Ontogenesis, Part 3

Sergei Viznyuk

Of all things the measure is Man, of the things that are,
that they are, and of the things that are not, that they are not.
Protagoras, 485-415 BC

The core concept underlying any mathematical formalism purporting to describe physical phenomena has to be that of information-generating entity, i.e., of measuring device. The information extracted by measurement, *the Word*, is the basis of all things real[1]. The information is not just a description of "reality" of some insinuated "system" that exists "out there", beyond the tip of someone's nose. The information and reality are the same thing[2].

> *In the history of physics, we have learned that there are no such things as colors or smells 'out there.' They are only in our minds. But it seems we have to go one step further. We have to learn that even the features of an object, like its position or its momentum, do not have a reality independent of our observation. The distinction between reality and our knowledge of reality cannot be made. It is high time that we finally accept this message of the quantum.*
>
> Anton Zeilinger [1]

The understanding of information generation and transformation mechanics paves the way to genuine explanation of physical phenomena, the explanation not hinged on assumptions, postulates, falsehoods, or laws, which themselves beg for explanation. A theory entailing more questions than providing answers is a diversion, not a step toward final solution.

The analysis [2, 3] has pegged the output state $\boldsymbol{\psi}$ of measuring device, aka *quantum state*, as a mathematical expression of objective reality. Reality comes into being through measurement consisting of quantum ensemble of correlated measurement events predetermined by internal state of measuring device. Measuring device is the source of information. Output states of measuring device are the *source states*. Event outcomes, their correlation, values of observables, are elements of reality carried by the source state. The concept of measuring device as information-generating entity led to answers [3] for some decades-old questions. Among challenges is the fact that measurement does not cause transition between device eigenstates, or variation in expectation value, because device-generated unitary transformation commutes with device operator. Another challenge is, in standard QM, the expectation value $\langle\boldsymbol{\psi}|\boldsymbol{X}|\boldsymbol{\psi}\rangle$ is not device $\boldsymbol{X}$ eigenvalue but weighted sum of eigenvalues, a mean over classical ensemble of distinct measurements. Yet $\boldsymbol{\psi}$ represents quantum ensemble, not classical ensemble; $\boldsymbol{\psi}$ is the output of a distinct measurement consisting of a quantum ensemble of correlated measurement events [3]. Therefore, in spite of standard QM interpretation, $\langle\boldsymbol{\psi}|\boldsymbol{X}|\boldsymbol{\psi}\rangle$ ought to represent the result of a distinct measurement over quantum ensemble – the device eigenvalue. This challenge, known as the problem of definite outcomes [4], is at the core of a broader measurement problem [5]. In this chapter I address both of these challenges.

---

[1] *In the beginning was the Word.* John 1:1
[2] *And the Word became flesh, and dwelt among us.* John 1:14

The first challenge is resolved if measurement is accompanied by registration (observation) (see Appendix C of [3]), through correlation of source device output with a registrar. Registration effectuates unitary transformation which does not commute with device operator. It results in covariance of device reading and scalar product of correlated registrar states (equation C5 in [3]). This covariance effectuates communication channel [6] between source device (the *emitter*) and registrar (depending on the setup, also to be called the *detector*, the *receiver*, or the *observer*). For the second challenge, the covariance of expectation value and scalar product of correlated registrar states dictates the value of scalar product must be such as to match device readings to device eigenvalues, for device readings to obey the same quantization rules as device eigenvalues.

I start with previously derived artifacts [2, 3]. The output basis states $\{\boldsymbol{\psi}_n\}$ of source device $\boldsymbol{X}$ of cardinality M have been explicated as superpositions (quantum ensembles) of event outcomes (device eigenstates) $\{\boldsymbol{x}_k\}$:

$$|\boldsymbol{\psi}_n\rangle = M^{-1/2}\sum_{k=1}^{M} exp(iy_n x_k + i\varphi_k - i\varphi_0)|\boldsymbol{x}_k\rangle \quad ; \ \{y_n = n-1\} \ ; \ n = 1,2 \dots M \qquad (1)$$

Here $\{\varphi_k\}$ are zero-sum phases of complex amplitudes $X_k = |X_k|exp(i\varphi_k)$ of eigenstates $\{\boldsymbol{x}_k\}$; φ_0 is global phase, subtracted to ensure $det(\boldsymbol{V}) = 1$, where $(\boldsymbol{V})_{k,n} = \langle \boldsymbol{x}_k|\boldsymbol{\psi}_n\rangle$; $\boldsymbol{V}$ is $SU(M)$ transformation from output state basis $\{\boldsymbol{\psi}_n\}$ to device eigenstate basis $\{\boldsymbol{x}_k\}$; φ_0 is given by:

$$\varphi_0 = \frac{\pi}{2M}\left(\frac{M(M-1)}{2} \ mod \ 4\right) = \frac{\pi \mathrm{A}_M}{2M} \qquad (2)$$

, where A_M is OEIS cyclic sequence A105198. Output states $\{\boldsymbol{\psi}_n\}$ are characterized [2, 3] by:

1. Equal probabilities $\{P_k = 1/M\}$ of event outcomes $\{\boldsymbol{x}_k\}$
2. Equidistant eigenvalues $x_k = \pi(2k-1-M)/M \ \ radians; \ \ k = 1,2, \dots M$ (3)
3. $\langle \boldsymbol{\psi}_n|\boldsymbol{X}|\boldsymbol{\psi}_m\rangle = -\langle \boldsymbol{\psi}_m|\boldsymbol{X}|\boldsymbol{\psi}_n\rangle \quad n, m = 1,2, \dots M$

Form (1) with conditions (3) is mandated [3] by orthogonality of output states. The orthogonality of pre- and post-measurement output states signifies the objective fact of completed measurement (completed *emission* by the source). Transition $\boldsymbol{\psi} \to \boldsymbol{\psi}'$ between pre- and post-measurement output state is interpolated by device-generated unitary transformation $\boldsymbol{U} = exp(i\boldsymbol{X})$: $\boldsymbol{\psi}' = \boldsymbol{U}\boldsymbol{\psi}$; $\boldsymbol{U}^M\boldsymbol{\psi} = (-1)^{M-1}\boldsymbol{\psi}$. The pre-measurement state $\boldsymbol{\psi}$ only exists in hindsight of post-measurement state $\boldsymbol{\psi}'$, as a reverse transform: $\boldsymbol{\psi} = \boldsymbol{U}^\dagger \boldsymbol{\psi}'$. The pre-measurement state does not exist as objective fact, contrary to assumptions [7] or statements[3] implying existence of some "initial" wave function, a non-factual supposition pre-empting the very fact of measurement and measurement outcome.

> *The "past" is theory. The past has no existence except as it is recorded in the present. By deciding what questions our quantum registering equipment shall put in the present we have an undeniable choice in what we have the right to say about the past.*
>
> John A. Wheeler [8]

[3] As in the quote from [19]: ... *the initial quantum mechanical wave function does not determine the result of an individual measurement*

The output states of isolated source device do not correlate with states of any other device. The commutativity of $\boldsymbol{X}$ and $\boldsymbol{U}$ leads to the fixed expectation value of the measurement by isolated device: $\langle\boldsymbol{\psi}|\boldsymbol{X}|\boldsymbol{\psi}\rangle = \langle\boldsymbol{\psi}|\boldsymbol{U}^{\dagger}\boldsymbol{X}\boldsymbol{U}|\boldsymbol{\psi}\rangle = \langle\boldsymbol{\psi}'|\boldsymbol{X}|\boldsymbol{\psi}'\rangle$. There is no discernible dynamics in output of isolated device. This pertains to early fundamental discovery of quantum physics: transitions between energy states only arise from interaction of the system with radiation field [9]. In QM, transitions always imply interaction with non-commuting device, such as detector. The isolated device cannot even be assumed to exist, because *the fact of existence* is classical information to be physicalized in a state of registrar correlated with the state [of existence] of isolated device; when, by definition of isolated device, such correlation does not exist. The "isolated system" is a fallacy leading to various paradoxes [10, 11, 12]. The variation in event probabilities and expectation values only arise when source device is coupled to observer/registrar [3]. Nature is participatory:

> *Registering equipment operating in the here and now has an undeniable part in bringing about that which appears to have happened. Useful as it is under everyday circumstances to say that the world exists "out there" independent of us, that view can no longer be upheld. There is a strange sense in which this is a "participatory universe."*
>
> John A. Wheeler [8]

Without coupling to observer/registrar, the output of source device is a *featureless unknown*. It can be formulated as a general principle:

- The information does not exist unless physicalized[4]

What could one say about the result of an experiment if there is no record of measurement? Without information recorded by the registrar, one cannot ascertain there was a measurement (emission), just as one cannot ascertain the opposite.

Device output state basis vectors (1) are marked by values $\{y_n\}$, canonical conjugate to eigenvalues $\{x_k\}$ of device $\boldsymbol{X}$ operator [3]. There is asymmetry between eigenvalues $\{x_k\}$ and $\{y_n\}$ in (1). That is because $\{x_k\}$ are in $radians$, while $\{y_n\}$ are in $bits$. I claim the natural unit of any variable ought to be the bit [13]. I convert x_k into $bits$, and shift y_n values to be zero-centered:

$$|\boldsymbol{\psi}_n\rangle = M^{-1/2}\sum_{k=1}^{M} exp\left(i\frac{2\pi}{M}y_n x_k + i\varphi_k - i\varphi_0\right)|\boldsymbol{x}_k\rangle \tag{4}$$

, where $x_k = (2k-1-M)/2\ \ bits$; $y_n = (2n-1-M)/2\ \ bits$; $n, k = 1,2, \dots M$. The redefined set of eigenvalues $\{x_k\}$ is identical to the set of conjugate values $\{y_n\}$. With eigenvalues now defined in $bits$, device $\boldsymbol{X}$ -generated unitary transformation $\boldsymbol{\psi}' = \boldsymbol{U}\boldsymbol{\psi}$ becomes

$$\boldsymbol{U} = exp\left(i\frac{2\pi}{M}\boldsymbol{X}\right) = \sum_{k=1}^{M} exp\left(i\frac{2\pi}{M}x_k\right)|\boldsymbol{x}_k\rangle\langle\boldsymbol{x}_k| \quad ; \quad \boldsymbol{X} = \sum_{k=1}^{M} x_k|\boldsymbol{x}_k\rangle\langle\boldsymbol{x}_k| \tag{5}$$

[4] E.g., a thought is not information, as it is immaterial. Even if thought is written down, the writing is material, but not the idea it conveys. A thought is not objective [information]

An output state of source device, up to global phase, ought to be one of the output basis states (4) (see Appendix A). The output state emitted by the source in a particular measurement is determined by $M-1$ phases, out of total M^2-M degrees of freedom defining device internal state [3].

