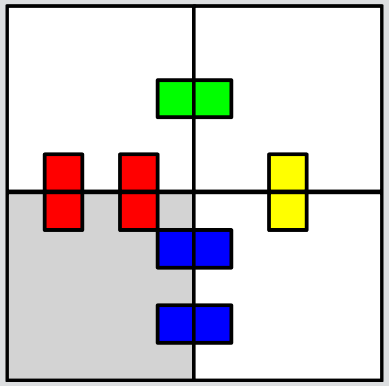
A Tour of DNA Tile Self-Assembly



Andrew Winslow
Department of Computer Science, UTRGV

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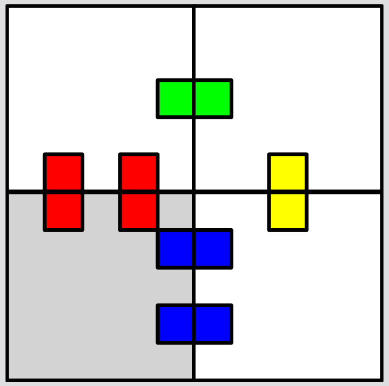

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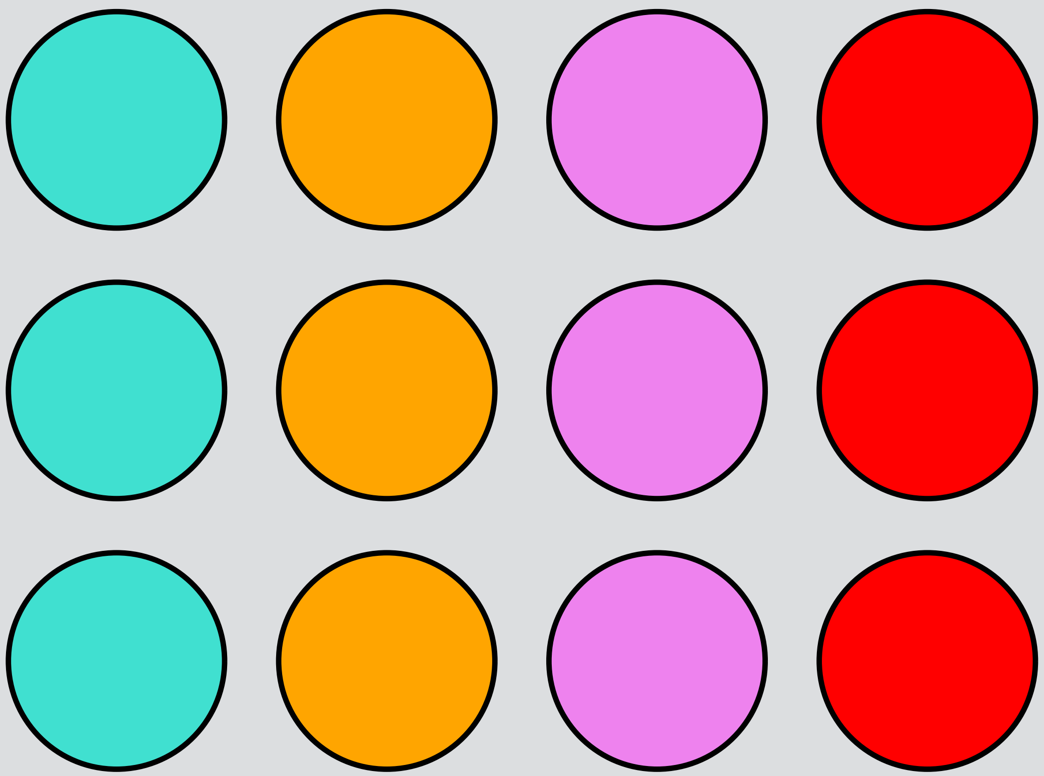
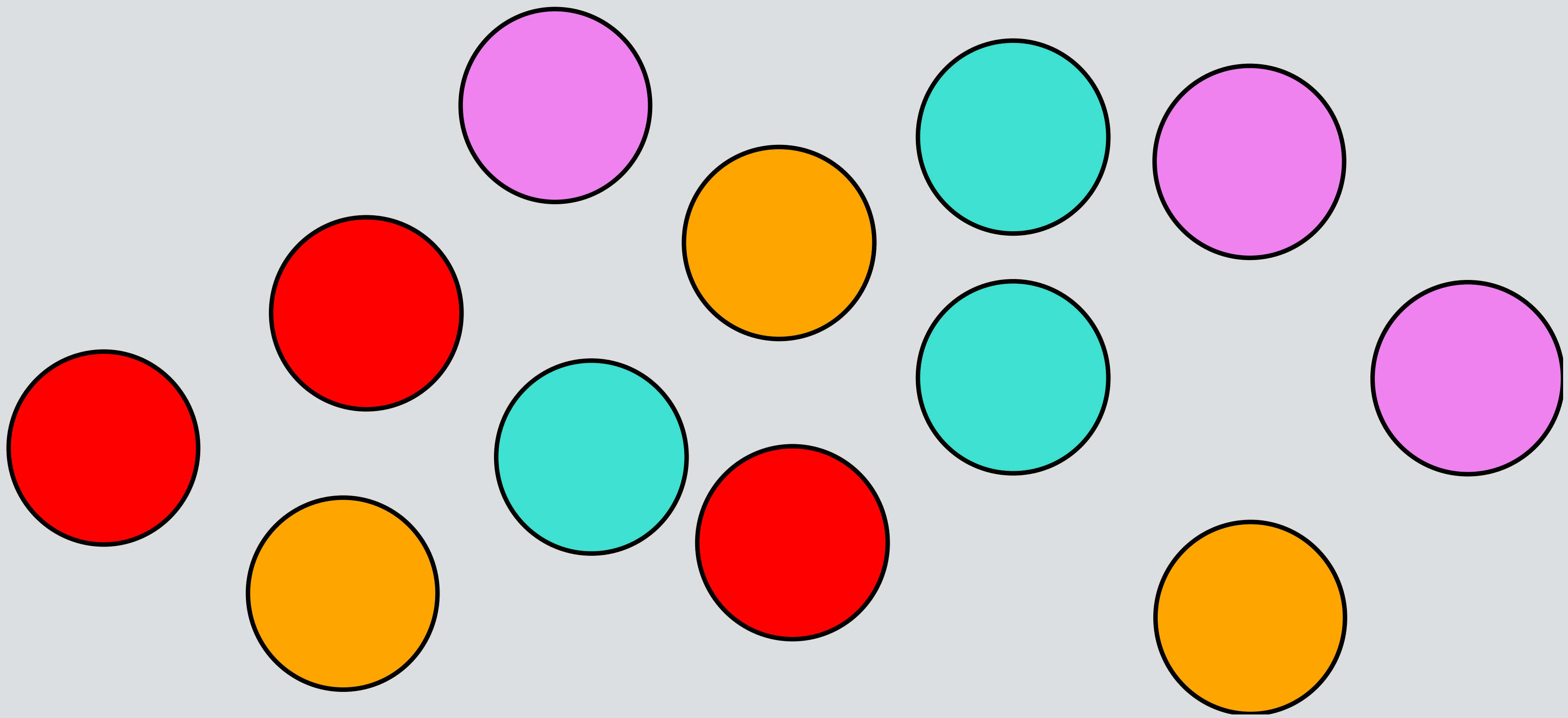
Self-Assembly

Simple particles coalescing into complex superstructures.



Self-Assembly

Simple particles coalescing into complex superstructures.



Self-Assembly

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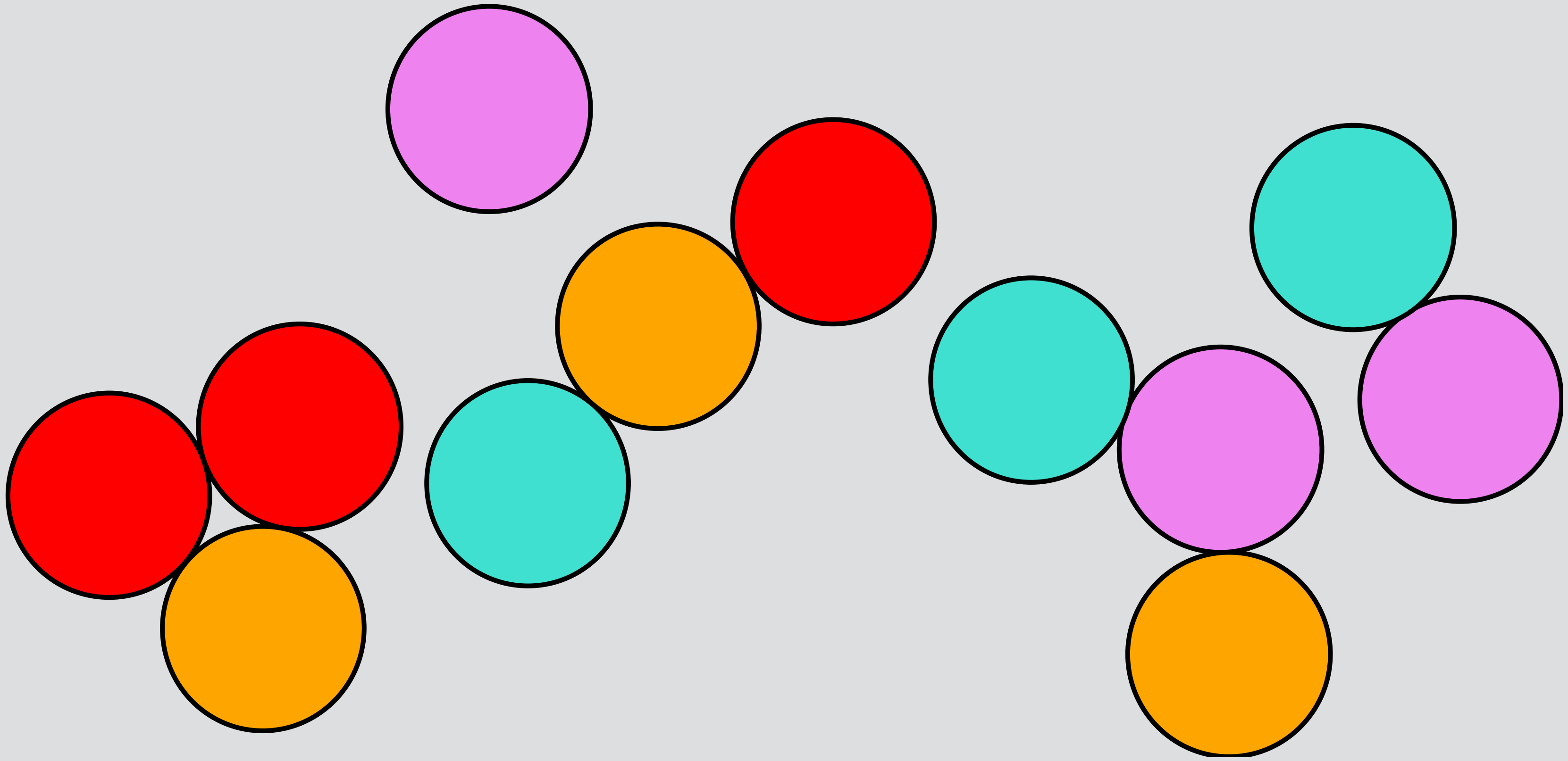

Self-Assembly

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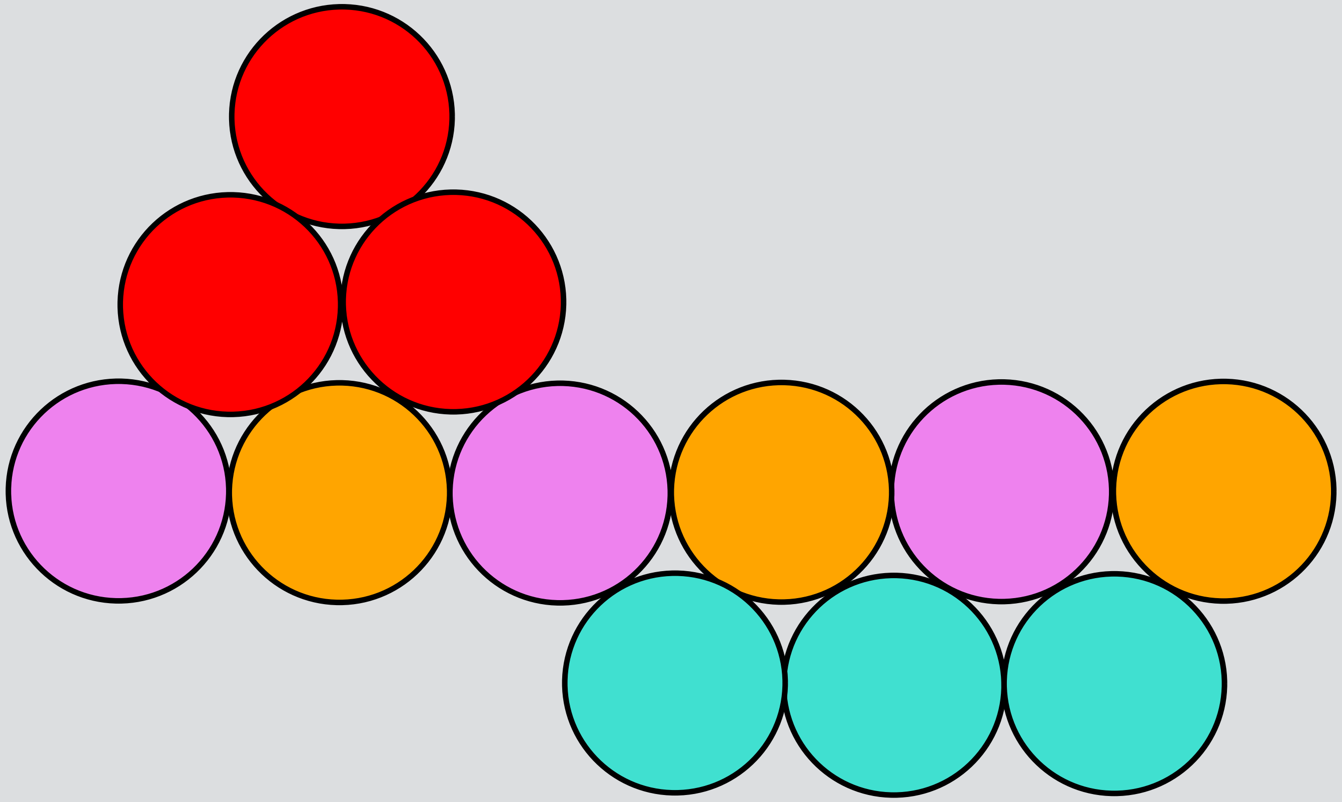
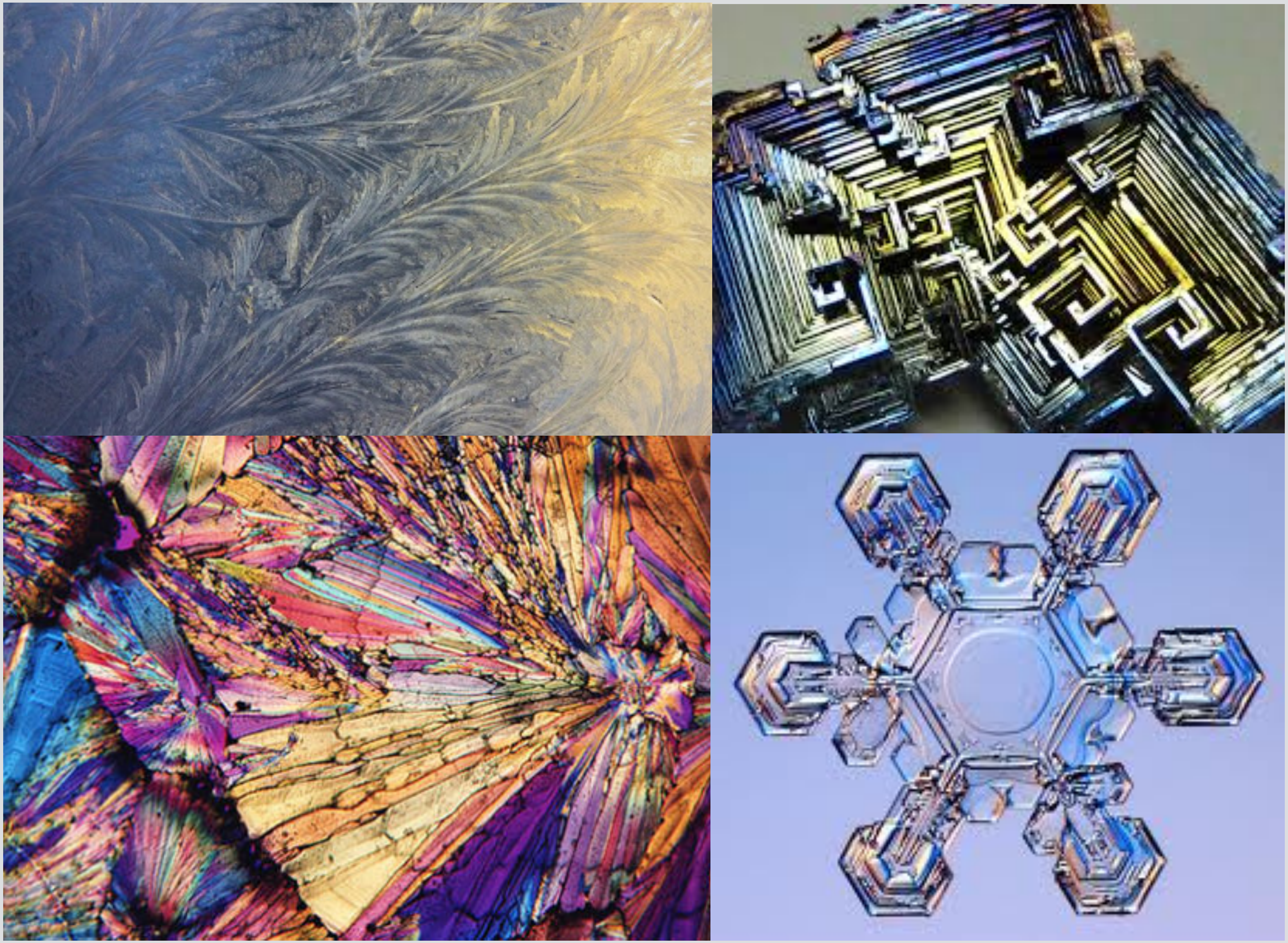
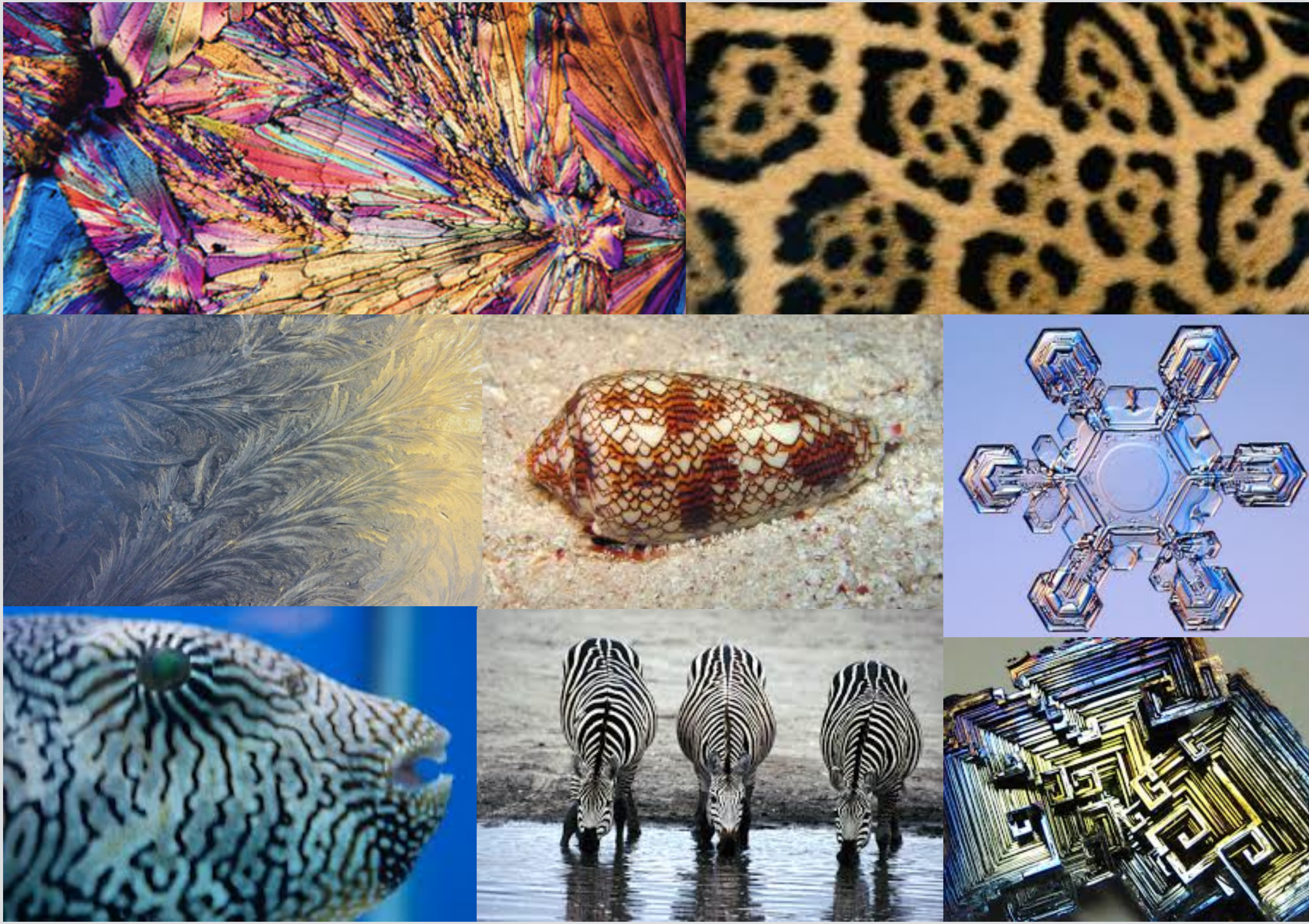


Crystallization

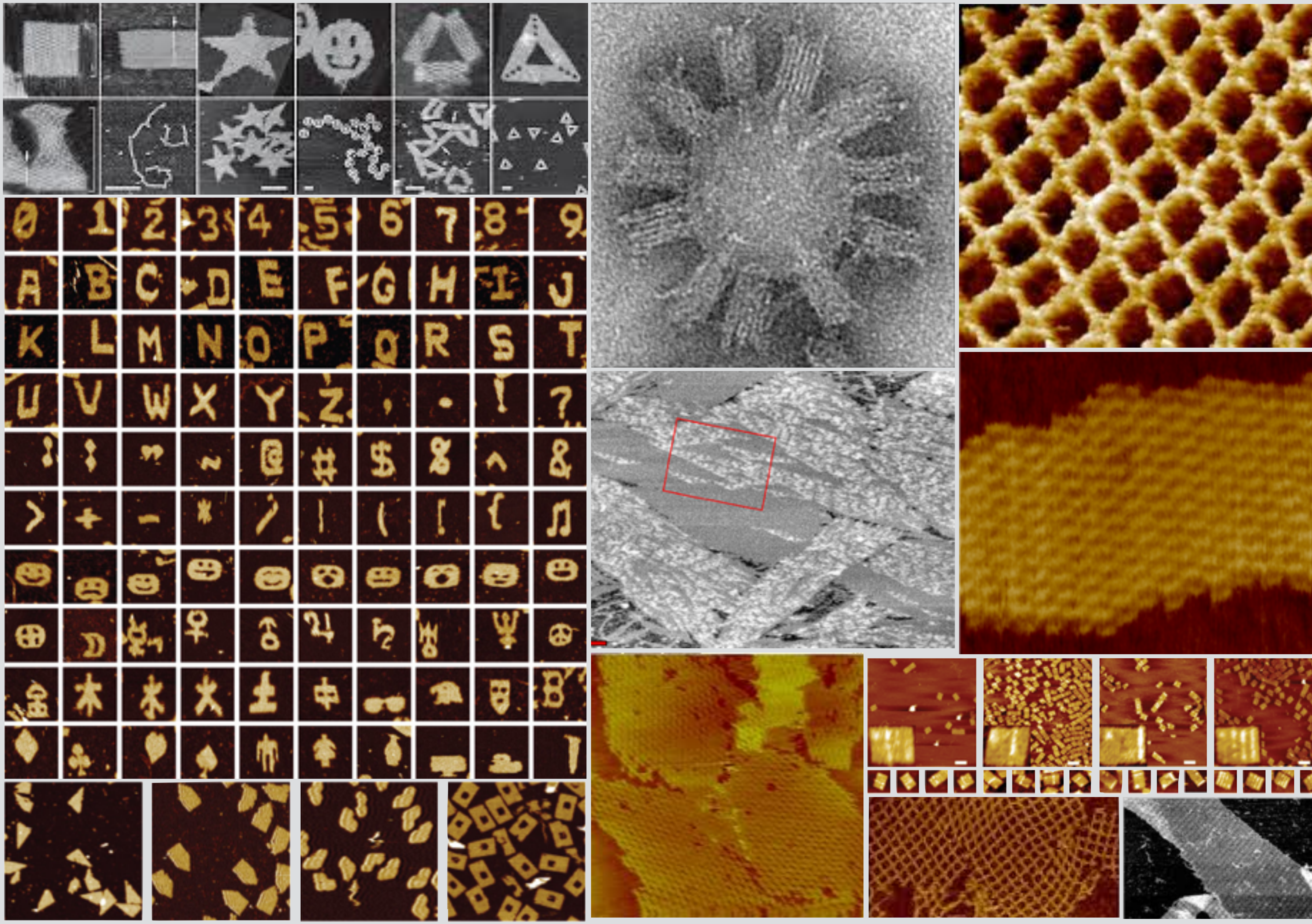


Morphogenesis

Natural self-assembly

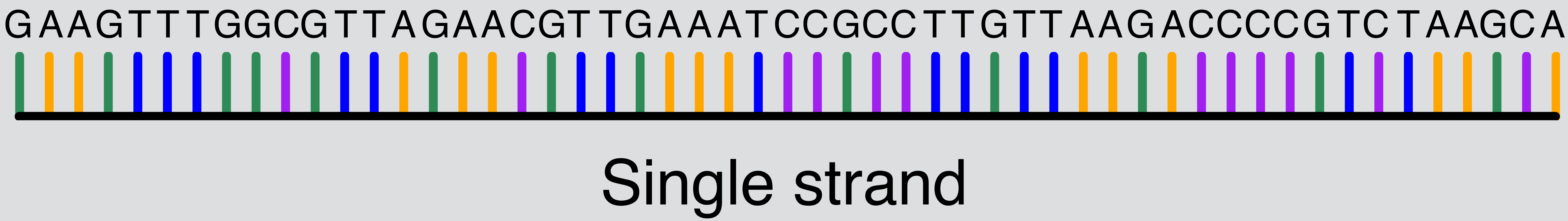


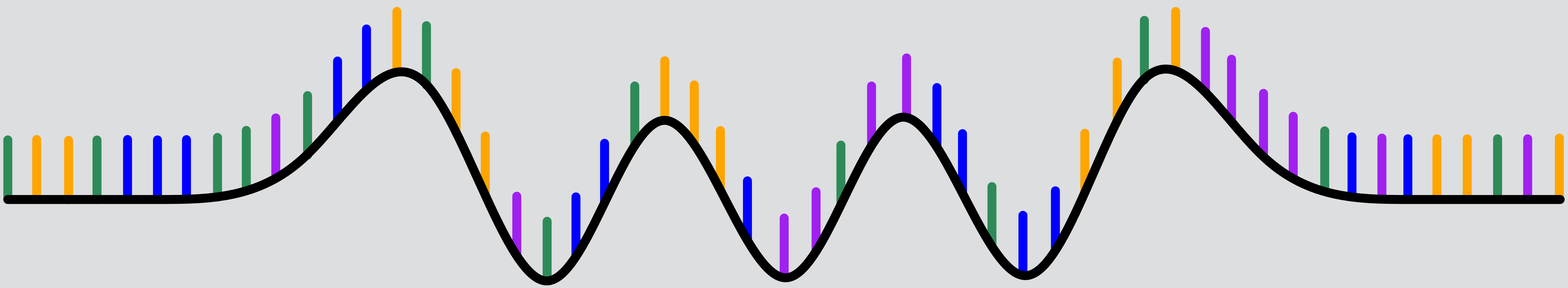
Synthetic DNA self-assembly

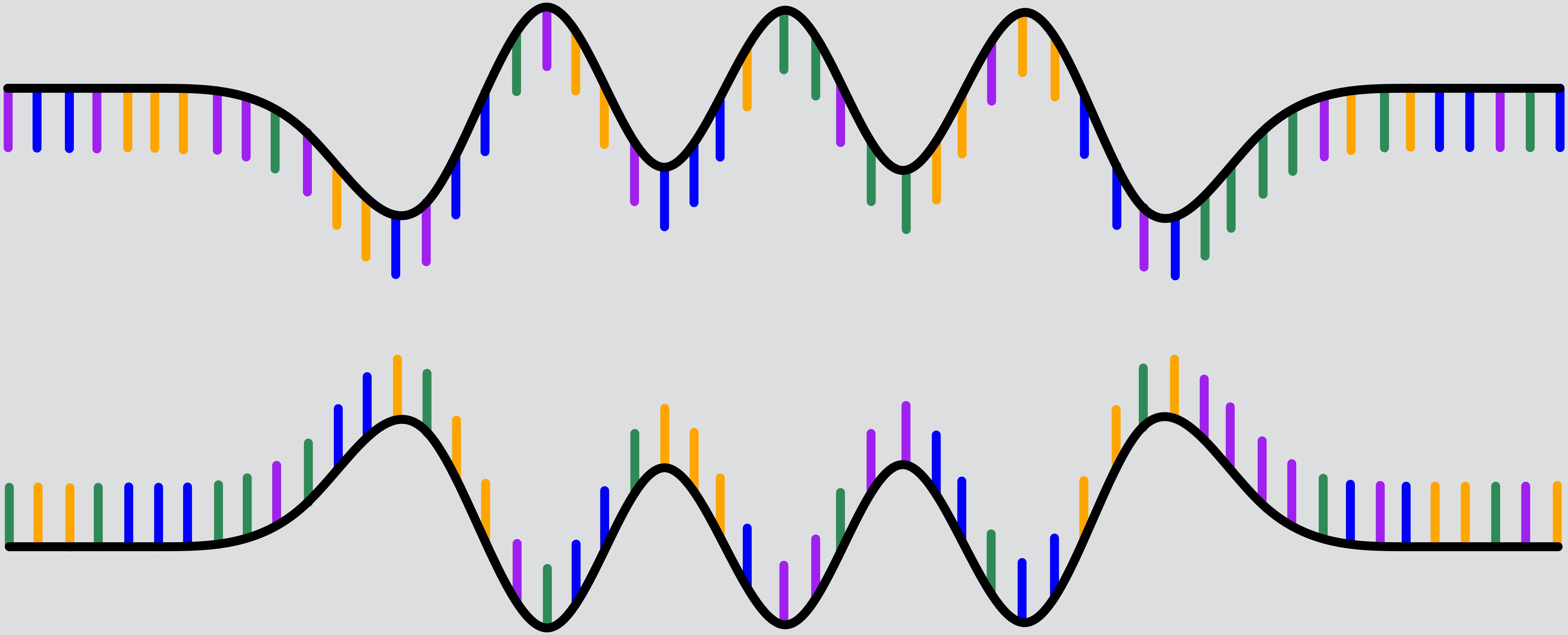


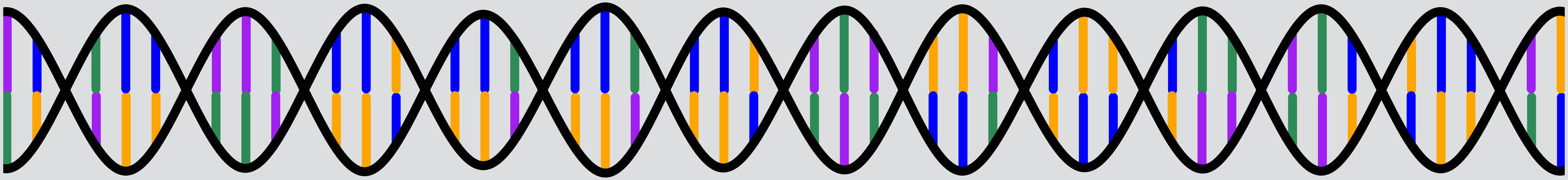
DNA

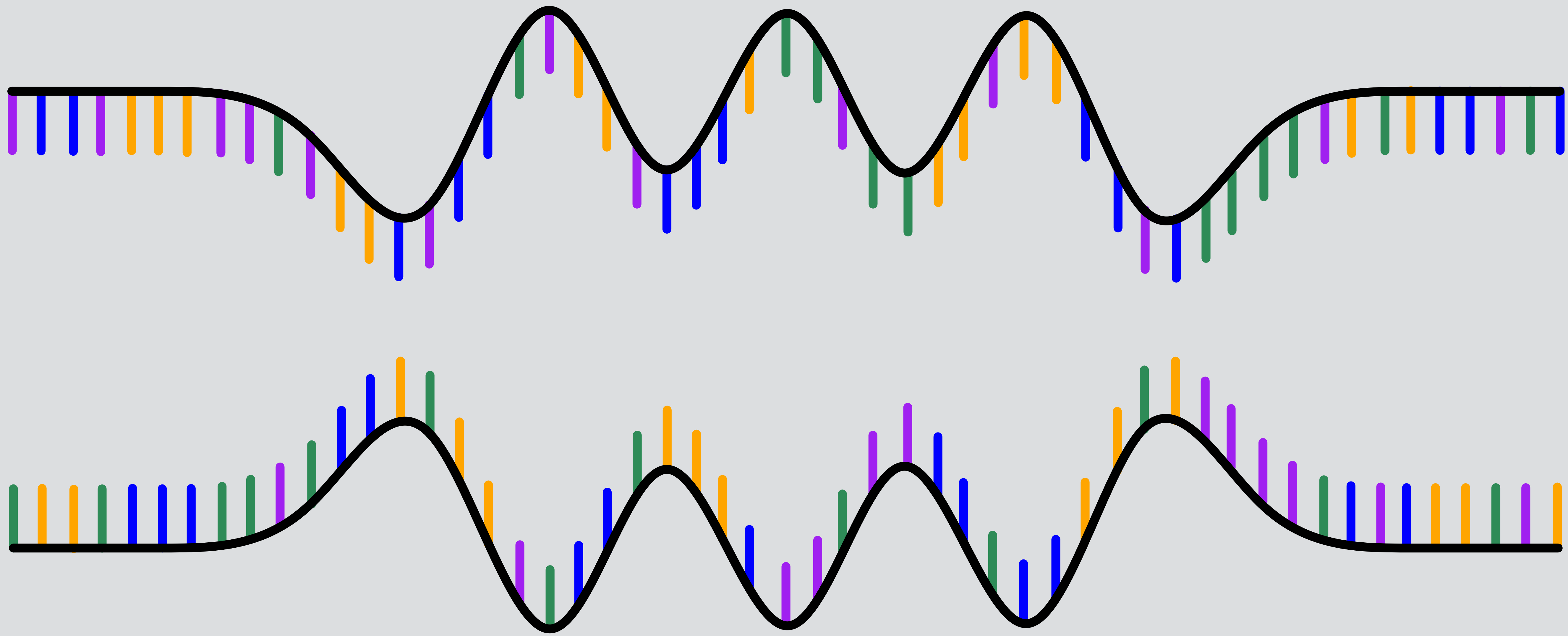

C
G
Base pairs
T
A

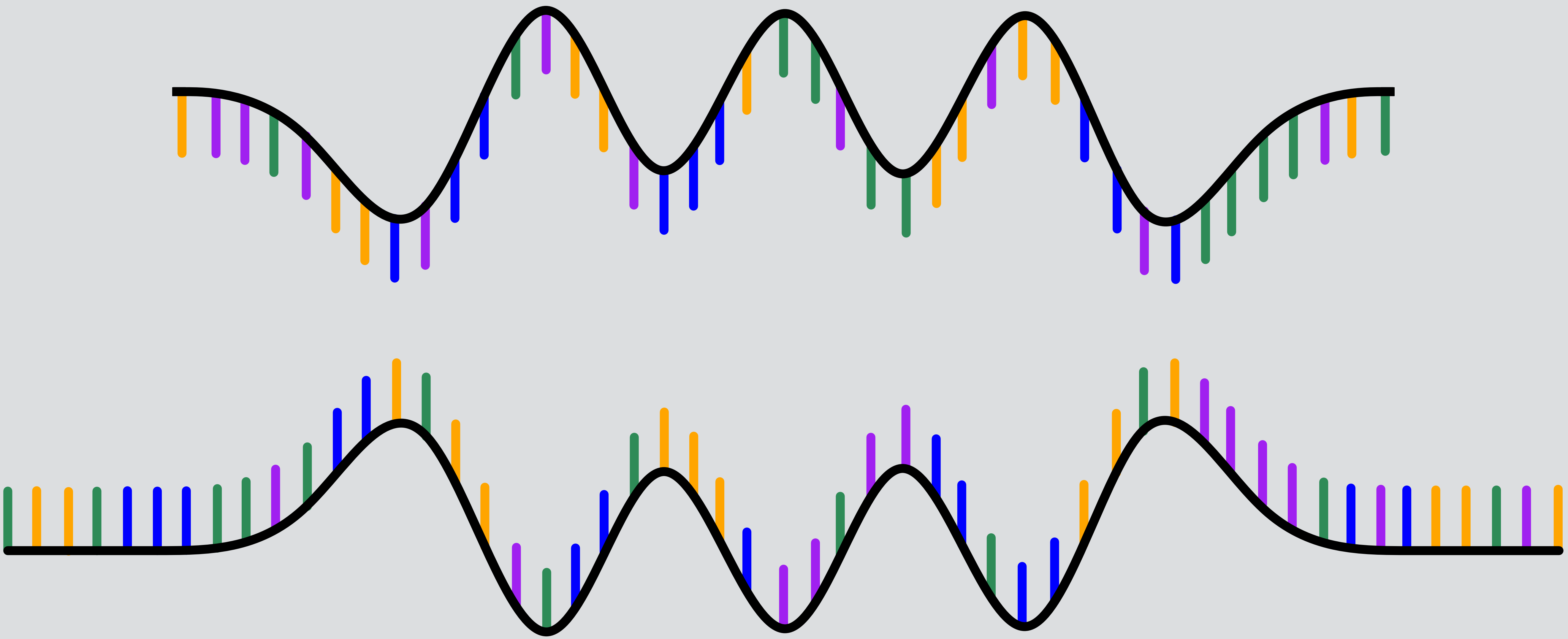

G A A G T T T G G C G T T A G A A C G T T G A A A T C C G C C T T G T T A A G A C C C C G T C T A A G C A
Single strand

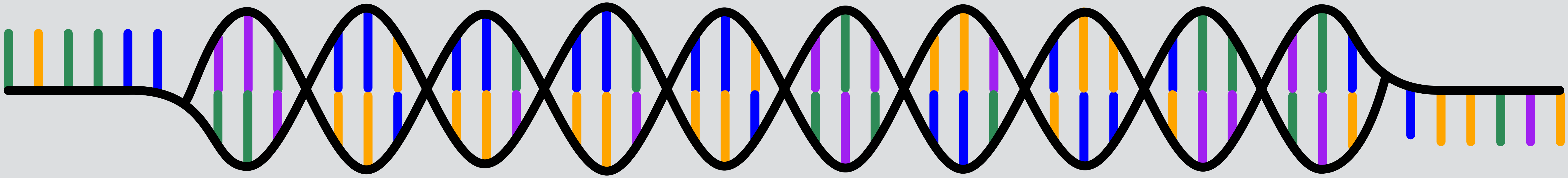


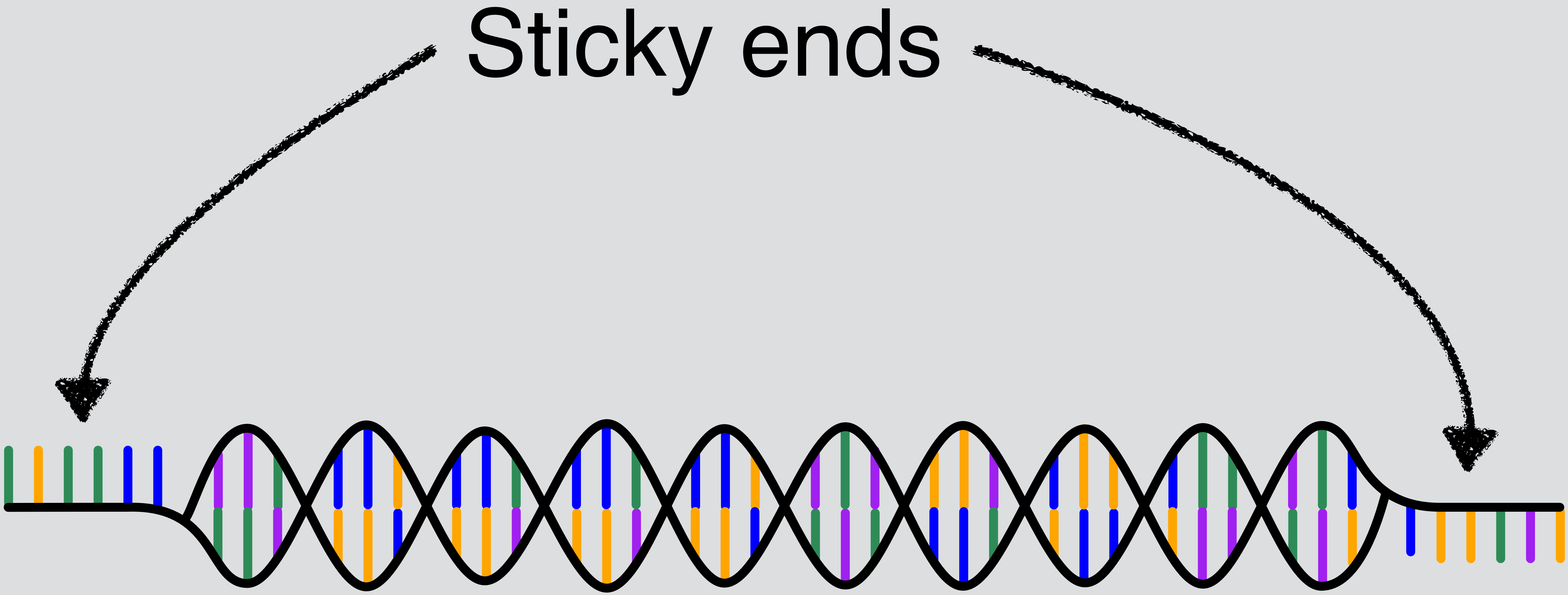




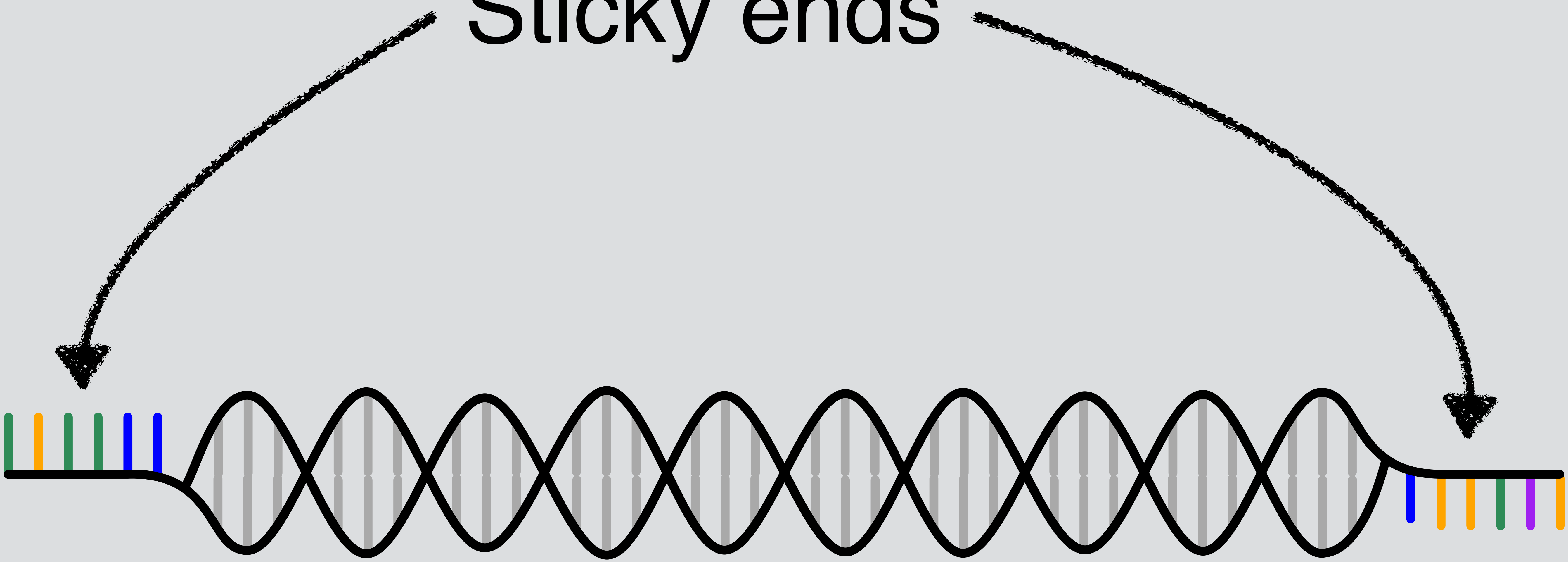


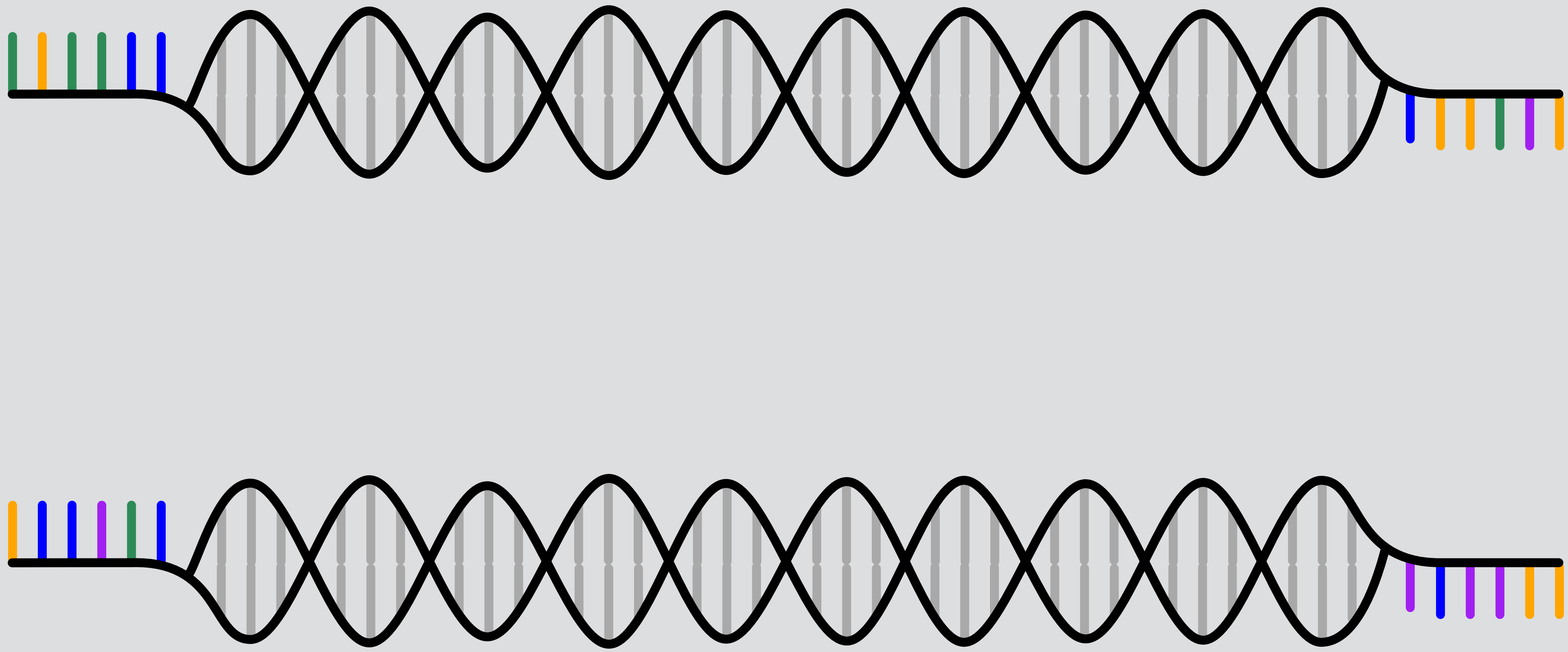


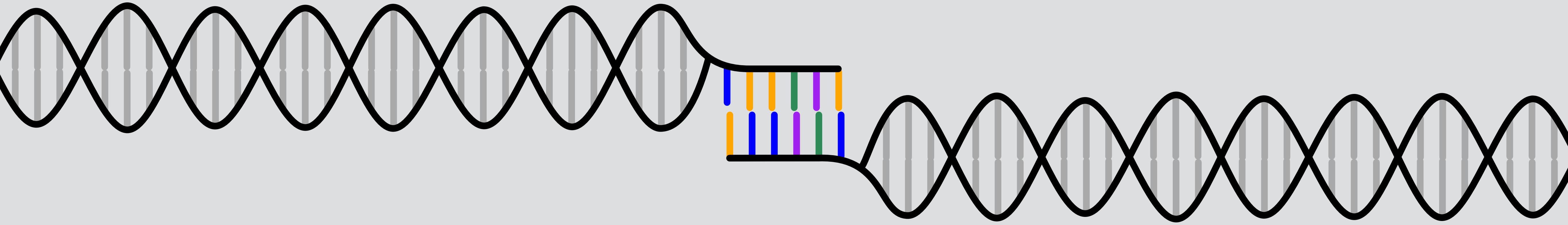


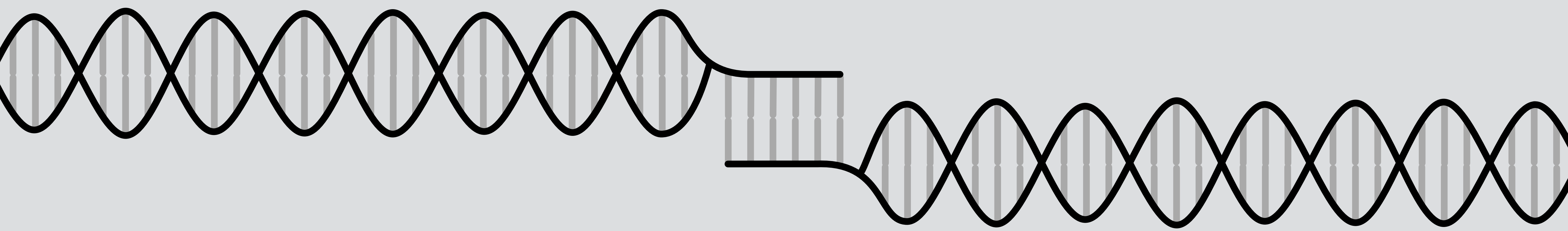

Sticky ends

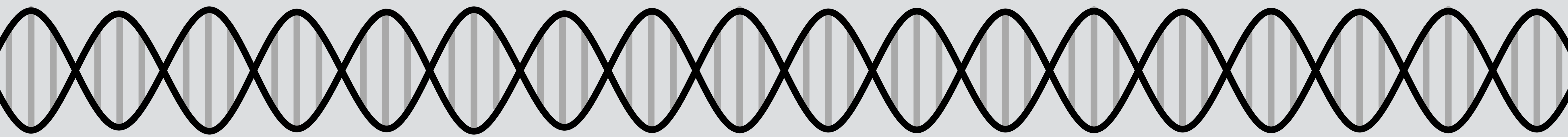
Sticky ends

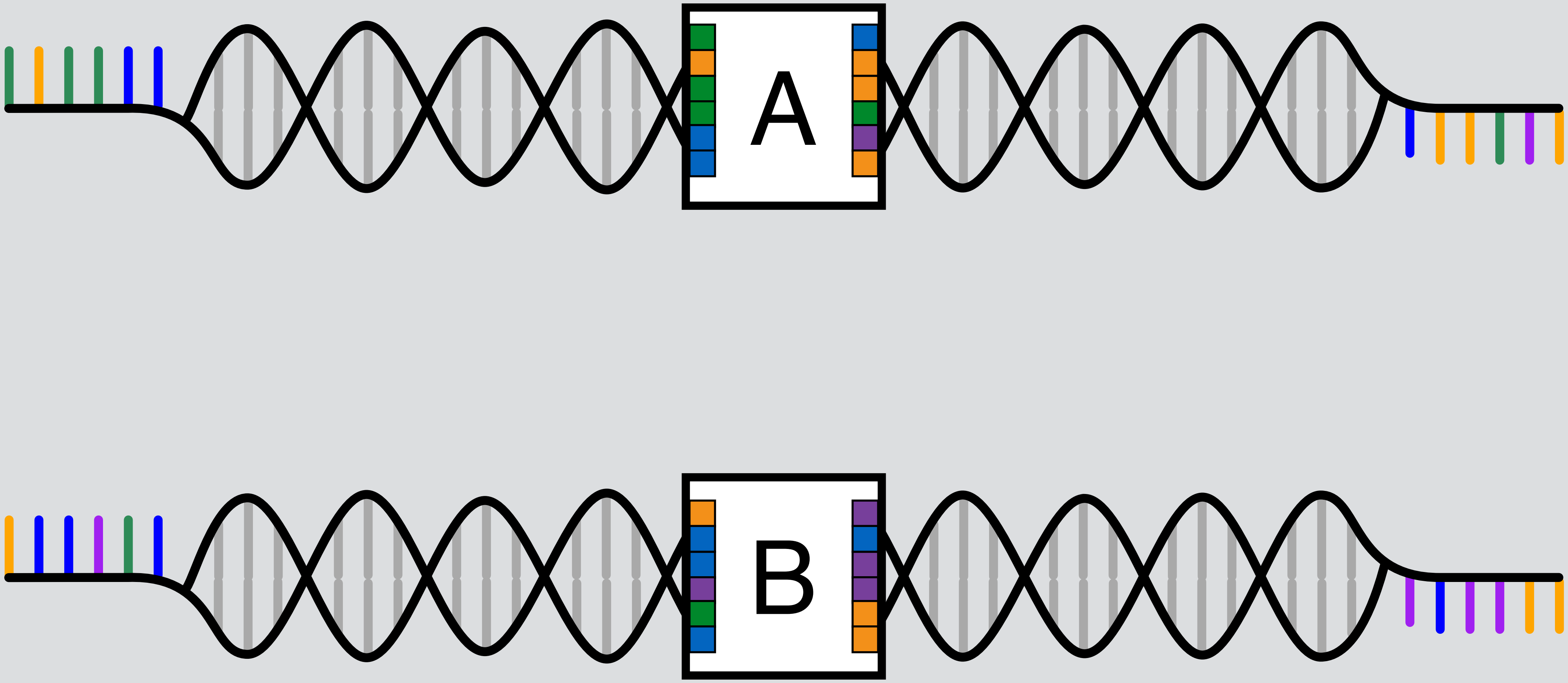


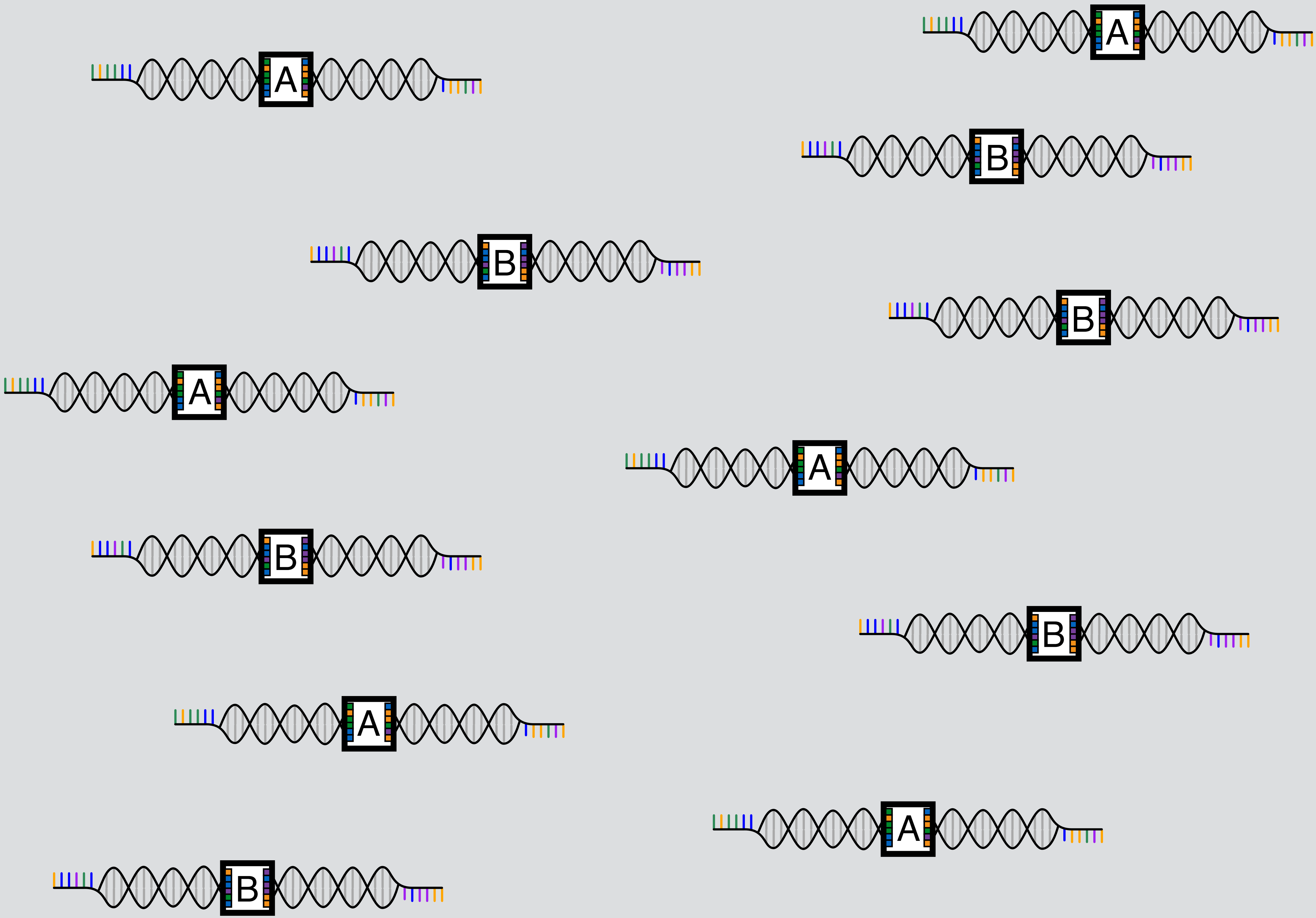


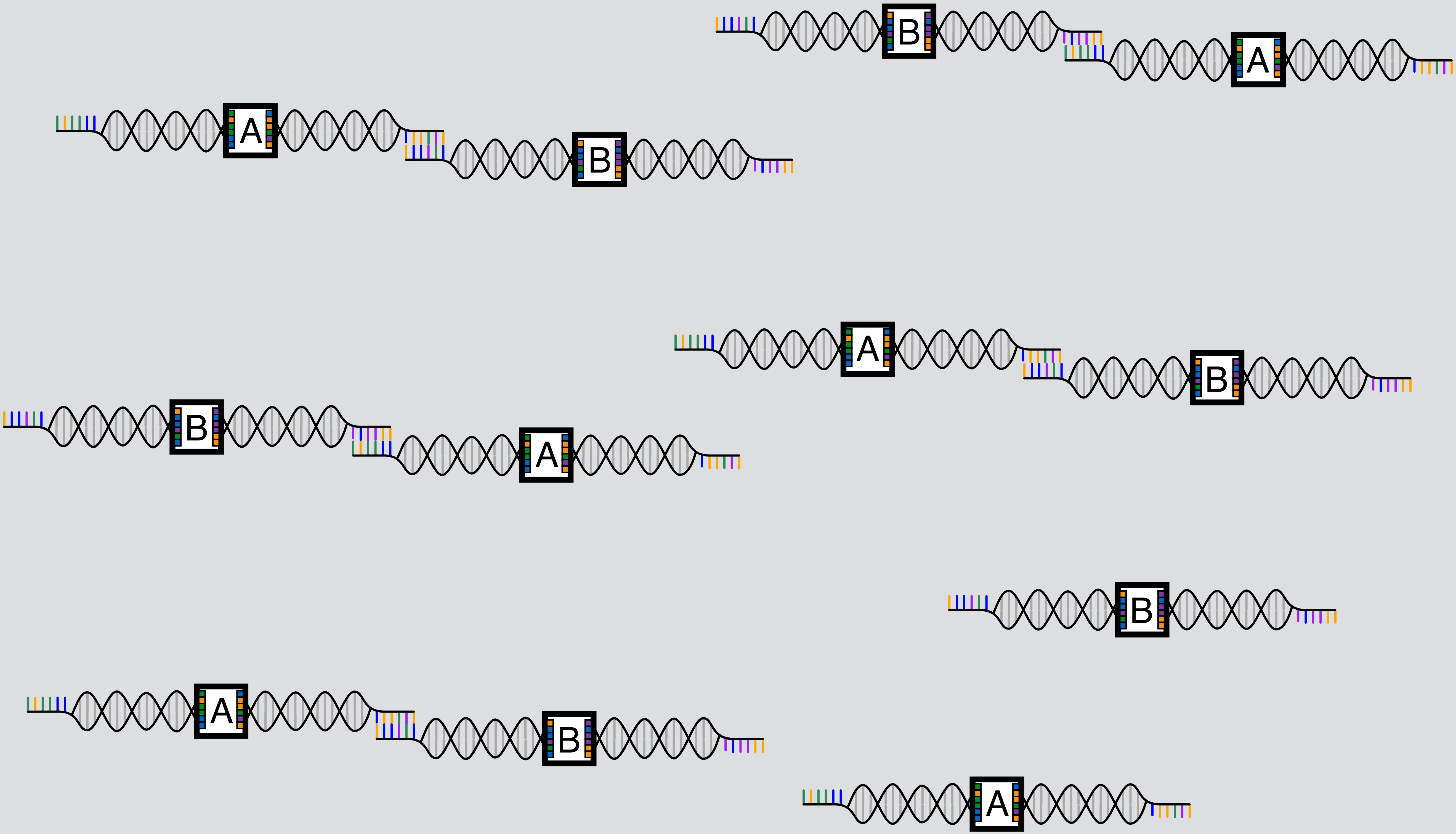







A
B


A
A
B
B
B
A
A
B
B
A
A
B


B
A
A
B
A
B
B
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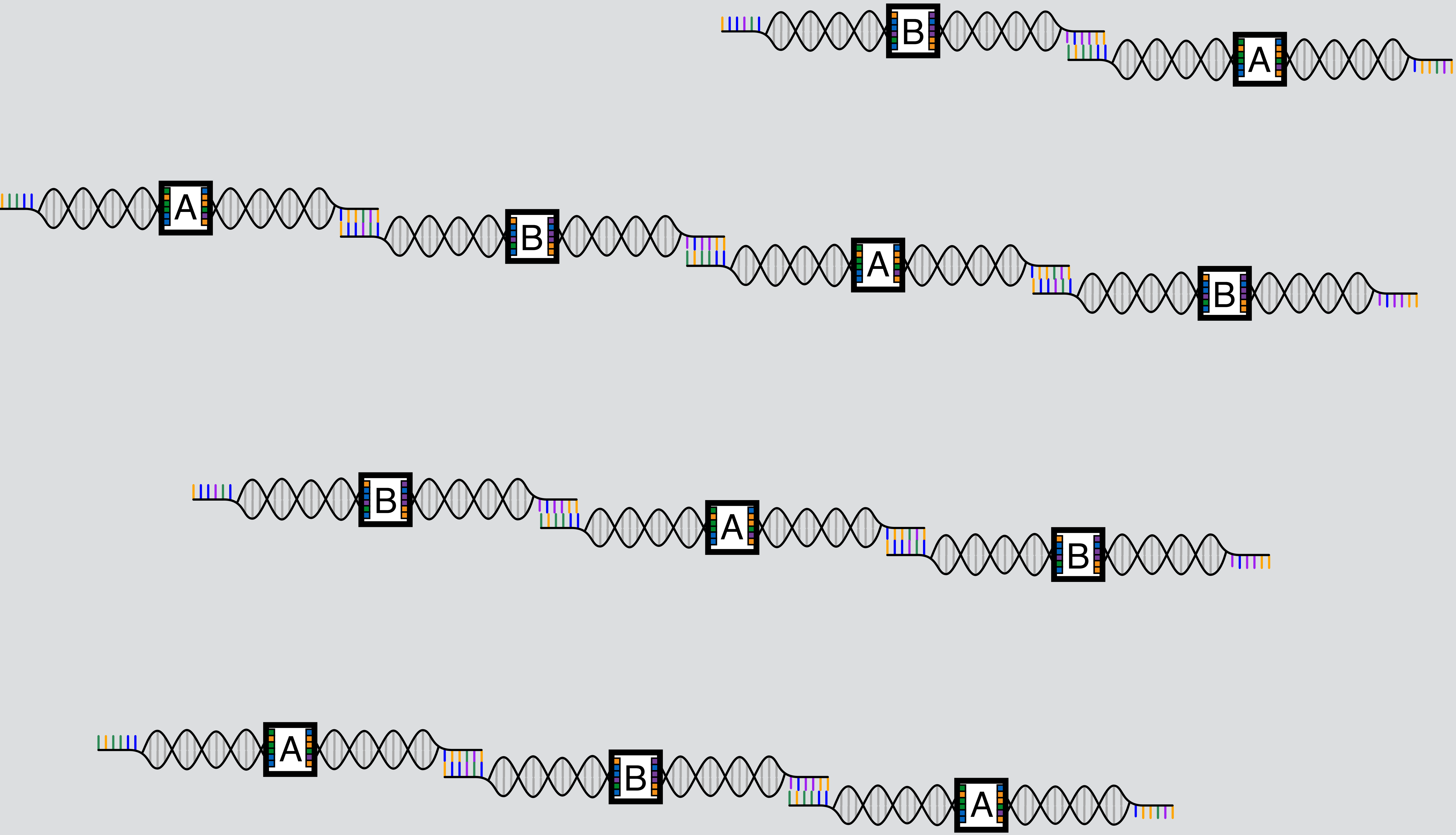
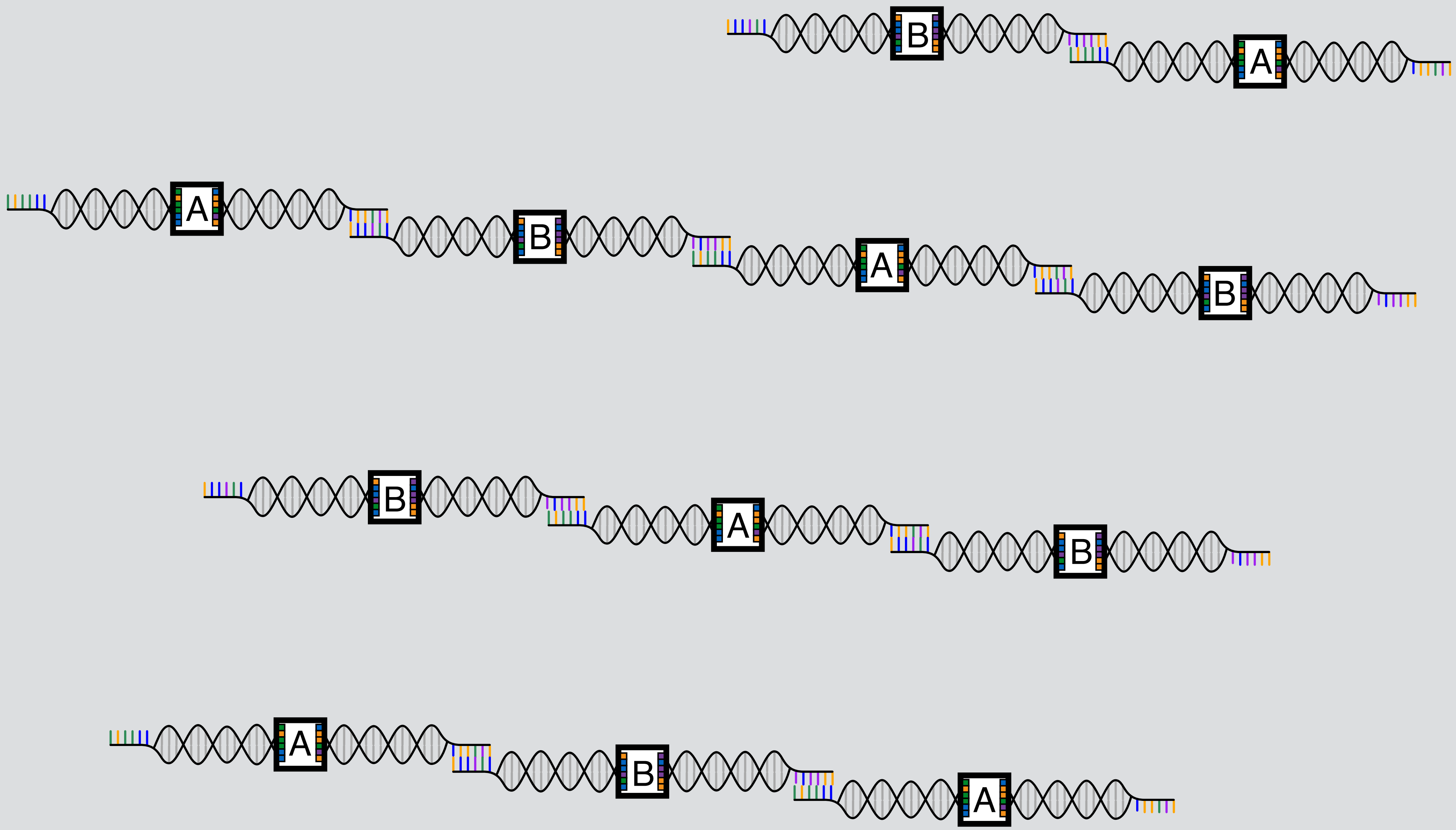
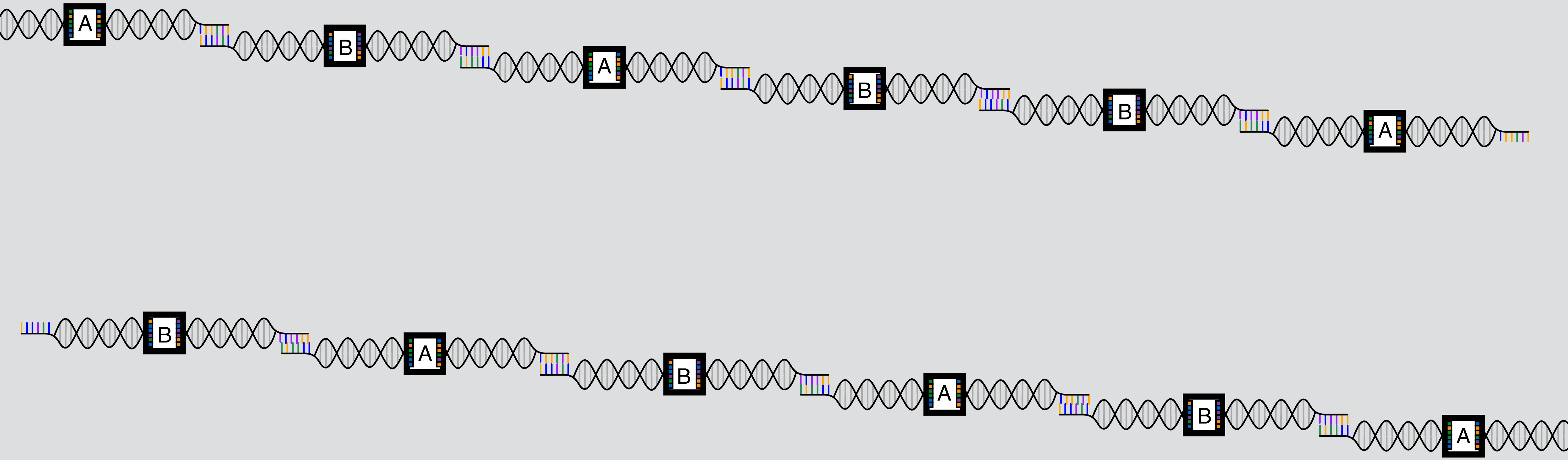
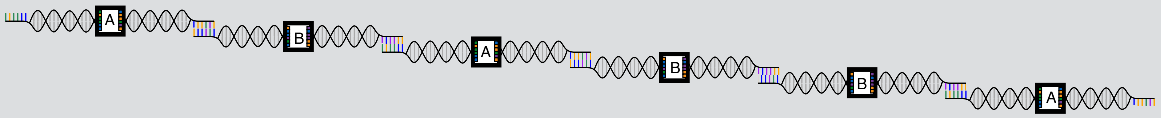
B
A
B
A


B
A
A
B
A
B
B
A
B
A
B
A


B A
A B A B
B A B
A B A


A
B
A
B
B
A
B
A
B
A
B
A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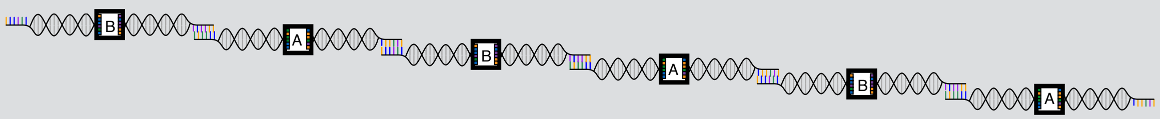
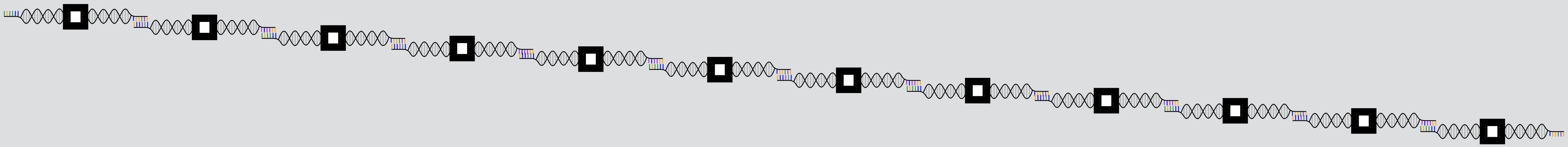
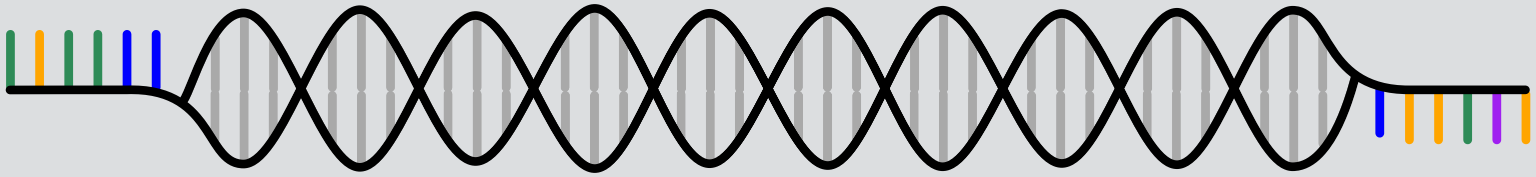
B
A
B
B
A

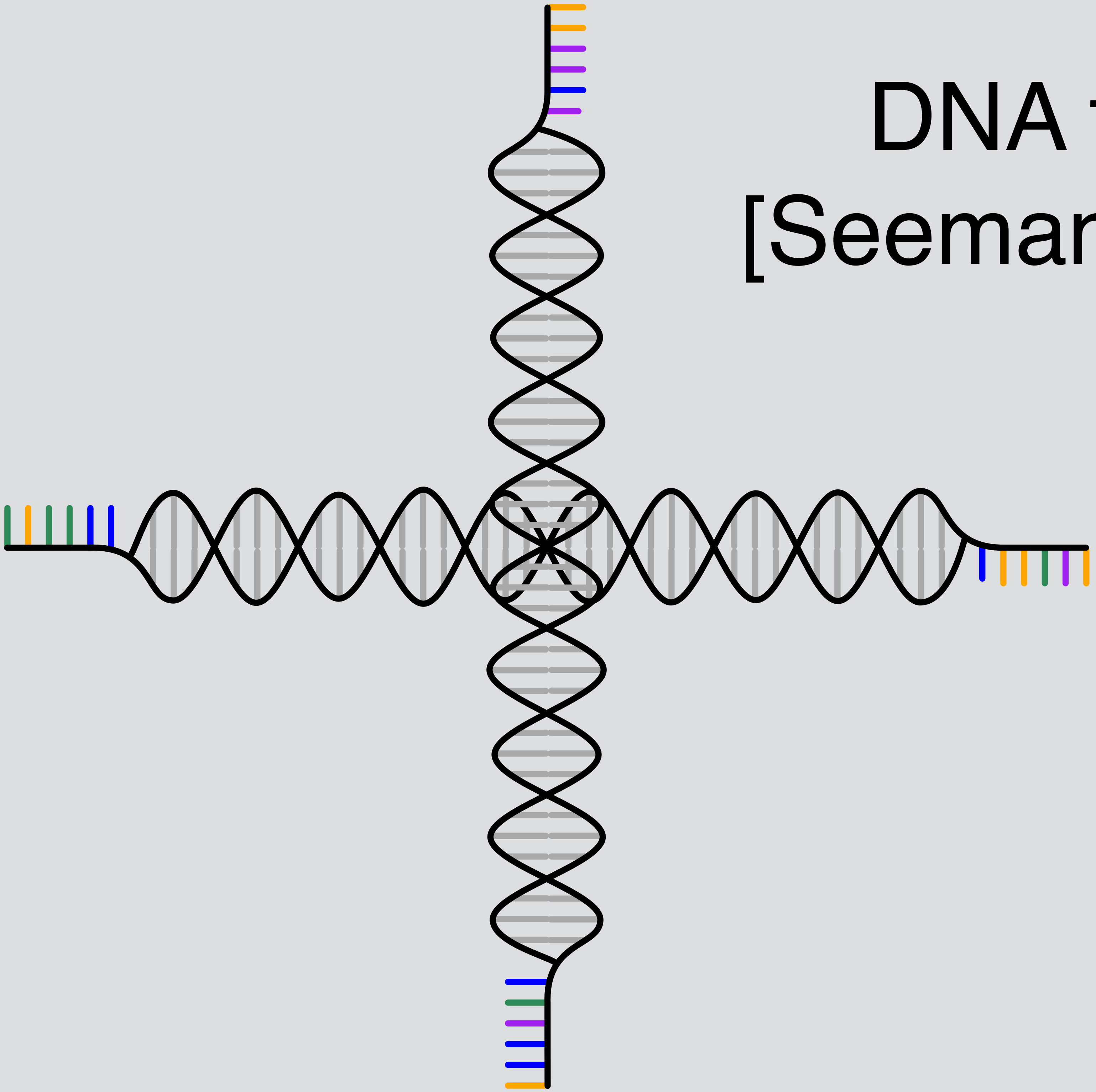

B
A
B
A
B
A



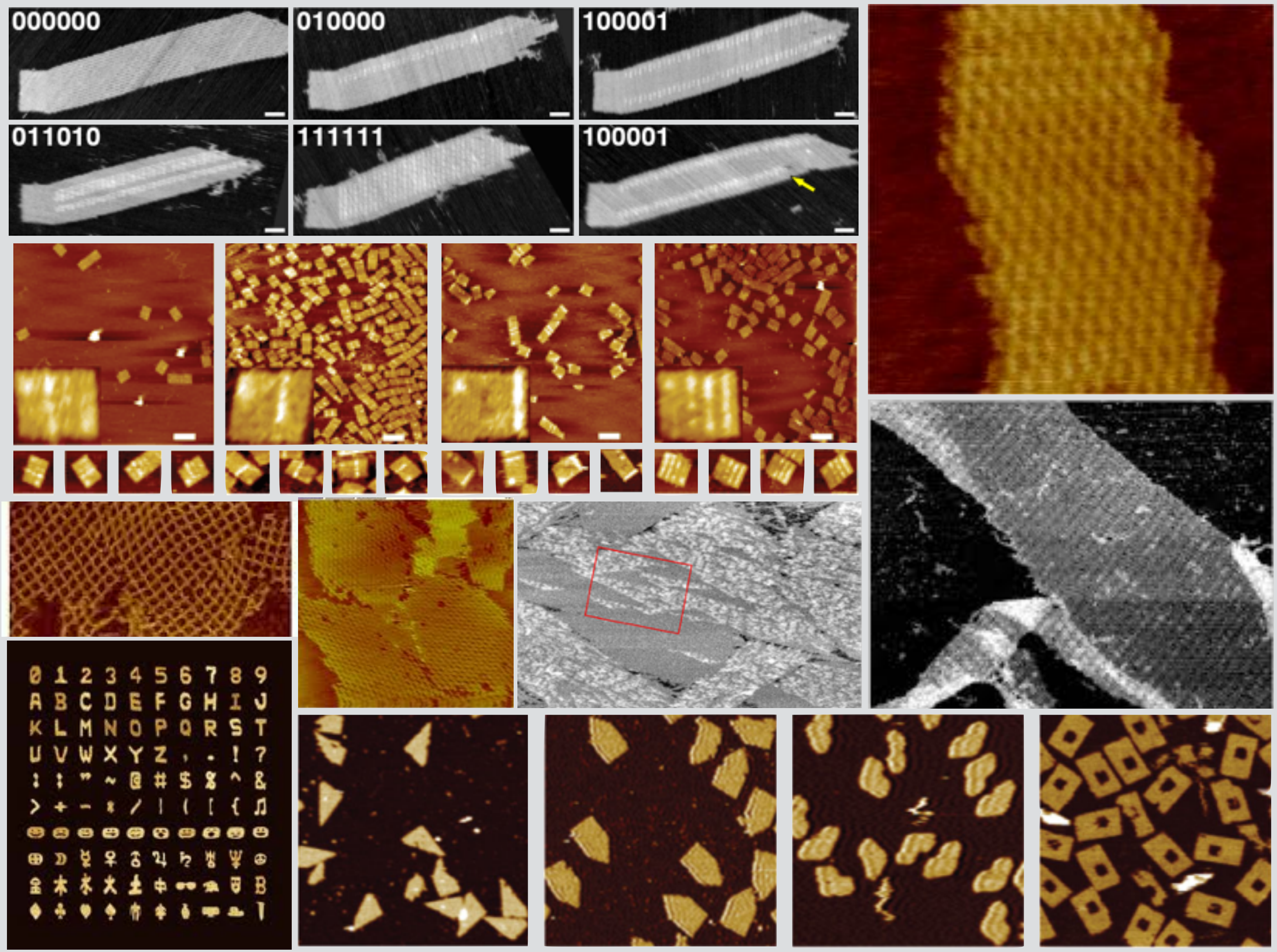
[Wei, Dai, Yin 2012]

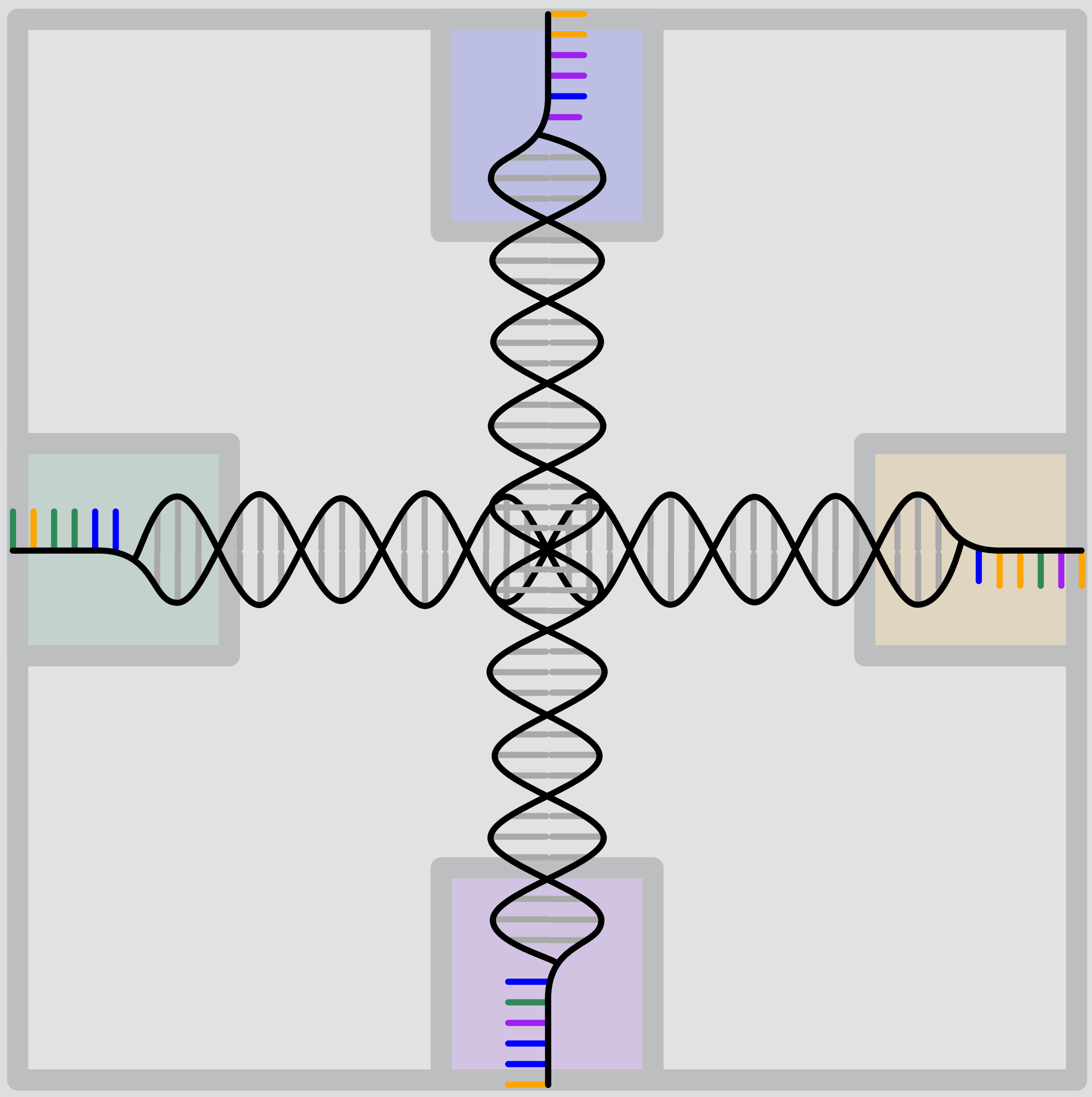


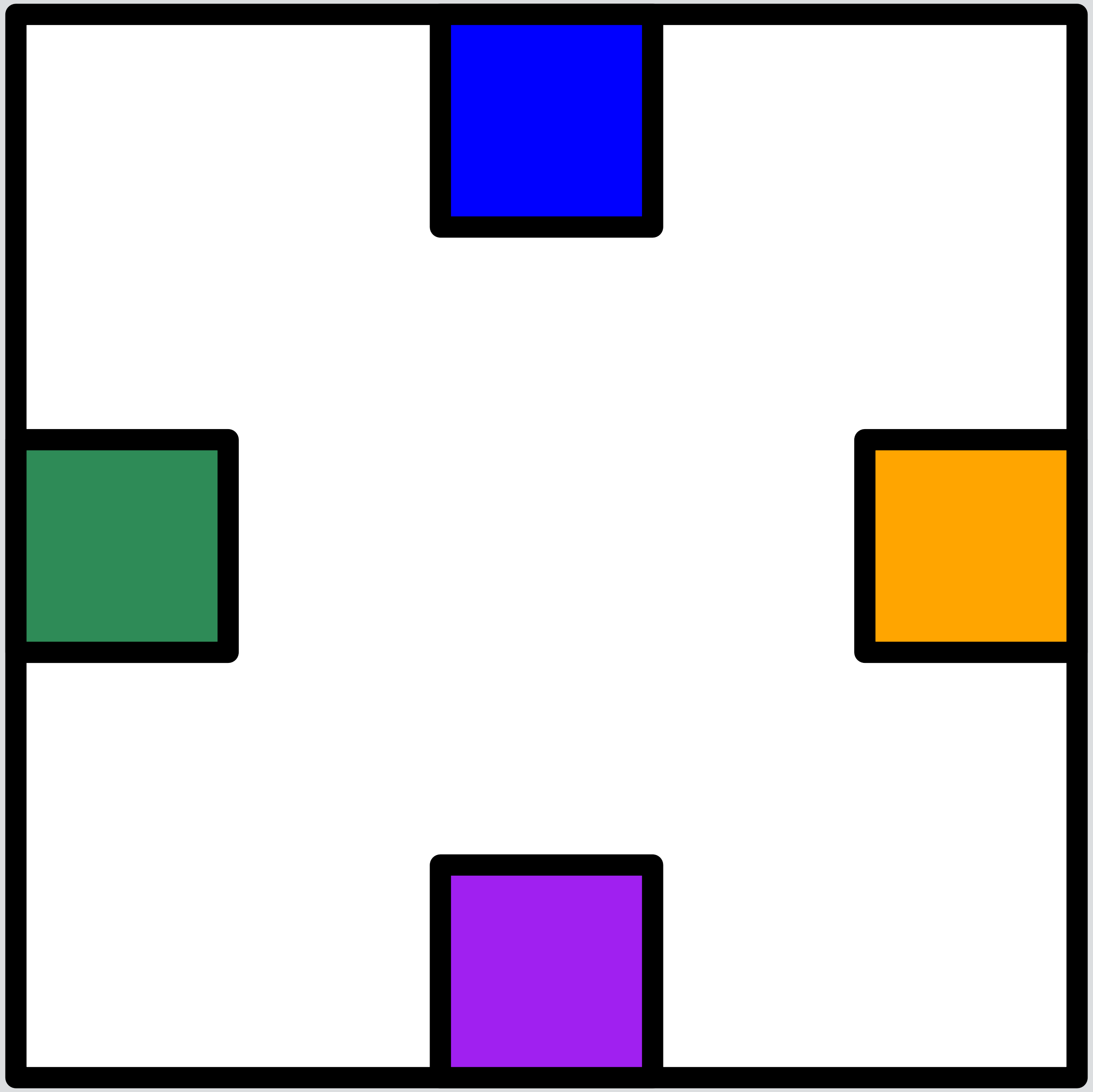
DNA tiles
[Seeman 1982]

