SLAC – PUB – 3537
December 1984
(T/E)

THE MEASUREMENT PROBLEM IN PROGRAM UNIVERSE*

H. PIERRE NOYES

Stanford Linear Accelerator Center

Stanford University, Stanford, California, 94305

and

CHRISTOFFER GEFWERT

Academy of Finland, Helsinki

and

Stanford Linear Accelerator Center

Stanford University, Stanford, California, 94305

Submitted to *Symposium on the Foundations of Modern Physics*

50 Years of the Einstein-Podolsky-Rosen Gedankenexperiment

Joensuu, Finland, 16-20 June 1985.

* Work supported by the Department of Energy, contract DE – AC03 – 76SF00515.

CONF-850683--1

ABSTRACT

We present a discrete theory that meets the measurement problem in a new way. We generate a growing universe of bit strings, labeled by $2^{127} + 136$ strings organized by some representation of the closed, four level, *combinatorial hierarchy*, of bit-length $N_{139} \geq 139$. The rest of the strings for each label, which grow in both length and number, are called *addresses*. The generating algorithm, called PROGRAM UNIVERSE, starts from a random choice between the two symbols "0" and "1" and grows (a) by *discriminating* between two randomly chosen strings and adjoining a *novel* result to the universe, or when the string so generated is *not* novel,by (b) adjoining a randomly chosen bit at the growing end of each string. We obtain, by appropriate definitions and interpretations, stable "particles" which satisfy the usual relativistic kinematics and quantized angular momentum without being localizeable in a continuum space-time. The labeling scheme is congruent with the "standard model" of quarks and leptons with three generations, but for the problem at hand, the implementation of this aspect of the theory is unimportant. What matters most is that (a) these complicated "particles" have the periodicities familiar from relativistic "deBroglie waves" and resolve in a discrete way the "wave-particle dualism" and (b) can be "touched" by our discrete equivalent of "soft photons" in such a way as to follow, macroscopically, the usual Rutherford scattering trajectories with the associated bound states. Thus our theory could provide a discrete description of "measurement" in a way that allows no conceptual barrier between the "micro" and the "macro" worlds, if we are willing to base our physics on counting and exclude the ambiguities associated with the *unobservable* "continuum".

1. INTRODUCTION

In our view, if the summation of "soft" photons by Stapp[1,2] indeed leads to the conclusion that he has constructed "classical" electromagnetic fields whose sources are the "hard" scattering events of quantum field theory, the "measurement problem" as conventionally posed has been successfully understood. There is no barrier between the "micro" and "macro" worlds. When to this is added the work of Stapp and others on the ERP "paradox", which has been carefully reviewed by him in a forthcoming paper[3], the door has been opened to an *objective* understanding of quantum mechanics with the characteristic that events in space-like separated regions cannot communicate *causal* effects, but *do* change the probabilities of events before any light signal transmitted from one of the space-like separated regions can be received in the other. We are in full agreement with the conclusion that the past is fixed but that current events affect the probabilities of future occurances anywhere in the known universe. We also believe that quantum mechanical practice in many cases of interest gives us an effective technique for calculating these probabilities.

However, there are still conceptual difficulties in taking this result at face value. For example, Chew has attempted to ground the underlying quantum theory in a "topological bootstrap theory"[4] with considerable success, and has related this approach to Stapp's result[5]. However, as Chew himself admits[6], he has had to assume that he can associate *continuous* momenta with his underlying "graphs", an idea at variance with the discrete foundations of the theory he is developing. In this paper we argue that a fully discrete foundation for the whole problem can be provided, with a considerable gain as to both conceptual clarity and future developments.

Our theory has a long early[7-9] and later[10-16] history, which we will not explore here, since it would raise more philosophical, mathematical and physical questions than we can treat with accuracy in a short presentation. Fortunately for the purpose at hand recent results allow a reasonably concise framework of discussion to be extracted.

The basic entities in the theory are ordered strings of the symbols "0, 1" labeled by a set of symbols $a, b, ..$ which are defined by ${}^aS^{(N)} = (..., {}^ab_n, ...)_N$, where ${}^ab_n \in 0, 1$ and $n \in [1, 2, ..., N]$. These strings combine by *discrimination*, defined by

$$D_N\ {}^aS^bS \equiv (..., {}^ab_n +_2\ {}^bb_n, ...)_N \equiv (..., ({}^ab_n - {}^bb_n)^2, ...)_N$$

to produce new strings, if $N \geq 2$. Here $+_2$ is addition modulo 2, or "exclusive or", or binary addition. Calling the null string 0_N, and using $\oplus$ for discrimination, ${}^aS \oplus\ {}^aS = 0_N$, and for a, b, c distinct we have the symmetric relation for any discrimination

$${}^aS \oplus\ {}^bS \oplus\ {}^cS = 0_N$$

Since it is well known in particle physics that we need at least four "particles" to start to pin down an observation, and in geometry that we need at least four "points" not in a plane to start constructing a 3-space, we extend this basic structure to define an "event" by

$${}^aS \oplus\ {}^bS \oplus\ {}^cS \oplus\ {}^dS = 0_N$$

In order to convince the reader that this structure will allow us to discuss *physics*, we show that this basic relation, when we have four instances of it involving four *labeled* strings of sequentially increasing length, allows us to *stabilize* our version of a "particle". Within our discrete restrictions our "partic satisfy the usual constraints of relativistic particle kinematics and *quantized* o al angular momentum, including "vector" conservation laws.

The next step is to generate the strings themselves. This we do by a simple computer algorithm called PROGRAM UNIVERSE, which provides a growing universe of bit strings using two basic operations. The first is discrimination, which, if the string produced is not already in the universe, increases the "size" (i.e. number of strings) of the universe. If the string produced by discrimination is already contained in the universe, the "length" of the strings (i.e. N) is increased by adjoining a single bit, randomly chosen between 0 and 1 for each string separately, at the growing end. It will be seen that this is called into play when we have encountered an *event* as defined above. The operation is called $TICK$. Hence the universe "ticks" "whenever" and "wherever" an event occurs. We will see that it is this feature of the construction which provides us with both the randomness and the "non-locality" already familiar in conventional quantum mechanics.

To label the strings we invoke the property of *discriminate closure* and by mapping the discriminately closed subsets of a lower *level* in such a way as to provide a *linearly independent basis* for the next level, construct the *combinatorial hierarchy*, i.e. the sequence

$$(2, 2^2 - 1 = 3)\ (3, 2^3 - 1 = 7)\ (7, 2^7 - 1 = 127)\ (127, 2^{127} - 1 \simeq 1.7 \times 10^{38})$$

This sequence *terminates* with the fourth level because the mapping cannot be continued beyond that point. In this way we generate the cumulative cardinals $3, 10, 137, 2^{127} + 136$ and use our construction to assign the corresponding $2^{127} + 136$ finite length strings as *labels* (called $a, b, c, d, \ldots$ above) for the growing portions of the strings, called *addresses*, which the program continues to generate. Note that for each label, both the number of address strings and their length continue to grow. We identify the third cumulative cardinal, 137, as a first approximation for $\hbar c/e^2$, and the last cardinal, $2^{127} + 136 \simeq 1.7 \times 10^{38}$, as a first approximation for $\hbar c/Gm_p^2$, steps which have to be justified during the further development of the theory. The second identification sets the mass scale for the theory as m_p, the mass of the proton. Since no more dimensional identifications can be made, from here on in we must *calculate* everything else. We emphasize that this approach is not *a priori* or "Pythagorean". If at a later stage we come to a conclusion in conflict with experiment, we must understand why, and failing that either modify our approach or abandon the theory altogether.

