What is Space?
This is an old debate, going back to the ancient philosophers.
Is Space:

A passive container, in which particles move?

An independent medium, with a life of its own?

The primary ingredient of reality, of which particles are a secondary manifestation?
Lucretius held the first view (space as container):

All nature, then, as self-sustained, consists

Of twain of things: of bodies and of void

In which they’re set, and where they’re moved around.
Aristotle held the second view (space as an independent entity):

“Nature abhors a vacuum.”

Theory of natural places.

Dualism: Both Space and, separately, Matter.
Today, the third view is triumphant.

Is space

A passive receptacle, in which particles move? No.

An independent medium, with a life of its own? Yes, but this is a half-truth.

The primary reality, of which particles are a secondary manifestation? Yes!
In today’s physics, the primary building-block of physical reality:

fills space and time

has the same basic properties in each fragment

acts locally

This provides a new, modern notion of what Space is. I’ll call it the *Grid*. 
Why “Grid”? 

It’s a distributed source of power, like the electric and computer grids.

“Grid” is short.

“Grid” is not “Ether”.

“Grid” is not “Matrix”.

Sunday, February 14, 2010
What are the Grid’s properties?

• The Grid is alive with *quantum* activity, that is:
  
  spontaneous
  
  unpredictable
  
  “viral”
  
• It has material parts (“condensates”).

• It comes equipped with rulers and clocks.

• It weighs and pulls.
Some History
Descartes and others proposed the “mechanical worldview”: Shape and size are the only primary properties, (and so) all forces are due to contact. To explain gravitational forces, Descartes postulated an invisible ocean, that pushes the planets around.
Newton subscribed to this worldview, philosophically. He wanted space to be full:
Newton:

That one body may act upon another at a distance through a vacuum without the mediation of anything else, by and through which their action and force may be conveyed from one another, is to me so great an absurdity that, I believe, no man who has in philosophic matters a competent faculty of thinking could ever fall into it.
But Newton’s mathematical theories, especially his law for gravitational forces, didn’t work that way. "Newtonians" realized that space had been emptied:
Voltaire: A Frenchman who arrives in London will find philosophy, like everything else, very much changed there. He had left the world a plenum, and he now finds it a vacuum.
Newton’s mathematical physics, based on empty space and action at a distance, was so successful that it dominated science for two centuries.
A big change started in mid-nineteenth century. James Clerk Maxwell, building on work of Michael Faraday, proposed laws for space-filling electric and magnetic fields, that gave them a life of their own.

Light was understood to be a self-reinforcing disturbance in these fields. New forms of “light” were predicted, and later observed.
Maxwell was delighted that space was full again:
Maxwell:

The vast interplanetary and interstellar regions will no longer be regarded as waste places in the universe, which the Creator has not seen fit to fill with the symbols of the manifold order of His kingdom. We shall find them to be already full of this wonderful medium; so full, that no human power can remove it from the smallest portion of Space, or produce the slightest flaw in its infinite continuity.
But Albert Einstein, in 1905, wanted to empty it out again:
Einstein, 1905:

The introduction of a “luminiferous ether” will prove to be superfluous inasmuch as the view here to be developed will not require an “absolutely stationary space” provided with special properties ...
Actually Einstein did not do away with the ether. His special relativity theory had its roots in Maxwell’s equations, and did not change them.

Rather, the essence of relativity is that the ether (or Grid) looks the same if you move through it at any constant velocity.
In 1920, after formulating general relativity, Einstein embraced a gravitational ether.
Einstein, 1920:

More careful reflection teaches us, however, that the special theory of relativity does not compel us to deny ether.
In 1982, I had a memorable discussion with Richard Feynman. He told me about his early ambition to make space empty:
Feynman, ~1950 (1982):

I was very disappointed when I realized that my formulation* was mathematically equivalent to the usual one. I thought it was absurd, in the usual formulation, that empty space didn't weigh anything. I had a slogan: “Empty space doesn't weigh anything, because there's nothing there.”

*Feynman’s formulation of quantum electrodynamics is based on the famous “Feynman graphs”, that record paths of particles. It appeared to make fields superfluous.
The Effervescent Grid
In quantum theory, fields become “self-starting”. They begin to have to have a rich *spontaneous* inner life.

This is dramatized, in quantum electrodynamics, by the phenomenon of vacuum polarization.
Feynman’s version of classical electromagnetism
Spontaneous activity in the electron-antielectron field
Modification of classical electromagnetism by vacuum polarization
Experimental measurements require such effects. That is what convinced Feynman that he needed fields after all (and he had them).
In QCD, the influence of spontaneous activity in the Grid (= “empty” space) is much more prominent than in QED.

It leads to dramatic new phenomena:

confinement of quarks and gluons

distant-dependent, or “running”, strength of interaction (asymptotic freedom)
What does it look like?

Here’s what eyes with better resolution than ours would see:
Matter is not what it used to be. It consists of small, more-or-less stable patterns of disturbance in the Grid.

Here, for example, is our modern proton:
We’ve come a long way from the sort of “hard, massy, impenetrable” building-blocks that the atomists envisaged, and that Newton adopted (sometimes).
The Material Grid
We are like fish who have suddenly realized that they live in water.
Besides the fluctuating fields, there are stable condensations - literally, materials - that fill space.

Q-Q

electroweak superconductor ("Higgs")

strong-weak superconductor
Quark-antiquark pairs have negative energy.