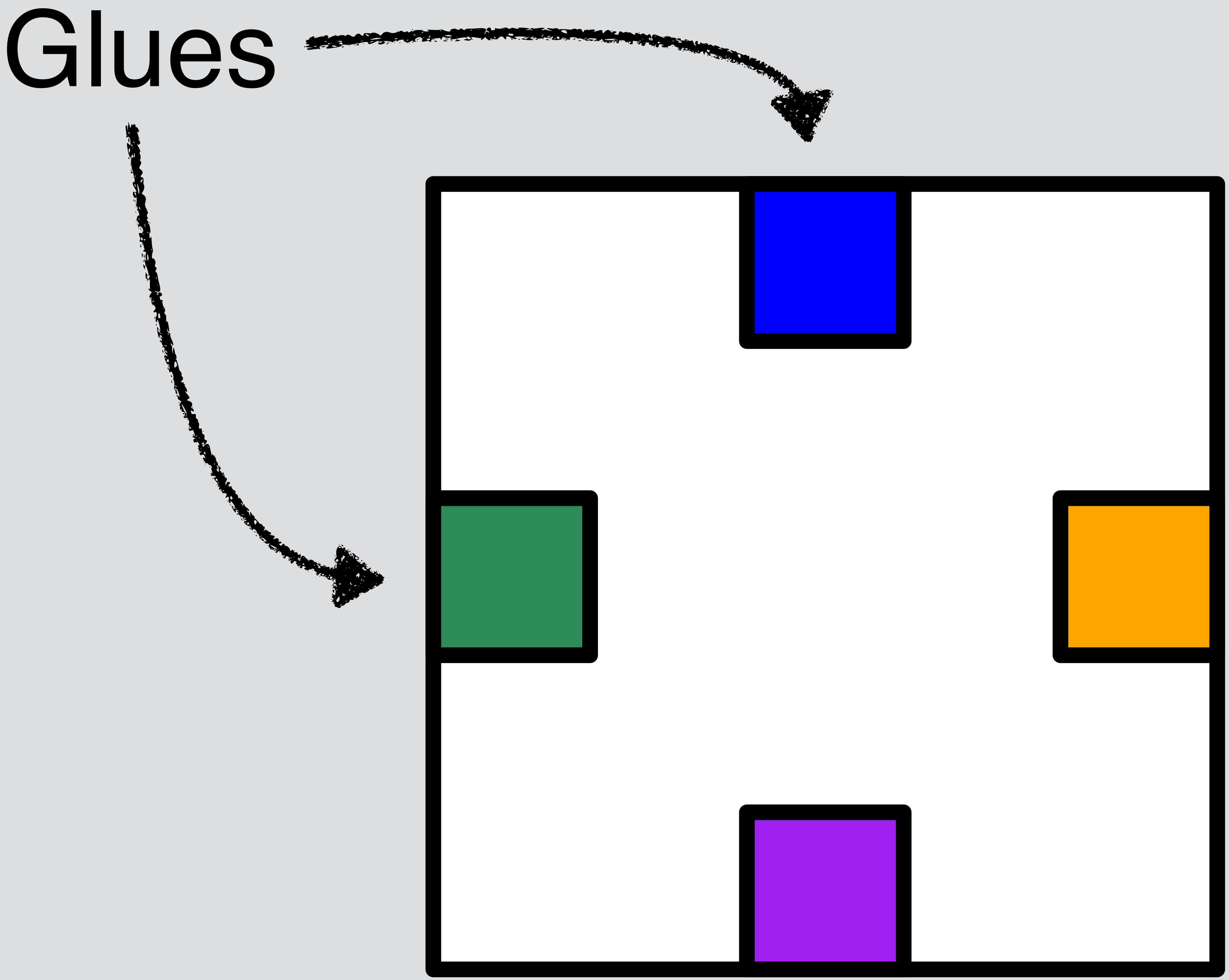


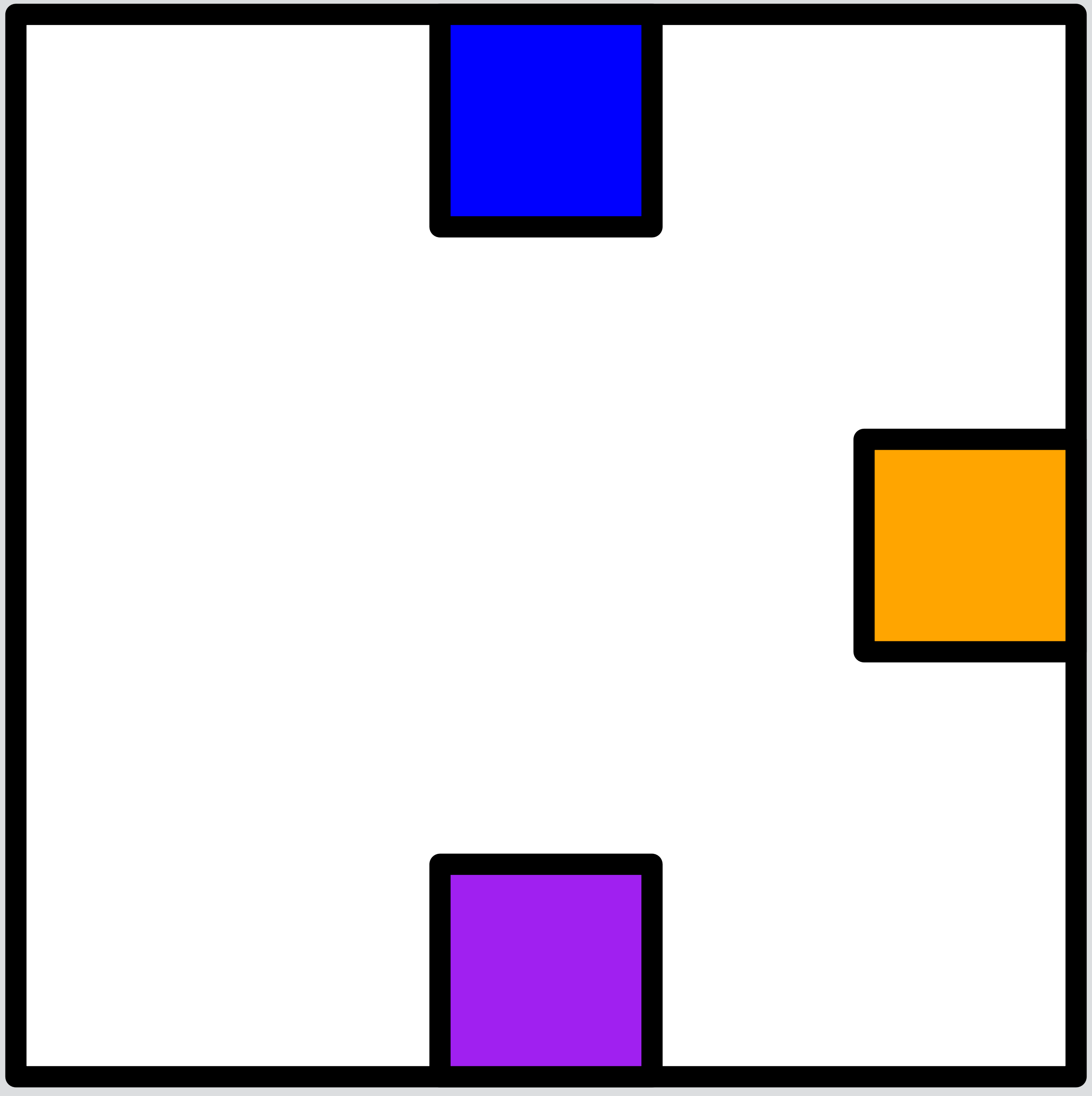
DNA tile self-assembly

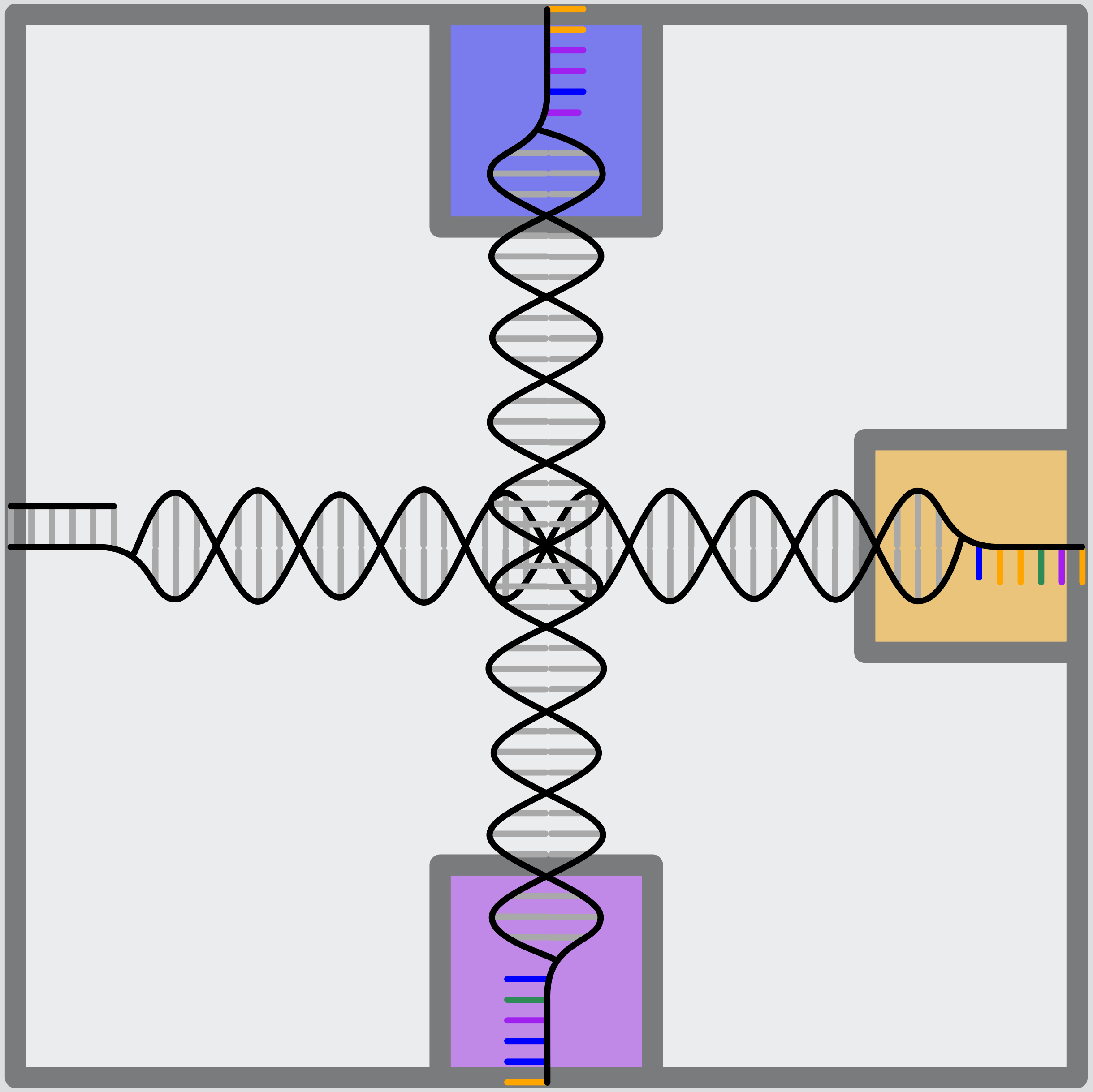




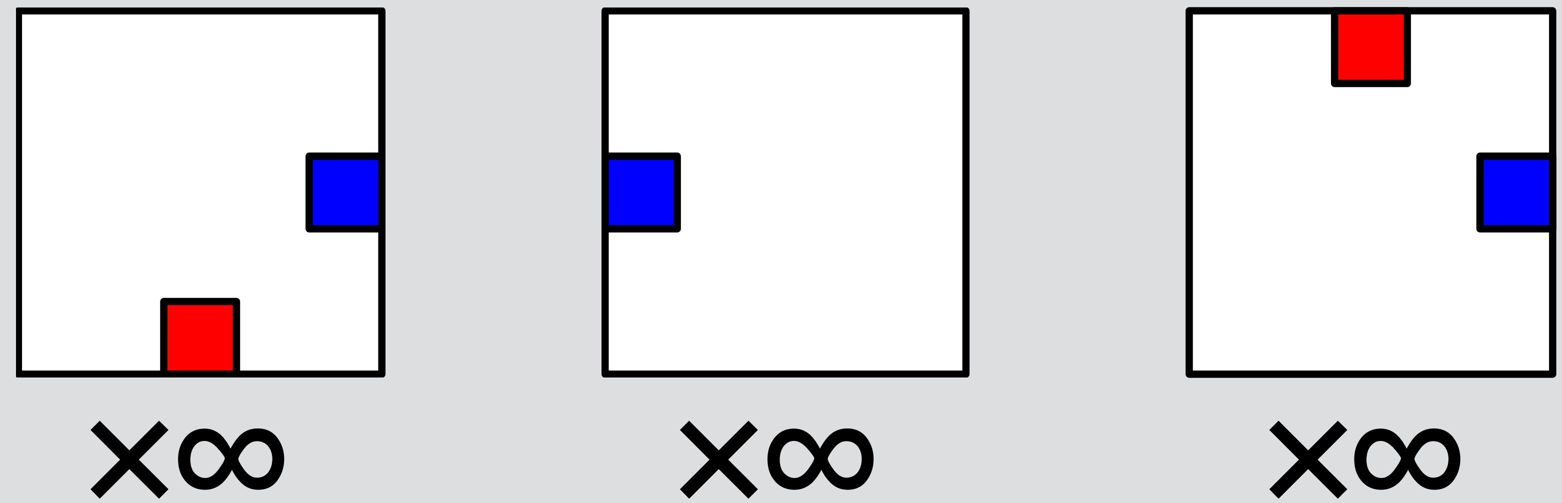


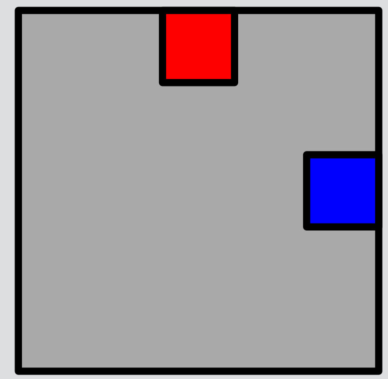

Glues





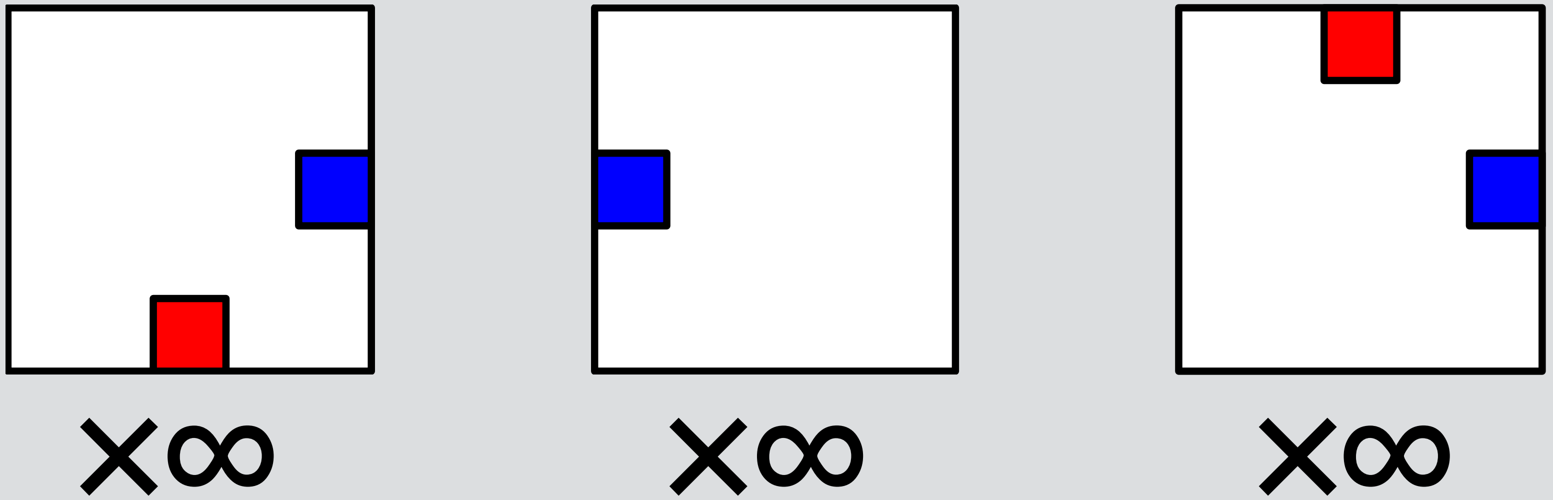
Tile types

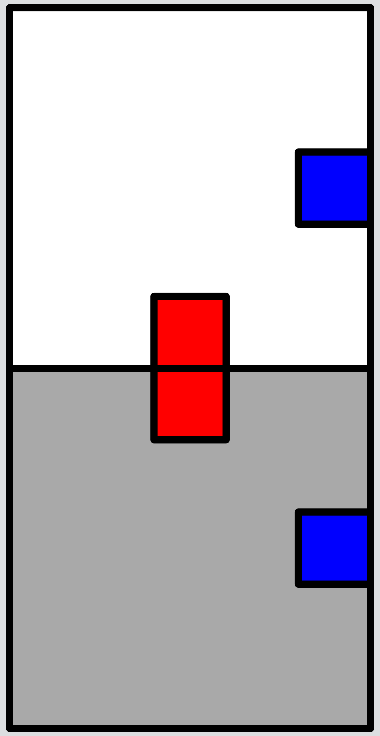




Seed tile

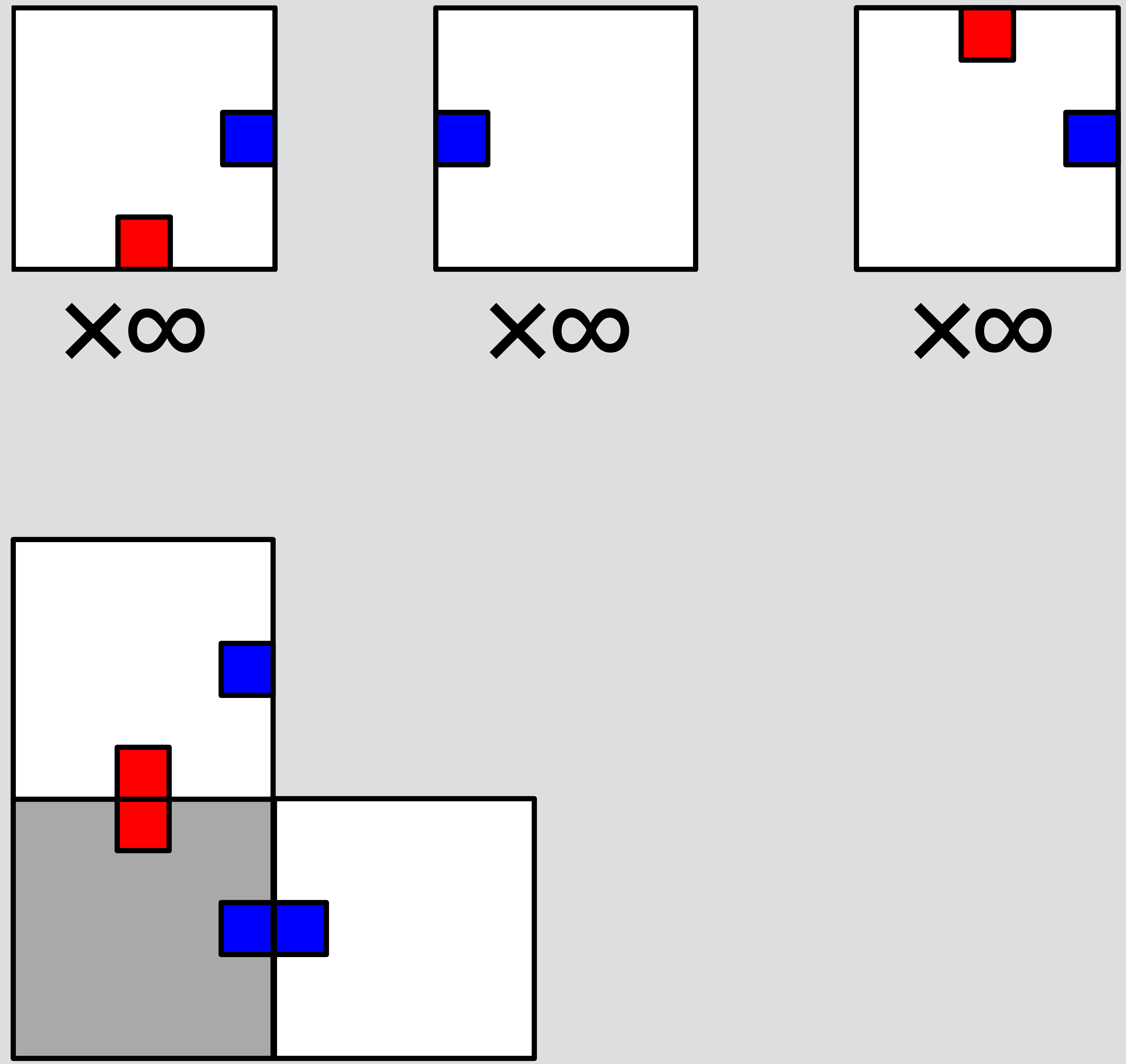
Tile types





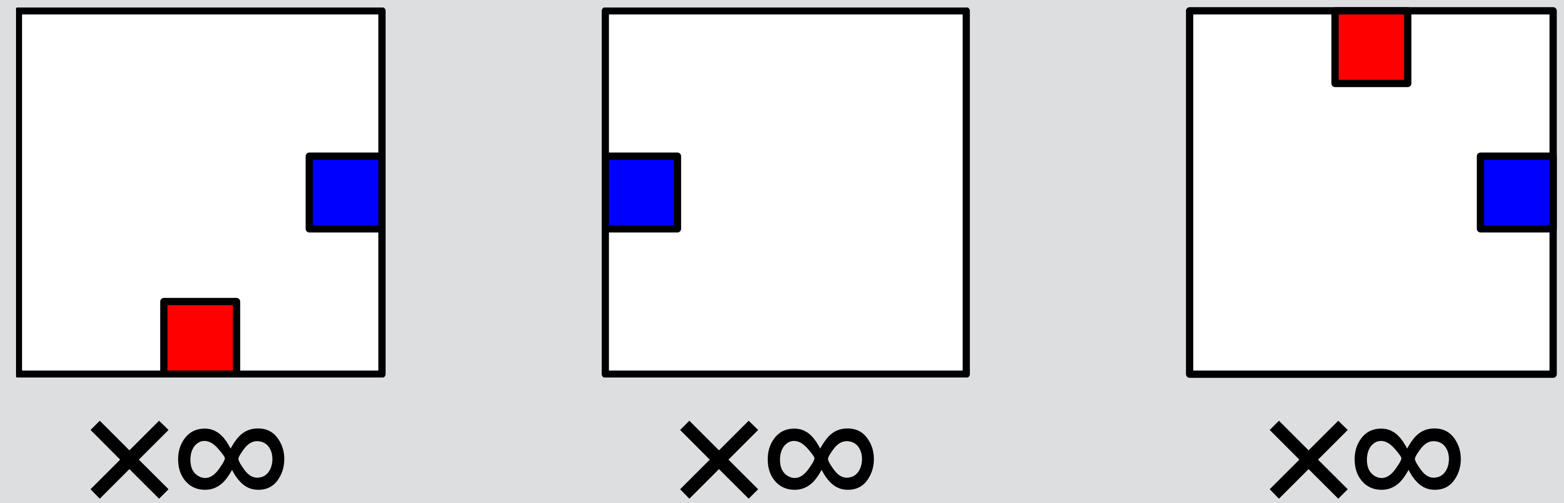
Seed tile

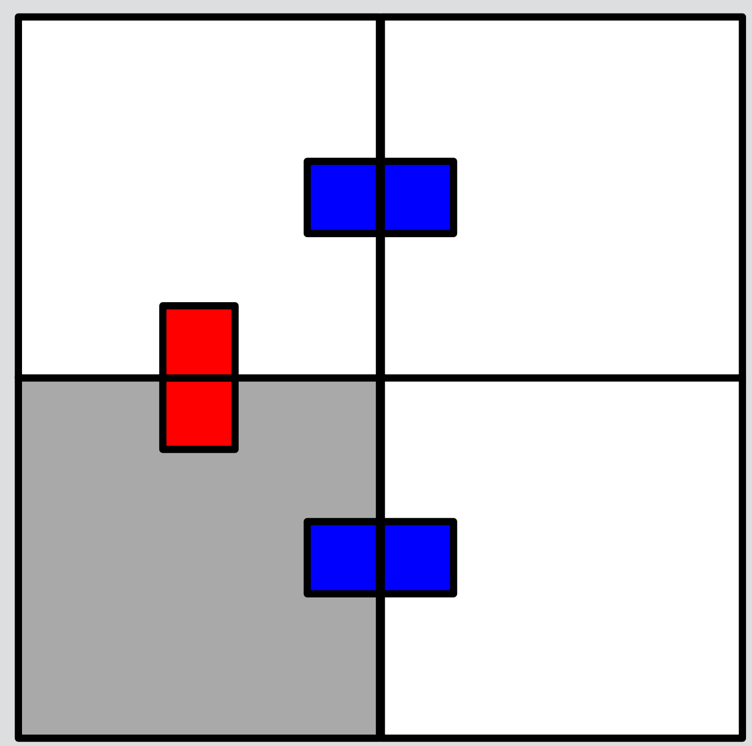
Tile types



Seed tile

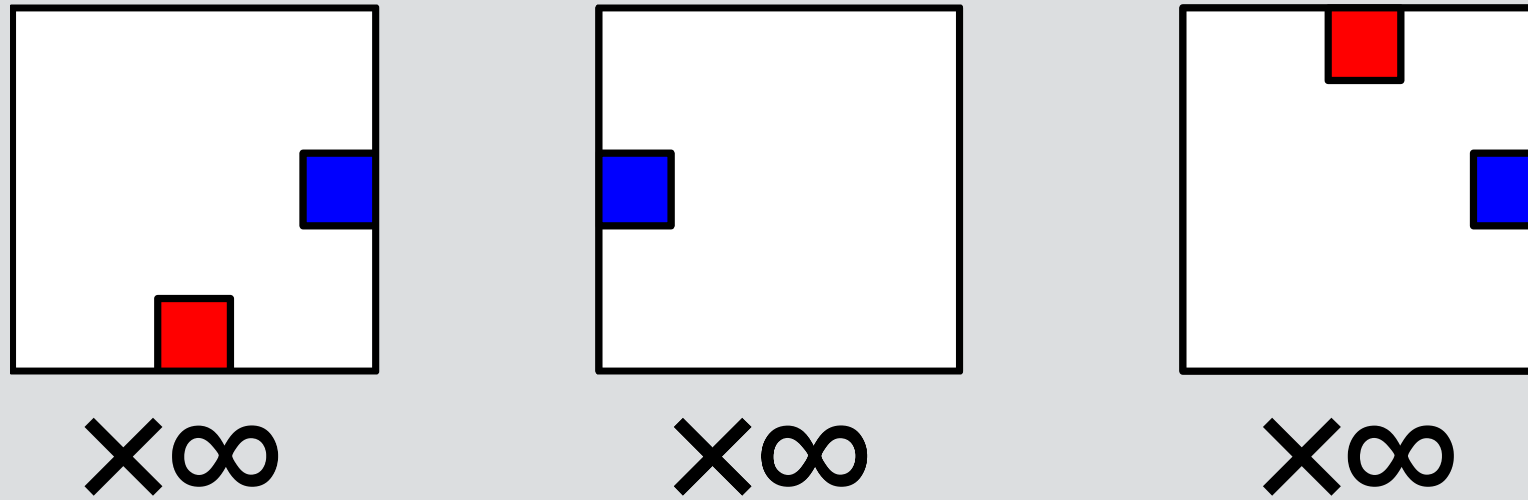
Tile types

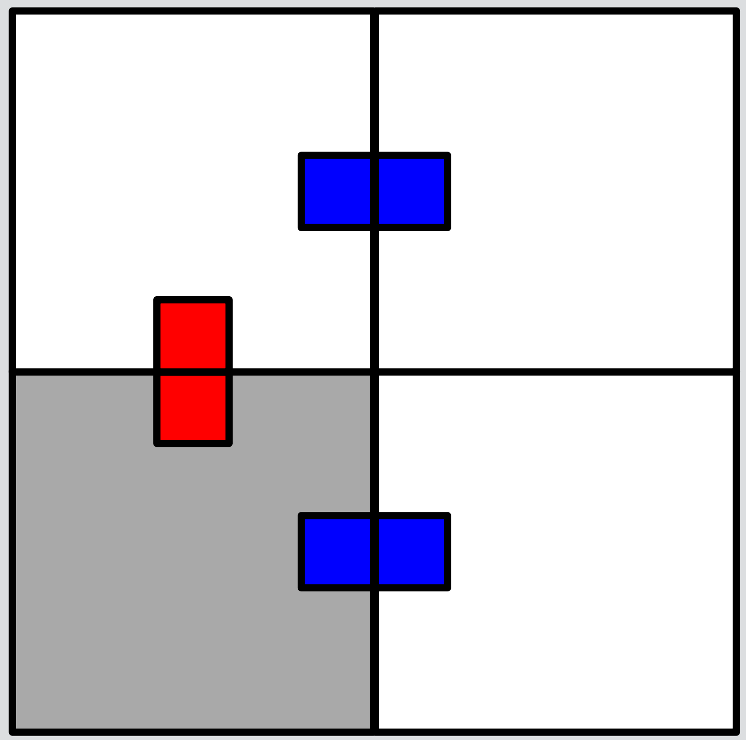




Seed tile

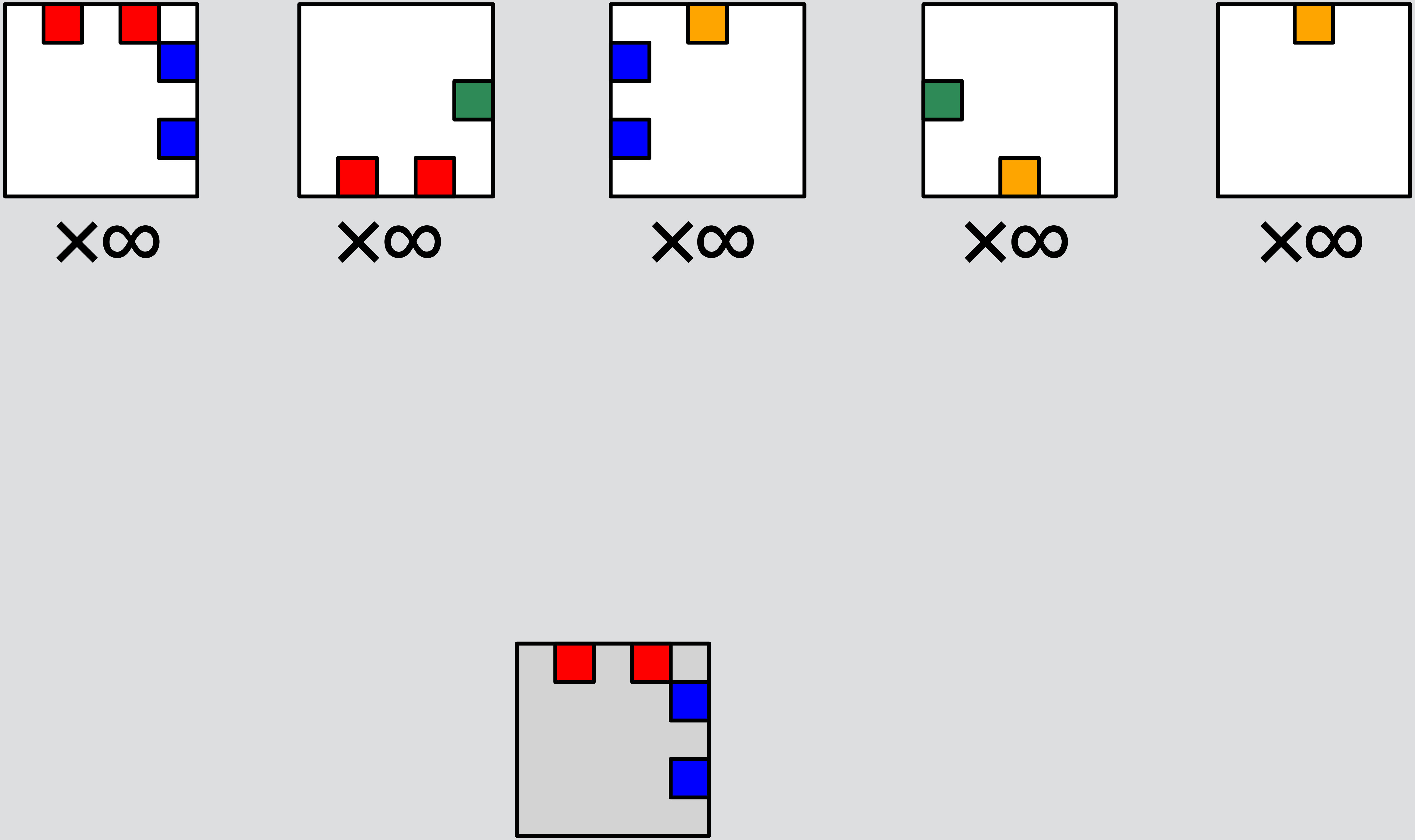
Tile types



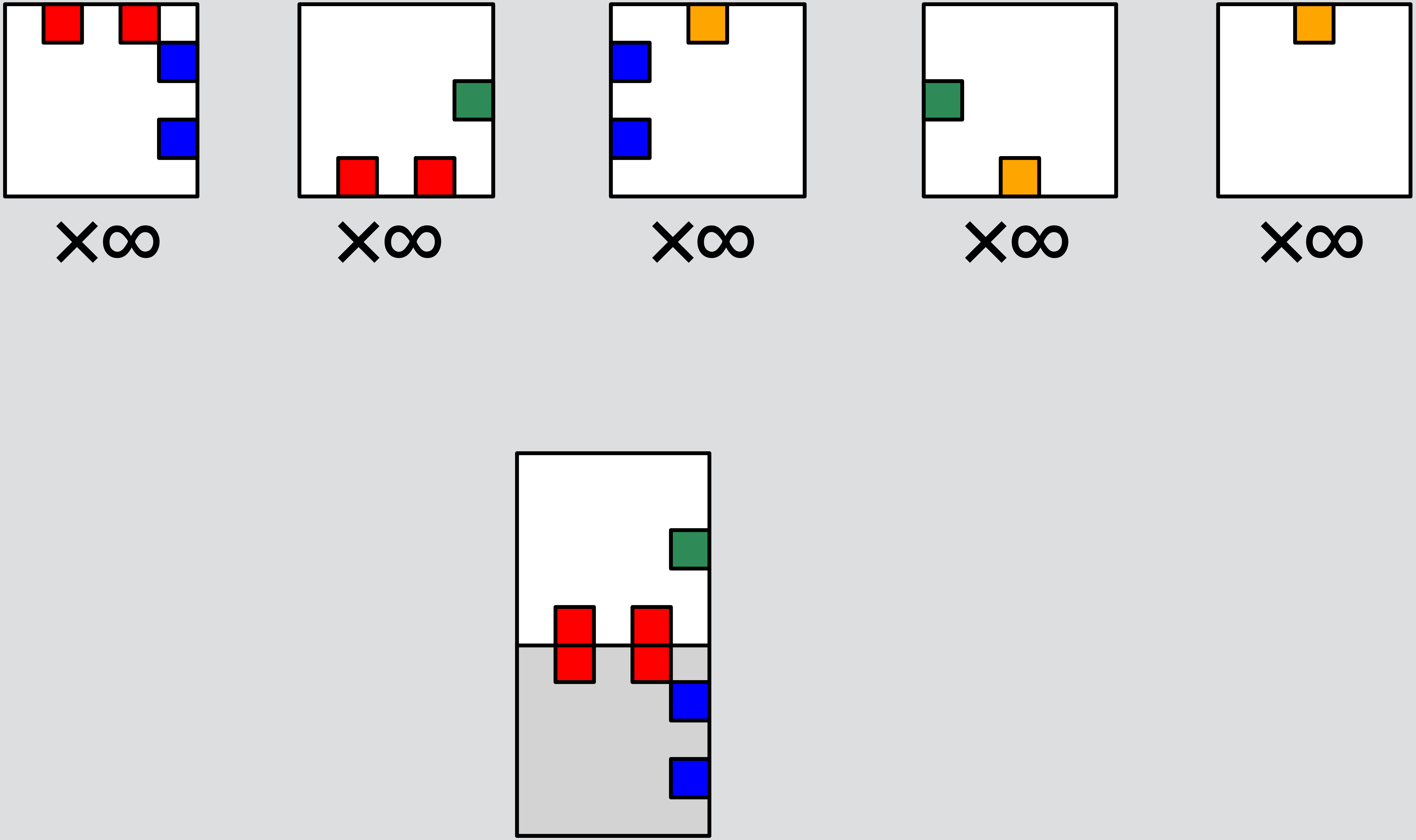


Seed tile

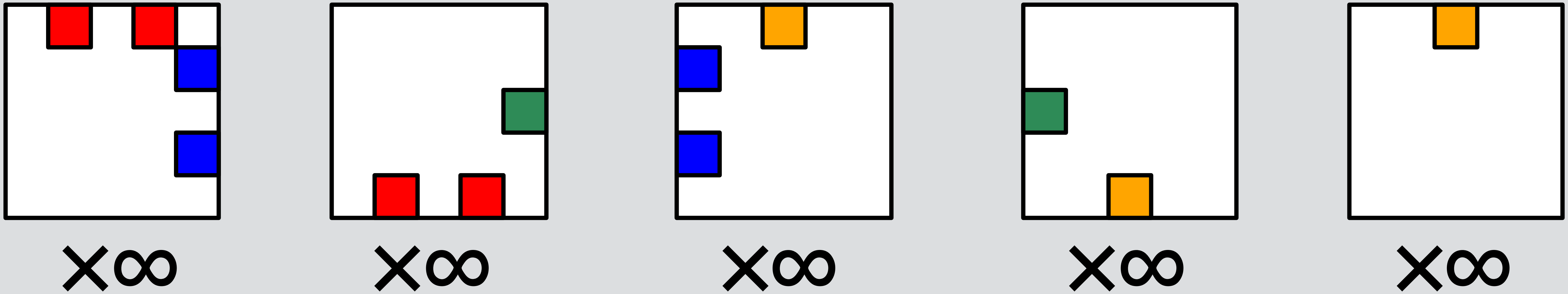
Temperature 1

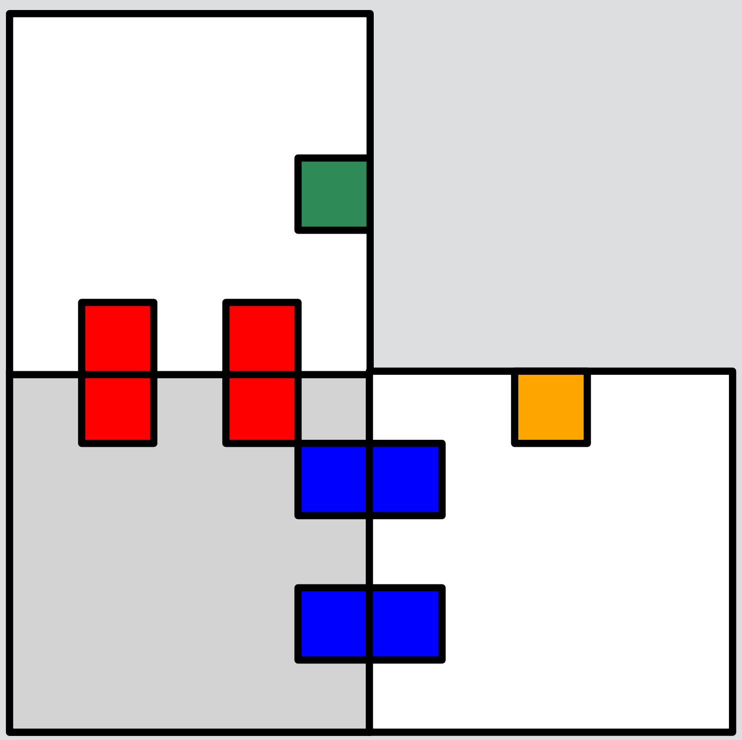


Temperature 2

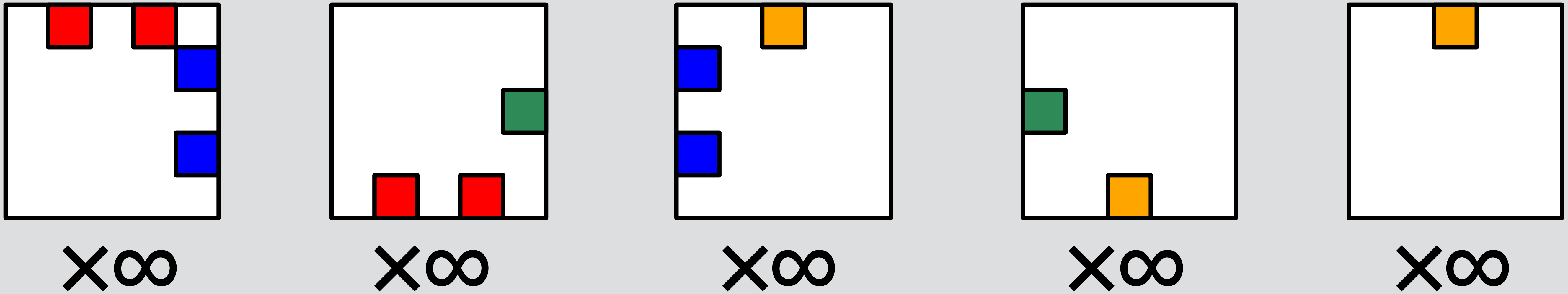


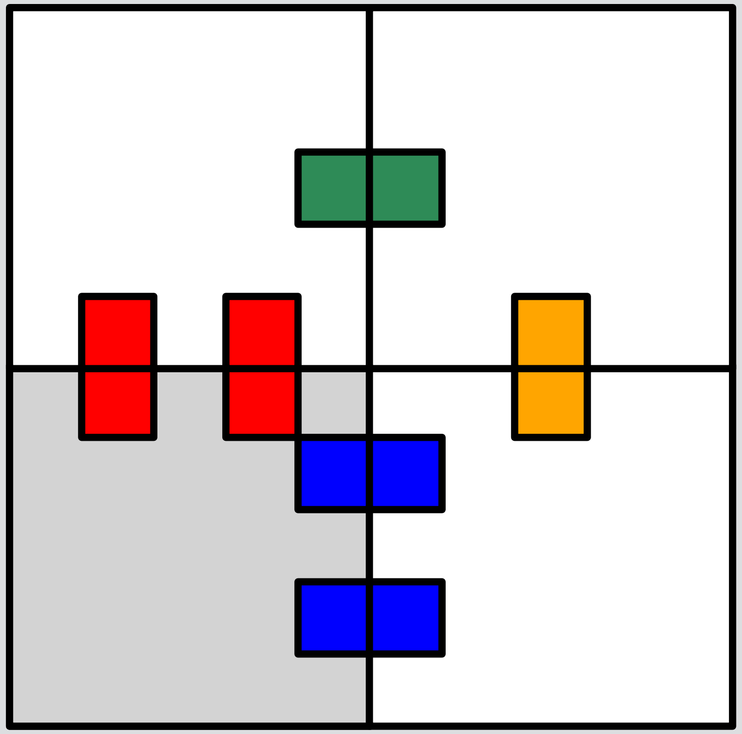
Temperature 2



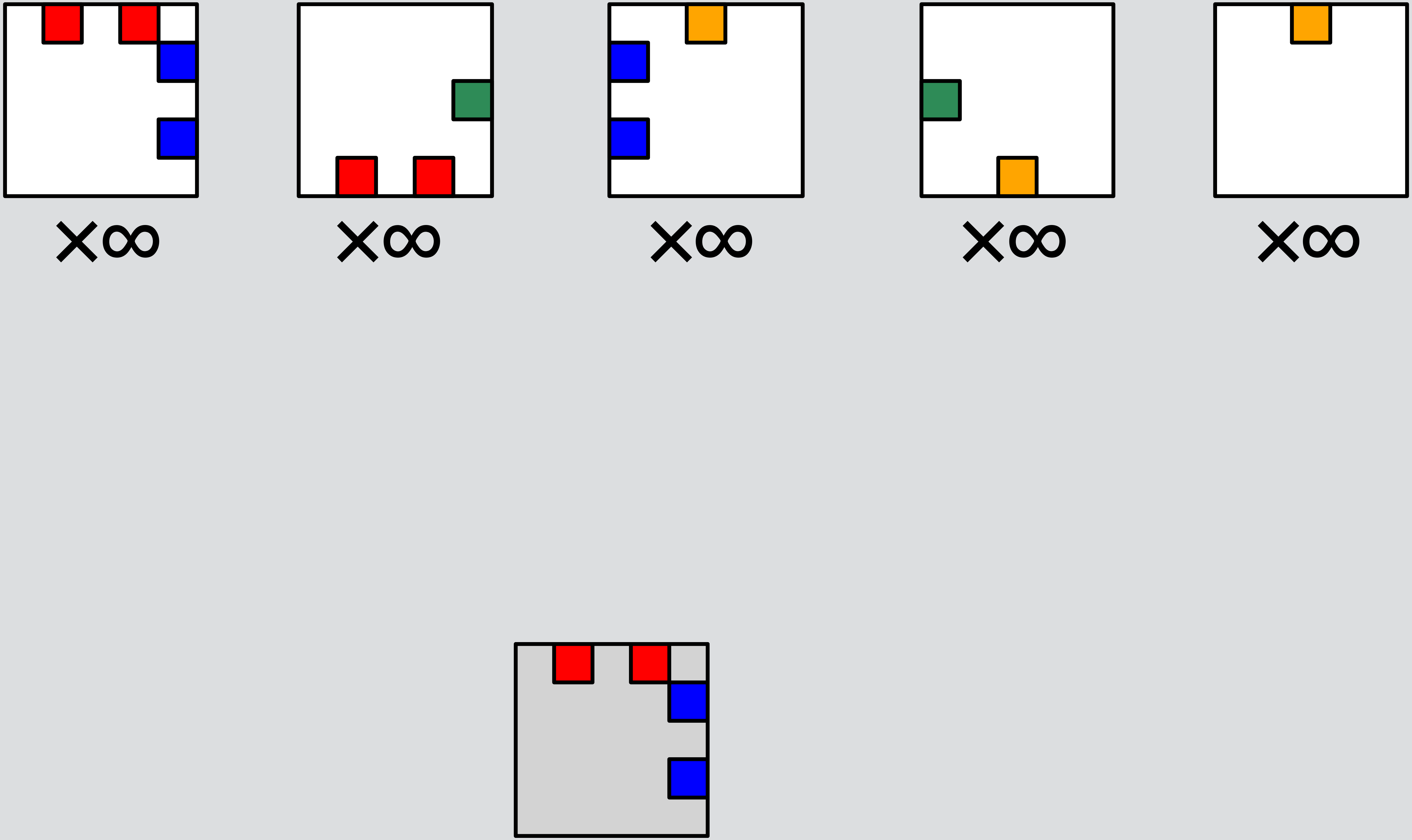


Temperature 2

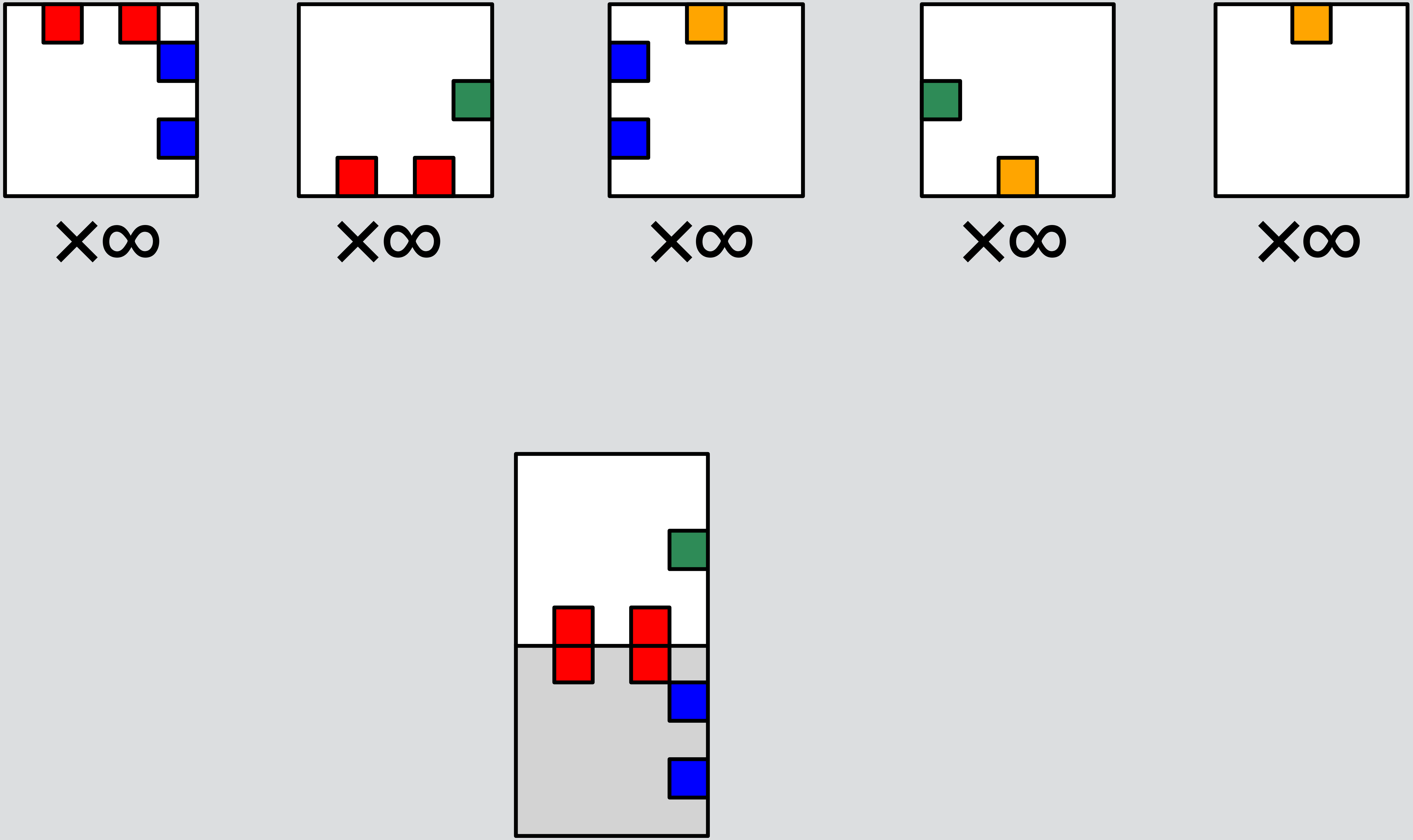




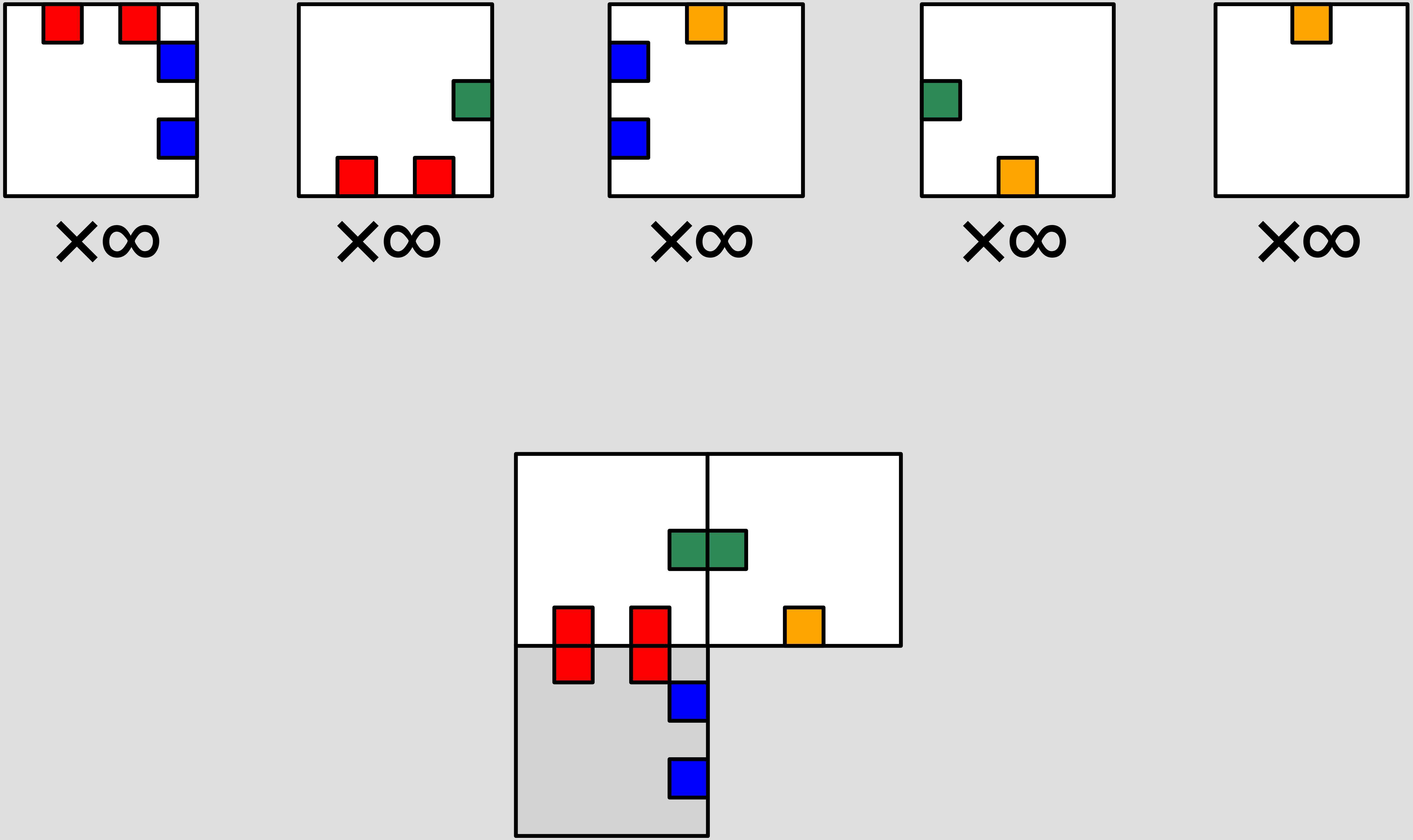
Temperature 2



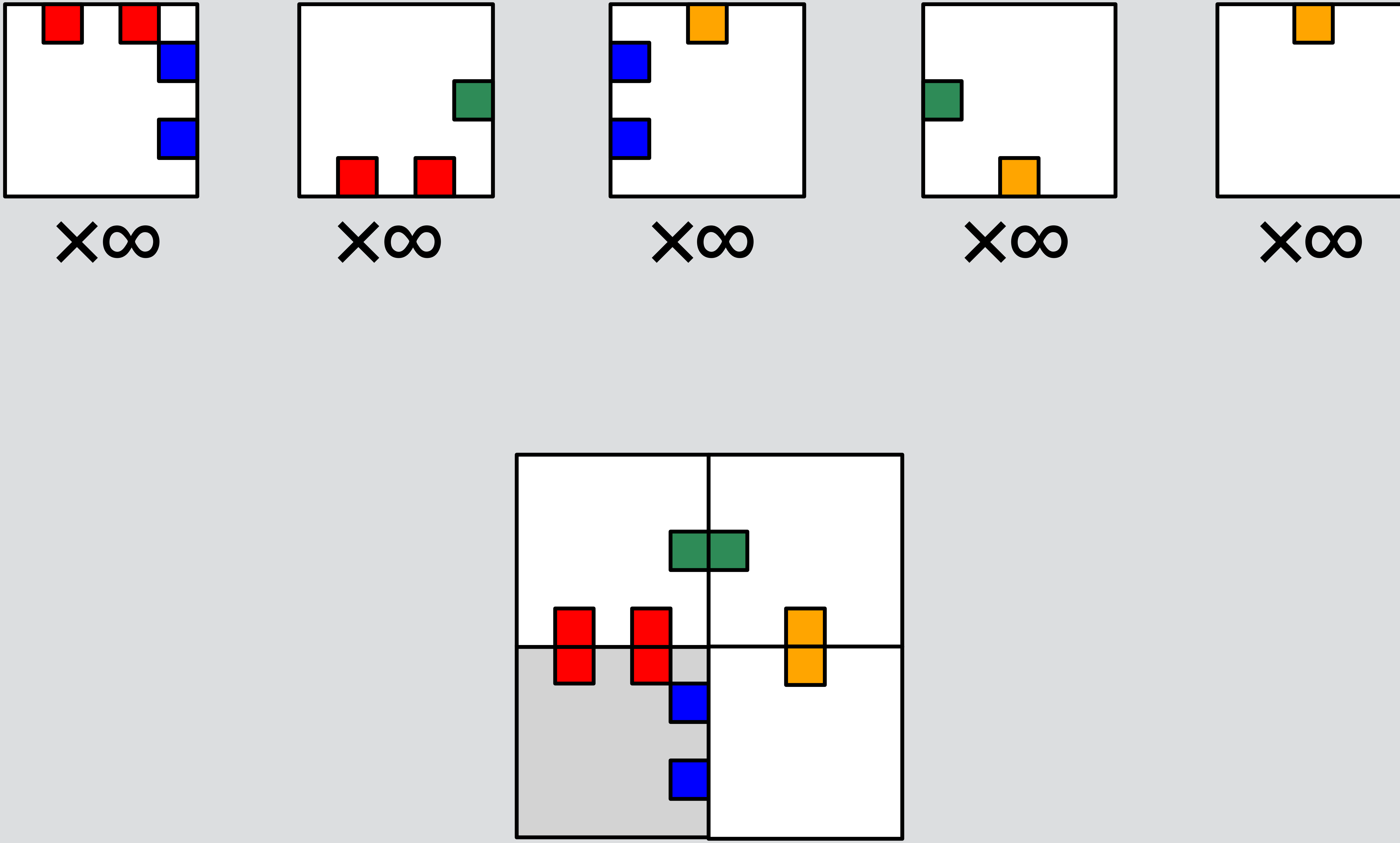
Temperature 1



Temperature 1

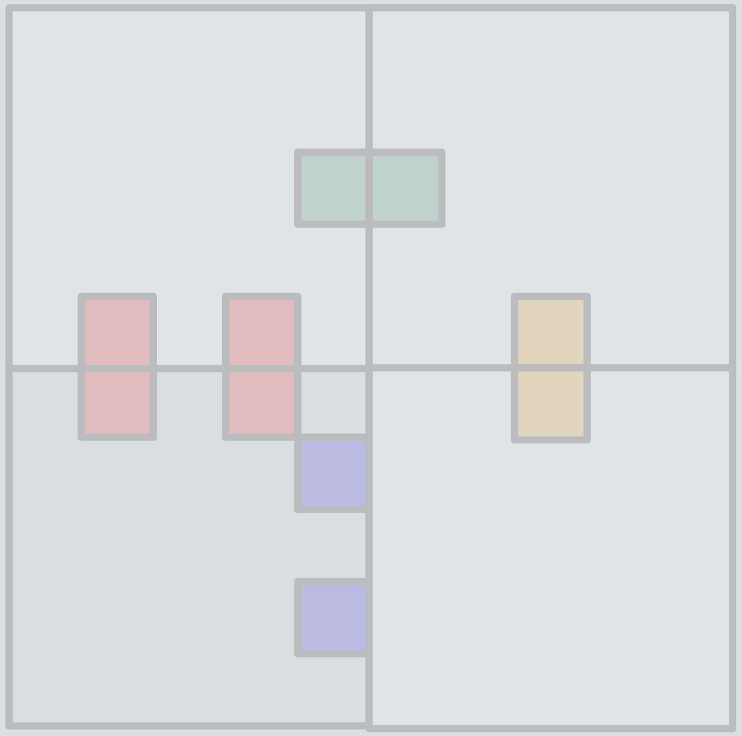


Temperature 1

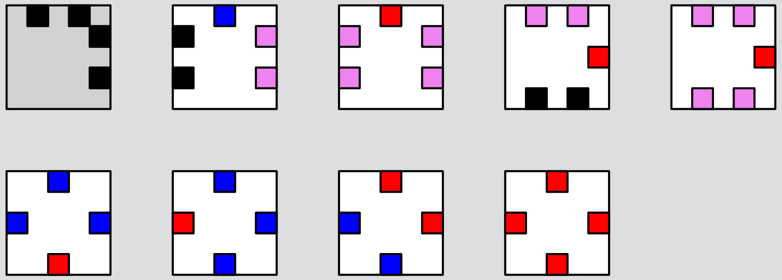


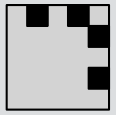
Temperature 1

abstract Tile Assembly Model (aTAM)
[Winfree 1998]

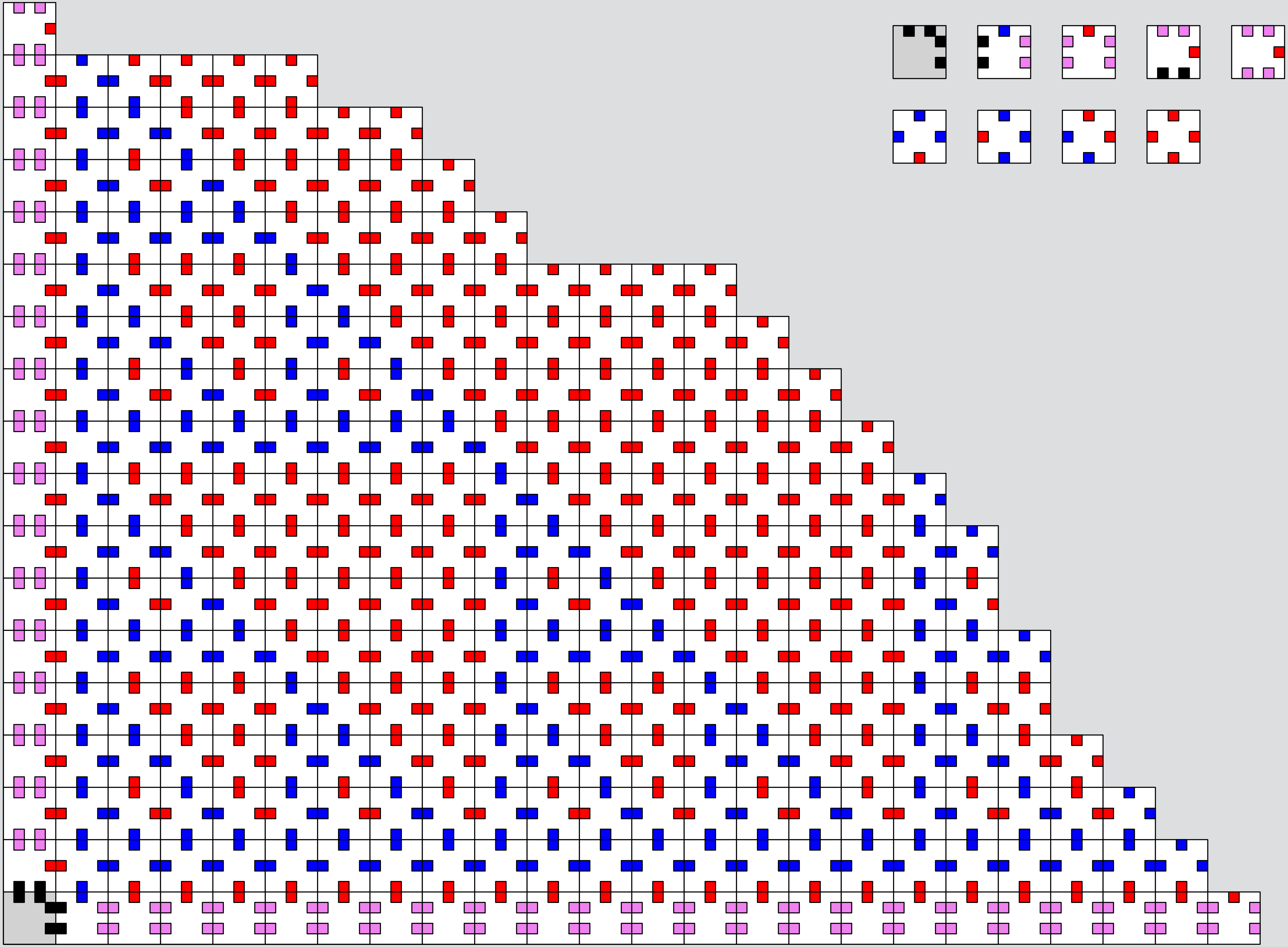


Temperature 1

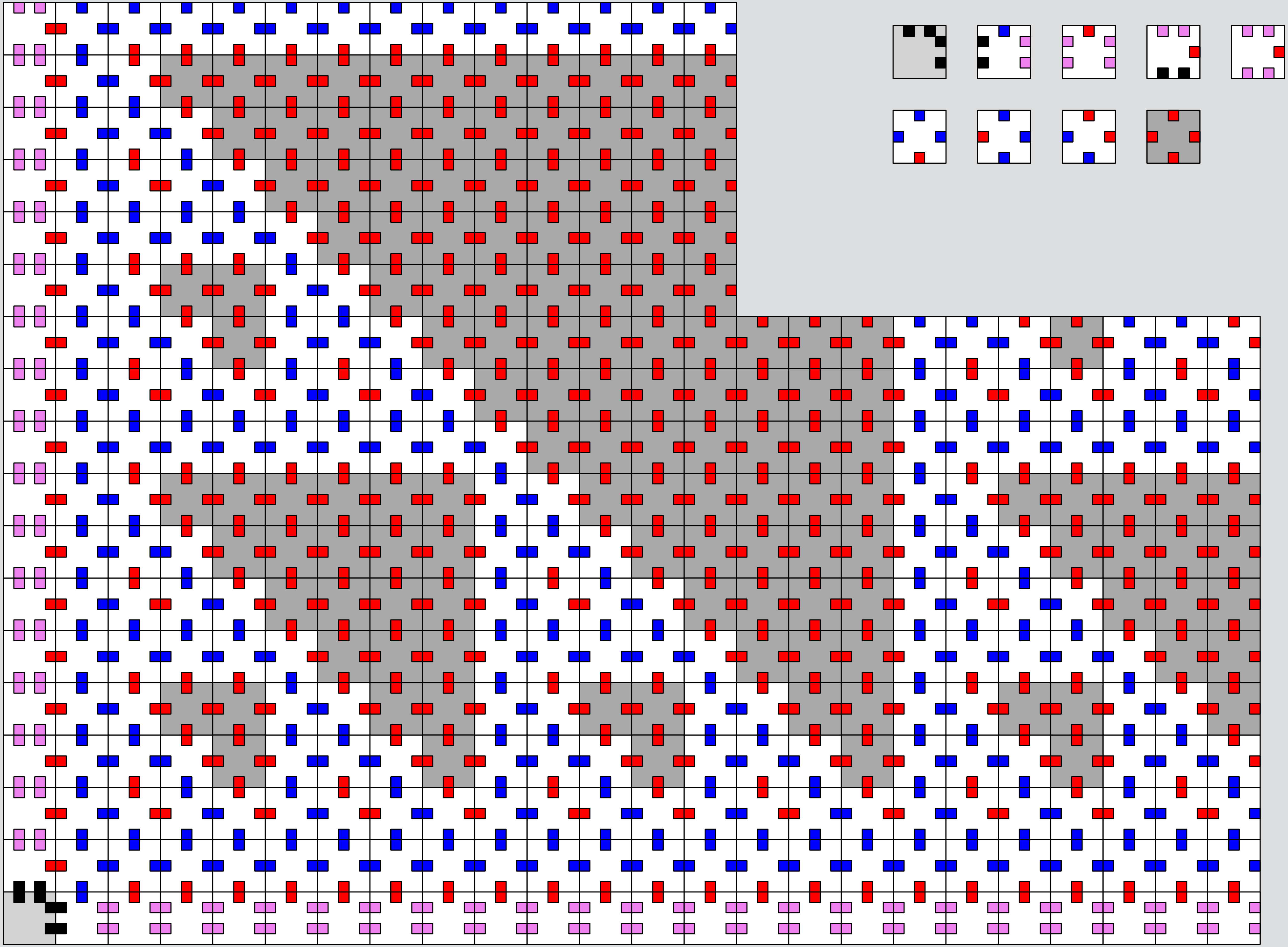




Temperature 2



Temperature 2



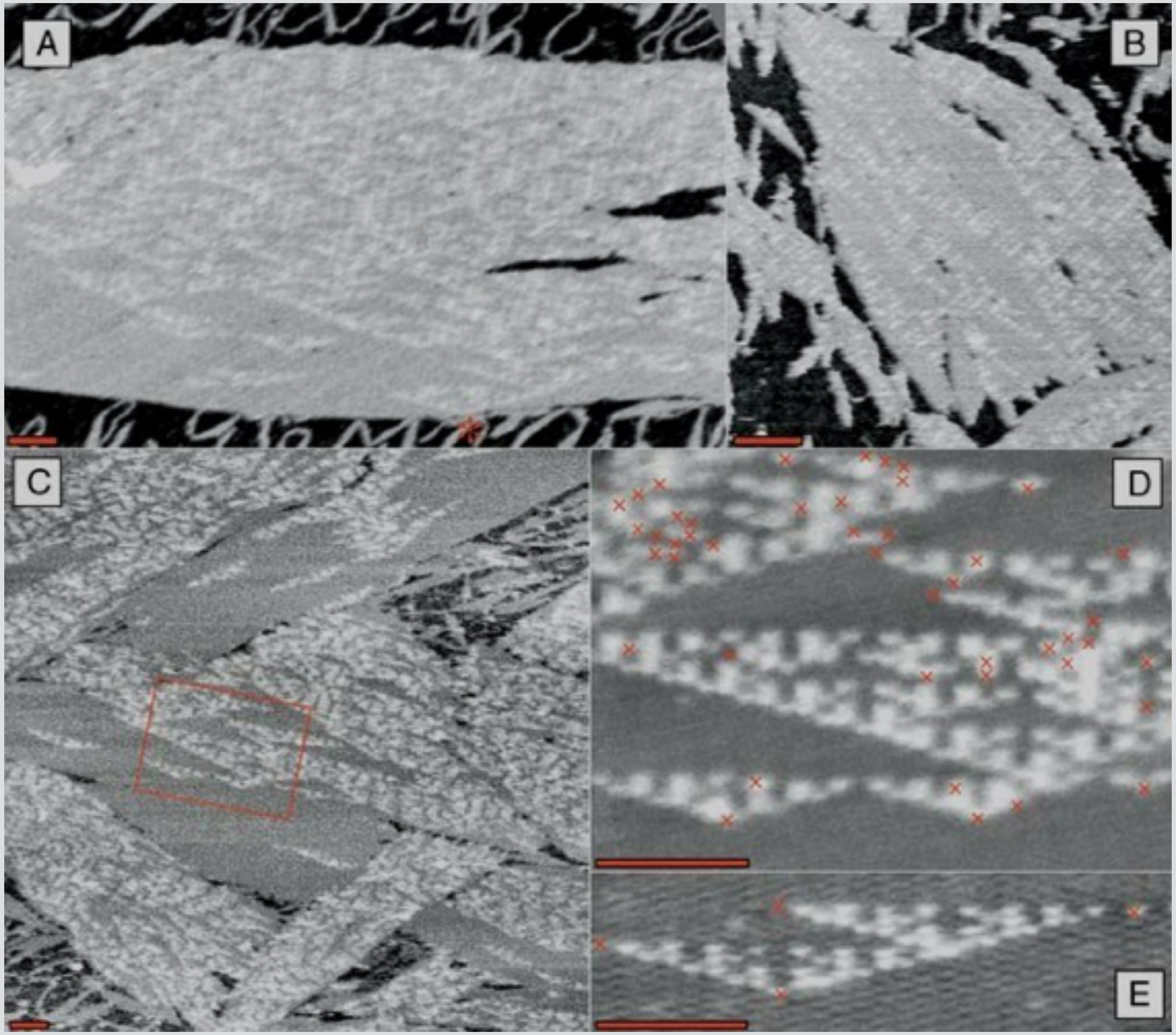
Temperature 2

Sierpinski triangle

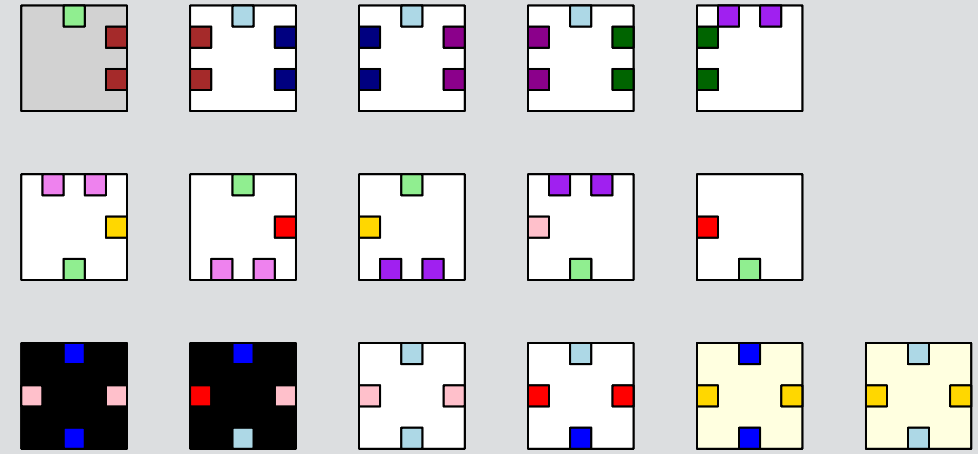
Temperature 2

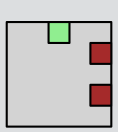
DNA Sierpinski triangles

[Papadakis, Rothemund, Winfree 2004]:

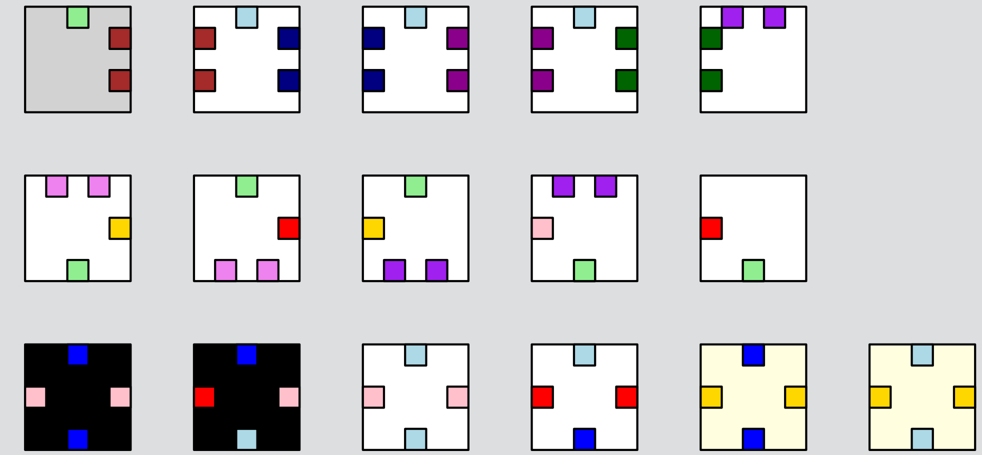


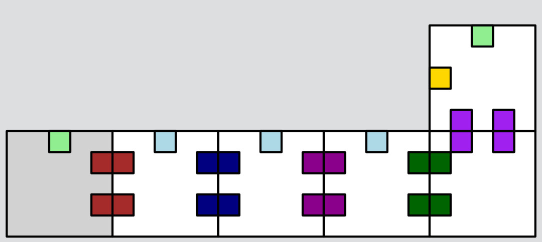
scale bars = 100 nm



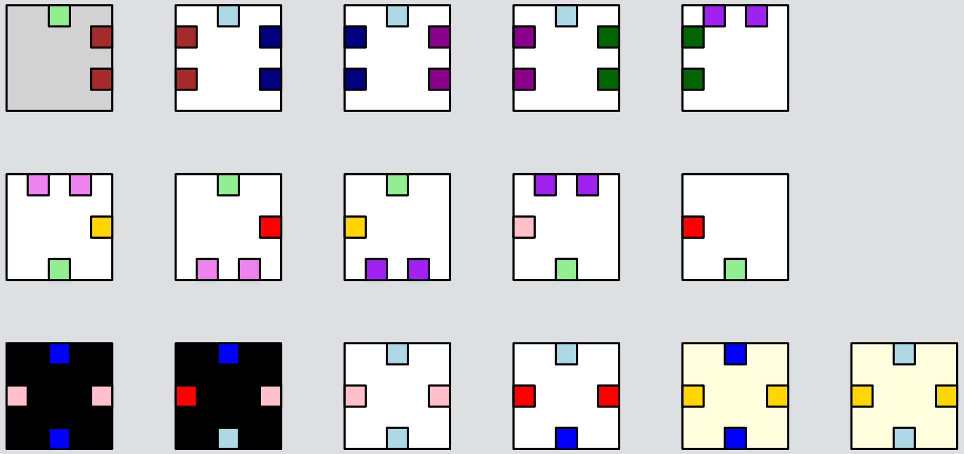


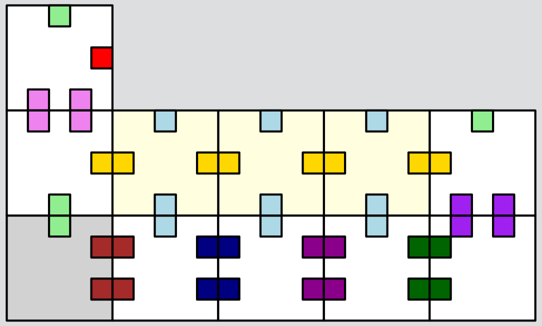
Temperature 2



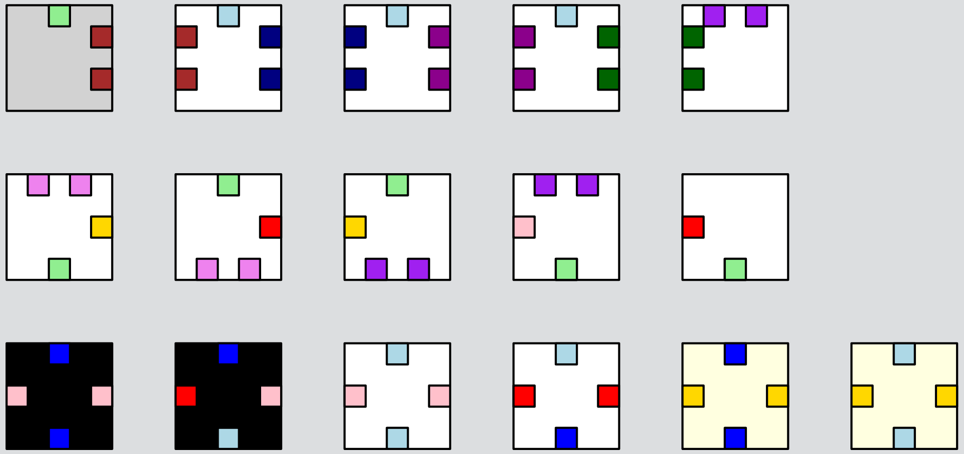


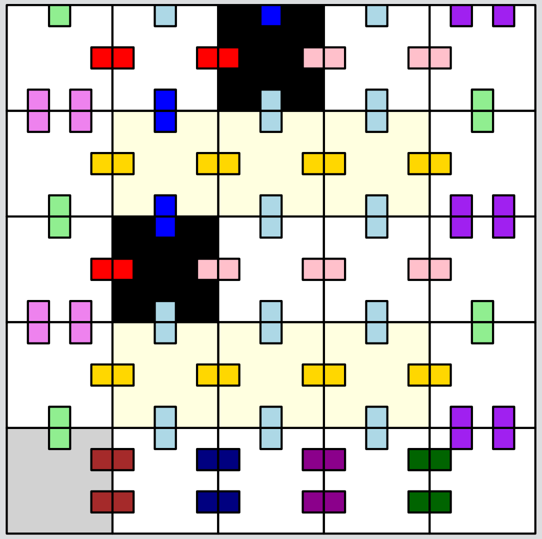
Temperature 2



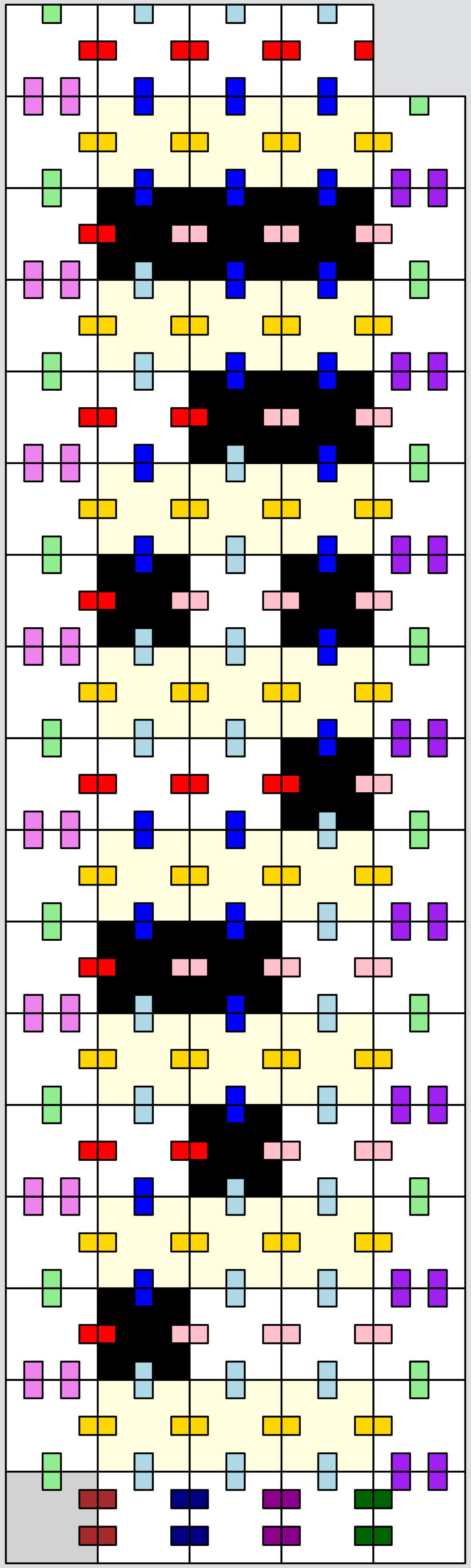


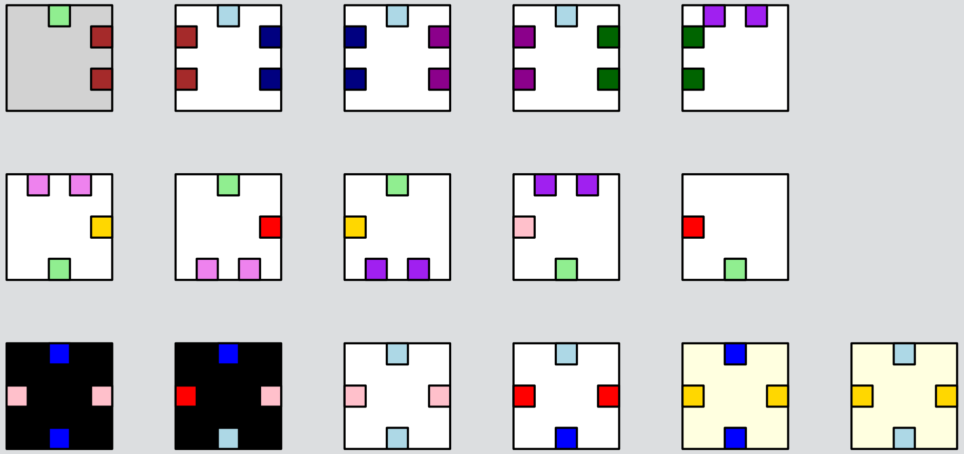
Temperature 2



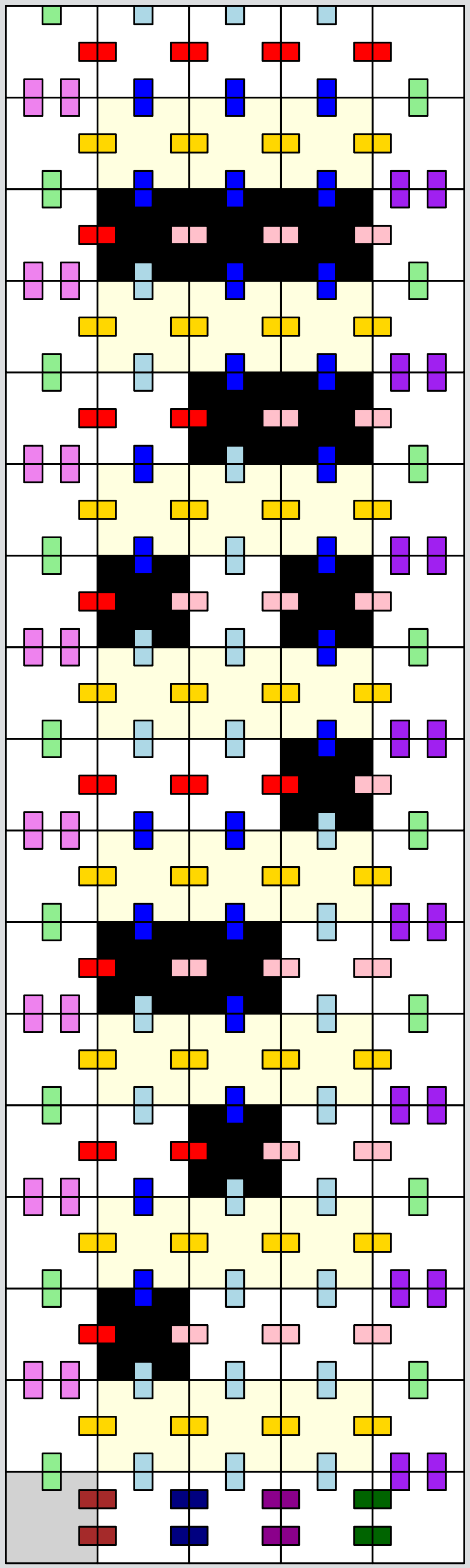


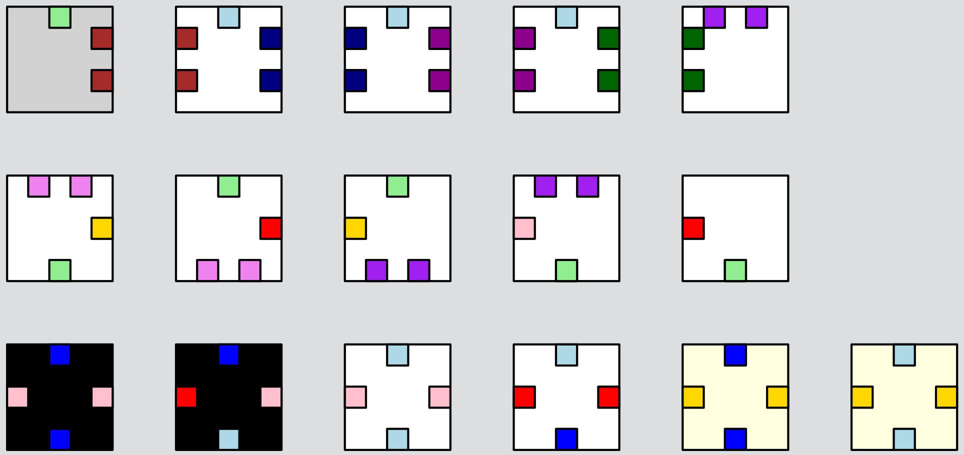
Temperature 2



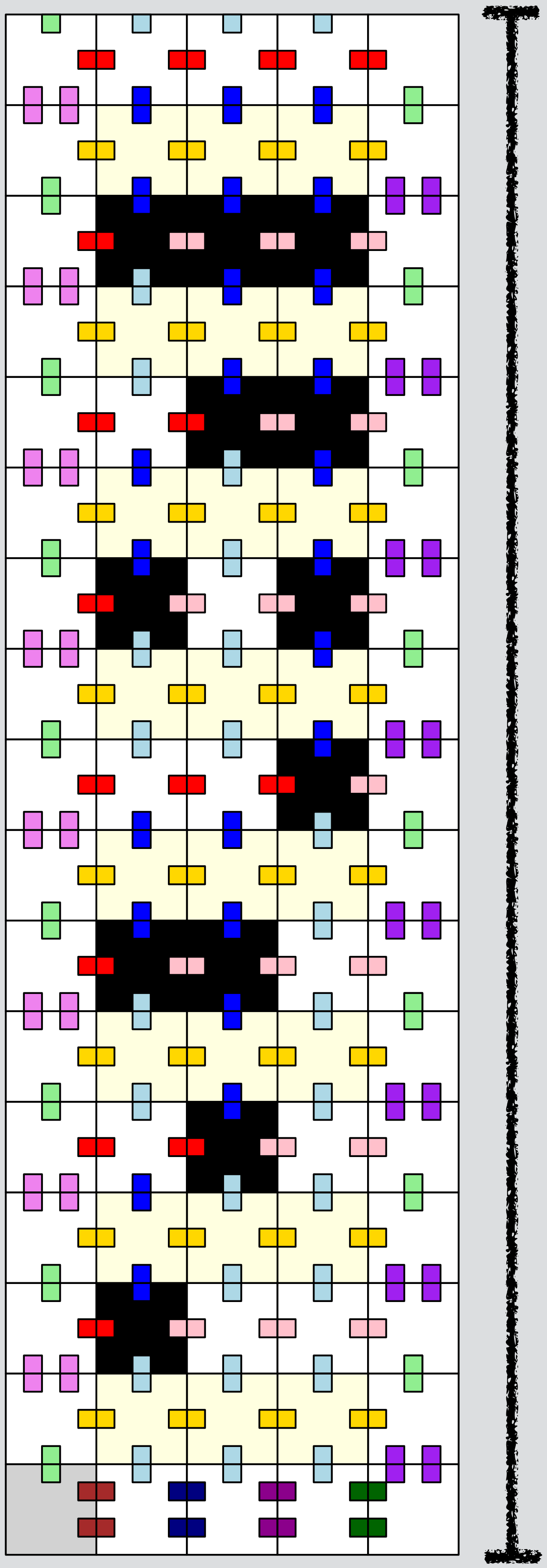


Temperature 2

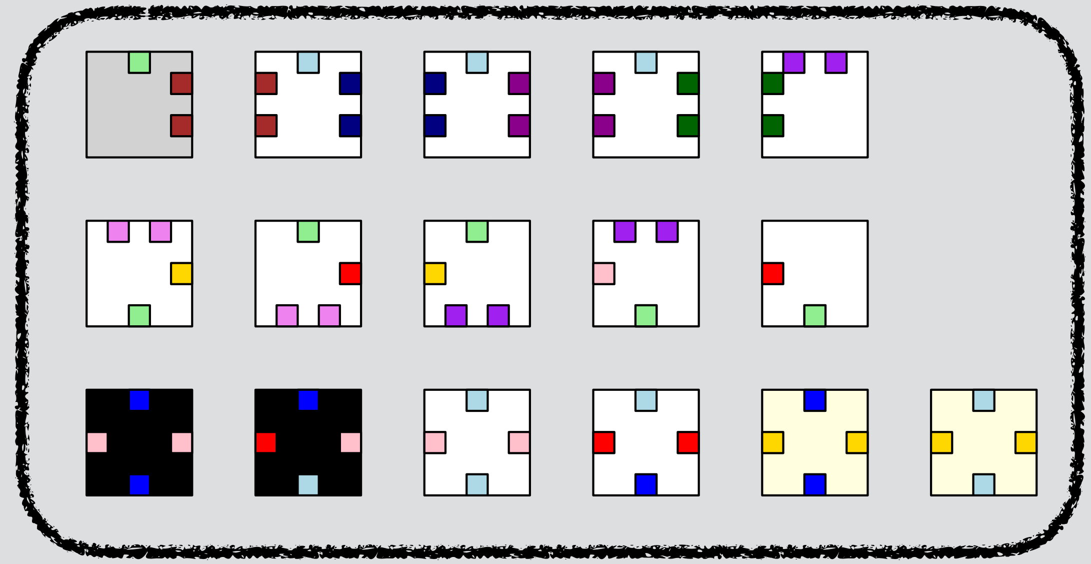




Temperature 2

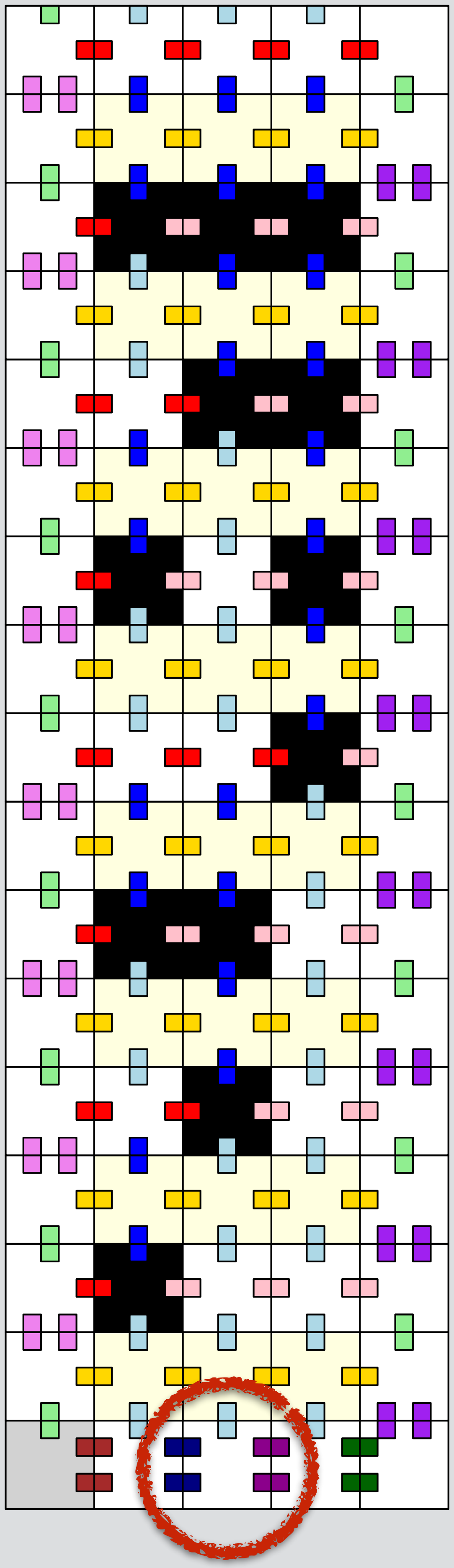


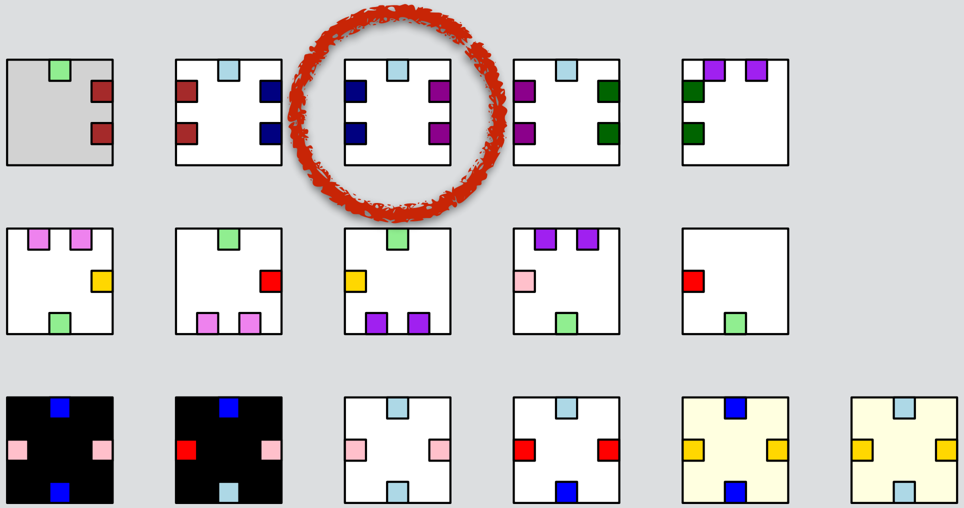
$\Theta(N)$



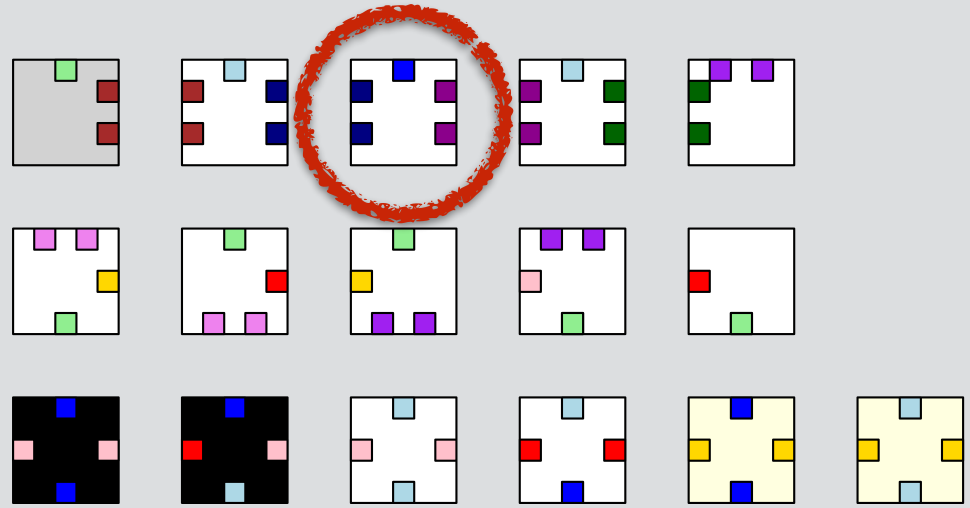
$\Theta(\log(N))$

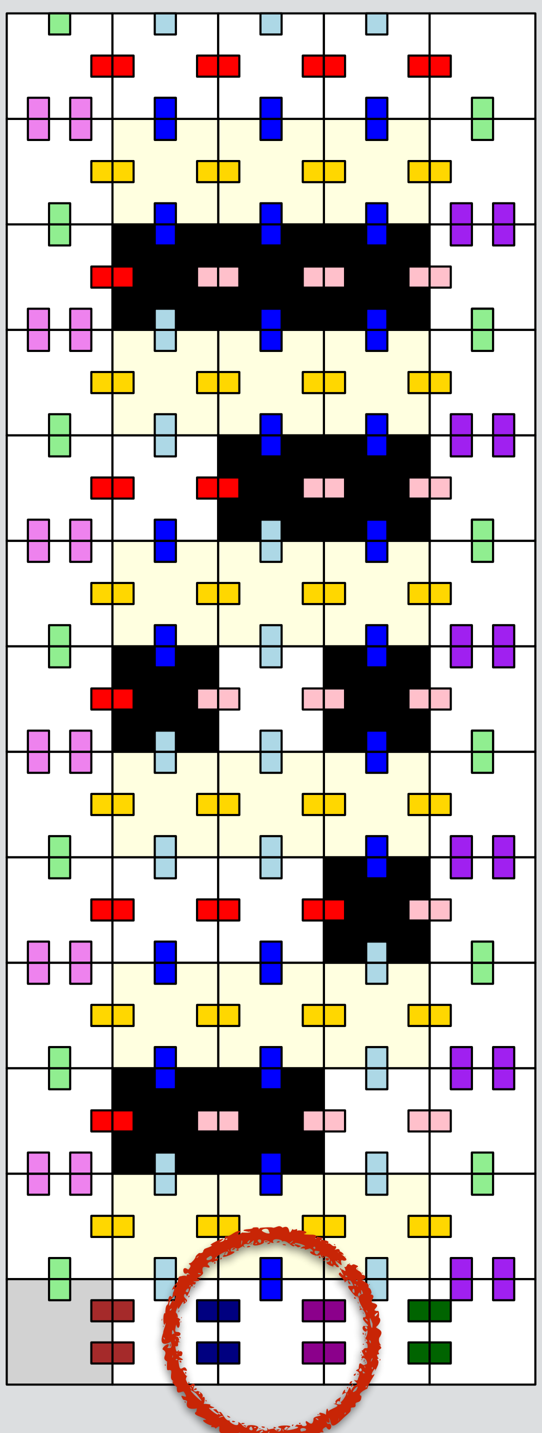
Temperature 2



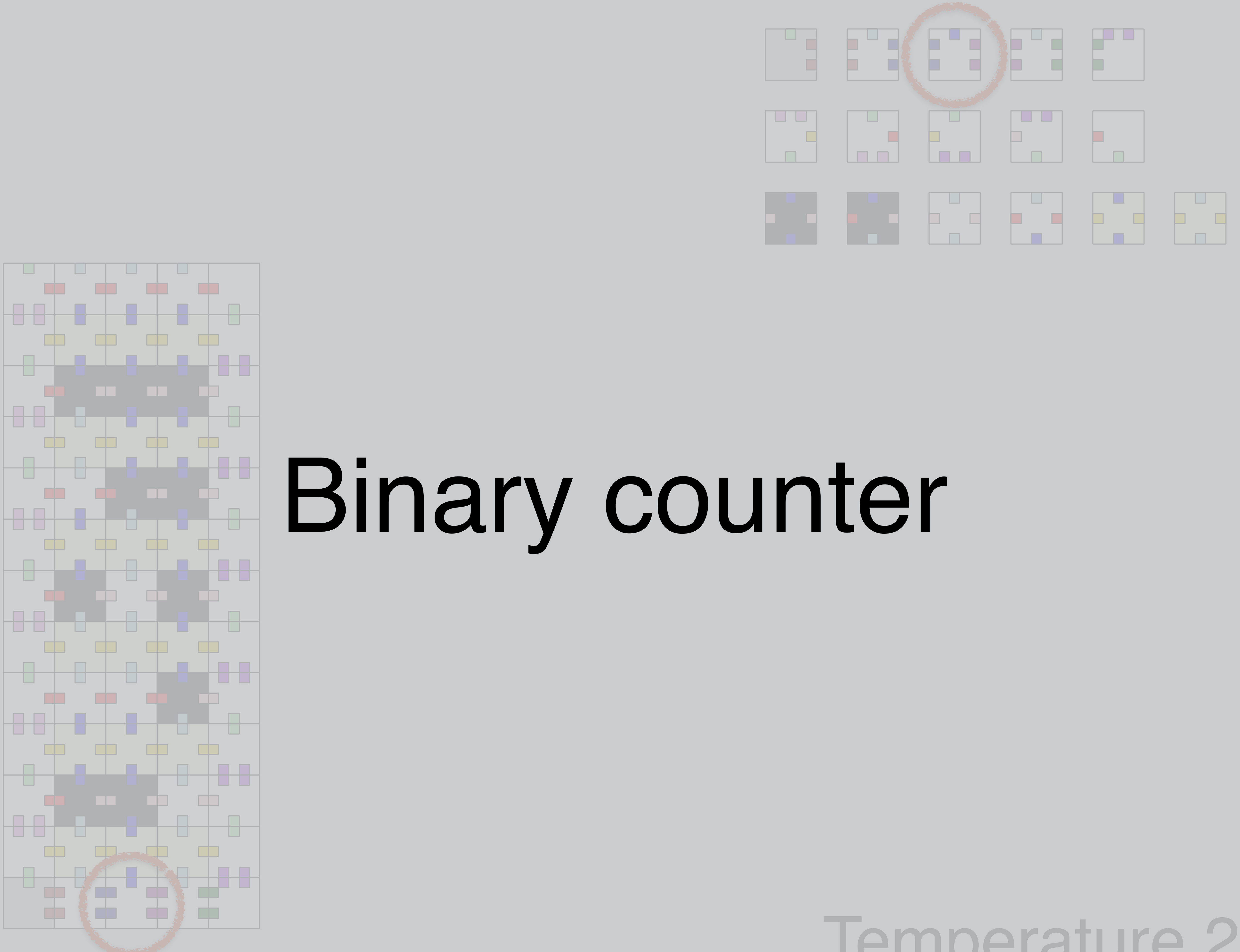


Temperature 2





Temperature 2

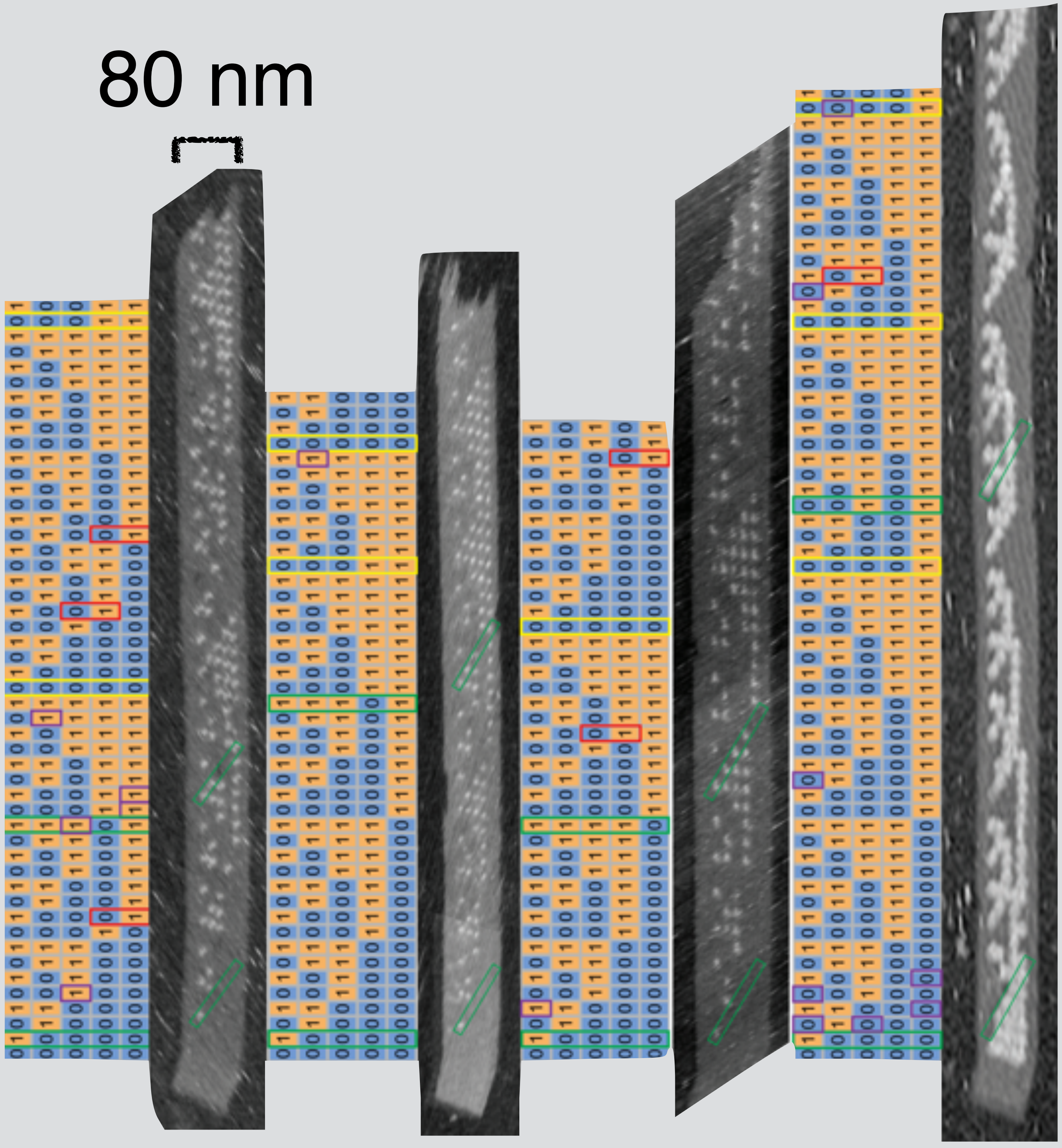


Binary counter

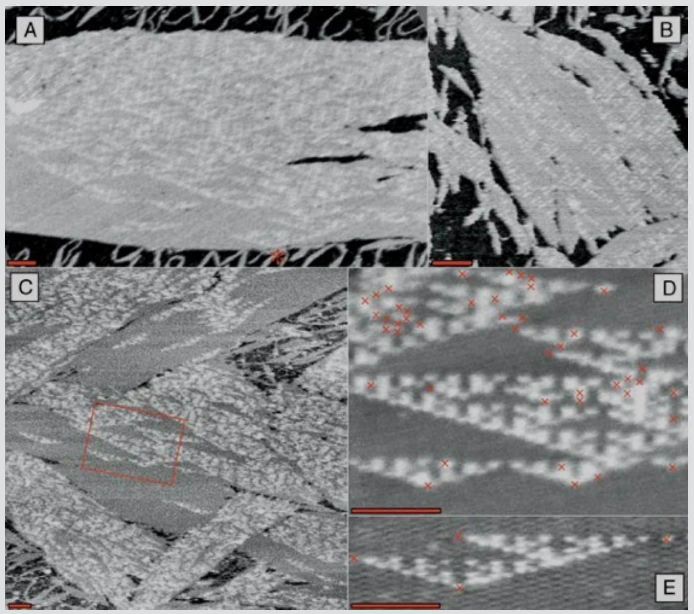
Temperature 2

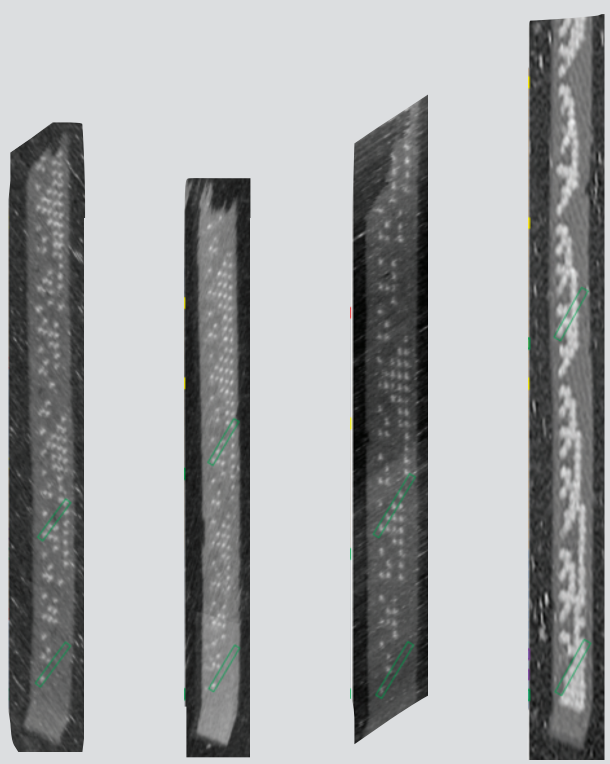
DNA binary counters

[Evans, 2014]

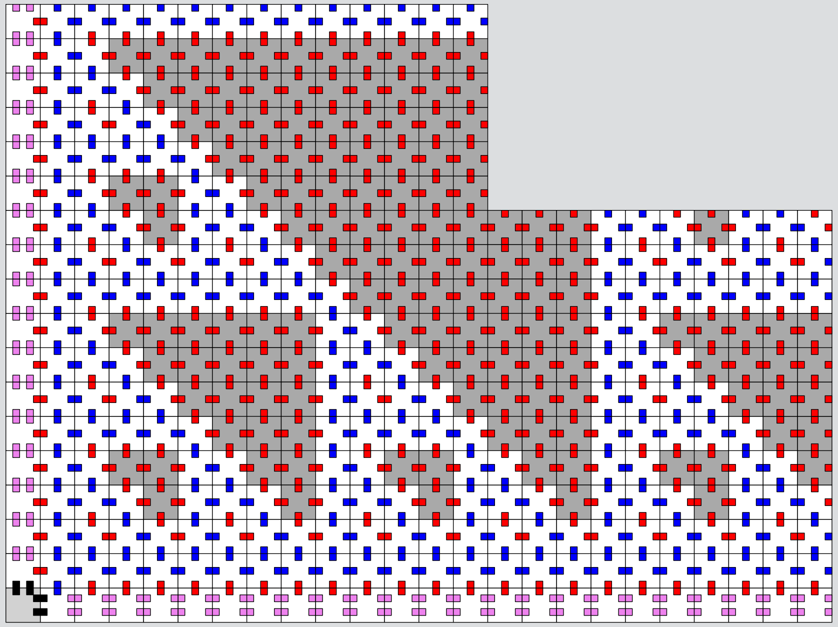


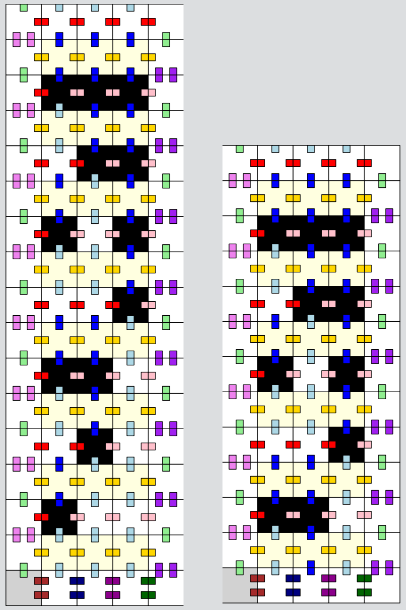
DNA tile self-assembly:



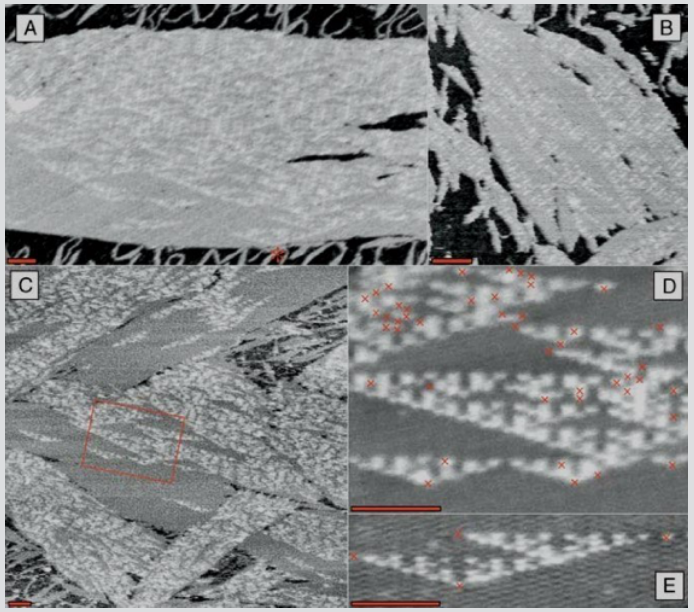


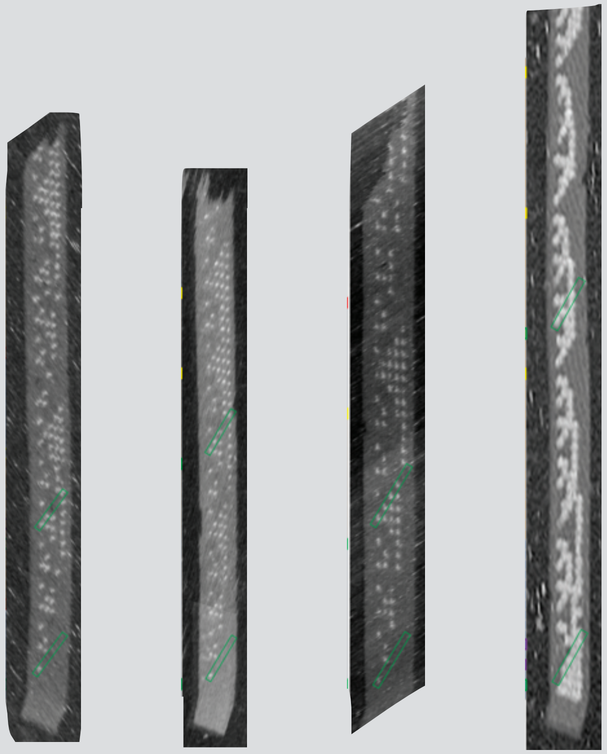
Tile self-assembly:



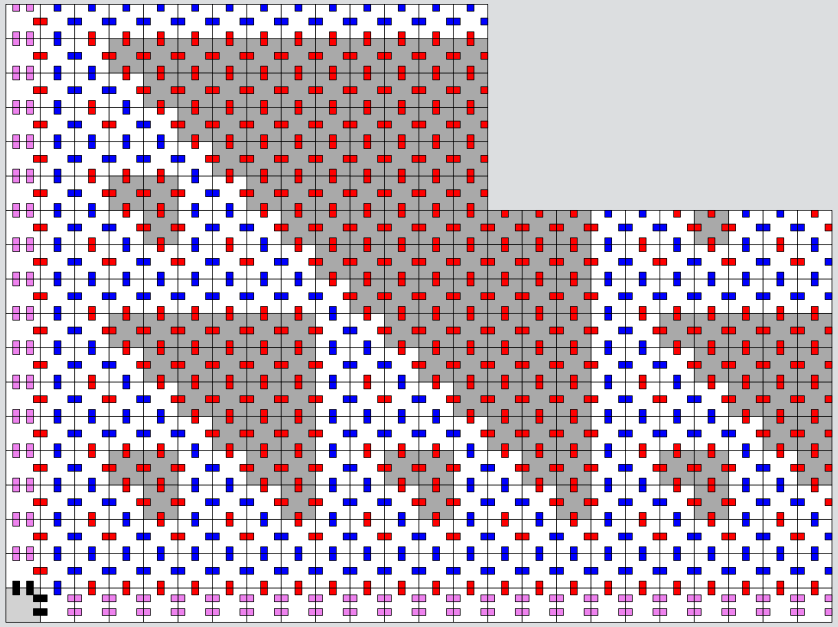


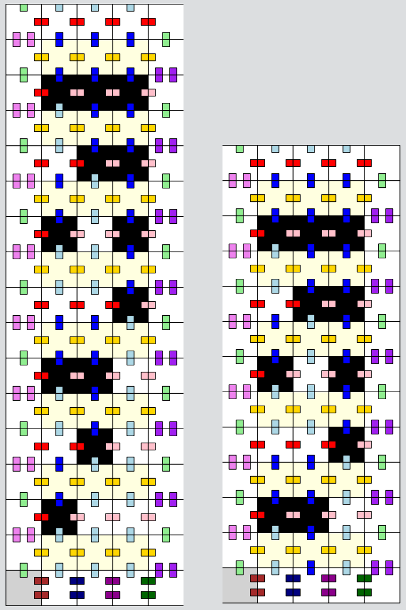
DNA tile self-assembly:

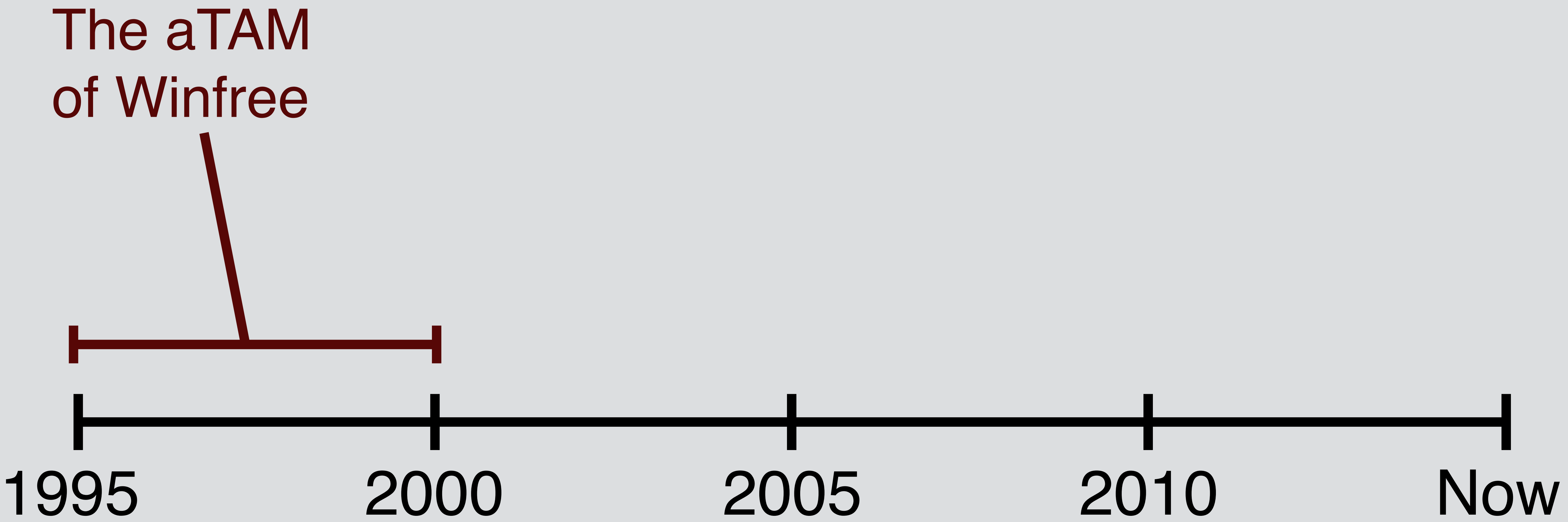


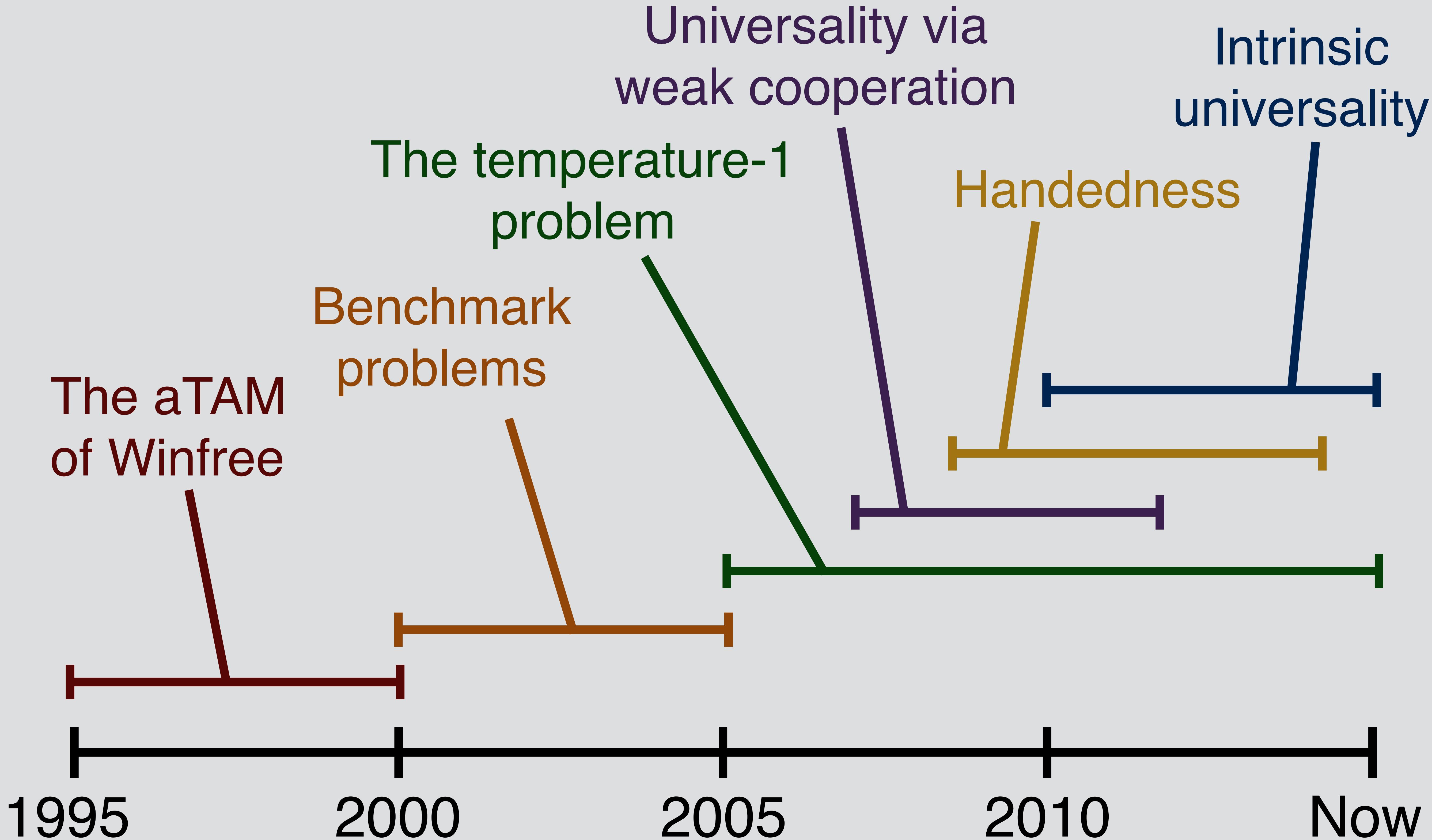


Tile self-assembly:

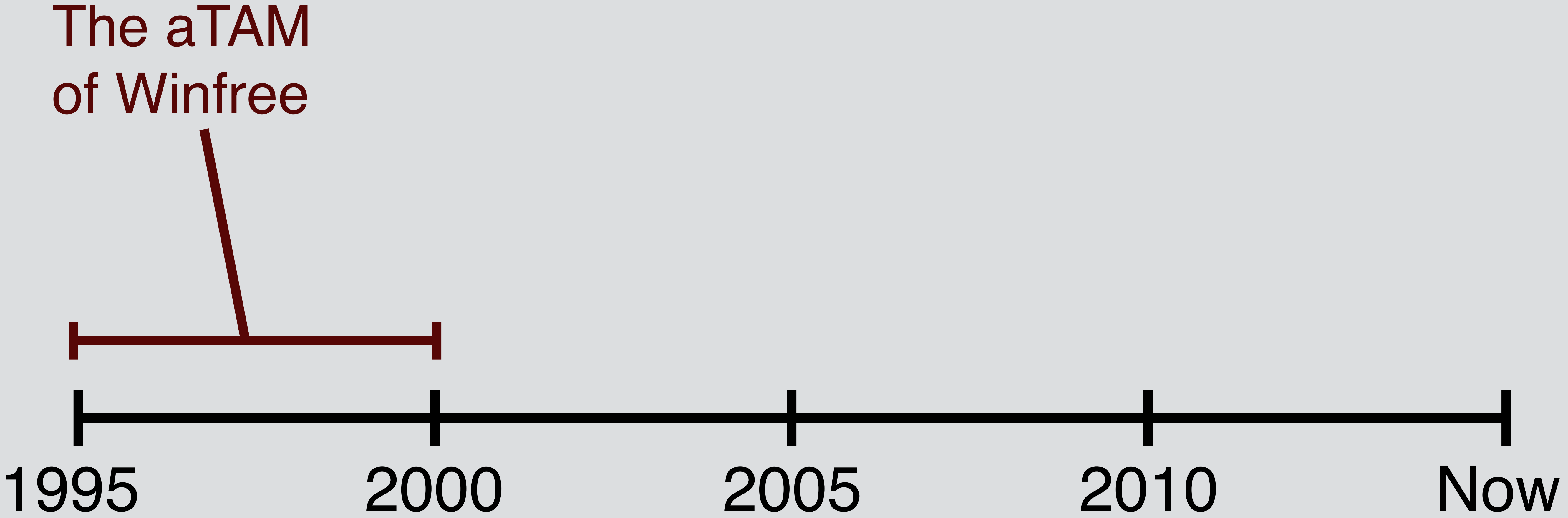





The aTAM
of Winfree
1995
2000
2005
2010
Now



Universality via weak cooperation
Intrinsic universality
The temperature-1 problem
Handedness
Benchmark problems
The aTAM of Winfree
1995
2000
2005
2010
Now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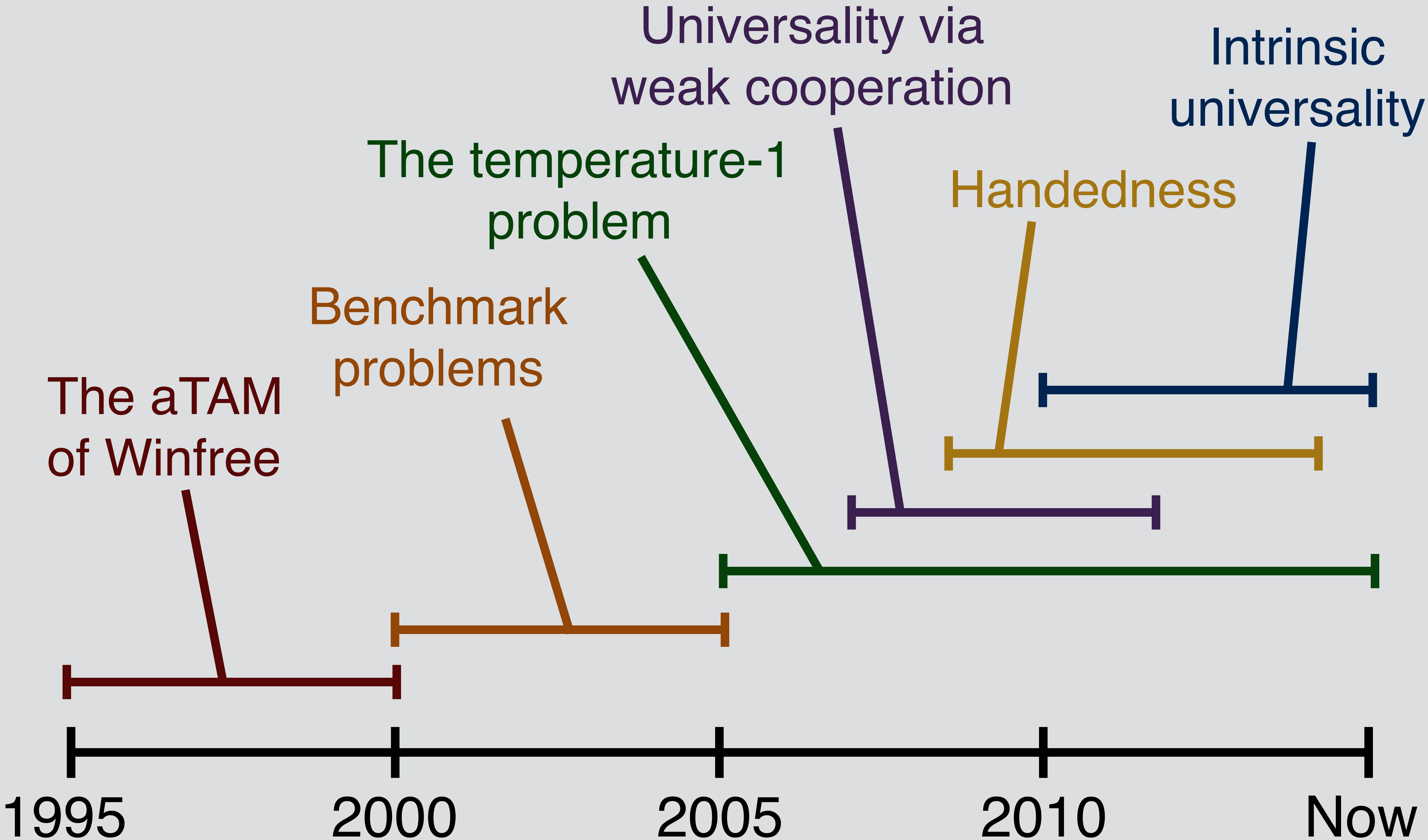
Universality via
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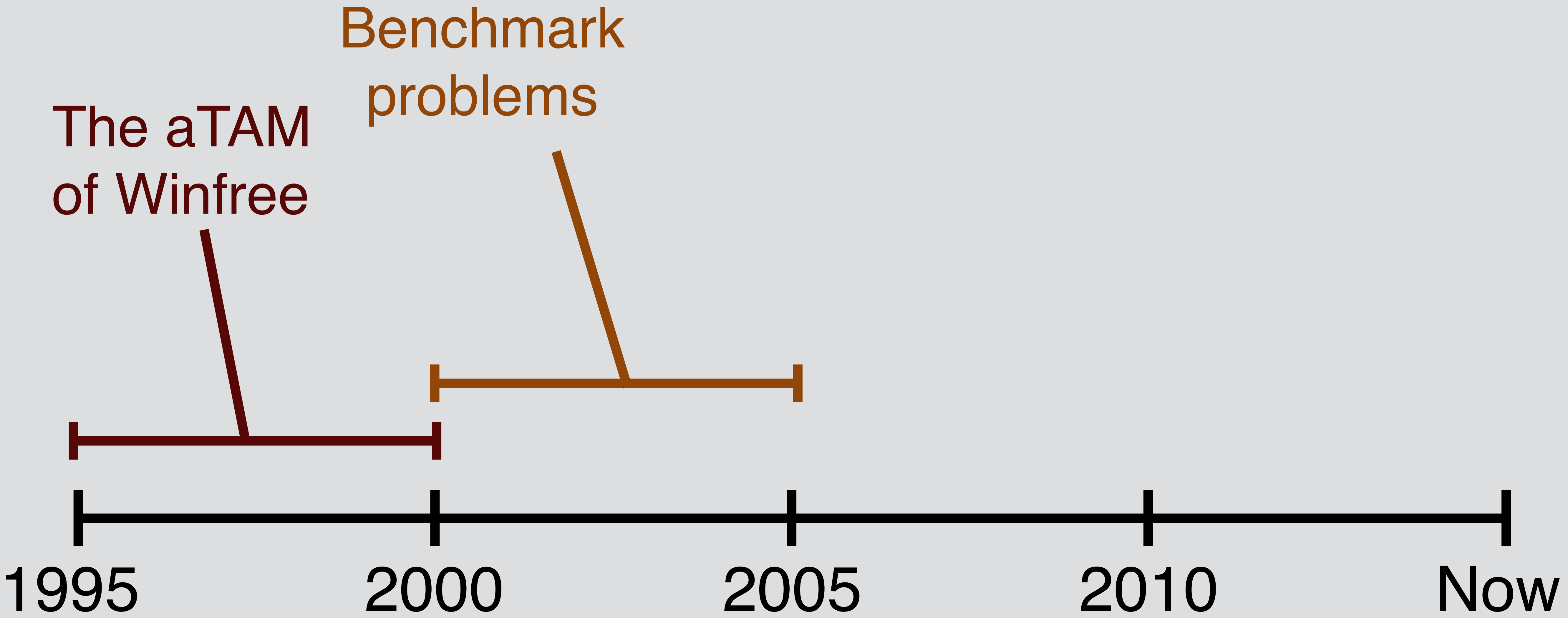
Benchmark problems
The aTAM of Winfree
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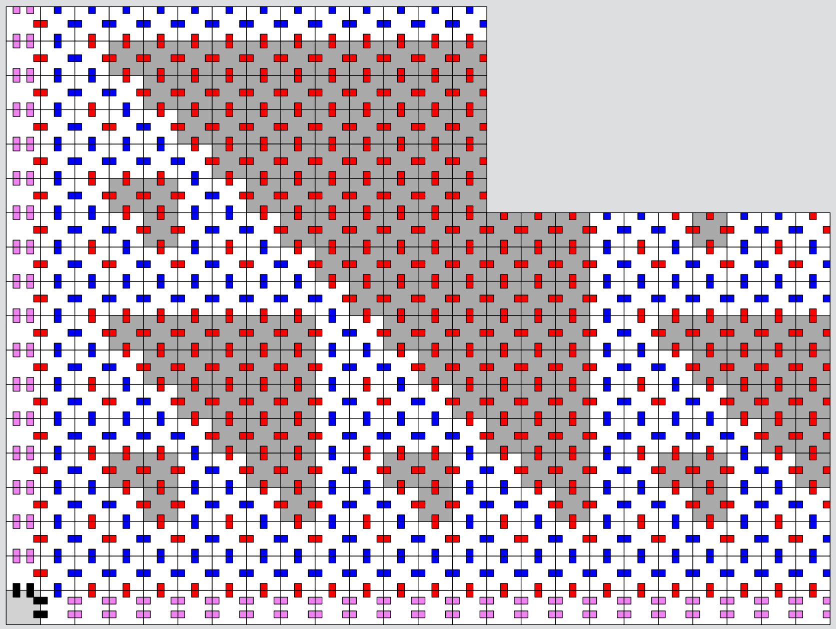
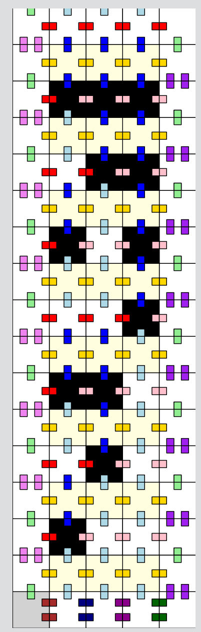
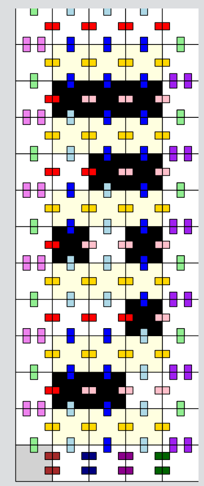






aTAM is “capable”

What is a “capable” model
of self-assembly?

