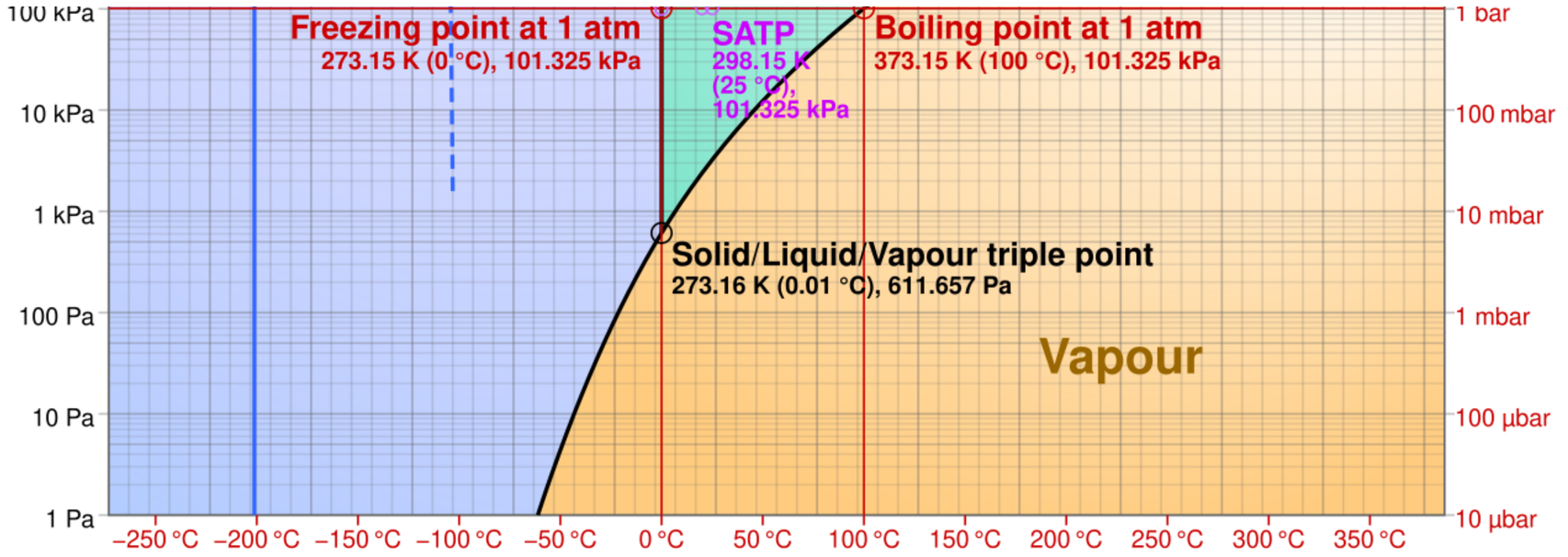
From Parts to Wholes:
Teaching ALife through Emergence, Embodiment, and Collective Intelligence

