Parallel Sorting on a Spatial Computer

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Max Orhai and Andrew P. Black
Portland State University

Maseeh College of Engineering and Computer Science
Undergraduate Research and Mentoring Program

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what is a *spatial computer*?

(definition based on 2012 Spatial Computing Workshop)

a networked system of computing devices distributed through a physical space, in which:

the 'problem'

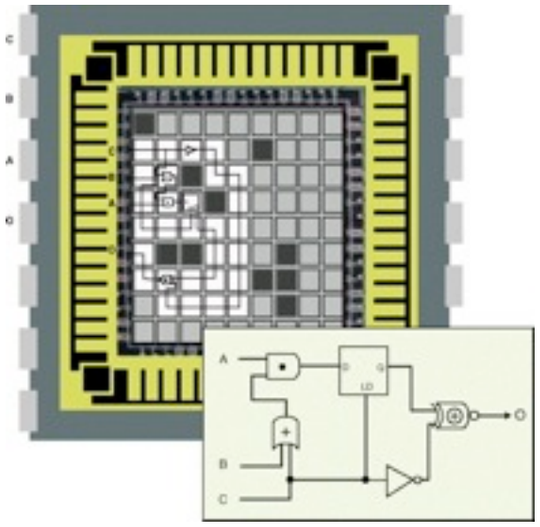
1. the *difficulty* of moving information between any two devices depends on the physical *distance* between them, and

the 'solution'

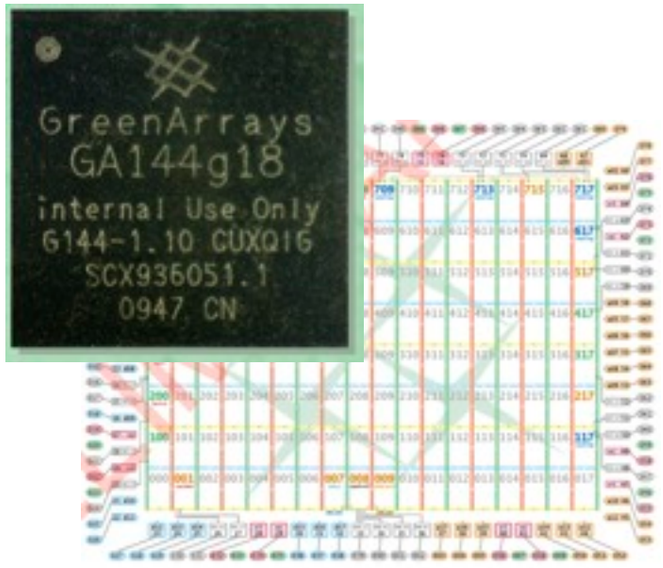
2. the *functional goals* of the system are defined in terms of the system's *spatial structure*.

are these spatial computers?

fine-grained → coarse-grained



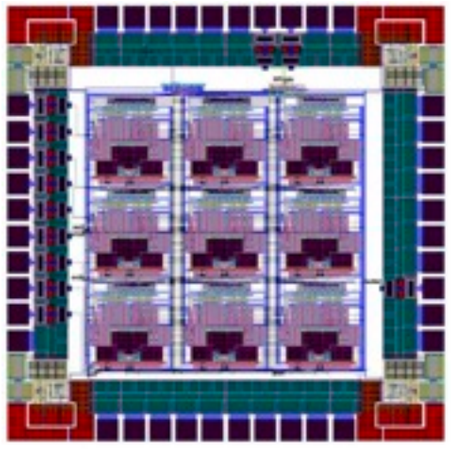
cell matrix tile
(Macias & Durbeck 2009)



GreenArrays *GA144*
asynchronous stack
machine array
(2010)

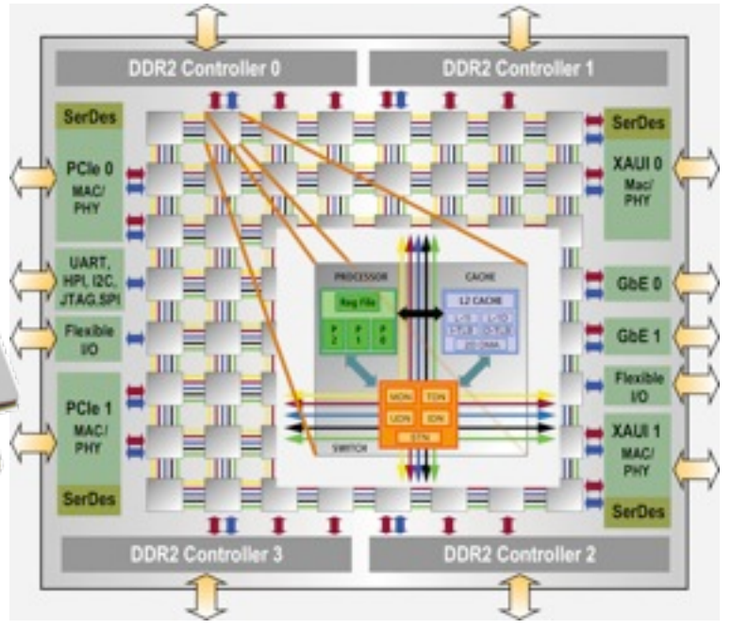
Inmos *transputer* array
(early 1980s)

XMOS *XMP-64*
dev kit (2010)



asynchronous logic automata
cell (Chen 2009)

Tilera *Tile64* (2008)



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message of this talk

spatial computing offers real insights into

1. the *costs* and *constraints* of communication in large parallel computer arrays
2. how to design *algorithms* that respect these costs and constraints

match the *communication structure* of the program to the *physical structure* of the computer network

our example: collision sort

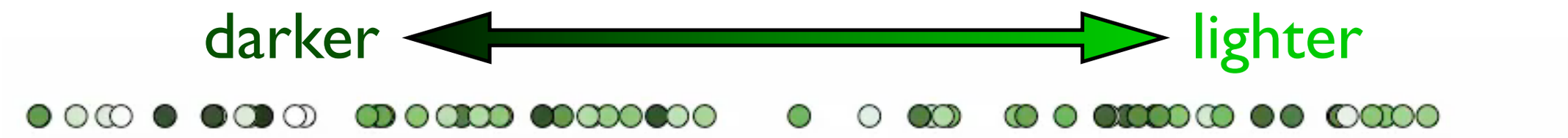
approach:
an entropy-reducing particle system

