



Crowds and Emergent Teamwork

Craig Reynolds

presented at PARC
June 25, 2009

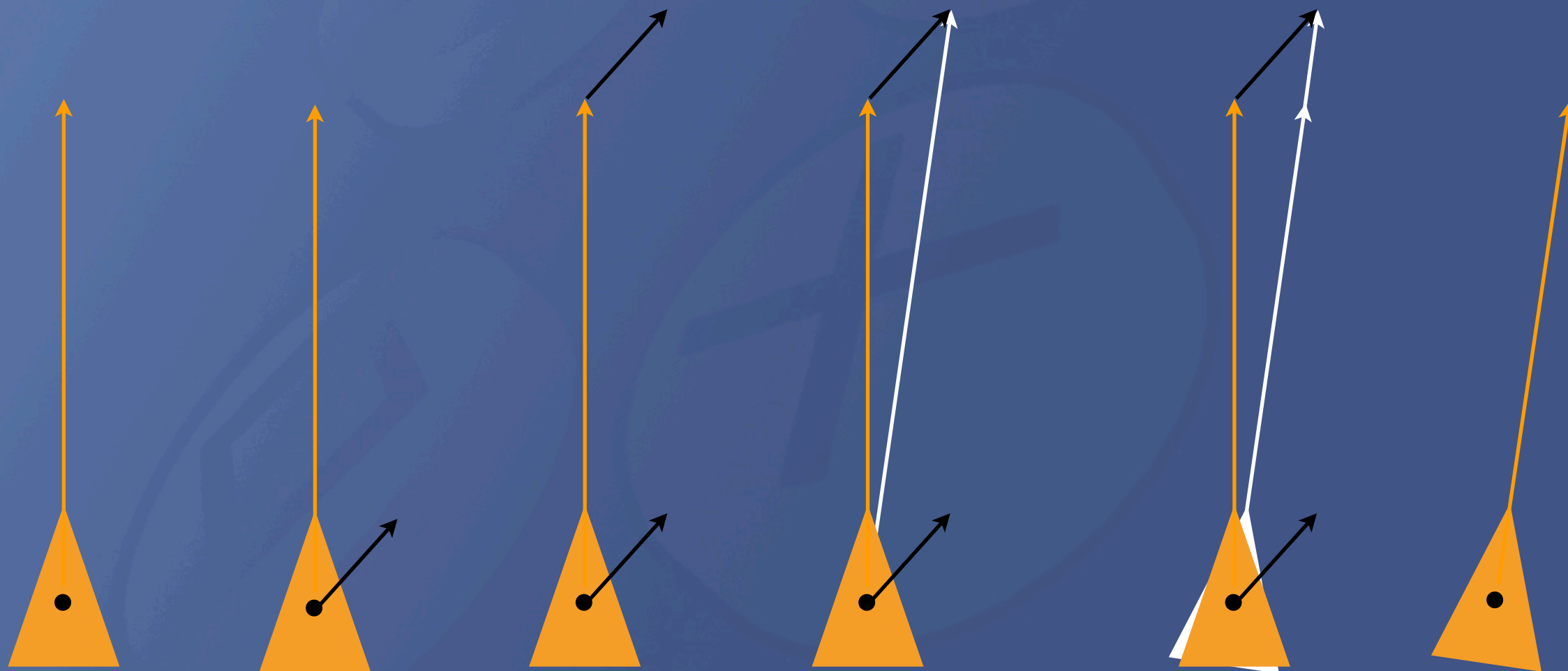


In this talk

- Steering behaviors
- Flocks and crowds
- “Non trudging crowds”
- Collective construction



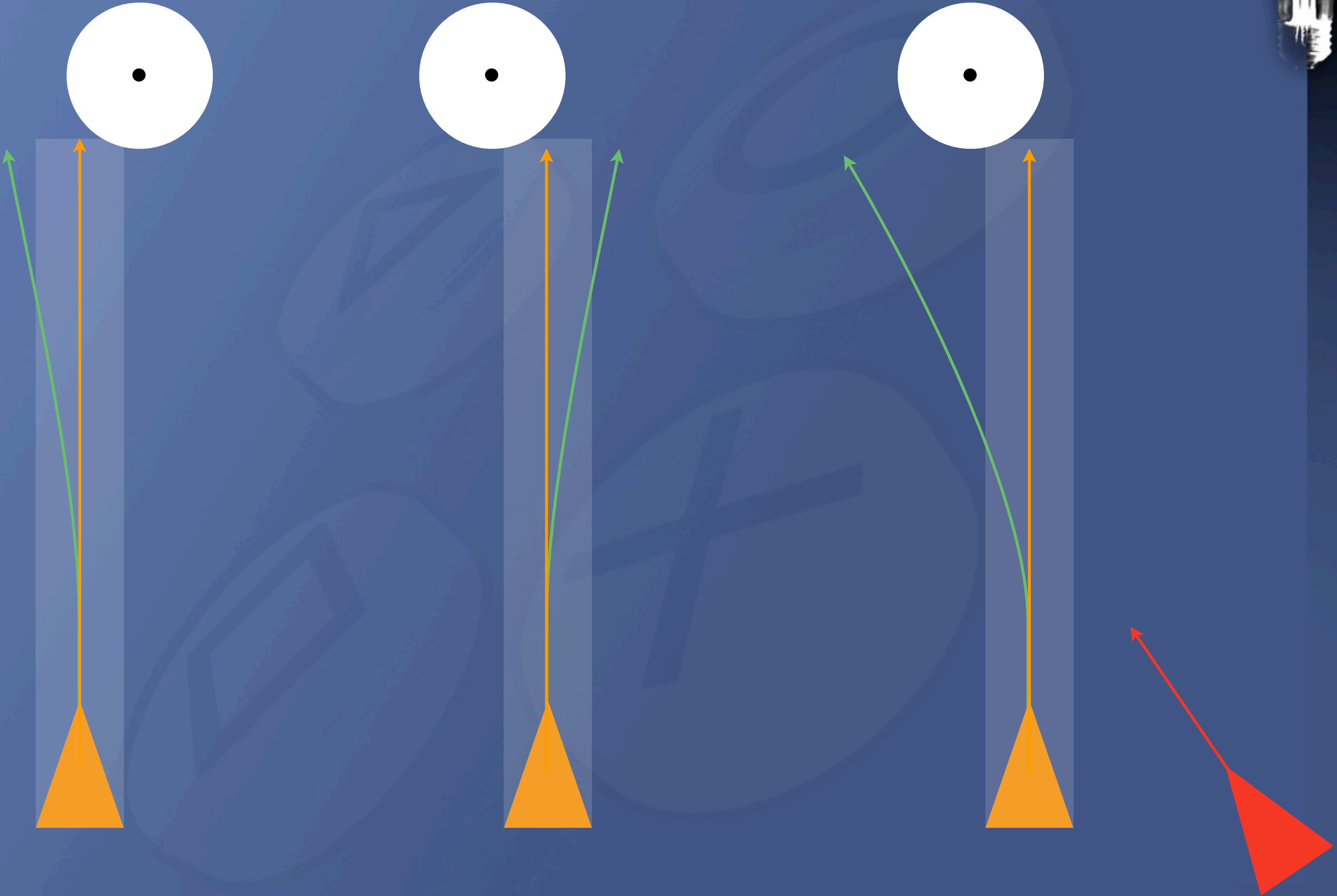
Steering behaviors and simple point mass vehicles

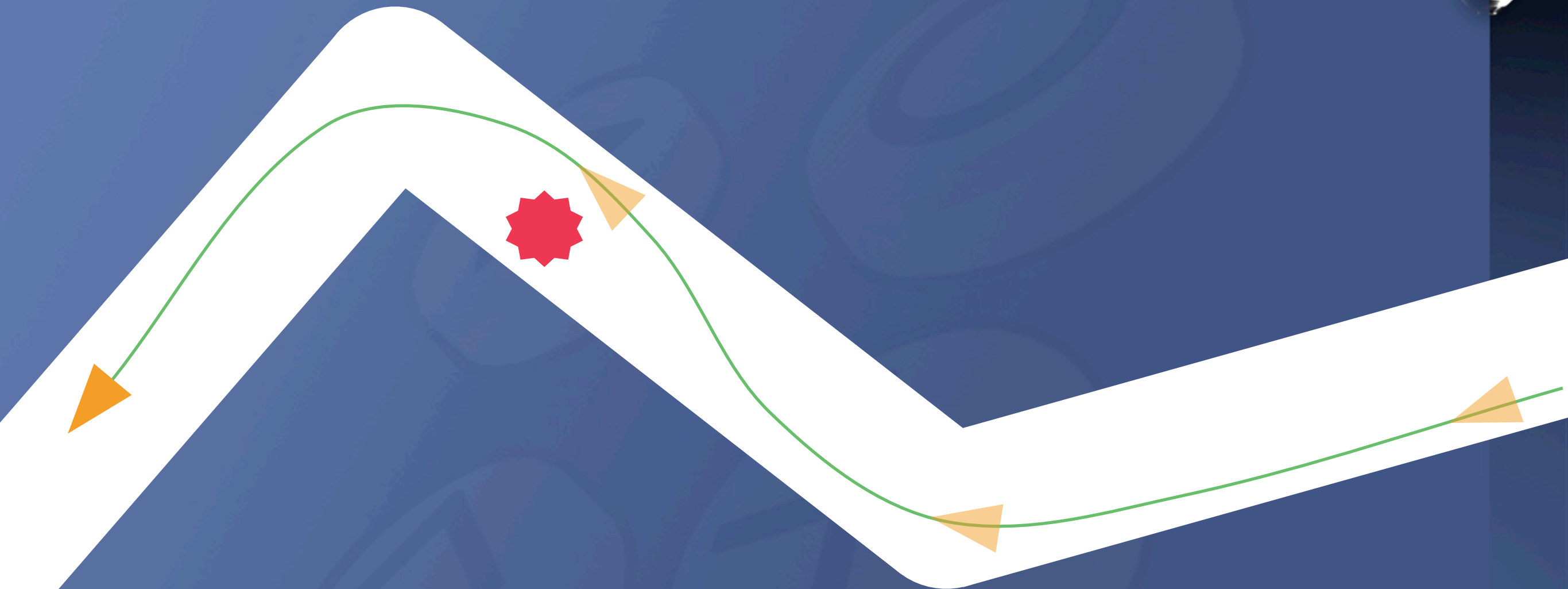




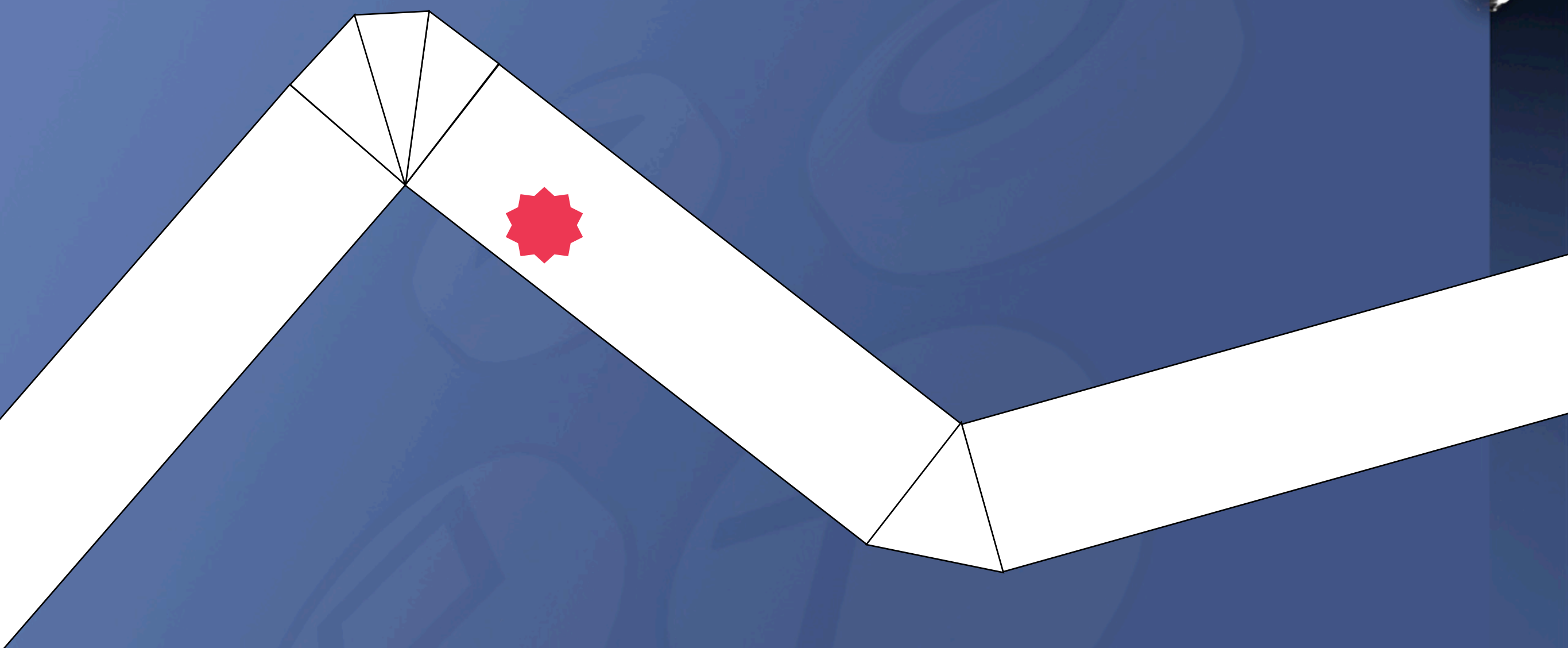
Steering behaviors

- seek / flee
- pursue / evade
- wander
- arrival
- avoid obstacle
- containment
- path following
- wall following
- flow field following
- flocking
 - separation
 - alignment
 - cohesion

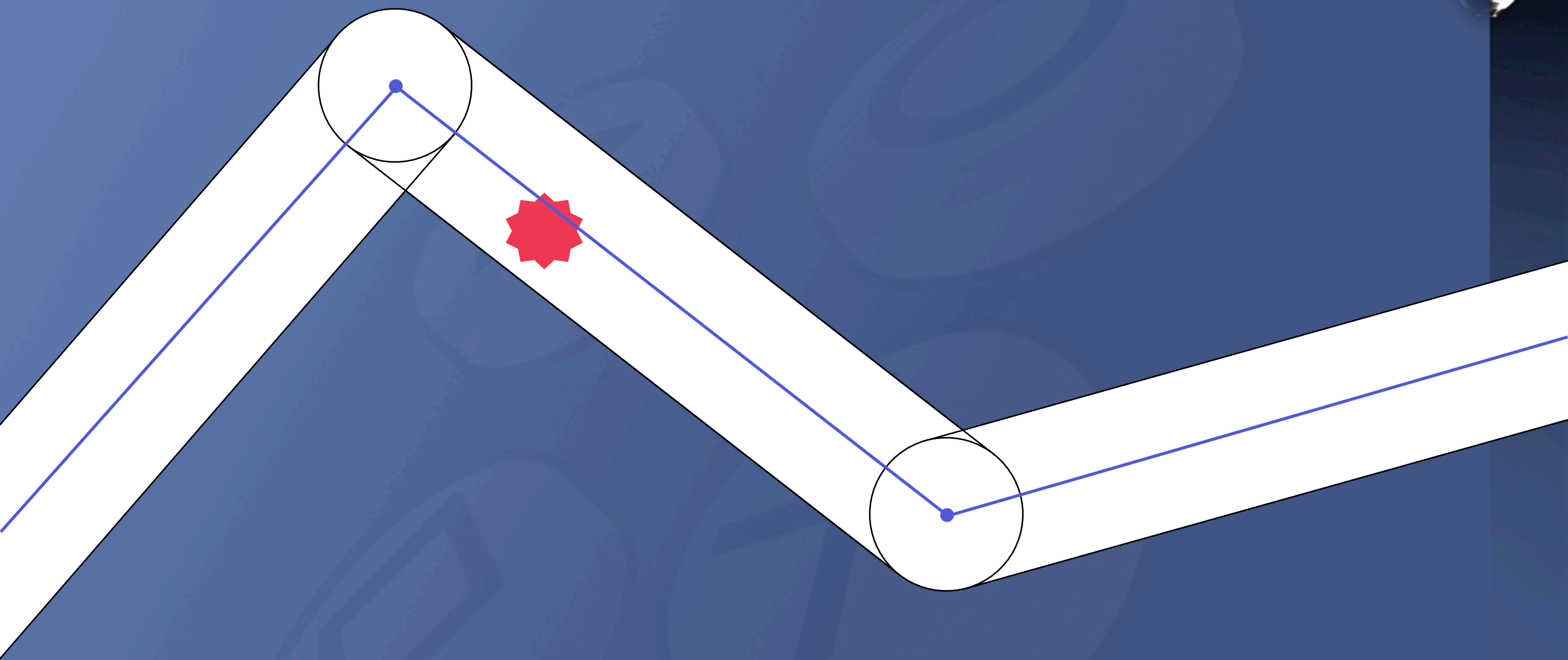




composed steering behaviors:
follow path and avoid obstacle



Navigation mesh



sphere swept along polyline



Demo





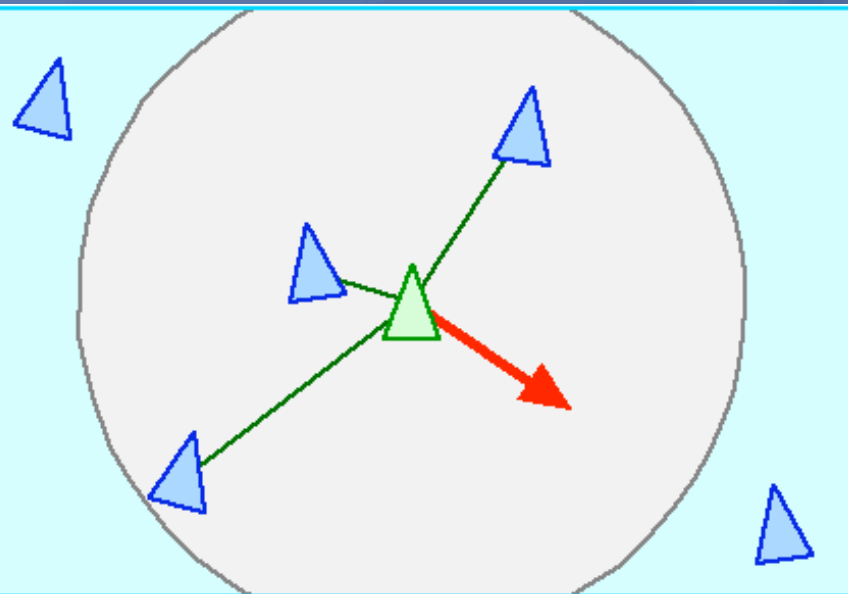
Flocks, herds, schools, crowds...

