EMERGENCE IN PHYSICS: SIGNPOSTS OF CREATIVITY

Arnold E. Sikkema
Trinity Western University

ASA Nashville
20 July 2013

Emergence

- A collective exhibits a feature unexpected from the features of its parts.
- Examples:
  - Wetness of water
  - Living things composed of non-living things.
  - Swarming
  - Mind/brain

Categories of Emergence

- Diachronic
  - historical; development over time
  - emergence of new features of…
    - the universe (e.g. atoms, life, humanity)
    - individuals (e.g. embryonic development, becoming conscious)
- Synchronic
  - snapshot, ontological, “at this moment”
  - functioning of the cell

Categories of Emergence

- Strong
  - inter-disciplinary
  - life: physics to biology
  - mind: biology to psychology
- Weak
  - intra-disciplinary
  - physics: phase transition
  - biology: swarming

Emergence and Science & Faith

- Origins
- Laws of nature
- Divine action
- Multi-faceted creation
- Creativity of the creator
- Expectation of continued unfolding of creation
- Emergence as description and/or explanation

Collective animal motion

- “active matter”, “self-propelled particles”
- leaderless swarming

Ballerini et al., *PNAS* **105** (2008) 1232

"Topological" Distance Dependent Interaction Rule

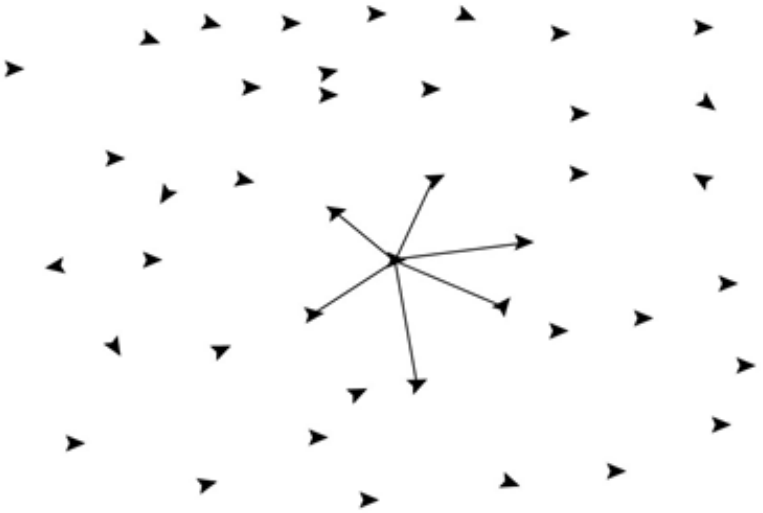


Fig. 1. Particle takes on average velocity and acceleration of *n* nearest neighbours. Here *n* = 6.

