Inspections in a Decohering Environment

“Around the Electronic Inspectors the decisive factor and most often overlooked: the Environment”

Introduction

The animation shows the fine-details of how a measurement happens. Specifically shown what happens to a macroscopic System (a cat), initially in a superposition of states, under the effect of the same Environment in standard conditions of temperature, pressure and humidity where also all Food and Beverage Controls operate. It is, visibly, a smooth continous process.

Displayed the reconstructed Wigner function of the System averaged over 4 ms, reconstructed with the data recorded in a 4 ms sliding time-window (credit CNRS, Laboratoire Kastler Brossel).

Two different phenomena are visible:
Electronic Inspection and Quantum Physics: a common ground

In the following, it'll become more clear how deeply and constantly these modern subjects intervene in the function of the Electronic Inspectors and their measurements (inspections).

Along past three decades Decoherence explained why:

- certain microscopic objects, commonly named "articles", seem to be localized in space:
  in the reality, particles do not exist and only there are waves (see figure on right side);
- microscopic systems are usually found in their energy eigenstates and therefore seem to
  jump between them, meaning that there are no quantum jumps;
- they appeared to exist two contradictory levels of description in physics (classical and
  quantum) when there is a single framework for all physical theories: the quantum theory;
- the Schrödinger equation of General Relativity (also named Wheeler-DeWitt equation)
  born in 1967 may describe the appearance of Time in spite of being Time-less. It has
  been understood that Time does not exist and what it really exists is an arrow of time
  in the form of a special initial condition.

Environment, the measurements’ “domain”

The Food and Beverage Bottling Line covers a finite spatial volume and the measurements last
for a finite interval of time, in our case commonly ranging: (0.1 - 20) ms. In general, it is defined
as the measurement’s “domain” the space-time region in which a process of measurement takes place. The Sun (see figures on right
side) is capable to repeatedly stop along tens of minutes an entire Beverage Bottling Line. How ?
In its most natural way, by mean of beams of light which are one of the two known causative relations (the second being gravitons)
between the measurements accomplished in our Factories here and now, and that object 149.5 millions of kilometer afar and ~8.5 minutes ago.

We’ll cite four different examples, all of them referred to our specific field of application, automatised Quality Controls in the Food and
Beverage Bottling Lines:

1. photons in the visible part of the spectrum, due to reflections into Inspectors’ mirrors are later amplified, forcing massive false
   rejects (> 40 %) in Full Bottle and Empty Bottle Inspectors equipped with Vision cameras;
Below: the smallest and strictly causally connected Environment is a huge sphere, centered in the Factory, whose volume is \(1.4 \times 10^{25} \text{ km}^3\).

2. photons in the visible part of the spectrum, in feeding cap Colour tri-chromatic sensors and later amplified, emulate caps of wrong colour, forcing massive false rejects (> 10%) in Full Bottle Bottle Inspectors equipped with cap Colour inspection;
3. thermal photons act on beverage characteristic creating a diurnal cycle. A beverage whose fill level is being inspected with high frequency em radiation, appear apparently underfilled at ~3 PM than at ~5 AM. Net effect front of a single sensitivity setup: huge false rejects at ~3 PM;
4. thermal photons act on the PET bottles characteristics, creating a diurnal cycle. PET containers tension shall be minimised at ~3 PM and maximised at ~5 AM. A PET container whose sealing (leakage) is inspected by mean of a Squeezer Full Bottle Inspector, equipped with inspection for pressure, inductive seal and difference of fill level, shall appear defective at ~3 PM and correctly sealed at ~5 AM.

Classic interpretation

Reading from the classic Physics point of view the last two of the four cases above, we see a common cause (written in italics) for the "measurement anomaly":

3. the beverage at ~3 PM cannot be inspected for HF fill level like at ~5 AM, because the Environmental conditions are different;
4. the PET container at ~3 PM cannot be inspected for sealing like at ~5 AM, because the Environmental conditions are different;

Modern interpretation

Re-reading from the modern Physics point of view the last two of the four cases above, it is detected (and, tentatively eliminated) an ambiguity in the Classic Physics point of view, causing approximation:

3. the beverage at ~3 PM cannot be inspected for HF fill level like at ~5 AM, because the correlation between Environment and beverage is different;
4. the PET container at ~3 PM cannot be inspected for sealing like at ~5 AM, because the correlation between Environment and container (mechanical characteristics) is different.