- 1987 boids model of group motion
- Early procedural animation of characters
- Applied to TV, movie and game production
- Focus was always on group **motion**

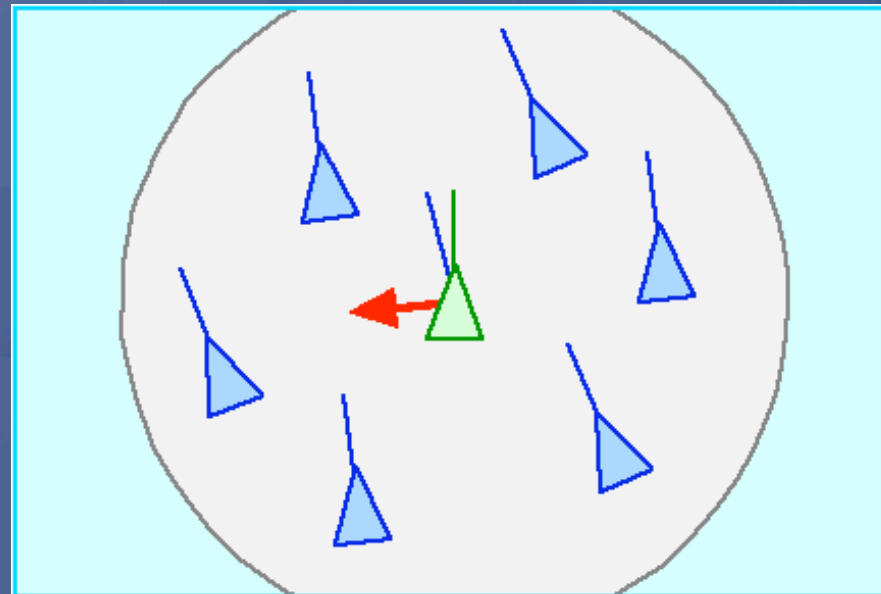


Flocking boids:

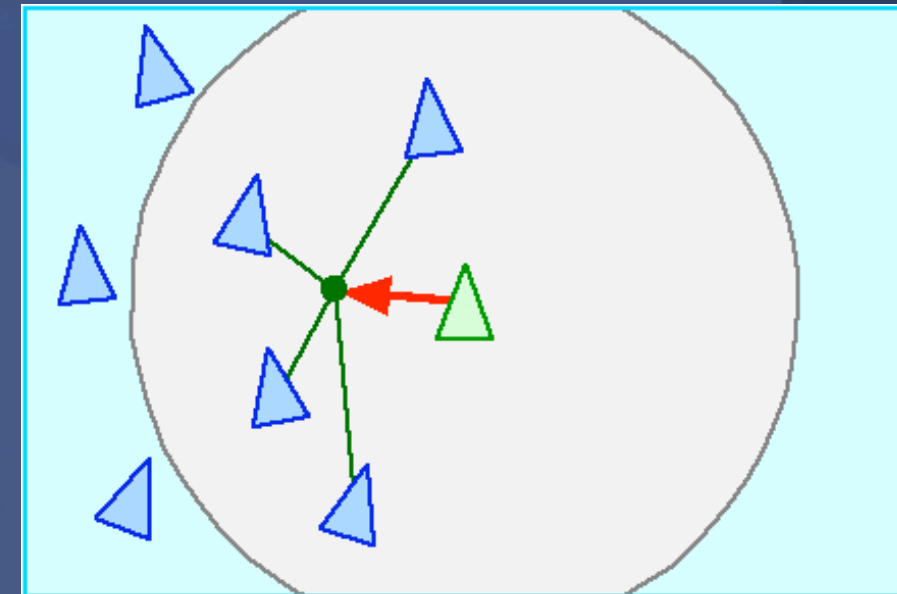
three component steering behaviors



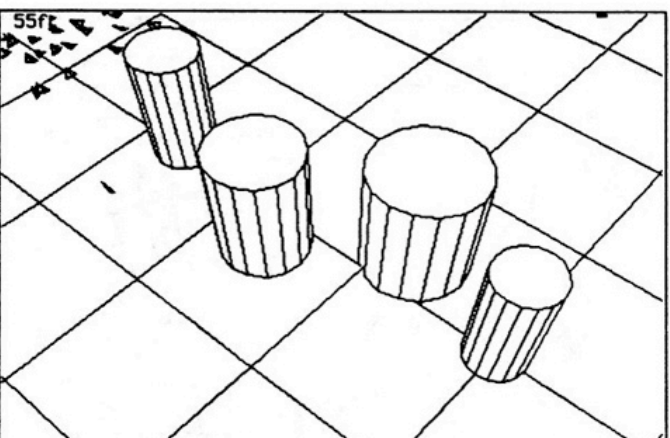
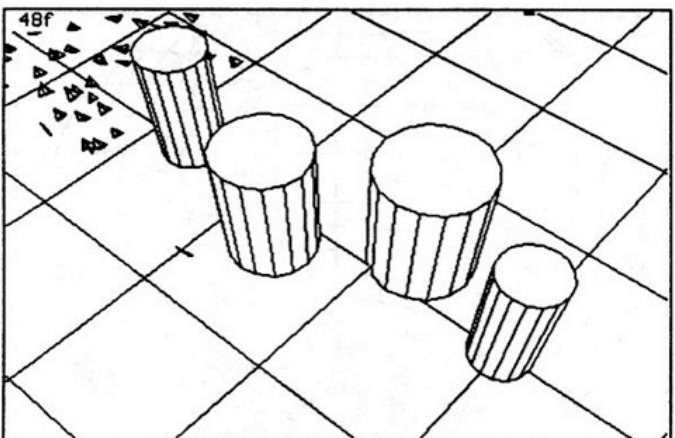
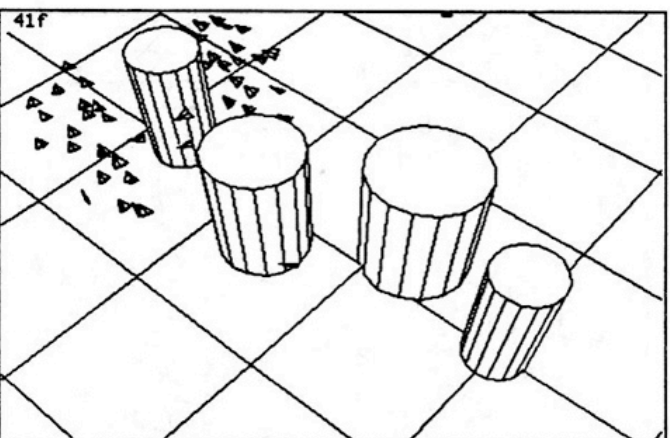
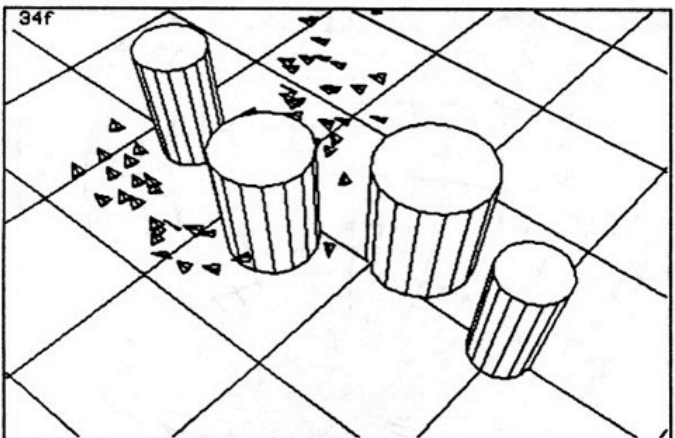
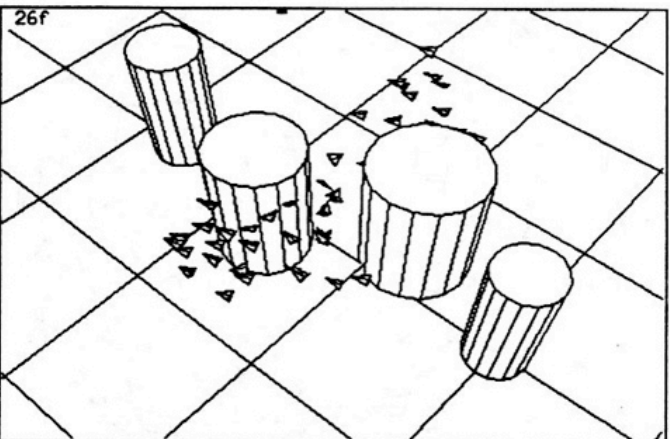
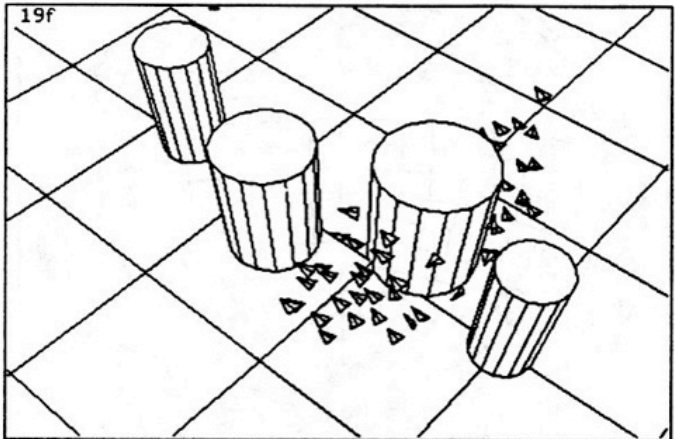
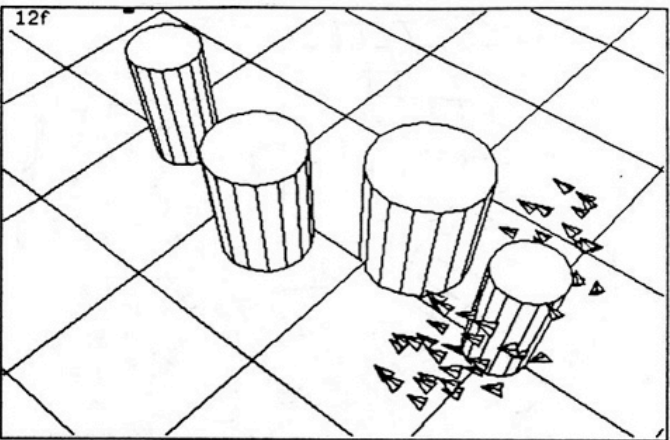
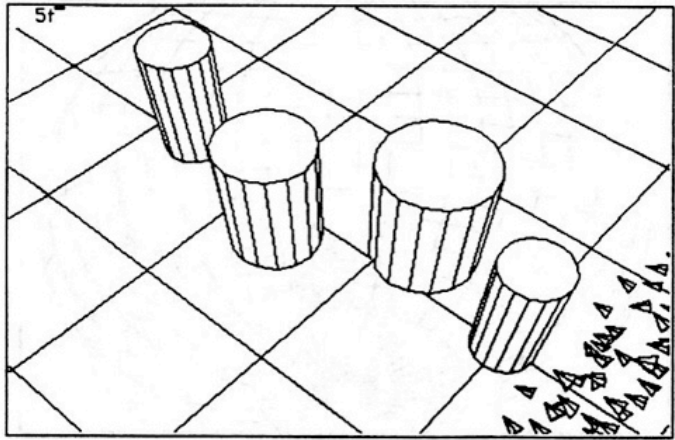
separation