Metric Distance Dependent Interaction Rule

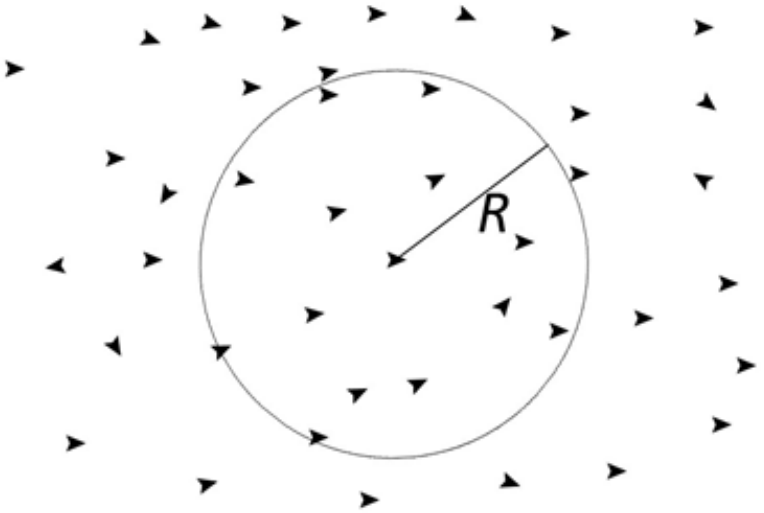