The benchmarks of a capable self-assembly model

The benchmarks of a capable self-assembly model

Algorithmic behavior $\xrightarrow{\text{demonstrated by}}$ Universal computation

The benchmarks of a capable self-assembly model

Usable

Algorithmic behavior

demonstrated by →

Efficient NxN square assembly

Universal computation

The benchmarks of a capable self-assembly model

Usable
Algorithmic behavior

demonstrated by →

Efficient NxN square assembly
Universal computation

Efficient = few tile types

(program size, time)

The benchmarks of a capable self-assembly model

Algorithmic behavior $\xrightarrow{\text{demonstrated by}}$ Universal computation

Usable algorithmic behavior $\xrightarrow{\text{demonstrated by}}$ Efficient NxN square assembly

few tile types

The benchmarks of a capable self-assembly model

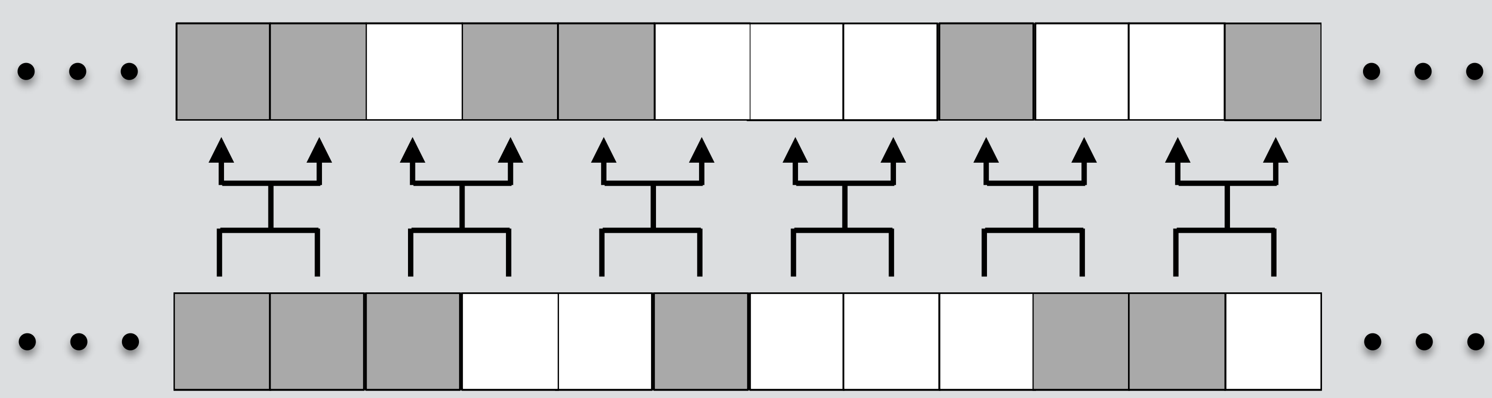
Algorithmic behavior $\xrightarrow{\text{demonstrated by}}$ Universal computation

Usable algorithmic behavior $\xrightarrow{\text{demonstrated by}}$ few tile types Efficient NxN square assembly

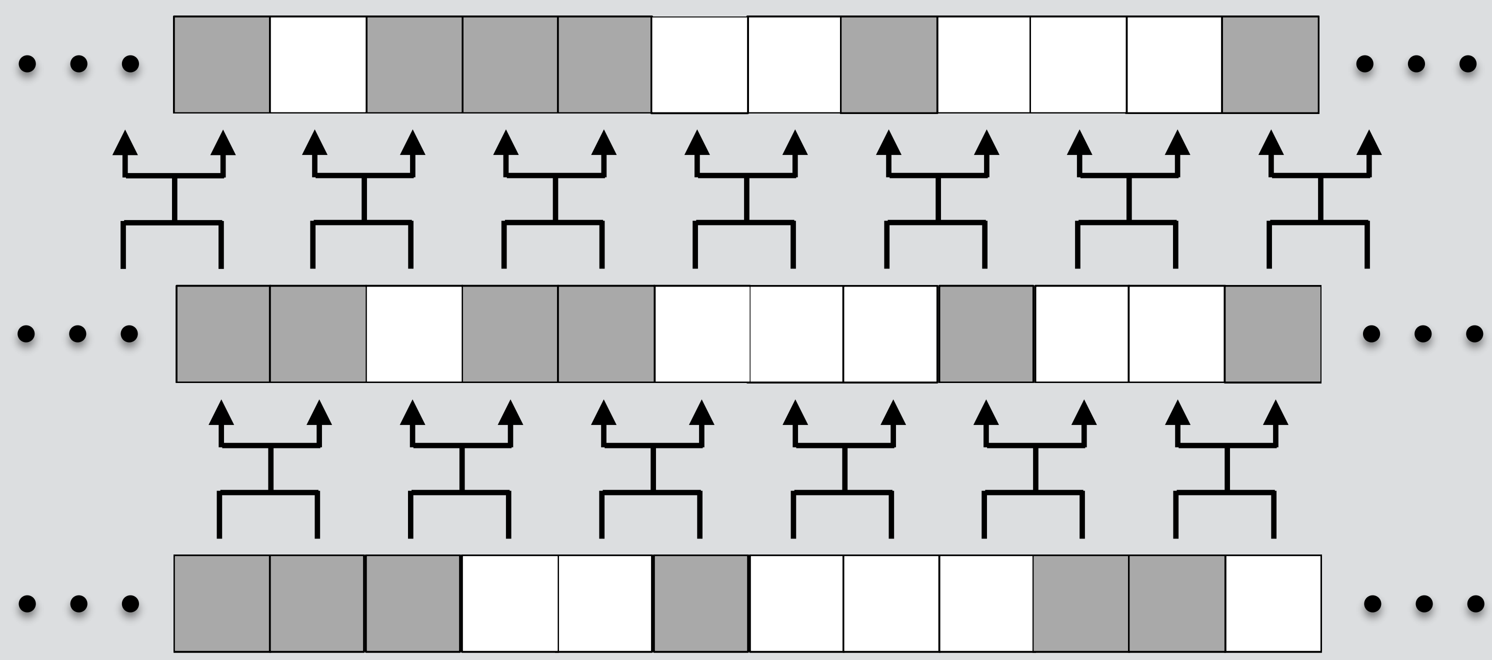
Blocked cellular automata

Blocked cellular automata

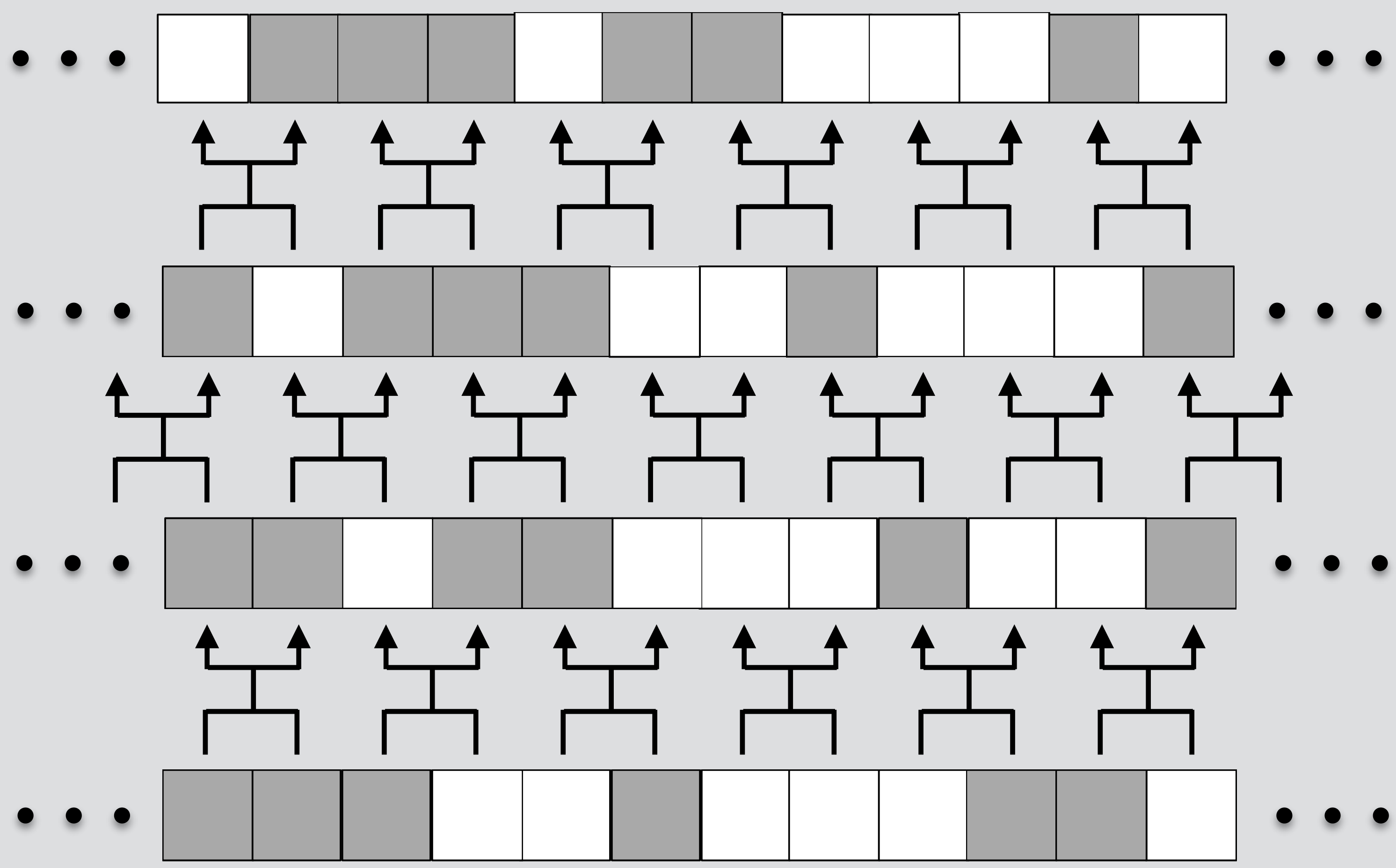
Blocked cellular automata



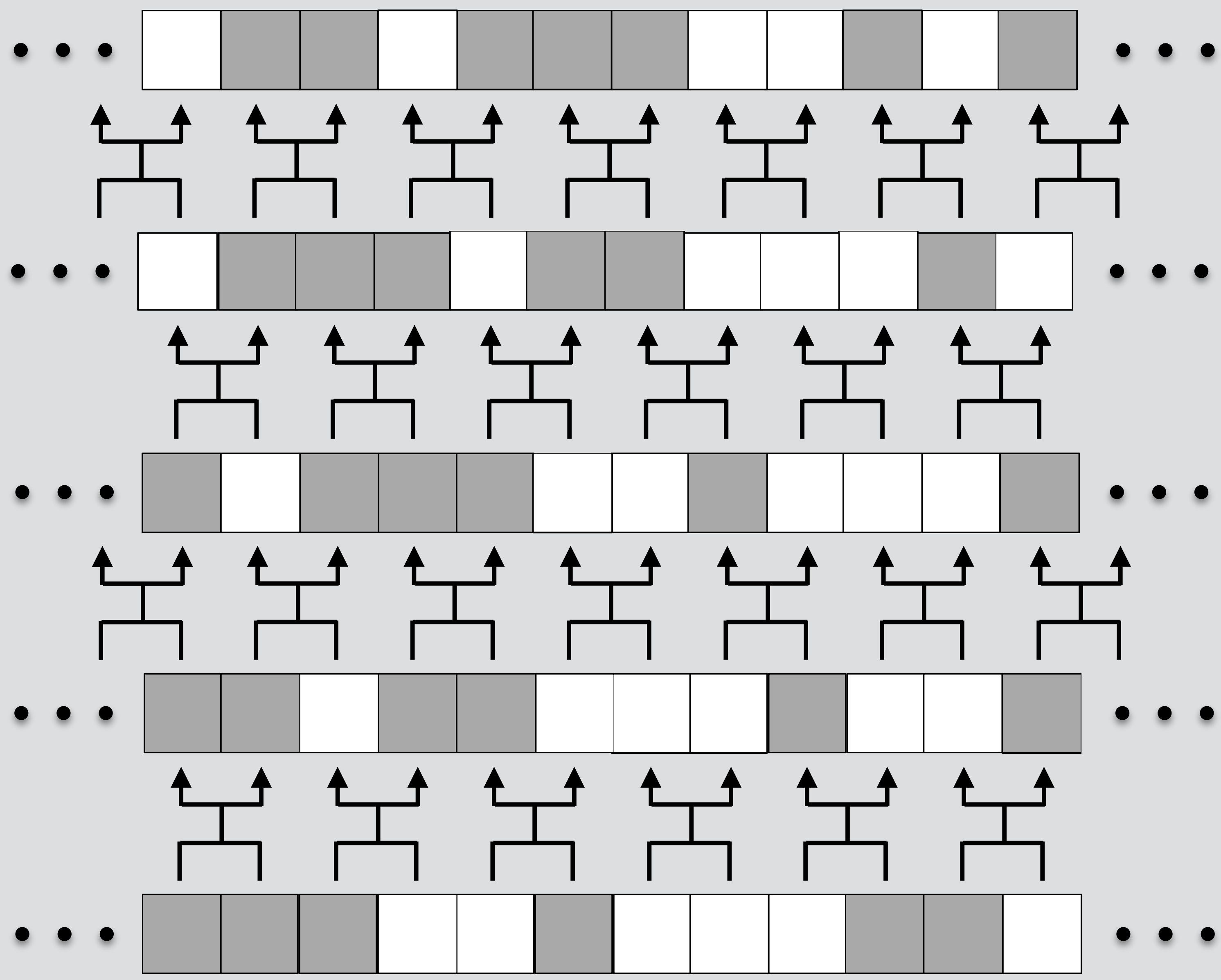
Blocked cellular automata



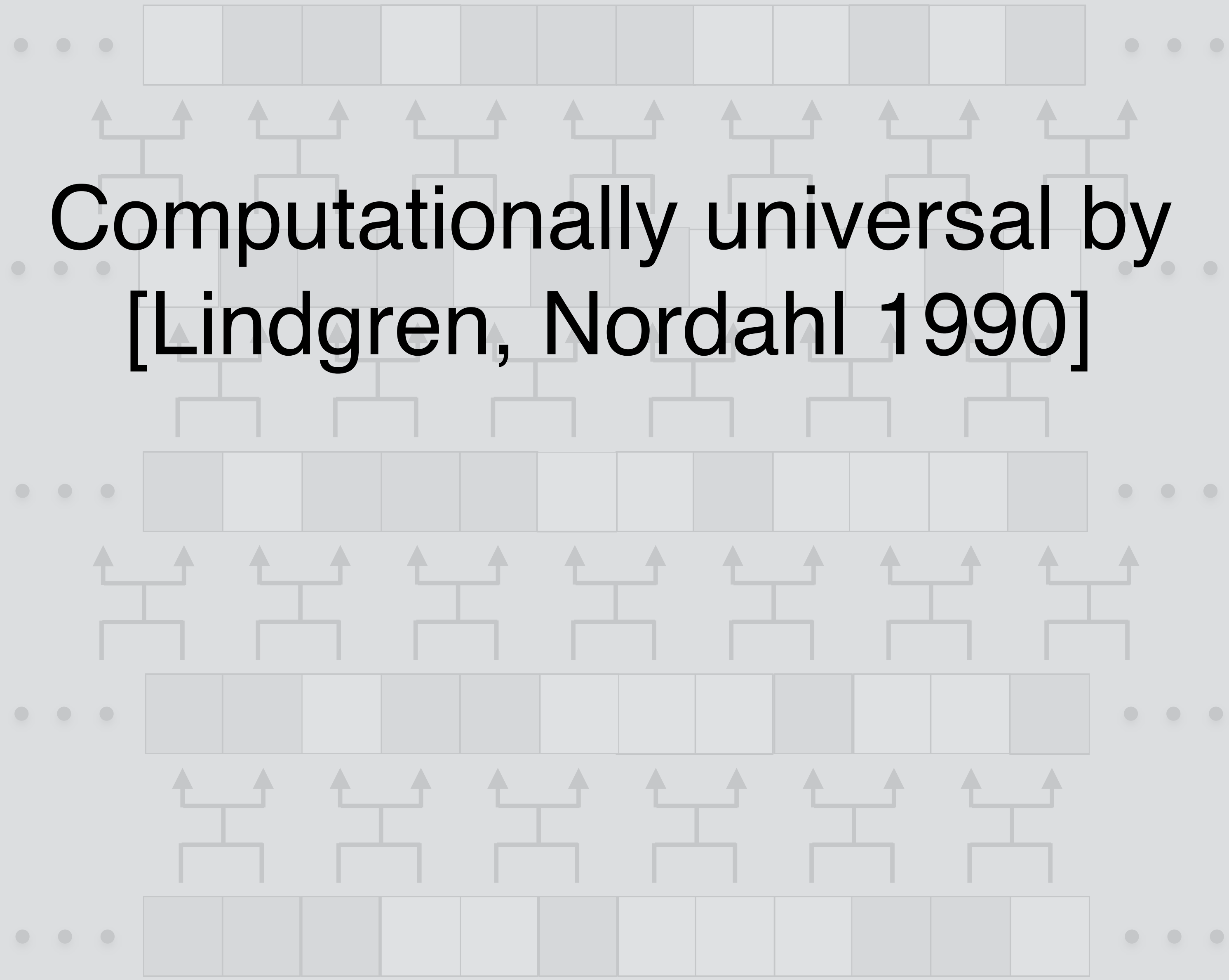
Blocked cellular automata



Blocked cellular automata

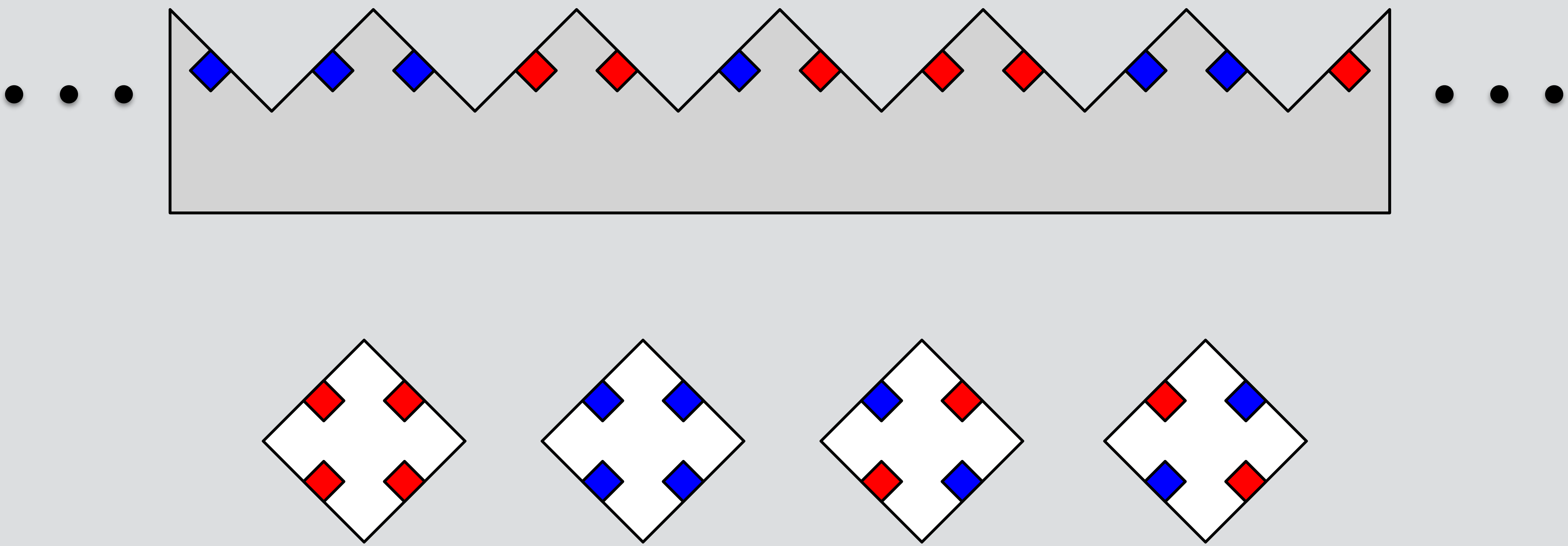


Blocked cellular automata



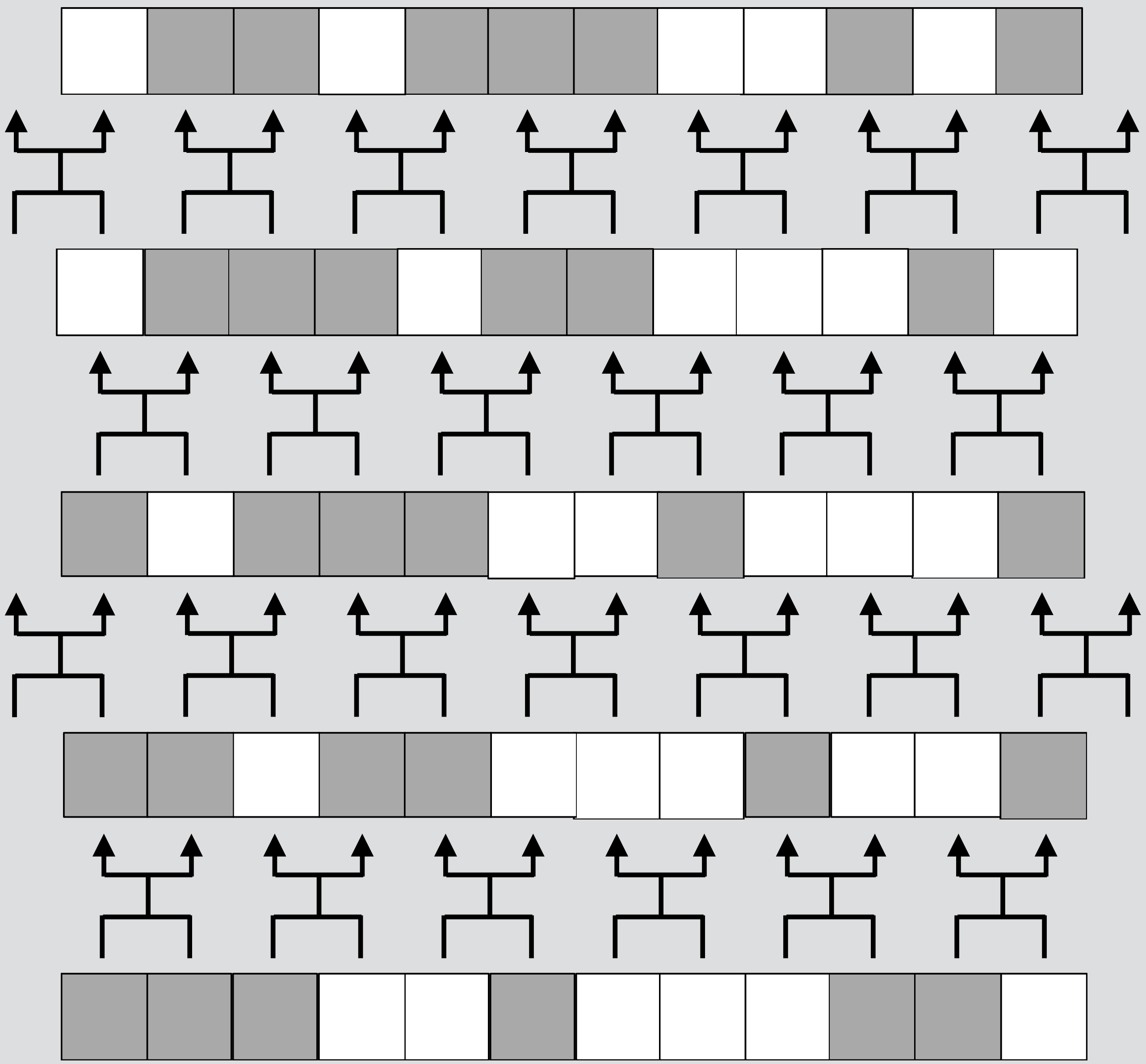
Computationally universal by
[Lindgren, Nordahl 1990]

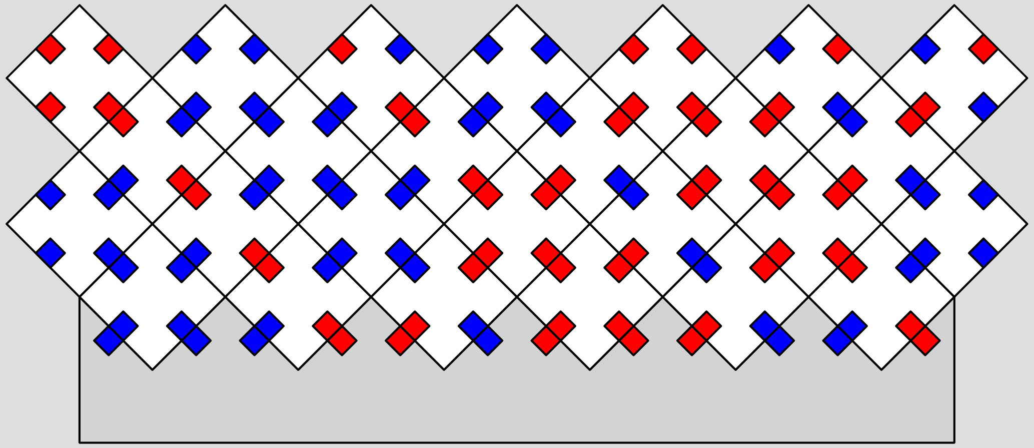
Universal computation (via blocked CA simulation)



Temperature 2

Universal computation
(via blocked CA simulation)
[Winfree 1998]

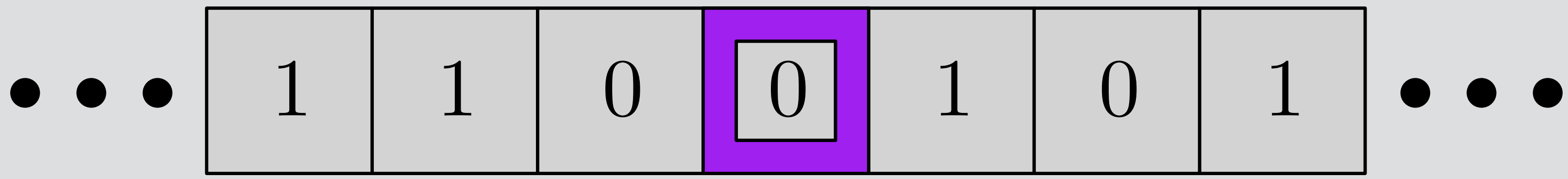




Temperature 2

Universal computation
(solution by “zig-zag” TM simulation)

Universal computation
(solution by “zig-zag” TM simulation)



Universal computation
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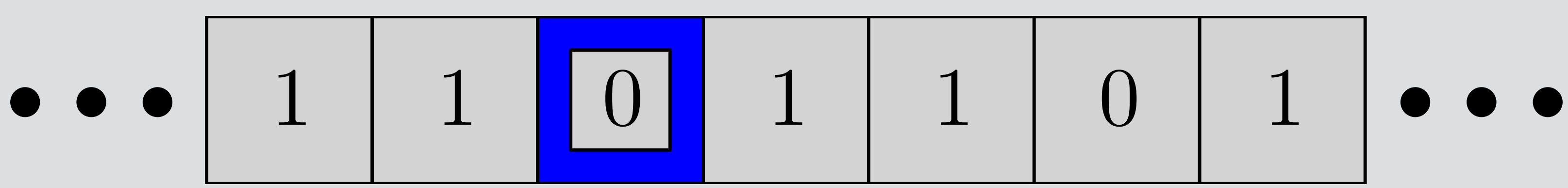
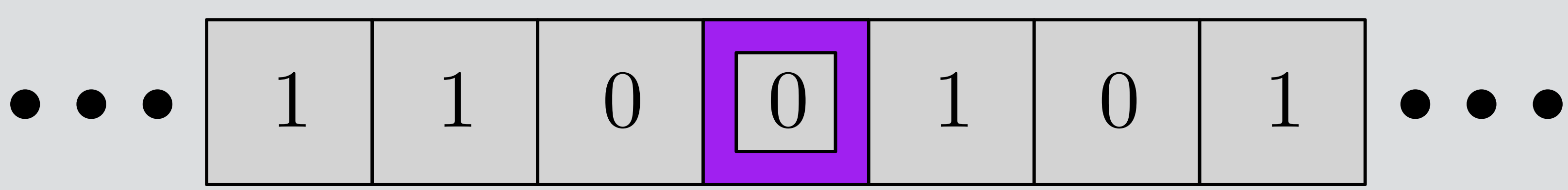
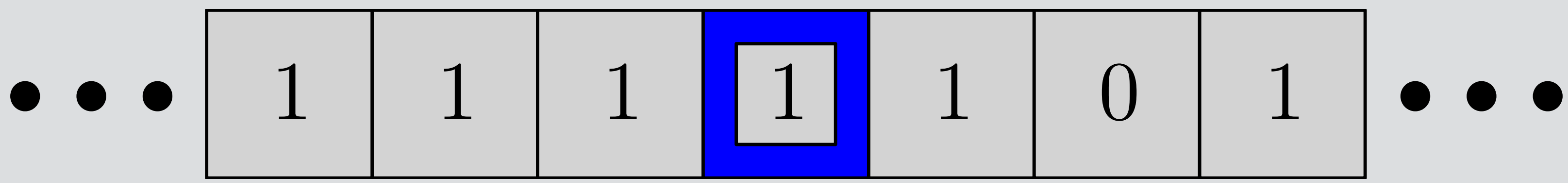


“write 1, move left, change to s_1”



Universal computation
(solution by “zig-zag” TM simulation)



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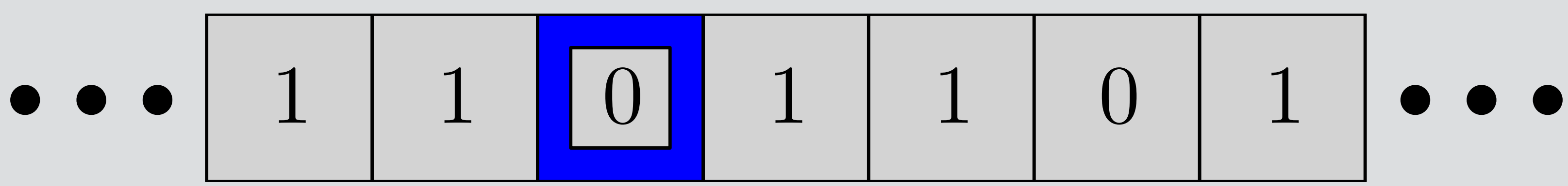

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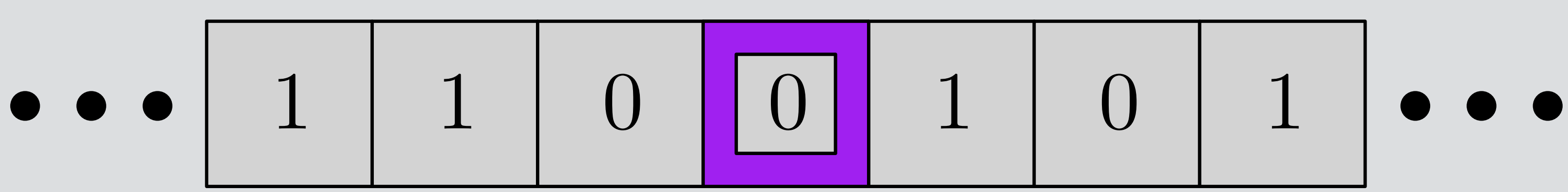

Universal computation
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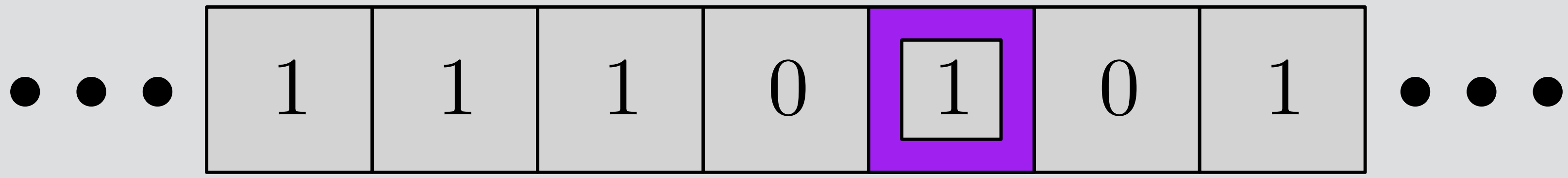
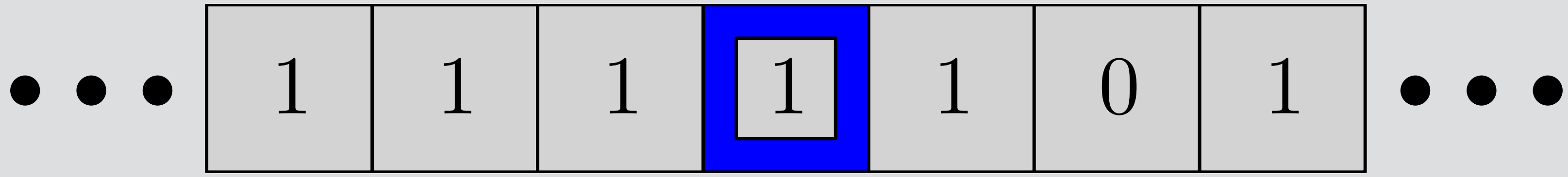


“write 0, move right, change to s_0”



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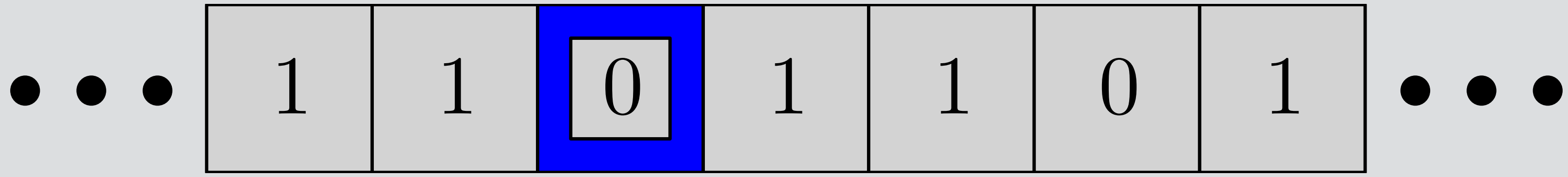

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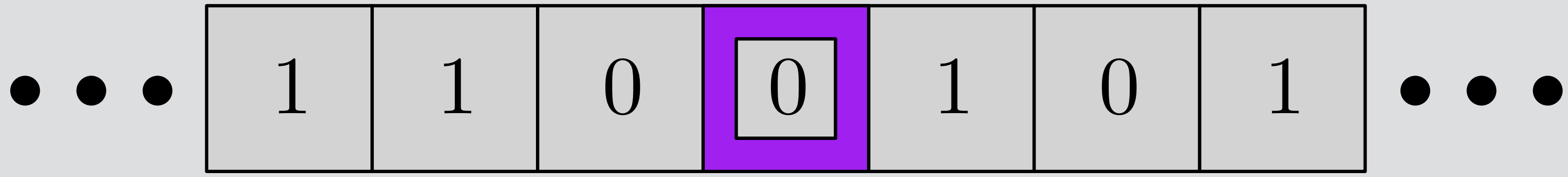

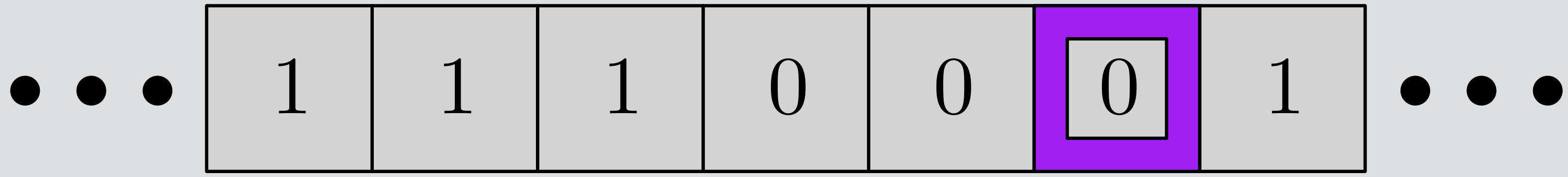

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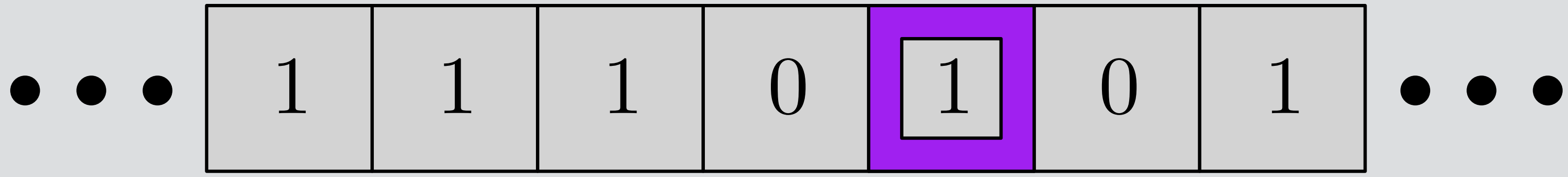

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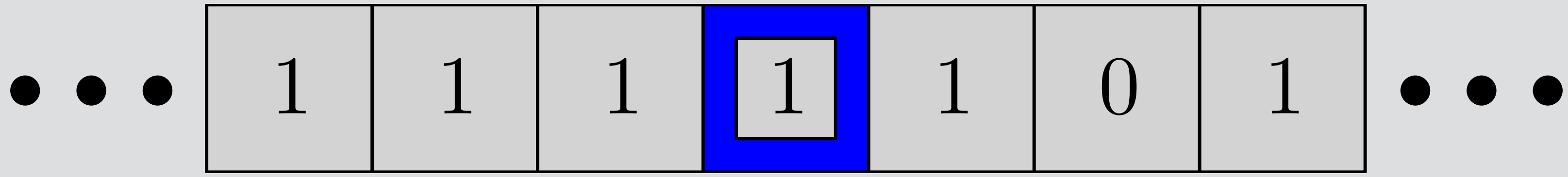

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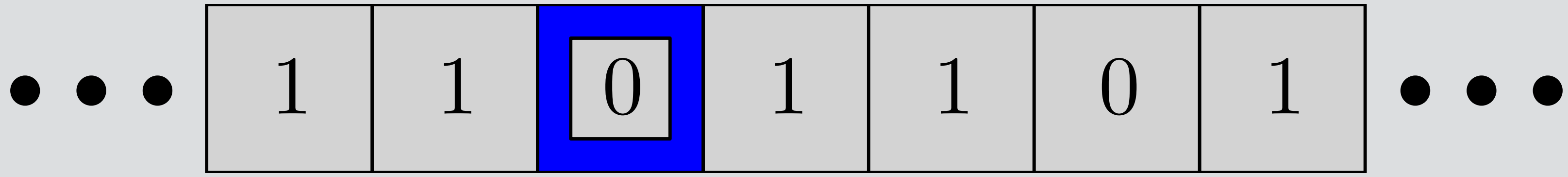

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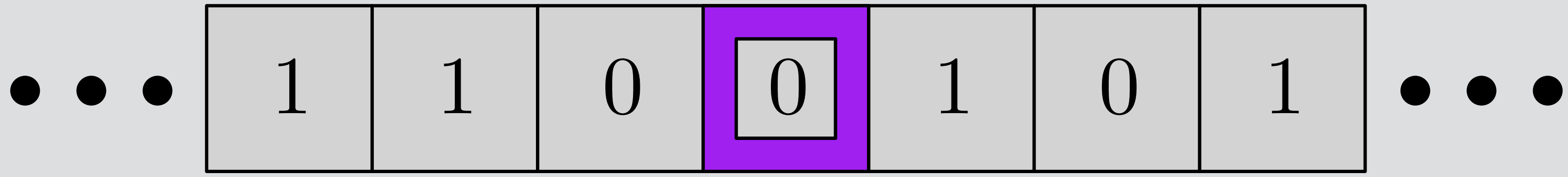
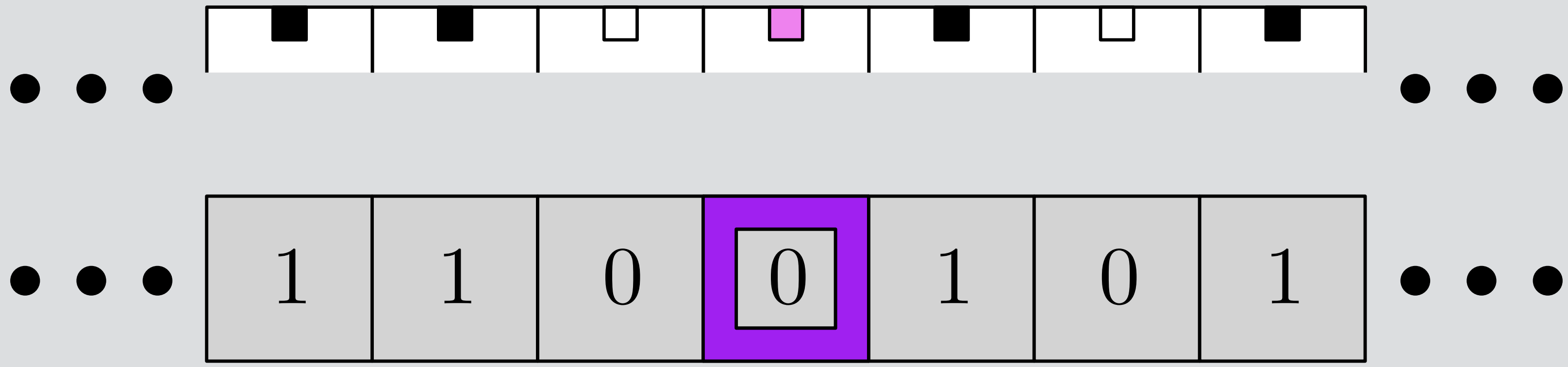
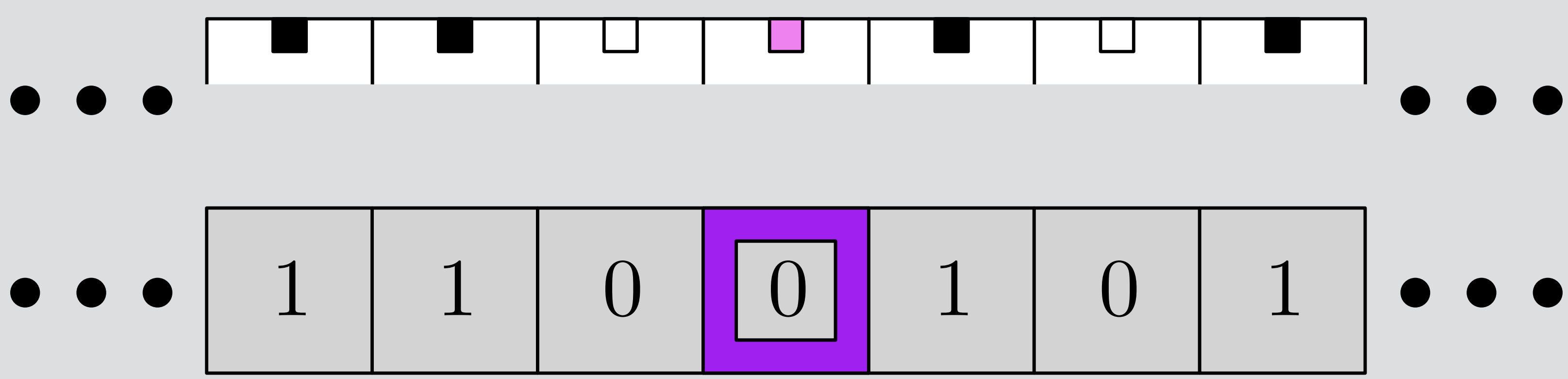


Universal computation
(solution by “zig-zag” TM simulation)



Temperature 2

Universal computation
(solution by “zig-zag” TM simulation)



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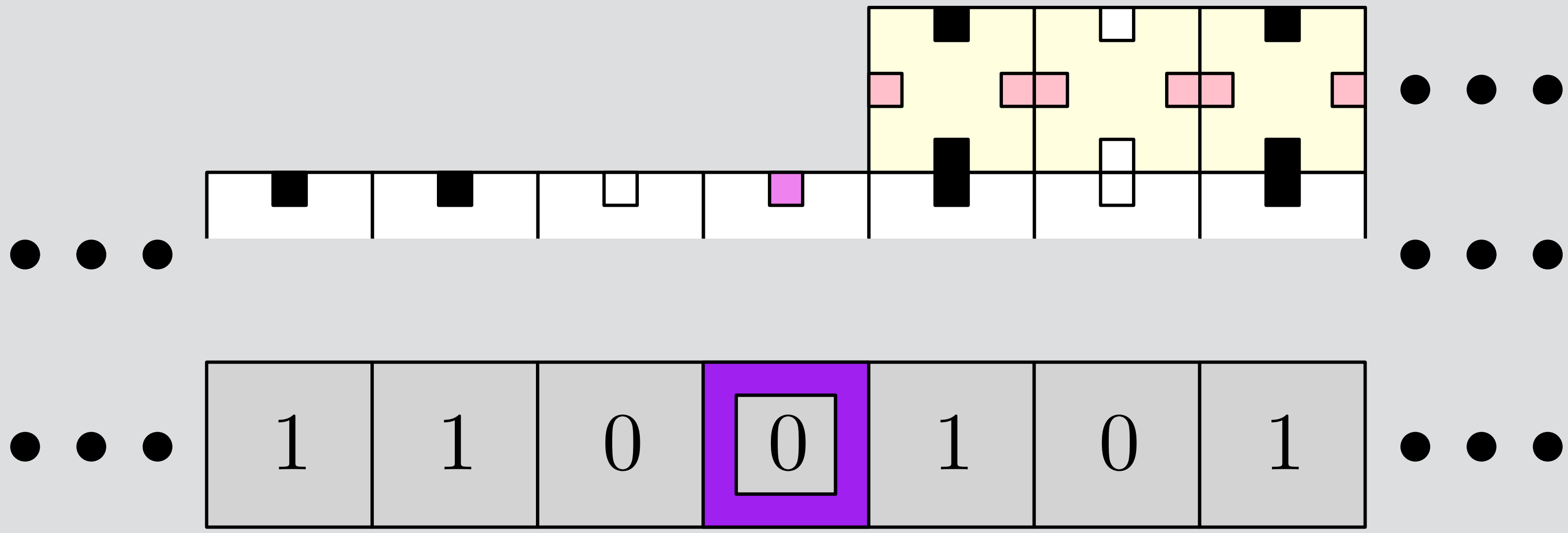

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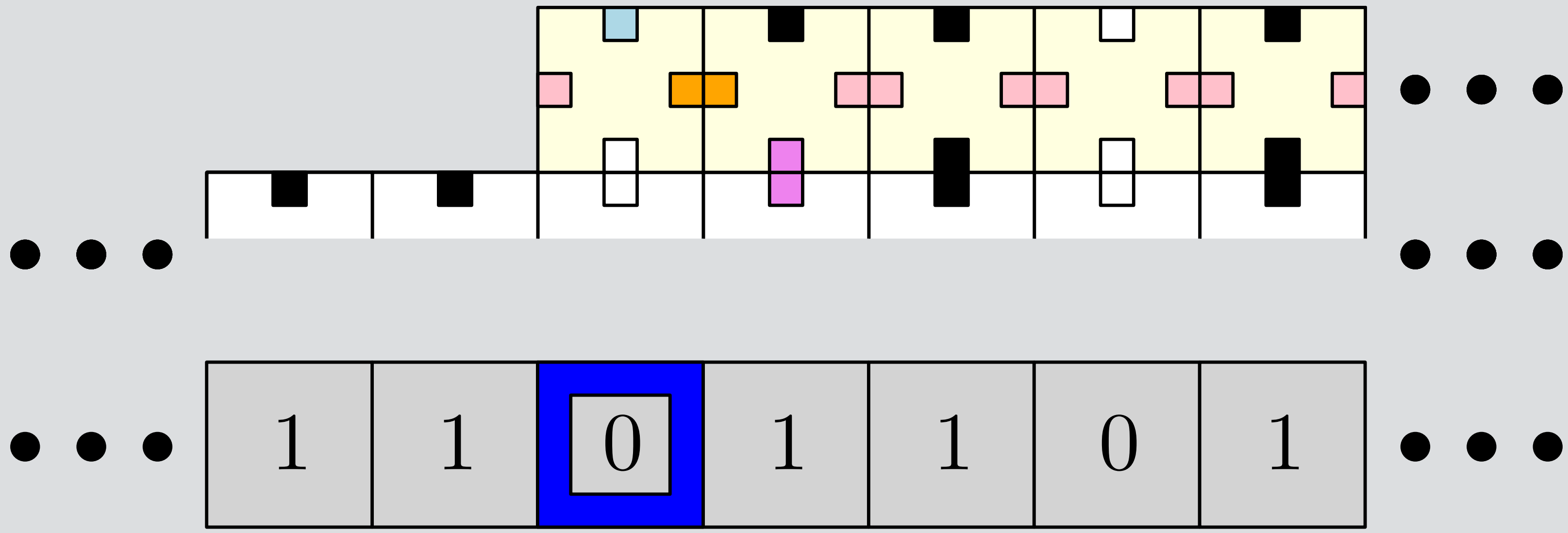

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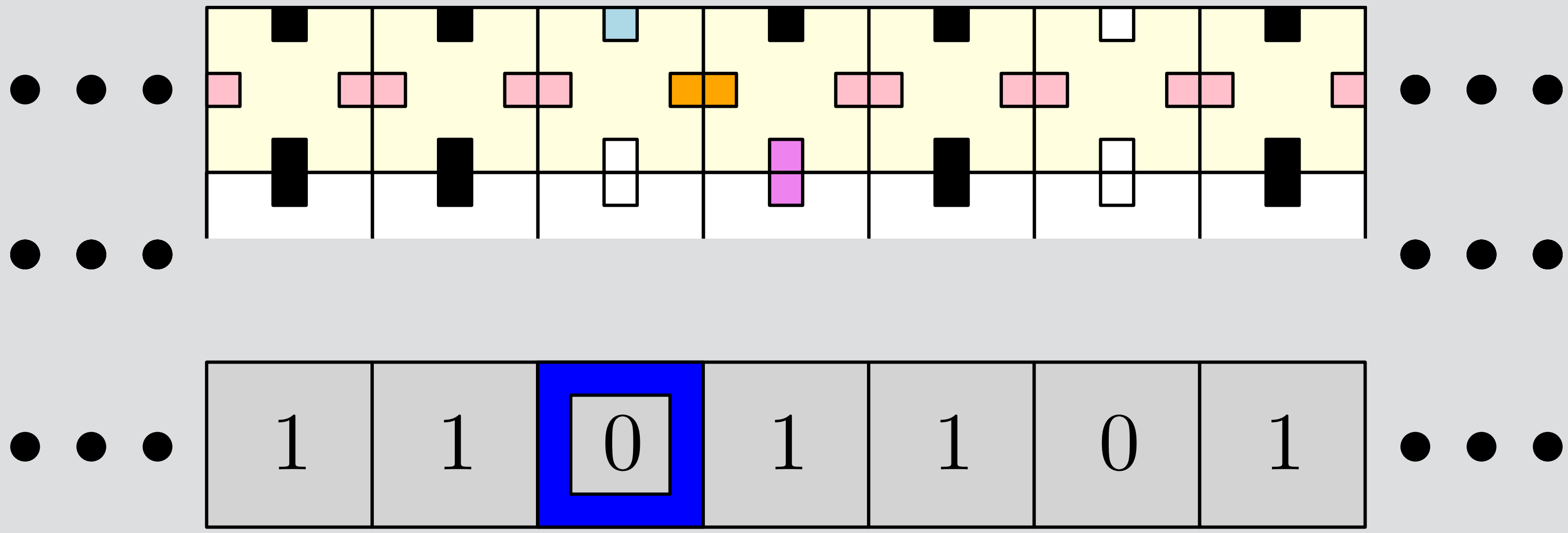

Temperature 2

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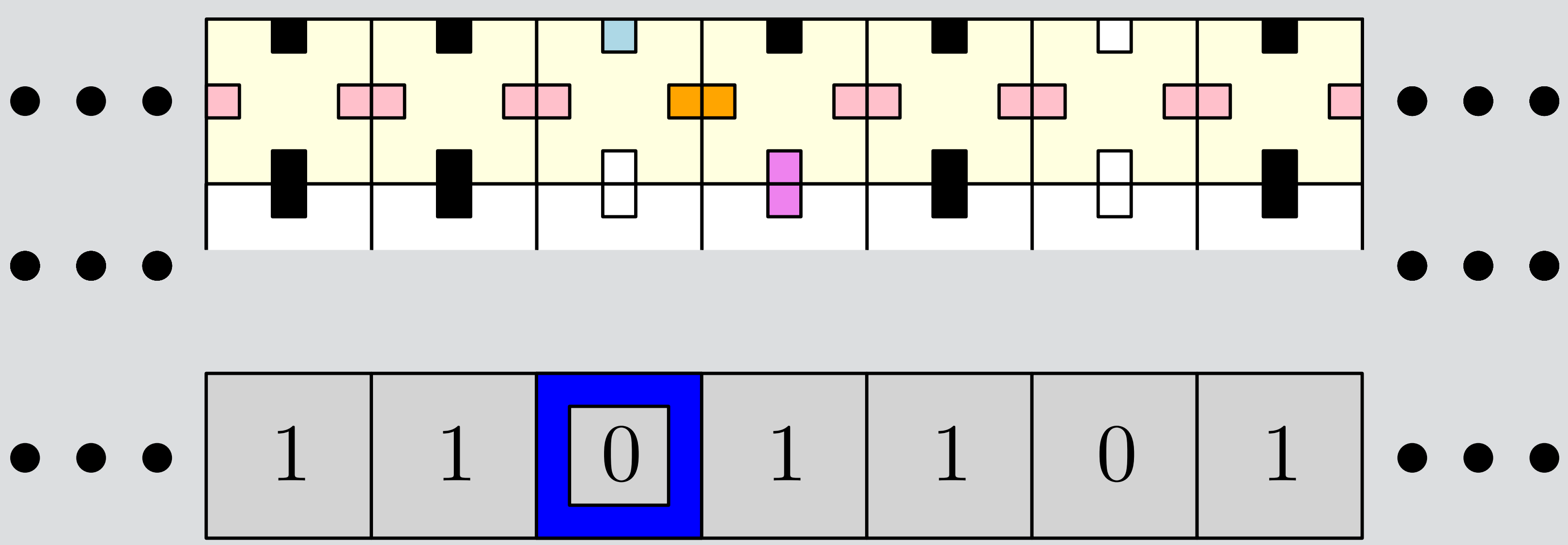

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Universal computation
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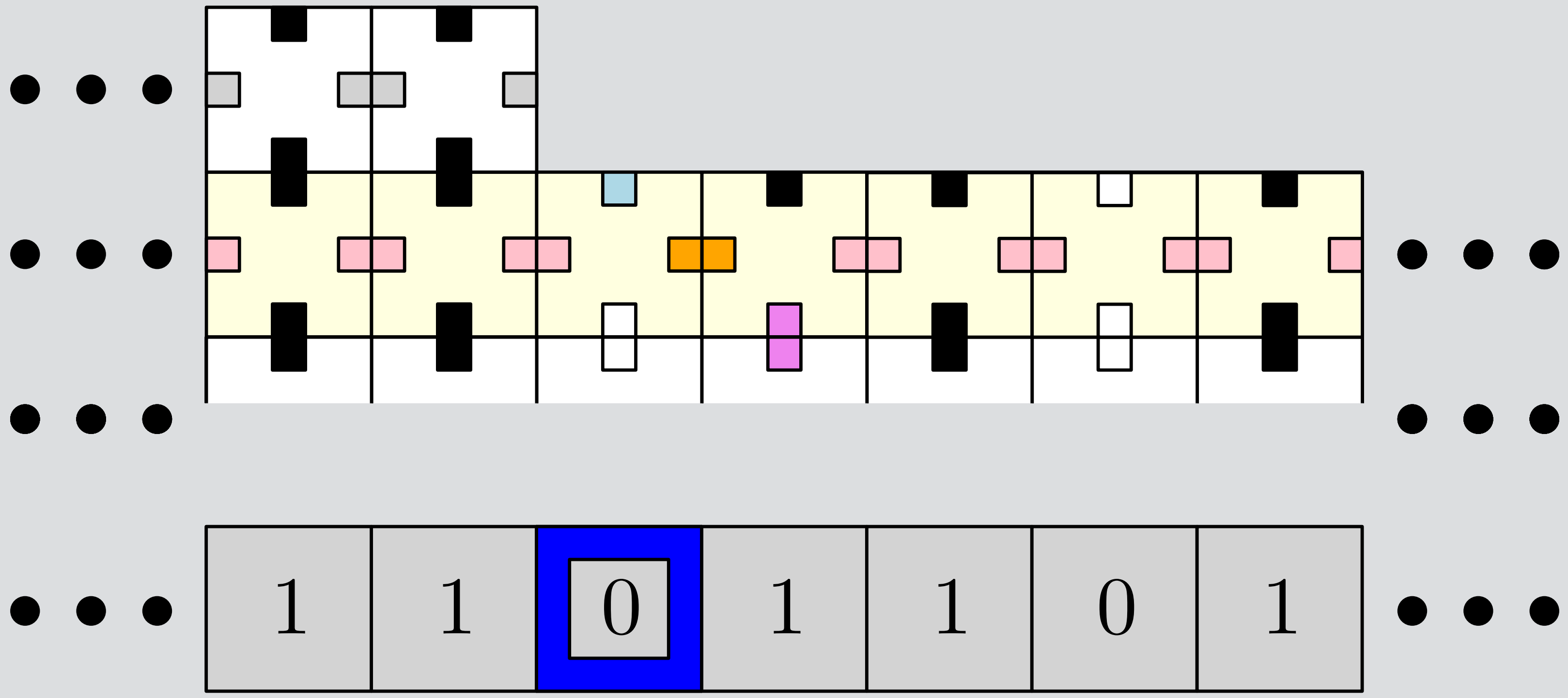

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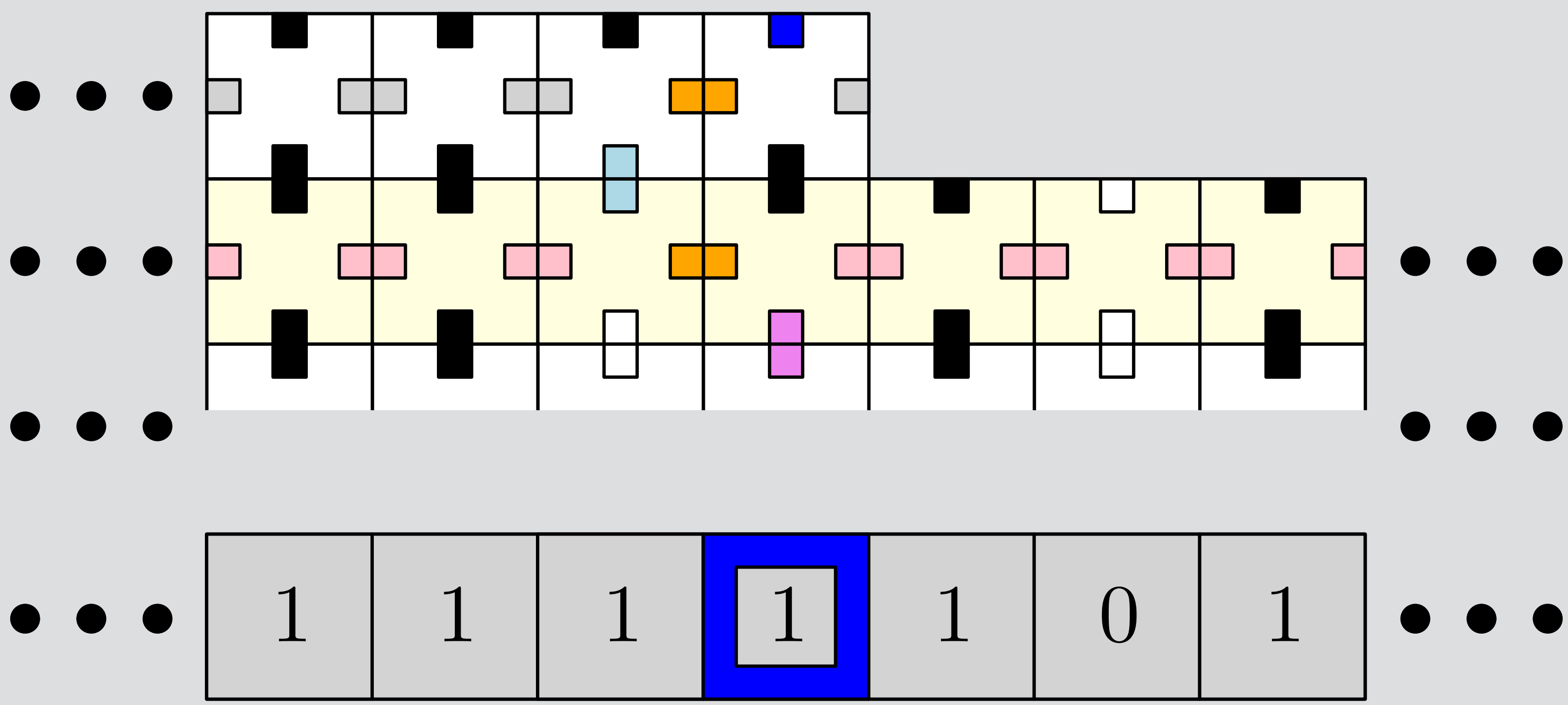

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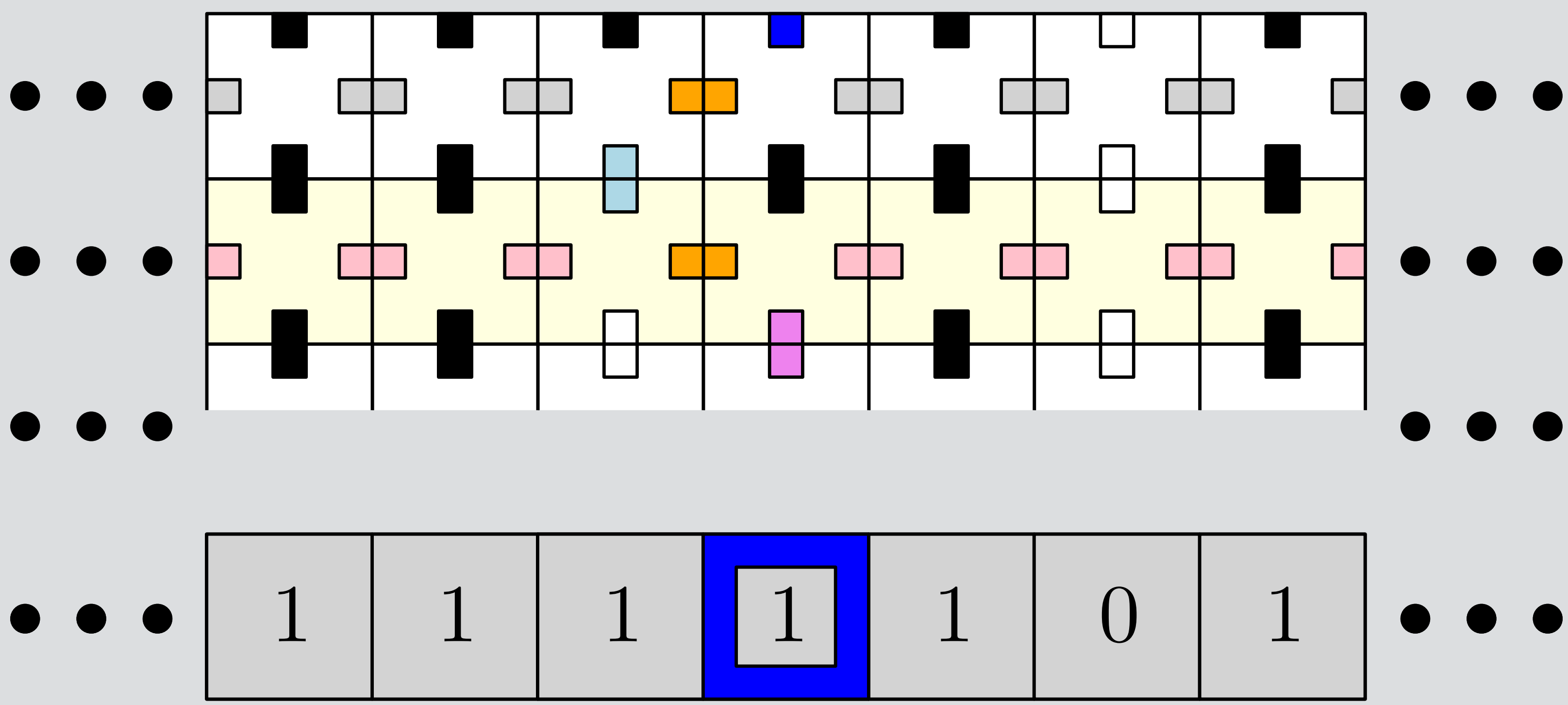

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Universal computation
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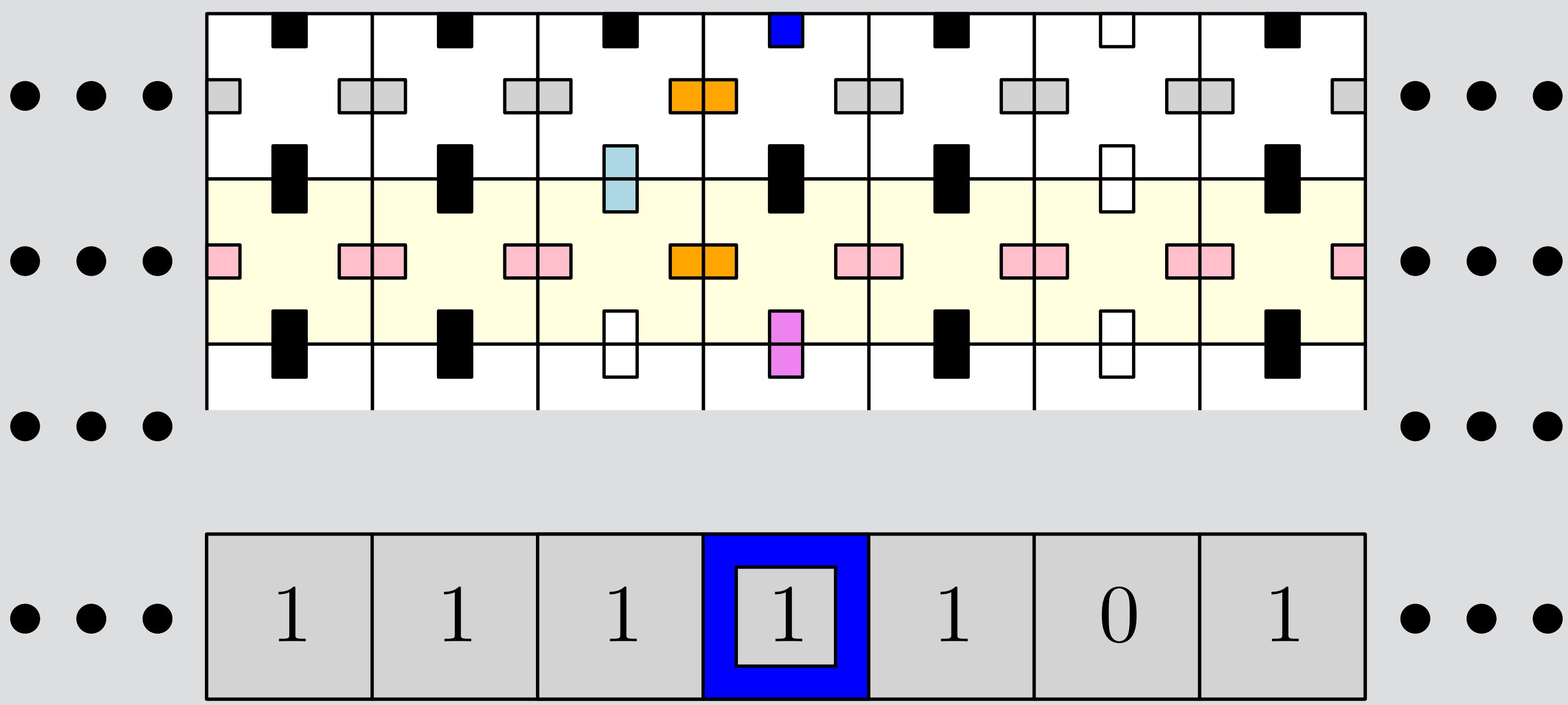
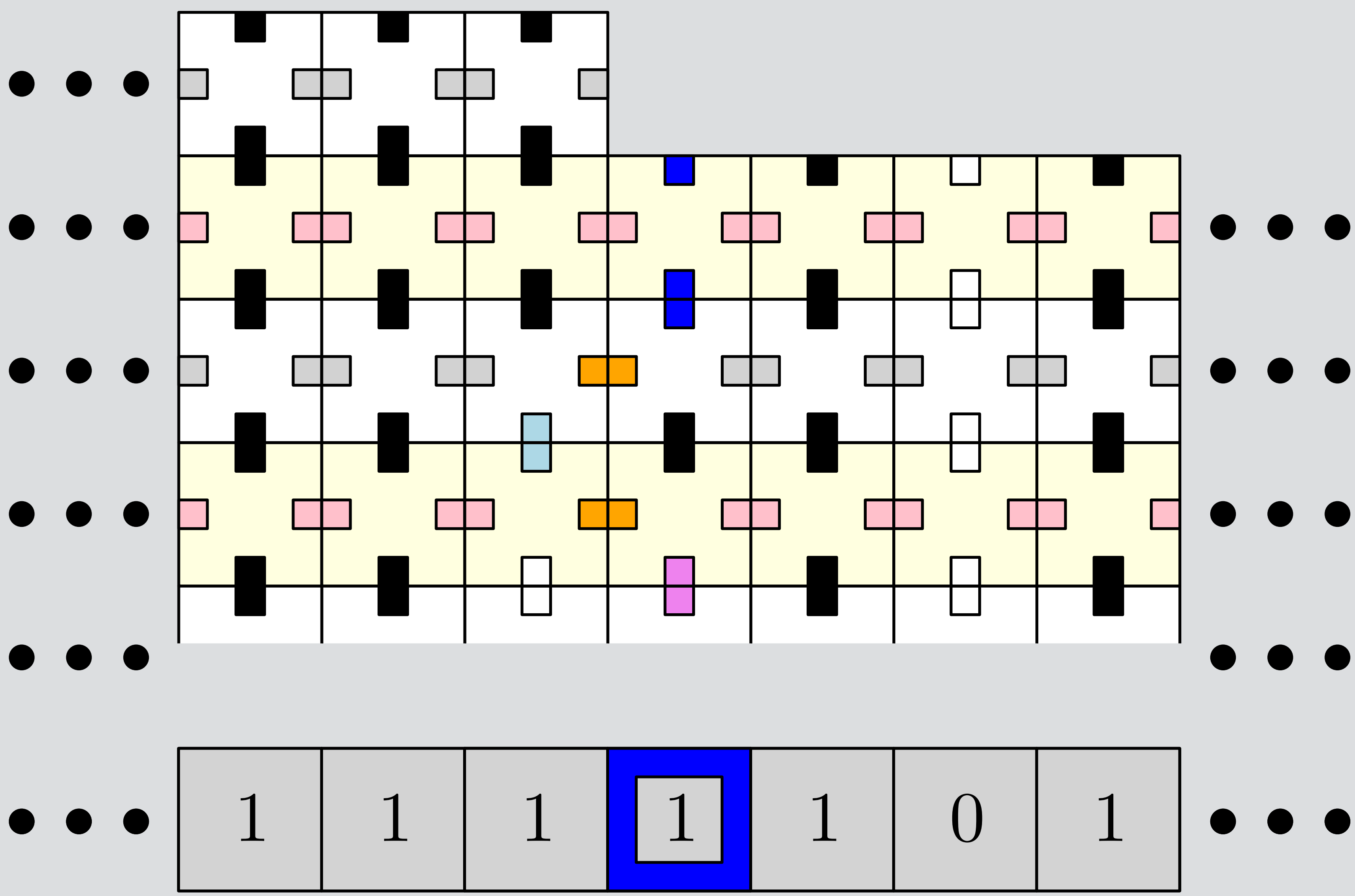


"write 0, move right, change to s_0"

Universal computation (solution by “zig-zag” TM simulation)



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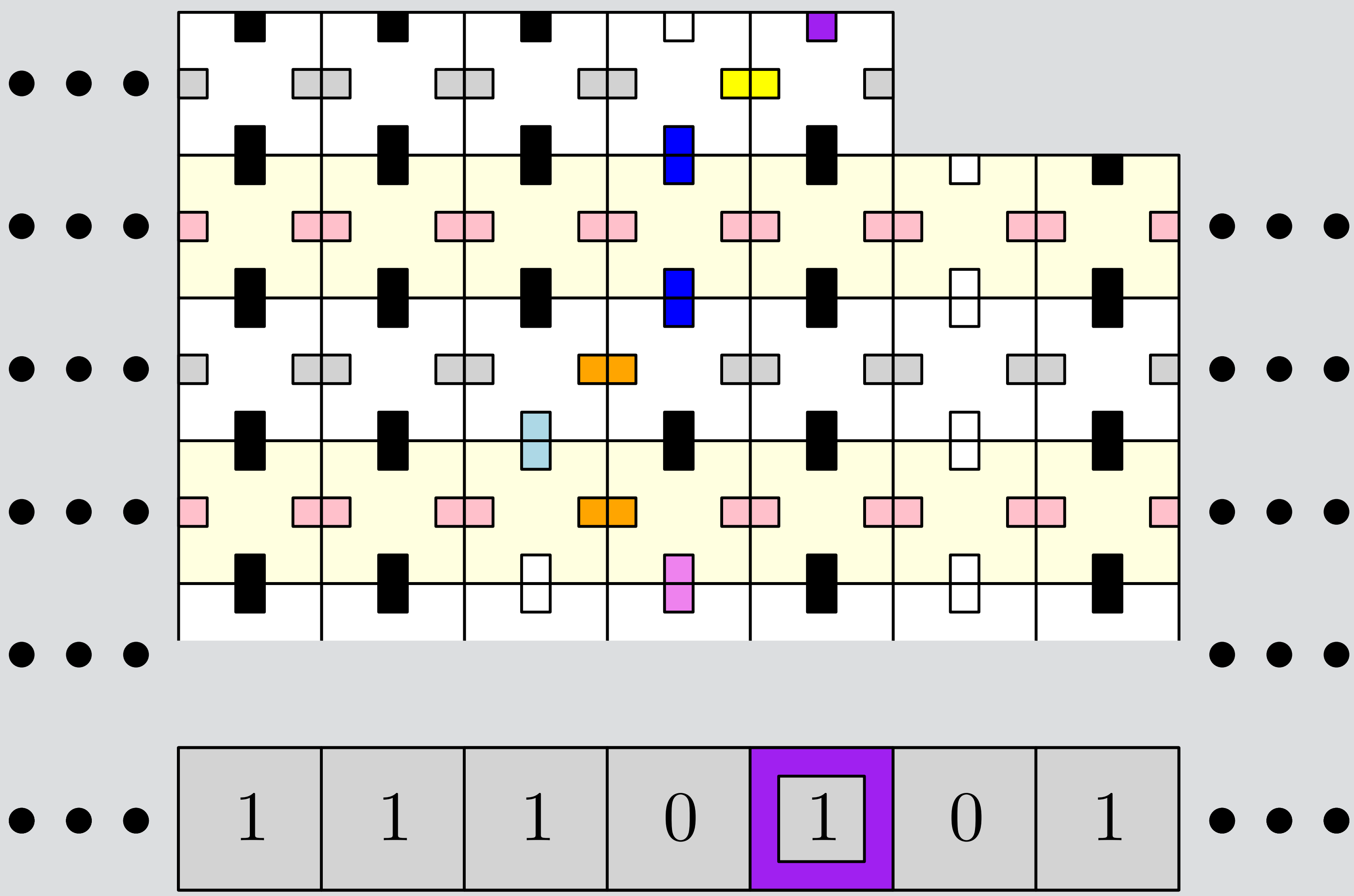

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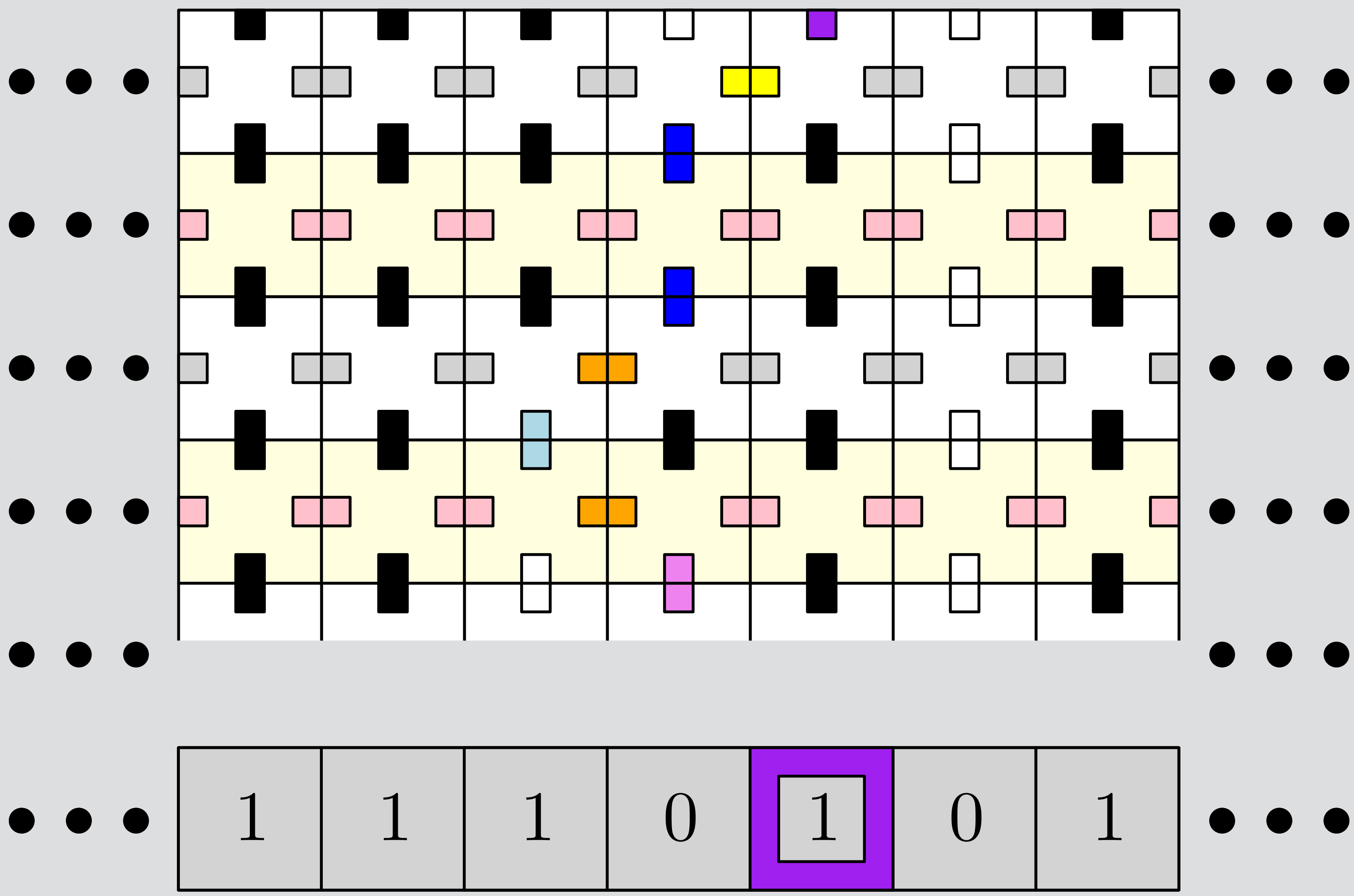
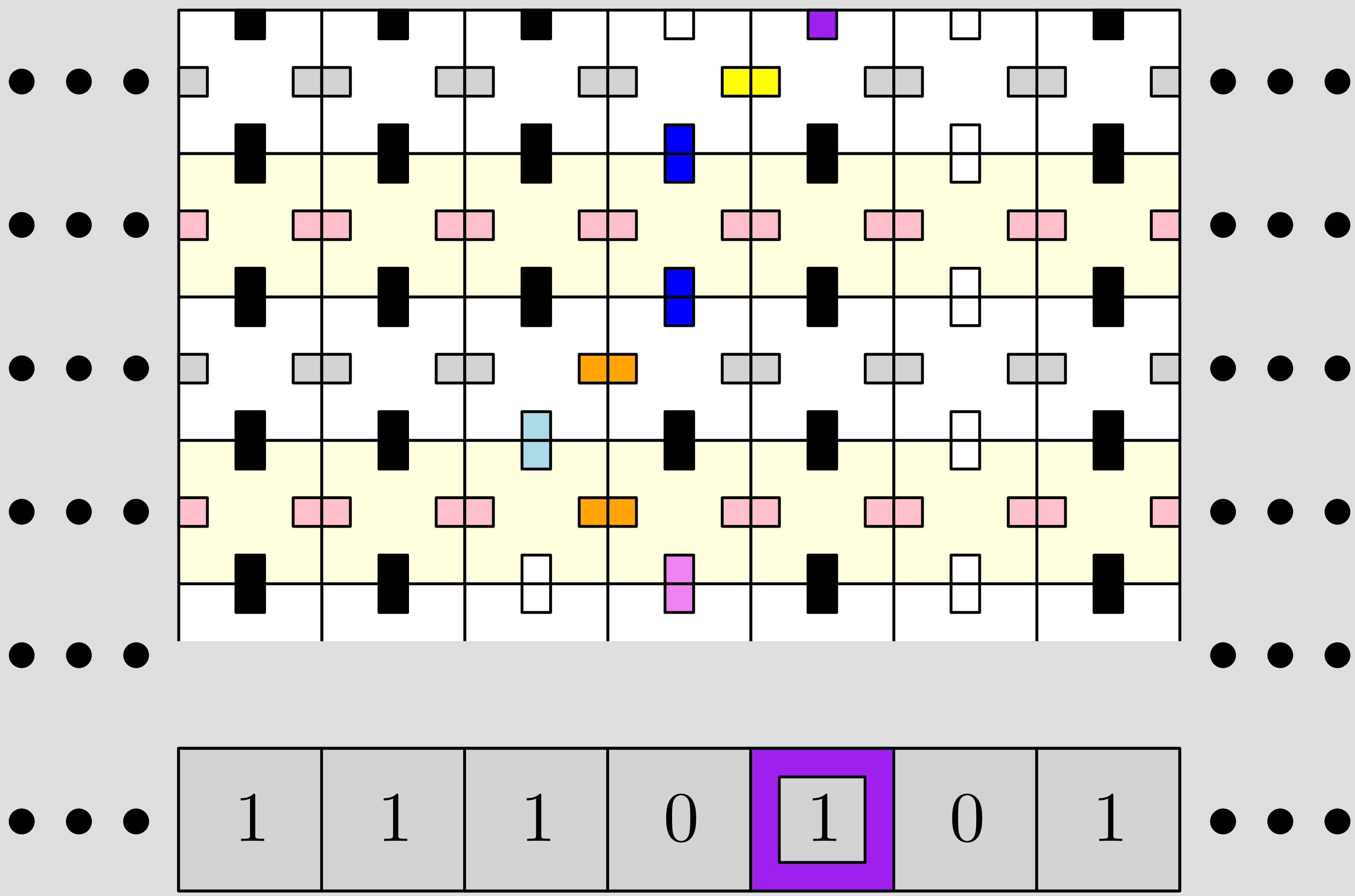


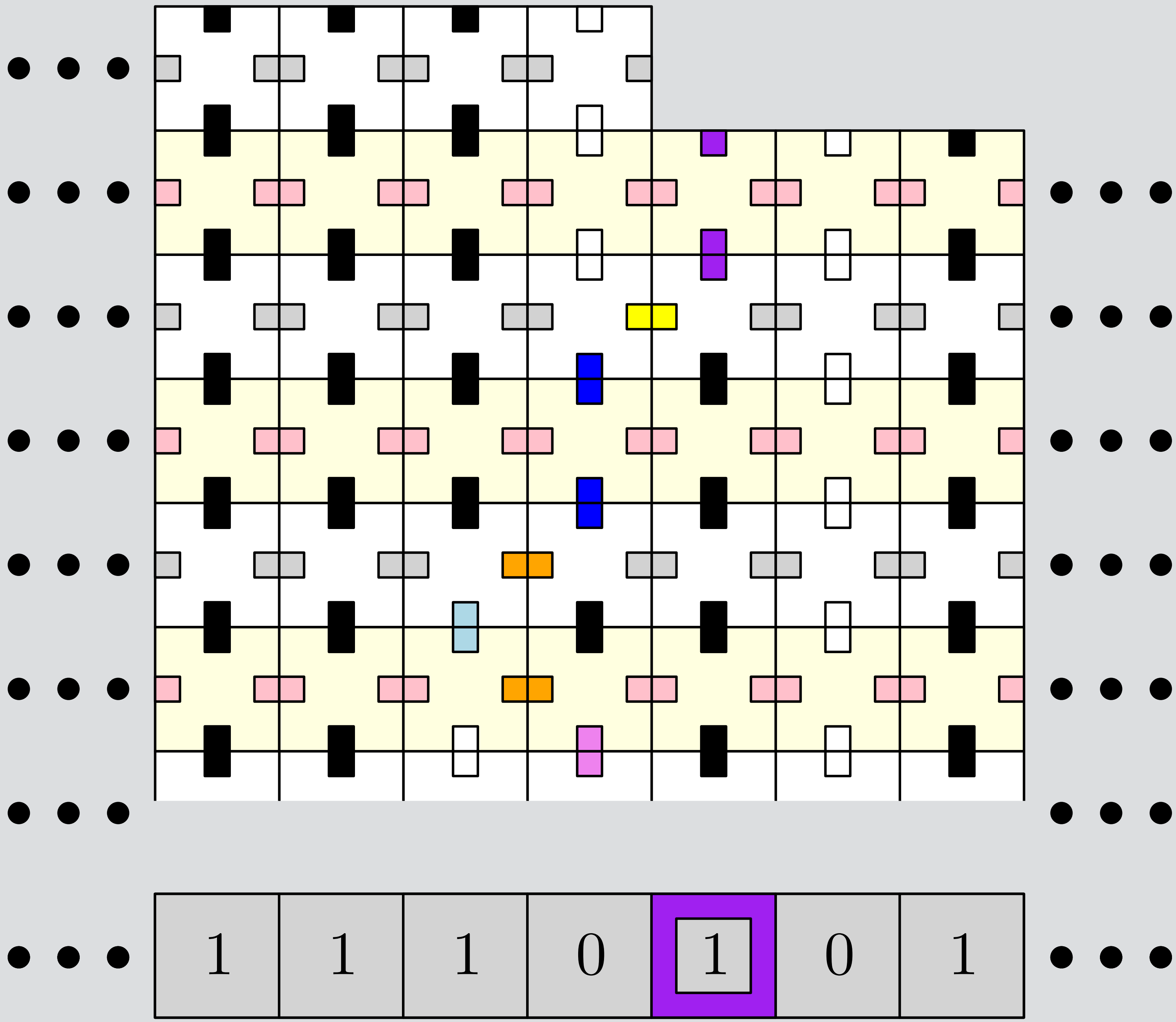
Temperature 2

Universal computation
(solution by “zig-zag” TM simulation)



“write 0, move right, change to s_0”

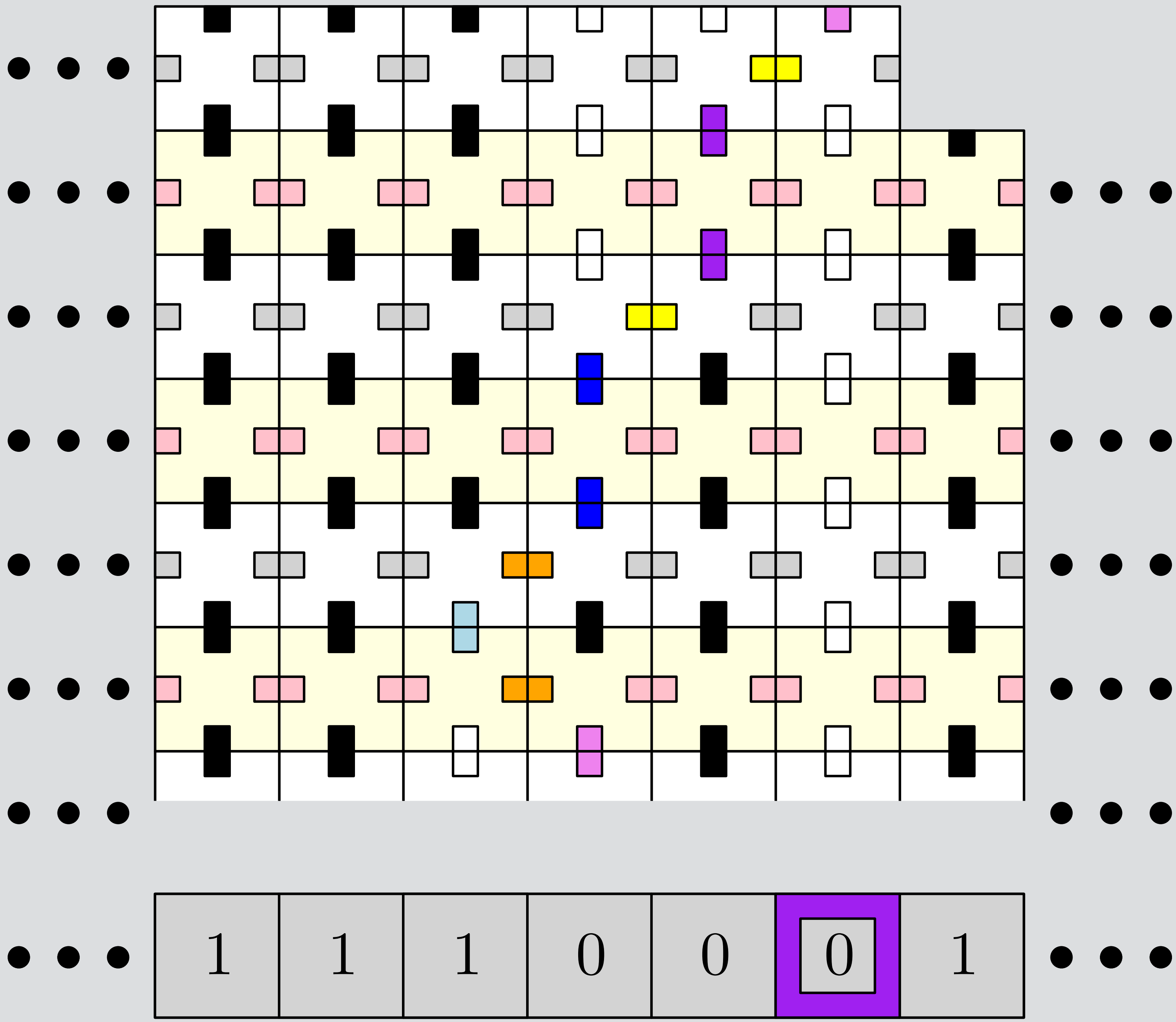
Universal computation



“write 0, move right, change to s_0”

Temperature 2

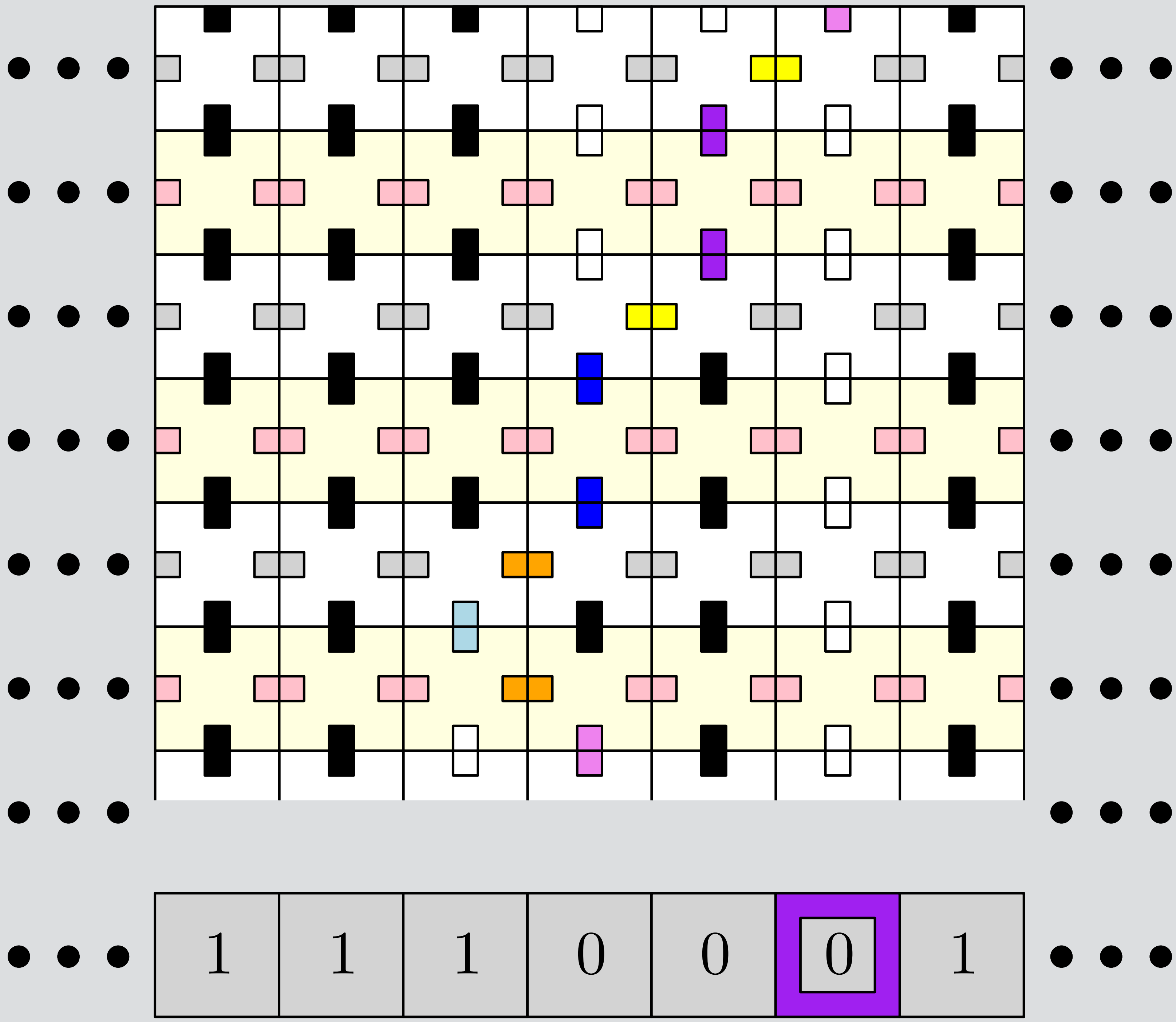
Universal computation



"write 0, move right, change to s_0"

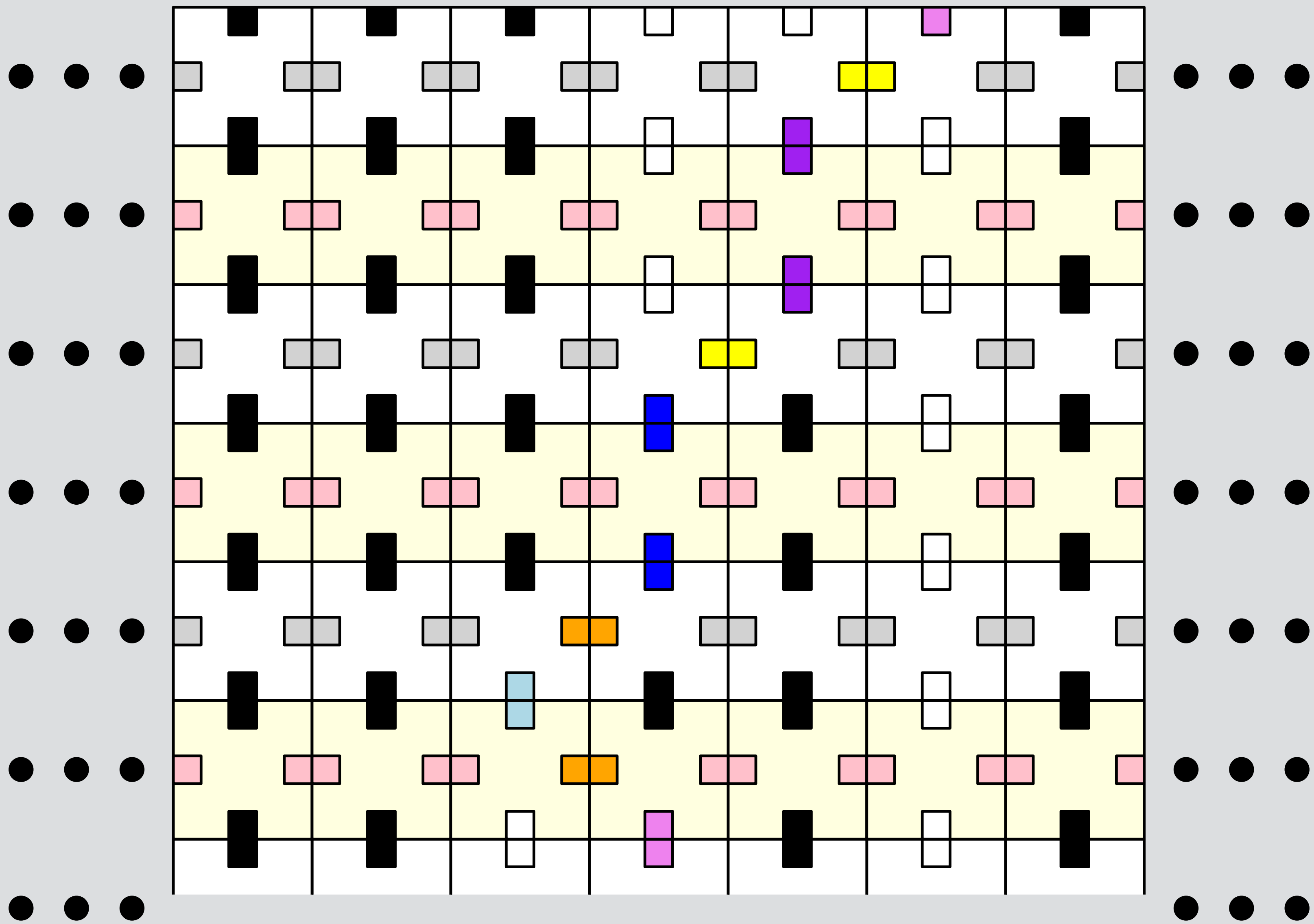
Temperature 2

Universal computation



Temperature 2

Universal computation



[Rothemund, Winfree 2000]

Temperature 2

The benchmarks of a capable self-assembly model

Algorithmic behavior $\xrightarrow{\text{demonstrated by}}$ Universal computation

Usable algorithmic behavior $\xrightarrow{\text{demonstrated by}}$ Efficient NxN square assembly

few tile types

The benchmarks of a capable self-assembly model

Algorithmic behavior —demonstrated by→ Universal computation

Usable algorithmic behavior —demonstrated by→ few tile types Efficient NxN square assembly

Efficient assembly of NxN square

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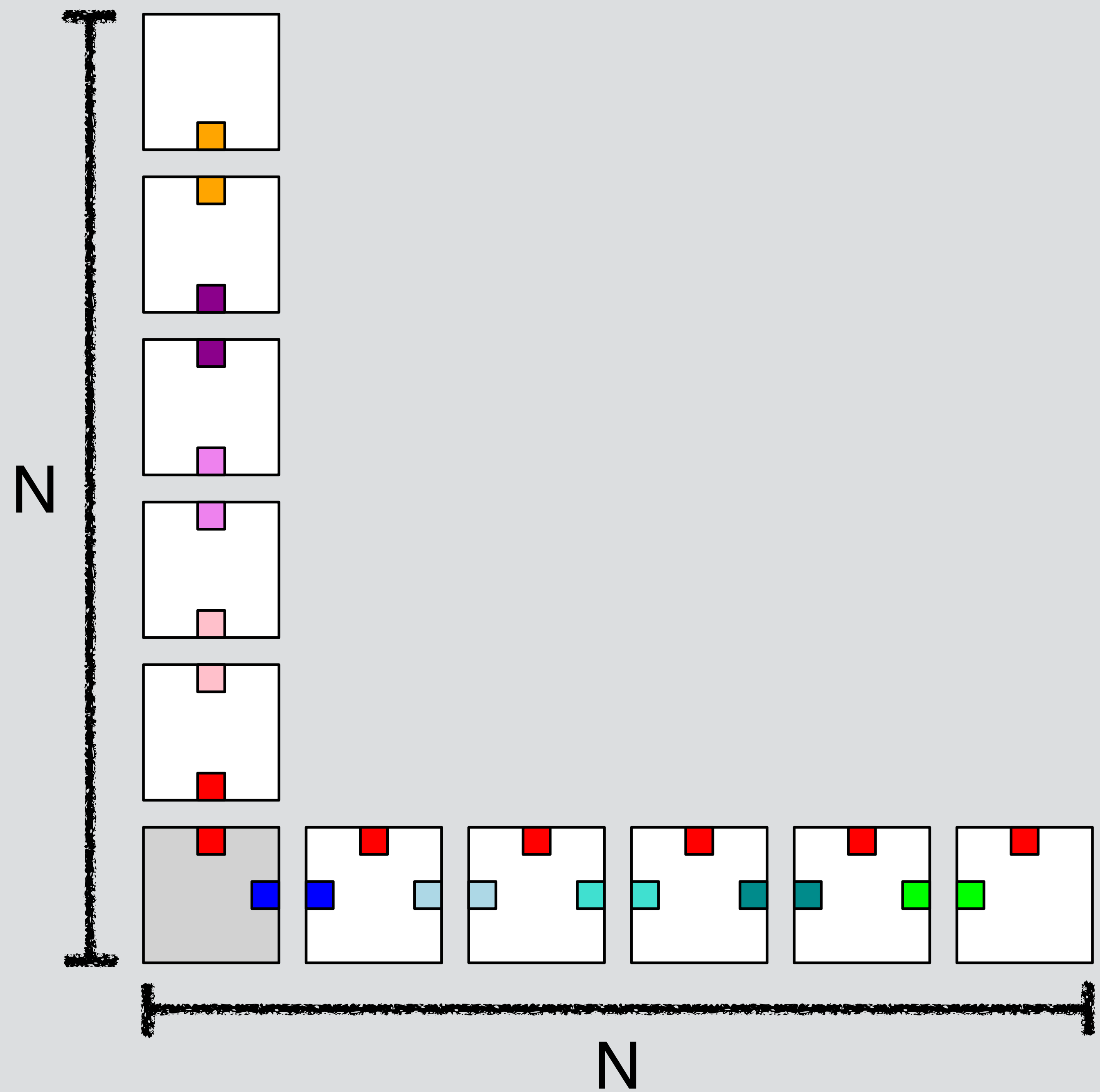
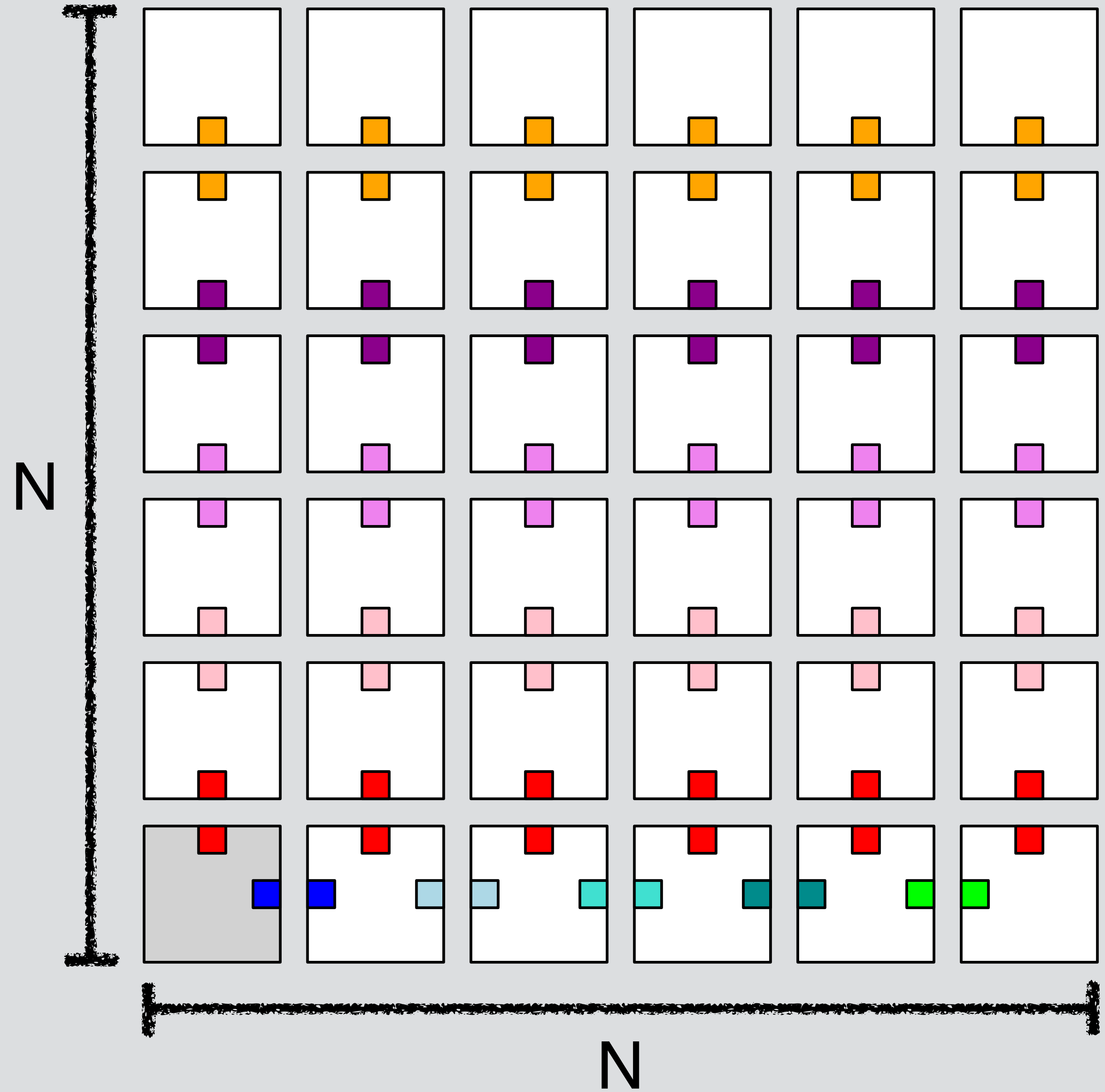


Temperature 1

Efficient assembly of NxN square



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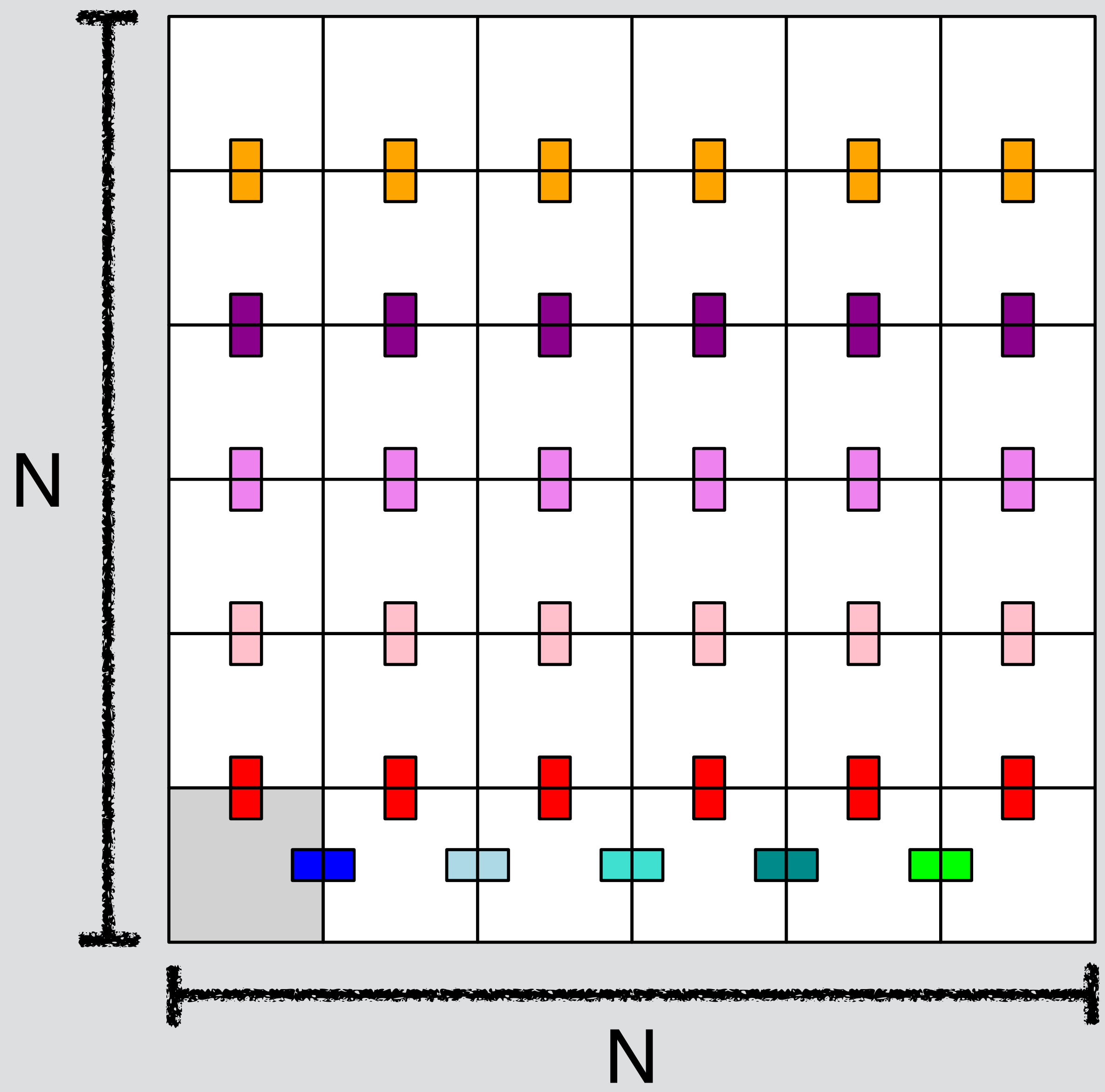
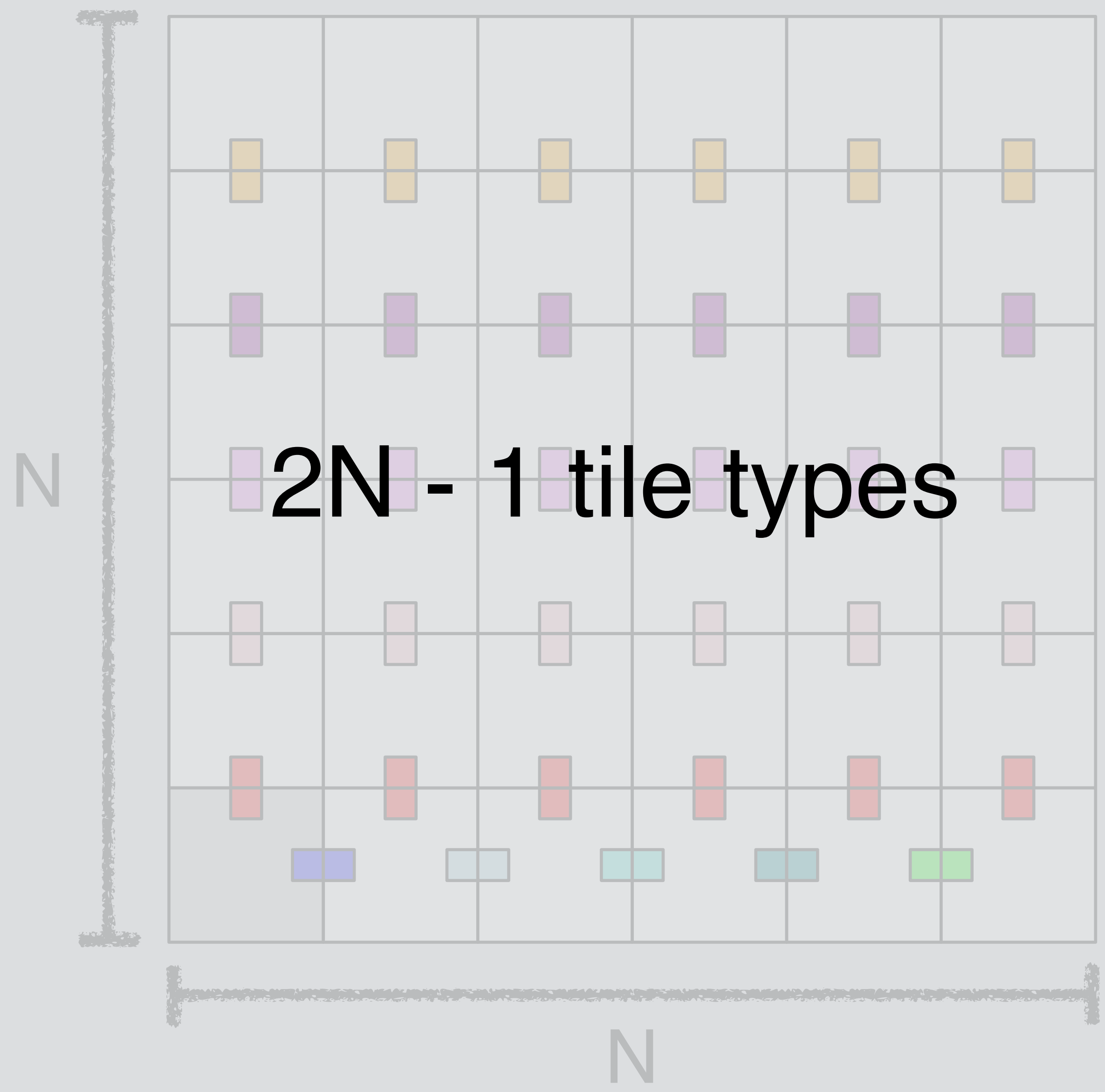


Temperature 1

Efficient assembly of NxN square



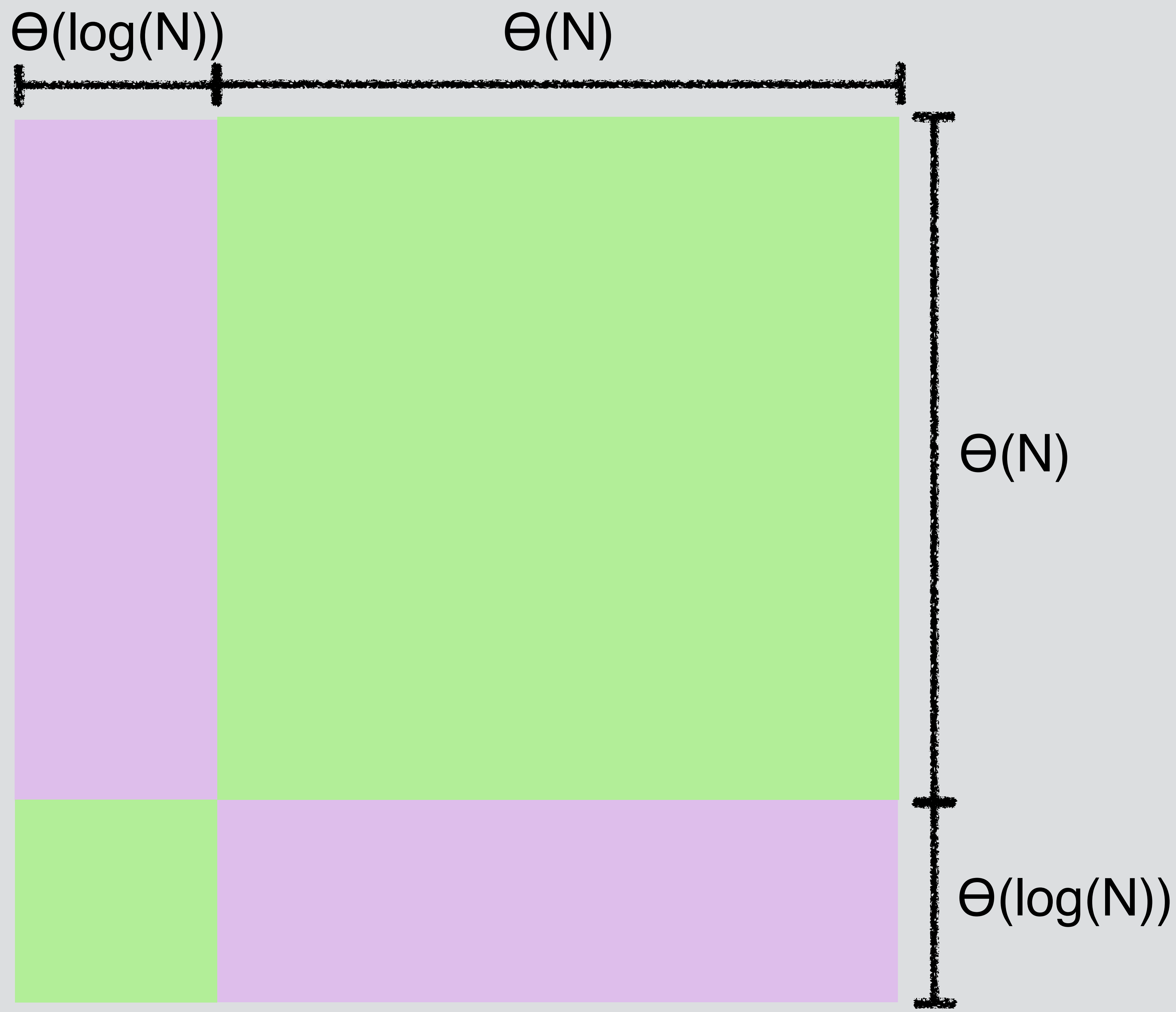
2N - 1 tile types

Temperature 1

Efficient assembly of NxN square

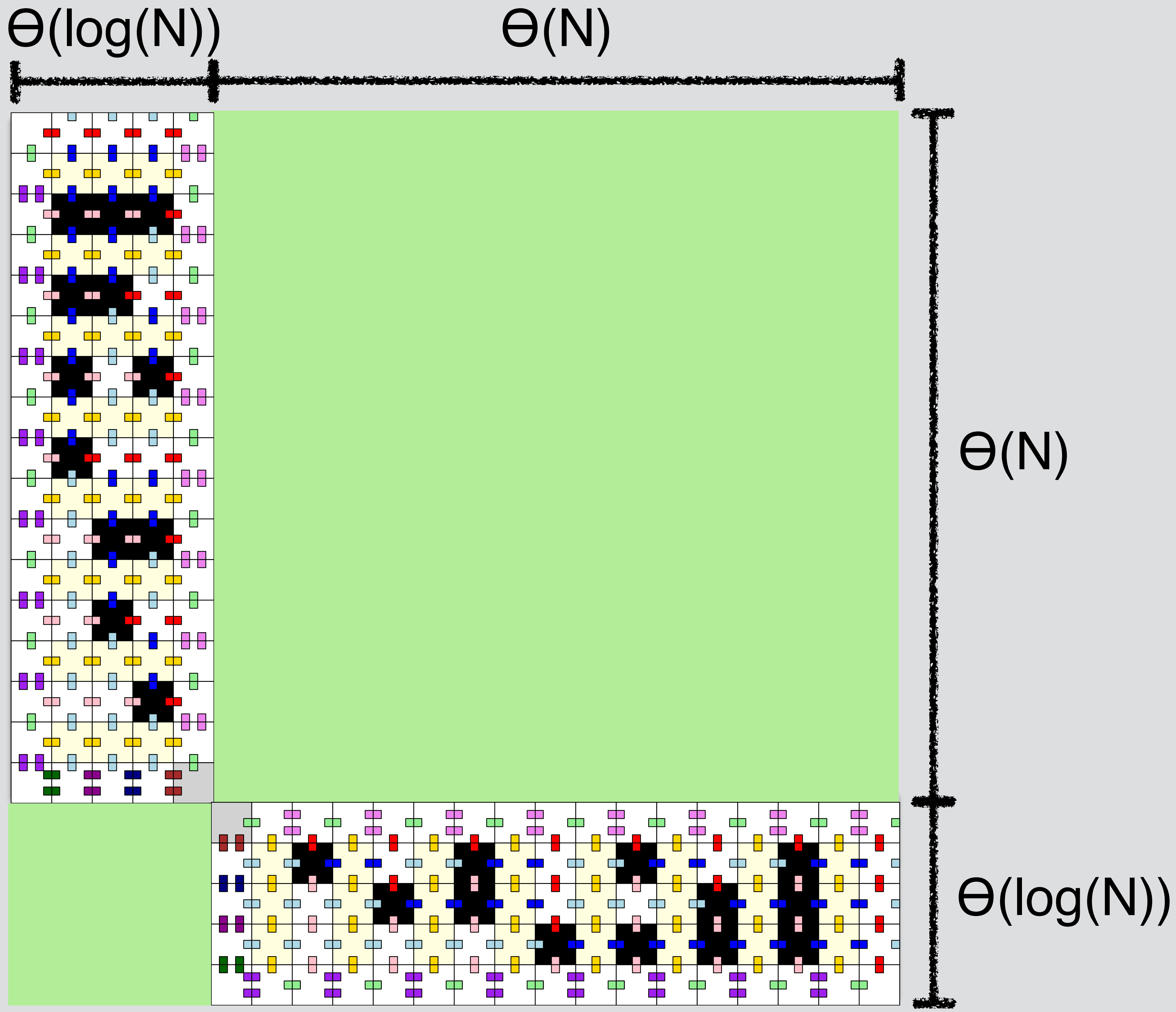
Temperature 2

Efficient assembly of NxN square



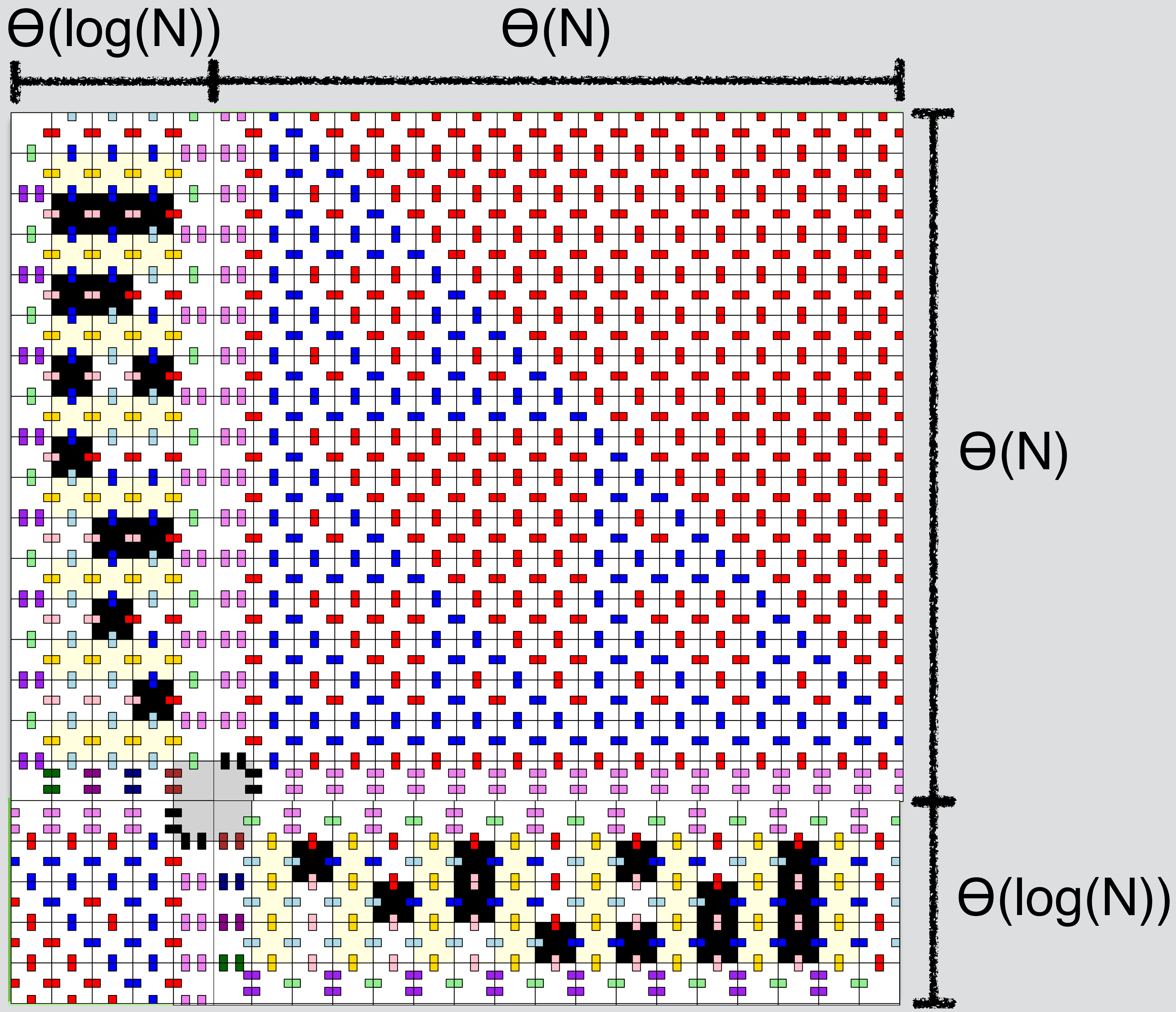
Temperature 2

Efficient assembly of NxN square



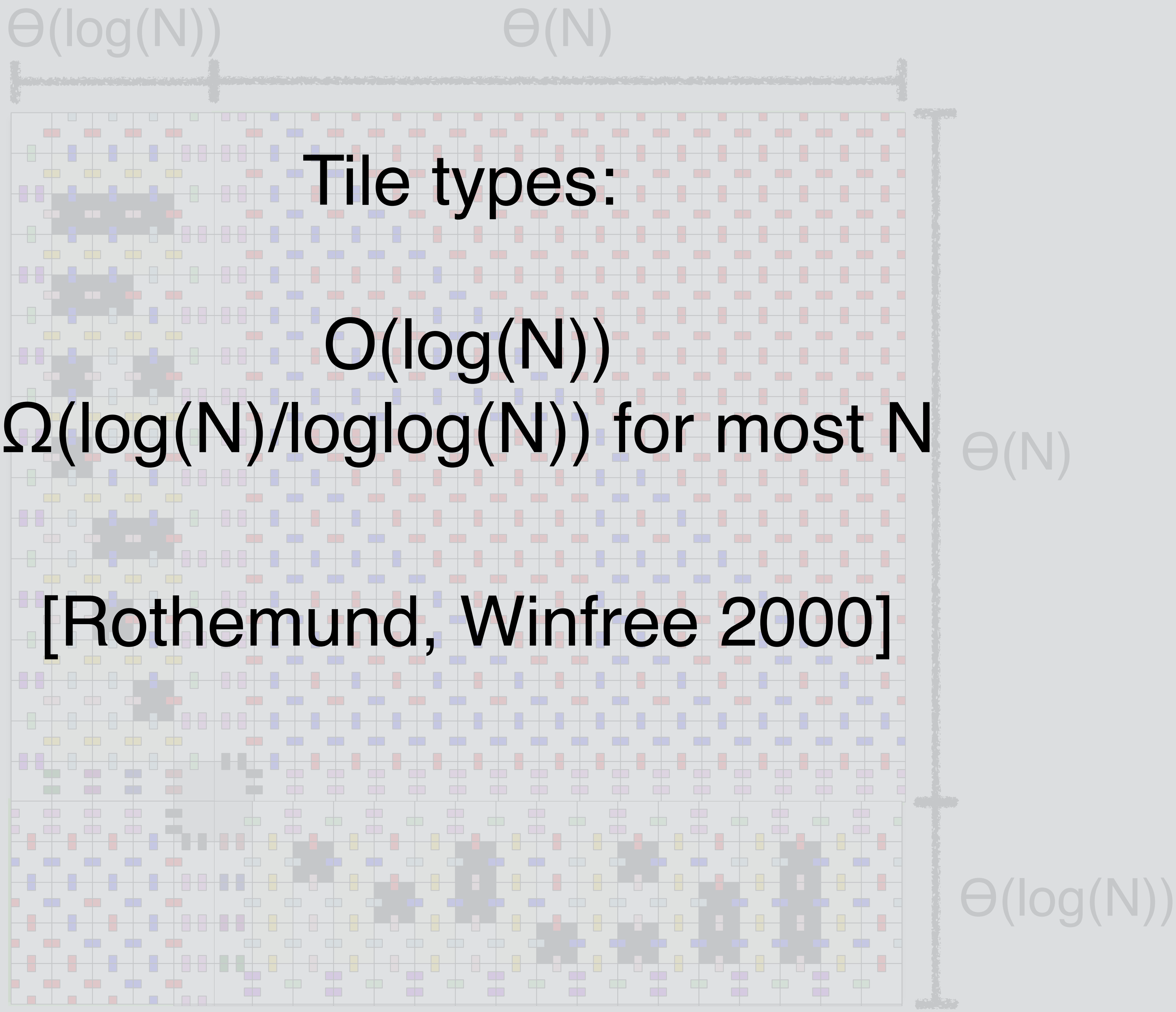
Temperature 2

Efficient assembly of NxN square



Temperature 2

Efficient assembly of NxN square



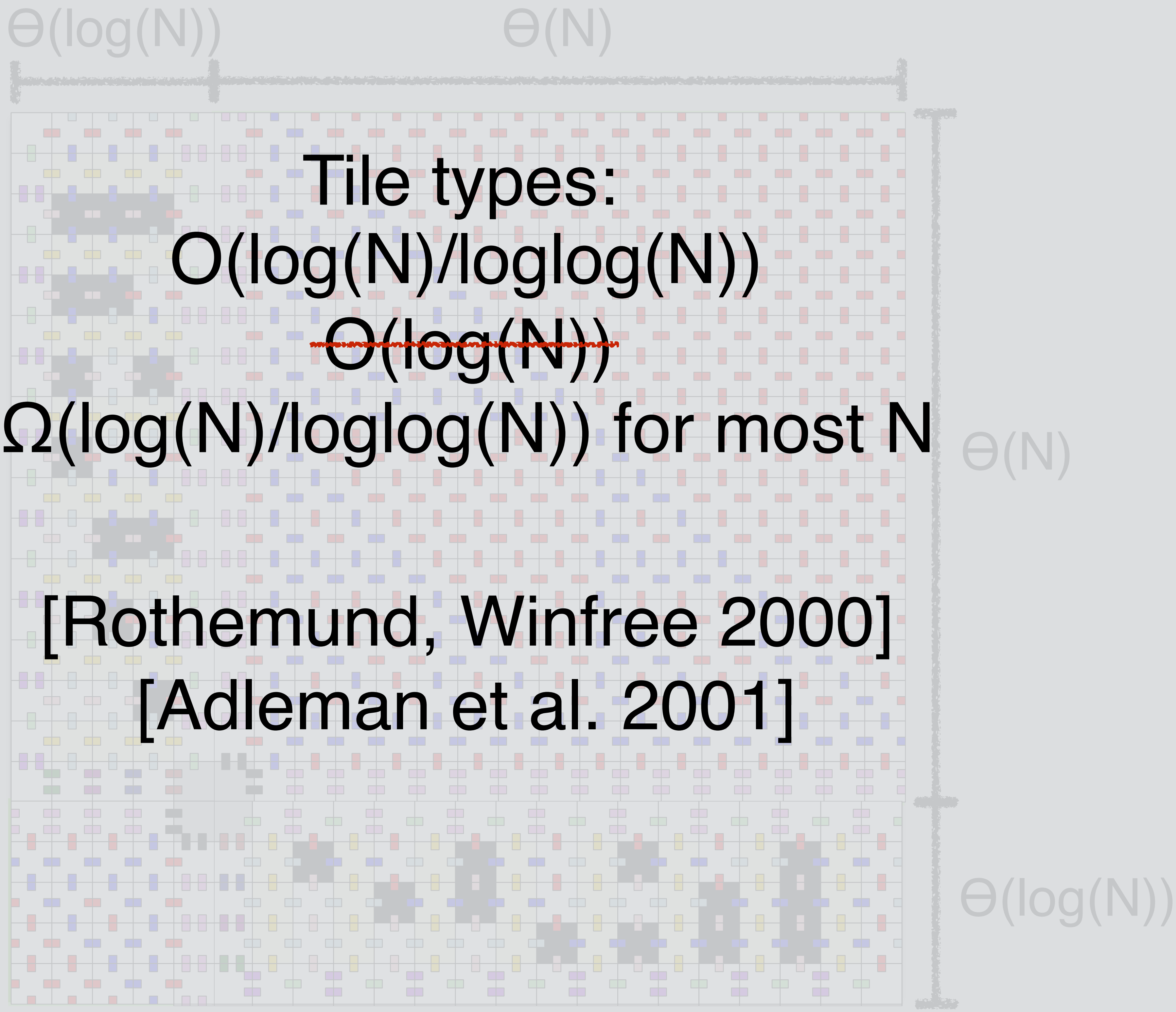
Tile types:

O(log(N))
Ω(log(N)/loglog(N)) for most N

[Rothemund, Winfree 2000]

Temperature 2

Efficient assembly of NxN square



Tile types:

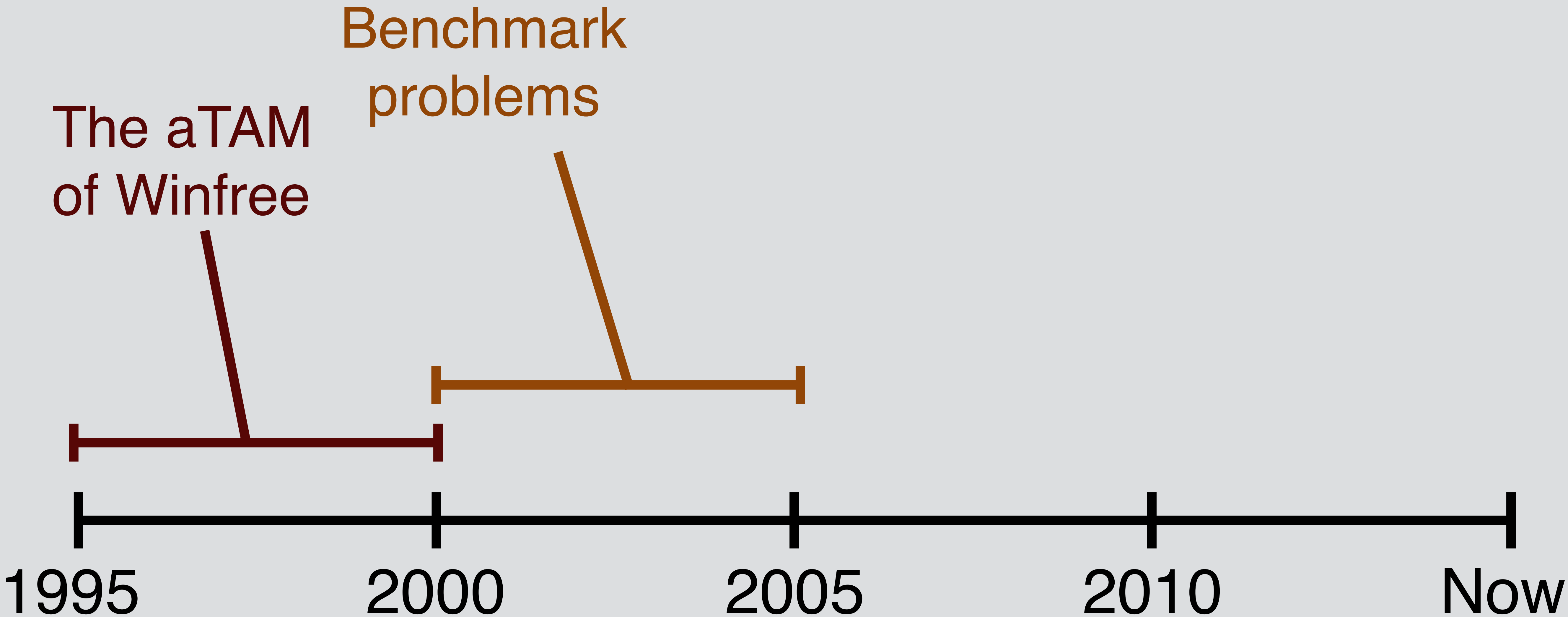
$O(\log(N)/\log\log(N))$

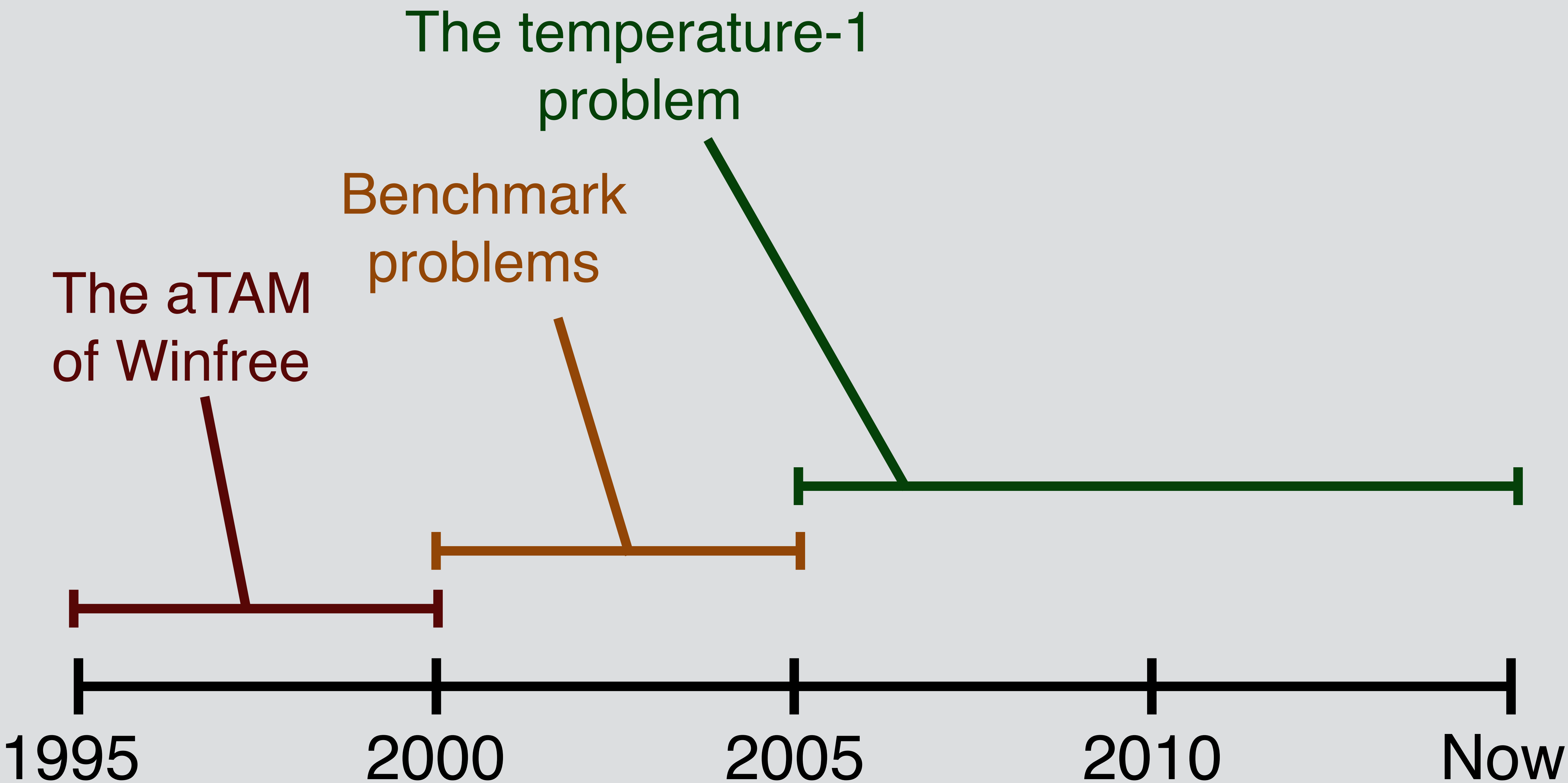
$\cancel{O(\log(N))}$

$\Omega(\log(N)/\log\log(N))$ for most N

[Rothemund, Winfree 2000]

[Adleman et al. 2001]


Benchmark
problems
The aTAM
of Winfree
1995
2000
2005
2010
Now



The temperature-1 problem
Benchmark problems
The aTAM of Winfree
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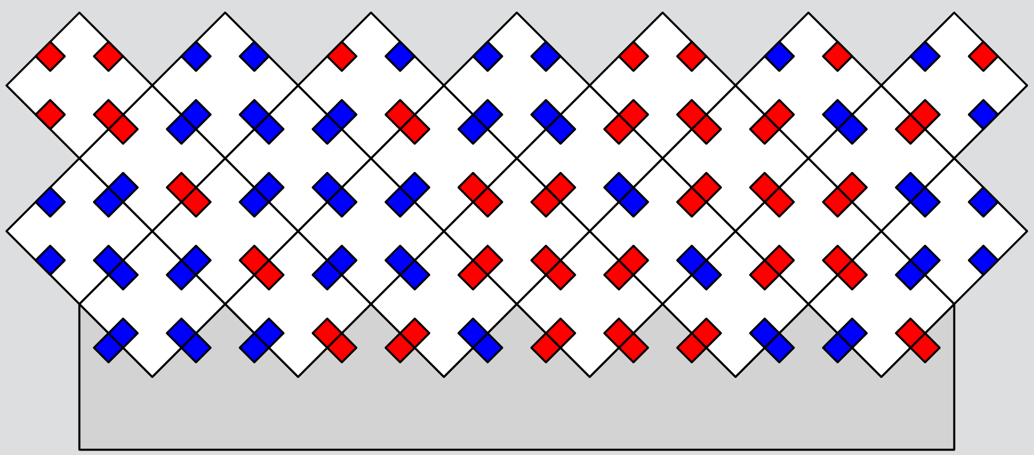
The benchmarks of a capable self-assembly model

Universal computation



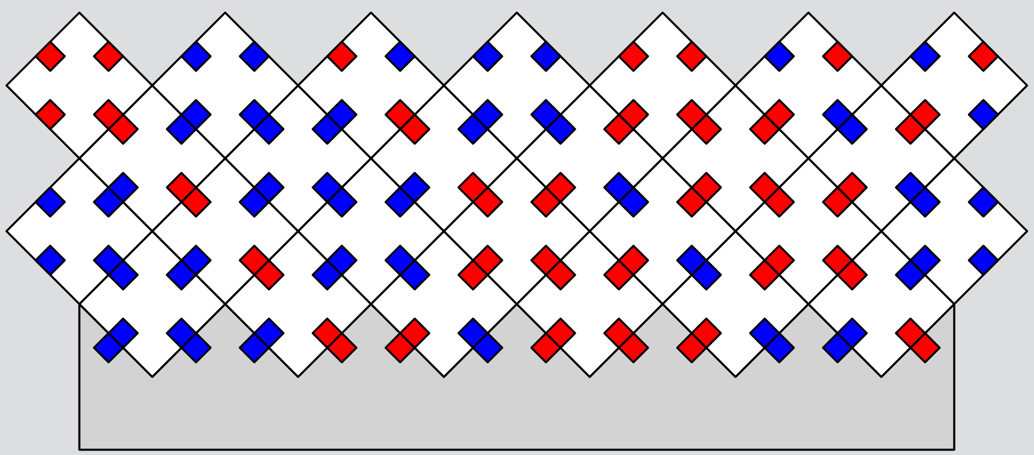
Temperature 2

NxN square assembly w/O(log(N)) tile types

Temperature 2

The benchmarks of a capable self-assembly model

Universal computation

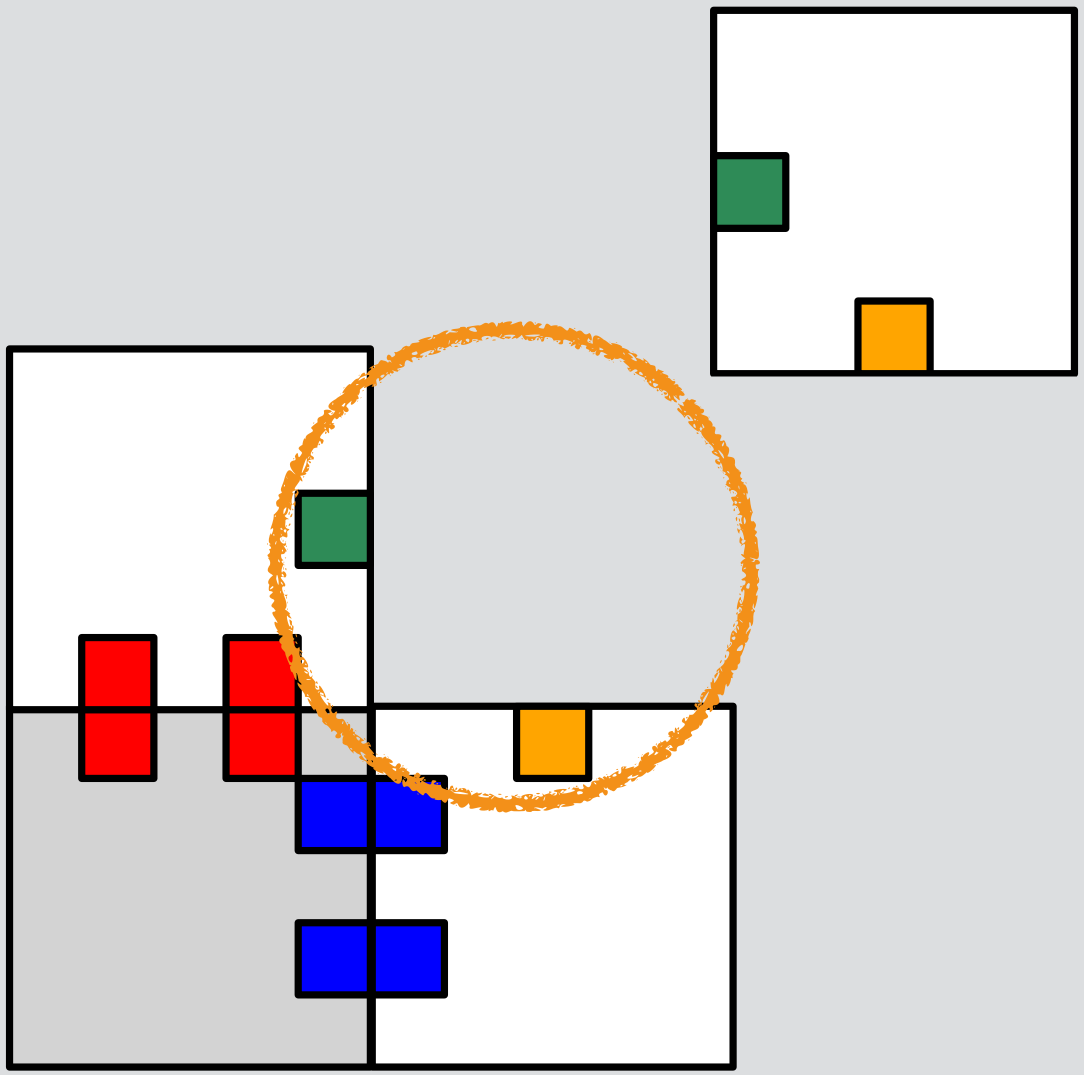


Temperature 2

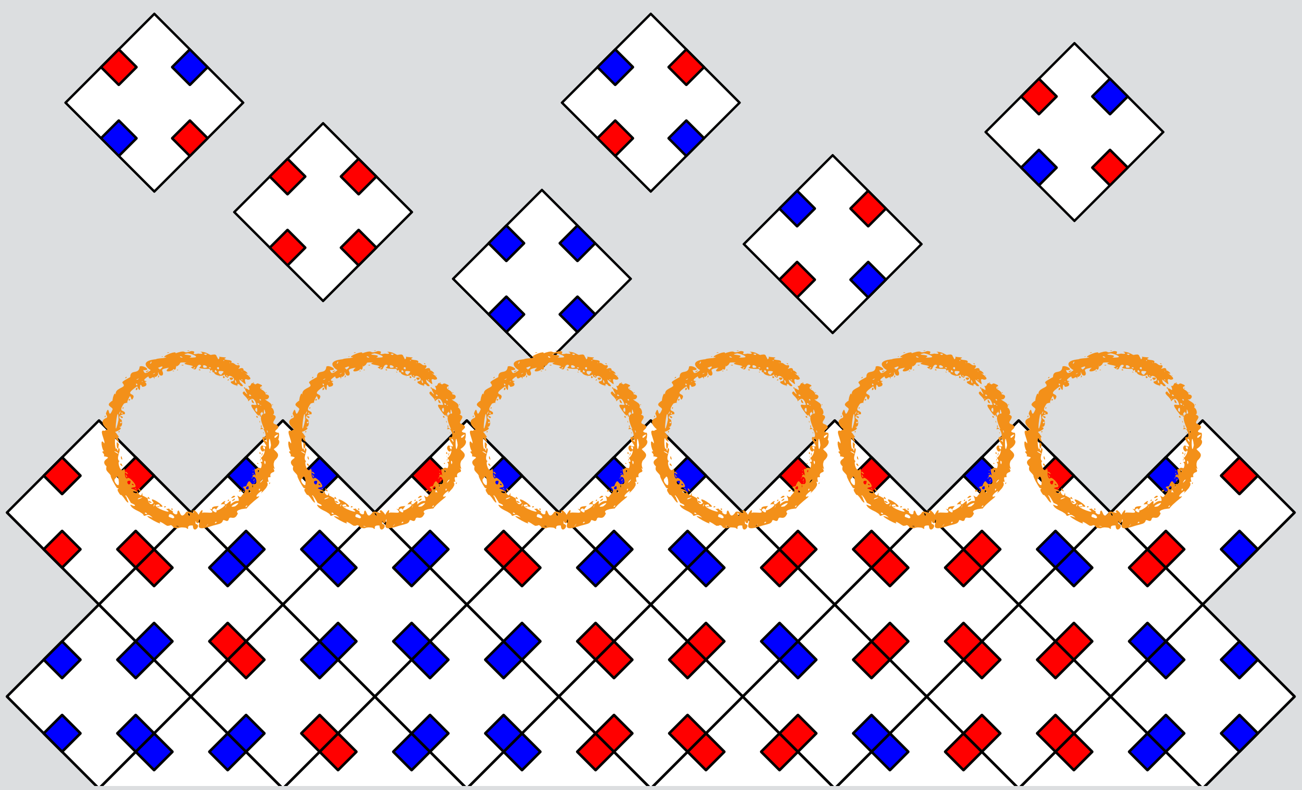
NxN square assembly w/O(log(N)) tile types

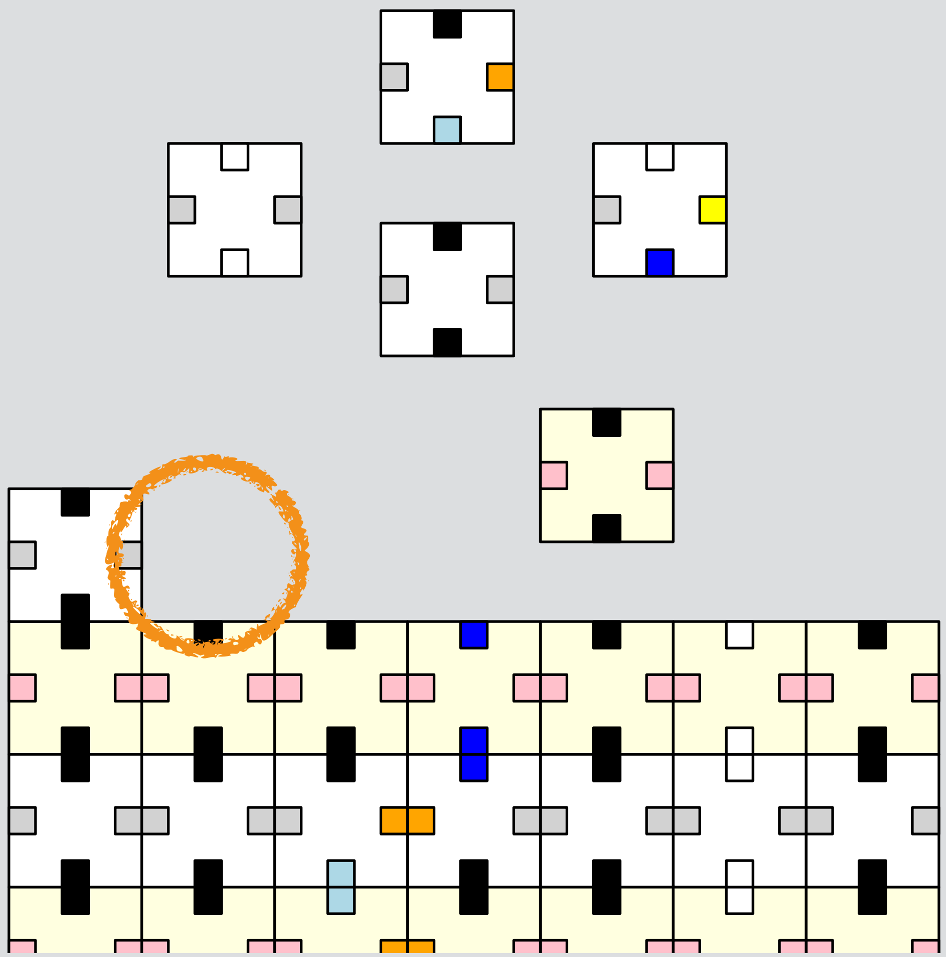
Temperature 2

Temperature 2 can do *cooperative bonding*.



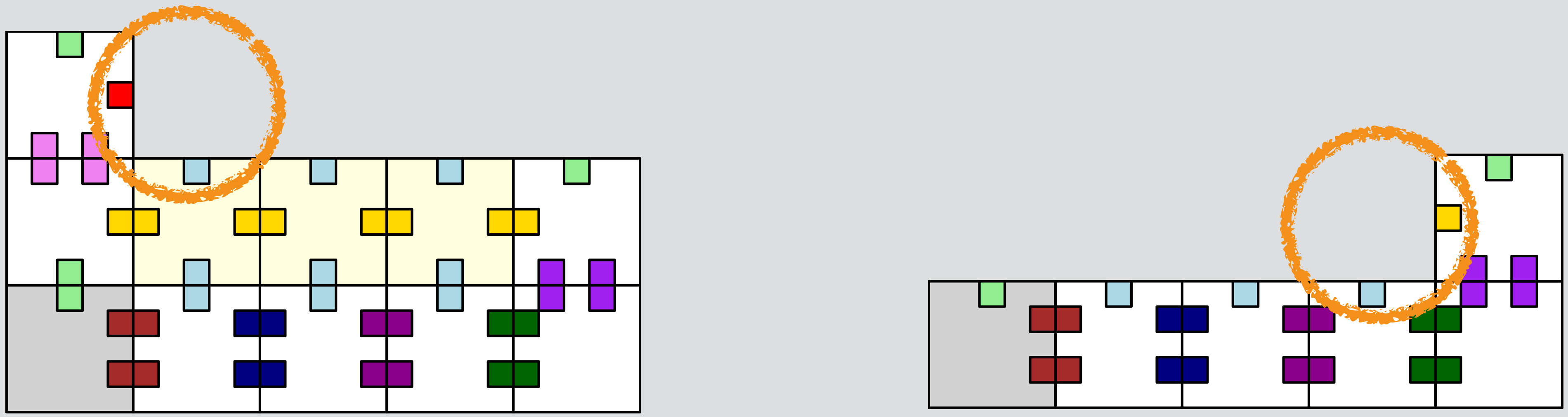
Computation uses cooperative bonding:



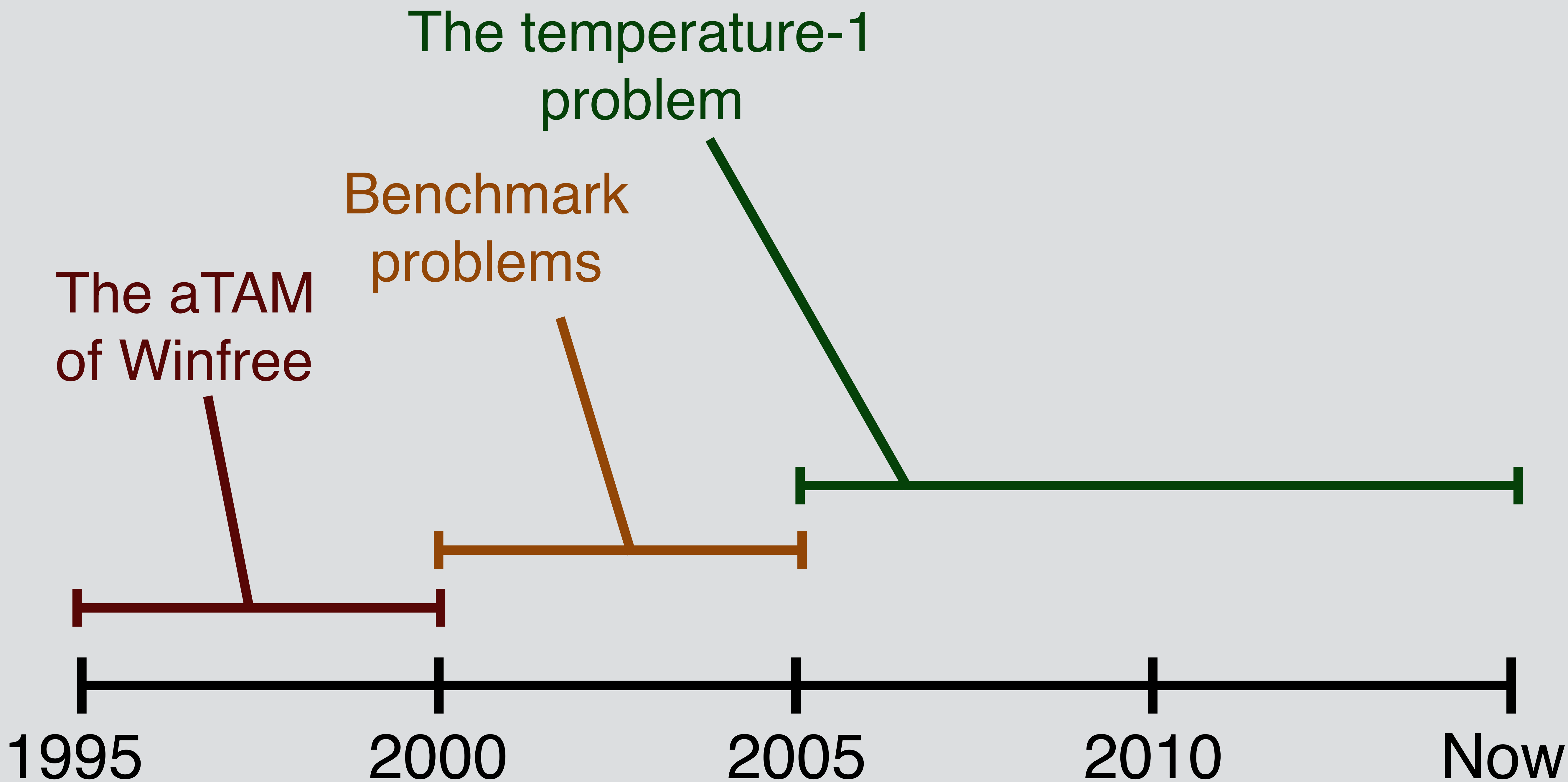


Is this required?

Efficient square assembly uses cooperative bonding:



Is this required?


The temperature-1
problem
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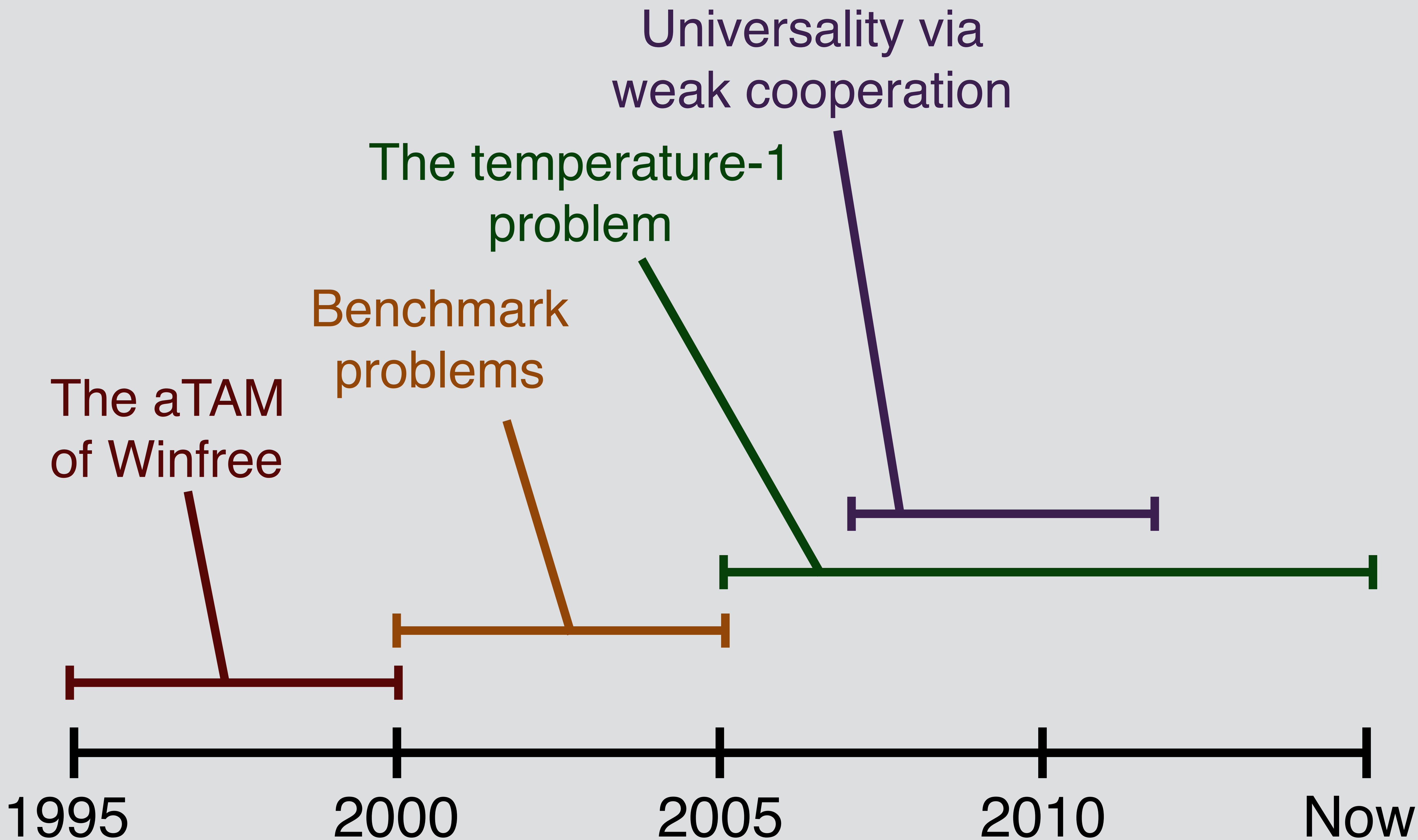

Universality via
weak cooperation
The temperature-1
problem
Benchmark
problems
The aTAM
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1995
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The temperature-1 problem:

Is the aTAM at temperature 1 computationally universal?

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Open since 2000, conjecture: no.

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“weak cooperation”

Can an augmented temperature-1 aTAM be computationally universal?

The temperature-1 problem:

Is the aTAM at temperature 1
computationally universal?

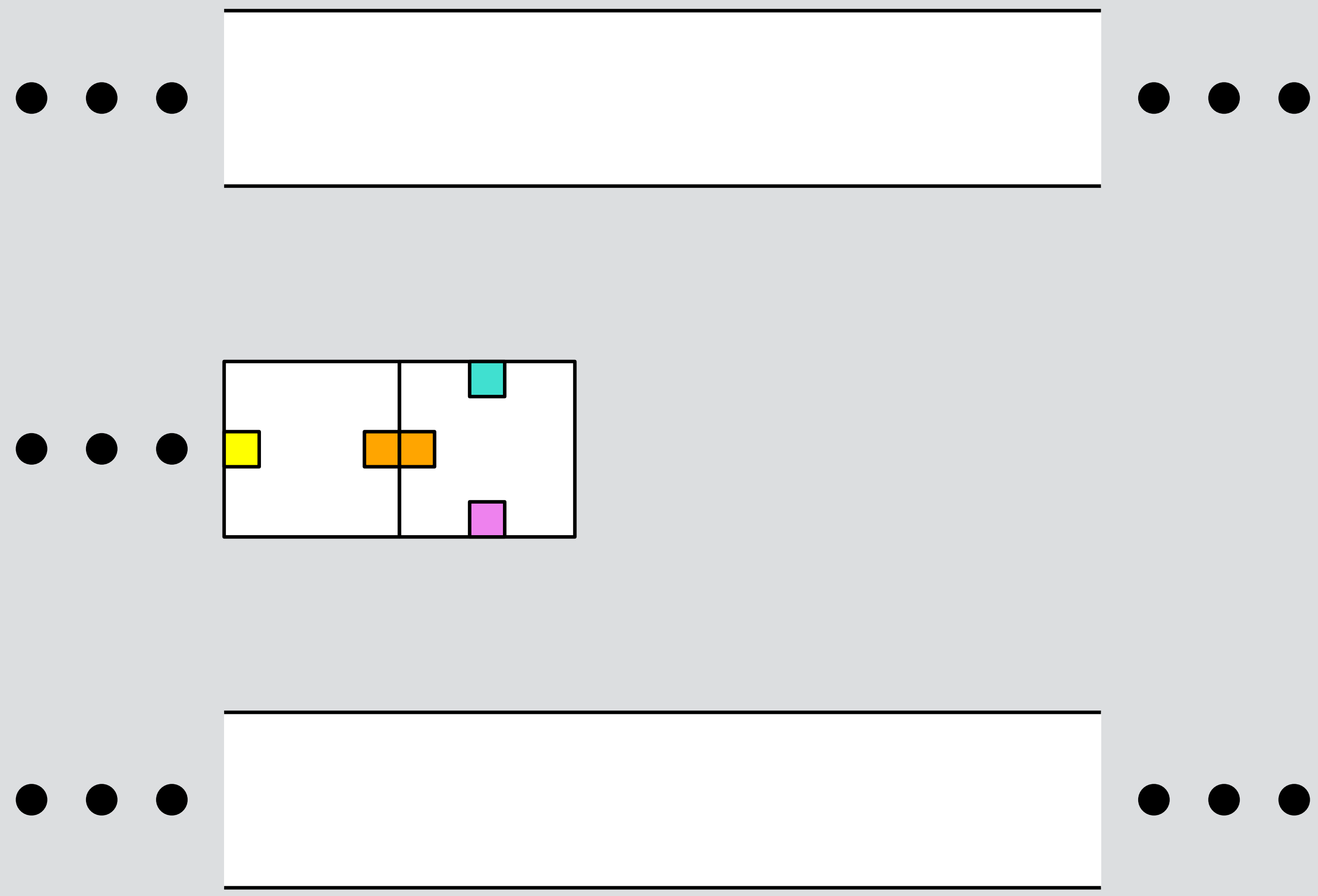
Open since 2000, conjecture: no.

"weak cooperation"

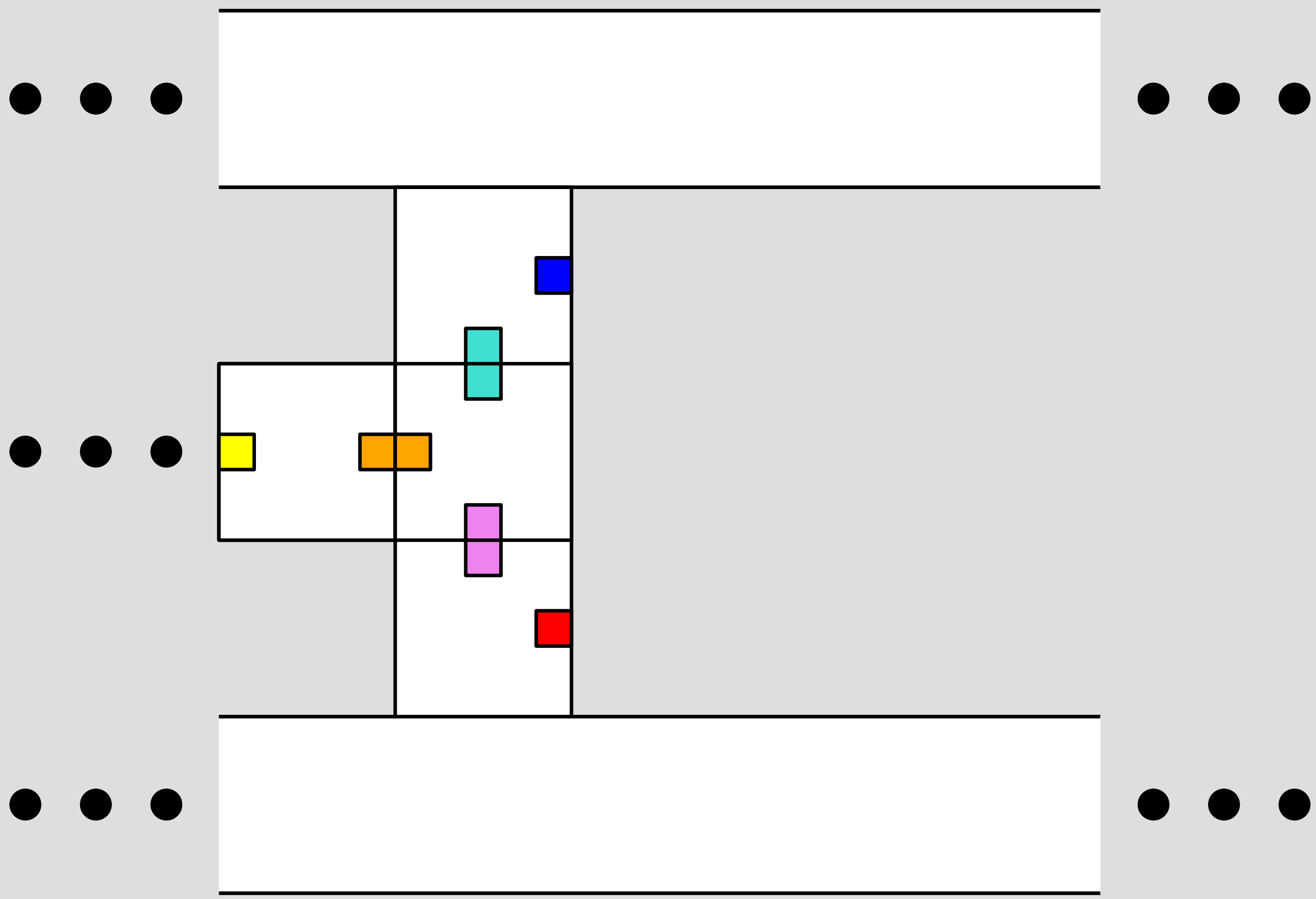
Can an augmented temperature-1 aTAM
be computationally universal?

Yes, several ways.

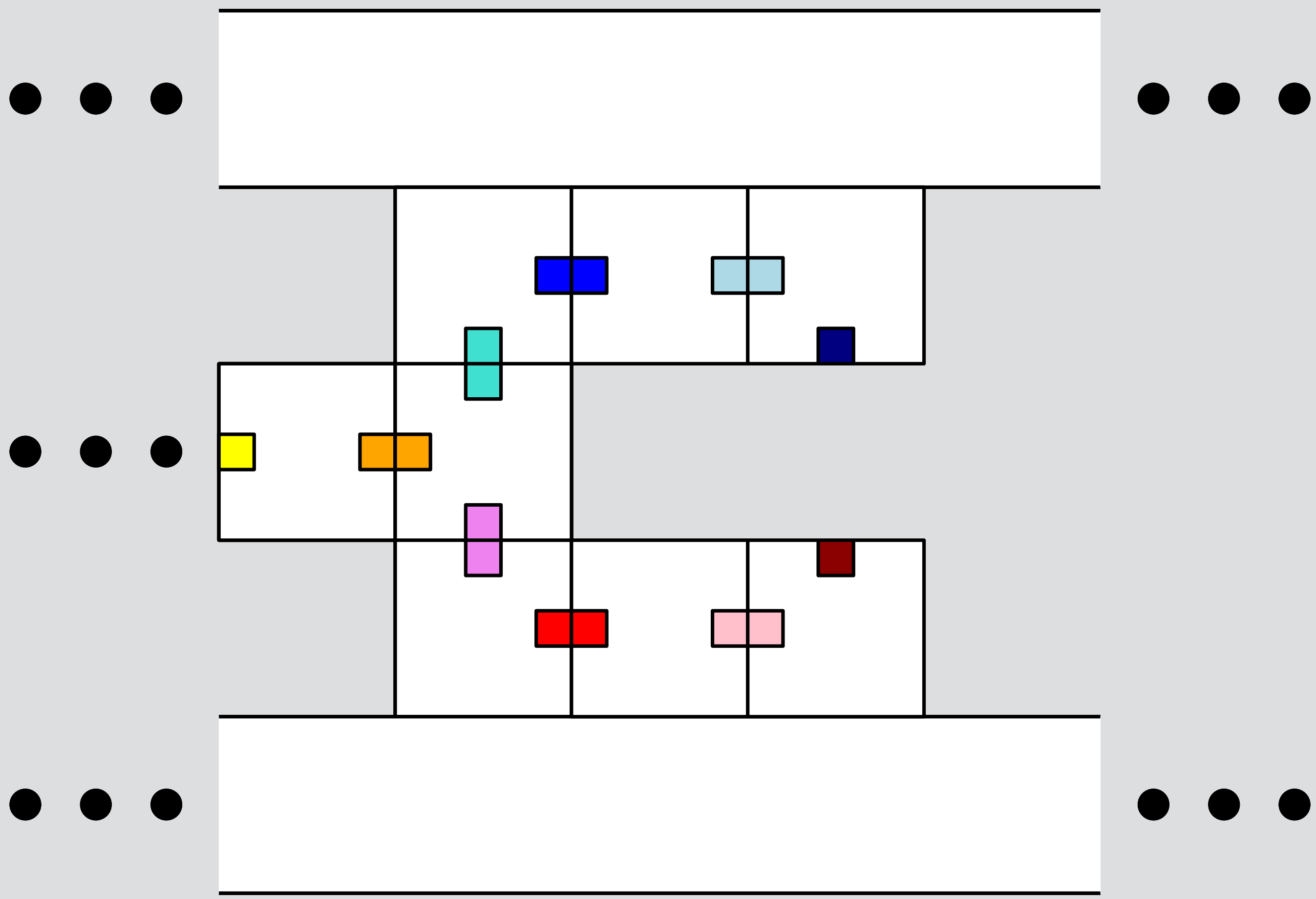
Reading a bit w/o cooperation



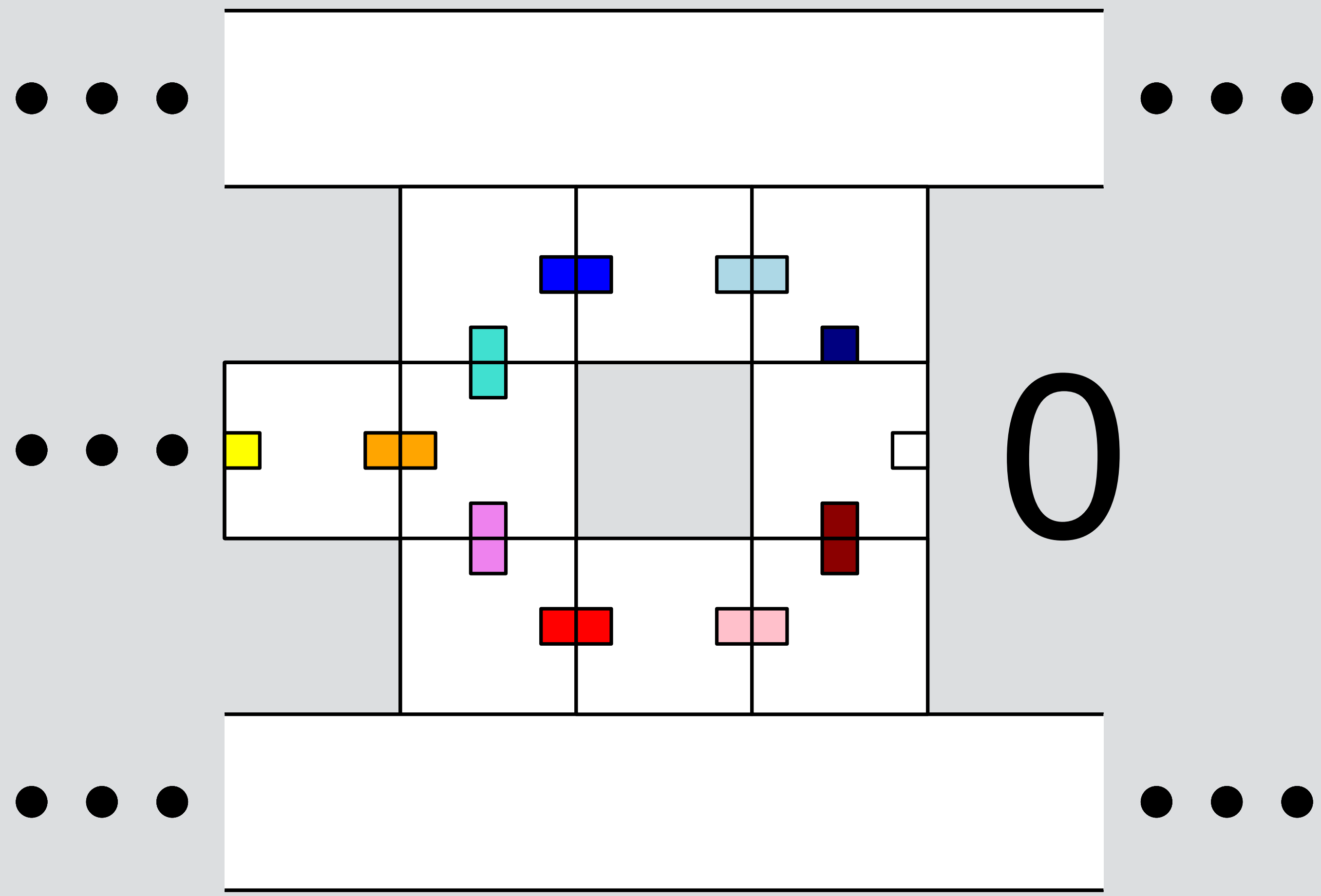
Reading a bit w/o cooperation



Reading a bit w/o cooperation

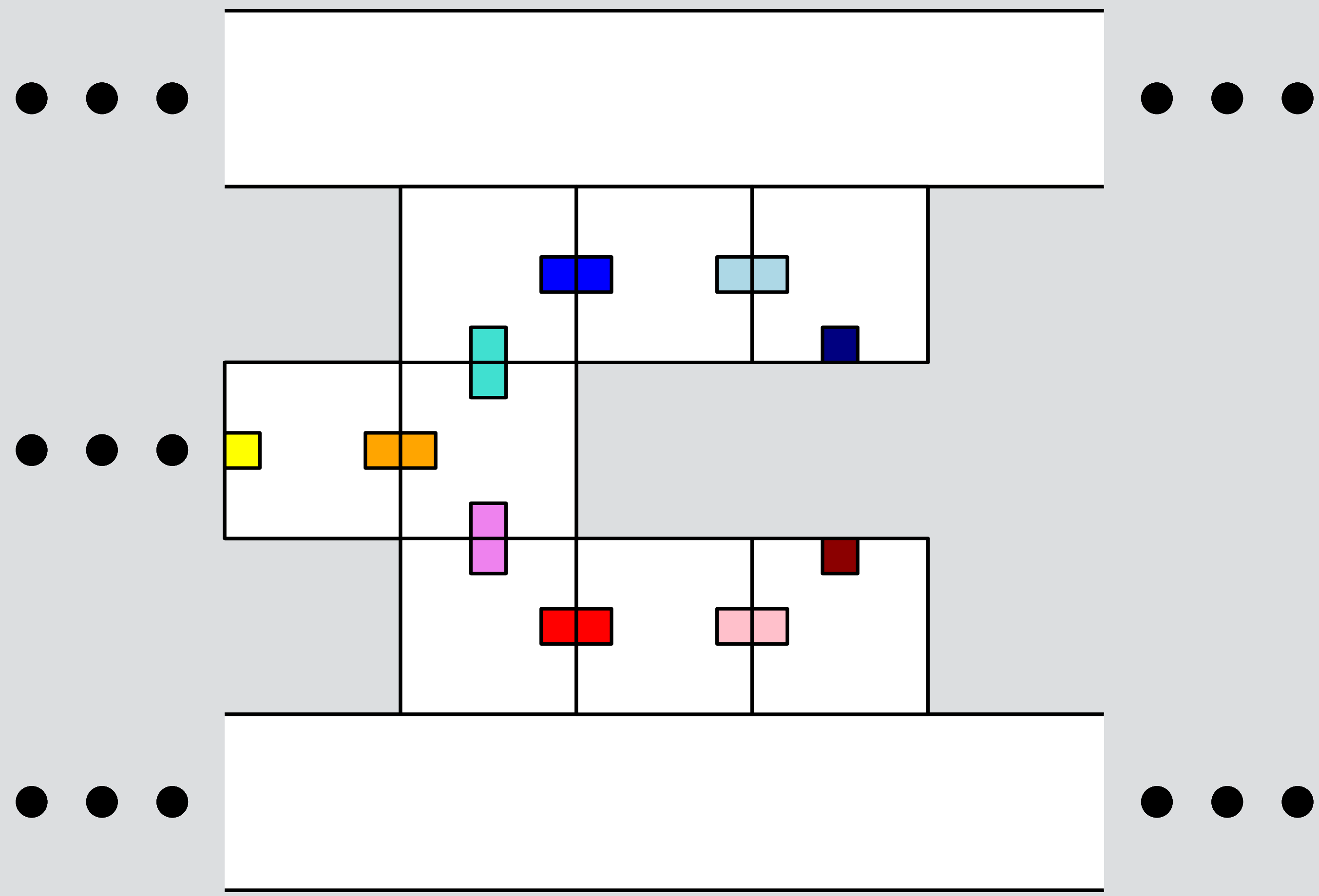


Reading a bit w/o cooperation



0

Reading a bit w/o cooperation



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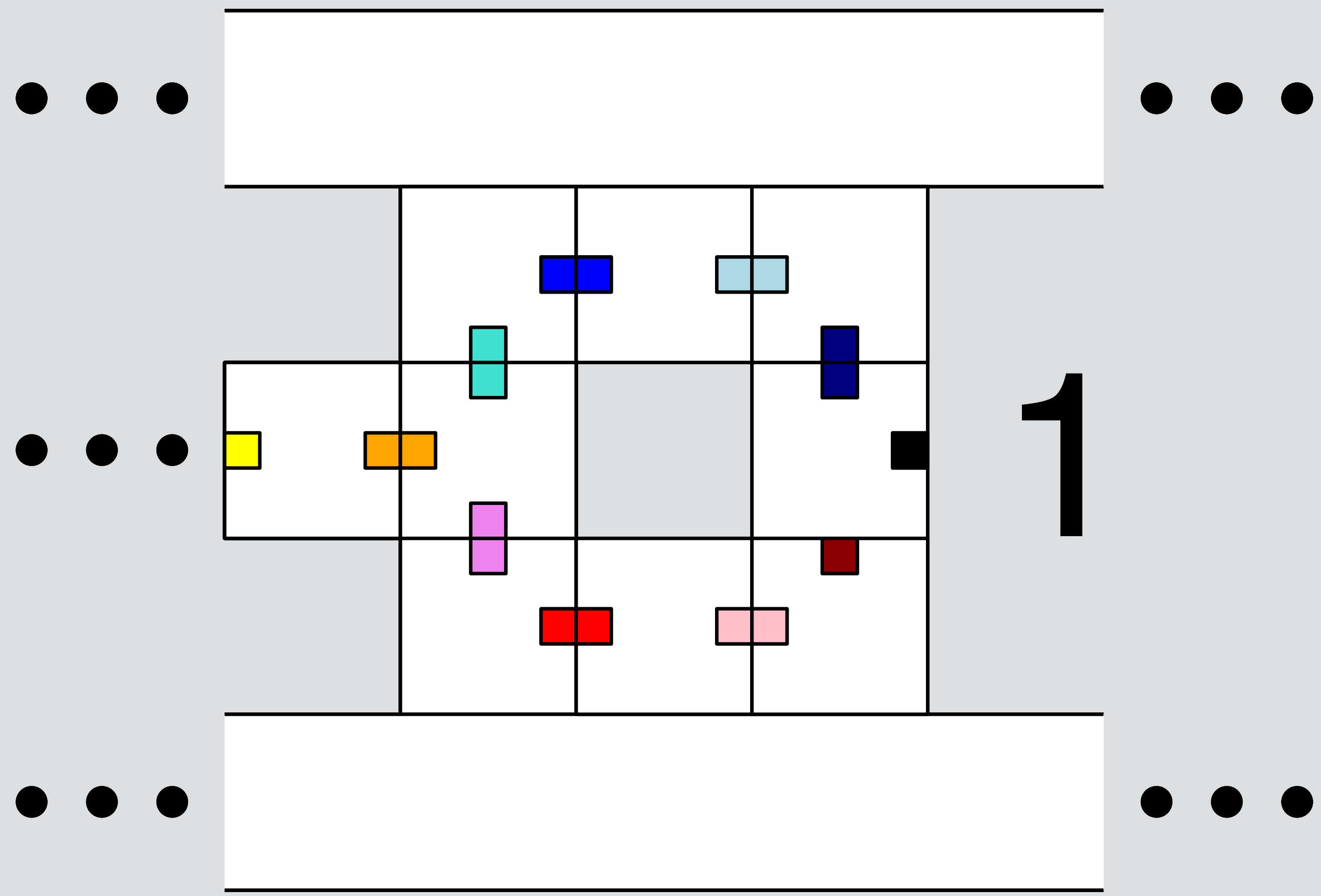

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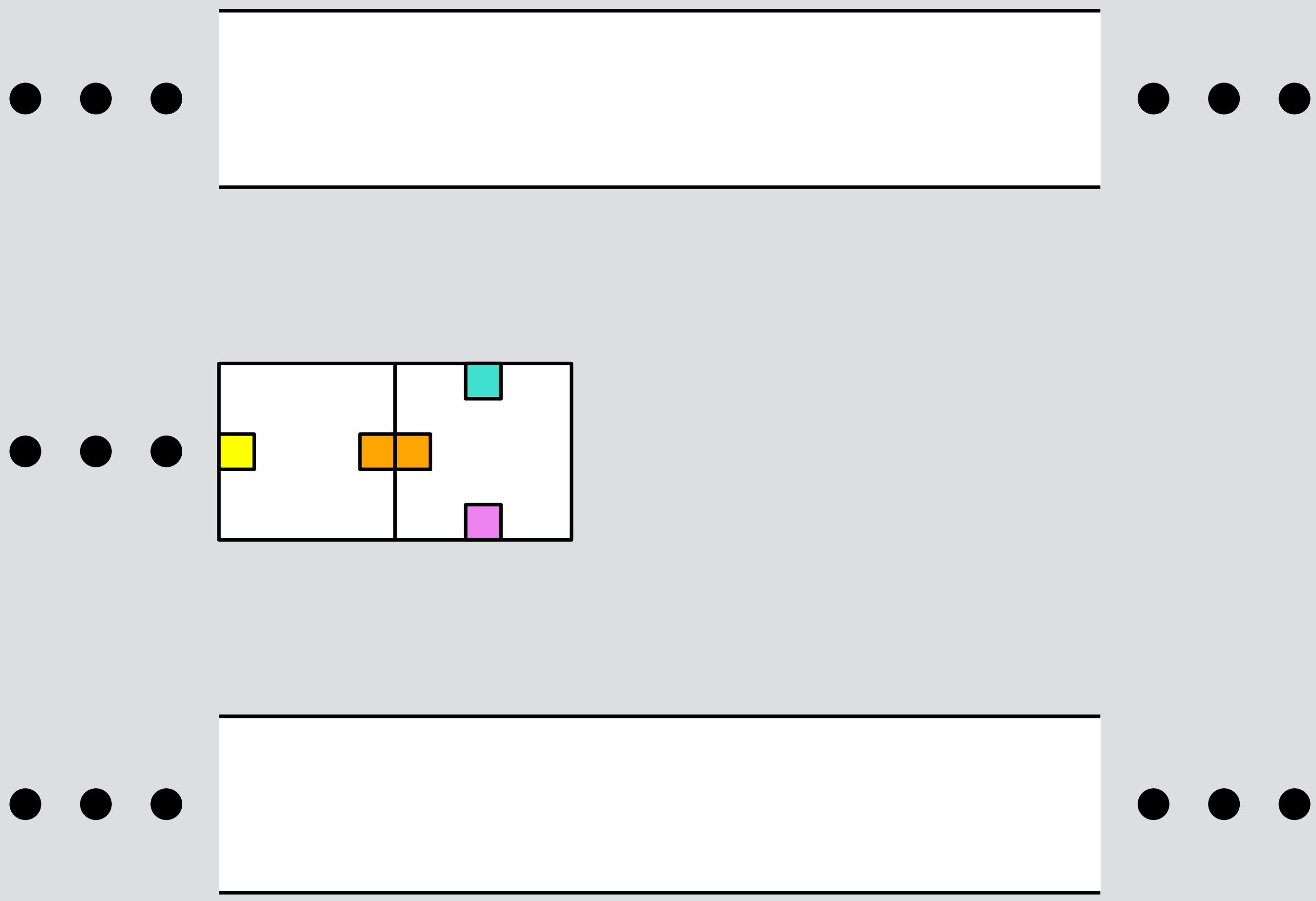
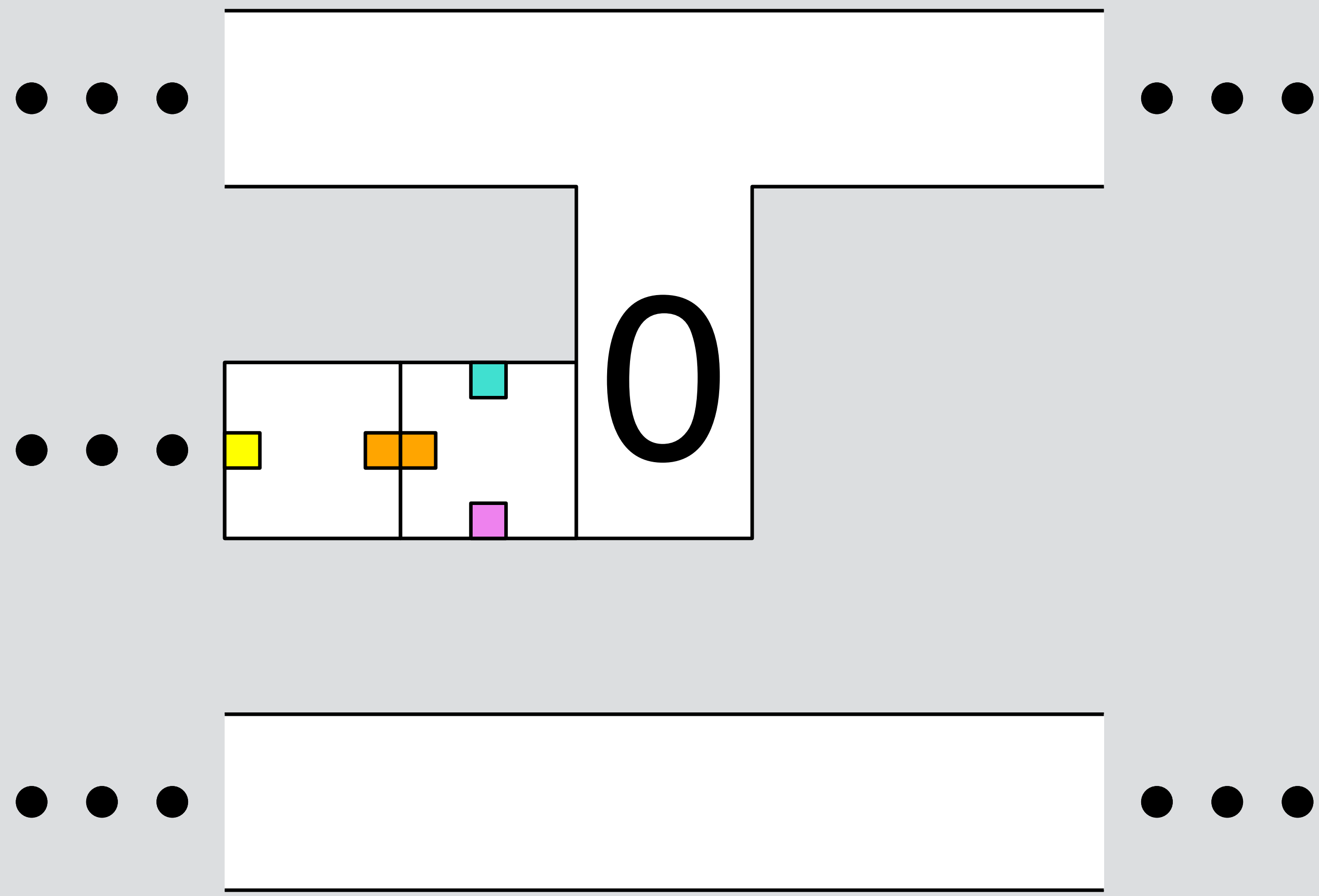


Reading a bit w/o cooperation



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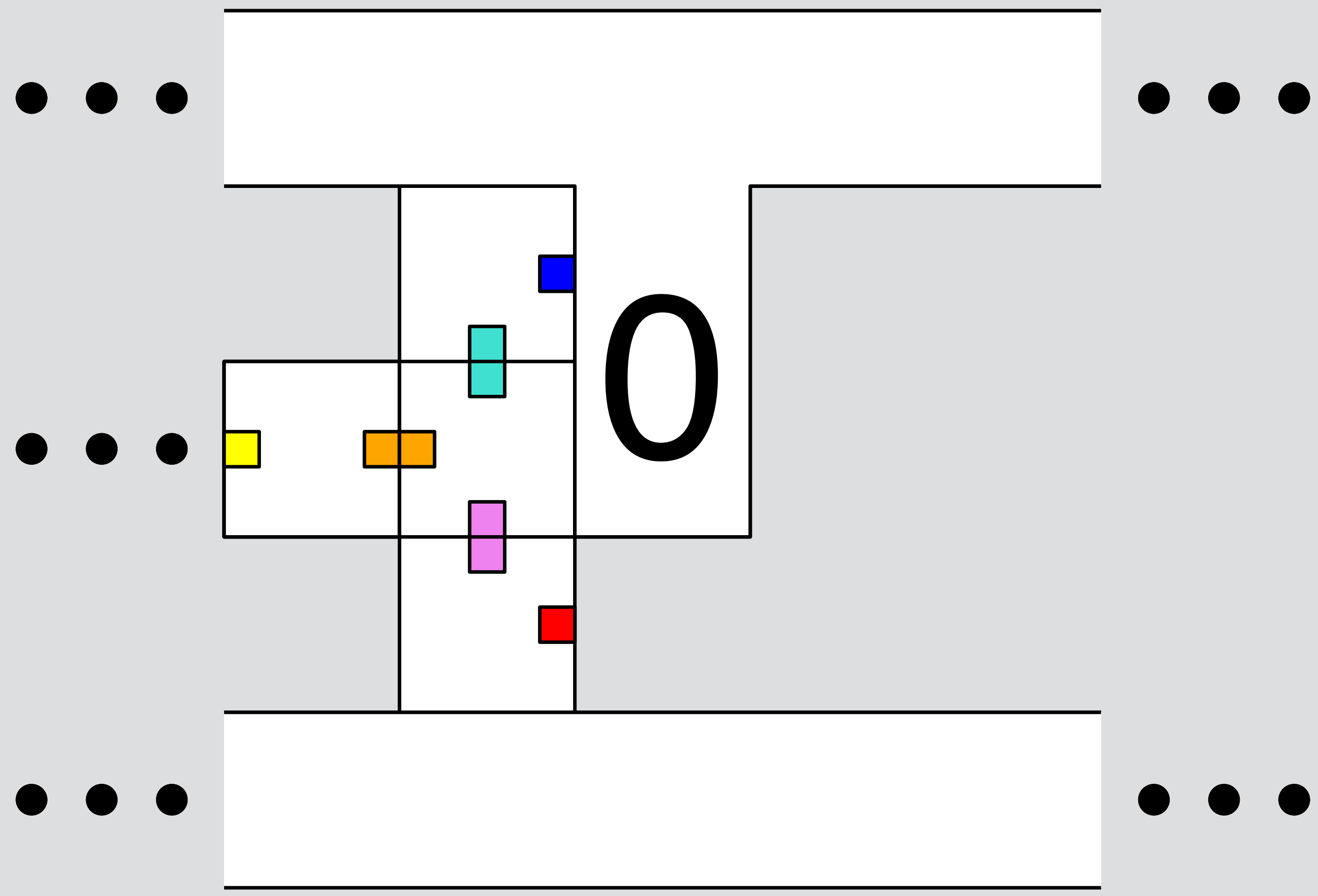

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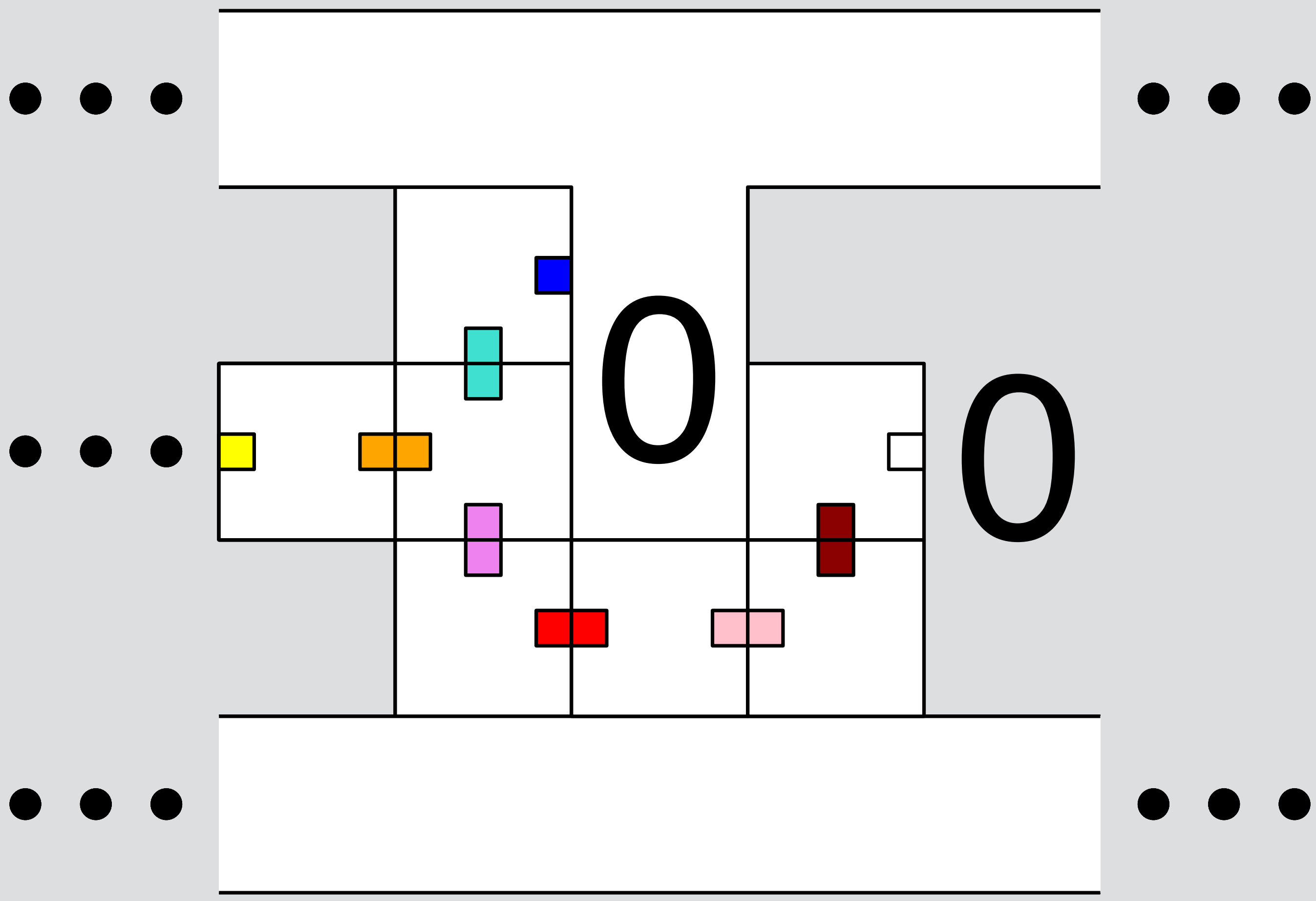

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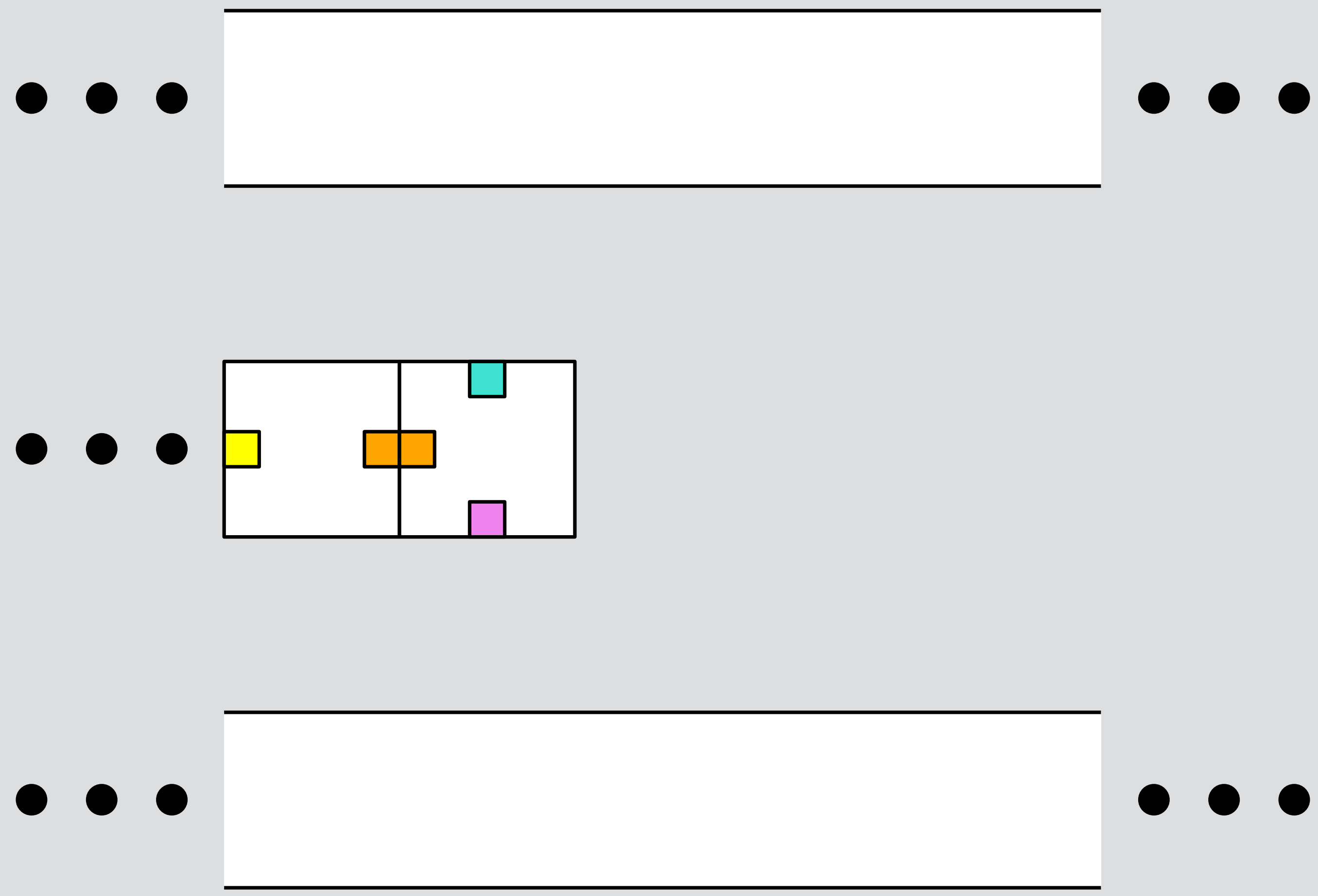

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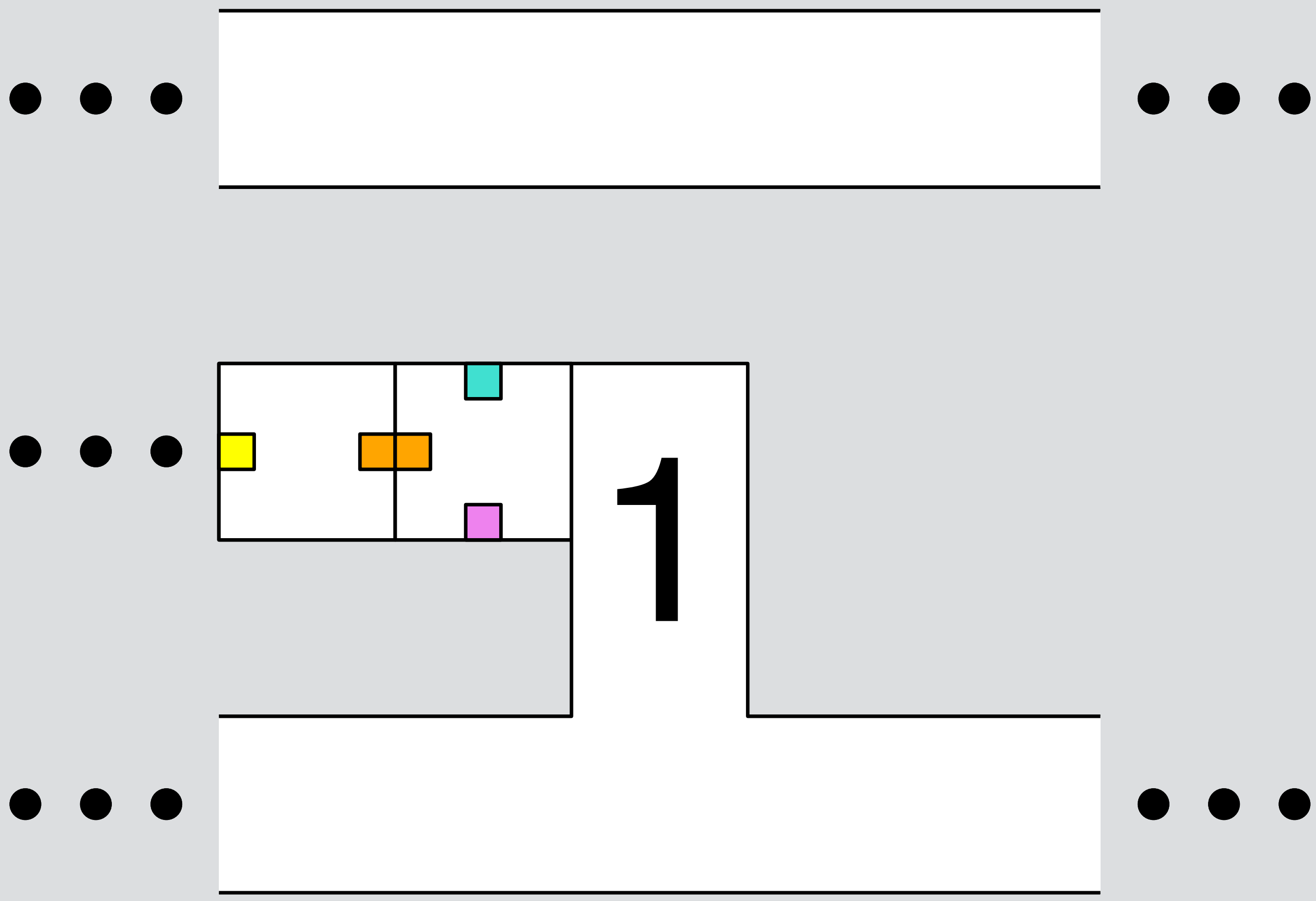

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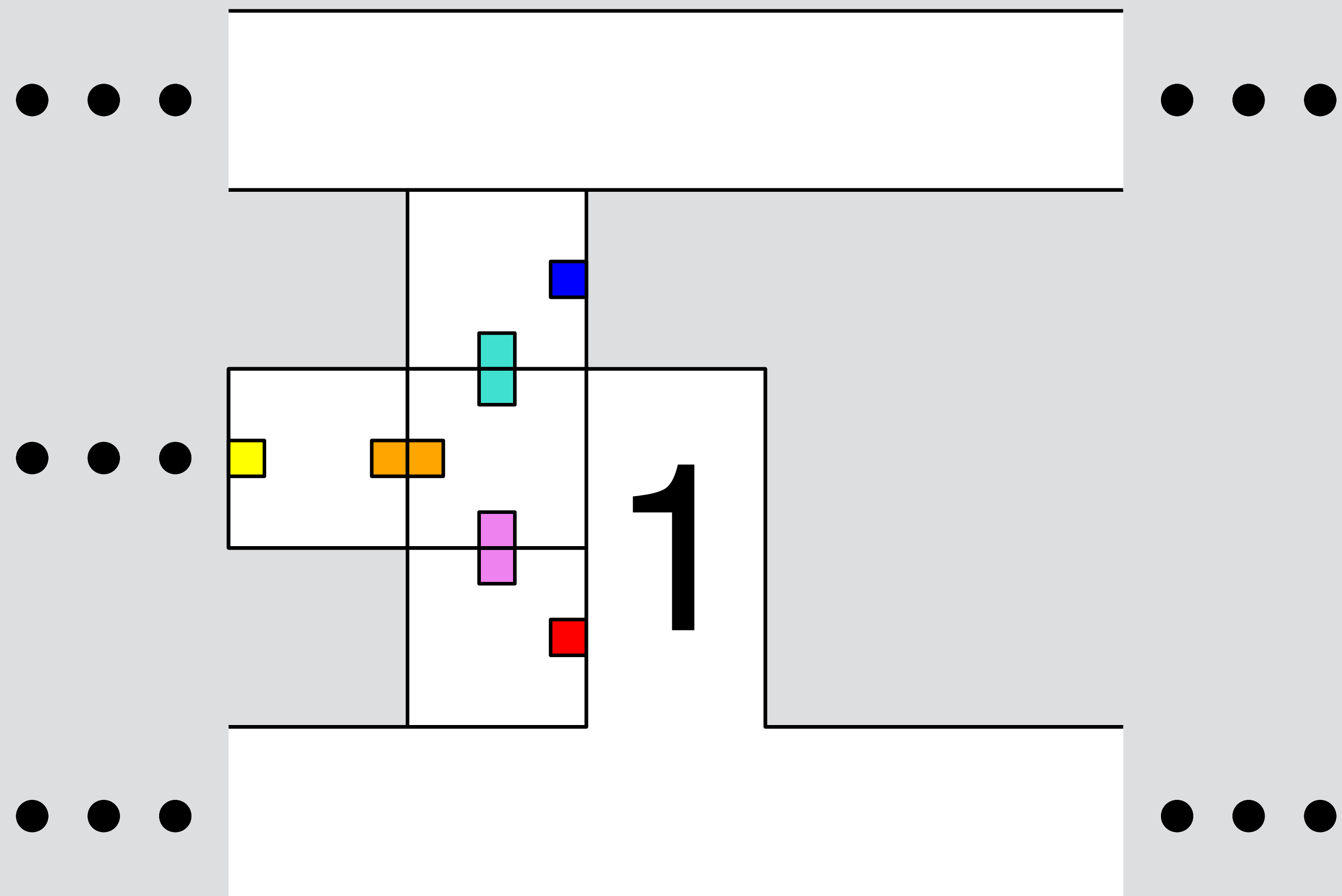

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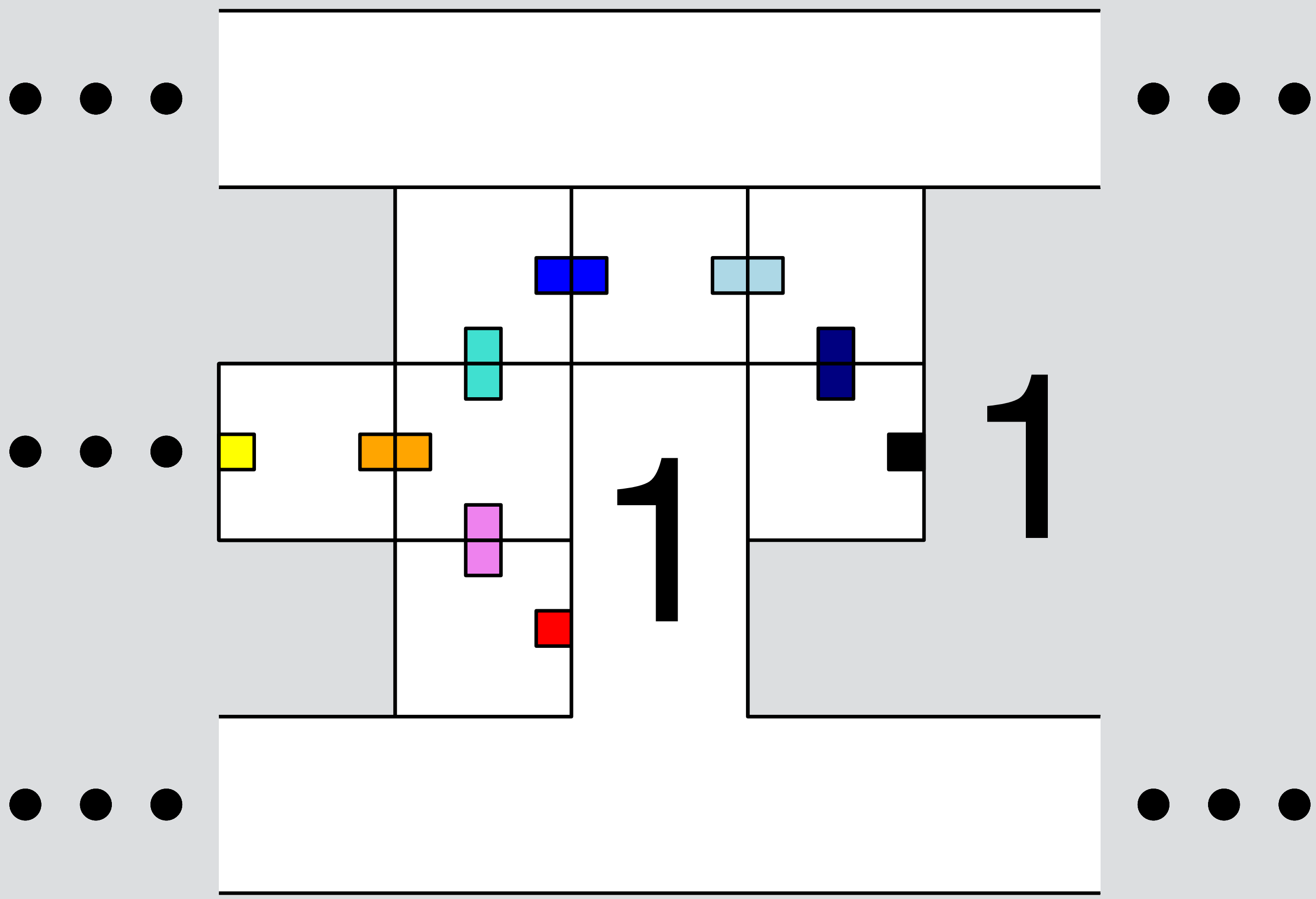
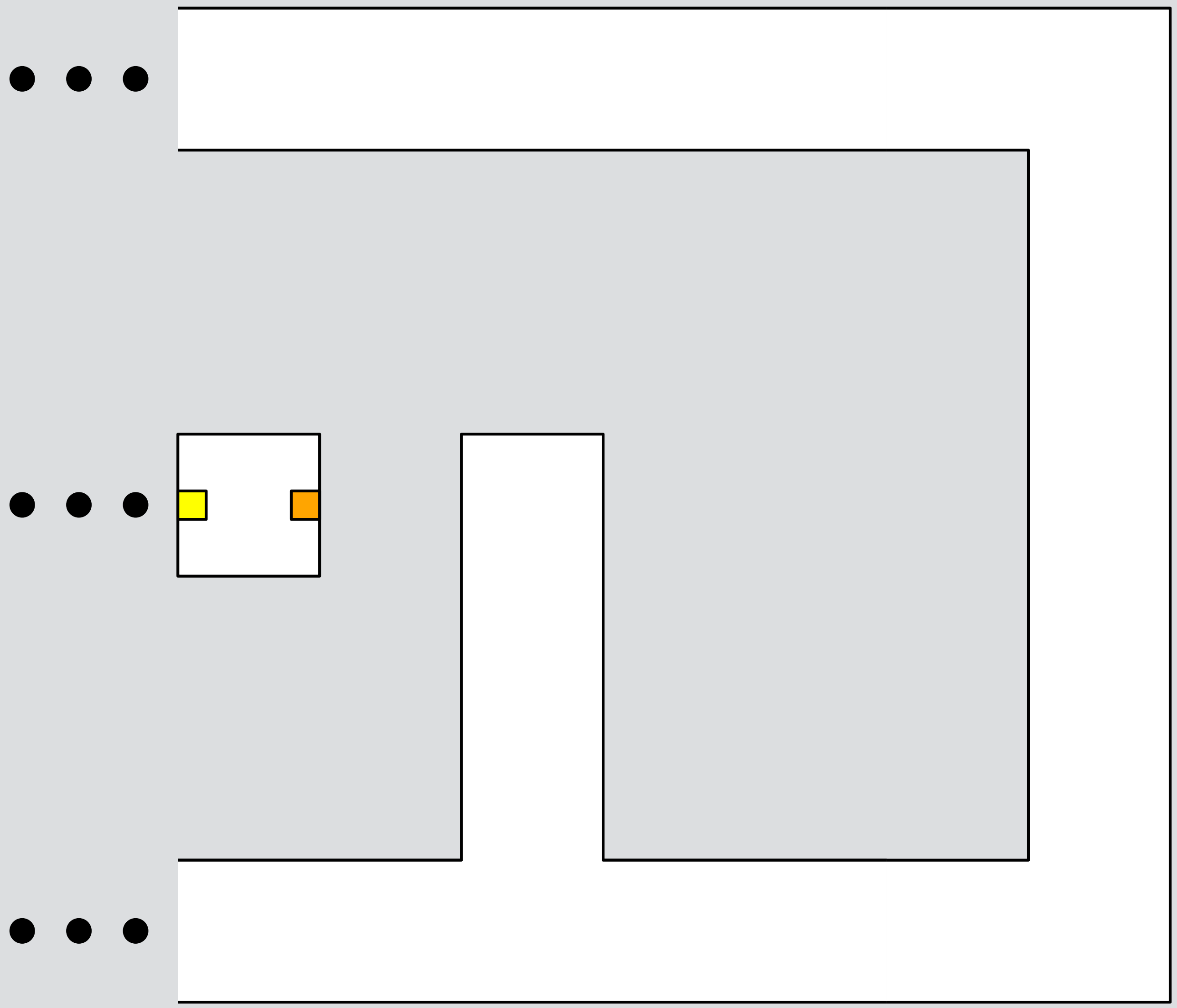


A planarity problem



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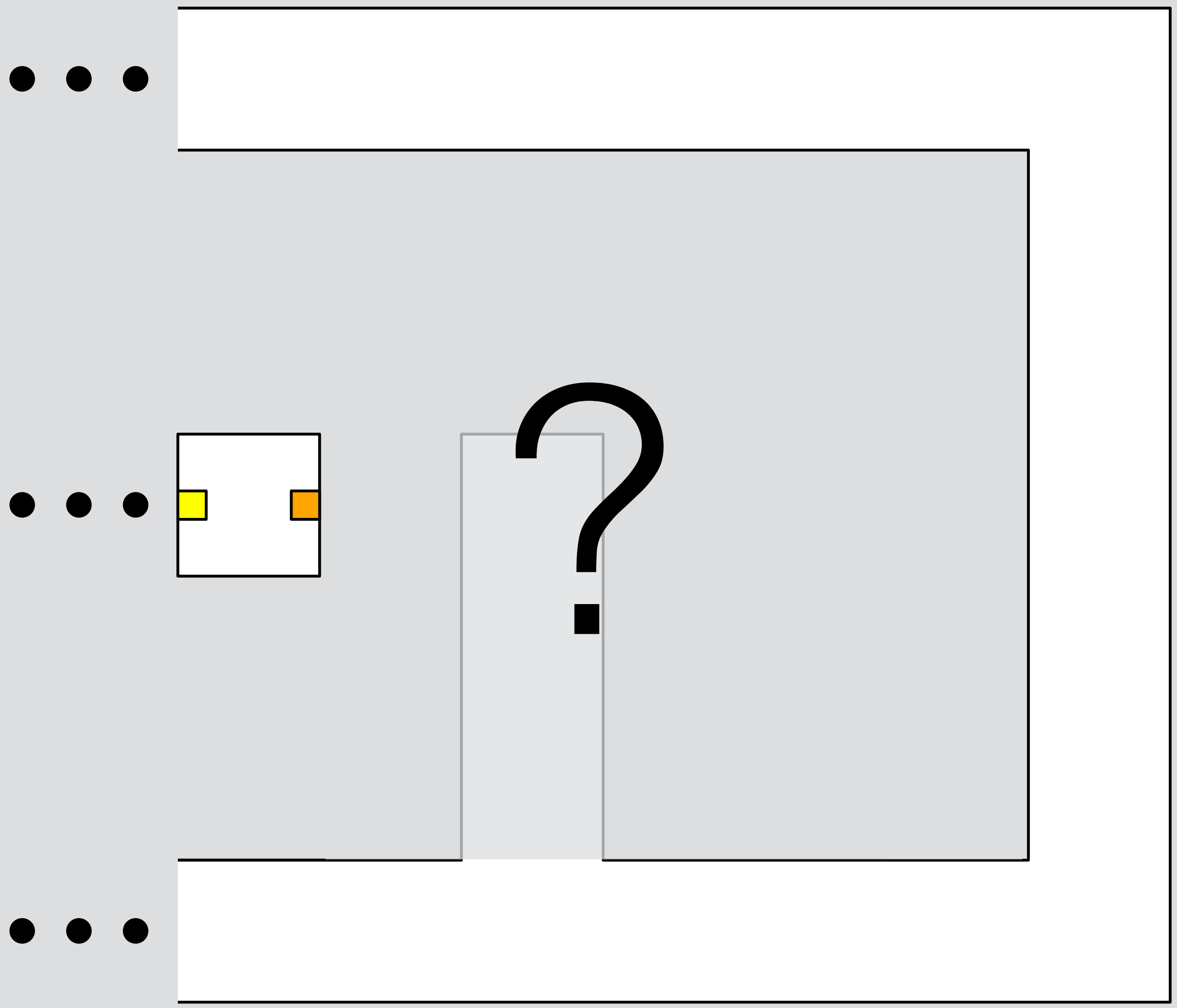

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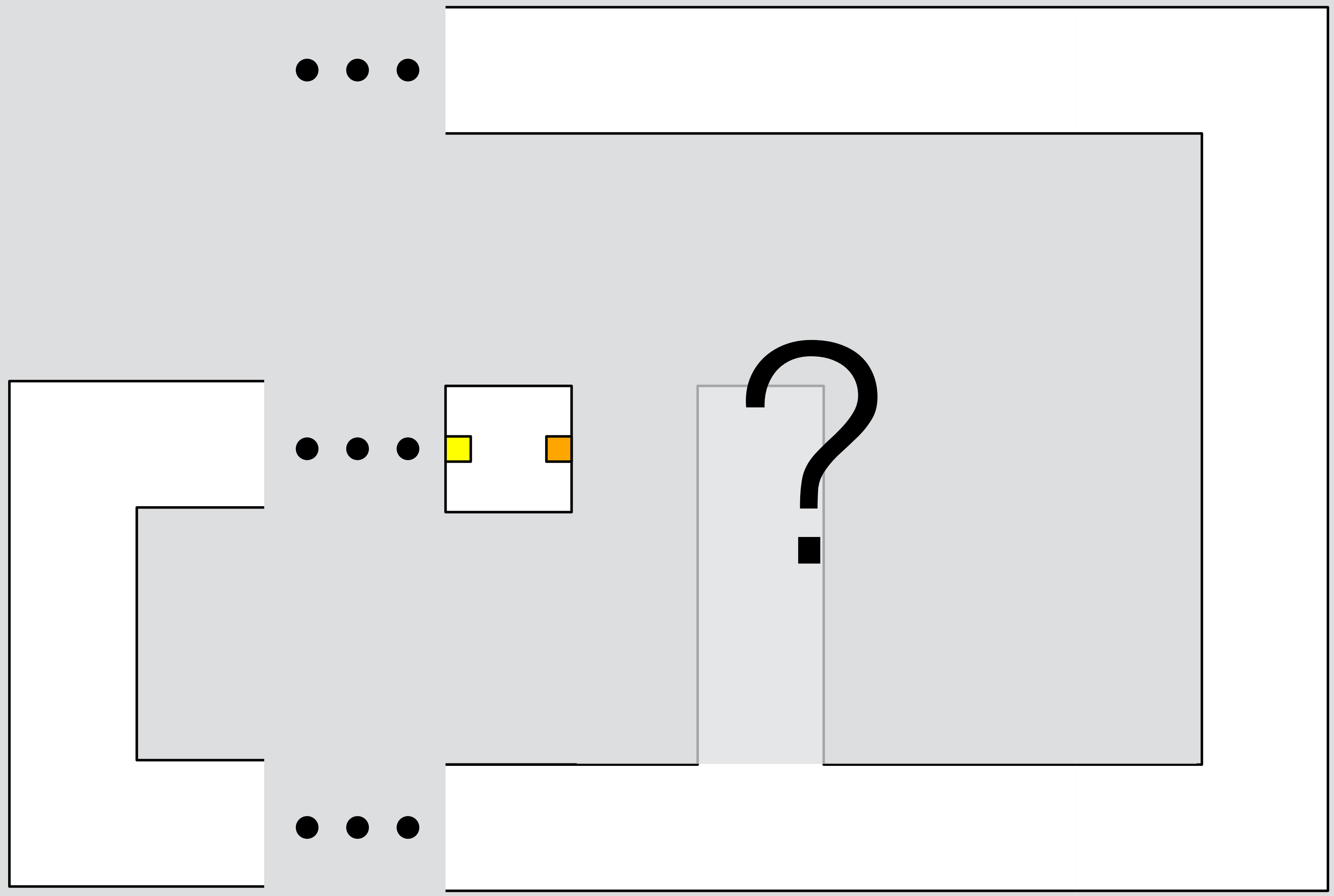

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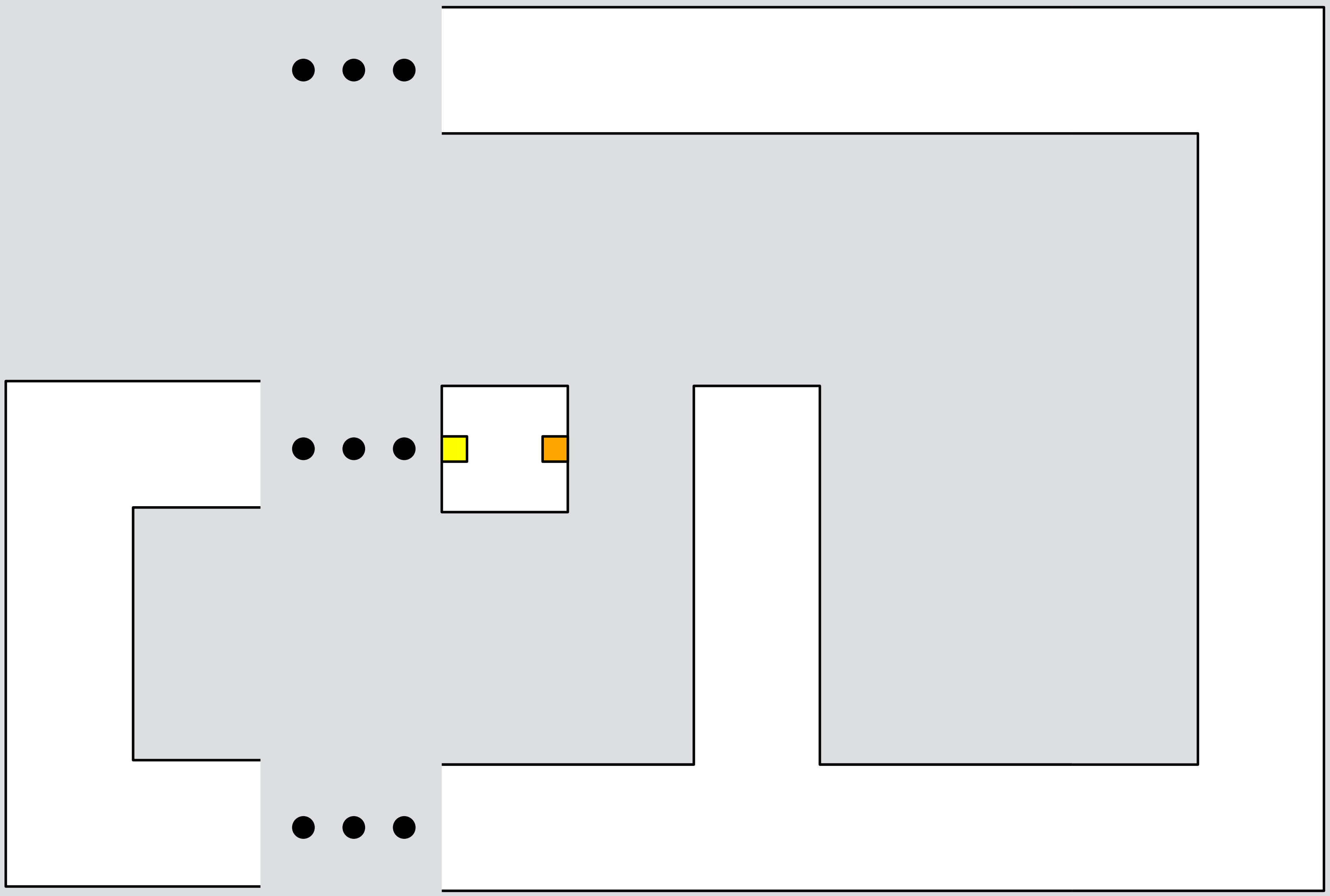

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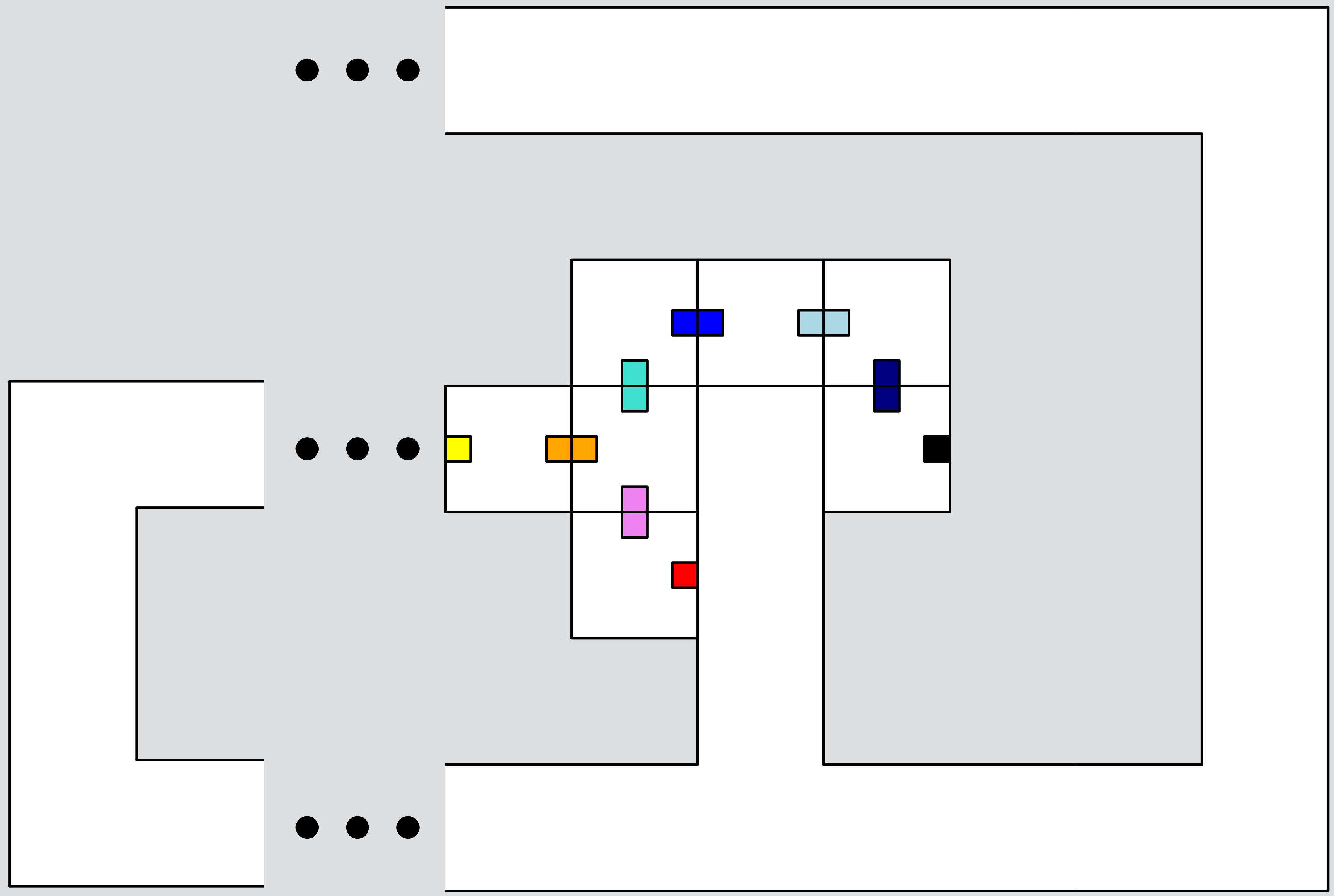

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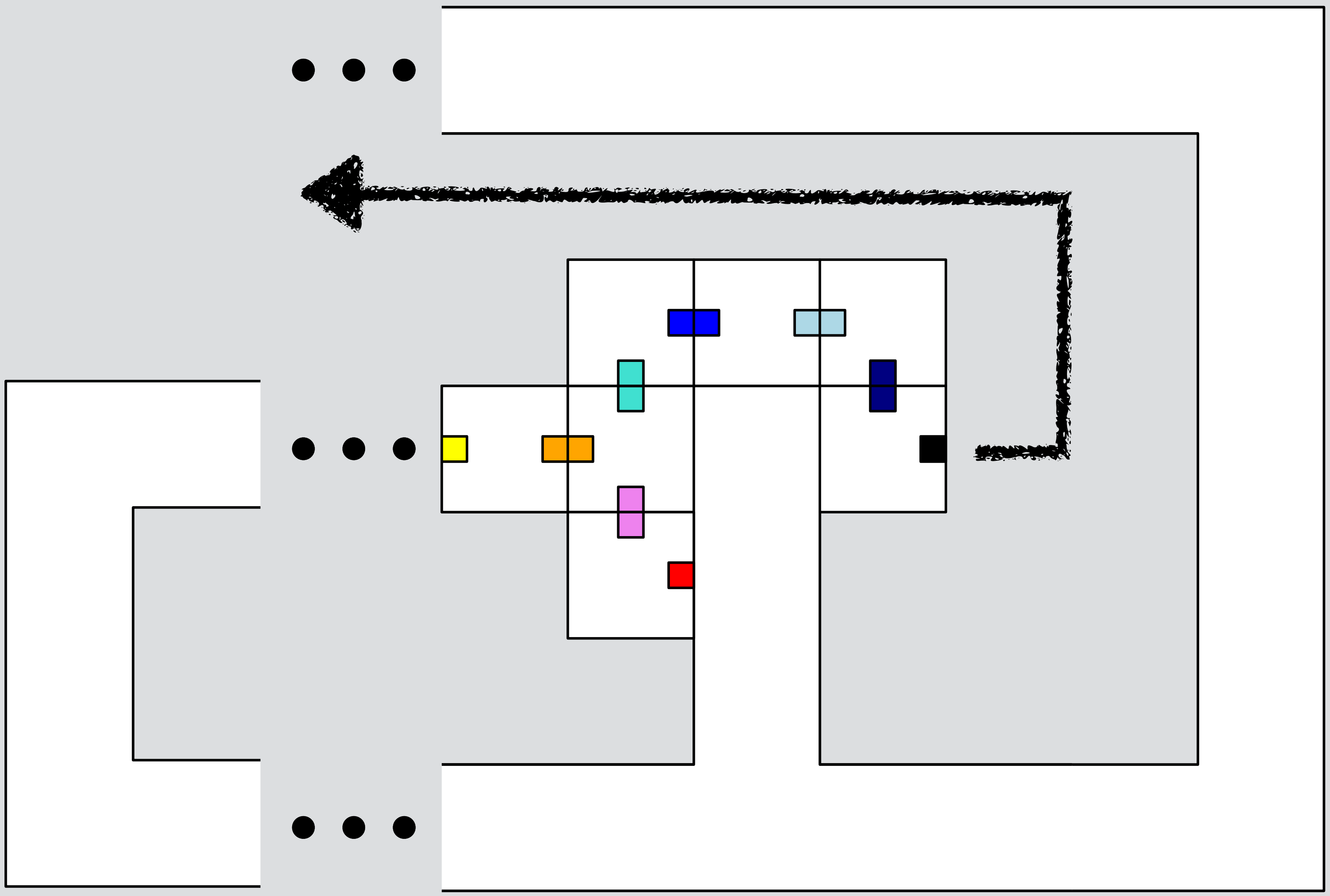

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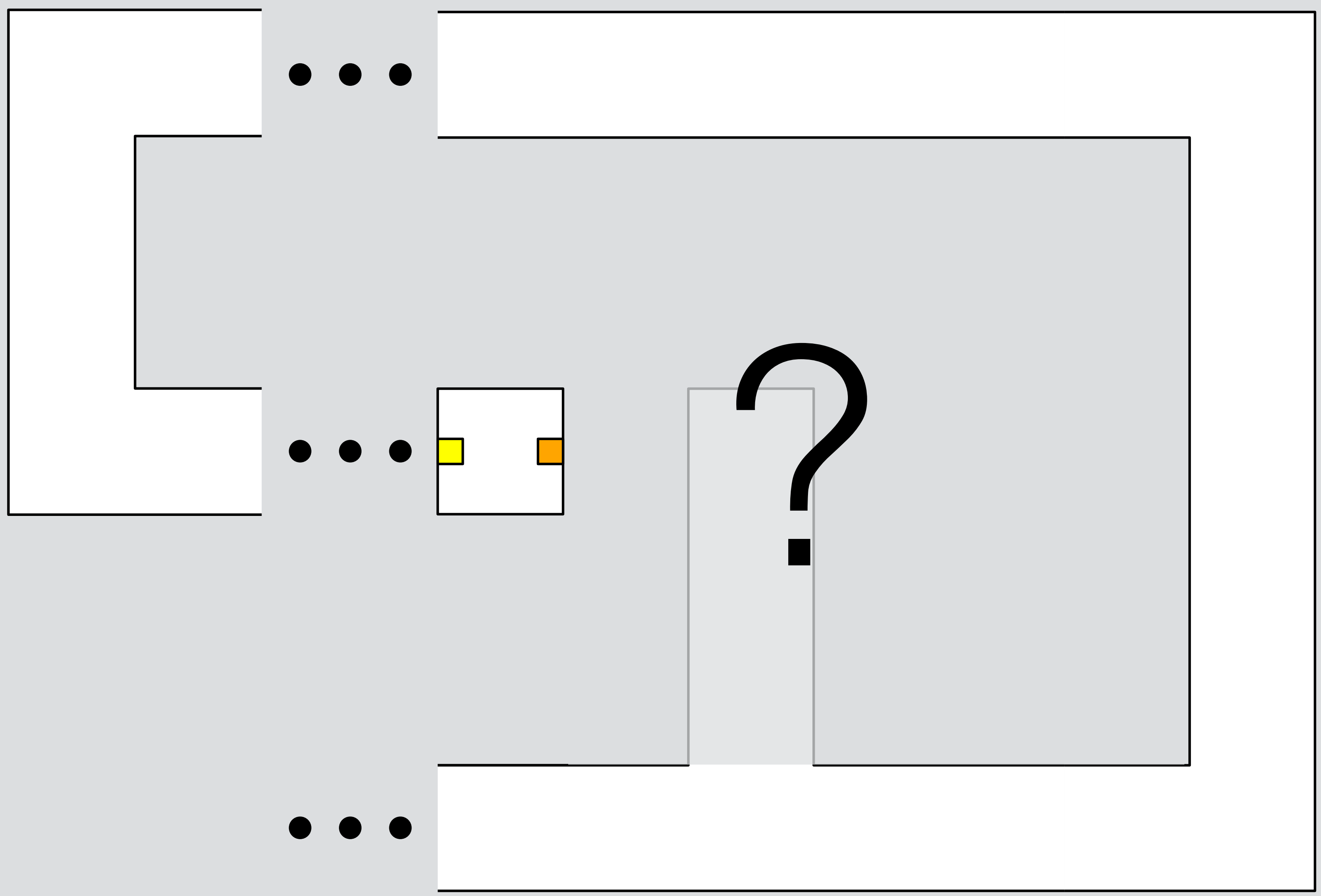

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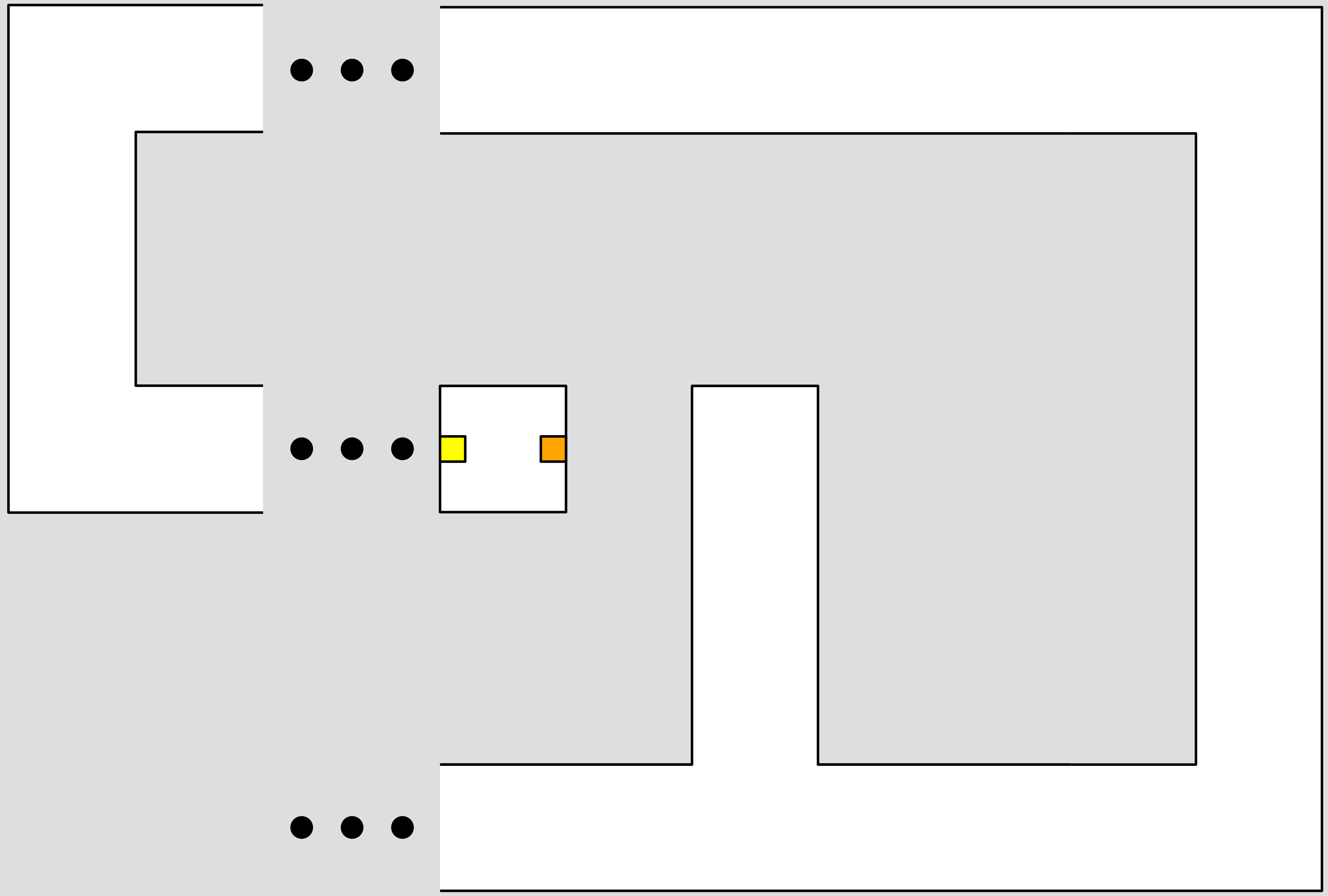

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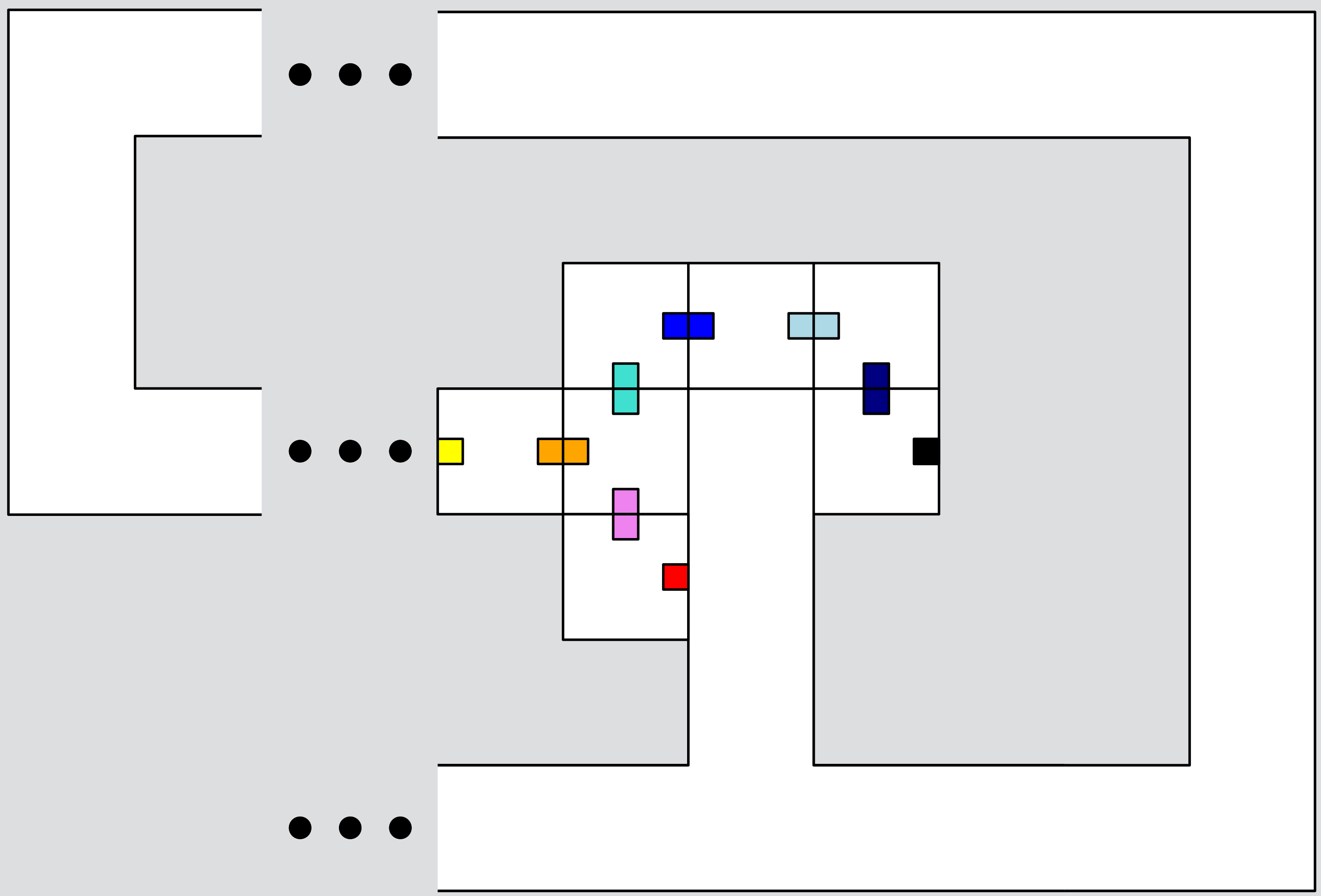

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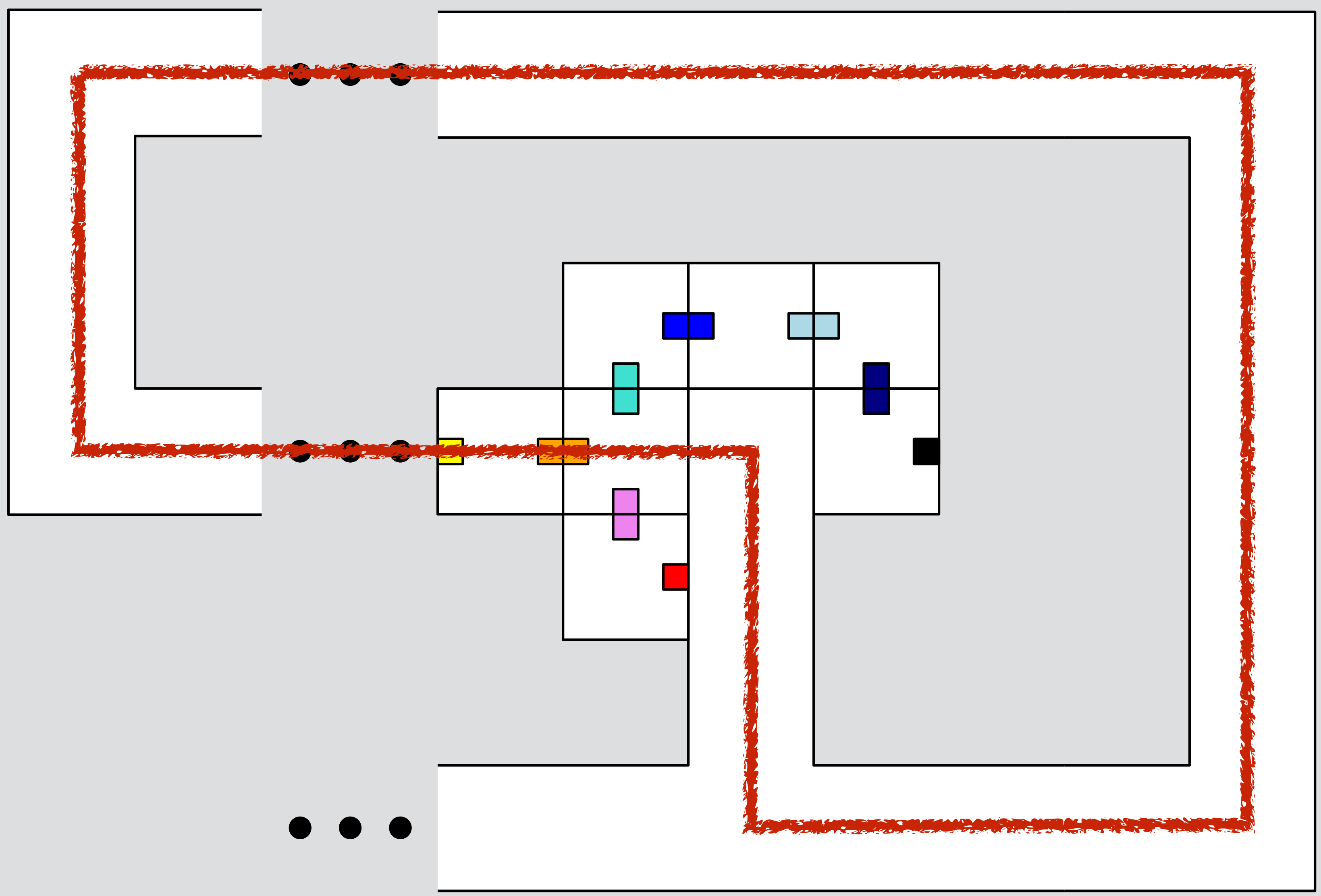

Planarity is the barrier to reading without cooperative bonding.