alignment



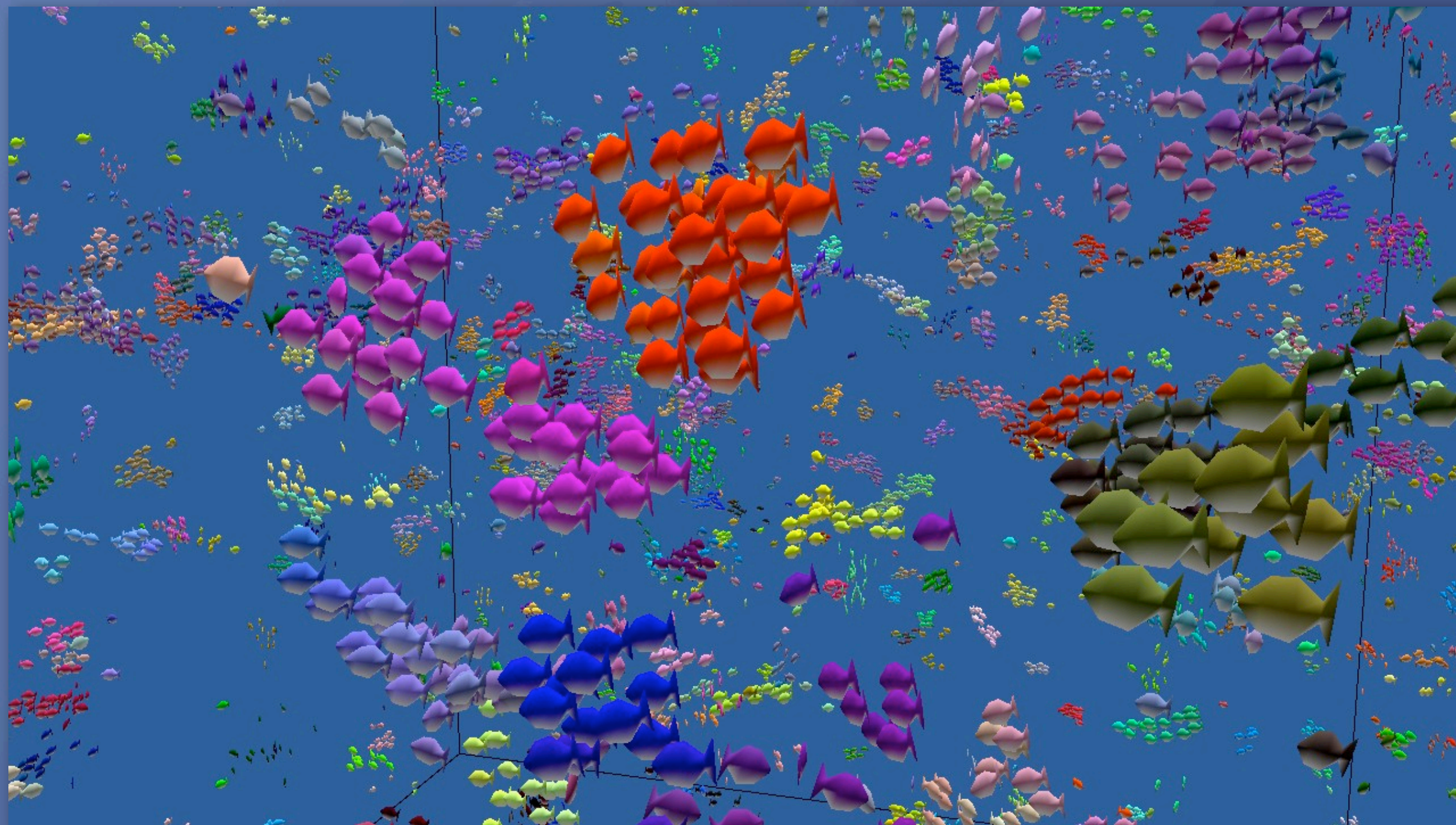
cohesion



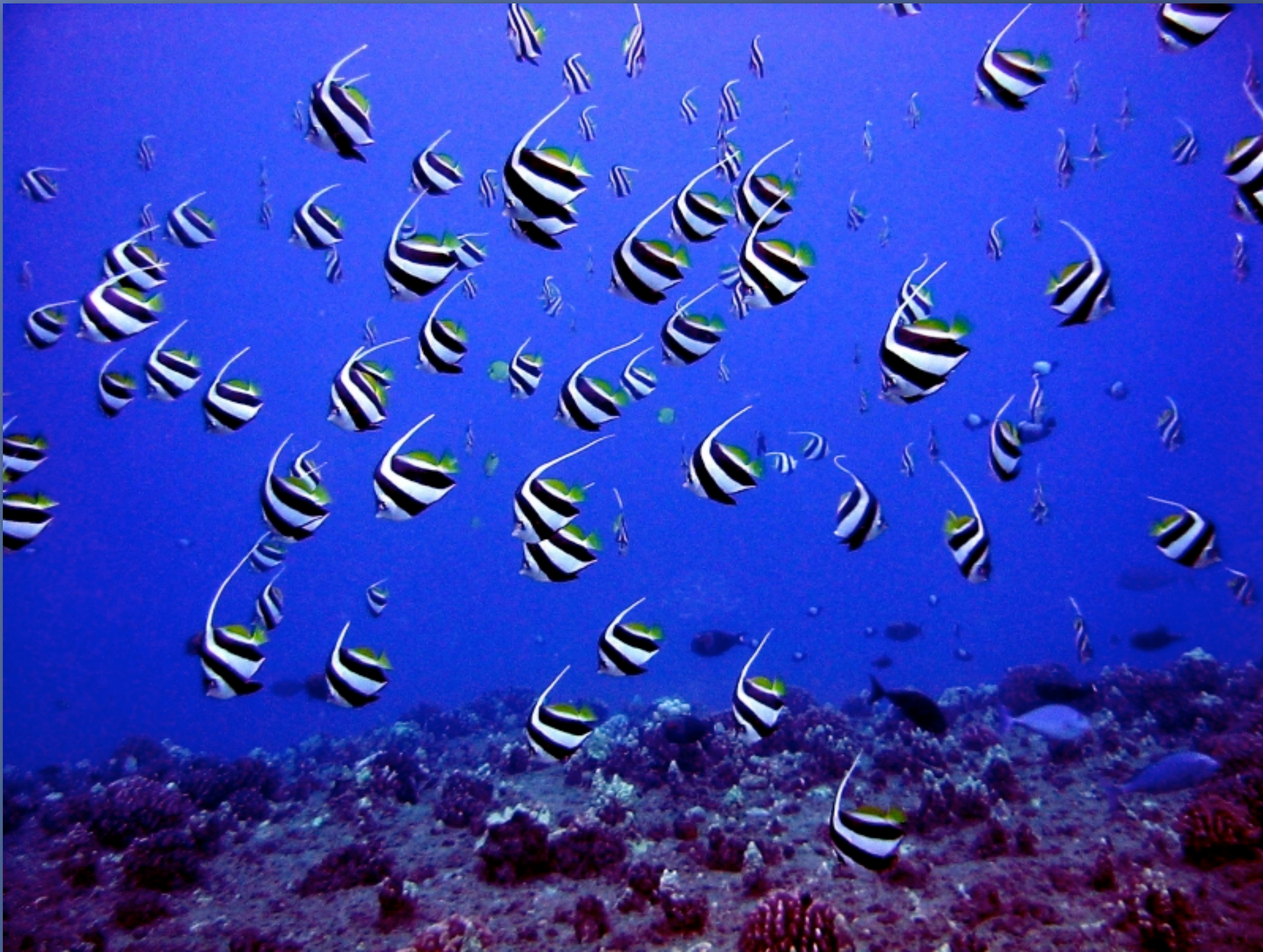


PSCrowd

(video)













iStockPhoto





Non-trudging crowds: what else do crowds do?

- Shoppers in a bazar
- Audience in a theater
- People at a party
- Players on a sport team
- Soldiers in combat
- Collective construction



Phulgalli market, India ©2007 by lecercle, via Flickr



Kuwait Stock Exchange ©2005 by miskam, via Flickr



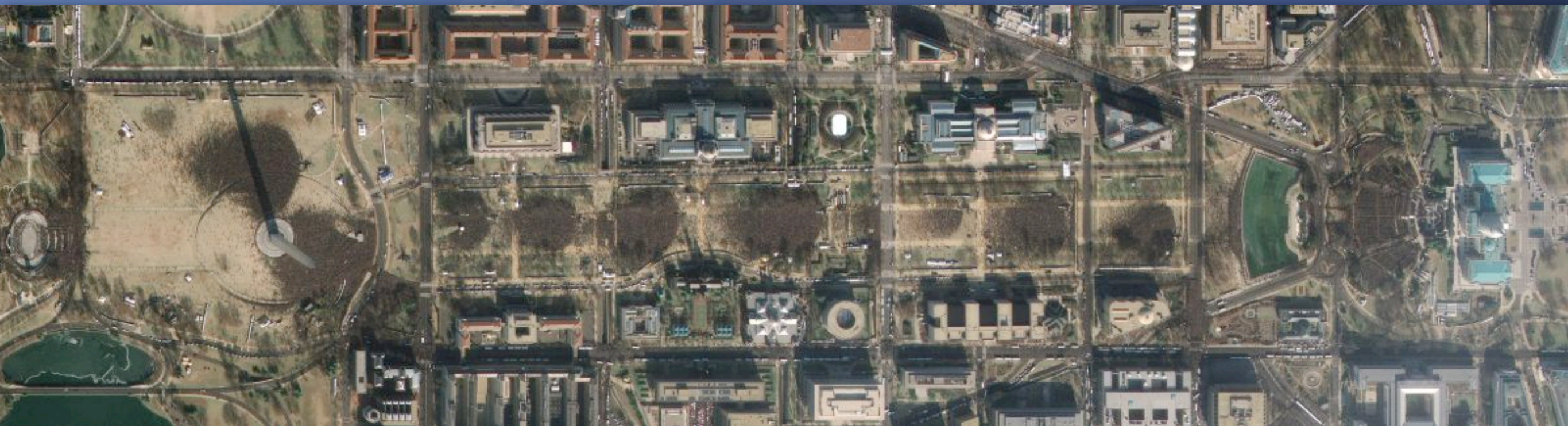
workers at Nash Motors during World War I ©1918 Wisconsin Historical Society, via Flickr







2 megaperson crowd



2009 Inaugural Celebration
Washington D.C. National Mall
GeoEye-1: 0.50-meter resolution
Collected January 20, 2009

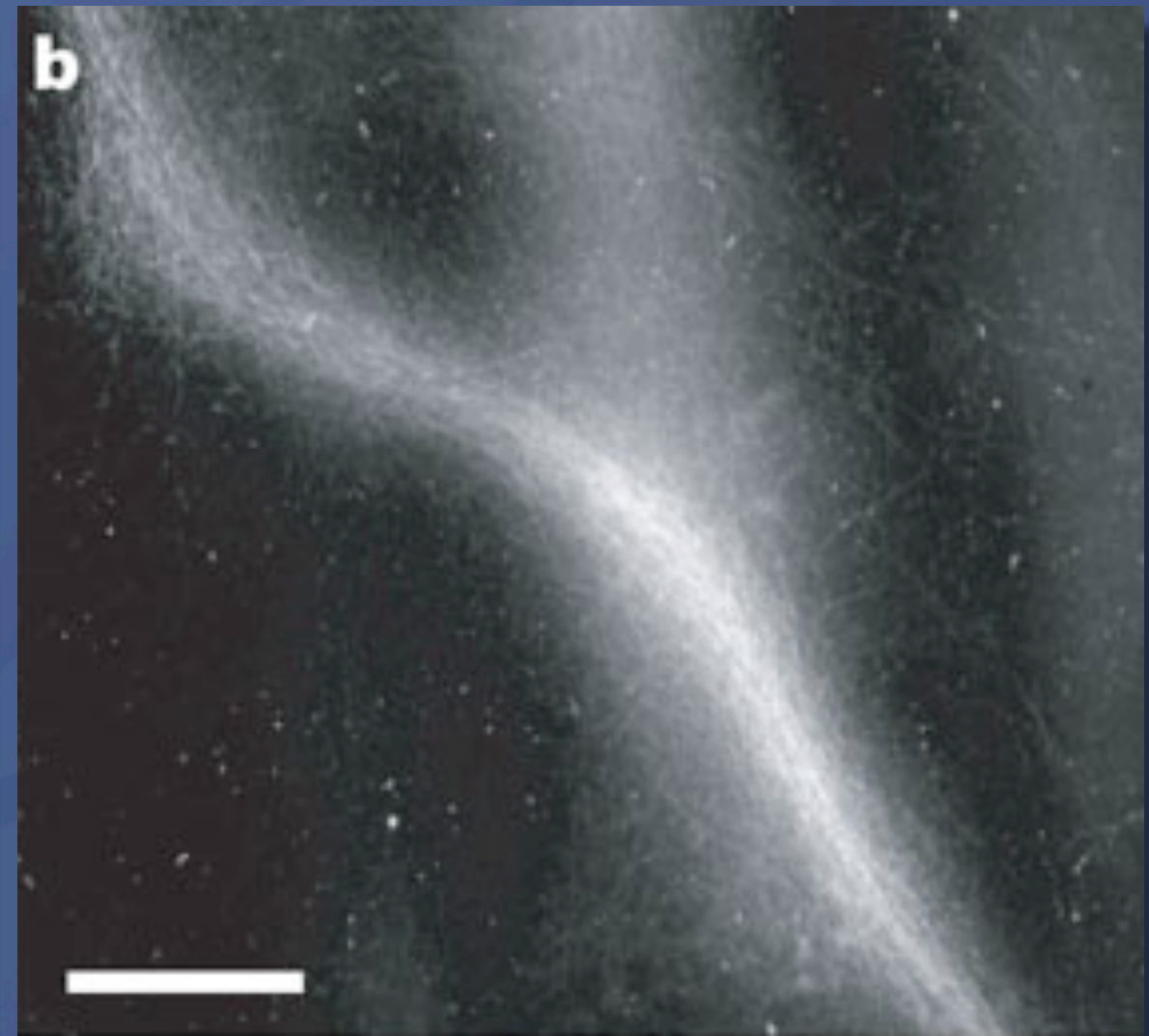
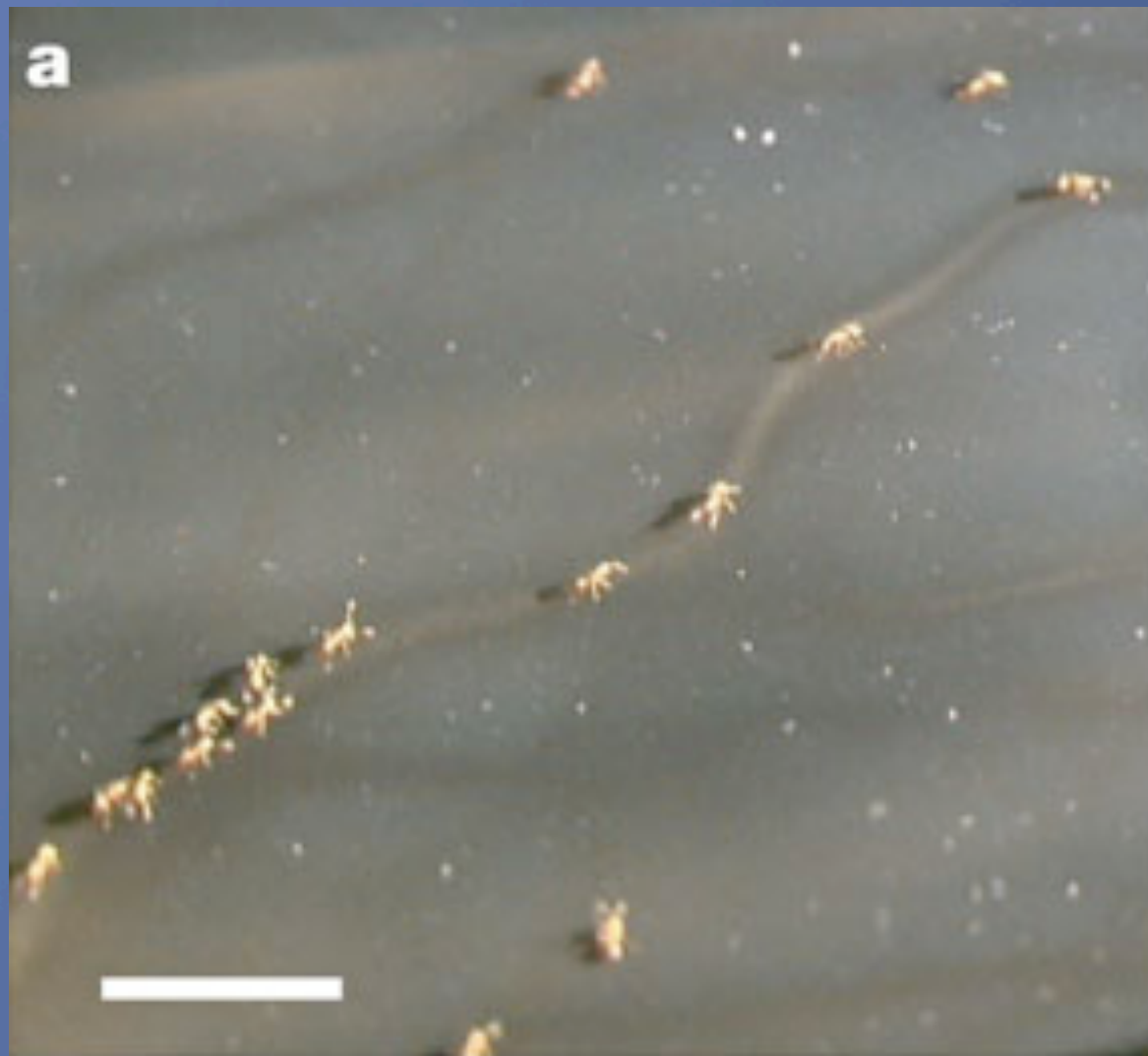
Provided by GeoEye
<http://www.geoeye.com/CorpSite/>



Emergent Teamwork in Nature



Collective foraging: exploration and retrieval



Jackson, Holcombe and Ratnieks, Nature 432 (16 December 2004)

