Abstract

Michael Levin is a developmental biology and regenerative medicine scientist who discovered that various kinds of living material can be induced, solely via bioelectric perturbations, to develop persistent forms or behaviors never occurring in nature. He proposed a general viewpoint, “beyond teleology”, where mysterious so-called “emergent” complex patterns or forms are, for scientists, more productively hypothesized to be caused by their pre-existence rather than being outcomes of detailed step-by-step processes. Simpler objects select attractors from a huge, non-physical, rationally and hierarchically structured “latent Platonic space”. Levin thus extends, to evolution, biology and cognitive sciences, the idea that mathematics is discovered, not invented. Among Levin’s labs’ extensive research is that recent simulations produced life-like behavior in biology motivated extensions of game theory’s prisoner’s dilemma. I will survey some of his ideas and results, and suggest that they might lead us to helpful preliminary questions in mathematics.

Surveying Michael Levin's Latent Platonic Spaces – Mathematical Objects from Biology?

Seth Chaiken
Assoc. Prof. Emeritus, UAlbany CS Dept.
🔗https://chaikens.github.io

Main sources
🔗Levin's Lab https://www.drmichaellevin.org/
🔗"personal, broader complement" blog
https://thoughtforms.life/

November 18, 2025

Michael Levin is Professor of Biology at Tufts University. He directs two labs there, and has affiliations with Harvard and a biotech company. Roughly 10 years ago he discovered that patterns in embryo development appear earliest in bioelectric fields.

How do those specific patterns form? And how do the local field values choose and activate particular gene networks to make the cells differentiate? These are wide open mysteries.

The labs interdisciplinary scope is well illustrated by mind maps on their website.

More recently, he started world-wide discussion of his speculation that biology is like math in a fundamental way. You'll find it all in Levin's personal blog.

The idea is that it is not enough to say things work, or calculate, the way they do just because that's what happens when you put together parts that interact according to fundamental rules. Instead, even the most complex forms or patterns already exist.

And they exist in a space whose structure we can study scientifically. That's what he calls Platonic Space.

I will survey these ideas and I'll say roughly what I make of them, from my knowledge of math. Unfortunately, there will be no new results.

Almost everything should be attributed to talks, papers and blog writings of Levin and his collaborators. I'll only explicitly cite work of others, and Levin's for details of his papers.

Web links point to references. And I'll put the slides on my website. I wish to thank Ron for asking me to give this talk and Joshua for inviting me to the colloquium.

Spaces in Mathematics (my remarks); Structure and Properties

Structures

Open sets $\mathcal{O}$ of topological space $(U, \mathcal{O})$, with defining axioms.
ODE System, with smoothness requirements on the functions.

Vector field — a geometric interpretation of this structure.

Vector field on a manifold — structure on a structure.
Trained Neural Net $\mathfrak{N}$ — (given its architecture).

Properties

- from axioms Existence and Uniqueness Theorems.
- of an instance — Each critical point's orbit is a stable attractor.
  — $\mathfrak{N}$'s behavior func: Input $\mapsto$ computed distribution

Care, Rigor. We often say "category" not "kind of space"

Distinguish types of spaces eg. category of topological spaces Top, from spaces $S \in \mathrm{Obj}(\mathrm{Top})$.

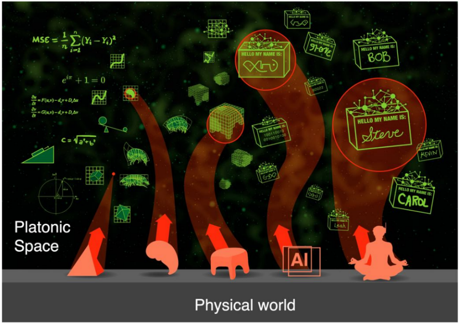
Levin's spaces are ... well ... a ... kinda mathematical. I'll touch on what mathematicians expect. A space is an object composed elements or points, and, importantly, a structure whose type tells what kind of space it is. So we're careful, to define the structure, for our spaces.

For example, a topological space has its structure of open sets. Likewise an ODE or a vector field over Euclidean space, different views of the same thing, has a structure. We might define structures on structures like vector fields on manifolds. Let's consider a trained neural network, its architecture, threshold functions, and weights, maybe also training method, to be a mathematical structure. One of $\mathfrak{N}$'s properties is the probability distribution of answers it gives for an input prompt.

Given a structure definition, we formulate properties. Some are theorems proved from the structure definition, the axioms. And others are properties a instance might have or not have, or are consequences of other properties we have assumed.

For us, a category is more than a classification. It's just so helpful to understand spaces in terms of structure specific and compatible maps or other relationships among instances.

We have to exercise rigor appropriately. If we are not careful we could by confused by word overload if we perhaps say some category is a space of spaces.



Michael Levin proposes that forms or patterns of even artificial living things pre-exist in "latent Platonic space." A physical thing is an "affordance" or "pointer" to a form, so life was caused by more than physics, chemistry and evolution. Platonic spaces are "rationally structured"; science explores / nature exploits their structure and contents.

Although (critics say) physics, chemistry, etc. might explain observations, Levin declares$ empirical (not philosophical) benefits: this "conceptual framework" was crucial for his surprising discoveries. I suggest Levin's intriguing view of his ($\approx$ 30year) and other biologists' work may lead to preliminary mathematical questions by perhaps, noticing life-like mathematical phenomena.

🔗[picture: Ingressing Minds: Causal Patterns Beyond Genetics and Environment in Natural, Synthetic, and Hybrid Embodiments, 2025]

This picture is from one of Michael Levin's preprints.

Michael Levin proposes that forms, even weird ones that exist only in the laboratory, actually pre-exist in a so-called latent Platonic space. A physical thing is an affordance or pointer to the form, so the pre-existence is the cause of that form, a new kind of teleology.

Levin's Platonic spaces are not arbitrary or mystical, so scientists can study them rationally.

(Furthermore,) Evolution discovered how to take advantage of the fact these things do what they do relying on fundamental, unchangeable laws of mathematics, physics, and chemistry.