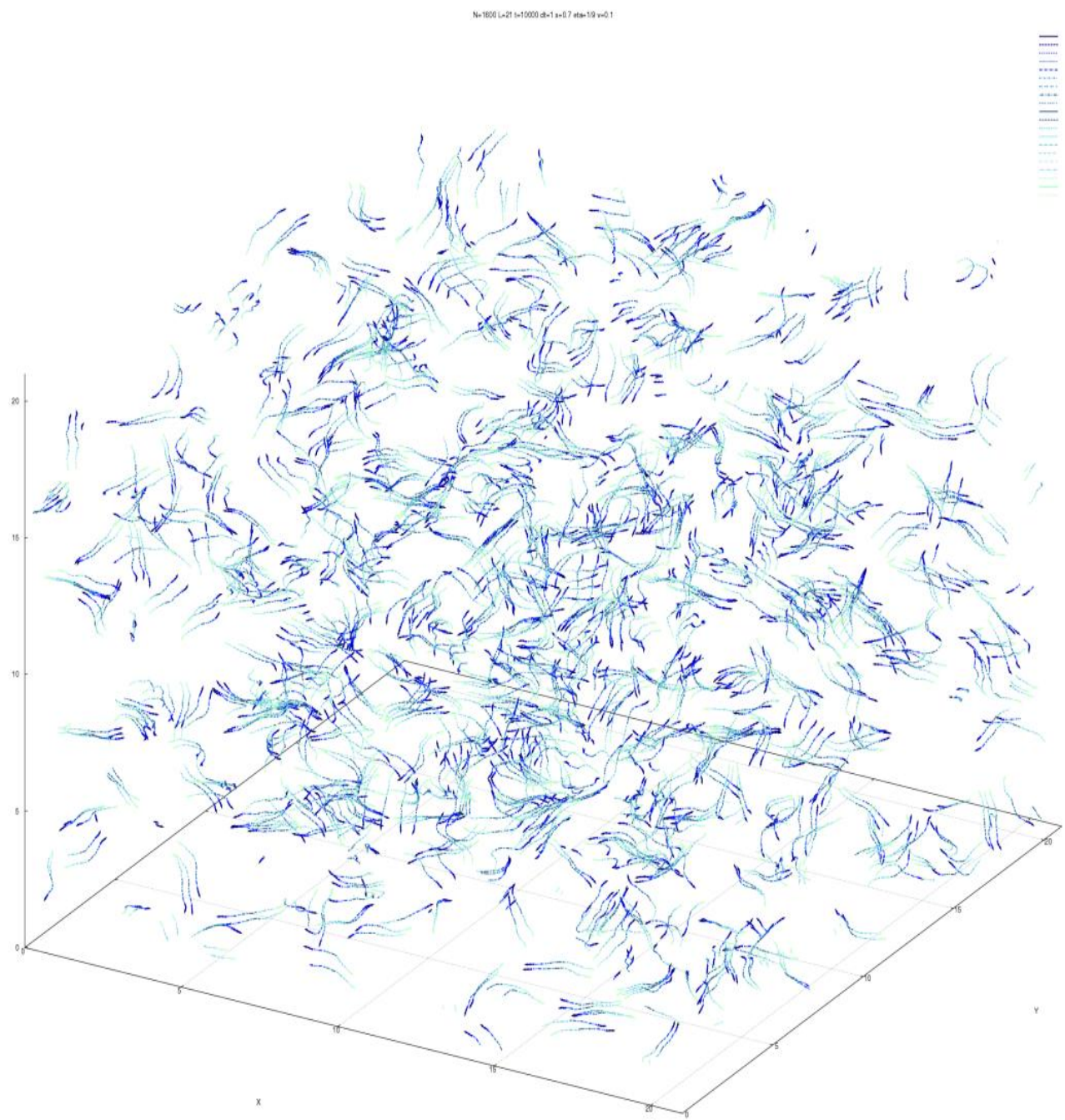
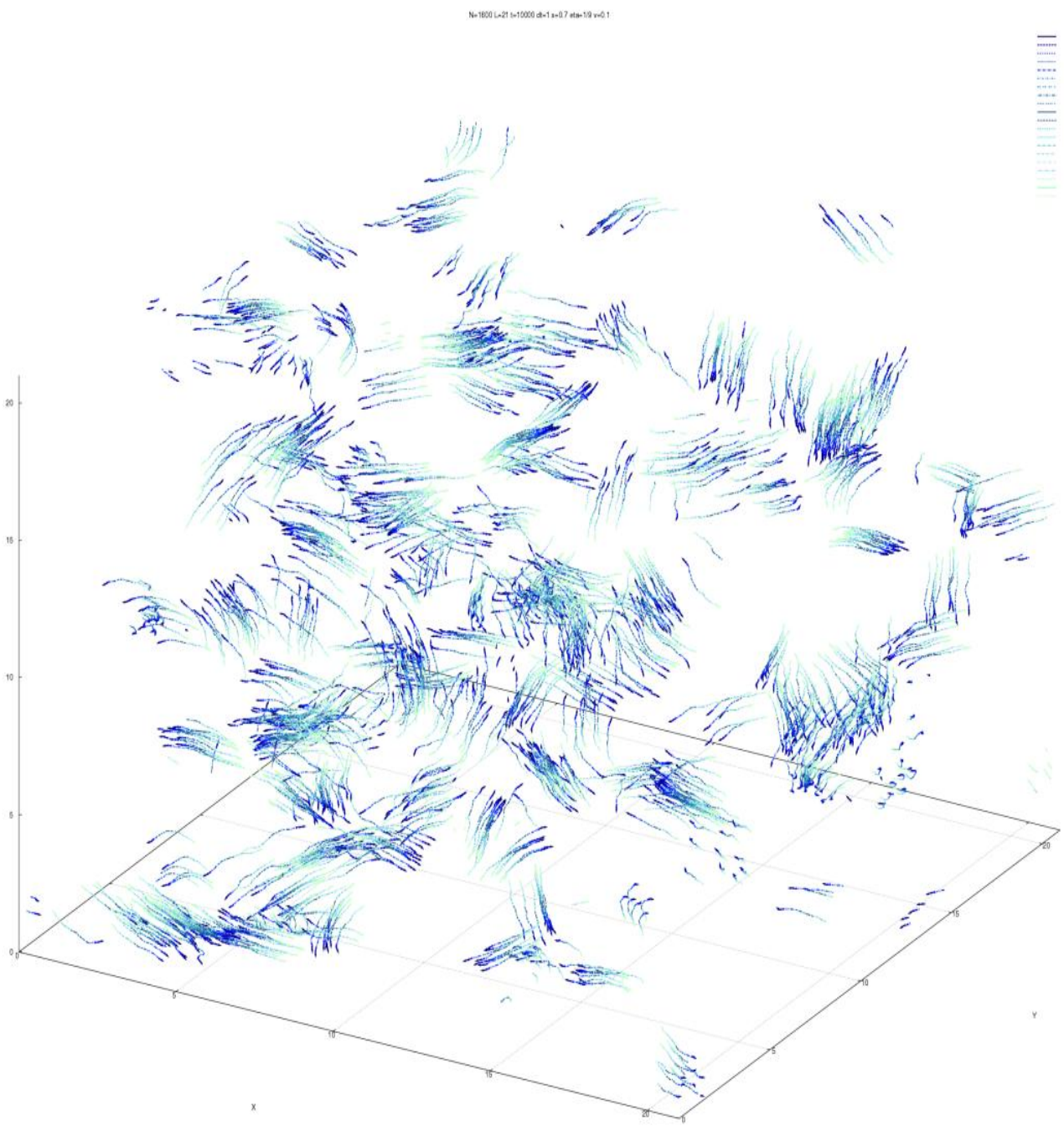