Pheromone trail networks of Pharaoh's ants on a smoked glass surface



Collective transport: optimizing traffic flow

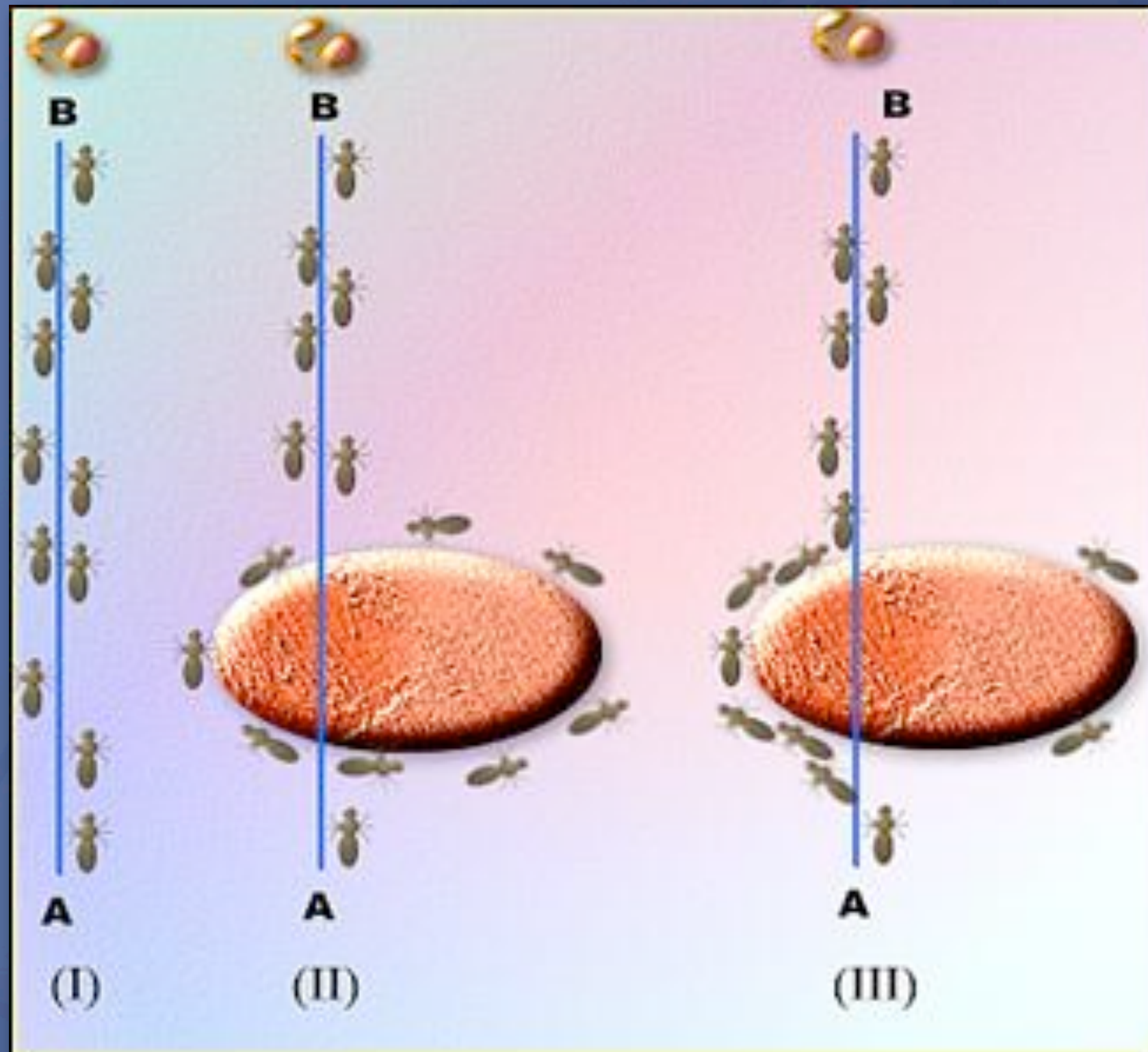


Scott Powell and Nigel Franks, in Animal Behaviour, 2007

Army ants covering “potholes” with their own bodies



Collective decision making: optimizing path length





Collective porting: carrying large objects



Staub Family in Brazil (blog post July 19 2006)



Nik Daum (blog post Nov 2, 2005)



Collective construction



Collective construction: humans build brick wall

- obvious where to place next brick
- add more people to build faster
- may use language to coordinate





Stigmergy

- Communication through the environment
 - often with pheromones
 - physical marks or structures
 - no abstract communication required
- Coined in 1959 to describe construction by termites
 - by the French biologist Pierre-Paul Grassé
 - from Greek words *stigma* (sign) and *ergon* (action)

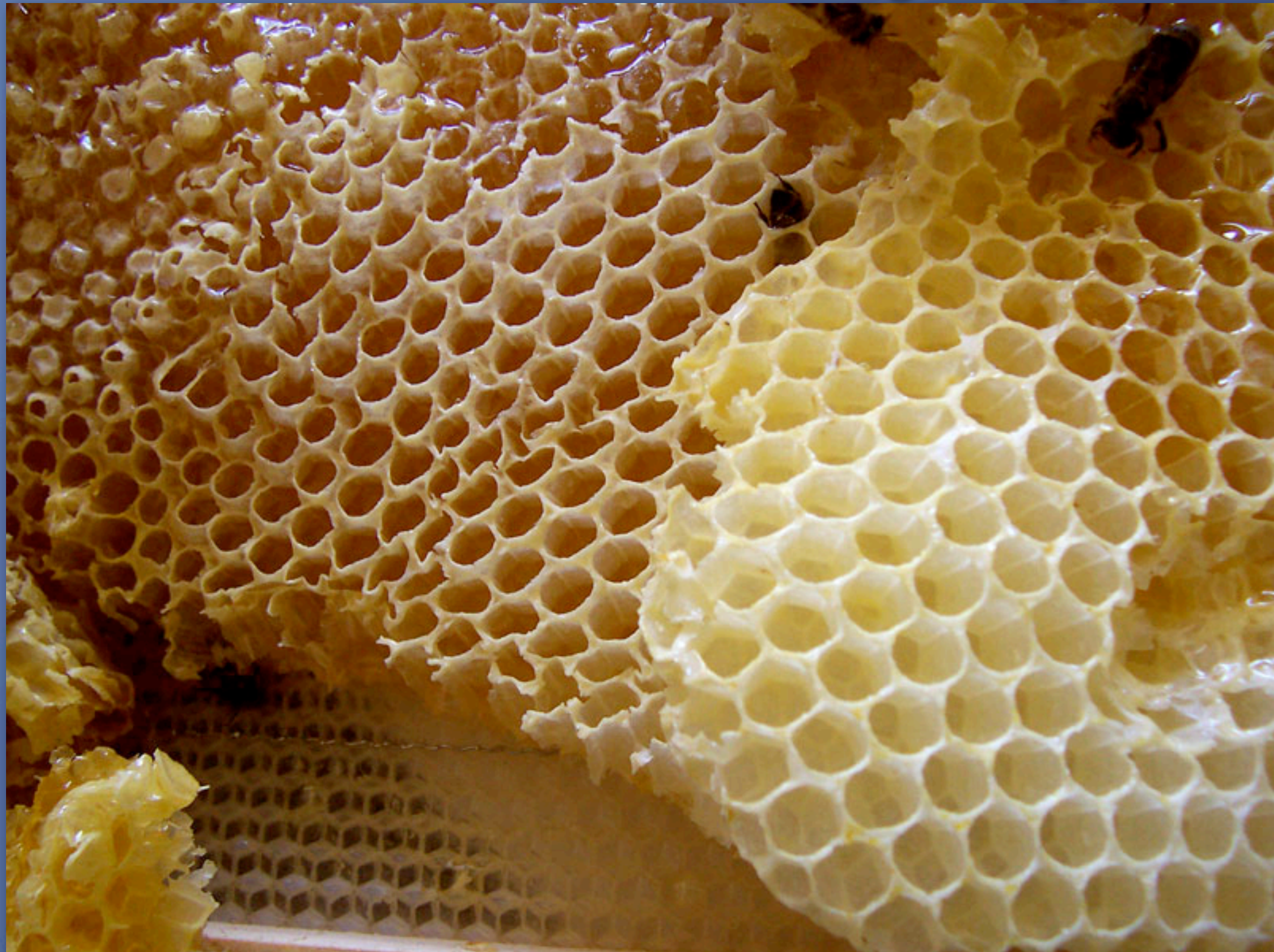


Collective construction: nest building by birds





Collective construction: bees building honeycomb





Paper wasp nest



*Paper wasp by Natasha Mhatre via Flickr
©2007, used with permission*

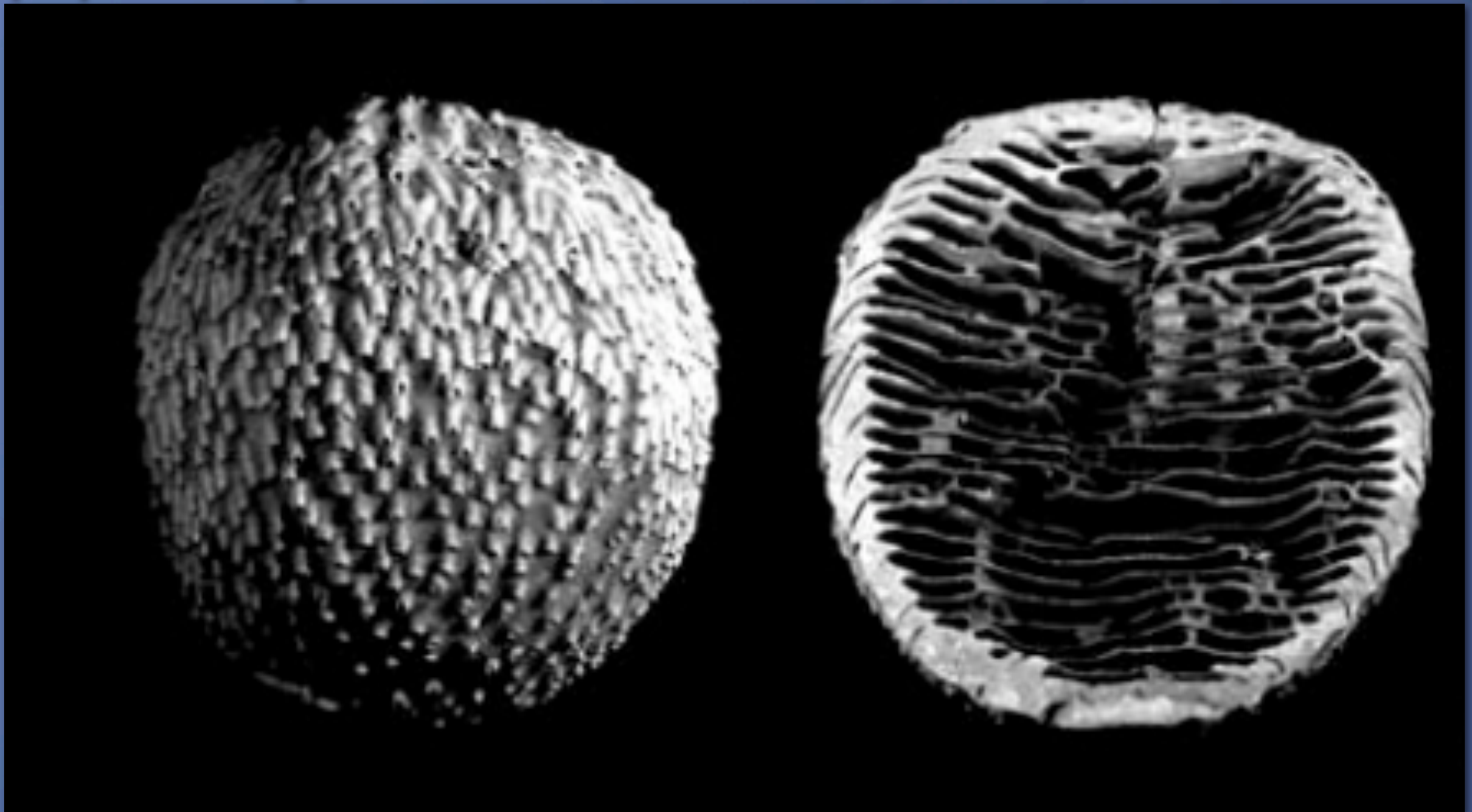
Potter wasp nest



*Potter wasp by Natasha Mhatre via Flickr
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Collective construction: paper wasp nest cross-section



Garnier, Gautrais, Theraulaz (2007) The biological principles of swarm intelligence, Swarm Intelligence