If device orthogonal output states $\{\boldsymbol{\psi}_n\}$ correlate respectively with not necessarily orthogonal states $\{\boldsymbol{q}_n\}$ of registrar $\boldsymbol{Q}$, the shared output state of emission+registration is:

$$|\boldsymbol{\chi}\rangle = \sum_{n=1}^{M} C_n|\boldsymbol{\psi}_n\boldsymbol{q}_n\rangle \;\;;\;\; \sum_{n=1}^{M}|C_n|^2 = 1 \;\;;\;\; \langle\boldsymbol{\psi}_m|\boldsymbol{\psi}_n\rangle = \delta_{m,n} \;\;;\;\; \delta_{m,n} \le |\langle\boldsymbol{q}_m|\boldsymbol{q}_n\rangle| \le 1 \qquad (6)$$

I shall merge phases of complex amplitudes $\{C_n\}$ with global phases of $\{\boldsymbol{q}_n\}$, as only their sums matter for further analysis. Expr. (6) is the output state of a global device $\boldsymbol{\Upsilon}$:

$$\boldsymbol{\Upsilon} = \sum_{n=1}^{M} \upsilon_n|\boldsymbol{\psi}_n\boldsymbol{q}_n\rangle\langle\boldsymbol{q}_n\boldsymbol{\psi}_n| \qquad (7)$$

The correlation of output states $\{\boldsymbol{\psi}_n\}$ of device $\boldsymbol{X}$ with states $\{\boldsymbol{q}_n\}$ of registrar ties measurement and recording of information into combined action by device $\boldsymbol{\Upsilon}$. Action of device (7) effectuates transformation $\boldsymbol{W}$ between device output states (6): $\boldsymbol{\chi}' = \boldsymbol{W}\boldsymbol{\chi}$, where:

$$\boldsymbol{W} = exp\left(i\frac{2\pi}{M}\boldsymbol{\Upsilon}\right) = \sum_{n=1}^{M} exp\left(i\frac{2\pi}{M}\upsilon_n\right)|\boldsymbol{\psi}_n\boldsymbol{q}_n\rangle\langle\boldsymbol{q}_n\boldsymbol{\psi}_n| \qquad (8)$$

The fact of completed emission+registration is signified by orthogonality $\langle\boldsymbol{\chi}'|\boldsymbol{\chi}\rangle = 0$. Applied cyclically, the orthogonality condition results in restriction on device output state (6): $\langle\boldsymbol{\chi}|\boldsymbol{W}^n|\boldsymbol{\chi}\rangle = \left(-\delta_{n,M}\right)^{M-1}$; $n = 1,2,\ldots M$. With the same argument as in Appendix A, this restriction mandates device $\boldsymbol{\Upsilon}$ output state (6), up to global phase, to be one of:

$$|\boldsymbol{\chi}_k\rangle = M^{-1/2}\sum_{n=1}^{M} exp\left(i\frac{2\pi}{M}\upsilon_n\chi_k - i\varphi_0\right)|\boldsymbol{\psi}_n\boldsymbol{q}_n\rangle \qquad (9)$$

, with characteristics similar to (3):

1. Equal probabilities $\{P_n = |C_n|^2 = 1/M\}$ of outcomes $\{\boldsymbol{\psi}_n\boldsymbol{q}_n\}$
2. Equidistant eigenvalues $\chi_k = (2k-1-M)/2\;\; bits;\;\; k = 1,2,\ldots M$ and conjugate variables $\upsilon_n = (2n-1-M)/2\;\; bits;\;\; n = 1,2,\ldots M$ (10)
3. $\langle\chi_n|\boldsymbol{\Upsilon}|\chi_m\rangle = -\langle\chi_m|\boldsymbol{\Upsilon}|\chi_n\rangle \quad n,m = 1,2,\ldots M$

Consider case $M = 2$. An emission by device $\boldsymbol{X}$ + recording by registrar effectuates transition between output basis states (9): $\boldsymbol{\chi}_1 \to (\boldsymbol{\chi}_2 = \boldsymbol{W}\boldsymbol{\chi}_1)$. The corresponding device $\boldsymbol{X}$ readings are:

$$\begin{aligned}\langle\boldsymbol{\chi}_1|\boldsymbol{X}|\boldsymbol{\chi}_1\rangle &= i\,[\langle\boldsymbol{\psi}_2|\boldsymbol{X}|\boldsymbol{\psi}_1\rangle G - \langle\boldsymbol{\psi}_1|\boldsymbol{X}|\boldsymbol{\psi}_2\rangle G^*]/2\\ \langle\boldsymbol{\chi}_2|\boldsymbol{X}|\boldsymbol{\chi}_2\rangle &= i\,[\langle\boldsymbol{\psi}_1|\boldsymbol{X}|\boldsymbol{\psi}_2\rangle G^* - \langle\boldsymbol{\psi}_2|\boldsymbol{X}|\boldsymbol{\psi}_1\rangle G]/2\end{aligned} \qquad (11)$$

, where $G = \langle\boldsymbol{q}_2|\boldsymbol{q}_1\rangle$ is the *coherence factor*.