Fig. 2. Particle takes on average velocity and acceleration of the particles within radius *R*.

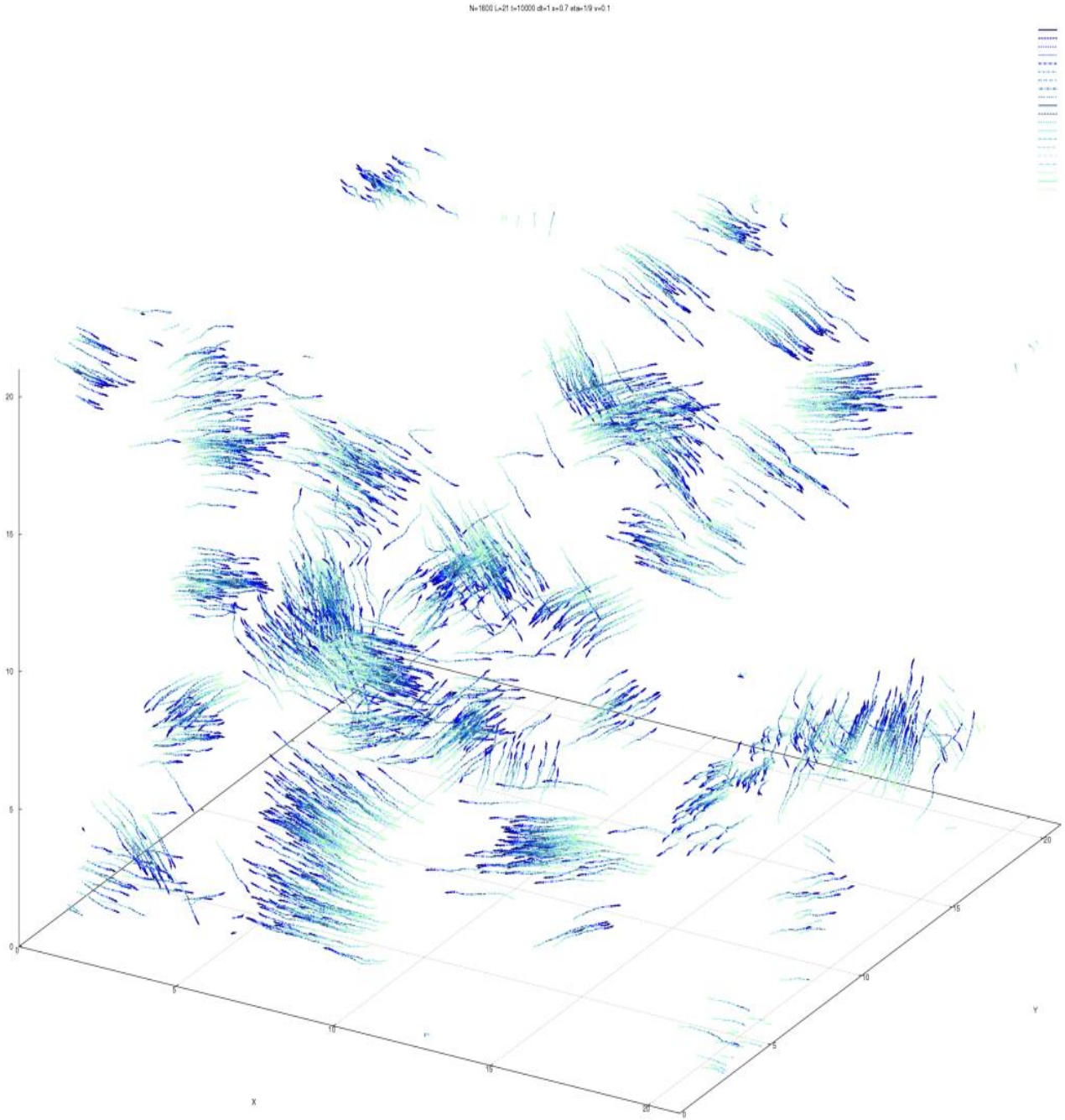


1 neighbour

Work done with NSERC USRA David Dvorak



5 neighbours



10 neighbours

Emergence as explanation

- Strategy: Emergence in physics is understood, so let's apply it to biology and psychology.
- Problem…

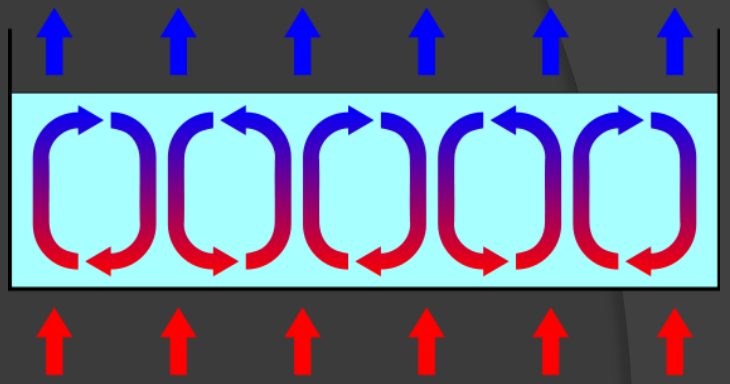
Emergence in physics

- atmospheric science
- crystal structure
- correlated electron systems

- common themes and principles
- more on relation of physics to other sciences

Emergence in Bénard cells & tornados — and a“whole-part” issue

- enduring structure despite material flow
- unclear boundaries
- external “control”