Out of this sphere, there is the much wider heliosphere where the Sun act also, preventing the dangerous arrival on the Earth surface of the majority of atomic nuclei and electrons, flying at relativistic speed and of high energy photons, gamma and X-rays. These all mere byproducts of the multitude of astrophysics events interesting clouds and those gigantic fusion energy-based reactors collectively named stars. A small portion of them reach however the surface and our Machinery, implying one more reason for the fact that it is unavoidable to experience measurement fluctuations, also in presence of standard cables' shielding. These examples are not simply extending the radius of the spherical space-time region, the “domain” (or, Environment) in which our measurements take place, well out of the assumed perimeter of the Food and Beverage Factories. This, because what really performs the inspection function in the over 100000 Electronic Inspectors into Food and Beverage Bottling Factories, are atoms of Silicium into the billions of transistors, themselves part of Integrated Circuits processing signals mainly incoming by CMOS- and CCD-cameras. Several stages of amplification, filterings and comparisons of these amounts with parameters, are the essence of the inspection process. A process finalised to Binary Classification, typical task for
Quantum Computers processing qubits rather than bits and a long chain of nonclassic measurement stages.

Tunnel-effect illuminates the way toward a technological breakthrough

A practical example of the many logical and experimental threads which carried to this modern scenario, given by the non-classic quantum mechanical Tunnel-effect discovered in 1958 by Esaki. On right side an application, the Tunnel-effect diode and, below, its nonlinear characteristic current-voltage curve. The animation below shows the time-evolution of the wave function of the electrons in those atoms of Germanium building up this electronic component. Electrons making what Classic Laws of Physics considers impossible, passing through a barrier of potential. Heisenberg's Uncertainty Principle allowed and made sense of this expected behaviour yet decades before the experimental discovery. What has been discovered later that the Tunnelling effect is ...too fast. Thorough testing by several Laboratories, the first of them Günter Nimtz, at different frequencies and for different kinds of particles, allowed the determination of superluminal speed across the barrier.

Above: evolution of the electron wave function through a potential barrier. The animation renders what let the Tunnel-effect diode (figures on right side) be so fast with respect to the other components: the Heisenberg Uncertainty Principle. The central white colour vertical bar is the potential barrier Classic Physics considered impossible to breakthrough. If we assume the video showing a single electron in a single Universe, then frequent superluminal propagation of the wave function implies paradoxical situations, synthesized in violations of the basic postulate of Relativity: the existence of a maximum limit speed. Tunnel-effect diodes are simply 'too fast' to be existing in a unique instance. What seems to cross the barrier five times faster than light is with today a few residual doubts, only an effect of our
Above: Tunnel effect diodes sport extremely high speed of operation, \(~ 1\) THz (1 terahertz equals 1000 GHz). This results from the fact that Tunnel diode only uses majority carriers, e.g., holes in an N-type material and electrons in a P-type material. The minority carriers slow down the operation of a device and, as a result, their speed is slower.

As an example, the graph below shows two microwave pulses at the same frequency of 8.2 GHz travelling through:

1. air (light violet)
2. a barrier (dark violet);

the latter traversed the same distance \(~ 1\) ns faster, a speed 4.7 \(c\), say nearly five times faster than light speed in vacuum (299 792 458 m/s). Superluminal if, and only if, the wave packet propagated is a unique instance existing in a single universe, say the classic point of view of the Special and General Relativity theories, dated 1905-1915. On the opposite, no violation at all of Relativity (no superluminal propagation) if what we are integrating into our measurement are a multitude of superimposed instances of the same object with multiversal existence in several mutually interfering branches.

On left side: Tunnel-effect hints to an interpretation of the events described by the Quantum Field Theory. In the example on left side, photons crossing air (1) or a barrier (2). When crossing the barrier they reach the opposite side \(~ 1\) ns before those which crossed the air, say 4.7 times faster than the maximum speed of light in vacuum postulated by Relativity.

Each one instance of the same object in a slightly different Environment what, after Decoherence discovery, is the modern meaning for World.

