Information in Physical Systems
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Interpretation of the action in terms of order/disorder

The laws of Physics allow us to get information about a physical system. It is natural to ask then how do these laws limit or generally identify the amount of information so obtained. Most all laws of physics derive from an action principle. We wish here to probe the question of how does the action and then the equations of motion of physics define the extent of information that they lead to. The following is a preliminary attempt at connecting the **action** to the **information (**we propose), that nature **“allows”** observers to know.

Information about a system is measured by the amount of uncertainty about that system. The more well determined a system the less information it has that is available to the observer. The less ordered the more information is available. Entropy of a system measures the equivalent uncertainty about it, consequently information available to an observer of a system is measured by its entropy. Both are then proportional to the number of states available to that system.

The Kinetic energy of a physical system measures the “un inhibited motion” associated with that system. This motion can be in any direction and involves at best elastic collisions. On its own, and with no boundaries, this motion increases the

physical volume occupied by this system and hence the number of states available to it. Such motion would then tend to increase disorder in that system, as this increases the states available for it.
Uninhibited motion which includes random elastic collisions preserves the total kinetic energy.
If these random collisions are constrained by physical forces (obtained from potentials or otherwise), either new bound states may occur or restrictions on the consequent motions would follow. Such collisions conserve the total energy: some kinetic energy may transform into potential energy and vice versa. Potentials in some cases determine these forces. In all cases physical forces restrict the free arbitrary motion and is responsible for placing the system in states that are **fewer** than when such forces are not present.
It is then possible to identify a potential energy function, or forces in general, by the reason for decreasing the number of states available for a system and hence to "increasing order" in that physical system compared to the arbitrary free motion associated with pure kinetic energy.

When one then considers the action density, as KE -V (that is the difference between kinetic energy and potential energy) one is looking at the competition between the increase (KE) and the decrease (V) of allowable states of a physical system. The integral over the volume of the system (or on all of space time available to it) then measures the net result of such a competition.

The net result is a measure of the disorder available to the system and hence a measure of its entropy. This then is also a measure of the amount of information one **can** know about the system. The higher the disorder (number of states) the more information is available.

The global variation near zero of the integral of the action is then the **optimum state of order/disorder** in this physical system. This optimum then what determines the optimum amount of information one can get from the system. The maximum information available is for pure kinetic energy, but this is reduced by the presence of a potential or generally a set of forces.
This optimum state is then defined by "the equations of motion derived" as a condition of this optimum.
If this optimum is a deterministic state, then one gets all the information allowed from it as there is no indeterminism left.

Information one may recall is a measure of the uncertainty left in a system: The measure of its entropy.

Thus, in Classical Mechanics, for example, all coordinates and momenta at future times are known exactly as determined by an initial set of conditions. All are known and there is no more information to be obtained. Full determinism follows.

If the initial set is not known the information still to be drawn would then be a function of such conditions. (Note here that the equations determined by the minimization of the action then do not alone determine whether information is zero or not. The determining factors are the initial conditions).

The equations of motion themselves tell us that the rate of change of kinetic energy (rate of increase of entropy, or rate of increase of available information) is given in terms of the rate of suppression of such increase as determined by the negative derivative of the potential energy function (rate of decrease of information due to forces).

In a non-equilibrium state for the system entropy will continue to increase.
The maximum entropy is reached when the system is at (thermal) equilibrium. In such a state Liouville's theorem applies.

The equations of motion which lead to Liouville's Theorem indicate that in Classical Mechanics
The optimum information is obtained when the volume occupied by the system in generalized coordinates space (position and momentum) remains constant. Thus, Equilibrium between KE and PE is a steady state and no further information other than the definition of the initial state is available.

When the relevant variables describing a physical system carry implicit in-determinism (e.g. state functions in Quantum Mechanics), then the equations of motion would determine exactly the future values of such variables but the uncertainty and the measure of information available is input through such initial states of the relevant variables.

Thus, although one does get from minimizing the action (amount of possible information or disorder) the selection of variables describing the system of interest also selects the state of indeterminism of that system.

For Quantum Mechanics stating that a state function is the correct variable to use, implies that whatever information is derivable from any system is given by how much information one puts in such state functions. The equations of motion of Quantum Mechanics, that are deterministic, simply transform one state to another. Indeterminism is then implicit in the use of state functions.

II. Quantum Mechanical Steady States

In solving for states in a Quantum system the equations minimizing the action (giving optimum information) would lead to states whose final determination depends on some boundary conditions. These states normally are eigen states of energy (Hamiltonian) and consequently only of other variables commuting with the Hamiltonian. These common eigenstates define then the optimum of information release (least) by the system. This embodies the exact eigenvalues values for the all observables that commute with the Hamiltonian. Uncertainty remains for all other observables that do not commute with the Hamiltonian. Available information involves all such other observables. The action simply does not allow such information to be completely determined; their eigenstates cannot arise from such an action at the same time as the value of energy for example.

If one insists on such non-eigenstates states as initial states their time development can be obtained by the action of the Hamiltonian leading to a spectrum of such states. One is forced into an increase of available information. No information change is incurred if one time develops solutions of the equations of motion. Available information remains limited for all observables that do not commute with the Hamiltonian.

The conclusion in this case is that by optimizing the action, nature seems to favor commuting sets of observables with the Hamiltonian (KE + V)!

Not all observables can commute with the Hamiltonian as then the Hamiltonian would be trivially the identity. Nature therefore allows only a limited amount of information about non-commuting observables.

