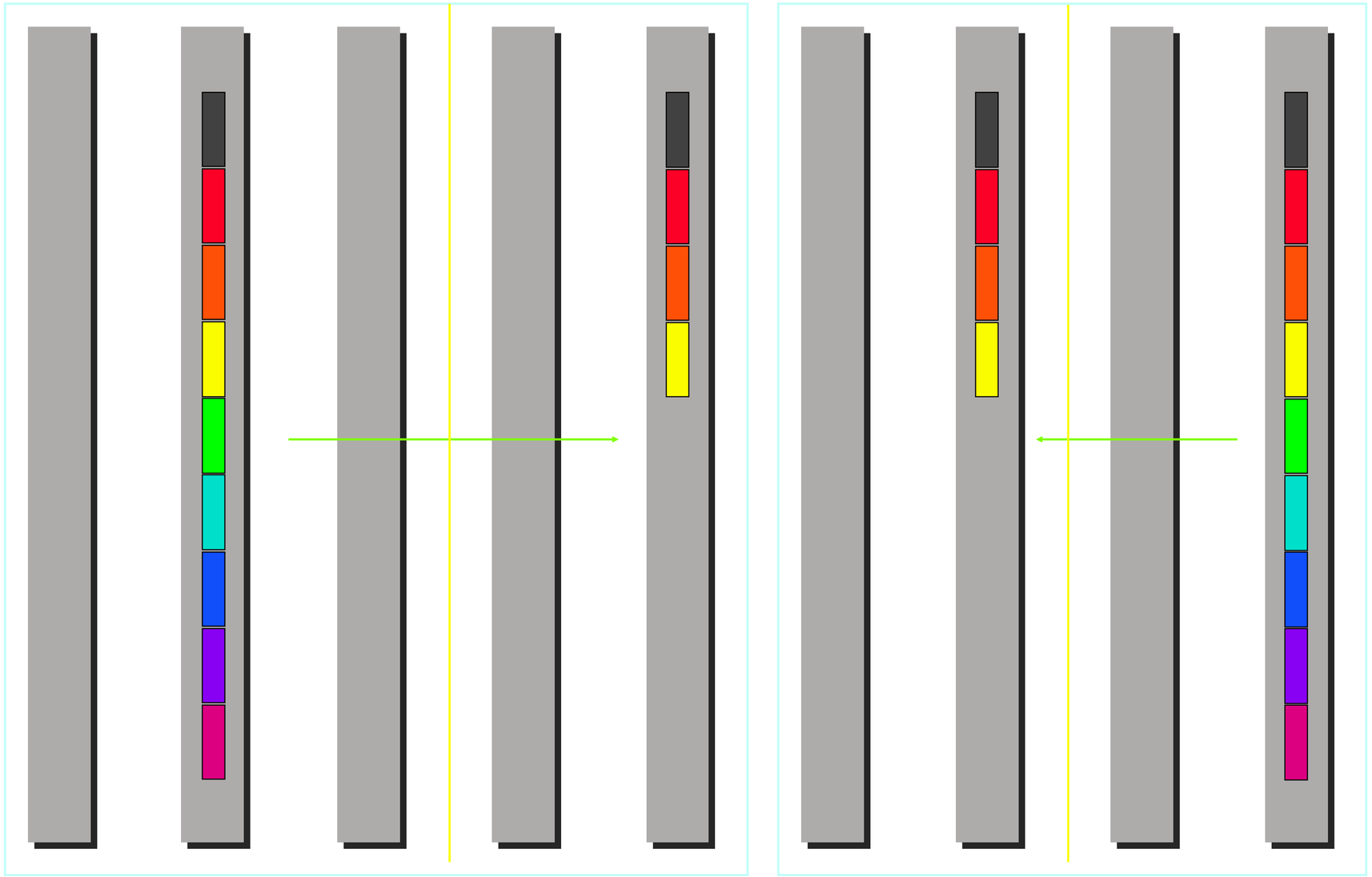


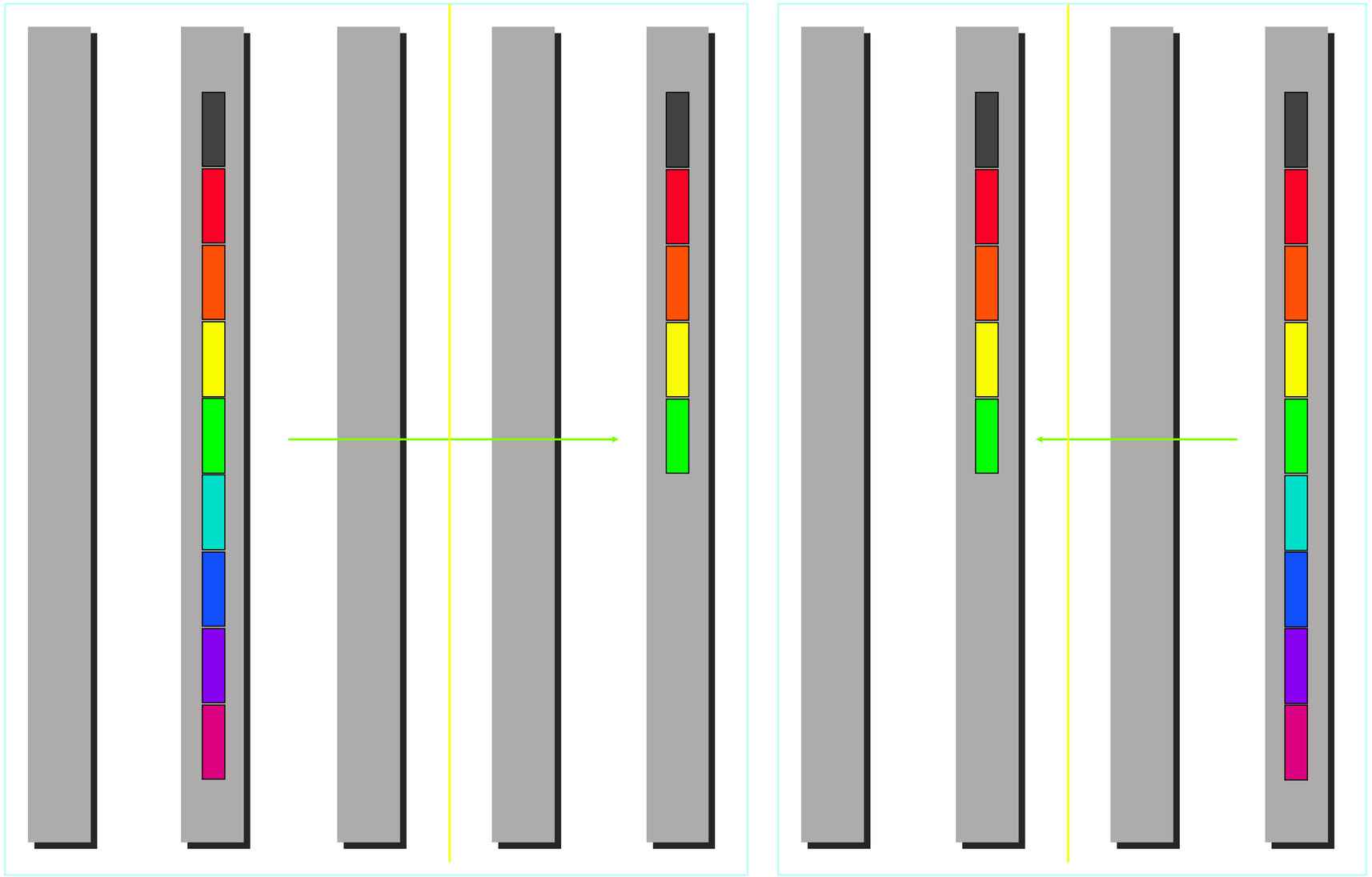


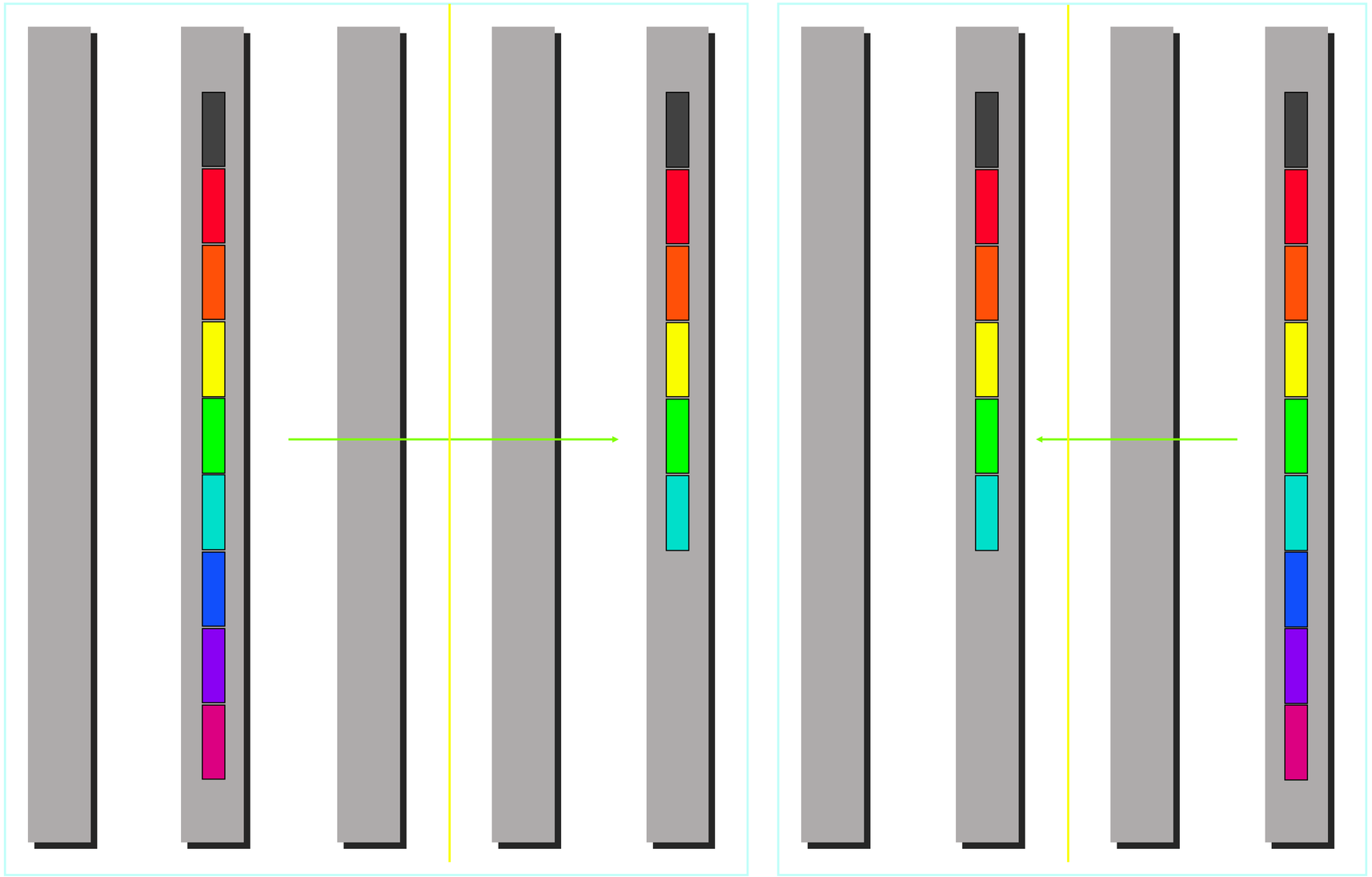


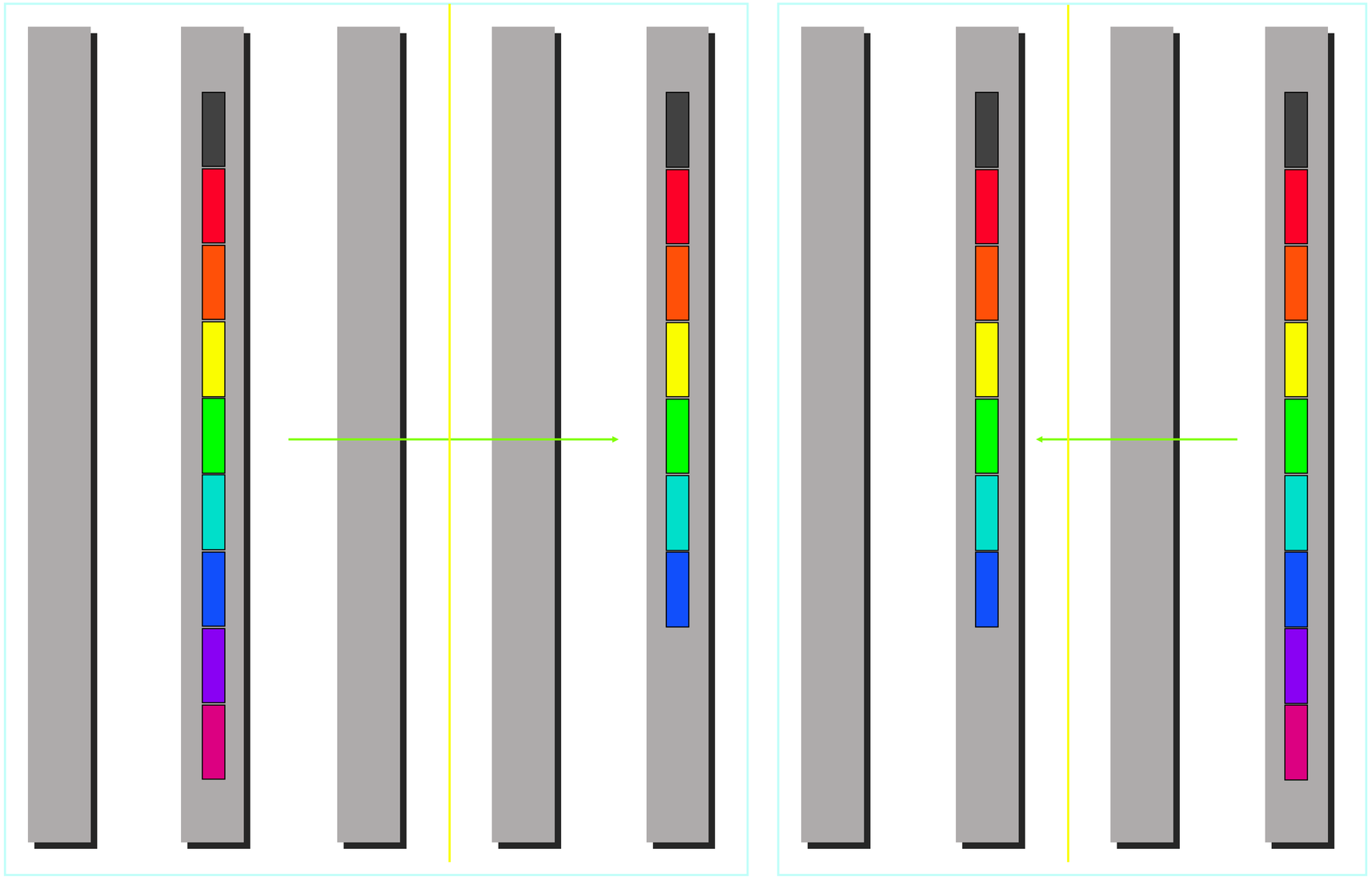


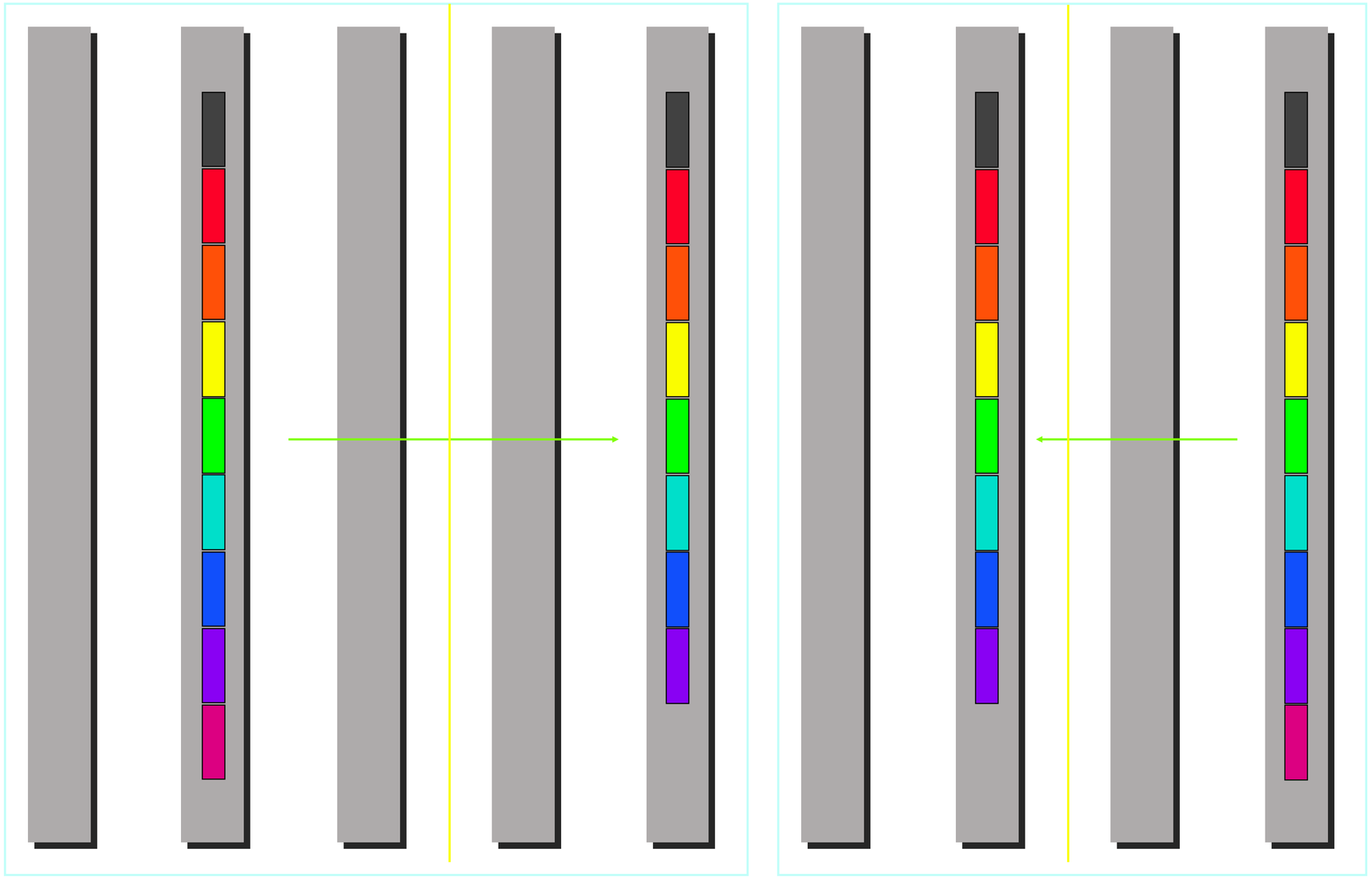


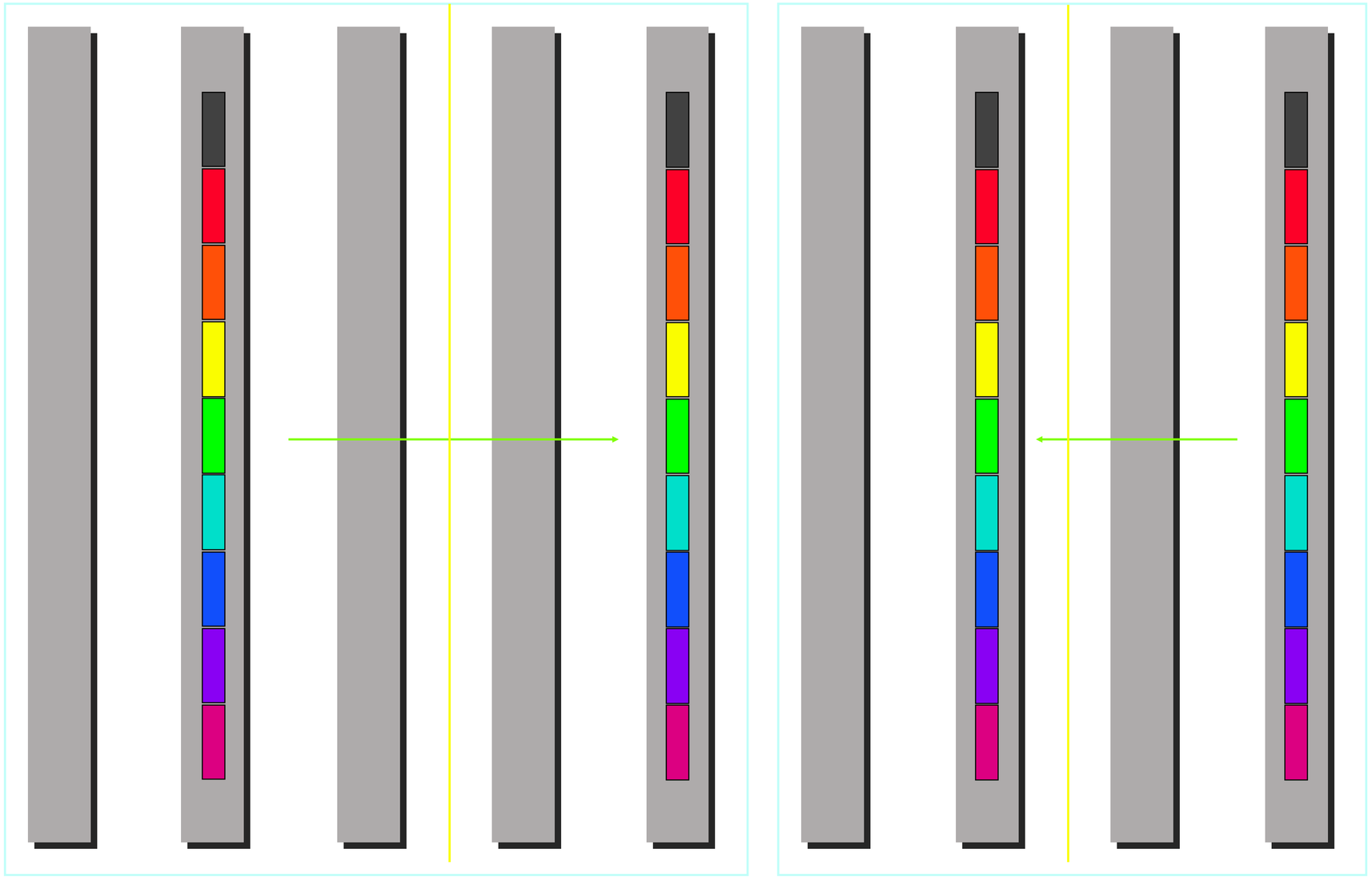


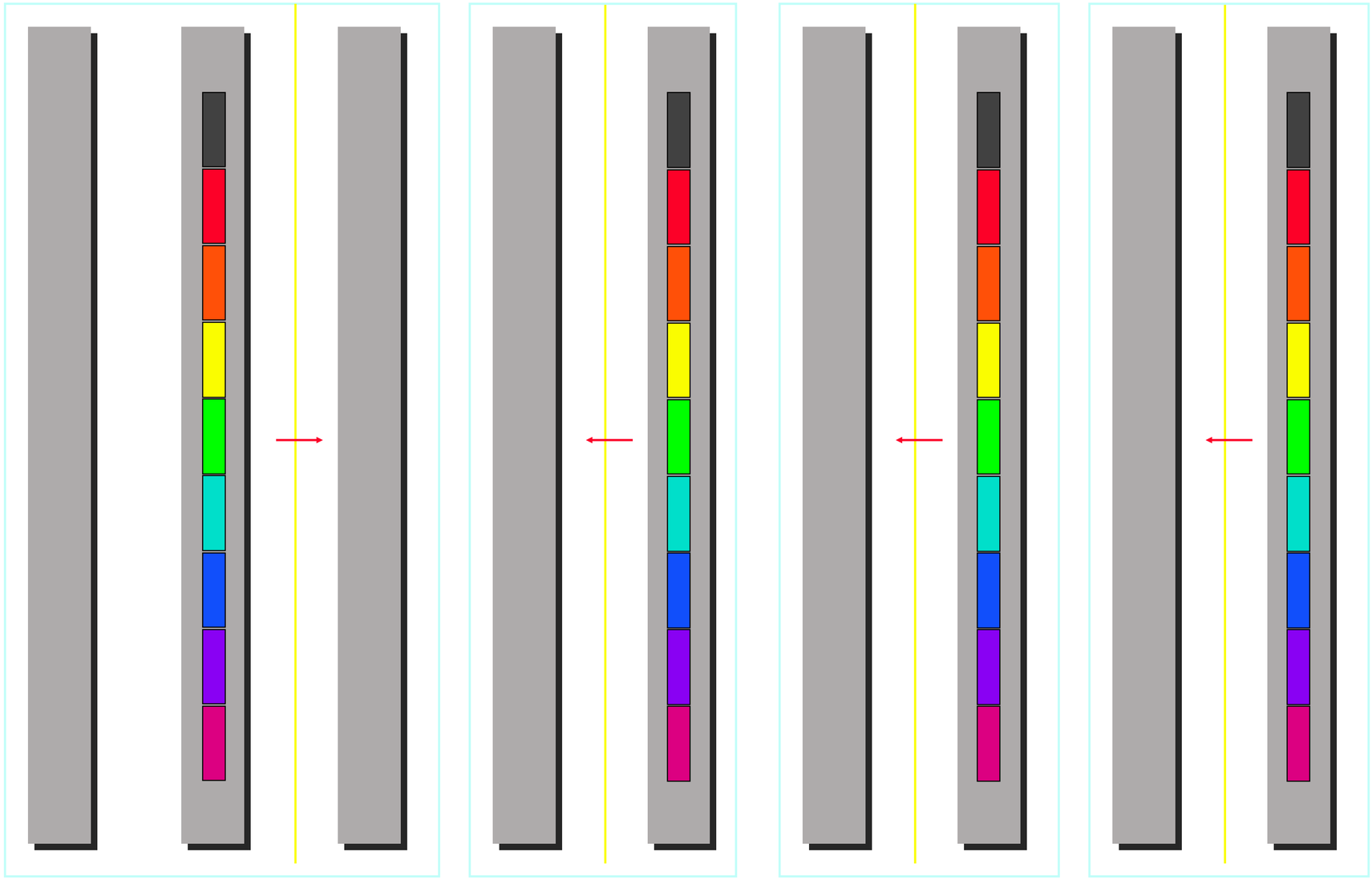


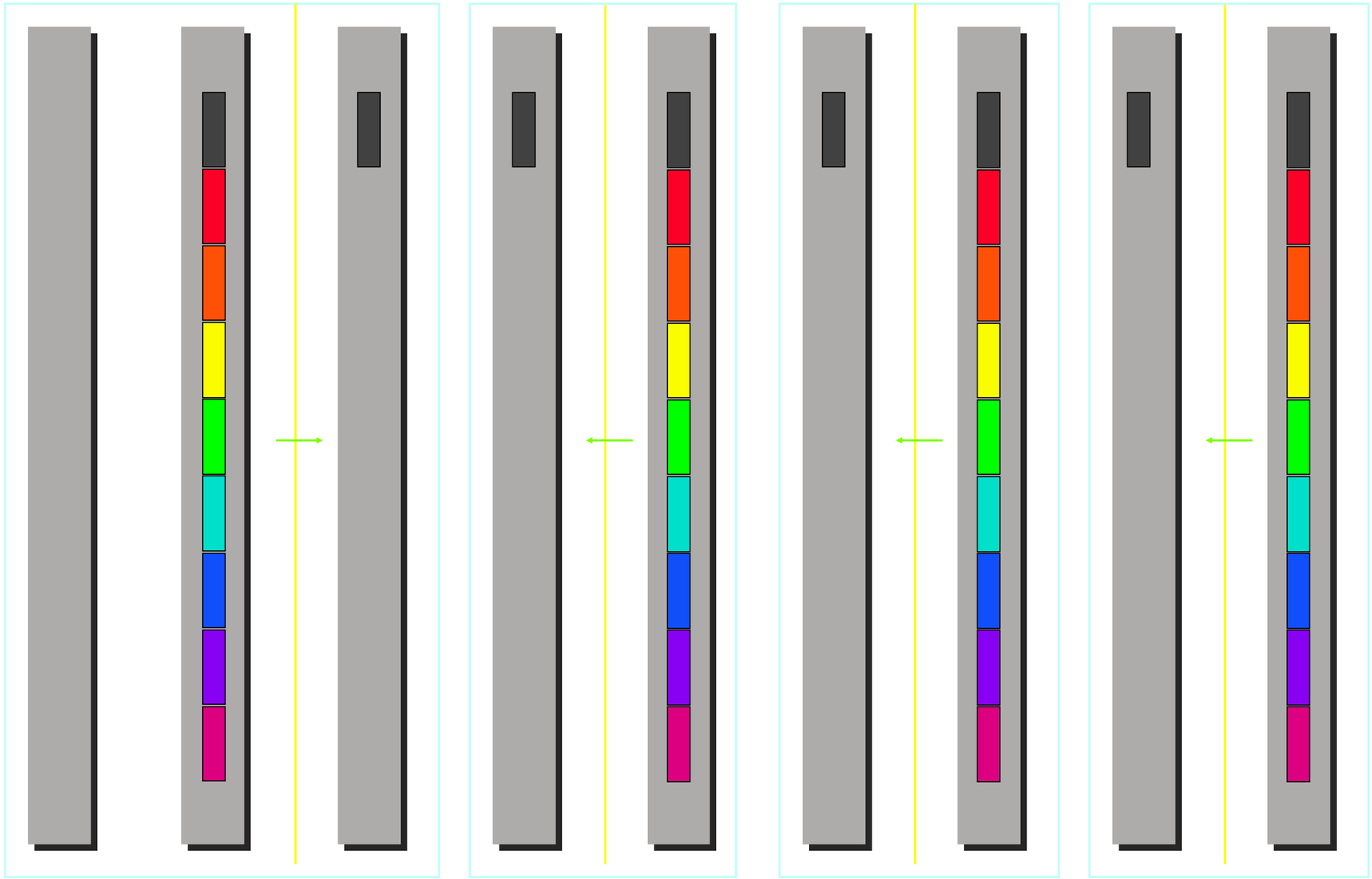


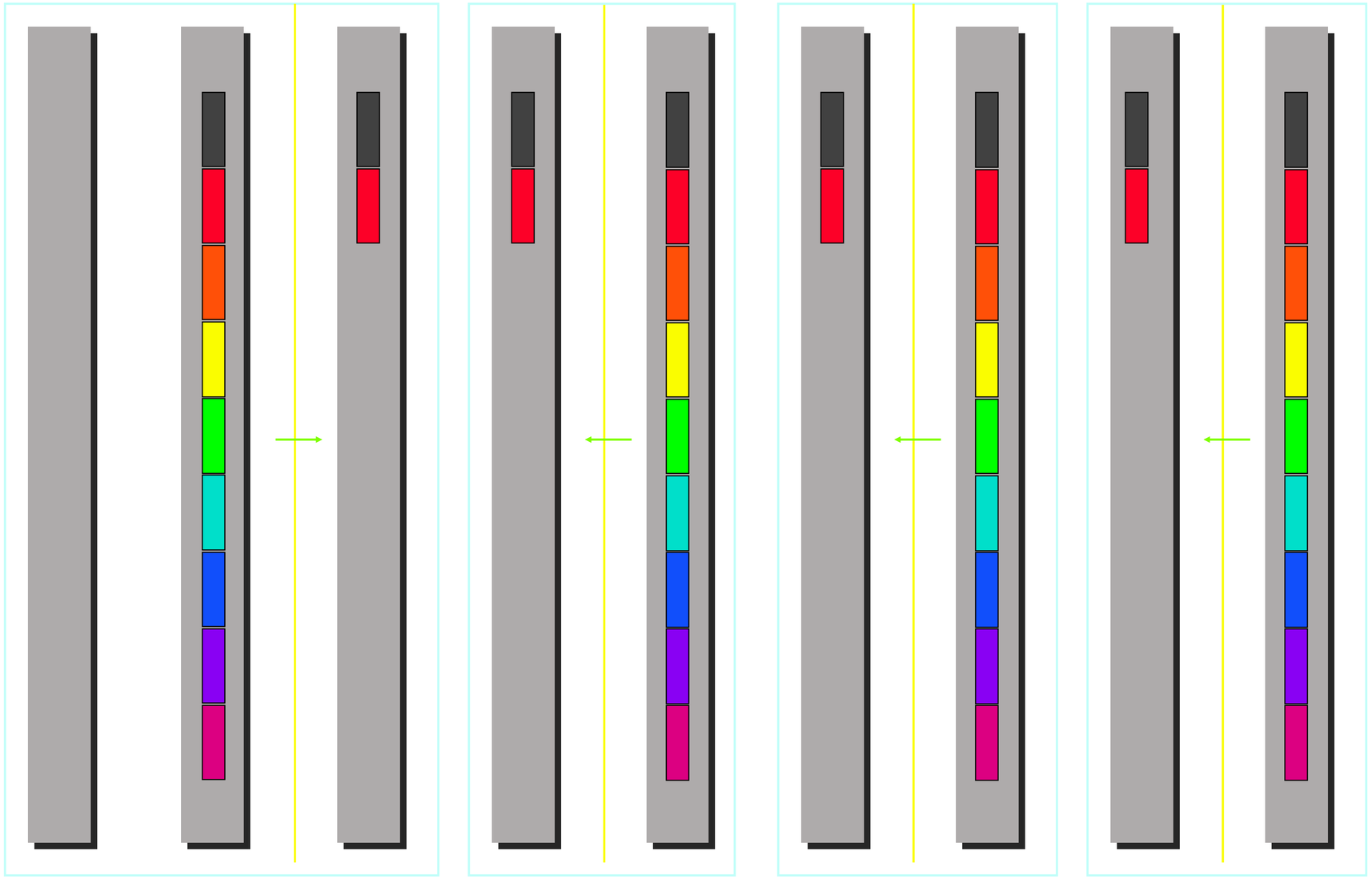


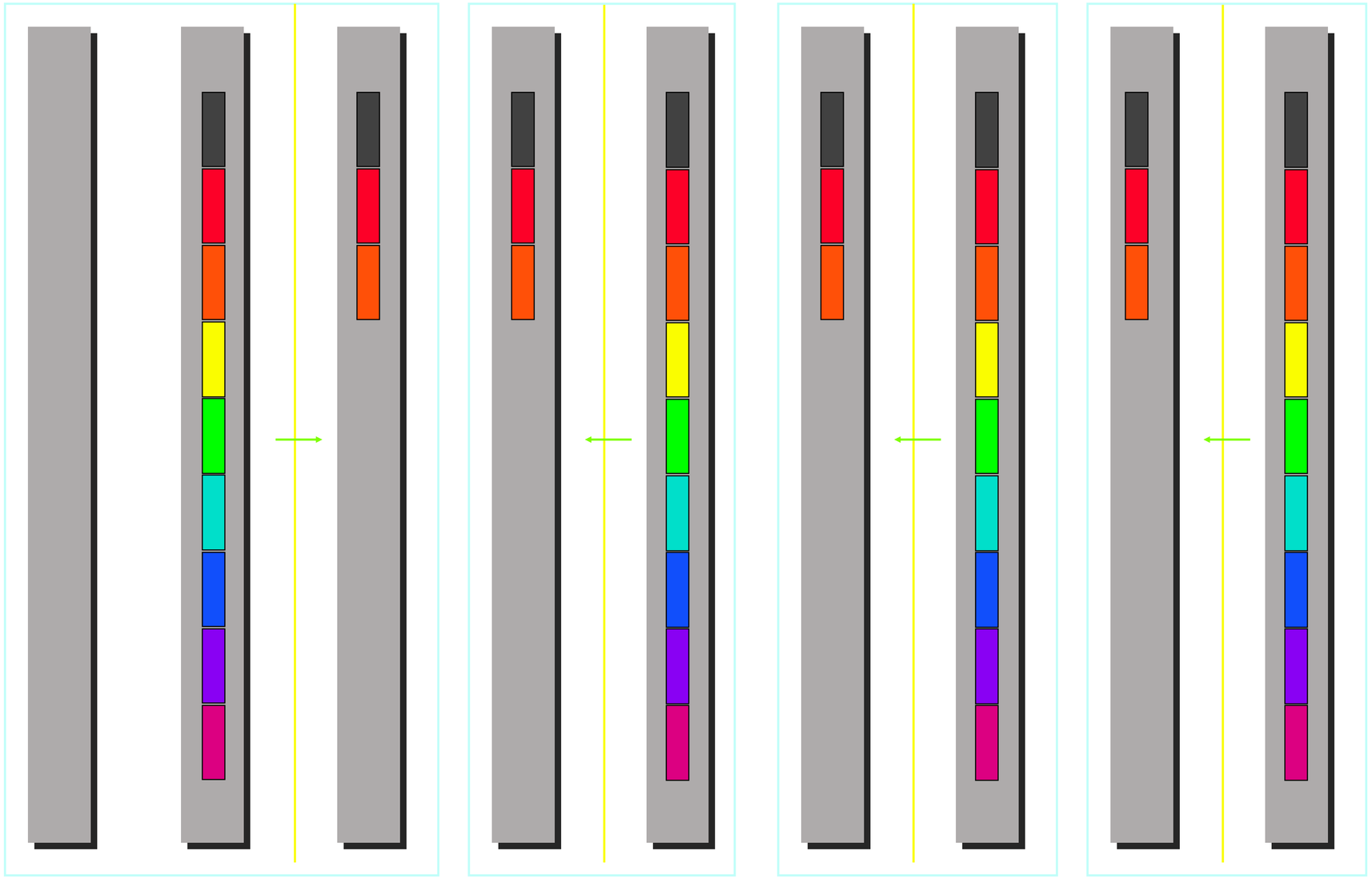


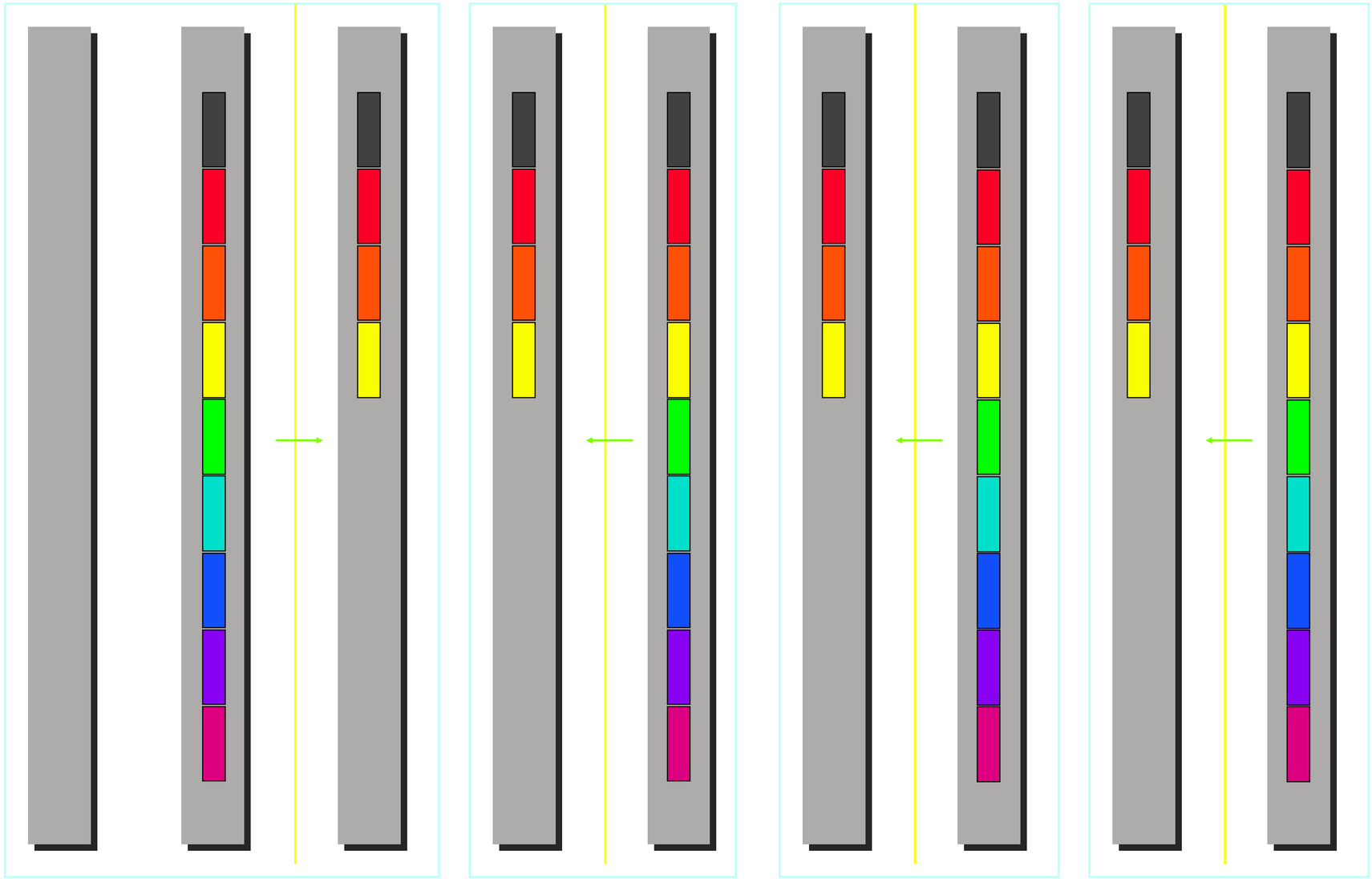