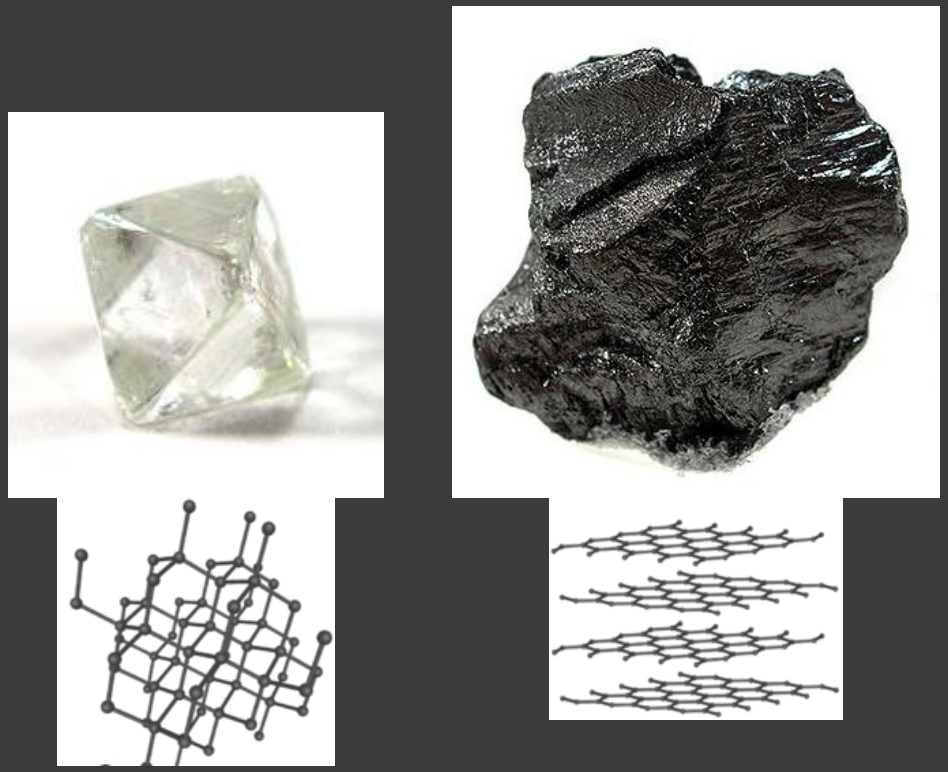


Wikipedia: Eyrian

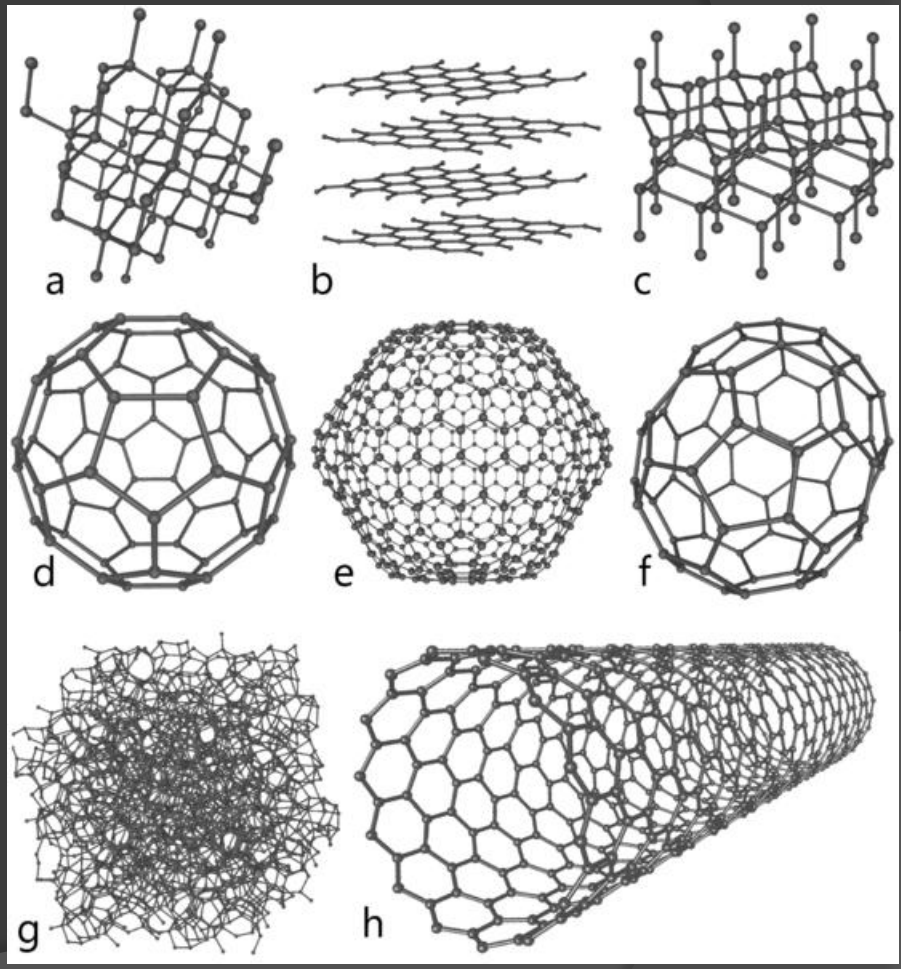
science.howstuffworks.com

Scott Camazine / Science Photo Library

The structure of solid carbon



Diamond-and-graphite-with-scale.jpg
Rob Lavinsky, iRocks.com – CC-BY-SA-3.0
Wikimedia Commons



