International Journal of Theoretical Physics, Vol. 21, Nos 6/7, 1982

Cellular Vacuum

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Received May 7, 1981

Could *any* universe satisfy the following conditions? (i) Each volume of space contains only a finite amount of information, because space and time come in discrete units. (ii) Over some range of size and speed, the mechanics of this world are approximately classical. Imagine a crystalline world of tiny, discrete "cells," each knowing only what its nearest neighbors do. In such a universe, we'll construct analogs of particles and fields, and ask what it would mean for these to satisfy constraints like conservation of momentum.[1] In each case classical mechanics will break down—on scales both small and large—and strange phenomena will emerge: a maximal velocity, a slowing of internal clocks, a bound on simultaneous measurement, and quantumlike effects in very weak or intense fields.

1. INTRODUCTION

A fantasy about conservation in cellular arrays was inspired by this first conference on computation and physics, a subject destined to produce profound and powerful theories. I wish this essay could include such a theory; alas, it only portrays images of what such theories might be like. The "cellular array" idea is popular already in such forms as Ising models, renormalization theories, the "game of life," and Von Neumann's work on self-reproducing machines.

[1]Why *should* a universe approximate classical mechanics? Perhaps only worlds with firm enough constraints can evolve things like us that make theories like these. And classical constraints alone might not suffice; stars make poor atoms, and constellations dreadful enzymes—so quantum states seem needed, too, for life. (We often think of quantum states as making things uncertain; but really it is only they that perfectly preserve our information!)

2. CELLULAR ARRAYS

Envision spacetime as a four-dimensional cubic array of "cell moments." At any moment, each cell has one of a certain few possible "states"; the rules for how states change from one moment to the next are the "vacuum field equations" of this universe. These rules are starkly local, each cell's state determined only by its own and neighbors' states of the preceding moment. Such models might appear to be too simple to be interesting, and yet they have already quite a large and deep theory.

A one-dimensional example illustrates a simple moving "packet": there are just four states: 1, P, "*" and Q. Initially all cells are "*" except, somewhere, this pattern:

$$*****1111P*********$$

A typical state-change rule has the form of $1{:}Q{:}P \to 1$, which means *when a cell in state Q sees a 1 to its left and a P to its right, it switches to state 1.* Now consider this complete set of rules:

$$1{:}1{:}P \to P, \qquad *{:}\,1{:}P \to *, \qquad *{:}P{:}P \to Q$$

$$Q{:}*{:}* \to P, \qquad Q{:}P{:}\,X \to Q, \qquad X{:}Q{:}\,X \to 1$$

where X means the transition does not depend on that neighbor's state. Unless otherwise specified, each cell remains in its previous state.[2] The

[2]It is no exaggeration to say that there are state interaction rules to do almost anything one can imagine. There are some "universal" sets of state-change rules with which a single cellular array can "simulate" any describable computation. The trick is cleverly to encode, into the universal array's initial conditions, some other set of state-change rules. The universal rules then "read" those other rules, to make the universal array behave just as those other describe —at lower speed, of course (Minsky, 1967). We even know a universal scheme in which each cell has just two states, depending only on four neighbors (Banks, 1971)! Apparently, the amount of information in our universe does not change over time—at least, classical and modern physics both seem perfectly reversible today. So many thinkers wonder, then, "why does so much seem to happen"—and they seek variety in chance, or quantum probability. They seem to feel that mechanisms cannot possibly create enough. But, universal machines (known only since the 1930s) now discredit such an intuition—since given enough space-time, one such mechanism can do what *all* other universes—both deterministic *and* probabilistic—can do! (Fredkin has recently shown how to make universal machines in reversible universes.) Could one imagine or desire more inventiveness?

configuration reproduces itself one unit over to the right, repeating this forever:

$t=0$	*	*	*	1	1	1	1	P	*	*	*	*	*	
1	*	*	*	1	1	1	P	P	*	*	*	*	*	
2	*	*	*	1	1	P	P	P	*	*	*	*	*	
3	*	*	*	1	P	P	P	P	*	*	*	*	*	
4	*	*	*	*	P	P	P	P	*	*	*	*	*	
5	*	*	*	*	Q	P	P	P	*	*	*	*	*	
6	*	*	*	*	1	Q	P	P	*	*	*	*	*	
7	*	*	*	*	1	1	Q	P	*	*	*	*	*	
8	*	*	*	*	1	1	1	Q	*	*	*	*	*	
9	*	*	*	*	1	1	1	1	P	*	*	*	*	

2.1. Size and Precision. In this example, the size of a packet is inverse to its speed. In general, there is an absolute constraint between the amount of information in any packet and the volume of that packet! And, just as in Heisenberg's principle, it is not so much a parameter's value that determines packet size, as its *precision*—the number of "bits of information" needed to specify it.[3]

If the information carried in a packet were "optimally encoded"—in accord with Shannon's information formula—then the packet's size would depend on the base-2 logarithm of its precision. Then why is there no logarithm in Heisenberg's principle? We'll conjecture that most physical information (particularly in photons) is encoded *not* in base-2, but in the less dense *base-1* form. Later we'll argue that particles with rest mass may employ denser codes![4]

2.2. Uniform Motion. One can prove that any bounded packet which moves within a regular lattice must have an asymptotically helical trajectory. Such trajectories will appear perfectly straight, on any large enough

[3]Technically, it matters little whether information moves along diagonals or only axes. Nor, technically, does it make much difference if the lattice be cubic or otherwise. Do not assume that nothing can be specified more closely than lattice mesh: a particle can be programmed to behave as though it were $3/17$ of the space between two cells (or an event $3/17$ of the time between "moments"). Nor should one assume speeds below that of light must go $1/2$, $1/3$, etc. that speed. Readers might discover their own ways to make packets move at, say, $(1-1/N)$th cells per moment. (The trick is to have them compute when *not* to advance.)

[4]This argument relates position not only to velocity but also to *any* other property, so this does not lead directly to the particular commutators of quantum theory.

scale. So we can deduce Newton's law of inertia (for compact particles) directly from the regularity of the lattice![5]

2.3. Maximal Speed. Since no cause-effect can propagate faster than the basic lattice speed of one cell per "moment," there is a largest possible speed. We will identify this with the speed of light. It is easy to design small light-speed packets, using simple rules that at each moment copy each cell's state into a neighbor; more machinery is needed for sub-light-speed propagation. There are fundamental differences between light-speed things (henceforth called "photons") and slower ones. Information behind a photon's wave front can never catch up—hence the information mechanics of photons must be relatively simple; they cannot do "three-dimensional" computations. One reason photons must use base-1 is that they cannot compute enough to "decode" base-2 information.

2.4. Time Contraction. *The faster a nonphoton moves, the slower must proceed its internal computations*! Imagine that some computation inside a packet at rest sends information back and forth through some number L of cells; the roundtrip will take time $2L$. Now, make the packet move in L's direction at $(N-1)/N$ the speed of light. The retrograde time remains of order L, but now it takes at least $(N-1)L$ moments for data to advance L spaces (relative to the packet) so the roundtrip time has then the order of NL. Therefore the speed of internal computations, relative to the fixed frame, must slow down by $N/2$.

This is the square of what Lorentz invariance requires; also, it yields no symmetry among different frames and does not say how "transverse" clocks are changed. It is hard to think of something less amenable to special relativity—what does it even mean to speak of length contraction here, or of the "same" packet with different speeds? And still, for all I know, there may yet be some way to embed invariance in such a world—perhaps by using more dimensions.

