Entropy as Disorder: History of a Misconception

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Before reading this essay, go to your kitchen and find a bottle of Italian salad dressing. Get one that's been sitting still for a while at a fixed temperature – that is, one in thermal equilibrium. You'll find an oil-rich layer at the top of the bottle and a vinegar-rich layer at the bottom (see figure 1). But think for a moment before spreading it over a delicious salad and eating up. That bottle's in thermal equilibrium, so it's in a state of maximum entropy. Doesn't entropy mean "disorder"? No one would call a stack of 50 pennies and 50 dimes disordered if all the dimes were on the top and all the pennies at the bottom. So why is this salad dressing at thermal equilibrium segregated like an ordered stack of coins?

Figure 1: A bottle of Italian salad dressing is not uniform in thermal equilibrium.
What can this tell us about the character of entropy?

The answer is that entropy doesn’t always mean “disorder” or “uniformity” or “smoothness” (in the sense of “smooth peanut butter”), and the rest of this essay explores that connection. The first section shows why the connection isn’t always appropriate. The second section asks: If entropy isn’t a measure of disorder, how did so many scientists get that impression? The third section asks the parallel question, not for scientists but for the general public. And the final section muses about words: when they help understanding, and when they hinder.

Entropy isn’t always Disorder

The fact that entropy doesn’t always mean “disorder” or “uniformity”[1] is clear from any bottle of Italian salad dressing.[2] Here are additional demonstrations:

1. Remove an ice cube from your freezer, place it in a sauce pan, and heat it. The cube changes from pure ice, to mixed ice plus liquid water, to pure liquid water, to mixed liquid water plus steam, to pure steam. That is, it changes from uniform to non-uniform to uniform to non-uniform to uniform, but at all stages its entropy increases.

2. Remove several ice cubes from your freezer, smash them into shards, collect the shards in a bowl, and set the bowl on your kitchen counter.[3] The shards melt into liquid water. The shards are disorderly and non-uniform, the water is uniform, but the water has the higher entropy.

3. A small sample of gas can be considered uniform. But a large sample cannot: A bottle of air, or even of pure nitrogen, with its base at sea level and its top ten kilometers above is dense at its bottom and near-vacuum at its top.

4. Place a cubic centimeter of air at room temperature and pressure within a one-liter vacuum chamber. The air expands throughout the chamber and becomes uniform. Repeat the experiment with a cubic centimeter of gold instead of air, and the end result is not uniform.

Typical vs. average. The two configurations shown in figure 2 provide more insight into the distinction between entropy and disorder.[4]