From (4),(5): $\langle\boldsymbol{\psi}_1|\boldsymbol{X}|\boldsymbol{\psi}_2\rangle = -\langle\boldsymbol{\psi}_2|\boldsymbol{X}|\boldsymbol{\psi}_1\rangle = i/2\ bits$. With this, (11) becomes:

$$\langle\chi_1|\boldsymbol{X}|\chi_1\rangle = -\langle\chi_2|\boldsymbol{X}|\chi_2\rangle = Re(\langle\boldsymbol{q}_2|\boldsymbol{q}_1\rangle)/2 = |\langle\boldsymbol{q}_2|\boldsymbol{q}_1\rangle|\cdot\cos(\tau\ radians)/2\ bits$$

, where τ is phase of $\langle\boldsymbol{q}_2|\boldsymbol{q}_1\rangle$. It shows, the transition from $\langle\chi_1|\boldsymbol{X}|\chi_1\rangle$ to $\langle\chi_2|\boldsymbol{X}|\chi_2\rangle$ in device $\boldsymbol{X}$ reading is covariant with phase τ changing value by $\pi\ radians$, or by $1\ bit$, if τ is cast to the same units and scale as eigenvalues $\{x_k\}$: $\tau(radians) \to 2\pi\cdot\tau(bits)/M$:

$$\langle\chi_1|\boldsymbol{X}|\chi_1\rangle = -\langle\chi_2|\boldsymbol{X}|\chi_2\rangle = |\langle\boldsymbol{q}_2|\boldsymbol{q}_1\rangle|\cdot\cos(\pi\cdot\tau\ (bits))/2\ bits \qquad (12)$$

For source device readings (12) to equal device eigenvalues $\{x_k\} = (-1/2\,,1/2)$ requires $|\langle\boldsymbol{q}_2|\boldsymbol{q}_1\rangle| = 1$, i.e., the registrar states $\boldsymbol{q}_1, \boldsymbol{q}_2$ to only differ in global phase. Otherwise, the registrar would not be a passive [observer], but part of the emitter[5]. Device $\boldsymbol{X}$ readings (12) are covariant with parameter τ because $\boldsymbol{X}$ and $\boldsymbol{Q}$ separately do not commute with transformation $\boldsymbol{W}$, effectuated by the combined act of emission+detection. Without coupling to registrar, device $\boldsymbol{X}$ reading is static $\langle\boldsymbol{\psi}_1|\boldsymbol{X}|\boldsymbol{\psi}_1\rangle = \langle\boldsymbol{\psi}_2|\boldsymbol{X}|\boldsymbol{\psi}_2\rangle = 0$, i.e., not covariant with any external parameter.

Source device readings (12) are only equal device eigenvalues when phase difference τ is integer number of $bits$. If τ is not integer number of $bits$, then there is not enough information to peg source component of shared state $\boldsymbol{\chi}$ to a source device eigenstate. "Enough or not enough information" is quantified by $R^2 = |\langle\chi|\boldsymbol{U}|\chi\rangle|^2$, equivalent to coefficient of determination in statistics. For cardinality $M = 2$ measurement:

$$\langle\chi_1|\boldsymbol{U}|\chi_1\rangle = -\langle\chi_2|\boldsymbol{U}|\chi_2\rangle = i\cdot Re(\langle\boldsymbol{q}_2|\boldsymbol{q}_1\rangle) = i|G|\cdot\cos(\pi\cdot\tau\ (bits)) \qquad (13)$$

Maximum $R^2 = 1$, reached at integer τ, corresponds to one of source device eigenvalues:

$$\begin{aligned}(\langle\chi_1|\boldsymbol{X}|\chi_1\rangle, \langle\chi_2|\boldsymbol{X}|\chi_2\rangle)_{\tau=0} &= (1/2\,,-1/2)\\ (\langle\chi_1|\boldsymbol{X}|\chi_1\rangle, \langle\chi_2|\boldsymbol{X}|\chi_2\rangle)_{\tau=1} &= (-1/2\,,1/2)\end{aligned} \qquad (14)$$