Levin declared, as you declare benefits of income on your tax return, that his viewpoint was necessary for him choose experiments that gave solid and surprising results.

My main point today is to suggest that mathematicians might find interesting, preliminary questions by looking for signs of life in math theory or experiments.

Levin's 22 min talk–Selections

Latent Space*

unobserved regularities that underlie observations

The talk motivates:

"ordered structured space that contains not only mathematical truths but also high order patterns that we recognize as kinds of minds"

💻Bioelectricity: a bridge between physics and cognition, by way of biology" by Michael Levin Oct 7, 2025

*LevinBot's definition, cites machine learning papers

"Latent space refers to a conceptual or mathematical space that describes or hypothesizes underlying regularities that are not directly observable in the data stream but need to be inferred. For example, in object perception, the visible input stream (e.g., stimulation of the retina) can be considered a function of latent causes, such as the identity of the object and its location or pose."

To hear where Michael Levin is coming from I'll play some selections. But first I'll define the idea of latent space that Levin started with: It holds the unobserved regularities that underlie observations.

The excerpts show his motivation for building up the idea.

You'll hear him explain the essential role of minds and cognitive agents play in biology. These agents are the mind-like things in latent Platonic space.

(The Levin Lab has chat bot trained on the lab's publications. When I asked it what is a latent space, I got this answer.)

“Cognition all the way down” (2:00) explained well

(Levin and Dennett, 2020, Aeon) explains how anthropomorphic thinking really helped scientists and engineers, after 1940-1950s cybernetics theories. Also *Bacteria to Bach ...*, Dennett (2017).

Keywords

cognition, (scaled) goals, execution, abstract mental goals, intentions, mind-matter interaction, transduction, interface, embodied minds, remapping memories, agents and agental material, computational matter, agenda, avoiding micromanagement, intelligence, space navigation, anatomical possibilities, perception-action loop, layering, multi-scale problem solving competency in environments, regeneration of forms/patterns, goal seeking (stopping), global plan, intents, fixing error, physiological software vs genetically specified hardware, programmability and reprogramming, computational networks, pattern memories, synthetic life forms, behavior and genetic expression patterns, latent Platonic space, ingression of patterns.

Dennett and Levin elaborate the idea of “cognition all the way down” in this magazine article. It explains what biologists gained by giving up their aversion to anything smacking of Teleology. Old fashioned teleology is Aristotle’s fourth or final cause that answers “Of what is its good?” ... say rain falls because it grows food for us people. But ... the modern view is that to assume living things have the goal to maintain and propagate themselves is a necessary principle for understanding biology. We lose that understanding if we reduce biological systems to physical machines.

Danial Dennett’s 2017 book Bacteria to Bach and Back Again, unfortunately one of his last, describes what life is in terms of this goal-having characteristic.

Levin's speculative hypotheses (my take)

1 Agent: Something with goals; can solve problems in multiple ways upon sensing an environment.

Scientists would be wise to consider all objects in our 4×10^9year evolution to have features and behavior characteristic of goal-seeking agents with intelligent cognitive abilities. (Degrees of ability? "physical $\oplus$ cognitive (or care) [possible goals] light-cones".)

2 This enables objects to navigate **latent Platonic spaces**, taking advantage of existing space structure and properties including "free lunches."

Levin's approach (paraphrased):

Do experiments and observe trajectory changes — to discover space structure and how trajectory control machinery works. The trajectories are not merely and mysteriously just "emergent"— There is something to discover.

Scientists would be wise to consider all the evolved objects of life to be goal-seeking agents with intelligent cognitive abilities. Of course, there's a wide range of degrees; Levin says the measures of degree are the agent's "physical and cognitive light cones"

What he means by an agent is that it has goals and can reach them by solving problems in multiple ways upon sensing the environment.

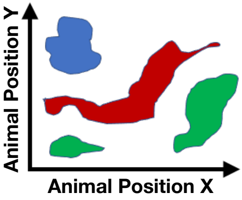
Second, this enables agents to navigate in latent Platonic spaces, taking advantage of existing space structure and properties. When properties are not the result of evolution, he calls them "free lunches".

I think one way Levin takes advantage of his claimed benefits is to do experiments; that's what scientists do anyway, but now with expecting to find existing structure and, from that, explanations of how the trajectories are controlled.

Space Examples: **Need additional relevant structures?**

Life Has Embodiment Outside of Familiar 3D space:

3D Space (behavior)

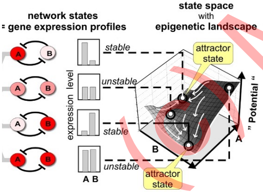


perception-action loop can happen in other spaces!

-> unconventional embodiment for AI's

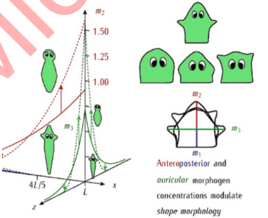
Transcriptional Space

Huang, S.; Ernberg, I.; Kauffman, S., Semin Cell Dev Biol 2009, 20, (7), 869-76.



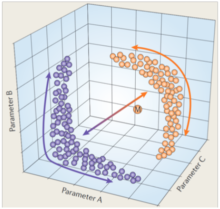
Morphospace

Cervera, J., Levin, M., and Mafe, S., (2021), BioSystems, 209:104511



Physiological Space

Marder, E., & Goaillard, J. M. (2006). Variability, compensation and homeostasis in neuron and network function. Nat Rev Neurosci, 7(7), 563-574.



Let's look at the examples. Birds navigating $\mathbb{E}^3$ can be trained to collect cigarette butts in cities. The other spaces that life traverses are more abstract, but mathematicians are adept with that.

Let me point out the bird's navigation system takes "free lunch" advantage of the optics of opaque obstacles, and of aerodynamics. So the birds' space has much more structure than $\mathbb{E}^3$. I would ask what additional structures in the others are needed to pose relevant questions?

The points in transcriptional space are vectors of mRNA concentrations. We have a dynamical system. What might we ask about the topology of some feasible manifold?