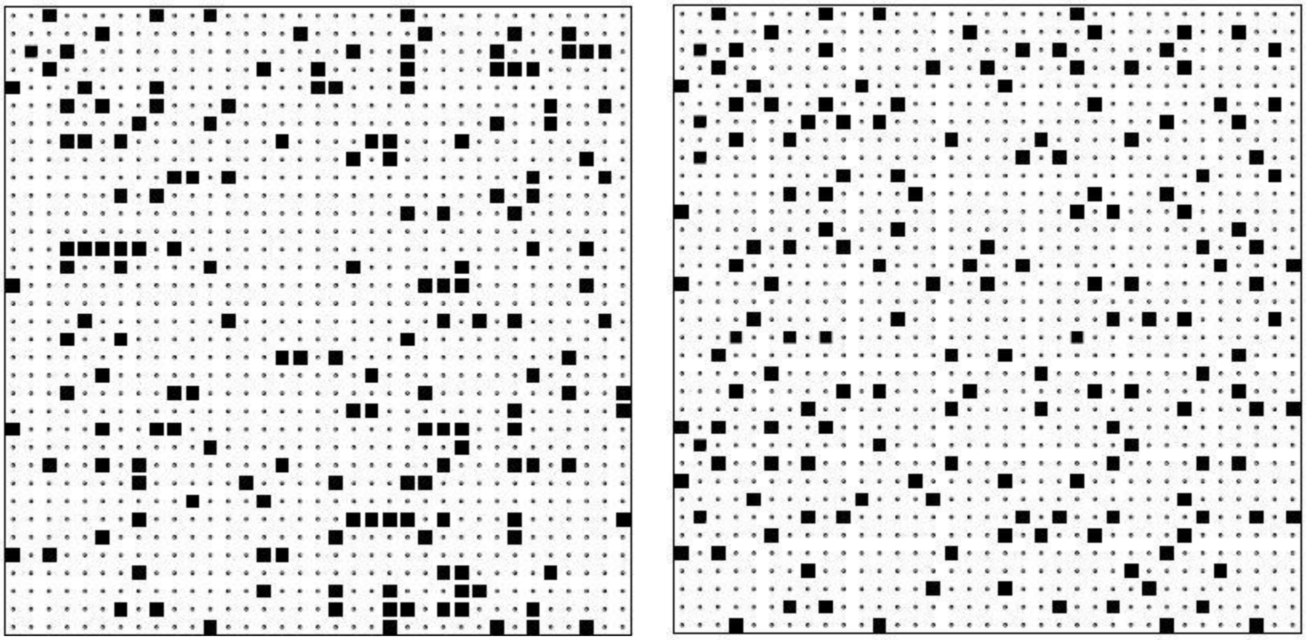


Figure 2: Two configurations, each generated at random.
Which is typical of the lower entropy pool?

Each configuration has 169 squares tossed at random onto 1225 sites, in accord with certain rules to be revealed in a moment. If I ask for the entropy of either configuration, the answer is of course zero: Each configuration of squares is exactly specified, so there is only one configuration ($W = 1$) that matches the specification, so the entropy $S = k_B \ln(W)$ vanishes. Asking for the entropy of a configuration – any configuration – is an uninteresting question.

Instead note that I sampled each configuration at random from a pool of configurations (to use the technical term, an *ensemble* of configurations) that was determined by the as-yet unrevealed rules. The question is, which pool was larger? Which configuration is typical of the larger – i.e. higher entropy – pool? Be sure to make a guess – however ill informed – before reading on.[5]

I have asked this question of hundreds of people – laypeople, physics students, physics teachers, physics researchers – and most of them assign the larger entropy to the pool of the right-hand configuration. That configuration is smooth, uniform, and featureless. The left-hand configuration contains irregularities that suggest some sort of pattern: I notice a dog about to catch a ball in the upper left. One of my students pointed out the starship *Enterprise* in the lower right. Nearly everyone sees the glaring void in the center of the upper half.

It's time to unveil the rules. To produce the left-hand configuration, I used a computer program to scatter the 169 squares onto the 1225 sites at random, subject only to the restriction that no two squares could fall on the same site. To produce the right-hand configuration, I added the restriction that no two squares could fall on adjacent sites. The left-hand configuration was drawn from the larger pool, so it is typical of the pool with larger entropy. (The right-hand configuration is of course a member of both pools.)

The rule prohibiting nearest-neighbor squares gives the right-hand configuration a smooth, bland, and (to many) "high-entropy" appearance. The left-hand configuration has voids and clumps and irregularities. But in fact one should *expect* random irregularities from a configuration sampled at random: the first configuration sampled might have a void in the upper left, the second in the lower left, the third in the center. The *average* configuration will be uniform but each individual configuration will, typically, be clumpy, and each will be clumpy in a different way.[6]

This is the character of averages. Very few people are of average height: most are either taller or shorter. Any manufacturer of shirts that fit only average people would quickly go bankrupt.[7] In most situations, the average is atypical.

Our minds, however, grasp for patterns even in randomness. This is why we find the starship *Enterprise* in the left-hand configuration. For the same reason the ancients looked up at the night sky, with stars sprinkled about at random, and saw the gods, heroes, and animals that became today's constellations.

What does "disorder" mean? The claim "entropy is analogous to disorder" fails for one additional reason: the word "disorder" is hopelessly vague. Entropy is a precise, measurable quantity.[8] Disorder is a matter of opinion. To prove this, I invite you to inspect figure 3, Jackson Pollock's[9] 1949 work "Number 34".

Figure 3: "Number 34" by Jackson Pollock.