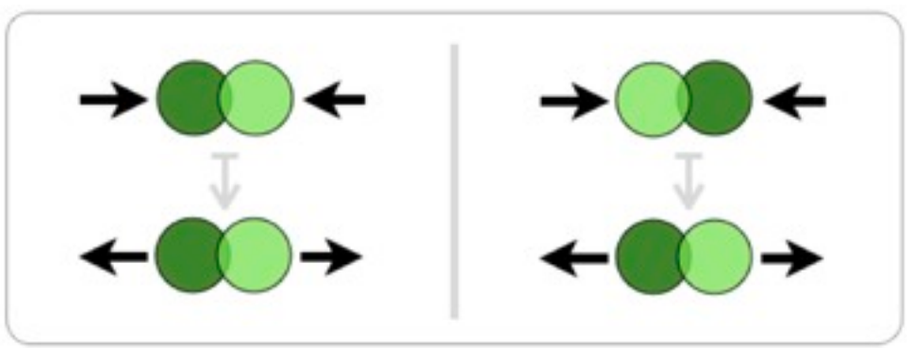
goal:
arrange particles by color

simulation physics ~ *computing machinery*

space ~ order
particles ~ data
collisions ~ comparisons

distributed computation of a *global* solution using only *local* information and *minimal* communication

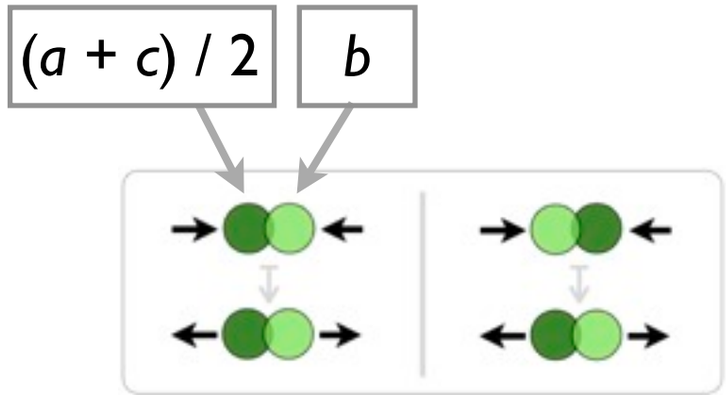




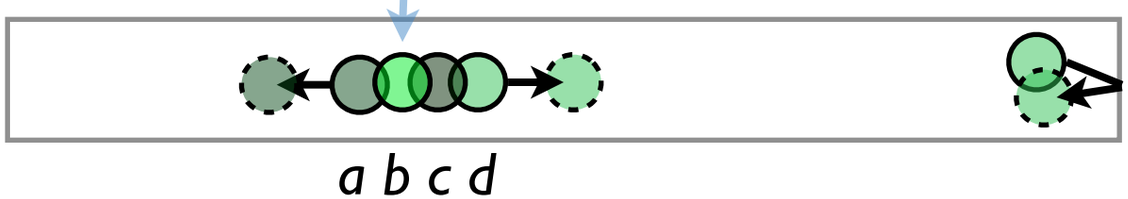
collision sort: mechanism

physics		*computation*
space	~	order
particles	~	data
collisions	~	comparisons

in a *single* step, the color of particle *b* is compared with the *average color* of overlapping particles *a* and *c*



multi-way collisions quantize time



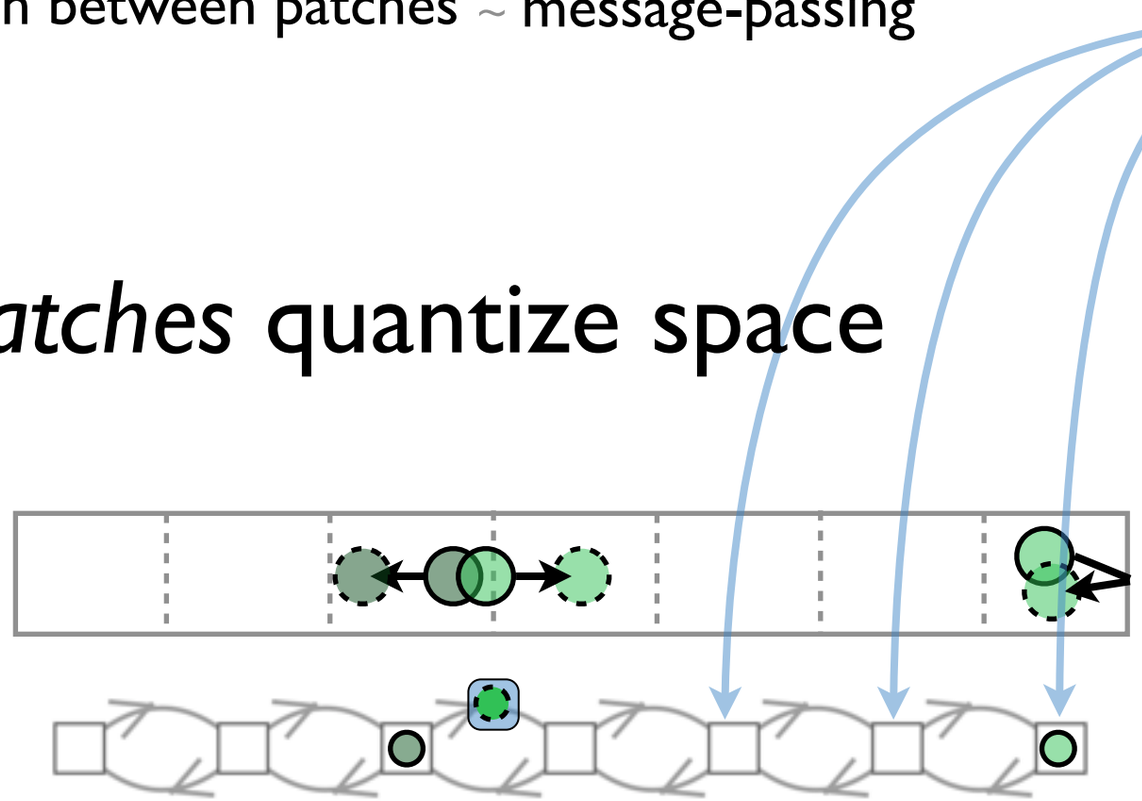
‘boundary collisions’ always cause rebound

collision sort: mechanism

physics		*computation*
space	~	order
particles	~	data
collisions	~	comparisons
patches of space	~	processors
motion between patches	~	message-passing

collisions *across* patches are *not* detected!