Our next step is to investigate the labeling scheme in more detail, and to show that this scheme allows us to describe both (massless) *chiral* and (potentially massive) *achiral* "*leptons*" which are associated only with "velocities" ± 1 (in physical dimesional units $\pm c$). This takes care of levels 1 and 2 of the hierarchy. We develop here only enough of the theory to show that at level 3 we can interpret the labels as describing two types of "*hadrons*", with quantum numbers conserved in events that distinguish "protons" and "neutrons", with their "antiparticles", from the level 2 achiral leptons. We can then derive the basic formalism of a covariant quantum scattering theory for systems with finite particle number, which can be developed in a more conventional way.[17–21]

At level three, our construction guarantees $(3+7+127 = 137)$ labels of length $N_{12} \geq 12$ and the first initial bits of a level 4 label consisting of all "0" 's $(0_{N_{12}})$

or of all "1" 's ($1_{N_{12}}$). From our definition of discrimination , the first leaves any label unaltered, and hence is our candidate for a "soft (coulomb) photon". But, with our definitions of "velocity" and the particle-antiparticle dichotomy, which incorporate a discrete version of the usual Feynman rules, the anti-null string 1_N both reverses velocities and changes particles to antiparticles, so in our framework is indistinguishable in its effects from the "soft" null string. Since this label string occurs with probability 1/137, we justify our initial approximation for $e^2/\hbar c$. As in the "coulomb gauge" approach to more conventional theories, spin dependent interactions will give corrections of order 1/137, and consequently corrections to our value that will allow us, ultimately, to calculate a second approximation for the observed value of $e^2/\hbar c$. Our scattering theory allows us to sum the "soft photons" in such a way as to give Rutherford scattering "trajectories" in macroscopic (laboratory) space, thus ty in the "micro" to the "macro" worlds. Invoking the high energy experiments which "find QED valid down to 10^{-16} cm", we then argue that the use of the e^2/r Coulomb law in the Parker-Rhodes calculation of m_p/m_e is justified. Following Parker-Rhodes[12] we then show, using appropriate statistical arguments, that the achiral leptons of level 2 can acquire an electromagnetic mass in the experimentally observed ratio to our standard m_p.

Further, our composite "particles" will contain high momentum components responsive to hard photons, and so are consistent with the successful "parton" model. A similar treatment of the level 4 Newtonian "graviton" completes the picture, but is not explored in detail. Spin 2 corrections should lead to the "weak field" version of the Einstein theory, as is discussed in more conventional terms by, for example, Weinberg[22] . As with the next order calculation of $e^2/\hbar c$, these corrections could get us into serious trouble if they fail to work out. We claim at this stage to have a digital version of quantum mechanics that works at least as well as the Stapp-Chew approach using a much simpler conceptual basis. This claim rests, in part, on a covariant finite particle number scattering theory[17-21] which we do not discuss here.

Granted this, we need only show that our composite "particles" exhibit the usual wave-particle dualism of relativistic "deBroglie waves". This requires us to connect an "internal" dichotomous spin-label with our address strings to provide a *signed* "vector" that can lead to interference nulls. We conclude this section by showing why we believe that our approach allows us to understand the EPR situation and the other "paradoxes" of measurement theory in a new way made possible by our avoidance of any need for *completed* infinities. Hence we argue that by sticking to a discrete framework compatible with constructive mathematics and the participatory philosophy being developed by one of us[23] the non-local, "fixed past -uncertain future" quantum mechanical theory developed during this century can be understood in terms simpler than those which, historically, came first.

2. BIT STRING PARTICLES

We now construct the particles of our theory from four sequential events, each of which involves four *labeled* bit strings ${}^aS^{(i)}, {}^bS^{(i)}, {}^cS^{(i)}, {}^dS^{(i)}$: $i \in 1,2,3,4$ of length $N^{(i)}$ with $N^{(1)} = N_1, N^{(2)} = N_1 + N_2, N^{(3)} = N_1 + N_2 + N_3, N^{(4)} = N_1 + N_2 + N_3 + N_4$, where $1,2,3,4$ refer to the four events characterized by the four positive integers N_1, N_2, N_3, N_4. These strings have an internal structure about which we know only that it has been constructed by the random choices mentioned briefly in the introduction and described in the next chapter. This algorithm (PROGRAM UNIVERSE) generates label strings ${}^{w}L, w \in a, b, c, d$ of bit length N_L, which is *fixed*, and address strings ${}^{w}A^{(i)}(N_i)$ where for $i > 1$ the length of the string, from the definitions above, only refers to the random bits added by the "ticks" subsequent to N_1. The strings have the structure ${}^{w}S(i) = [{}^{w}L, {}^{w}A^{(i)}(N_i)]$. Our definition of event

$$^{a}S^{(i)} \oplus^{b} S^{(i)} \oplus^{c} S^{(i)} \oplus^{d} S(i) = 0_{N^{(i)}}$$

therefore implies that

$$^{a}L \oplus^{b} L \oplus^{c} L \oplus^{d} L = 0_{N_L};\ ^{a}A^{(i)} \oplus^{b} A^{(i)} \oplus^{c} A^{(i)} \oplus^{d} A^{(i)} = 0_{N_i}$$

It is important to realize that we do not have access to the actual bit string content of either the label or the address strings. These are *indistinguishables* in the sense of Parker-Rhodes' theory[12]. Of the label strings we have by construction the fact that they form a representation of the *combinatorial hierarchy* with exactly four levels, so we are allowed to base our definition of a particle on exactly four labels. Again by construction, any address string has a unique label which remains *invariant* as the bit string universe evolves, and which changes by the addition of a random bit with each "tick" at the growing end of the string. This generation process leaves the label and the earlier bits in the address string unchanged. There will be many addresses with the same label after the construction has proceeded to large values for N_1. What we have done by specifying the above four events is to pick out a specific example in each case.

In the current construction, we make use of the fact that each address string of length N can be characterized by two parameters, N^1 and N^0, giving the number of ones $N^1 = \Sigma_{n=1}^{N} b_n$ and the number of zeros $N^0 = N - N^1$ in the string, independent of the ordering parameter along the string n. The fact that the strings engage in events gives us further structural information independent of order. We organize this information as follows. For our immediate purposes we take label d as our referent at reference event (1), with address string ${}^dA^{(1)}(N_1)$ characterized by the two integers N_1, ${}^dN^1(1)$. For the second event, which occurs N_2 "ticks" after the reference event, we define the eight positive or zero integers $n_a, n_b, n_c, n_{ab}, n_{bc}, n_{ca}, n_{abc}, n_0$ added in the N_2 "ticks" after the reference event with the significance that n_a (n_b, n_c) is the number of the ones in the address string ${}^aA^{(2)}(N_2)$, $({}^bA^{(2)}(N_2), {}^cA^{(2)}(N_2))$ which do not coincide in their ordered position n with the ones in strings b or c (c or a,b or c), $n_{ab}(n_{bc}, n_{ca})$the number of ones which coincide in the designated pairs, n_{abc} the number of ones which coincide for all three strings, and n_0 the number of zeros which coincide. It follows immediately from our definition of discrimination and event that

$$N_2 = n_a + n_b + n_c + n_{ab} + n_{bc} + n_{ca} + n_{abc} + n_0$$

that the number of ones in a is

$${}^aN^1(2) = n_a + n_{ab} + n_{ca} + n_{abc}$$

that the number of ones in b is

$${}^bN^1(2) = n_b + n_{ab} + n_{bc} + n_{abc}$$

that the number of ones in c is

$${}^cN^1(2) = n_c + n_{bc} + n_{ca} + n_{abc}$$

and that the number of ones in d is

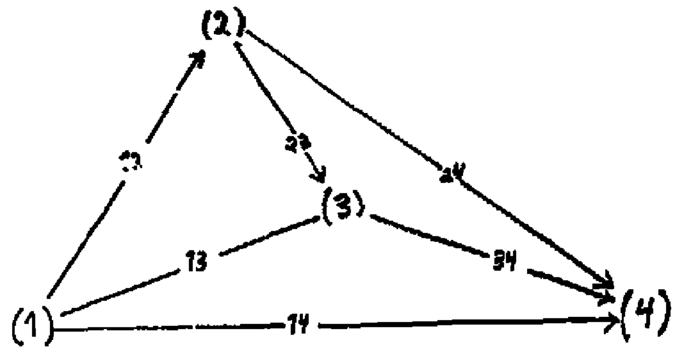
$$^dN^1(2) = n_a + n_b + n_c + n_{abc}$$

Since these refer to event (2), we extend the notation by $n_a \to n_a(2), n_b \to n_b(2)$... and so on.