2.5. Angle and Aperture. In real optics it takes *twice* the aperture, for any given wavelength, to halve a beam's divergence—while "optimal" encoding of the angle should only need a single extra "bit"—another hint that nature uses "base-1" codes for photons—perhaps because only base-1

[5]But what is a straight line? In a cellular array, any two points define a shortest length but usually no shortest path. But then one can define the geodesic from A and B as the set of points that lie on maximal numbers of paths between A and B. Physics often uses "all possible paths" ideas, anyway, in theories based on variational mechanics. Perhaps such a formulation could be made for discrete mechanics—to bring along (without an extra cost) the wanted macroscopic isotropic geodesics.

codes could let a discrete mechanism "add" fast enough to make things linear at light speed.[6]

2.6. Frequency and Time. The angular precision of a real photon depends only on how many wavelengths cross the aperture. So one can keep a beam's shape fixed while shrinking aperture and wavelength both—and that must mean the wavelength information must be stretching longitudinally—just as implied by the energy–time form of Heisenberg's principle.[7]

3. SPHERICAL SYMMETRY

No regular lattice is invariant under rotation, Euclidean or Lorentz, since it needs different information to move along different axes. So, just as waves in crystals show Bragg diffraction, "discrete vacuums" must show angular anisotropies (that might reveal themselves on some small scale of size or extreme energy). But we will not touch on such problems here, because I feel they have deflected almost everyone from more important, finite things! Physics has to face some day those problems anyway—of finite geodesic, differential, and isotropy, because (I will argue) they already lurk beneath the surface of our modern theories. But here our main concern is seeing how a discrete world could have some other ordinary properties on ordinary scales. We will just note several possibilities.[8]

[6]Growth of the sidelobes of diverging beams can be controlled by "interference" from the beams' interiors, because oblique contributions from the front can meet less oblique contributions from inside. But information can move directly forward only when portions of the front "hesitate." If that happens periodically, the group velocity falls below C, and there's no photon. But for expanding waves, which grow asymptotically planar, the totality of such delays can be bounded to a finite delay (or phase shift) in each direction.

[7]For a diffraction slit, anyway. For a circular aperture something is wrong, because halving the diameter should make the information stretch *four* times further along time; the uncertainty principle has only a factor of 2.

[8]The discrete lattice does imply an absolute kinematic frame, and an absolute distinction between space and time. One cannot quarrel with relativity; still, from an informational view it is hard to see how physics could be entirely independent of frame: the information must be *somewhere*, to represent each motion. And while no physics theory can stand, that lacks Lorentz invariance on ordinary scales, still no one can be sure what happens at the ultimate extremes. Some day, for instance, red-shift measurements of the primordial microwaves might show us one distinguished inertial frame. Still, physicists could argue that this does not violate *equivalence*—because it is easy to shield experiments from microwaves. Suppose, though, that some later day reveals the red shifts of the oldest gravitons—then shielding is unthinkable. And now observers in their different frames must truly find some differences in natural law—if only different measures for those rays. Most likely, though, we will never measure this, but still one wonders if that old "conspiracy" of relativity could reach *that* far?

3.1. Liquid Lattice Model. One could imagine cell connections so randomly irregular that, in the large, the space is isotropic—like water, which is almost crystalline from each atom to the next, but isotropic on the larger scale. But then, to build our packets into such a world, we would have to find transition rules insensitive to local cell-connection fluctuations.

3.2. Continuous Creation. Instead of starting with a liquid vacuum, we could randomly insert new cells from time to time. This would cool and red shift cosmically old photons (by lengthening their unary frequency counters) and uniformly expand the universe. But, again, it would be hard to design things to survive such changes without changing.[9]

3.3. Spherical Propagation. So little is known about approximating isotropic propagation in regular lattices that we can only pose some problems:

1. Describe a cellular array in which local disturbances cause asymptotically spherical expanding wave fronts. I do not think much would come from seeking this in finite difference equations, because one must bound the variables. One can invent constructions that slowly grow increasingly spherical polygons, but a solution of physical interest must propagate at light speed. Section 4.1 suggests doing this with an "exchange particle" mechanism. I suspect some such technique may be necessary to physically transfer information from one place to another in order to maintain long-range metric constraints.