Can read, but might get trapped.

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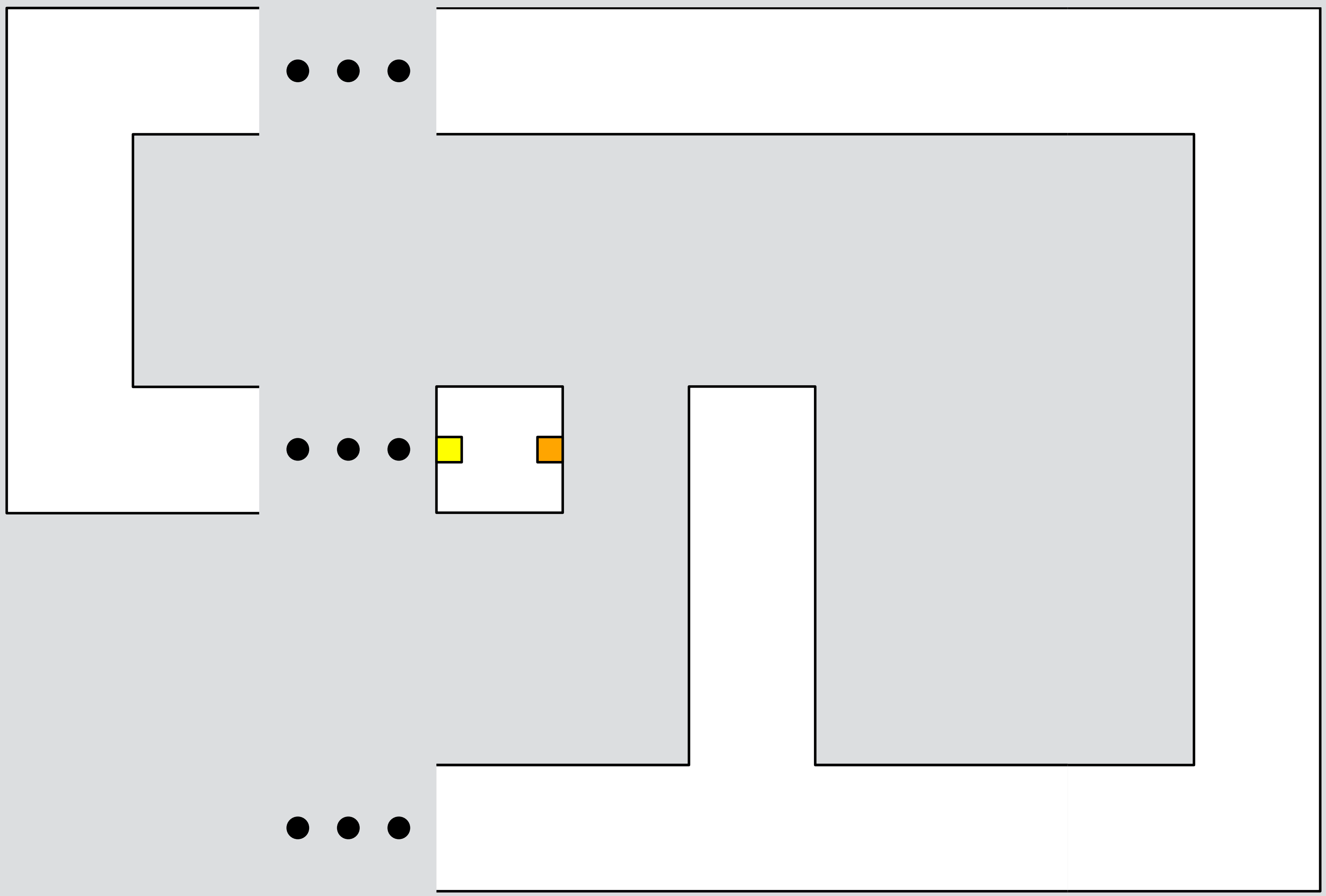
Approach 1: 3D

[Cook, Fu, Schweller 2012]



Temperature 1

Approach 1: 3D

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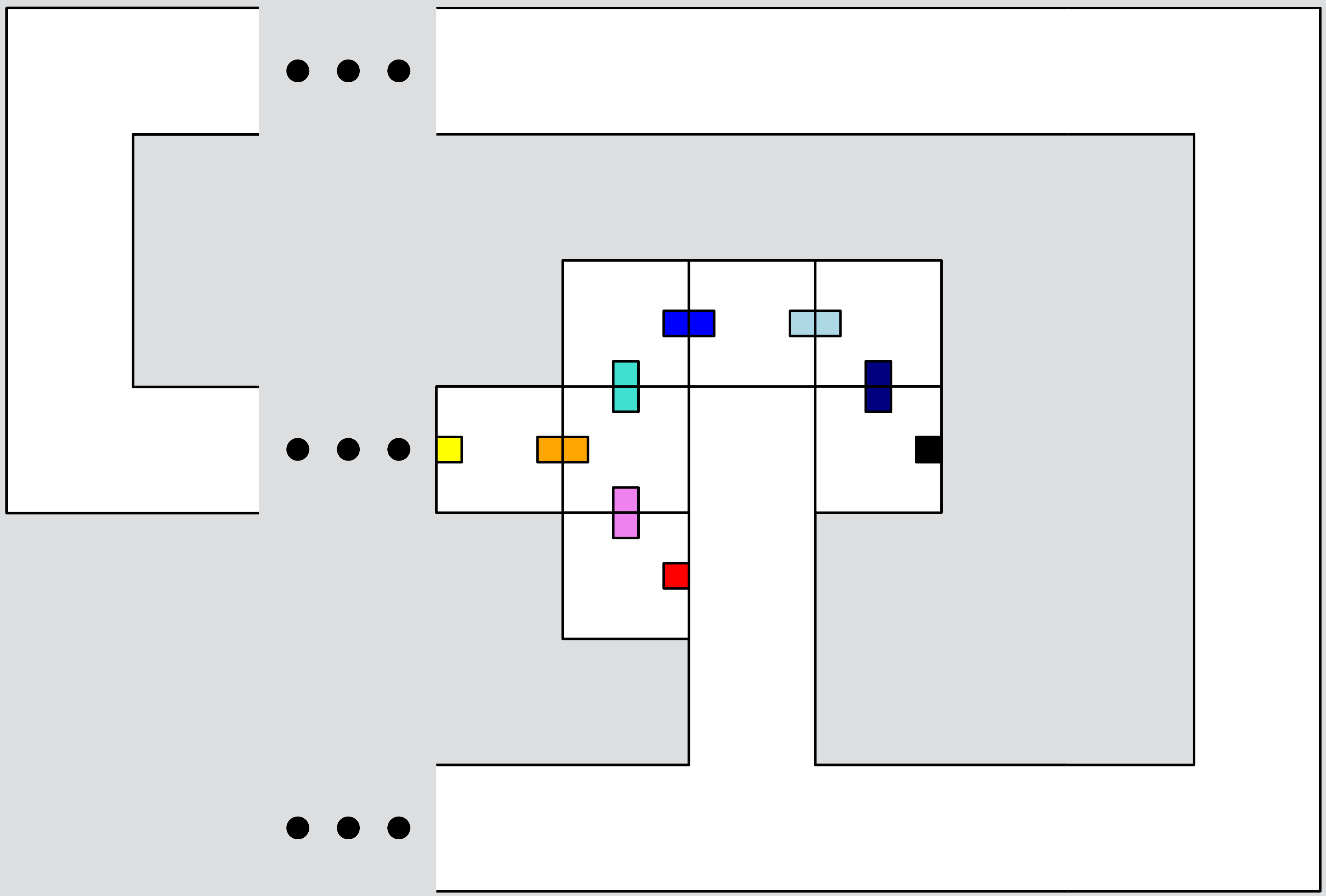

Temperature 1

Approach 1: 3D

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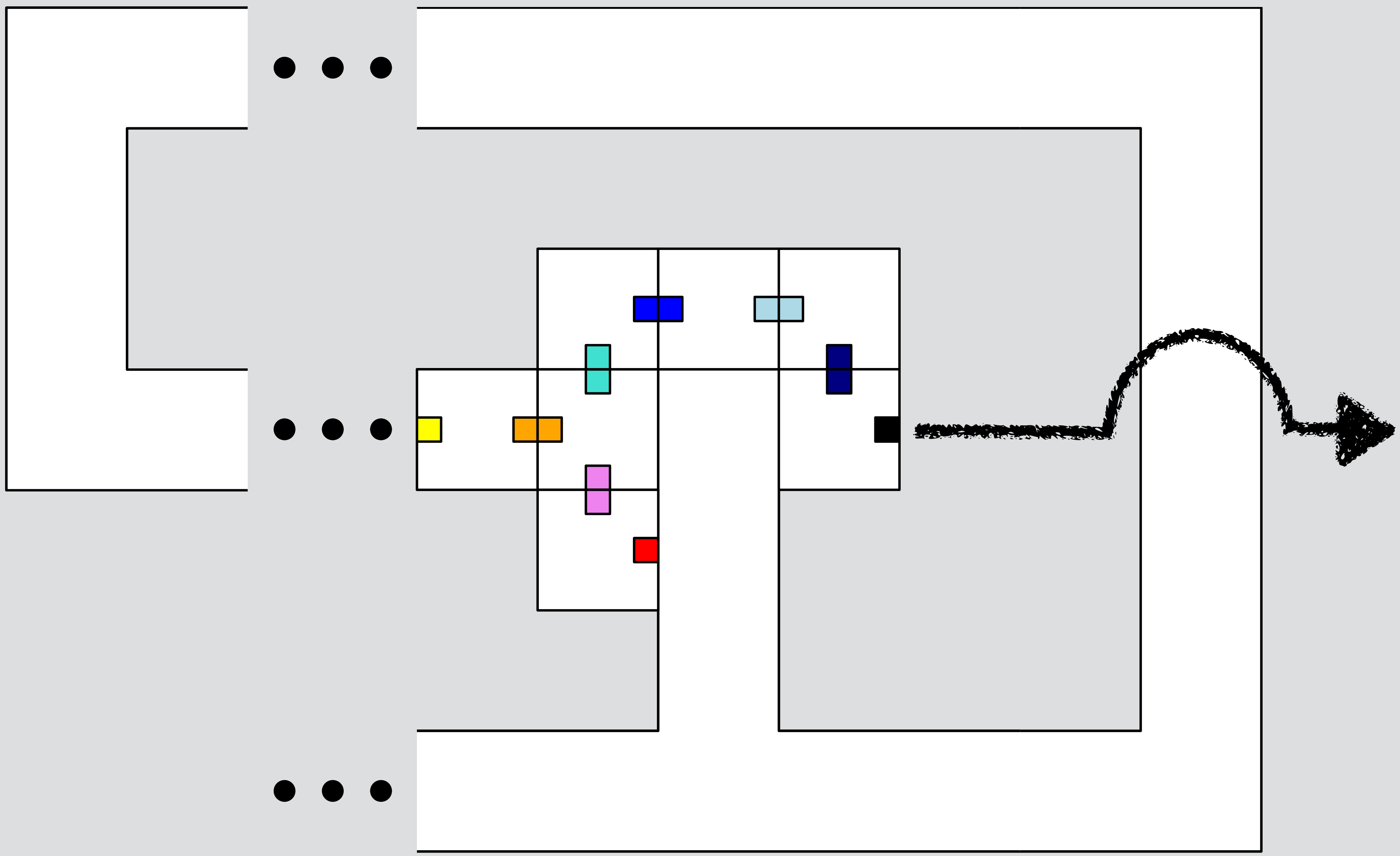
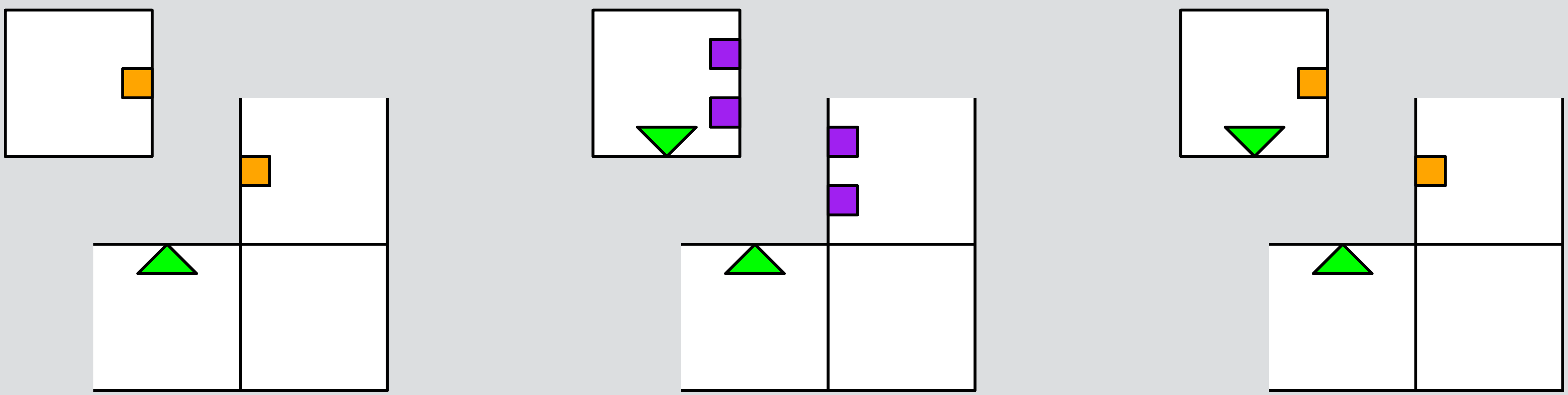


Temperature 1

Approach 2: Negative Glue

[Patitz, Schweller, Summers 2011]



Temperature 1

Approach 2: Negative Glue

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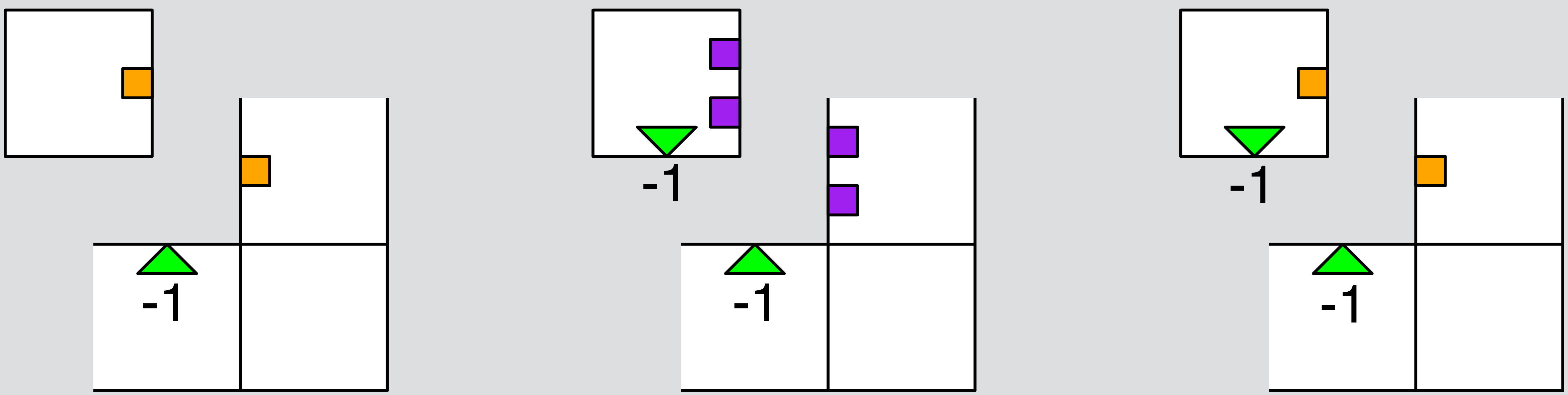

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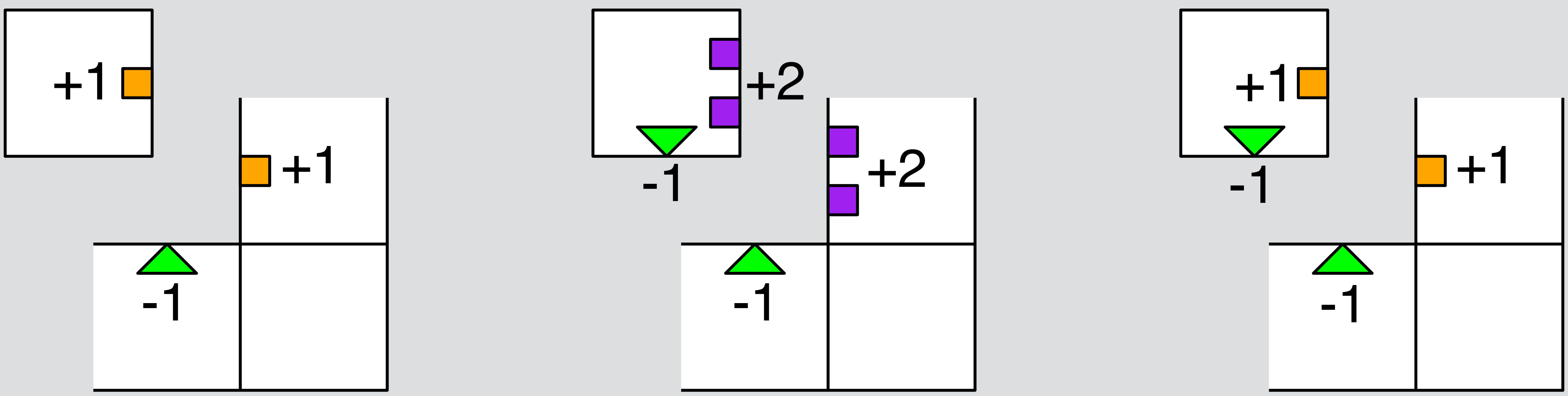

Temperature 1

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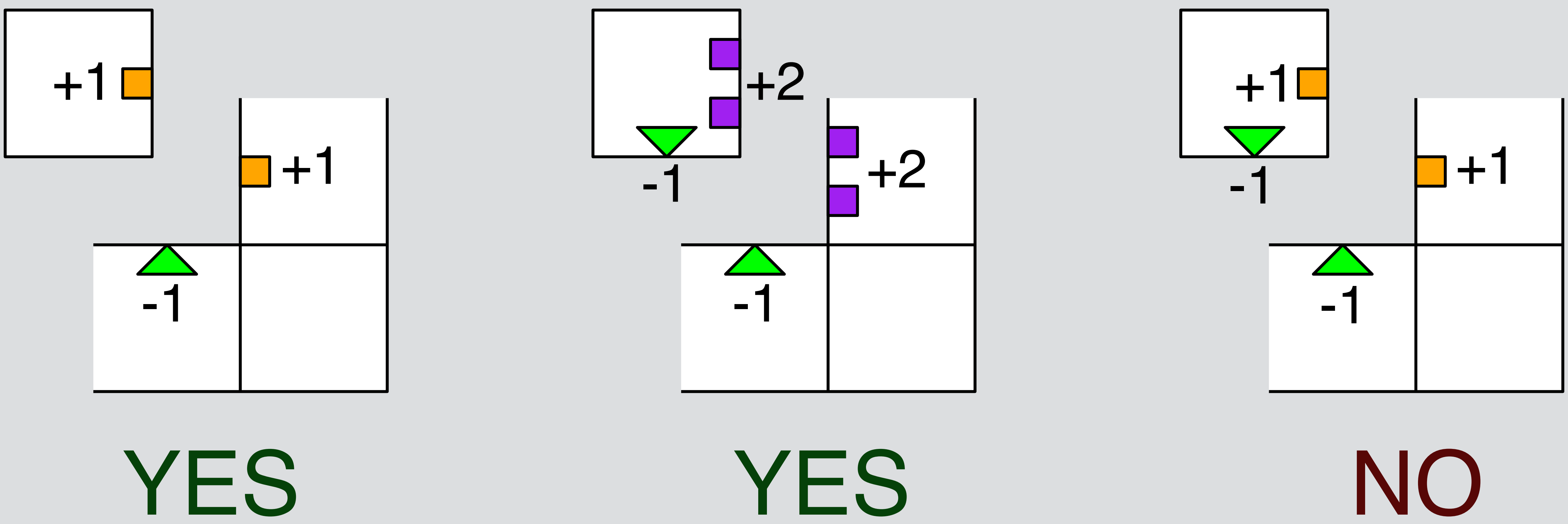

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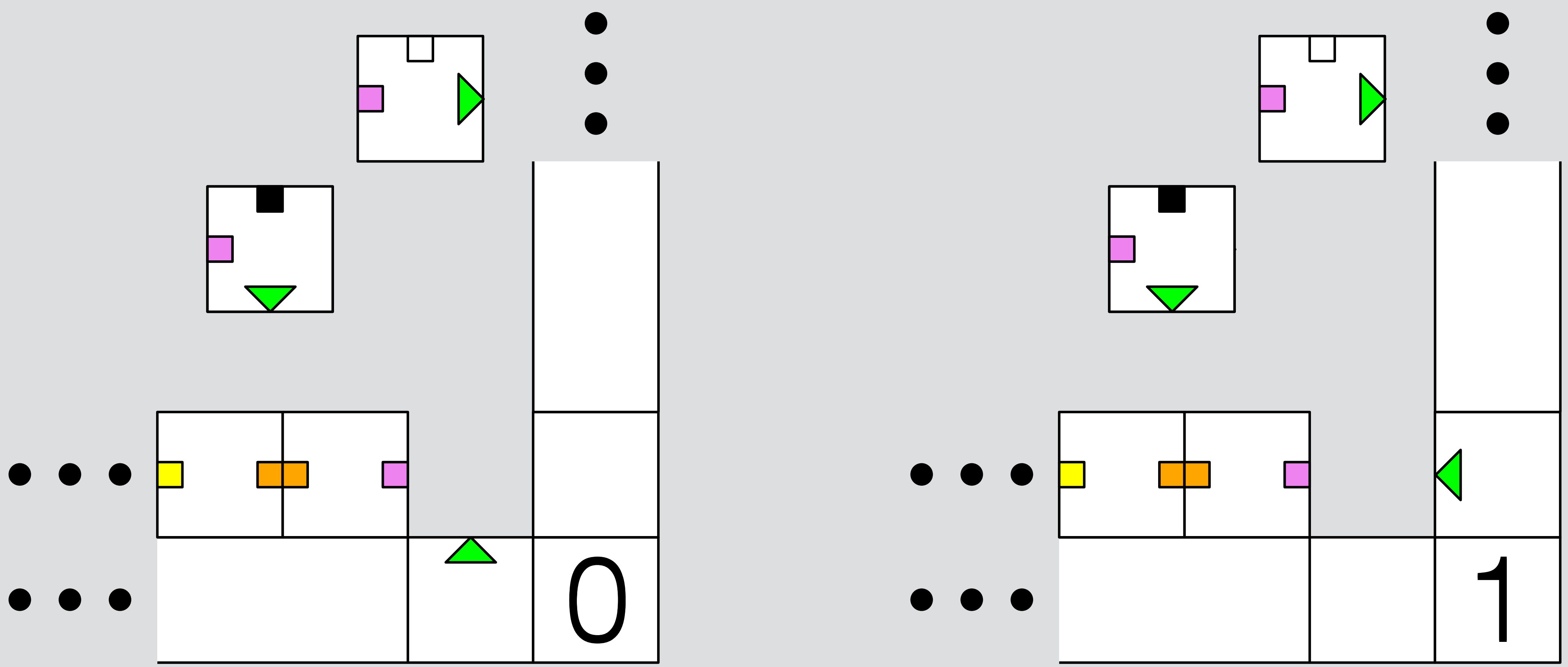

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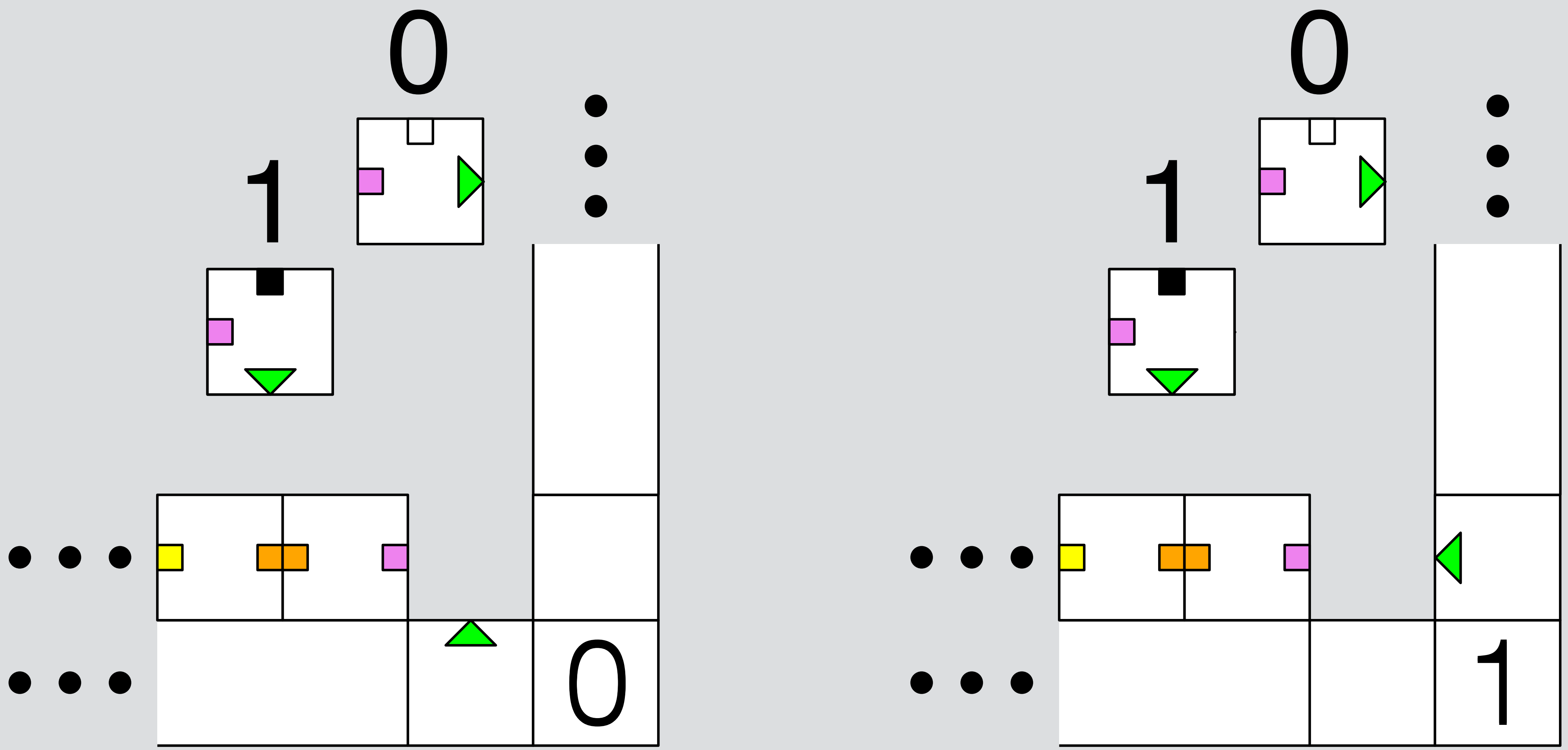

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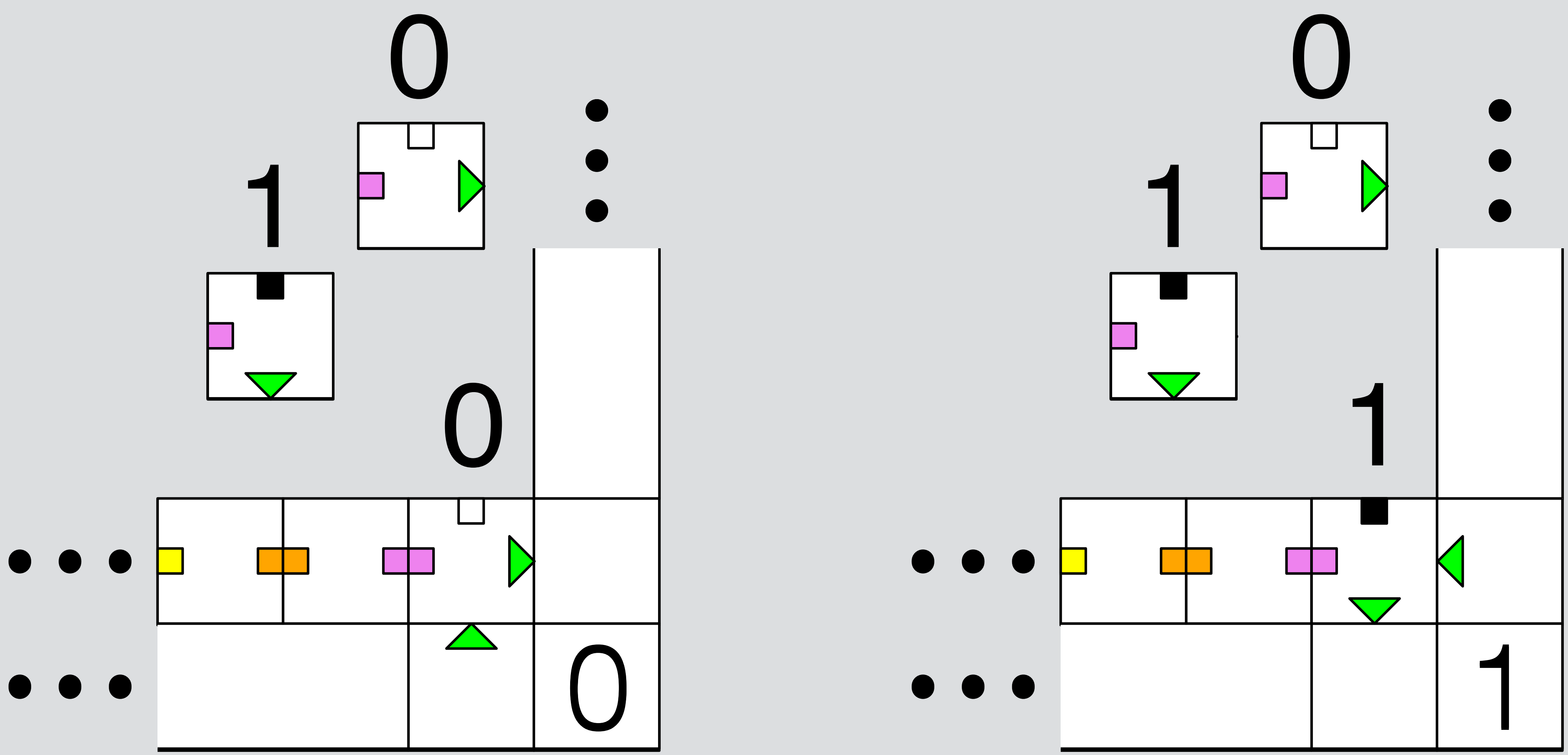
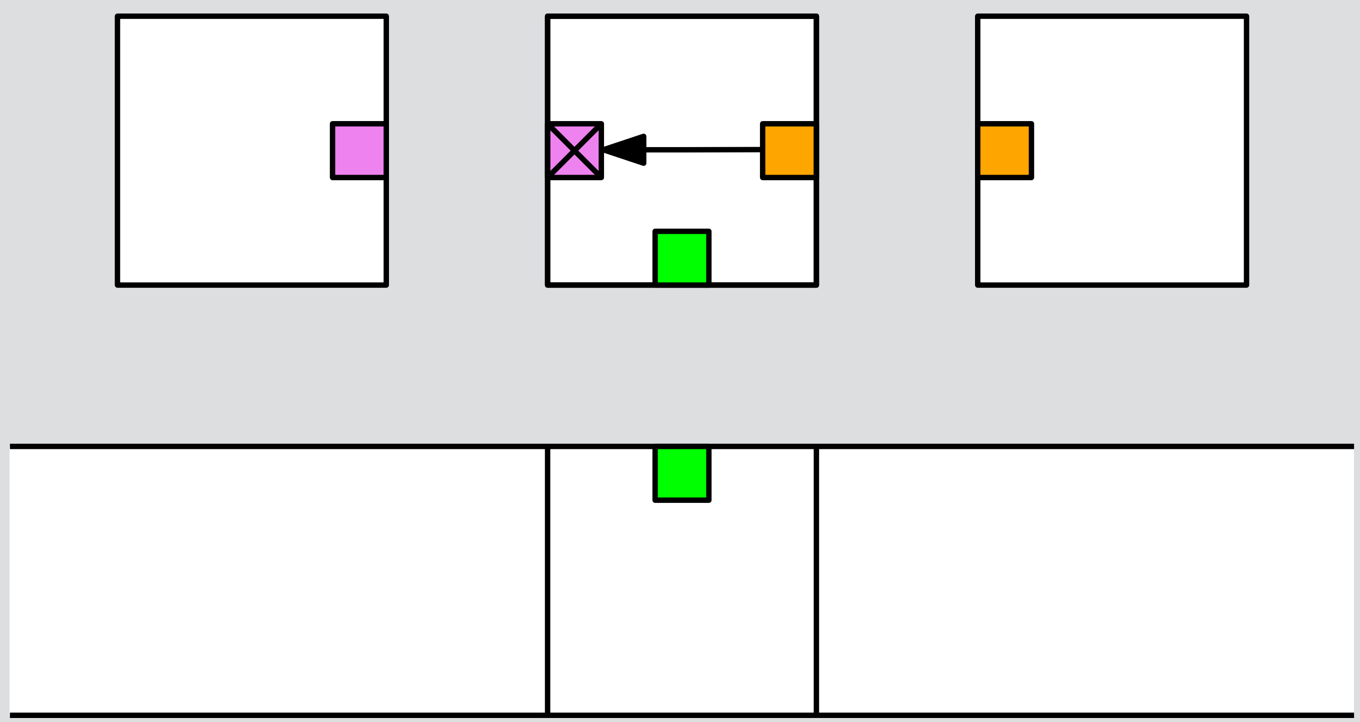


Temperature 1

Approach 3: Signal Tiles

[Padilla et al. 2014], [Jonoska, Karpenko 2014]



Temperature 1

Approach 3: Signal Tiles

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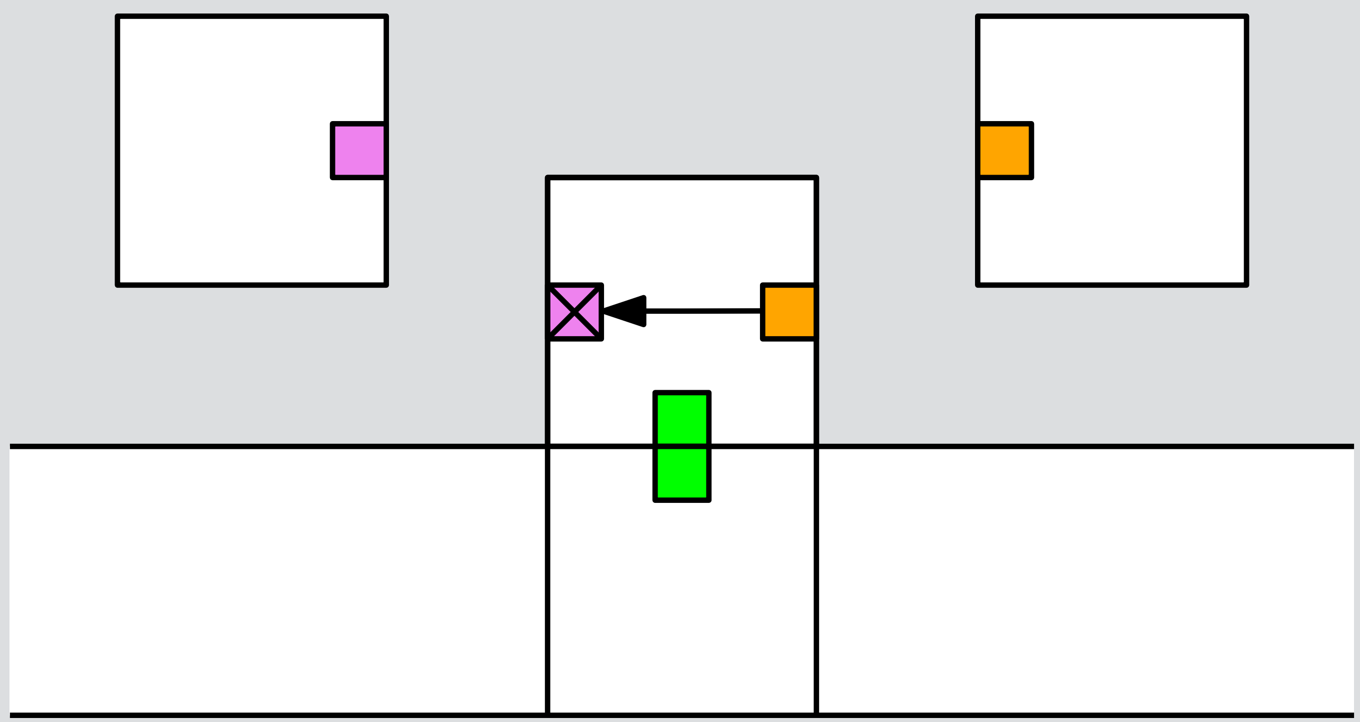

Temperature 1

Approach 3: Signal Tiles

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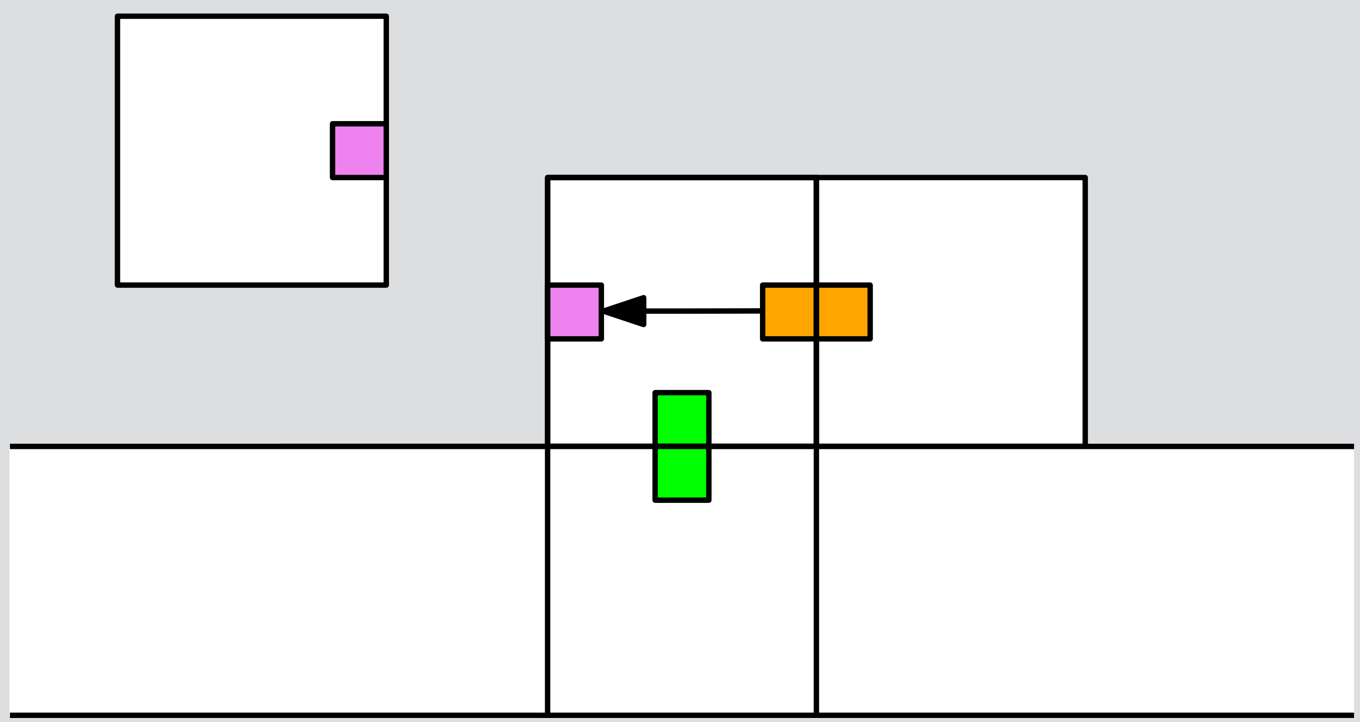

Temperature 1

Approach 3: Signal Tiles

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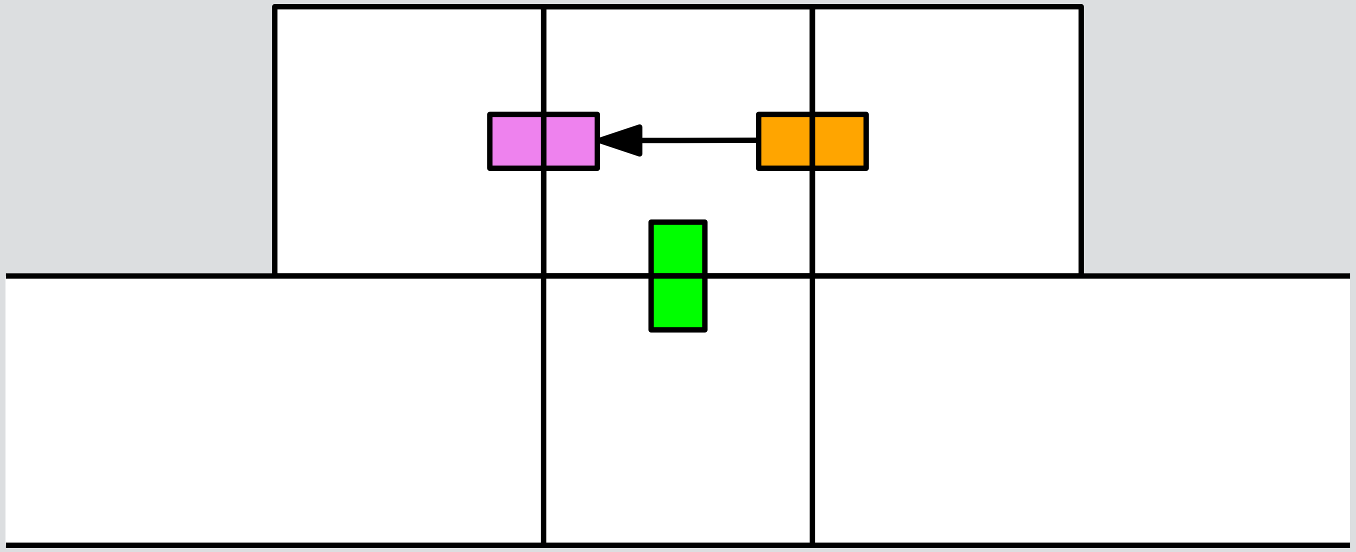

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Approach 3: Signal Tiles

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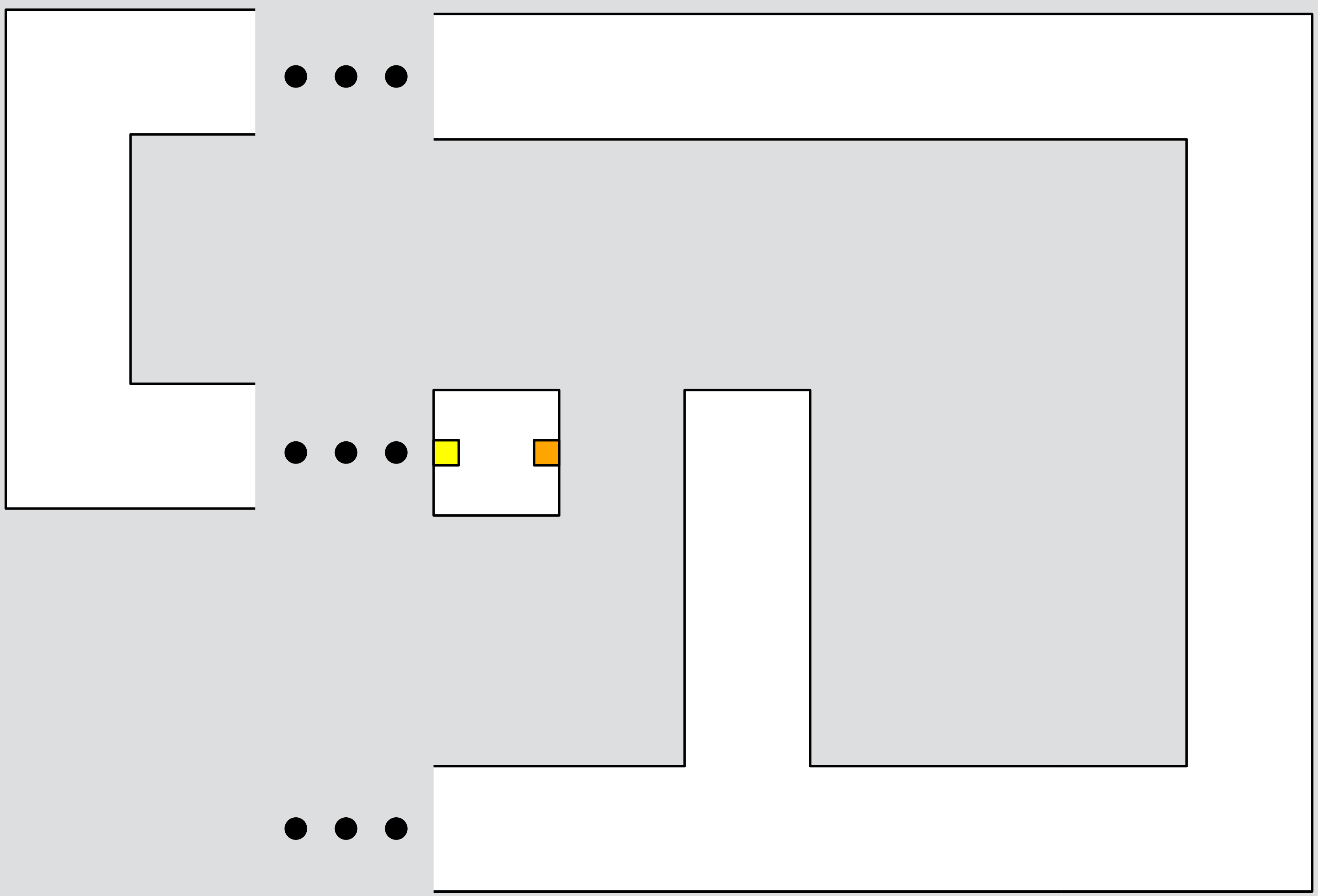
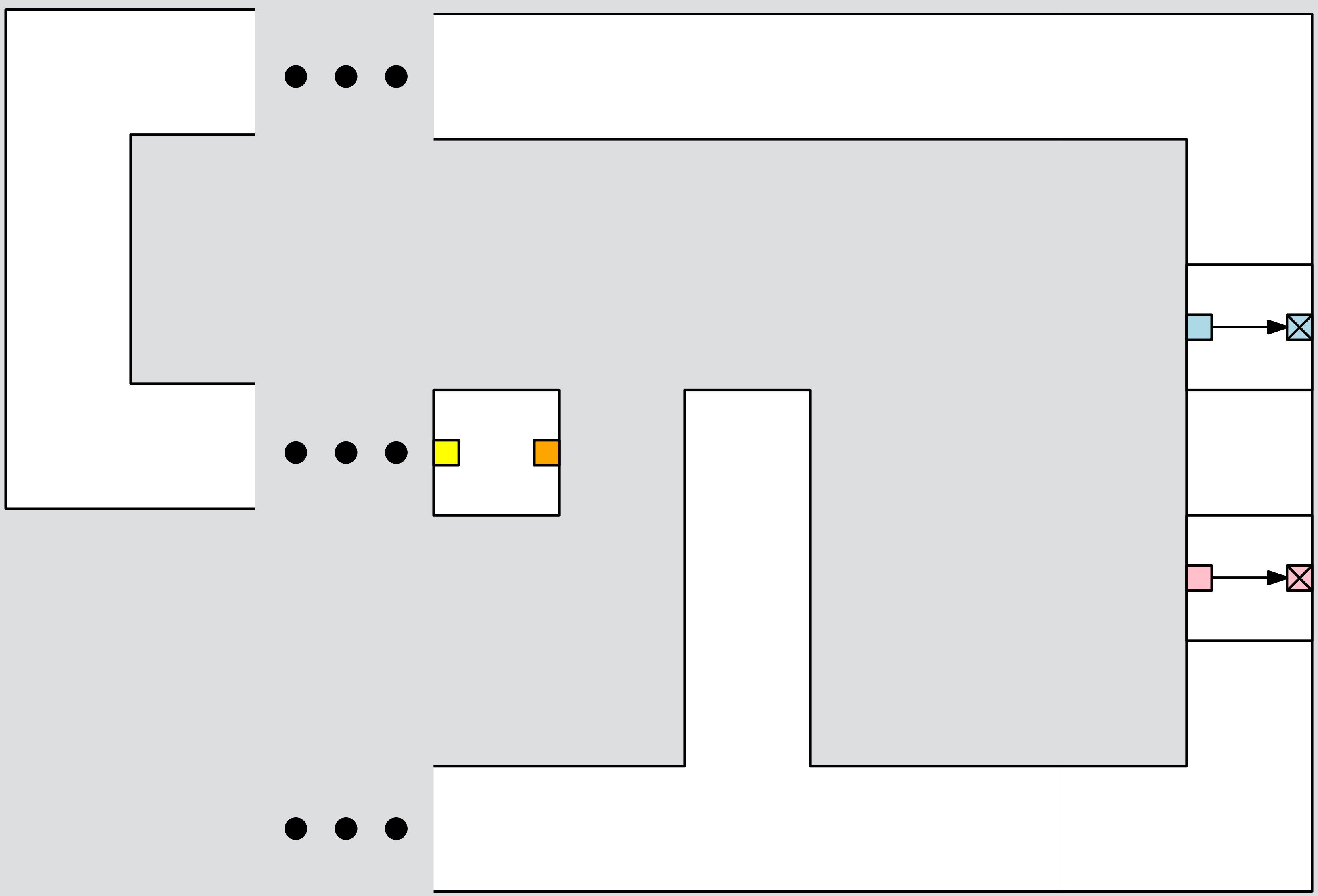


Temperature 1

Approach 3: Signal Tiles

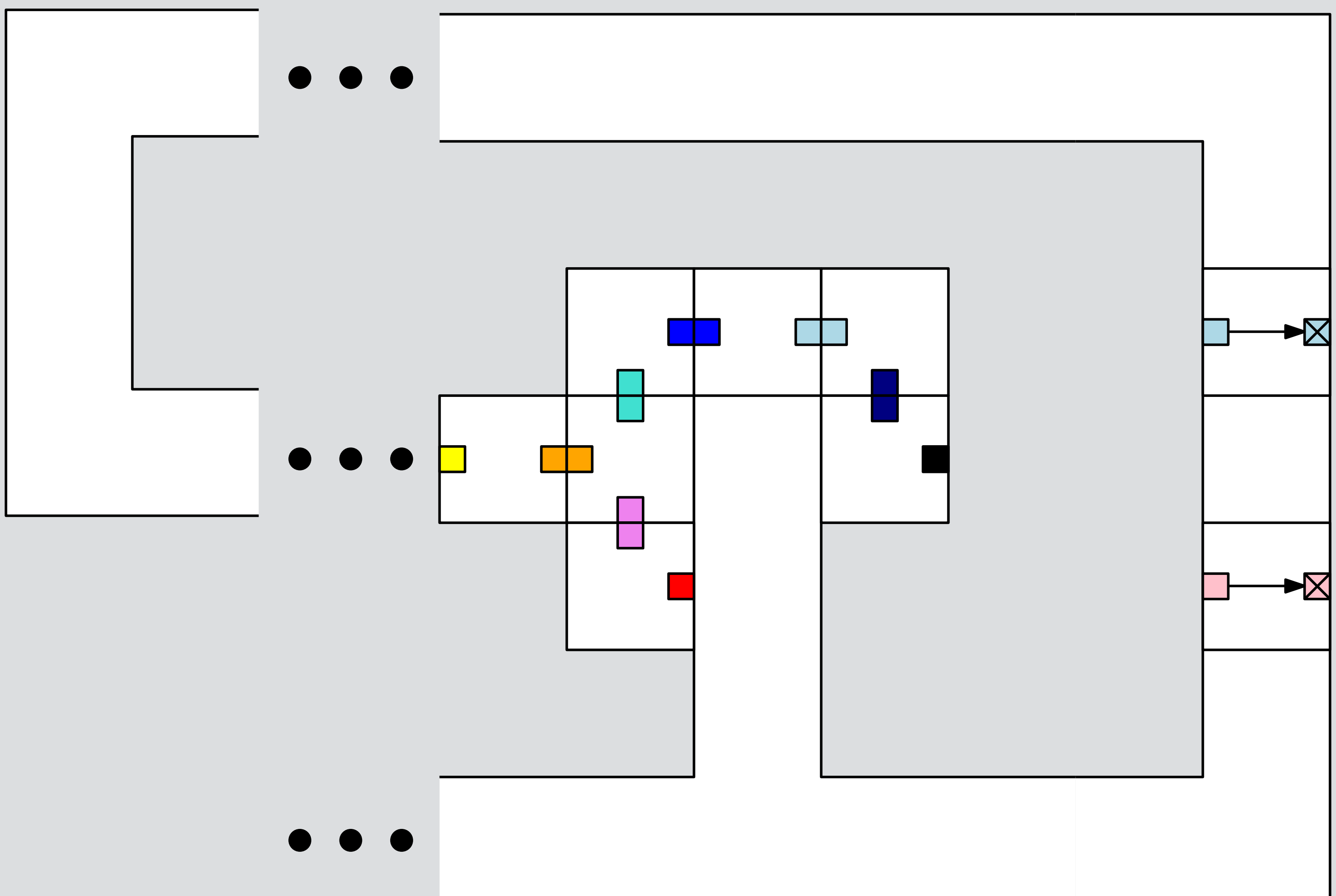
[Padilla et al. 2014], [Jonoska, Karpenko 2014]



Temperature 1

Approach 3: Signal Tiles

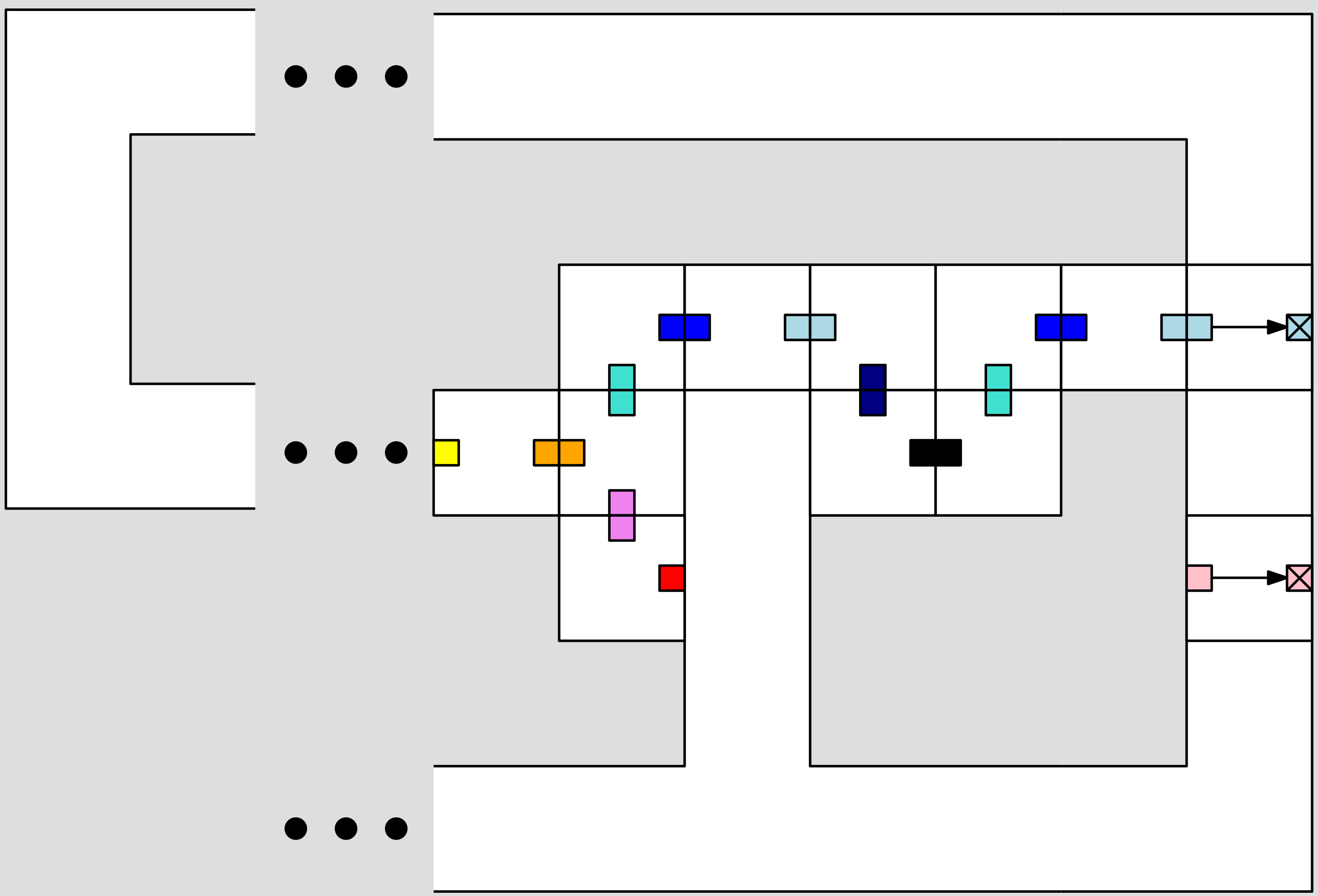
[Padilla et al. 2014], [Jonoska, Karpenko 2014]



Temperature 1

Approach 3: Signal Tiles

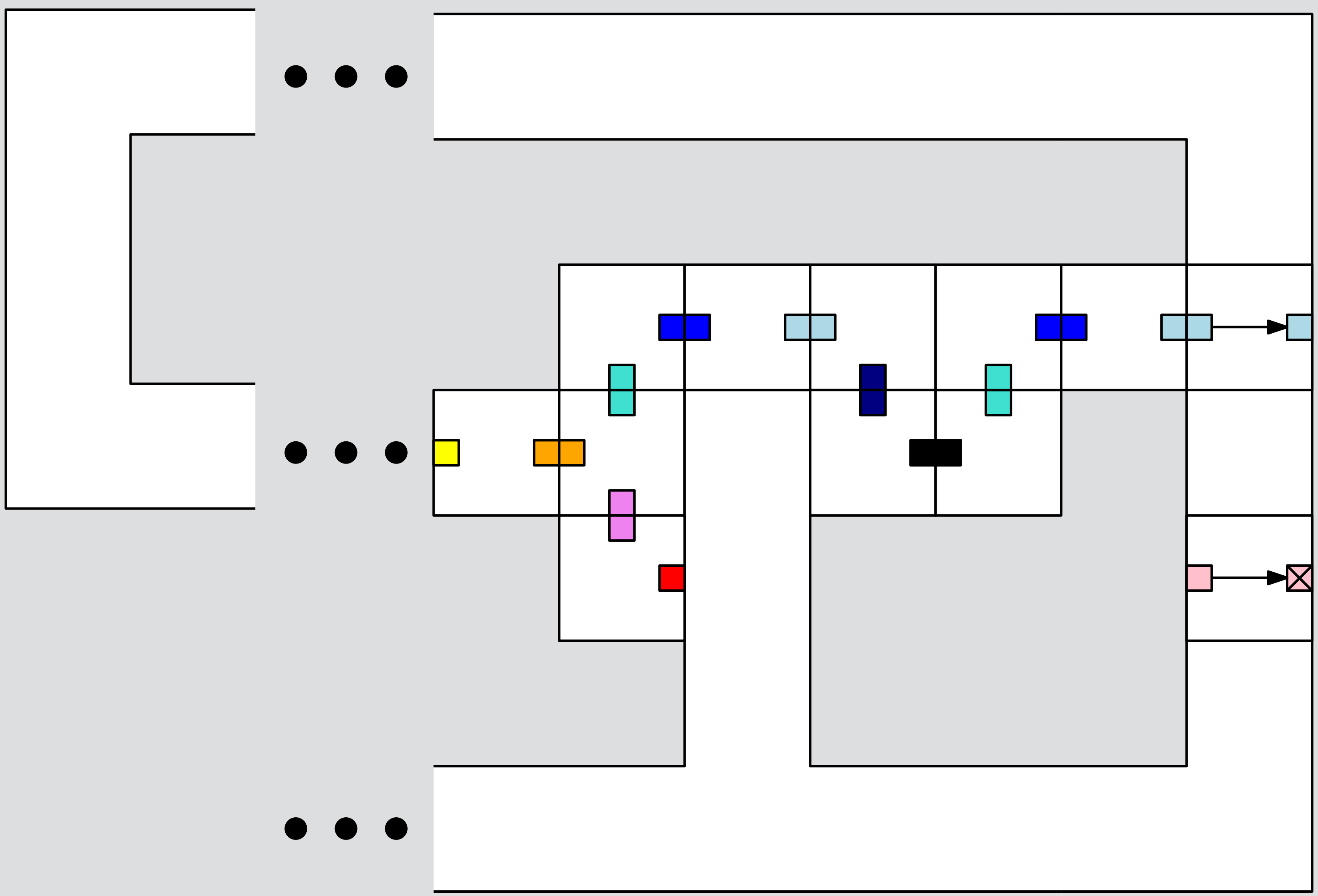
[Padilla et al. 2014], [Jonoska, Karpenko 2014]



Temperature 1

Approach 3: Signal Tiles

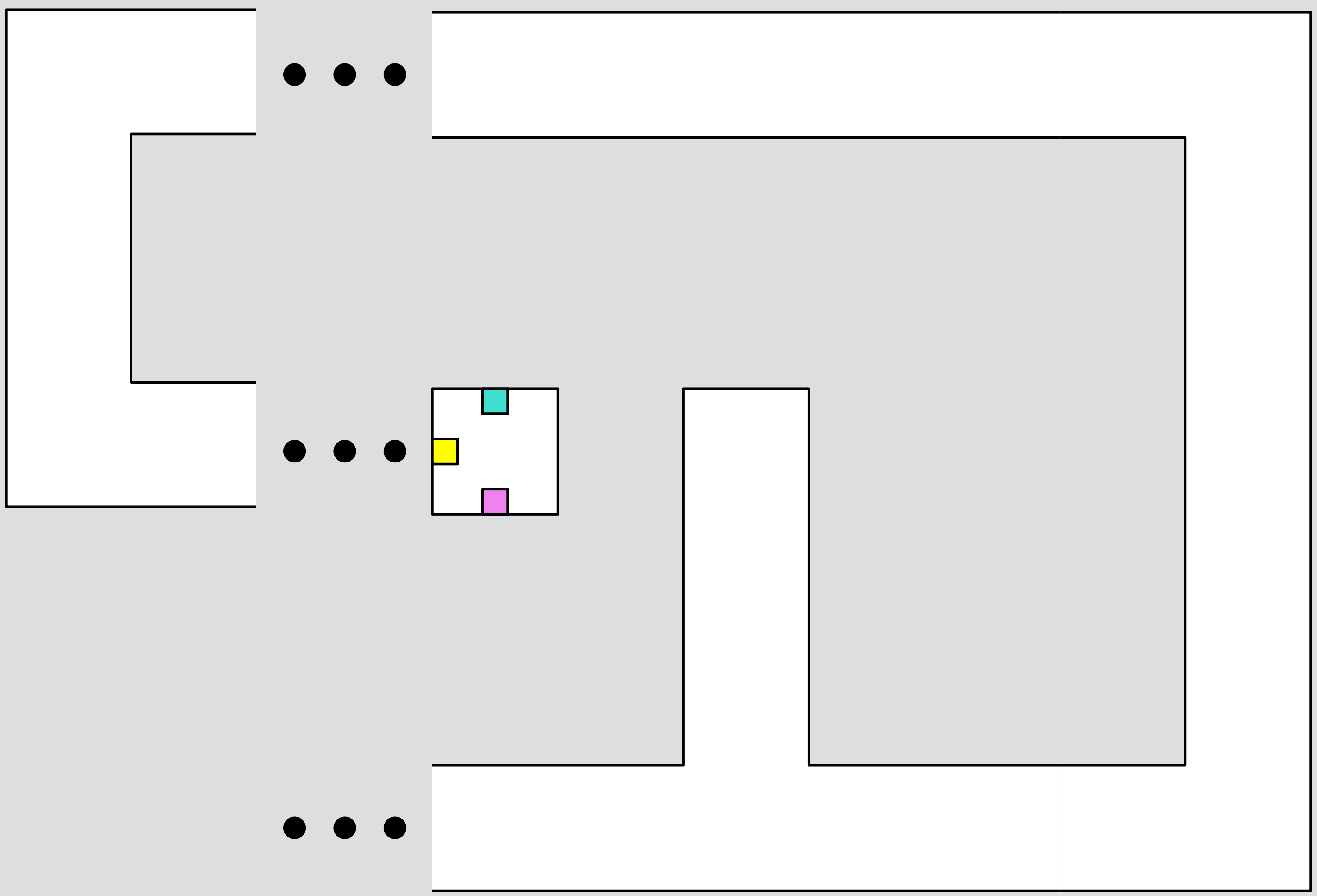
[Padilla et al. 2014], [Jonoska, Karpenko 2014]



Temperature 1

Approach 4: Polyomino Tiles

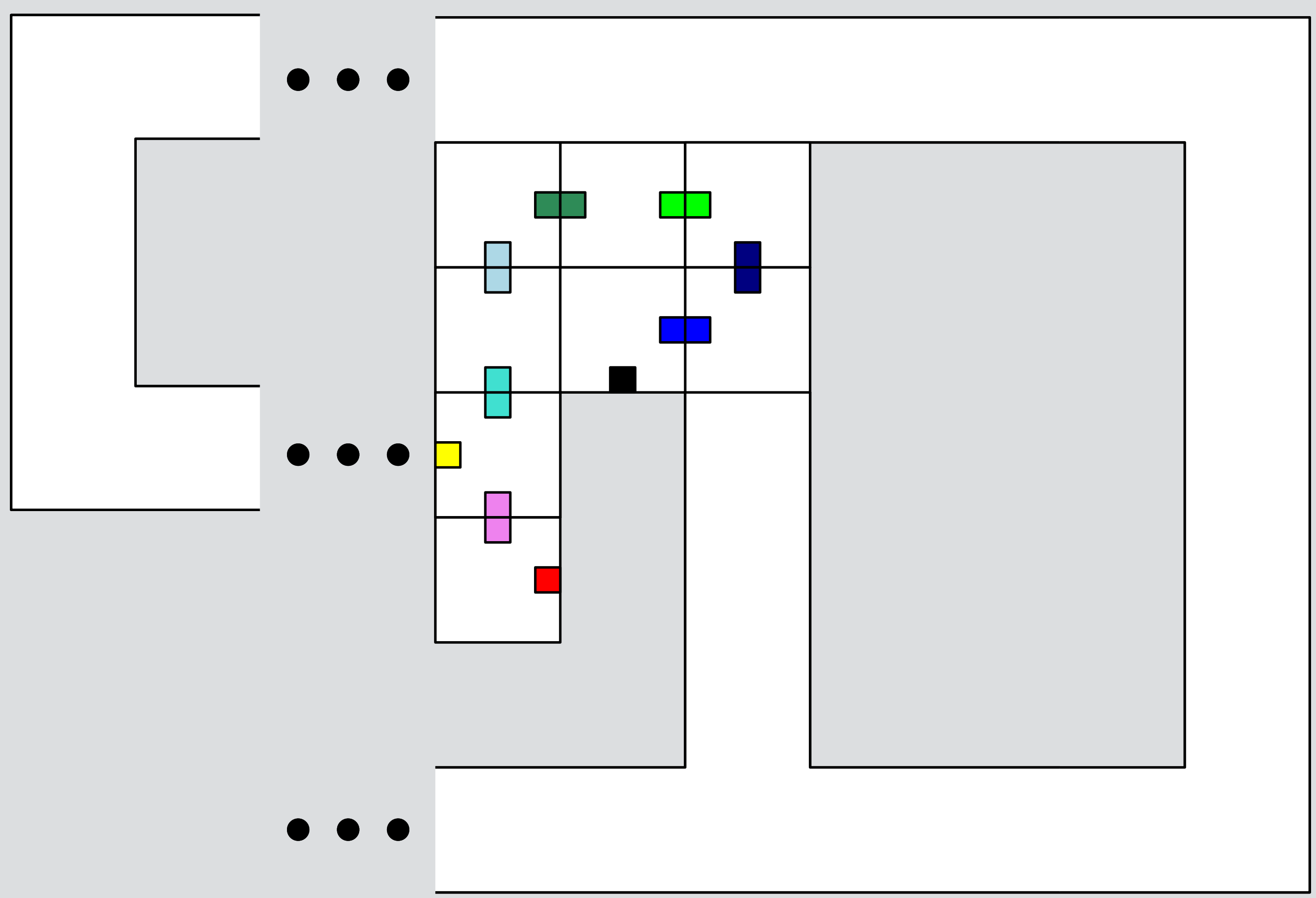
[Hendricks et al. 2014], [Fekete et al. 2015]



Temperature 1

Approach 4: Polyomino Tiles

[Hendricks et al. 2014], [Fekete et al. 2015]



Temperature 1

Approach 4: Polyomino Tiles

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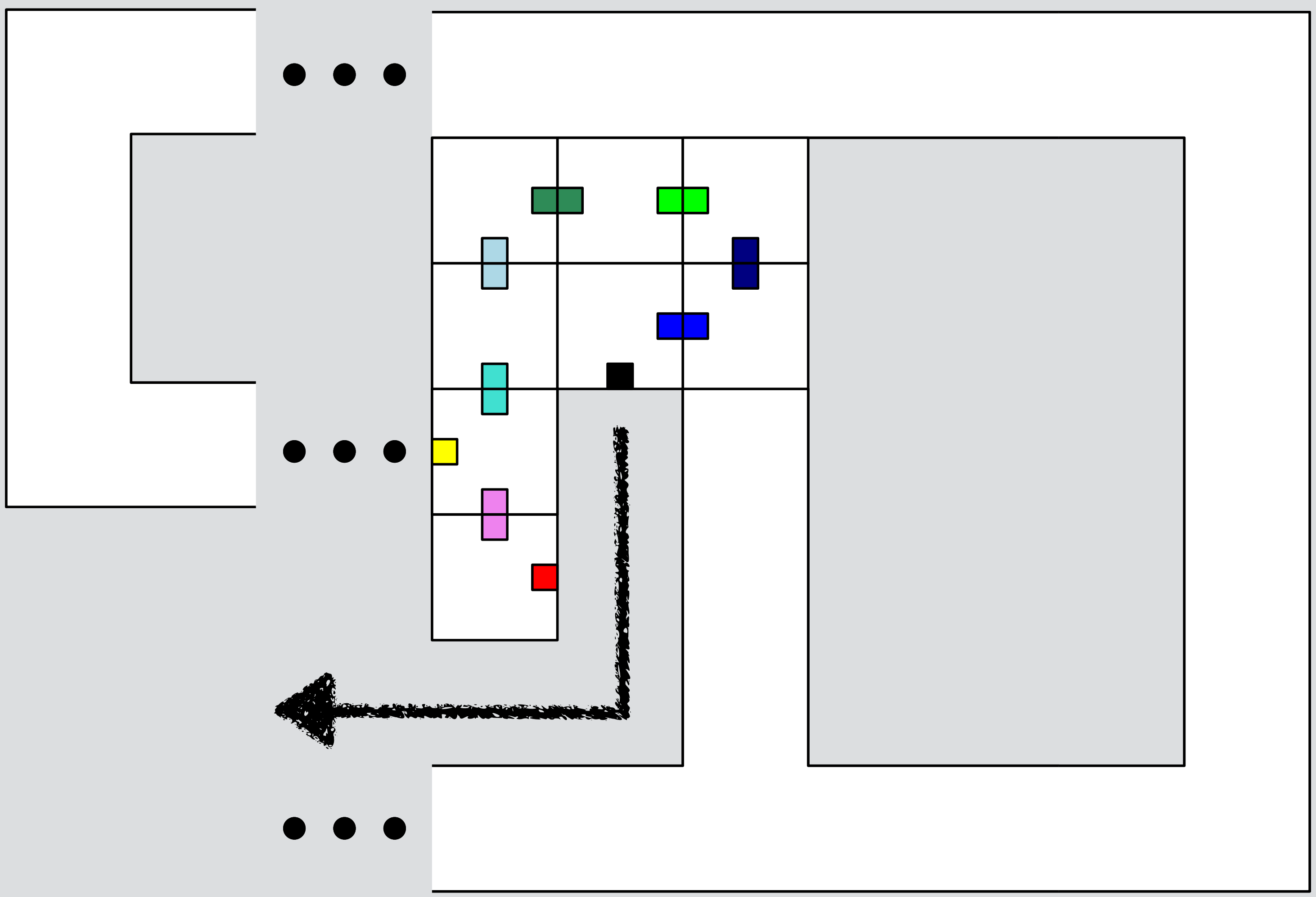
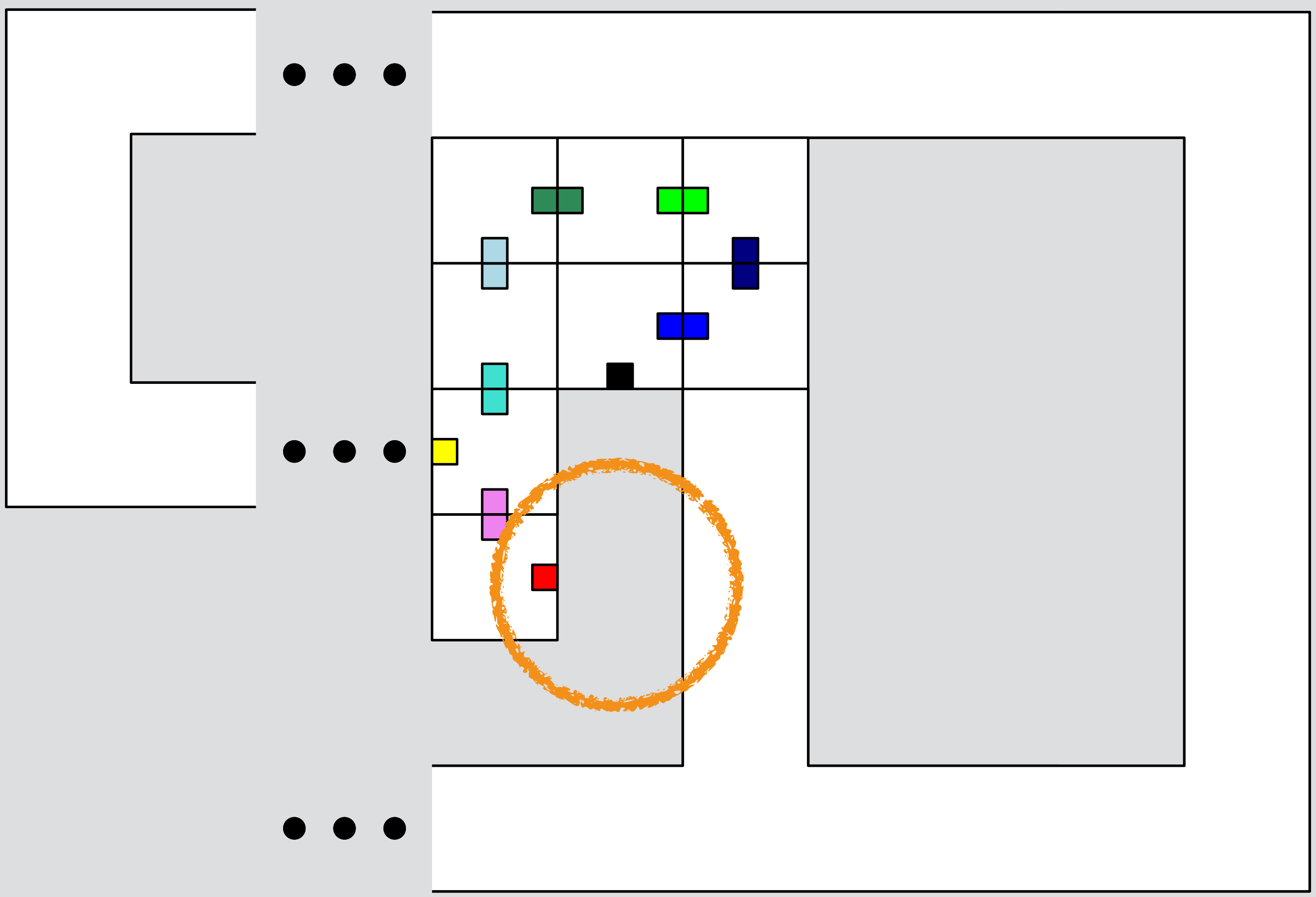


Temperature 1

Approach 4: Polyomino Tiles

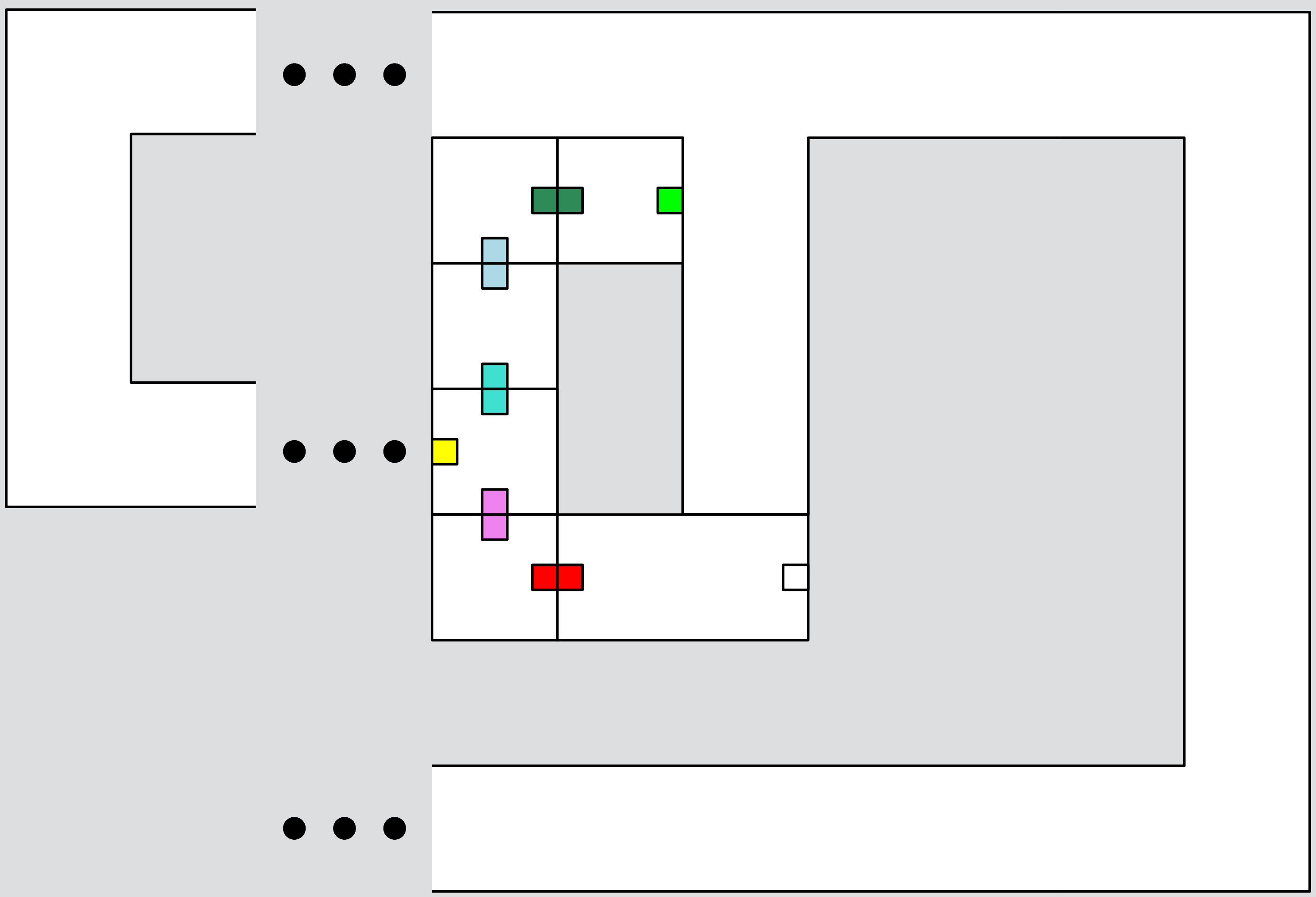
[Hendricks et al. 2014], [Fekete et al. 2015]



Temperature 1

Approach 4: Polyomino Tiles

[Hendricks et al. 2014], [Fekete et al. 2015]



Temperature 1

Approach 4: Polyomino Tiles

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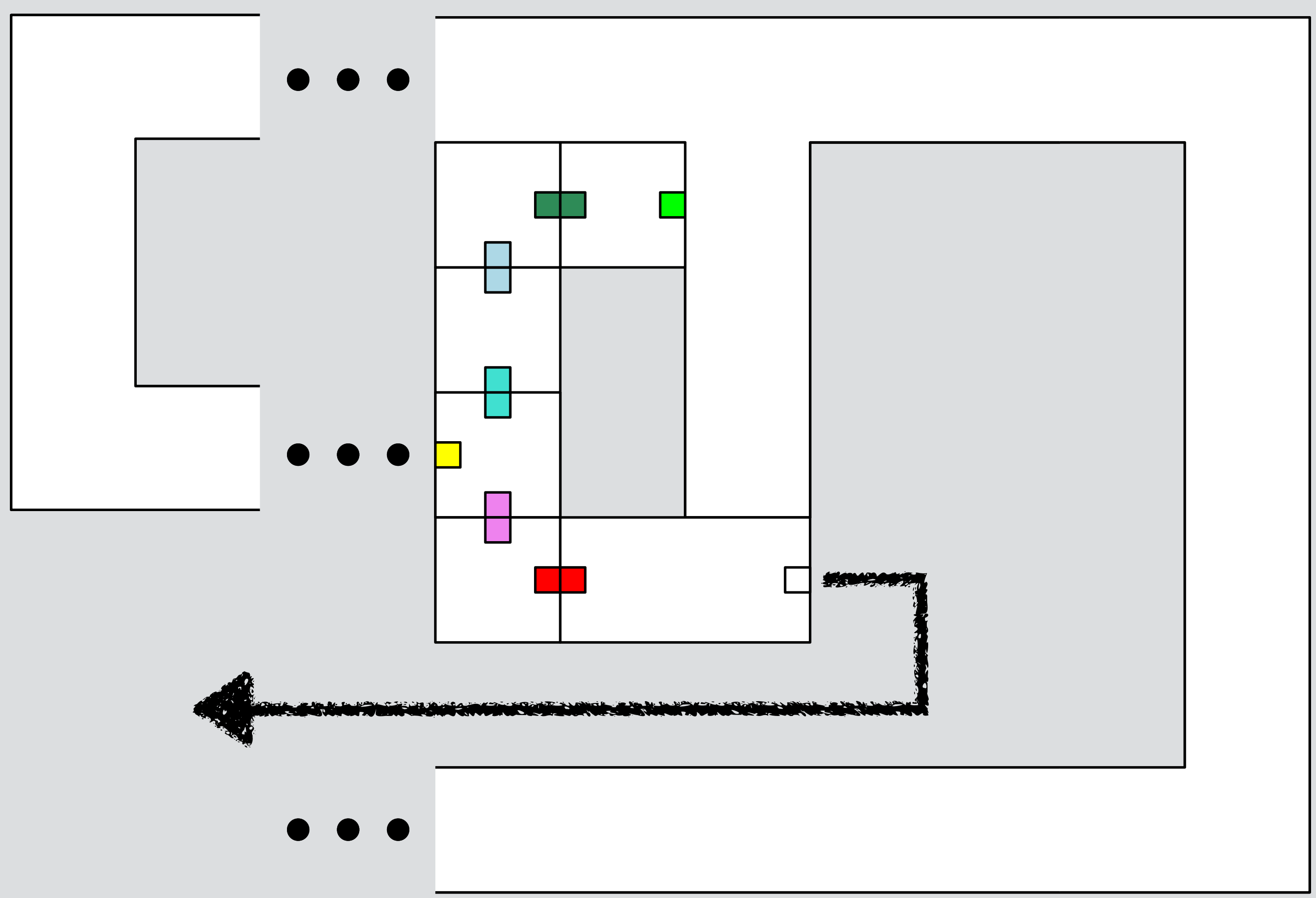
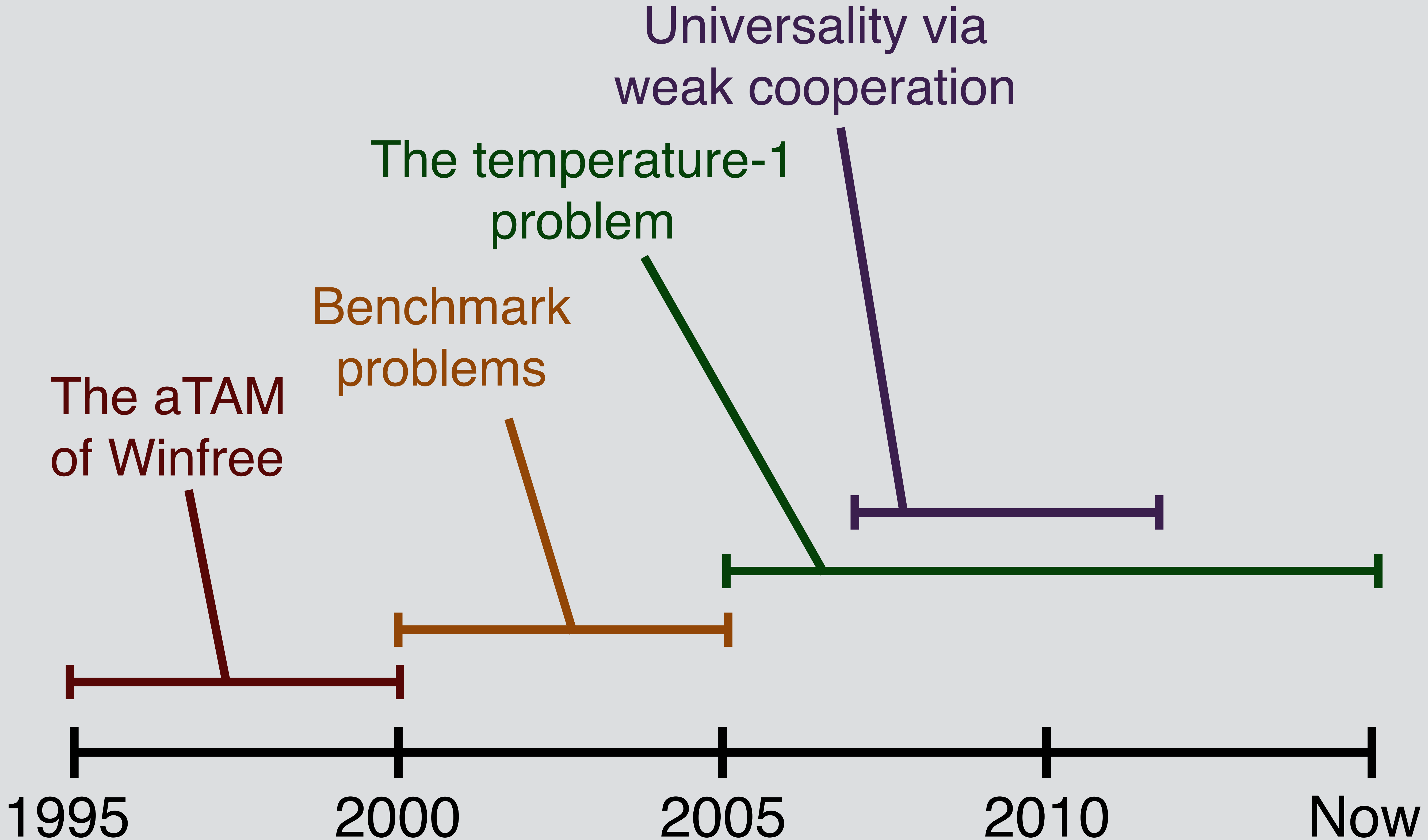
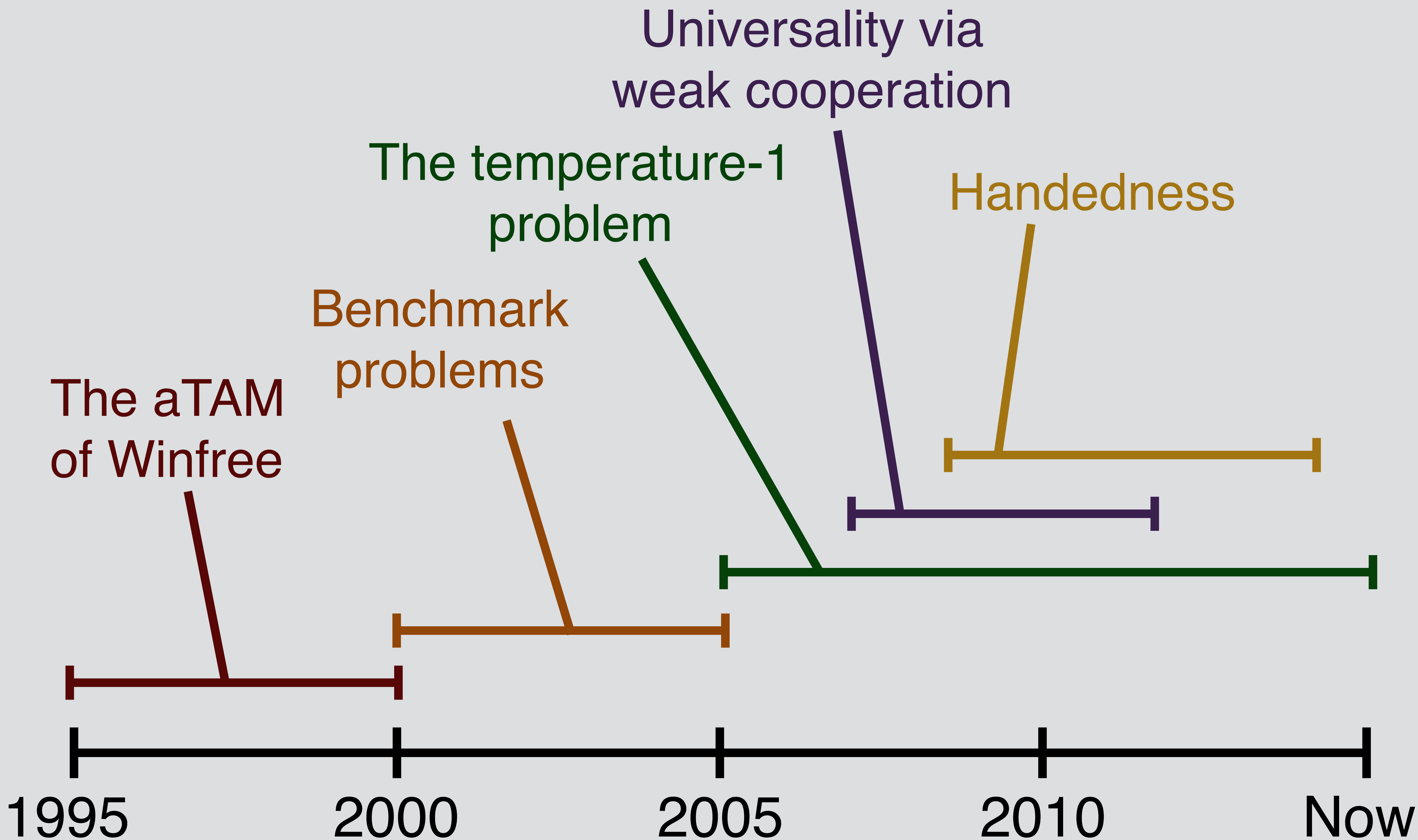
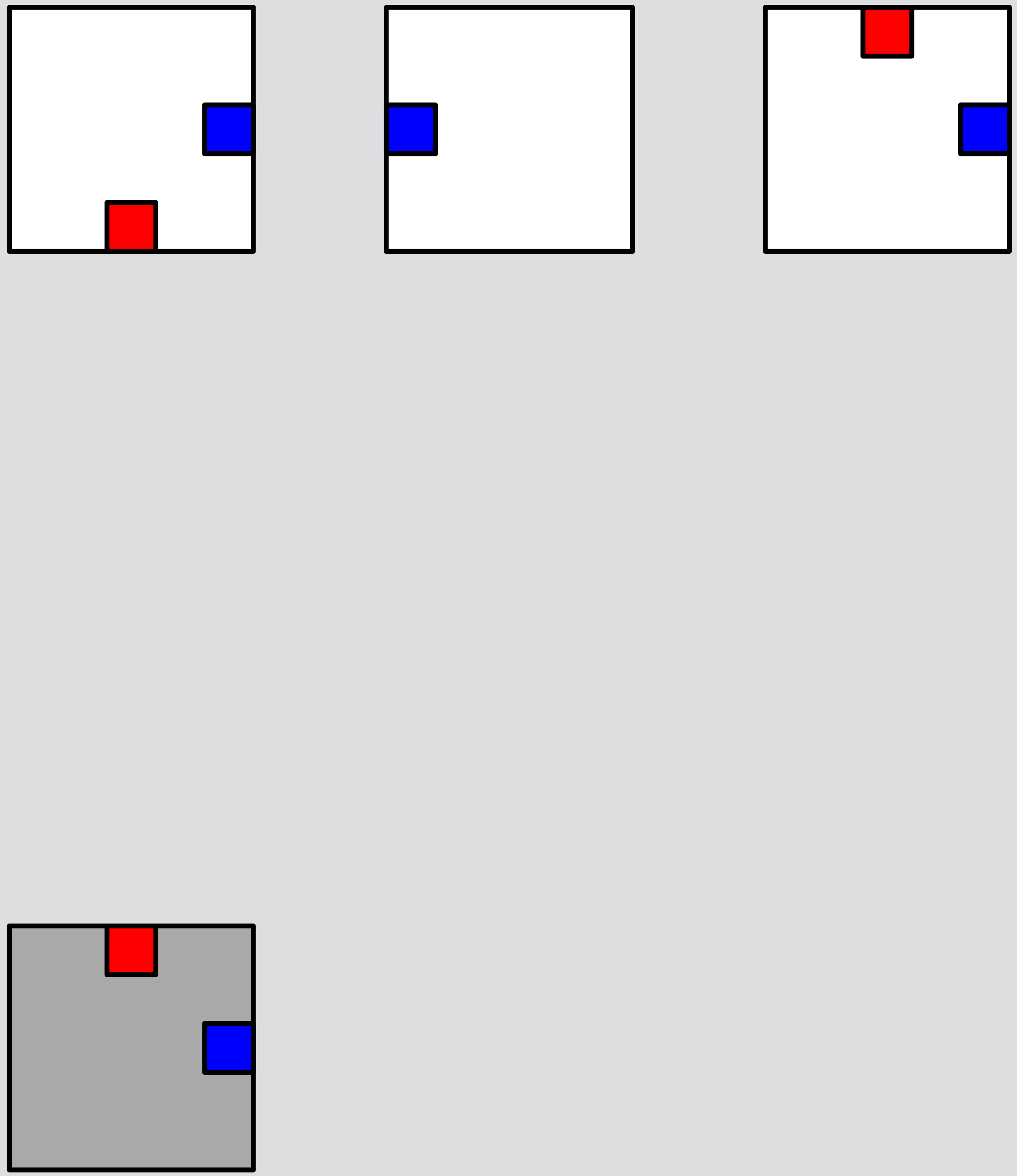


Temperature 1


Universality via
weak cooperation
The temperature-1
problem
Benchmark
problems
The aTAM
of Winfree
1995
2000
2005
2010
Now

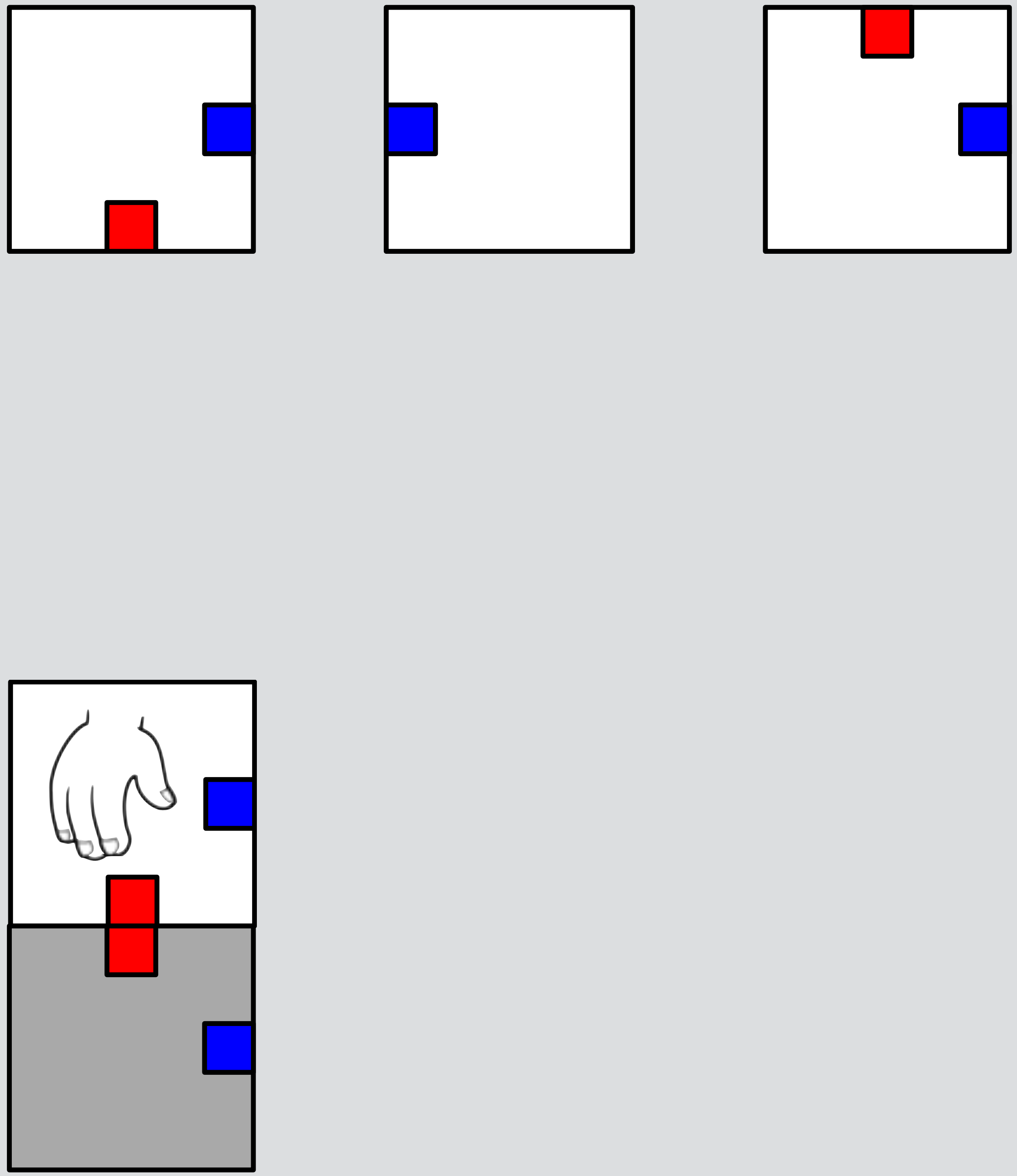

Universality via
weak cooperation
The temperature-1
problem
Handedness
Benchmark
problems
The aTAM
of Winfree
1995
2000
2005
2010
Now

One-handed assembly (aTAM)



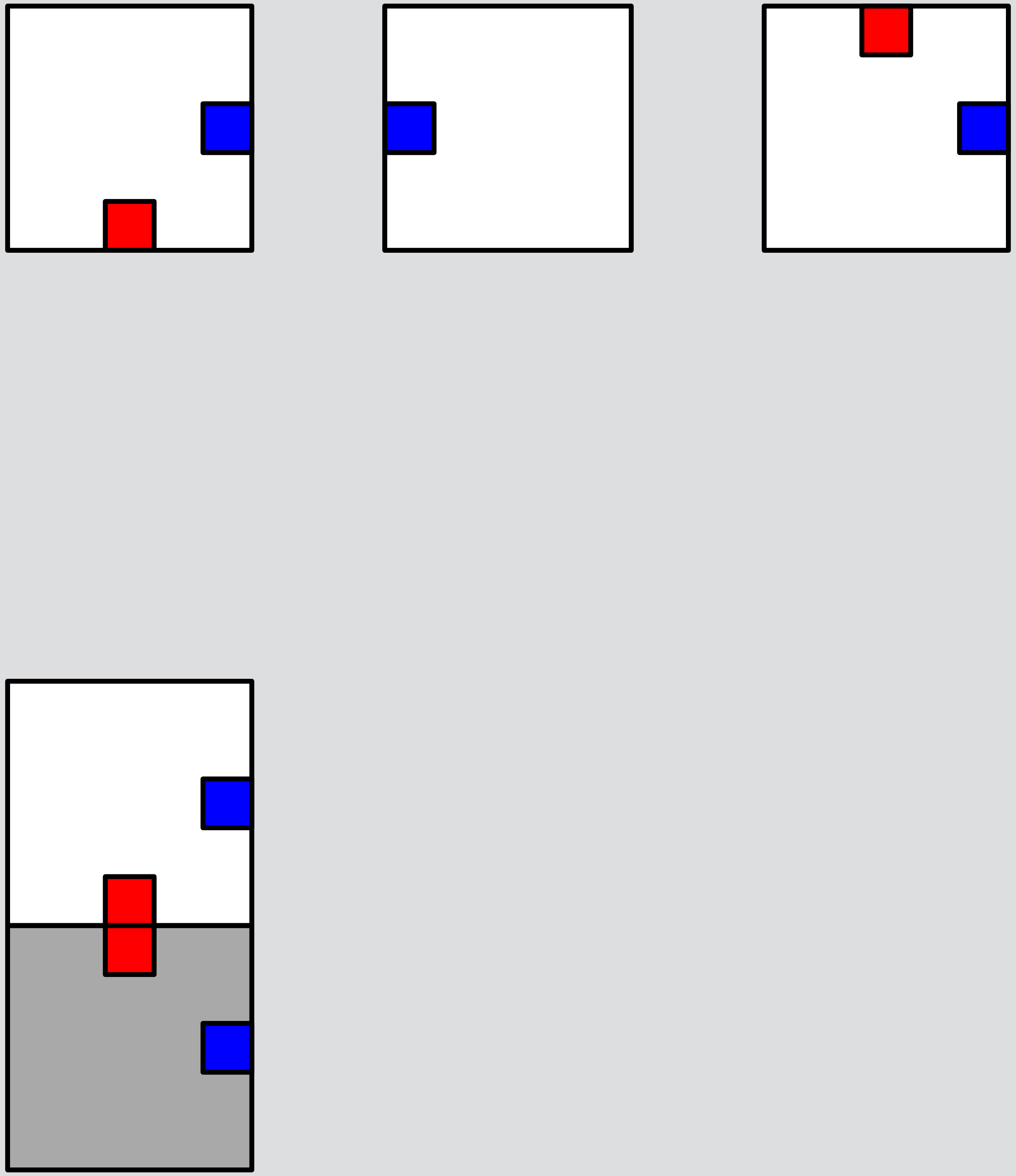
Temperature 1

One-handed assembly (aTAM)



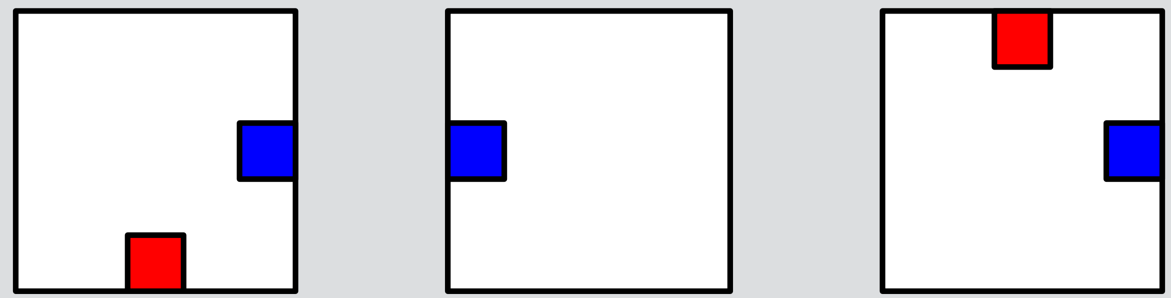
Temperature 1

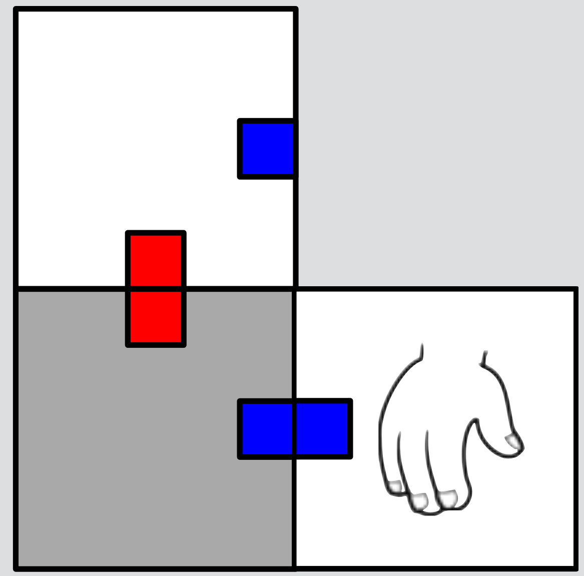
One-handed assembly (aTAM)