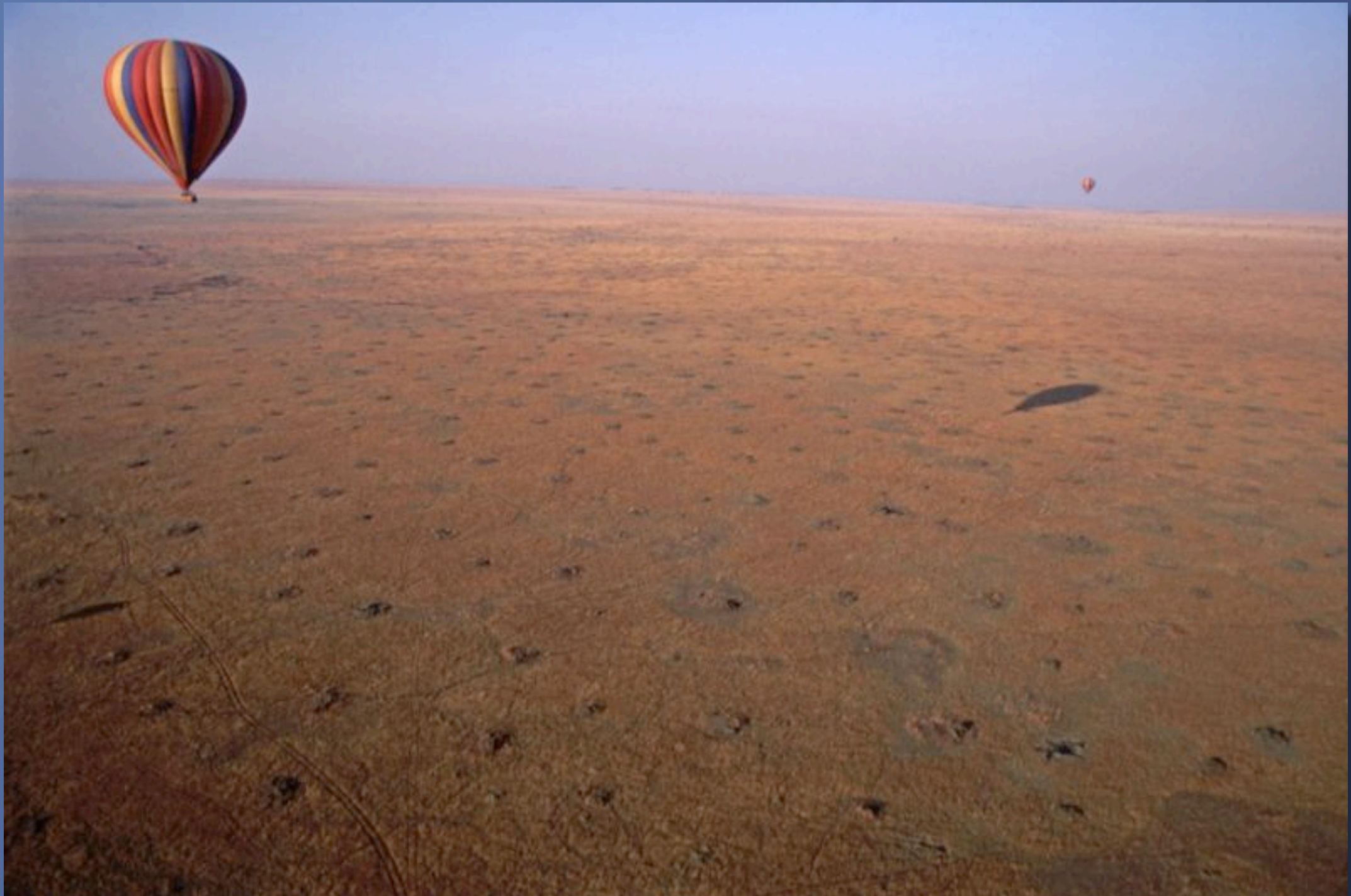


Collective construction: termite mound size





Collective construction: termite mound abundance





Collective construction: micro structure of termite mounds



Scott Turner, SUNY Syracuse, used with permission

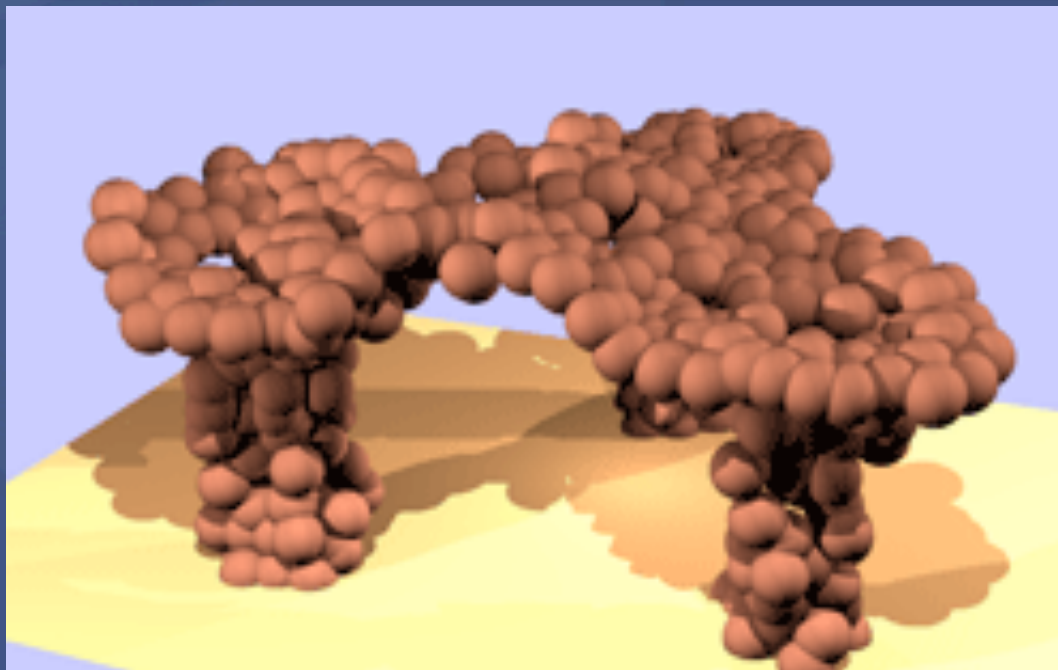
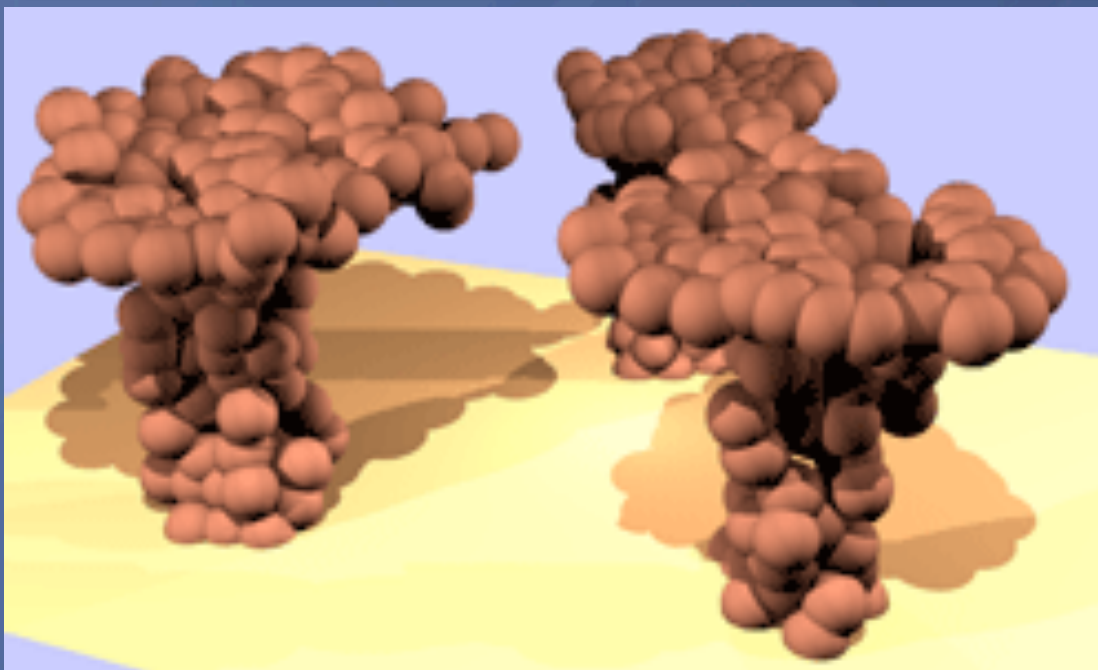
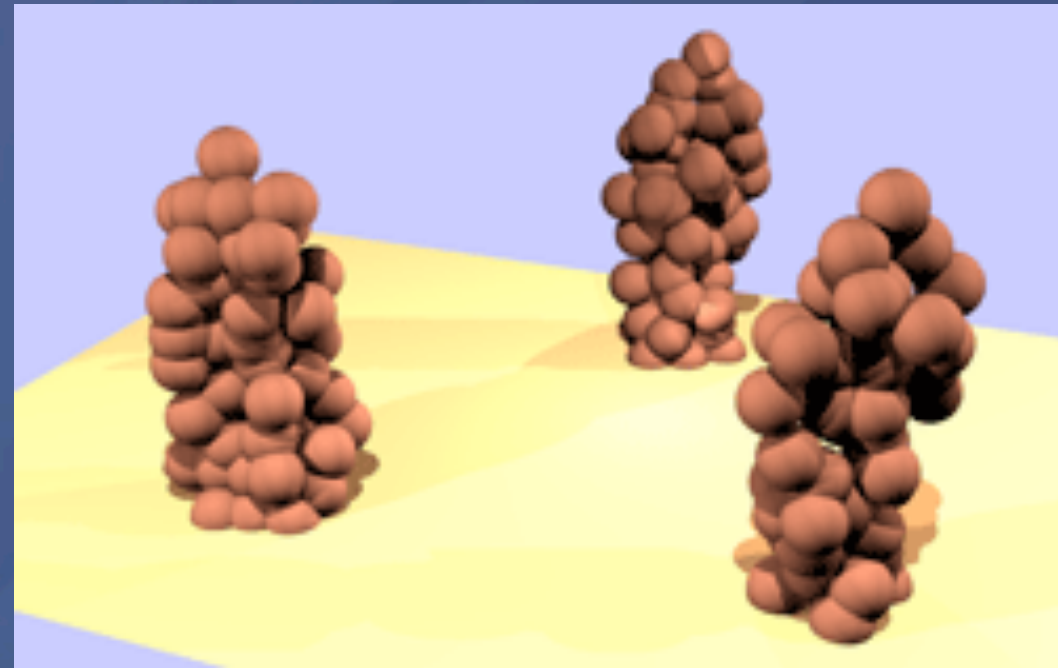
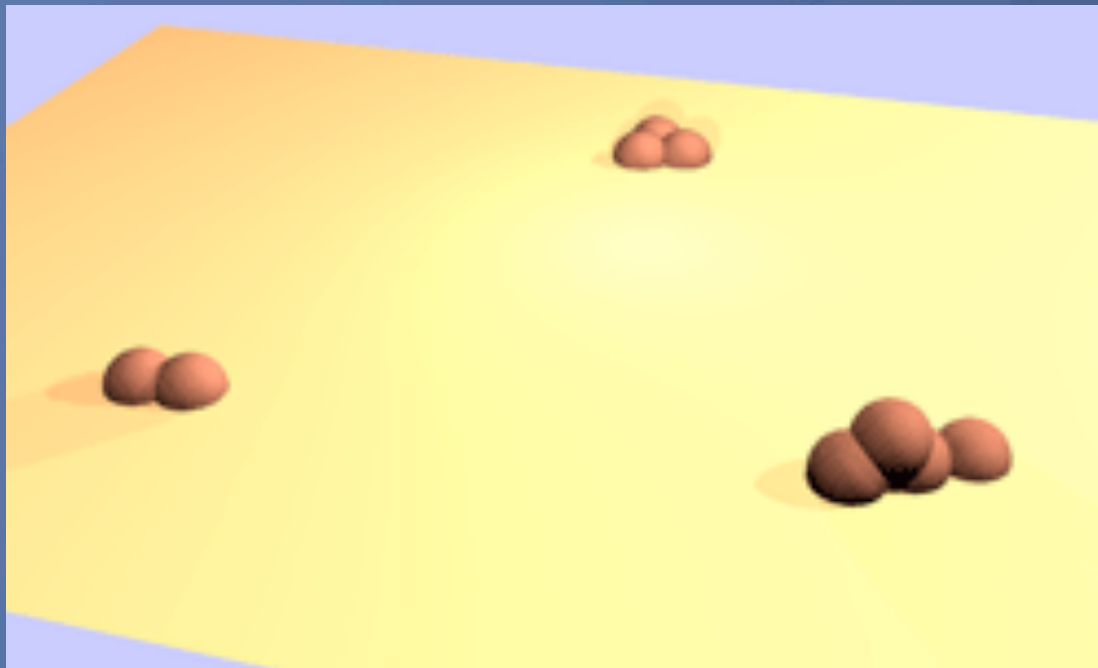


Termites repair mound with “spongy build”



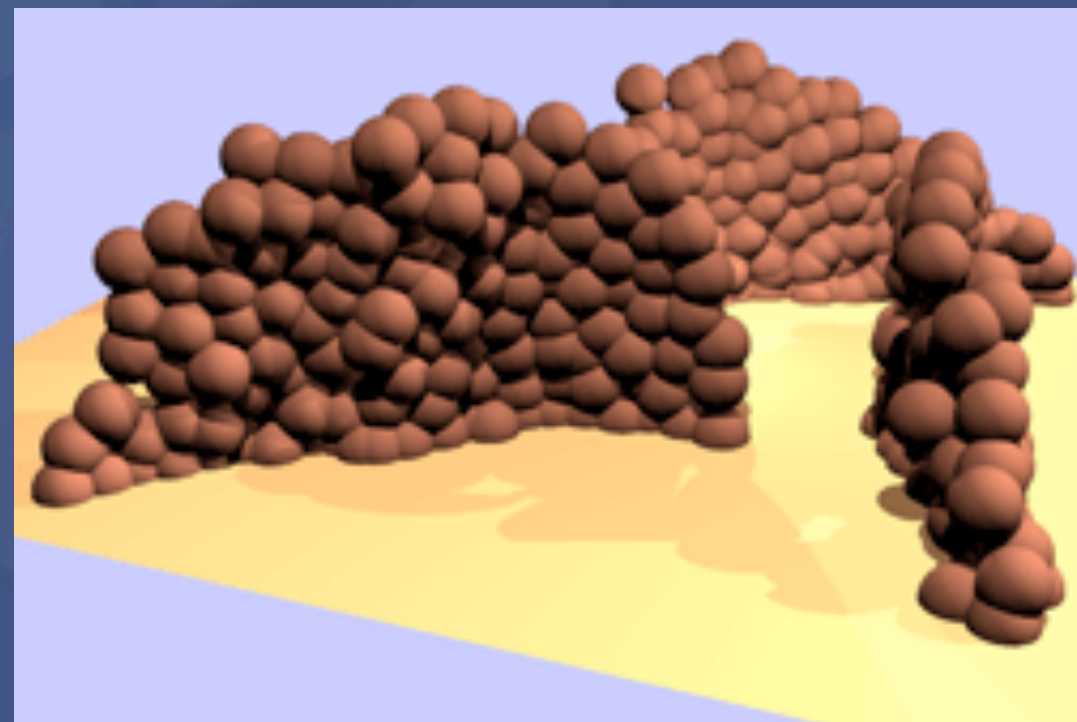
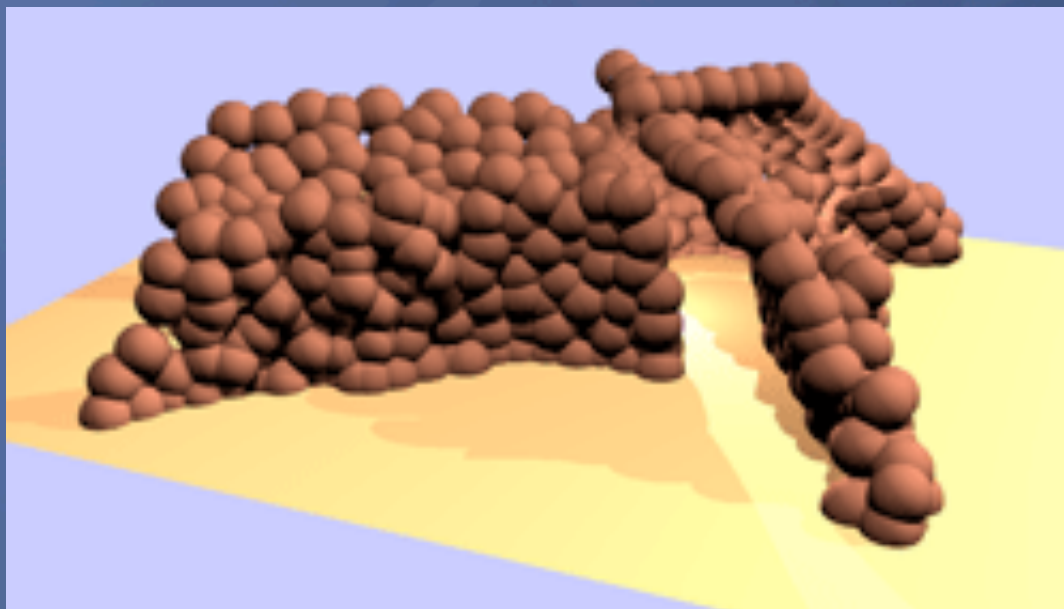
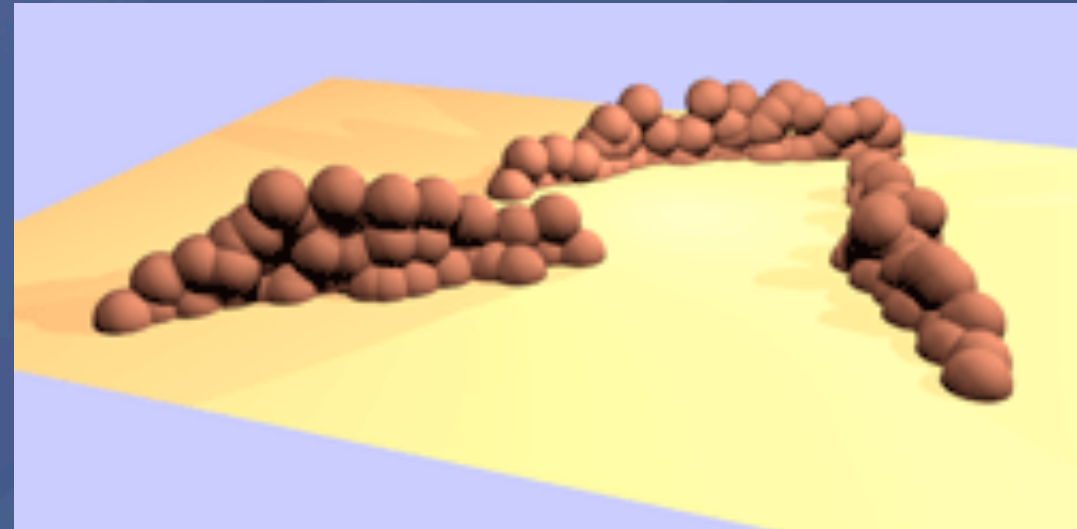
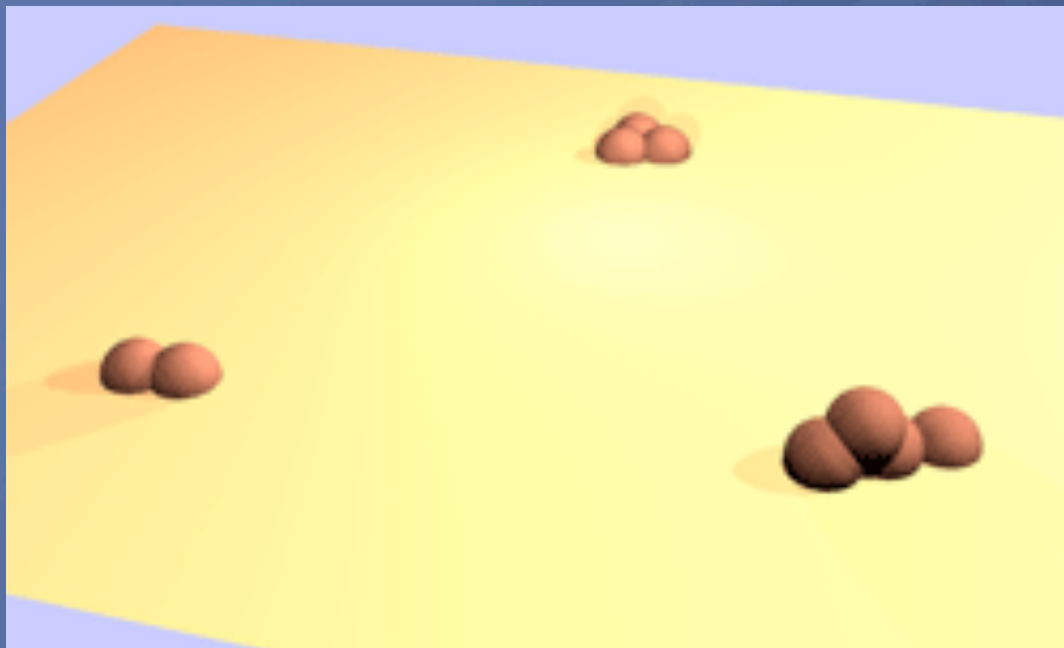