Wave packets which, because of the:
- Heisenberg’s Uncertainty Principle;
- linearity of the Quantum Mechanics wave functions which let the semiconductors switch and amplify;

are irreducibly superimposed multiversal objects, behaving dependently of what is happening elsewhere. Tunnel-effect can only be understood within the nonclassic point of view of Quantum Mechanics where, like a dam, the Uncertainty Principle separates Classic and Modern ideas we have about the physical world.

Several confirmations

The concept of propagation speed makes sense if Time exists as a fundamental, because the concept of Speed derivates by those of Space and Time. Then, the conundrum is Time. We saw elsewhere the General Relativity assumption about the time-ordered sequence of submanifolds (slices or, leaves, of the manifold \(\mathcal{M}\)) constituting a Foliation, whose details and properties we examined here. (Trigger-Physics/index.html) In this framework, what clocks measure is proper time \(\gamma\) along their own worldline \(\gamma\), maintaining coherence with the General Covariance Principle over which Relativity theory is based.

Above: the negative differential resistance of the Tunnel-effect diode, in a current-voltage graph. The nonlinear and nonclassic feature of the diode identified in the red coloured negative differential electric resistance, base of its impressive speed performances. The tunnelling effect is inherently very fast..., too fast when we consider that recent thorough testing has determined...
In 1967 the Wheeler-DeWitt equation was capable to join General Relativity and Quantum Mechanics:

\[ \dot{H}(x)\psi = 0 \]

and, what is truly relevant, without any reference to the Time. How? In brief, the \( \Psi \) term above is the superposition of all of the elemental wave functions related to all of the existing wave packets. More, from the point of view of that superposition, no time evolution exists at all. On the opposite, correlated sets of wave packets part of the superposition witness the initial condition effect historically named \textit{Time}.

In 1983 Don Page and W. Wootters showed how entangled particles could be used in a Quantum Physics test, to see that the time-ordered sequencing (of the relativistic spatial foliation \( M \)) is in the reality only felt by objects correlated with others because of Entanglement.

Entangled couples of particles:
- have notoriously one of their properties strictly related and are unrelated to the Environment, until a measurement is accomplished on one of them by a third party or the Environmental Decoherence prevails;
- also when widely separated in the 4-D ordinary space-time, they continue to share the same small Hilbert space;
- are explicitly cited by the Relative State formulation of Quantum Mechanics.

Objects related to the Environment feel the effects of Time: Thermodynamics being a relevant example. The experiment thinked by Page and Wootters involves Entangled photons. It had been first time executed along 2013 by a multinational team guided by Ekaterina Moreva. The figure below shows the Optoelectronics layout of the test, including beam splitters, lenses, filters, plates and LASER light commonly adopted into camera-equipped Electronic Inspectors.

It has allowed to form an entangled state of the polarization of two photons, one of which is used as a clock to gauge the evolution of the second:
- an “internal” Observer that becomes correlated with the clock photon sees the other system evolve;
- an “external” Observer that only observes global properties of the two photons can prove it is static.
independent experiments and theories, before and after his own. Some of them, of Bell-Aspect type about Entanglement, verified until 30 σ, thirty standard deviations!

"Time is an emergent property, deriving from quantum correlations and not a fundamental of Physics" (image abridged by Jochen Magnus, 2011)

The recently published results confirm the analysis given in 1983 by Page and Wootters: Time is an emergent property, deriving from quantum correlations (namely, Entanglement), and not a fundamental of Physics. Then, now that it is established on the dual theoretical and experimental base that Time is a derived concept of Physics, the superluminal speed of the experiments developed on Tunnel-effect, has to be moved from the paradox rank to that of unavoidable effect. We cannot calculate any speed, where no Time evolution exists.

Following the Quantum Theory of Measurement, each one time a “good measurement” happens, a correlation between two systems and respective wave functions, a new history branches itself out of the others. This process, introduced by Everett (1957), later adopted by many eminent physicists.
The term Multiverse has no relation with the known “Parallel Universes”, made popular by Science-Fiction. “Parallel” means not interacting or ambients causally disconnected, say no exchange at all of Signals and Energy. Multiverse is nearly the opposite: a superposition of all of the mutually interfering wave packets, corresponding to the wave functions of all objects. Renamed “Multiverse” to mark the conceptual difference.

A tree-like structure from our point of view. A multiply-connected object, as seen by Topology point of view. Several coexisting instances of each one object, each one part of a slightly different ($\delta = 1$ bit) Environment.