So to reach the lowest possible energy, space fills up with such pairs, until their mutual repulsion makes it no longer profitable.

Pions are vibrations in this material!
W and Z bosons are heavy in Grid, in the same way that photons are heavy in ordinary superconductors.

The standard model of electroweak interactions is based on the idea that the Grid is a kind of exotic superconductor.

We don’t know what the cosmic superconductor we live in is made from.

Vibrations in the new superconducting material = Higgs particles.
In unified field theories of the different interactions, we postulate an additional layer of Grid superconductivity.

Strong-weak superconductivity shorts out interactions that our nice symmetric equations need, but which we “observe” to be very feeble.

Symmetry still works at short distances, or high energies. Then different forces come together, and unify.
These concepts have both explanatory and predictive power:

Patterns of symmetry and multiplets in the standard model; relative strength of basic interactions, including gravity; very small but non-zero neutrino masses.

To achieve quantitative success in unification, we need low-energy (LHC-accessible) supersymmetry.
Unification ❤ SUSY

Gravity fits too! (roughly)

large energy, short distance →

↑ inverse coupling strength
Grid’s Rulers and Clocks

metric field
In general relativity, space-time comes equipped with its own rulers and clocks. This is the metric field $g_{\mu \nu}(x)$.

The phenomena of gravity arise from disturbances in this field.

Usually the metric field is taken to be fundamental, but in many ways it resembles a condensate, and that view of it may become important.
Grid Weighs
Recently astronomers have discovered that approximately 70% of the density of the Universe is Grid density.

\[ \rho_{\text{Grid}} \] is accurately constant in space: no clumping.

\[ \rho_{\text{Grid}} \] also stays constant as the universe expands!
With all the structure we’ve discovered in space, we should expect it to weigh something (as Feynman anticipated).

So is the discovery of Grid density a triumph for theoretical physics? Yes and no.
More honestly:

Is this a triumph for theoretical physics? Yes and NO.
The trouble is that simple estimates of various contributions to the density are much too big:

quark-antiquark condensation: \(10^{44}\)

electroweak superconductivity: \(10^{56}\)

strongweak superconductivity: \(10^{112}\)

energy of spontaneous quantum activity (Feynman’s worry):
  
  without SUSY: \(\infty\)

  with SUSY: \(10^{60}\)

metric condensation: ?
This is embarrassing.
Summary and Conclusions
The primary ingredient of physical reality:

- fills space and time
- has the same basic properties in each fragment
- acts locally
- is alive with *quantum* activity that is:
  - spontaneous
  - unpredictable
  - “viral”
• contains material components (condensates)

• contains rulers and clocks (metric field)

• weighs and pulls
What we ordinarily call matter consists of more-or-less stable patterns of excitation in the Grid, which is more fundamental.

At least, that’s how things look today.
On the other hand, inflationary cosmology relies on a very large $\rho$ in the early universe, so maybe that’s encouraging.
If Grid weighs, its density and pressure should obey $\rho = -p/c^2$.

This “well-tempered equation” characterizes a boost-invariant density, that looks the same to moving observers.
In the context of cosmology, negative pressure causes the expansion of the universe to accelerate.

Recently astronomers have discovered that approximately 70% of the density of the Universe is Grid density.

Remarkably, the density $\rho$ stays constant (as does $p$) even as the universe expands!
ether | ˈēθər | noun
3 (also aether) archaic Physics a very rarefied and highly elastic substance formerly believed to permeate all space, including the interstices between the particles of matter, and to be the medium whose vibrations constituted light and other electromagnetic radiation.
Why “Grid”?

Layers of structure:
dark energy
condensates
metric field
quantum fields

“empty” space
The Grid

(Persistence of Ether)
In 1909, he explicitly connected that idea to his photon hypothesis:
Einstein, 1909: Anyway, this conception seems to me the most natural: that the manifestation of light's electromagnetic waves is constrained at singularity points, like the manifestation of electrostatic fields in the theory of the electron. It can't be ruled out that, in such a theory, the entire energy of the electromagnetic field could be viewed as localized at these singularities, just like the old theory of action-at-a-distance. I imagine to myself, each such singular point surrounded by a field that has essentially the same character of a plane wave, and whose amplitude decreases with the distance between the singular points. If many such singularities are separated by a distance small with respect to the dimensions of the field of one singular point, their fields will be superimposed, and will form in their totality an oscillating field that is only slightly different from the oscillating field in our present electromagnetic theory of light.
Special Relativity and the Grid
In 1905, there were two theories of relativity:

The Galilean relativity of particle mechanics.

The Lorentz/Poincare relativity of electromagnetic field theory.

Einstein assumed the primacy of electromagnetic relativity, and modified mechanics. It’s ironic that this is often said to have eliminated ether.
Indeed, special relativity makes a field description of reality almost inevitable.

For when there is a limiting velocity, fields are (at least) very convenient:
Keep track of these ...
Keep track of these ...

... or all these!
Keep track of these ...

To get simple equations, we need the fields everywhere (at each time).
The fields fill space.

They have a life of their own (e.g. free Maxwell equations $\Rightarrow$ electromagnetic waves).

In these powerful senses, they are ethers.

Of course, they are not "mechanical" (Galilean invariant) ethers. They look the same after boosts.
Space-filling grids are *convenient*, but are the necessary ingredients in reality-construction?

(Recall: Both Einstein and Feynman had reservations.)