Termite stigmergic building: pillar construction and the roofed gallery





Termite stigmergic building: Wall construction and enclosure of space

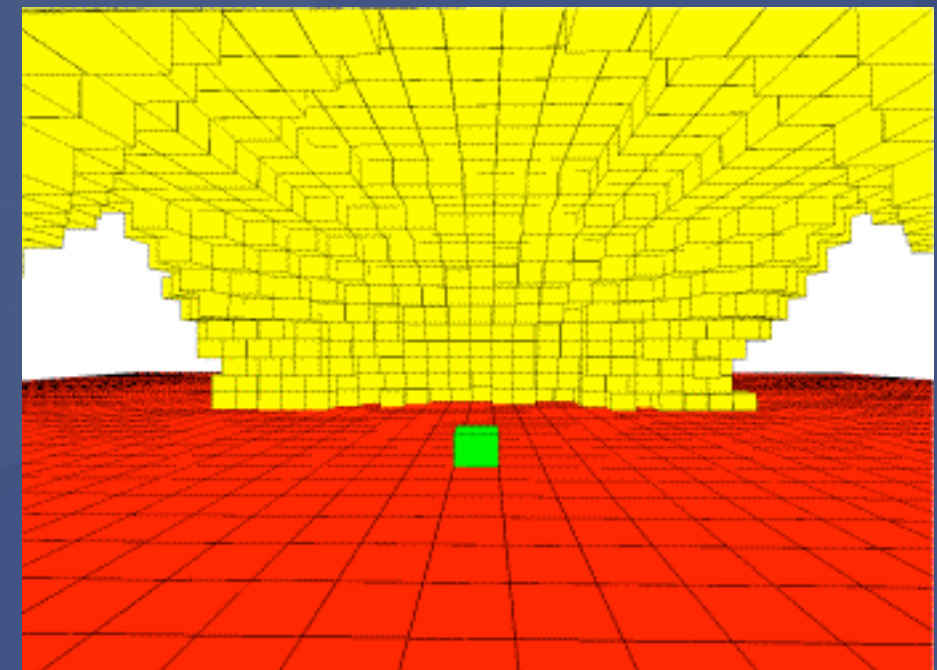
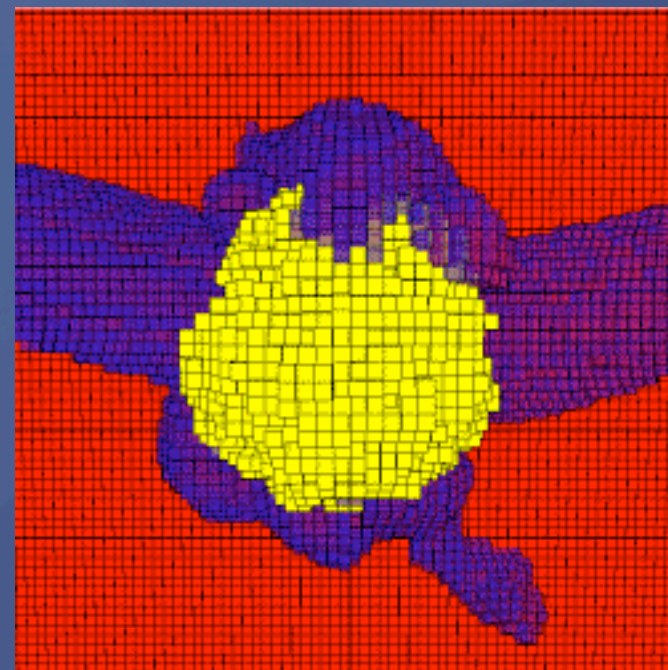
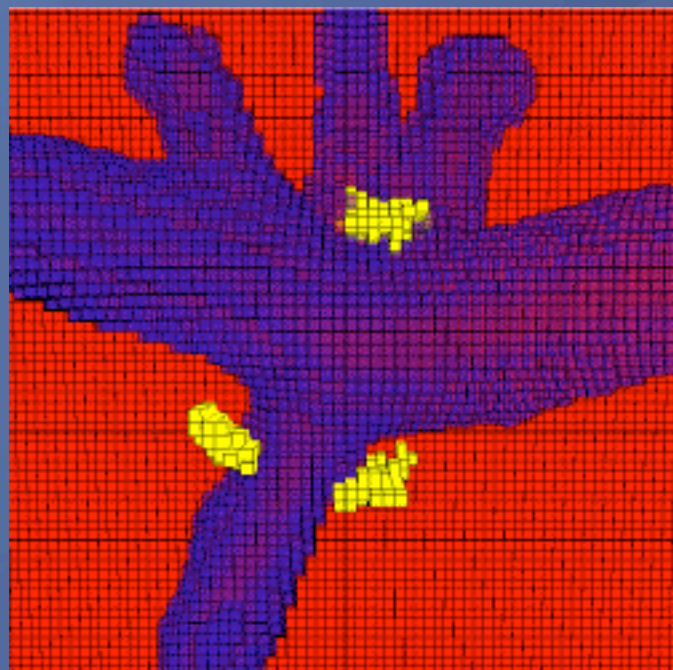
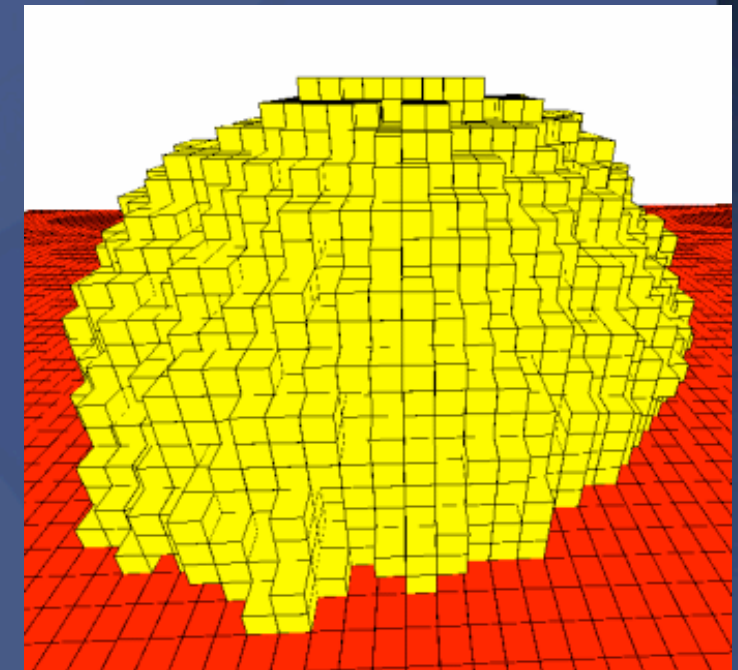
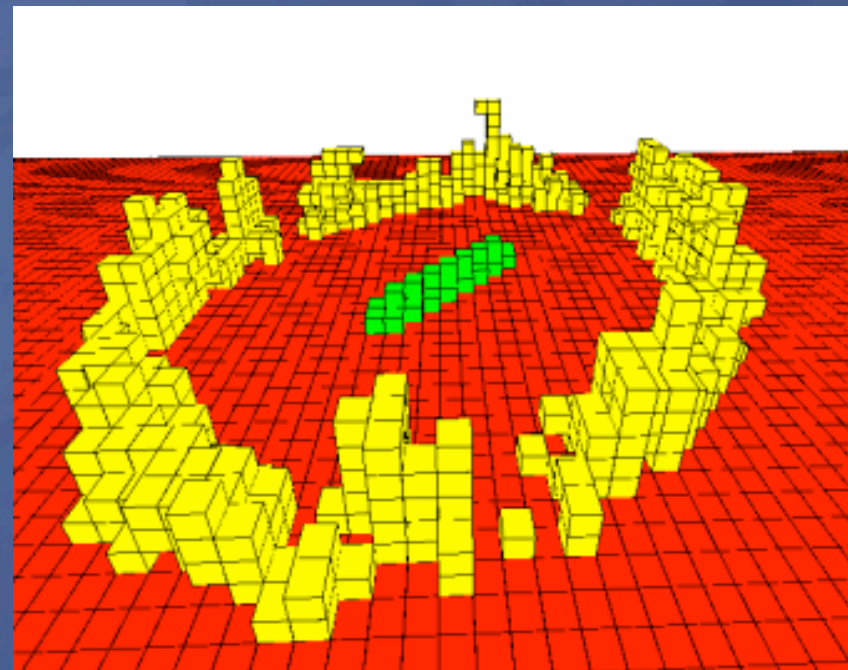
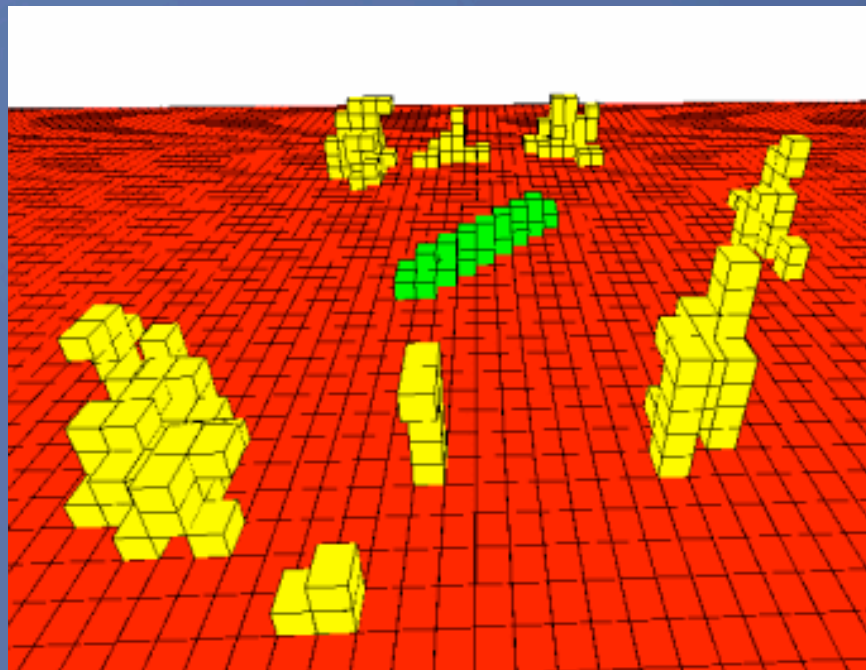




Collective construction:
previous simulation results by other authors



The role of logistic constraints in termite construction of chambers and tunnels





Termite model: discrete voxel space



Feltell, Li and Jensen, International Journal of Modelling Identification and Control, 2008



Collective construction: my recent experiments



Construction with “bricks”

- Moving autonomous agents
- Passive bricks
- Gathering bricks together
- Piling bricks on top of other bricks
- Unaligned, irregular assemblies



Progression of models

- Central disk building
- Central tower building
- Emergent tower building



Disk construction

- Forage for bricks
- Return to edge of construction site
- Deposit brick near edge of disk
- Repeat...

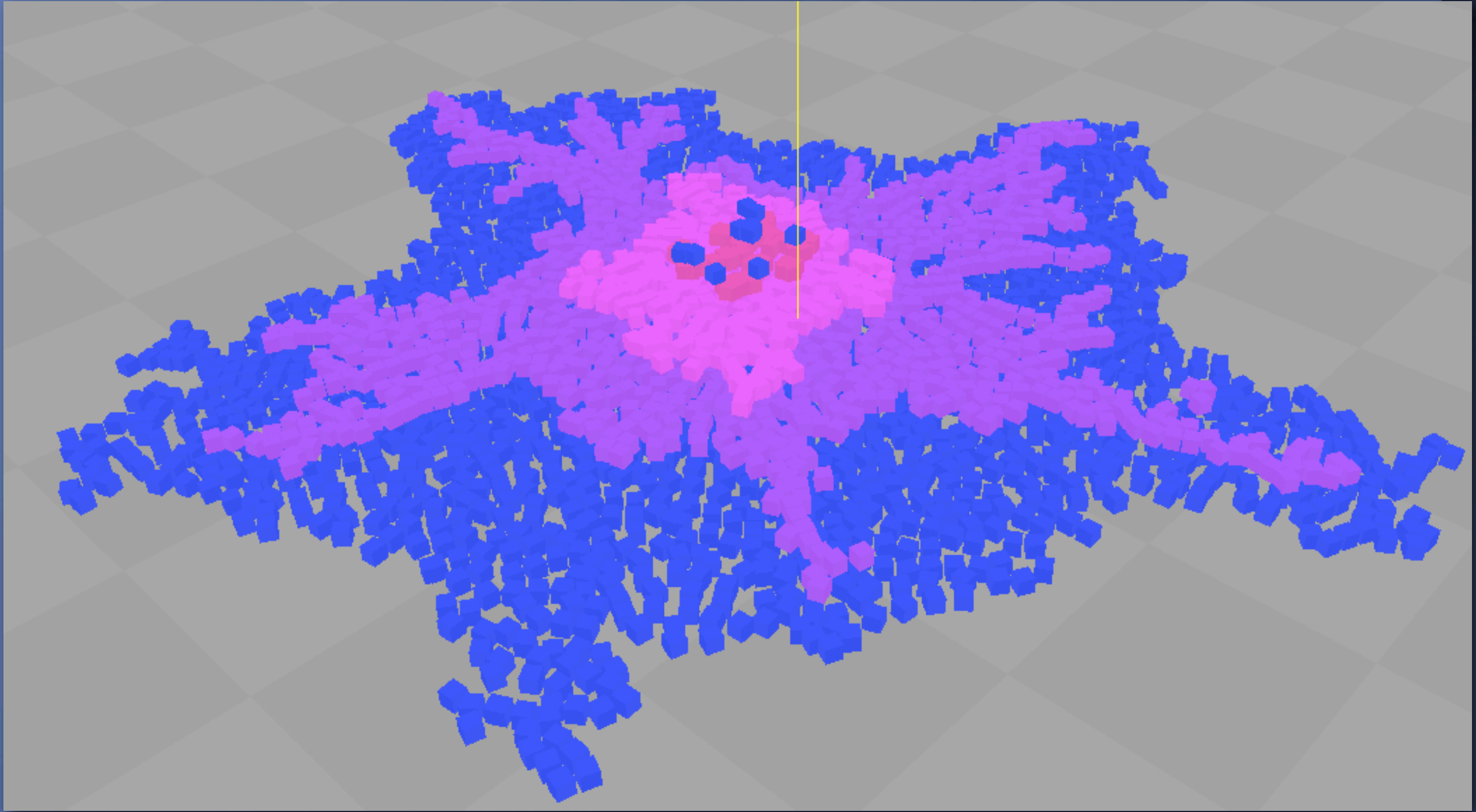




Heap construction

- Forage for bricks
- Return to edge of construction site
- Choose one of:
 - Deposit brick near edge of disk
 - Jump on top of disk, then deposit
- Repeat...