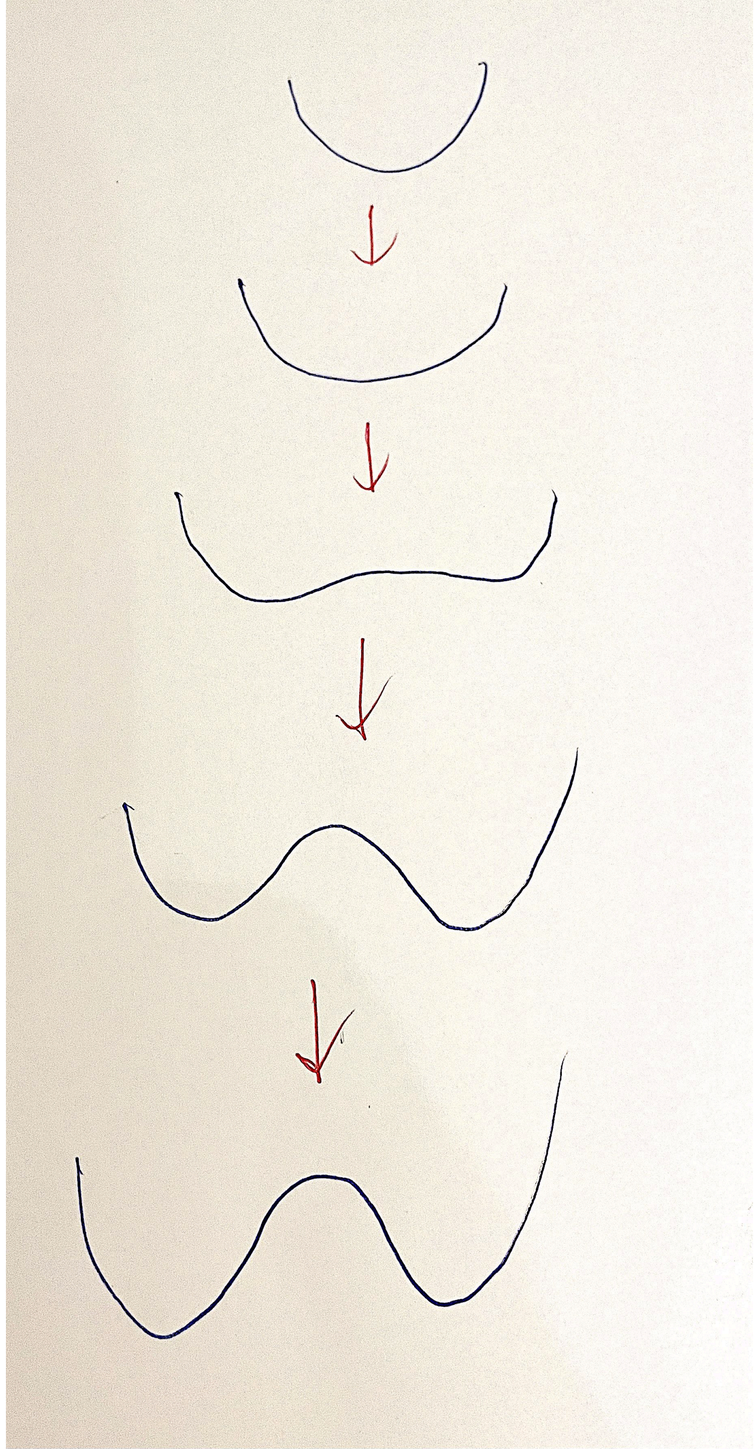
by Takashi Ikegami

Phase Diagram



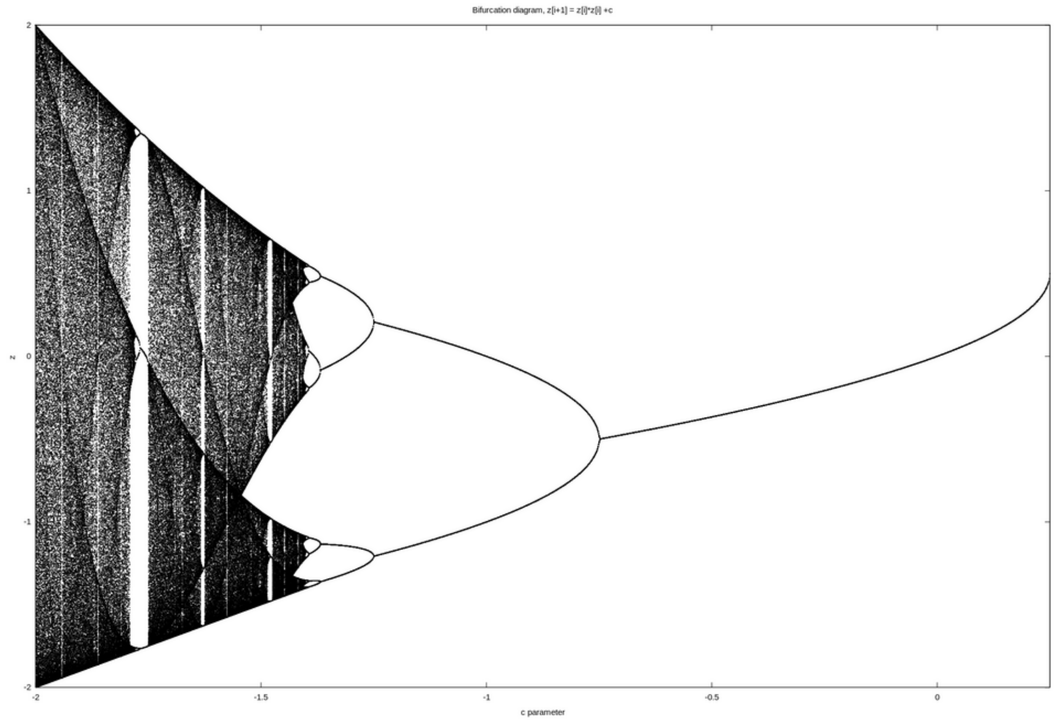
Water in 3phases

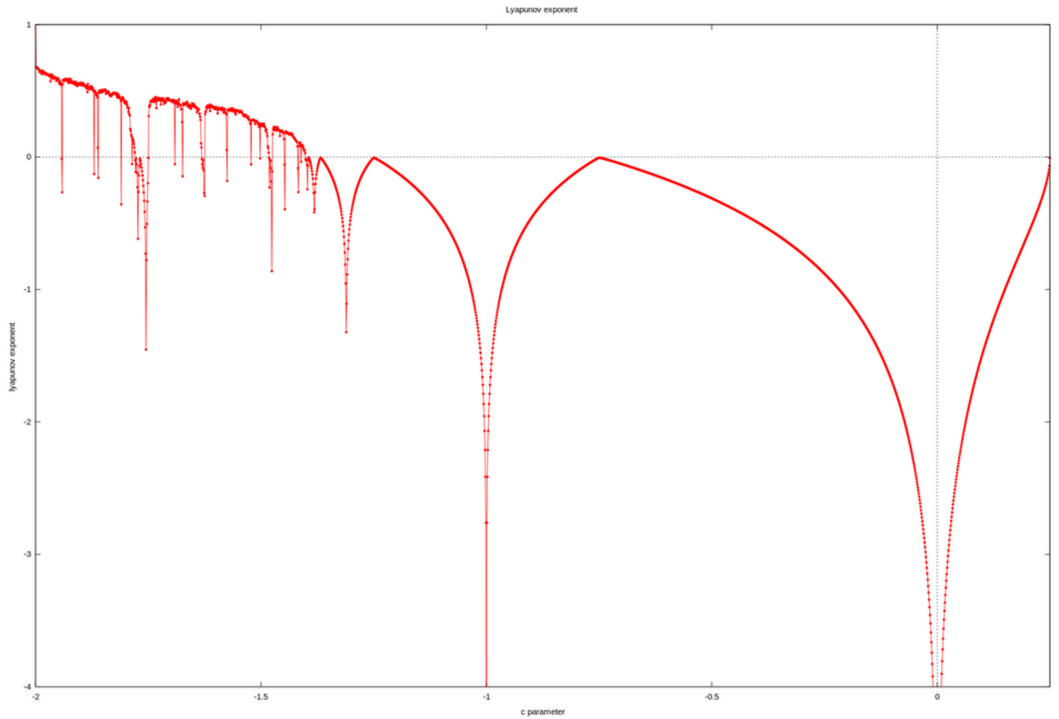
The Landau picture :
Spontaneous Symmetry Breaking
and
Order parameters