Levin's Free Lunch Examples

First: Triangle most fit with 60^O angles. 2nd:

1. Voltage gated ion channels "embody" Boolean logic.
2. So the universal property of the NAND gate did not have to be evolved.

Computer Sci (Math) Question

Identify properties (probabilistic?) of observed boolean (partial?) functions and circuits. (Much is known!?)

More generally...

I think we would say the same thing as about the wide range of biological control and reaction networks and fields: They embody differential equations/dynamical systems; a huge collection of mathematical properties is known.

Prospecting for Mathematical Gold

What is the mathematical nature of the "affordances or interfaces"? Look at biology results and conceptualize the difference between a space of transversals from its ambient space.

Let me explain his free lunch idea a little more.

Levin's first example is that once some hypothetical evolution finds that 60 degrees is optimal for the first two angles in a triangle, it doesn't have to keep going.

Another example is the laws of Boolean algebra. I would then ask how does nature take advantage of that math? I guess there's lots of literature on that.

Levin cited the discovery that a 10 variable dynamical system model of a biochemical reaction network displayed the effects in behavioral science: conditioning, habituation, desensitization. They found these effects didn't occur in randomly constructed systems. So this might give us good questions in dynamical systems.

Again, trying to make sharper mathematical distinctions may help our interdisciplinary research.

My modest proposal

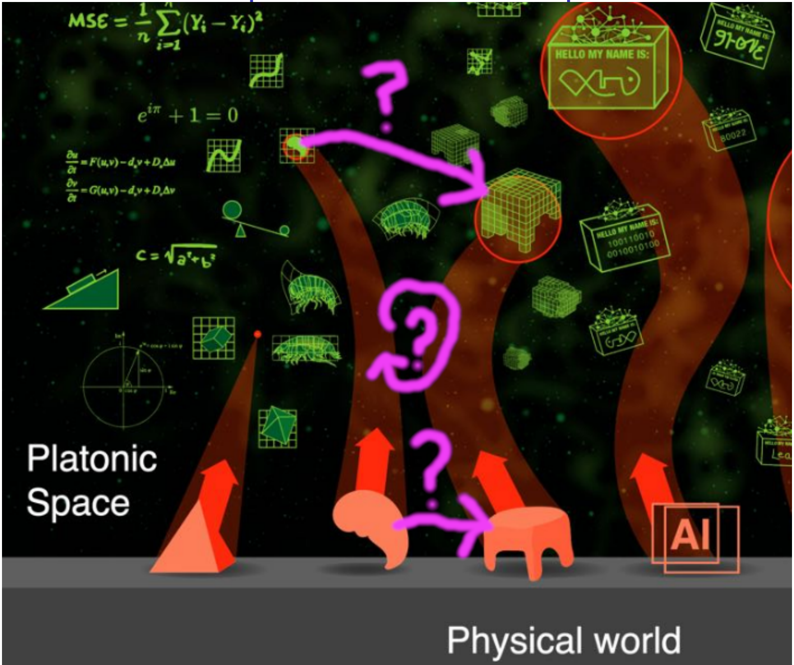
Ask sharp mathematical questions! Let's try to discover something by conjecturing rigorous, 20th century math models for Levin's Platonic spaces view of some biologists' working concept details.

Higher Category Theory

Like definitions of homotopy composition, morphism composition (modeling some kind of transformation, or environment change) might not be strictly associative, but associative up to a 2-morphism of 1-morphisms (or higher).

Levin said these spaces should be studied more rigorously. My modest proposal is to ask sharp mathematical questions. Let's conjecture mathematical models informed by modern foundations such as category theory. And keep this kind of math in mind when doing interdisciplinary study and even better, collaborations.

Put the Functorial pattern into Levin's picture



You can't resist marking up Levin's picture with commutative diagram. The hard part, the interesting part, is what are the morphisms, in Physical Space and in Platonic Space?

Lauren Ross described it well.

"How do we clarify distinction between explanation ... [and] description, classification, prediction"

"with causal explanation, main goal is control"

(citation: Lecture (8) Explanation in Biology: principles and pragmatics - Copied from thoughtforms.life, Oct. 2025)
Lauren Ross, Logic and Philosophy of Science Department University of California, Irvine)

"causal explanation" in Math Language!

Understand two categories Afford, Plat and $F : \text{Afford} \to \text{Plat}$ well enough to prove F is a functor.

They might need to be Higher Categories

if morphism composition is not strictly associative.

Lauren Ross spoke in the now on-going Platonic Space Symposium. She compared different kinds of scientific results. Explanation we understand control, why a change in an environment produces in a change in the result.

In mathematical language, this means understanding a map between categories enough to prove it is a functor.

In Levin's setup, the functor would go from our hypothetical category of affordances or physical objects to a category of objects in a Platonic Space. When we propose the morphisms, we'll have to investigate associativity. Our models might need to be higher categories.

Rest of Talk

1. 2025 Levin Lab grid of player Prisoner's Dilemma simulation.
2. 2025 Life-like patterns from sorting algorithms.
3. A take-away.
4. Speculative ideas for future dreaming (work?).
5. Pointers to more information.

(? 2025 a simulation of programming morphogenesis.)

Extending Iterated, Spatialized Prisoner's Dilemma to Understand Multicellularity: Game Theory With Self-Scaling Players, Shreesha, Pigozzi, Goldstein and Levin, IEEE Transactions On Molecular, Biological, And Multi-Scale Communications, June 2025.

Simulations

- Prisoner's dilemma game extensions and reinforcement learning of strategy
- Model cell differentiation in 2-d tissues

Life-like Results

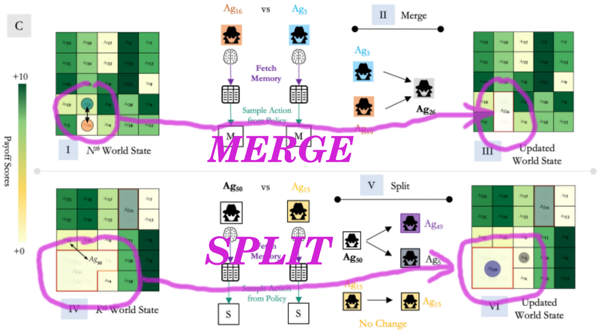
- Intermediate patterns like in morphogenesis
- $1 < |\text{memory}| \leq 4 \implies$ convergence to single cell type
- Punctuated equilibrium dynamics
- "Smaller sized individuals around larger sized agents" emergence of "skin" was not programmed

They extended the well-known Prisoner's Dilemma in game theory in a few ways to model cell differentiation.