Eight_Allotropes_of_Carbon.png
Michael Ströck, Wikimedia Commons

Explaining crystal structure

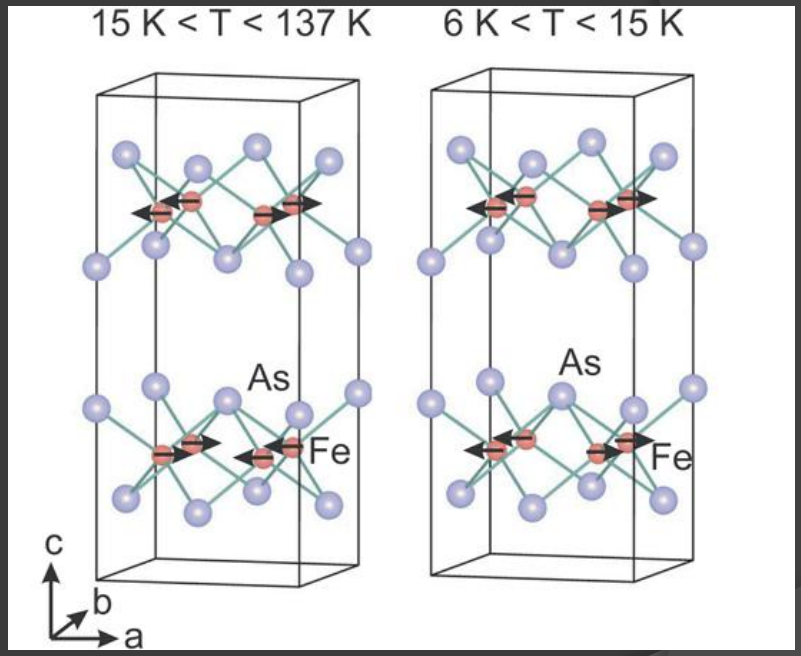
- Crystal structures have been rationalized, but not predicted.
- Rationalizations rely upon “art keyed to experiment”, and not just *a priori* knowledge. [Laughlin & Pines, “The Theory of Everything”, *PNAS* **97** (2000) 28]

“art keyed to experiment”

- Human creativity…
  - requires encounter with the world (*empirical*).
  - is needed to understand, describe, explain the features of the world (*theoretical*).
- Divine creativity manifested in the world.
- *Imago Dei*:
  - we’re creative, because God is.

Correlated electron systems

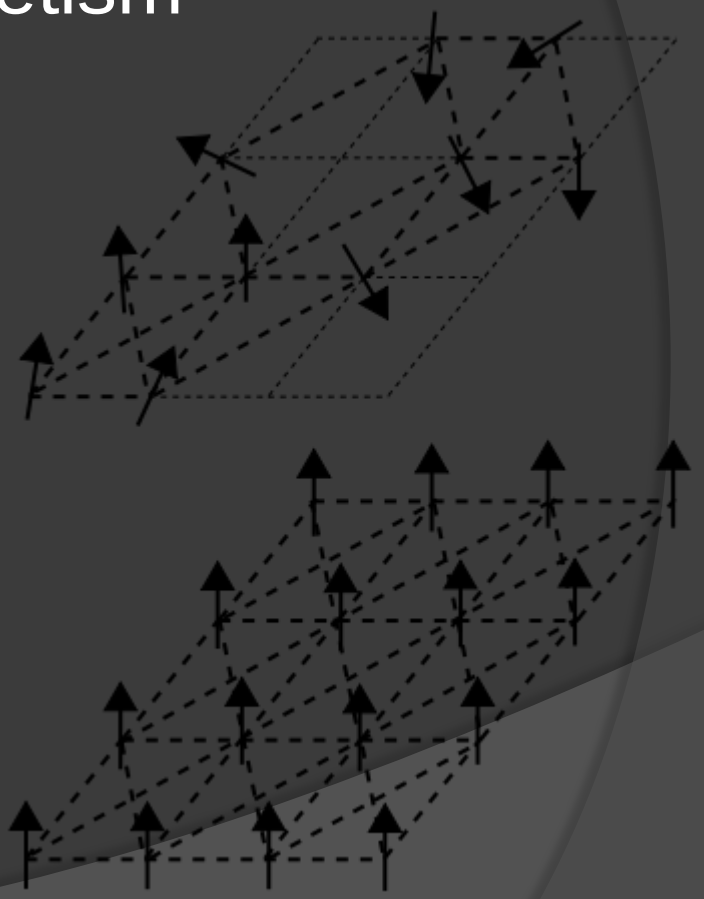
- **superconductivity & magnetism**: “a low-energy collective effect of huge numbers of particles that *cannot be deduced from the microscopic equations* of motion in a rigorous way and that disappears completely when the system is taken apart…”
  - R.B. Laughlin’s Nobel Lecture, *Reviews of Modern Physics* **71** (1999) 863.