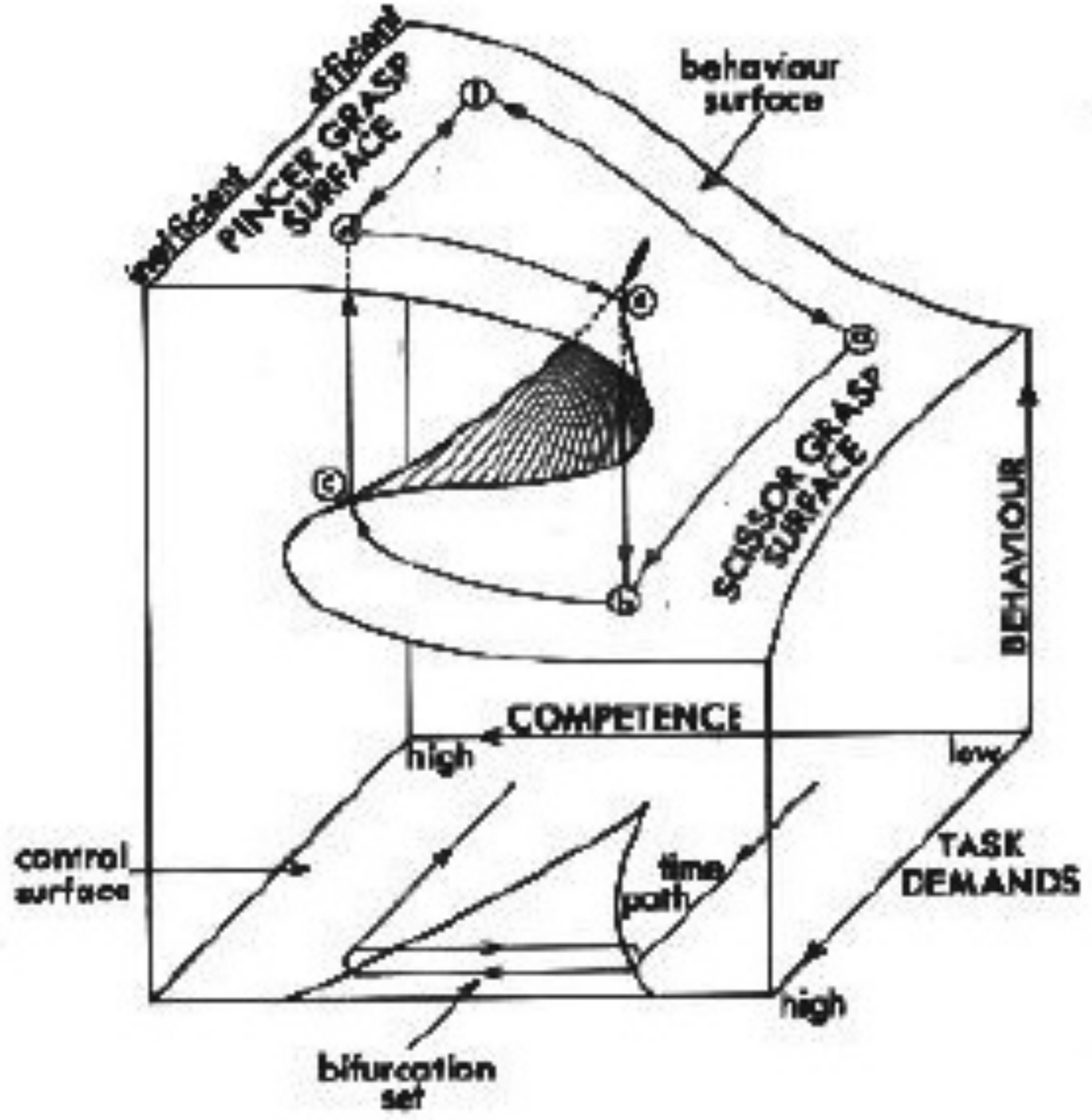


Bifurcation in Dynamical systems: Stability and attractors

$$f(x) = x^{**}2 + c$$



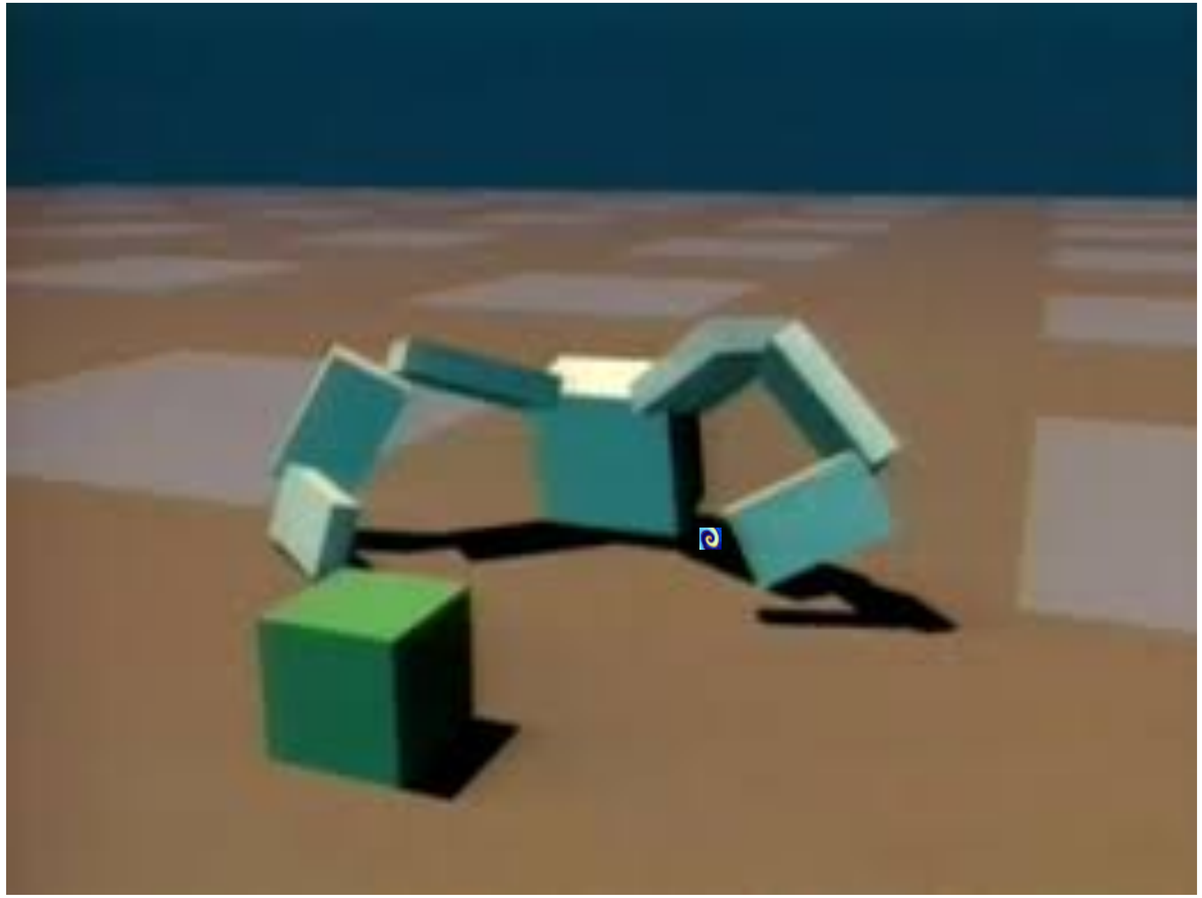




Rene F.Thom： The Catasroph Theory

A bifurcation describes a change in the stability structure of a dynamical system, whereas a phase transition describes a collective macroscopic change emerging from many