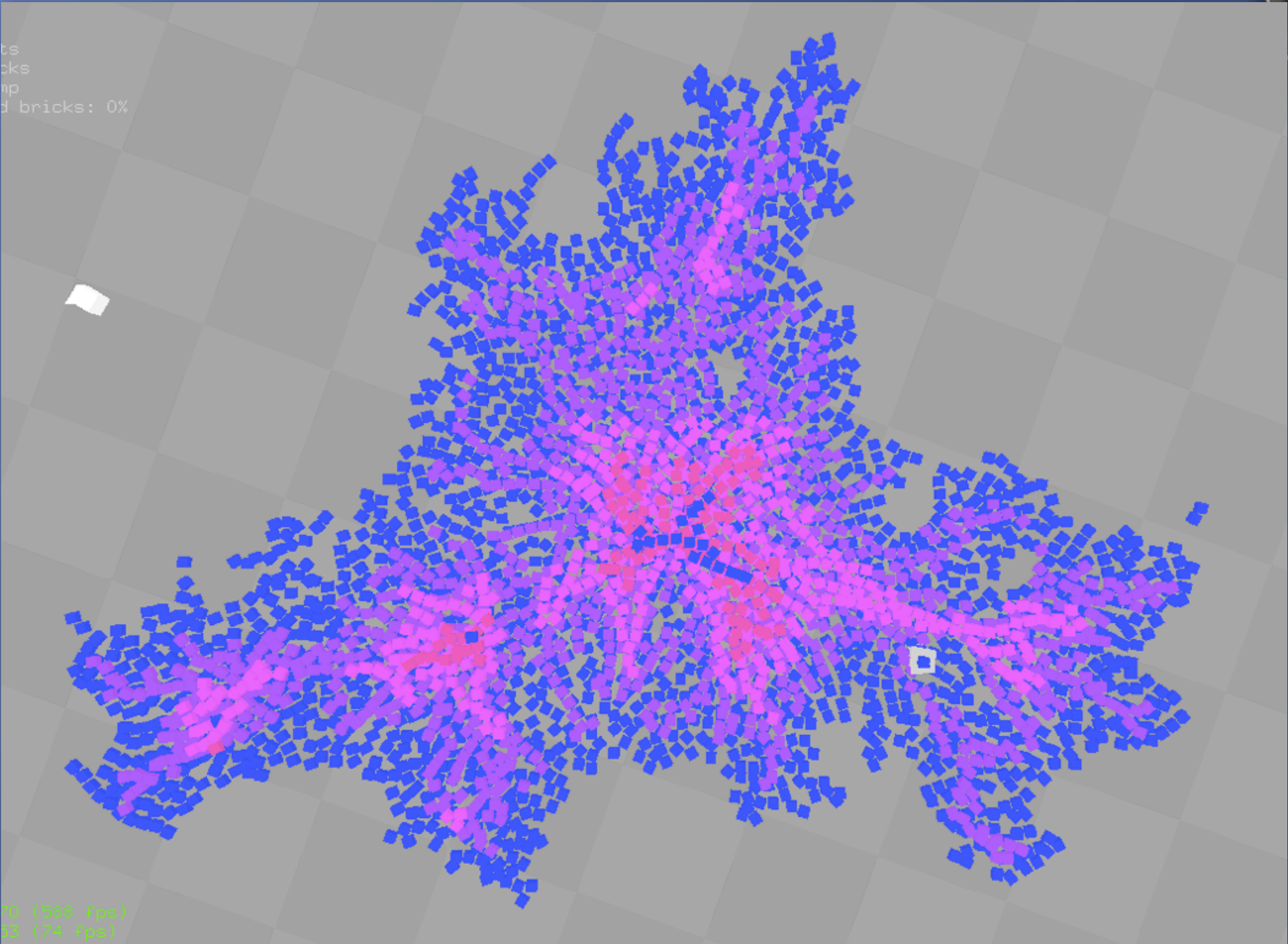


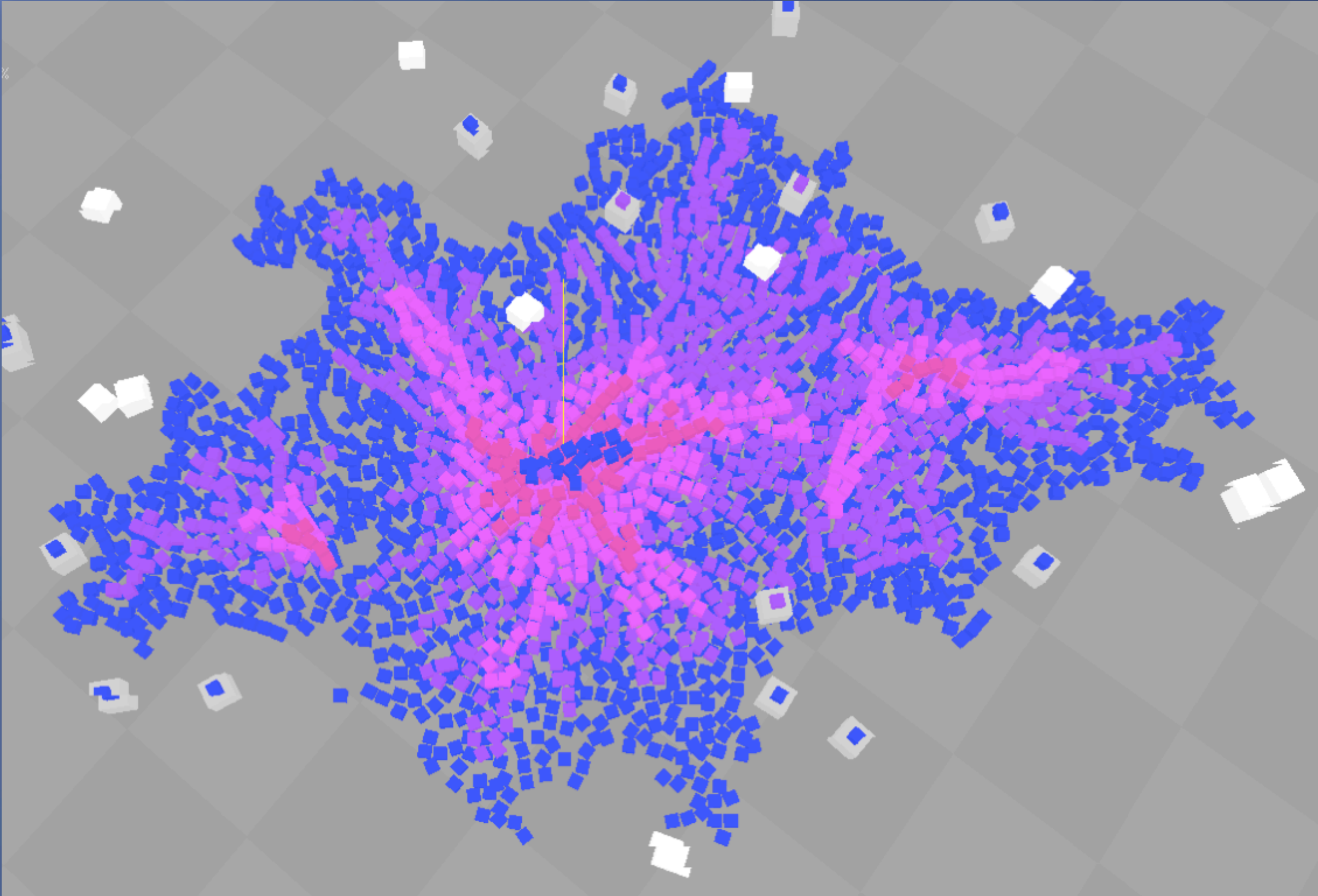


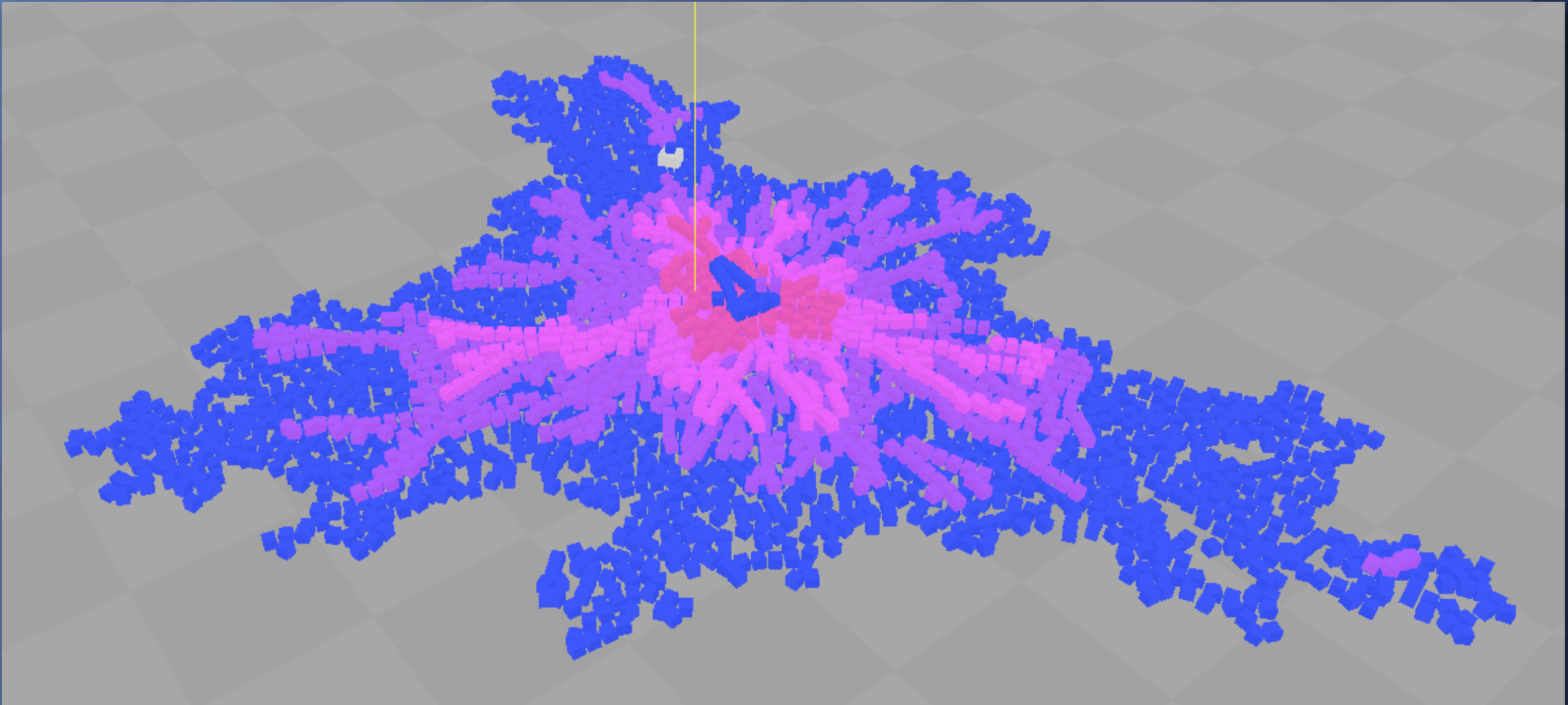


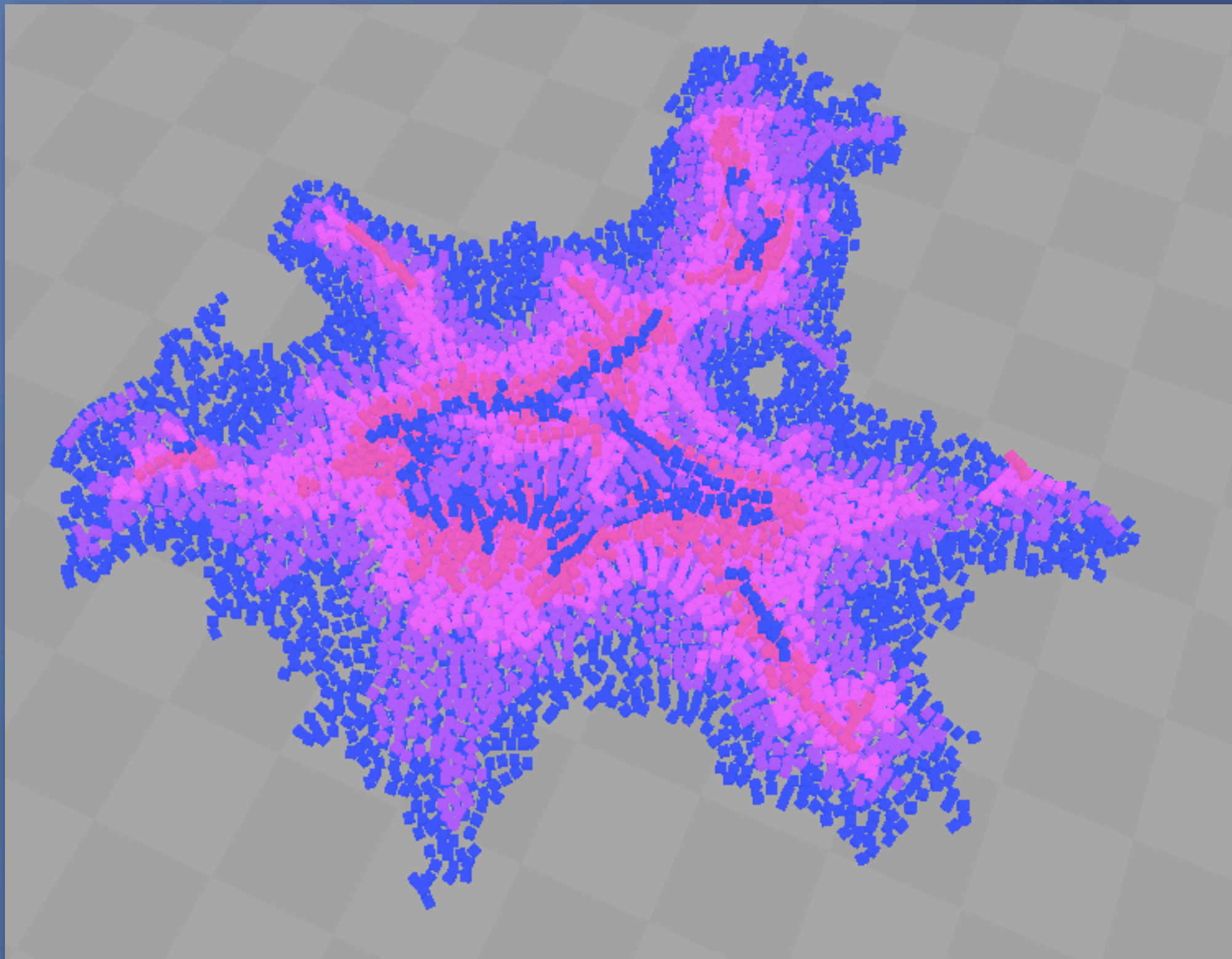
ts
cks
mp
d bricks: 0%

70 (588 fps)
53 (74 fps)

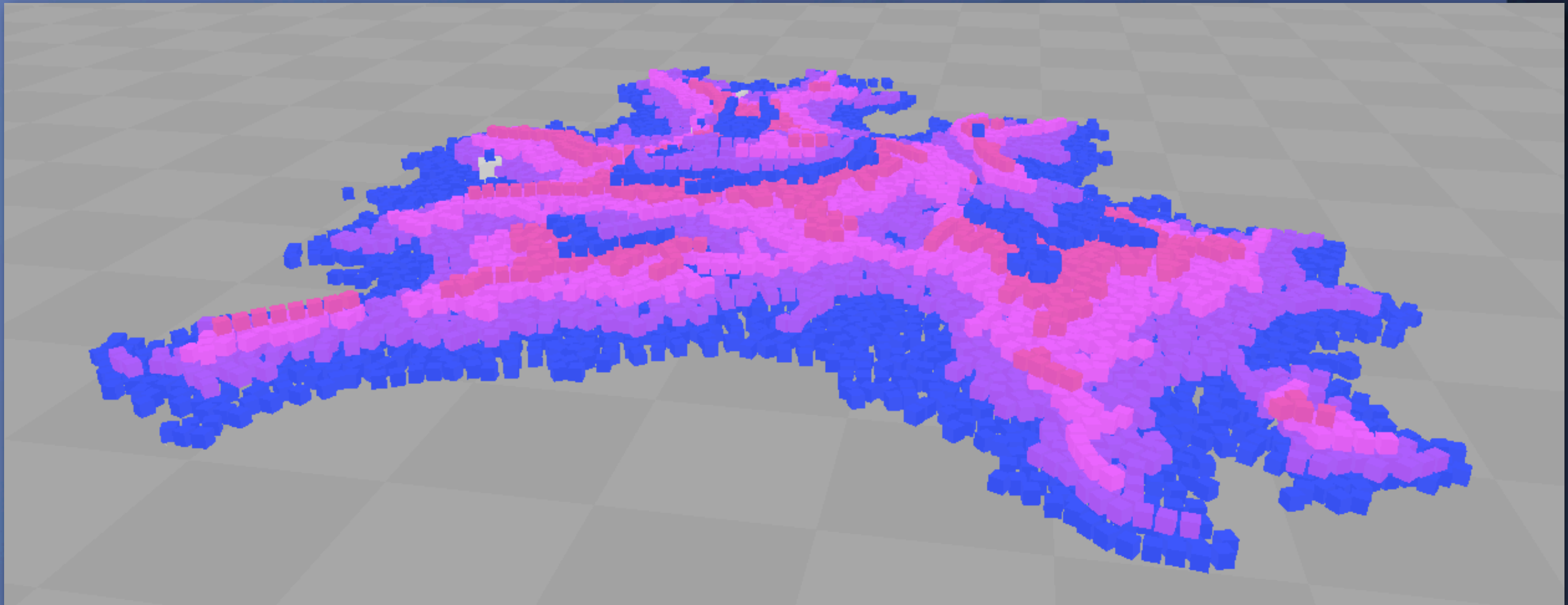








8000 bricks



8000 bricks



Stackers demo

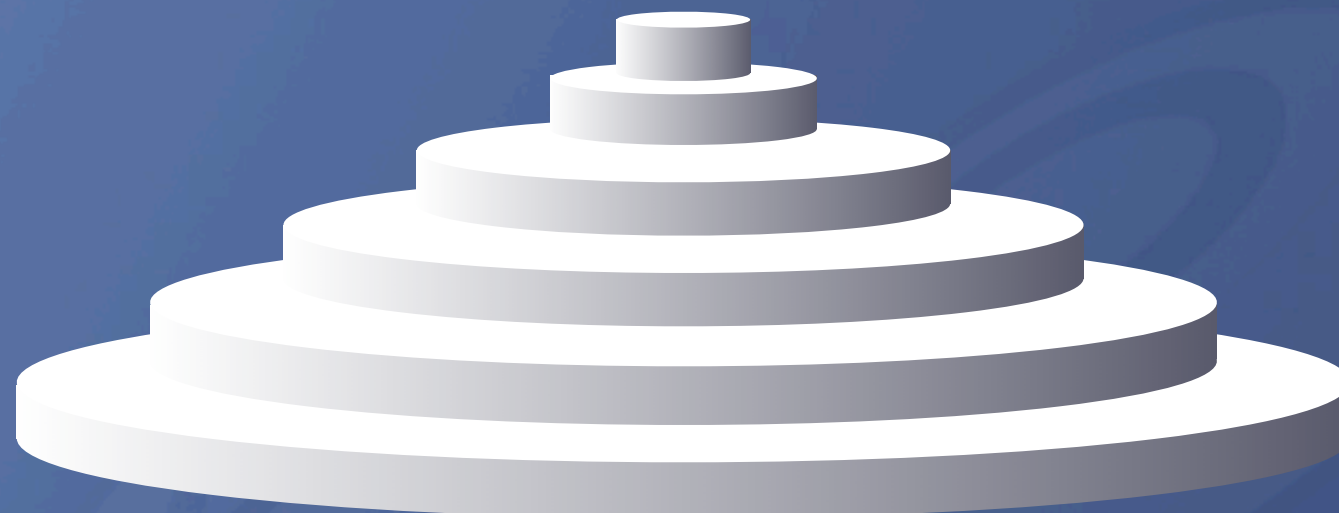
part 1: central disk

part 2: central heap



Emergent construction site selection

- Forage for brick
- Select construction site
- Proceed as for fixed global construction target