W. Tian *et al.* “Interplay of Fe and Nd Magnetism in NdFeAsO Single Crystals” *Phys. Rev. B,* **2010**, 82, 060514; www.ameslab.gov/dmse/highlight/iron-magnetism

Correlated electron systems

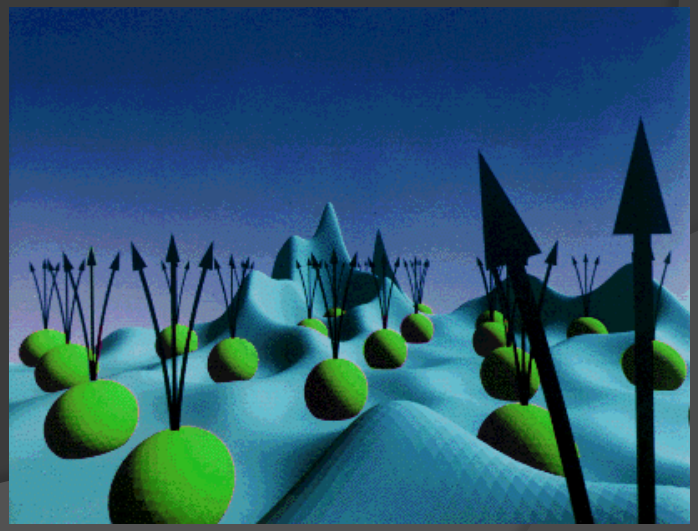
- superconductivity & magnetism
- **spin glasses, frustration**



Wikipedia

Correlated electron systems

- superconductivity & magnetism
- spin glasses, frustration
- **fractional quantum Hall effect**
  - All fundamental particles have charges in multiples of *e*, but in 2-D systems with strong magnetic fields, particles emerge which have charges of *e*/3, *e*/5, *e*/7, etc.



cts.iisc.ernet.in/Nobel_prize/fqhe.html

Common themes and principles

- robustness of the ordered macroscopic whole relative to variations in microscopic parts
- universality near phase transitions
- incalculability
- surprise
- symmetry breaking

Surprise

- *Horatio:* O day and night, but this is wondrous strange!
- *Hamlet:* And therefore as a stranger give it welcome. There are more things in heaven and earth, Horatio, Than are dreamt of in your philosophy.

Surprise

- “[mesoscopic ordering] rules that are dreamt up without the benefit of physical insight are nearly always wrong, for correct rules are really natural phenomena and therefore must be discovered, not invented.” [Laughlin, Pines, *et al.* 2000]

Surprise

- Physics research continues to routinely unveil phenomena that were completely unexpected.
- Standard calculation methods “tend to be the least reliable precisely when reliability is most needed, i.e., when experimental information is scarce, the physical behavior has no precedent, and the key questions have not yet been identified.” [Laughlin & Pines 2000]

Value of reformational philosophical concepts vis-à-vis emergence

- irreducibility
- idionomy
- enkapsis
- anticipation

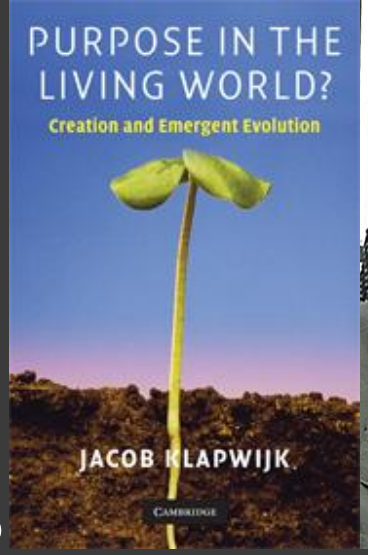
Irreducibility of physics to math

- the uncertainty principle
- “Does God know the electron’s location and speed?”
- Location and speed are not attributes that the particle *has*.
- These “properties” are instead aspects of the *laws* which describe the particle.
- Our desire to ascribe location and speed to a particle is *reductionism*:
  - attempting to describe the state of a *physical* system in terms of only *kinematics*.
  - *c.f.* describing a *biotic* system in terms of only *physics*.