interacting degrees of freedom, often in the thermodynamic limit.

What about Emergence?



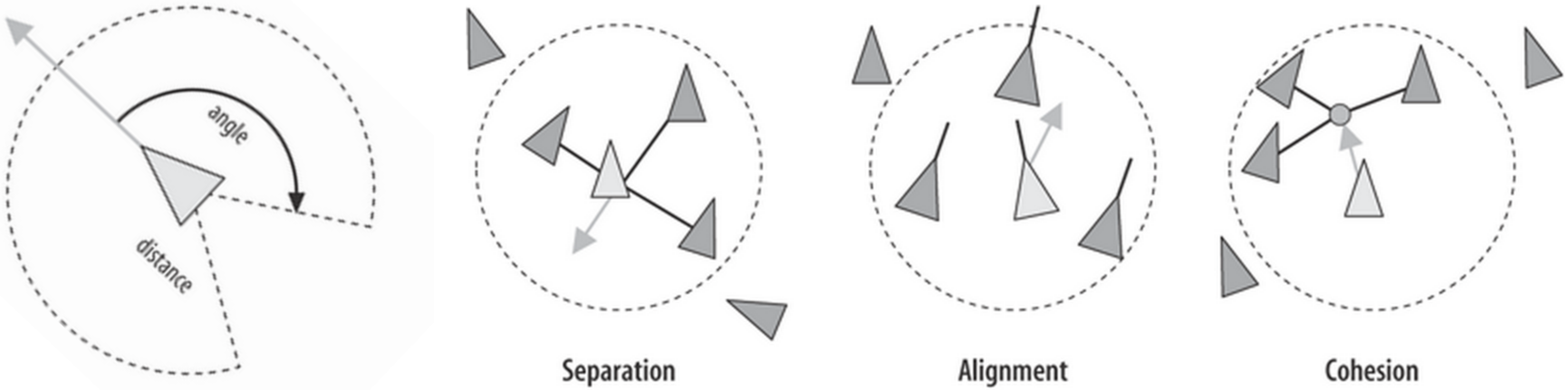
[Evolving Virtual Creatures]

Karl Sims
https://
www.karlsims.com ›
papers › siggraph94

1994 ·

Boids model (simulations)

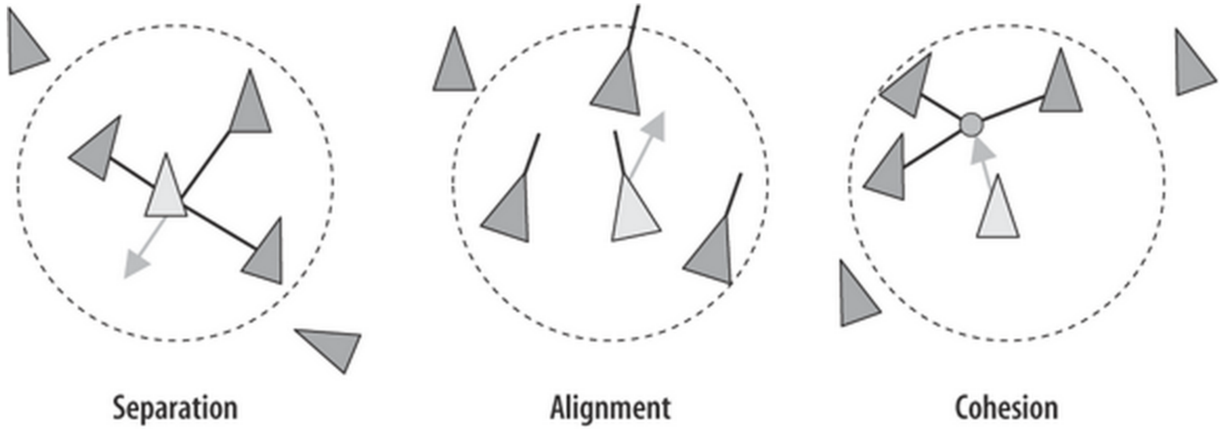
$$\frac{d\vec{v}}{dt} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3$$