Temperature 1

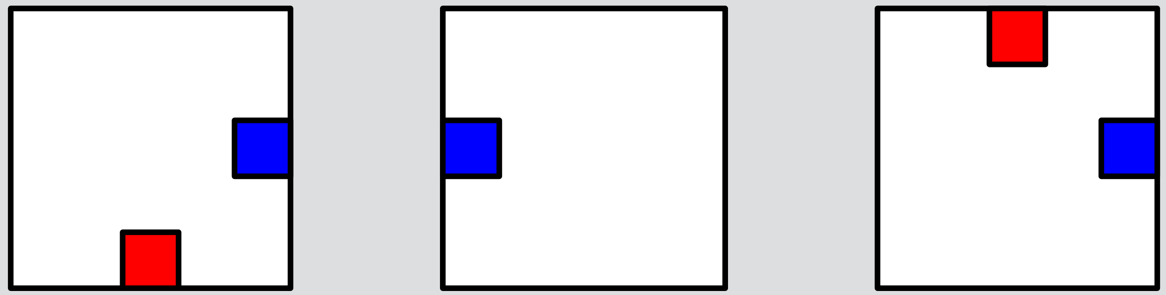
One-handed assembly (aTAM)

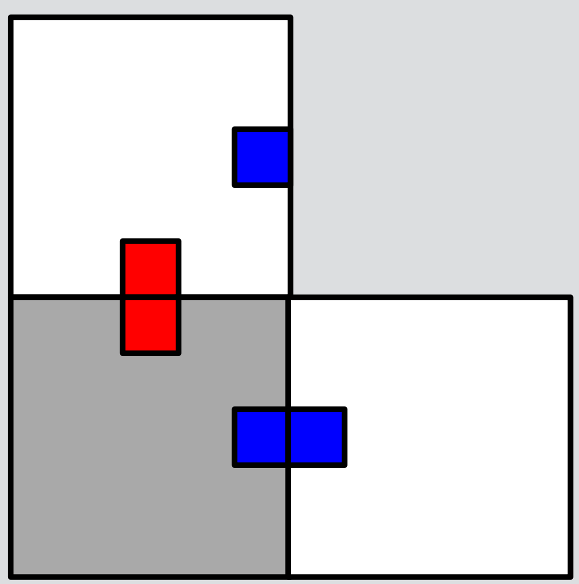




Temperature 1

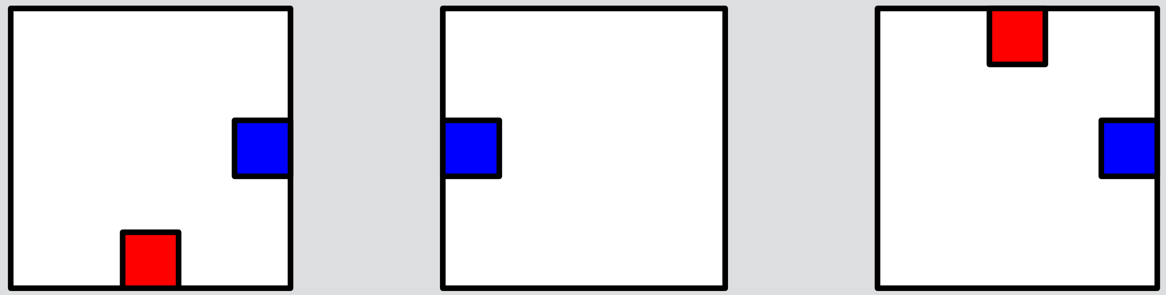
One-handed assembly (aTAM)

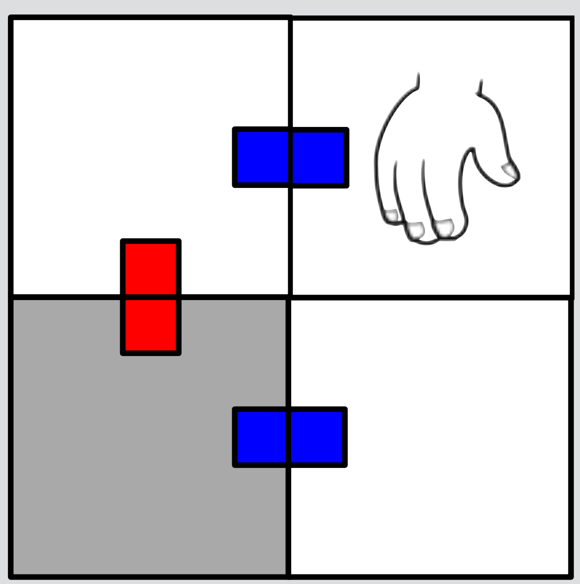




Temperature 1

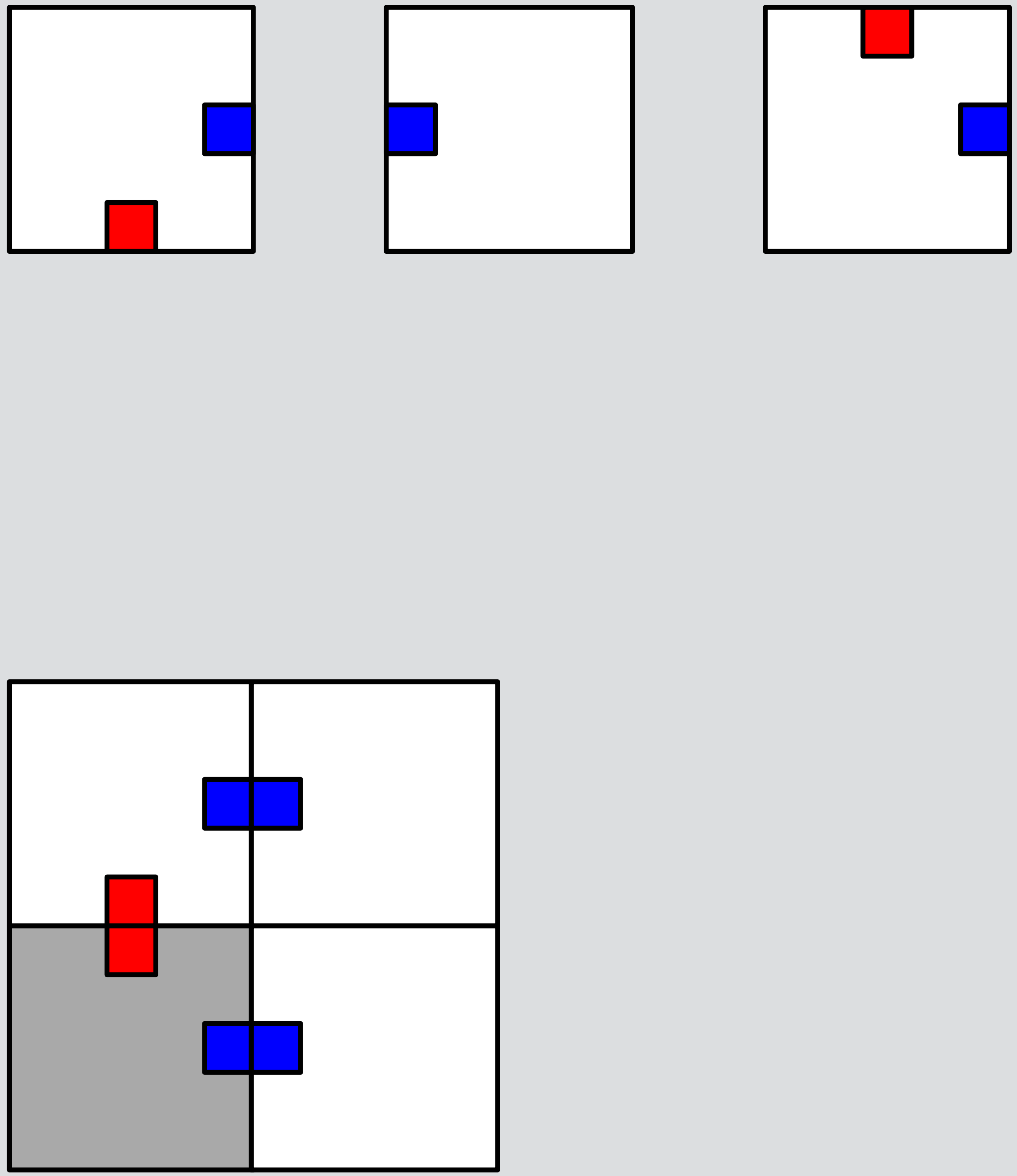
One-handed assembly (aTAM)





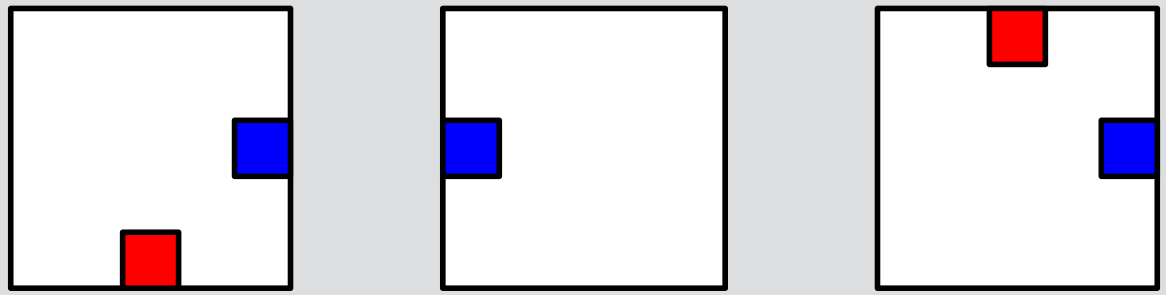
Temperature 1

One-handed assembly (aTAM)

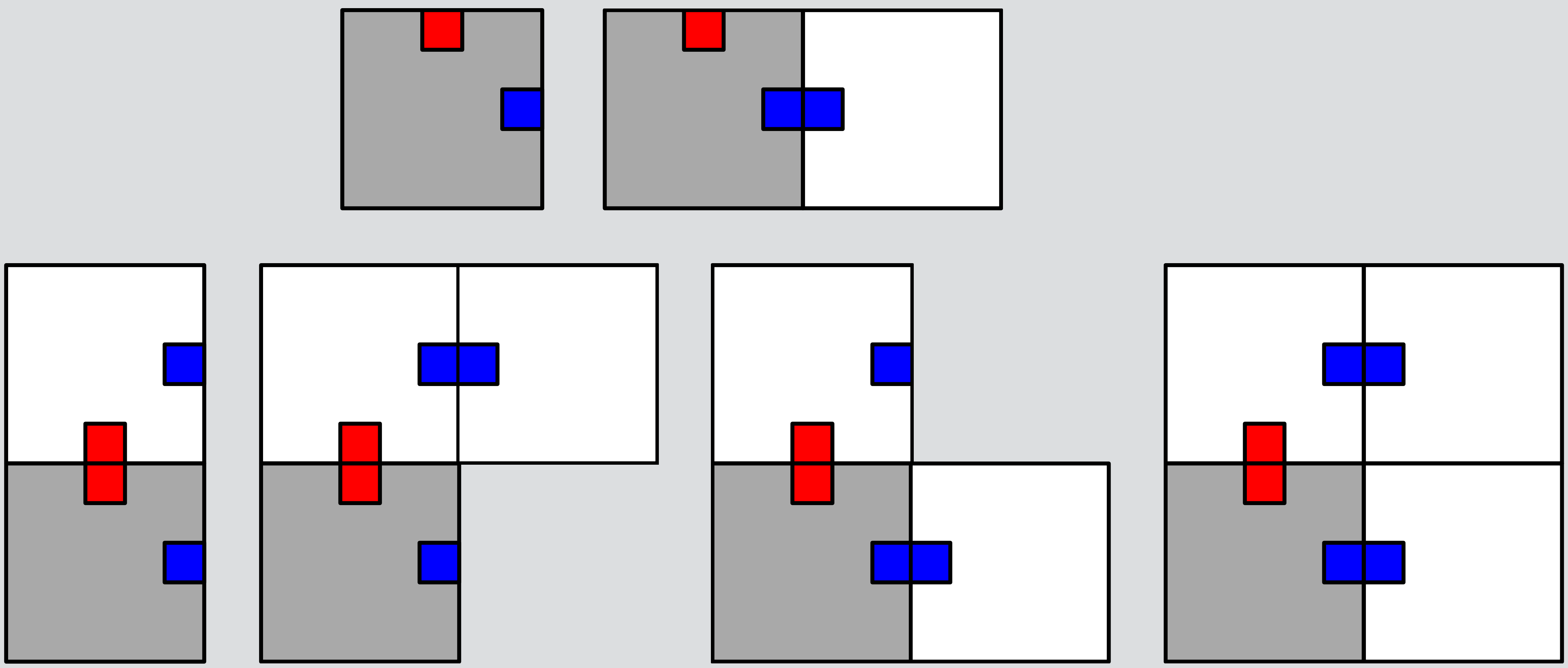


Temperature 1

One-handed assembly (aTAM)

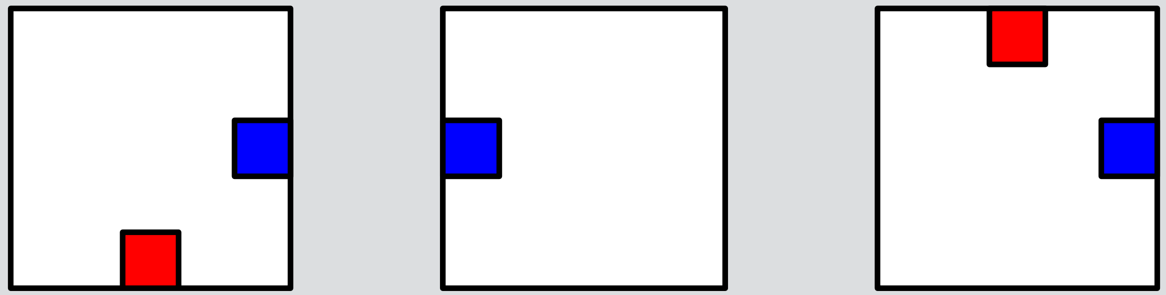


Producible assemblies:

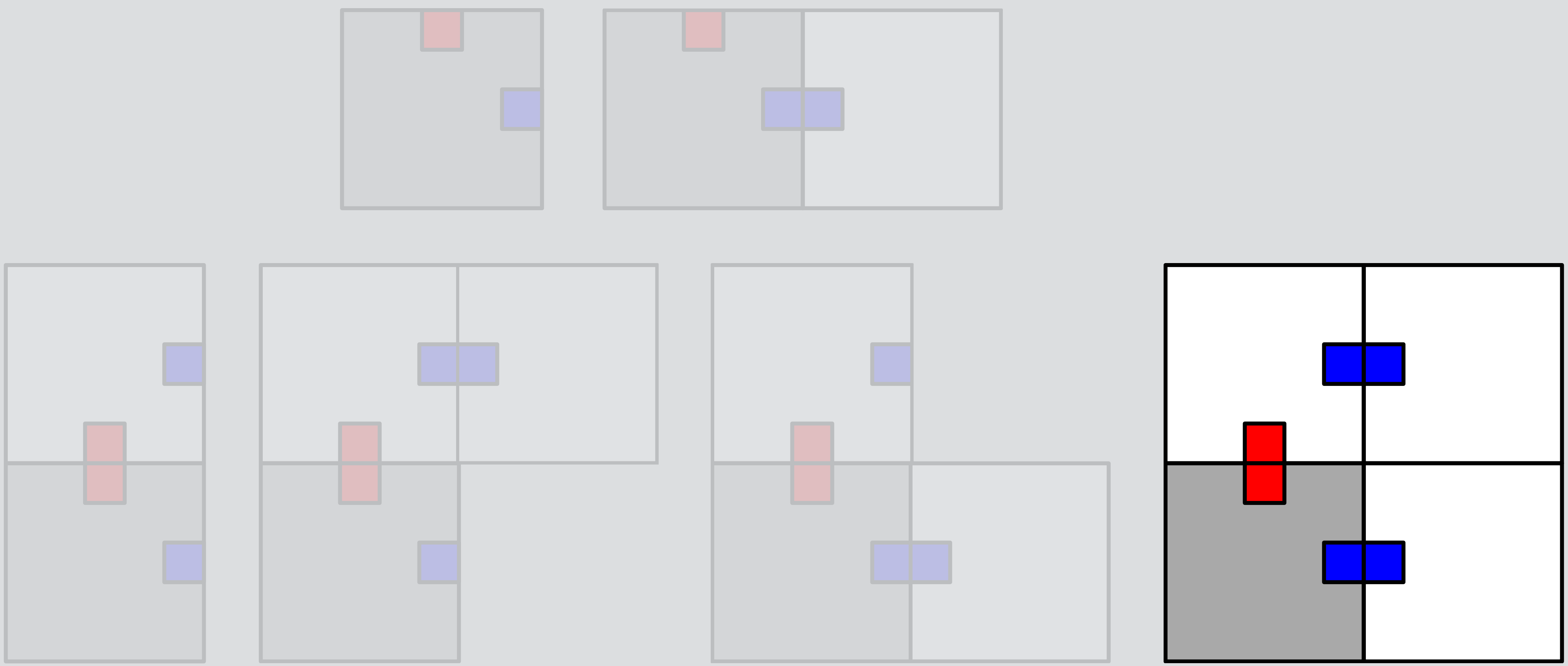


Temperature 1

One-handed assembly (aTAM)



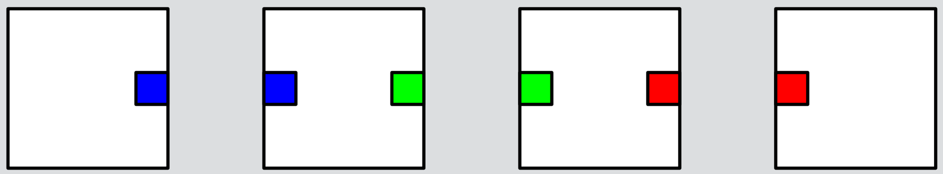
Terminal assemblies:



Temperature 1

Two-handed assembly (2HAM)

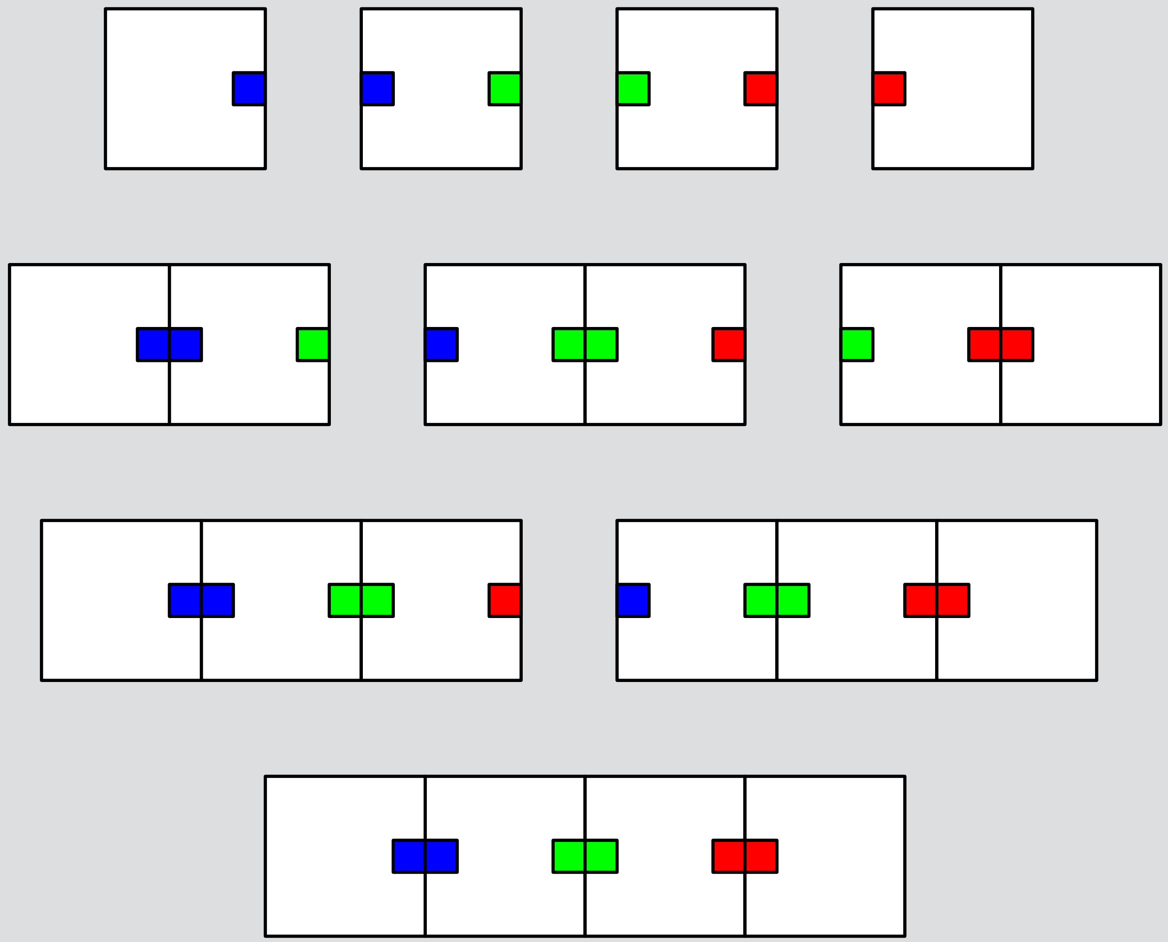
Two-handed assembly (2HAM)



Temperature 1

Two-handed assembly (2HAM)

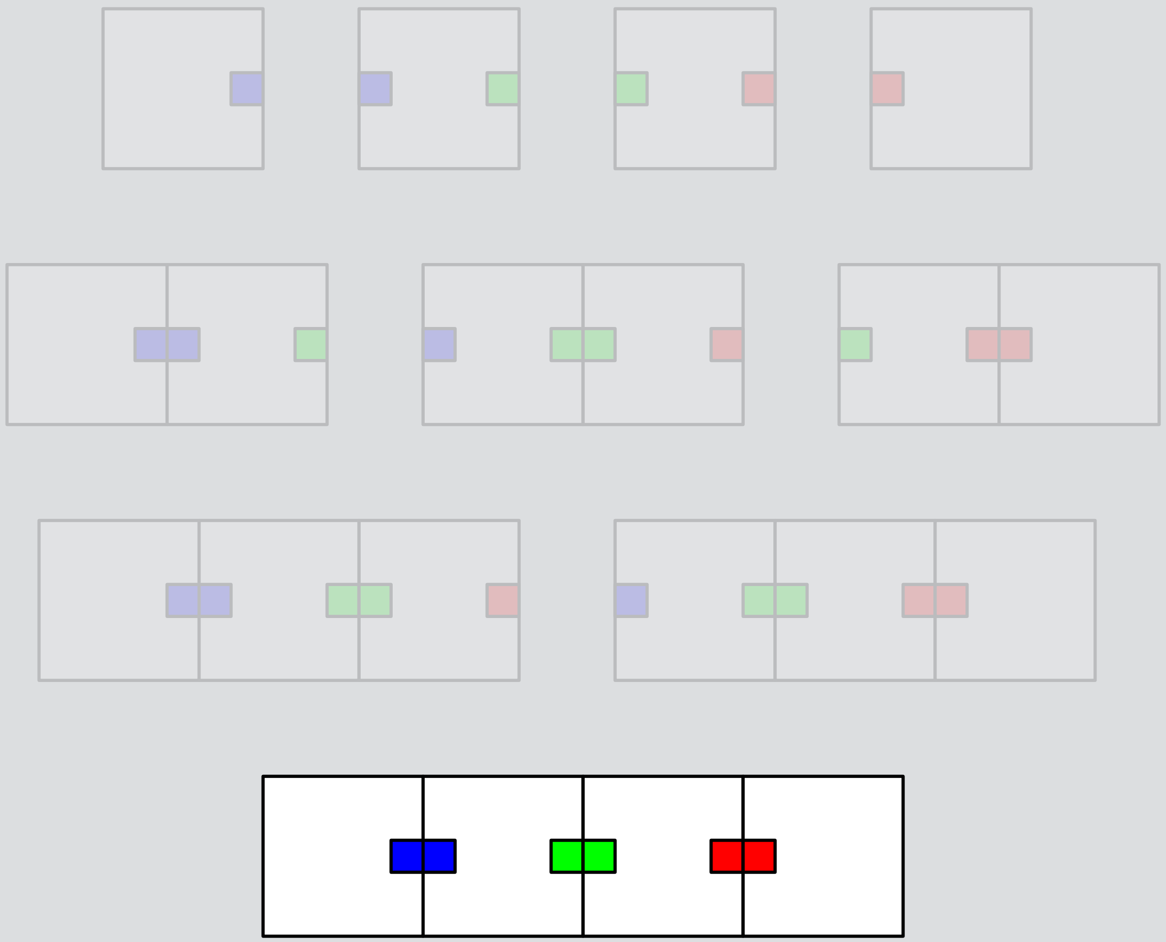
Producible assemblies:



Temperature 1

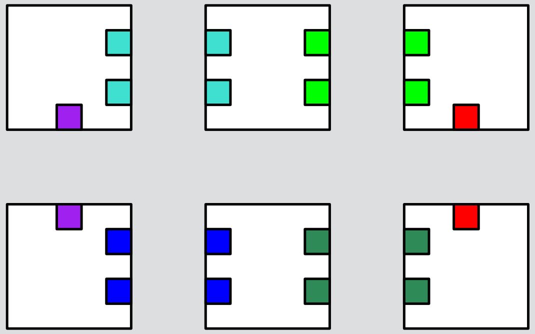
Two-handed assembly (2HAM)

Terminal assemblies:



Temperature 1

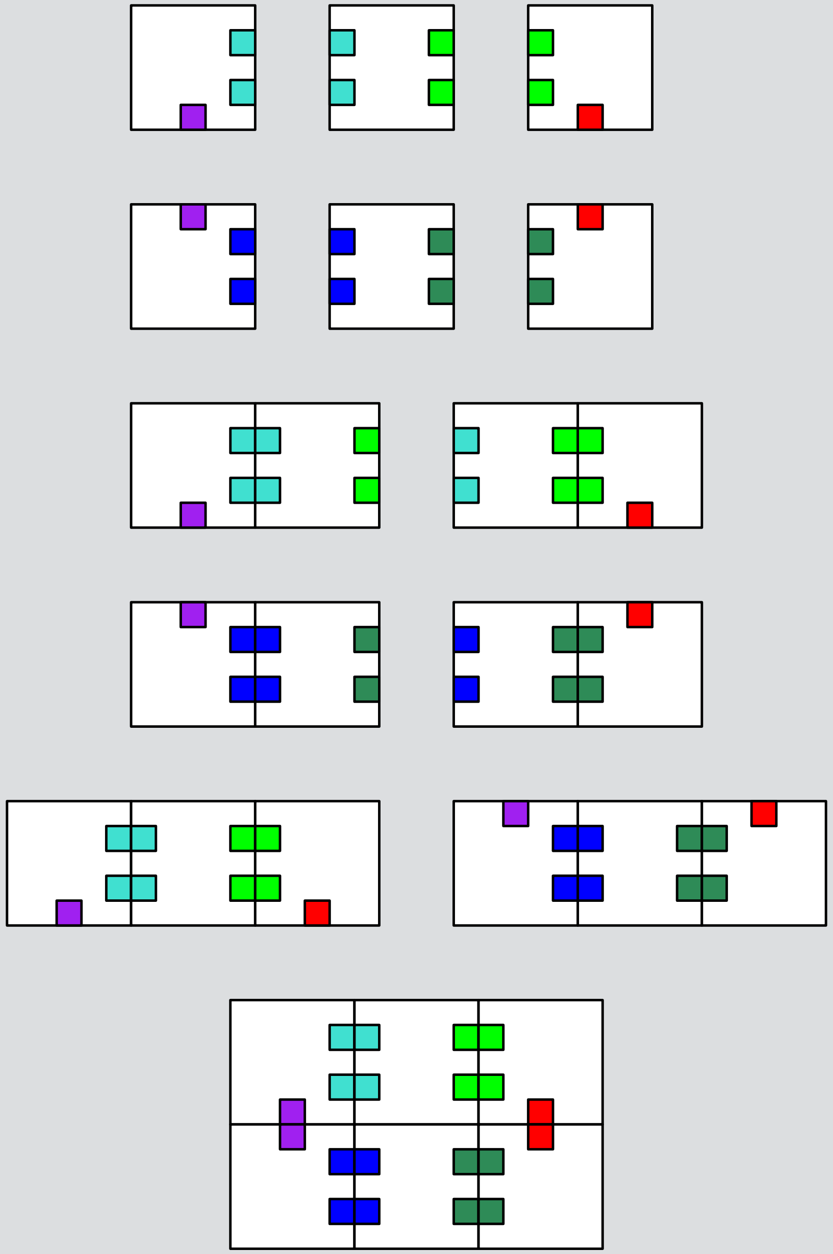
Two-handed assembly (2HAM)



Temperature 2

Two-handed assembly (2HAM)

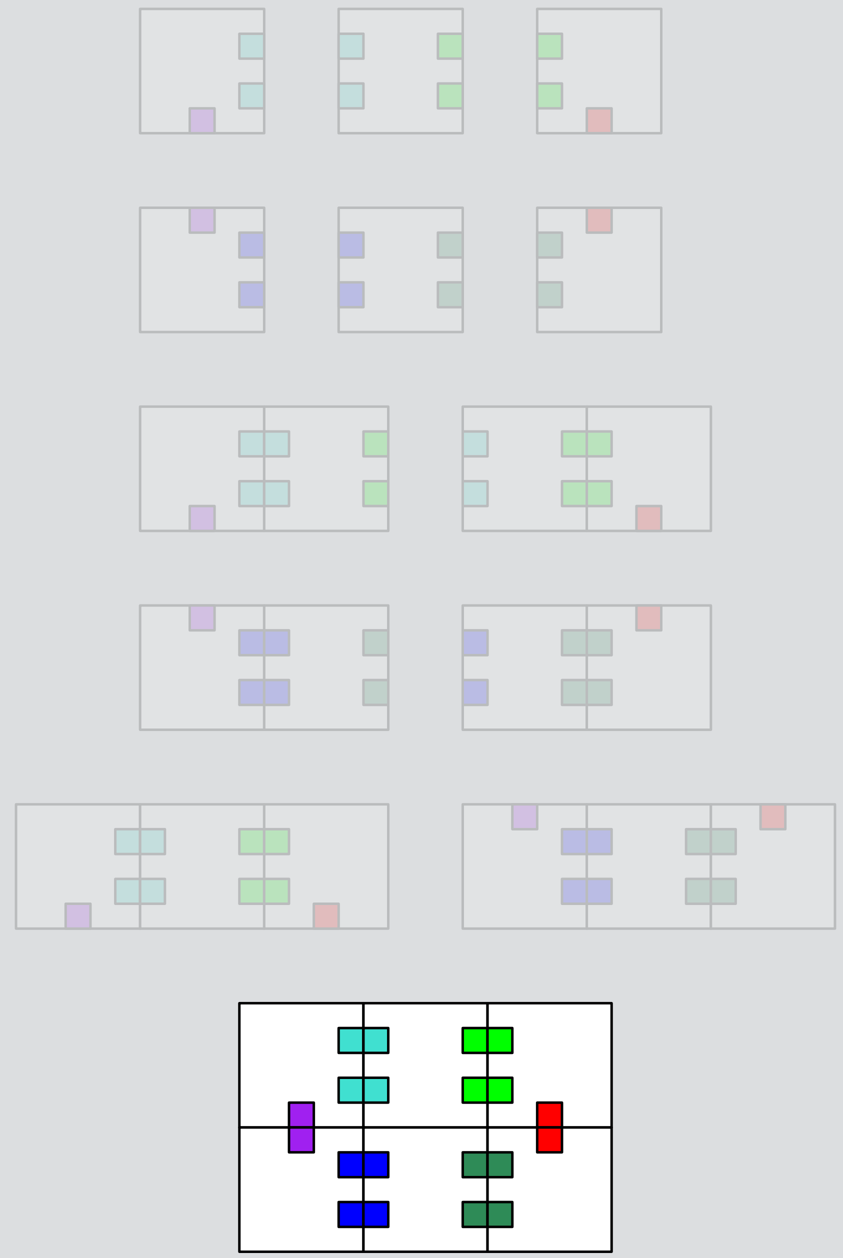
Producible assemblies:



Temperature 2

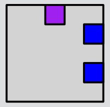
Two-handed assembly (2HAM)

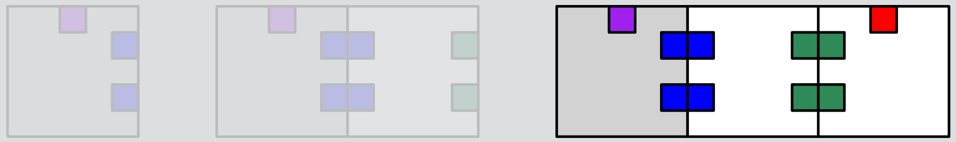
Terminal assemblies:

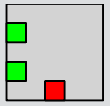


Temperature 2

aTAM

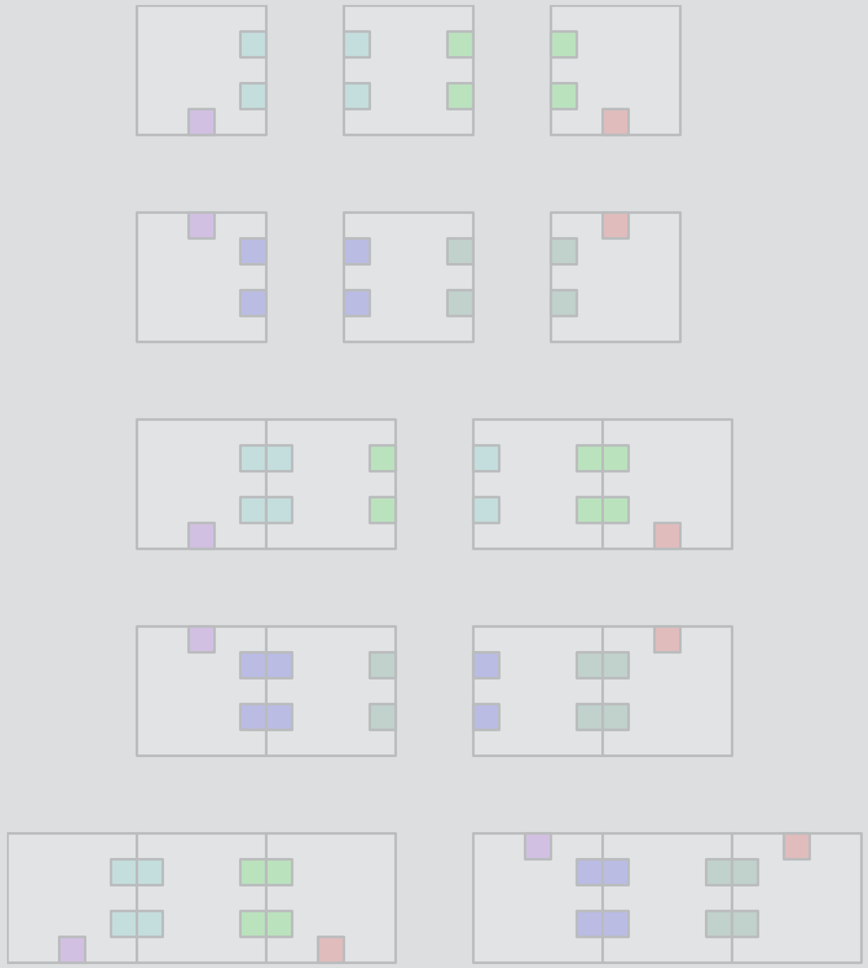
Producible w/seed  :

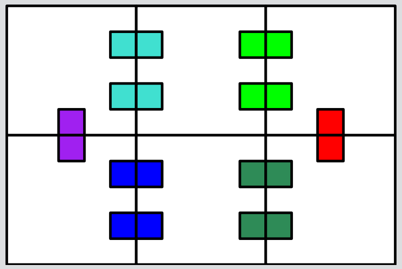


Producible w/seed  :

2HAM

Producible:





Temperature 2

Is a seed necessary for some results?

no spurious nucleation

universal computation?

efficient shape construction?

Is a seed necessary for some results? No!

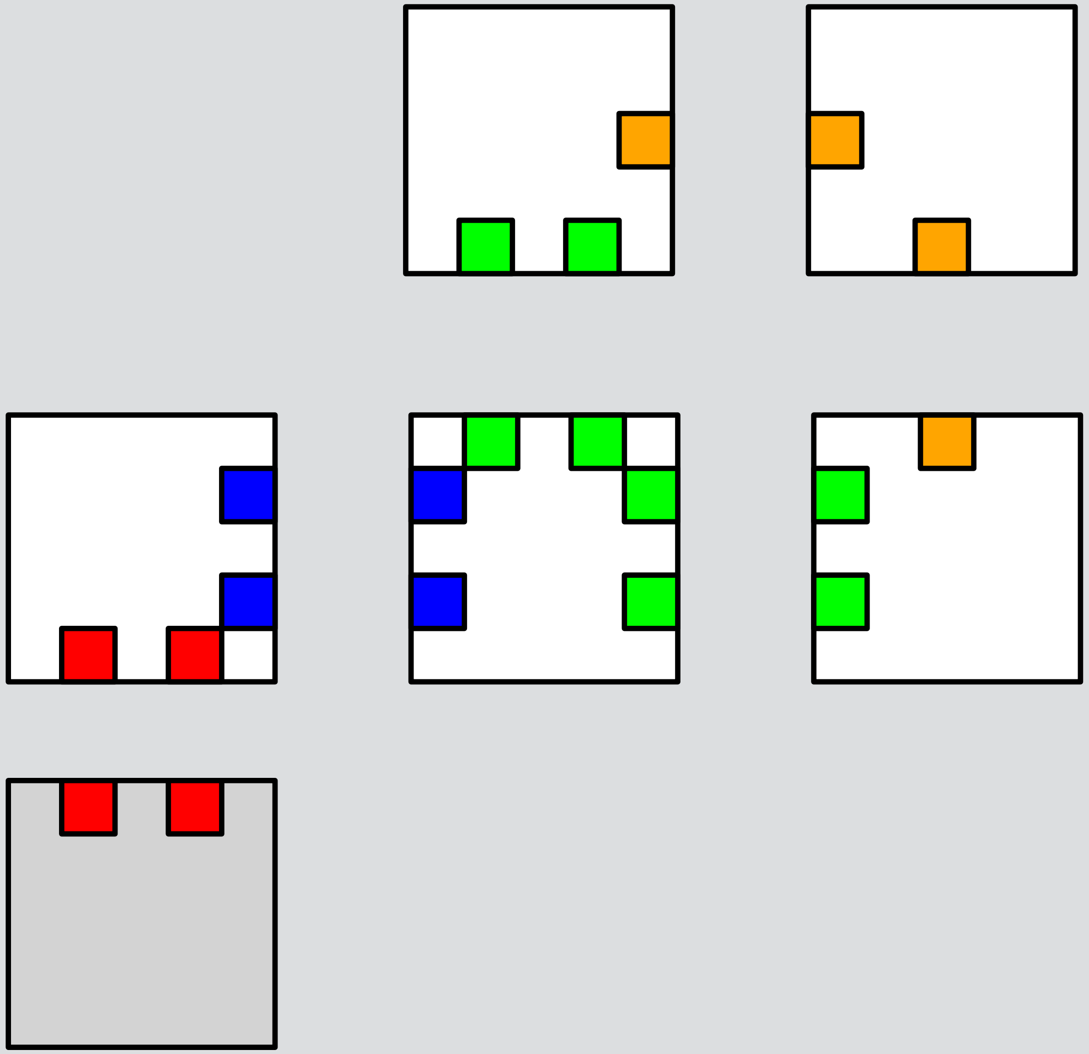
no spurious nucleation

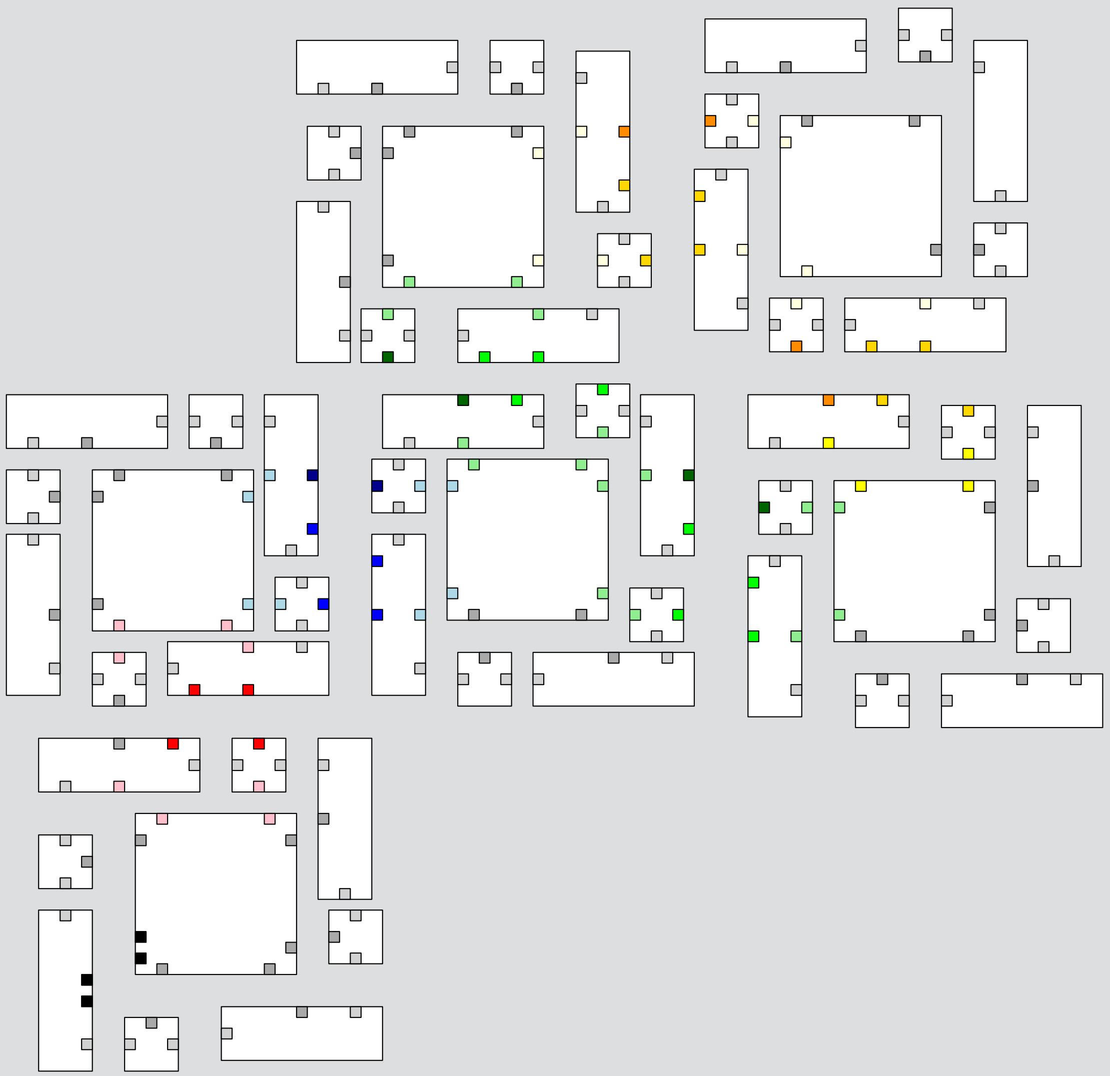
universal computation?

efficient shape construction?

Every aTAM system can be *simulated* by a 2HAM system.

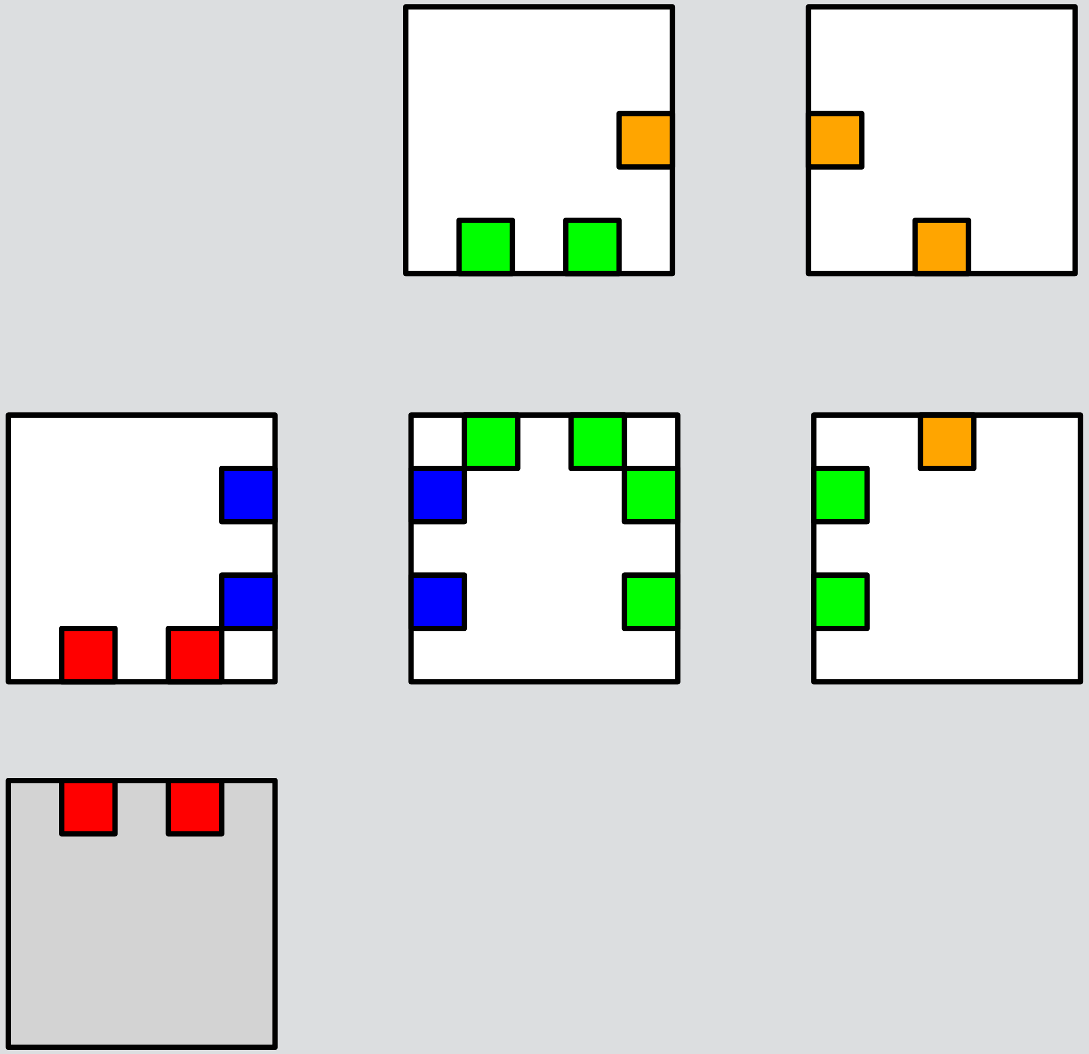
Every aTAM system can be *simulated* by a 2HAM system.



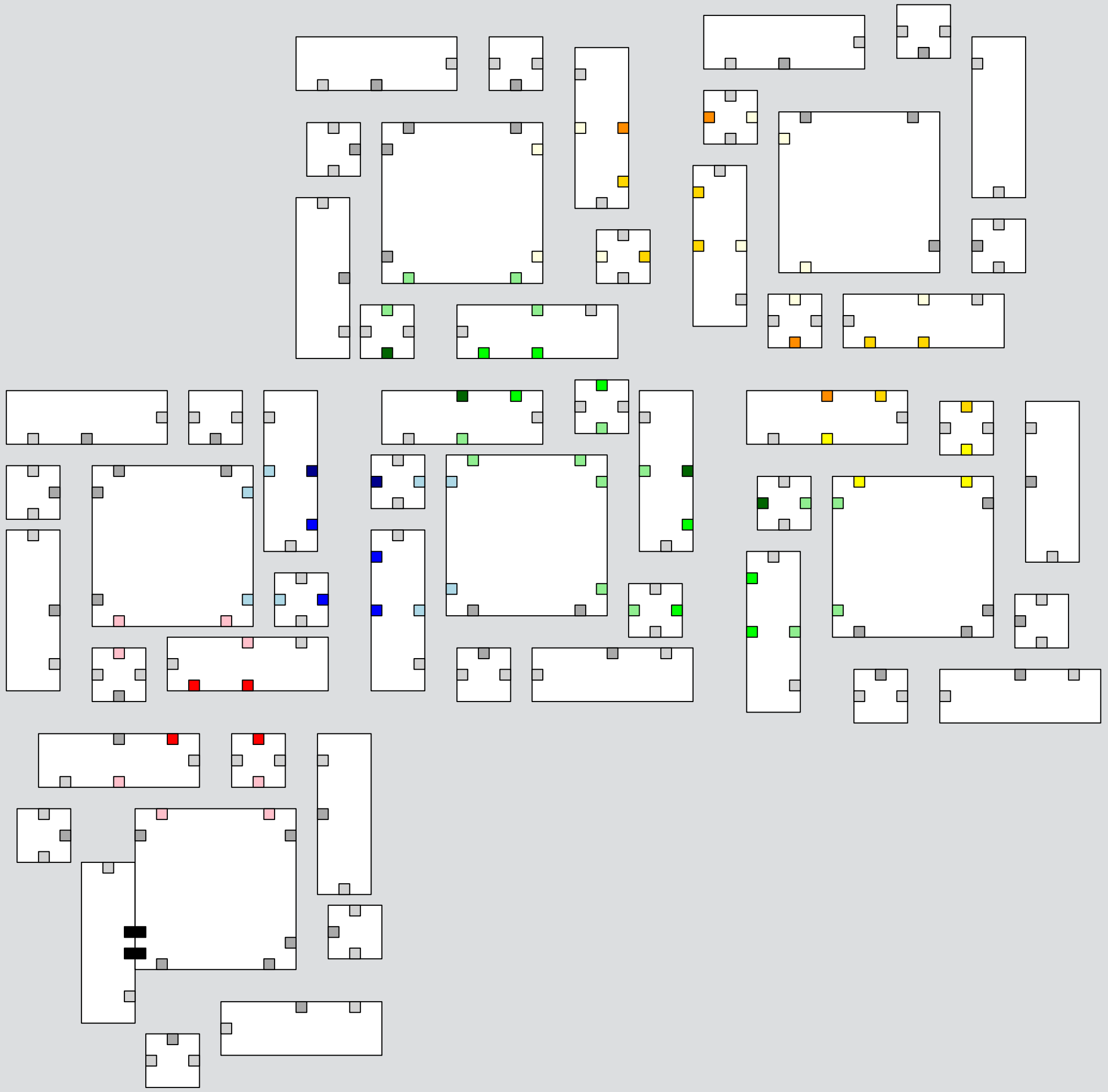


Temperature 2

Every aTAM system can be *simulated* by a 2HAM system.



aTAM



2HAM

Temperature 2

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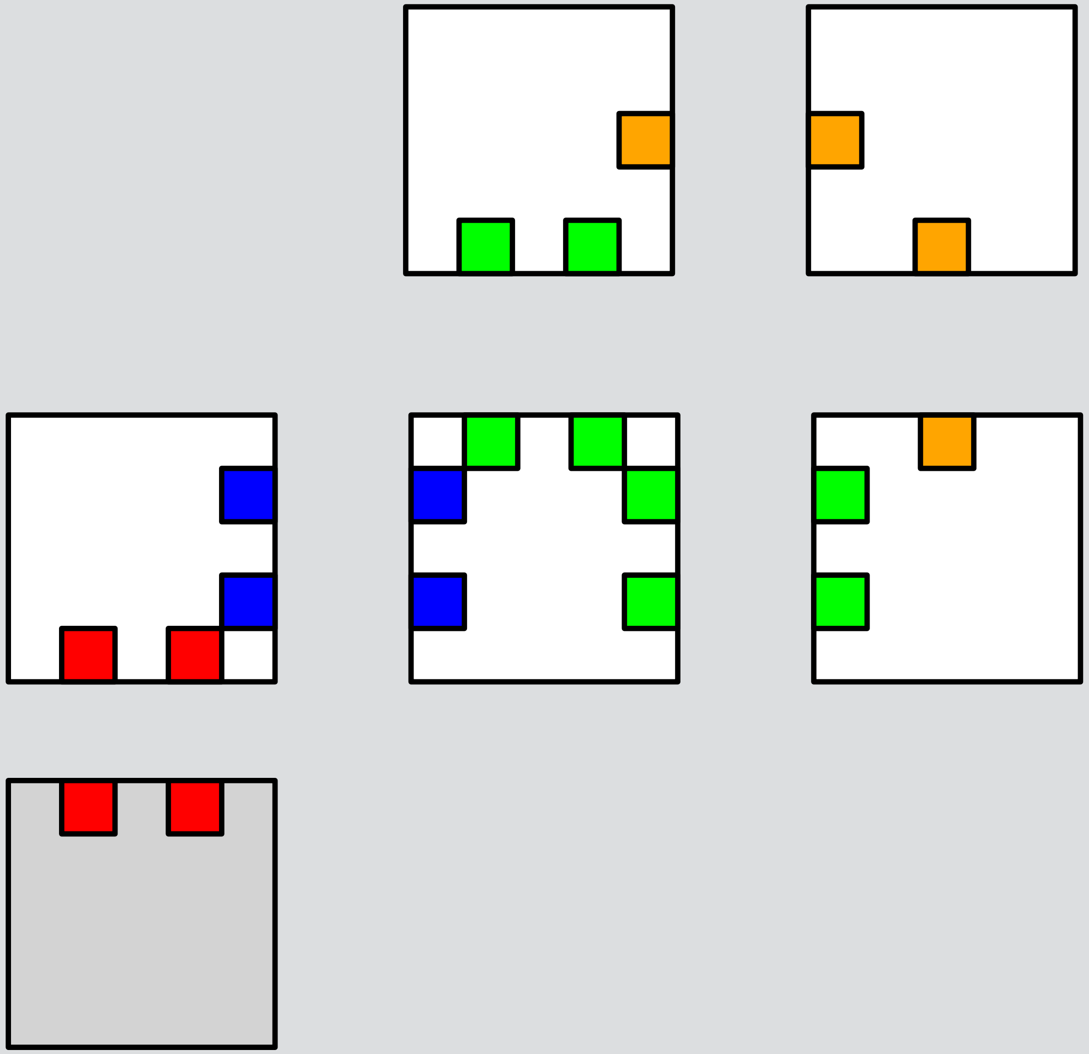
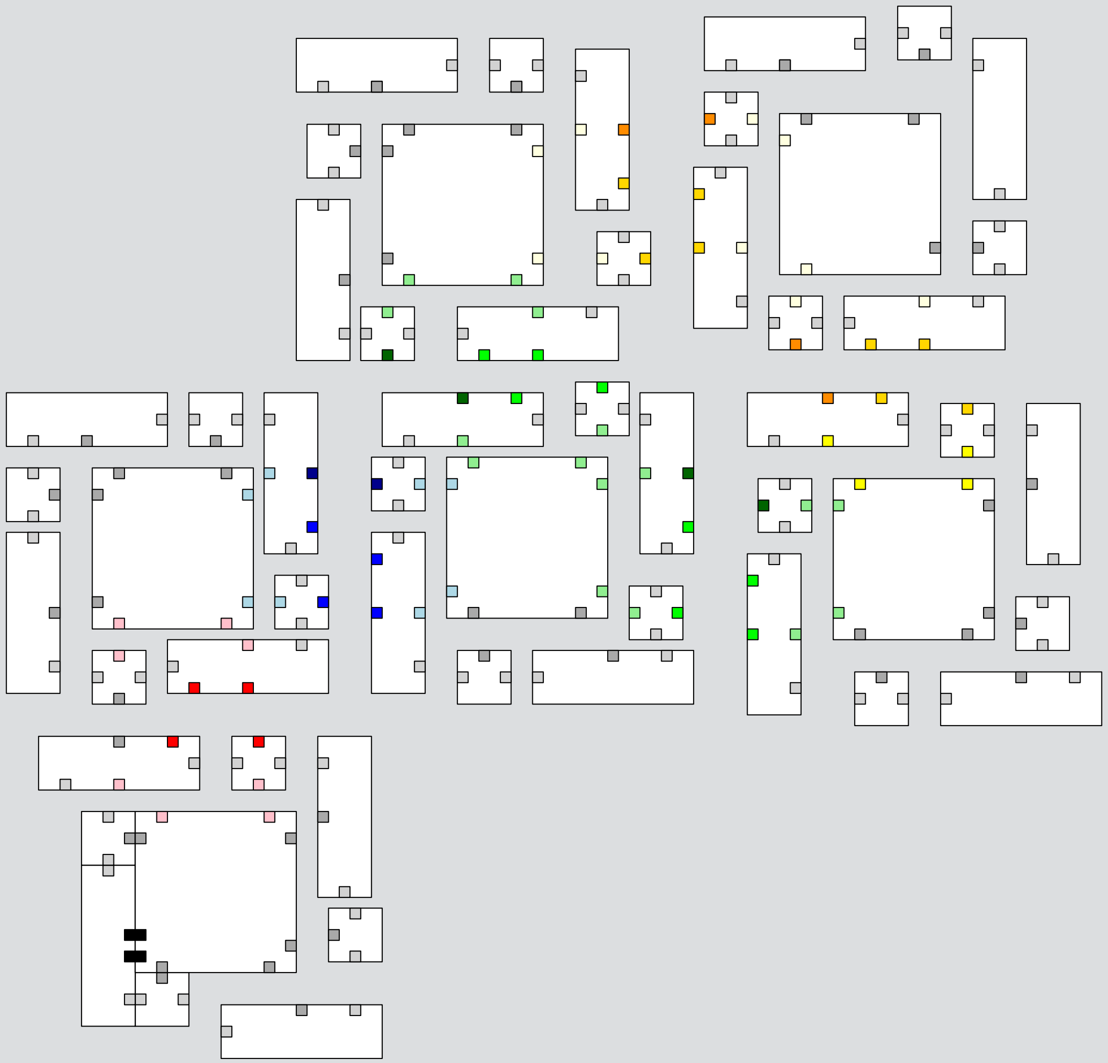


aTAM



2HAM

Temperature 2

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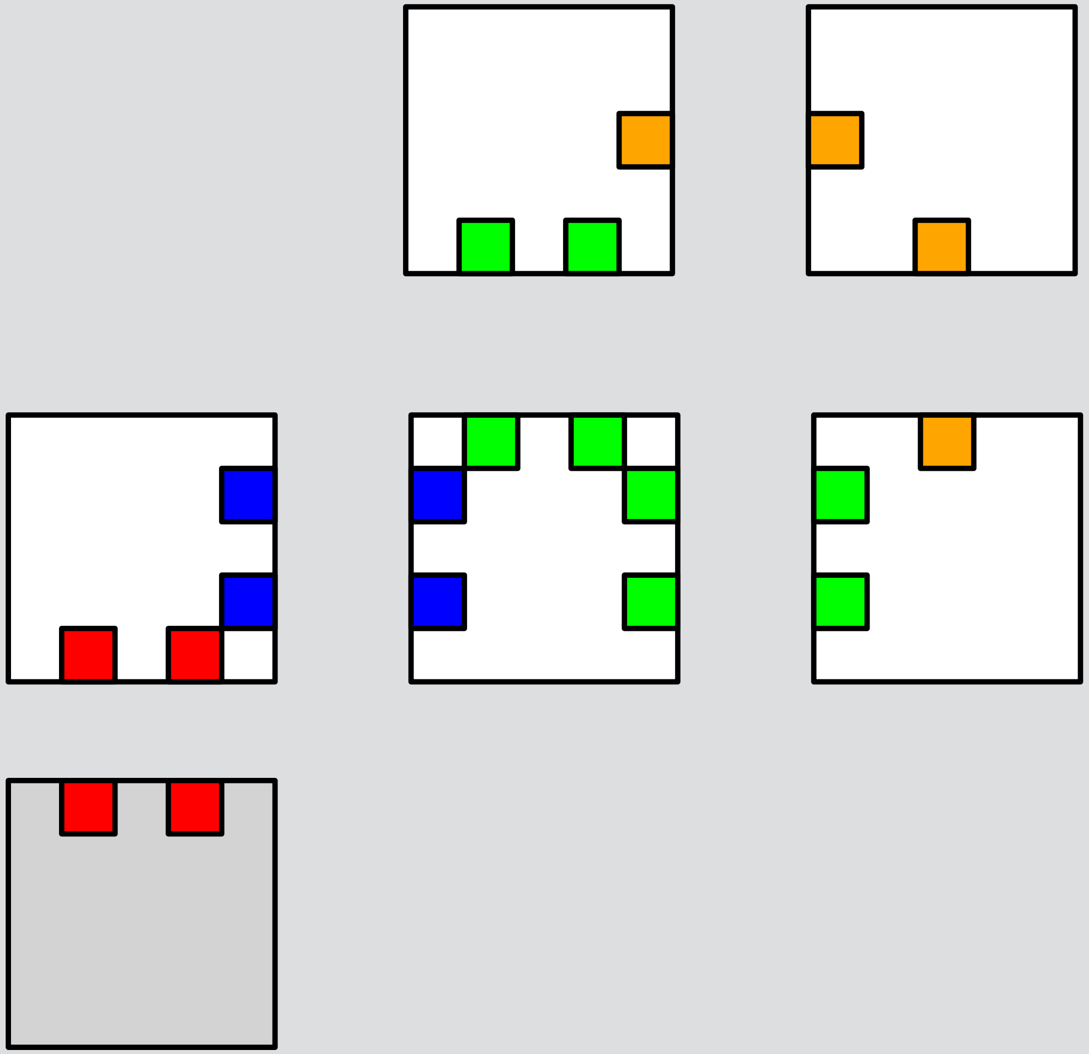
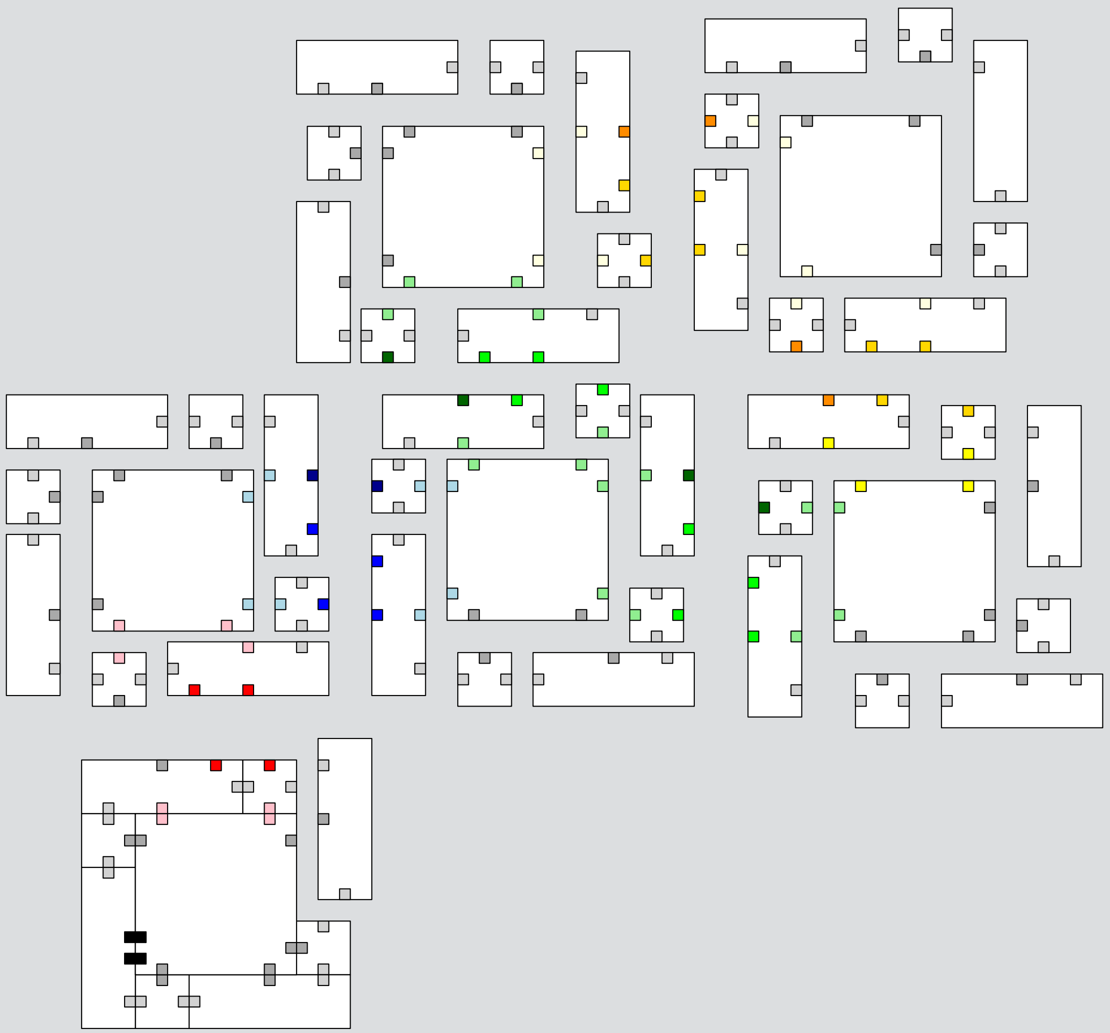


aTAM



2HAM

Temperature 2

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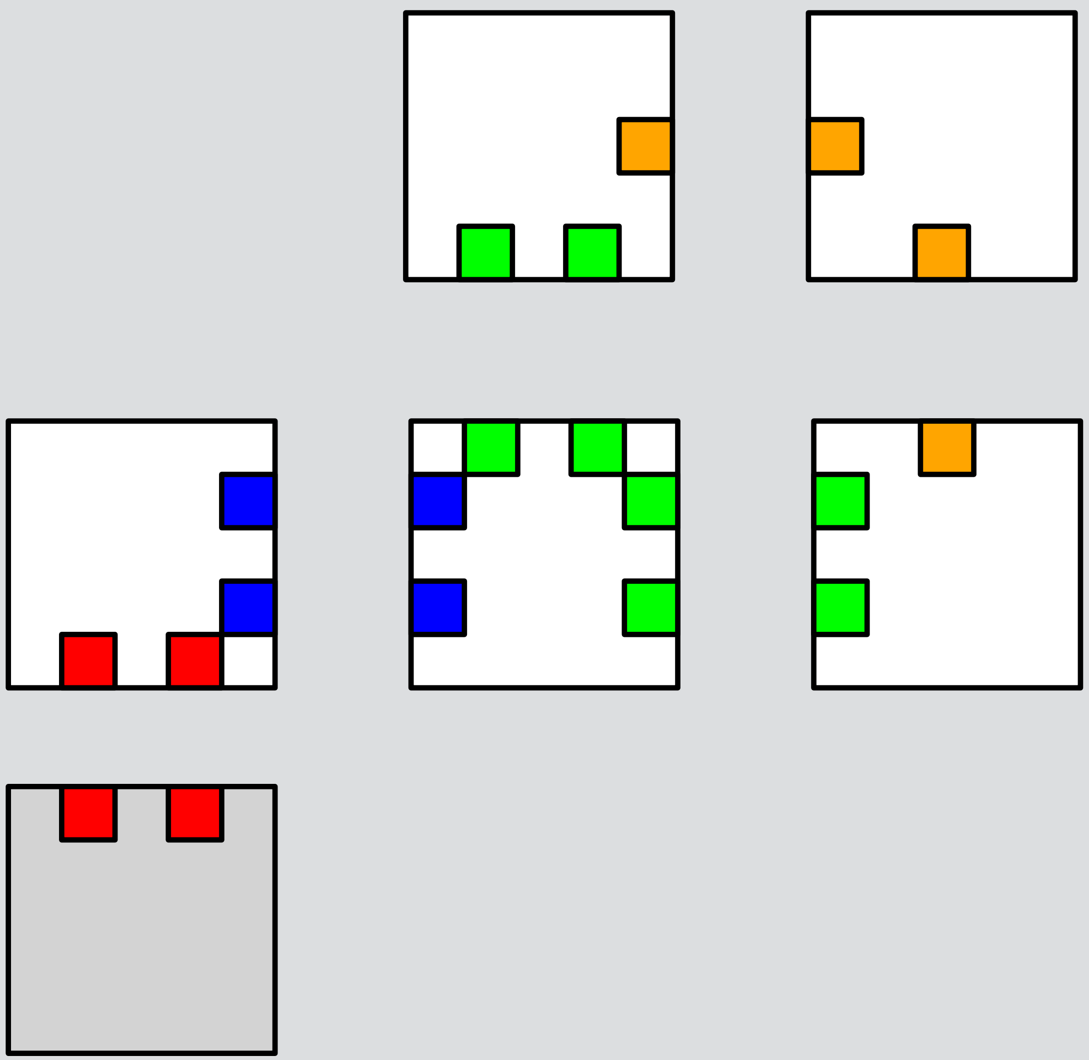
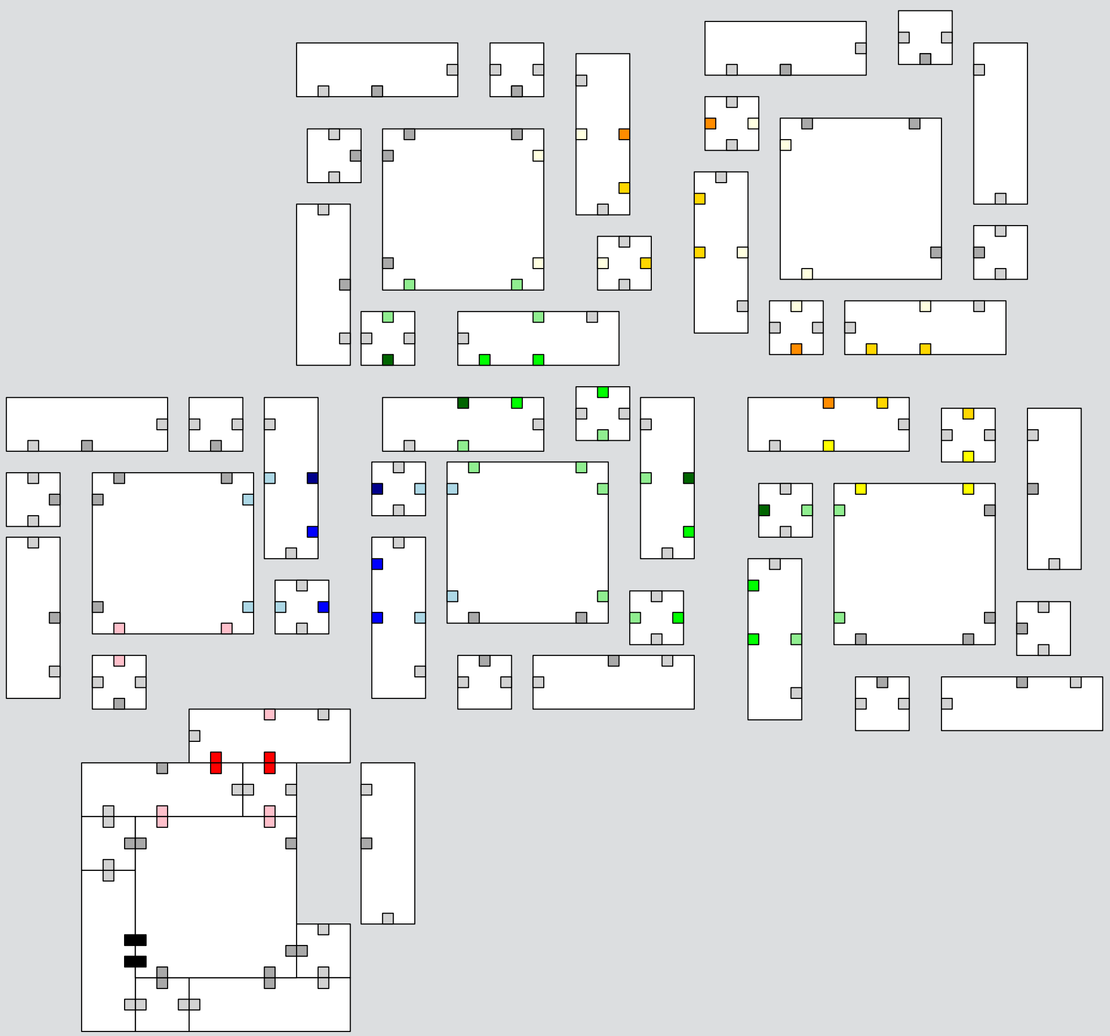


aTAM



2HAM

Temperature 2

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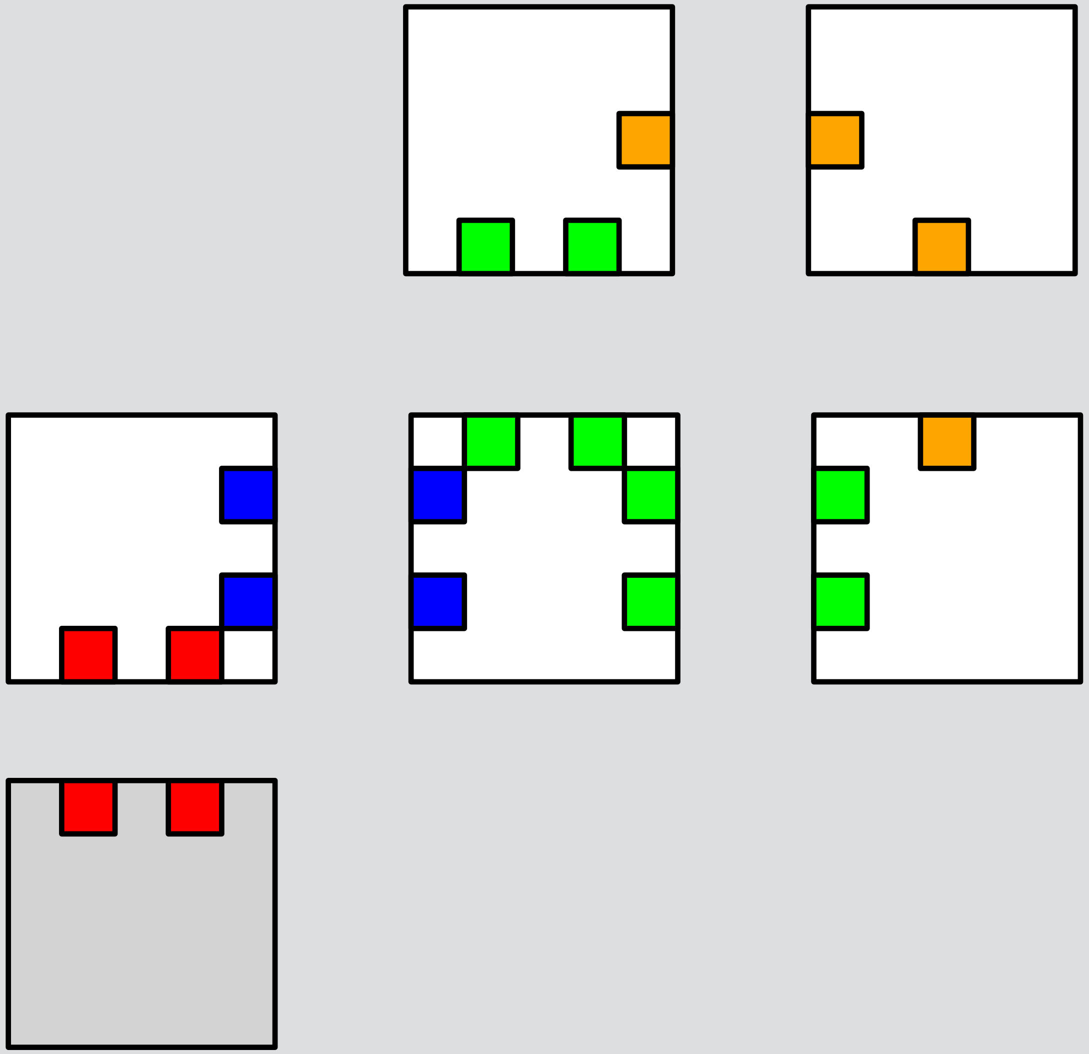
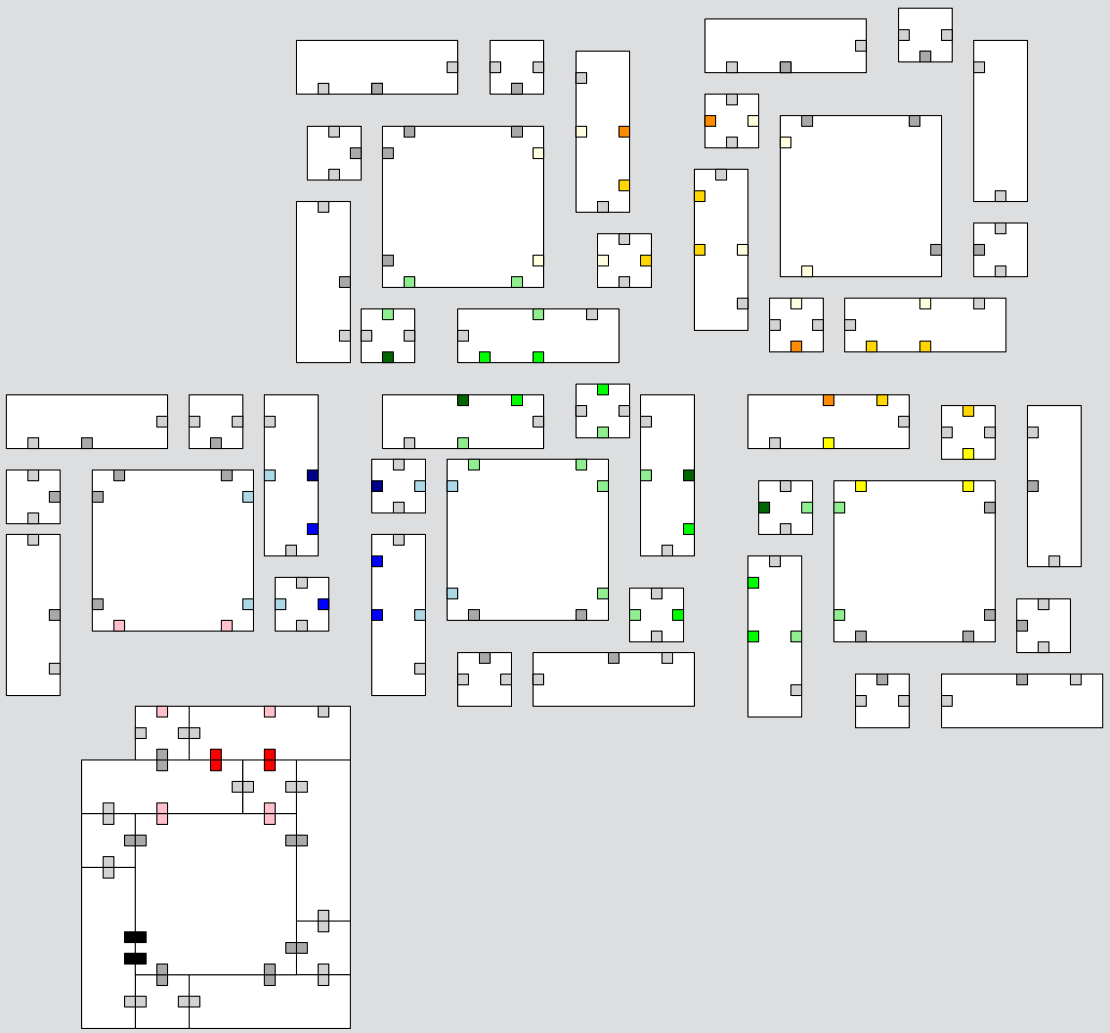


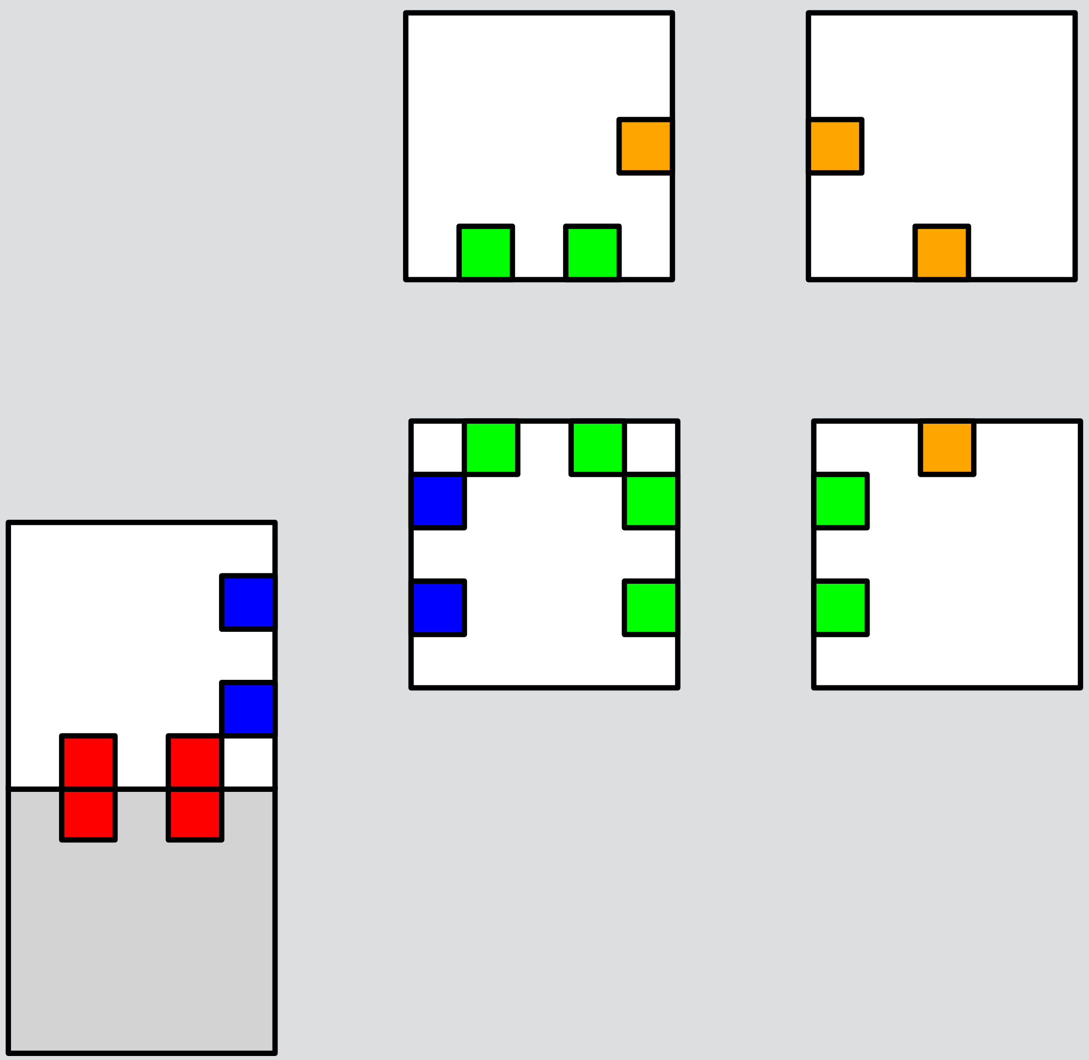


aTAM

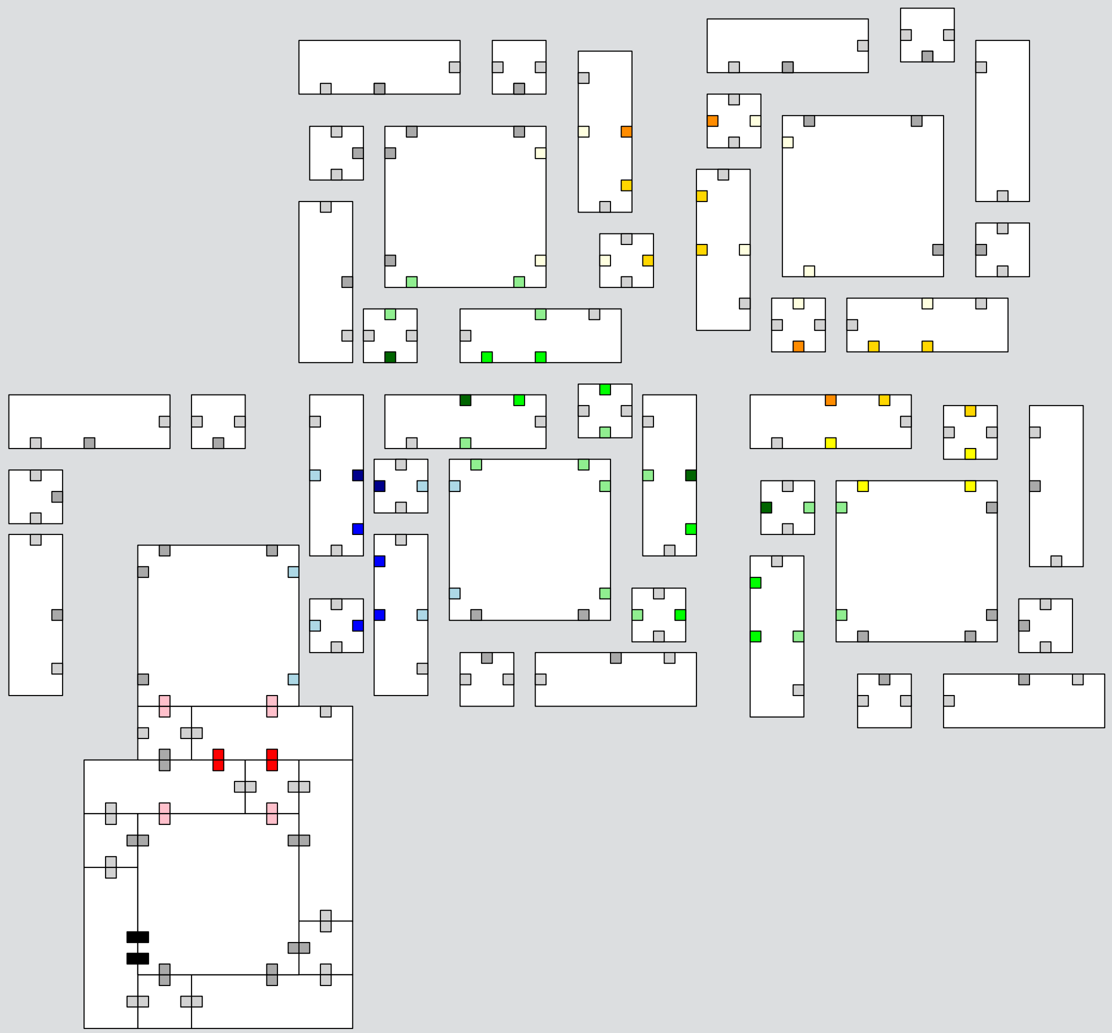
2HAM

Temperature 2

Every aTAM system can be *simulated* by a 2HAM system.



aTAM



2HAM

Temperature 2

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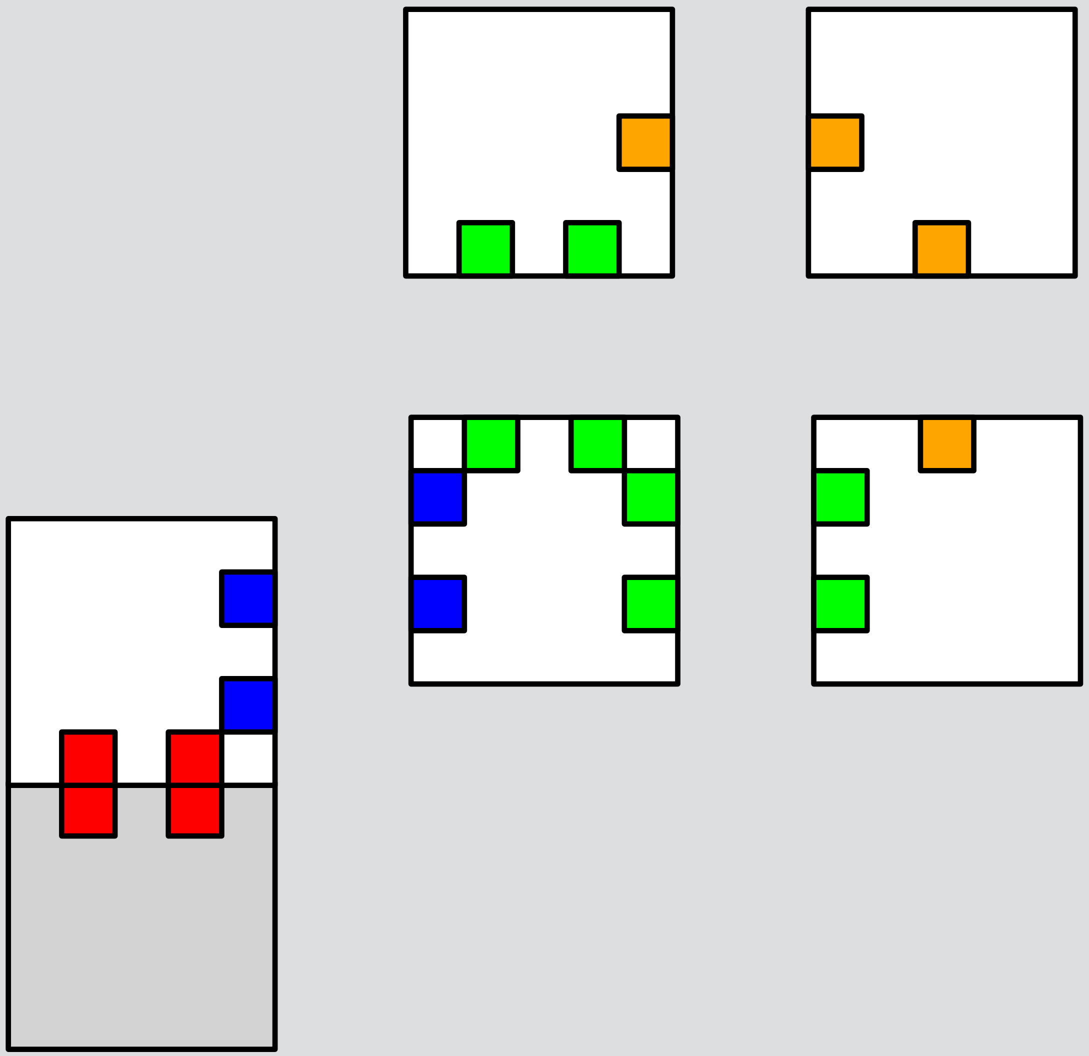
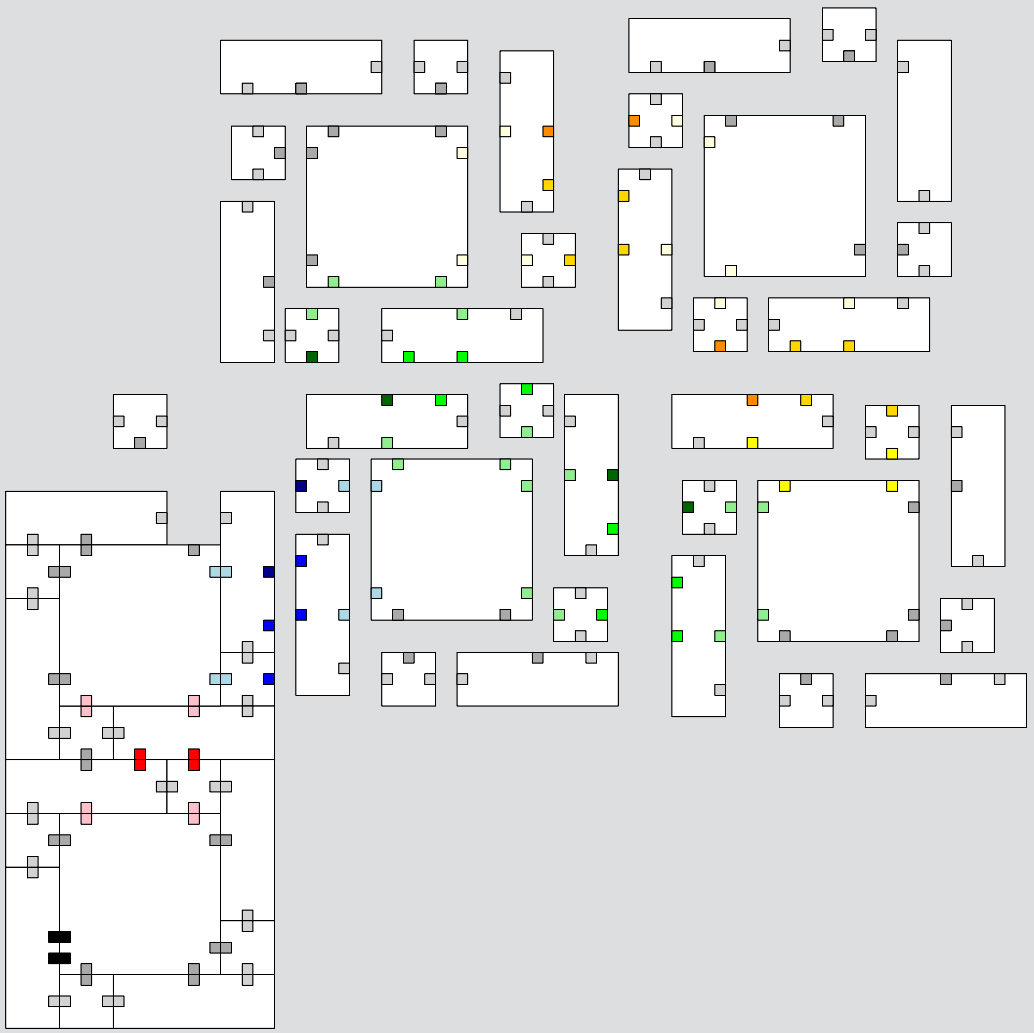


aTAM



2HAM

Temperature 2

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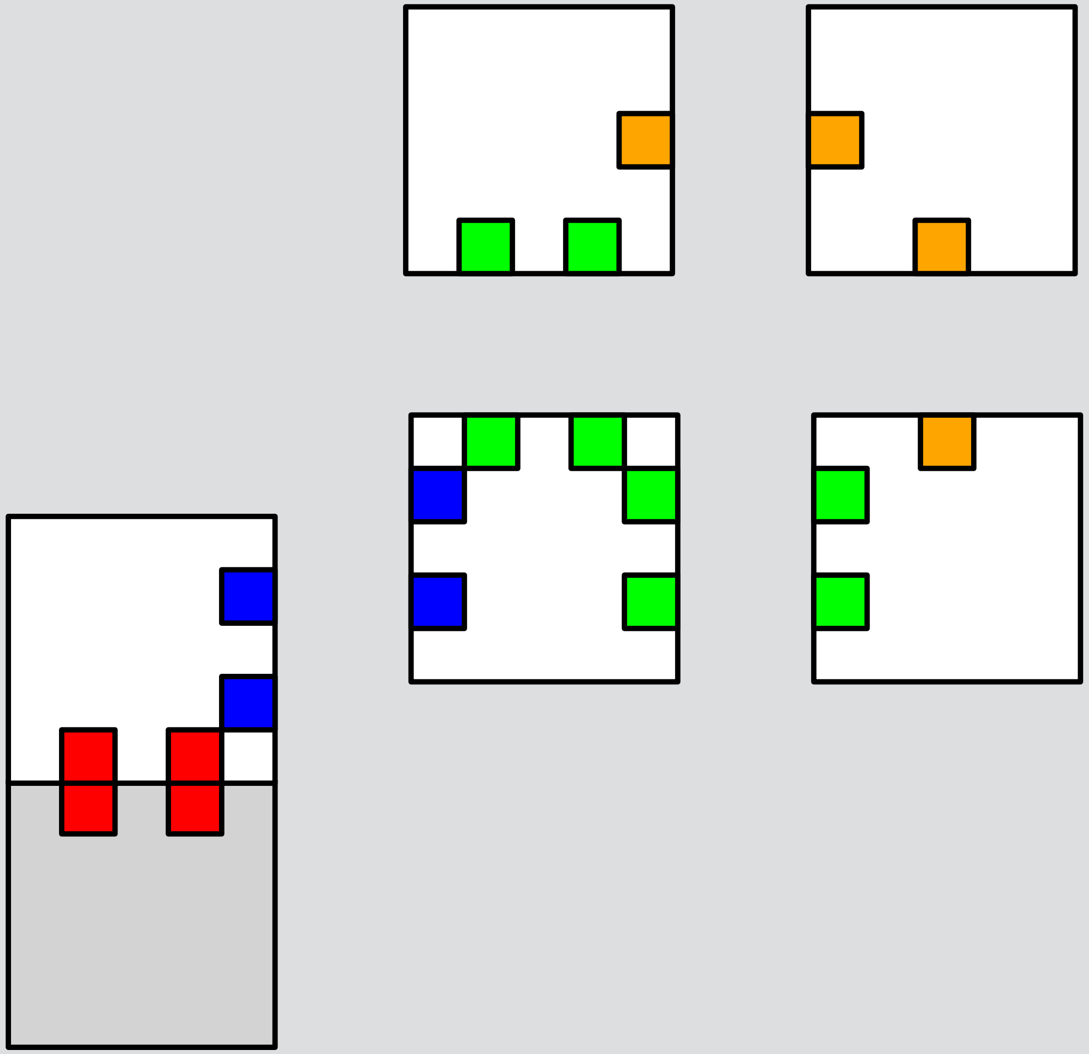

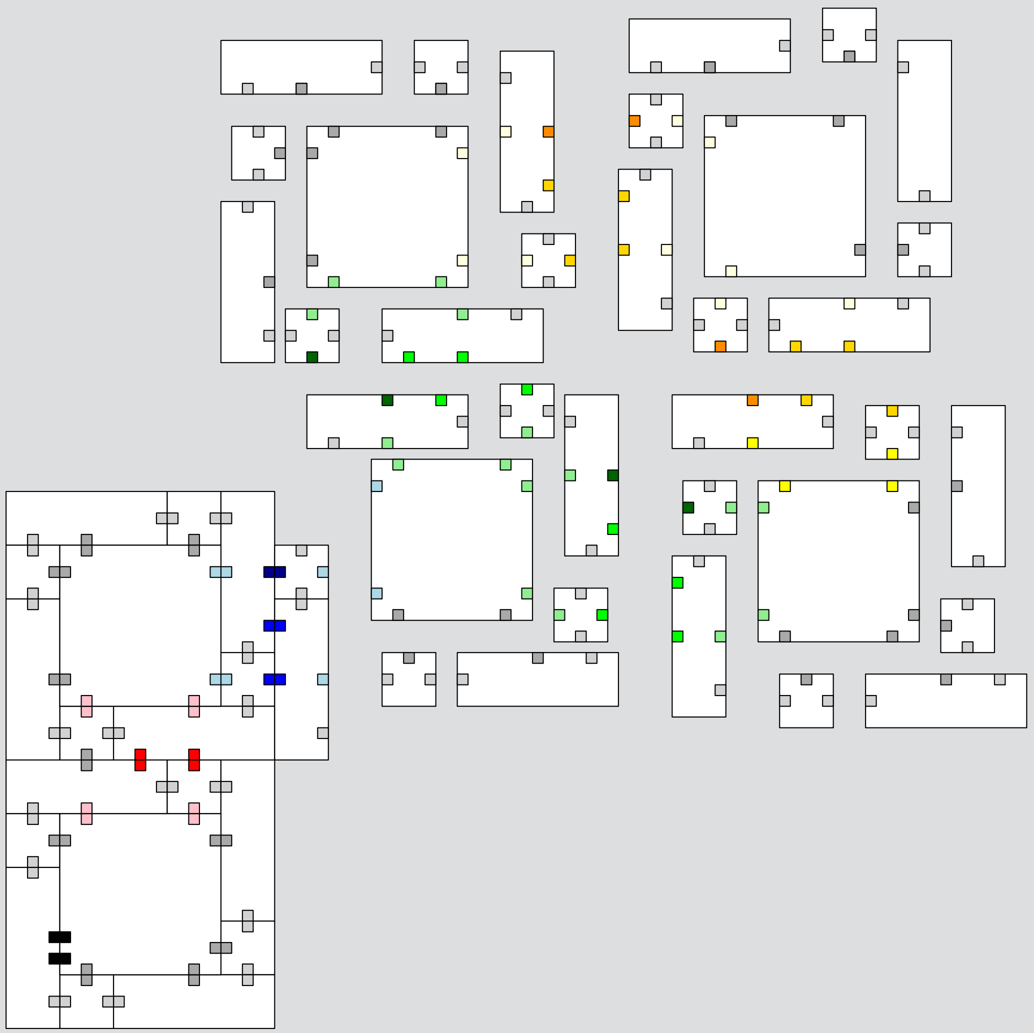

Temperature 2

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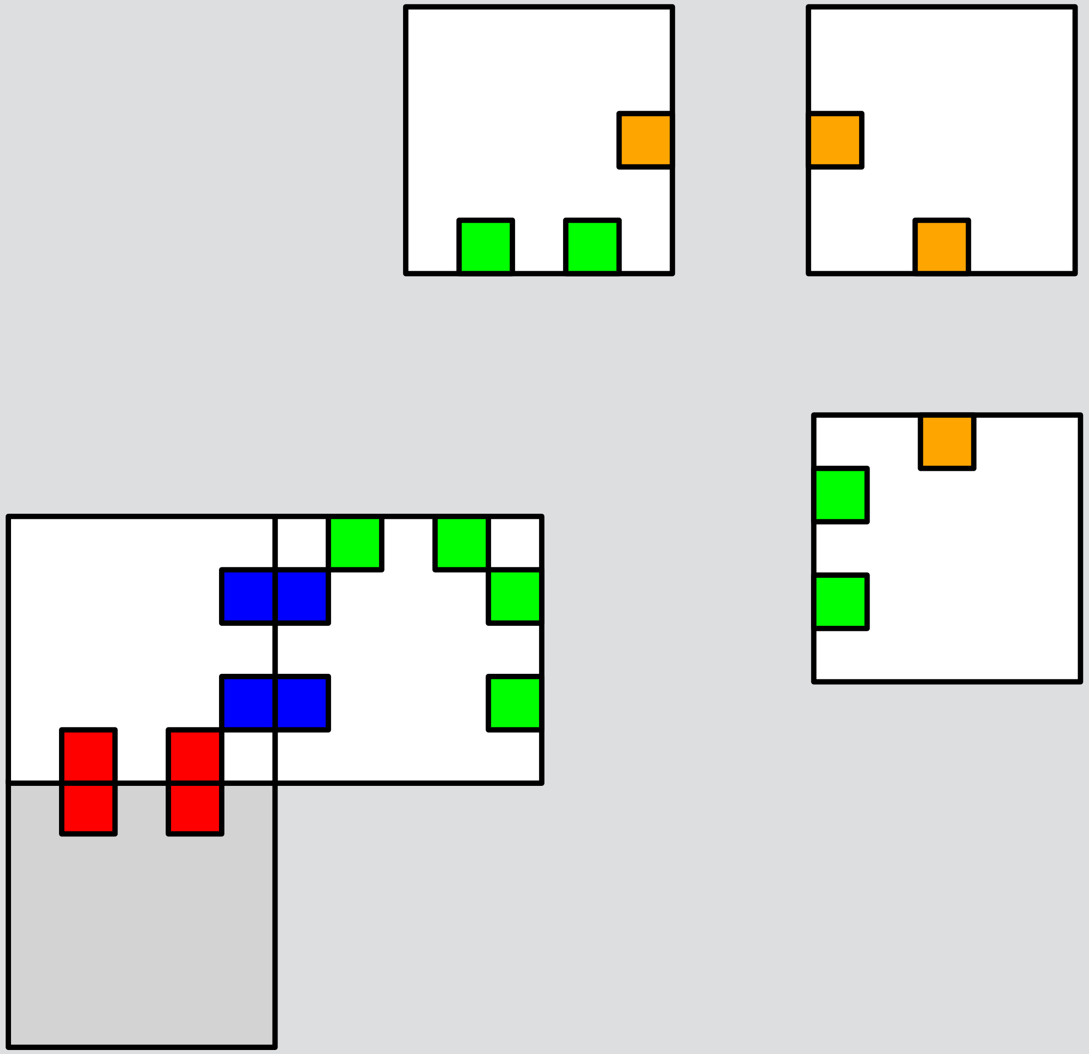
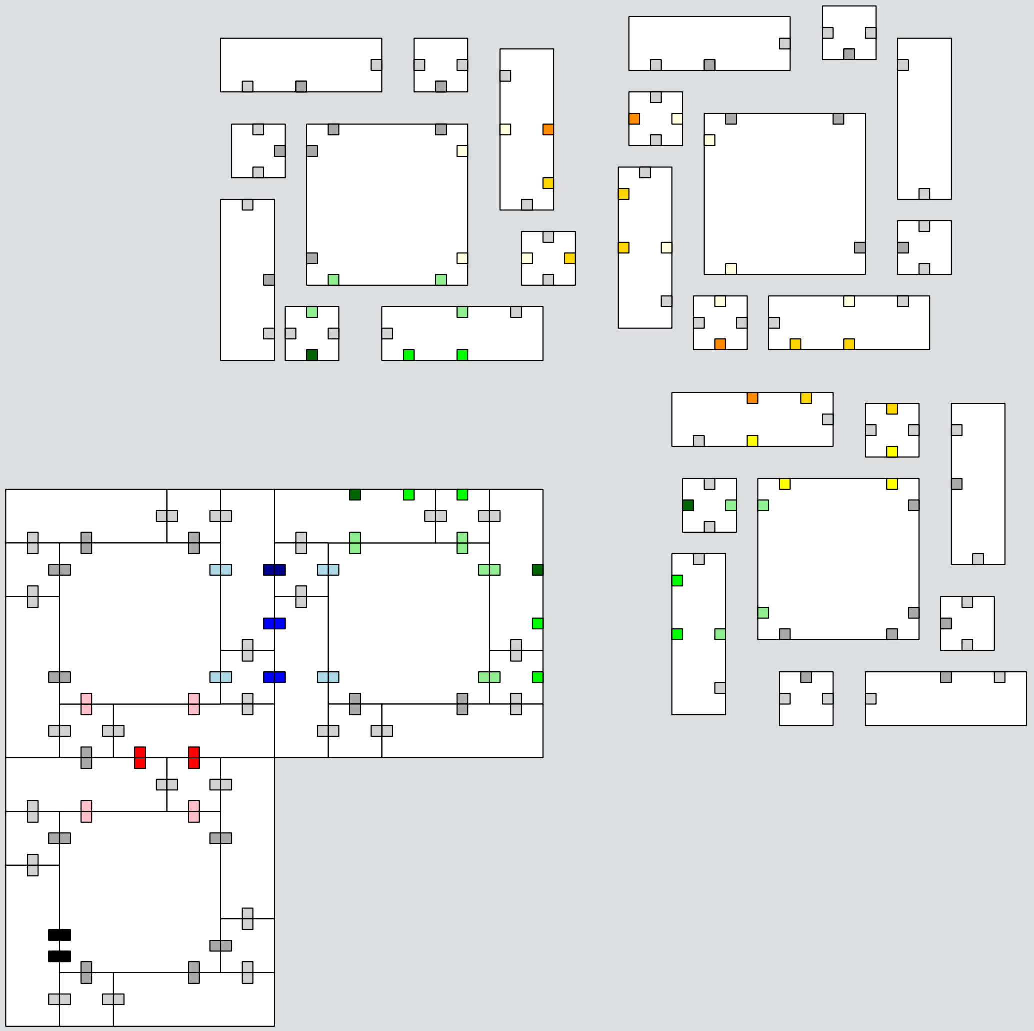


aTAM



2HAM

Temperature 2

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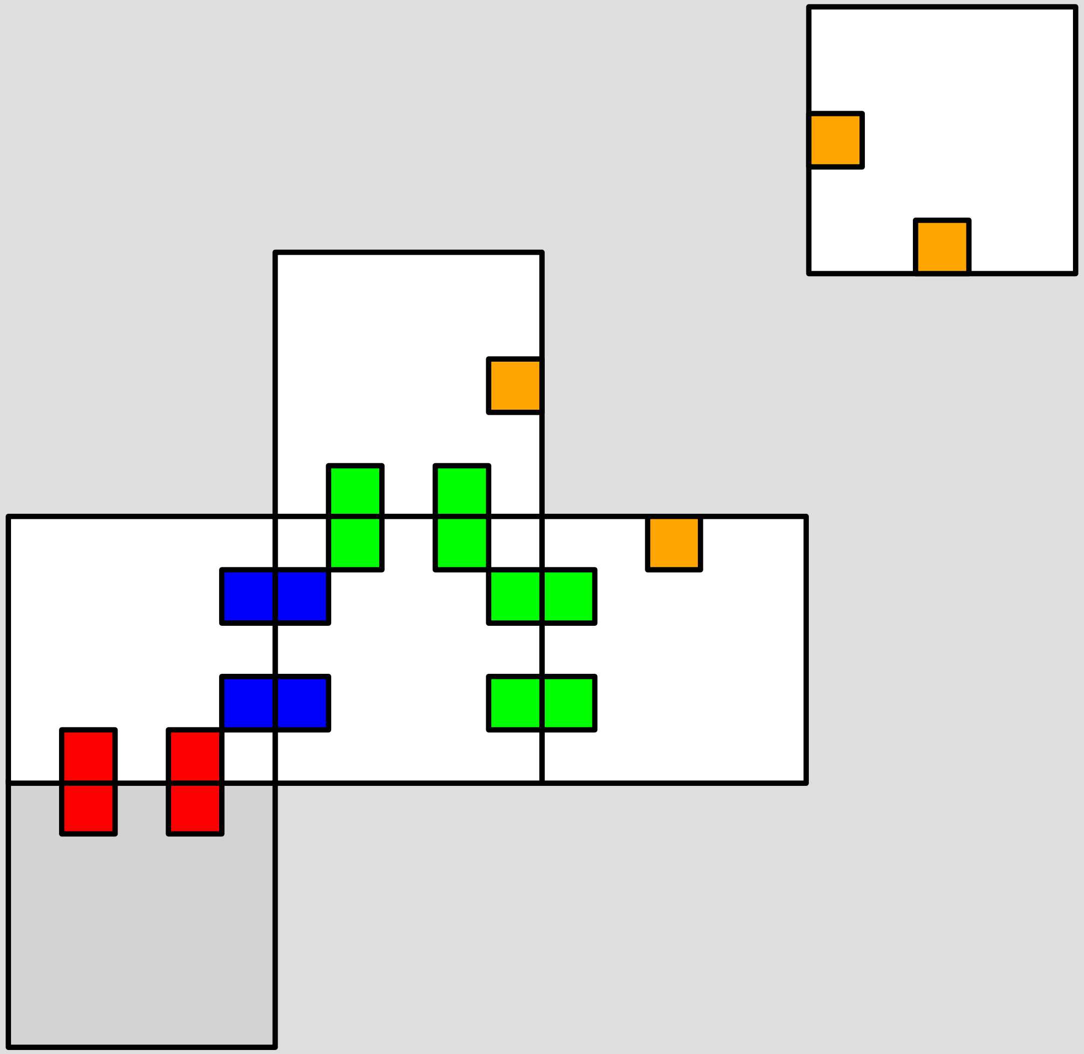
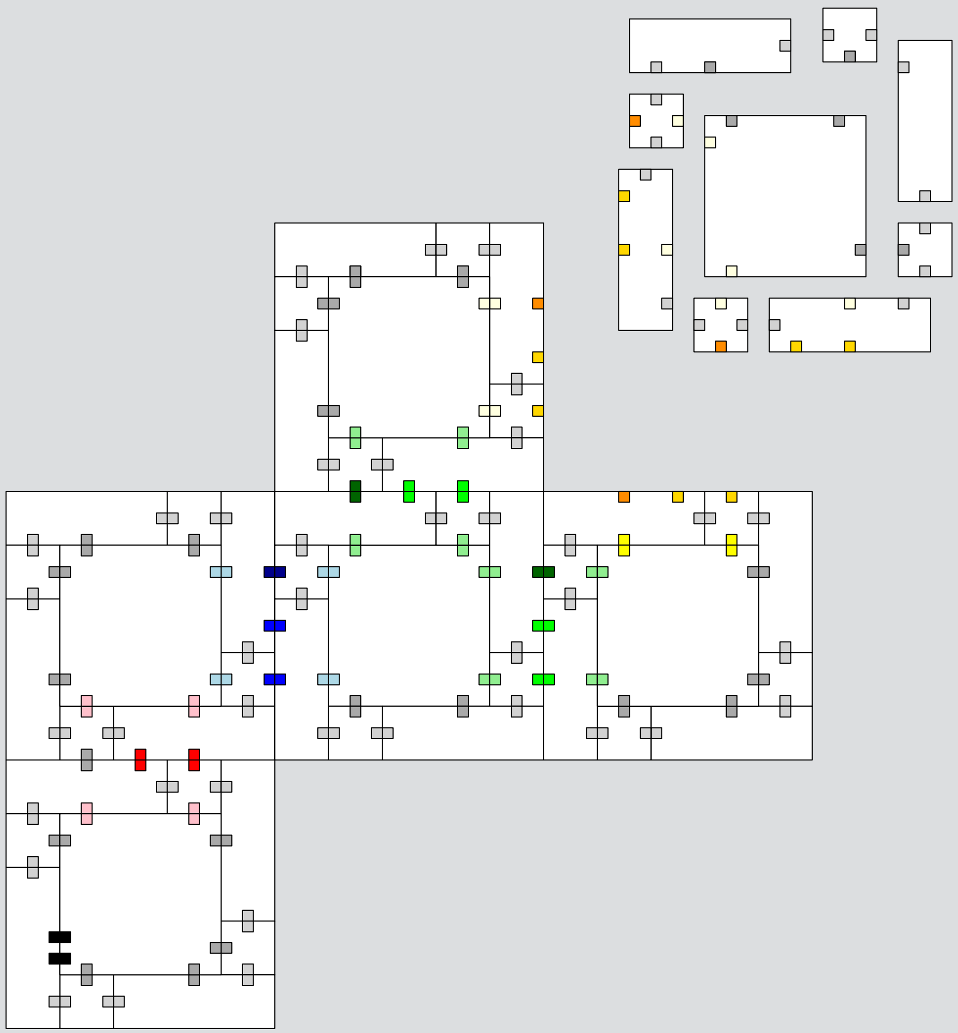


aTAM



2HAM

Temperature 2

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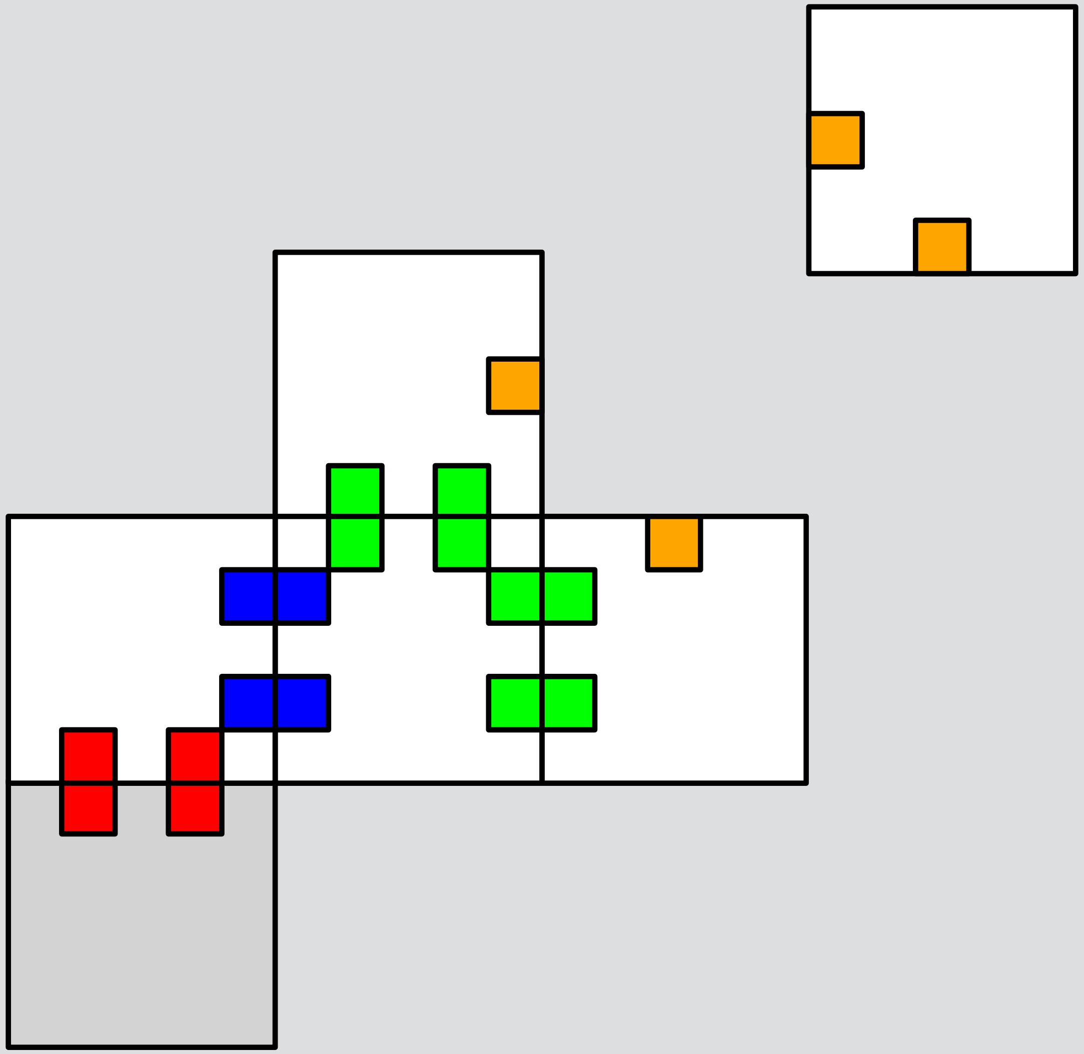
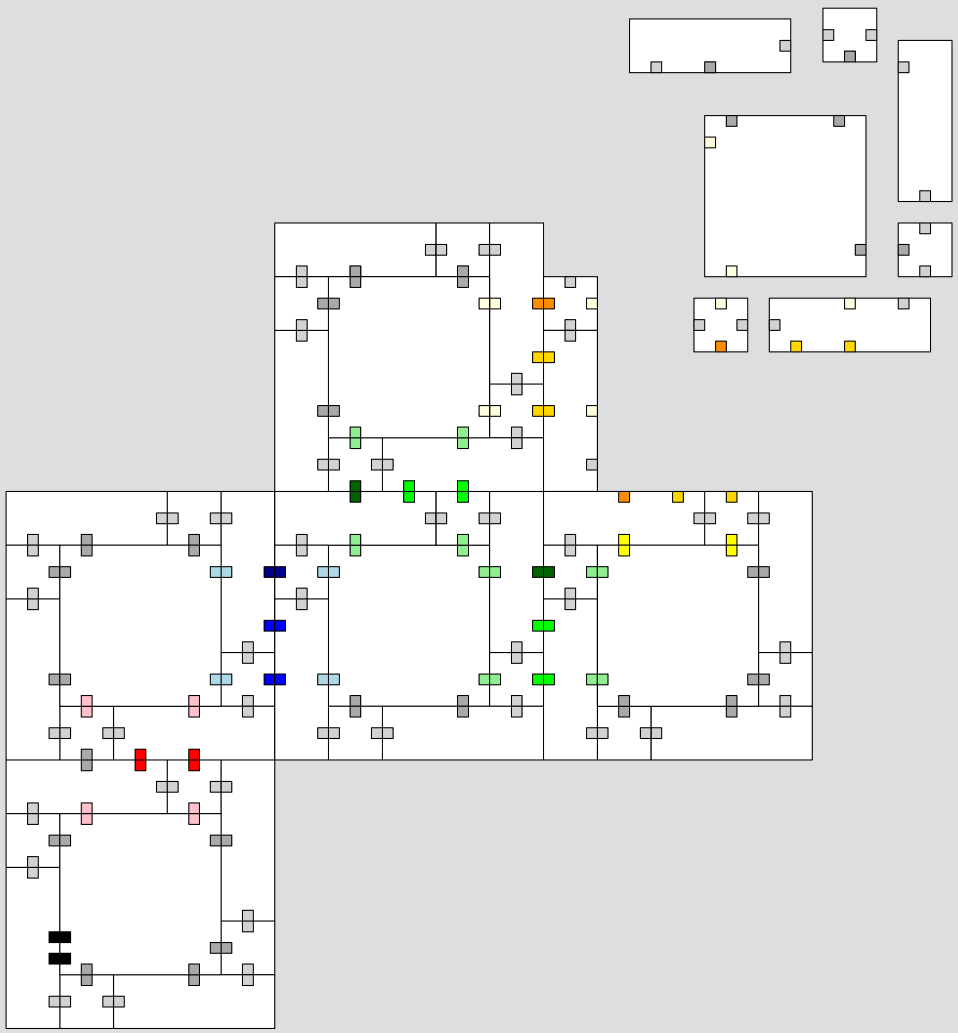


aTAM



2HAM

Temperature 2

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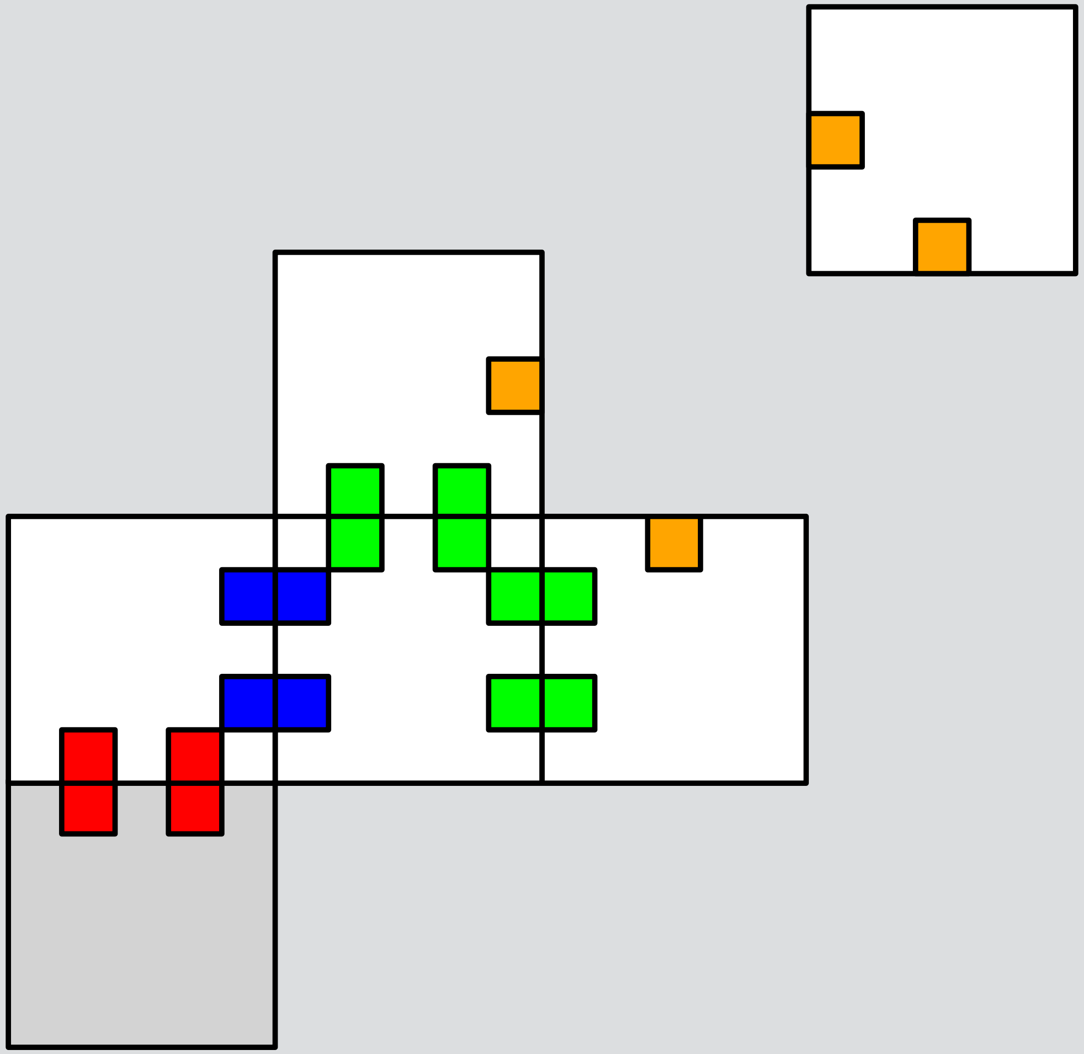
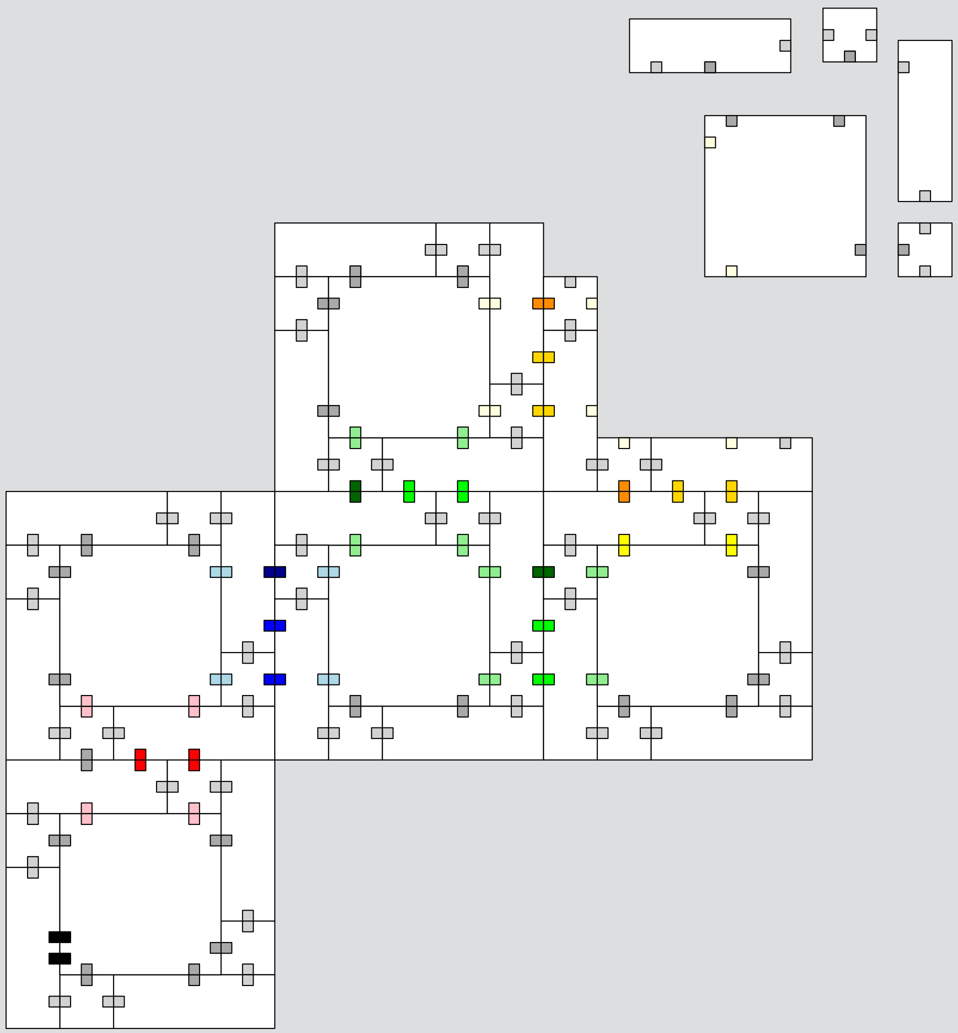


aTAM



2HAM

Temperature 2

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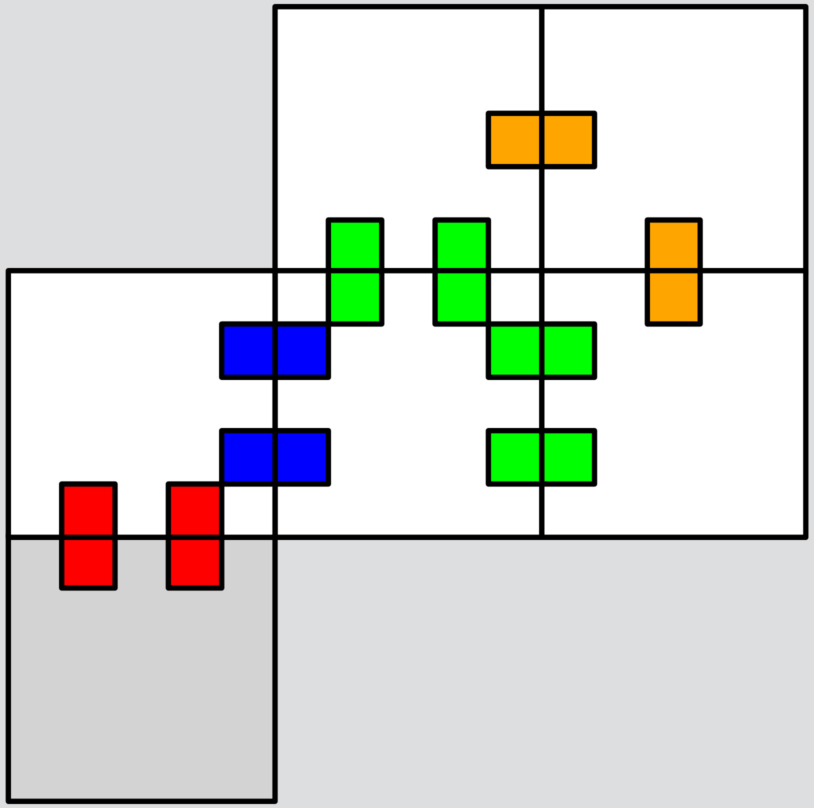
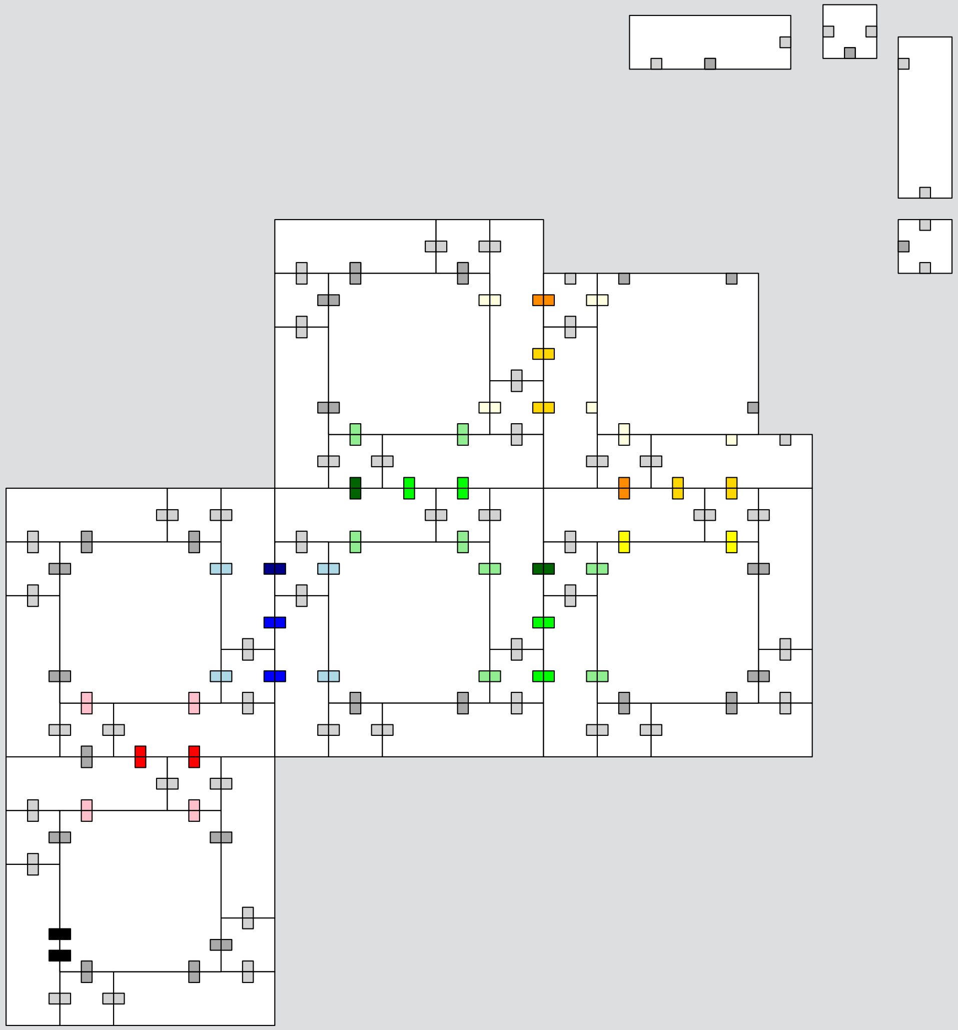