The simulations gave these life-like results. Typical morphogenetic 2-d patterns, convergence to a single cell behavior, and periods of slow change alternating with shorter periods of rapid change.

The most interesting result was that the model was not programmed explicitly for producting a typical biological form—it was programmed only for rewarding long run cooperation.

Extensions: Agent grid, Adj. M/S, fitness selection



Player Y / Player X	Cooperate [C]	Defect [D]	Merge [M]	Split [S]
Cooperate [C]	8.0	0.0	8.0	0.0
Defect [D]	10.0	5.0	10.0	0.0
Merge [M]	8.0	0.0	0.0	0.0
Split [S]	0.0	0.0	0.0	0.0

Prisoner's dilemma Payoff Table **Merge[M] and Split[S] extensions**

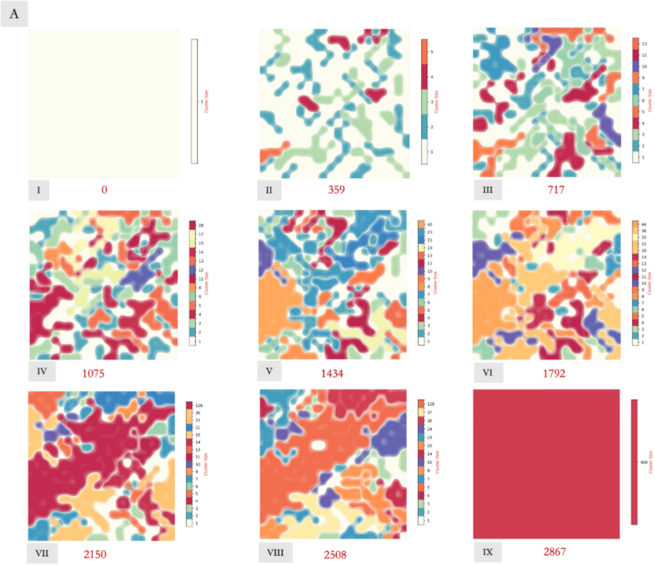
Two player prisoner's dilemma was extended to a grid of original players. Random adjacent pairs play against each other. But besides choosing to Cooperate or Defect, players might choose to Merge or Split. The payoff table is extended for this.

In merge, two players are replaced by a new player that occupies a larger region of the grid. The merged player gets a memory and strategy table derived from the two's.

Split undoes the most recently preceding merge.

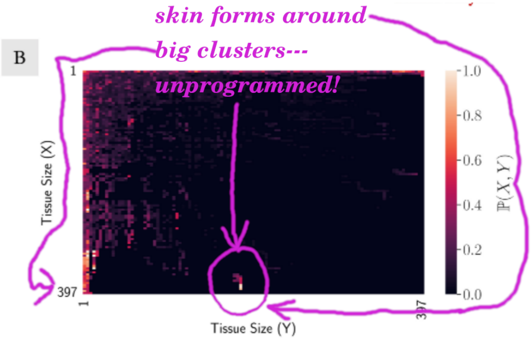
Each player's average payoff is called its fitness. Sometimes, randomly, the simulation picks a player whose fitness is below all its neighbors and replaces its memory and strategy by that of its most fit neighbor.

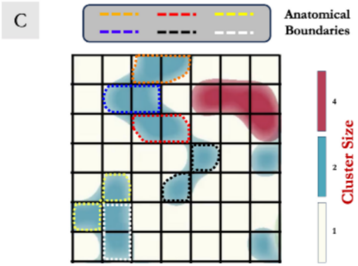
Result: Patterns like Life's Morphogenesis



The colors indicate sizes of merged clusters. Game playing history had patterns like what's observed in life. When the players' memory size is greater than 1, there's convergence to merging into one player.

Result: Another Life-like Pattern





Prisoner's Dilemma summary

- The cooperative common behavior of cells in an organ, and also biological form, emerges when simulating a natural biology motivated extension in game theory where agents can split and merge.
- Merely rewarding long-run cooperation, supporting limited memory based strategies, and some fitness selection $\implies$ life-like development patterns and results (organs with boundary membranes), without anything to explicitly program or reward them in the simulation rules.

Complex Process from very simple local interaction

Zhang, Goldstein and Levin (2025)
Classical sorting algorithms as a model of morphogenesis: Self-sorting arrays reveal unexpected competencies in a minimal model of basal intelligence.

- Runs of randomized parallel sorting algorithms
- Keys' code was faulty
- Multiple variants of keys' code

Observations

Problem solving & pattern formation behavior characteristic of life.

Conclusion

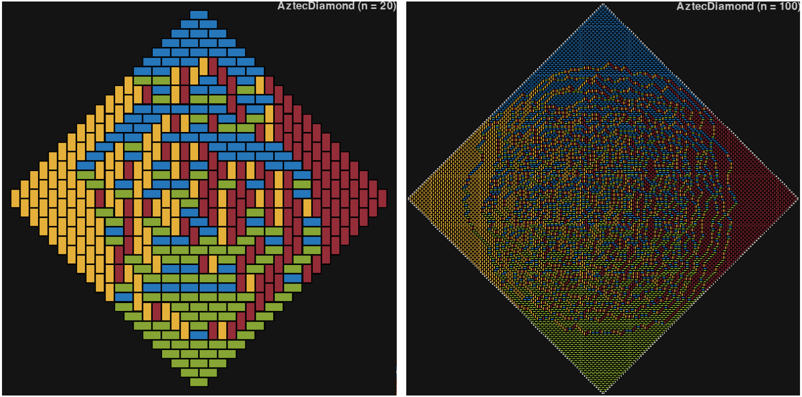
Do seek phenomena from behavioral, information & bio. sciences in simpler systems

Similar pictures in statistical & dynamical combinatorics of James Propp, Jessica Striker, & others in Dynamical Algebraic Combinatorics!

