FINAL DRAFT
International Standard

ISO/IEC FDIS 4879

Information technology — Quantum computing — Vocabulary

ISO/IEC JTC **1**

Secretariat: **ANSI**

Voting begins on:
2024-02-28

Voting terminates on:
2024-04-24

Reference number
ISO/IEC FDIS 4879:2024(en)

ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org
Published in Switzerland

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INTRODUCTION

For most of computing history, the foundational hardware technology has been binary digital transistor logic. In such digital systems, data and programs represented as binary classical digits (bits) are encoded into physical transistors that have and can switch between two definite internal states: on and off. The field of quantum computing introduces a new approach to the underlying computing hardware by shifting from classical logic (“on” or “off”) to a quantum logic where the “quantum bits” or “qubits” (the simplest units of quantum information) are encoded into physical registers that exhibit quantum-mechanical phenomena such as superposition and entanglement.

This shift from the classical digital representation found in today’s conventional computers to a quantum digital representation in tomorrow’s computers is expected to bring increases in computing power and new, innovative software applications, allowing us to tackle more complex computational problems and carry out powerful analysis of more complex data patterns that are already challenging or impossible for today’s technology. Quantum computing holds the potential to revolutionize fields from chemistry and logistics to finance and physics.

However, the increase in power and capability that quantum computing will provide, will also pose an important security threat once quantum computers become large enough (or cryptographically relevant, as it is sometimes described). As strong as today’s cryptographic mechanisms have been against conventional computers, almost all cryptographic protocols used are vulnerable to quantum-computing-based attacks with known algorithms. This widely known risk associated with the power of quantum computing is very concerning for governments, institutions and individuals whose encrypted data are safe today, but may become decryptable once quantum computers reach large enough size.

This document aims to assist in the understanding of quantum computing concepts and the exchange of information.

Information technology — Quantum computing — Vocabulary

1 Scope

This document defines terms commonly used in the field of quantum computing. This document is applicable to all types of organizations (e.g. commercial enterprises, government agencies, not-for-profit organizations) to exchange quantum computing concepts.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at https://www.iso.org/obp
- IEC Electropedia: available at https://www.electropedia.org/

3.1 Background

3.1.1
model
physical, mathematical, or otherwise appropriate representation of a system, entity, phenomenon, process or data

[SOURCE: ISO/IEC 22989:2022, 3.1.23, logical has been changed to appropriate]

3.1.2
model parameter
internal variable of a *model* (3.1.1) that affects how it computes its outputs

[SOURCE: ISO/IEC 22989:2022, 3.3.8]

3.1.3
machine learning
process of optimizing *model parameters* (3.1.2) through computational techniques, such that the model's behaviour reflects the data or experience

[SOURCE: ISO/IEC 22989:2022, 3.3.5]

3.1.4
simulator
device, computer program, or system that behaves or operates like a given system when provided a set of controlled inputs

3.1.5
program
computer program
syntactic unit that conforms to the rules of a particular *programming language* (3.1.6) and that is composed of declarations and statements or instructions needed to solve a certain function, task, or problem

[SOURCE: ISO/IEC 2382:2015, 2121374, modified — Notes to entry omitted]

3.1.6

programming language

artificial language for expressing *programs* (3.1.5)

[SOURCE: ISO/IEC 2382:2015, 2121374, modified — Notes to entry omitted]

3.1.7

programming

designing, writing, modifying, and testing of *programs* (3.1.5)

[SOURCE: ISO/IEC 2382:2015, 2121374, modified — Notes to entry and domain identifier <fundamental terms> omitted]

3.1.8

coding

<computer programming>process of expressing a *program* (3.1.5) in a *programming language* (3.1.6)

[SOURCE: ISO/IEC 2382:2015, 2121374, modified — Notes to entry omitted]

3.1.9

algorithm

process for computation, defined by a set of rules, that will yield a corresponding output

Note 1 to entry: Definition modified from ISO/IEC 18031:2011(en), 3.1.

3.2 Quantum physics background

3.2.1

Hilbert space

vector space equipped with an inner product operation which allows distances, angles and vector norms to be defined

Note 1 to entry: When used in the context of *quantum physics* (3.2.3), the space of *quantum states* (3.2.7) of a *quantum system* (3.2.6) is described by a complex Hilbert space, referred to as the state space.

Note 2 to entry: All possible quantum states can be represented as *operators* (3.2.2) on the quantum system's Hilbert space.

3.2.2

operator

mathematical entity that transforms the elements of an input space to the elements of an output space

Note 1 to entry: In *quantum physics* (3.2.3), simple operators can be mathematically represented by a matrix that acts via matrix multiplication on vectors in a *Hilbert space* (3.2.1).

3.2.3

quantum physics

quantum mechanics

fundamental theory of physics, in which physical properties of systems are completely determined by vectors in a complex *Hilbert space* (3.2.1) whose dynamics are determined by specific types of linear transformations on that space

Note 1 to entry: There are many different formulations of quantum physics, but the specific linear transformations allowed must all correctly describe stronger correlations than can arise in classical physics, such as those that are probed by Bell and Kochen-Specker tests.