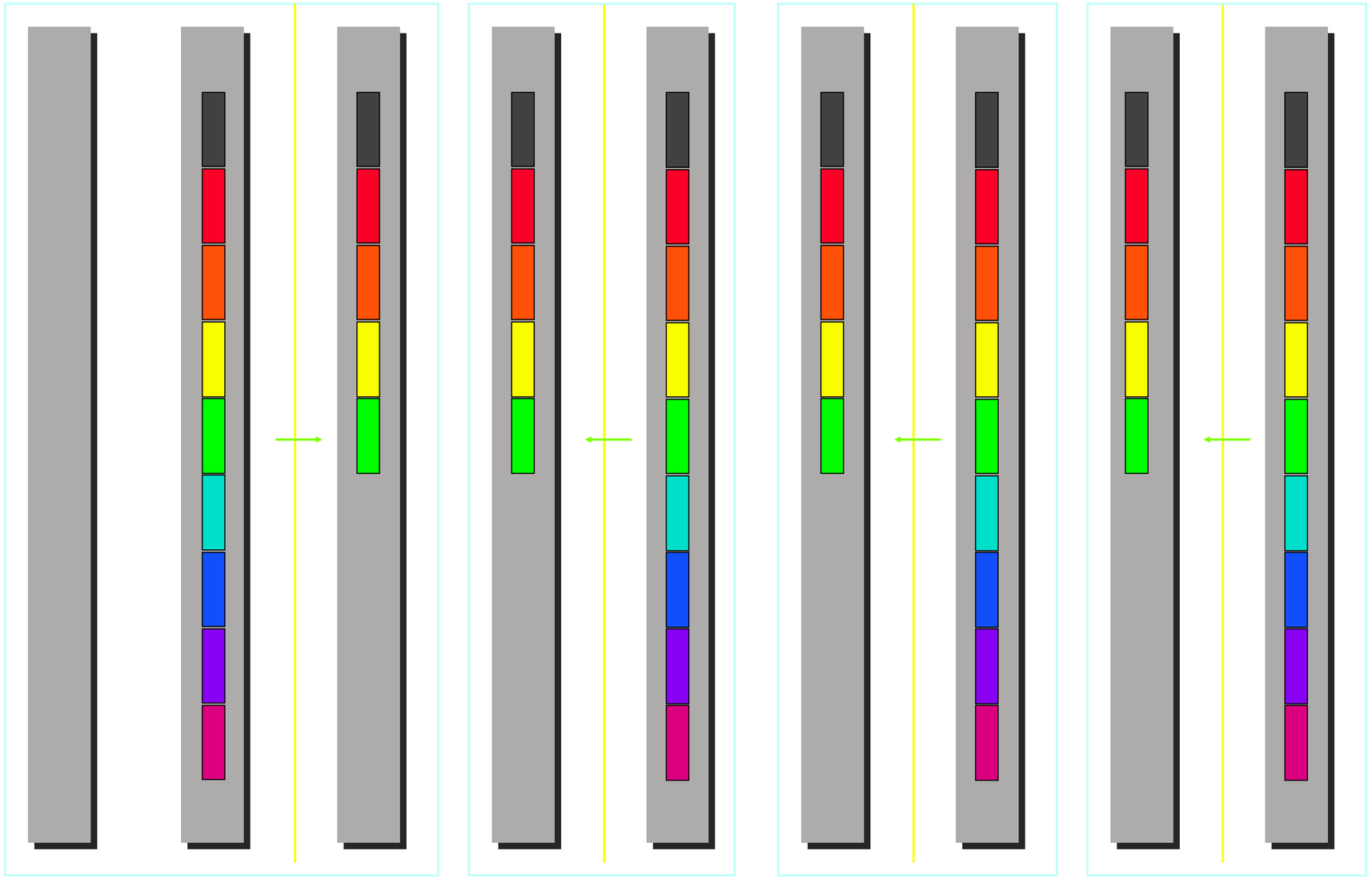


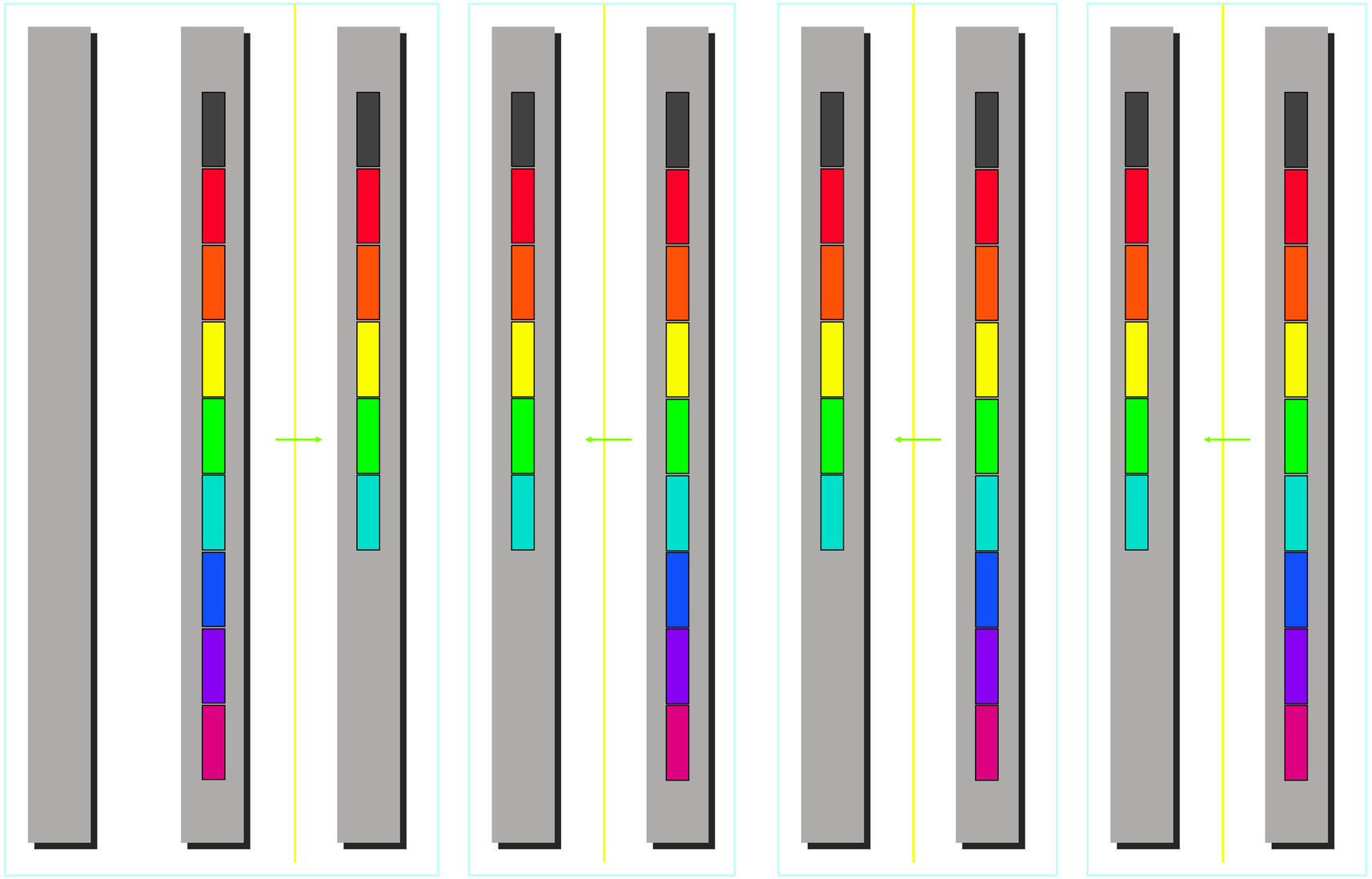


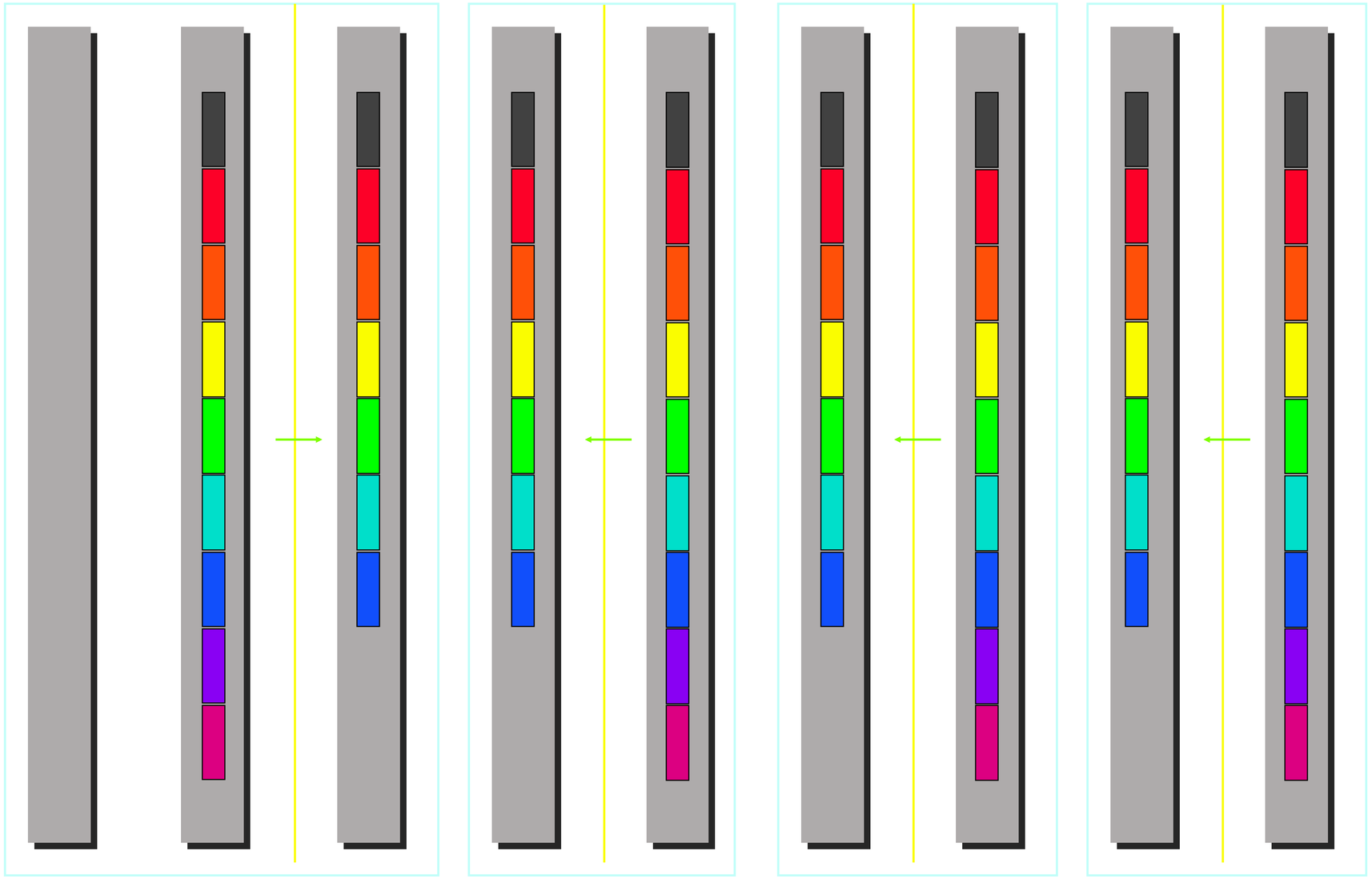


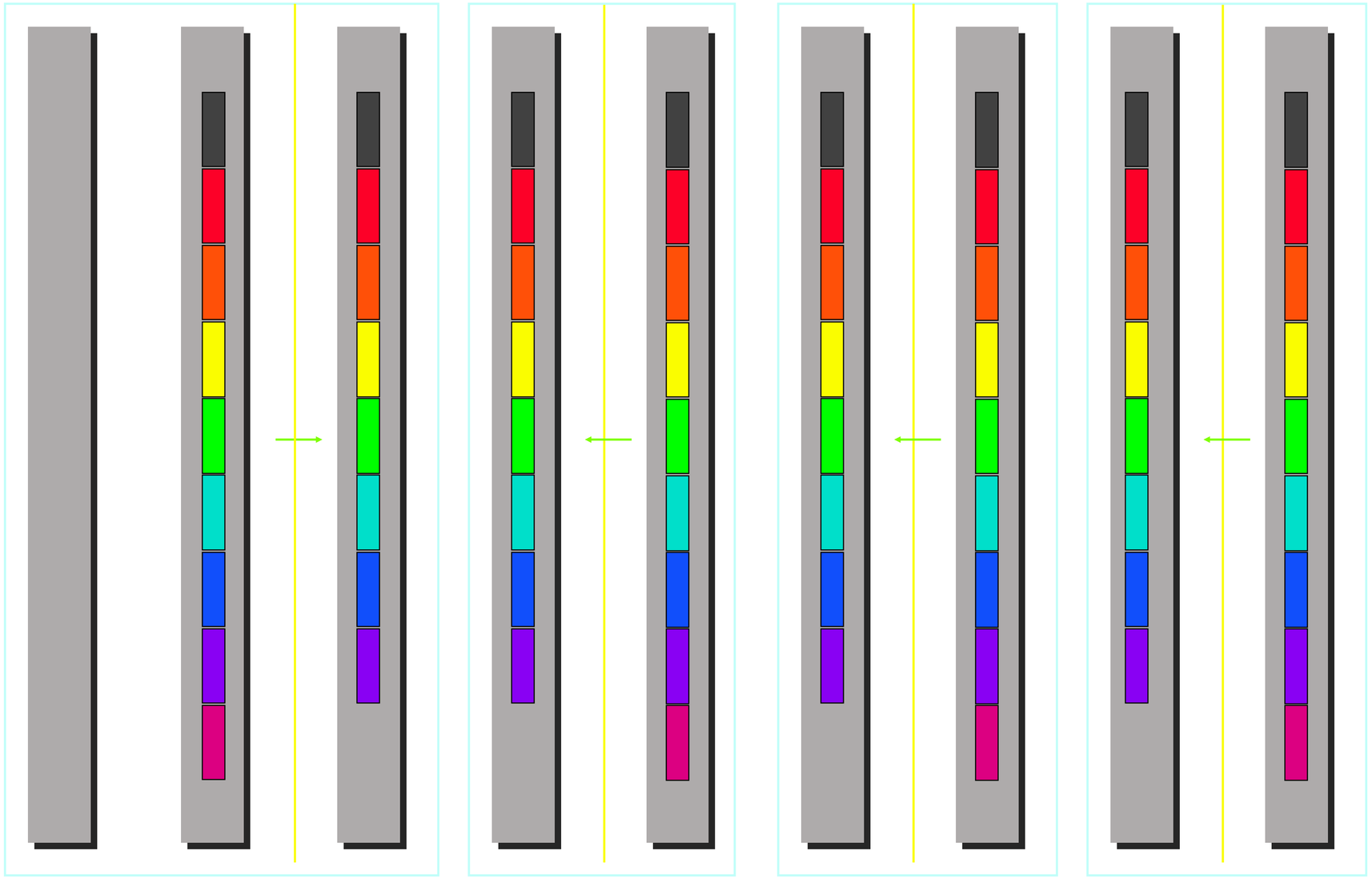


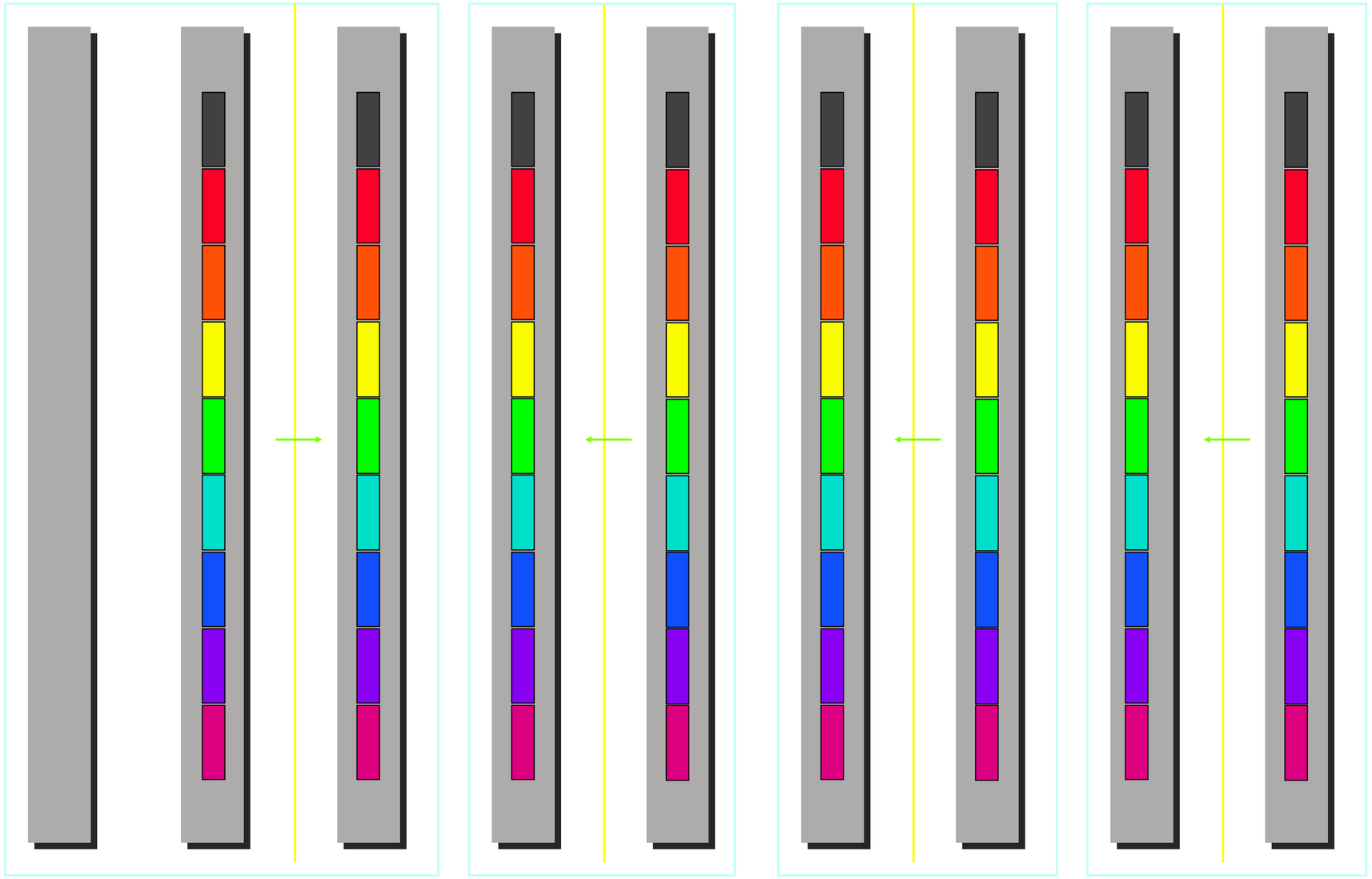


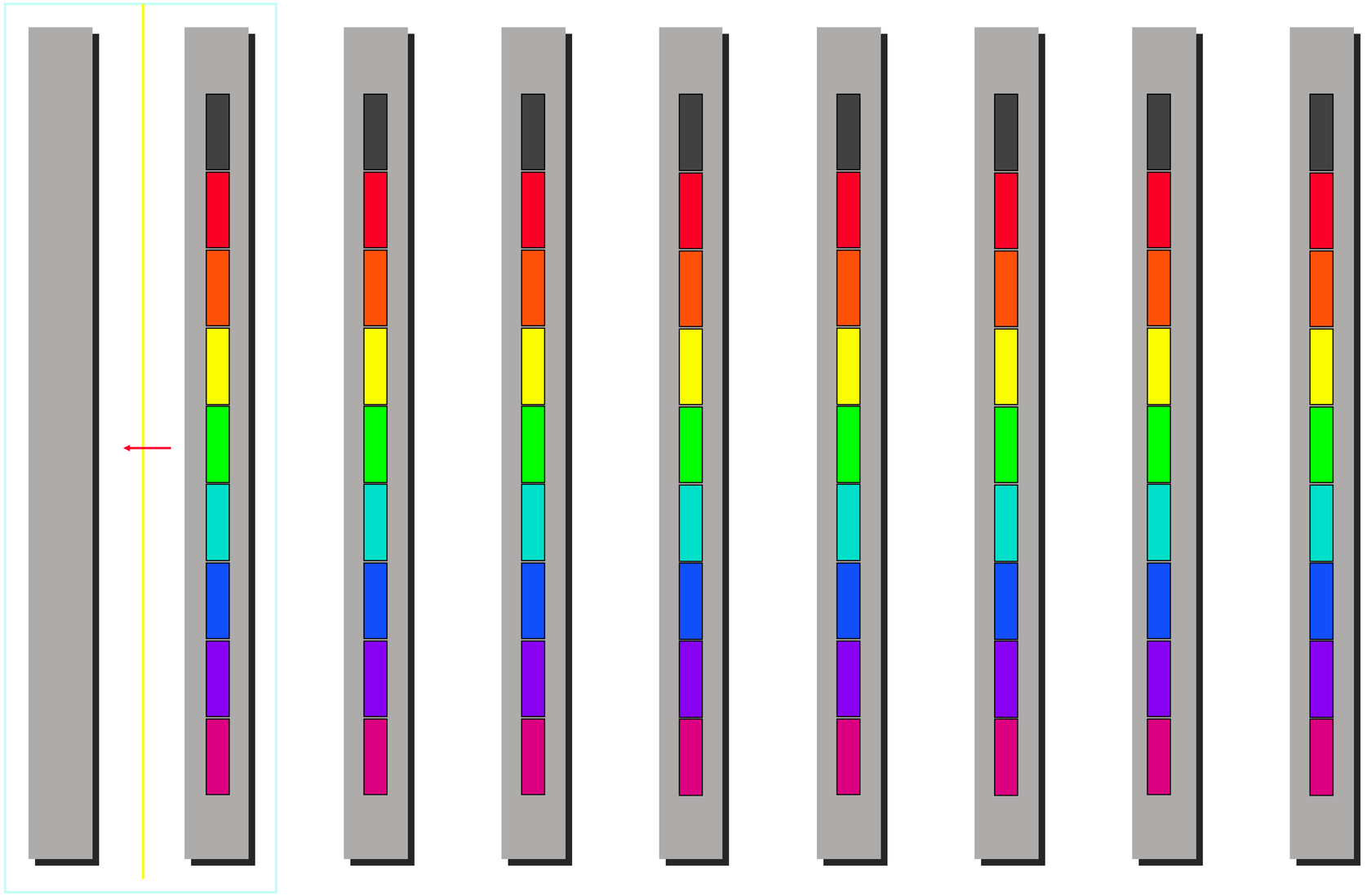


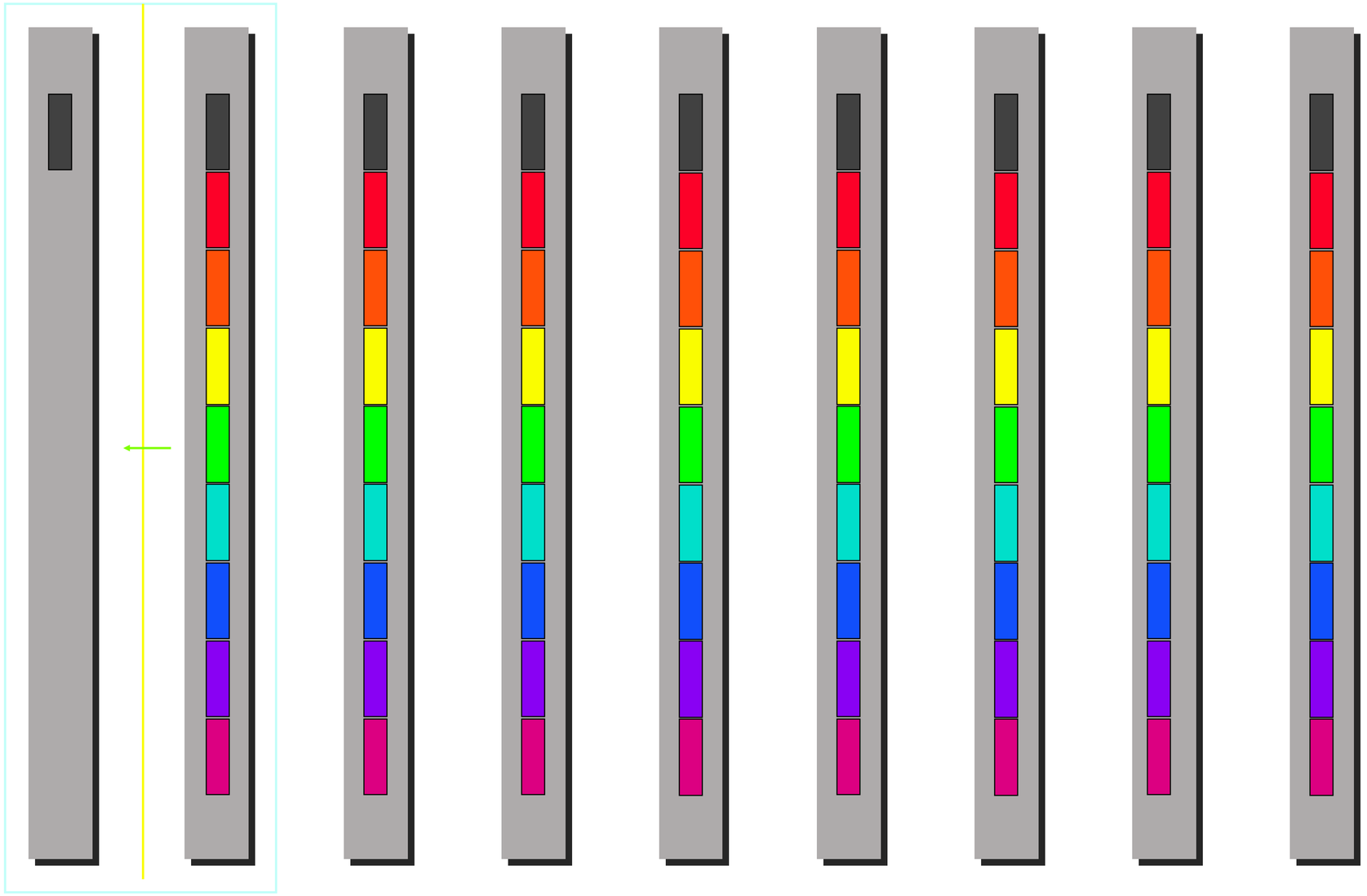


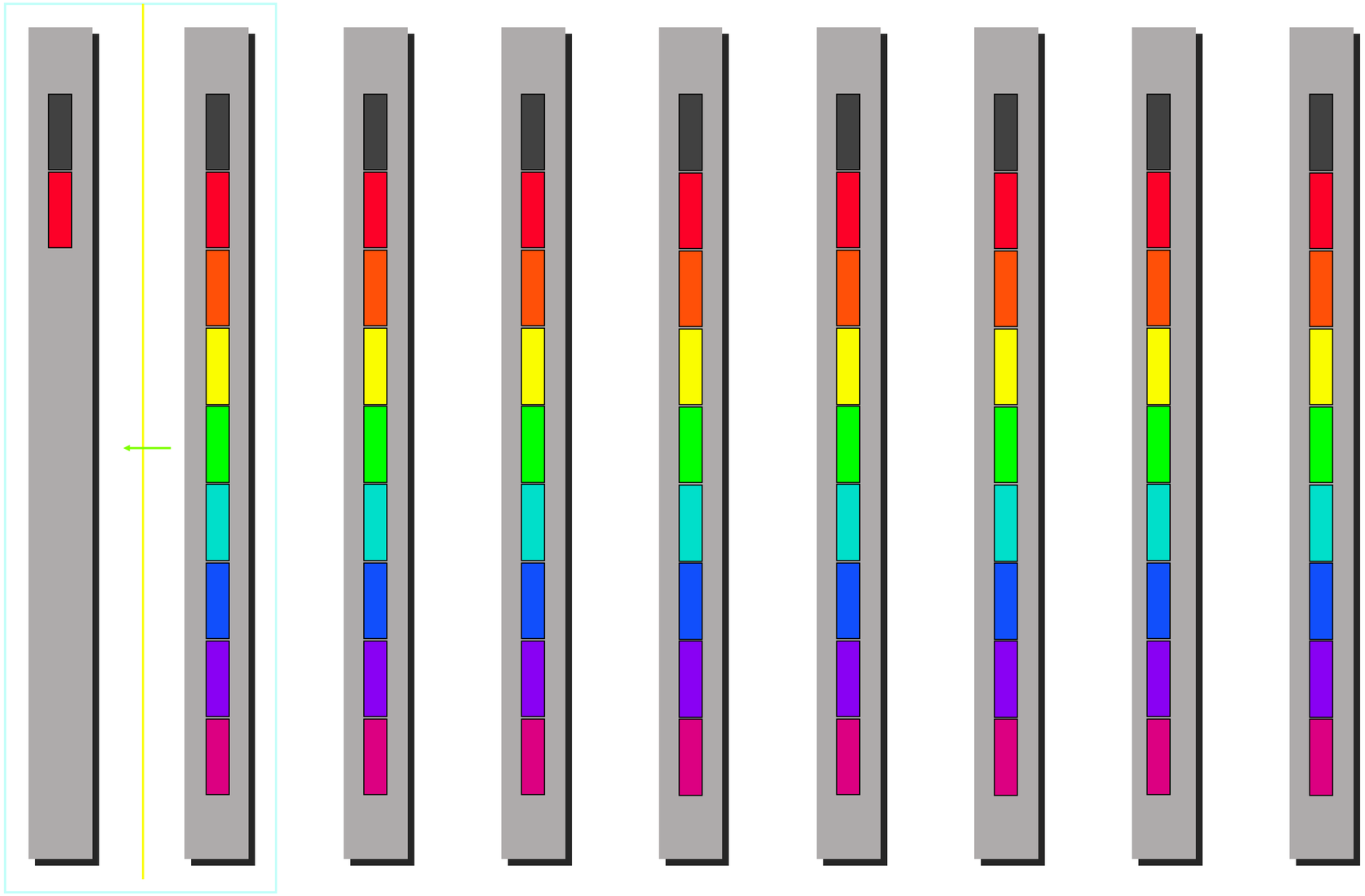


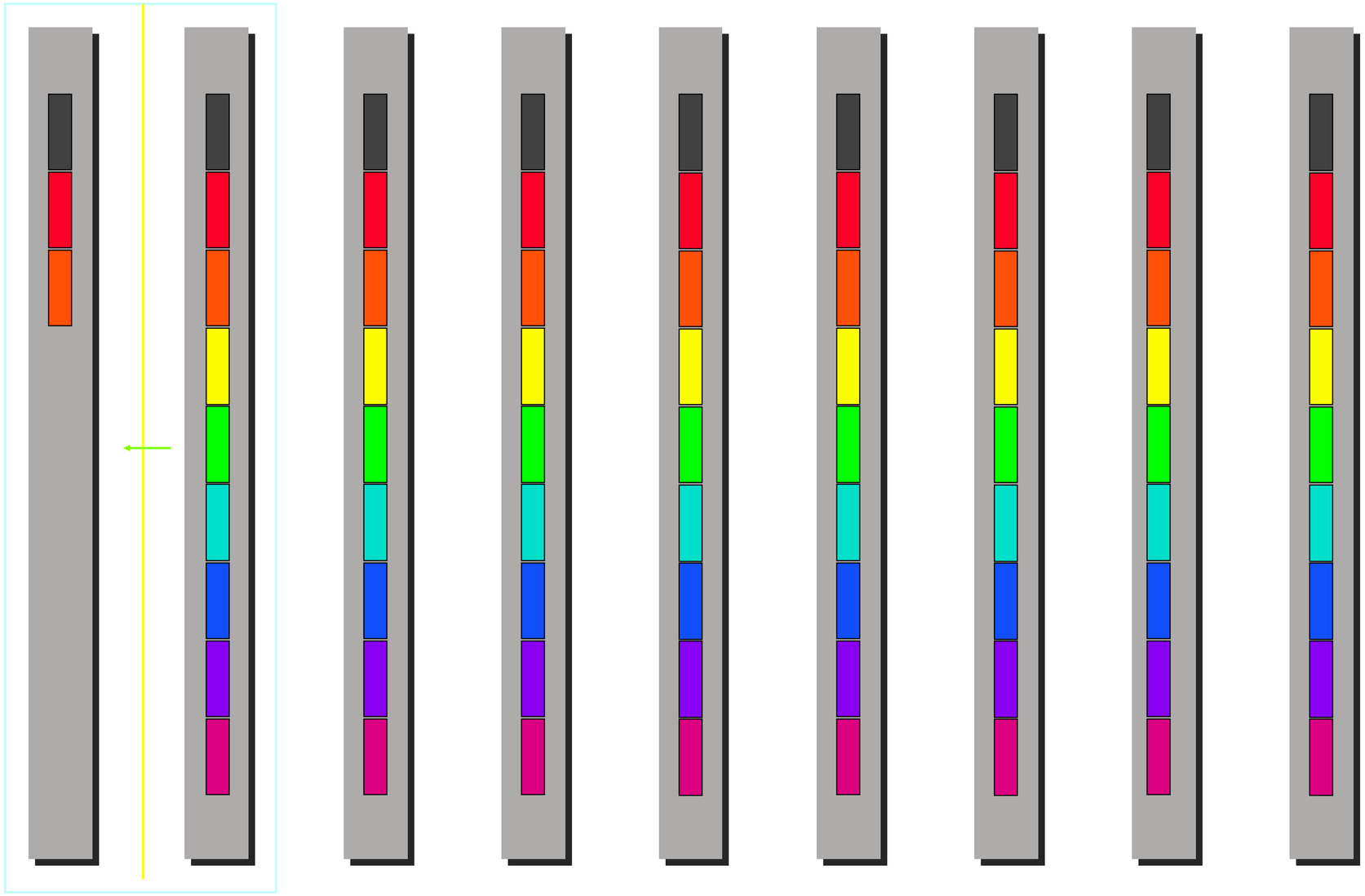


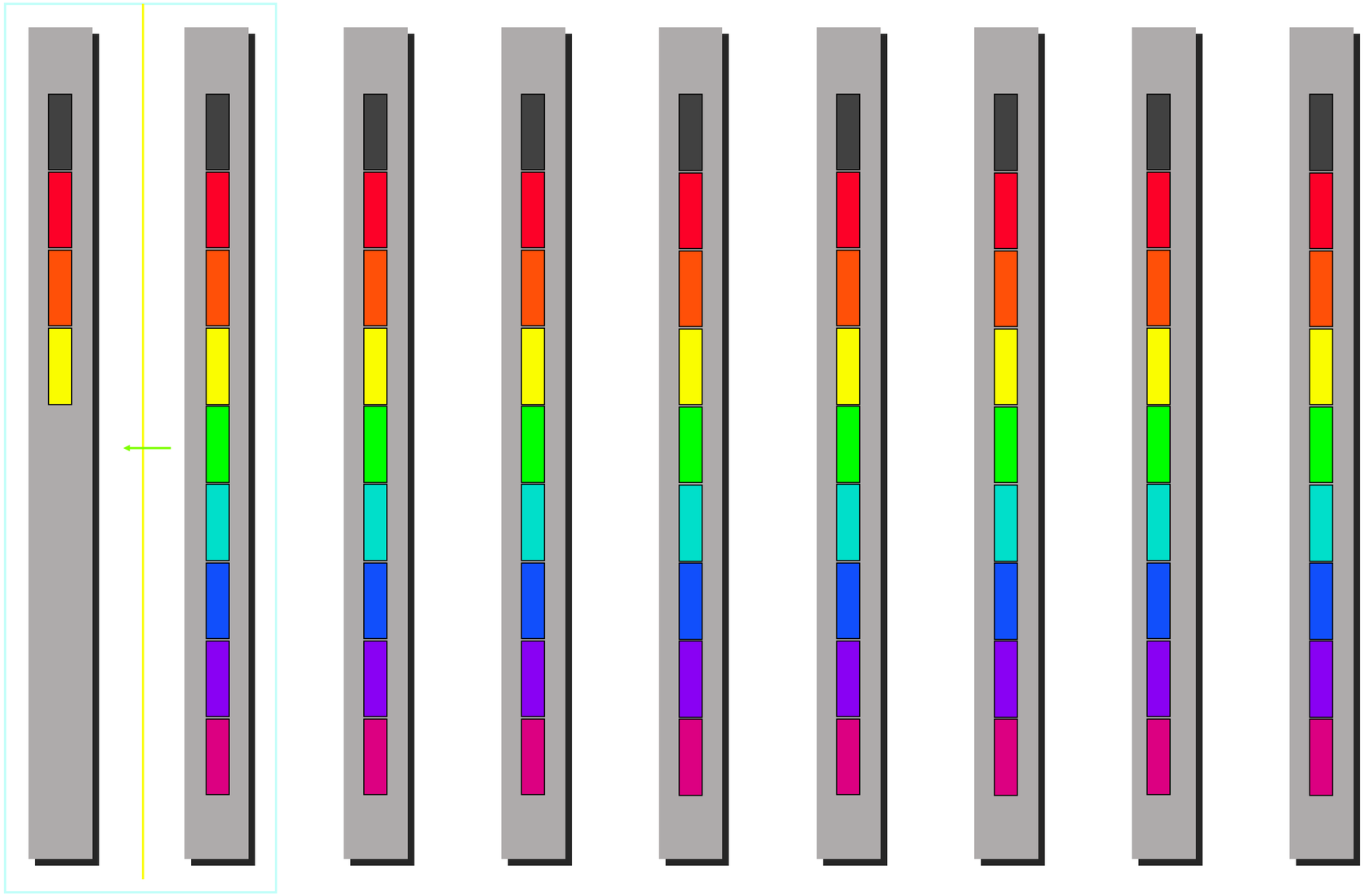


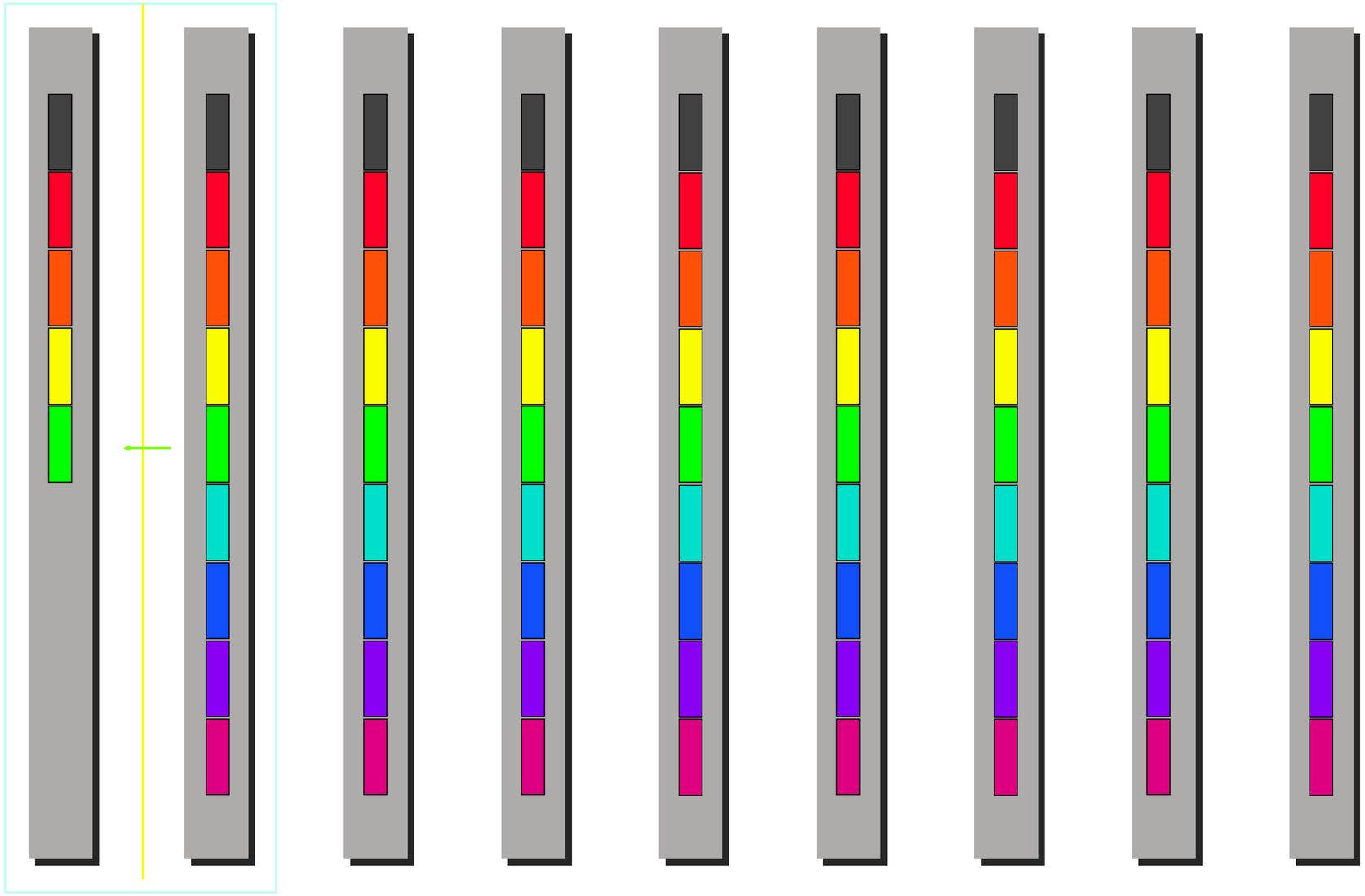


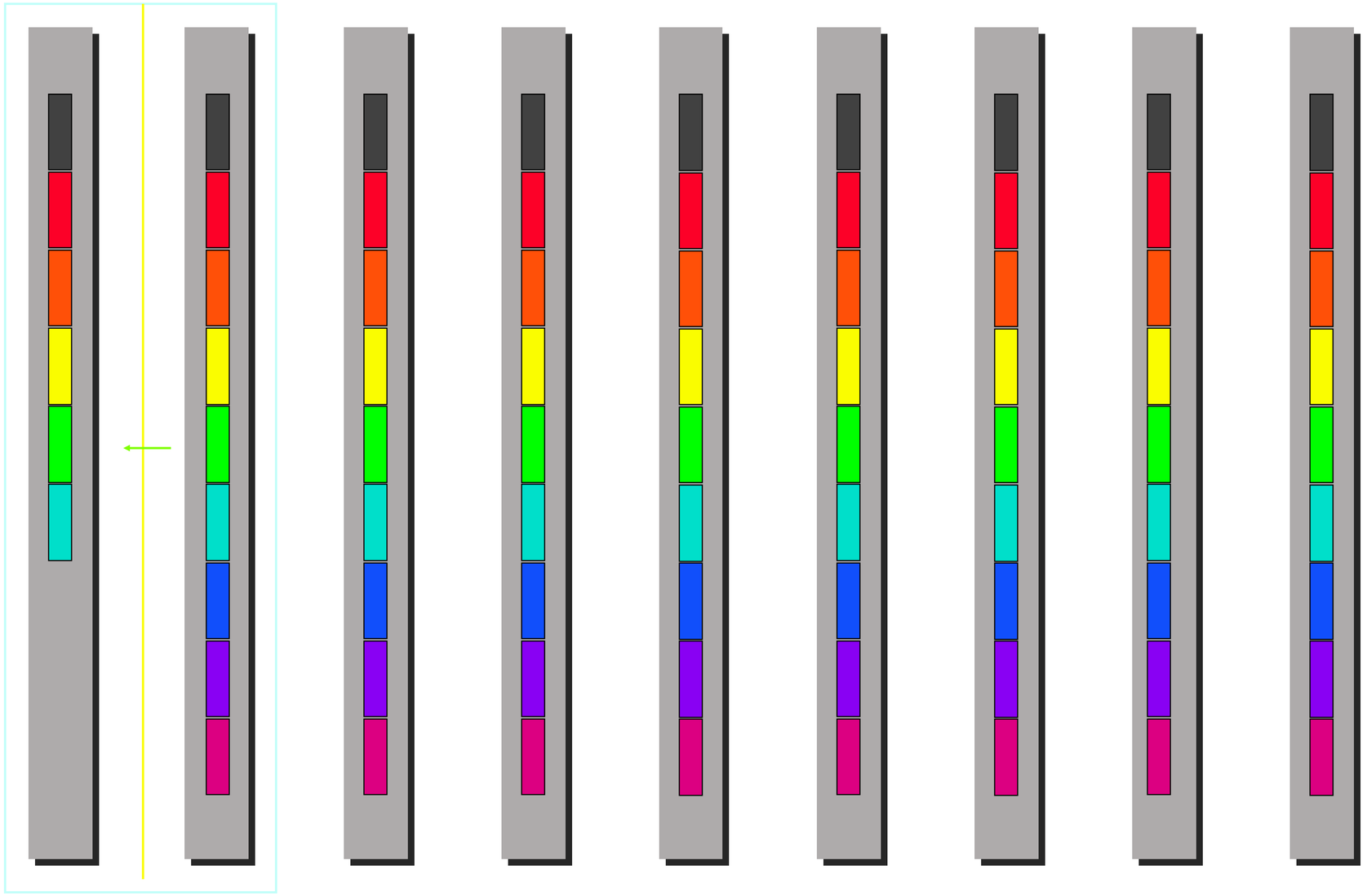