For cardinality $M = 3$ measurement, $\langle\boldsymbol{\psi}_1|\boldsymbol{X}|\boldsymbol{\psi}_2\rangle = -\langle\boldsymbol{\psi}_2|\boldsymbol{X}|\boldsymbol{\psi}_1\rangle = \langle\boldsymbol{\psi}_2|\boldsymbol{X}|\boldsymbol{\psi}_3\rangle = -\langle\boldsymbol{\psi}_3|\boldsymbol{X}|\boldsymbol{\psi}_2\rangle = \langle\boldsymbol{\psi}_3|\boldsymbol{X}|\boldsymbol{\psi}_1\rangle = -\langle\boldsymbol{\psi}_1|\boldsymbol{X}|\boldsymbol{\psi}_3\rangle = i/\sqrt{3}\ bits$.Then, from (9):

$$\begin{aligned}\langle\chi_1|\boldsymbol{X}|\chi_1\rangle &= \frac{2}{\sqrt{3}}Re[G\cdot exp(-i\,\pi/6)]\ \ bits\\ \langle\chi_2|\boldsymbol{X}|\chi_2\rangle &= \frac{2}{\sqrt{3}}Re[G\cdot exp(i\,\pi/2)]\ \ bits\\ \langle\chi_3|\boldsymbol{X}|\chi_3\rangle &= \frac{2}{\sqrt{3}}Re[G\cdot exp(-i\,5\pi/6)]\ \ bits\end{aligned} \qquad (15)$$

---

[5] Which is also a valid configuration, realized, e.g., with emitter coupled to a matter oscillator (antenna). The matter oscillator acts as a secondary source – re-emitter. Depending on coherence factor, re-emitter is passive or scattering

$$\langle \chi_1|\boldsymbol{U}|\chi_1\rangle = G \cdot exp(2\pi i/3)$$
$$\langle \chi_2|\boldsymbol{U}|\chi_2\rangle = G$$
$$\langle \chi_3|\boldsymbol{U}|\chi_3\rangle = G \cdot exp(-2\pi i/3)$$

, where coherence factor $G = [\langle \boldsymbol{q}_1|\boldsymbol{q}_2\rangle + \langle \boldsymbol{q}_2|\boldsymbol{q}_3\rangle + \langle \boldsymbol{q}_3|\boldsymbol{q}_1\rangle]/3$.

Device readings (15) would match device eigenvalues $\{x_k\} = (-1{,}0{,}1)$ if registrar states $\{\boldsymbol{q}_n\}$ only differ by certain phase τ: $\langle \boldsymbol{q}_1|\boldsymbol{q}_2\rangle = \langle \boldsymbol{q}_2|\boldsymbol{q}_3\rangle = \langle \boldsymbol{q}_3|\boldsymbol{q}_1\rangle = exp(2\pi i \cdot \tau(bits)/3)$; $\tau = 0{,}1{,}2$. Then (15) becomes:

$$\langle \chi_1|\boldsymbol{X}|\chi_1\rangle = 2 \cdot \cos(2\pi\tau/3 - \pi/6)/\sqrt{3} \quad bits$$
$$\langle \chi_2|\boldsymbol{X}|\chi_2\rangle = -2 \cdot \sin(2\pi\tau/3)/\sqrt{3} \quad bits \tag{16}$$
$$\langle \chi_3|\boldsymbol{X}|\chi_3\rangle = 2 \cdot \cos(2\pi\tau/3 - 5\pi/6)/\sqrt{3} \quad bits$$

Like in $M = 2$ case, device readings (16) are covariant with phase τ, cast to same units and scale. Maximum $R^2 = 1$, reached at integer τ, corresponds to one of source device eigenvalues:

$$\begin{aligned}(\langle \chi_1|\boldsymbol{X}|\chi_1\rangle, \langle \chi_2|\boldsymbol{X}|\chi_2\rangle, \langle \chi_3|\boldsymbol{X}|\chi_3\rangle)_{\tau=0} &= (1, 0, -1)\\ (\langle \chi_1|\boldsymbol{X}|\chi_1\rangle, \langle \chi_2|\boldsymbol{X}|\chi_2\rangle, \langle \chi_3|\boldsymbol{X}|\chi_3\rangle)_{\tau=1} &= (0, -1, 1)\\ (\langle \chi_1|\boldsymbol{X}|\chi_1\rangle, \langle \chi_2|\boldsymbol{X}|\chi_2\rangle, \langle \chi_3|\boldsymbol{X}|\chi_3\rangle)_{\tau=2} &= (-1, 1, 0)\end{aligned} \tag{17}$$

The fact of completed emission by the source, signified by transition between orthogonal output states, is $1\ bit$ of information, equal to the increment $\Delta\tau = 1\ bit$ which advances cyclic eigenvalue assignment (14),(17) by one position. This [equivalence] principle alludes to the fact, discussed in [3], that device output information is encoded in phases [of complex amplitudes].