In 1950, art critic Parker Tyler wrote[10] that "Number 34" displayed "a deliberate disorder". Just six years later, art critic Ray Faulkner wrote[11] that it displayed "a strong basic structure." If the same entity is both "disordered" and "structured", then the term "disordered" is of limited utility.

Entropy as Disorder: Scientific Development

I hope I've convinced you that entropy is not always disorder, but this invites the question: Why do so many scientists claim that entropy and disorder are intimately connected?

This historical question (like most historical questions) is complex but there's a reasonably direct outline:[12] The idea of entropy developed through thermodynamics in the years 1824 to 1865; the ideas of disorder were developed through the kinetic theory of gases in the years 1867 to 1872; they were combined in the context of gases by Hermann von Helmholtz in 1882 — and for a gas with no external forces, the equilibrium state *is* indeed uniform and the metaphor of entropy as disorder *is* appropriate.[13] (All of the "entropy isn't disorder" situations raised in the first section relied on non-gases, or on gases with external forces.) The remainder of this section fleshes out this outline.

Today's science of thermodynamics was founded by Sadi Carnot in his 1824 book *Reflections on the Motive Power of Fire*.[14] Carnot published this book at age 28 years; he never followed up on his insights and died tragically of cholera eight years later.

The task of building upon Carnot's foundation fell to Rudolf Clausius, who did so in a series of nine papers from 1850 to 1865. In these papers Clausius noted, with increasing precision, the importance of the ratio heat/temperature, calling it "transformation–value" or "uncompensated transformation" or "transformational content". Finally, in 1865, he coined the term "entropy", writing

> "I propose to call the magnitude *S* the *entropy* of the body, from the Greek word τροπη, *transformation*."[15]

The words "disorder" and "chaos" appear nowhere within these nine papers.

At about the same time the kinetic theory of gases was under development. A milestone was the 1872 paper "Further Studies on Thermal Equilibrium among Gas Molecules" by Ludwig Boltzmann.[16] This paper does not predict but rather assumes sample homogeneity and isotropy, appropriate for gases with no external forces. It does not use the terms "entropy"[17] or "disorder", but says that molecules are in "rapid irregular motion" (and in "the liveliest motion"), and concludes of Boltzmann's quantity H that "there always exists a certain quantity which, in consequence of any atomic motion, cannot increase, and this quantity agrees up to a constant factor with the value found for the well-known integral $\int dQ/T$."

Hermann von Helmholtz combined these two streams in an 1882 paper[18] when he wrote

> "Unordered [ungeordnete] motion, in contrast, would be such that the motion of each individual particle need have no similarity to that of its neighbors. We have ample ground to believe that heat-motion is of the latter kind, and one may in this sense characterize the magnitude of the entropy as the measure of the disorder [unordnung]."

This seems to be the first paper to explicitly draw an analogy between entropy and disorder. It does so only "in a certain sense", and it does so in the context of gases without external forces, where the analogy is appropriate.

The first critique of the analogy between entropy and disorder that I have uncovered is Satyendra Ray's 1934 paper "The solid–gas, – a criticism of the definition of entropy as disorderliness".[19] Ray critiques the analogy in the same context that I did: that of two-phase coexistence. (He uses the two phases of gas and solid rather than of oil and vinegar, but with the same conclusion.) The critique has been amplified since 1934 by many authors from many perspectives.[20,21]