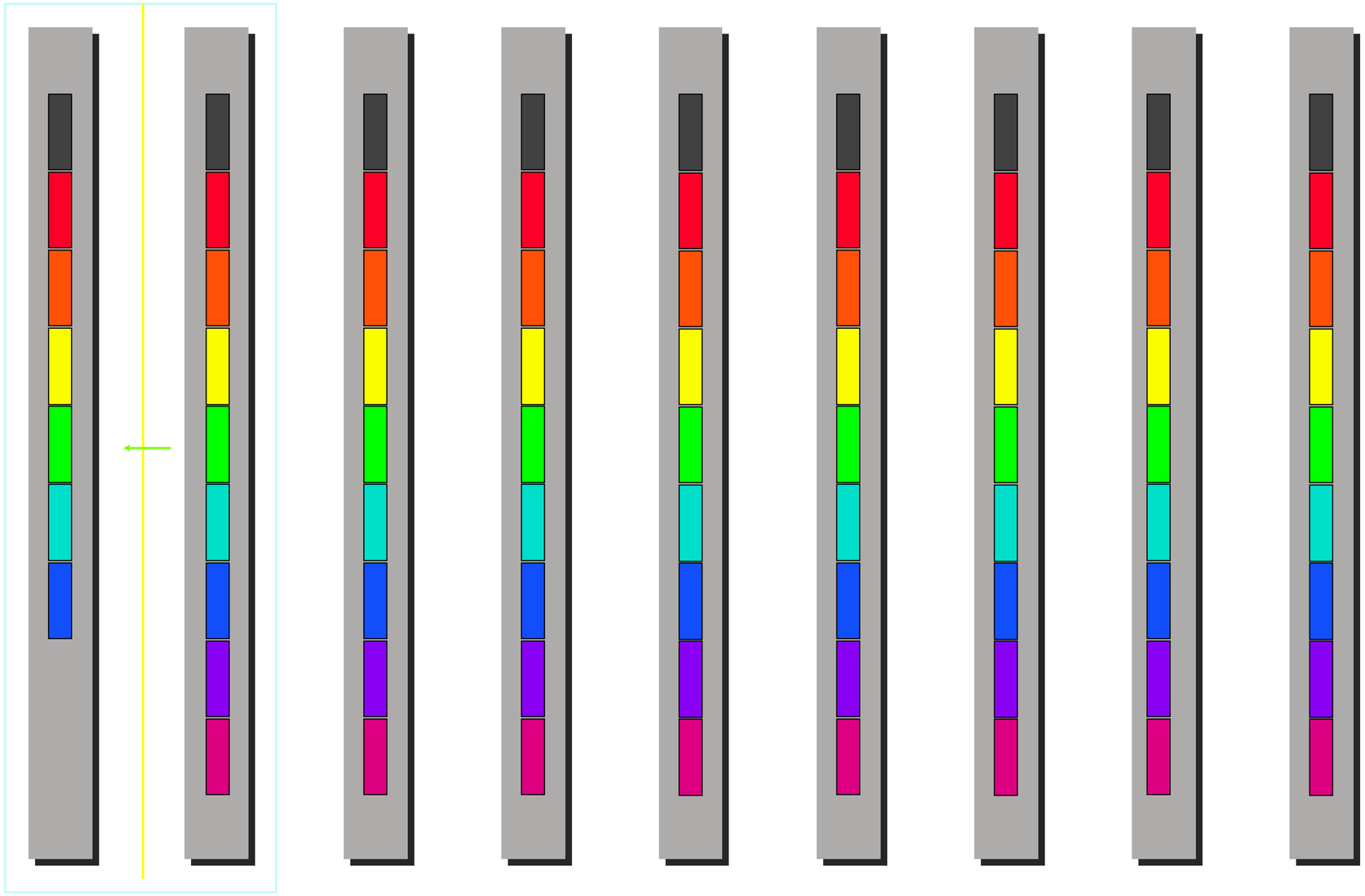


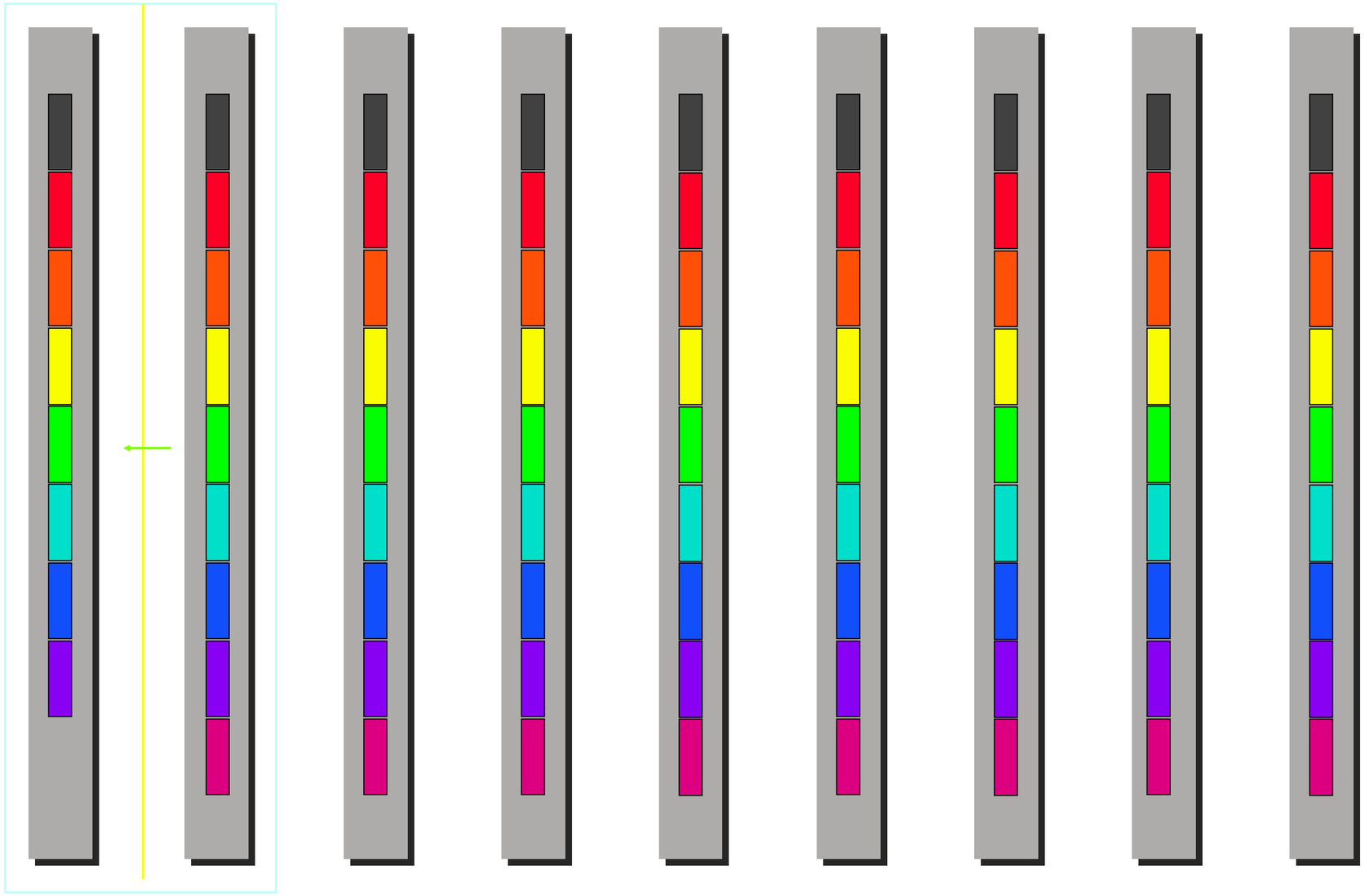


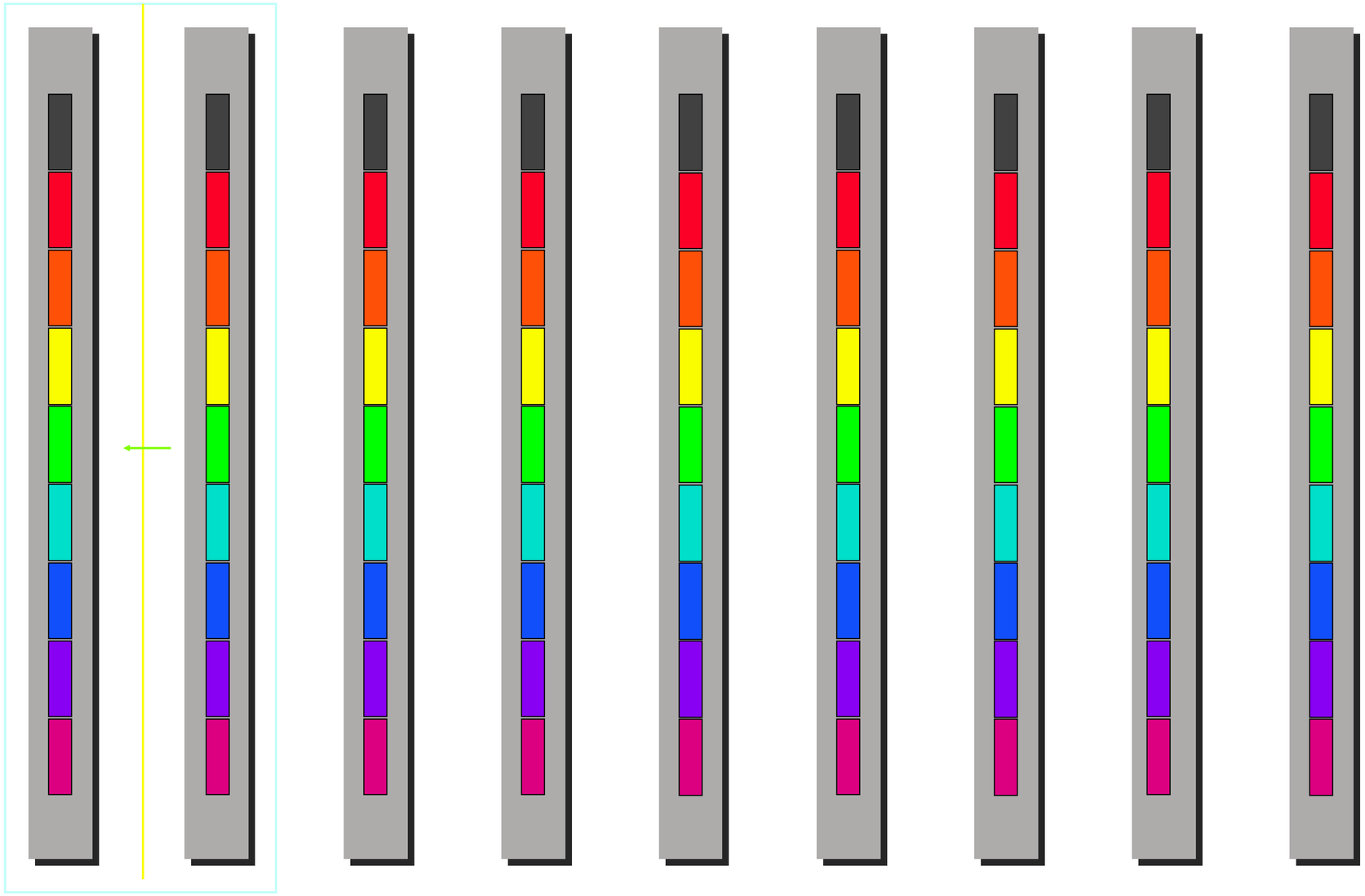


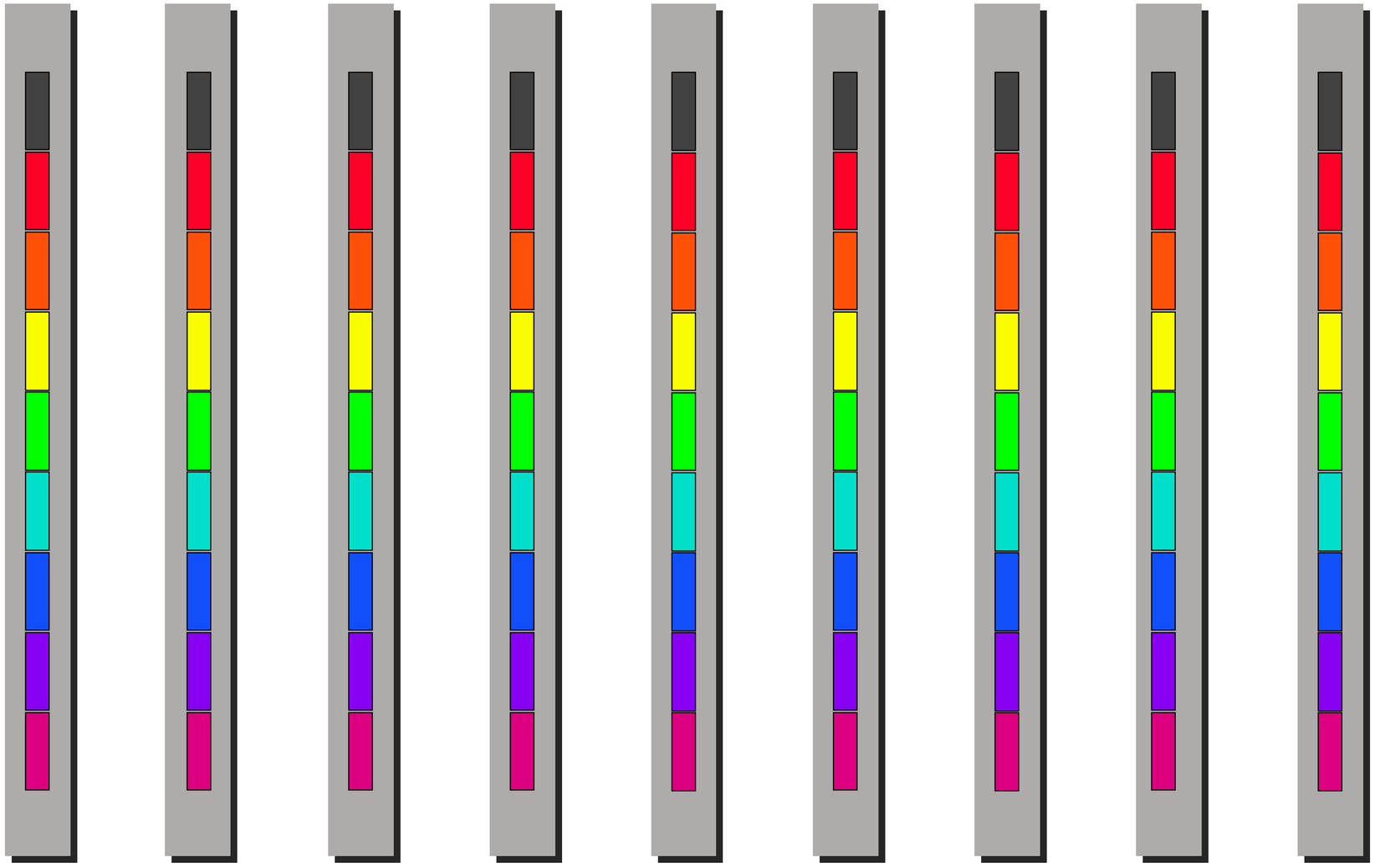




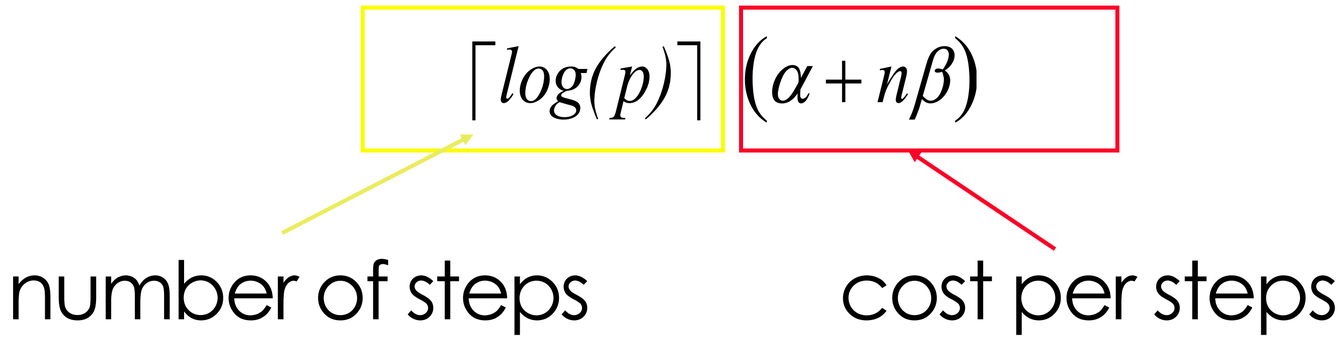




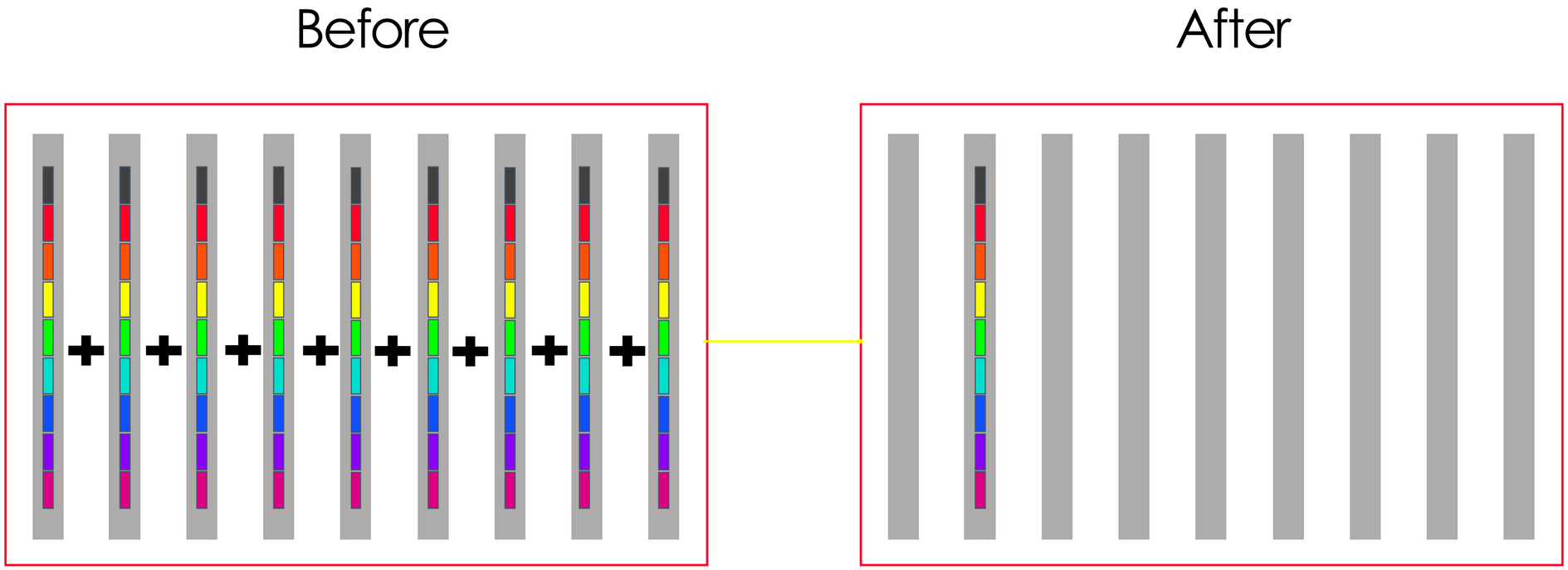


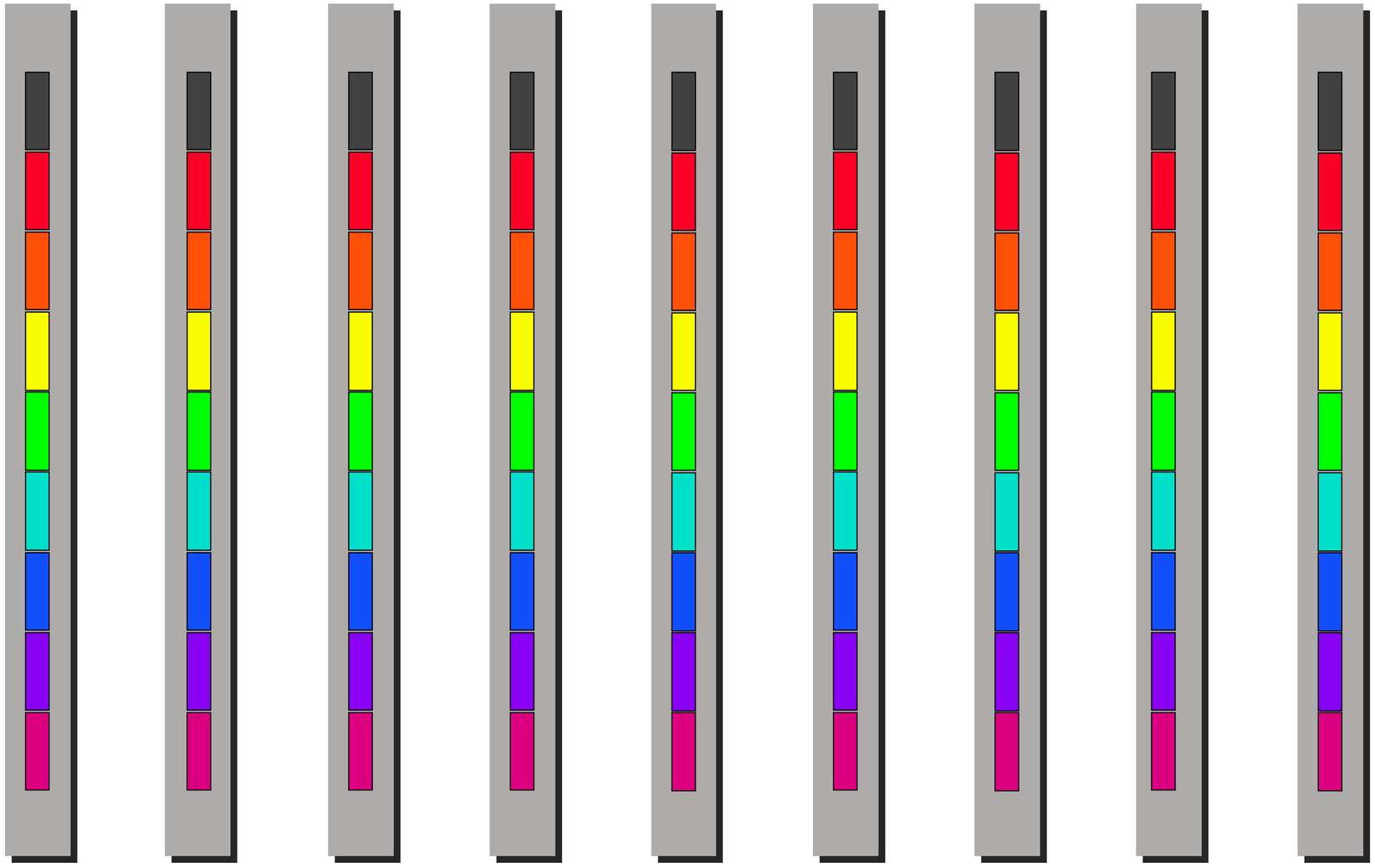


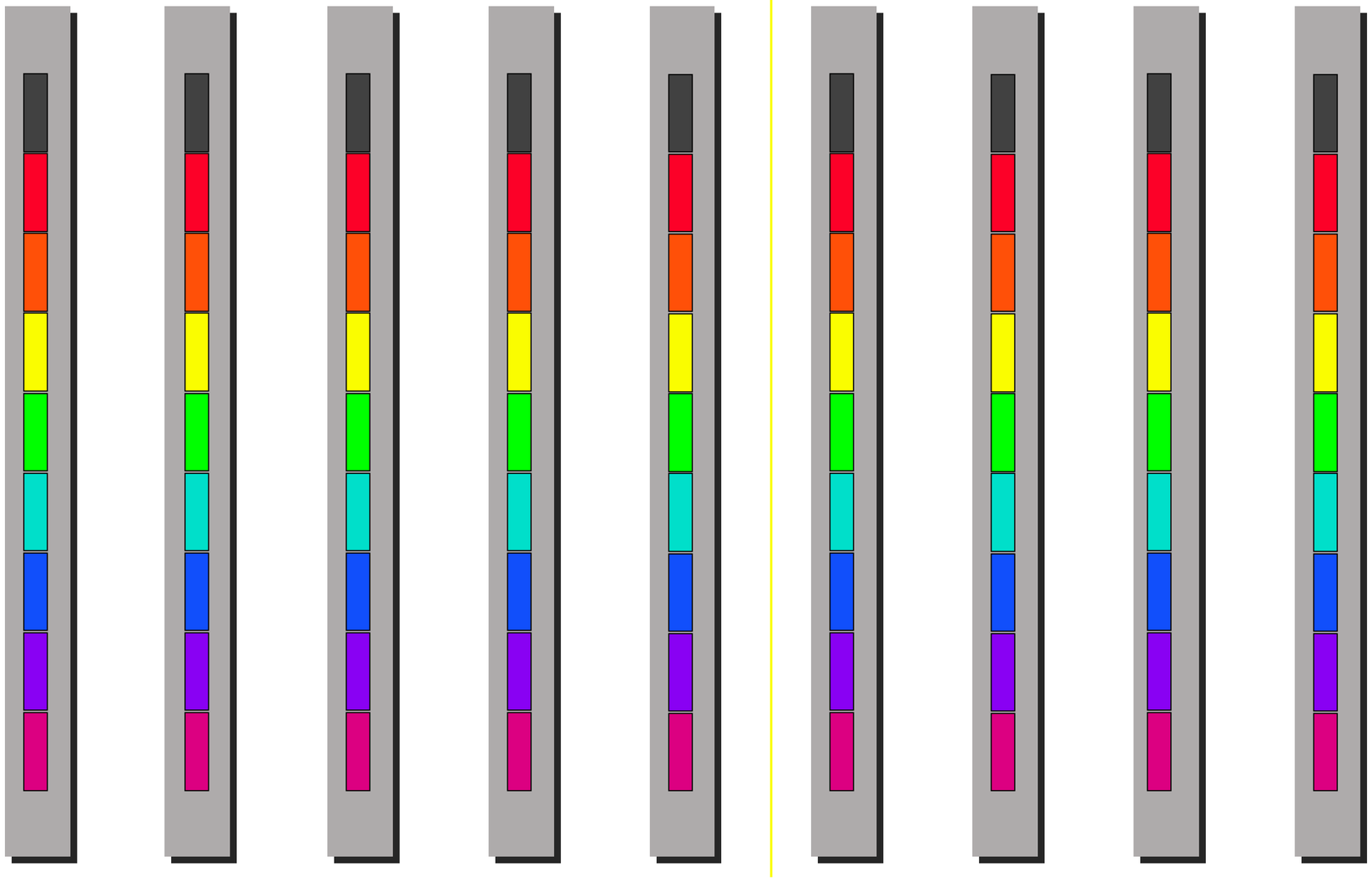
Cost of minimum spanning tree broadcast

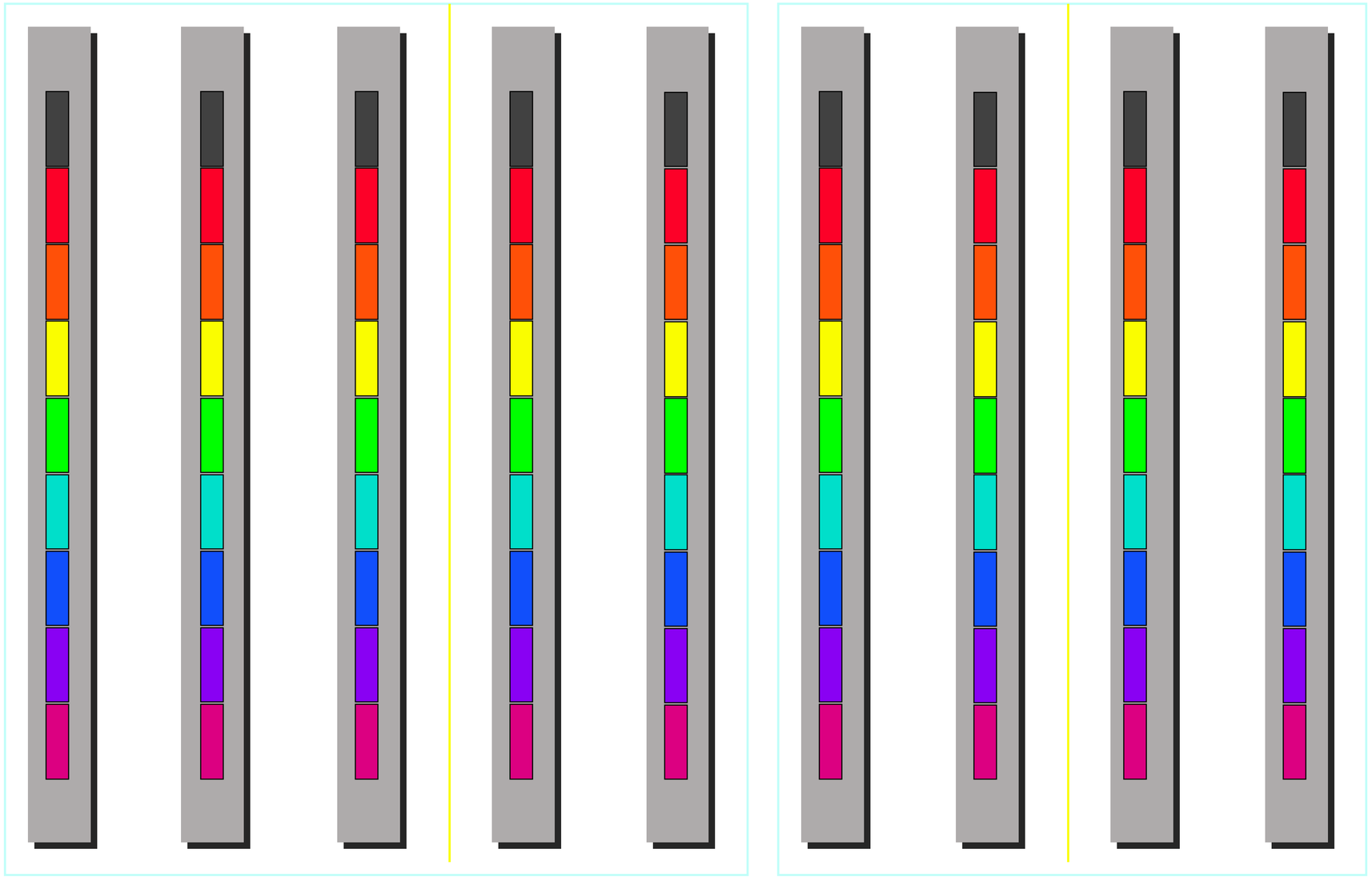


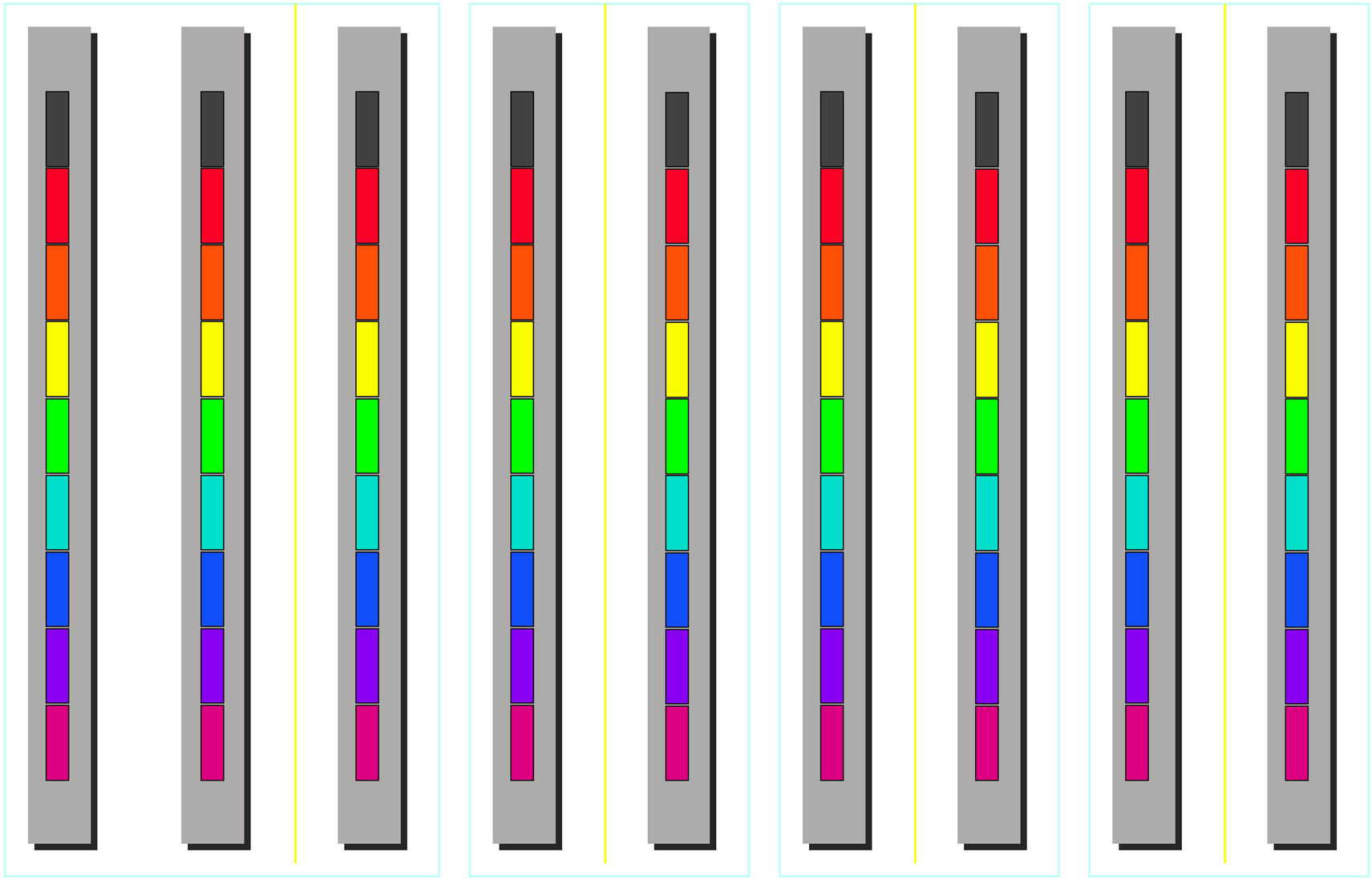
Reduce(-to-one)