For the third event, (3), which occurs N_3 "ticks" after the second event we define the number of ones added in appropriate positions by $N_3 = \Delta n_a + \Delta n_b + \Delta n_c + \Delta n_{ab} + \Delta n_{bc} + \Delta n_{ca} + \Delta n_{abc} + \Delta n_0$, and the obvious extensions $\Delta n_a \to \Delta n_a(3)$ and so on. Clearly we also have in terms of these eight integers obvious definitions for $\Delta^a N^1(3)$ and so on. Similar definitions apply to the fourth, and last, event. We see that the string content, ignoring the order of the symbols but keeping track of the correspondences between zeros and ones required by the discriminations, for the three events subsequent to the reference event is defined by 24 positive or zero integers which must increase from event to event in a random way generated by PROGRAM UNIVERSE, but with the structural restrictions we have taken some care to define.

For what follows, it is easier to visualize what is going on if we think of the four events 1,2,3,4 as situated at the four corners of a tetrahedron with six directed edges: $(1) \to (2), (1) \to (3), (1) \to (4), (2) \to (3), (2) \to (4), (3) \to (4)$, or (12), (13), (14), (23), (24), (34) for short (see figure).

Concentrating on individual strings, the actual order in which the symbols 0,1 occur in the address string is unimportant, but their numbers N^0, N^1 with $N^0 + N^1 = N$ are. These allow us to define a parameter β bounded by -1 and +1 and the related parameter γ^2 by



$$N\beta(N,N^1) = 2N^1 - N;\ \gamma^2\beta^2 = \gamma^2 - 1$$

With each label we asscciate a parameter m_w, which it will eventually be the task of the theory to compute, and two additional quantities $E_w(N,N^1)^2 = m_w^2\gamma^2$, $p_w(N.N^1)^2 = m_w^2\gamma^2\beta^2$. This has been done, transparently, so that $E^2 - p^2 = m^2$ and hence so that the assignment of the parameter m_w to label ^wL is *invariant* no matter how N and N^1 change as the universe evolves. Thus our basic entities support the necessary properties for relativistic kinematics including, when we come to physical interpretation, the limiting velocity c. Note that when the address string is 1_N, $\beta = +1$, and when it is 0_N, $\beta = -1$. For these special cases γ in undefined and we must take $m \equiv 0, E \equiv p$ for consistency.

With each of these six "edges" we can then associate six (rational fraction) "velocity" parameters β, namely $\beta_{(12)}, \beta_{(13)}, \beta_{(14)}, \beta_{(23)}, \beta_{(24)}, \beta_{(34)}$ defined by

$$N_2\beta_{12} = 2\Delta^a N^1(2) - N_2$$

$$[N_2 + N_3]\beta_{13} = 2[\Delta^b N^1(2) + \Delta^b N^1(3)] - [N_2 + N_3]$$

$$[N_2 + N_3 + N_4]\beta_{14} = 2[\Delta^c N^1(2) + \Delta^c N^1(3) + \Delta^c N^1(4)] - [N_2 + N_3 + N_4]$$

$$N_3\beta_{23} = 2\Delta^c N^1(3) - N_3$$

$$[N_3 + N_4]\beta_{24} = 2[\Delta^b N^1(3) + \Delta^b N^1(4)] - [N_3 + N_4]$$

$$N_4\beta_{34} = 2\Delta^a N^1(4) - N_4$$

If these definitions of the edges are examined with care, it will be seen that we have assigned a to (12) and to (34), b to (13) and to (24), and c to (14) and to (23). It is important to realize that these assignments are *arbitrary*; all that matters is that each of the three labels is assigned to two edges in such a way that each of the three labels is associated with each of the three events (2), (3), (4).

There are also six "velocity" parameters associated with the referent d, namely

$$N_2\beta_d(12) = 2N_d^1(12) - N_2$$

$$[N_2 + N_3]\beta_d(13) = 2N_d^1(13) - [N_2 + N_3]$$

$$[N_2 + N_3 + N_4]\beta_d(14) = 2N_d^1(1) - [N_2 + N_3 + N_4]$$

$$N_3\beta_d(23) = 2N_d^1(23) - N_3$$

$$[N_3 + N_4]\beta_d(24) = 2N_d^1(24) \quad [N_3 + N_4]$$

$$N_4\beta_d(34) = 2N_d^1(34) - N_4$$

where

$$^{d}N^{1}(12) = \Delta n_{a}(2) + \Delta n_{b}(2) + \Delta n_{c}(2) + \Delta n_{abc}(2)$$

$$^{d}N^{1}(13) = ^{d}N^{1}(12) + \Delta n_{a}(3) + \Delta n_{b}(3) + \Delta n_{c}(3) + \Delta n_{abc}(3)$$

$$^{d}N^{1}(14) = ^{d}N^{1}(13) + \Delta n_{a}(4) + \Delta n_{b}(4) + \Delta n_{c}(4) + \Delta n_{abc}(4)$$

$$^{d}N^{1}(23) = ^{d}N^{1}(13) - ^{d}N^{1}(12)$$

$$^{d}N^{1}(24) = ^{d}N^{1}(14) - ^{d}N^{1}(12)$$

$$^{d}N^{1}(34) = ^{d}N^{1}(14) - ^{d}N^{1}(13)$$

Hence we can replace 12 of our unknown integers with these 12 velocity parameters which we interpret as the velocities with which quantum numbers corresponding to the labels a, b, c move along the edges of the tetrahedron.

Mach showed long ago that the most compelling way to define *mass*, or more precisely speaking mass ratios relative to some arbitrary standard, is by invoking Newton's third law in particulate collisions. We extend this definition to the relativistic case by requiring relativistic energy-momentum conservation at the four events. Noting that since these events involve d as well as a, b, c this fixes four more parameters in terms of the masses m_a, m_b, m_c, m_d. For consistency, this requires that the six velocities $\beta_d(12), \beta_d(13), \beta_d(14), \beta_d(23), \beta_d(24), \beta_d(34)$ all be the same, fixing six more parameters. The remaining two parameters N, N^1 are replaced by our initial condition

$$N_1\beta_d(1) = 2N_d^1(1) - N_1$$

and the corresponding energy $E_d = m_d\gamma$. In this way we claim to have proved that our four sequential events describe a particle d of mass m_d moving with constant velocity $\beta_d(1)$ containing three internal partons of mass m_a, m_b, m_c which conserve relativistic energy and momentum, but whose internal momenta are otherwise arbitrary.

We now note that the choice of the referent d, like the assignment of a, b, c to the three events (2), (3), (4), was *arbitrary*. We will show in Chapter 4 that the labels ${}^aL, {}^bL, {}^cL, {}^dL$ can be interpreted in terms of familiar particulate quantum numbers which are also conserved in events. Thus our system $(abcd)$ resembles in detail the "four point function" of S-matrix theory. In particular we will see later that this symmetry is related to the usual CPT symmetry of Feynman diagrams. Which of the four quantum numbers becomes the referent will then depend on how the "boundary conditions" described in Chapter 5 are set. We thus claim to have established the essential kinematics for S-matrix theory in 3+1 momentum-energy space directly from our discrete bit string structure. This justifies us in introducing our first physical dimensional constant c with dimensions $[L/T]$. Of course, only mass *ratios* are thus defined, relative to some mass standard which, so far, remains arbitrary.

To get our corresponding unit of length, we adapt Stein's basic idea that relativity and the uncertainty principle come from random walks of finite step length[12] to the bit string context by assuming that an address string of finite length can be interpreted as an element from a random walk in which "1" represents a step in the positive direction and "0" a step in the negative direction. Introducing the dimensional constant h with dimensions $[ML^2/T]$, we take the step length to be hc/E. This completes the definition for $m = 0$, in which case all steps are in the same direction with $v = \pm c$. For finite masses we then have that, for example, the distance from (1) to (2) is given by $r_{12} = (h/m_a c)|\beta_{12}|\sqrt{1-\beta_{12}^2}N_2$, and so on. Thus our tetrahedron acquires a spacial significance in 3+1 space-time, even though its "edges" are not "lines" composed of points. Thanks to the usual algebraic connection between the sides of a triangle and the angles, eg $cos\theta_{(12),(13)} = (r_{12}^2 + r_{13}^2 - r_{23}^2)/2r_{12}r_{13}$, we can now give a meaning to *directions* even though we have not started from a continuous space. Further, the usual definition of orbital angular momentum $\underline{L} = \underline{R} \times \underline{P}$ gives, we believe, the usual integral restrictions on the z-component thanks to the fact that our construction allows only certain angles to occur. The details have not been worked out as of this writing, but will be available at the Symposium.