patches quantize space

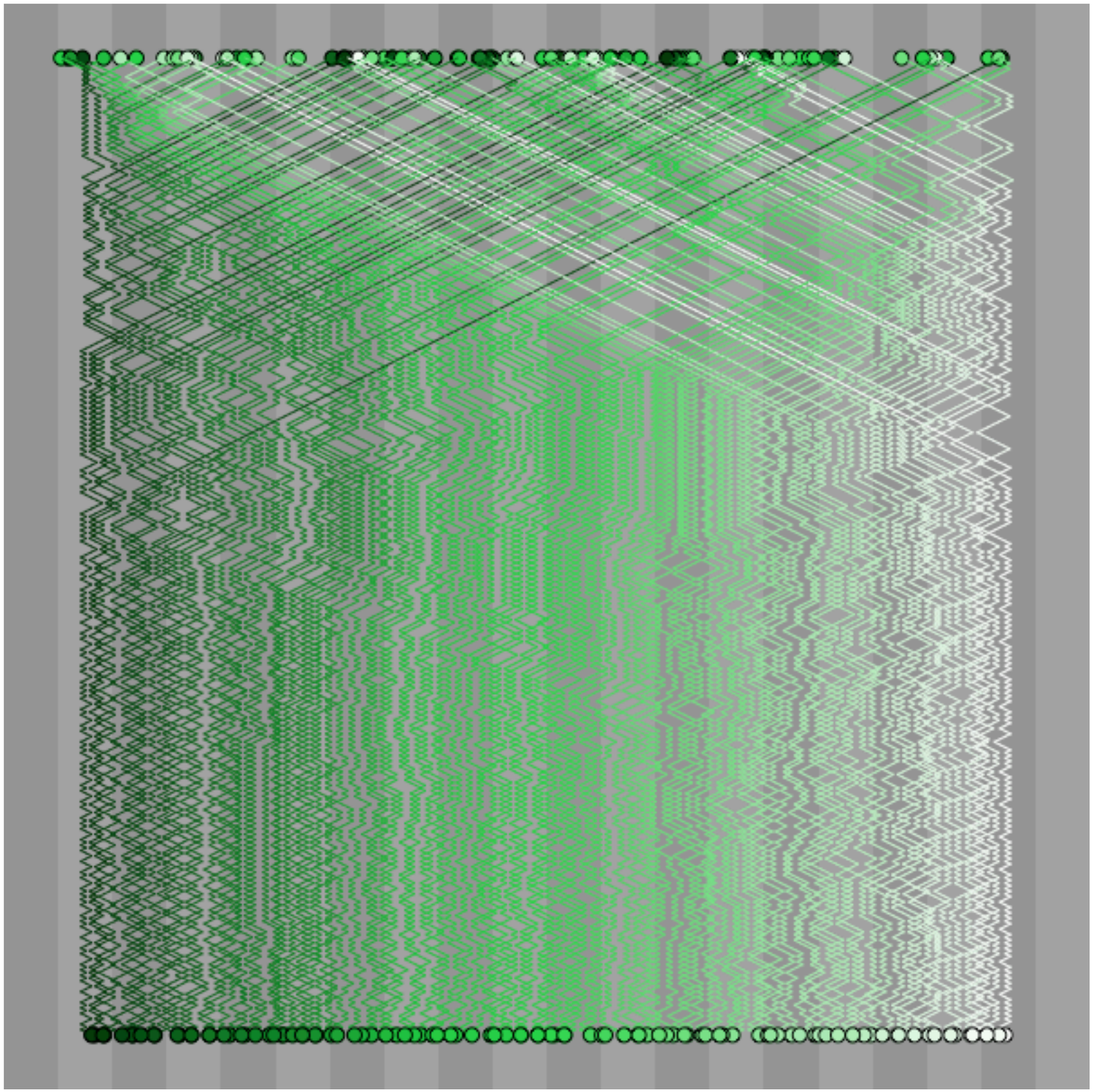


loop (one *step*):

- accept incoming particles from neighbors
- detect collisions and alter velocities accordingly
- increment positions, sending outgoing particles to neighbors

collision sort: low speed

100
particles



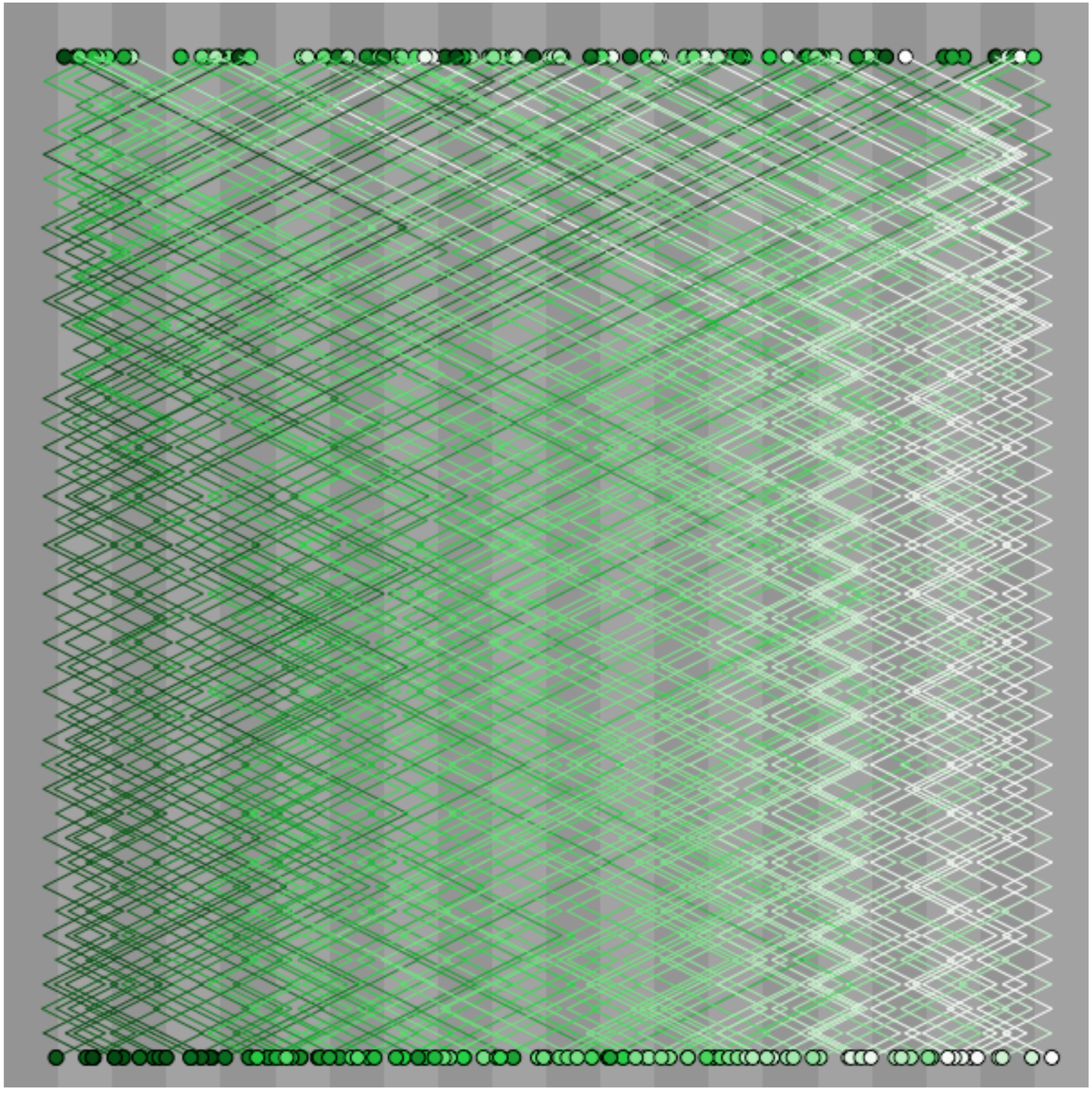
constant
speed:

0.1

patch-widths
per step

collision sort: high speed

100
particles



constant
speed:
0.9

patch-widths
per step

collision sort: variable speed

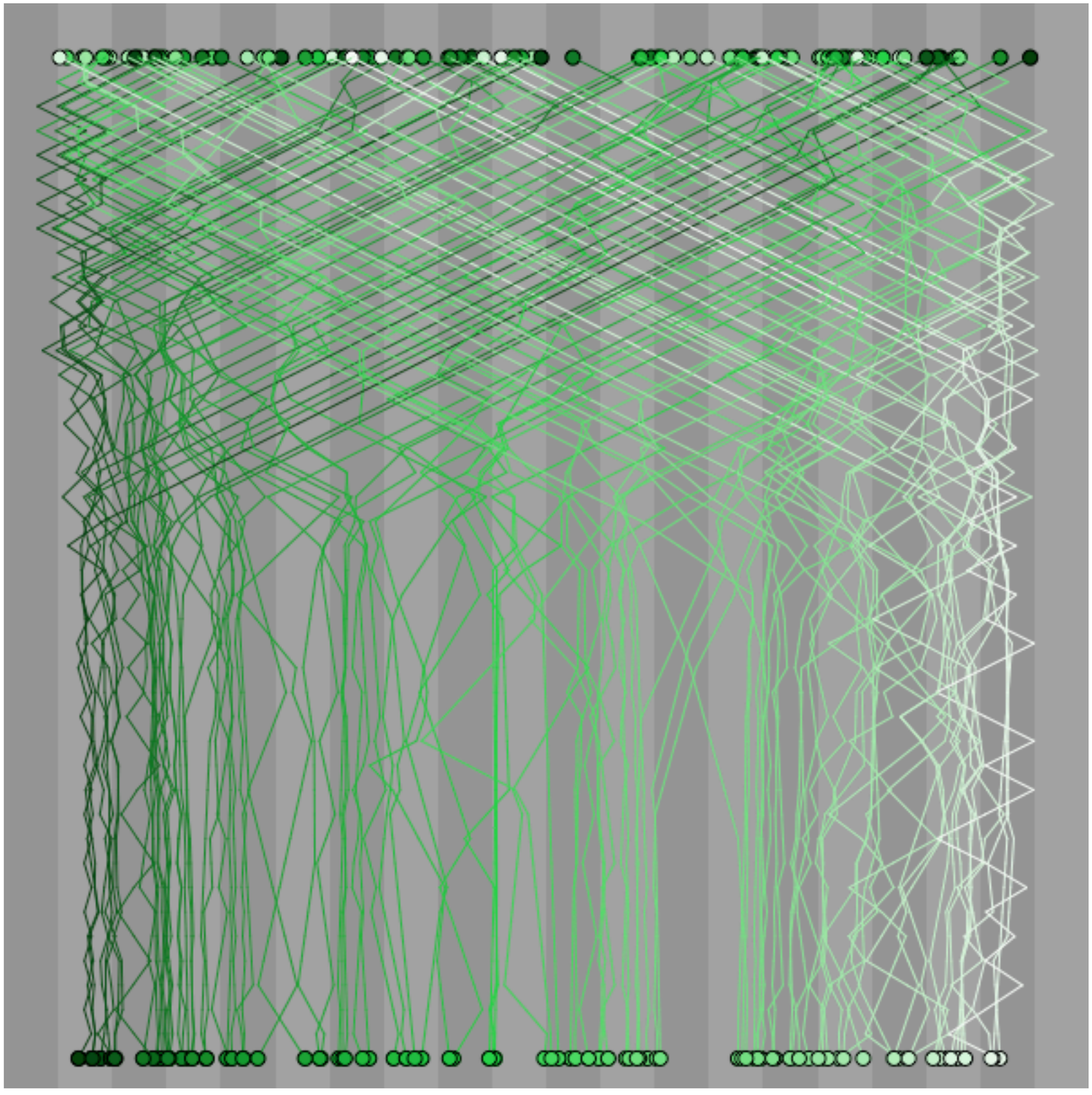
100 particles

speeds proportional to color differences

maximum speed:

0.9

patch-widths per step



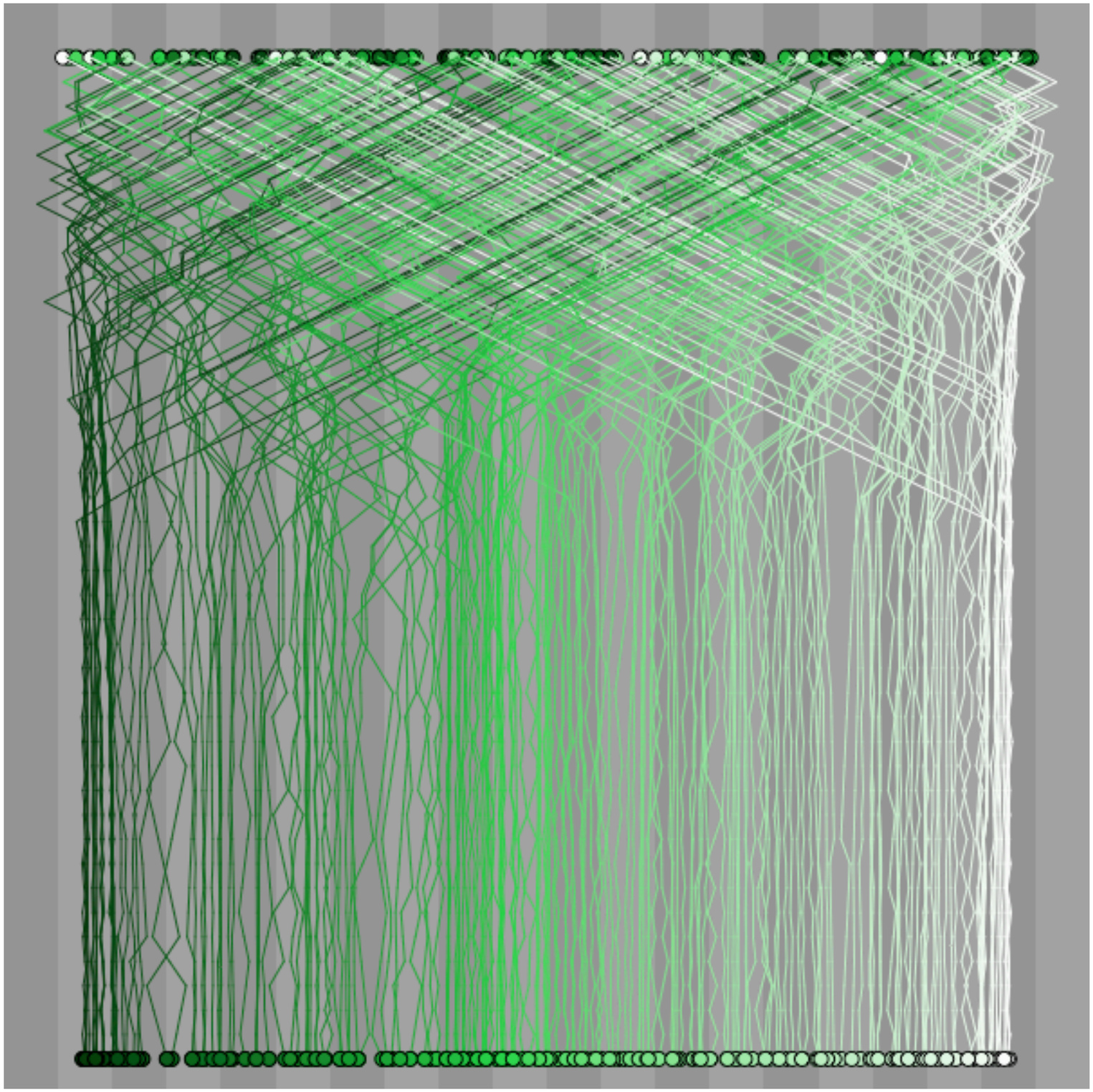
collision sort: more data

200
particles

speeds
proportional
to color
differences

maximum
speed:
0.9

patch-widths
per step



0

time

40
steps

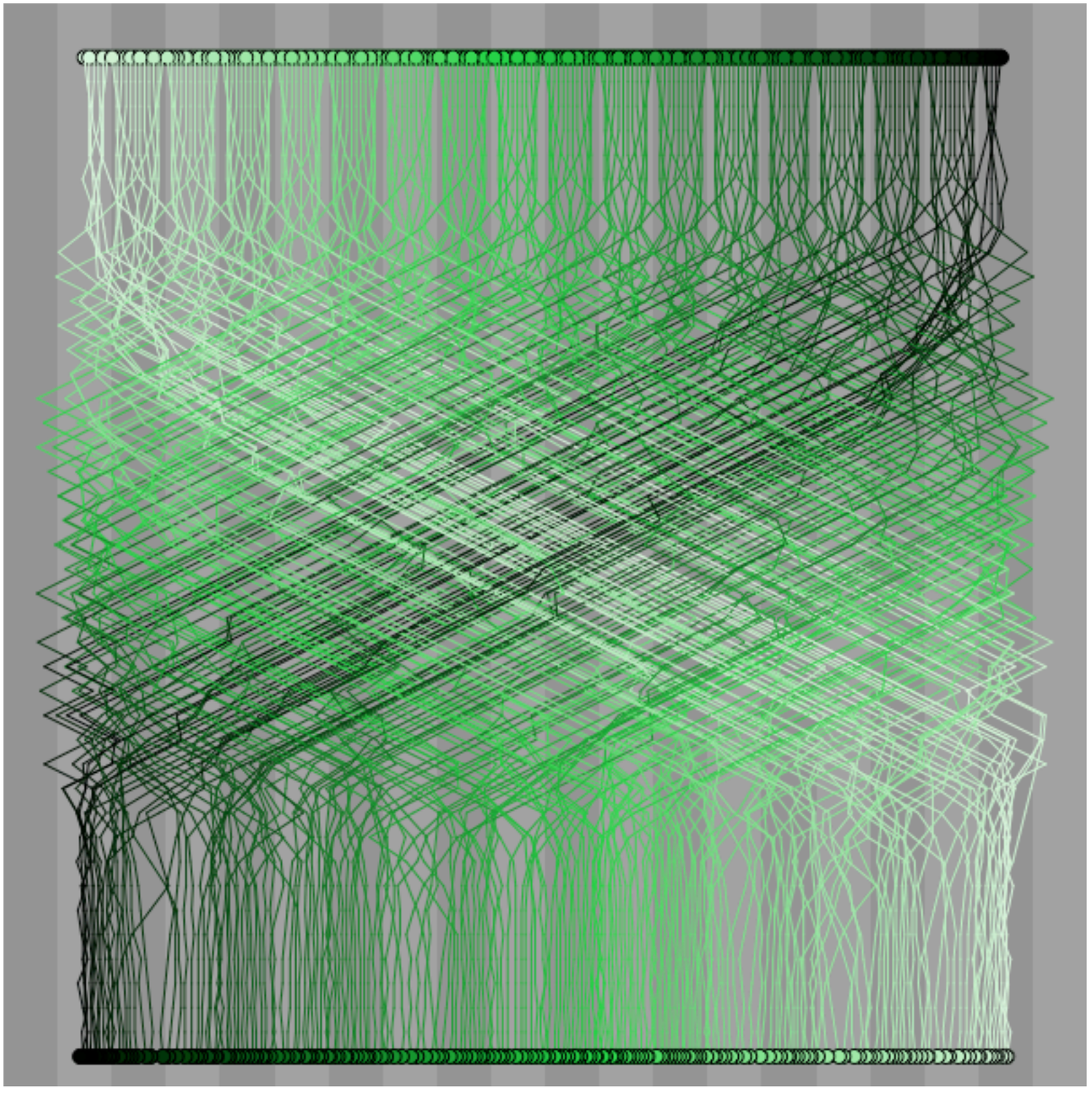
collision sort: worst case?