2. Describe a cellular array in which "particles" exert inverse-square forces on one another, with only light-speed delay. Such issues concerned physics long before relativity, but "ether" theorists never found good solutions. One idea was for particles continuously to emit force waves that increment other particles' momenta. But then the information content of such waves would grow as their intensities decay, and that would be incompatible with any information density bound.[10]

3.4. Force Streams. Making each particle emit showers of randomly oriented "force pellets" solves both inverse-square and weak-field informa-

[9]Richard Stallman pointed out to me that if the expansion of the universe is to locally increase the space between points, it is hard to avoid the idea that the number of cells in the volume must increase; then perhaps only an amorphous cellular system is acceptable, because one can hardly change the number of cells in a volume if the cells are in a lattice.

[10]It would violate conservation for weak fields simply to vanish below a certain threshold. But if a discrete model represents them as sparse information distributions then conservation can be maintained, but interactions would seem quantized rather than continuous.

tion problems. But it leaves a probably equivalent problem of how each particle could approximate a uniform spherical distribution of its pellets. Another variation fills the universe with a gas of light-speed momentum pellets whose "shadows" cause inverse-square forces. This transfers the isotropy burden to the universe as a whole. Unfortunately (according to Feynman, 1963) this too quickly drags everything to rest within the distinguished inertial frame of that isotropy (see Footnote 8).

3.5. Curvature. Suppose a spherical force field were known to have emerged from a "unit charge." Now represent that field by marking space itself as a family of equipotential surfaces. These markings need no further local information at all, because the field intensity at any point can be determined just from local curvature. The trouble is, for such a field to act on any particle, the particle will have to find that curvature, and when that curvature is very small, the particle must probe great distances. How, then, could any particle respond as though the interaction works at light speed? We have an answer, shortly.

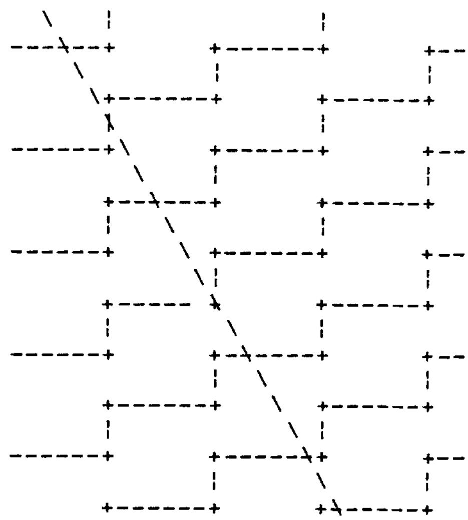
4. FIELDS

The idea of field abandons that of force, and only asks the vacuum to constrain some local quantity. This promises to reduce information density, just as a single differential equation replaces infinite summations in Huyghen's principle. It might seem natural to start applying difference equations (instead of the partial differential equation of physics) to discrete quantities (instead of continuous vector fields). But that will not work for us, because it needs precision beyond bound, which would make the computations take so long there would be no link between causality and speed of light.

"Action at a distance" was solved by fields—by writing nature's laws in differential form. But what of "action at a differential distance"? Modern theories still assume that nature can use methods that are infinitely rapid and precise. (When wave equations specify relations between partial derivatives, how can the vacuum measure and compute those "informational infinities"?) To be sure, a discrete theory asks its cells to act upon their neighbors. But there, where distance is itself *defined* in terms of "that which interacts" it is really quite a different kind of question.

We have all become so comfortable with "real" numbers that we have come to think they are really real—and then we grumble when our theories give us series that make us pick and choose which terms to keep or throw away! I will argue that the finite view might show us how to make such choices. But let us set philosophy aside and try to make mechanics come directly from the field, avoiding all derivatives and real numbers. We will try a scheme in which the state-change laws control a family of surfaces, to operate directly on the field's "shape."