Entropy as Disorder: Popular Imagination

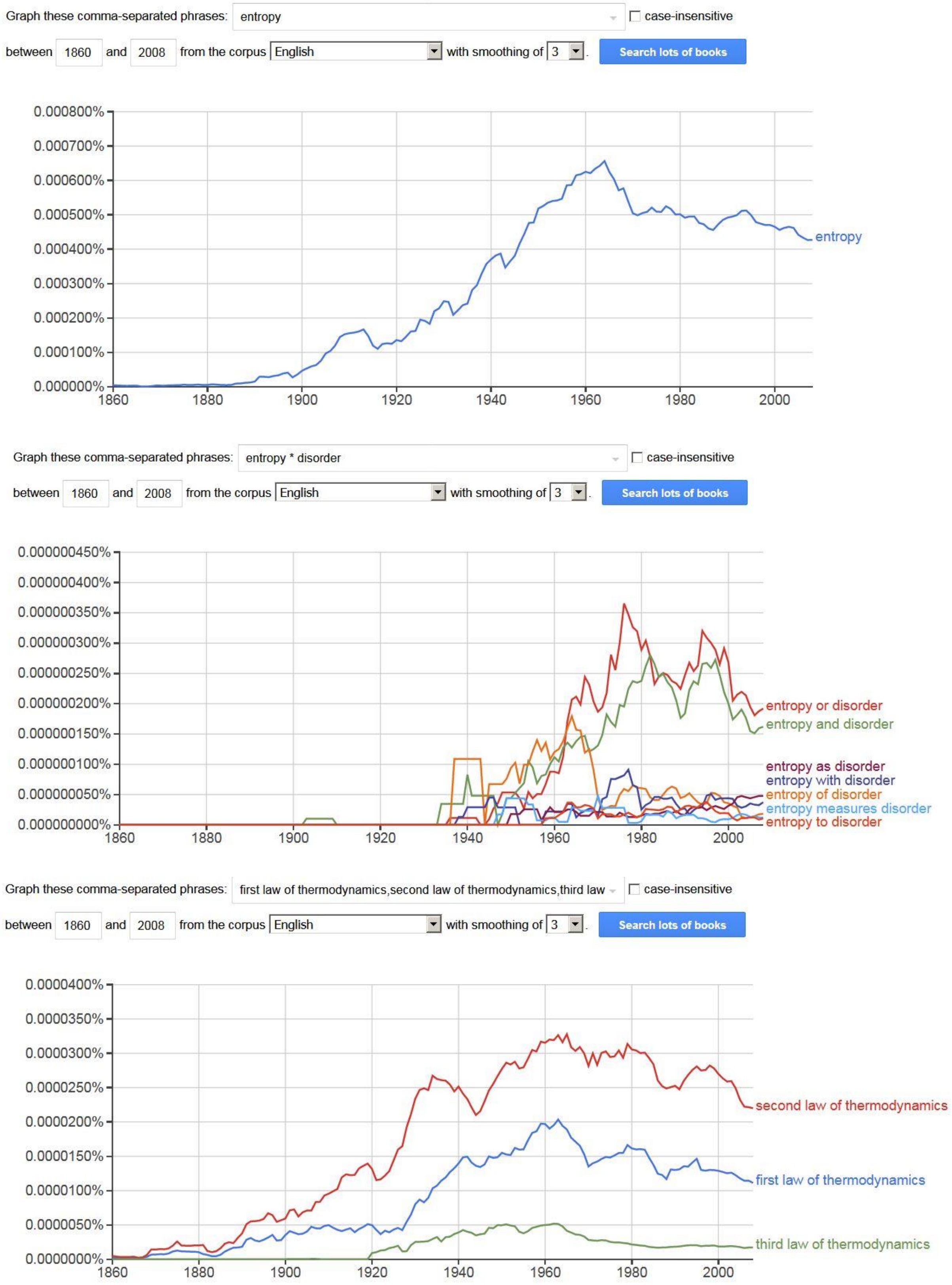
A cartoon by Mark Thompson, appearing in the *New Yorker* on 19 February 2015, shows an irate parent walking into a child's exceedingly messy room. The child explains: "I blame entropy."

Figure: Blame it on physics.

This cartoon is evidence enough that the word "entropy" has entered into everyday language. You'll never find the term "dipole moment" in the *New Yorker,* despite the fact that dipole moment is a far simpler concept than entropy.

When and how did the word "entropy" make the transition from a technical physics term to the vocabulary of the wider world? This question is more difficult than the question of the previous section, because to see how "entropy as disorder" arose in the scientific mind one must search the vast scientific literature. To see how that connection arose in the popular mind one must search the far vaster popular literature.

This is a job for computers. The Google Ngram Viewer allows one to look for the frequency of certain phrases, such as "entropy as disorder" throughout a huge swath of literature extracted from the Google Books digitization project. Figure 4 shows the results of several such searches:



Graph these comma-separated phrases: entropy ☐ case-insensitive

between 1860 and 2008 from the corpus English with smoothing of 3.