This paper on unexpected competencies in a minimal model of of basal intelligence. If you and your neighbor's keys are out of order, swap places. They found life-like behavior in variants of one of the simplest algorithms in computer science. They concluded that we should do behavior science experiments on very simple systems. I was going to talk more about this. But I want to first look into very recent work on statistics of random tilings, things like Ising models, subject to kinds of non-uniform probabilities. You can see pictures like Levin shows of morphogenesis.

Some Discrete Mathematicians such as James Propp and Jessica Striker have named related stuff "Dynamical Algebraic Combinatorics."

Tilings of Aztec Diamond with Dominoes

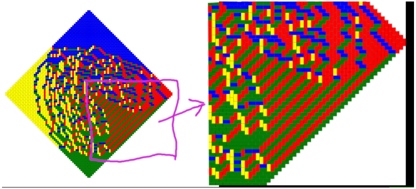


Theorem (Jockusch, Propp and Shor 1995 4 KINDS?!)

(the Arctic Circle Theorem): Fix $\epsilon > 0$. Then for all sufficiently large n, all but an ϵ fraction of the domino tilings of the Aztec diamond of order n will have a temperate zone whose boundary stays uniformly within distance ϵn of the inscribed circle.

Recent

- Bufetov, Petrov, Zografos. Domino Tilings of the Aztec Diamond in Random Environment & Schur Generating Functions (2025) arXiv:2507.08560

(Visualizations) 

- Tomas Berggren. “Domino tilings of the Aztec diamond with doubly periodic weightings.” Ann. Probab. 49 (4) 2021

1970 T. BERGGREN

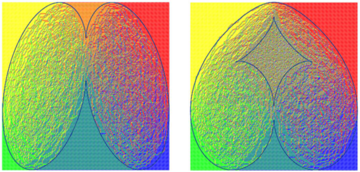


FIG. 6. *Two examples of periodic weighting of the Aztec diamond which is covered by Theorem 1.1 but not studied in the rest of the paper.*

Pessimism

Maybe all this stuff is what today's biological, bioinformatics and data scientists do anyway, but it's interesting.

Take-Away (I think)

- Local, similar interactions between elements in a planar lattice result in interesting dynamical patterns, quite generally.
- The hard forward problem is predicting pattern properties without simulating.
- The even harder backward problem is to find parameters or boundary conditions for a given pattern.
- Biology, including theorizing about agents/goals, may lead us to new, interesting examples: Both of rules and dynamic patterns.
  - **Why?** Evolution made use of the Platonic Space subsets that made us possible, not at all obvious how, so it's a good bet that its tractable structures will have interesting mathematics.
  - perturbation tolerance, programmability, mix of randomness and predictables (e.g. fingerprints), etc.

Speculative Questions

- Might goals/purposes (now accepted in biology) force any solution to the problem of achieving them to have certain structure and properties? For example,
  - The problems of communication, community cohesion, culture maintenance (teaching), etc. solved by language during human evolution can only be solved by systems whose structure has properties identified by Chomsky and later cognitive scientists?
  - Geoffry Hinton (2024) recounted that feature based learning systems are far more effective for producing intelligence than reasoning systems. Could it be that the problems solved by certain kinds of intelligence require that every solution has the multi-level feature recognition and learning structure embodied by natural and artificial neural nets?

More

- Levin asks to find simple systems with agental behavior, as in his bubble-sort project. Are there some behaviors impossible in simpler systems, versus some that are possible? Computer scientists, beginning with Godel and Turing have studying this more or less abstractly for well over fifty years, starting with Godel and Turing. It's called Computational Complexity. But today's problems are different.

  For example, (1) to-date, the only successful AI neural networks are huge. (2) Formalizing math well-enough for really assisting research (Mathematical Components library, etc. in Rocq (COQ), Lean, etc.) uses a large, intricate, hard to understand body of code. Meanwhile, human math learning seems to be an easy (for some!) step-by-step experience, but it relies on the unquestionably large human brain.

How I started

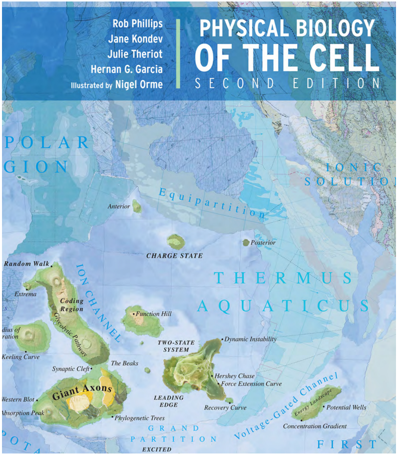
- Sept 21, 2023 Michael Levin "Emergent Selves and Unconventional Intelligences: where philosophy and engineering meet" at Topos Institute Colloquium.
- I proposed group discussion of Levin's Fall 2025 Levin's asynchronous Symposium On The Platonic Space.
  thoughtforms.life/symposium-on-the-platonic-space/

Good start: Its kickoff talk, Aug 28, 2025 by Levin. And then:

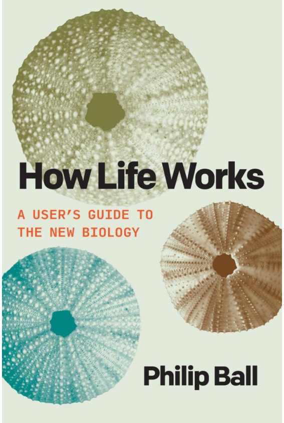
- Patterns of Form and Behavior Beyond Emergence
- Levin, Platonic Space: brief argument and research agenda Oct 29, 2025 (linked from Symposium discussion)
- Ingressing Minds: Causal Patterns Beyond Genetics and Environment in Natural, Synthetic, and Hybrid Embodiments, 55pp, 2025
- Levin's **Forms of life...** blog entry on *Platonic Space ...* .