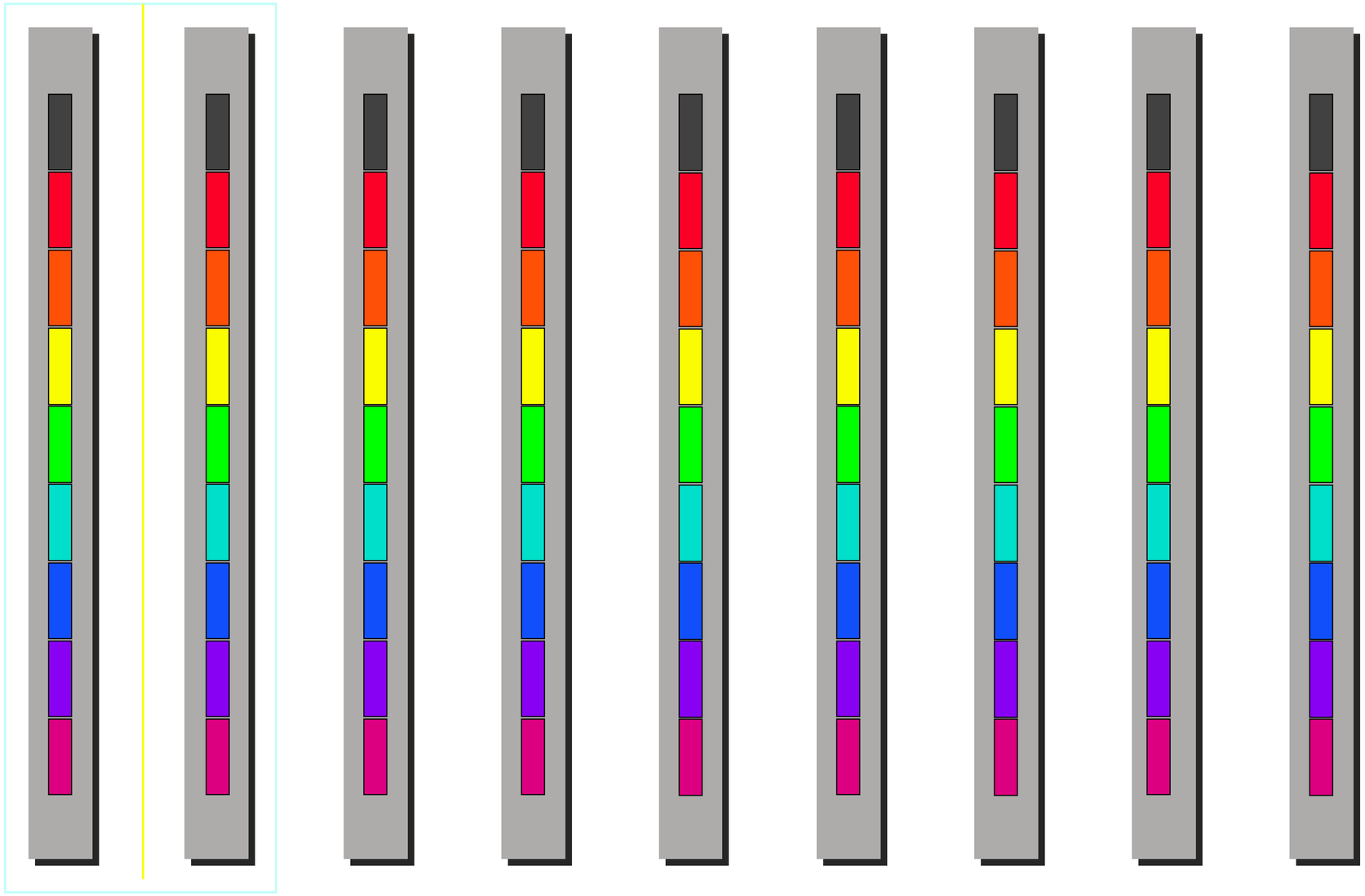


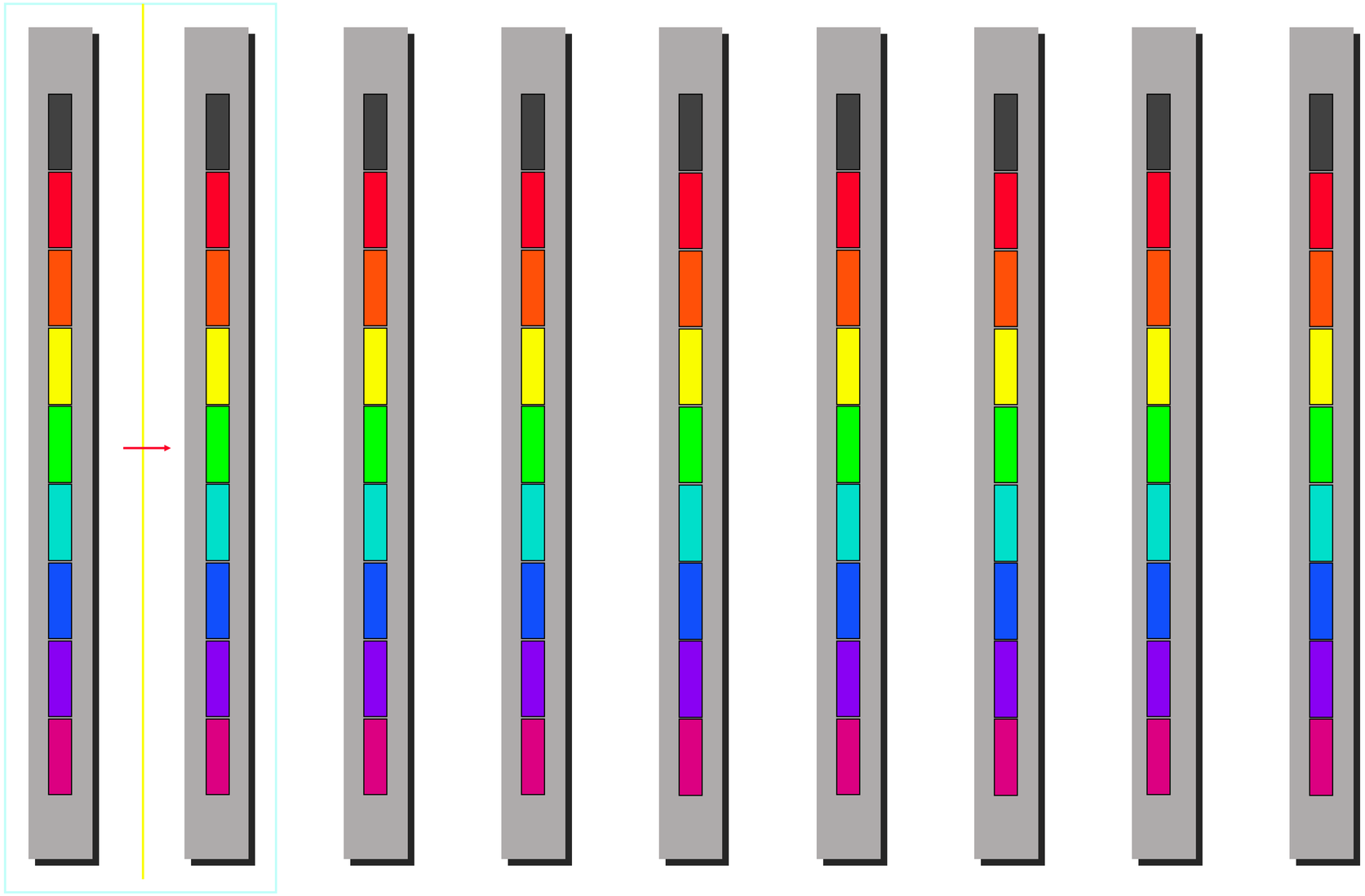


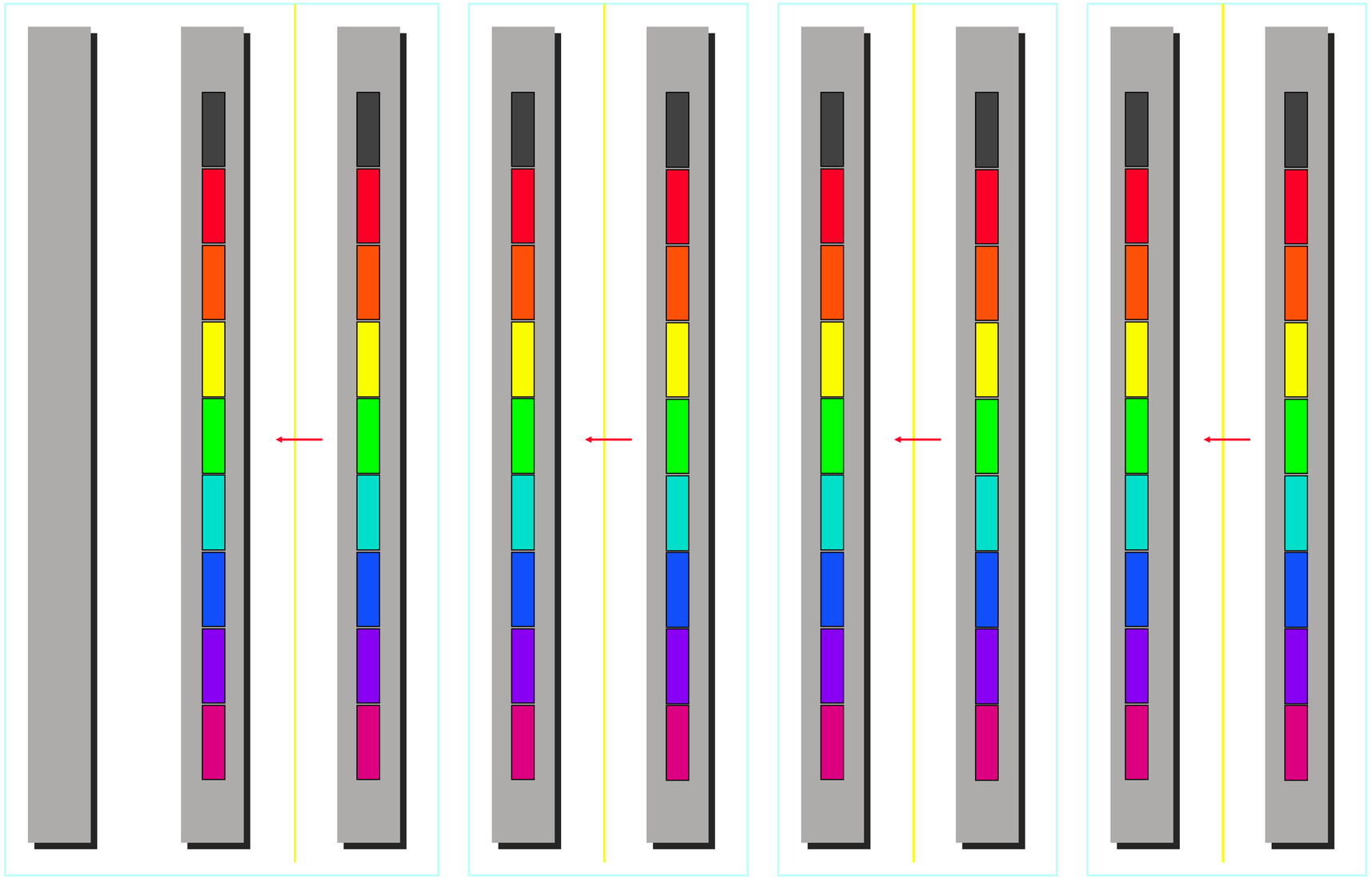


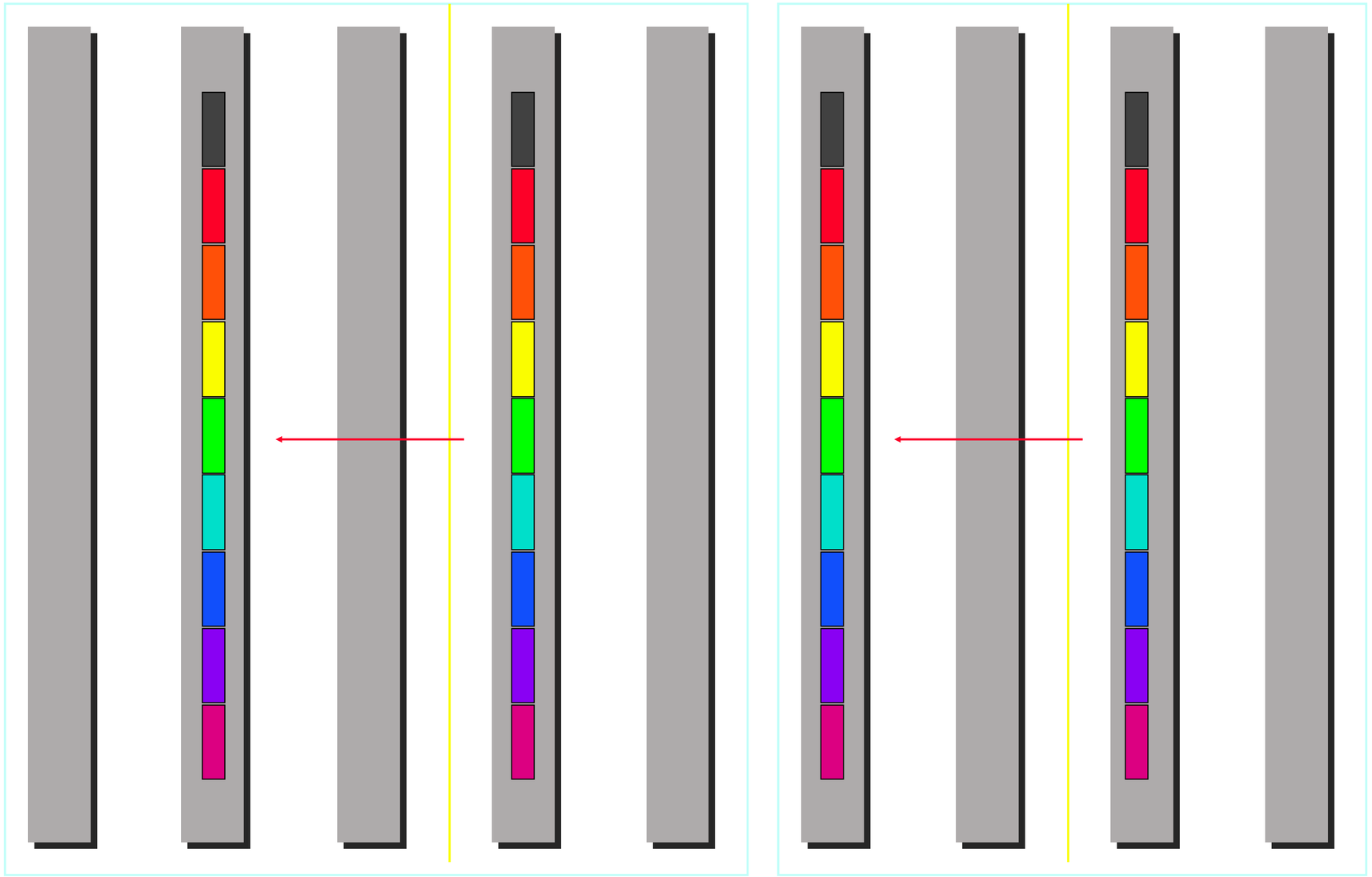


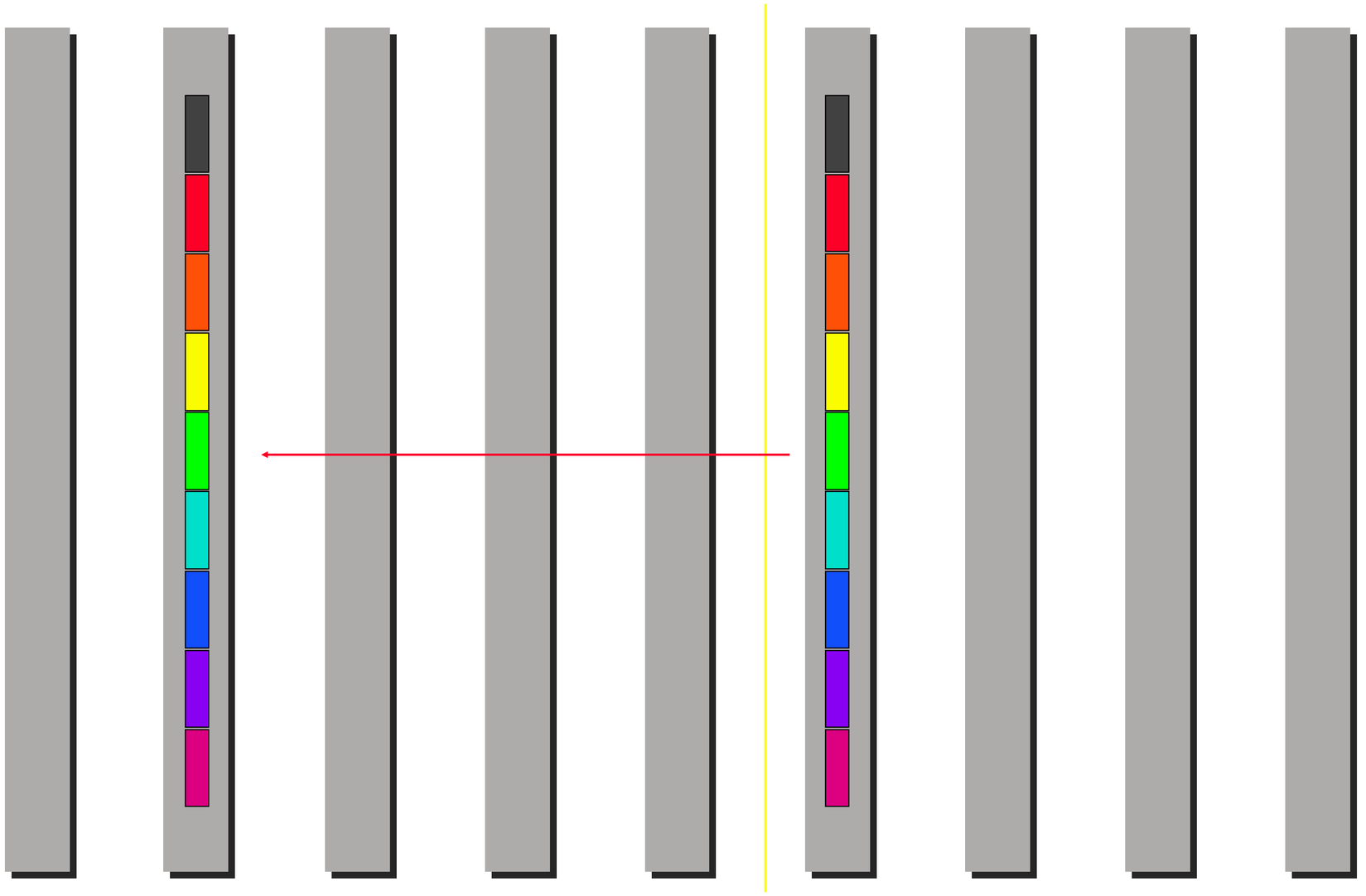








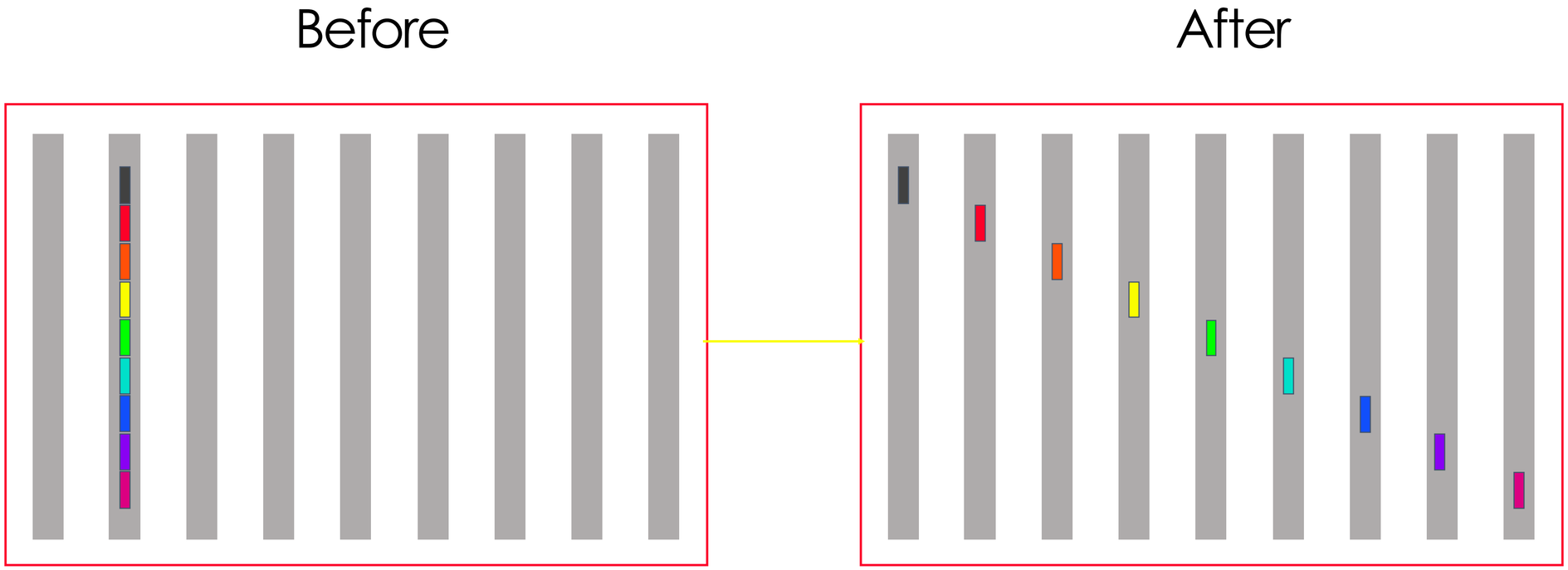


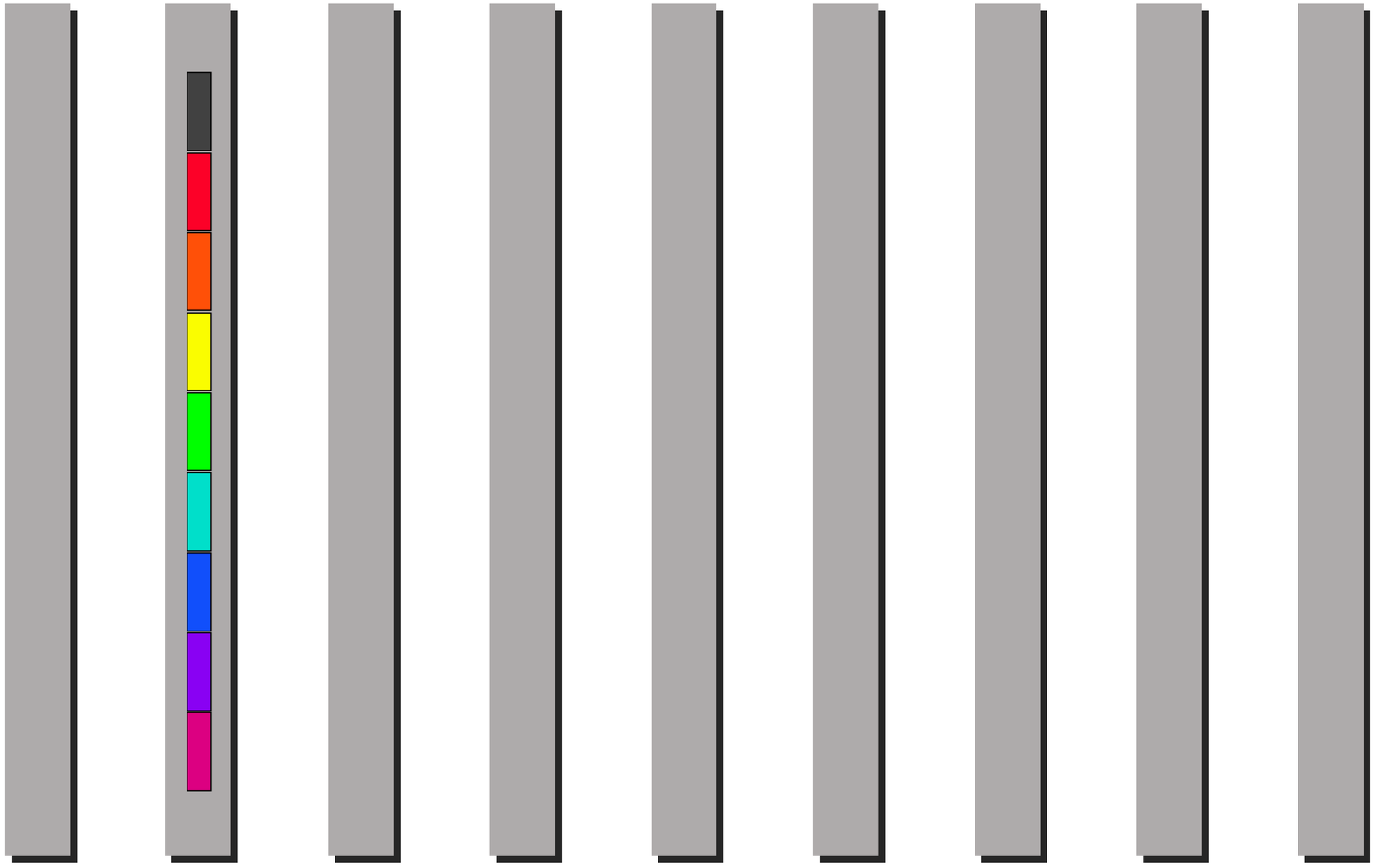


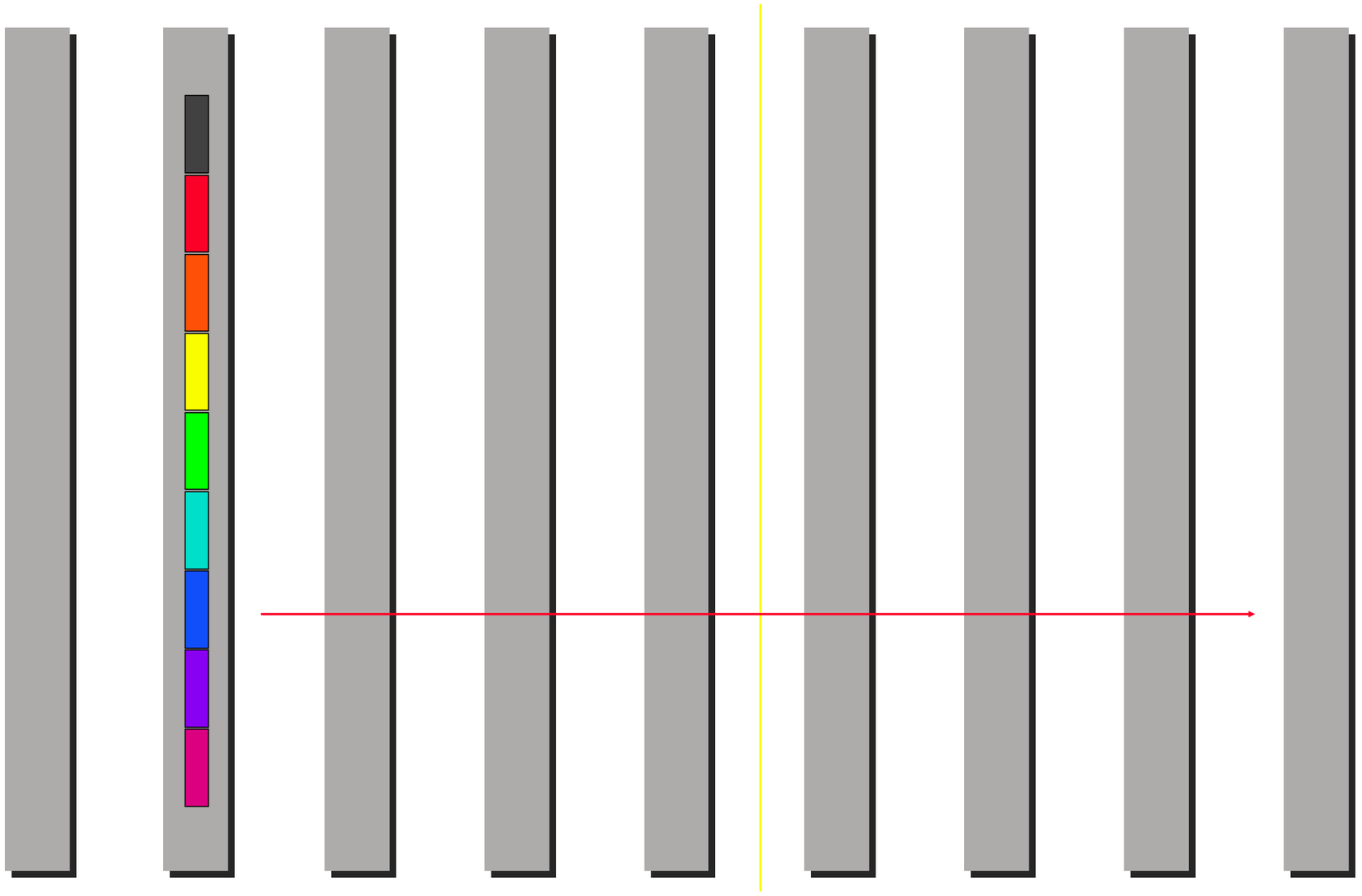
Cost of minimum spanning tree reduce(-to-one)

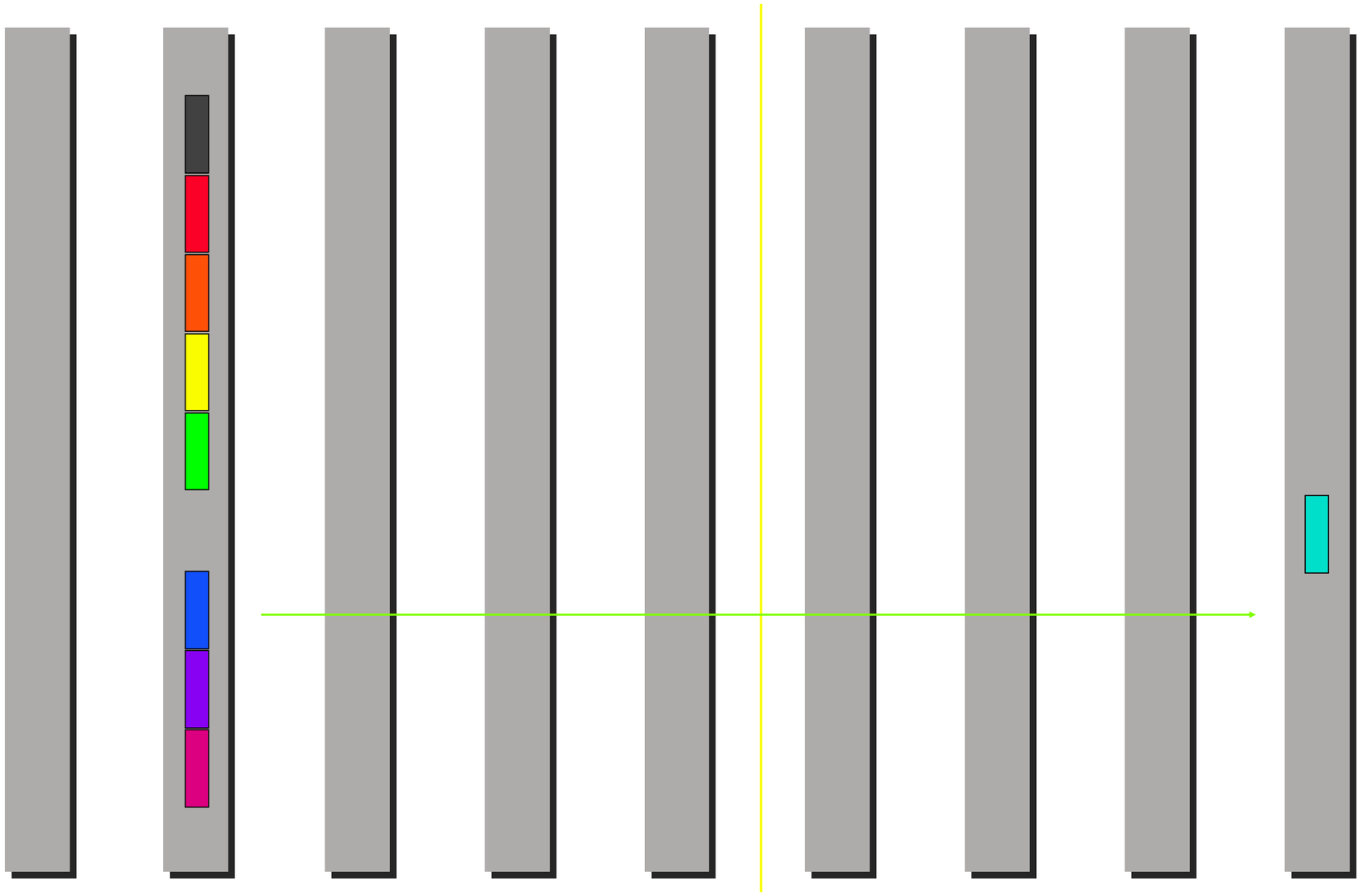
$$\lceil log(p) \rceil \ (\alpha + n\beta + n\gamma)$$