Despite the pictorial character of our tetrahedra, it is important to keep in mind that these "edges" are not "lines". Interactions can occur, once we have introduced the degrees of freedom needed for a complete scattering theory, at "points" within the tetrahedra, but only in terms of the finite step length hc/E. Thus we can find "points" at discrete intervals which can made as close together as we like if we use high enough energy "probes", but nowhere "in between"; these interactions can involve any of the "partons". Hence if, as we anticipate, our theory contains QED we expect that the conventional interpretation of high energy experiments which show that "QED is valid down to $10^{-16}cm$" will survive. But we will be debarred from going to the continuum limit and can never construct the "space" of Euclidean (or Minkowski) geometry. It is in this way that we keep our theory discrete, and never get into having to use "continuous lines". We claim that this is a real conceptual triumph for our approach.

3. GENERATING AND LABELING THE BIT STRINGS

Our computer algorithm (Program Universe 2)[24] starts from nothing (in the computer, other than program and available memory) and generates a growing universe characterized by two cardinals: $SU, N \in integers$. For computer operations any element of the universe may be simulated by an ordered string of the symbols 0, 1 containing N such symbols which we can call $U[i], i \in 1, ..., SU$. We use two operations to increase these cardinals:(1) PICK, which picks any string from the universe with probability $1/SU$ and a second string (shown to be different by discrimination) with the same prior probability and generates a string by discrimination; if the new string is not already in the universe it is adjoined and SU is increased by one. If the string produced by PICK is already in the universe we invoke (2) TICK which picks a bit for each $U[i]$, randomly chosen between the two symbols 0, 1, adjoins it at the head of the string, and hence increases N by one; the code then returns to PICK. As already noted, this defines an *event*. The flow is thus $PICK \rightarrow [novel(adjoin)\ OR\ contained(TICK)] \rightarrow PICK...$.

To get the program started we assign the first string in the universe the value R (i.e. a random choice between 0 and 1) and the second again the value R, provided only it differs from the first. We now enter the main program at PICK, and continue till doomsday. We say that each tick follows an *event*. Note that by this specification of events and the integral ordering of the ticks (even though, outside of the computer simulation, it turns out to be unknowable) we have abandoned the concept of *simultaneity*, and not just "distant simultaneity" as is customary in special relativity.

To bring out the structure generated by this simple program, we consider first the short strings generated in the initial stage, and show that these can be used to generate a representation of the combinatorial hierarchy. We start from the concept of *discriminate closure* initially introduced by John Amson[9]. Using $+$ for discrimination, since $a + a = 0$, and a,b linearly independent (l.i.) iff $a + b \neq 0$, there are sets of strings which close under discrimination called discriminately closed subsets (DCsS). For example, if a and b are l.i., the set $\{a, b, a+b\}$ closes, since any two when discriminated yield the third. Similarly if c is l.l. of both a and b, we have the DCsS $\{a, b, c, a+b, b+c, c+a, a+b+c\}$. Provided we call singletons such as $\{a\}$ DCsS's as well, it is clear that from n l.i. strings we can form $2^n - 1$ DCsS, since this is simply the number of ways we can choose n distinct thing one, two,... up to n at a time.

The first construction of the hierarchy[9] started from *discrimination* using ordered bit strings as already defined. Starting from strings with two bits (N=2) we can form $2^2 - 1 = 3$ DCsS's, for example $\{(10)\}, \{(01)\}, \{(10), (01), (11)\}$. To preserve this information about discriminate closure we map these three sets by non-singular, linearly independent 2×2 matrices which have only the members of these sets as eigenvectors, and which are linearly independent. The non-singularity is required so that the matrices do not map onto zero. The linear independence is required so that these matrices, rearranged as strings, can form the basis for the next level. Defining the mapping by (ACDB)(xy)=(Ax+Cy,Dx+By) where A,B,C,D,x,y $\in 0, 1$, using standard binary *multiplication*, and writing the corresponding strings as (ABCD), three strings mapping the discriminate closure at level 1 are (1110), (1101), and (1100) respectively. Clearly this rule provides us with a linearly independent set of three basis strings. Consequently these strings form a basis for $2^3 - 1 = 7$ DCsS's. Mapping these by 4x4 matrices we get 7 strings of 16 bits which form a basis for $2^7 - 1 = 127$ DCsS's. We have now organized the information content of 137 strings into 3 levels of complexity. We can repeat the process once more to obtain $2^{127} - 1 \simeq 1.7 \times 10^{38}$ DCsS's composed of strings with 256 bits, but cannot go further because there are only 256×256 linearly independent matrices available to map them, which is many to few. We have in this way generated the critical numbers $137 \simeq hc/2\pi e^2$ and $1.7 \times 10^{38} \simeq hc/2\pi G m_p^2$ and a hierarchical structure which terminates at four levels of complexity: $(2,3), (3,7), (7,127), (127, 2^{127} - 1)$. It should be clear that the hierarchy defined by these rules is *unique*, a result achieved in a different way by John Amson[10].

In the context of program universe, since the running of the program provides us with the strings and also an intervention point (adjoin the novel string produced by discrimination from two randomly chosen strings) where we can organize them conceptually without interfering with the running of the program, we can achieve the construction of a representation of the hierarchy in a simpler way. The procedure is to construct first the basis vectors for the four levels by requiring linear independence both within the levels and between levels. Since adding random bits at the head of the string will not change the linear independence, we can do this at the time the string is created, and make a pointer to that $U[i]$ which is simply i, and which does not change as the string grows.

Once this is understood, the coding is straightforward, and has been carried through by Manthey[15,34]. Each time a novel string is produced by discrimination, it is a candidate for a basis vector for some level. All we need do is find out whether or not it is l.i. of the current (incomplete) basis array, and fill the levels successively. Calling the basis strings $B_\ell[m]$ where $\ell \in 1,2,3,4$ and $m \in 1,..,B[\ell]$ with $B[1]..B[4] = 2,3,7,127$, we see that the basis array will be complete once we have generated 139 l.i. strings. Since the program fills the levels successively, it is easy to prove that if we discriminate two basis strings from *different* levels we must obtain one of the basis strings in the highest level available during the construction, or level 4 when the construction is complete, i.e. *if* $i \neq j$ *and both* $< \ell_{last}$ *then* $B_i + B_j =$ *some* B_{last}.

Once we have 139 l.i. basis strings, which will happen when the bit string length N_{139} is greater than or equal to 139, we can insure the generation of some representation of the combinatorial hierarchy by going to $TICK$. Then the only alteration of these N_{139} initial bits that can occur from then on will be the filling up, by discriminate closure, of any of the remaining elements of the hierarchy in this representation as a consequence of the continuing random discriminations. Since we keep on choosing strings at random and discriminating them, discriminate closure insures that we will eventually generate all $2^{127}+136$ elements of the hierarchy [BUT NO MORE]. Of course there will eventually come to be many different strings with the same initial bits, N_{139}. We fix this number, and from now on call the first N_{139} bits in a string the *label*, and the remaining bits the *address*. Finally we note that when the label array is complete we know that among the labels L_i at any one level we can find exactly B(l) l.i. strings and no more; it becomes arbitrary which of the many possible choices we make, so the "basis" becomes a structural fact and does not single out any particular strings. It follows immediately that *if* $i \neq j$ *and both* $< \ell_{last}$ *then* $L_i + L_j =$ *some* L_{last}.