> *Otherwise stated, every physical quantity, every it, derives its ultimate significance from bits, binary yes-or-no indications, a conclusion which we epitomize in the phrase, it from bit.*
>
> John A. Wheeler [13]

Expressions (12),(16) identify conditions under which source expectation values coincide with eigenvalues of source device operator:

1. The measurement (emission) is *observed*, i.e., recorded by a *passive registrar*
2. $R^2 = |\langle \chi|\boldsymbol{U}|\chi\rangle|^2 = 1$. Eigenstates of $\boldsymbol{U} = exp\left(i\frac{2\pi}{M}\boldsymbol{X}\right)$ are eigenstates of $\boldsymbol{X}$. Therefore, $R^2 = 1$ implies expectation value $\langle \chi|\boldsymbol{X}|\chi\rangle$ equals an eigenvalue of source device $\boldsymbol{X}$

$R^2 = |\langle \boldsymbol{q}_2 | \boldsymbol{q}_1 \rangle|^2 \cdot \cos^2(\pi \cdot \tau\ (bits))$ from (13) gives normalized interference pattern intensity in cardinality $M = 2$ measurement, such as double-slit experiment (Figure 1). Source device $\boldsymbol{X}$ is two emitting slits. Registrar $\boldsymbol{Q}$ is a photosensitive pixel on the screen. Each pixel is a distinct registrar. Eigenstates $\boldsymbol{x}_1, \boldsymbol{x}_2$ of device $\boldsymbol{X}$ are the emits of slit 1 and 2 in direction of pixel $\boldsymbol{Q}$. At the peak of signal intensity $R^2 = 1$, expectation value (14) is one of the emitter eigenvalues, implying the source component of shared output state is in an emitter eigenstate. Yet it does not equate to an assertion that photon followed a definite slit trajectory. Such an assertion would amount to a hidden trajectory account associated with pilot wave theory [14]. The assertion requires output states (9) to be correlated with a registrar able to distinguish emitter eigenstates. Pixel $\boldsymbol{Q}$ is not able to distinguish eigenstates $\boldsymbol{x}_1, \boldsymbol{x}_2$. It does not capture expectation value of the emitter output. It only registers the fact of emission, by being set to “on”. Alluding to the principle stated earlier, for information to exist, it has to be physicalized, in a definite state of a registrar. Pixel $\boldsymbol{Q}$ only physicalizes the fact of emission, not the rest of information in emitter output.

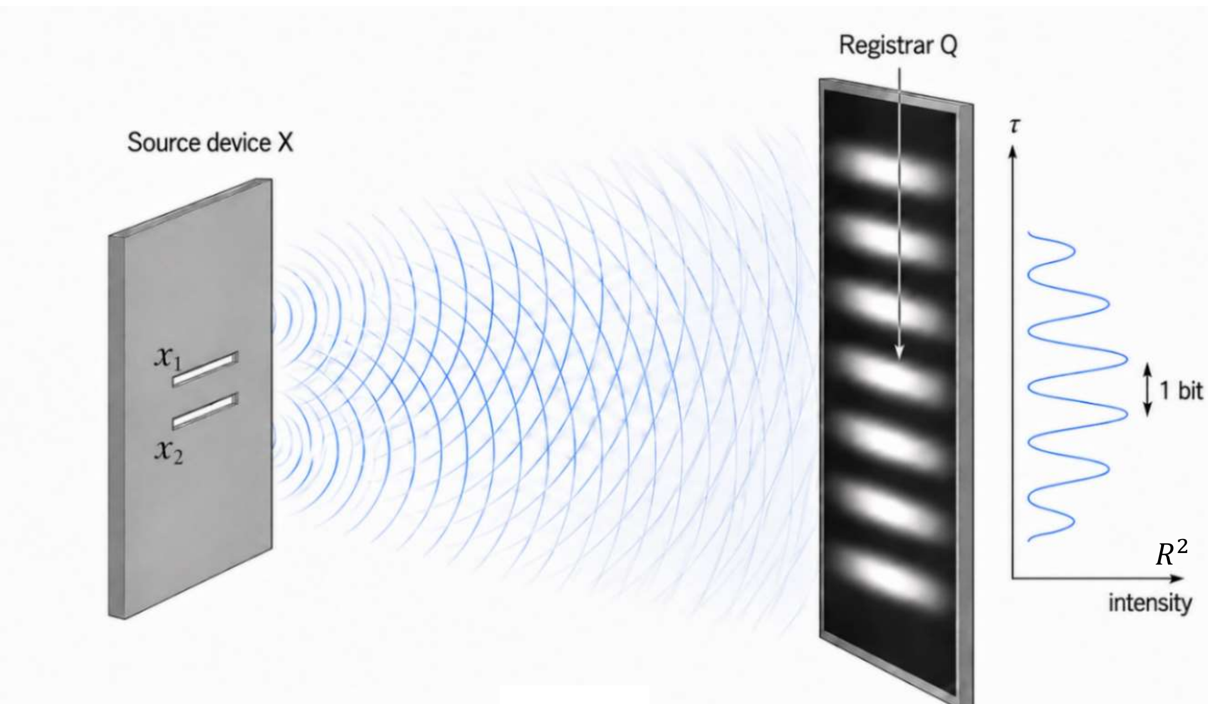

Figure 1

Parameter τ is effectively the position, measured in bits, of the registrar with respect to the source. Thus, τ is a global parameter of the shared emitter+detector configuration, not a hidden variable local to the detector or to the emitter. Parameter τ does not have to be indicative of spatial position of the registrar, as in double-slit example. It could refer to a position in time, which would result in oscillating signal intensity, the temporal interference pattern.