200 particles in reverse order

proportional speeds

maximum speed: 0.9

patch-widths per step



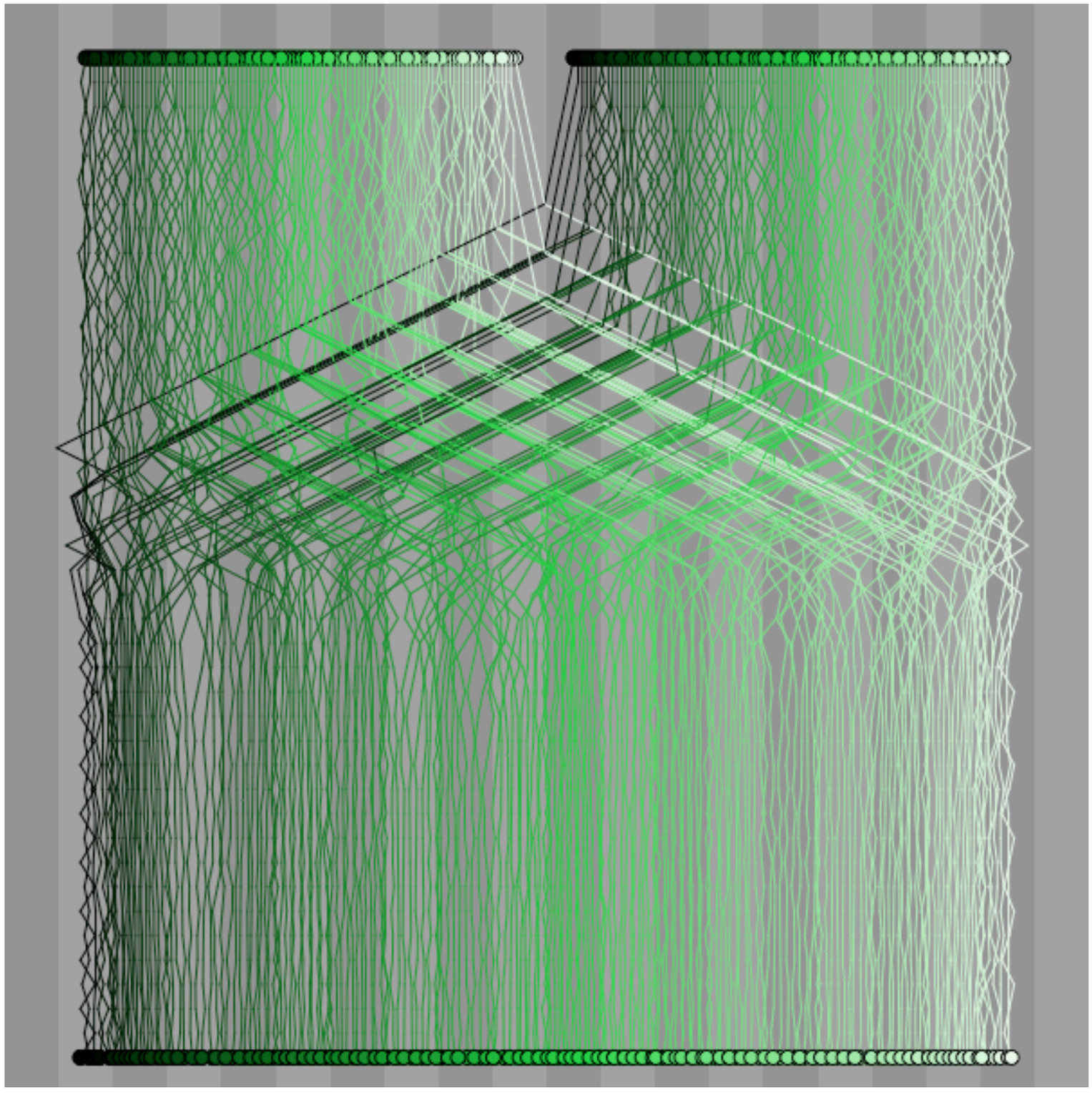
collision sort: worst case?

200
particles
in two sorted
subsequences

proportional
speeds

maximum
speed:
0.9

patch-widths
per step



collision sort: in 2D

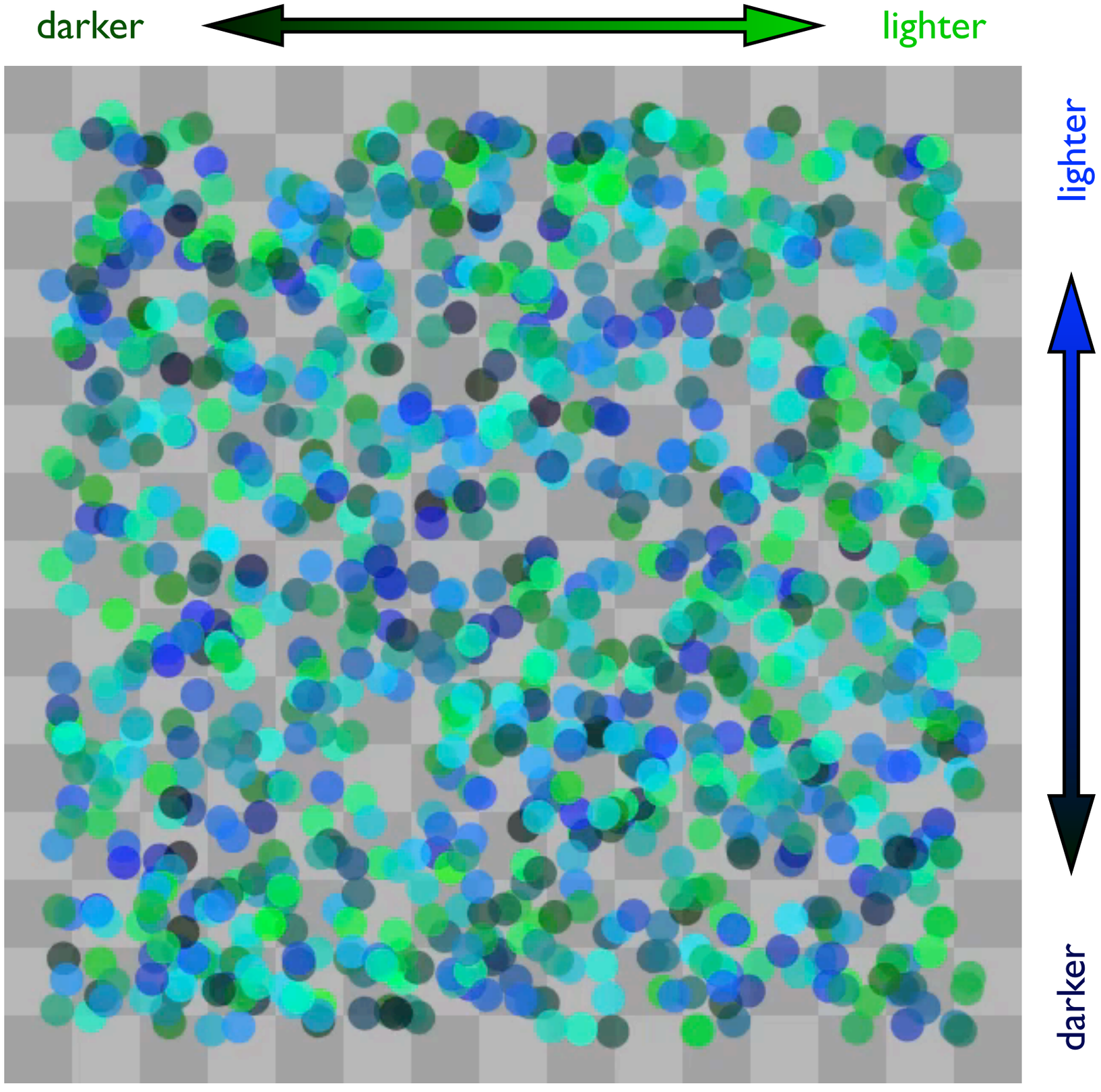
1000 particles each with *both* blue *and* green values