Between them, the nobelists:
- Richard Feynman,
- Stephen Weinberg,
- Alan Guth,
- Murray Gell-Mann,

and also some of the most brilliant minds of Physics like:
- David Deutsch,
- James Hartle,
- John A. Wheeler,
- Stephen Hawking,
- Leonard Susskind,
- Lev Vaidman,
- Avshalom Elitzur,
- Yakir Aharonov,
- Dieter Zeh.

The idea clearly explained in DeWitt (2004, pages 138-144). That’s why no violation of the light limit speed $c$ exists in the Tunnel-effect: the new Events are observed along a new branch, a new history, and no referral to prior measurements and results make sense to apply. Since two decades this is the mechanism conceived underlying correlations superior to $30 \sigma$ (thirty standard deviations) in the worldwide Bell-Aspect experiments studying Entanglement. Also, others explained decades ago on the base of Everett, 1957 (in eds. DeWitt, 1973) how this mechanism effectively prevents causal violations effects of an hypothetical topologic structure like the Einstein-Rosen bridge (also known as wormholes), whose existence is not forbidden by General Relativity, from creating paradoxical causal violations. Doing this, Quantum Mechanics is today backing General Relativity coherence, showing that these extremal scenarios of another theory are not in contradiction with its basic assumptions. Entanglement idea derives by what in 1935 Einstein, Podolski and Rosen figured what at first sight appeared as a flaw into Quantum Mechanics, one proving at least its incompleteness. It later resulted that the single-world classic point of view of General Relativity is an approximation. Each “good measurement” establishes a new additional thread along the sum of all of the yet existing histories. In this framework of correlated, non-interacting, systems it is explained (see Everett in eds. DeWitt, et al., 1973, pages 78-83) why and how they are implicit consequences of the Quantum Theory of Measurement, however incomprehensible they may appear as seen by the classic approximation.

The two figures below synthetise the situation:

- **left side**, the modern paradigm, where Time does not exist. Measurements as a natural process continously happening and each possible measurement’s result is actual: the starting point of a new branch of the general history;
- **right side**, the classic point of view today disproved by theory and experiments. An initial condition is perceived like Time by apparatuses and Observers into some of the branches, which are have no information about the content of the other branches of the history. Time, in the reality, a proved effect of the Entanglement condition of apparatuses and Observers.
Above: signature of John Von Neumann, who created much of the Quantum logic and terminology

Basic Quantum Terminology

**Coherent**, typically applied to a system, in modern Physics is a synonymous of *superimposed*. In this sense, superimposed (or, coherent) are the orthonormal eigenvectors constituting a base for the wave function $\Psi$, representing an object, however complex or massive may it be. Then, **decoherent** means reduced by a measurement to one definite value (*eigenvalue* of the *eigenstate*), the only one we perceive in the multitude of alternatives.

**Eigen** means "characteristic".

**Eigenstate** is the measured state of some object possessing quantifiable properties like position, momentum, energy etc. The state being measured and described have to be observable (e.g. like the common electromagnetic...
Thermodynamics there is a precise signification when saying that information is never lost by a closed system. Please refer to the two figures below, showing in two and three dimensions the time evolution of a defined volume in the phase space. The volume of the region $\Gamma(t)$ represents the information we have about a system at three successive times $t = 1, 2, 3$. Visibly, the information does not increase. Sturm-Liouville’s Theorem holds its full validity also in those mesoscopic and macroscopic space-time scales where the Optoelectronic devices in the Electronic Inspectors are sensible.

On left side: evolution of a defined volume $\Gamma(t)$ in the phase space. The region $\Gamma(t)$ represents the information we have about a system at three distinct and successive times $t = 1, 2, 3$. Visibly, the information we have does not increase. Liouville’s Theorem holds its full validity, included those mesoscopic and macroscopic space-time scales where the Optoelectronic devices in the Electronic Inspectors are sensible (abridged by image Susskind, 2005)

This is the origin of the third constrain appearing above, about the fact that Information cannot decrease in A but has to increase the Information we had about A before the measurement; on practice the origin of the Second Principle of Thermodynamics.