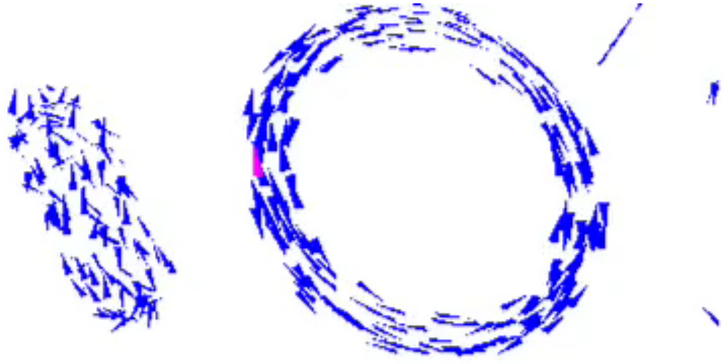


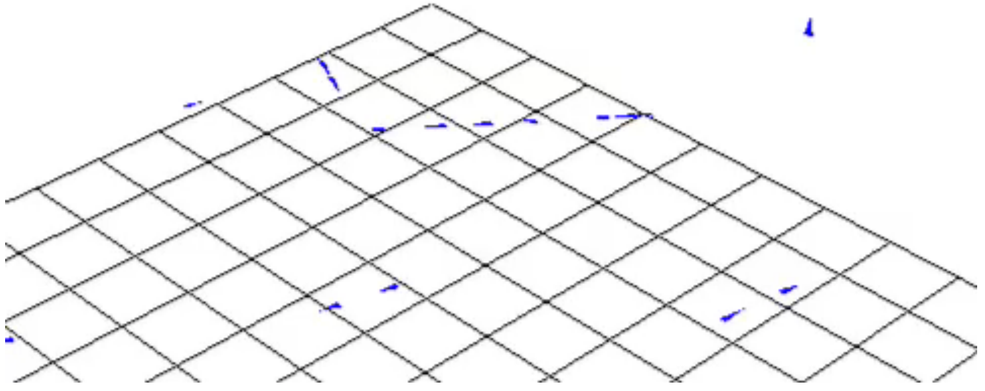
cf. Reynolds, C. W. (1987). Flocks, herds, and schools: A distributed behavioral model. Computer Graphics, 21(4), 25–34.

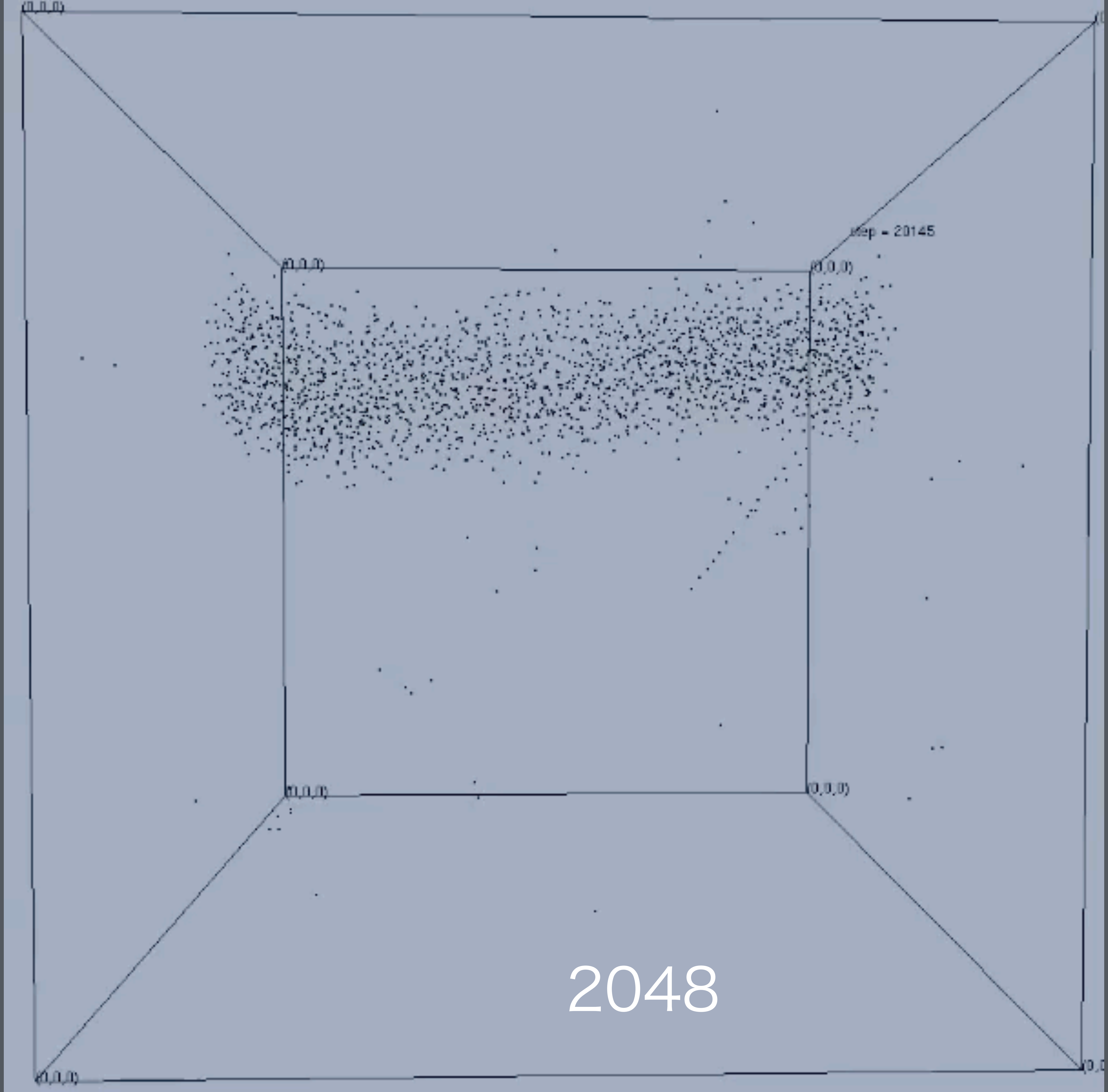
Takashi Ikegami, Yoh-ichi Mototake, Shintaro Kobori, Mizuki Oka, Yasuhiro Hashimoto: Life as an emergent phenomenon: studies from a large-scale boid simulation and web data, Phil.Roy.Soc.,375, pp.1-15, 2017.

Norihiro Maruyama,Daichi Saito, Yasuhiro Hashimoto and Takashi Ikegami: **Dynamic organization of flocking behaviors in a large-scale boids model.** *Journal of Computational Social Science*, pp.1-8 (2019).