Fixed global construction target



Emergent construction target



Self-reinforcement and recruitment

- Without additional goals:
 - many small towers
 - Bricks added/removed at same rate
- Use *score* to climb density gradient:
 - construction target must score higher than pick-up score
 - forage target must score lower than last drop-off score
- Generally bricks are moved from low to high density
 - Higher density attracts more agents
 - More agents lead to higher tower with more density



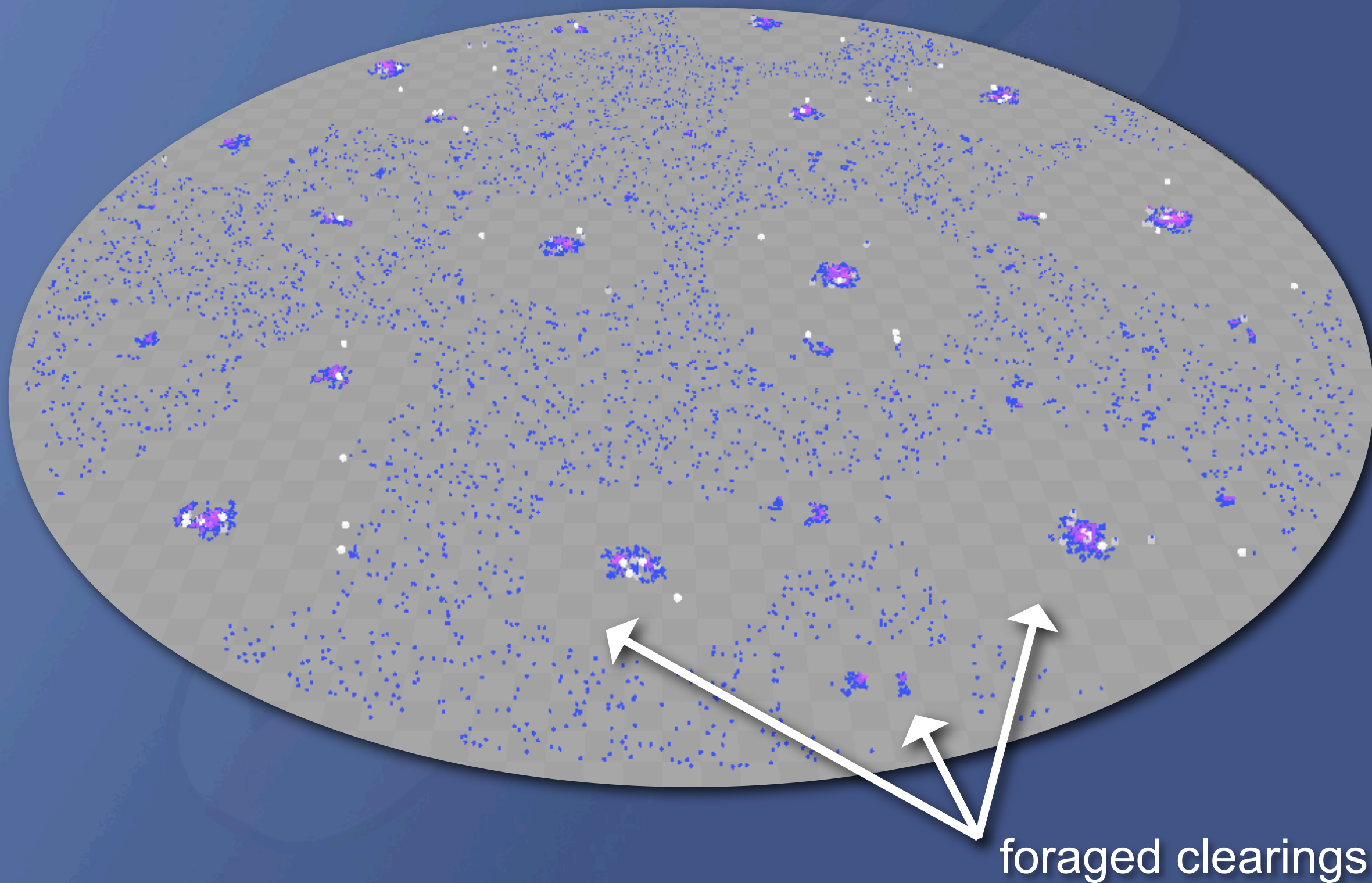
Termites: emergent pillar placement



Scott Turner, SUNY Syracuse, used with permission



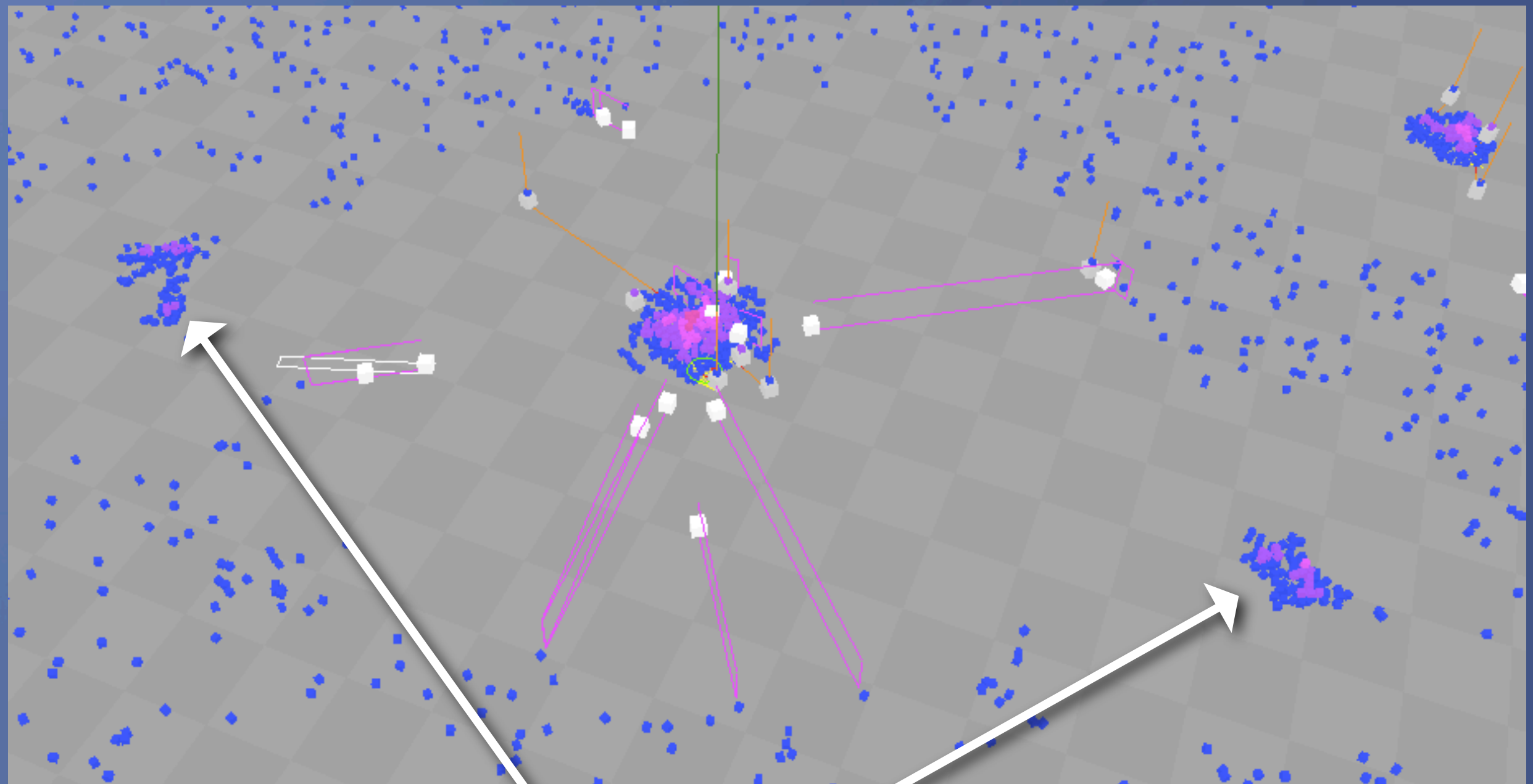
Emergent construction sites



foraged clearings



Emergent recruitment



ghost mounds



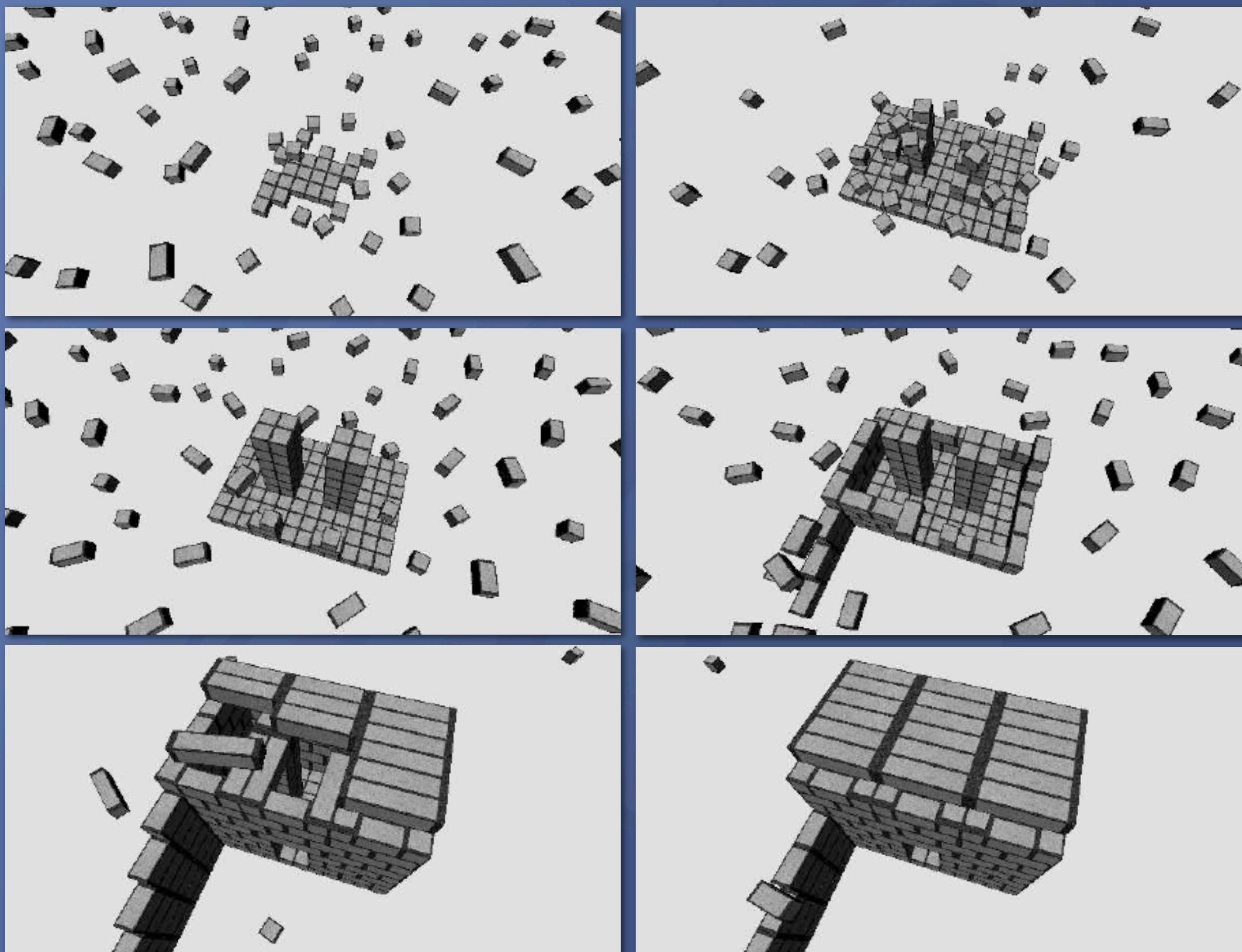
Stackers demo part 3



Future work:
ideas about construction styles



Stigmergic Self-Assembly of Prespecified Artificial Structures in a Constrained and Continuous Environment

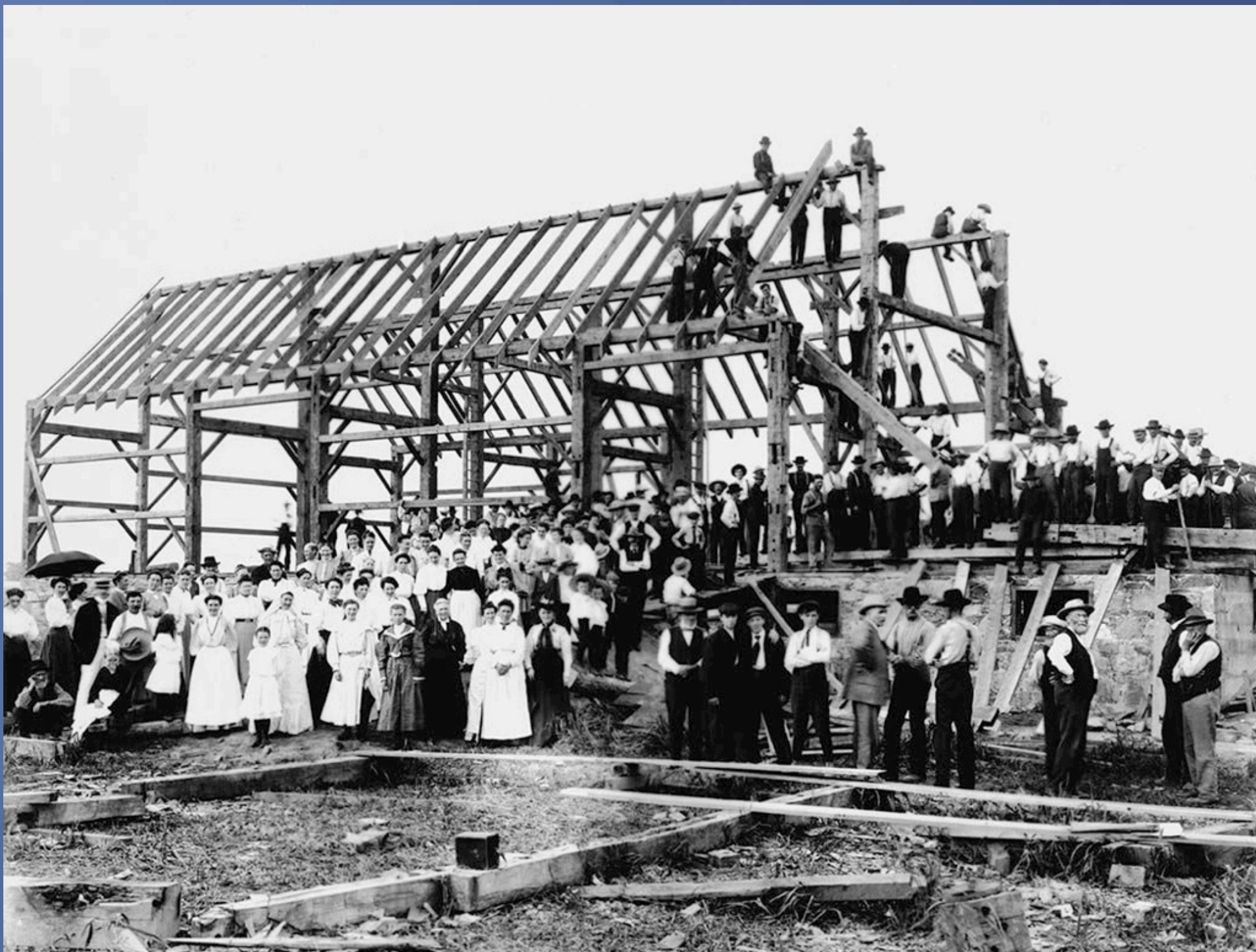




Mesa Verde Cliff Dwellings ©2007 by James Gordon, via Flickr



circa 1900, Washington University Archives



Barn raising near Toronto, Canada -- circa 1910 -- via Wikimedia Commons



modern construction of traditional English cottage -- ©2007 Ichthus Architects



circa 1950, Carlanna Lake Dam, Ketchikan Museums



circa 1915, trestle under construction, Snoqualmie Falls Lumber Company, by Clark Kinsey, U. Wash. Library



circa 1890, (re?)construction of stone footing, Mission B.C. Virtual Quilt





Thank you