proportional speeds

maximum speed:

0.9

patch-widths per step per axis



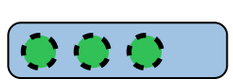
collision sort: performance

the total cost of any parallel
algorithm is a combination of
local computation costs and
communication costs

for simplicity, we assume that
local computation is cheap,
and focus on the
cost of *communication*
between system components

collision sort: performance

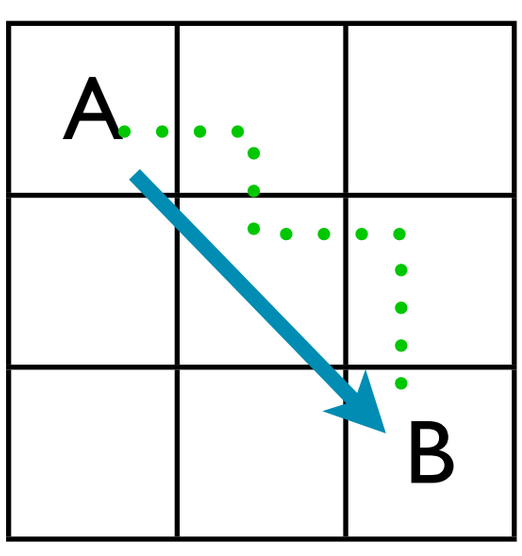
messages may convey *multiple* particles



because each processor need only

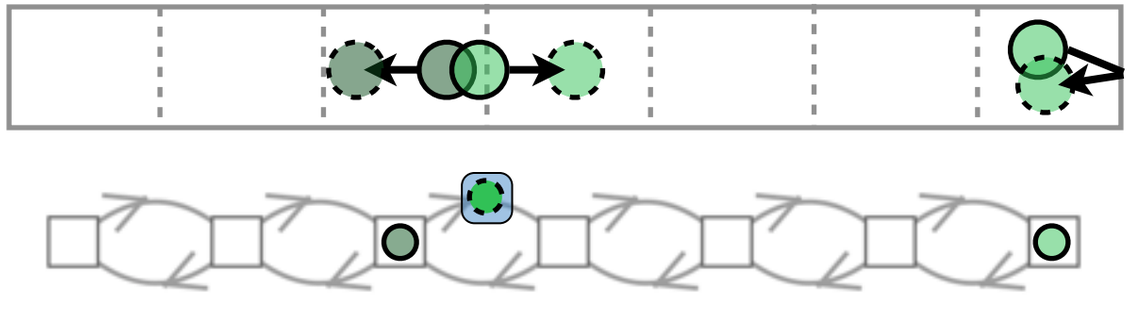
- *receive* at most one and
- *send* at most one message

per neighbor during each loop cycle,



communication cost is *the minimum possible*, under these assumptions:

- a one-patch-per-step information speed limit
- message cost independent of message size
- local computation is free



collision sort: performance

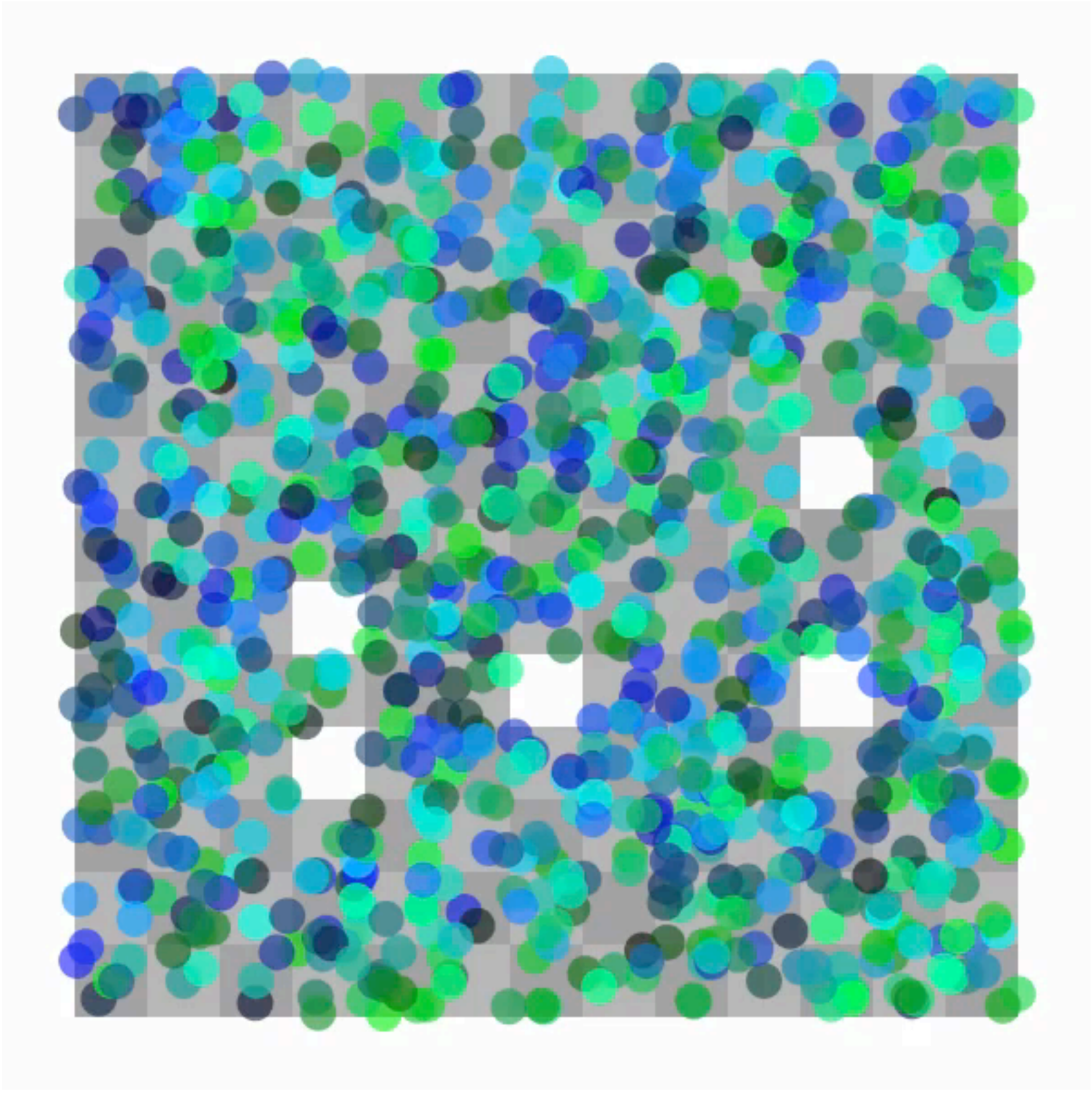
what about *component failure*?