Separation
Alignment
Cohesion



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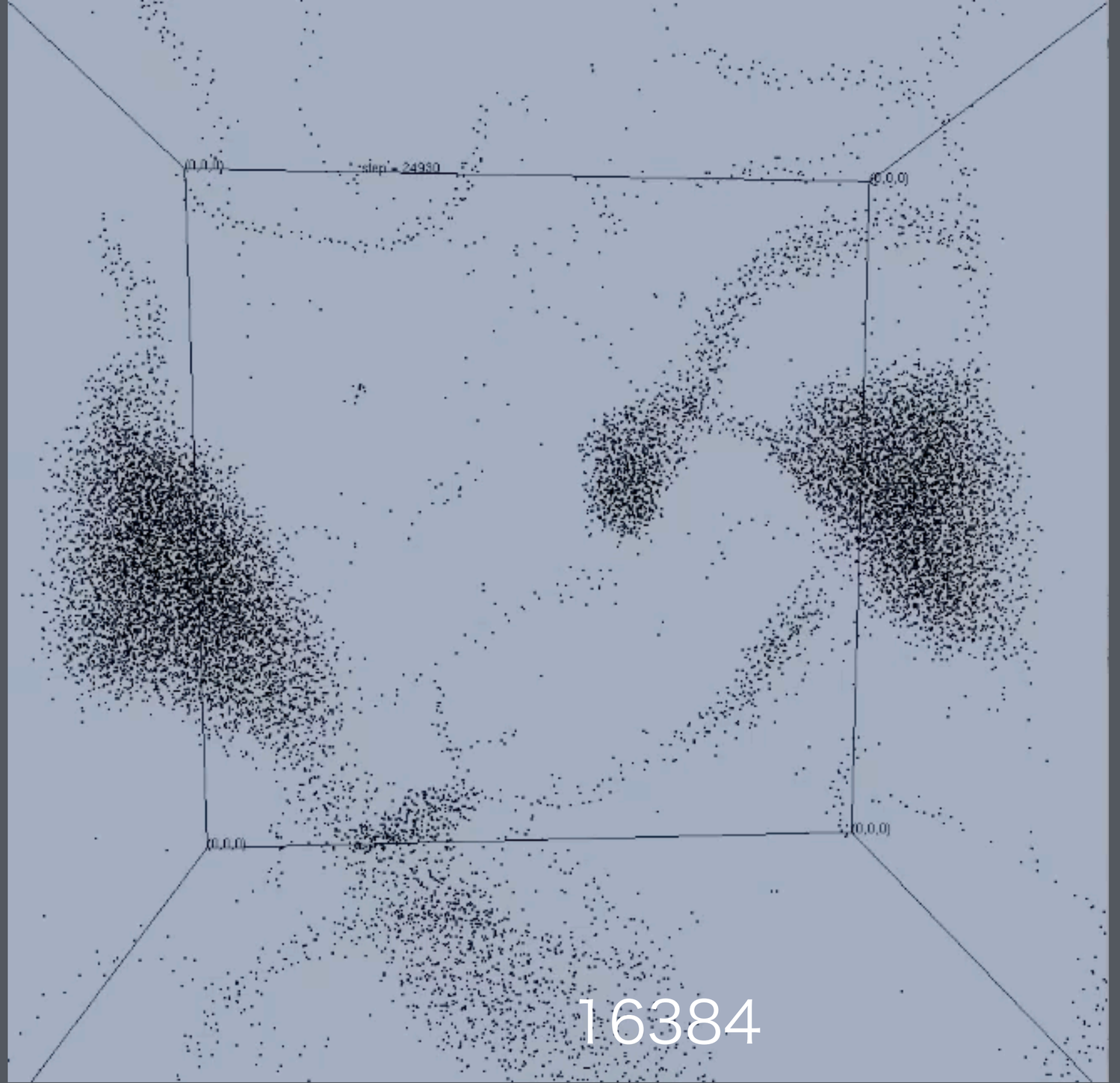
2048