On left side: Time $t$ evolution of a region $x$. $y(t, x)$ is their Liouville function. The spreading of the Liouville function with time made evident by the fact that the graphic is not monometric: $1 \text{ cm}$ on the $y$ axe equals $4$ on the $x$ axe. Liouville function and its underlying concepts regarding the phase-space operates wherever: we’ll encounter it again as a useful tool to evaluate what rejects’ rates may be expected after changing an inspection’s sensitivity, given initial conditions.
In 2010 they started to be spot objects of the size of a visible hair (~ 0.1 mm) existing in two separate places, whose separation was measured with a scanning electron microscope. Along 2012 it has been first time experimentally detected one more counter intuitive result, yet envisaged by Quantum Mechanics: LASER photons spontaneously jumping back, rather than proceeding forward in a crystal lattice.

![Diagram](image)

Above: the setup used in 2001 by Zeilinger et al. which allowed to verify that also macromolecules entails fully their properties in the non-classic domain of Quantum Mechanics and respect the Heisenberg Uncertainty Principle. Fullerene C70, is an allotropic form of Carbonium 70 atoms (figure abridged by Zeilinger, et al., 2001)

Above: close up on the molecule of Fullerene C60, an allotropic form of Carbonium with 60 atoms. Visible the isosurfaces of ground state electron density. Discovered in 1990, was the first used after 1993 to test Decoherence in the mesoscopic scale of dimensions. The Van der Waals diameter of the molecule C60, accounting also for the thickness of the electronic clouds around nuclei, is 1 nm

And this, not in the atomic or subatomic realm where Quantum Mechanics was only supposed to act. Rather, on the same mesoscopic scale of the semiconductors' junctions part of the phototransistors of which are equipped nearly all of the photo-sensors used as Triggers by the most Beverage Bottling Controls. A new paradigm is arising, one whose powerful fruits are commercial applications as different as the Quantum Computers, simultaneously parallel processing in several other Universes, now used by companies like Google, Inc. or Lockheed-Martin Corp. and academic researches sponsored by the Society of Lloyd's yet in 2007. Why these private companies should be investing money in something, at first sight, seemingly theoretical? The answer is in some way related to the discovery of Decoherence.
Close-up on Decoherence

"Decoherence: process that classicalizes a quantum phenomenon, so that its former wavy character disappears"

Triggered Events lie in the space-time and energy boundaries separating the fields of application of Classic and Quantum Physics. We all agree that macroscopic objects are composed of collections of microscopic, like molecules and atoms. As a consequence, Triggered Events are finely rooted there, in the microscopic scale of distances. But, we all are convinced to see individual Events referred to individual Objects. The Objects to whom we are referring being always and only human-, space-, time- and energy-proportioned objects.

No one, in absence of instruments, is capable to discern:

- grains of dust whose diameter is < 0.01 mm;
- Events separated by a time interval < 0.001 s;
- radiant energy < 0.1 nJ;

because our eyes, and the neuronal system supporting their function, are not biologically developed for that. But, in the end, these limits does not matter that much. Since 1985 they are known the factors which let the multitudes of paths above described, fruit of Feynman’s own intuition, be reduced to the individual alternative we are experiencing. An introductory definition for this modern concept is the process that classicalizes a quantum phenomenon, so that its former wavy character disappears. Decoherence is the theory of universal Entanglement: it does not describe a distortion of the system by the Environment, but rather a change of state of the Environment by the system. The Environment includes a multitude of air molecules and photons, mainly at thermal frequencies. Imagine a macroscopic body as massive as a Bowling Ball like that in one of the figures below, on right side. In this case, scattering of photons or atoms off such a macroscopic object, even very small dust particles or macromolecules, causes no recoil. But, this inefficiency in the measurement results over compensated by the multitude of scattering Events, occurring in our daily life and industrial Environmental conditions, even along small time intervals, say:

- atmospheric pressure: ~1 bar;
- temperature: (-30 - 60) °C;
- relative humidity: (0 - 100) %.

Young’s experiment with and without air

The two figures below representing the Young double-slit experiment with and without molecules of gas (air), interposed along the paths of electrons.

Two completely different distributions of the hits counted on the following screen:

1. on left side, in a vacuum;
2. on right side, with the gas molecules of air.
Decoherence is what impedes us to see all objects in their superimposed reality. It is mainly due to the collisions between the molecules of air and the electronic clouds around each one atom. These collisions carry away the phase correlations between the histories where the electron arrived at several other points. The next two sections shall detail what is detected with and without interposed gas. It'll be accounted how Decoherence phenomenon, discovered in 1970, was hiding the direct sight of the true constantly happening behaviour of the matter and radiation, first detected only in 1989.