Graph these comma-separated phrases: entropy * disorder ☐ case-insensitive

between 1860 and 2008 from the corpus English with smoothing of 3.

Graph these comma-separated phrases: first law of thermodynamics,second law of thermodynamics,third law ☐ case-insensitive

between 1860 and 2008 from the corpus English with smoothing of 3.

Figure 4: When did “second law of thermodynamics” become a household phrase?

All three graphs suggest the same story: that at some time in the vicinity of 1915 to 1930 an association between entropy and disorder took hold in the popular mind. What event sparked that association? Many significant trends and events occurred in that time interval: World War I; flappers; silent movies; founding of the US National Park Service; the Armenian Genocide. But it seems unlikely that any of these events precipitated a wide-ranging association between entropy and disorder. There is, however, one event in this time interval that might be the culprit.

In 1918, Henry Adams posthumously published his autobiography, *The Education of Henry Adams.*[22] This book would prove to be enormously influential: It won the 1919 Pulitzer Prize in biography, and in April 1999 the editorial board of Modern Library named it the twentieth century's best nonfiction book in English. Before drawing a connection between this book and the popular image of entropy, I present some context.

John Adams (1735–1826) signed the US Declaration of Independence, served as the second president of the United States, and authored the profound statement that "Facts are stubborn things; and whatever may be our wishes, our inclinations, or the dictates of our passion, they cannot alter the state of facts."[23] He was also father to John Quincy Adams (1767–1848), sixth president of the United States. John Quincy Adams in turn fathered Charles Francis Adams (1807–1886), United States minister to Great Britain during the US Civil War. And Charles Francis Adams fathered Henry Brooks Adams (1838–1918), journalist, historian, novelist, and the autobiographer at the focus of our attention here.

In what way does this famous book promote the misconception that entropy always reflects disorder? The book doesn't use the word "entropy" or the word "thermodynamics", and only twice uses "disorder". But it five times uses "kinetic theory of gases" and frequently uses "anarchy" and "chaos". For example chapter XXXI, "The Grammar of Science", claims that "The kinetic theory of gas is an assertion of ultimate chaos. In plain words, Chaos was the law of nature; Order was the dream of man."[24] This is a good example of the overextension we've seen before in the scientific realm: Adams starts with an accurate observation concerning the kinetic theory of gases and ends with an inaccurate conclusion concerning all of nature – crystals, liquids, magnets, superconductors, liquid crystals, alloys, hurricanes, trees, planets, stars, salad dressing.

More telling than any specific passage is the overall tone of Henry Adams's *Education* that things are going downhill and that nature is responsible. That tone comes through even more clearly in other writings by Adams, which draw an explicit connection between "entropy" and "bad things". His 1909 essay "The Rule of Phase Applied to History"[25] claims to use Gibbs's phase rule to calculate that "nature's power" acting through the "sharp curve" of history would "bring Thought to the limit of its possibilities in the year 1921." His 1910 "Letter to American Teachers of History"[26] asserts that "physicists cease to be physicists unless they hold that the law of Entropy includes Gods and men as well as universes" and that "the law of Entropy imposes a servitude on all energies, including the mental."

In conclusion, I hope I've convinced you that entropy is not a synonym for disorder or uniformity. The association between entropy and disorder was started by scientists like Boltzmann and Helmholtz in connection with gases, where it's appropriate. The association was inappropriately championed into the popular imagination by Henry Adams. There might have been earlier champions, but Adams certainly *was* one such champion and I suspect that he was the keystone.

Musing about Words

Most words have more than one meaning.

Take, for example, the word "run". In the sentence "Athletes run 26 miles, 385 yards in a marathon", the word "run" is a verb. In the sentence "The narrow run tumbles down picturesque cascades through the forest", the word "run" is a noun. In the sentence "We've run out of salad dressing, so I'll run to the grocery store and run up our bill to buy more", the word "run" is used three different times with three distinct meanings.

Another example is the word "force". The Oxford English Dictionary lists 36 definitions of "force" as a noun. In its oldest use, dating to 1303, it had the meaning of "military strength or power". The word "force" would not take on its physics meaning until three and a half centuries later when, in 1665, Thomas Salusbury used the word in his translation of the works of Galileo.