4.1. Mechanism 1: Field as Surface with Exchange Force. Consider now a classical potential field. To represent the field, we will simply "mark" those vacuum cells that happen to be near some closely spaced potentials.[11] Then to obtain mechanics, the structure needs a way to act on charge: *each time a particle crosses a surface it adds, to its kinetic energy, a unit vector normal to that surface*. This (i) eliminates the need for a local gradient computation, (ii) simplifies interactions for the particle, and (iii) permits light-speed reactions on the field. How could a particle compute that surface normal, without having to pause for lateral exploration? A trick: since equipotential surfaces are nearly parallel, the particle can make the exploration as it moves along its proper trajectory! This is because each surface, in this discrete space, is locally composed of polygons—which *separately* supply components as the particle goes through!



[11]What "mesh size" might the lattice have? If adjacent potentials differed by 10^{-20} V, this would defeat present-day experiments. If we put 10^{20} cells between such surfaces (for room to represent momenta) then we would end up with the order of 10^{40} cells across a nucleus—if nothing changed down to the nuclear scale. But things *do* change there; we later argue that things like protons exist *because* that scale lacks room for ordinary fields to work! So halfway in between might do, say, 10^{30}.

Each surface micropolygon is normal to a lattice axis, so the particle need only add a unit scalar constant to its kinetic energy component along that axis. This solves the particle's derivative problem.[12] But how can the field maintain those surfaces? Some sort of local "force" must work to move them in accord with the Laplacian,

$$\frac{d}{dx}\left(\frac{d\Phi}{dx}\right)+\frac{d}{dy}\left(\frac{d\Phi}{dy}\right)+\frac{d}{dz}\left(\frac{d\Phi}{dz}\right)$$

so some physical activity must represent the information in *those* derivatives. We now propose only a sketchy "approach" to this, hoping the reader will not be upset when left in hopeless tangles of loose ends. We will fill the vacuum with a gas of light-speed "exchange" photons—call them "ghotons" —that bounce between, and push apart adjacent surfaces. A perfect gas will not do, because the "pressure" must depend on local distance between surfaces—so we will give every X-surface element an X-ghoton, to bounce between that surface and the next, and the same for Y and Z. (To ensure a single ghoton for each oriented surface element, each element emits ghotons continually— but returning ones annihilate the ones they meet.)

The field intensity components $E_x = d\Phi/dx$, etc., are inverse to the axial projections of the intersurface distances. Hence each x-surface element sees one reflected ghoton each $2/E_x$ moments. Therefore the impact frequency is proportional to E_x—and the "vector pressure" is proportional to the field's gradient. So the difference from both sides is

$$\frac{d}{dx}\left(\frac{d\Phi}{dx}\right)\cdot\frac{d\Phi}{dx}$$

This shows how differentials can emerge, in spite of local finiteness, by using "exchange forces." My intuition is that even if mechanics were continuous—but still had information limitations, some process like "exchange" would still be needed. (The extra factor $d\Phi/dx$ could be taken out, by ghoton-counting tricks, but actually it cancels anyway when Maxwell's scalar equation is rewritten in terms of surface motion rather than potential change at a point. Would this reveal a fatal flaw because, when weak fields change, the surfaces must move faster than light?)

To realize the wave equation, the ghotons must cross-interact so as make the Laplacian sum *accelerate* the potential—but I do not see exactly

[12] How can we properly change a particle's velocity, when making unit increments to its particle's kinetic energy? A strange idea: let us represent kinetic energies as squares—*literally*!—so that a velocity is an energy square's edge. It is tempting to imagine this inside our cubic lattices. In any case, it would seem easier to think of energy as "real" than momentum.

how to do this. If each surface of an analogous family of *continuous* surfaces were to emit ghotons in proportion to area, the pressures would be in equilibrium when the intersurface spacings are just like those of a Coulomb field with the same curvature. But it looks hard to make a discrete version of that, and I will only mention some of the problems.