Eigenstates $\boldsymbol{x}_1$, $\boldsymbol{x}_2$ of source device point to the same pixel state; hence pixel does not record which-slit information. Which-slit information, captured by registrar or elsewhere, would have suppressed interference [12, 15]. The presence of interference is a testimony that which-slit information is not registered anywhere.

In [3] it was shown all information in output state (4) of the emitter is contained in event correlations, encoded in relative phases $\{\varphi_k\}$ of superposed emitter eigenstates, in amount given by Shannon entropy $H_\mathrm{S} = \log_2 M\, bits$. This information specifies, which of the M output basis states $\{\boldsymbol{\psi}_n\}$ is the output of a particular measurement (emission). The global phases of emitter output states $\{\boldsymbol{\psi}_n\}$ are non-consequential, as long as emitter is not coupled to the detector. When emitter is correlated with detector, global phases of emitter output states merge into relative phases of $\{\boldsymbol{\psi}_n \boldsymbol{q}_n\}$ superposed basis elements of the shared emitter+detector output state (6). Operational significance of relative phase is manifested by interference effects - device readings (12),(16). Aharonov-Bohm effect [16] is another example.

Relative phases of $\{\boldsymbol{\psi}_n \boldsymbol{q}_n\}$ basis elements of the shared emitter+detector output determine which of the M output states (9) of the emitter+detector device (7) is the output (6) of a particular emission+registration. The information in source device $\boldsymbol{X}$ output states (4) could be extracted and orthogonality of output states established via conditions (3) only if device $\boldsymbol{X}$ is coupled to a detector. Similarly, the information from output states (9) of emitter+detector device (7) could be extracted and their orthogonality established via conditions (10) only if device (7) is coupled to a higher-level registrar. Information about output of the combined emitter-registrar device (7) may be recorded by a higher-level registrar without eliminating interference, provided that the higher-level record does not distinguish source eigenstates. The observation of interference would exclude distinguishable which-path record, but not the fact of emission, the detector position, or the accumulated interference pattern.

Objective reality arises in correlation of the source with a registrar. In the present paradigm, objective reality does not exist outside and independent of registrar. The emission does not happen unless detected by registrar, correlated with the source device. The existence of the source device is ascertained by the fact of emission. Neither photon, nor its source exist unless registered by the detector. As I have shown, detection requires a correlated state of the source and the registrar [6]. Specifically, electromagnetic field is the correlated state of the emitter and the detector. Photon is the outcome of transition of shared state $\boldsymbol{\chi}_1 \to \boldsymbol{\chi}_2$ in combined act of emission by the source and registration by the detector, effectuated by global device (7). Photon is not a hypostatized entity which travelled from another galaxy for millions of years before hitting detector. Radiation is not an entity which exists on its own, "out there", in the open space. Assuming otherwise leads to insurmountable paradoxes, e.g., vacuum catastrophe [17], the consequence of an assumption that vacuum is filled with gravitating zero-point energy radiation modes [18].

Appendix A

The orthogonal output basis states $\{\boldsymbol{\psi}_n\}$ of source device $\boldsymbol{X} = \sum_{k=1}^{M} x_k |\boldsymbol{x}_k\rangle\langle\boldsymbol{x}_k|$ were defined [3] as superpositions (1) of device eigenstates, and redefined with standardized eigenvalues and conjugate variables as superpositions (4). States $\{\boldsymbol{\psi}_n\}$ satisfy cyclic and orthogonality conditions:

$$\begin{gathered} \langle\boldsymbol{\psi}_n|\boldsymbol{\psi}_m\rangle = \delta_{n,m} \\ \boldsymbol{\psi}_{n+1} = \boldsymbol{U}\boldsymbol{\psi}_n \\ \boldsymbol{U}^M\boldsymbol{\psi}_n = (-1)^{M-1}\boldsymbol{\psi}_n \end{gathered} \qquad (A1)$$

, where $\boldsymbol{U}$ is the device-generated unitary transformation:

$$\boldsymbol{U} = exp\left(i\frac{2\pi}{M}\boldsymbol{X}\right) = \sum_{k=1}^{M} exp\left(i\frac{2\pi}{M}x_k\right)|\boldsymbol{x}_k\rangle\langle\boldsymbol{x}_k| \qquad (A2)$$

Theorem: Any output state of device $\boldsymbol{X}$, satisfying conditions $(A1)$, is one of the basis states (4).