I started following Levin after his talk on the Topos Institute Colloquium. And then I told Ron about this fall's Platonic Space Symposium. A good start is Levin's 1 hour kickoff talk there. And then, see his recent lecture on Platonic Space and its 55 page paper. His blog posting and conversation is also helpful.

Other Cool Writings



(2013) Rob Phillips et al.
Cell biology organized by
physics principles
not cell components



(2023) a favorite of Levin
30 year physical sciences editor for
Nature now prolific freelance
popular science writer

Here are a couple of other resources I found recently. The first is a solid textbook that organizes cell biology by physical principles. I don't think you can see, I tried to blow up the cover, [look at screen] some names on the map are "charge state", "Equipartition", "random walk", "Dynamic Instability", there are also biological ones.

How Life Works, Philip Ball (2023)

Gene Regulation

- ... first challenge ... genes don't relate to traits in any straightforward way.
- ... complexity lies not with genes but how they are regulated.
- ... not governed ... precisely defined ... network.
- ... rules ... different levels of organization that don't relate [obviously] to those ... above and below.

proteins "disordered, not globular" ["floppy" ... [lots function as adapters or messengers]

Necessity of Disorder, Redundancy

- Some ... error is necessary for evolution ...
- ... evolution requires ... the right amount ...
- On progression ... prokaryotic to eukaryotic ... unicellularity to multicellularity ... vertebrates ... mammals.
- locus of causation ... to higher organizational levels ...
- ... new ways of handling information ... cognition

"How Life Works" is the story of the enormous change in biology due to genome data over the last 20 years. Knowing DNA sequences raised more, and much harder questions than they answered. The apparent hierarchy of life's components are now known to have loosely determined highly circular and redundant interactions. The genome alone does not determine biological forms.

Proteins not at all like the machine-like molecules revealed by crystallography have great importance.

And evolution to more complex organisms required deep and complex causal systems.

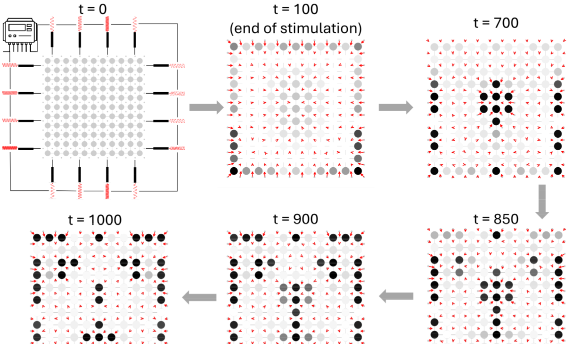
Quote from Ball

"If the first challenge to the conventional story of our own biology comes with the recognition that genes don't relate to traits in any straightforward way, and the second comes from the discovery that our organismal complexity lies not with the genes themselves but with how they are regulated, the third major shift in thinking is that this regulation is not governed by simple switching processes in a precisely delineated interactome network. The reality is startlingly different, and there is plenty about it that we still don't understand. What we do know, though, is astonishingly, gratifyingly ingenious. It reiterates the point that life has rules at many different levels of organization that don't relate in any obvious way to those of the levels above and below. None is more fundamental than any other."

Extra Material

Manicka & Levin Oct 2025 Field-mediated [morphogenesis simulation]

- Levin **had** proved patterns of frog faces, etc. occur first in bioelectric fields.
- Tissue morphogenesis, by bioelectrical interactions, modeled by a non-linear dynamical system
- Variables have 11×11 array structure.
- Electric field $\overrightarrow{e}$ at cell adjacencies.
- Stimulation: Initial time series applied around the boundary.



Through his work of 10-20 years ago, Levin proved the patterns of frog faces first develop as bioelectric fields. The expected level of scientific care was taken, for example, when different ion channel proteins were used to make the same field patterns, the results were the same.

Gradient descent was used to find 2 stimulations to produce a face pattern.

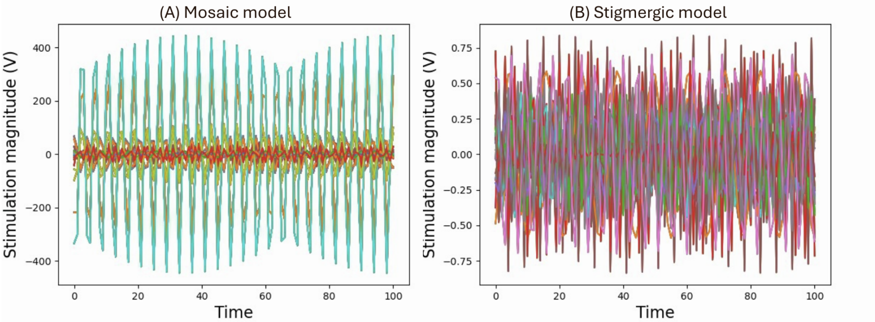
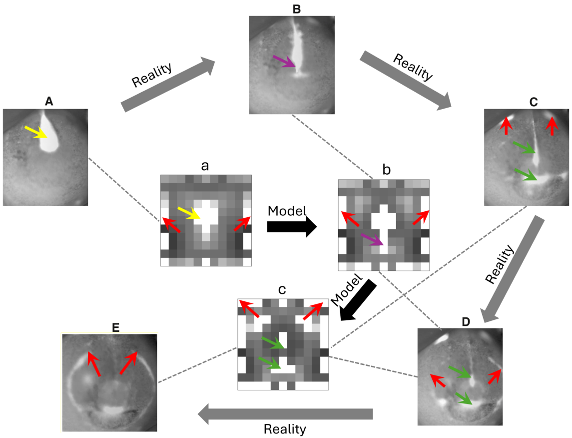


***Figure S4.* Profiles of the exogenous stimulation applied to the vertebrate face patterning models.** (A) Timeseries of the oscillatory stimulation applied to the boundaries of the mosaic model during the initial 10% (equal to 100 steps) of the simulation phase, and (B) equivalently for the stigmergic model. The total number of traces in each panel is 44, indicating the total number of field grid points at the boundary of the 11x11 tissue with a 12x12 layout of the field grid points. Due to the bilateral symmetry of the smiley pattern, the total number of distinct traces is only 22, corresponding to one vertical half of the boundary, with the other being its mirror reflection.