The wave equation's second time derivative means velocity must be represented, not just position—we would need it, anyway, for representing field momentum. There is room enough because both gas and surface elements are one dimensional (velocity could be coded into ghoton trains). We also need machinery to keep the surfaces smooth—perhaps by some exchange *inside* the surfaces. Surely the whole thing must be done with a vector potential. Best of all would be to find a way to do without those surfaces at all, to leave the field as nothing but a cloud of interacting ghotons—from which particles could directly draw momentum, as Robert Forward pointed out to me.[13]

Given so many problems, is the subject worth pursuit? I think it is because our present theories have such weak foundations. We tend to view (for instance) terms of Feynman diagrams as mere approximations—because we see them as low-order terms of power series. Our finite information theory hints, instead, that those exchange devices are what is really real, because there must be something physical to transfer information. And then (oh, joy) those scary analytic integrals become the artifacts, originating from the error of continuous approximation to something that by nature is discrete!

4.2. Mechanism 2: Interactions Between Dispersed Quantities. How could two packets ever interact, if information is dispersed in space? Consider a collision between two bodies A and B whose momentum information is very precisely specified—hence very large in size. In classical physics, momentum is itself distributed, and in quantum theory its probability amplitude. But in a discrete theory what is dispersed is neither momentum itself—nor its probability—but *the information that defines it*. This gives the problem a different character, one of *access* to information. What happens when "A scatters B," if some of B's momentum information lies halfway across the galaxy?

If A must "know" the farthest fringe of B's momentum data, the interaction must be delayed—confirming neither classical nor quantum

[13] The surface–ghoton impact rate is proportional to the field's potential energy density. (The impact rate per surface element is proportional to field intensity, and so is the number of surface elements per unit volume. Hence the impact density scales with energy.) This could produce a space curvature proportional to energy—if every ghoton–photon event caused the photon to hesitate for a moment! Could some analogous processes yield space-time curvature?

expectation. It seems to me there is just one way a discrete vacuum could approximate a classical collision: by "estimating" the dispersed particles' momenta. In order that they interact at all, the particles must work with less than all the information classically required. So now we will sketch a scheme for prompt, conservative interaction—that does not achieve all its goals, but illustrates again how discrete models lead to quantumlike phenomena. We shall assume that if A and B interact it is because of the following:

(2a) At some space-time locus an "event" occurs in which the incoming particles' momenta are "estimated", and the outgoing momenta are determined by applying classical rules to these estimates.[14]

Because of estimation errors, the scattered momentum sums will not exactly equal the initial sums, so we need an "error conservation" mechanism:

(2b) Each scattered particle leaves a "receipt" with the other, recording how much momentum was actually removed. The "event locations" of (2a) are the receipts from previous interactions, because they contain information needed to estimate the new "real" momenta.

We shall further assume the following:

(2c) The new trajectories are determined only by the "estimates"; the receipts go along invisibly until combined into subsequent interactions.

It might well seem more logical for "receipt" momentum to continuously cancel, between interactions, against "observable" momentum. However, that would violate least action, producing interference patterns corresponding to curved trajectories.

If we combine mechanics in this way with unobservable receipts, deterministic systems show some qualitative features that resemble quantum, mixed-state systems. Thus one can always measure the "real" momentum in event 1 by the location of event 2. But one cannot yet "observe" the "receipt" momentum of event 1, because it is not until event 2 that it first combines with any "real" momentum—which cannot be "observed" until some subsequent event 3—by which time it is already mixed with another

[14]It certainly seems unlikely that there is any way to define deterministic "events" to be consistent with quantum facts. (Some might prefer alternatives with no "events" at all, as in a quantum theory with amplitudes but no probabilities, but then we must suffer the dreadful spectre of Schrödinger's cat.) Perhaps it might still be possible to approximate the standard view (in which "observations" replace mixed by pure states) in discrete models with symmetrical past-future state-change rules, i.e., with bidirectional causality. The basis of this thin conjecture is just that this permits global constraints to hold in space-time regardless of light-speed limits, hence opens again the hidden variable problem.

It might be worth exploring "discrete-phase" models in which states can cycle through some large but finite group of phases. Then one should obtain some "all possible paths" phenomena, and interesting kinds of interference. A remarkably simple example of such an array, that can "self-reproduce" arbitrary spatial patterns at remote locations, was discovered by Fredkin and described in Minsky (1969).

estimate! And so on. One can never simultaneously measure both estimates and receipts, though all adds up eventually. And all this involves no probabilities at all, just temporary inacessibility of information!