Proof: Since eigenstates $\{\boldsymbol{x}_k\}$ constitute basis in Hilbert space of device $\boldsymbol{X}$, an arbitrary output state $\boldsymbol{\psi}$ is a superposition of eigenstates:

$$\boldsymbol{\psi} = \sum_{k=1}^{M} C_k|\boldsymbol{x}_k\rangle \qquad (A3)$$

Measurement (emission) by device $\boldsymbol{X}$ effectuates unitary transformation $(A2)$ from pre-emission state $\boldsymbol{\psi}$ to post-emission state $\boldsymbol{\psi}'$: $\boldsymbol{\psi}' = \boldsymbol{U}\boldsymbol{\psi}$. From $(A2)$,$(A3)$:

$$\boldsymbol{\psi}' = \boldsymbol{U}\boldsymbol{\psi} = \boldsymbol{U}\left(\sum_{k=1}^{M} C_k|\boldsymbol{x}_k\rangle\right) = \sum_{k=1}^{M} C_k exp\left(i\frac{2\pi}{M}x_k\right)|\boldsymbol{x}_k\rangle$$

The completed emission is signified by orthogonality condition $\langle\boldsymbol{\psi}|\boldsymbol{\psi}'\rangle = 0$. Applied cyclically $(A1)$, it results in M equations for M probabilities $\{P_k = |C_k|^2 \geq 0\}$, and eigenvalues $\{x_k\}$:

$$\sum_{k=1}^{M} P_k \cdot exp\left(i\frac{2\pi}{M}x_k n\right) = \left(-\delta_{n,M}\right)^{M-1} \quad ; \quad n = 1,2, \ldots M \qquad (A4)$$

The solution to $(A4)$ is $\{P_k = 1/M\}$; $\{x_k = (2k-1-M)/2\} \Longrightarrow \{C_k = M^{-1/2}exp(i\varphi_k - i\varphi_0)\}$, where $\{\varphi_k\}$ are arbitrary zero-sum phases $\sum_{k=1}^{M}\varphi_k = 0$. I add a set of zero-sum phases to $\{\varphi_k\}$:

$$\varphi_k \to \varphi_k + \frac{2\pi y_n x_k}{M}$$

, which leads to

$$C_k = M^{-1/2}exp\left(i\frac{2\pi}{M}y_n x_k + i\varphi_k - i\varphi_0\right) \qquad (A5)$$

$(A3)$ with $(A5)$ gives orthogonal output basis states (4) marked by conjugate variables $\{y_n\}$. The global phase φ_0, given by (2), is subtracted to ensure transformation $(\boldsymbol{V})_{k,n} = \langle\boldsymbol{x}_k|\boldsymbol{\psi}_n\rangle$ is $SU(M)$ with $det(\boldsymbol{V}) = 1$. Q.E.D.

References

[1] A. Zeilinger, Dance of the Photons: From Einstein to Quantum Teleportation, New York: Farrar, Straus and Giroux, 2010, p. 286.

[2] S. Viznyuk, "Ontogenesis, Part 1," 2023. [Online]. Available: https://www.academia.edu/109685658/Ontogenesis_Part_1.

[3] S. Viznyuk, "Ontogenesis, Part 2," 2025. [Online]. Available: https://www.academia.edu/145582169/Ontogenesis_Part_2.

[4] E. Schrödinger, "The Present Situation in Quantum Mechanics," *Naturwissenschaften,* vol. 23, no. 48, p. 807–812, 1935.

[5] J. Von Neumann, Mathematical Foundations of Quantum Mechanics, Princeton University Press, 1955.

[6] S. Viznyuk, "The basics of information transmission," Academia.edu, 2024. [Online]. Available: https://www.academia.edu/114308803/The_basics_of_information_transmission.

[7] M. Schlosshauer, Decoherence and the quantum-to-classical transition, Springer, 2007.

[8] J. Wheeler, "Law Without Law," in *Quantum Theory and Measurement*, Princeton University Press, 1983, pp. 182-213.

[9] P. Dirac, "The Quantum Theory of the Emission and Absorption of Radiation," *Proc. Roy. Soc. A,* vol. 114, pp. 243-265, 1927.

[10] D. Frauchiger and R. Renner, "Quantum theory cannot consistently describe the use of itself," *arXiv:1604.07422 [quant-ph],* vol. 9, 2018.

[11] E. Wigner, "Remarks on the Mind-body Question," in *The Scientist Speculates*, London, Heinemann, 1962, pp. 284-301.

[12] S. Viznyuk, "Where unfathomable begins," Academia.edu, 2021. [Online]. Available: https://www.academia.edu/45647801/Where_unfathomable_begins.

[13] J. Wheeler, "Information, Physics, Quantum: The Search of Links," in *Proc. 3rd Int. Symp. Foundations of Quantum Mechanics*, Tokyo, 1989.

[14] D. Bohm, "A suggested interpretation of the quantum theory in terms of hidden variables," *Phys. Rev.,* vol. 85, pp. 166-179, 1952.

[15] M. Scully, B. Englert and H. Walther, "Quantum optical tests of complementarity," *Nature,* vol. 351, pp. 111-116, 1991.

[16] Y. Aharonov and D. Bohm, "Significance of Electromagnetic Potentials in the Quantum Theory," *Phys. Rev.,* vol. 115, no. 3, pp. 485-491, 1959.

[17] R. Adler, B. Casey and O. Jacob, "Vacuum catastrophe: An elementary exposition of the cosmological constant problem," *Am. J. Phys.,* vol. 63, no. 7, p. 620–626, 1995.

[18] S. Viznyuk, "Planck's law revisited," 2017. [Online]. Available: https://www.academia.edu/35548486/Plancks_law_revisited.

[19] J. S. Bell, "On the Einstein Podolsky Rosen Paradox," *Physics,* vol. 1, no. 3, pp. 195-200, 1964.