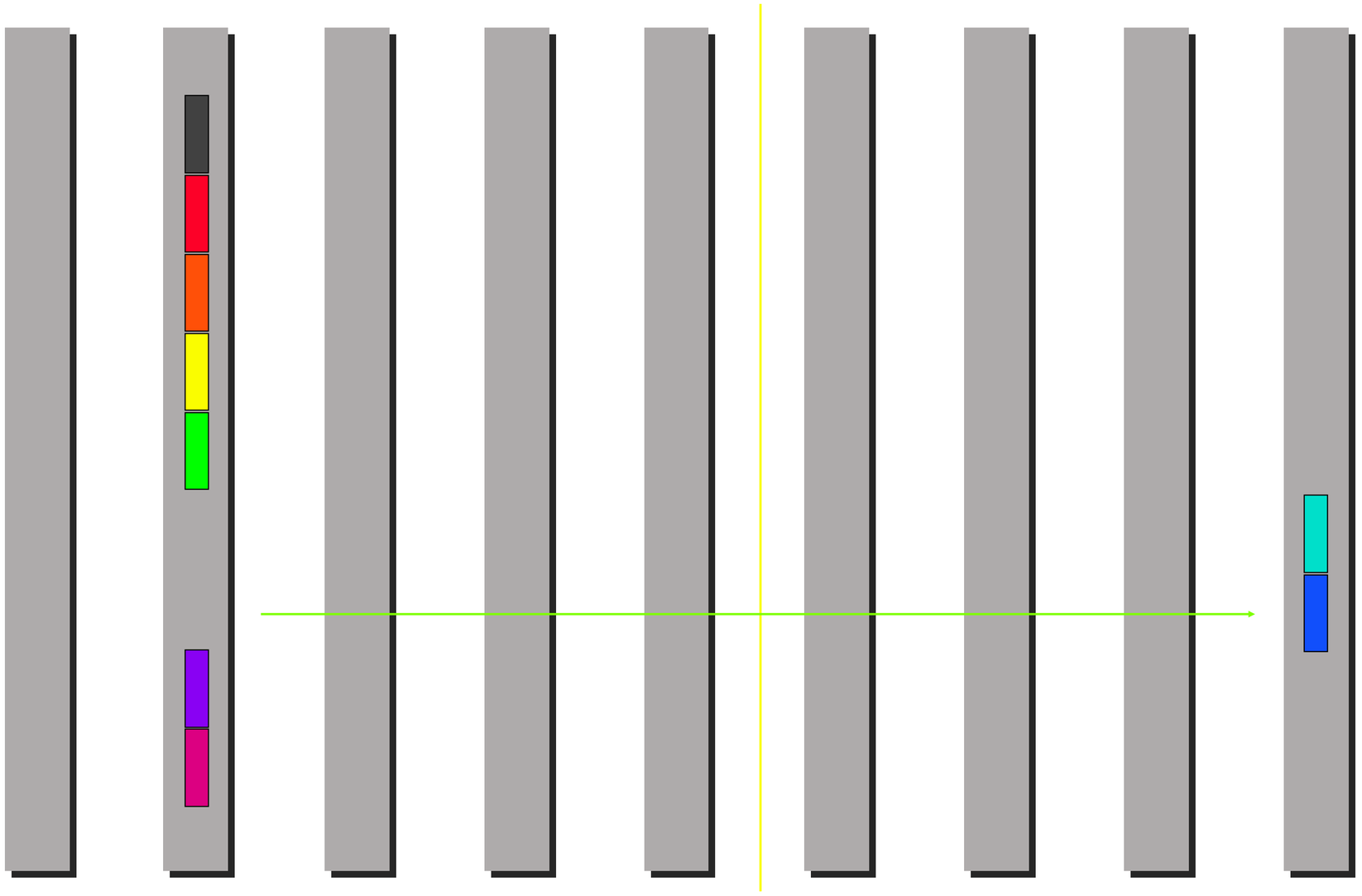
Scatter

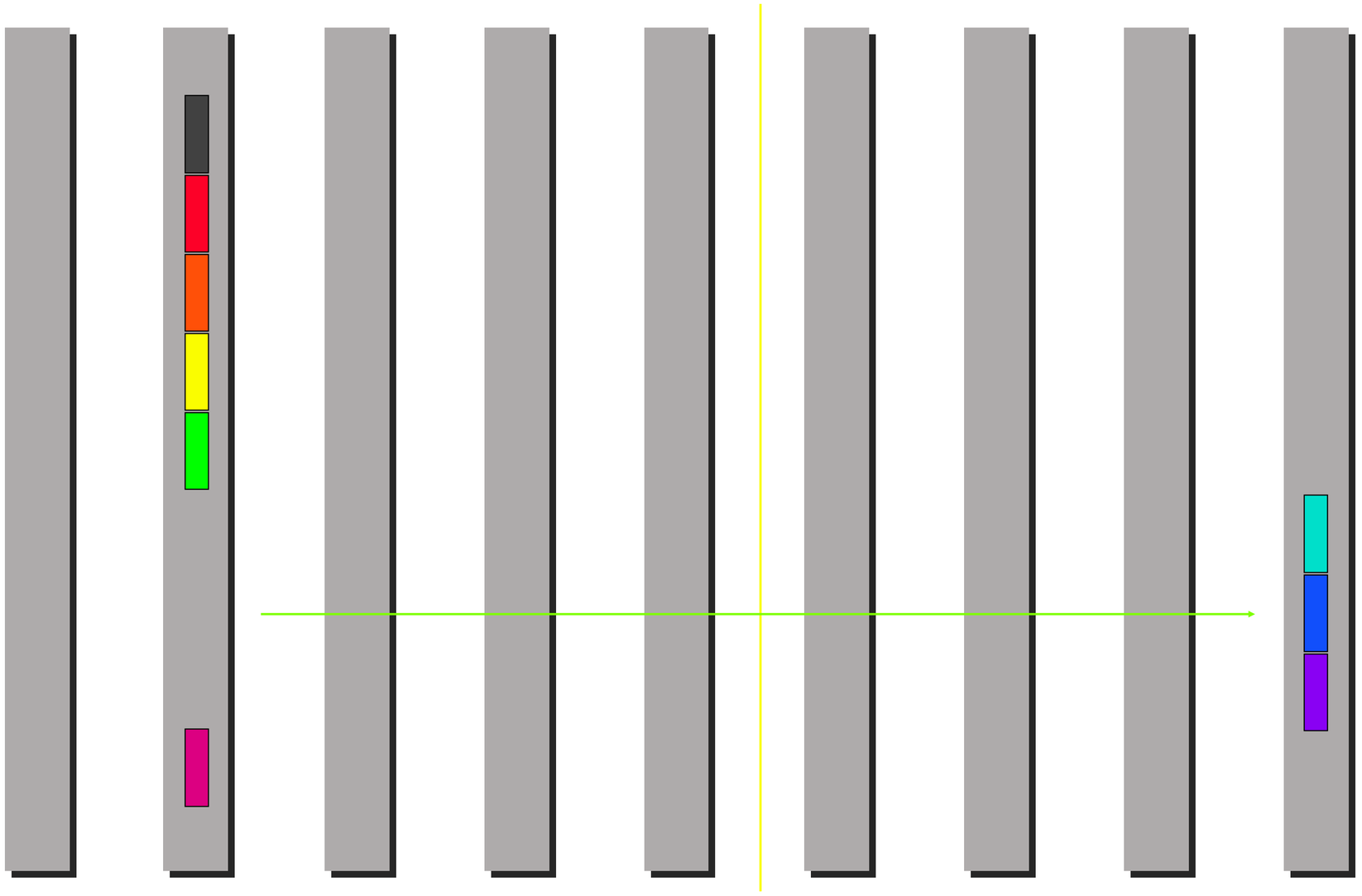


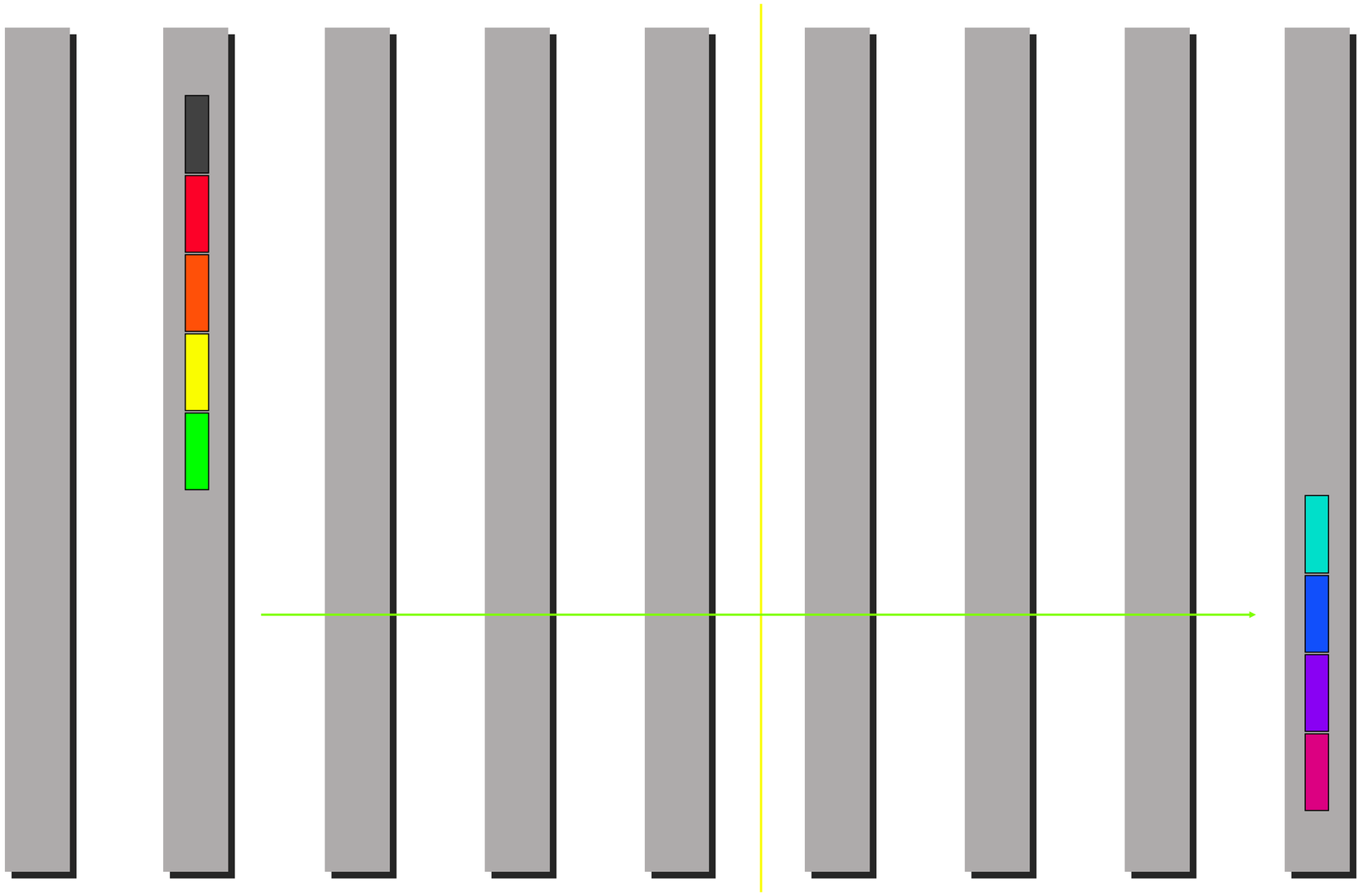


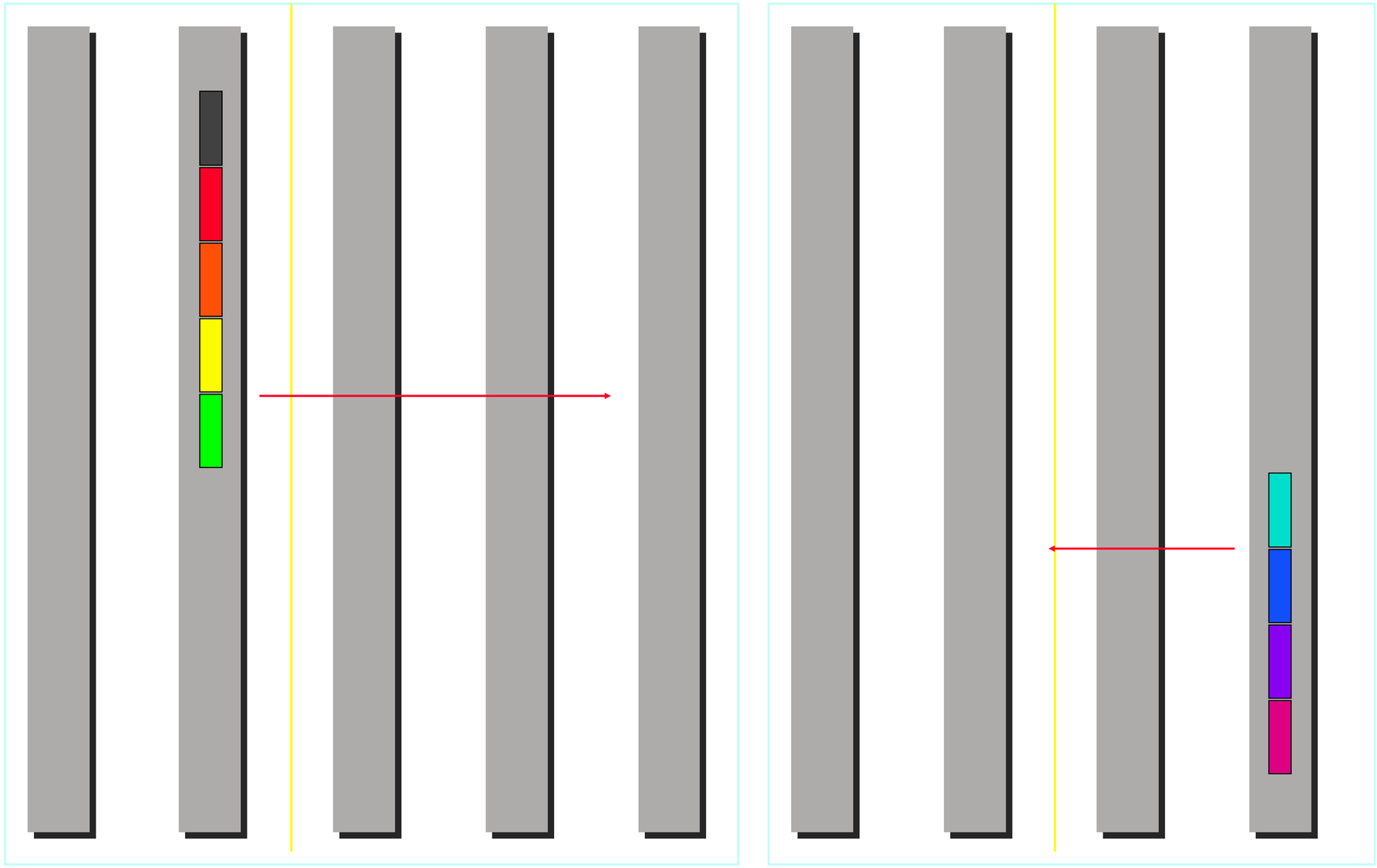


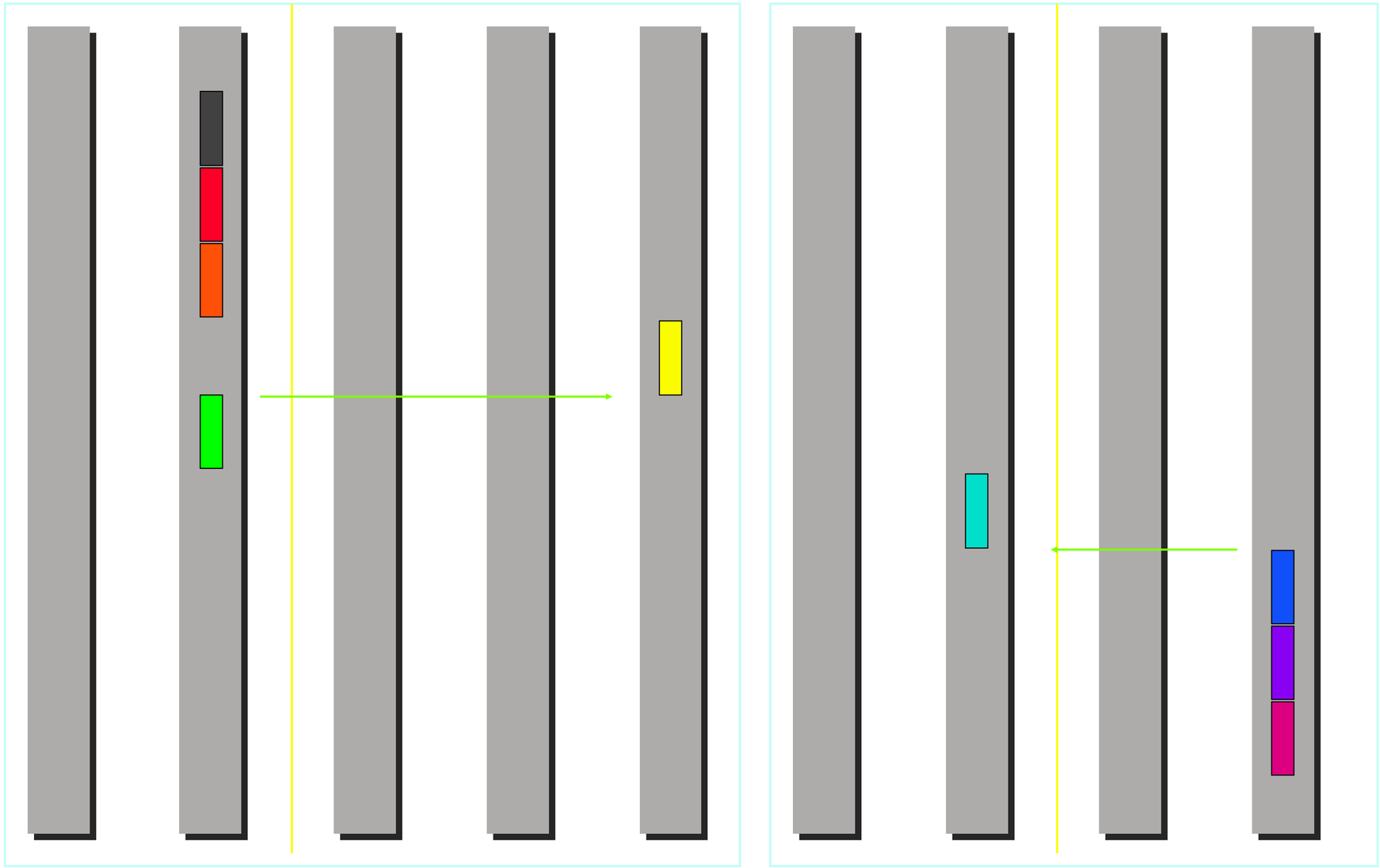


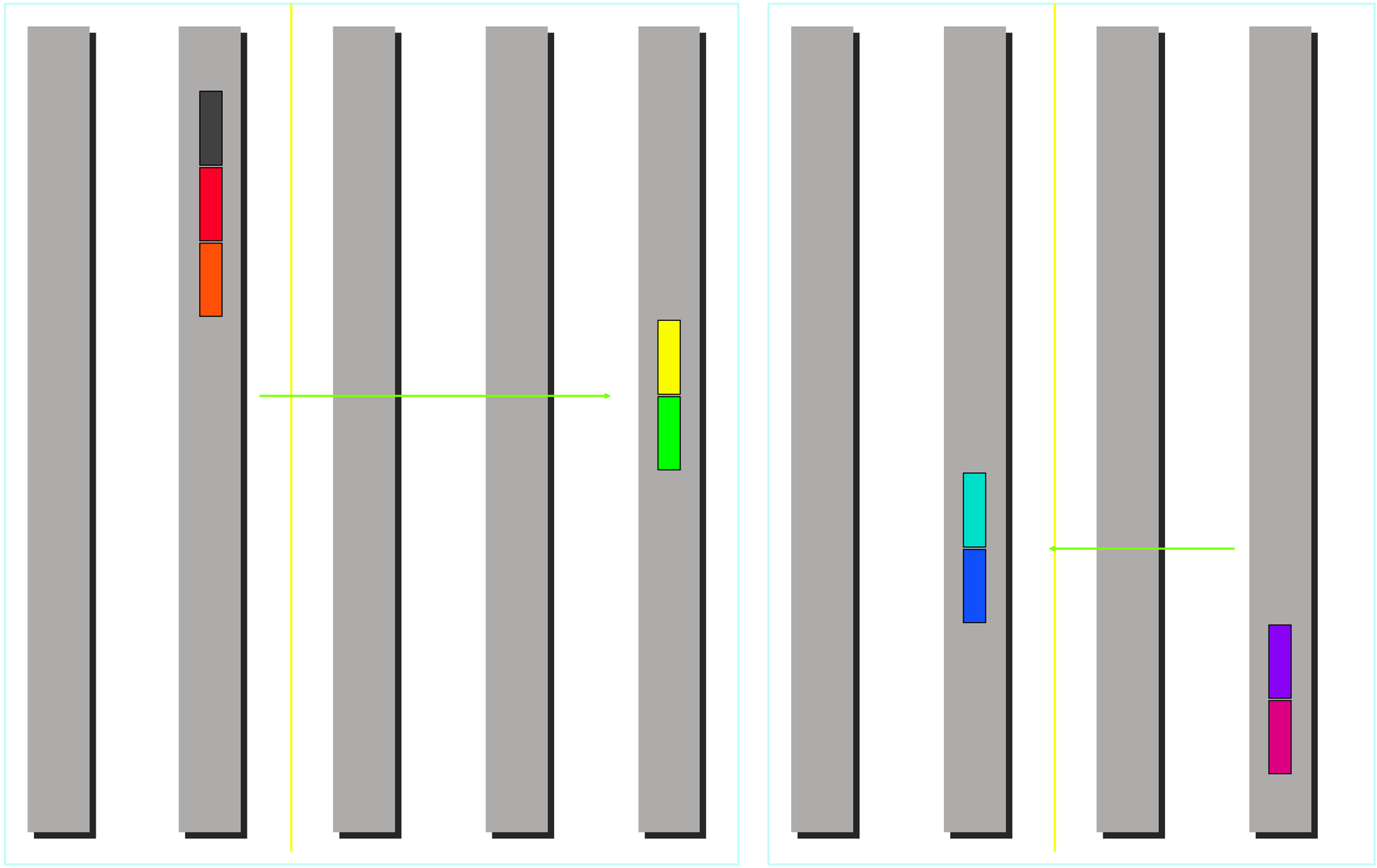


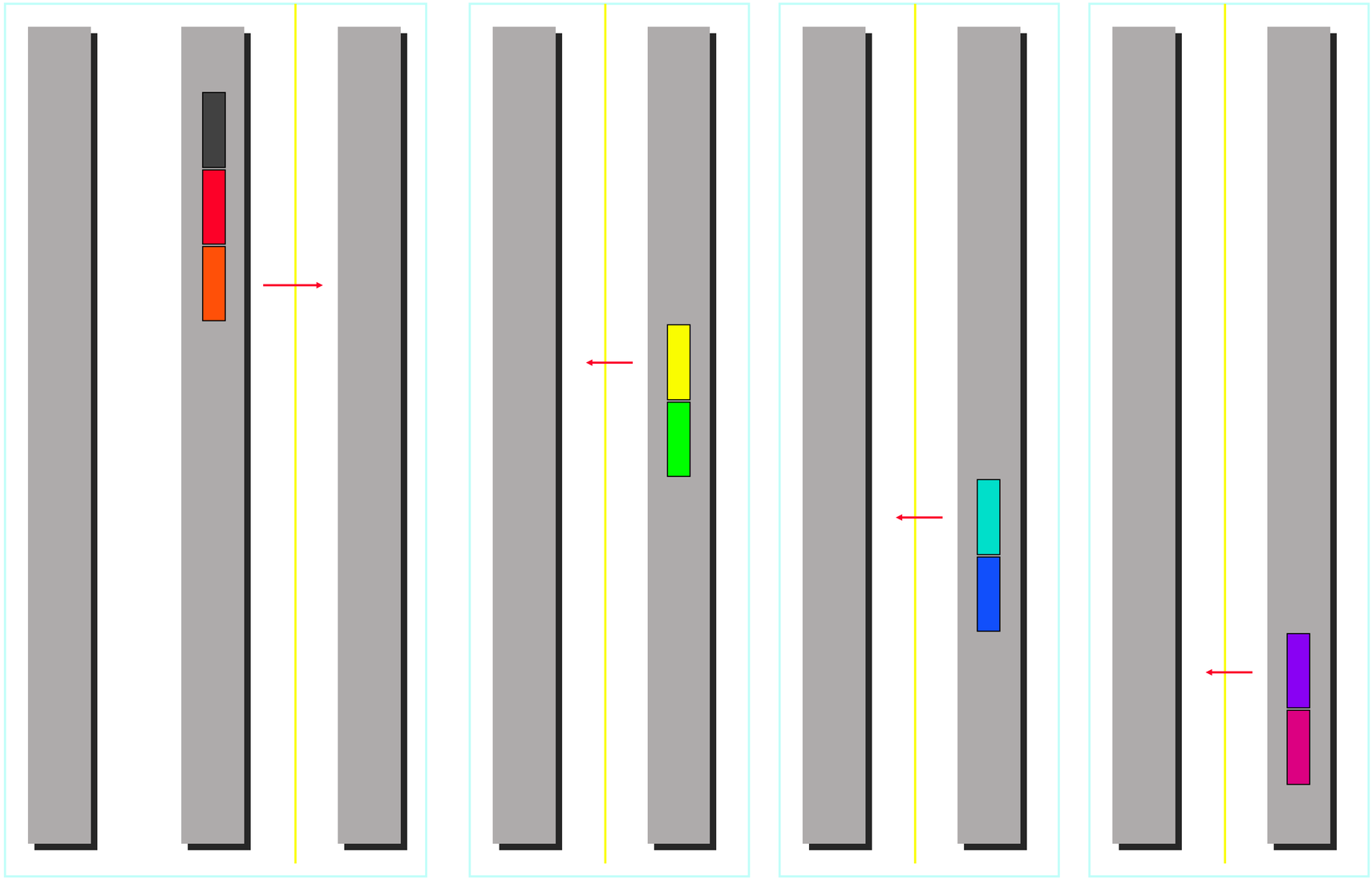


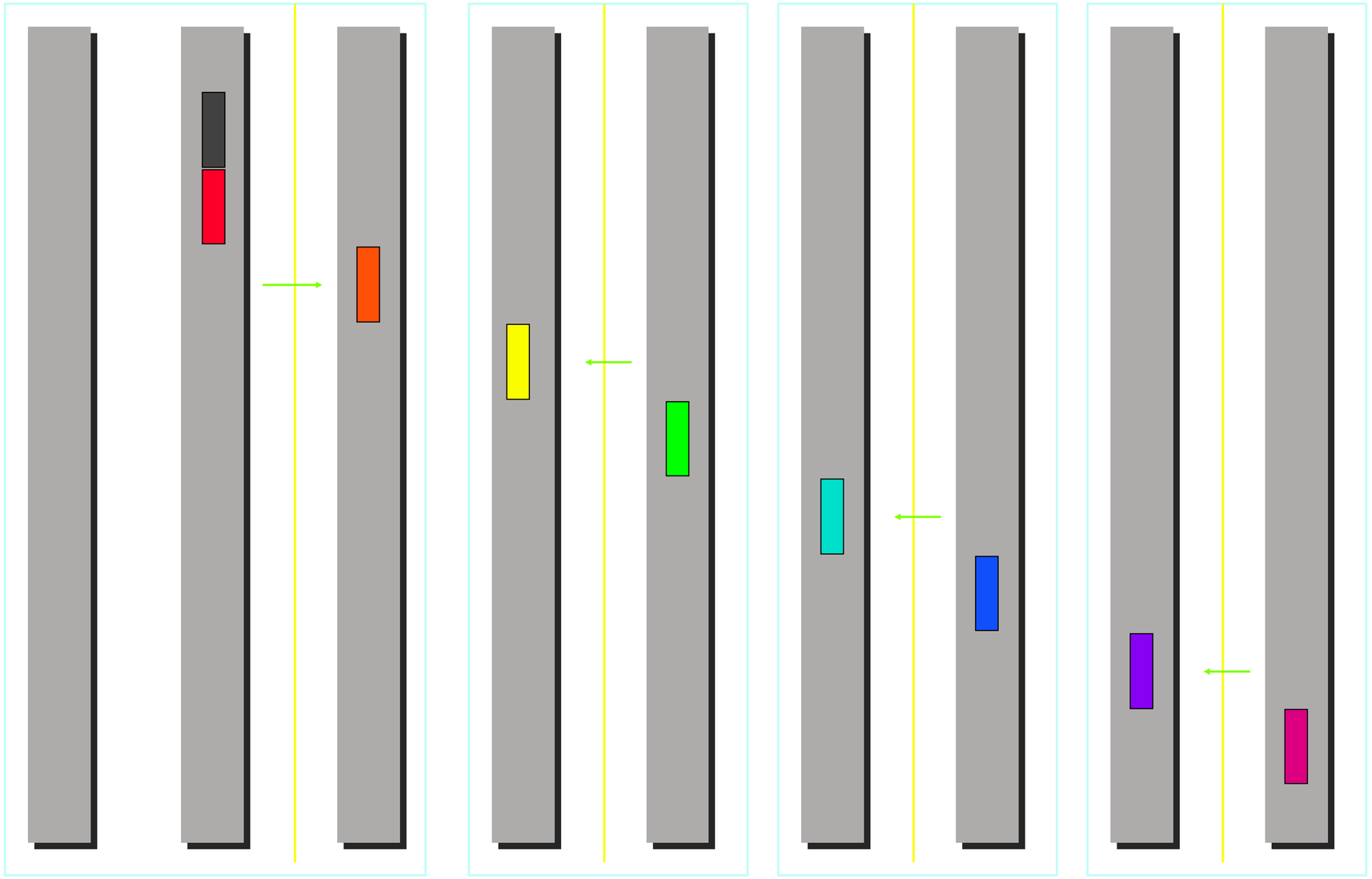


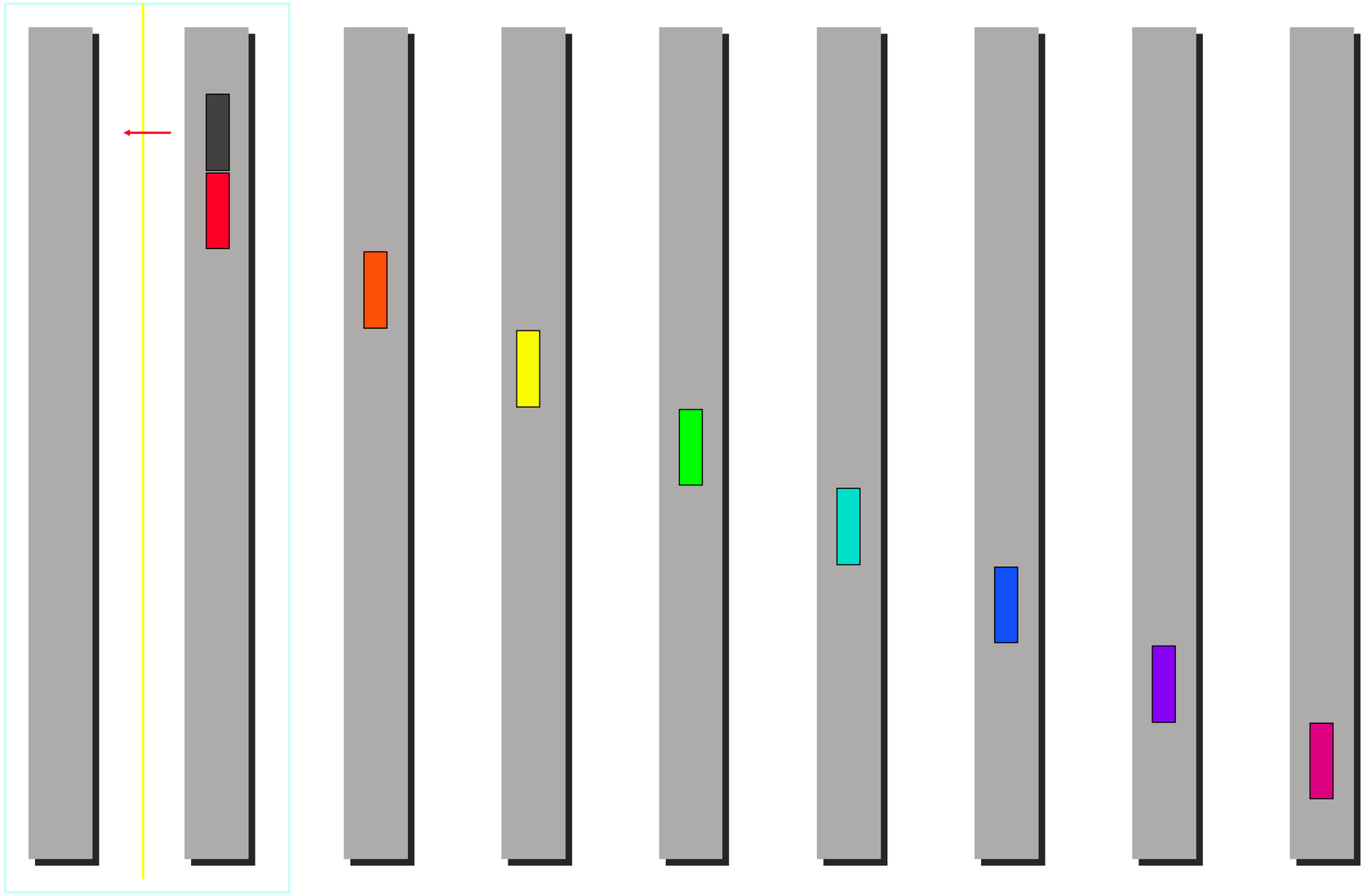


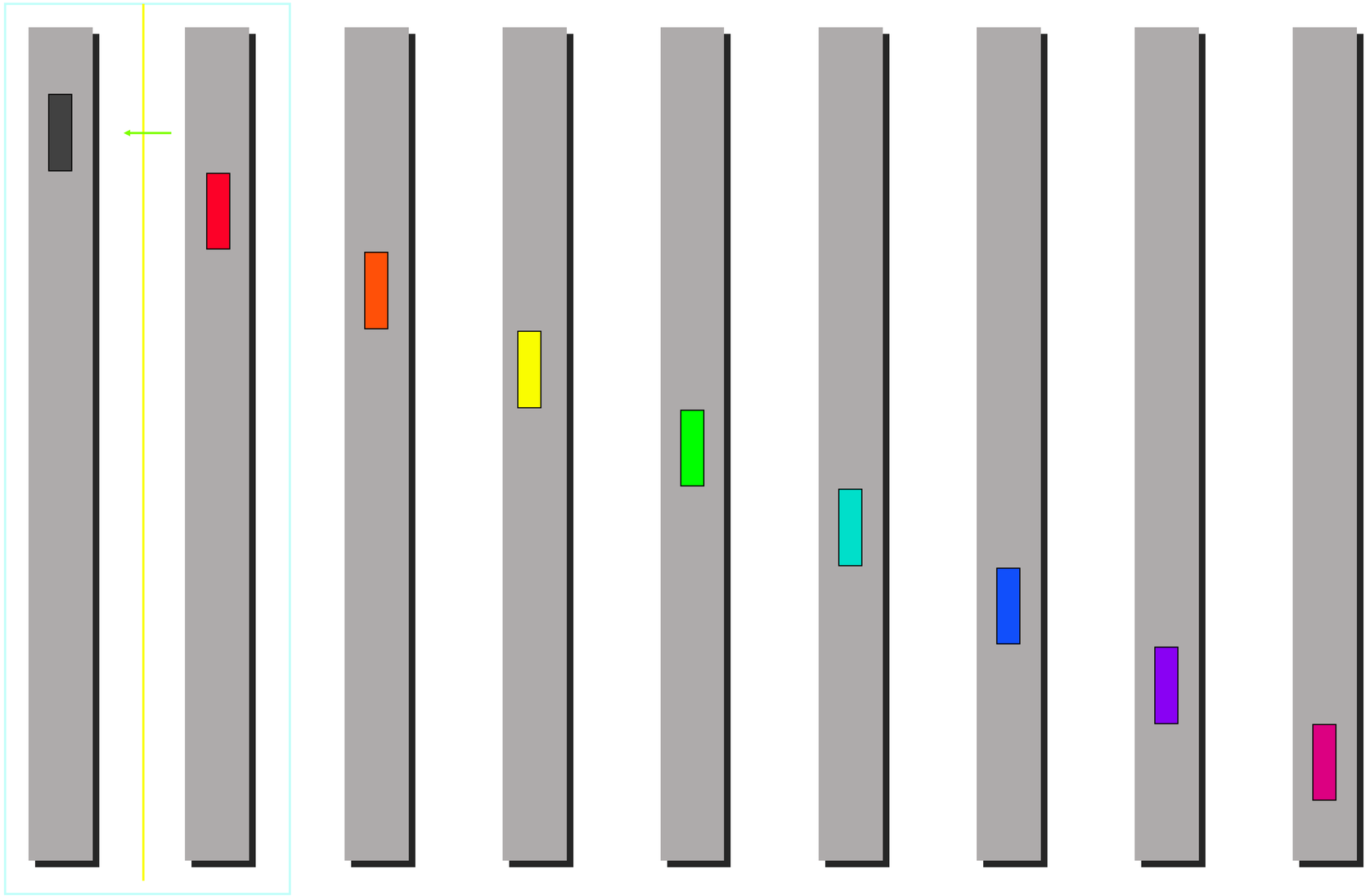