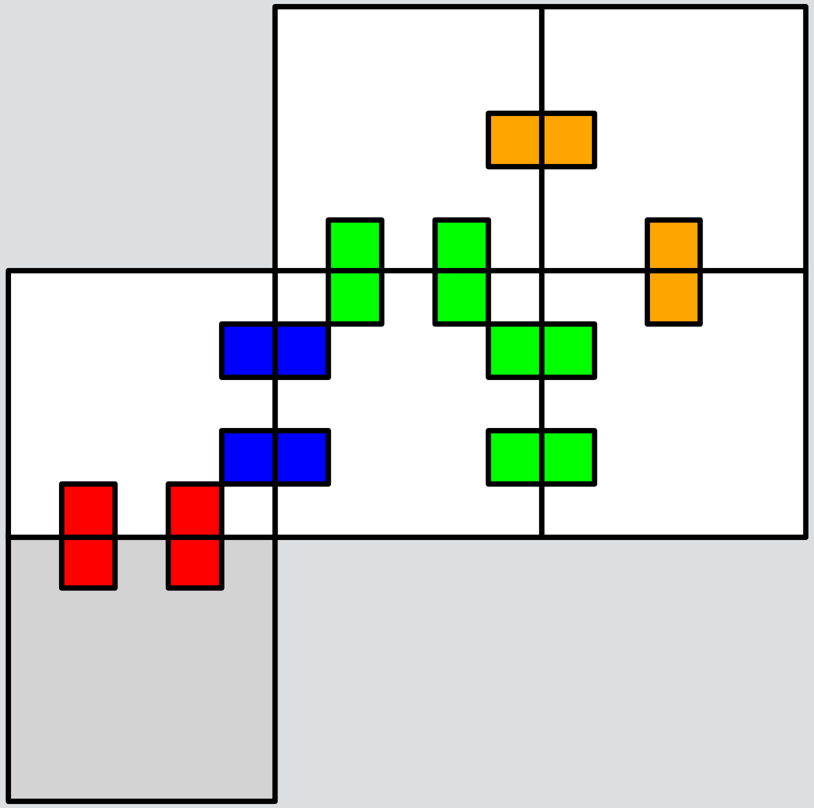
aTAM

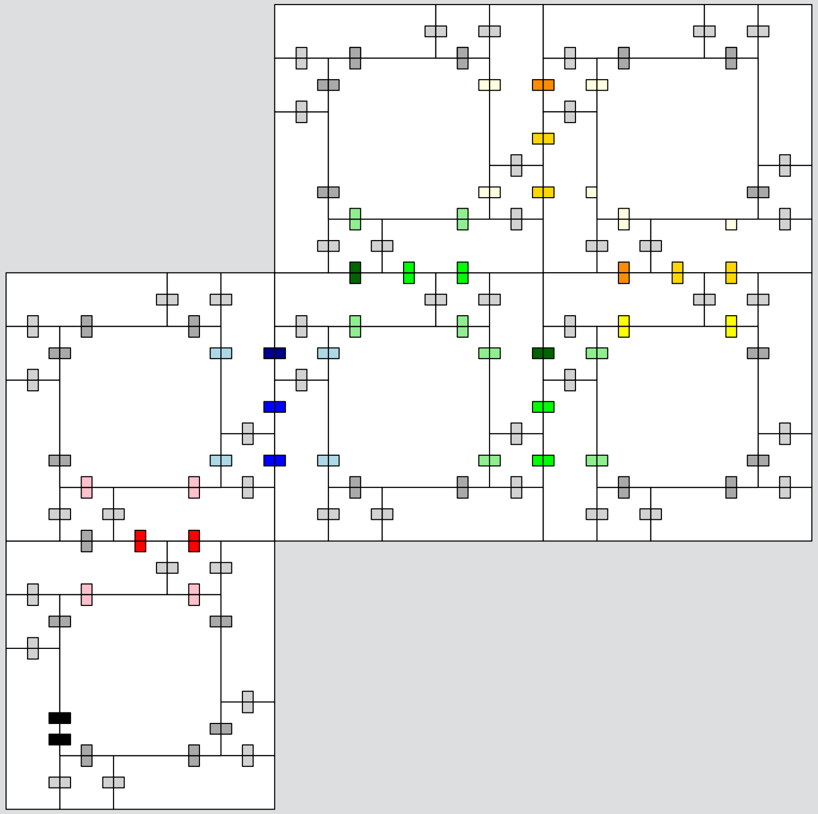


2HAM

Temperature 2

Every aTAM system can be *simulated* by a 2HAM system. [Cannon et al. 2013]

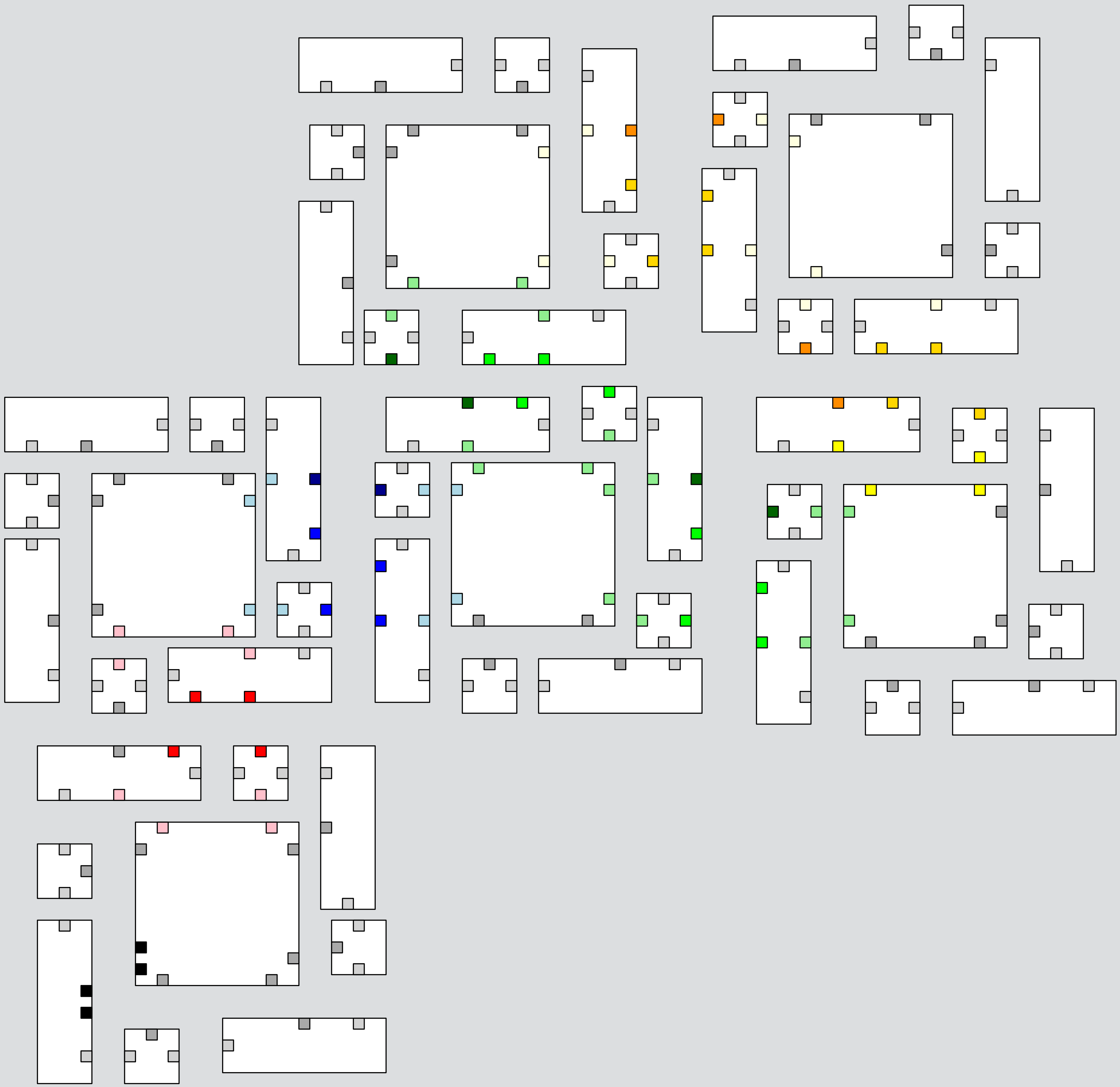




aTAM

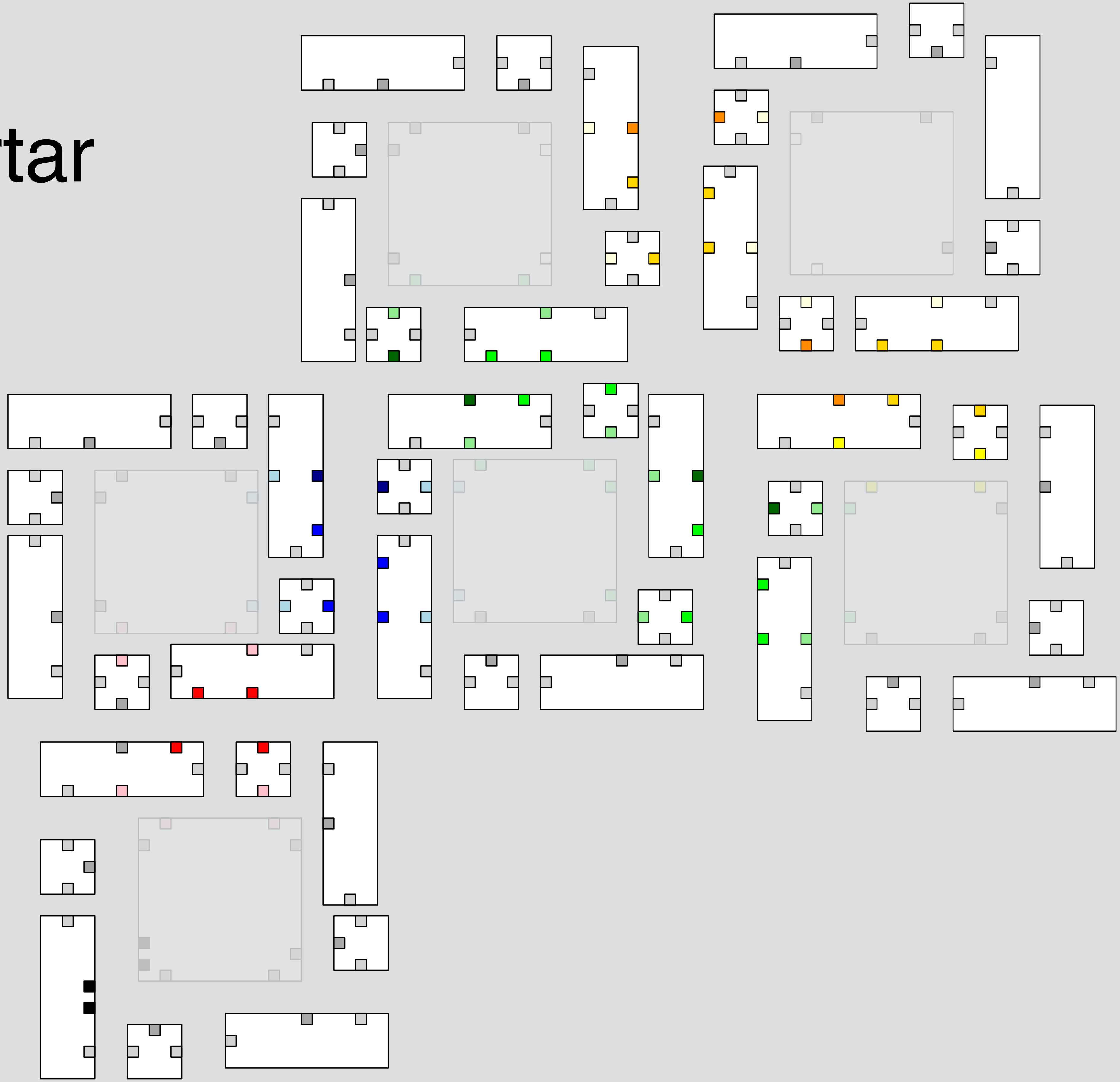
2HAM

Temperature 2



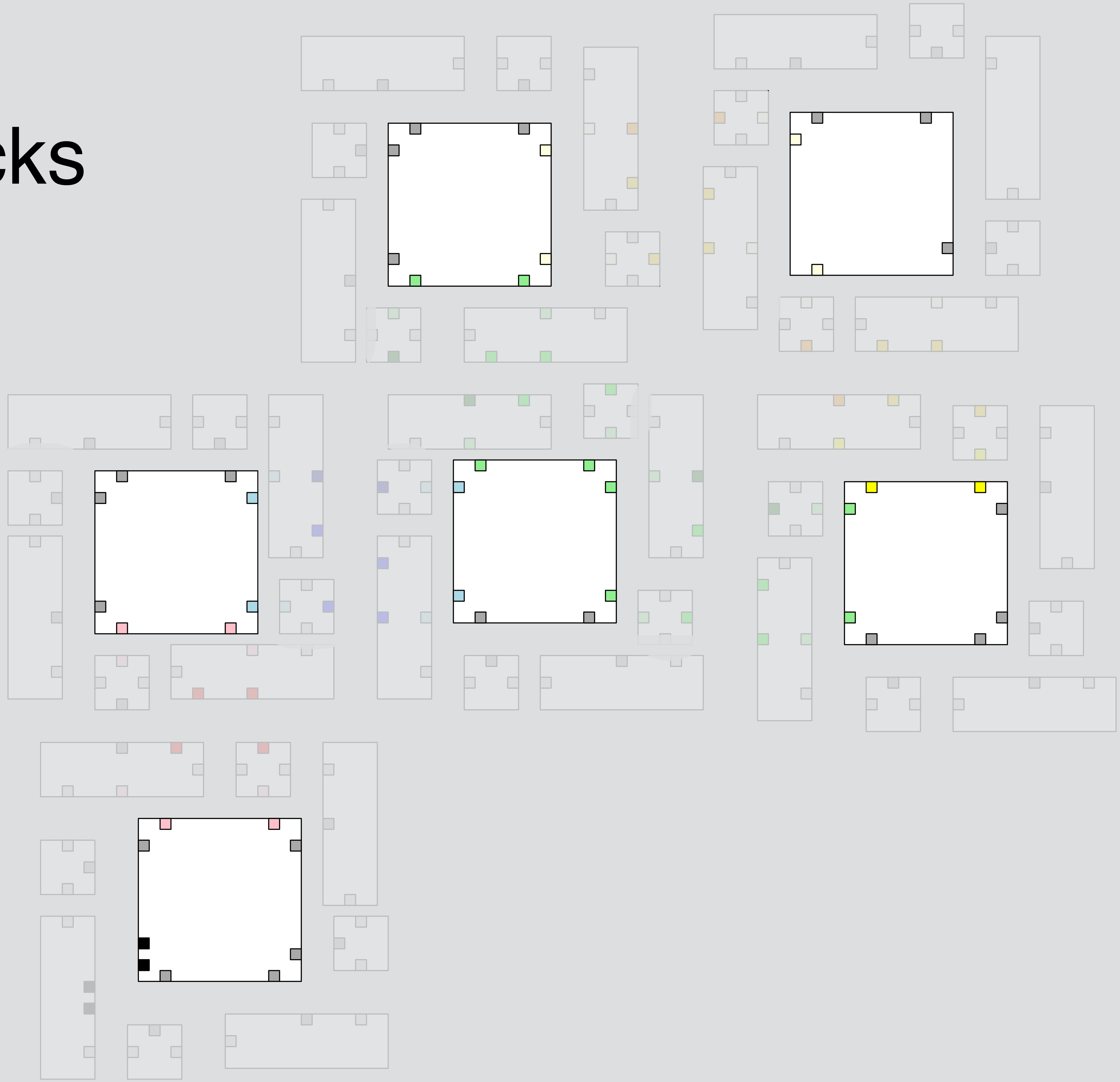
Temperature 2

Mortar

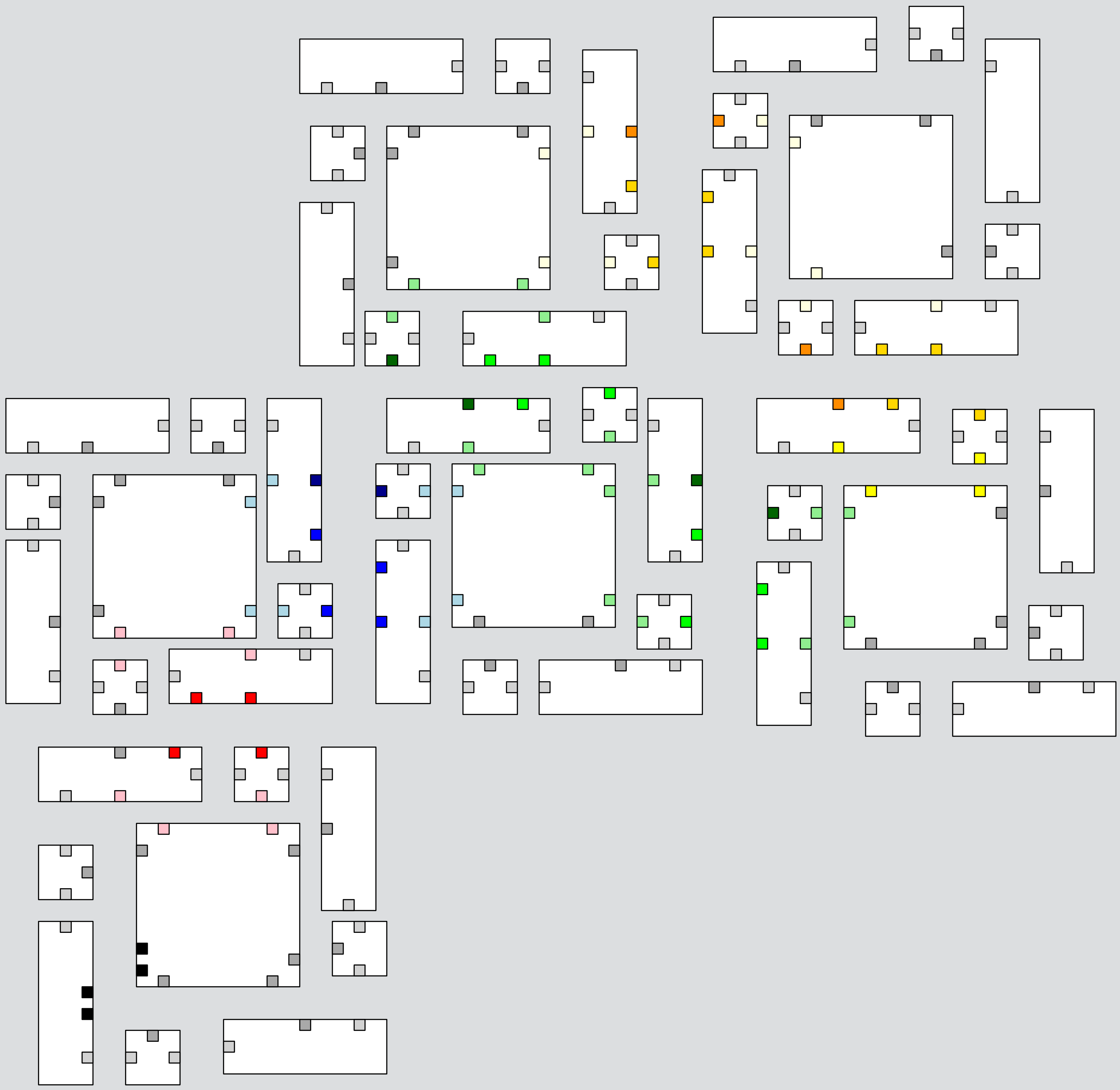


Temperature 2

Bricks



Temperature 2



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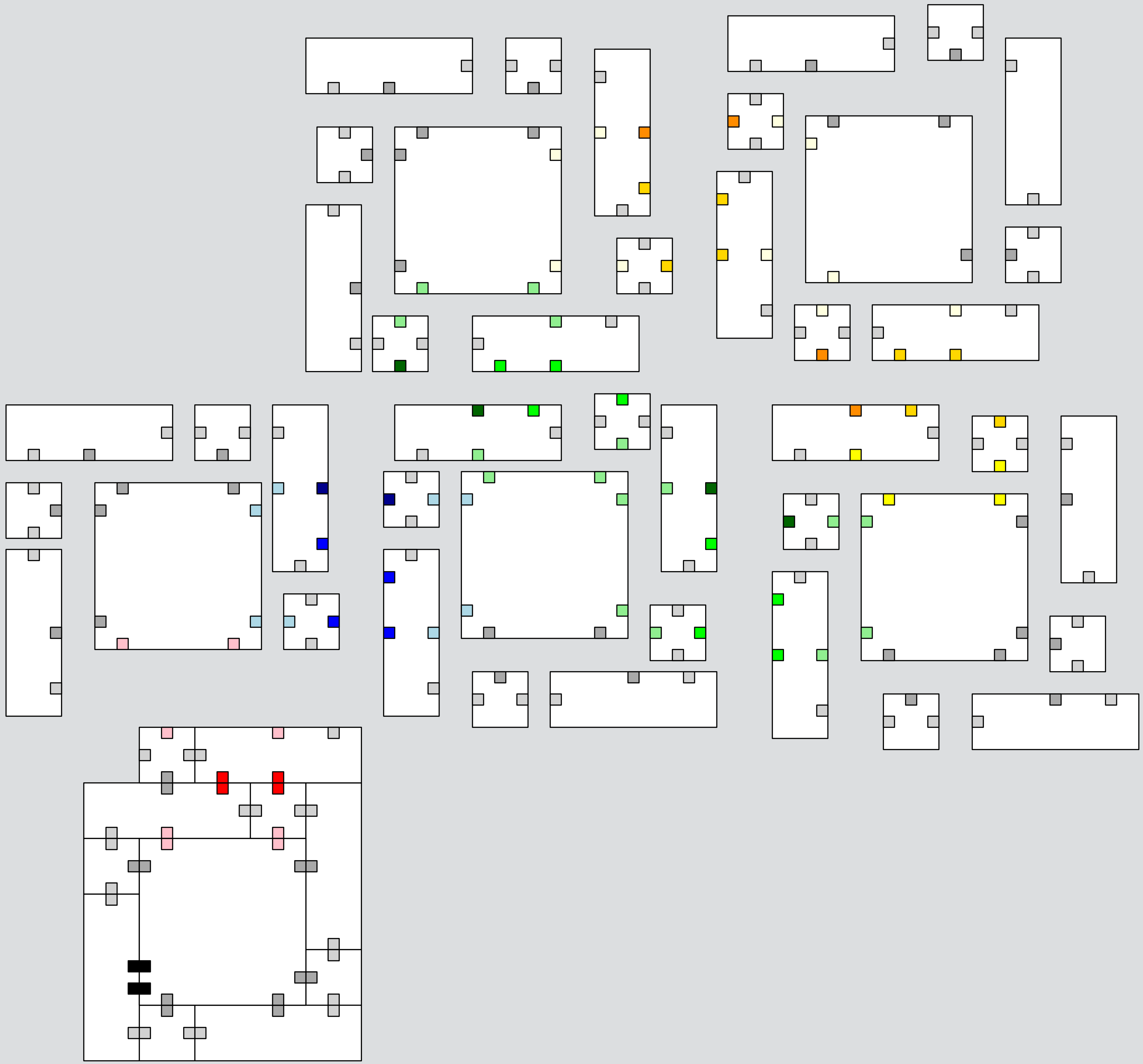

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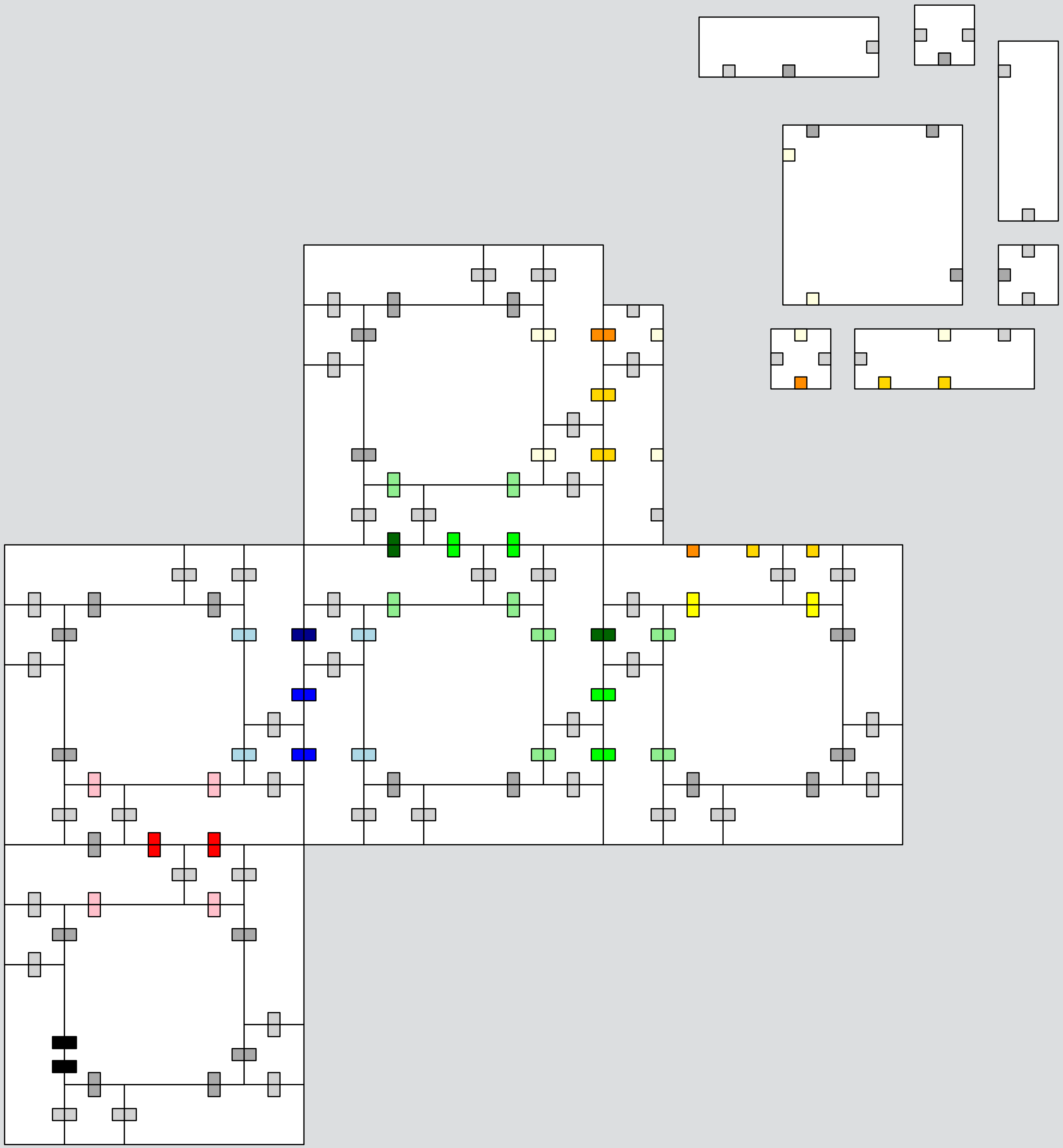

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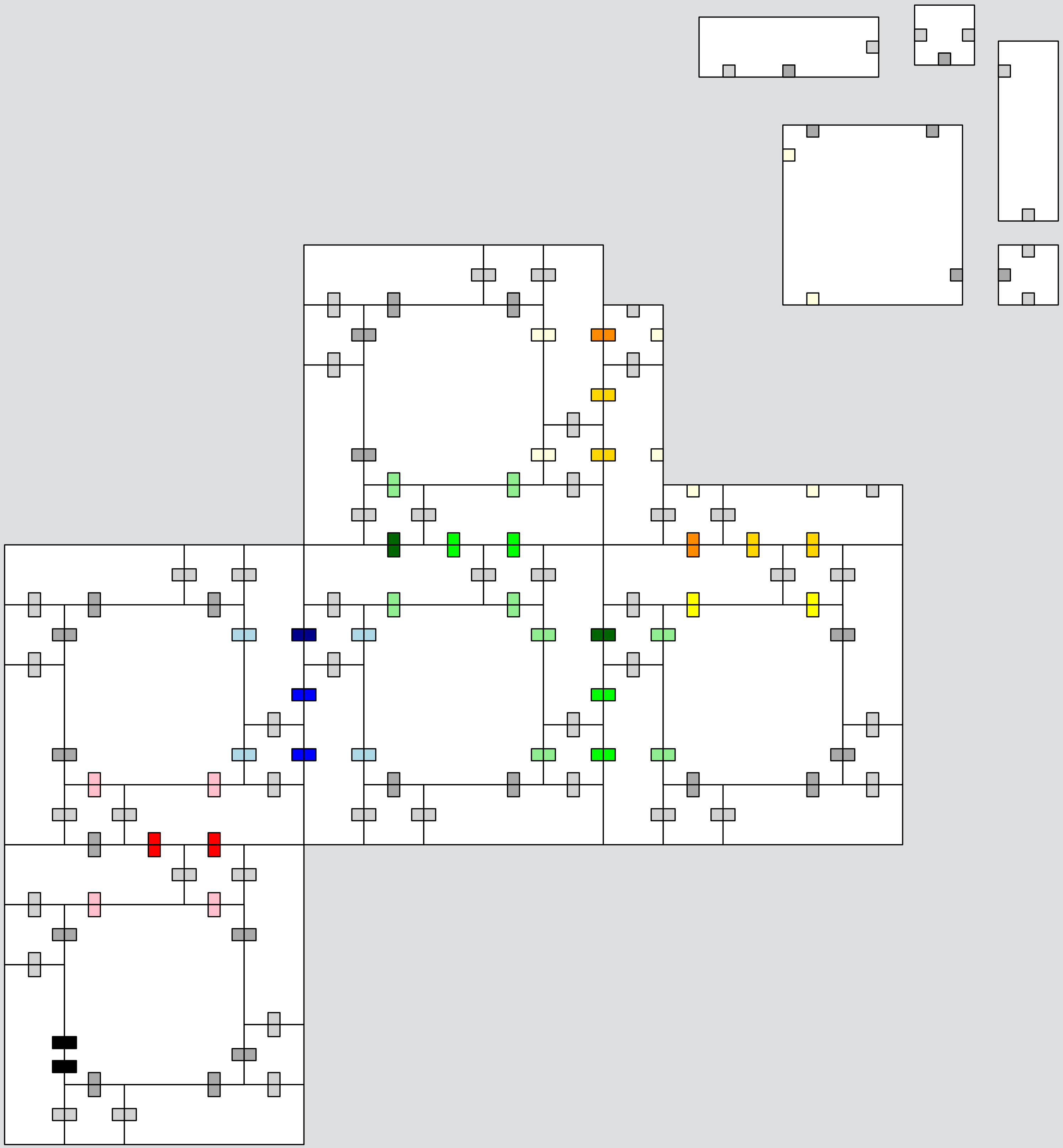

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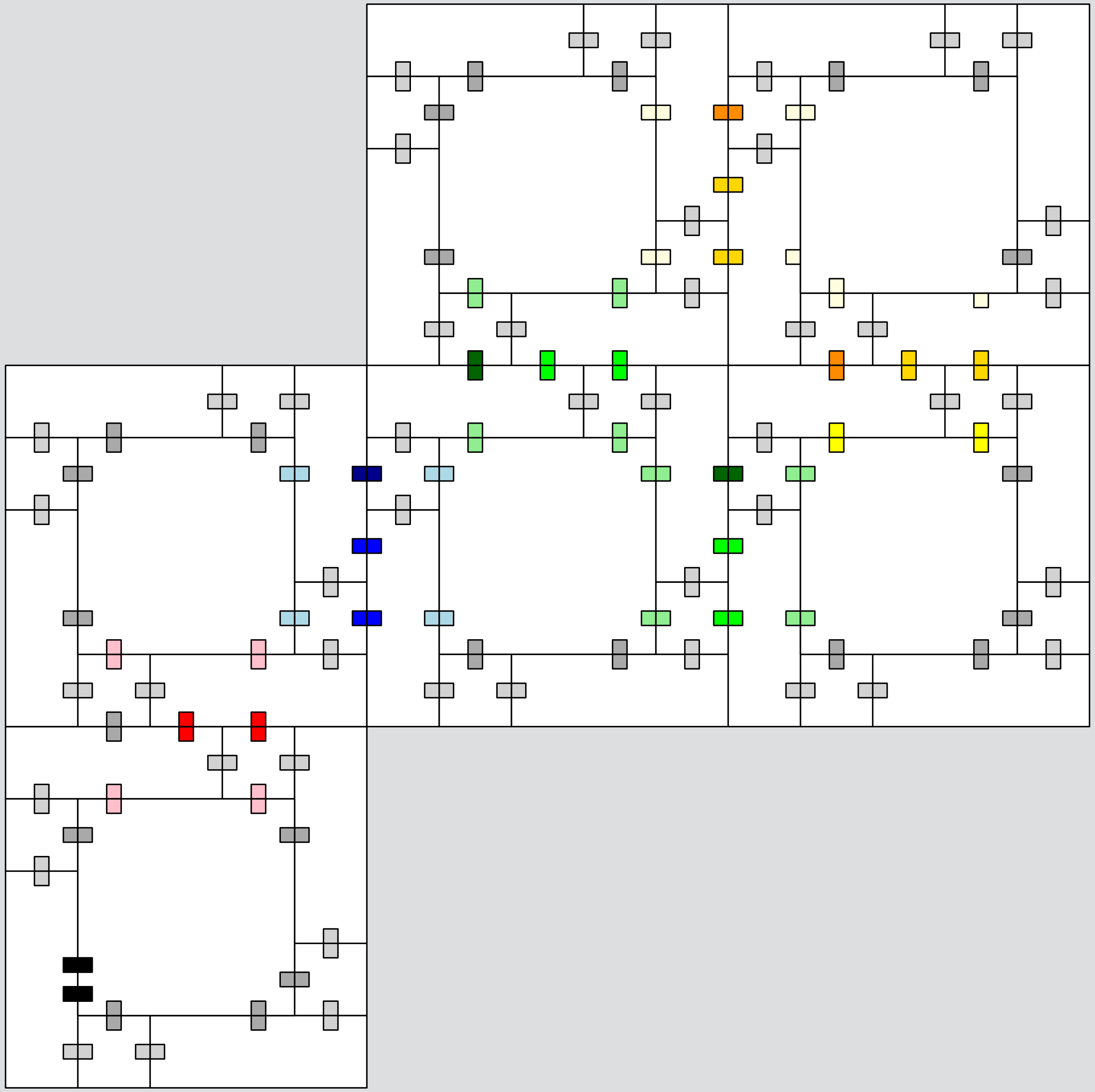

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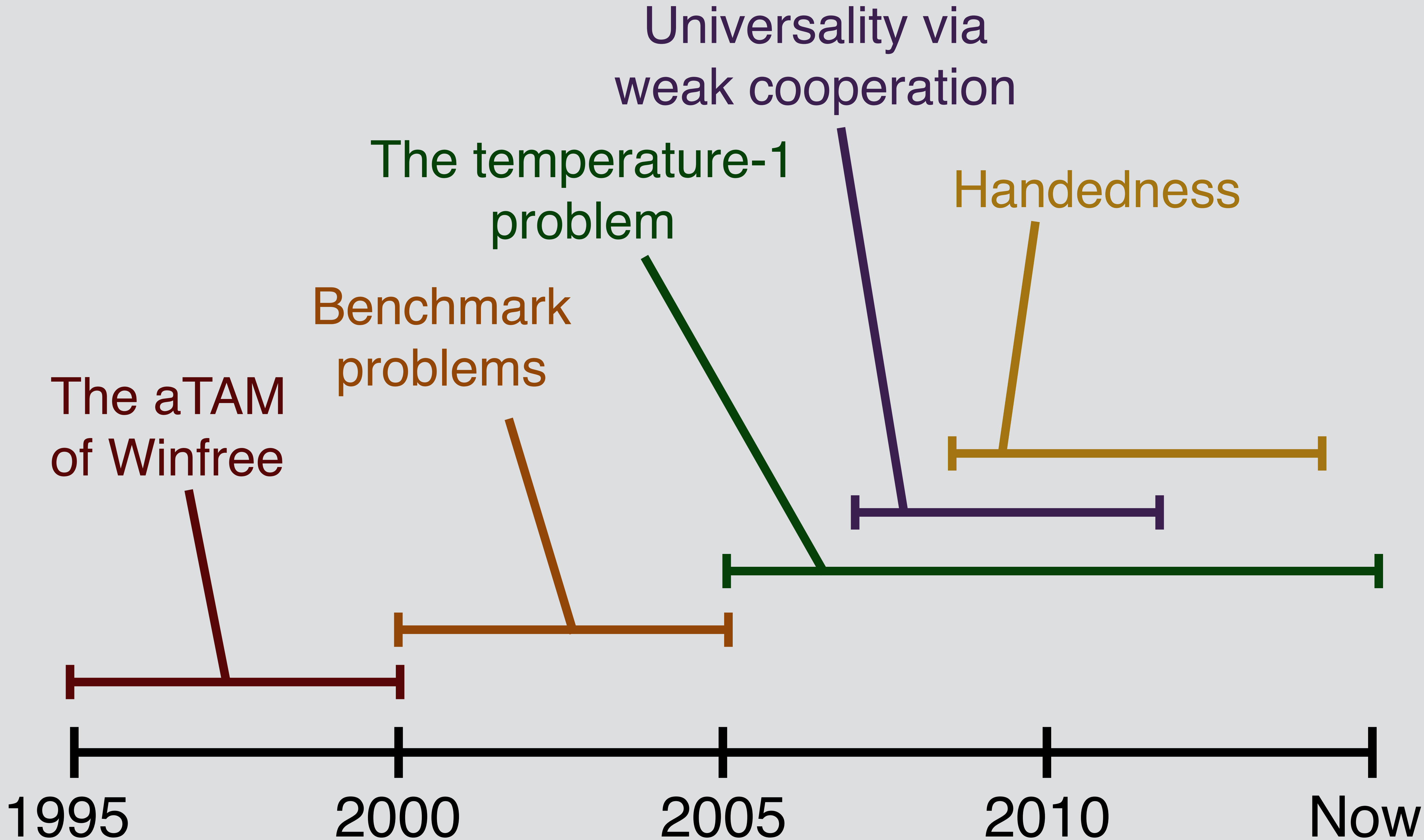
Universality via
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Handedness
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1995
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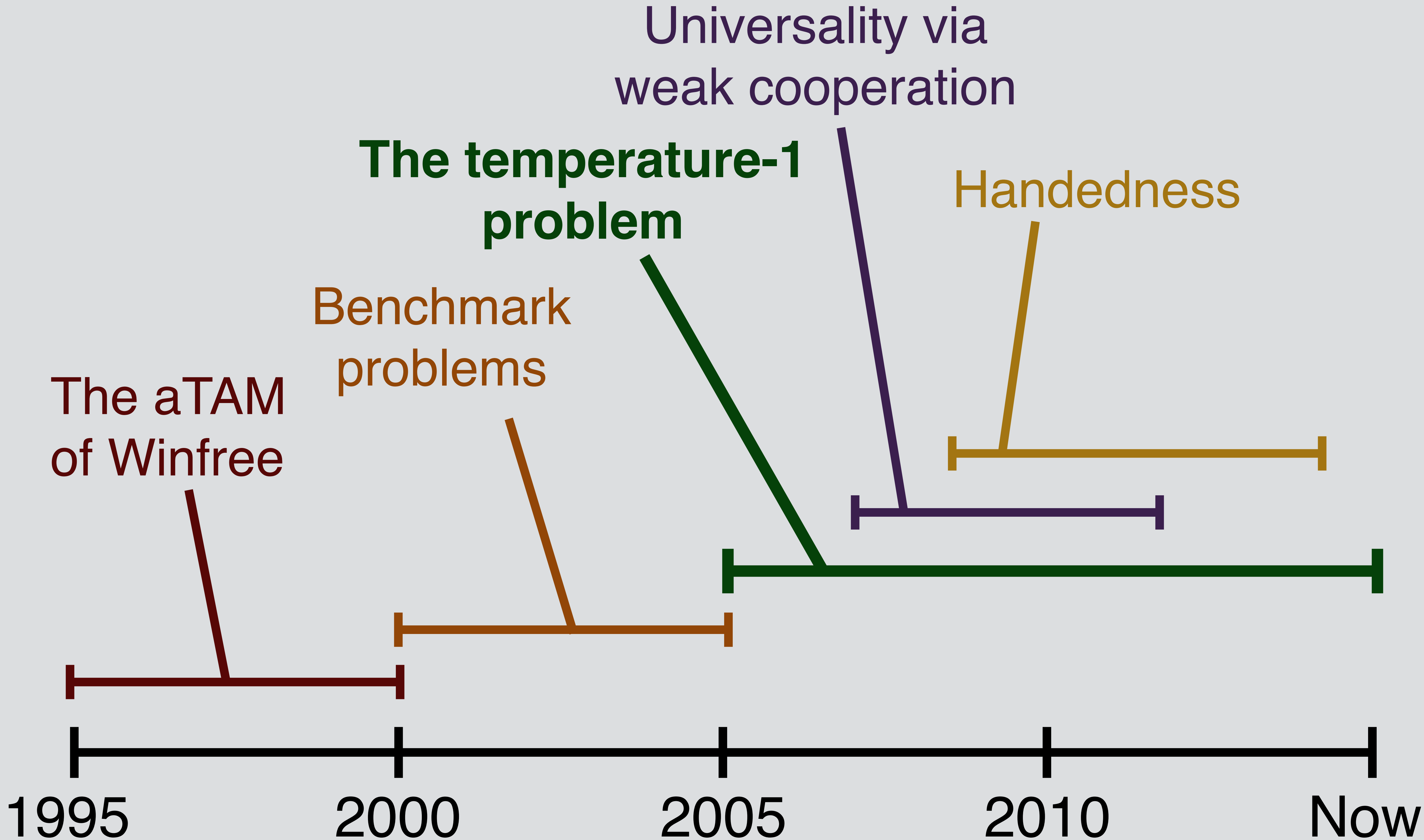
Now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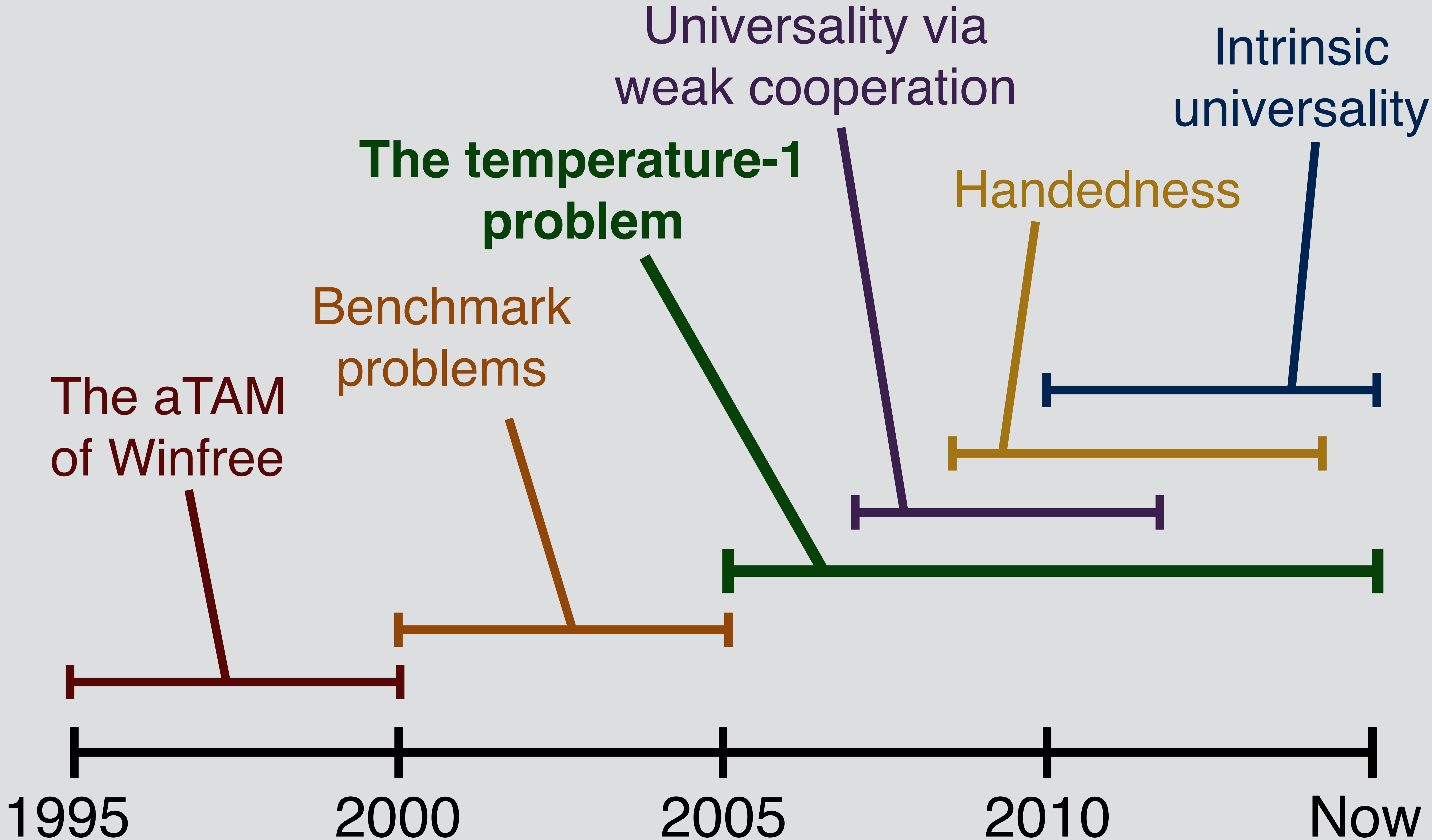
Universality via
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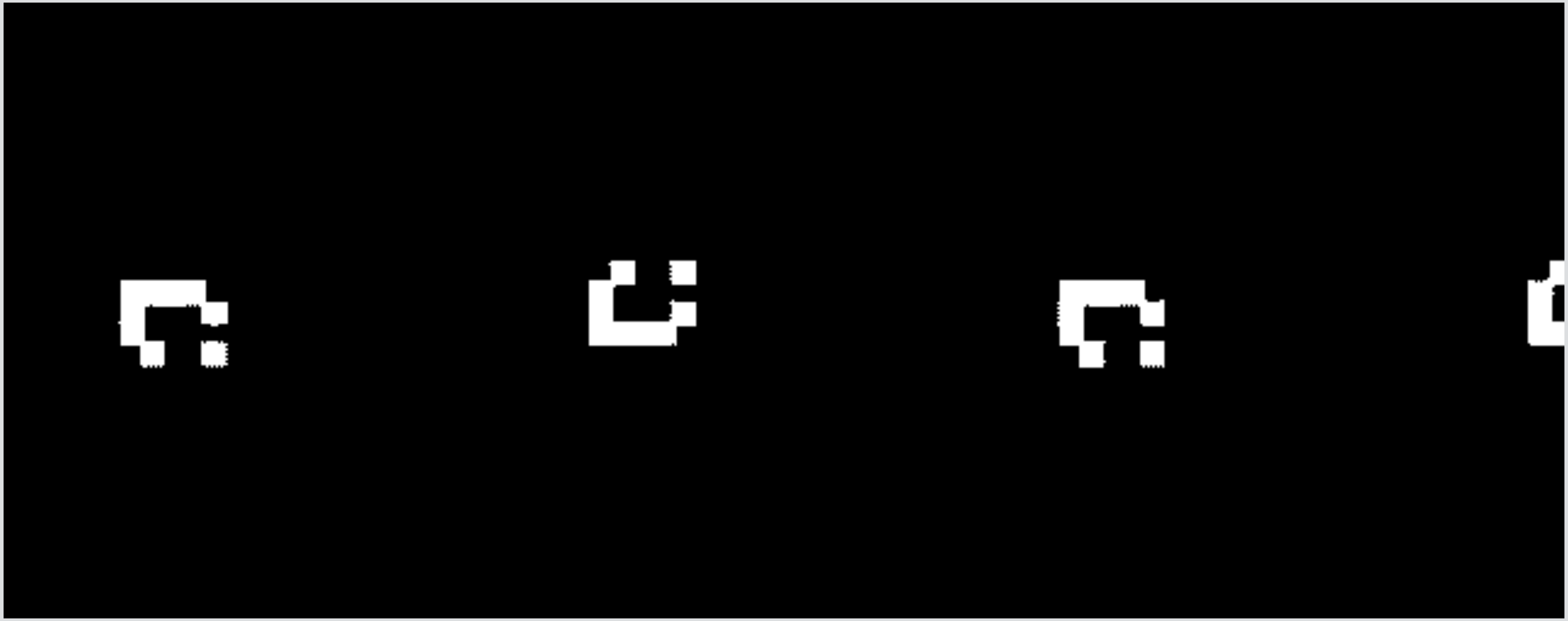
Intrinsic universality

In cellular automata:



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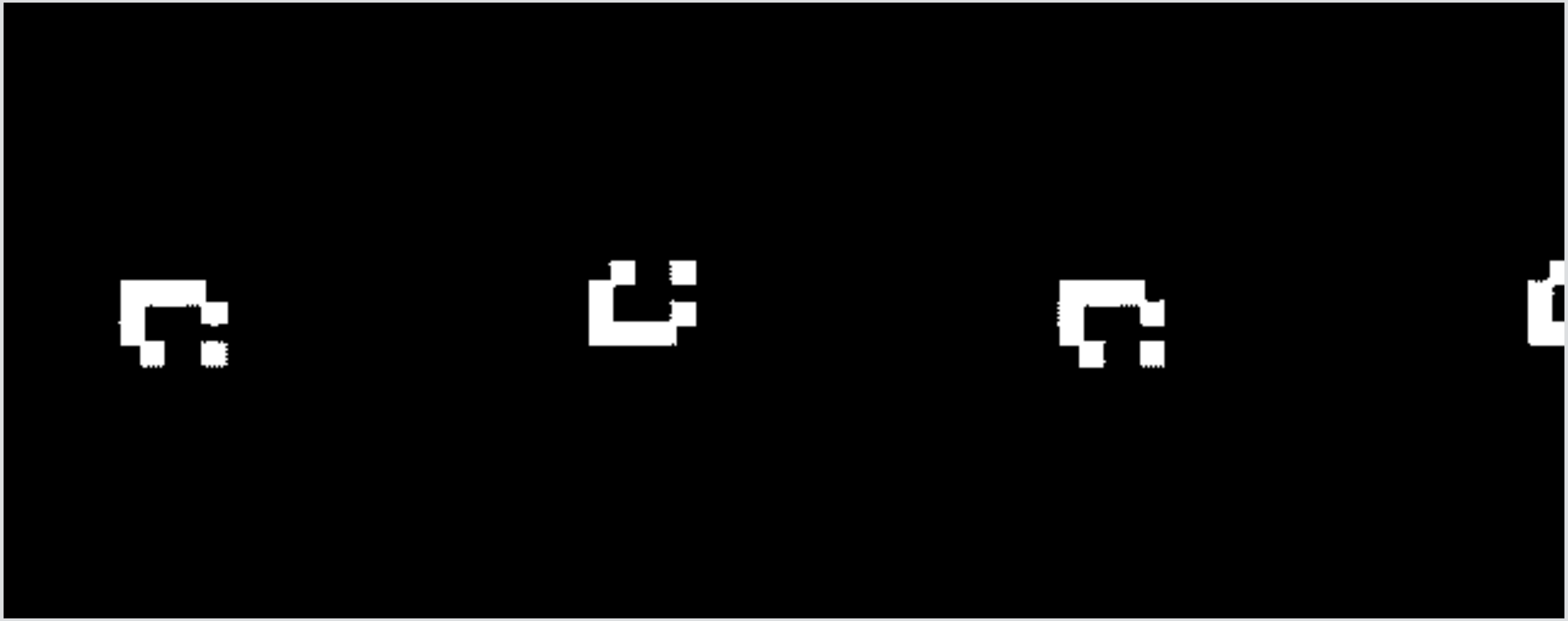

State of aTAM computation:

(circa 2008)

Temperature-1 universal computation is open.

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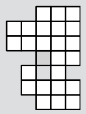
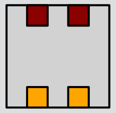
Claim: temp-1 is *intrinsically universal* for temp-2.

Simulation: same behavior (with scale and fuzz)

 ⇔ 

Temperature 1 Temperature 2

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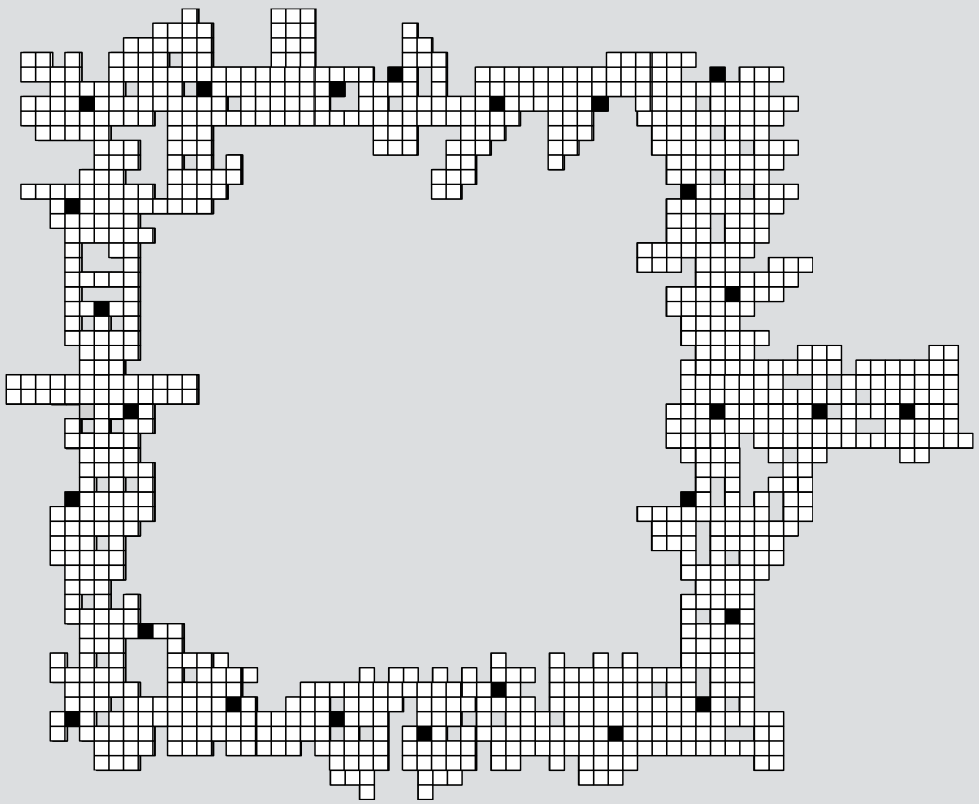
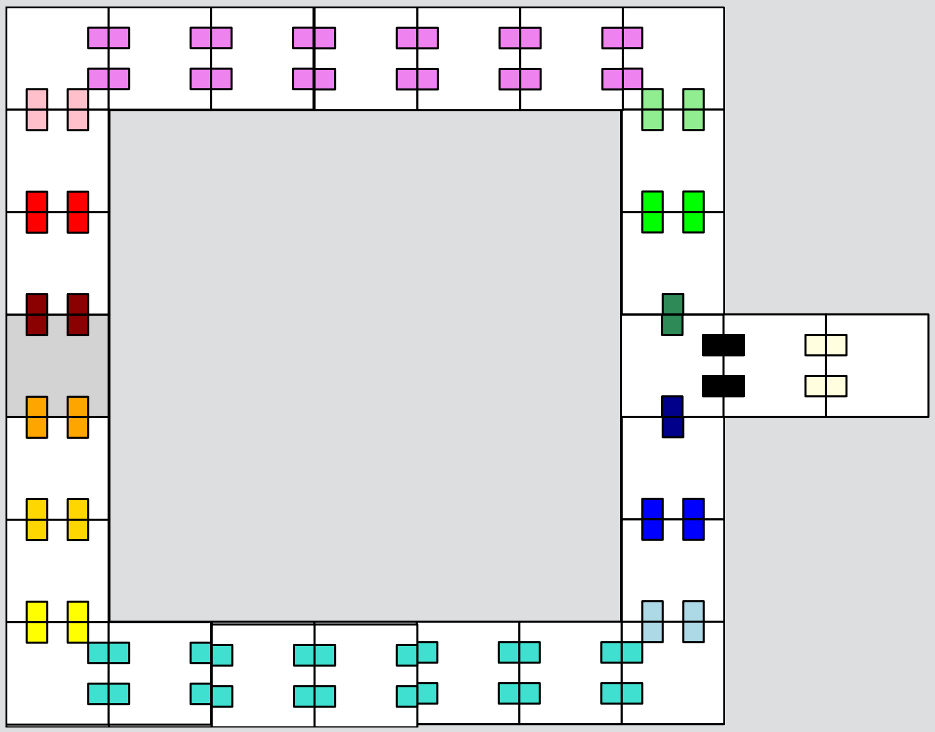


Temperature 1

⇔



Temperature 2

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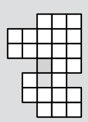
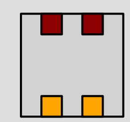
 ⇔ 

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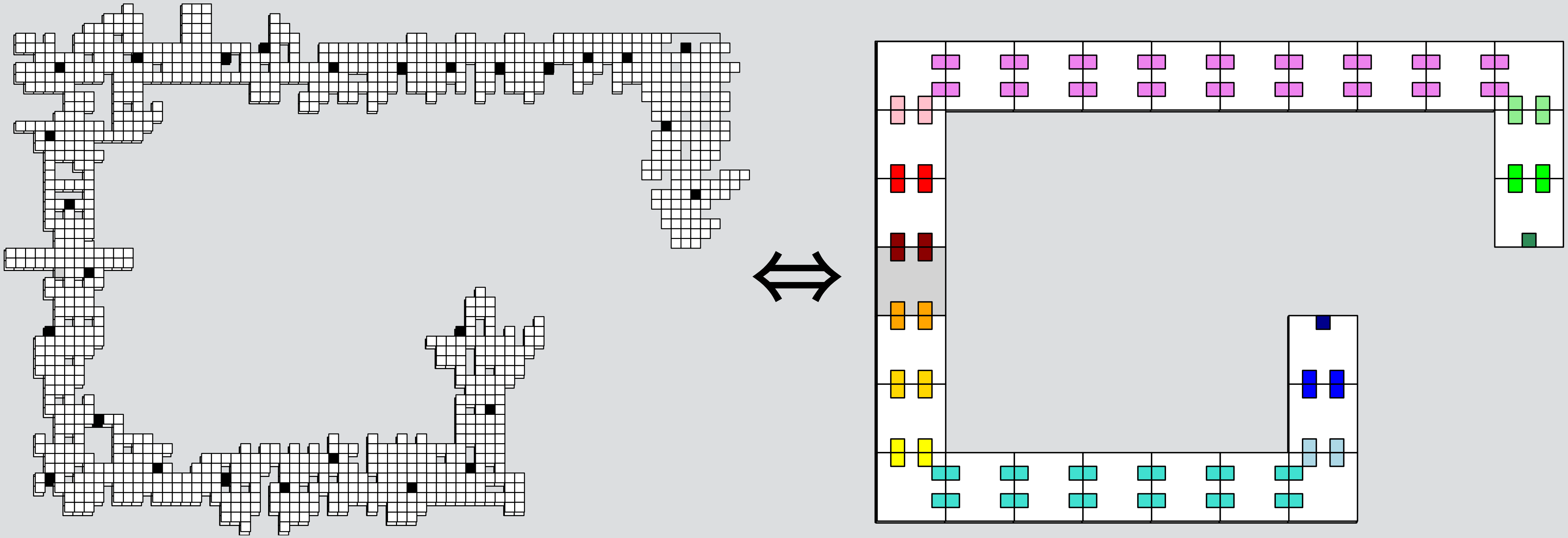

Temperature 1 Temperature 2

Is intrinsic universality too much to ask?

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No: temp-2 is intrinsically universal for all temps.
[Doty et al. 2012]

There exists a temp-2 system that
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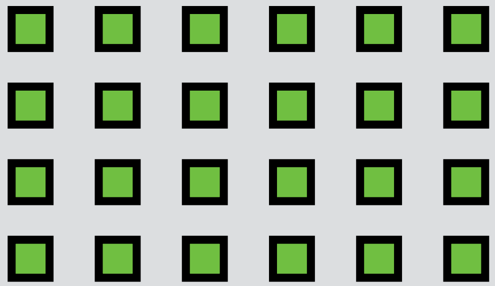

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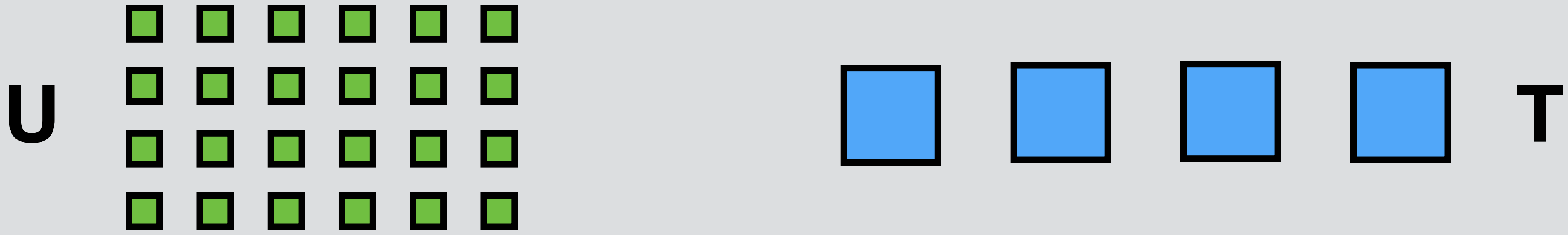

Temperature 2

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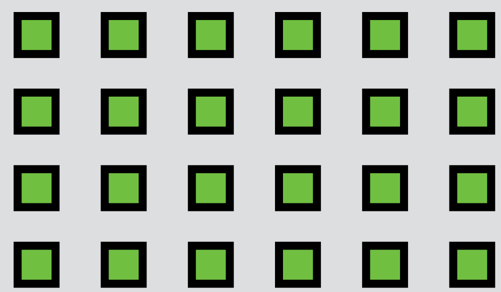
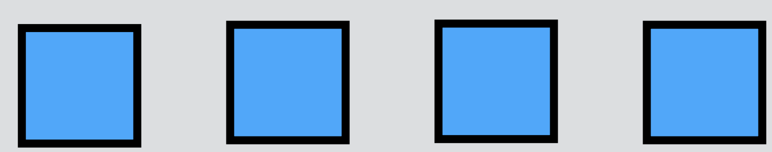
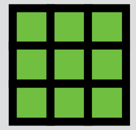
U 

 T



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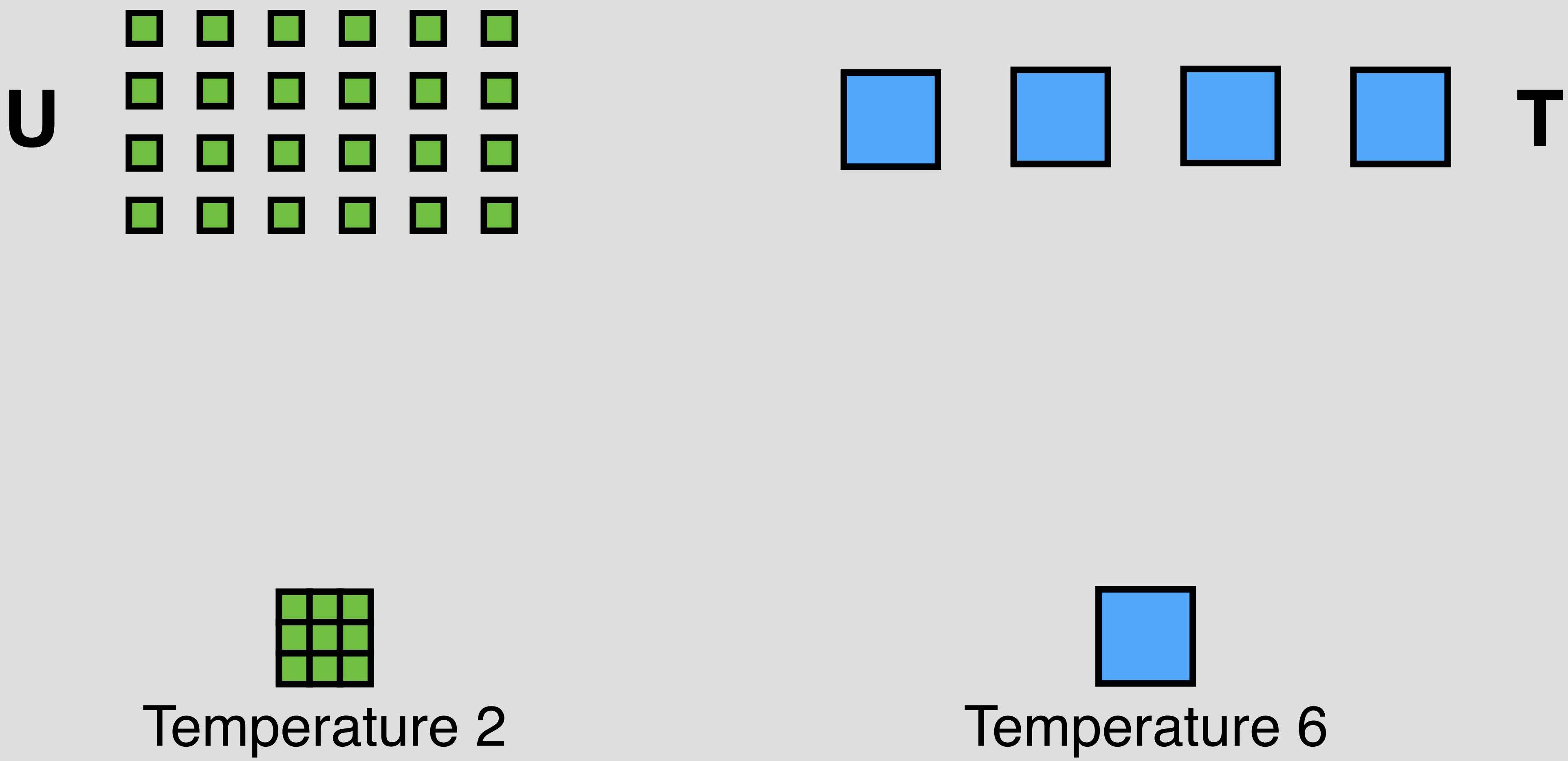

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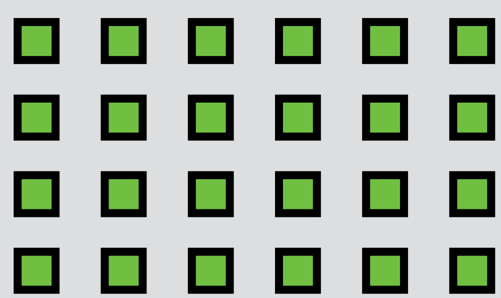

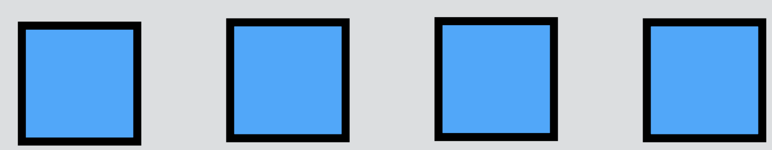

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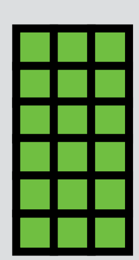

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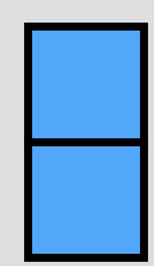

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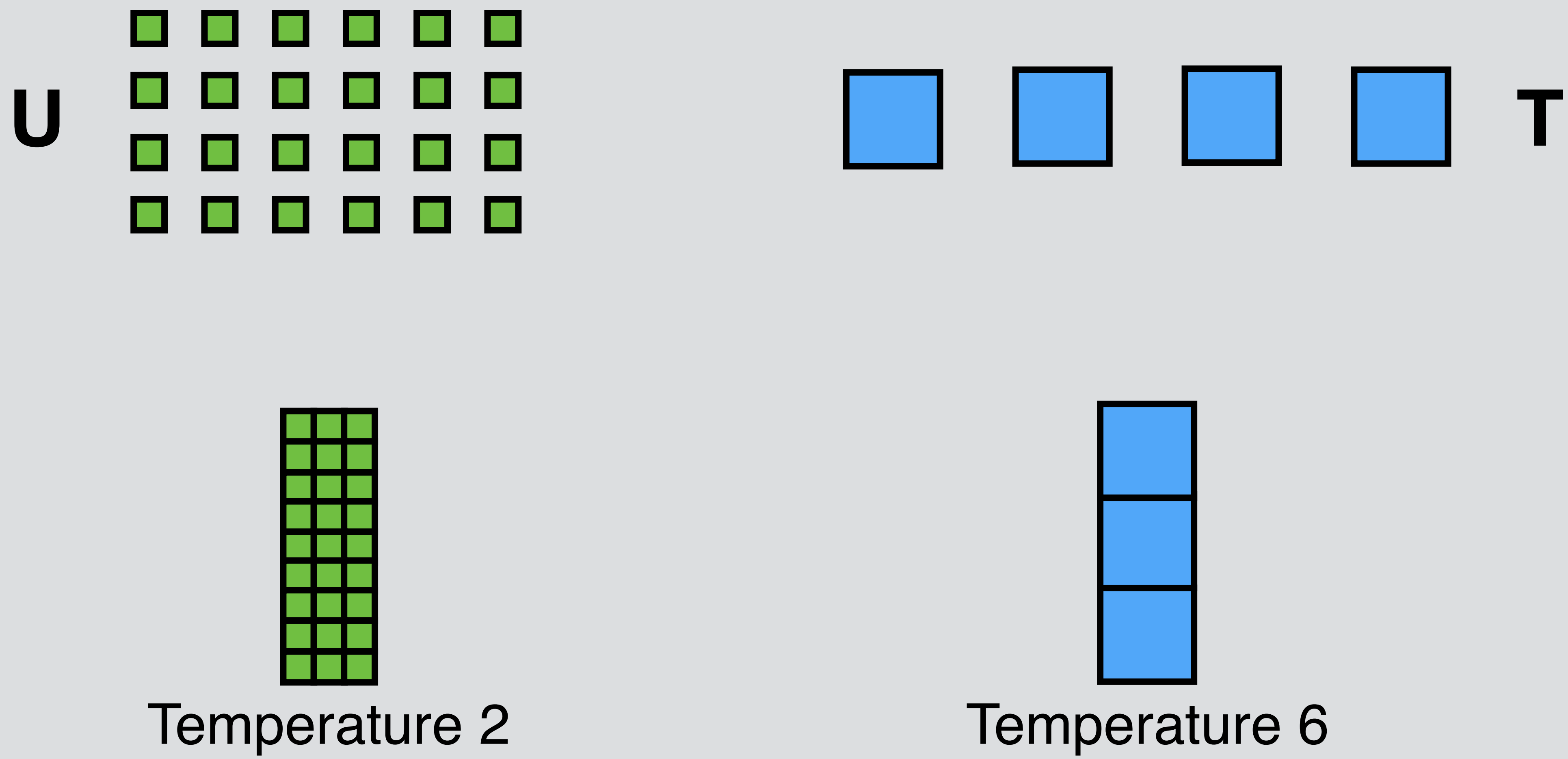

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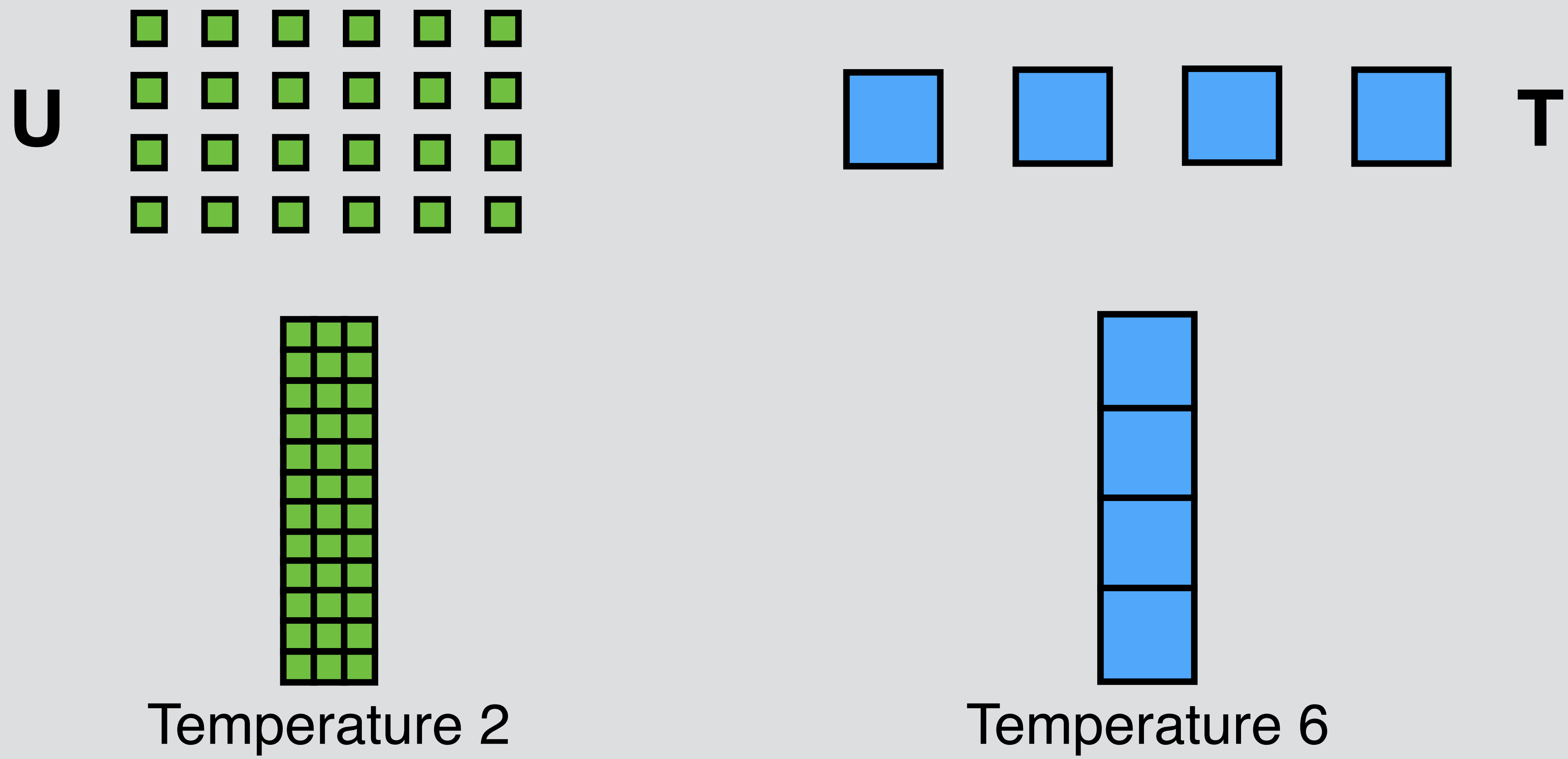

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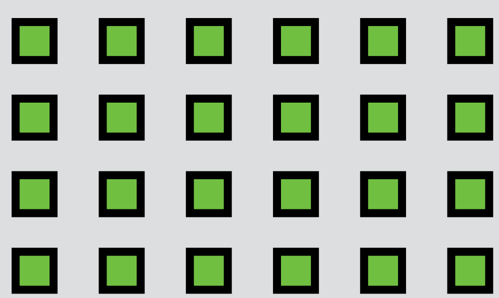

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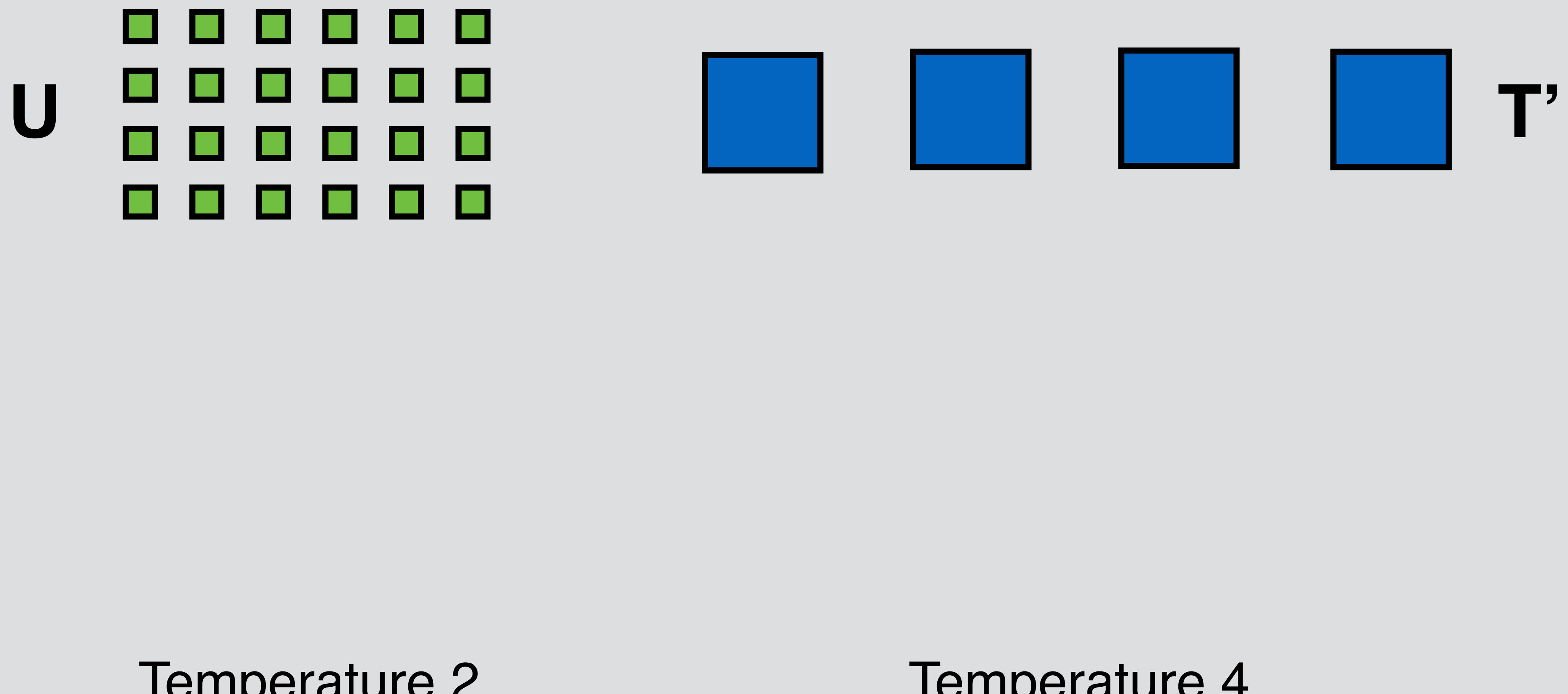

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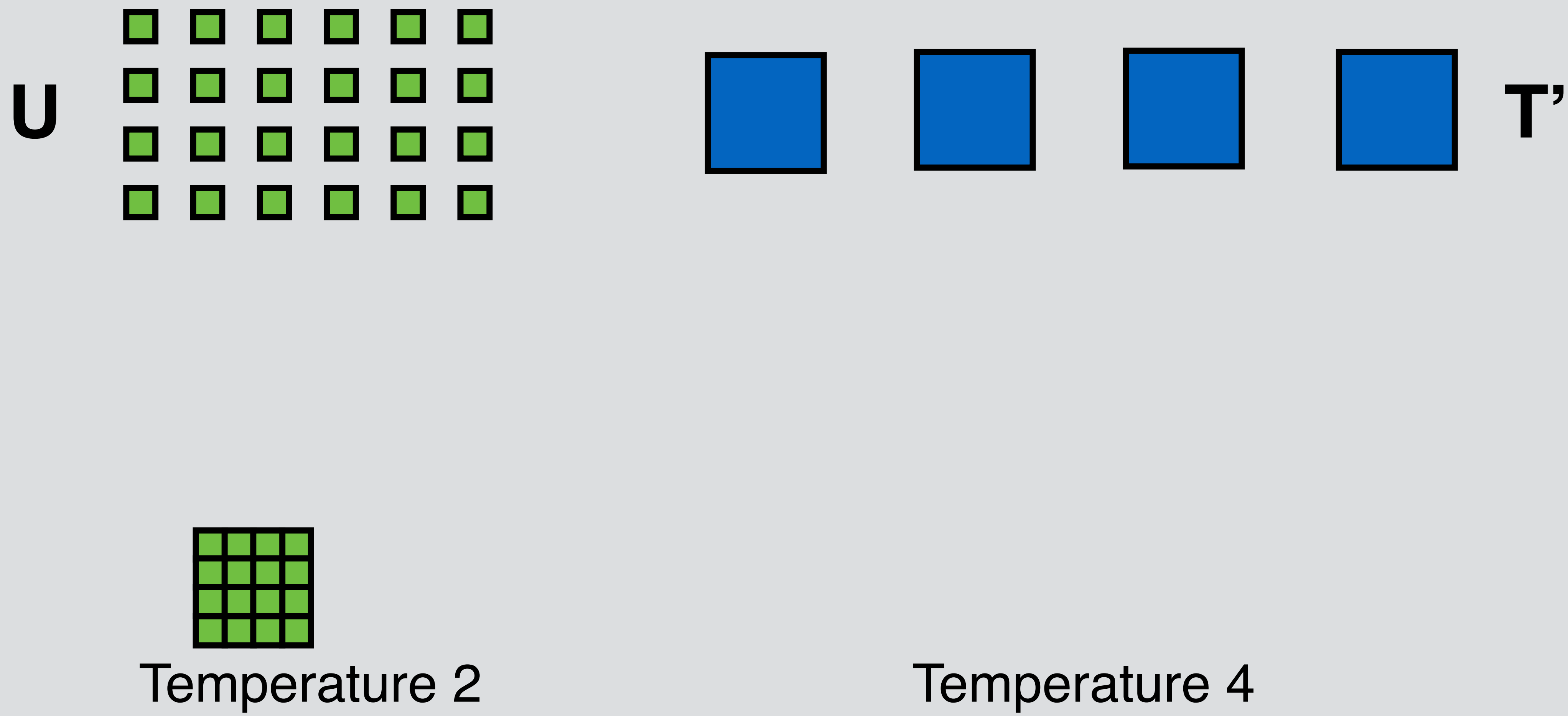

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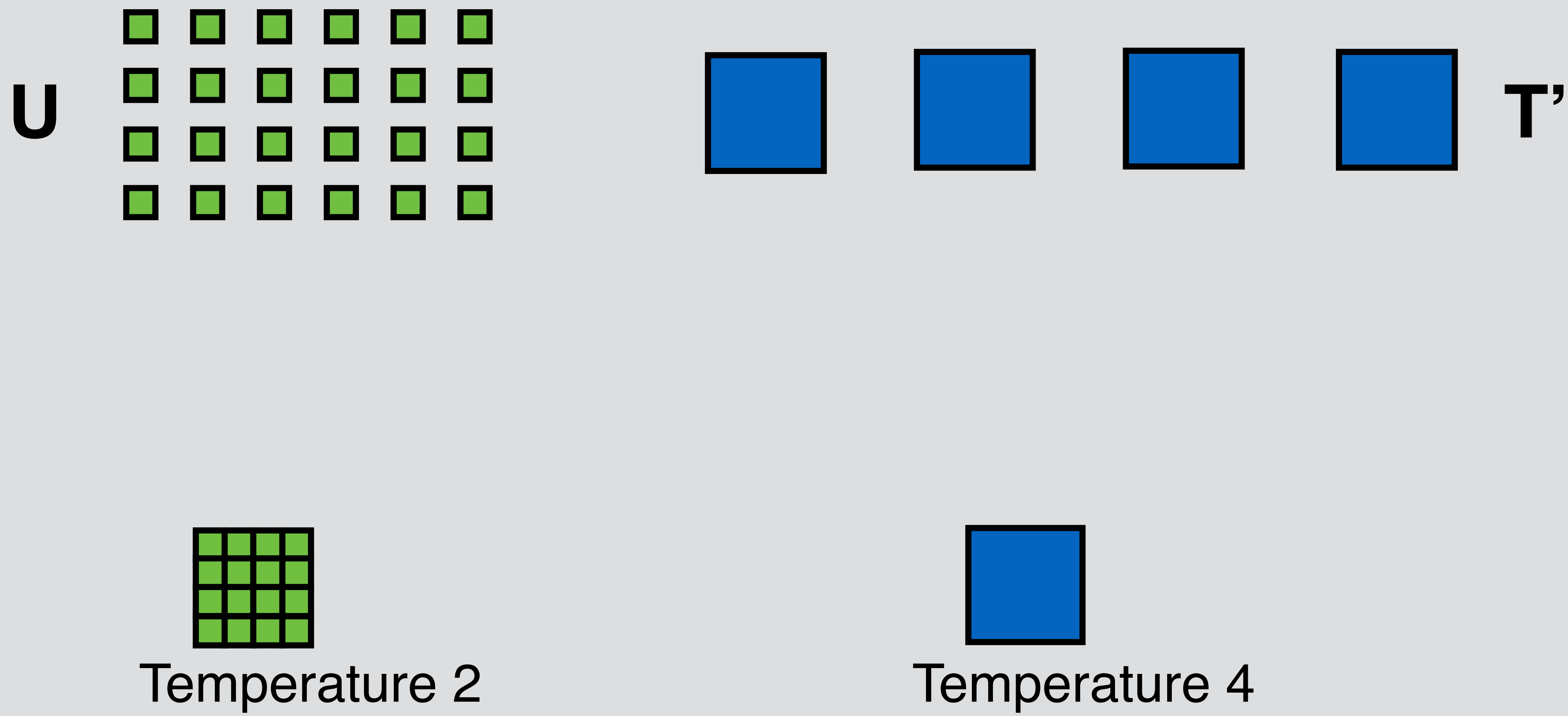

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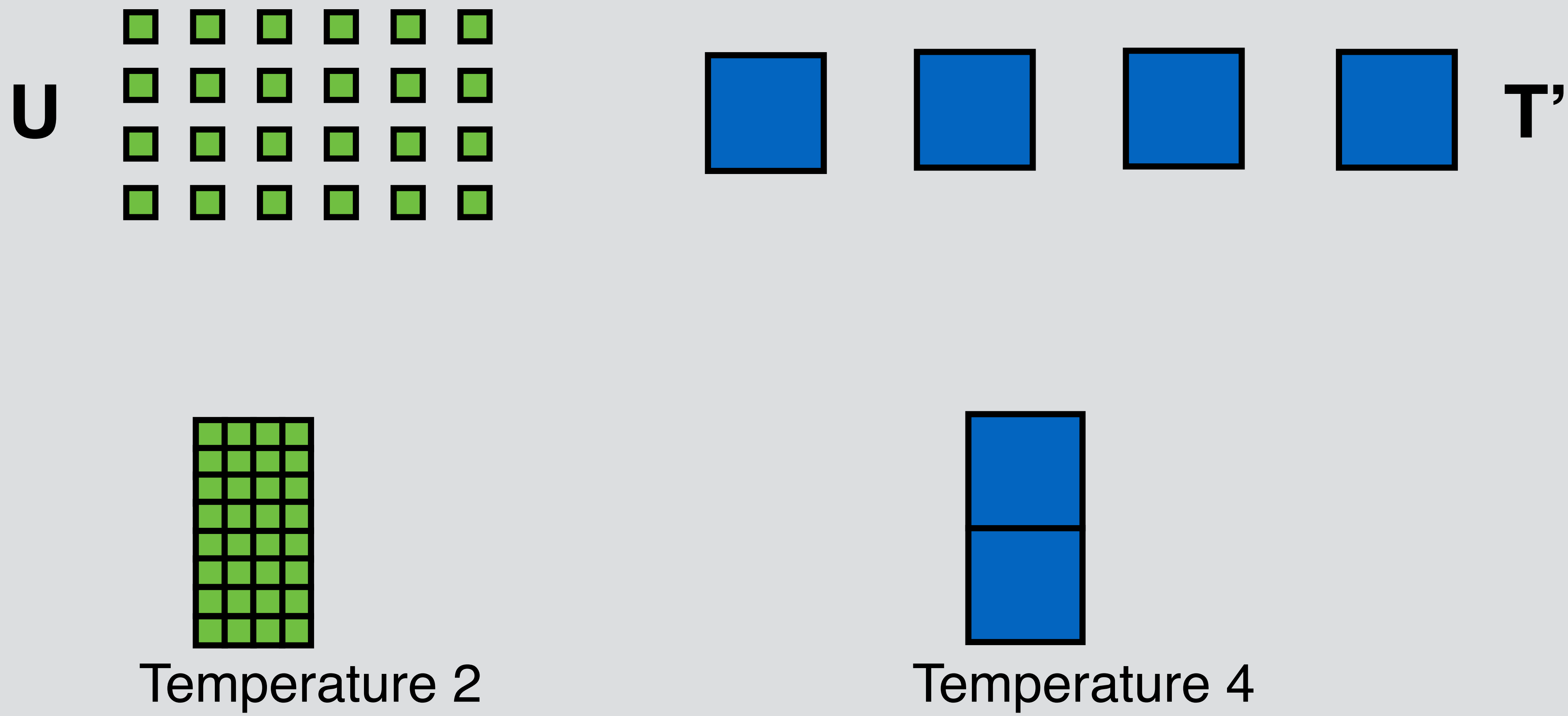

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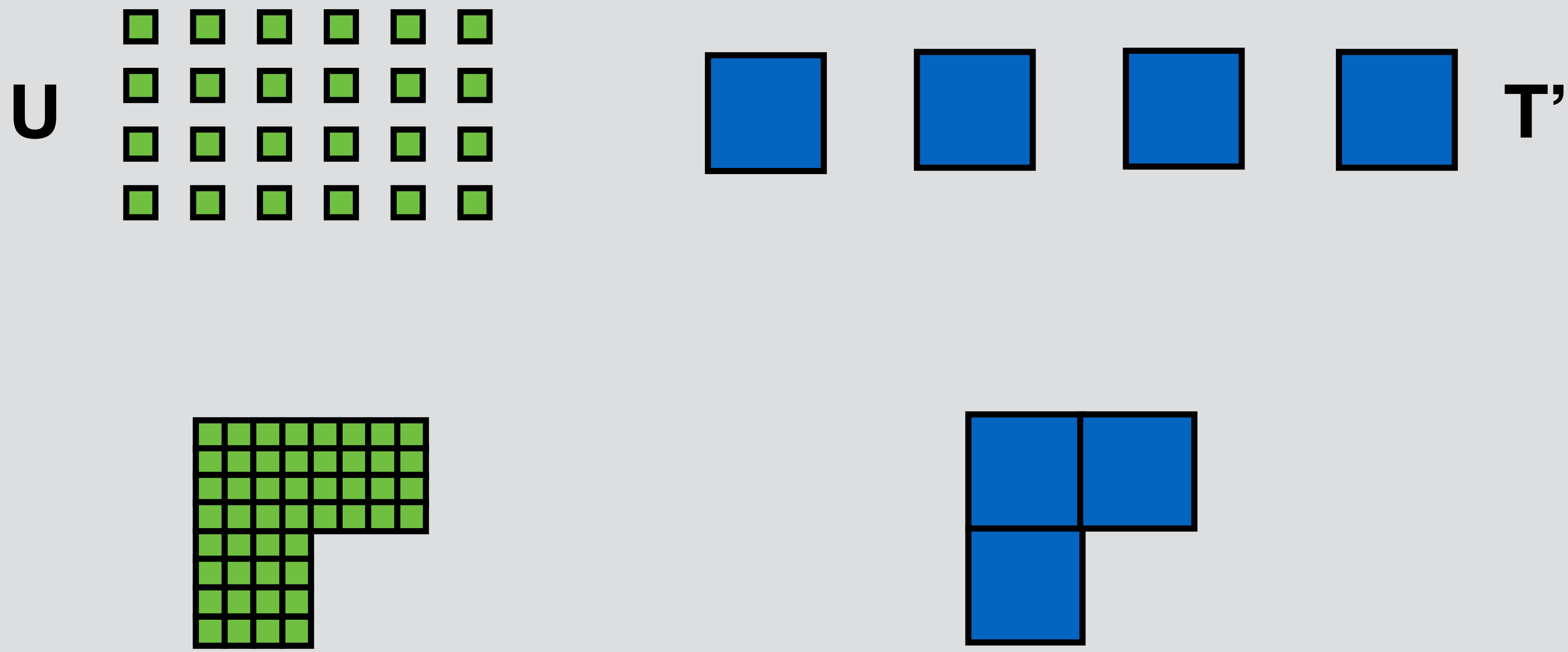

Temperature 2

Temperature 4

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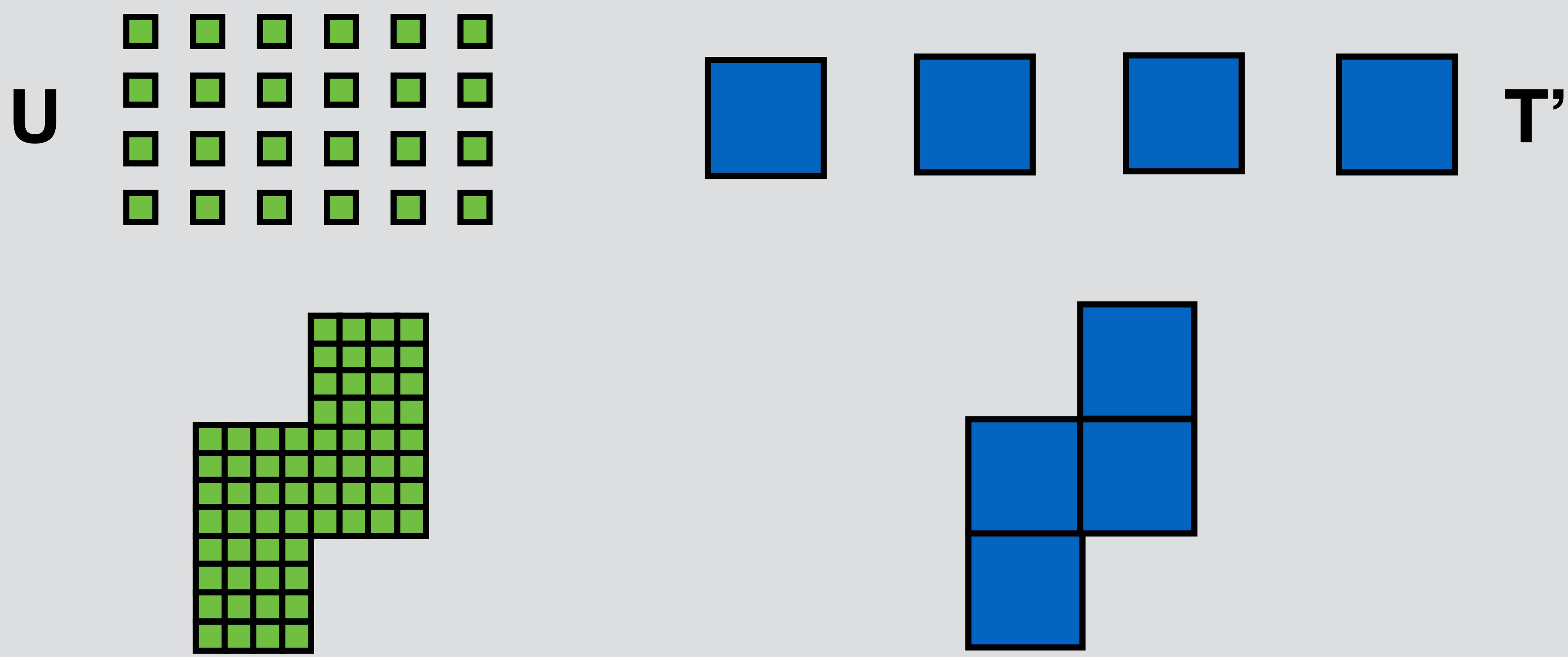


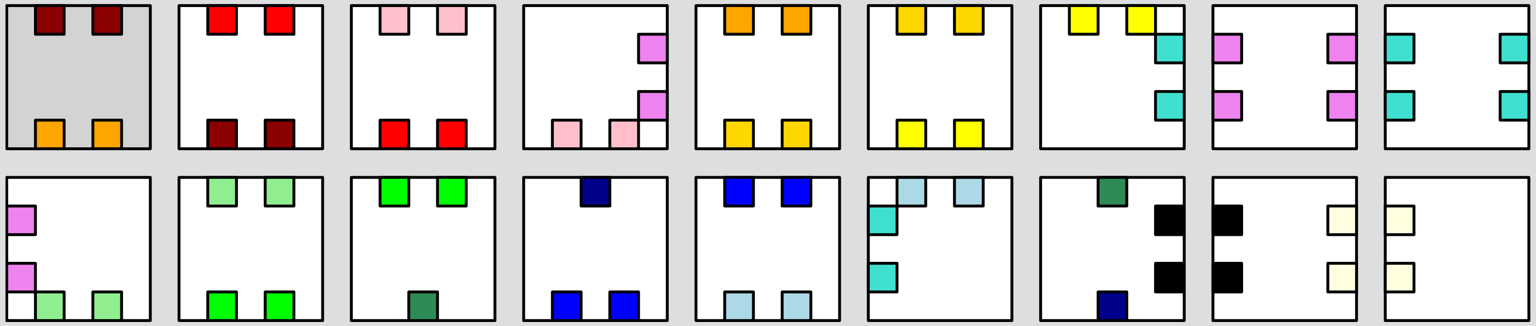
Temperature 2

Temperature 4

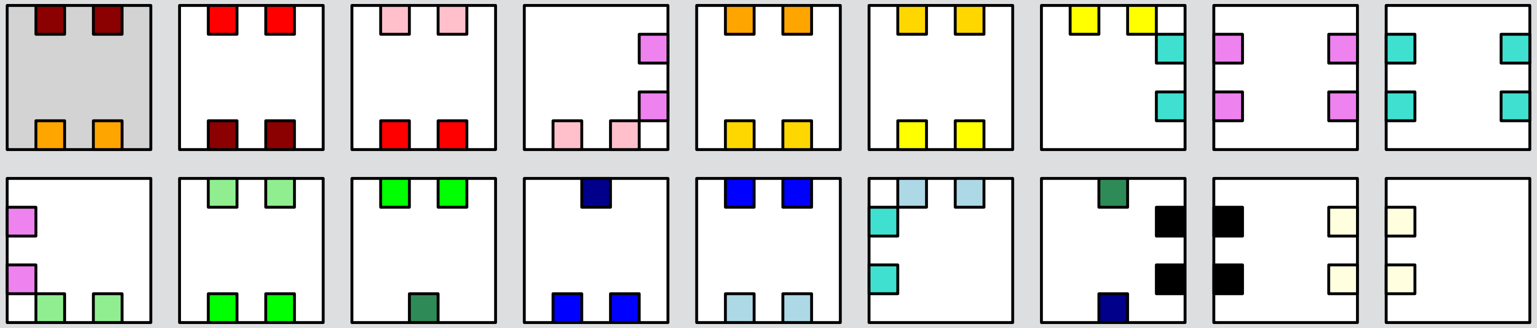
Claim: temp-1 is *intrinsically universal* for temp-2.

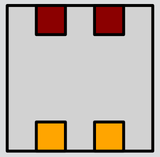
~~Claim: temp-1 is *intrinsically universal* for temp-2.~~

There is a temp-2 system
not simulated by any temp-1 system.