Above: Thomas Young's double-slit experiment, on left side in vacuum and on right side with air along the paths of electrons emitted by lamp filaments. Counting the hits on the screen, two completely different distributions arise, a difference due to Decoherence. Decoherence is mainly due to the collisions between molecules of gas and the electron, carrying away the phase correlations between the histories where the electron arrived at point y on the screen by passing through the L slit by those histories where the electron arrived at point y on the screen passing through the U slit.

1. Double-slit in a Vacuum

Many of the ideas about the concepts of measurement, space, matter and radiation into today's academic journals originate by ideas published or however circulating decades ago. There are reasons why this is happening. No theory can ignore the experimental evidences and these last are constantly improved. And, there are some special experiments, like Thomas Young's, first accomplished centuries ago and providing some strong clues about the everything reality, which had to wait centuries. The nobelist Richard Feynman decades ago imagined this when called it: "a phenomenon which is impossible ... to explain in any classical way, and which has in it the heart of quantum mechanics. In reality, it contains the only mystery of quantum mechanics". Feynman was writing about interference fringes appearing in the double-slit Young's arrangement when many simultaneously electrons were fired. *Many
There are only waves and, knowingly, waves are superpositions of other waves.

Field emission: electrons are emitted from a very sharp tungsten tip (thinner than 1/1000 mm) when a potential (3 – 5) kV is applied between the tip and a first anode ring; this effect is known as field emission.
These show how, hit after hit, what in the start looks like mere noise, develop in the end a wave like pattern. The bright spots begin to appear here and there at random positions: these are electrons’ constructive wave packets, detected one by one and looking like particles. These electrons were accelerated to 50,000 V, and therefore the speed is ~40 % of the speed of the light, i.e., it is ~120,000 km/second. These electrons can go around the earth three times in a second. They pass through a one-meter-long electron microscope in 1/100 000 000 of a second. The De Broglie wavelength for the accelerated electrons is \( \lambda = 0.0055 \text{ nm} \).

Interference fringes are produced only when two electrons pass through both sides of the electron biprism simultaneously. If there were two electrons in the microscope at the same time, such interference might happen. But this cannot occur, because there is no more than one electron in the microscope at one time, since only ten electrons are emitted per second. When a large number of electrons is accumulated, something like regular fringes begin to appear in the perpendicular direction shows. Clear interference fringes can be seen in the last scene of the experiment after 20 minutes. It should also be noted that the fringes are made up of bright spots, each of which records the detection of an electron. The final resulting pattern on the screen does not resembles at all any interferential, rather hints to a corpuscular character of the objects. Although electrons were sent one by one, interference fringes could be observed. Interference fringes are expected only when electron waves pass through on both sides of the electron biprism at the same time, but nothing other than this. Whenever electrons are observed, they are always detected as individual particles. When accumulated, however, interference fringes are formed. Please recall that at any one instant there was at most one electron in the microscope. We remark that these figures are what is detected on the screen after having been hit by material particles, like molecules, atoms, neutrons, or electrons. We are not speaking of objects since centuries considered wavelike, like the light
necessary explanatory power is the Relative State formulation of Quantum Mechanics, also named Many-Worlds Interpretation of Quantum Mechanics (images abridged by Amelino-Camelia, Kowalski, 2005)

The interpretational bifurcation reached in 1982 after Alain Aspect’s group experiment on Entanglement:

1. Bohm-De Broglie’s interpretation explains it but only after paying the unacceptable price to postulate that light (and, gravitational interaction) does not defines the limit speed for all causal correlations: it needs to introduce tachyions;
2. Copenhagen’s interpretation of Quantum Mechanics, has no explanation for what registered during this experiment;
3. Everett’s Relative State formulation, since the start included exactly what is observed;

reproposed itself in 1989, this time with many more accumulated experimental evidences. The aspect of interference fringes, visible above on right side, develops itself always and also for individual particles, …also if the molecules, atoms, neutrons, protons or electrons are fired after the precedently fired particle yet hit the screen.