Estimates and receipts also permit tunneling—interactions that involve more momentum than available. All is repaid when receipts eventually return their information in new estimates, but every particle at every moment carries some invisible receipts not measured yet. The model can even show some qualitative features of quantum interference; if ever two particles were involved in the same interaction, they can share identical receipt information that gives them some coherent, "same random" properties in later interactions. Perhaps *any* information-limited mechanism for conservation and fast interaction needs some such two-part scheme.

Could anything like this yield "correct" quantum mechanics? Almost surely not, since that would solve the "hidden variable" problem, which probably has no solution under light-speed limitations. (Without that limitation, one might imagine ways to make the invisible receipts diffuse ergodically between interactions, gathering information; and using that to control the distribution of events. But that exploration would have to proceed arbitrarily much faster than light—and it would not help to appeal to an ensemble of similar situations, since some needed information lies outside the relevant light cone.) It is hard to lose causality, but better to face facts.

4.3. Mechanism 3: Particles as Products of Vacuum Saturation. Why do we have particles with rest mass? I will argue that they are needed to conserve fields! We have supposed that fields use *base-1* in order to be fast. What happens when a field gets so intense that (in our surface model) neighbor planes are forced together? Must their information be destroyed? No, because there is a loophole: we can provide that at some certain threshold of intensity, the vacuum state rules change things to a coding that is more compact, e.g., base-2. That must sound silly, but it has some interesting consequences.

To be concrete, we go back to that field–surface representation, and propose that: *when field surfaces are forced into contact, they are replaced, in pieces, by "base-2 abbreviations."* Now, this "abbreviation" process must be almost instantaneous, or else the threatened information will be permanently lost. But then the light-speed limitation means that this abbreviation cannot depend on much! So we "deduce" the following:

(3a) *Each "abbreviation" replaces a standard unit of field.* Since the locally compressed surfaces are nearly parallel, we need only to record a single spatial orientation.

(3b) *Each "abbreviation" contains a single unit direction vector.* Perhaps this is why "spin" comes in absolutely standard units. The potential energy of the compressed field must also be recorded, and (3a) means that its magnitude is a fixed "quantum."

(3c) *"Abbreviations" carry fixed amounts of potential energy.* The surfaces of squashed, time-dependent, fields also contain momentum to be conserved.

(3d) *Each "abbreviation" carries a (variable) momentum vector.* If the energy encoded in these "abbreviations" is ever to interact again, or even to decay back to field, they will need to be able to do some computation, hence the following.

(3e) *"Abbreviations" must move at less than light speed.* These properties so unmistakably resemble particles with *rest mass* that we conjecture: *Particles with rest mass are compressed, densely encoded representations of fragments of unary-coded fields.* Since the rest mass corresponds to the potential energy drawn from the field in (3c), the velocity of (3e) is determined by the momentum drawn from the field in (3d). Thus we "deduce" (without relativity!) that if energy and momentum are conserved throughout, then:

(3f) *A particle's rest mass is proportional to the potential energy of the field consumed to create it.* So, in this fantasy, it is purely to preserve energy and momentum of strong fields that we must suffer the creation of particles —because conversion to more compact information code is the only way to conserve information. The resulting abbreviations must move slowly and act slowly. They must act strangely, too, because we cannot keep reusing that stratagem of extending conservation by recoding. To be sure, there are many encodings intermediate between base-1 and base-2; the latter are the most compact possible codes. The closer the encoding approaches that ultimate density, the fewer ways remain for different particles to share the same space—so we must see either stronger exclusion rules, or more interactions in which particle identities are changed or lost entirely. So we can conclude, at least qualitatively, the following.

(3g) *Particles with rest mass have strong, short-range forces.* Ultimately some information must be lost, at *some* threshold of intensity.[15] If conservation of energy has the top priority, then geometric information has to be sacrificed first.