In the physics sense of the word "force", the meaning "strength or power" is absurd on its face: force is measured in newtons; strength is measured in newtons/meter^2; power is measured in newton meters/second. To say "force means strength or power" in a physics context is to make a grotesque dimensional error. Yet in the military sense of the word, "force means strength or power" is perfectly reasonable.

The word "force" took a journey from everyday usage to become a technical physics term. The word "entropy" journeyed in the opposite direction. We have seen that the term was coined by Clausius in 1865 with a precise, technical, quantifiable meaning. Yet already in 1910 Henry Adams was writing that "the law of Entropy imposes a servitude on all energies, including the mental." (It is not clear to me what Adams meant by this phrase, but he certainly did *not* mean anything involving the quotient of heat/temperature.)

In the physics sense, the word "entropy" doesn't mean "undesirability". Yet you can find published statements like

> "Entropy is why ice cream melts and people die. It is why cars rust and forests burn."[27,28]

In the physics sense, the word "entropy" doesn't mean "immorality" or "wickedness". Yet you can find published statements like

> "DEAR ABBY: … it's a sad fact that when good and bad associate, it isn't the rotten guy who gets good, it's the good guy who gets rotten. In scientific language, each entity seeks the lowest energy level. It is related to the concept of entropy, which is fact, not theory. – S.A.S."[29,30]

In the physics sense, the word “entropy” doesn’t mean “badness” or “blandness”. Yet you can find published statements like

> “Re-creations of 70’s schlock, from ‘Starsky & Hutch’ to ‘The Dukes of Hazzard,’ all seem to obey the second law of movie dynamics: remakes drift to a state of inert uniformity known as entropy.”[31]

I don’t need to tell you that powerful and poorly understood currents course through society: currents of creation and currents of destruction. Some people like to sound sophisticated by calling the currents of destruction “forces of entropy”.[32] But they clearly aren’t using the physics meanings of these two words, because force is measured in joules/meter whereas entropy is measured in joules/kelvin.

We are teachers of physics, not agents of the language police, and we cannot stop people from using the word “force” to mean “strength” or “power”. But we *can* warn our students that this is not the meaning of the word “force” in physics.

And we cannot stop people from using the word “entropy” to mean “disorder” or “destruction” or “moral decay”. But we *can* warn our students that this is not the meaning of the word “entropy” in physics.

Acknowledgements: This paper grew out of a talk presented at the Summer 2017 AAPT meeting in Cincinnati. I thank Harvey Leff for inviting me and the attendees at that talk for their comments, questions, and encouragement. My first encounter with Henry Adams’s connection to entropy came through Wallace Stegner’s lyrical 1954 book *Beyond the Hundredth Meridian*. Stella Ocker, Jason Stalnaker, and three anonymous referees suggested presentation improvements in this essay.

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[1] By “uniform” I mean “uniform on a macroscopic scale”. All phases of all materials are of course granular on the atomic scale.

[2] Todd P. Silverstein, “The real reason why oil and water don’t mix,” *Journal of Chemical Education*, **75**, 116–118 (1998).

[3] Thomas A. Moore and Daniel V. Schroeder, “A different approach to introducing statistical mechanics,” *American Journal of Physics*, **65**, 26–36 (1997).

[4] D.F. Styer, “Insight into entropy,” *American Journal of Physics*, **68**, 1090–1096 (2000).

[5] “Wheeler’s first moral principle. … Guess the answer to every puzzle. Courage: no one else needs to know what the guess is. Therefore make it quickly, by instinct. A right guess reinforces this instinct. A wrong guess brings the refreshment of surprise.” Edwin F. Taylor and John Archibald Wheeler, *Spacetime Physics*, first edition (W.H. Freeman and Company, San Francisco, 1963) page 60; second edition (1992) page 20.

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[6] This conclusion cannot be avoided by invoking “the law of large numbers” or “the thermodynamic limit”. For if we had a million times more squares scattered on a million times more sites, then the configurations in figure 2 would be absolutely typical for a window containing one-millionth of the total sites.