Note 2 to entry: Measurement outcome probabilities are determined from the complex vectors, typically via the Born rule.

Note 3 to entry: Importantly, quantum physics is able to successfully describe the behaviour of light and matter in operating regimes where classical theories of physics can break down, like ultrasmall sizes or energies or at low temperatures.

Note 4 to entry: In the context of *quantum computing* (3.4.3), it is normally sufficient to consider *quantum state* (3.2.7) evolution as being governed by the non-relativistic Schrödinger equation through the *Hamiltonian* (3.2.12), for particles with mass, or the quantum electrodynamics formulation of Maxwell's equations, for light. However, quantum dynamics also includes broader contexts, such as the dynamics of relativistic systems, which are governed by the Dirac equation.

3.2.4
quantum
making use of or arising from the laws of *quantum physics* (3.2.3) in an essential way

3.2.5
quantum
discrete, finite, indivisible, and measurable unit of a physical property such as energy

3.2.6
quantum system
system whose properties are determined by the laws of *quantum physics* (3.2.3), and cannot be completely described by just the laws of classical physics

3.2.7
quantum state
description of the state of a *quantum system* (3.2.6) defining the probability distribution of possible outcomes of any measurement upon it

Note 1 to entry: A quantum state can be mathematically represented by a vector or, more generally, a *density operator* (3.2.2) in the complex *Hilbert space* (3.2.1). (See Note 1 to entry in *quantum operator* (3.2.11) for discussion of density operators.)

Note 2 to entry: A *quantum* (3.2.4) wave-function is the mathematical representation of a quantum state in a particular basis of the Hilbert space. Wave-functions are often defined over continuous parameters, such as position, momentum and phase.

3.2.8
quantum superposition
complex linear combination of two or more different *quantum states* (3.2.7)

3.2.9
basis states
members of a set of *quantum states* (3.2.7) which span the *Hilbert space* (3.2.1) of a *quantum system* (3.2.6)

Note 1 to entry: Any quantum state in the Hilbert space can be written as a linear combination, or *quantum superposition* (3.2.8), of basis states.

Note 2 to entry: A set of basis states is often chosen to be complete and orthonormal. That is, the set spans the entire Hilbert space, and individual elements are orthogonal and normalised to length 1.

3.2.10
quantum entanglement
property of a *quantum state* (3.2.7) within a joint *quantum system* (3.2.6), consisting of at least two subsystems, for which the quantum state cannot be described in terms of independent characteristics of its individual constituents

3.2.11
quantum operator
operator (3.2.2) that acts on *quantum states* (3.2.7) in *Hilbert space* (3.2.1)

Note 1 to entry: In *quantum physics* (3.2.3), non-pure (or mixed) states, which are classical statistical mixtures of distinct pure quantum states, are represented by Hermitian density operators instead of complex vectors. Density operators contain information about both coherences between the *basis states* (3.2.9) used to represent the quantum state, and about the statistical distribution of those states.

3.2.12
Hamiltonian
<quantum physics>*quantum operator* (3.2.11) which determines the coherent evolution of a *quantum system* (3.2.6)

Note 1 to entry: The Hamiltonian operator usually corresponds to the total energy of a quantum system.

Note 2 to entry: The expectation value of the Hamiltonian gives the total energy for a particular quantum state.

3.2.13
eigenstate
<quantum physics>*quantum state* (3.2.7) left unchanged by the action of a *quantum operator* (3.2.11), except for a complex scaling factor

3.2.14
eigenvalue
<quantum physics>complex scaling factor corresponding to the *eigenstate* (3.2.13) of a *quantum operator* (3.2.11)

Note 1 to entry: Eigenvalues are real for Hermitian *operators* (3.2.2) and complex roots of unity for unitary operators.

3.2.15
eigenspace
<quantum physics>*Hilbert space* (3.2.1) spanned by a set of *eigenstates* (3.2.13) that share the same *eigenvalue* (3.2.14)

3.2.16
quantum measurement
process that outputs a physical property of a *quantum state* (3.2.7)

Note 1 to entry: Quantum measurement usually involves interaction with a meter system which encodes the output of the physical property.

Note 2 to entry: In quantum computing, quantum measurement is often modelled as a *projective measurement* (3.2.17).

3.2.17
projective measurement
quantum measurement (3.2.16) for which instantaneously repeated measurements do not change the *quantum state* (3.2.7) achieved after an initial measurement

3.2.18
quantum coherence
existence or extent of unambiguous phase relationships between possible states of a *quantum system* (3.2.6)

Note 1 to entry: Quantum coherence in a quantum system is often defined between populations of different *basis states* (3.2.9) in an individual *quantum state* (3.2.7) of that quantum system.

3.2.19
decoherence
loss or degradation of *quantum coherence* (3.2.18)

Note 1 to entry: Decoherence requires interaction between a *quantum system* (3.2.6) and environmental degrees of freedom.

3.2.20
coherence time
characteristic time scale for *decoherence* (3.2.19)

Note 1 to entry: Different measurement protocols can be designed to probe different types of *decoherence* (3.2.19), and give rise to different complementary coherence times. Important examples of commonly used protocols are Ramsey, Hahn echo and CMPG.