4. QUANTUM NUMBERS, LEPTONS AND BARYONS

In Chapter 2 we have seen that, given four labeled strings ${}^{w}S$ where $w \in a, b, c, d$ and these distinct labels are themselves strings of bit length N_L, and given four sequential events $i \in (1), (2), (3), (4)$ characterized by four integers N_i and address strings ${}^{w}A^{(i)}(N_i)$, we can construct particles $(abcd)$. Any one of the four labels can be taken as the referent, and moves with constant velocity, energy, momentum and mass m_w. The remaining three labels describe partons with arbitrary (under specified digital restrictions) velocities, energy, momenta and angular momenta satisfying the usual conservation laws, and with arbitrary mass ratios to the referent mass. Our next step is to investigate these masses in more detail using the labels generated by PROGRAM UNIVERSE and organized into the four levels of the combinatorial hierarchy.

PROGRAM UNIVERSE "starts up" in such a way that we reach the the situation with $SU = 3, N_U = 2$ composed of the three strings (10),(01),(11), which is the first level of the hierarchy. Since

$$(10) \oplus (01) \oplus (11) = (00)$$

the universe must then "tick". This tick adds either a one or a zero at the end of each string; we can now interpret the first two bits as labels with $N_L = 2$ and the third bit as an address. Since this corresponds to $\beta = \pm 1$, these level 1 labels must be assigned *exactly* zero mass

As the program chooses and discriminates between these strings, we can generate eight labeled strings corresponding to $m = 0$ which are

$$(00)(0),\ (00)(1),\ (10)(0),\ (10)(1),\ (01)(0),\ (01)(1),\ (11)(0),\ (11)(1)$$

It can also happen that the universe "ticks" for a while in such a way that 0 becomes 0_N and 1 becomes 1_N, which obviously does not change this structure. It is important to realize that once we have introduced the label-address dichotomy, the string 0_N, which is excluded in the hierarchy construction itself, can have interpretable significance.

We now turn to physical interpretation by taking the critical step of defining a "quantum number" $2h^1_w$ for the level 1 labels, $({}^w b_1, {}^w b_2)$, where w takes on the values $a = (10), b = (01), c = (11), d = (00)$, as $2h^1_w = {}^w b_1 - {}^w b_2$, with the consequence that $h_a = +1/2, h_b = -1/2, h_c = 0 = h_d$. It is easy to show, in the current context, that this quantum number is *conserved* in all events.

The next critical fact to note is that the string $(11)(1)$ reverses both the sign of this quantum number and the sign of the velocity parameter β when any string is discriminated with it. Thus labels fall into two classes, L and $\bar{L} = L \oplus 1_{N_L}$ which we call *particles* and *antiparticles* respectively. Further, the reversal of the sign of the velocity caused by discrimination with the address string 1_N applies just as well to strings with $|\beta| < 1$ as to the case we are considering at the moment. We are now in a position to identify the quantum numbers h^1_a and h^1_b as the two *helicity* states of some massless particle-antiparticle pair. Since the helicity does not reverse when we reverse the velocity (but not the overall time sense, which is currently undefinable), these are "pseudovectors", and if we take the dimensional unit of this quantum number as $\hbar$, we can identify them as strictly massless *chiral* two-component *neutrinos*. From now on we will refer to labels with $|h_L| = 1/2$ in terms of the unit $\hbar$ as particles and (when we encounter them later on) with $|h| = 0, 1$ as *quanta*. We also see that if we think of the reversal of the velocity as the reversal of the time sense instead we have the usual

Feynman rule that a particle "moving forward in time" will be equivalent to an antiparticle "moving backward in time". Therefore we have established the CPT theorem in our context.

Two of the remaining four strings, namely (00)(0) and (11)(1) are of particular interest, since the former leaves any string untouched on discrimination, while the second, thanks to the CPT theorem, has the same effect. If we articulate our basic event structure further in the case of neutrino-antineutrino "scattering" ($w, w' \in a, b$) by writing

$$^{w}S \oplus^{w'} S =^{e} S =^{w} S \oplus^{w'} S$$

we see that $e \in c, d$ and that these two strings can be "exchanged" without altering the system. They are therefore our candidates for "soft" quanta, which are necessarily massless -- a point which Stapp and Chew emphasize. As we will see, our scattering theory will allow us to sum any number of such processes and will then lead to the kinematics of Rutherford scattering in an appropriate large number approximation, when we are in 3+1 "space". As yet we do not have sufficient structure to define either this space or the coupling constant. Further, because we can encounter either address string associated with either neutrino in the "final state", this primitive scattering process already has the "crossing symmetry" on which conventional S-matrix theory is based.

Before we leave this primitive universe of massless neutrinos and quanta, it is interesting to note that they will remain constituents of the universe as it evolves and provide an ultimate (but ever increasing) boundary. Since we do not as yet have enough structure to define directions, this boundary is *isotropic*. Once we have developed enough structure for them to scatter from massive constituents, the first scatterings will define an "event horizon" whose isotropy or lack of it will depend on the details of the way PROGRAM UNIVERSE generates these scatterings. About this we will only be able to make statistical statements. Strings which engage in scatterings after these first "horizon" events will then define, statistically, the energy and particle density of the universe. We will not discuss cosmology further in this paper.

The level 1 structure we have discussed will persist until we encounter an address string with the structure $(1_N 0)$ or $(0_N 1)$. Then the program will start to construct level 2. The basis will close off when we have three l.i. basis strings, which are also l.i. of the level 1 strings, and their discriminate closure in a total of seven strings. The simplest representation of this situation is to use level two label strings with the structure $(00)(b_3 b_4 b_5)$ with basis strings $(00)(100), (00)(010), (00)(001)$. The mapping matrix construction can give the equivalent set $(1100), (1110), (1101)$. Since we have previously worked out a lot of the details using this basis, we will stick to it here. After the labels close off, we can again encounter the situation in which, for a while, the only address strings will be 1_N and 0_N, so we continue our discussion in terms of the structure for the first level

$$level\ 1:\ ({}^i b_1\ {}^i b_2)(000)(1_N\ or 0_N)$$

where $i \in 1,2,3,4$ and, to be specific, $1:(10),\ 2:(01),\ 3:(11),\ 4:(00)$. Note that $1 = \bar{2}$ and $3 = \bar{4}$. The corresponding structure for the second level is

$$level\ 2:\ (00)({}^j b_3\ {}^j b_4\ {}^j b_5\ {}^j b_6)(1_N\ or\ 0_N);\ b_3 = b_4$$

where $j \in 1,2,3,4,5,6,7,8$ and, again to be specific, $1:(1110),\ 2:(0001),\ 3:$

(1101), 4 : (0010), 5 : (1100), 6 : (0011), 7 : (1111), 8 : (0000). Again note that $1 = \bar{2}$, $3 = \bar{4}$, $5 = \bar{6}$, $7 = \bar{8}$.

Within level 2, we now define helicity by $2h_j =^j b_3 + {}^j b_4 - {}^j b_5 - {}^j b_6$ and find that $h_1 = h_3 = +1/2$; $h_2 = h_4 = -1/2$; $h_5 = +1$; $h_6 = -1$; $h_7 = h_8 = 0$. We now have enough structure to define a second quantum number within this level, $\ell_j =^j b_3 - {}^j b_4 + {}^j b_5 - {}^j b_6$ with the consequence that $\ell_1 = +1$, $\ell_2 = -1$, $\ell_3 = -1$, $\ell_4 = +1$, $\ell_5 = \ell_6 = \ell_7 = \ell_8 = 0$. By appropriate invocation of the Feynman rules, we again can show that these quantum numbers are conserved in events, that the elementary scattering diagrams have crossing symmetry, and that the CPT theorem is satisfied, now in the 3+1 energy-momentum space, which we now have enough structure to construct. Clearly ℓ can now be identified as lepton number. Thus, with both level 1 and level 2 before us, we claim to have, still massless, *chiral* (two component) neutrinos, *achiral* (four component) leptons and massless vector and scalar quanta with zero lepton number. We do not explore here the coupling between level 1 and level 2, since by our constructive algorithm for the hierarchy this necessarily involves level 3 labels. We note that, in contrast with the conventional theory, and in agreement with the topological bootstrap theory, our basic neutrinos and scalar and vector quanta are massless. When we go on to the next two levels, we will see how the *achiral* leptons acquire mass.