III. States or solution that do not minimize information?

All observables not commuting with the Hamiltonian seem not to minimize information available to such observables. They can take a number of values. Nature does not restrict them to their eigenvalues! As they do not optimize information available about them unless they commute with a specific Hamiltonian and then only within that system. One can conclude that all information is known only about the set of observables whose operators commute with that of the Hamiltonian. None is known about those that do not have this property. Quantum systems are "allowed" to give only partial information by nature.

Further then, starting with an arbitrary state, its quantum time evolution can be determined, and the result will optimize release of information according to the criteria above: observables commuting with the Hamiltonian only are fully known; Information about all others is not known. In this latter case the likelihood of measuring a value can though be computed. Information comes with an inherent statistical probability distribution.

IV. Bell's Theorem. This theorem proves that once operators are associated with observables, information cannot be attributed to the existence of underlying "hidden variables". Thus, Operators and their algebra are essential to the determination of available information in a quantum system.
(This theorem shows that any hidden variable approach in computing spin expectations will lead to classical statistical values that are LARGER than what one gets when non-commuting operators of the spin operators are used for the same expectation. Question: Can one show from information theory alone that operators always give a lower value than a pure classical statistical expectation?

V. Quantum mechanical Measurement and the Collapse of the state function

It is often stated, in a quantum mechanical measurement, that the collapse of the state function, leads to a multitude of realities and hence that reality depends on the observer making a measurement, which seems ridiculous.

If one considers the state function as the "optimum information" allowed by nature "about a physical system" rather than being "the actual reality of that system" the problem is far better understood. The state function describes only the optimum information we can learn about that system. Although it is "a statement about the real nature of the system". Upon performing a measurement, that is after asking a question about the nature of the system by specifying a request of knowing the value of an observable, The answer (the result of the measurement) is simply an answer to that asked question and represents, rather, what we are allowed at that point to know about it!

Our conscious knowledge of that system changes with the measurement we make but not the physical nature of the system being studied. One asks a question about the system and one gets an answer. The nature of the system is independent of that question or of who asked it.

In this sense therefore a quantum description of a physical system is a display of its reality but also is only a statement of how much knowledge we are allowed to know about it when a specific question is asked. This partial knowledge is reduced to the particular question we ask in a measurement. Nature's reality (of that system) does not in any way depend on measurements we make.

When a follow up question is asked at a later time, the collapse of the state function that occurs is actually only in our "knowledge about the system". It represents the conditional state preceding any follow up question. The deterministic equations of quantum mechanics lead us to the new "available information" should we ask a follow up question.

In sum, Physical equations, the consequences of the Lagrangean we use, simply determine for us how much information we can learn about a physical system (without changing its nature that is set up by its initial conditions). The reality of a physical system changes as time flows by according to the rules of nature. The physical equations we set up simply describe how much at any one point we can learn about it. Our Physical laws determine information about a system not its reality. Information is always partial NOT complete.

VI. Having introduced the interpretation of the action and its optimization to optimizing entropy or information, it is important to note that such optimization of informational entropy has been related some time ago to physical results, in particular to a construction of the partition function of statistical mechanics and others. In fact, two books, one as late as 2004, have been written dealing with these topics.

I wish to include here references for such work below for completeness.

Khalil Bitar,
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Related references.

E.T. Jaynes Primary Papers (1957):

1. Jaynes, E.T., "Information Theory and Statistical Mechanics," *Physical Review*, Vol. 106, No. 4, pp. 620-630 (May 15, 1957) American Physical Society
2. Jaynes, E.T., "Information Theory and Statistical Mechanics II," *Physical Review*, Vol. 108, No. 2, pp. 171-190 (October 15, 1957) American Physical Society

Key Book:

• Jaynes, E.T., "Probability Theory: The Logic of Science," edited by G. Larry Bretthorst, Cambridge University Press (2003)

What Jaynes did: He showed that the maximum entropy principle could derive statistical mechanics from information theory principles alone, treating it as a form of statistical inference rather than requiring physical assumptions American Physical Society.

B. Roy Frieden Primary Book (1998):

- Frieden, B. Roy, "Physics from Fisher Information: A Unification," Cambridge University Press (1998), ISBN 978-0521599181 Wikipedia

Updated Edition (2004):

- Frieden, B. Roy, "Science from Fisher Information: A Unification," Cambridge University Press (2004), ISBN 978-0521832563 Wikipedia

What Frieden claimed: He argued that Fisher information provides a physical measure of disorder and that extremizing "physical information" (Fisher information minus "bound information") could derive physical laws from quantum mechanics to general relativity Cambridge Core.

Note: His work is controversial—critics argue he essentially renamed Lagrangian terms and that it's not clear his approach offers advantages over traditional action principles.

Rolf Landauer **Seminal Paper (1961):**

- Landauer, R., "Irreversibility and Heat Generation in the Computing Process," *IBM Journal of Research and Development*, Vol. 5, No. 3, pp. 183-191 (1961) ACM Digital Library

What Landauer showed: Any irreversible erasure of one bit of information requires a minimum energy dissipation of kT ln(2) (about 0.018 eV at room temperature), connecting information theory fundamentally to thermodynamics and resolving Maxwell's demon paradox Wikipedia.

These three works form the foundation for exploring action as information—Jaynes connects entropy to inference, Frieden (controversially) connects Fisher information to dynamics, and Landauer establishes the physical reality of information. Together they suggest deep connections between information theory and fundamental physics!