Above: 61 years before it was observed, the Schroedinger equation of 1927 prefetched the result of the firing of an electron toward the slits. Wave packets are superpositions of discrete or infinite amounts of superimposed waves. The animation shows the entire process of diffraction of a wave packet in the multitude of its components, as seen by the double-slit zenithal point, perpendicular over the electrons’ path.

The experiment had been repeated with material bodies of progressively increasing size and mass: we are no more in the domain of particles, rather in the mesoscopic scale close to human direct unaided sight. Also mesoscopic macromolecules, including several hundredths of atoms appearing like a small grain of dust well visible by common microscopes were tested, without any change in the final result. There are only waves and, knowingly, waves are superpositions of other waves. More, or neutrons have now to be supposed having a brain, because it seems that they know what was the path choose by each one of the neutrons fired before.
Physics has since 1957 a unique theory with the explanatory power for the images on right side and, what is more important, it is not an ad-hoc one born to explain Tomomura experiment, because it was conceived 31 years before Tonomura's result. This interpretation ("The Many-World Interpretation of Quantum Mechanics") in brief explains that all of the objects are waves and that they all are superimposed and part of a last grand superposition. Thomas Young's experiment with matter had been extensively repeated on a worldwide base after 1989, reconfirming the veridicity of the interference fringes on side. Today they exists also cheap and valuable Optoelectronics plus software kits, to be connected to a computer thus allowing to whoever to witness and register single-electrons interferences in the two-slit configuration.

2. Double-slit with air

On the opposite, a decoherent set of histories is one for which the quantum mechanical interference between individual histories is small enough to guarantee an appropriate set of probability sum rules, what represented by the bell-shaped distribution observed above, on right side. It is the continuous measurement of an object by all other objects, in our industrial Environment mainly molecules of that mix of O, N, He, CO₂ we name air, under the permanent bath of light, the reason why we do not see simultaneous alternative Triggered Events. In other terms, the Environment induces a super selection, separating in two or more subspaces the (Hilbert) space where objects really exist. What above, around one century ago induced what was then the mainstream interpretation of Quantum Mechanics (Copenhagen's school) to establish a Wave-Particle Duality which further experiments, improved technologies and theories, showed a mere illusion.

Since decades it is clear that is Decoherence what lets us perceive in a unique status for what is superposition of states and that, all is:

- waves;
- branching superpositions of waves.
On left side: evolution of the coherent history of the wave function $\Psi$. In two branches $\Psi(1)$ and $\Psi(2)$, separately evolved in five branches $\Psi(1,1)$, $\Psi(1,2)$, $\Psi(2,1)$, $\Psi(2,2)$, evolving in further seventeen branches. Such scenario is cited today in the scientific literature very frequently. An amount of technological facts encounters there its only explanation (figure abridged by Zurek, Riedel, Zwolak, 2013)

**Decoherence speed**

Imagine a physical object as heavy as a Bowling Ball in an Environment in standard conditions of temperature, air pressure and humidity. It is a superposition of a multitude of possible correlations between its elementary components (quarks, gluons, leptons, etc.) and all of the others building up what we name Environment. Its even and odd components have equal classical components but opposite quantum interferences. The Laboratoire Kastler Brossel of the French CNRS processed such an object subtracting their Wigner functions, then isolating the interference feature displaying their quantumness. The result is the evolution of this signal over 50 ms, exhibiting a fast decay after only a few milliseconds due to Decoherence, of the original pure interference pattern which represented the physical object.

"Why do we only experience individual sharp superpositions, single bowling balls, rather than multitudes?"

*Because all others get damped out by decoherence, before we have the time to observe them*
How fast Decoherence happens is known since two decades. In the Table below, showing the Decoherence Rates (or, Localization Rates), expressed in units of $\text{m}^{-2}\text{s}^{-1}$, are represented three cases representative of objects of micro-, meso- and macroscopic scales:

- an electron, not binded to any atom;
- a dust particle, at the limit of unaided eyes visibility;
- a bowling ball.

How fast Decoherence happens is known since two decades. In the Table below, showing the Decoherence Rates (or, Localization Rates), expressed in units of $\text{m}^{-2}\text{s}^{-1}$, are represented three cases representative of objects of micro-, meso- and macroscopic scales:

On left side: magnesium fluoride multicoating anti reflective treatment, well visible by its pink colour in this camera, is a practical example of quantum interference. Here, destructive interference is used to increase the Signal-to-Noise relation of the Information contained in the image.