Once again, once we encounter an address string of the form 1_N0 or 0_N1, PROGRAM UNIVERSE requires us to start constructing level 3. In analogy with our previous step, we now use for the third level structure

$$level\ 3 : (00)(0000)({}^k b_7\ {}^k b_8\ {}^k b_9\ {}^k b_{10}\ {}^k b_{11}\ {}^k b_{12}\ {}^k b_{13}\ {}^k b_{14})(1_N\ or 0_N)$$

with $k \in [1, 2, 3, ..., 128]$. We also add 0_8 at the end of the level 1 and level 2 labels, before starting the new address labels. For the moment we will restrict ourselves to the situation in which $b_{11} = b_{12} = b_{13} = b_{14} = 0$, and consider only the 16 strings generated from some l.i. choice of four basis vectors of length 4. Consider first the strings (1110), (0001), (1101), (0010) we encountered before, and the four new ones now available (1011), (0100), (0111), (1000). We define the quantum numbers $2h_k =^k b_7 +^k b_8 -^k b_9 -^k b_{10}$, $B =^k b_7 -^k b_8 +^k b_9 -^k b_{10}$and $2i_z =^k b_7 -^k b_8 -^k b_9 +^k b_{10}$. Using the usual Gell-Mann Nishijima relation $Q = i_z + B/2$, we have precisely the quantum numbers for protons and antiprotons with baryon number and charge $B = \pm 1 = Q$ and neutrons and anti-neutrons with $B = \pm 1$, $Q = 0$; the two helicity states $\pm 1/2$ also occur in the correct way. As before, all the usual rules of S-matrix theory work out.

What about $b_{11} - b_{14}$? Since we already have four l.i. basis vectors, only 3 of these are allowed to be l.i to complete the basis for level 3. We take the basis to be the familiar (1100), (1110), (1101), but now with the interpretation given in Table I.

Although for brevity in the caption we have called this the "SU3 octet", speaking with more precision what we have is just the discrete quantum numbers which are conventionally discussed in terms of that octet. From our point of view, all we have is a transparent rule for defining eight sets of quantum numbers for eight bit strings we have derived from the combinatorial hierarchy. We believe that it is a conceptual advantage in our approach that discrete quantum numbers are just that, and need never be referred to "continuous groups". All we encounter in high energy experimental physics are discrete quantum numbers and their connections. These are all we need to, or intend to, construct.

Table I

The SU3 octet for "I,U,V spin"

	$(b_{11}b_{12}b_{13}b_{14})$	$2I_z$	$2U_z$	$2V_z = 2(I_z + U_z)$
STRING:	1110	+1	+1	+2
	0010	-1	+2	+1
	1100	+2	-1	+1
	1111	0	0	0
	0000	0	0	0
	0011	-2	+1	-1
	1101	+1	-2	-1
	0001	-1	-1	-2

$$2I_z = b_{11} + b_{12} - b_{13} - b_{14};$$

$$2U_z = -2b_{11} + b_{12} + 2b_{13} - b_{14};$$

$$2V_z = -b_{11} + 2b_{12} + b_{13} - 2b_{14}$$

We now have a ready interpretation for level 3. We identify this octet with the "color octet" of QCD. We started our discussion of baryons by taking these four bits to be (0000). Since, as we can see from Table I, either this string or(1111) represent a "color singlet" our initial discussion of nucleons and anti-nucleons, with associated mesons generated by discrimination, remains valid. But with color added, these two-particle, two-antiparticle spin states can become"up" and "down" quarks and antiquarks. All that remains is to show that the only states we can form as particles correspond to (qqq) and $(q\bar{q})$, and that the quarks and associated gluons remain in the picture as "partons" along the lines of Chapter

2. This has not yet been accomplished as of this writing, but we are confident that we will have more to say along these lines at the Symposium.

To go on to level 4, we see that we have two basis vectors with the structure of $(B)_2 0_{12}$ at level 1, three with structure $0_2(B)_4 0_8$ at level 2 and seven with structure $0_8(B)_8$ at level 3. According to our constructive algorithm, we can immediately put together $2 \times 3 \times 7 = 42$ of these to form 42 of the basis vectors for level 4, without changing the massless address strings 0_N and 1_N. But this does not complete the 127 basis strings needed for constructing the level. Hence, for the last time, we argue that PROGRAM UNIVERSE will eventually produce an address string with the structure $0_N 1$ or $1_N 0$ and from then on will have to continue adding to the label string ensemble until at some label length $N_L + N_{139} \geq 139$ the basis is complete and the label length fixed from then till doomsday. If we are content to stick with the first three level labels as an approximation and interpret these added bits as addresses, we see that they correspond to systems with $|\beta| < 1$, and hence to massive particles. In this way our hardons are shown to have to be massive but the first generation leptons and electromagnetic quanta remain exactly massless. We will discuss below how the electrons and positrons acquire mass. Further discriminations will eventually produce all $2^{127} + 136$ non-null labels at this label length, while the addresses continue to grow both in bit length and in number as long as the program continues.

Clearly the eventual structure, with this number of distinct quantum number states, is immensely complicated in detail, but we can already make some useful comments about some of the connections which will have to emerge. One is that there are three simple structures of the form $(B)_{14}0_{28}$, $0_{14}(B)_{14}0_{14}$, $0_{28}(B)_{14}$ where (B) are the 42 basis vectors already discussed. This gives $3 \times 42 = 126$ of the 127 basis vectors needed to close the hierarchy. Yet each of them will also close on itself, so we anticipate that the coupling between these three structures will be weak. The first one looks like it still has a massless address label, but if we use instead simply three identical repetitions, i.e. $(B)_{14}(B)_{14}(B)_{14}$, the properties will be the same, and we trust can be discussed ignoring, in first approximation, the anticipated weak coupling to the rest of the scheme. If we now consider only the label 1_{14} or its equivalent 0_{14} which couples "softly" to all of the first three levels, this will occur with probability $1/137$ and we can now, with confidence, accept this as our first approximate evaluation of the strength of the coulomb interaction. With this in hand, we can then expect that the structures we first encounter in particle experiments at low energy will be the familiar $\nu_e, \bar{\nu}_e; e^{\pm}, \gamma; p, \bar{p}, n, \bar{n}$ with the weak vector bosons, up and down quarks, and gluons coming along in due course. At least we have the right quantum numbers for the first generation of the standard model, and believe we have made it look worth while to see if the couplings can be worked out and compared with experiment. Further, the structure we discussed above suggests that the next two generations will also be there. Finally, when we ask about the 127^{th} basis vector, 1_{42} with the associated 0_{42} which occurs with probability $1/(2^{127} + 136)$ and couples to everything, we can also with confidence assume that this is the "soft" Newtonian gravitational interaction with this number as a first approximation to the coupling constant $Gm_p^2/\hbar c$, and choose our final dimensional constant to be either m_p or G according to our taste.

From here on in we have to calculate everything, so it is time to indicate how we propose to do that.

5. SCATTERING AND MEASUREMENT

In our construction of a particle $(abcd)$ with referent d and partons a, b, c we ignored one critical fact about the kinematics, namely that we cannot satisfy *all* the constraints by treating the "edges" of the tetrahedron using the *classical* kinematics for free particles. The clue as to how to proceed was given us long ago by Wick[25] in his discussion of how the energy principle is respected *externally* when a system is discussed at short distance in the light of the uncertainty principle and the limiting velocity of special relativity. He concluded that at short enough distances and times the energy can have arbitrarily large values. In particular, since he was discussing Yukawa's meson theory[26], he assumed that if two nucleons are coupled to what we are calling a "parton" of mass m_π responsible for nuclear forces, the range of the nuclear force is limited by $r < \hbar/m_\pi c$. Further, if the rest energy $m_\pi c^2$ is supplied by a sufficiently energetic *measurement*, this nuclear force quantum can appear as a free particle in the final state. We conclude that the missing parameter in the treatment of Chapter 2 is the *virtual* energy E_d between the first and the last event, which can have any value, fixed for the particular example under discussion. Once this is grasped, our kinematics becomes consistent.