if messages are *acknowledged*, then any 'undeliverable' particles can simply have their velocities reversed, just as in a boundary collision:

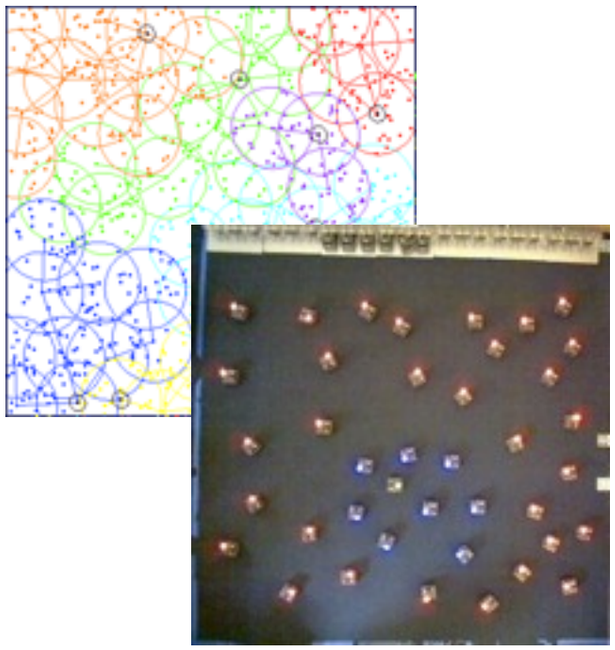
particle bounce ← message bounce

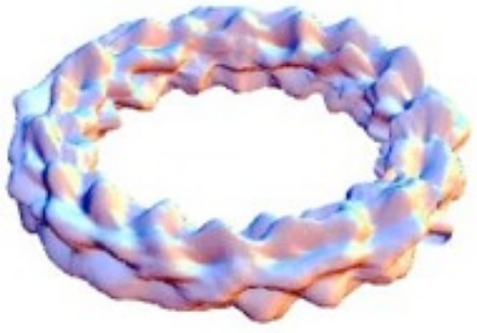
fault tolerance is an 'emergent property' of this rule!

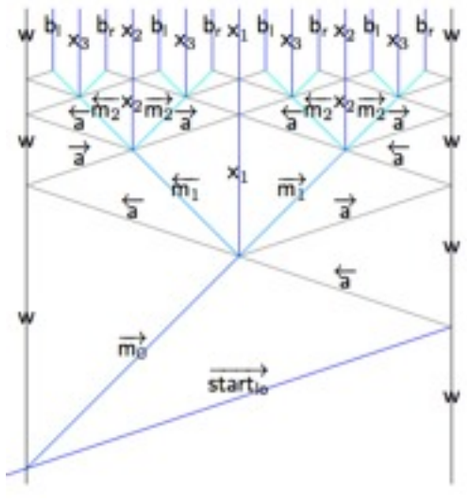
collision sort: fault-tolerance



related work: spatial computing







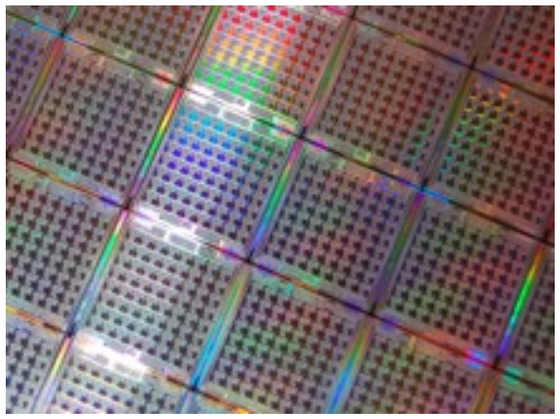
research efforts:

- MIT CSAIL *amorphous computing* project, c. 2000
  → BBN *Proto* language
- Laboratoire IBISC (Computer Science, Systems Biology and Complex Systems) at U. d'Evry
  → *MGS* topological simulation language
- abstract geometric computation (*continuous signal machines*)
  D. Duchier, J. Durand-Lose, M. Senot at U. d'Orleans

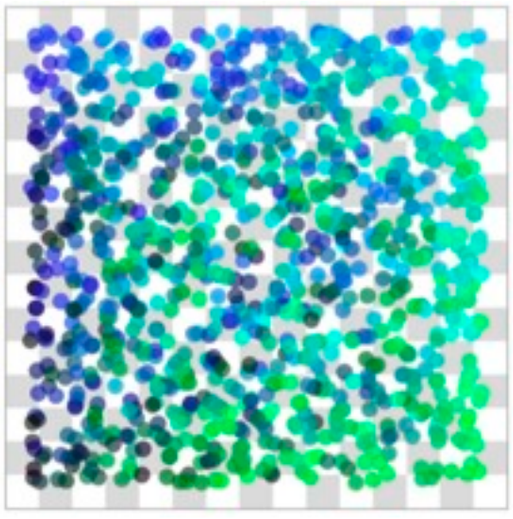
application domains:

- large-scale sensor networks
- distributed control systems
- mobile robot swarms
- biological modeling
- computability theory

conclusion



Tilera processor arrays



large-scale parallel computer arrays *can b*e spatial computer systems, if programmed in a way that respects physical distances.

spatial computing gives us a *cost model* that approximates the physics of information transmission, and that *leverages our intuition* about physical objects to design concurrent algorithms.

references:

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