Below: bowling balls decohere in a time extremely short, explaining our sensation of their unique existence in a definite place.

We’ll be now more precise about how our operative ambient conditions [thermal background temperature $\sim 300$ K ($\sim 27$ $^\circ$C) in air at a pressure of 1 atmosphere], imply extremely high localization rates for an object of the size of a bowling ball, but fourteen orders of magnitude smaller for an object as small as an electron. The effect of air, or any other surrounding substance, and black-body radiation from the surrounding is strongly temperature dependent (typically $\propto T^5$), and can hence be reduced by nine orders of magnitude by working at liquid Helium temperatures or, in a smaller extent, taking profit of a Peltier-effect cell. Exactly the strategy followed when looking for maximum performances of Optoelectronics’ devices, first of all: the CCD-sensors. Comparing these results with conditions of minimised scattering, like the exposure of these objects to the cold ambient with the only cosmic background radiation, at a temperature of $\sim 3$ K ($\sim -273$ $^\circ$C), the macroscopic bowling ball decoheres in a time $10^{28}$ shorter than what we experience.

On left side: the classic or non-classic behaviour of the objects as an effect of Decoherence by the
These studies allowed to answer the main question arising after 1957:

"Why do we only experience individual sharp superpositions, single bowling balls, rather than multitudes?"

.....because all of the others get damped out by Decoherence, before we have the time to observe them.

Decoherence limits

Decoherence is a process with the same fundamental limits seen in the start of this page, with respect to the volumes of space causally connected with the Trigger Events, a subject we'll deepen in the following.

Refer to the figure below, where:

- blue coloured, 3-D volume (encoded in 2-D for graphic rendering) of space hosting the environmental factors E (e.g. air, thermal photons) and the quantum system S;
- red coloured, 3-D volume causally disconnected;
- M, Trigger Event;
- S, quantum system interacting ("measured") by the Trigger;
- A, macroscopic measurement instrument, e.g. a Trigger photosensor.

The majority of the space is always causally disconnected. We are indicating as a black colour bold inclined line, the worldline of the macroscopic measurement instrument A (the Trigger). Inclined with respect to the Time axe, to manifest the fact that the instrument is over a non inertial platform.
What precedes has an interesting implication: the macroscopic measurement device A (the Trigger, in our case) continues to remain in superposition of statuses, not decohered, for all what is so far to result causally disconnected. Say, all what in the figure below lies in the space and is shown in red colour. The reduced volume that we consider Environment of a Food and Beverage Bottling Line, assures that all triggerings and measurements are always derived by interactions with decohered states. As visible by the figure below, this assumption is a fiction useful to simplify an extremely complex relation. As all fictions, it cannot provide definitive solutions nor improvements on hard-to-tackle technical issues.

This subject is reminiscent of the Problem Solving method searching for the root cause of a problem centered on the point where the effects are felt. A strategy commonly followed when an evident cause cannot be encountered in the space-time volume we choose to consider the connected Environment.

In these cases, we are searching for all of the thinkable cause-effect relations:

- in space volumes progressively increased;
- going backward in time.

The answer of modern Physics to this point is dual, stating that all:

- subsystems are in a superposition of statuses, as seen by all of the other subsystems, causally disconnected because too far;
- what lies into the future lightcone of the measurement Event M is related to M and gives rise to effects S + A conditioned by the Environment E.

Above: all measurement systems, Bottling Controls and Machinery, are themselves superpositions of waves like the photon wave packet depicted above. Particles do not exist at all and the reason we are still naming waves in that way, is mere custom.
On right side: photons are superpositions of wave packets of something, a fundamental concept (an axiom) we’ll name here energy without even to try to explain its nature. The well known diffraction of white light in a spectrum, corresponds to a macroscopic observation of a reality whose arena lies in the microscale. Something we are capable to perceive directly only because effect of the participation of a multitude of photons of objects S and of the environment E into the causally connected (blue colour) volume of space, part of the future lightcone of the Event M (the Measurement), shall be decohered. This, means that the macroscopic measurement device A continues to remain in a super position of statuses for all what lies in the causally disconnected - red coloured - space (image adapted by L. Susskind, R. Bousso, 2012)