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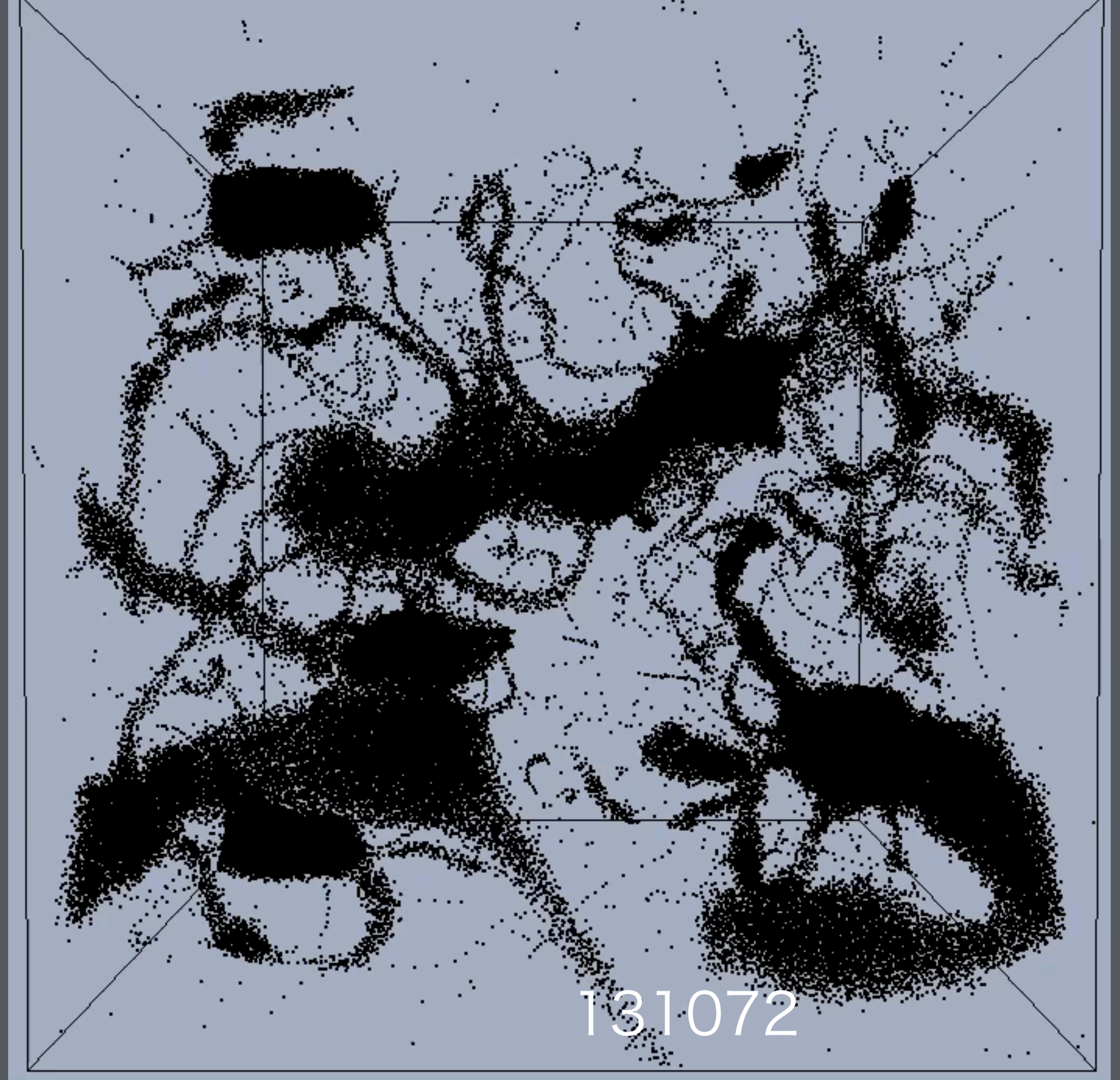
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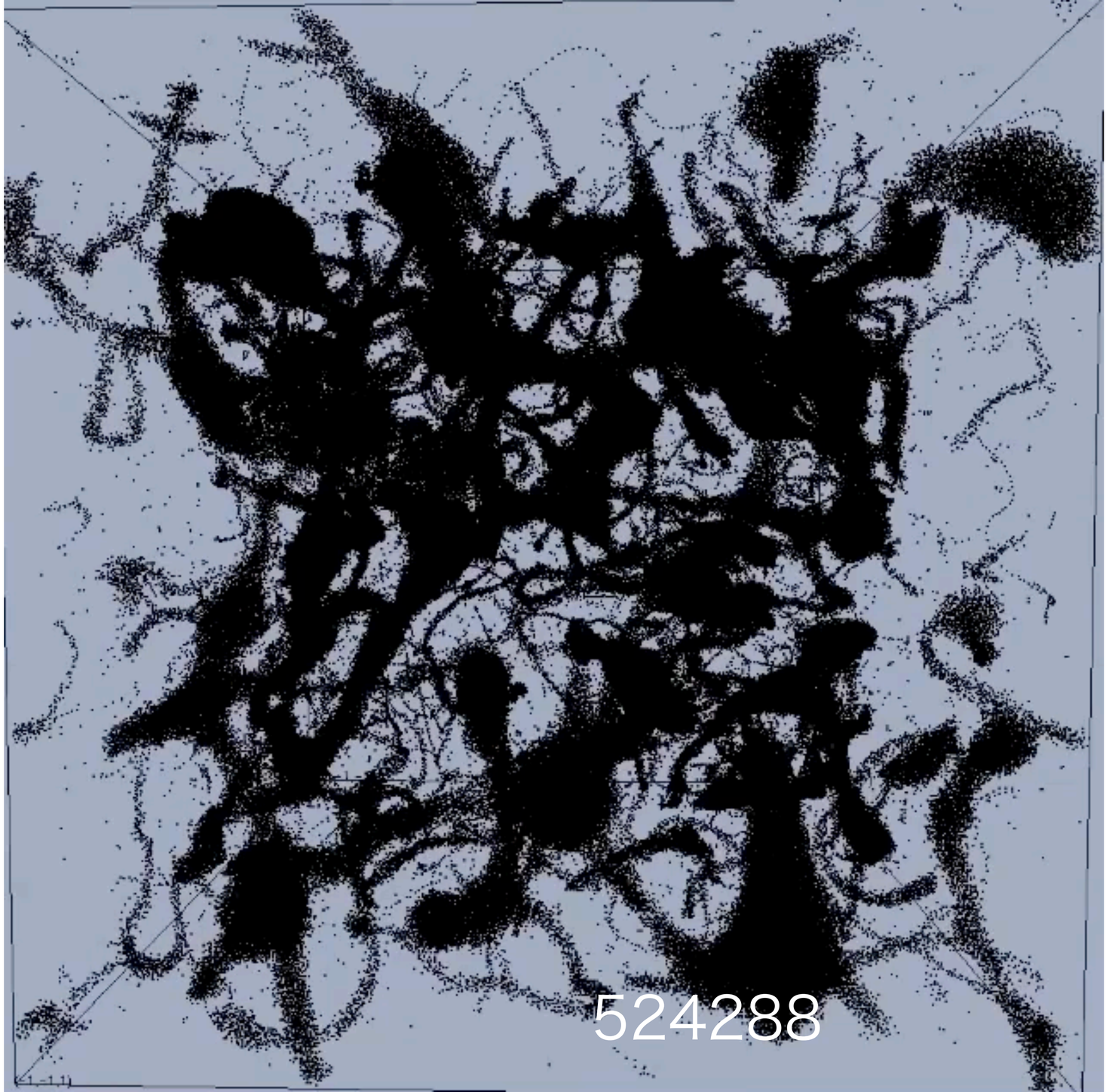
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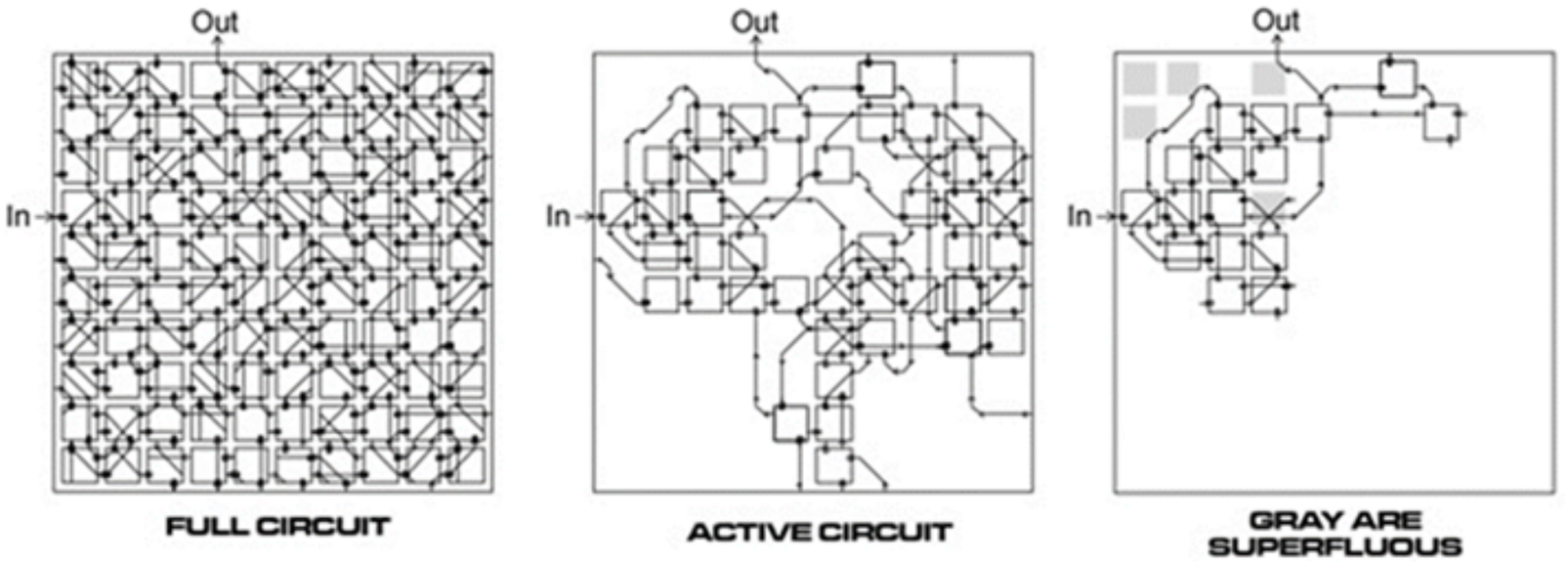