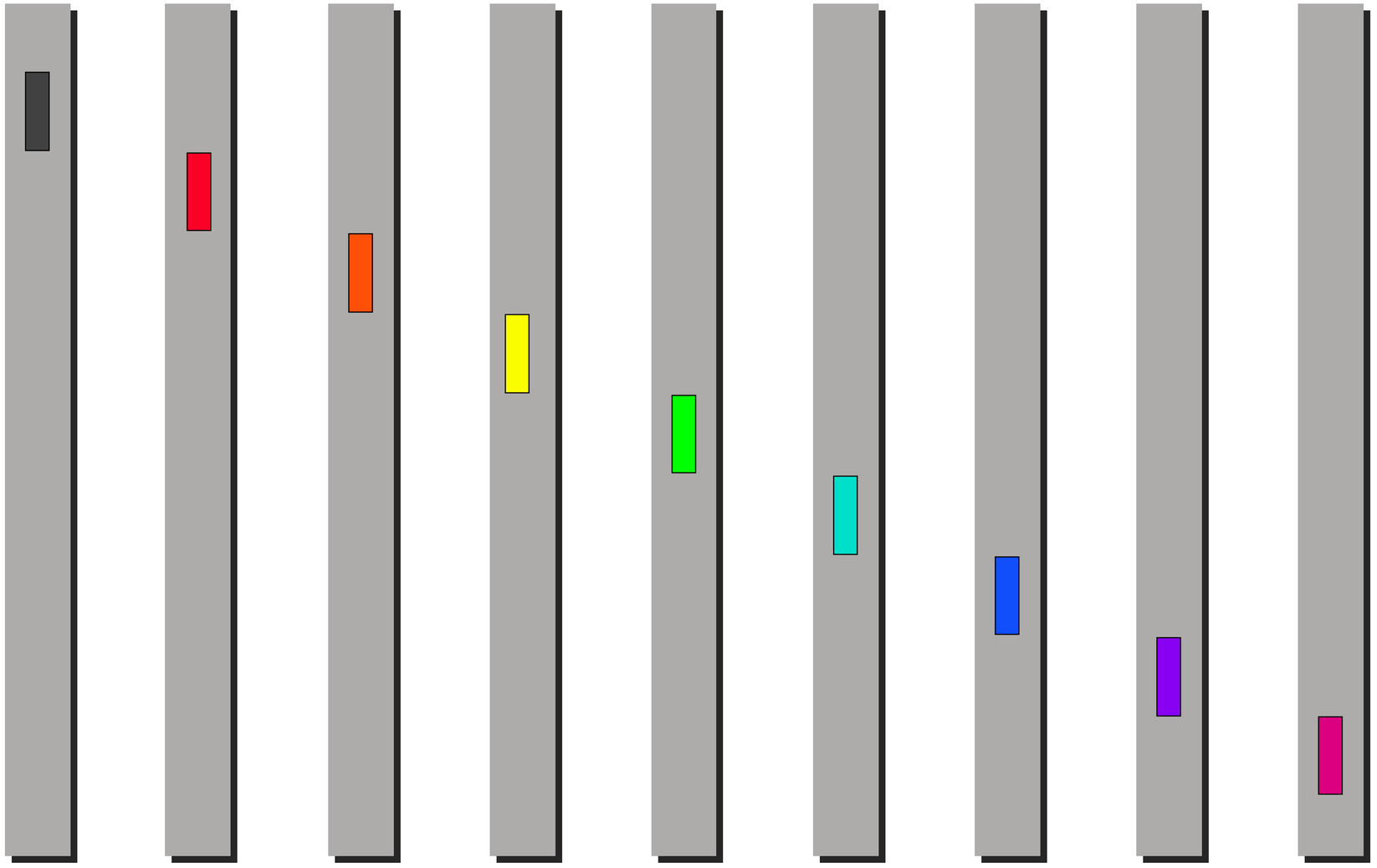












Cost of minimum spanning tree scatter

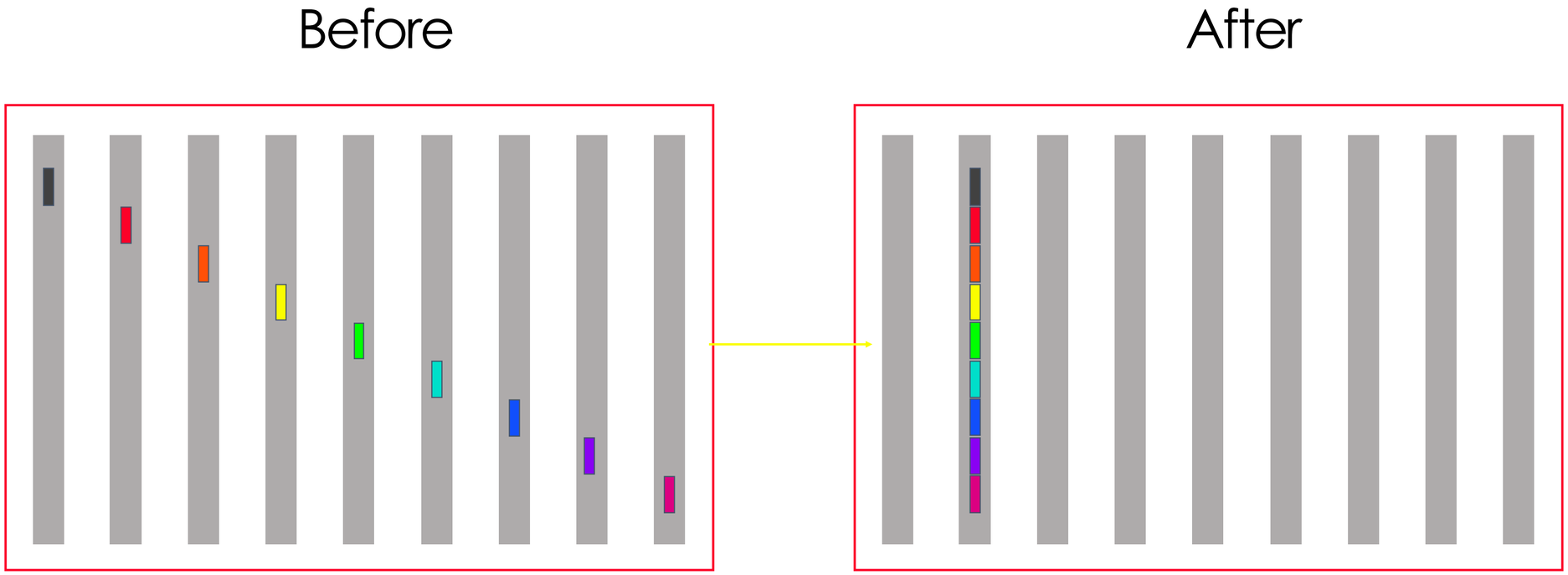
- Assumption: power of two number of nodes

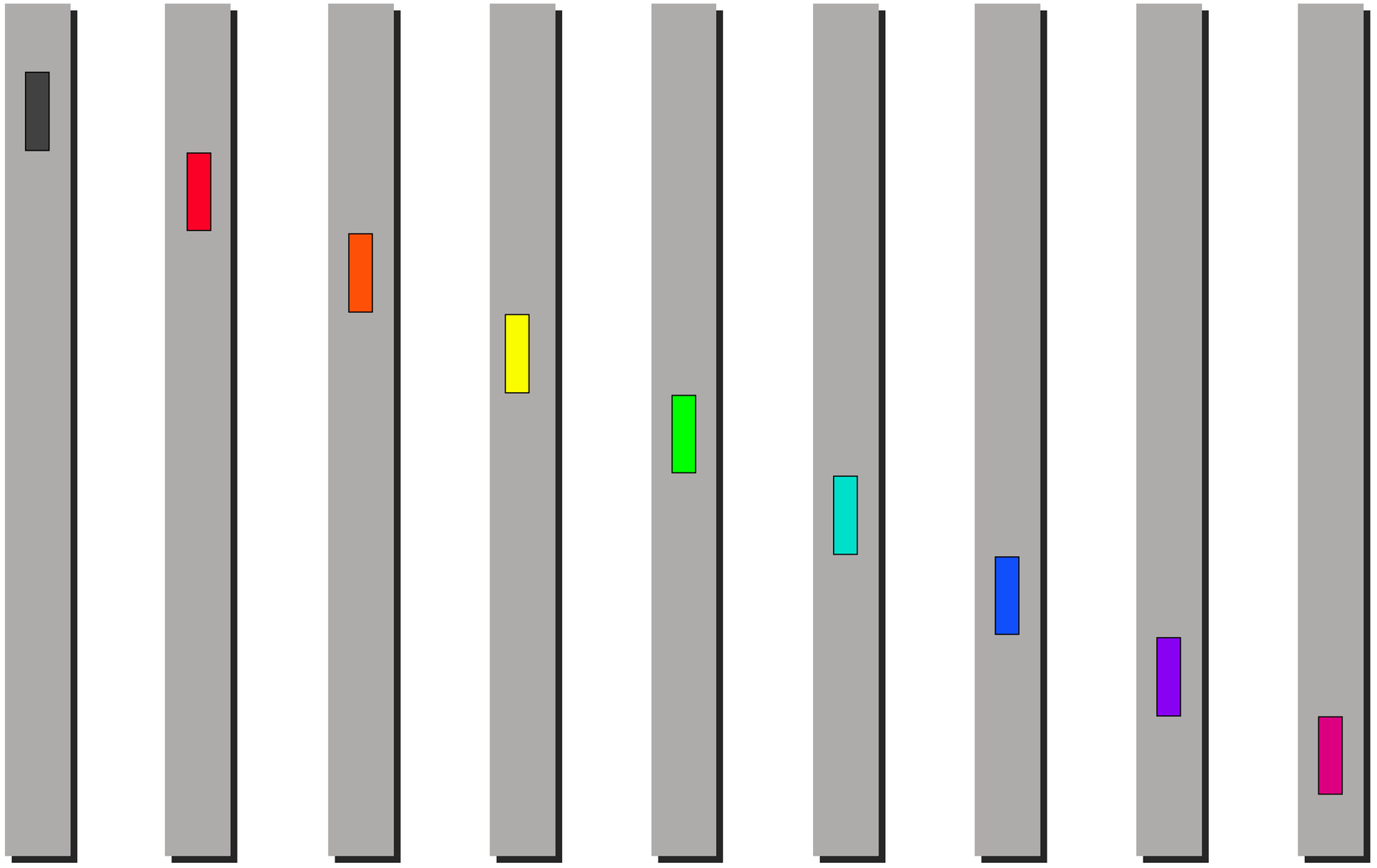
$$\sum_{k=1}^{log(p)} \left(\alpha + \frac{n}{2^k} \beta \right)$$

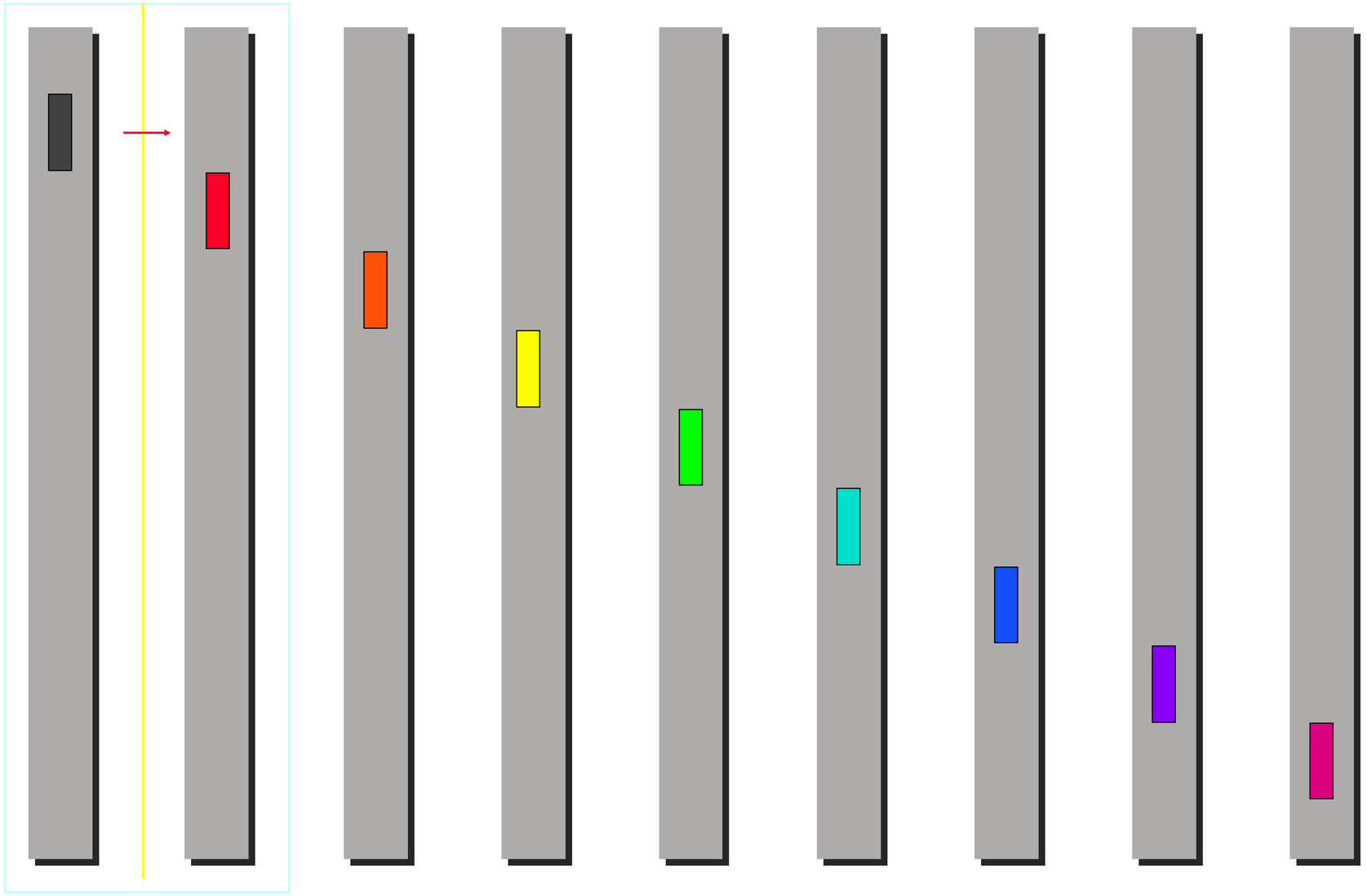
$$=$$

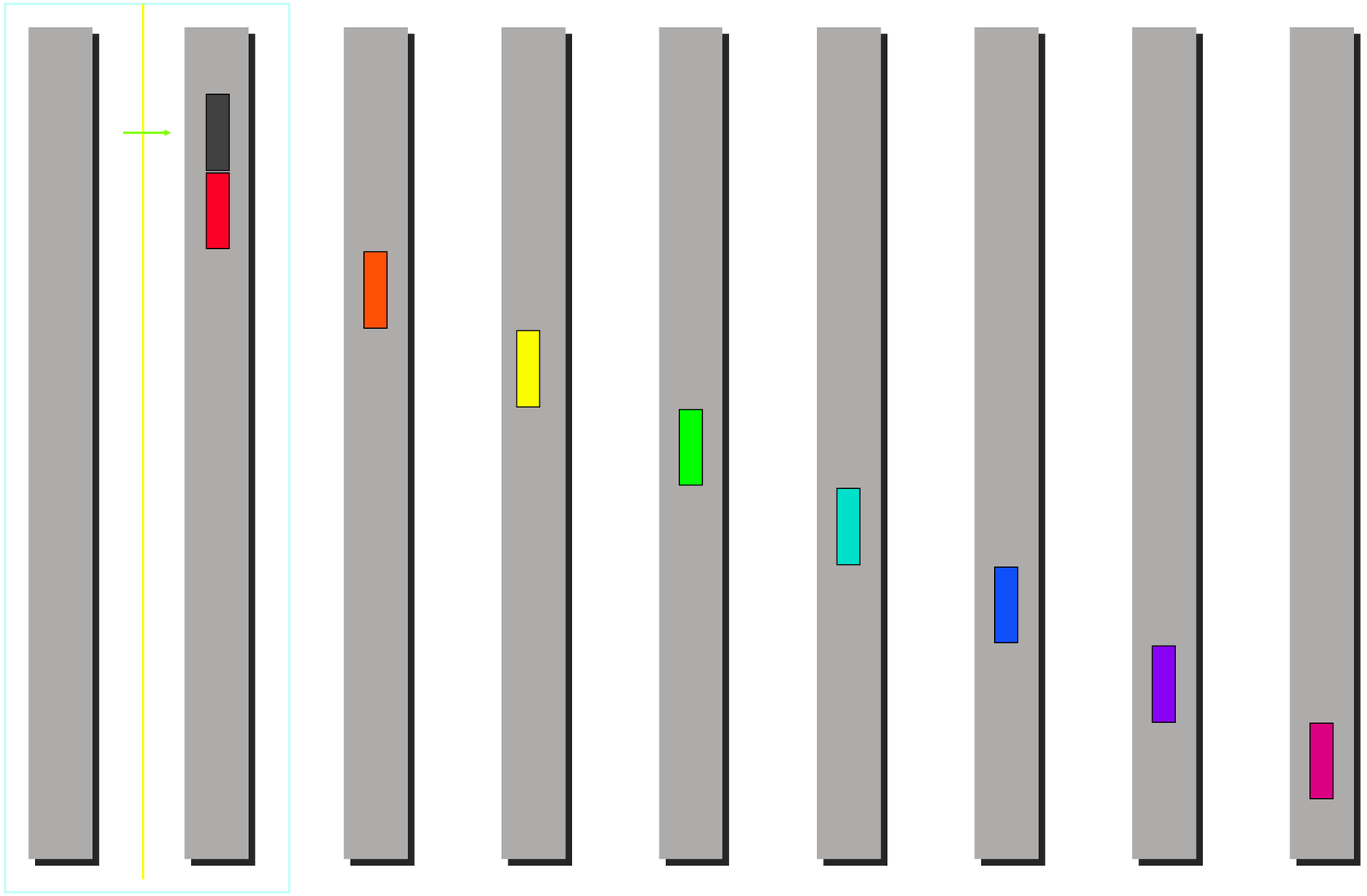
$$log(p)\ \alpha + \frac{p-1}{p} n\beta$$