Simulated and real bioelectric pattern trajectories compare.



selected details

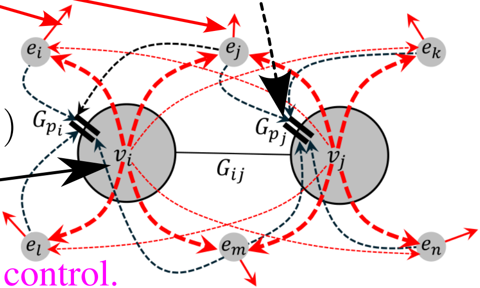
$$G_r \frac{dG_{p_i}}{dt} = -G_{p_i} + 2W\left(\sigma\left(-\sum_{j\in N_{F_i}} \frac{\|\vec{e_j}\|}{|N_{F_i}|} + B\right)\right) - 1$$

$$\vec{e_i} = \frac{k_e}{\varepsilon_r}\sum_j \frac{q_j}{\|\vec{r_{ji}}\|^2}\,\delta(\vec{r_{ji}} - \sqrt{2}rR)$$

conductivity of ion channel

electric field

q_i :Charge $= C(v_i$:cell elec. pot.$)$



Params tuned to max meas. of variability & control.

details if needed

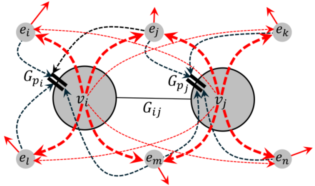
$$C\frac{dv_i}{dt} = -\frac{G_{p_i}(v_i - E_p)}{1 + e^{\frac{z(v_i - v_{th})}{v_T}}} - \frac{G_{d_i}(v_i - E_d)}{1 + e^{\frac{-z(v_i - v_{th})}{v_T}}} + \sum_{j \in N_{C_i}} (v_j - v_i) G_{ij}$$

$$G_{ij} = \frac{2GG_r}{1 + \cosh\left(\frac{v_i - v_j}{v_0}\right)}$$

$$G_r \frac{dG_{p_i}}{dt} = -G_{p_i} + 2W\left(\sigma\left(-\sum_{j \in N_{F_i}} \frac{\|\vec{e_j}\|}{|N_{F_i}|} + B\right)\right) - 1$$

$$\vec{e_i} = \frac{k_e}{\varepsilon_r} \sum_j \frac{q_j}{\|\vec{r_{ji}}\|^2} \delta(\vec{r_{ji}} - \sqrt{2}rR)$$

$$q_j = Cv_j$$



Where:

$r = 5\mu m$, the radius of a cell
n_c = total number of cells
N_{C_i} = the set of neighboring cells of cell i
n_f = total number of field grid points
N_{F_i} = the set of neighboring (within perception range) field grid points of cell i
$v_i = V_{mem}$ of cell i (Volts)
$\vec{e_i}$ = electric field vector at field grid point i; $\|\vec{e_i}\|$ measured in (Volts/m)
q_j = charge content of cell j (Coulombs)
$\vec{r_{ji}}$ = distance vector from cell j to fiel grid point i
G_{ij} = the conductance of the gap junction connecting cells i and j (Siemens)
$G_{p_i} = P * G_r$; $P \in [0.0,2.0] \in [0.0,2.0]$,
the conductance of the polarizing ion channel of cell i (Siemens)

$G_{d_i} = 1.5\ nS$, the conductance of the depolarizing ion channel of cell i (S)
$G_r = 1.0e^{-9}\ S$, the reference value for scaling ion channel and gap junction conductance (Siemens)
$C = 0.1e^{-9}$ F, the capacitance of the cell membrane (Farads)
$E_p = -55\ mV$, the equilibrium potential of polarizing channel
$E_d = -5\ mV$, the equilibrium potential of depolarizing channel
G = Gap junction strength $\in [0.0,1.0]$(A. U.)
R = field action range (A. U.)
W = field transduction weight (A.U.)
B = field transduction threshold (Volts/m)
$\sigma(.)$ = sigmoid transformation
$\delta(\vec{r_{ji}} - d)$ = delta function with value 1 when $\|\vec{r_{ji}}\| \leq d$ and 0 otherwise
$k_e = 8.987e^9 Nm^2C^{-2}$, the Coulomb electric field constant
$\varepsilon_r = 10^7$, the presumed relative permittivity of cytoplasm

Possibly Useful Out-takes

Levin's kickoff talk ∈ https://thoughtforms.life/symposium-on-the-platonic-space/

Research Program:

- Build new interfaces to observe new ingressing forms - our synthetic morphology work provides tools/vehicles/periscopes for exploration of the space.
- Infer a rigorous mapping between properties of the pointers and the patterns they facilitate
- Quantify the "free lunch" aspects - how much information/influence/evolvability is injected into the physical world? Free compute?
- Are the contents of this space under positive pressure?
- Is the space sparse? Are some attractors "better" than others?
- Are the contents of this space purely passive (eternal, unchanging) or can we define a kind of "chemistry" of how these things interact and live in their own space?
- Are mathematical objects really "low agency"? Can we extend standard behaviorist tests to their native space?
- Why? Where did the Platonic Space and its structure/contents 'come from'? Could it have been otherwise?

This outline's from Levin's kickoff talk Platonic Space Symposium.

Building interfaces includes putting developing tissue is novel environments. He calls for more rigorous mappings. These mappings take low dimensional pointers to high dimensional patterns. It's a kind of coarse-graining. This kind of thing happens all over like in Fourier series, compressed sensing, and even that we transform words into thoughts.

While preparing this talk, I've begun to think that today's neural network AIs, which are definitely mathematical objects, prove that they can have high agency. (maybe: I've had the wild idea that it might be fascinating to anthropomorphize mathematical theories!)