Thompson's evolved FPGA tone discriminator contained components that were not logically connected to the output, yet were functionally indispensable, apparently through subtle physical interactions in the silicon substrate.

Hardware Evolution: Automatic Design of Electronic Circuits in Reconfigurable Hardware by Artificial Evolution (Distinguished Dissertations) – 1999/1/15

Adrian Thompson

Martin M. Hanczyc, Taro Toyota, Takashi Ikegami, Norman Packard and Tadashi Sugawara:
Chemistry at the oil-water interface: Self-propelled oil droplets. *J. Am. Chem. Soc.* 129(30): 9386 - 9391 (2007

Table 1: List of emergent abilities of large language models and the scale (both training FLOPs and number of model parameters) at which the abilities emerge.

	Emergent scale			
	Train. FLOPs	Params.	Model	Reference
Few-shot prompting abilities				
• Addition/subtraction (3 digit)	2.3E+22	13B	GPT-3	Brown et al. (2020)
• Addition/subtraction (4-5 digit)	3.1E+23	175B		
• MMLU Benchmark (57 topic avg.)	3.1E+23	175B	GPT-3	Hendrycks et al. (2021a)
• Toxicity classification (CivilComments)	1.3E+22	7.1B	Gopher	Rae et al. (2021)
• Truthfulness (Truthful QA)	5.0E+23	280B		
• MMLU Benchmark (26 topics)	5.0E+23	280B		
• Grounded conceptual mappings	3.1E+23	175B	GPT-3	Patel & Pavlick (2022)
• MMLU Benchmark (30 topics)	5.0E+23	70B	Chinchilla	Hoffmann et al. (2022)
• Word in Context (WiC) benchmark	2.5E+24	540B	PaLM	Chowdhery et al. (2022)
• Many BIG-Bench tasks (see Appendix E)	Many	Many	Many	BIG-Bench (2022)
Augmented prompting abilities				
• Instruction following (finetuning)	1.3E+23	68B	FLAN	Wei et al. (2022a)
• Scratchpad: 8-digit addition (finetuning)	8.9E+19	40M	LaMDA	Nye et al. (2021)
• Using open-book knowledge for fact checking	1.3E+22	7.1B	Gopher	Rae et al. (2021)
• Chain-of-thought: Math word problems	1.3E+23	68B	LaMDA	Wei et al. (2022b)
• Chain-of-thought: StrategyQA	2.9E+23	62B	PaLM	Chowdhery et al. (2022)
• Differentiable search index	3.3E+22	11B	T5	Tay et al. (2022b)
• Self-consistency decoding	1.3E+23	68B	LaMDA	Wang et al. (2022b)
• Leveraging explanations in prompting	5.0E+23	280B	Gopher	Lampinen et al. (2022)
• Least-to-most prompting	3.1E+23	175B	GPT-3	Zhou et al. (2022)
• Zero-shot chain-of-thought reasoning	3.1E+23	175B	GPT-3	Kojima et al. (2022)
• Calibration via P(True)	2.6E+23	52B	Anthropic	Kadavath et al. (2022)
• Multilingual chain-of-thought reasoning	2.9E+23	62B	PaLM	Shi et al. (2022)
• Ask me anything prompting	1.4E+22	6B	EleutherAI	Arora et al. (2022)

Emergent Abilities of Large Language Models

Jason Wei, Yi Tay, Rishi Bommasani, Colin Raffel, Barret Zoph, Sebastian Borgeaud, Dani Yogatama, Maarten Bosma, Denny Zhou, Donald Metzler, Ed H. Chi, Tatsunori Hashimoto, Oriol Vinyals, Percy Liang, Jeff Dean, William Fedus

arXiv:2206.07682 [cs.CL]

Emergence is not merely the appearance of complexity; it is the formation of a new level of organization with its own effective variables, such as an order parameter, an attractor, a role, or an agent-level identity.

In ALife, emergence is not merely the appearance of complex patterns.
It is the formation of new effective descriptions: a strategy, a program, a role, a morphology, a collective behavior, or even an artificial organism.