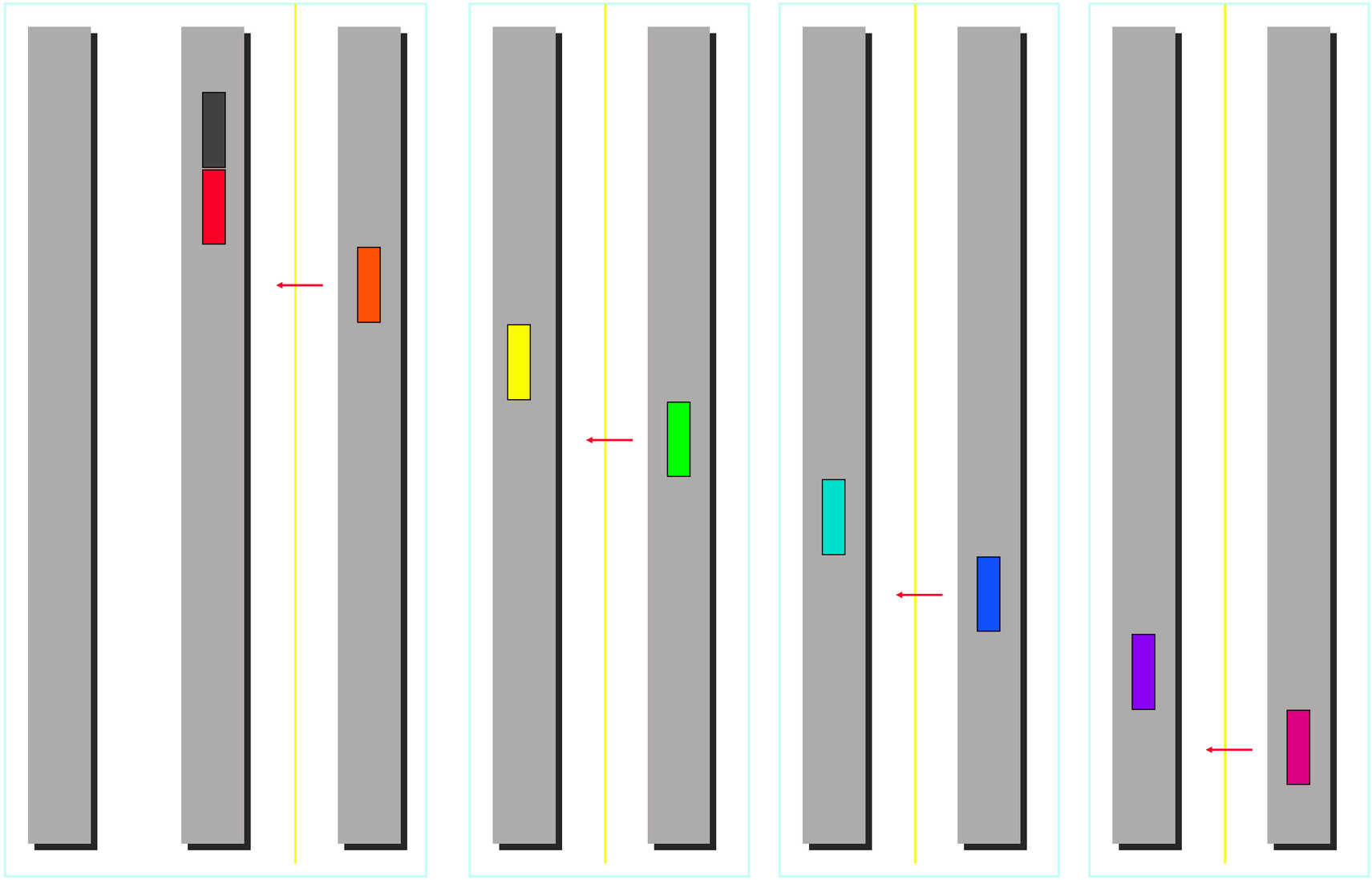
Gather

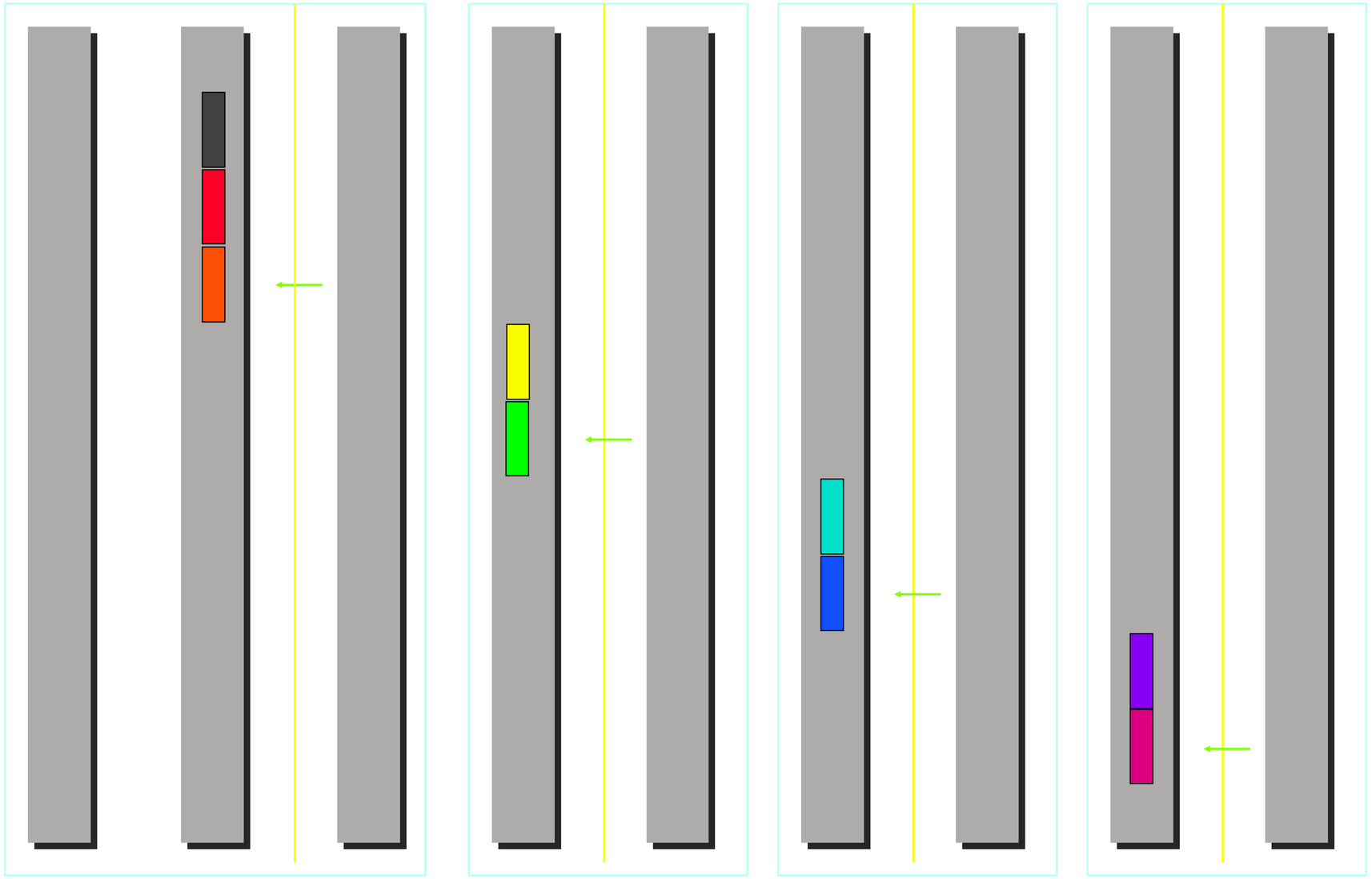


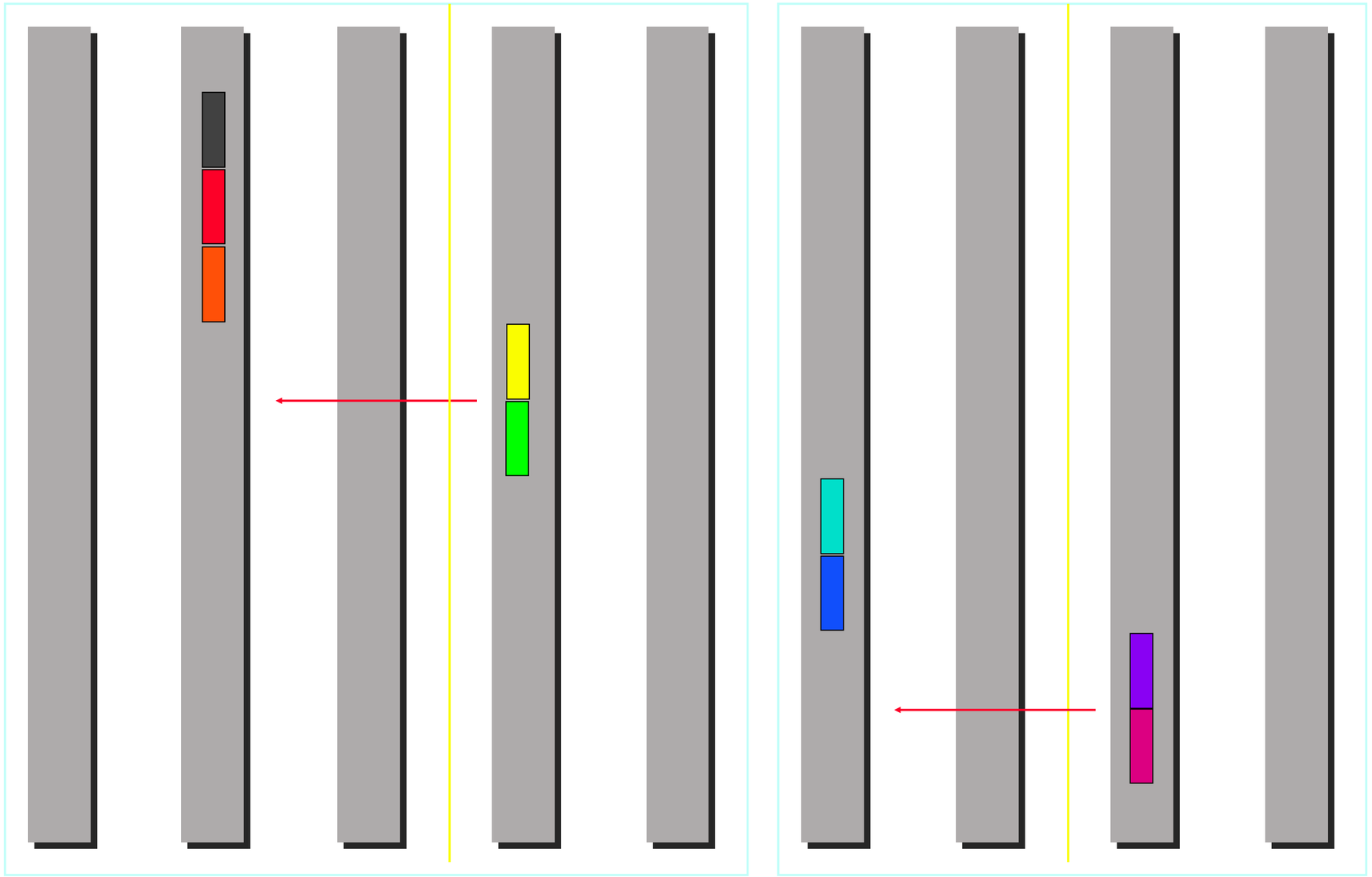


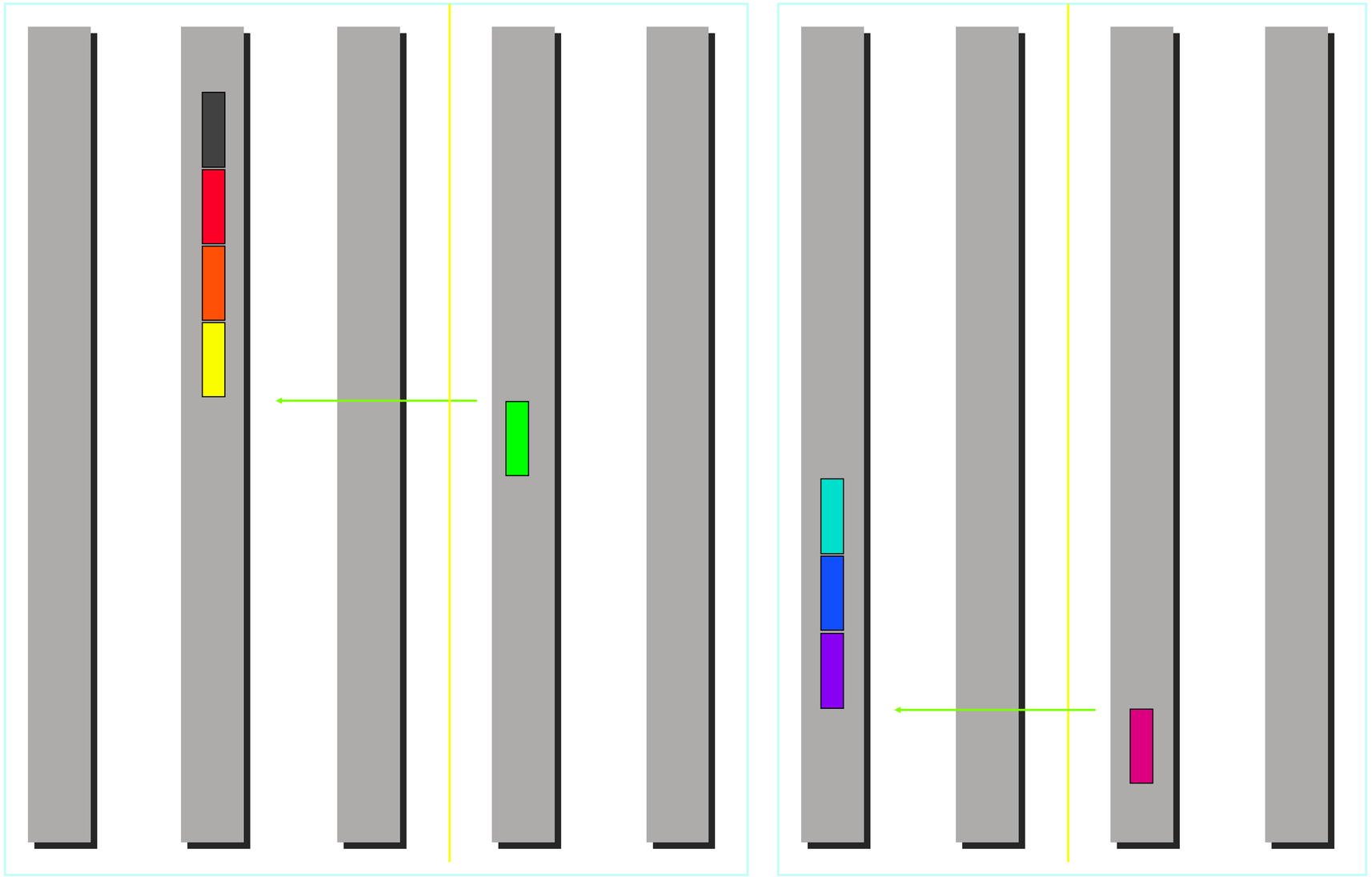


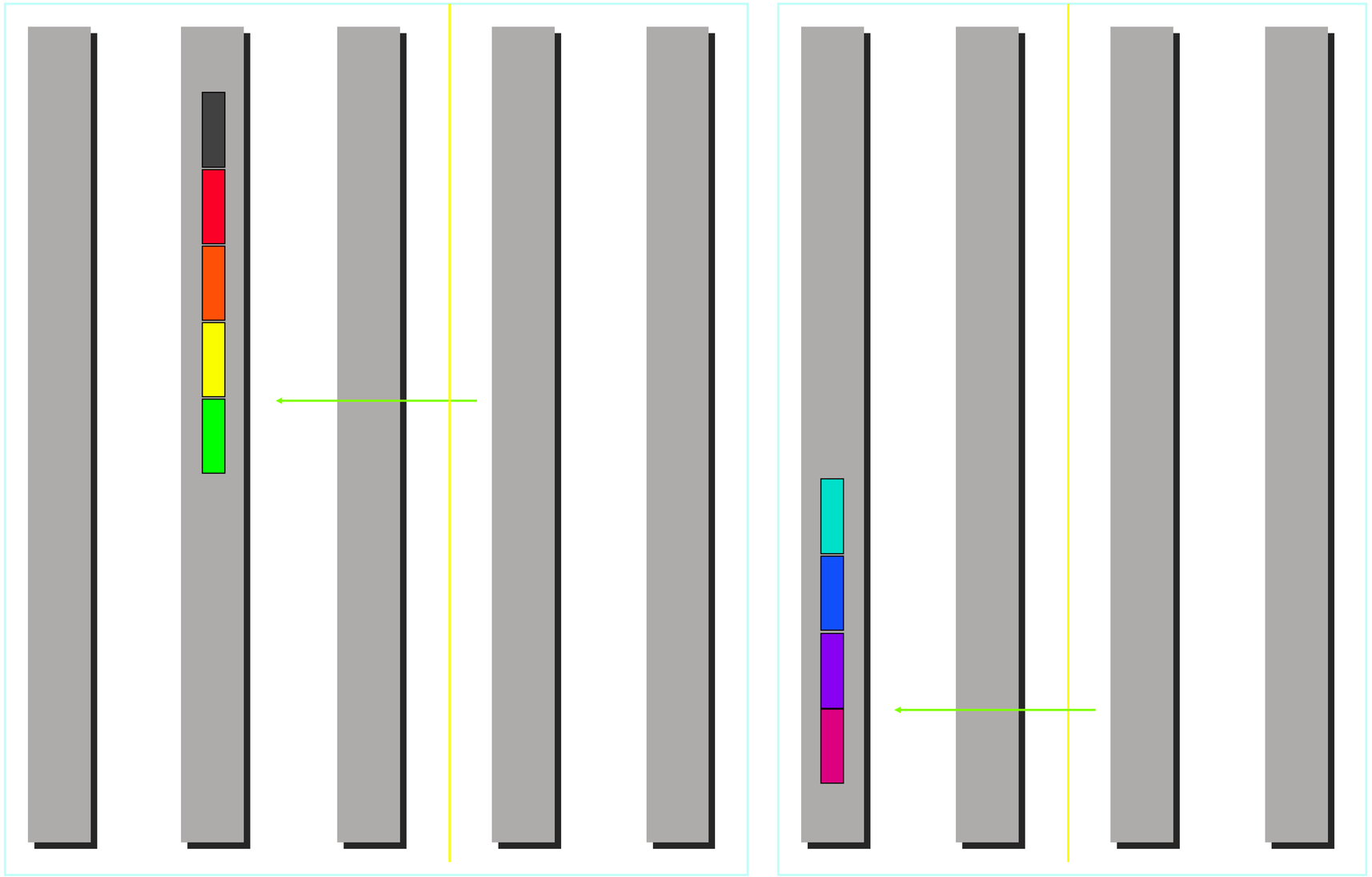


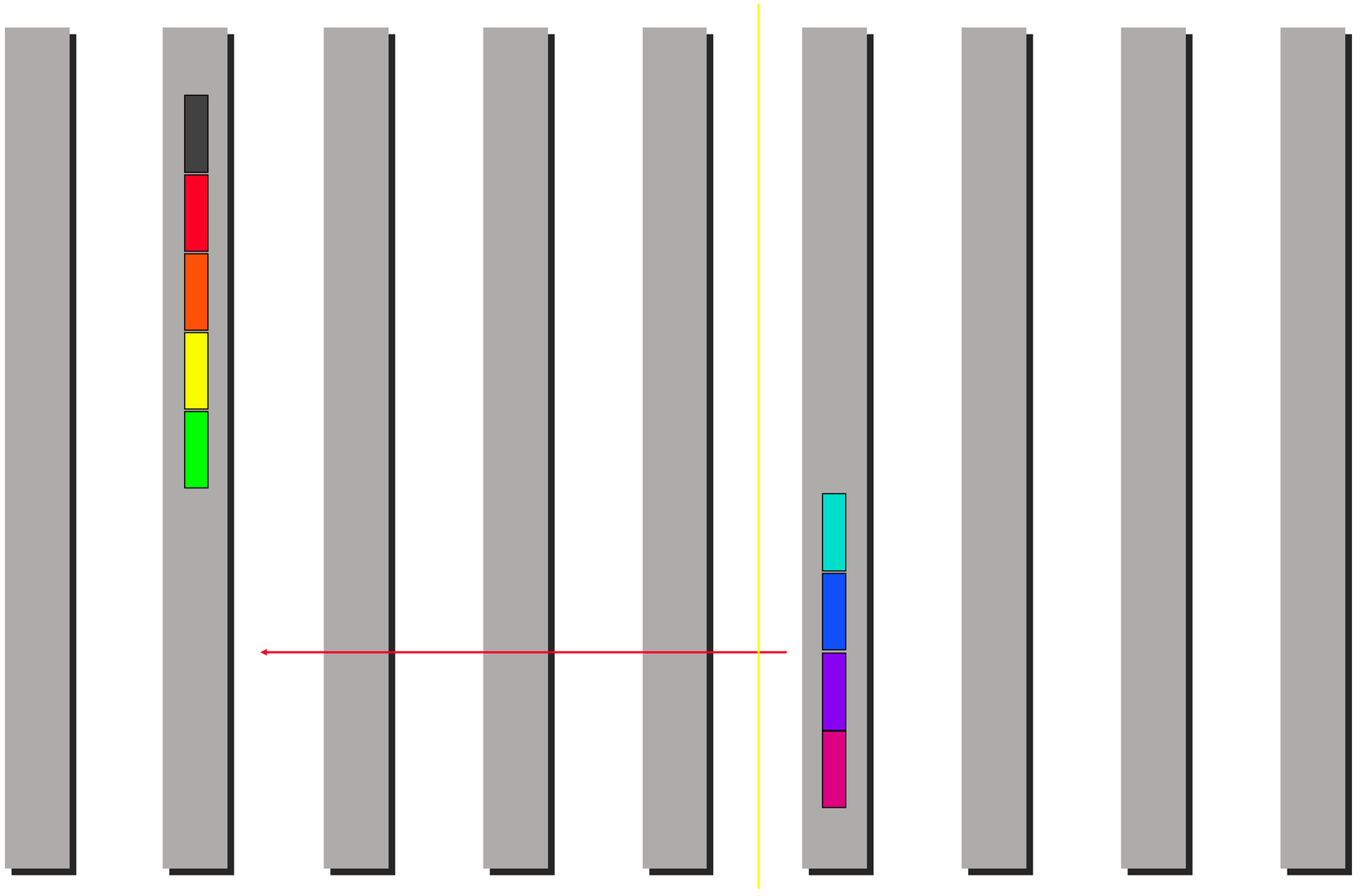


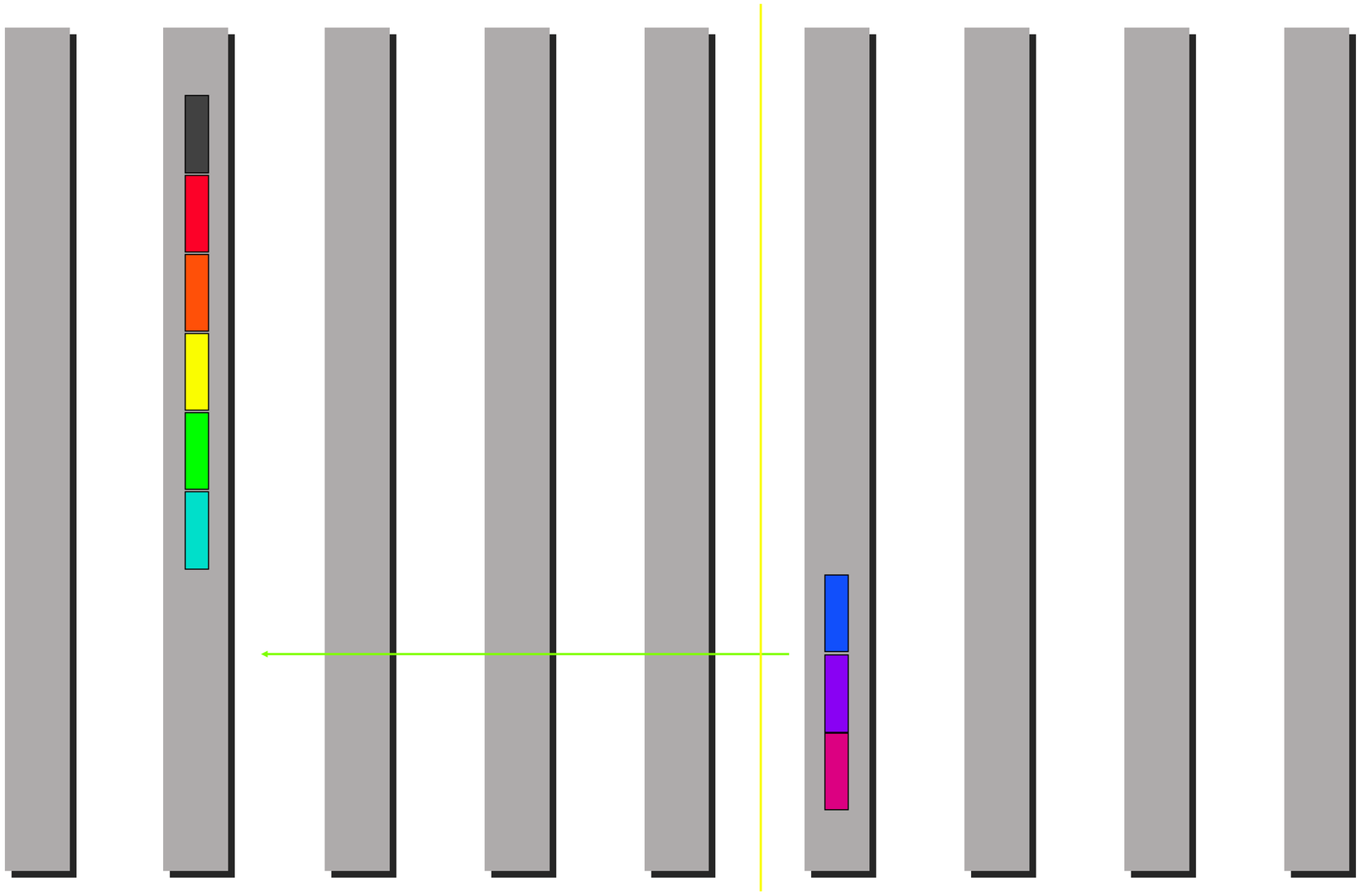


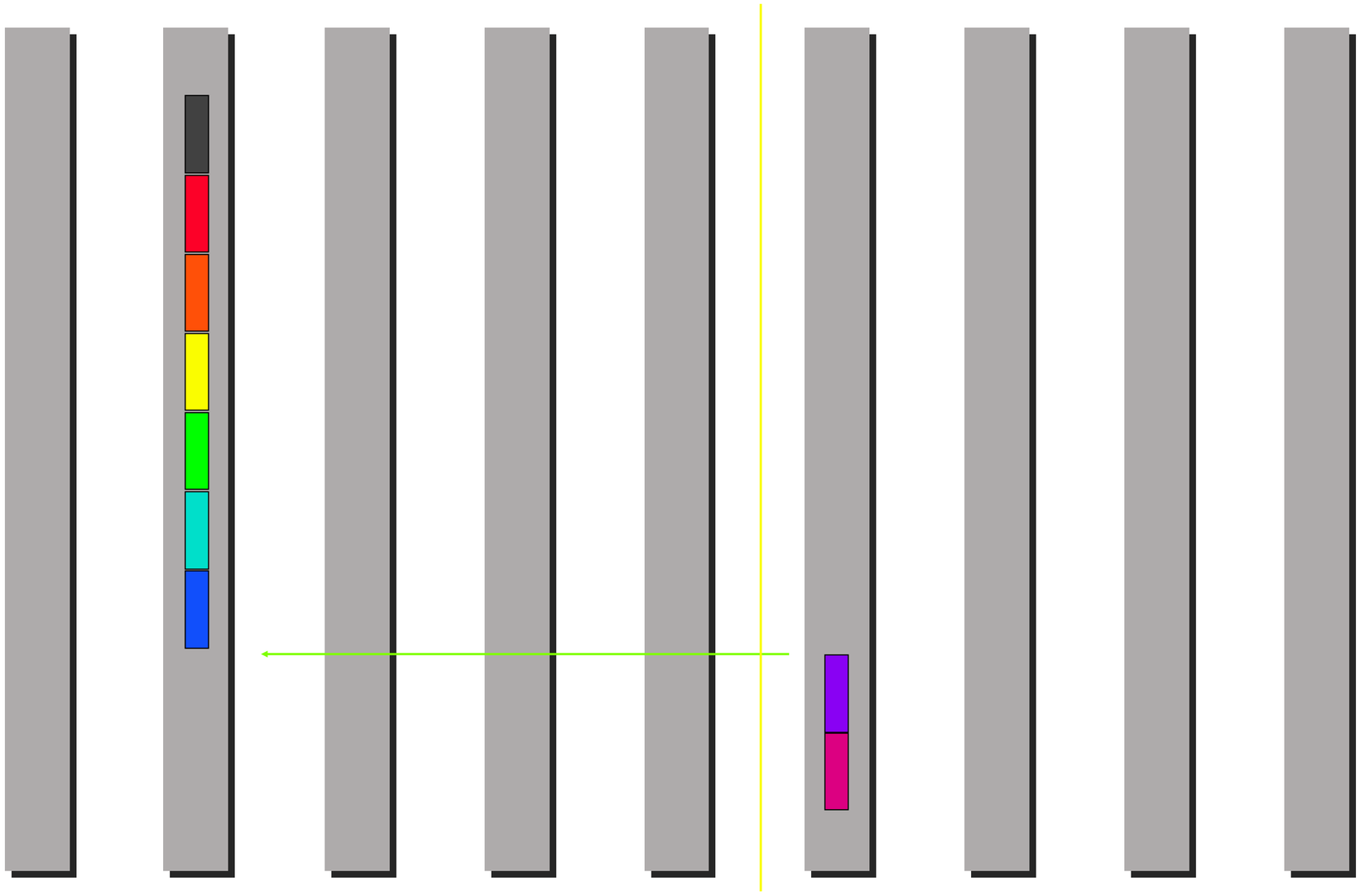


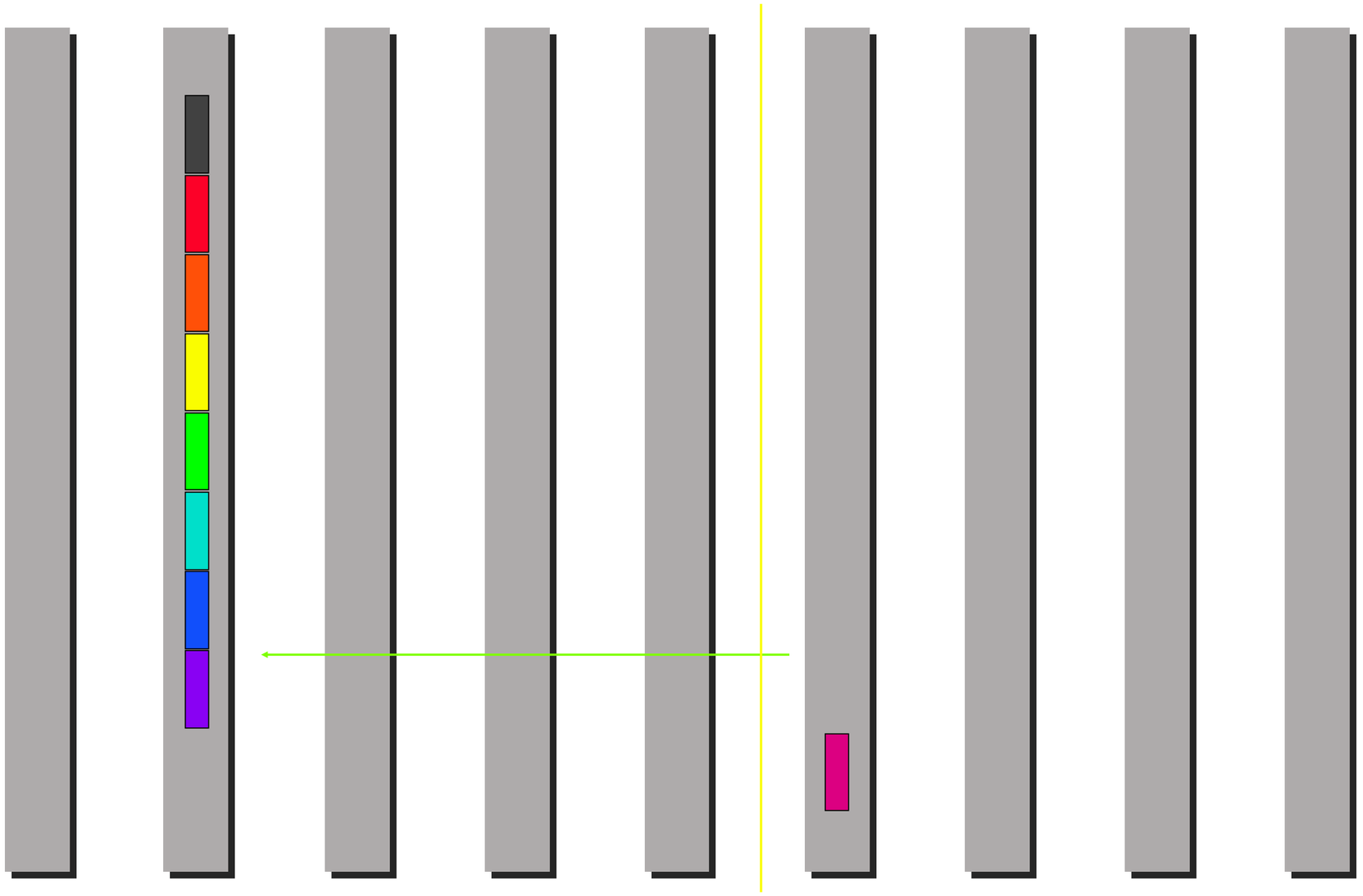


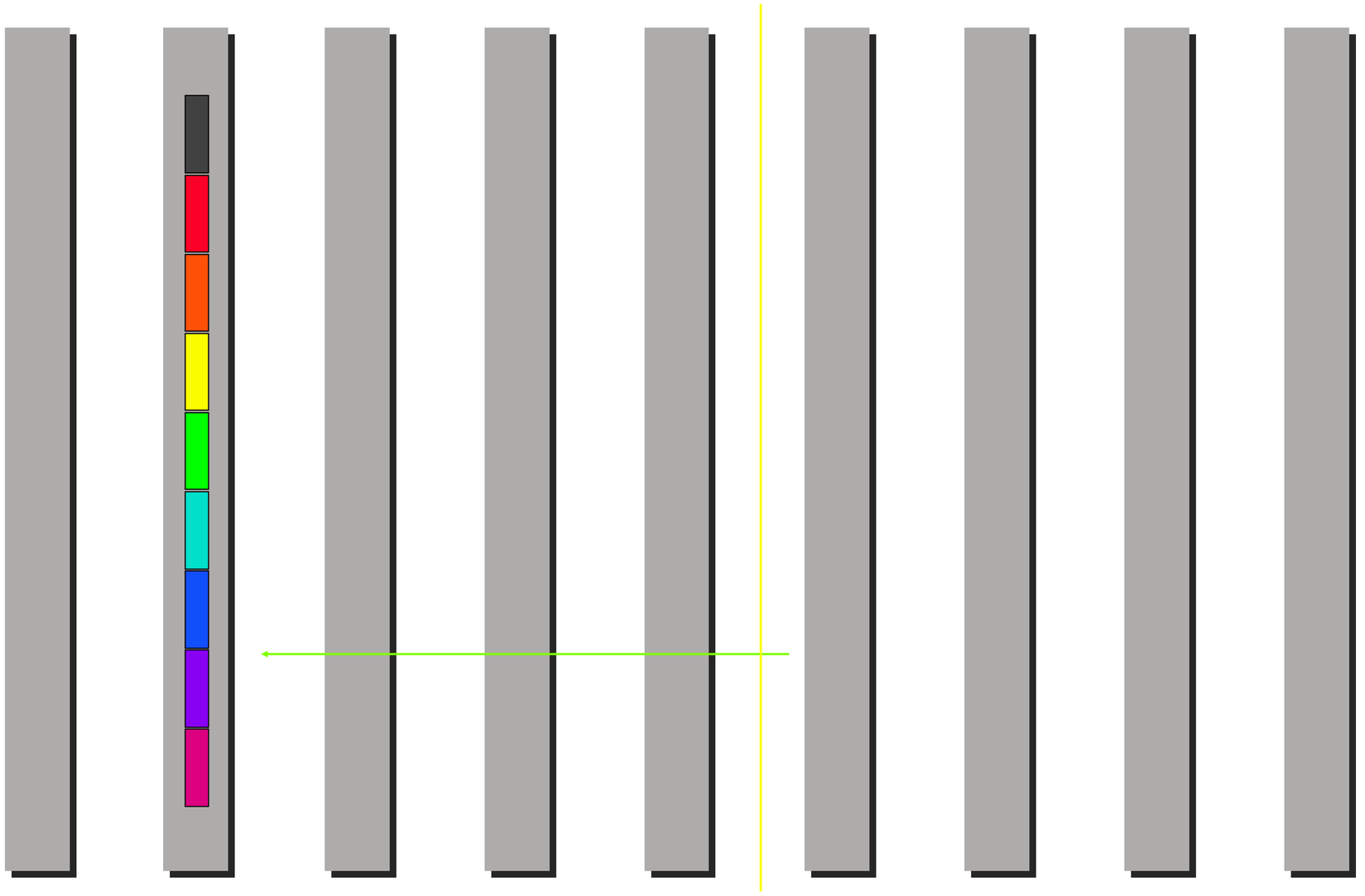


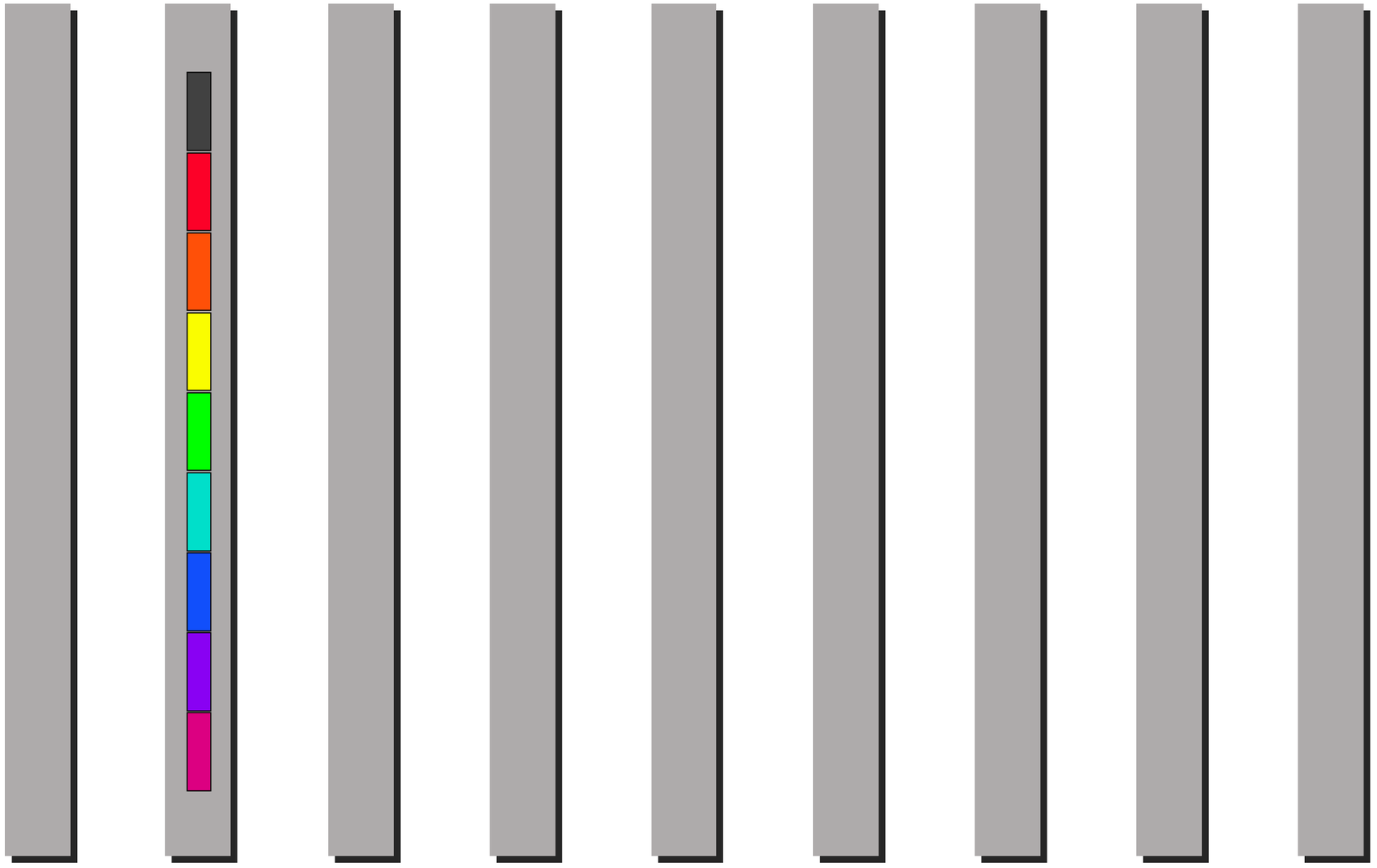












Cost of minimum spanning tree gather

- Assumption: power of two number of nodes

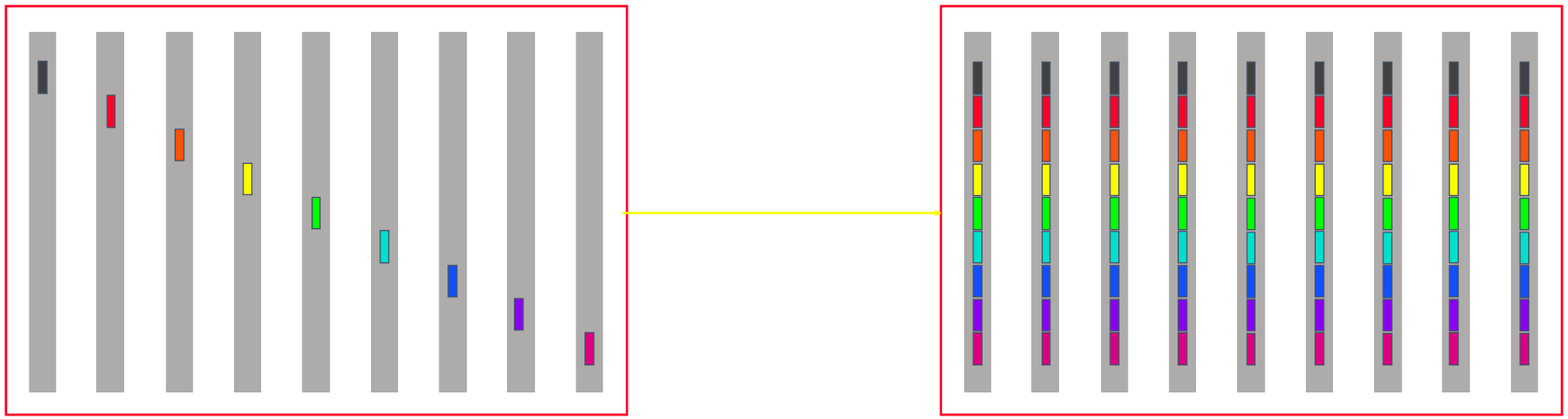
$$\sum_{k=1}^{log(p)} \left(\alpha + \frac{n}{2^k} \beta \right)$$