[7] A more extreme example comes from family size. In the 2010 census, the average American family had 3.14 members – π to three significant digits – despite the fact that *no family whatsoever* had 3.14 members. See Table 2 in Daphne Lofquist, Terry Lugaila, Martin O’Connell, and Sarah Feliz, “Households and Families: 2010,” U.S. Census Bureau, issued April 2012, at http://www.census.gov/prod/cen2010/briefs/c2010br-14.pdf.

[8] See, for example, Ihsan Barin, *Thermochemical Data of Pure Substances* (VCH Publishers, Weinheim, Germany, 1995).

[9] Richard P. Taylor, Adam P. Micolich, and David Jonas, “Fractal analysis of Pollock's drip paintings,” *Nature*, **399**, 422 (3 June 1999).

[10] Parker Tyler, “Jackson Pollock: The Infinite Labyrinth,” *Magazine of Art*, **43**, number 3, 92–93 (March 1950).

[11] Ray Nelson Faulkner, *Art Today: An Introduction to the Fine and Functional Arts* (Holt, Rinehart and Winston, New York, 1956) page 433.

[12] Stephen G. Brush, *The Kind of Motion We Call Heat* (North-Holland, Amsterdam, 1976).

[13] Given the vagueness of the word “disorder”, we must ask the exact meaning of the phrase “a gas at equilibrium is disordered”. First consider an ideal gas subject to no external forces: An atom is equally likely to occupy any position within its container, and pairs of atoms are uncorrelated. The velocity of the atom is equally likely to point in any direction. But the speed of the atom is very much *not* “equally likely to have any value”: indeed, the probability of the atom having speed between v and $v + dv$ is given by the Maxwell-Boltzmann distribution

$$\sqrt{\frac{2}{\pi}\left(\frac{m}{k_B T}\right)^3}\, v^2 e^{-mv^2/2k_B T}\, dv.$$

In contrast, for a real gas subject to no external forces, an atom is equally likely to occupy any position within its container, but pairs of atoms *are* correlated. (See for example David Chandler, *Introduction to Modern Statistical Mechanics* [Oxford University Press, New York, 1987] chapter 7.) The velocity remains equally likely to point in any direction, and the speed probabilities follow the Maxwell-Boltzmann distribution as long as relativistic and quantal effects are negligible.

[14] Sadi Carnot, *Réflexions sur la Puissance Motrice du Feu* (Chez Bachelier, Libraire, Paris, 1824).

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[15] Rudolf Clausius, “Ueber verschiedene für die Anwendung bequeme Formen der Hauptgleichungen der mechanischen Wärmetheorie,” read at the Philosophical Society of Zürich on 24 April 1865. (Translated by John Tyndall as “On Several Convenient Forms of the Fundamental Equations of the Mechanical Theory of Heat” in *The Mechanical Theory of Heat, with its Applications to the Steam-Engine and to the Physical Properties of Bodies* [John Van Voorst, London, 1867] pages 327–374, at page 357.)

[16] Ludwig Boltzmann, “Weitere Studien über das Wärmegleichgewicht unter Gasmolekülen,” *Sitzungsberichte der Kaiserlichen Akademie der Wissenschaften*, Vienna, **66**, 275–370 (1872). (Translated by Stephen G. Brush as “Further Studies on the Thermal Equilibrium of Gas Molecules” in *The Kinetic Theory of Gases: An Anthology of Classic Papers with Historical Commentary* [Imperial College Press, London, 2003] 262–349; excerpts quoted here appear on pages 262, 263, and 291.)

[17] Perhaps because he was at the time engaged in a priority quarrel with Clausius. See Giovanni Gallavotti, “Ergodicity: a Historical Perspective,” *European Physical Journal* H, **41**, 181–259 (2016).

[18] Hermann von Helmholtz, “Die Thermodynamik chemischer Vorgänge,” *Sitzungsberichten der Akademie der Wissenschaften zu Berlin*, **1**, 23, 2 February 1882. (Translated as “The Thermodynamics of Chemical Processes”. See Ralph Baierlein and Clayton Gearhart, “The disorder metaphor,” *American Journal of Physics*, **71**, 103 (2003). See also the translation by E.F.J. Love in *Physical Memoirs Selected and Translated from Foreign Sources* [Taylor and Francis, London, 1888] pages 43–62, at page 56.)