- Levin studies Developmental Biology and Regenerative Medicine.
- He first showed that “bioelectric fields” *control morphogenesis* in Xeopus (aquatic frog) embryo eyes and in Planaria (flat worms) and found ion channel changes produce novel forms.
- He found that each cut-off piece of his novel two-headed Planaria grew back into that two-headed form, indicating the pieces retain a *non-genetic* memory of the whole form. (Unaltered Planaria do this.)
- The bioelectric fields powered by ion transport across cell membranes are now known to exist in *all cellular tissues*, not just neural (bacterial films too!)

- He asserts that cognition in the brain is the same kind of problem solving activity that controls morphogenesis of tissues and organisms.
- The spectra of kinds of *intelligence* and *agency* that brains, bodies, reaction networks, etc. occupy are broader than most people consider. He characterizes, cybernetically, agency as goal-seeking, and intelligence as the ability to solve problems in multiple ways. (Physics and Math are at the lower end! Levin later asks maybe not.)

“future medicine is going to look a lot more like a kind of semantic psychiatry than it’s going to look like chemistry.”

- Observation of such spaces are done in living systems and simulations.
- Levin declared this view is empirically effective. It was necessary to lead him to novel experiments giving unexpected discoveries.
- Although a discovery once made can be explained by the ordinary causality sciences, he said he could not have made them without his latent Platonic Space approach.

I think it's interesting to ask mathematical questions, beginning with the most elementary, about these Platonic spaces, such as dimension, perhaps fractal. Many have mathematical representations (examples: morphological, gene expression, bioelectric field spaces.)

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Outtake Research Ideas

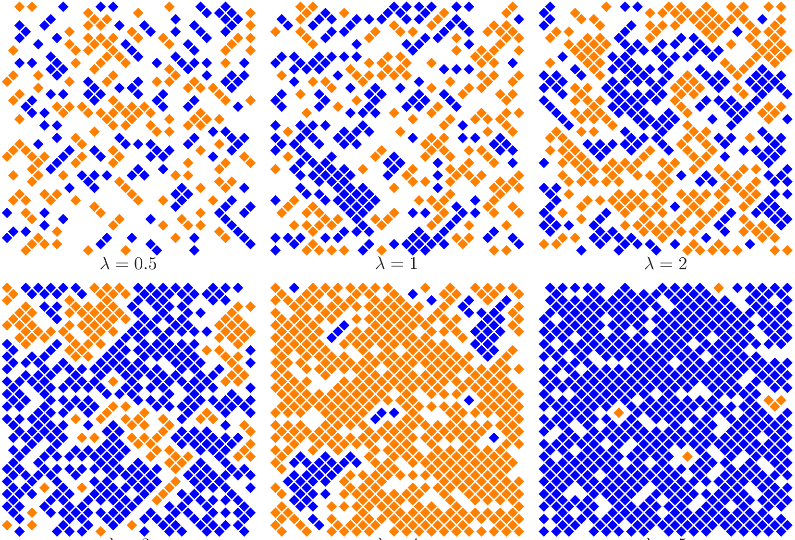
- What examples of transformations on affordances mapping to Latent Platonic Spaces are somehow functorial? Might there be higher category structure (associative law holds up to morphisms between morphisms ...)?
- Voronoi diagrams seem to appear. [?? Look into devel. bio. refs and Physical Biology of the Cell
  What properties do their defining metrics have?
- Properties of prime residues relate to prime multi-year Circada reproductive cycles.

Tilings and Dynamical Combinatorics

Dynamical Combinatorics

Apply Levin et. als. approach for bubble-sort and ... work on behavior of distributed sorting subject to failures and multiple local algorithms to algorithms on graphs; and tiling pattern statistics and Dynamical Algebraic Combinatorics, work of James Propp et. al.

James Propp et. al.



$\lambda = 0.5$ $\lambda = 1$ $\lambda = 2$

$\lambda = 3$ $\lambda = 4$ $\lambda = 5$

James Propp on Aztec Diamond Tilings

The most likely domino tilings of the Aztec diamond shape have a circular region with a disorderly pattern plus narrow regions on the borders filled with 4 regular patterns, one for each side. He and coworkers utilized Markov chain sampling by so-called shuffling algorithms. Propp and Willson in 1996 introduced the "coupling from the past" procedure to get around the problem the goal to sample the stationary distribution might be poisoned by the initial state. The idea is to remember some the state n steps ago, re-do the random process n steps, and use the result to possibly decide to increase the number of steps to get a better sample.

Levin's Prisoner's Dilemma strategy also uses a memory of (just up to 4) past plays with each opponent and their scores.

Platonic Spaces

"Mathematicians are already very comfortable ... that there is a non-physical space of truths which we discover, ... and space has a structure that enables exploration. I make the conjecture that this space contains not only ... facts about triangles ..., but also a very wide variety of high-agency patterns"

Minds Everywhere!

that we call kinds of minds. ... physical bodies don't create, or even connect to (and thus have) minds – instead, minds are the patterns, with their ingressions into the physical world enabled by the pointers of natural or synthetic bodies. ... whenever ... is built acts as an interface to numerous patterns ... .

Here are some quotes from Levin's talks. His first point is that the Platonic patterns or forms taken advantage of by life are much more intricate than what's in mathematics.

Second, he considers these forms or patterns mind-like, and even the same thing as minds!

More

- Connections with fractals, holograms, compressed sensing. (Hologram fragments all project the original image with loss of resolution)
- Why do living things have so many different types of parts (e.g., chemical species) compared to non-living things?
- What ideas from category theory can give us fruitful insight resulting from the hierarchy and repetition of things with common type (latter called "symmetry" by Fields and Levin) found in biological structures?
  Category theory develops consequences of two fundamental mathematical phenomena associativity and transitivity.
- Same question for hierarchy and processing possibly "embodying" Martin-Loff dependent type theory/functional programming, the logic foundation for today's very productive automated proof assistants: Rocq (COQ), Lean, Agda, etc.