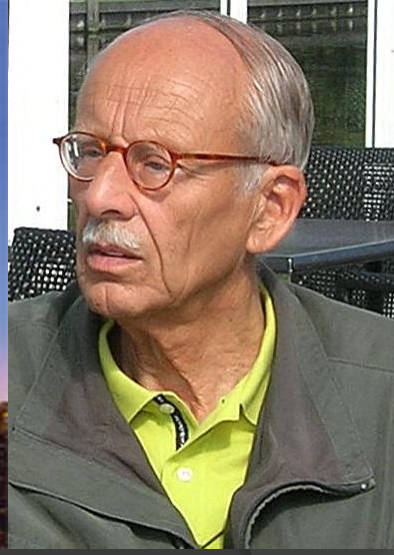
Emergence & Idionomy

- Laughlin, Pines, *et al.* 2000
  - “the possibility that as-yet-undiscovered **organizing principles might be at work at the mesoscopic scale**, intermediate between atomic and macroscopic dimensions, and the implications of their discovery for biology and the physical sciences. The search for the **existence and universality of such rules**, the proof or disproof of organizing principles appropriate to the mesoscopic domain, is called the middle way.”

Emergence & Idionomy



Cambridge UP, 2008


allofliferedeemed.co.uk

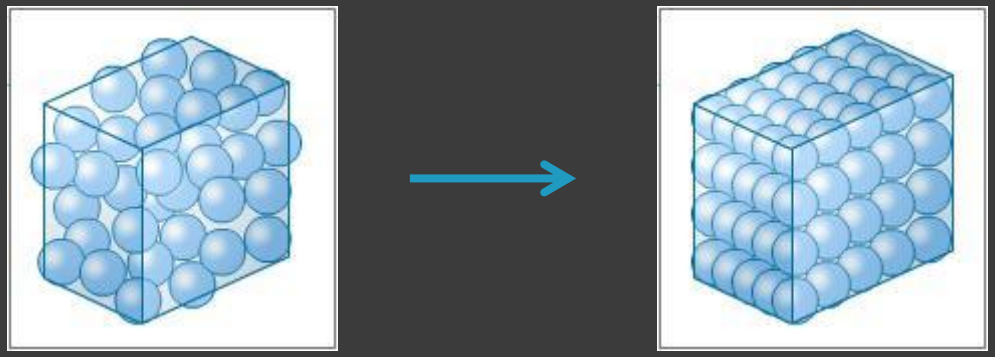
- How do new kinds of entities respond to new kinds of laws?
- Klapwijk on the limits of scientific theorizing:
  - "a believer has good reason to confess that the idionomy that we encounter in distinct levels of being…is, in the final analysis, grounded in…laws of the creator God… [W]e see a world that is open to its Creator, [which] shows a fundamental receptivity to laws of a higher…. The world of becoming…is responding to divine orderings." *Phil. Ref.* **76** (2011) 27

Emergence & Enkapsis

- Jitse van der Meer (CPC 2011):
  - “Top-down causation occurs in encaptic wholes. But an encaptic whole is not a model for evolutionary [diachronic] emergence because it requires the prior existence of an encapsulating whole to control an encapsulated whole.”
- value in synchronic emergence
  - the nature (e.g. form) of a collective influence parts’ behaviour

Emergence & Anticipation

- symmetry breaking



liquid solid

www.tutorvista.com/content/physics/physics-i/matter/matter-states.php

Physics “anticipates” biology

- How are electrons (e.g.) open to the biotic?
- Their physical properties allow them to be “parts of” a greater whole with supra-physical properties.
- Indeterminism is fruitful.
- The scale of electron, atom, molecule is…
  - small enough to experience quantum openness
  - large enough for biochemical processes

Extended paper version

"Nuancing Emergentist Claims: Lessons from Physics"

In Gerrit Glas & Jeroen de Ridder (eds.), *The Future of Creation Order, Proceedings of the Christian Philosophy Conference, Amsterdam, 16-19 August 2011* (Heidelberg: Springer, 2014; in press).