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[19] Satyendra Ray, "The solid-gas, – a criticism of the definition of entropy as disorderliness," *Proceedings of the Indian Science Congress*, **21**, 166–167 (1934).

[20] Karl K. Darrow, "The concept of entropy," *American Journal of Physics*, **12**, 183–196 (1944).
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Ed Purcell, personal communication reported in Stephen Jay Gould, *Bully for Brontosaurus* (Norton, New York, 1991) pages 265–268.
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F.L. Lambert, "Entropy is simple, qualitatively," *Journal of Chemical Education*, **79**, 1241–1246 (2002).
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Jeffrey A. Phillips, "The macro and micro of it is that entropy is the spread of energy," *The Physics Teacher*, **54**, 344–347 (2016).

[21] R.H. Fowler and E.A. Guggenheim, *Statistical Thermodynamics* (Cambridge University Press, Cambridge, UK, 1939) does not mention disorder at all, but remarks that the related concept of absolute entropy "has caused much confusion and been of very little assistance" (page 192).

[22] Henry Adams, *The Education of Henry Adams* (Houghton Mifflin Company, Boston, 1918).

[23] John Adams, "Statement for the Defense at the Boston Massacre Trial" (3–4 December 1770), see http://founders.archives.gov/documents/Adams/05-03-02-0001-0004-0016.

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[24] Reference [22] at page 451.

[25] Henry Adams, "The Rule of Phase Applied to History," written 1 January 1909, published on pages 264–311 of *The Degradation of the Democratic Dogma* (Macmillan, New York, 1919), excerpts quoted here appear on pages 302, 305, and 308.

[26] Henry Adams, "A Letter to American Teachers of History," written 16 February 1910, published on pages 134–263 of *The Degradation of the Democratic Dogma* (Macmillan, New York, 1919), excerpts quoted here appear on pages 209 and 251.

[27] Gilbert L. Wedekind, *Spiritual Entropy* (Xulon Press, Fairfax, Virginia, 2003) page 68.

[28] Using the rusting of iron to illustrate entropy arguments is particularly common and particularly specious. The rust reaction is

$$4\ \mathrm{Fe} + 3\ \mathrm{O_2} \rightarrow 2\ \mathrm{Fe_2O_3}.$$

Anyone can look up the entropy values of iron, oxygen, and iron oxide at room temperature and atmospheric pressure. (See reference [8], pages 675, 1239, and 702.) The entropy of the reactants is 724.6 J/K, the entropy of the products is 174.8 J/K. The rust reaction results in an entropy *decrease!*

Of course, this doesn't mean that when a car rusts, the entropy of the universe decreases: although the entropy of the iron plus oxygen decreases, the entropy of the surroundings increases by even more. But the same observation holds for the reverse reaction: in a blast furnace, oxygen is stripped from iron oxide to produce elemental iron. In this process, too, the entropy of the universe increases.

[29] Abigail Van Buren, "Dear Abby: Improving 'Rotten Apples'," *Los Angeles Times,* 31 August 1970, page C5.

[30] This statement was particularly damaging to me, because I read it the summer after I was introduced to the concept of entropy in my high school chemistry class. My understanding of entropy was weak at the time, and after reading this statement by S.A.S. I felt that I would never grasp it. How could morality be related to the entries in a table of entropy values? How could morality be measured in units of joules/kelvin? Little did I realize, at age fifteen years, that the weakness lay in S.A.S., not in me.

[31] Alessandra Stanley, "Red Update Alert: Poseidon Goes Belly Up Again," *New York Times,* 18 November 2005.

[32] Editorial Board, "No Justice, No Police," *New York Times,* 6 January 2015.

Notes: This reprint incorporates an erratum published in *The Physics Teacher* volume 58, page 5 (January 2020): The last sentence of footnote 13 was incorrect in the published version and has been corrected here. I thank Professors Jan Tobochnik and Dan Schroeder for pointing out my error.

See also "Addendum to 'Entropy as Disorder': What about Gibbs potential?" http://www.oberlin.edu/physics/dstyer/entropy.