The critical step here is to recognize that the probability with which discrete quantum numbers move along any edge of our tetrahedron (or any internal "line" in a scattering process with external energy E_d) occurs is proportional to $1/(E'_d - E_d - i0^+)$, where the $i0^+$ is there to remind us that to calculate any observable quantity we must sum over all kinematically allowed values for E'_d and take the limit $E'_d \to E_d$. Given this, and the quantum number restrictions in events we have already derived, it is possible to derive the integral equations (sums for the discrete theory) of momentum space scattering theory. The critical ingredients remaining are manifest covariance, proper attention to the degrees of freedom implied by the finite number of degrees of freedom set by the number of particles considered (in technical terms "unitarity", and "clustering" - i.e the proper asymptotic separation of clusters of subsystems into a consistent simpler description. This theory exists[27] and will be assumed in what follows.

In the non-relativistic limit, the scattering equations for the scattering of two finite mass particles due to the exchange of a quantum of finite mass m_π are the same as that due to a potential energy proportional to $e^{-m_\pi r}/r$. Since we have already showed that the coupling constant for "soft" (coulomb) zero mass quanta $e^2/\hbar c$ is given in first approximation by $1/137$ we have available to us the whole momentum space formalism of atomic and nuclear physics, and in particular the coulomb potential e^2/r. Corrections due to spin will be of order $1/137$ and can be computed in a straightforward way from the scattering theory. Since, experimentally, QED is good down to $10^{-16} cm$, we claim we are justified in using this potential energy as an internal virtual energy in our calculations.

What is still missing in our fundamental theory are the mass ratios of the particles relative to our standard m_p. Since we have electrons in the theory which are initially massless we assume, following Parker-Rhodes[12], that this mass comes from the internal energy due to the coulomb interaction, i.e. that $m_e c^2 = < e^2/r >$. Since this calculation has been published several times[10,12,13,15,16], we are brief here. The minimal meaningful distance in a zero velocity system with spherical symmetry is the Compton radius $h/2m_p c$; r must start from this value, and scales a random variable y greater than or equal to one. Similarly, since charge is conserved, $< e^2 >= (hc/[2\pi \times 137]) < x(1-x) >$, where in both cases we have replaced discrete by continuous variables; in the case of charge x should properly be an average over the charges in the $2^{127}+136$ available quantum number labels. Hence $m_p/m_e = 137\pi / < x(1-x) >< 1/y >$. Since we have now established our space as necessarily three-dimensional, the discrete steps in y must each be weighted by $(1/y)$ with three degrees of freedom. Hence $< 1/y >=$ $[\int_1^\infty (1/y)^4 dy/y^2]/[\int_1^\infty (1/y)^3 dy/y^2] = 4/5$. Since the charge must both separate and come together with a probability proportional to $x(1-x)$ at each vertex, the other weighting factor we require is $x^2(1-x)^2$. For one degree of freedom this would give $< x(1-x) >= [\int_0^1 x^3(1-x)^3 dx]/[\int_0^1 x^2(1-x)^2 dx] = 3/14$. Once the charge has separated into two lumps each with charge squared proportional to x^2 or $(1-x)^2$ respectively, we can then write a recursion relation[10,12,13,15,16] $K_n = [\int_0^1 [x^3(1-x)^3 + K_{n-1}x^2(1-x)^4] dx]/[\int_0^1 x^2(1-x)^2 dx]$ and hence $K_n = 3/14 + (2/7)K_{n-1} = (3/14)\Sigma_{i=0}^{n-1}(2/7)^i$ Therefore, invoking again the three degrees of freedom, we must take $< x(1-x) >= K_3$ and we obtain the Parker-Rhodes result $m_p/m_e = 137\pi/[(3/14)[1+(2/7)+(2/7)^2](4/5)] = 1836.151497...$in comparison with the experimental value of 1836.1515 ± 0.0005

The success of this calculation encourages to believe that the seven basis vectors of level 3 will lead to a first approximation for $m_\pi/m_e \approx 7$ with corrections of order $1/7$, but this has yet to be done. In any case, we now have enough structure to go on to our discussion of the wave-particle dualism and the problem of measurement.

The laboratory paradigm we start with is two "counters" with volumes $\Delta x \Delta y \Delta z$ whose geometrical dimensions are measured by standard macroscopic techniques and a time resolution Δt measured by standard clocks. When two counters separated by a macroscopic space and time interval larger than the volumes and time resolutions of the counters have fired, some random walk connecting those two volumes has occured. The connection to the bit string universe is the understanding that what we have called an *event*, and connected constructively to relativistic quantum scattering theory, initiates the chain of happenings that end in the firing of a counter or equivalent natural "event", eg the ionization of a hydrogen atom (which we now know how to describe in terms of our scattering theory). But we do not know within those macroscopic counter volumes where this random walk started and ended.

To meet this problem, we construct an ensemble of "objects" (i.e labeled ensembles with a specified rational fraction β for the velocity parameter) all characterized by the same vector velocity $\vec{v}$ and the same label (or mass) chosen in such a way that, after k steps, each of length $\ell = (h/mc)[1 - (v/c)^2]^{1/2} = hc/E$, the peak of the random walk distribution will have moved a distance ℓ in the direction of $\vec{v}$. Our basic "quantization condition" is $E = hc/\ell$, which defines a second length by $p = h/\lambda$. We take as our unit of time the time to take one step, $\delta t = \ell/c$. Once "time" is understood in this digital sense, the velocity of the peak of each subensemble in this coherent ensemble has a velocity c/k. We call this *coherent* ensemble of ensembles a *free quantum particle* of mass m, velocity $\vec{v}$, and momentum $\vec{p} = m\vec{v}/[1 - (v/c)^2]^{1/2}$. There is a second "velocity" associated with this ensemble of ensembles, namely that with which "something" moves at each step always in the direction $\vec{v}$. We call this v_{ph}; clearly $v_{ph} = kc$, and $vv_{ph} = c^2$. Since this velocity exceeds the limiting velocity it cannot support any direct physical interpretation, and in particular any which would allow the supraluminal transmission of information; of course it can provide for the supraluminal correlations experimentally demonstrated in EPR experiments. Associated with each of the two velocities and the label (or mass) there are two characteristic lengths $\lambda_{ph} = \ell = hc/E; \lambda = k\ell = h/p$.

Now we consider two basis states for a spin 1/2 fermion which we write as $(10)\vec{p}$ and $(01)\vec{p}$ where $\vec{p}$ stands for an address ensemble triple. We have seen that such a "particle" can scatter from another and lead to a final state in a different direction. But there are only two possible states in the new direction. To preserve the (asymptotic) rotational invariance of our theory therefore requires that the new state be expressable as a *coherent* sum of the two states referring to the new direction. Then Lorentz invariance leads directly to the usual spin 1/2 formalism using two-component spinors and Wigner rotations. The operational consequences can be followed through and lead to the usual density matrix formulation with all the "interference" phenomena reduced to probability statements.

Since we have now established a digital version of quantum scattering theory and the wave particle dualism correctly tied to achieveable laboratory measurements, our results differ little in practice from standard quantum mechanics. But the conceptual foundation is quite different. We have managed to get rid of both the space-time continuum and continuous energy and momentum, without disturbing the successful contact between current experiments and the usual formalism *as used in practice*. Since we have, in a sense, "points" where events can occur due to discrete discriminations, but no "lines" connecting them, our particles can "pass through" each other, sometimes scattering and sometimes not; only the probabilities can be computed. The interference phenomena of the "wave theory" come about because we have internal "spin directions" which can be given external and macroscopic (statistical) significance directly from laboratory counting experiments. The overall coherence of the theory is provided by the "ticking" universe.