(3h) *Particle creation cannot conserve all of a field's topology.* This is because a base-2 particle moves slower than its field *and* takes time to "decay." Therefore, when it returns its information to its field, this will happen at some remote, "wrong" place—so the global configuration of the

[15] That is, unless the basic state rules themselves are reversible. Fredkin has shown local time reversibility to be compatible with many cellular array computations, and it would certainly seem of physical interest to consider time-reversible vacuum-state rules, for in some sense they would conserve everything (Fredkin, 1982).

field will have been changed. We speculate next that properties like *charge* amount to imperfect attempts to conserve the originating field's topology.

4.4. Mechanism 4: Conservation and Topology. What happens to the torn edges of those disrupted surfaces? Could one simply remove an entire equipotential? (Physically, the idea seems nonsensical—but we will ignore that.) Topologically, removing some potential shells would seem equivalent to creating dipole pairs of charge. So making charges can "save some topology" provided that (i) they are made in pairs and (ii) they carry charge fields like the fields they came from. To the extent that charges represents abbreviated topology, one would certainly expect that unpaired charges never vanish.

Can we pursue this down to the very lattice elements? Mechanism (3b) argues that a "unit vector" suffices to abbreviate the surface normal of the collapsing field. But at lattice resolution there are no unit vectors—only microscopic collisions between axis-parallel "field-surface polygons." These have three axis symmetry classes each with eight different signed ways that dihedral edges can meet surfaces (and other ways for vertices and edges to collide). Abbreviating any such event replaces some local field configuration by some sort of oriented A(xis)–(O)bject.

Each such subelementary event creates a pair of these AOs, and each must soon be joined by ones along the other axes—but those may be quite far away, depending on the field's direction cosines. Now, one can scarcely imagine creating an observable particle from a single AO—with its single-axis, scalar momentum; better to wait until enough AOs combine to make a "genuine" momentum vector. How might those AOs find their complements? The simplest scheme would keep each AO attached to its disrupted surface-edge, propelled by unbalanced ghotons until another is encountered; then a "$\frac{2}{3}$ AO" is formed. If two such meet, one axis will be twice represented—so the two of them must wait to cancel with an appropriate ($-\frac{1}{3}$) AO—and so forth. Of course that "so forth" is pure bluff; I have said too much already, and real physicists will think of better reasons why and how subelementary particles must be bound by unobservably large forces.

5. SUMMARY AND CONCLUSION

We started with the idea that in a cellular array, no field can work at light speed except with "base-1" information codes. We found that to approximate a Coulomb field requires something like an exchange force. Finally we saw that "base-2" things with "rest mass" must emerge from suitably intense fields—just to conserve information before it is squeezed to death. So, starting with a simple, finite field idea, we ended with a cluttered world of sluggish, complicated objects with queer interactions, internal structures, exclusion rules, and short-range forces.

Conservation also caused "uncertainty" to invade our simple world, because the local finiteness requires that all information be dispersed. To make fast interaction possible at all, and conservation too, something must keep the books—and we proposed a complicated system of "events," "receipts," and "estimates." Are there much simpler schemes that permit both exact conservation and lightspeed interaction? The present schemes, though incomplete, seem too complex already.

In spite of all these problems—indeed, perhaps because of them—the informational and computational clarity of such models could stimulate new insights. For all its faults, that perfectly deterministic "receipt" idea offers a useful contrast to the common views of probability. Precisely in those questions of isotropy, those very problems could stimulate a more exacting view of what subelementary events must be. Perhaps it is just where things do not work so smoothly and we have to build those "shuttles" that our mathematical divergences reveal some point where finite methods should suffice instead. It remains to be seen whether discrete physics can lead to "real" theories, given better ideas and more hard work.

ACKNOWLEDGMENT

This essay exploits many unpublished ideas I got from Edward Fredkin. The ideas about field and particle are original; Richard Feynman persuaded me to consider fields instead of forces, but is not responsible for my compromise on potential surfaces. I also thank Danny Hillis and Richard Stallman for other ideas.

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