$$=$$

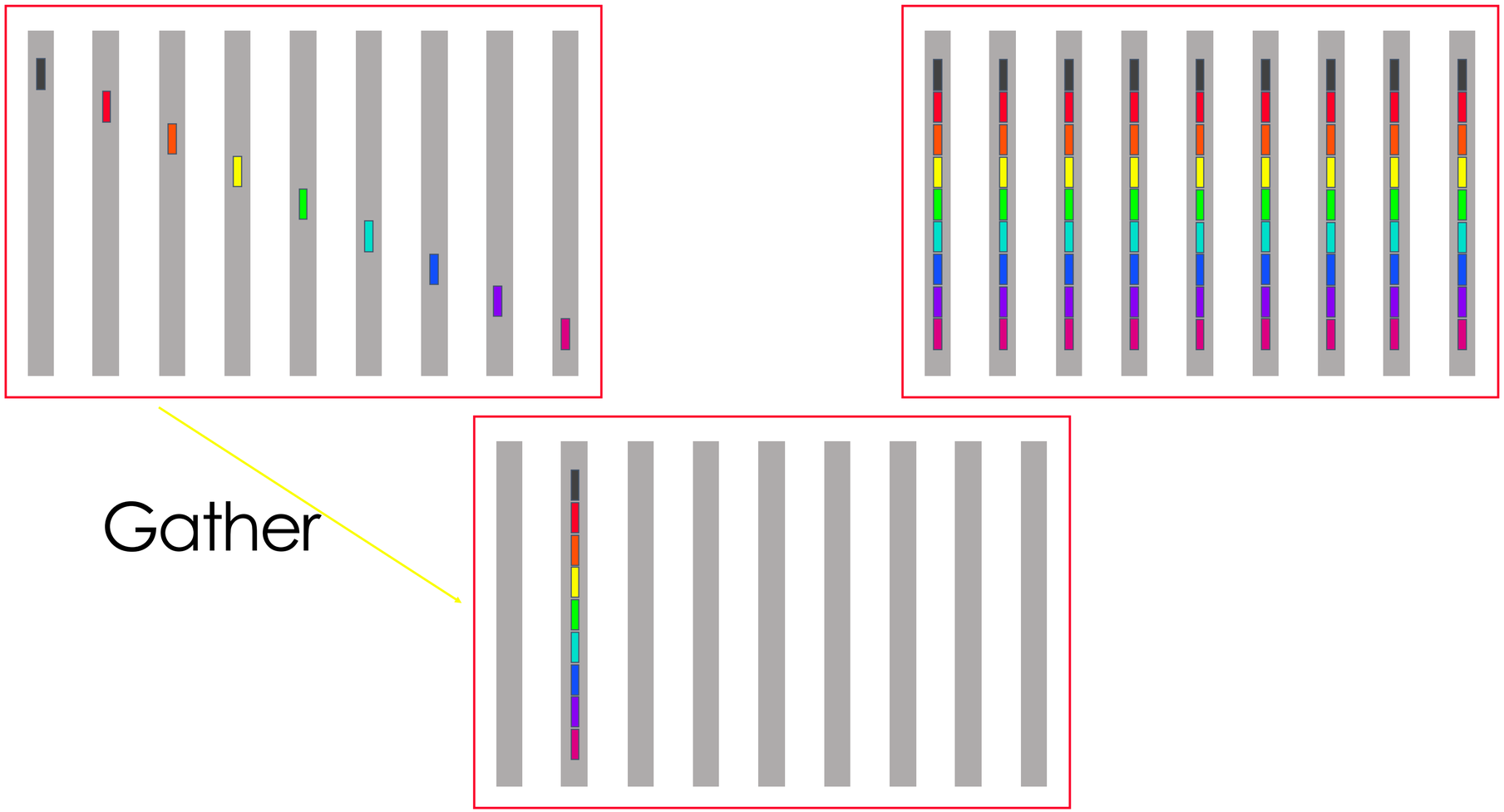
$$log(p)\ \alpha + \frac{p-1}{p} n\beta$$

Using the building blocks

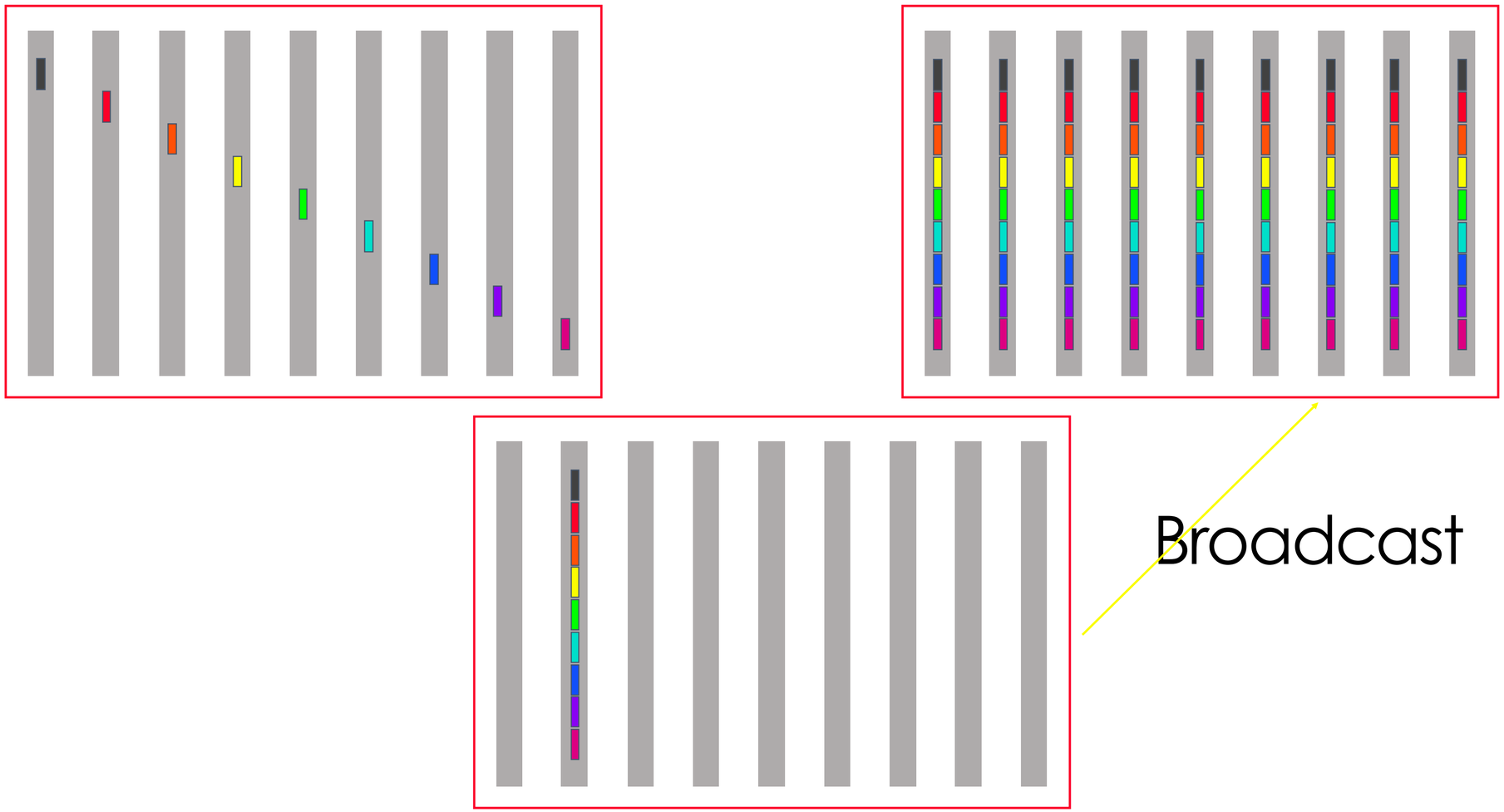
Allgather



Allgather



Allgather (short vector)



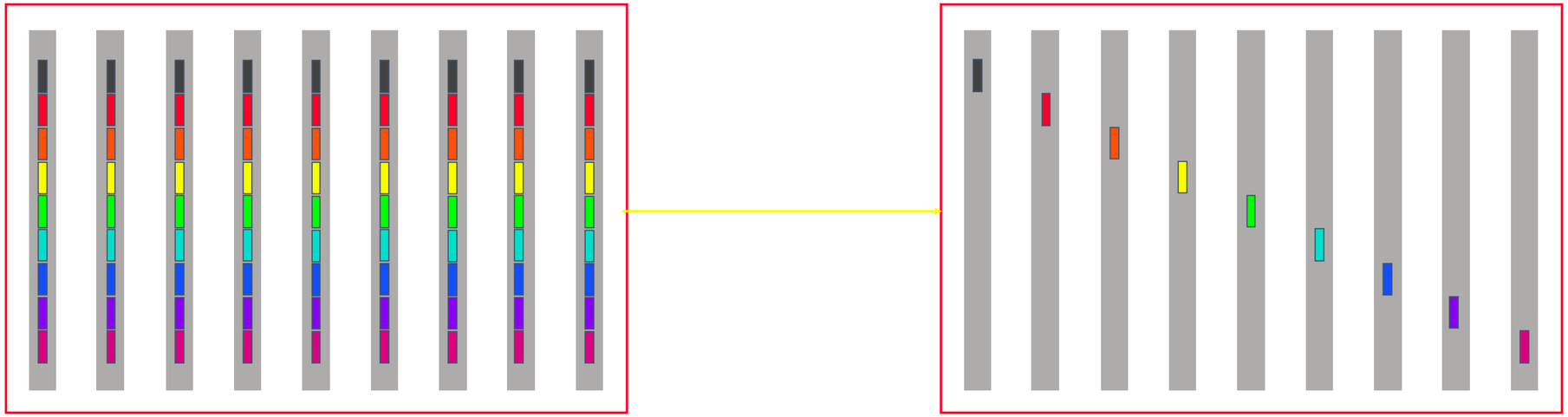
Cost of gather/broadcast allgather

- Assumption: power of two number of nodes

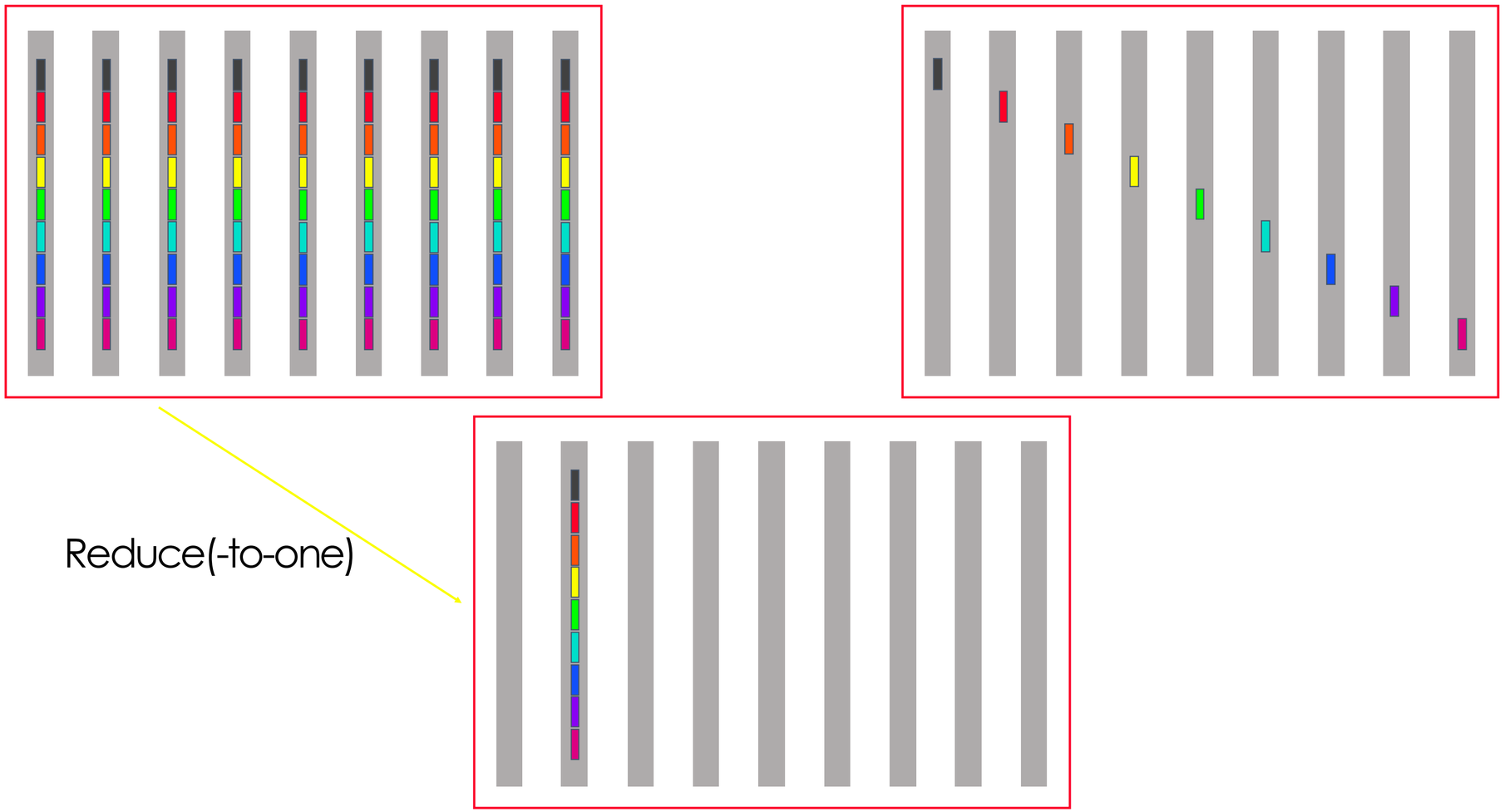
gather $\log(p)\alpha + \frac{p-1}{p} n\beta$

broadcast $\frac{\log(p)(\alpha + n\beta)}{2\log(p)\alpha + \left(\frac{p-1}{p} + \log(p)\right) n\beta}$

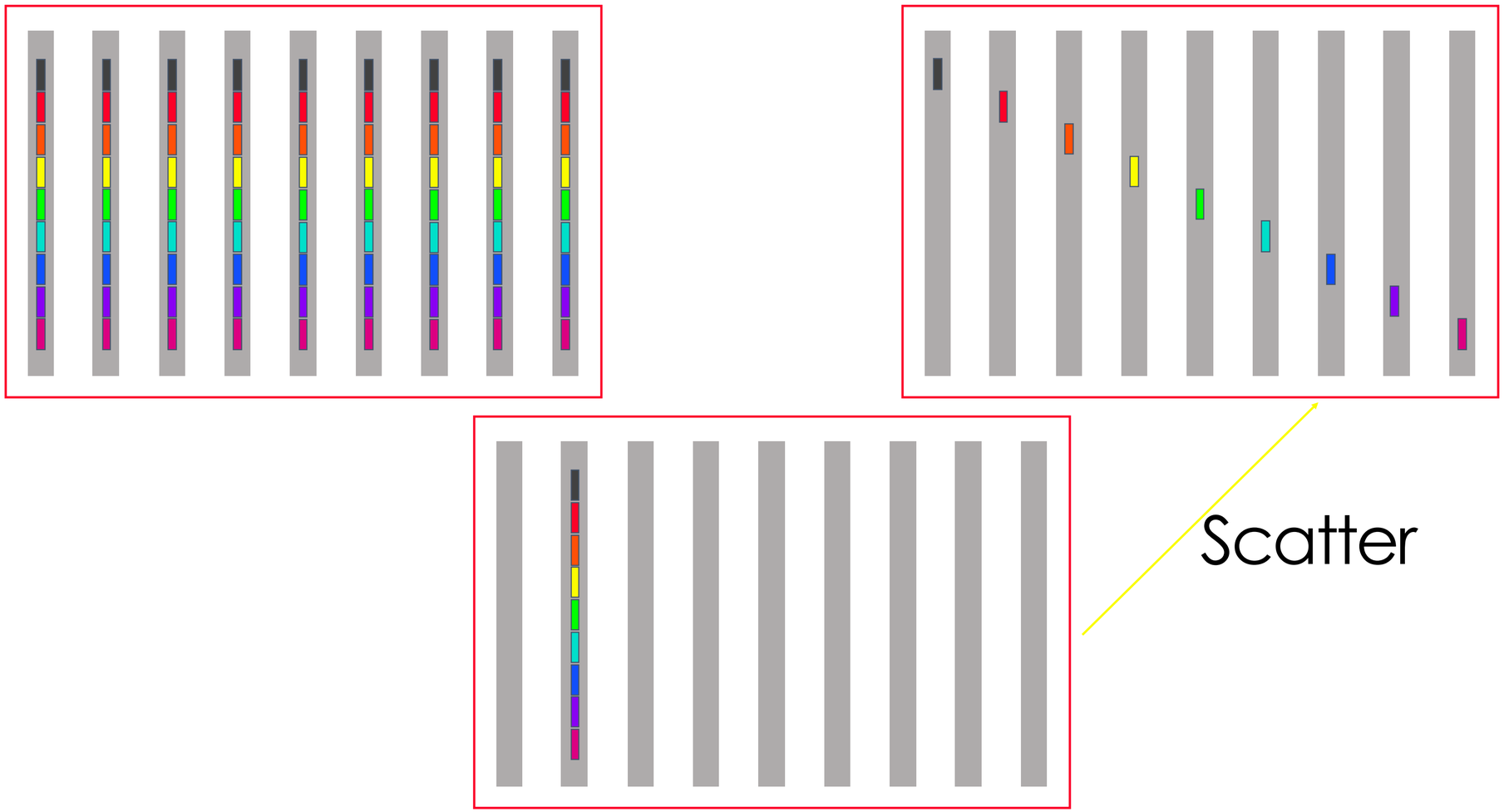
Reduce-scatter (small message)



Reduce-scatter (short vector)



Reduce-scatter (short vector)



Cost of Reduce(-to-one)/scatter Reduce-scatter

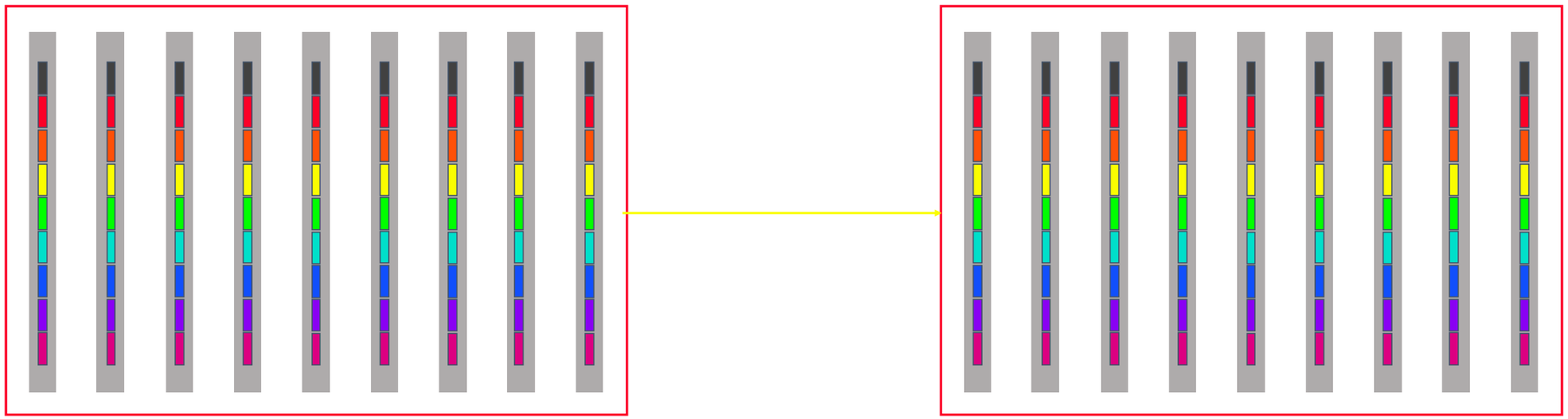
- Assumption: power of two number of nodes

Reduce(-to-one) $log(p)(\alpha + n\beta + n\gamma)$

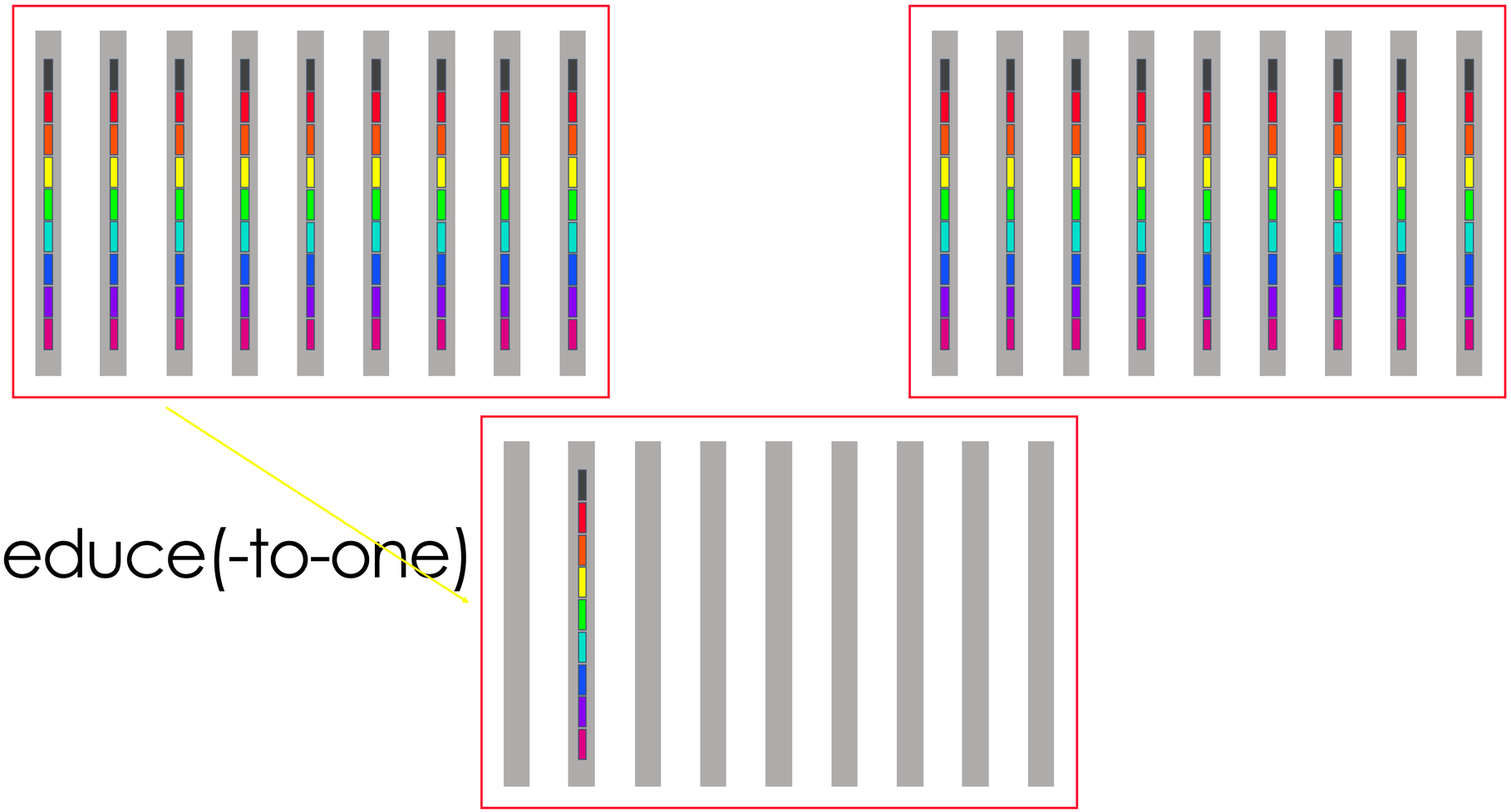
scatter $log(p)\alpha + \frac{p-1}{p}n\beta$

$$2log(p)\alpha + \left(\frac{p-1}{p} + log(p)\right)n\beta + log(p)n\gamma$$

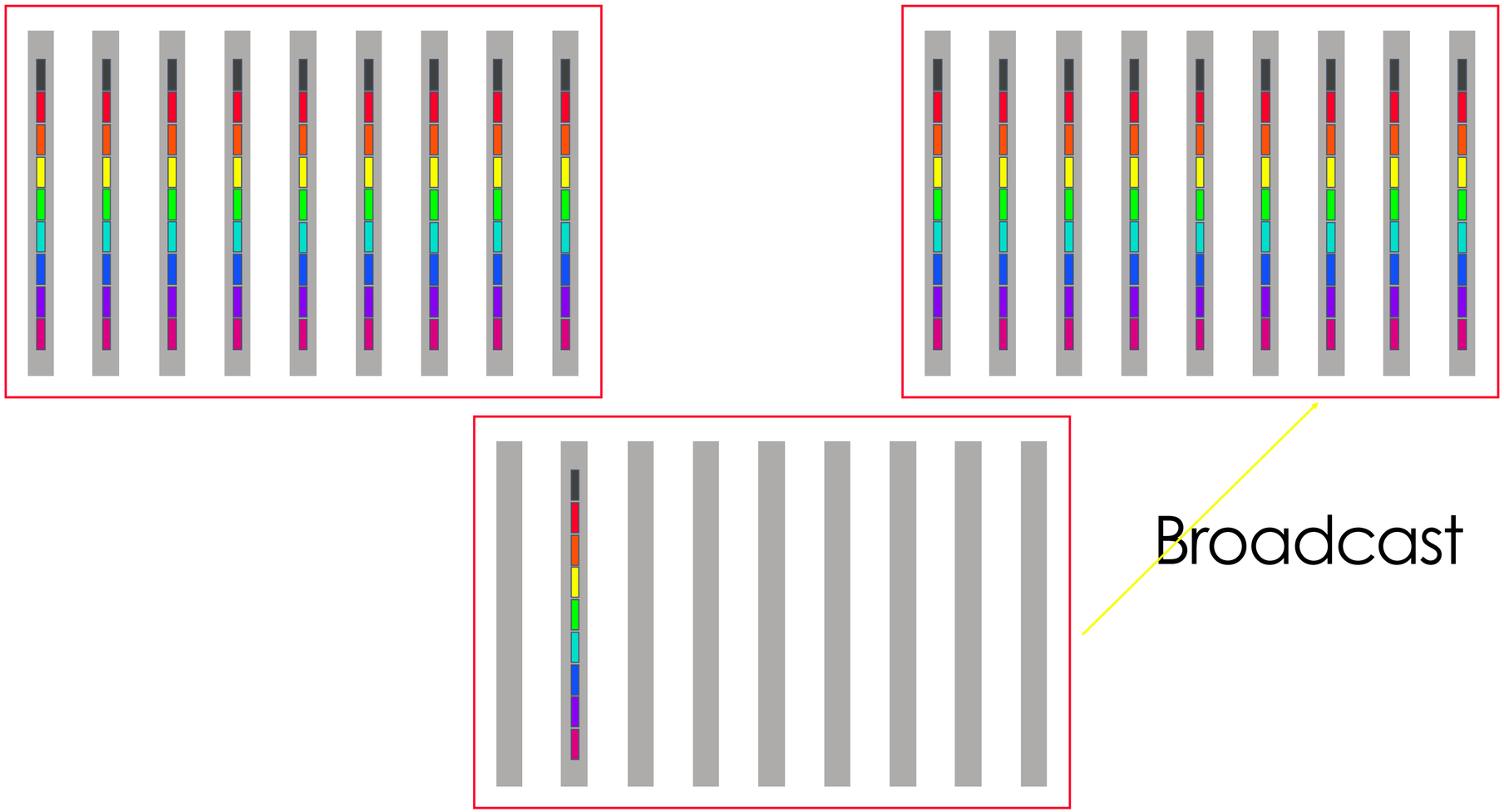
Allreduce (Latency-optimized)



Allreduce (Latency-optimized)



Allreduce
(short vector)



Cost of reduce(-to-one)/broadcast Allreduce

- Assumption: power of two number of nodes

Reduce(-to-one) $log(p)(\alpha + n\beta + n\gamma)$

broadcast $log(p)(\alpha + n\beta)$

$$\frac{}{2log(p)\alpha + 2log(p)n\beta + log(p)n\gamma}$$

Recap

Reduce(-to-one)

$$log(p)(\alpha + n\beta + n\gamma)$$

Scatter

$$log(p)\cancel{\alpha} + \cancel{\frac{p-1}{p} n\beta}$$

Gather

$$log(p)\cancel{\alpha} + \cancel{\frac{p-1}{p} n\beta}$$

Broadcast

$$log(p)(\alpha + n\beta)$$

Reduce-scatter

Allreduce

Allgather

Recap

Reduce(-to-one)

$$log(p)(\alpha + n\beta + n\gamma)$$

Scatter

$$log(p)\alpha + \frac{p-1}{p}n\beta$$

Gather

$$log(p)\alpha + \frac{p-1}{p}n\beta$$

Broadcast

$$log(p)(\alpha + n\beta)$$

Reduce-scatter

$$2log(p)\alpha + log(p)n(\beta + \gamma) + \frac{p-1}{p}n\beta$$

Allreduce

Allgather

Recap

Reduce(-to-one)

$$log(p)(\alpha + n\beta + n\gamma)$$

Scatter

$$log(p)\alpha + \frac{p-1}{p}n\beta$$

Gather

$$log(p)\alpha + \frac{p-1}{p}n\beta$$

Broadcast

$$log(p)(\alpha + n\beta)$$

Reduce-scatter

$$2log(p)\alpha + log(p)n(\beta + \gamma) + \frac{p-1}{p}n\beta$$

Allreduce

$$2log(p)\alpha + log(p)n(2\beta + \gamma)$$

Allgather

$$2log(p)\alpha + log(p)n\beta + \frac{p-1}{p}n\beta$$

Recap

Reduce(-to-one)

$$log(p)(\alpha + n\beta + n\gamma)$$

Scatter

$$log(p)\cancel{\alpha} + \cancel{\frac{p-1}{p} n\beta}$$

Gather

$$log(p)\cancel{\alpha} + \cancel{\frac{p-1}{p} n\beta}$$

Broadcast

$$log(p)(\alpha + n\beta)$$

Reduce-scatter

$$2log(p)\alpha + log(p)n(\beta + \gamma) + \cancel{\frac{p-1}{p} n\beta}$$

Allreduce

$$2log(p)\alpha + log(p)n(2\beta + \gamma)$$

Allgather

Recap

Reduce(-to-one)

$$log(p)(\alpha + n\beta + n\gamma)$$

Scatter

$$log(p)\cancel{\alpha} + \cancel{\frac{p-1}{p} n\beta}$$

Gather

$$log(p)\cancel{\alpha} + \cancel{\frac{p-1}{p} n\beta}$$

Broadcast

$$log(p)(\alpha + n\beta)$$

Reduce-scatter

$$2log(p)\alpha + log(p)n(\beta + \gamma) + \cancel{\frac{p-1}{p} n\beta}$$

Allreduce

$$2log(p)\alpha + log(p)n(2\beta + \gamma)$$

Allgather

$$2log(p)\alpha + log(p)n\cancel{\beta} + \cancel{\frac{p-1}{p} n\beta}$$

Summary of MST algorithms

- Small message: Minimum Spanning Tree algorithm
  - Emphasize **low latency**

- **Can we do better**

- Problem of Minimum Spanning Tree Algorithm?
  - It prioritize latency rather than bandwidth
  - Hence: Some links are idle

- Next class: Large message size algorithm