Specifically: 

[Meunier et al. 2014]





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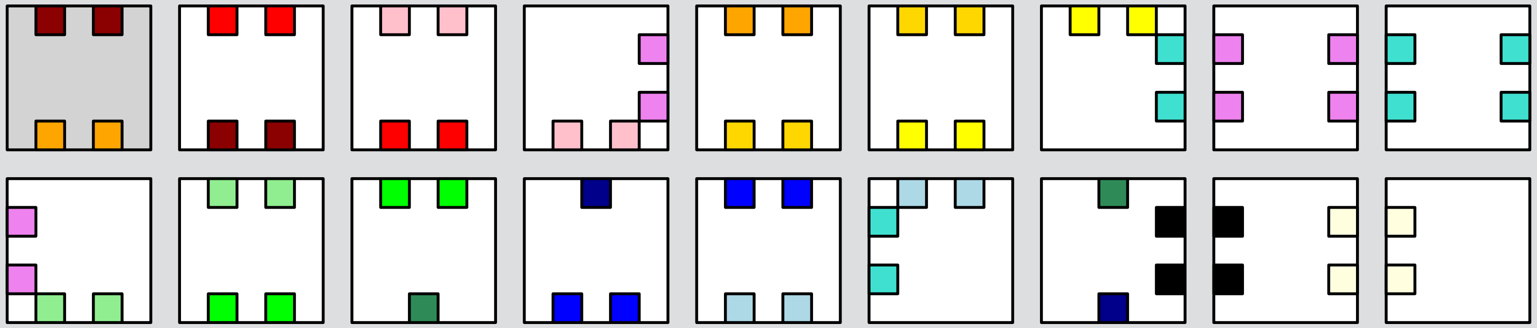

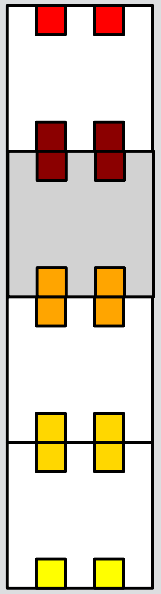

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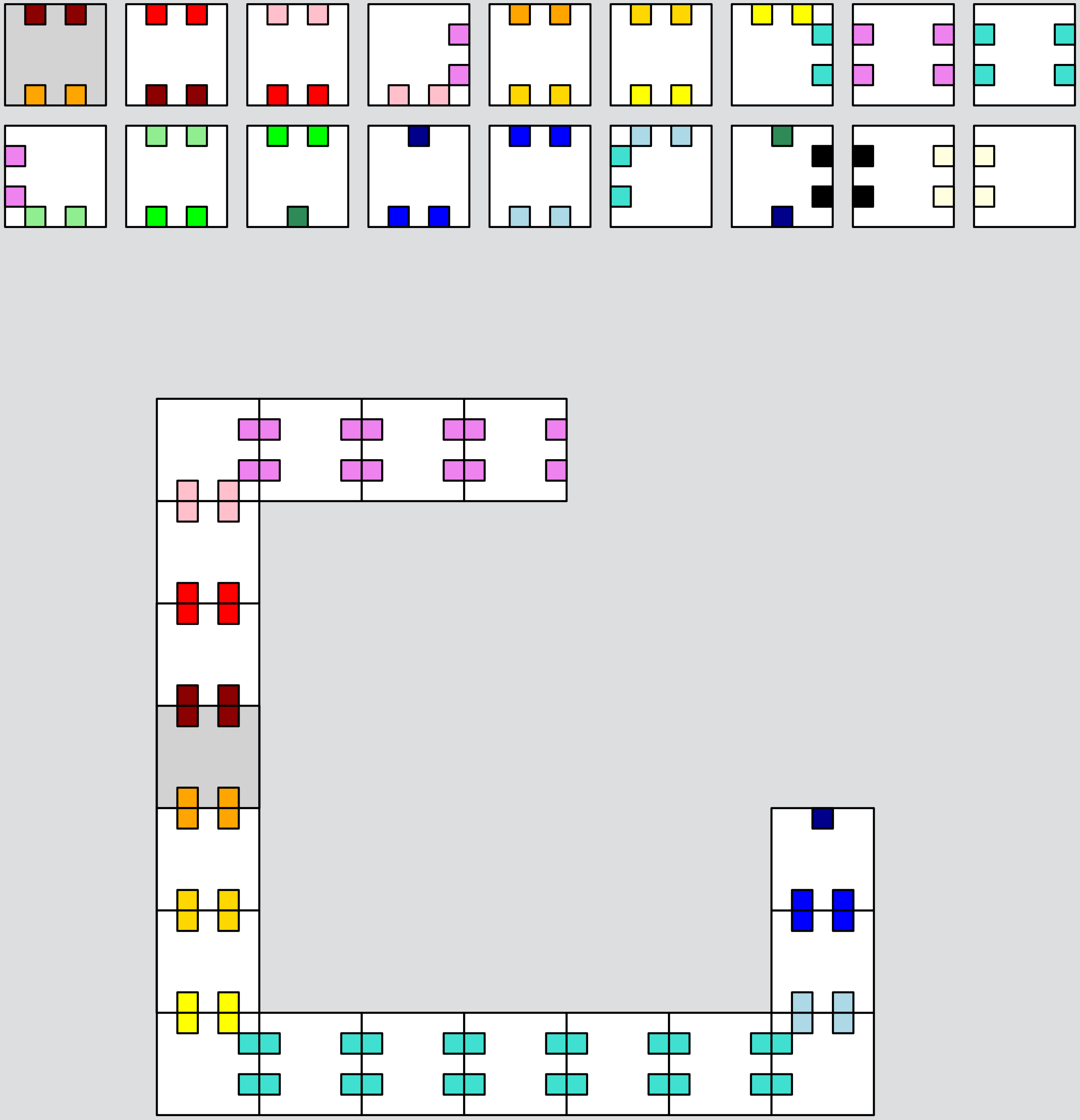

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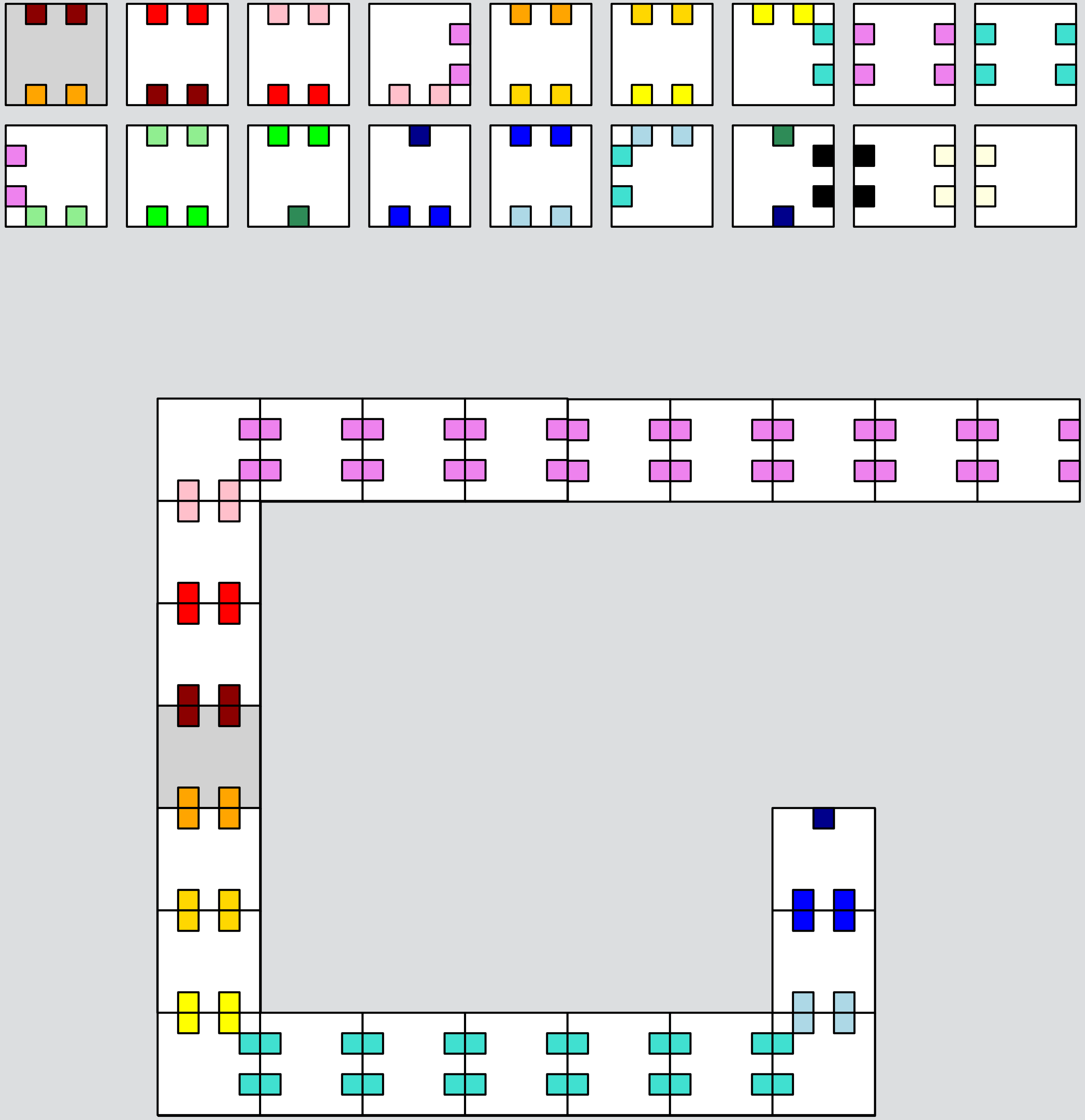

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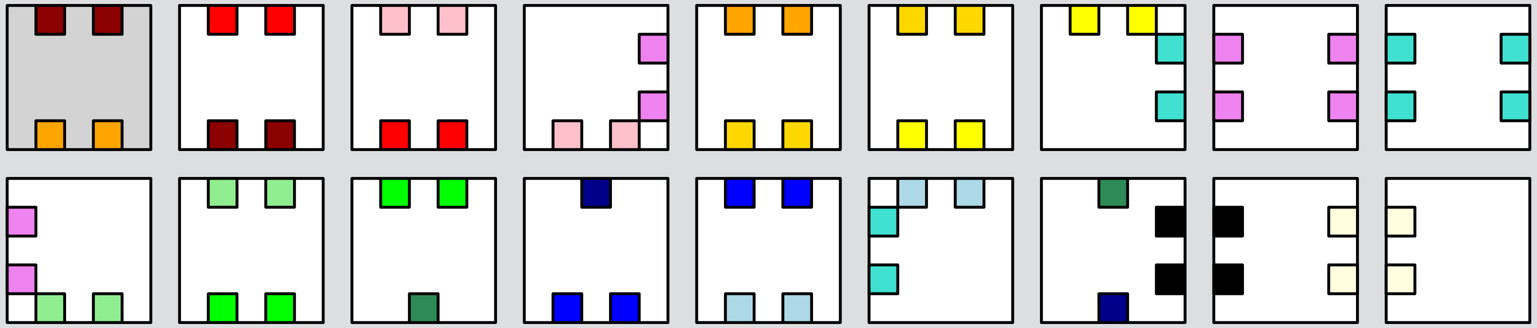

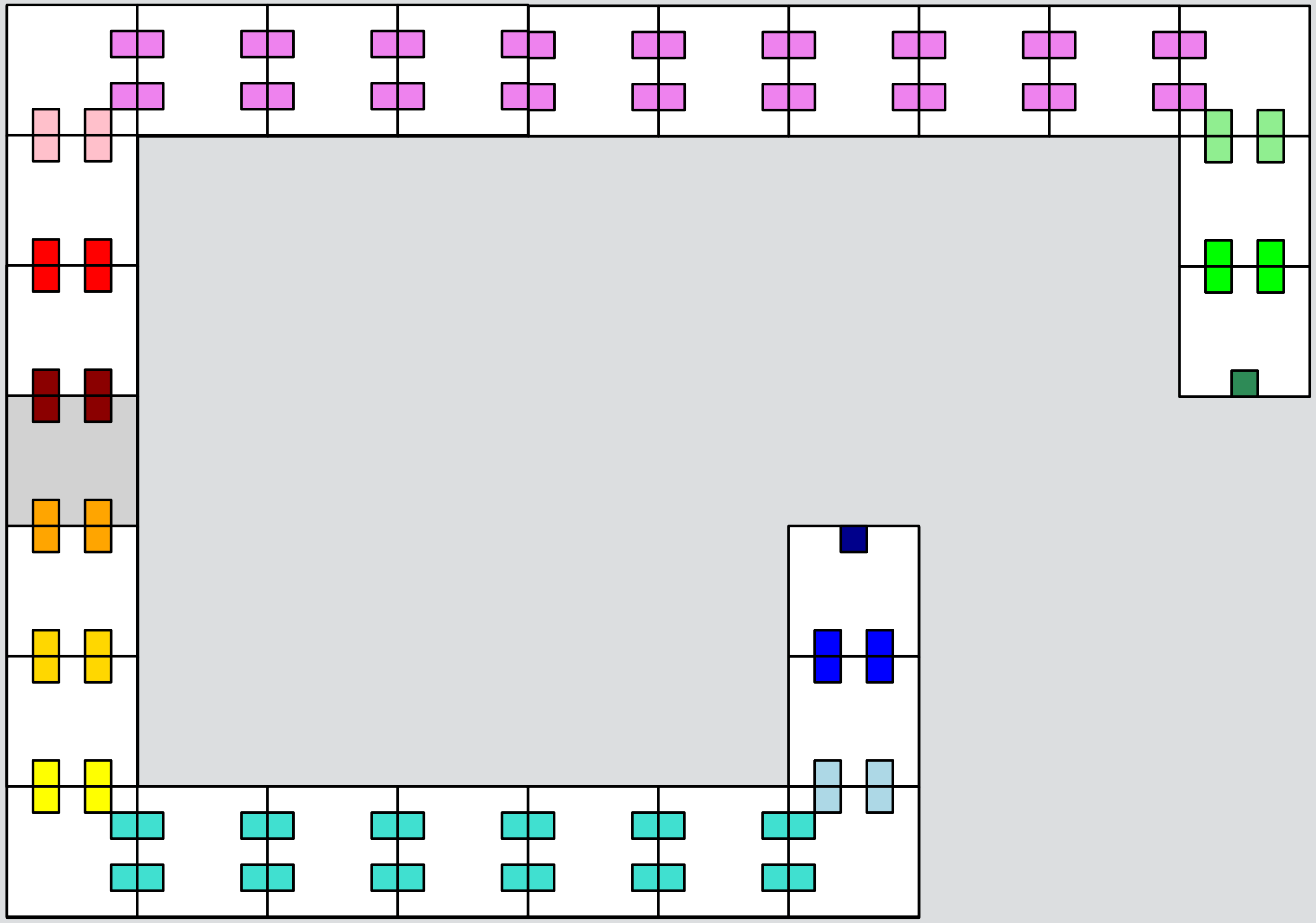

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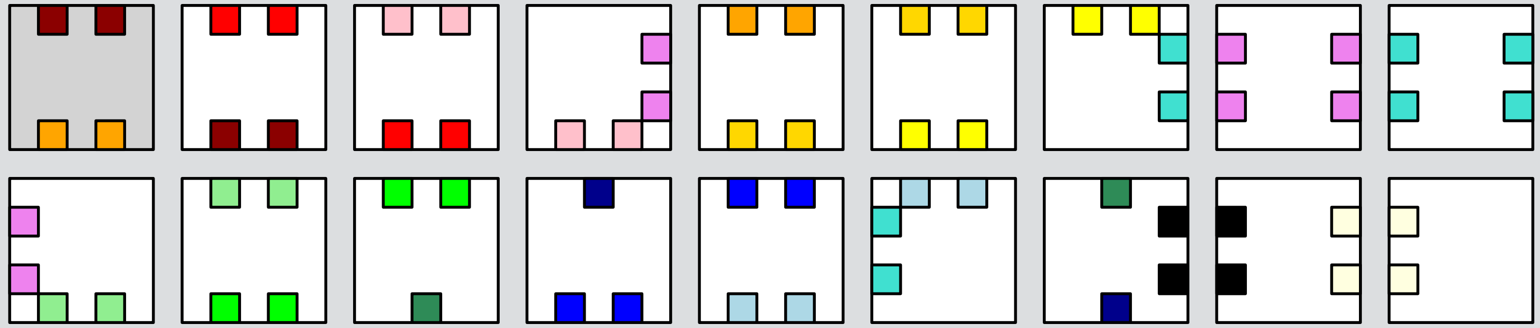

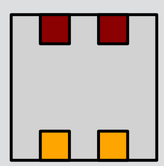

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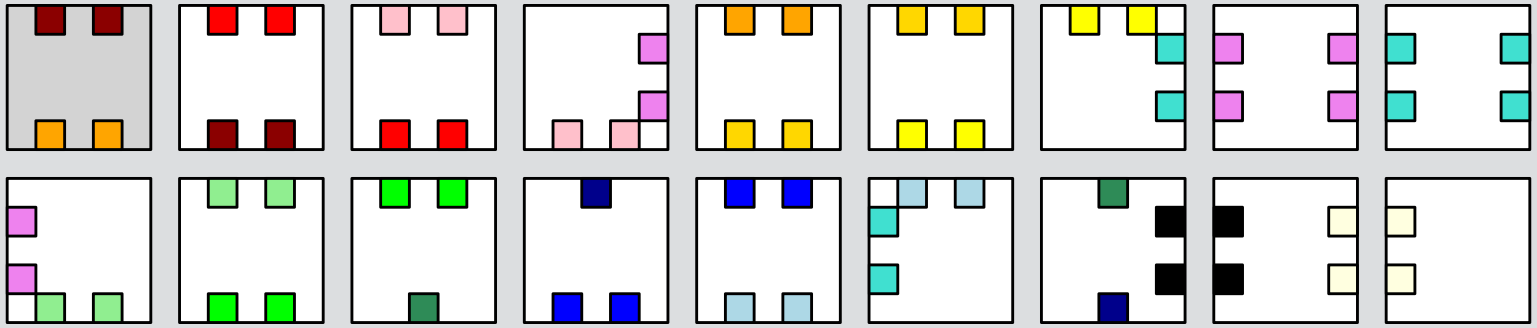

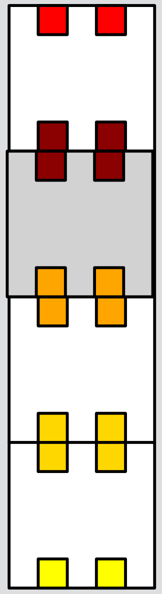

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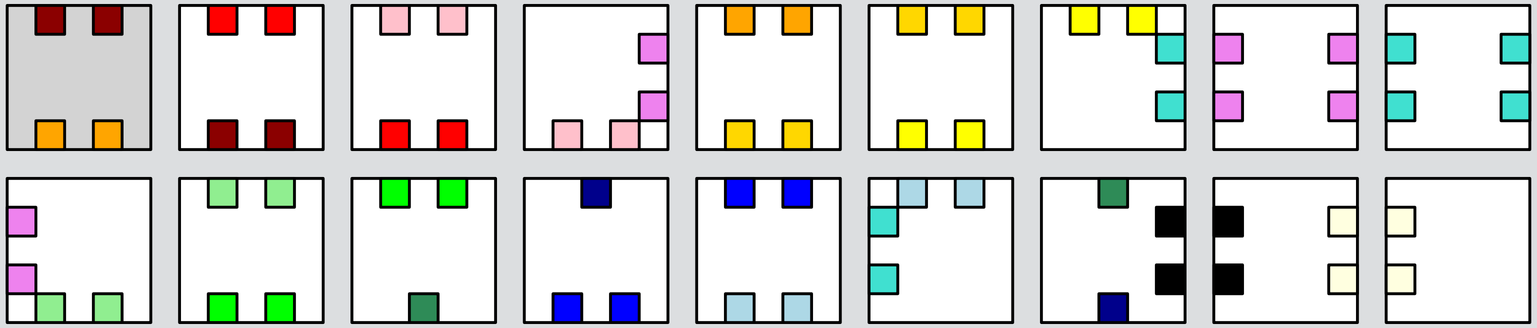

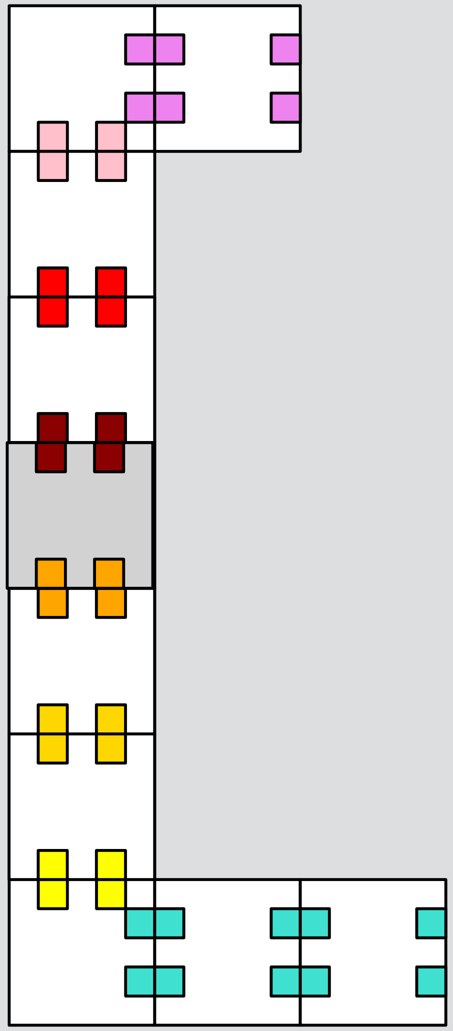

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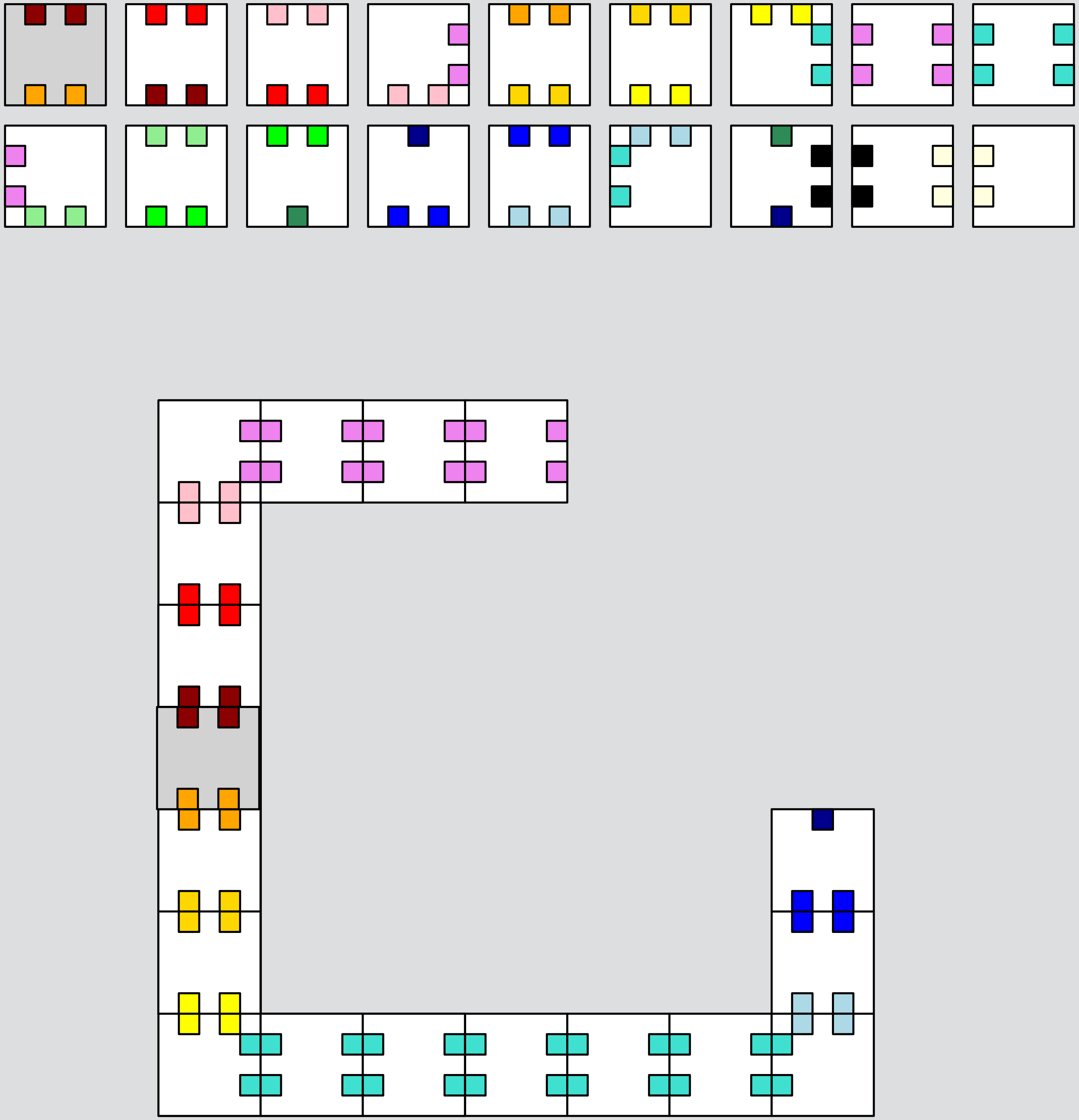

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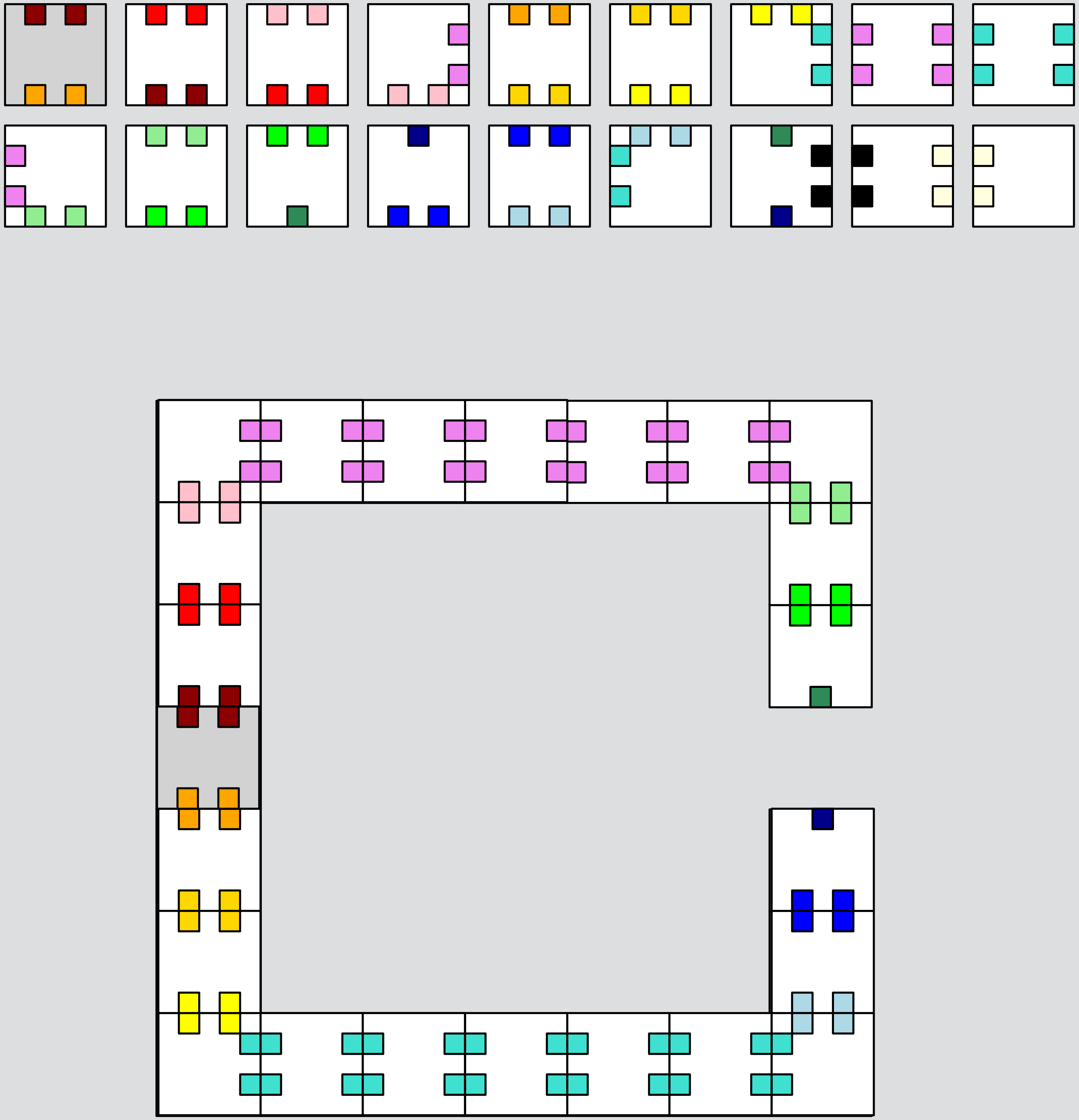

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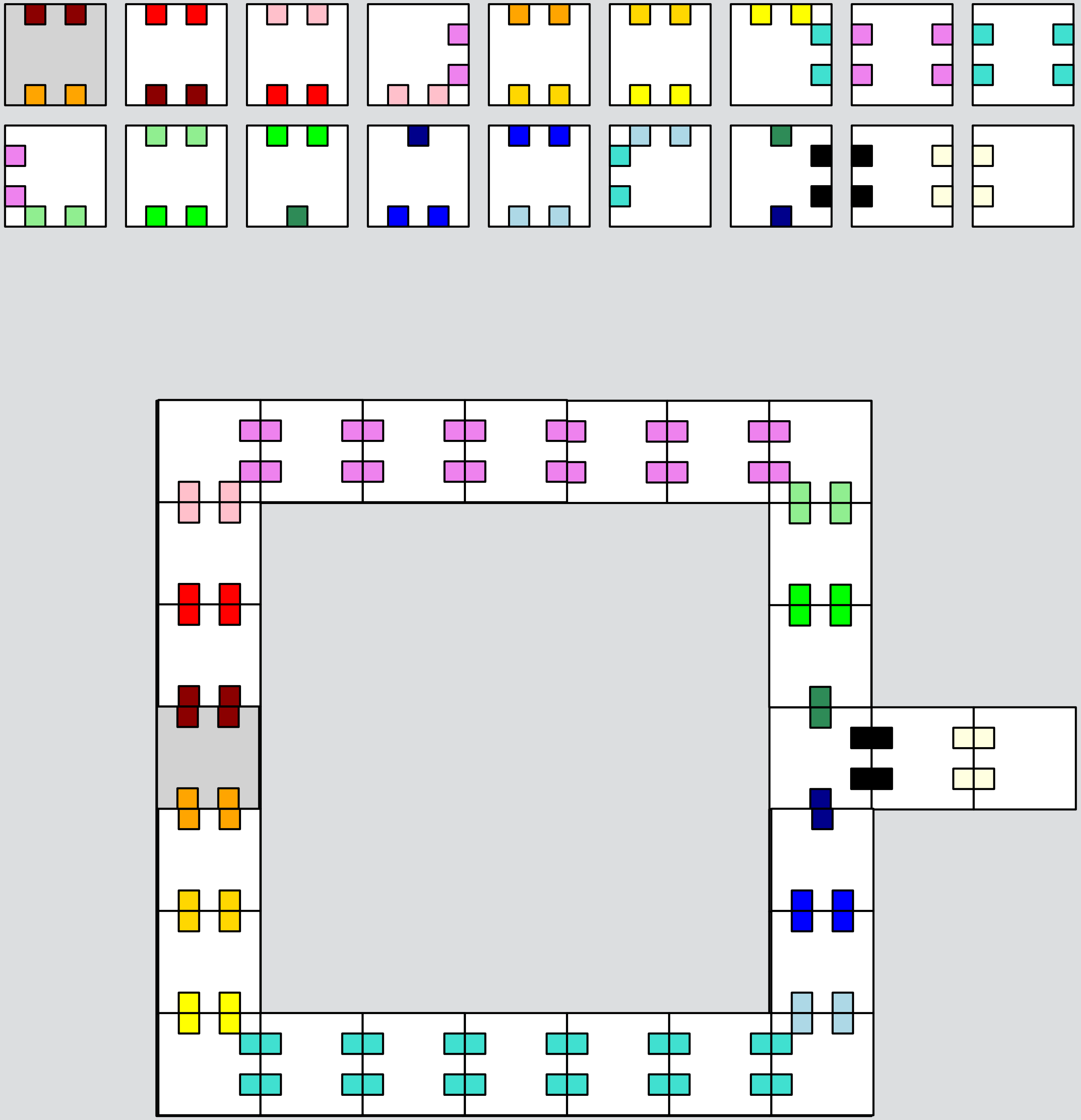

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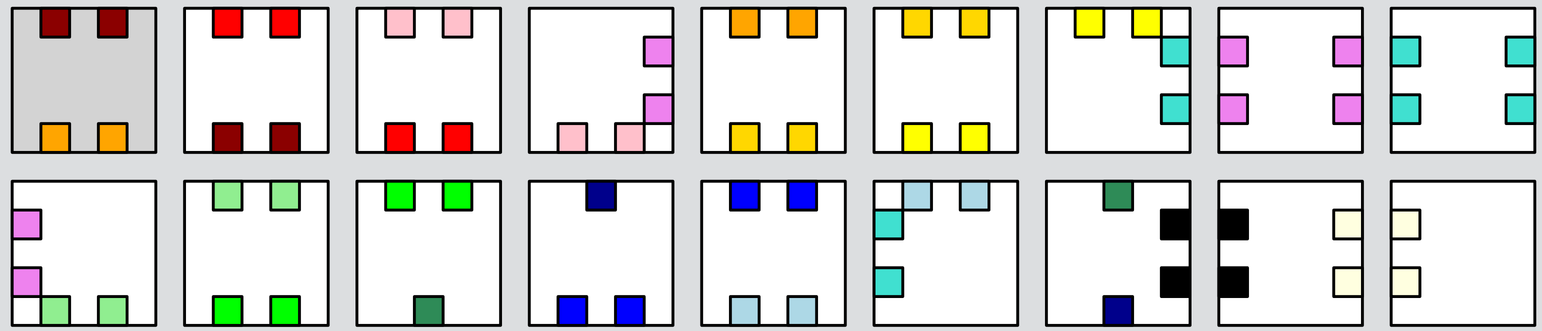
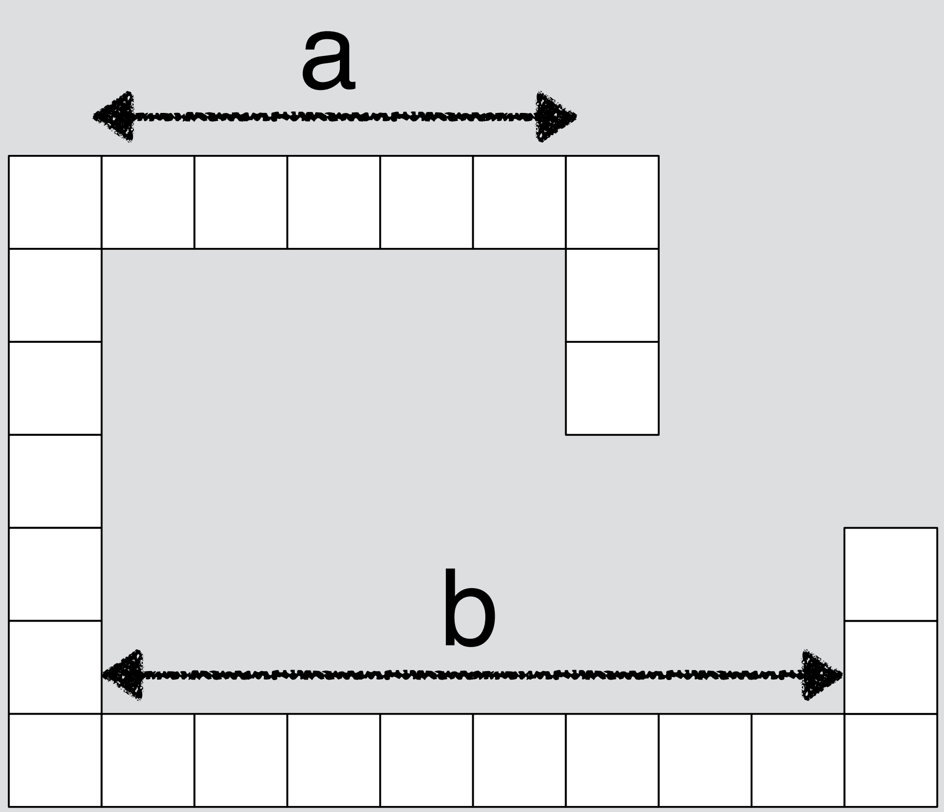
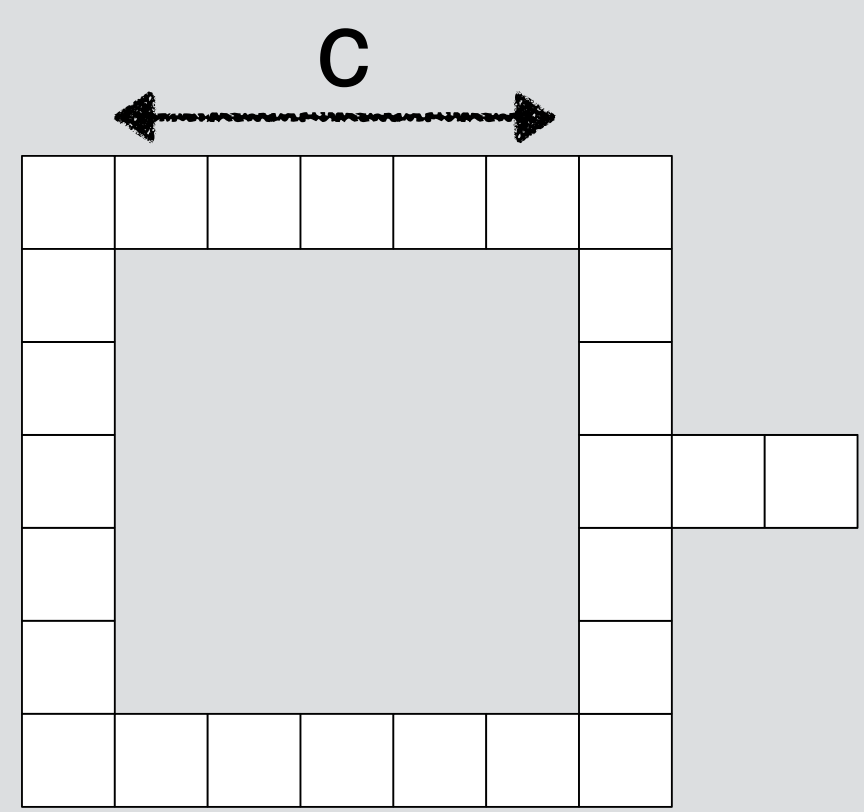


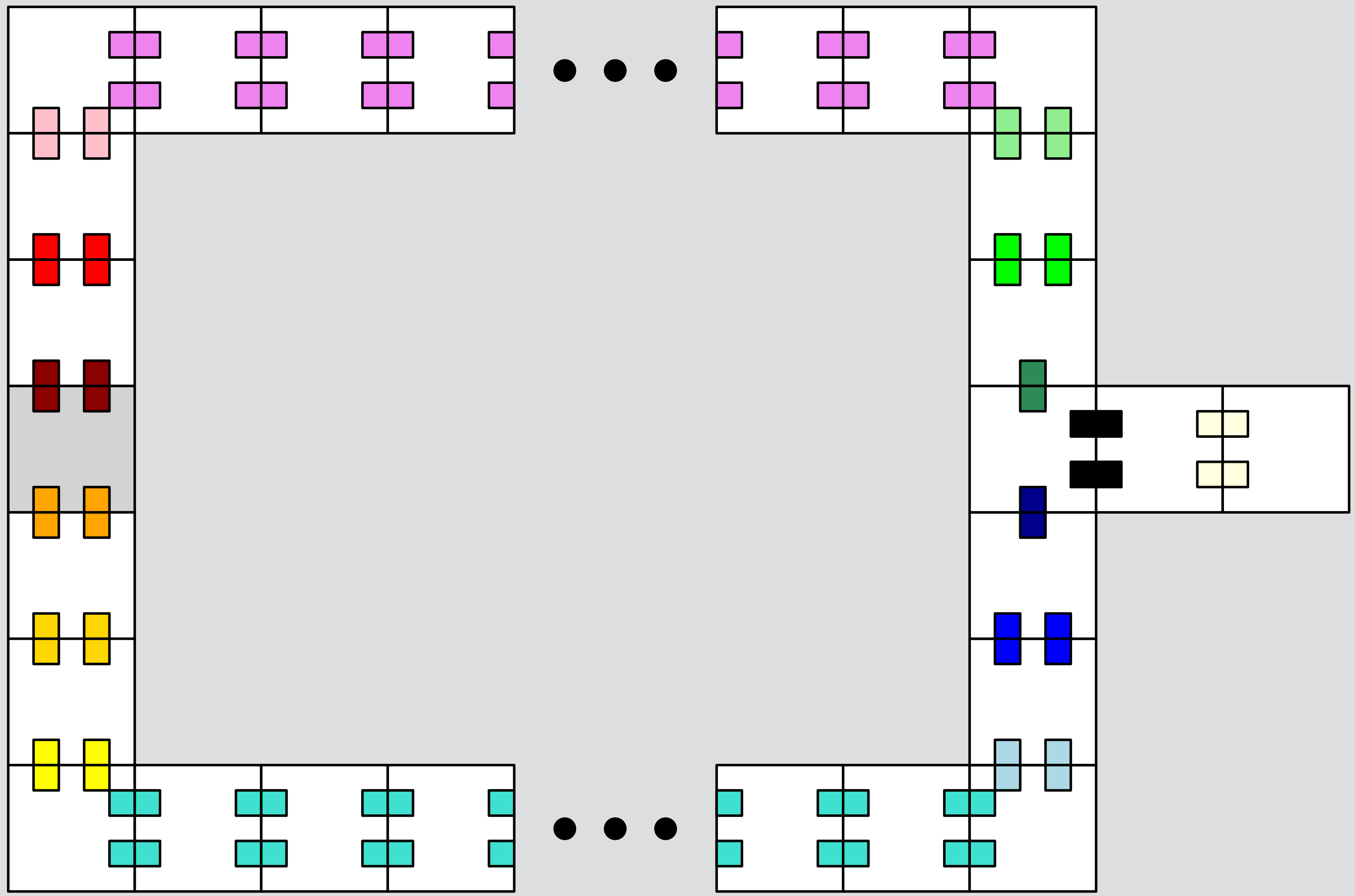
at temperature 2 assembles



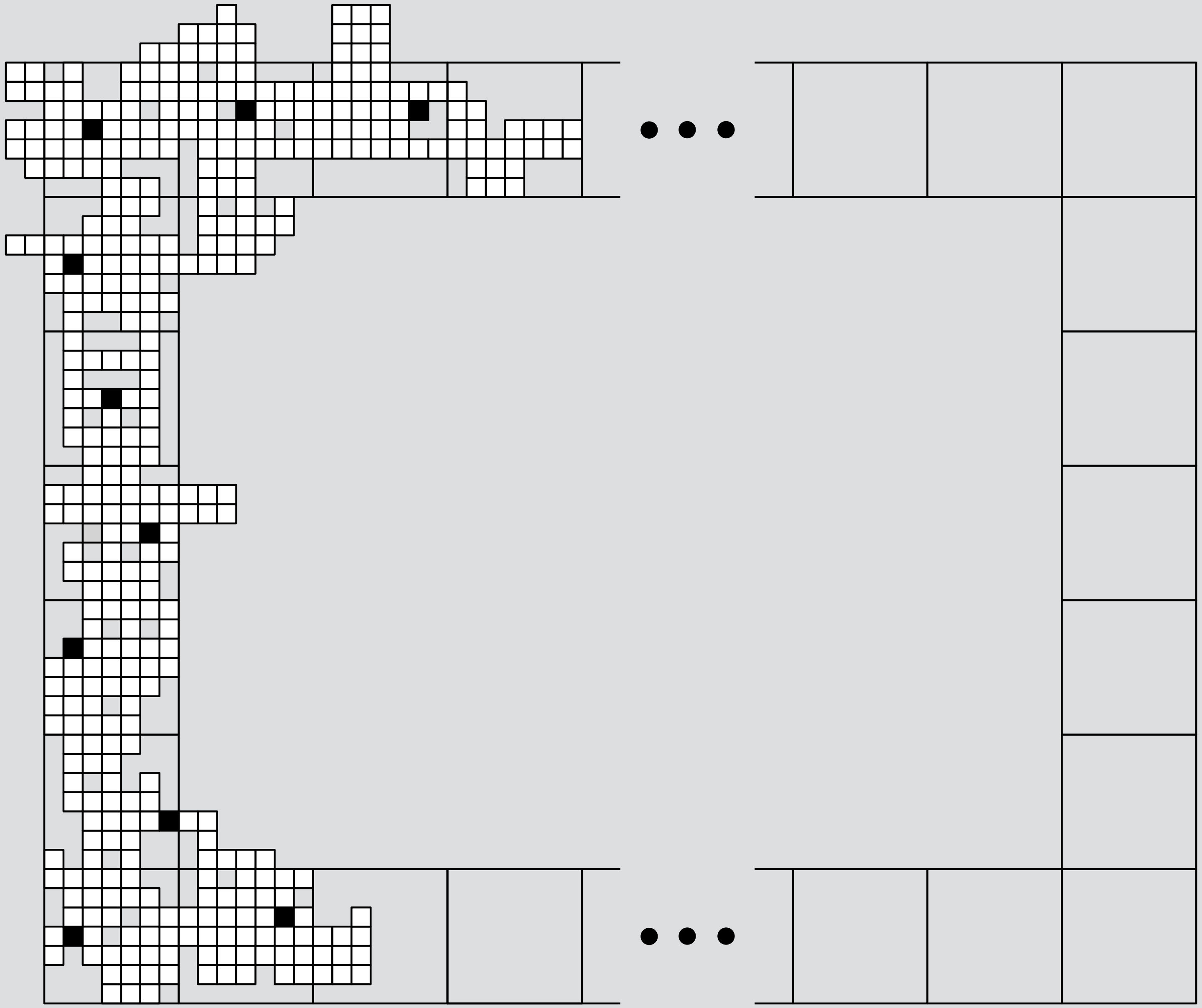


for all a, b, c ≥ 0

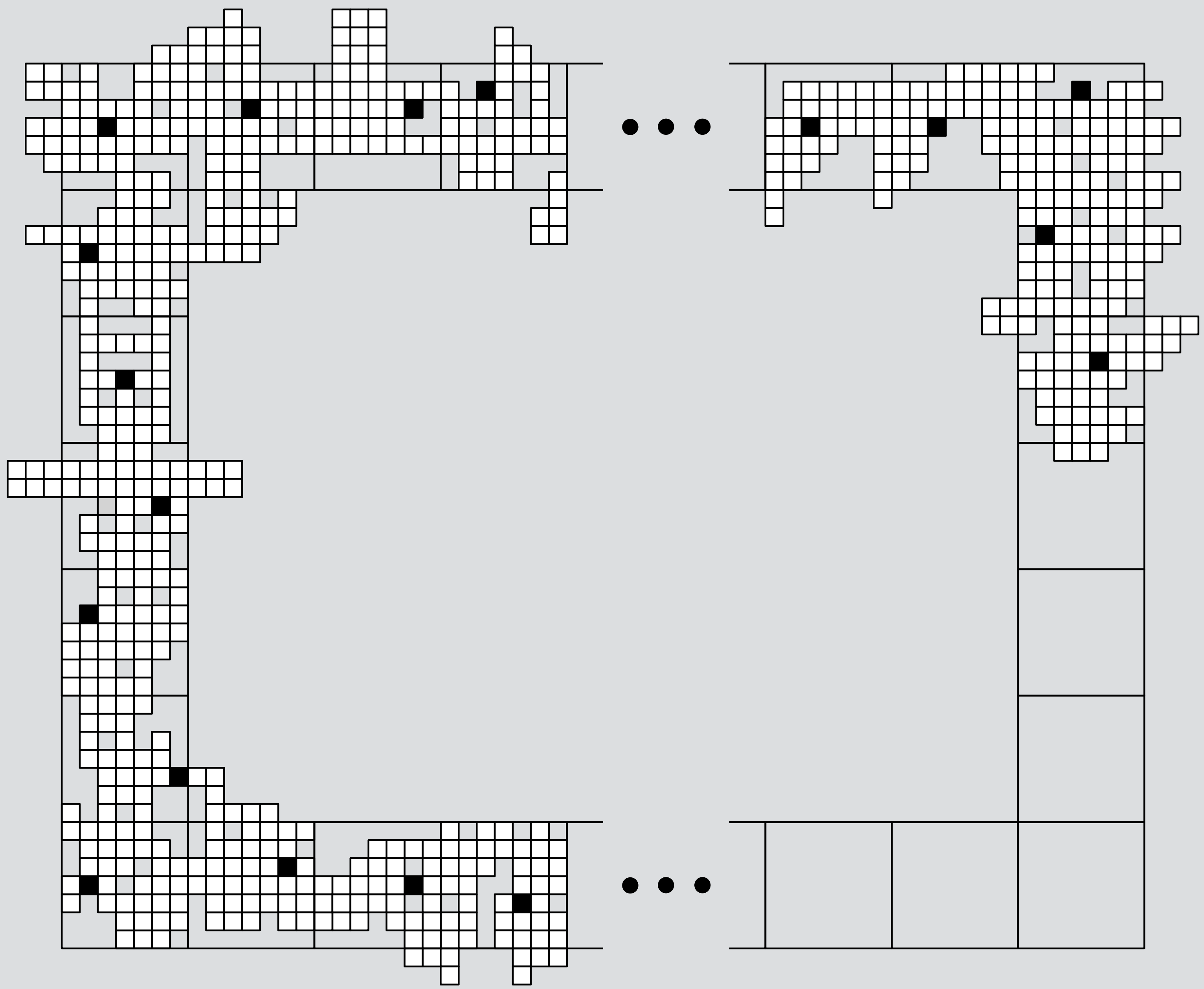
Claim: simulation will fail.



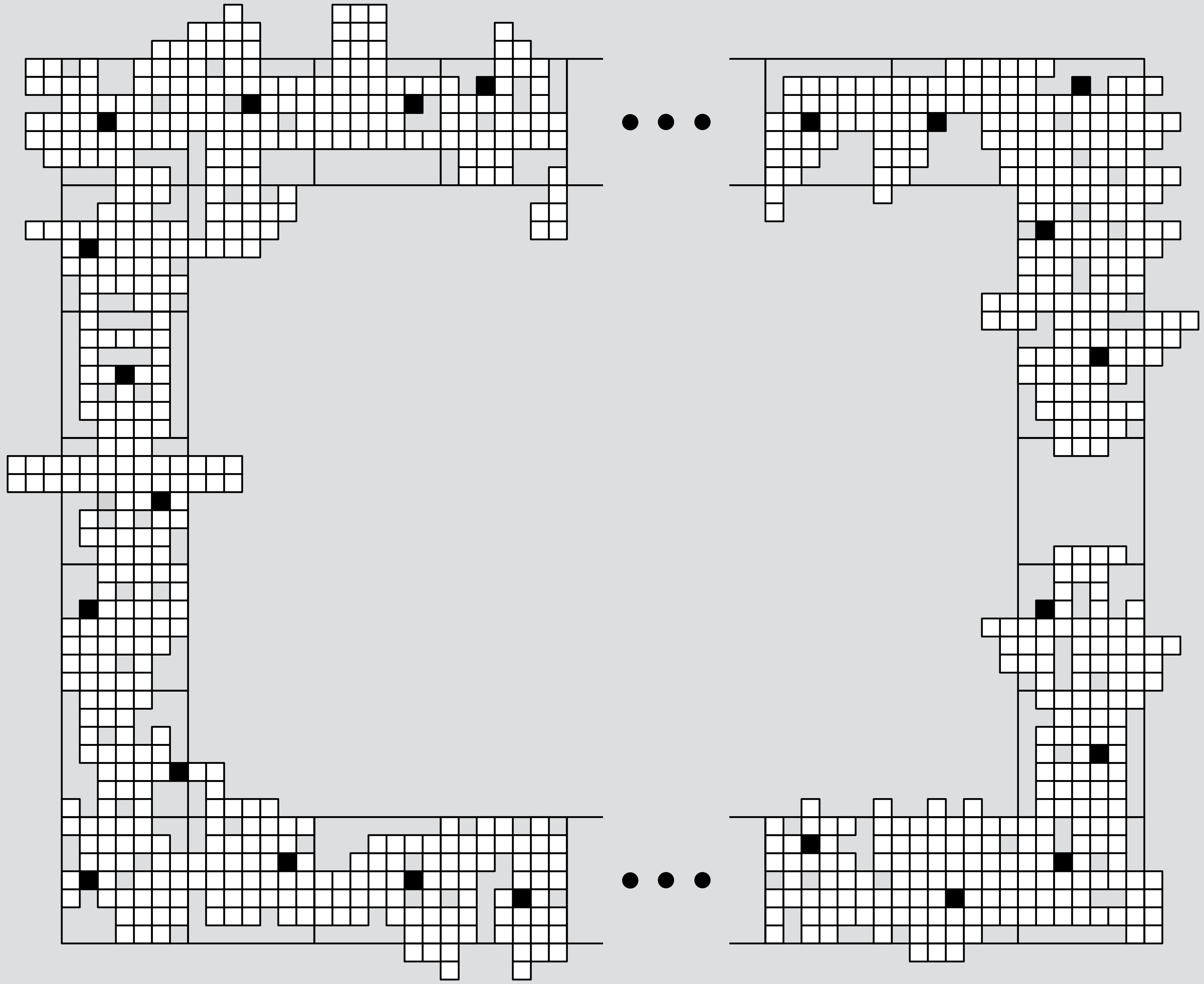
Claim: simulation will fail.



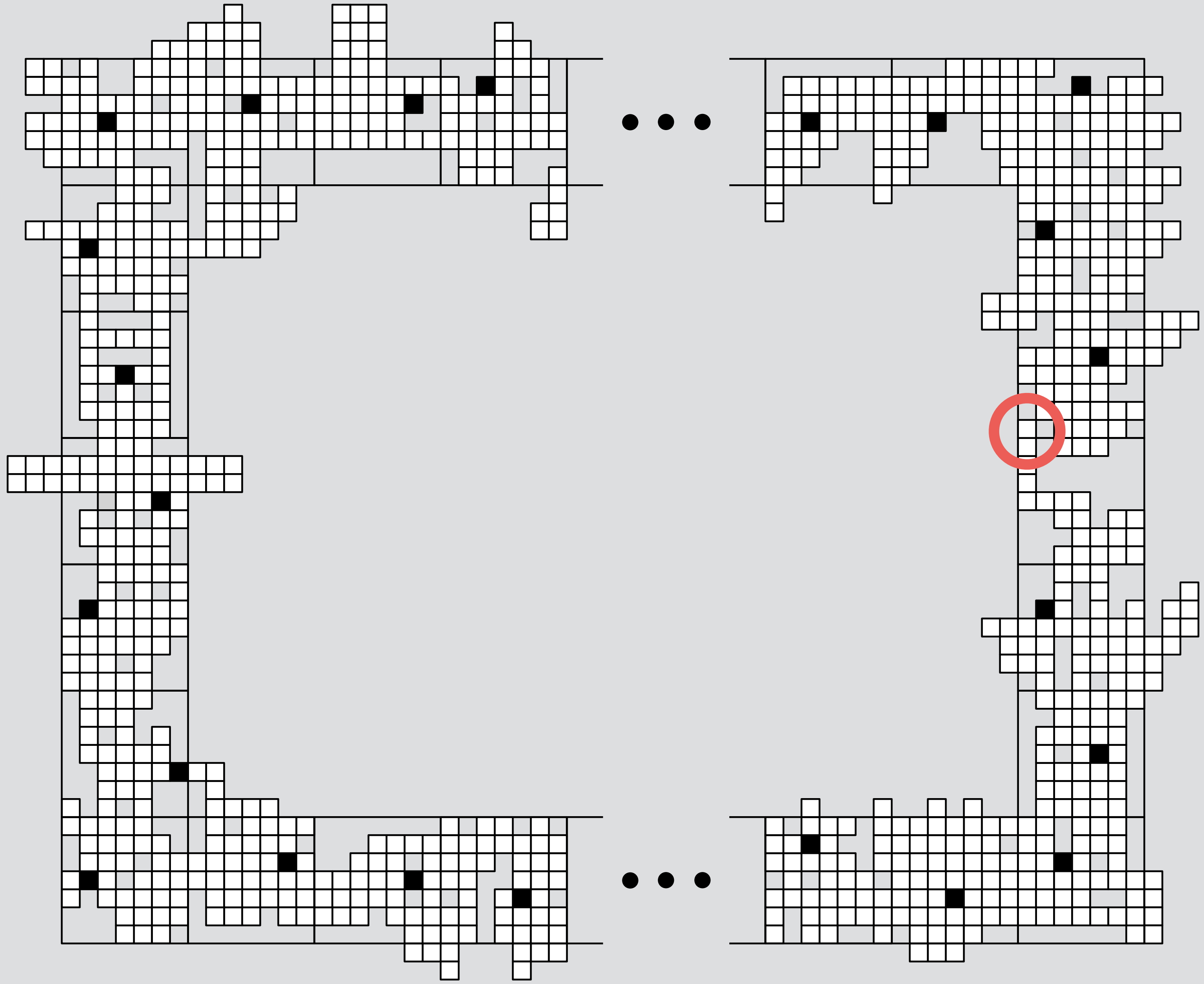
Claim: simulation will fail.



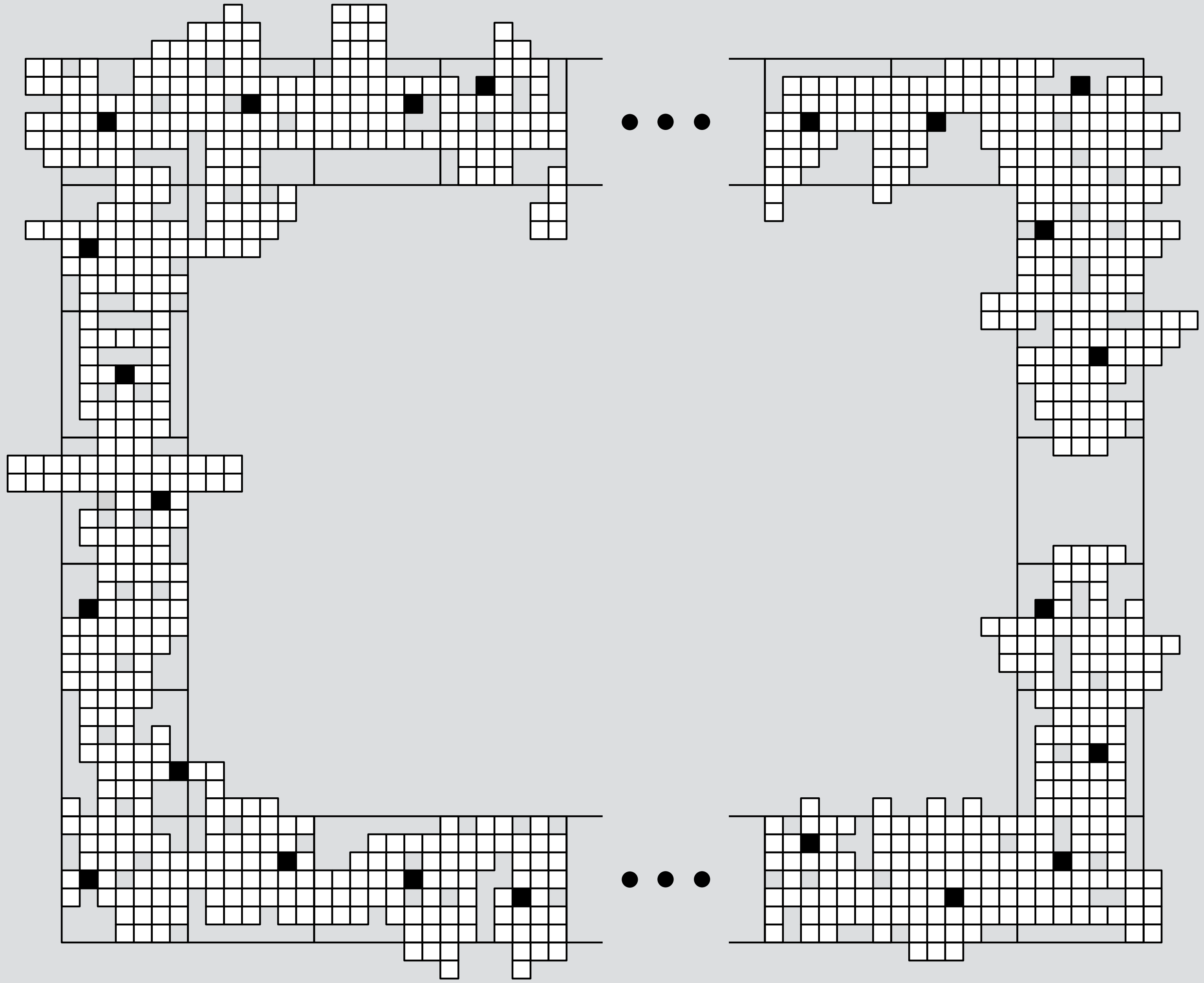
Claim: simulation will fail.



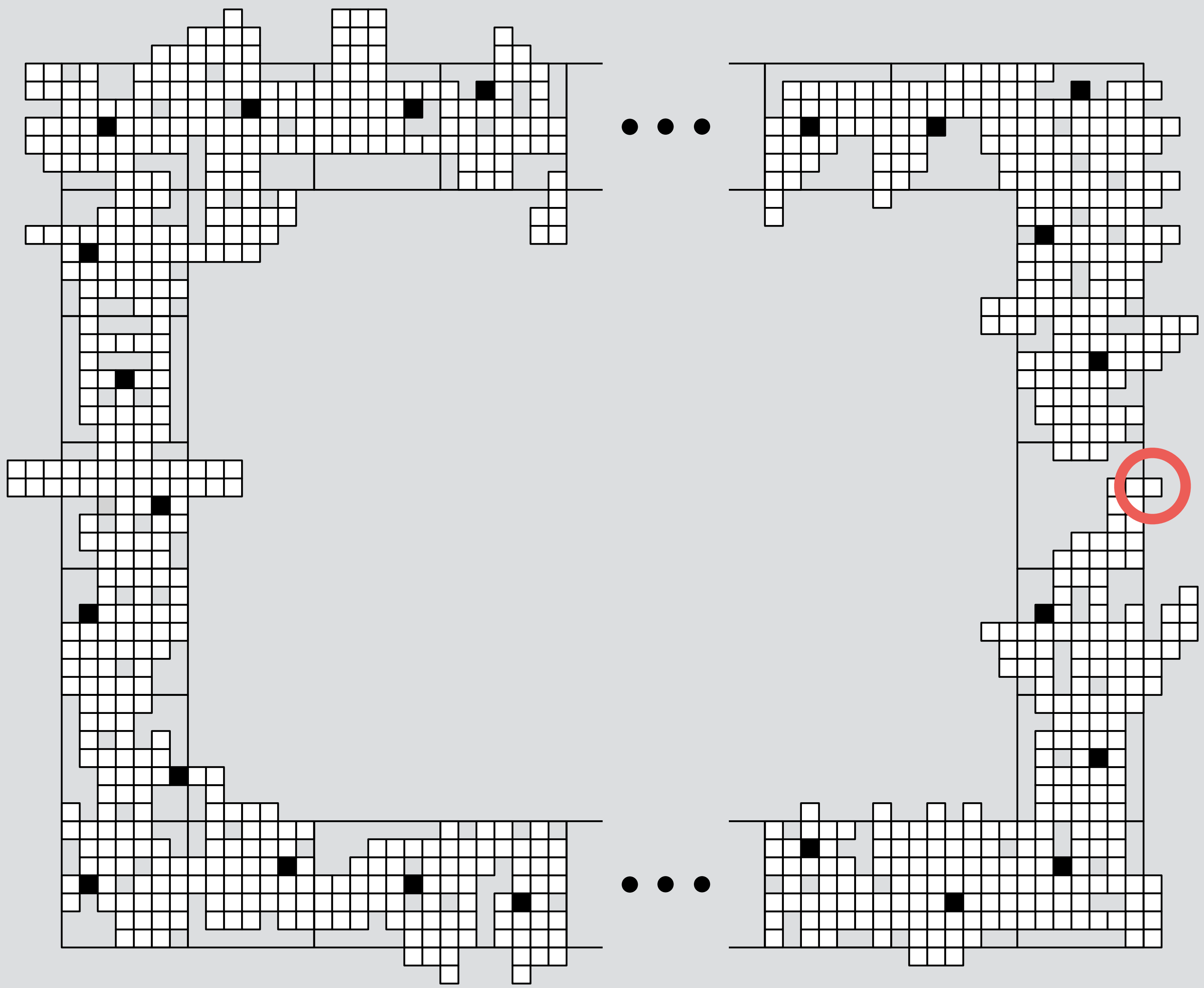
Claim: simulation will fail.



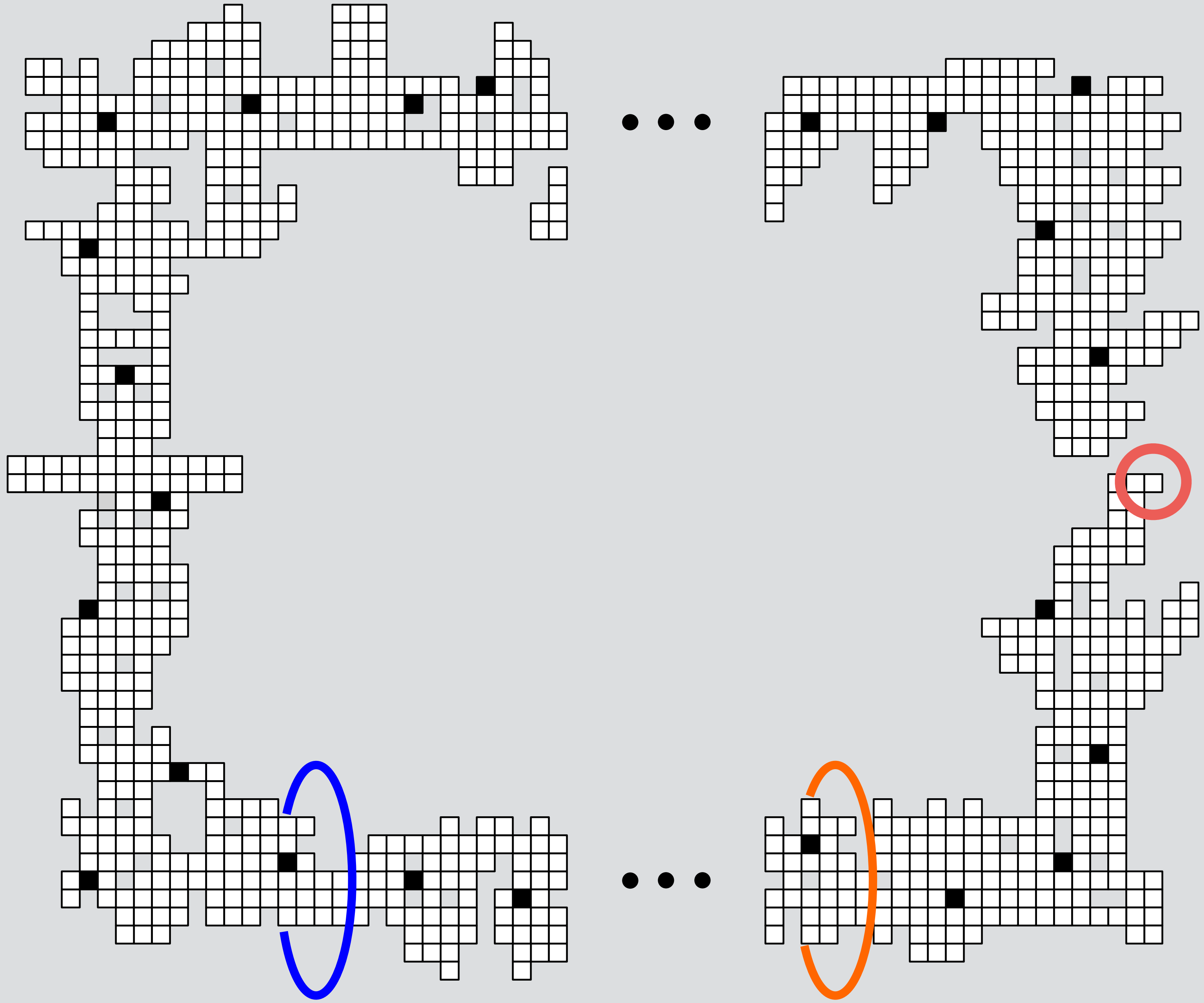
Claim: simulation will fail.



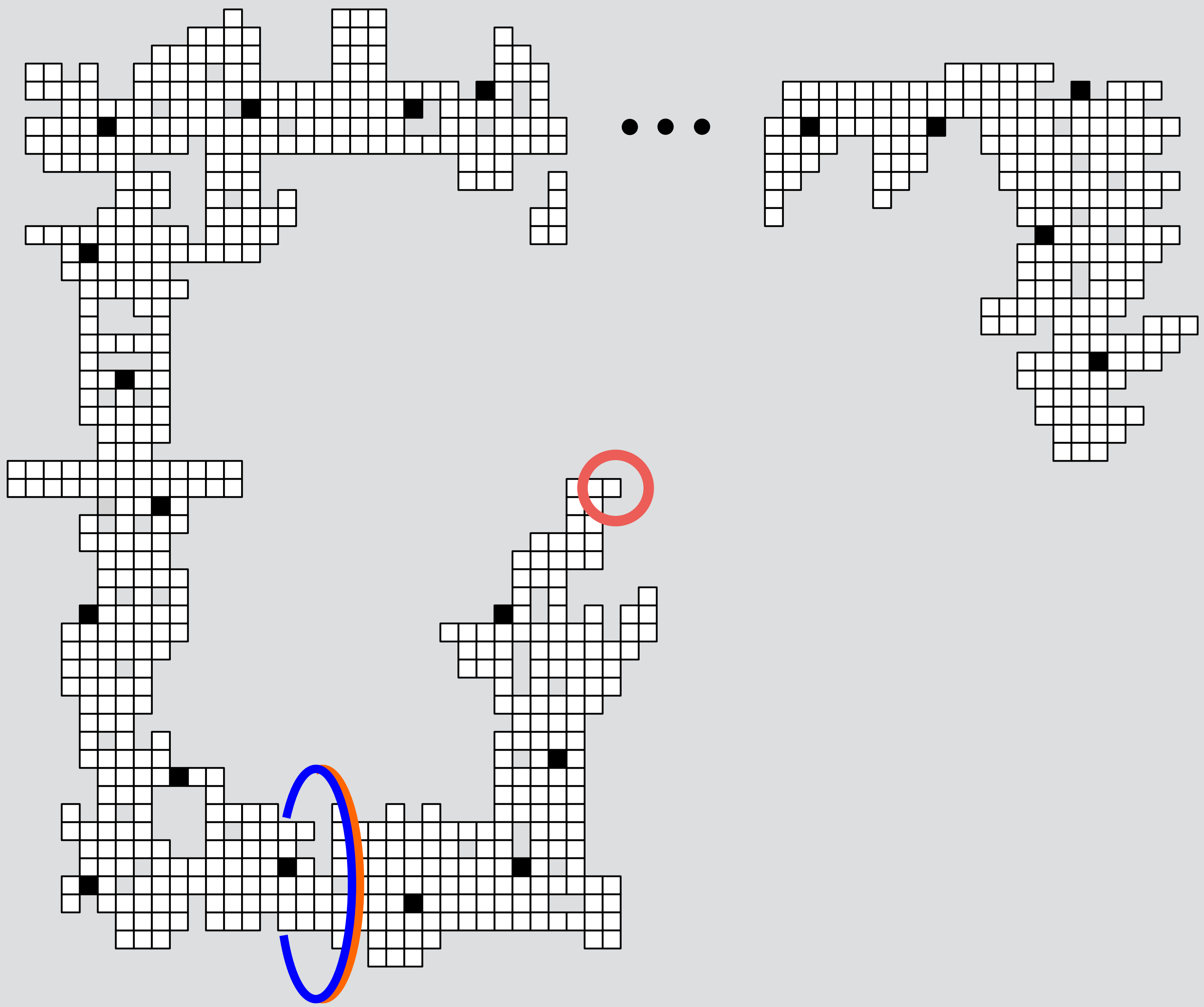
Claim: simulation will fail.



Claim: simulation will fail.



Claim: simulation will fail.



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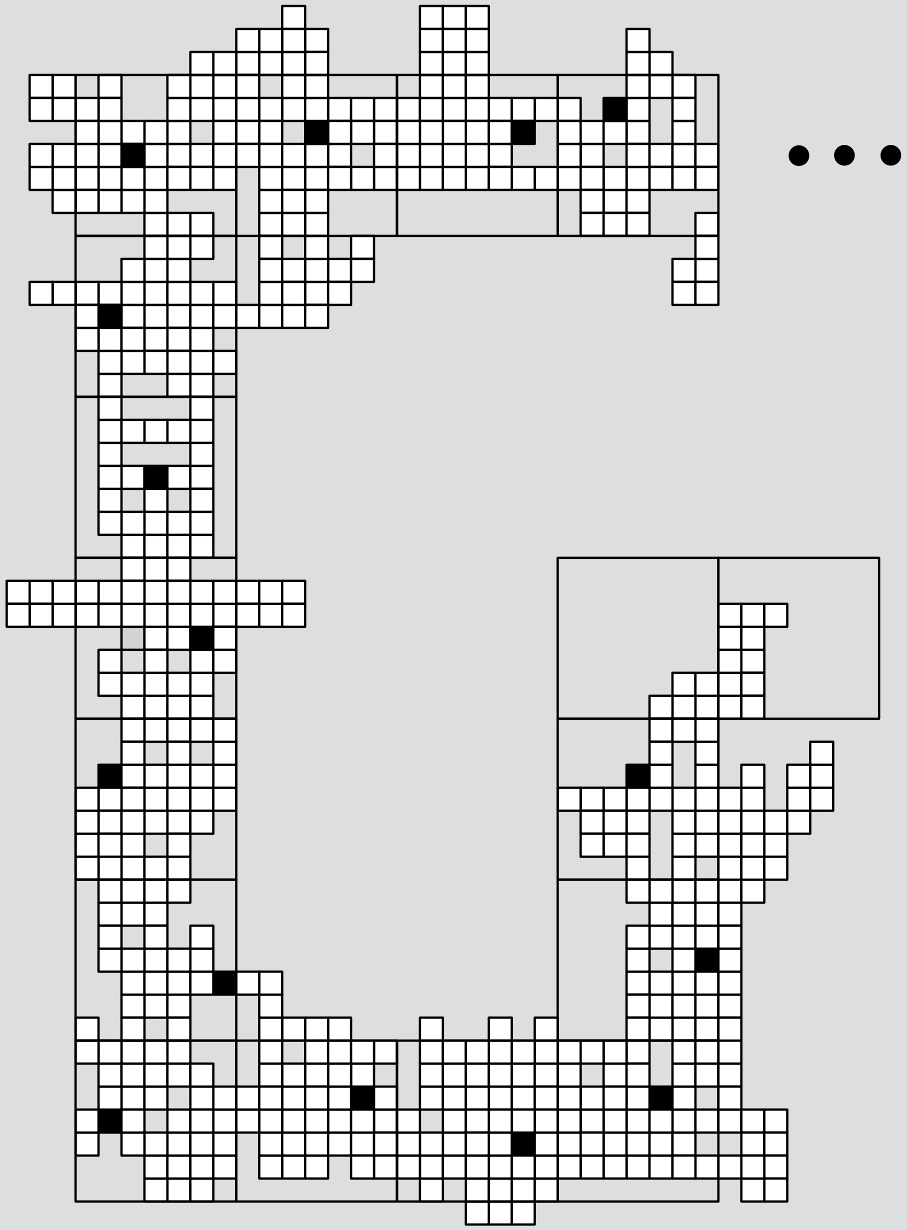

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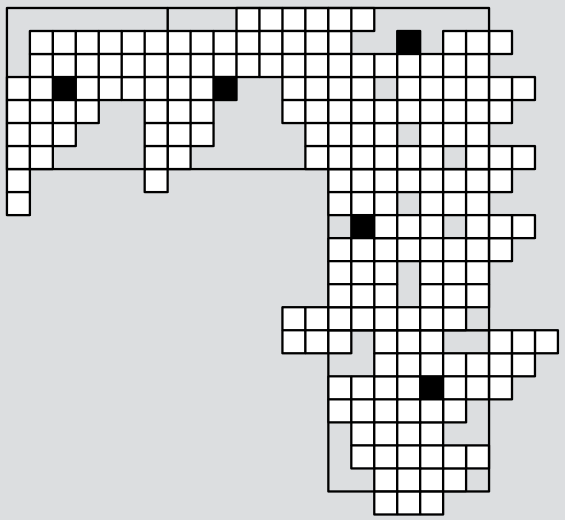
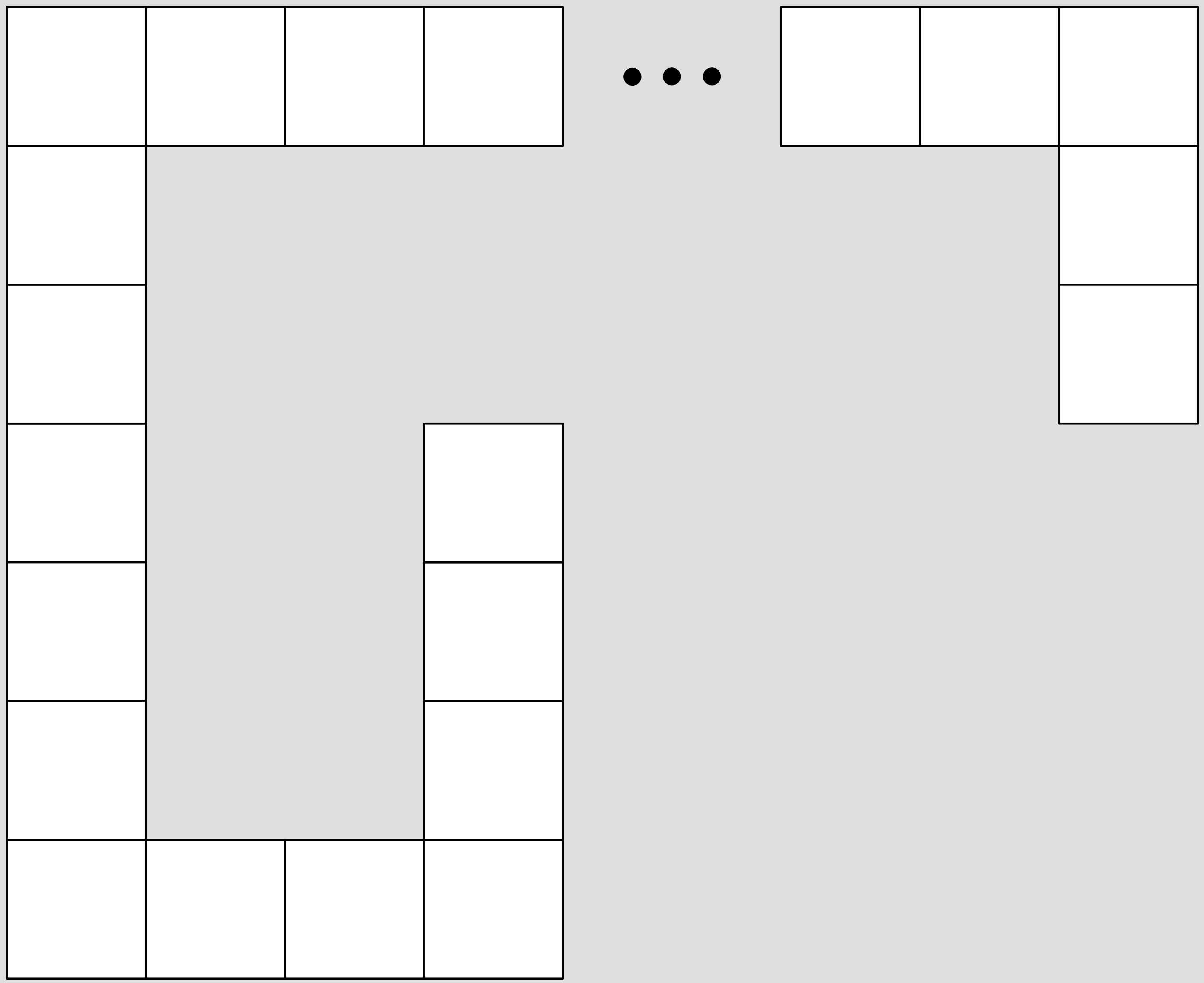
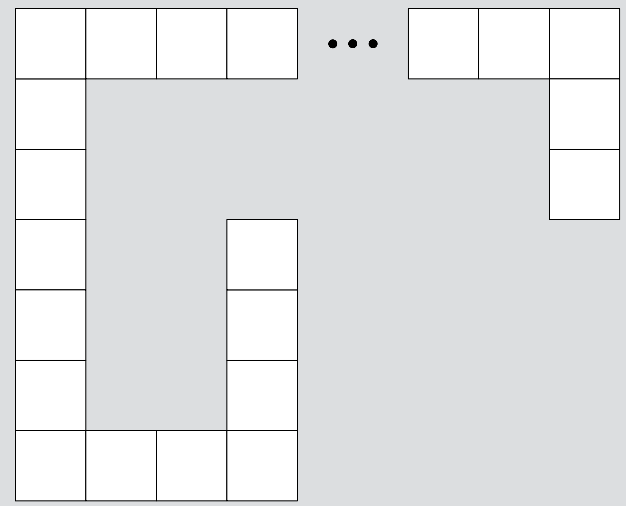


Claim: simulation will fail.

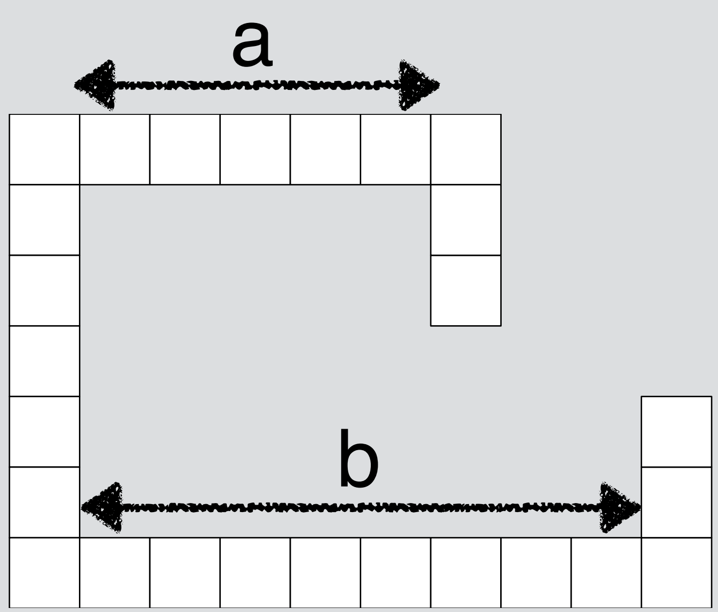


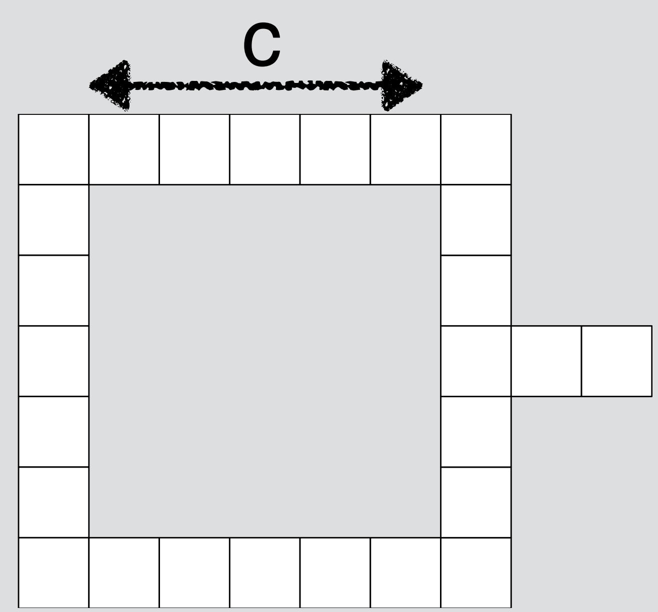
Claim: simulation will fail.

Assembled by temperature-1 “simulation”:



Shapes assembled by  at temperature 2:



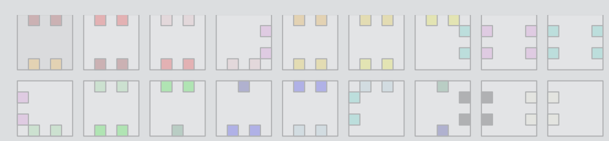


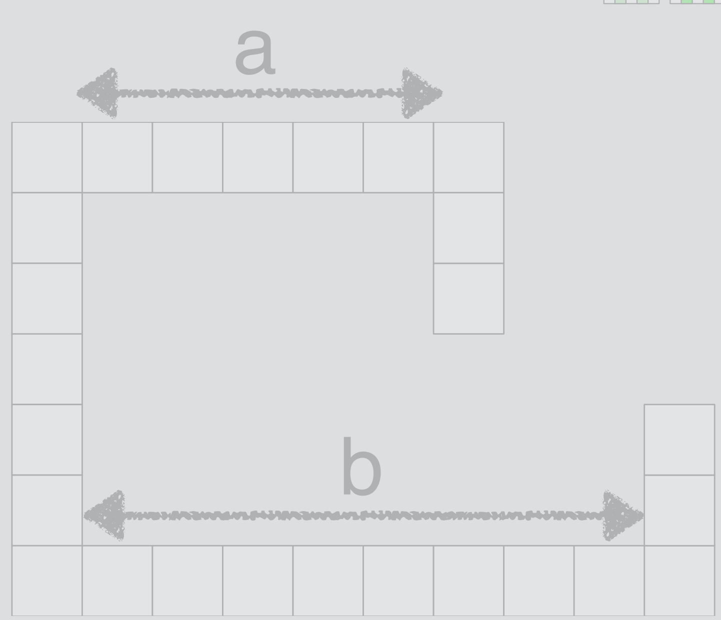
for all a, b, c ≥ 0

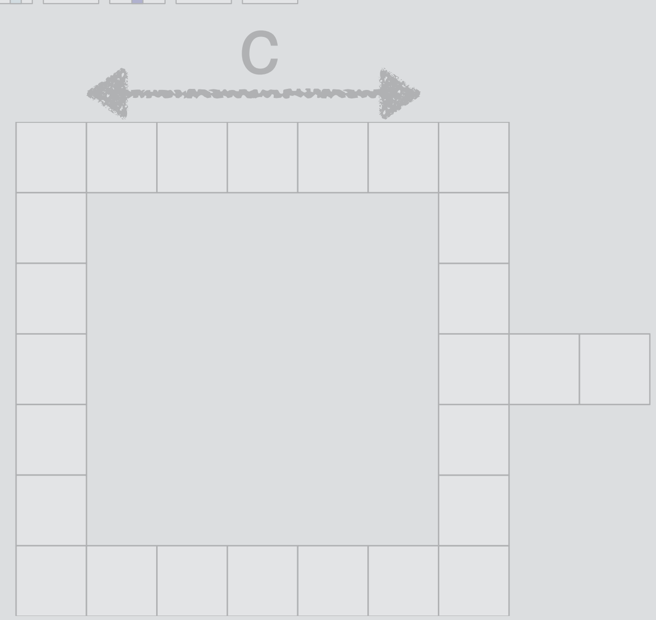
Claim: simulation will fail.

Assembled by temperature-1 “simulation”:

SIMULATION FAILED

Shapes assembled by  at temperature 2:





for all a, b, c ≥ 0

Fruits of intrinsic universality

The tile assembly model is intrinsically universal

David Doty[*] Jack H. Lutz[†] Matthew J. Patitz[‡] Robert T. Schweller[§]
Scott M. Summers[¶] Damien Woods[‖]

Intrinsic universality in tile self-assembly requires cooperation

Pierre-Etienne Meunier[*] Matthew J. Patitz[†]
Scott M. Summers[‡] Guillaume Theyssier[§] Andrew Winslow[¶]
Damien Woods[‖]

The two-handed tile assembly model is not intrinsically universal

Erik D. Demaine[*] Matthew J. Patitz[†] Trent A. Rogers[‡]
Robert T. Schweller[§] Scott M. Summers[¶] Damien Woods[‖]

Signal Transmission across Tile Assemblies: 3D Static Tiles Simulate Active Self-assembly by 2D Signal-Passing Tiles

Jacob Hendricks[1,*], Jennifer E. Padilla[2,**],
Matthew J. Patitz[1,*], and Trent A. Rogers[3,*]

One Tile to Rule Them All: Simulating Any Tile Assembly System with a Single Universal Tile[*,]**

Erik D. Demaine[1], Martin L. Demaine[1], Sándor P. Fekete[2],
Matthew J. Patitz[3], Robert T. Schweller[4],
Andrew Winslow[5], and Damien Woods[6]

It's a Tough Nanoworld: in Tile Assembly, Cooperation is not (strictly) more Powerful than Competition

Florent Becker[*] Pierre-Étienne Meunier[†]

The Simulation Powers and Limitations of Hierarchical Self-Assembly Systems

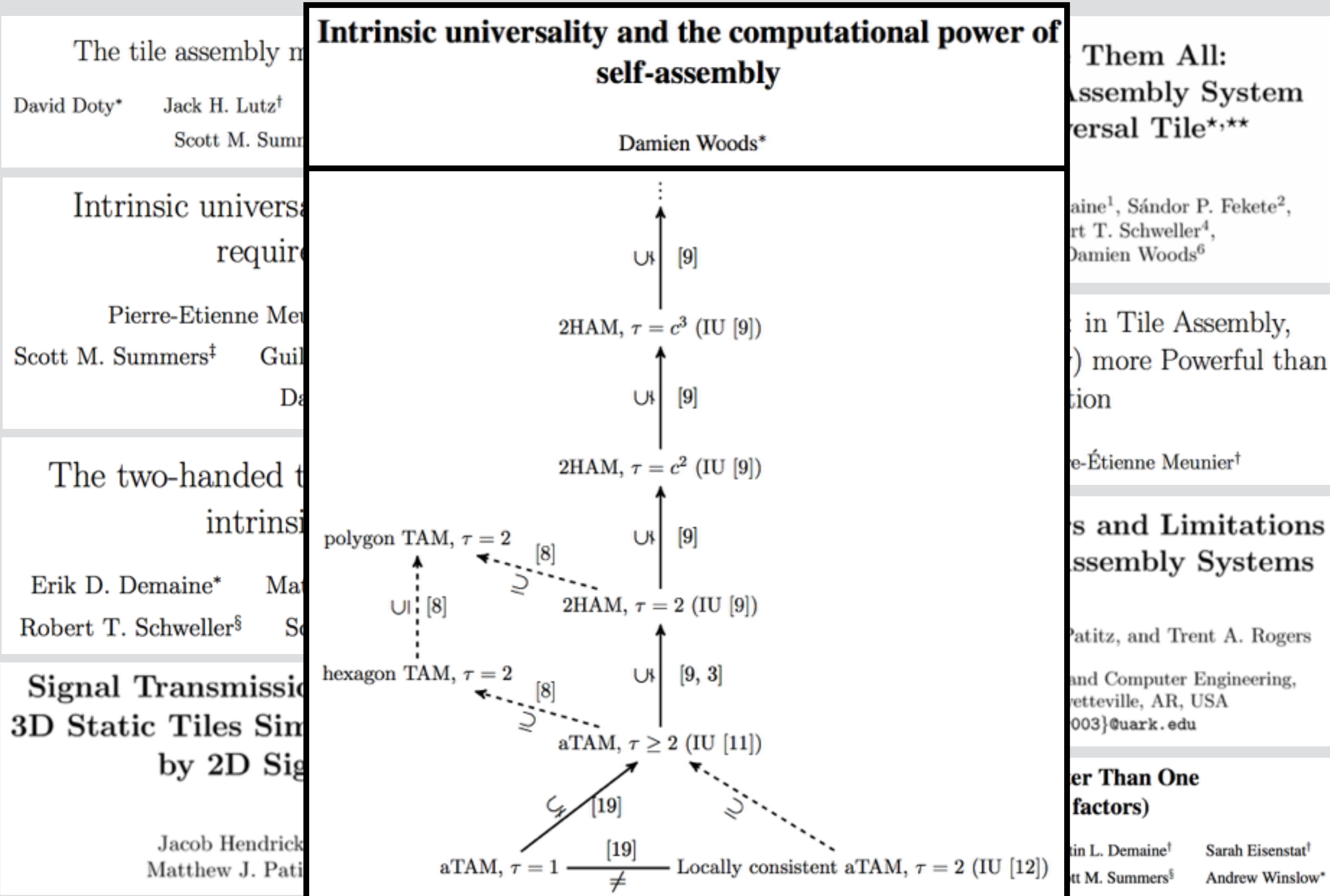
Jacob Hendricks[(✉)], Matthew J. Patitz, and Trent A. Rogers

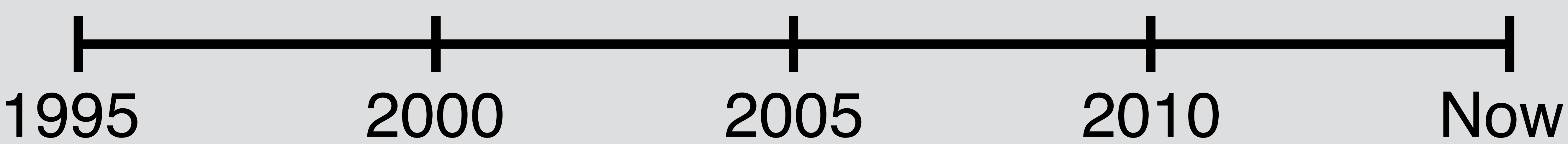
Deptartment of Computer Science and Computer Engineering,
University of Arkansas, Fayetteville, AR, USA
{jhendric,patitz,tar003}@uark.edu

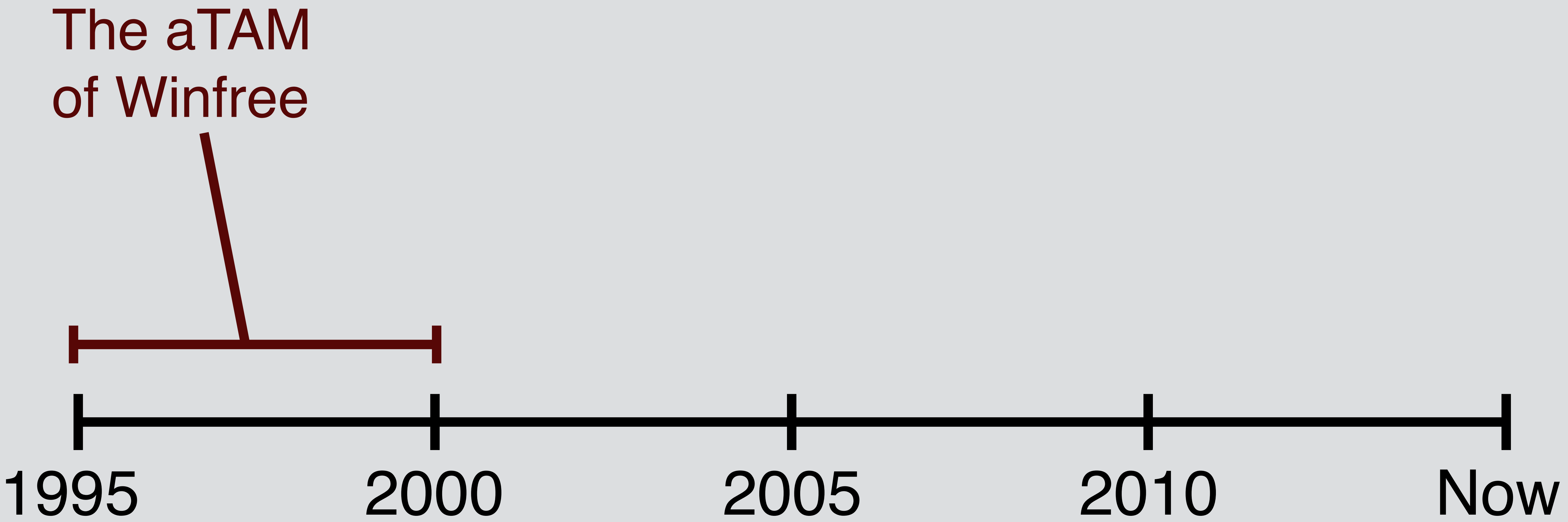
Two Hands Are Better Than One (up to constant factors)

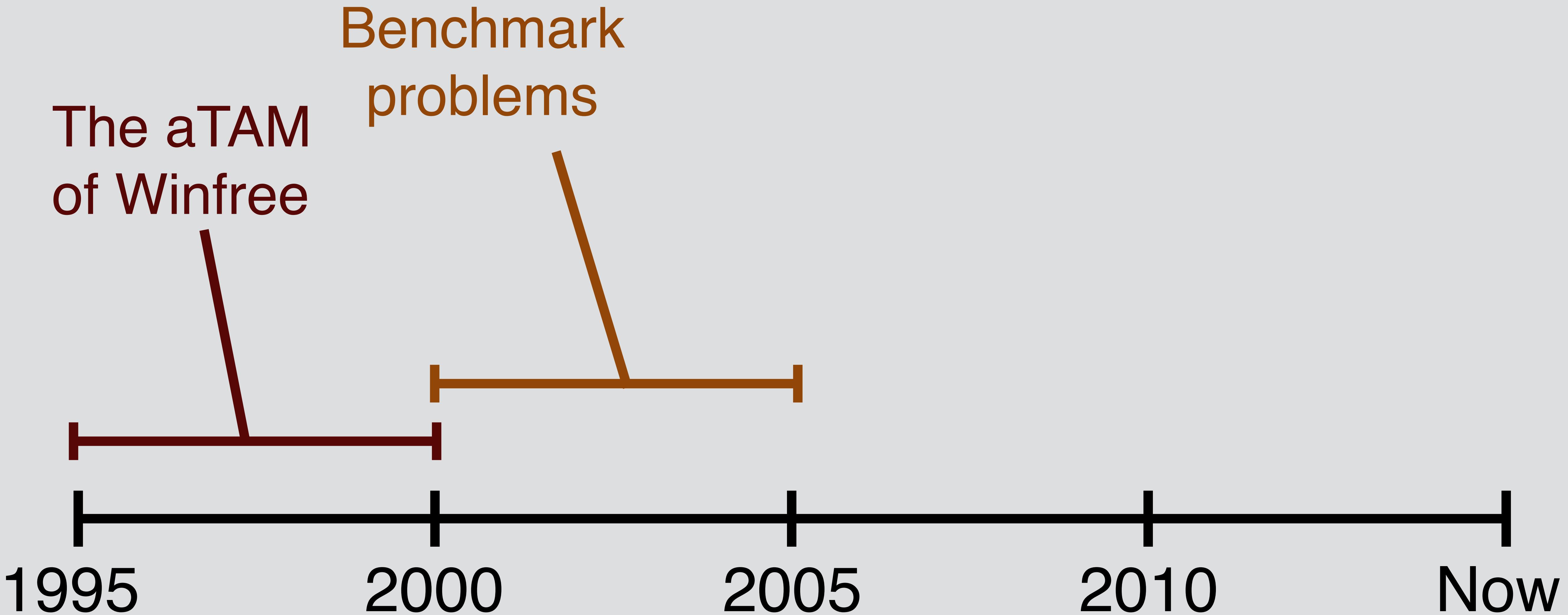
Sarah Cannon[*] Erik D. Demaine[†] Martin L. Demaine[†] Sarah Eisenstat[†]
Matthew J. Patitz[‡] Robert Schweller[‡] Scott M. Summers[§] Andrew Winslow[*]

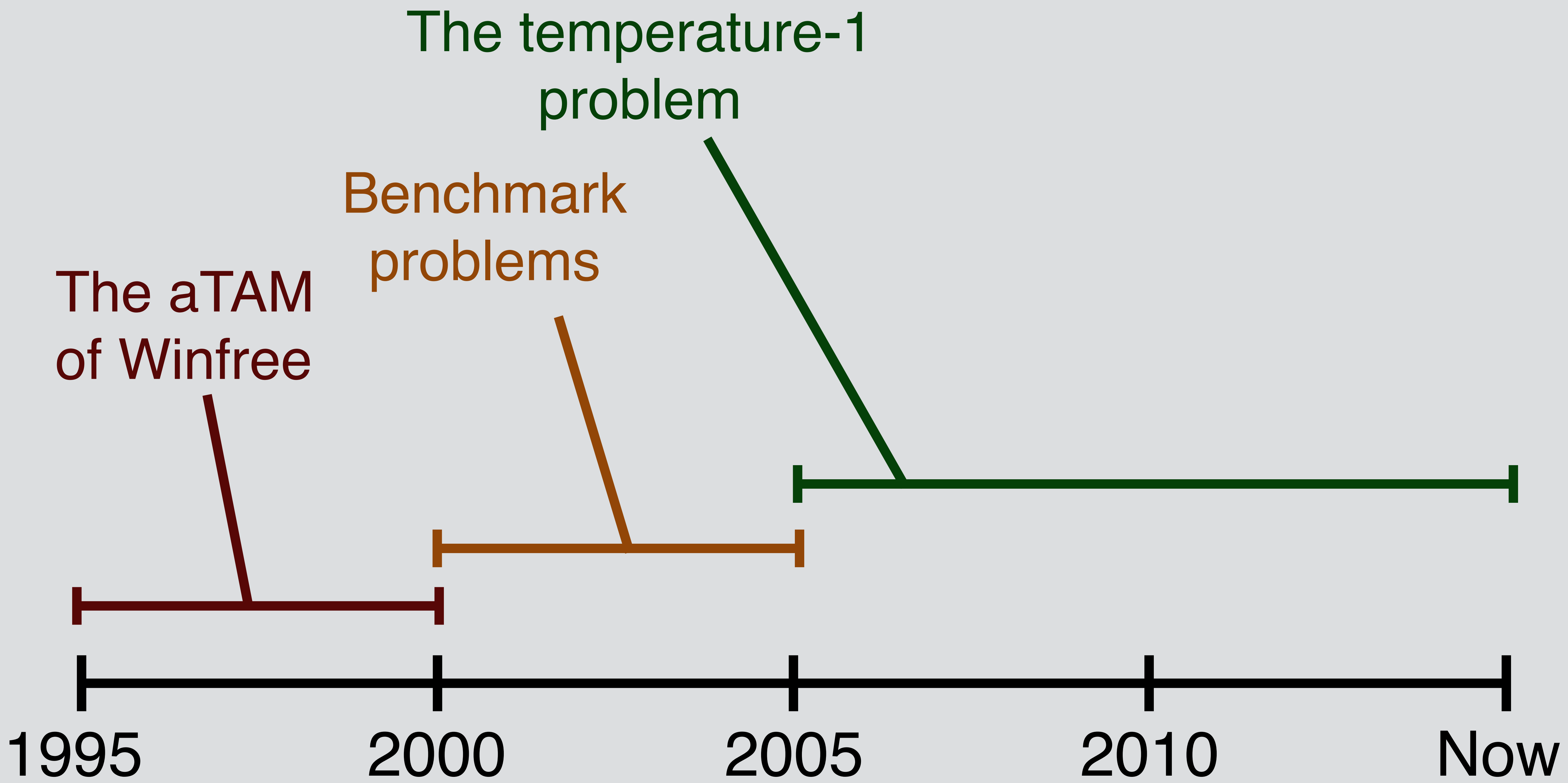
Fruits of intrinsic universality

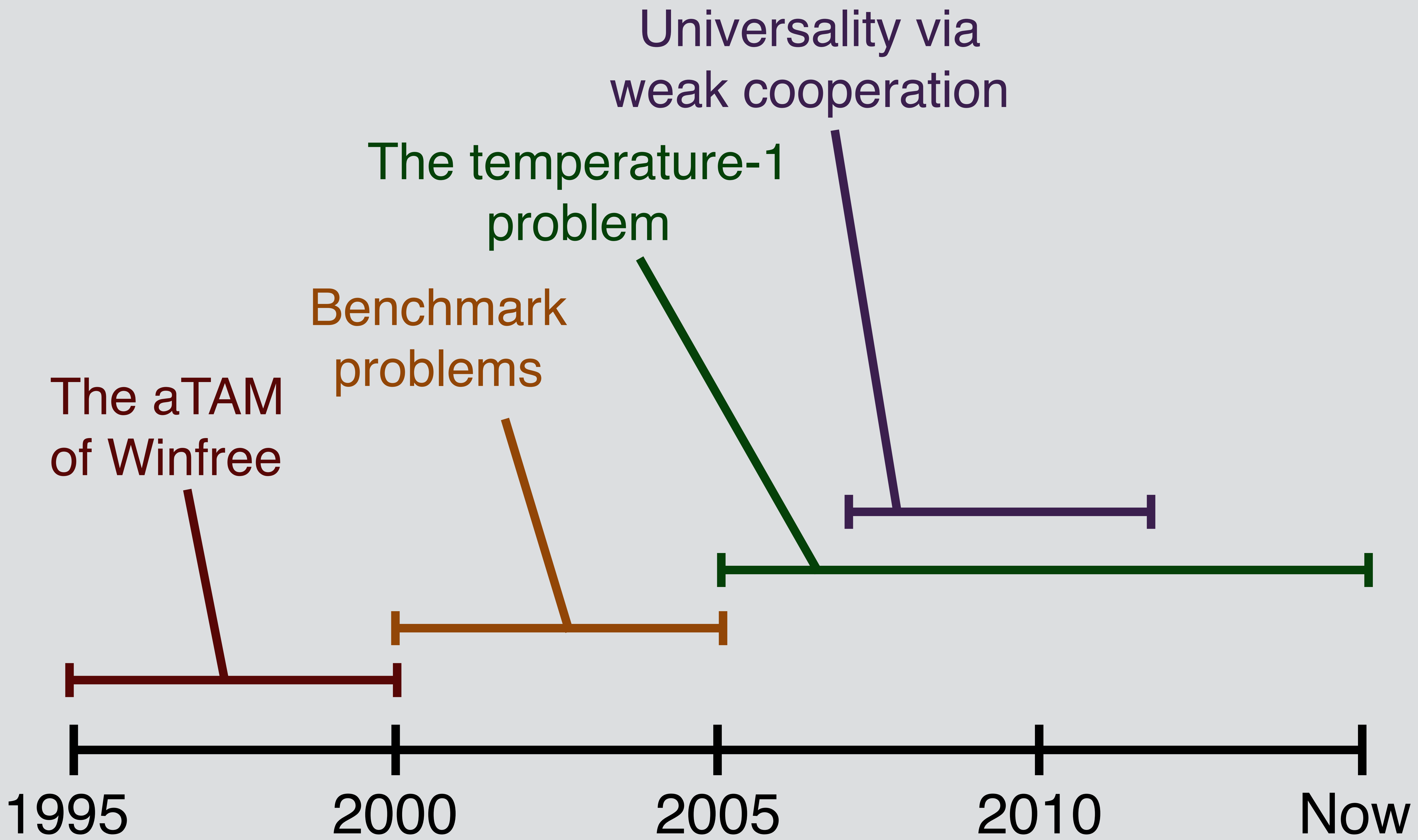


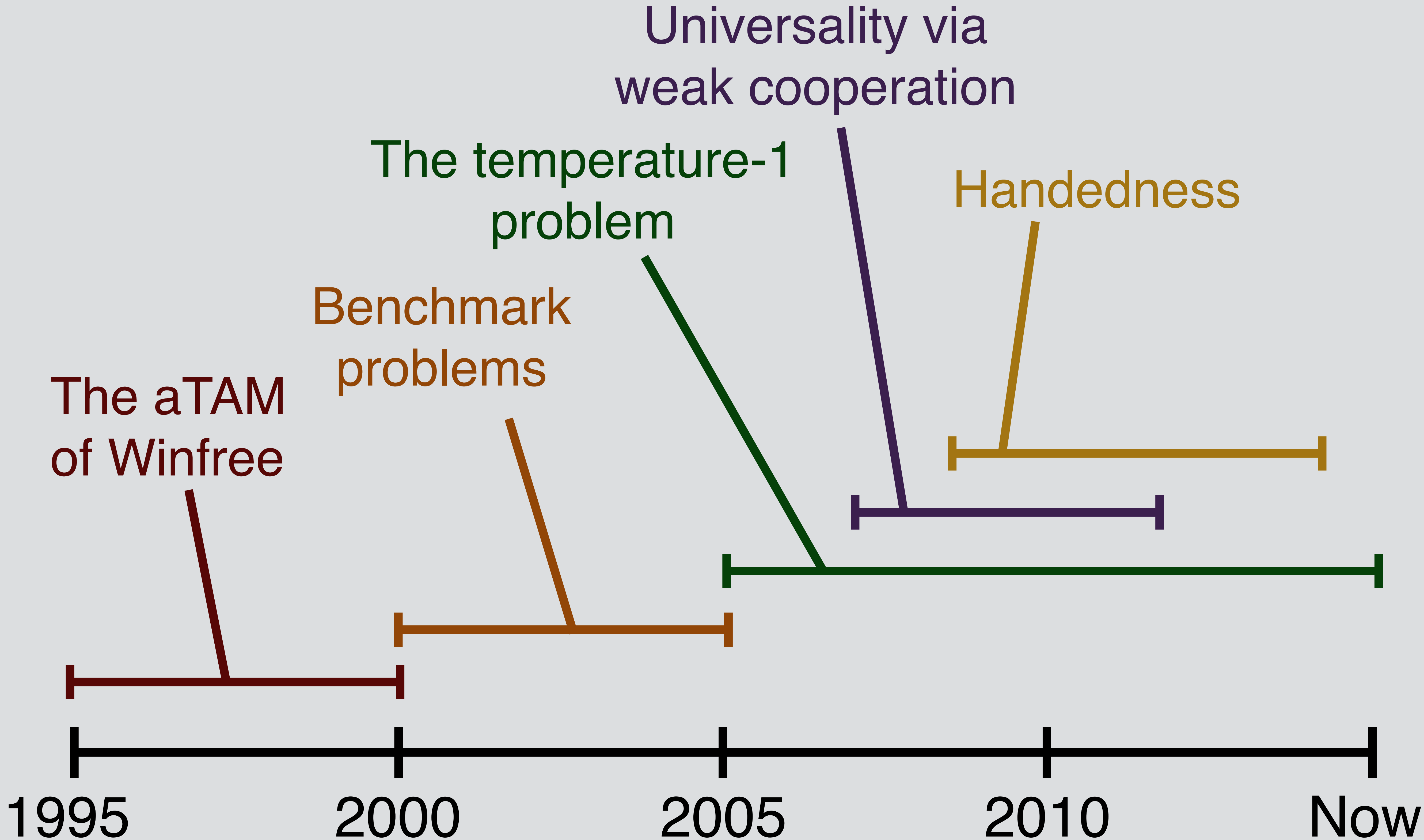

1995
2000
2005
2010
Now


The aTAM
of Winfree
1995
2000
2005
2010
Now


Benchmark
problems
The aTAM
of Winfree
1995
2000
2005
2010
Now


The temperature-1 problem
Benchmark problems
The aTAM of Winfree
1995
2000
2005
2010
Now


Universality via
weak cooperation
The temperature-1
problem
Benchmark
problems
The aTAM
of Winfree
1995
2000
2005
2010
Now


Universality via
weak cooperation
The temperature-1
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Handedness
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The aTAM
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1995
2000
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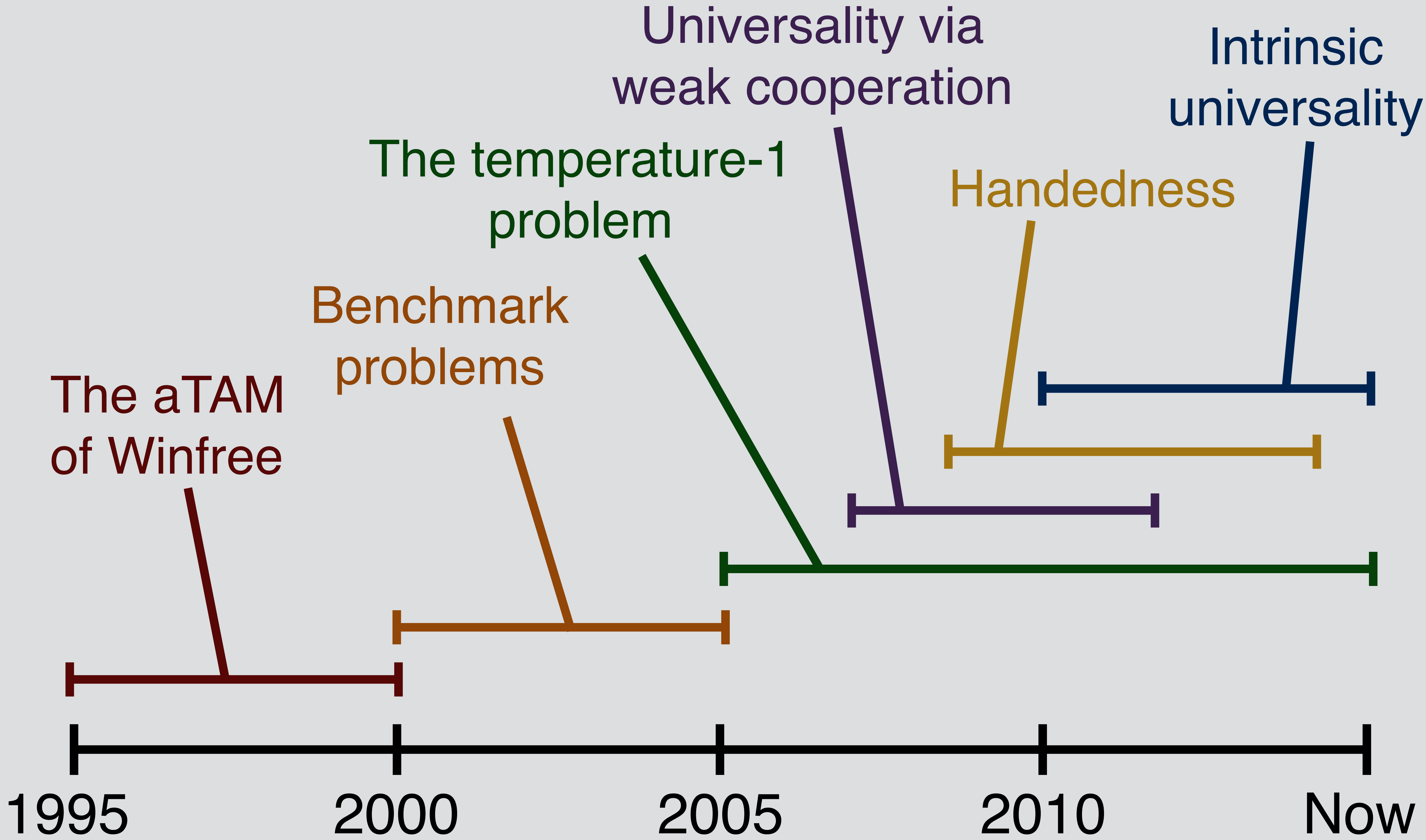
2010
Now



The aTAM
of Winfree
Benchmark
problems
The temperature-1
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Universality via
weak cooperation
Handedness
Intrinsic
universality
1995
2000
2005
2010
Now

Complete references and more in:

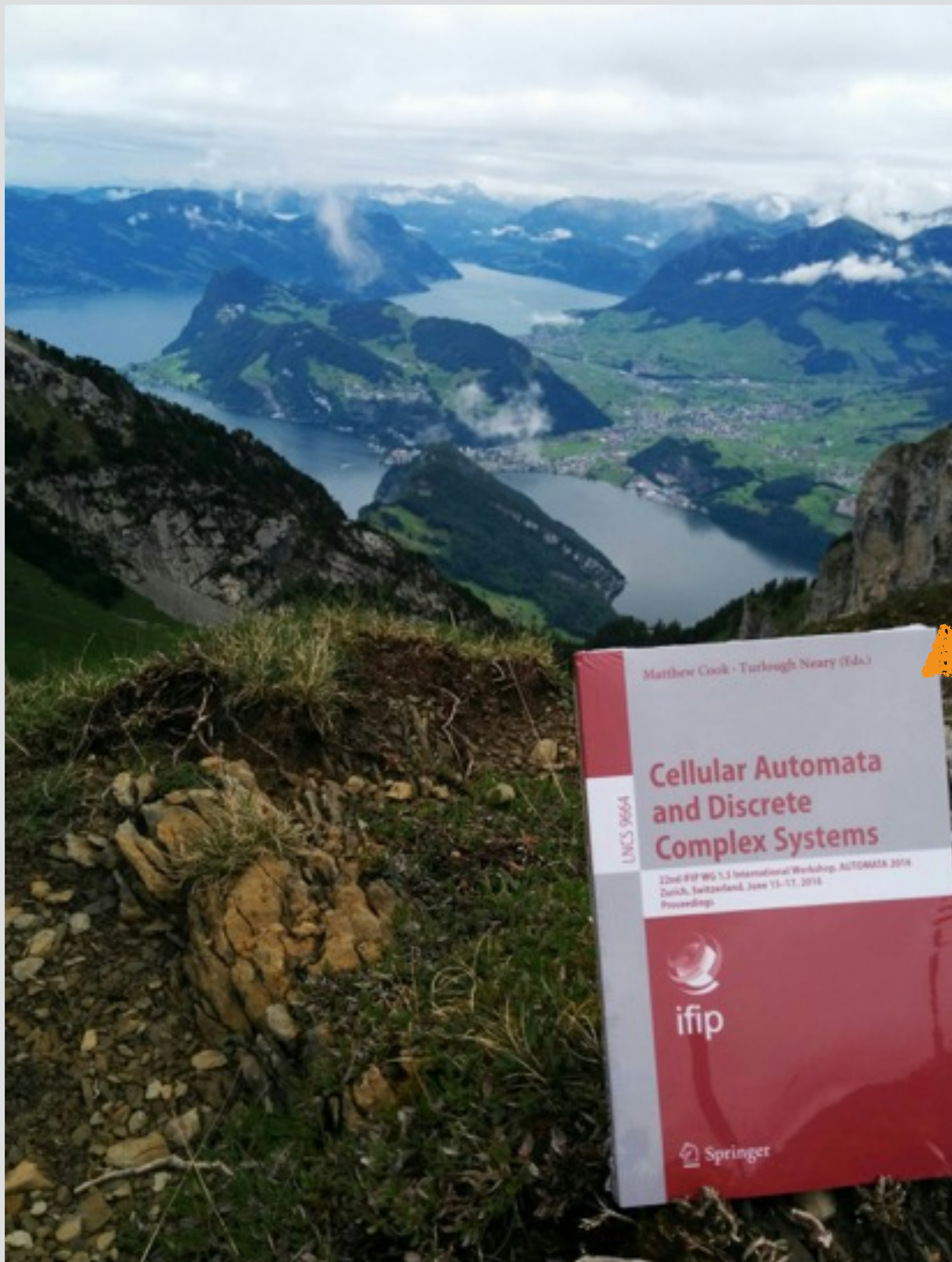
A Brief Tour of Theoretical Tile Self-Assembly

Andrew Winslow[1]

Université Libre de Bruxelles, Brussels, Belgium
awinslow@ulb.ac.be

Abstract. The author gives a brief historical tour of theoretical tile self-assembly via chronological sequence of reports on selected topics in the field. The result is to provide context and motivation for the these results and the field more broadly.

Complete references and more in:



A Brief Tour of Theoretical Tile Self-Assembly

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