Although the strings themselves are *indistinguishables* and the "ticks" are unobservable, this overall non-local background provides the necessary distant correlations needed to reproduce the experimental results of the double slit experiment, the EPR experiments and, so far as we can see any other current observations. In contrast approaches based on the von Neumann "projection operator" and consequent "collapse of the wave function" make such experiments appear paradoxical, and in some sense to require a "conscious observer" for their interpretation. For us, all of this controversy over the foundations of quantum mechanics can disappear into the mists of history. The critical connection between the micro and the macro worlds provided by the "soft photons" and their summation comes to us through the familiar finite equations of quantum scattering theory, and does not require us to make a detour into the mysteries and paradoxes of the quantum theory of continuous fields. We claim that we can have our cake in the sense of successful contact with experiment, and eat it too in the sense that we have an underlying digital algorithm which can be directly grounded in constructive mathematics and which never need invoke *completed* infinities. Thus we claim to have arrived at an *objective* quantum mechanics with all the needed properties.

6. CONCLUSIONS

The objective of this paper has been to provide discrete, constructive foundations for quantum theory in terms of which the "measurement problem" takes on a simpler conceptual form, closely related to the counter technology and interpretive practice used in high energy physics. We start from the symbols 0,1, binary addition, *sequence* represented by the integers, and a random operator R which gives us either 0 or 1 with equal prior probability. From these we construct the discrimination operation for ordered bit strings and the strings themselves employing PROGRAM UNIVERSE. We show that when this program is fully evaluated it provides an algorithmic definition of *events* sequentially ordered by the integers but accessible for purposes of interpretation only by statistical arguments. We use the *combinatorial hierarchy* to organize the information content of the early stages of the construction into four *levels* characterized by the cumulative cardinals 3,10,137 and $2^{127}+136$. When the information carrying capacity of this construction is exhausted, we use these elements as *labels* to organize the growing universe of strings into *labeled ensembles* of *addresses*.

By considering four sequential events specified by four integers involving four distinct labels $(abcd)$ we construct a tetrahedron which, by taking any one of the labels as a referent, describes a particle with three internal partons. Picking four masses (later to be computed) corresponding to the labels and defining mass by relativistic energy-momentum conservation at the four events, we show that we can replace the (unknowable) bits in the strings by physically interpretable parameters. This allows us to construct a discrete version of 3+1 momentum space in which the referent has the mass, energy and momentum of a free particle and the partons and particle have some unknown internal energy E'. In terms of this mass and energy the partons satisfy the usual conservation laws, including *quantized* orbital angular momentum.

By examining the construction in detail we show that the first three levels contain the quantum number structure of familiar particles, but only acquire mass when the construction is completed at level 4 of the combinatorial hierarchy. The quantum numbers are suggestive of the standard model of quarks and leptons with three generations, but the details are yet to be worked out. Identifying the "propagator" for quantum numbers "moving" along the "edges" of the tetrahedron with the $1/(E' - E - i0+)$ of quantum scattering theory, the finite particle number quantum scattering theory follows in a straightforward way. Since the construction necessarily contains "soft" massless quanta, the scattering theory allows us to sum these and identify the coulomb potential energy e^2/r with $\hbar c/e^2 = 137 + O(1/137)$. This allows us to relate our theory to macroscopic counter experiments. Using a random walk paradigm, this boundary condition allows us to identify the internal periodicities of relativistic deBroglie "waves". Our identification of "spin" ties the internal and external degrees of freedom together, explaining "wave-particle dualism" and "quantum wave interference" in agreement with current experiments.

The construction requires the dimensional physical parameters $c, \hbar$ and m_p or G for interpretation, but once these are fixed, everything else must be computed. Taking the mass unit as m_p gives a prediction for G good to order 1/137. The hadrons are massive, but the leptons and electromagnetic quanta remain massless; Electrons and positrons acquire mass through their electromagnetic interactions, but electron-type neutrinos and anti-neutrinos remain massless. Identifying the internal coulomb energy of the electron (or positron) composed of the partons given by our construction, we calculate its mass ratio to the proton mass standard in agreement with experiment.

Independent of these details, the conceptual framework we have established dissolves for us the "paradoxes" of measurement theory and leads to an *objective* quantum mechanics, as is argued at the end of the preceding chapter. We therefore claim to have met the problem of understanding why quantum theory predicts that causal effects cannot be transmitted faster that the limiting velocity, yet requires that quantum events change the probabilities of subsequent events in space-like separated regions. Thus the universe we have constructed has a fixed past, but a future which we can only predict in terms of probabilities.

REFERENCES

1. H.P.Stapp, *Phys. Rev.* D 28, 1356 (1983)
2. –, "Time and Quantum Process", presented at Conference *Physics and the Ultimate Significance of Time*, March 16, 1983, Center for Process Studies, Claremont, CA 91711, and LBL-17576 preprint.
3. –, "Bell's Theorem and the Foundations of Quantum Mechanics", *Amer. J. Phys.* (in press) and LBL-16482 preprint.
4. G.F.Chew, *Found. of Phys.* 13, 273 (1983)
5. G.F.Chew, "Gentle Quantum Events as the Source of Explicate Order", LBL-5811 preprint.
6. G.F.Chew, talk at the First Annual Regional Meeting of the Alternative Natural Philosophy Association, Stanford, Nov. 23-25, 1984, available from HPN.
7. E.W.Bastin and C.W.Kilmister, *Proc. Roy. Soc.*, A 212, 559 (1952).
8. –*Proc. Camb. Phil. Soc.*, 50, 254, 278 (1954), 51, 454 (1955); 53, 462 (1957); 55, 66 (1959).
9. T.Bastin, *Studia Philosophica Gandensia*, 4, 77 (1966).
10. T.Bastin, H.P.Noyes, J.Amson and C.W.Kilmister, *Int'l J Theor. Phys.*, 18, 455-488 (1979).
11. I.Stein, Seminar at Stanford, 1978, and papers at the 2nd and 3rd annual meetings of the Alternative Natural Philosophy Association, Cambridge 1980, 1981.
12. A.F.Parker-Rhodes, *The Theory of Indistinguishables*, Synthese Library, *150*, Reidel, Dordrecht, 1981.

13. H.P.Noyes, in *The Wave-Particle Dualism* S.Diner, et al., (eds), Reidel, Dordrecht, 1984, pp. 537-556.

14. M.J.Manthey and B.M.E.Moret, Communications of the ACM, 26, 137-145, 1983.

15. H.P.Noyes, C.Gefwert and M.J.Manthey, in *Proc. 7th Int'l Cong. on Logic, Methodology and Philosophy of Science*. Salzburg, 1983 (in press) for a much more detailed version see – "Toward a Constructive Physics", SLAC-PUB-3116 (rev. September 1983).

16. H.P.Noyes, M.J.Manthey and C.Gefwert "Constructing a Bit String Universe: a Progress Report", *Proc. of the Oxford Quantum Gravity Discussion Conference* (in press) and SLAC-PUB-3290.

17. J.V.Lindesay, Ph.D Thesis, Stanford, 1981, available as SLAC Report No. 243.

18. H.P.Noyes, *Phys. Rev.* C 26, 1858 (1982).

19. H.P.Noyes and J.V.Lindesay, *Australian J. Phys.*, 36, 601 (1983).

20. H.P.Noyes and G.Pastrana, *Proc. Few Body X*, Karlsruhe, 1983.

21. J.V.Lindesay and A.Markevich, *Proc. Few Body X*, Karlsruhe, 1983.

22. S.Weinberg, *Gravitation and Cosmology*, Wiley, New York, 1972, pp. 285-289.

23. C.Gefwert, *A Participator: the Metaphysical Subject*, SLAC-PUB-3277 (December, 1983) and *The Proposition-as-Rules Idea*, SLAC-PUB-3303, (March 1984), to be submitted to *Synthese; On The Logical Form of Primitive Recursive Functions*, SLAC-PU B-3334 (May 1984) and *On The Logical Form of Mathematical Language*, SLAC-PUB-3344 (May 1984), to be submitted

to the *Journal of Philosophical Logic*.

24. For *Program Universe 1* see Ref. 15 ; *Program Universe 2* has also been coded by M.J.Manthey in *Pascal* with concurrency, an effort which made this paper possible.

25. G.C.Wick, *Nature*, **142**, 993 (1938).

26. H.Yukawa, *Proc. Phys. Math. Soc. Japan*, **17**, 48 (1934).

27. J.V.Lindesay, H.P.Noyes, A.Markevich and G.Pastrana (in preparation).