A Functional Guide to Information, Intelligence, and Agency

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Introduction

This essay presents functional definitions of *information*, *intelligence*, and *agency* (summarized in Figure 1 below). It then applies these concepts to describe:

- How the universe is filled with packets of information, including photons and high-energy particles.
- How human systems collect and correlate the information streaming around us, resulting in the growth of intelligence and agency.

Finally, this essay answers the questions posed by this contest regarding the impact of unknowability and uncertainty on humanity's understanding of the physical world.

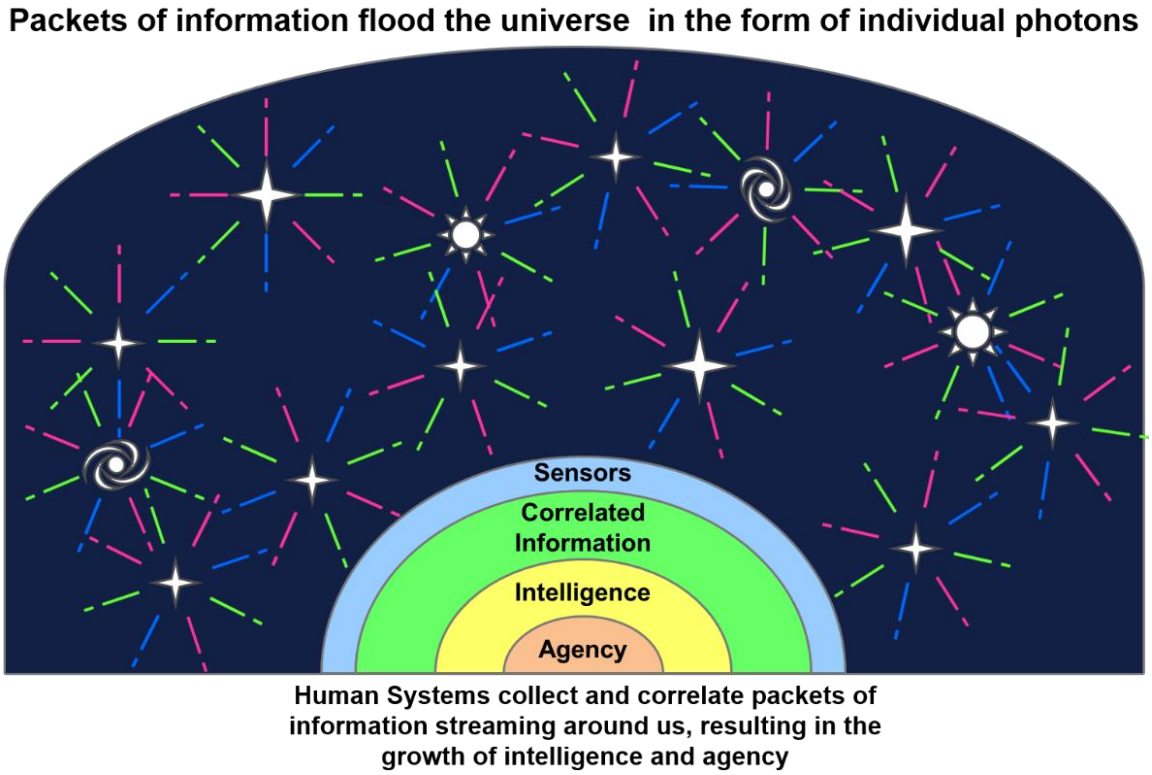

Figure 1 – Information in the Universe

Part 1 – Information and Intelligence

Definitions

We begin with the following functional definitions.

Information: an interaction or arrangement of matter that represents a physical state of another entity

- Example: A hydrogen atom (an entity) can emit a photon of a specific wavelength (a packet of information) when one of the atom's orbiting electrons jumps from one discrete energy state to another. Thus, the emitted photon represents the existence of the electron and the hydrogen atom.
- Example: A high-energy cosmic ray (e.g. a proton) indicates the existence of a high-energy astronomical source.
- Information about an entity's physical state may include one or more of the following parameters: existence, composition, configuration, motion, energy, etc. In the first example above, the photon can also represent the energy of the electron (moving from one discrete state to another) and can also represent the motion of the hydrogen atom relative to an observer, by the doppler shift of the wavelength.

Correlated Information: distinct packets or bundles of information that are combined to form a larger register of information, which correlates with the original entity

- Example: The eye of a vertebrate animal, e.g. a mouse, senses many individual photons to create a coherent image on the mouse's retina. The retinal image is spatially correlated to the actual physical environment, i.e. each photon can be precisely mapped back to its origin.
- Example: The same mouse's central nervous system can store successive images in memory to create a time-correlated record of images.

Intelligence: the ability to processes* correlated information

- This definition is very broad and includes systems which simply have the ability to store and retrieve correlated information.
- Example: A single cell organism has intelligence based on its ability to precisely store, retrieve, and replicate packets of genome data.
- Example: A mouse has intelligence based on its ability see, remember, and then recall images in sequence when it navigates along pathways or through a maze.

* Information processing can include packet conversion, transmission, storage and recall from memory. For example, an eye *converts* a retinal image to nerve signals, which are *transmitted* by electro-chemical signals to the brain, where the info is further processed and *stored* in memory. Analogous processes exist in digital information systems.

[Additional examples of information and processing are given in the addendum.]

Information and Intelligence in the Universe

This section will describe how packets of uncorrelated information from across the universe are sensed and processed to create registers of correlated information. To simplify the discussion, the emphasis will be placed on photons and how they are sensed by human systems.

We begin with a brief description of how the human eye and central nervous system (CNS) process photons from an astronomical object to create a spatially and temporally correlated register of information.

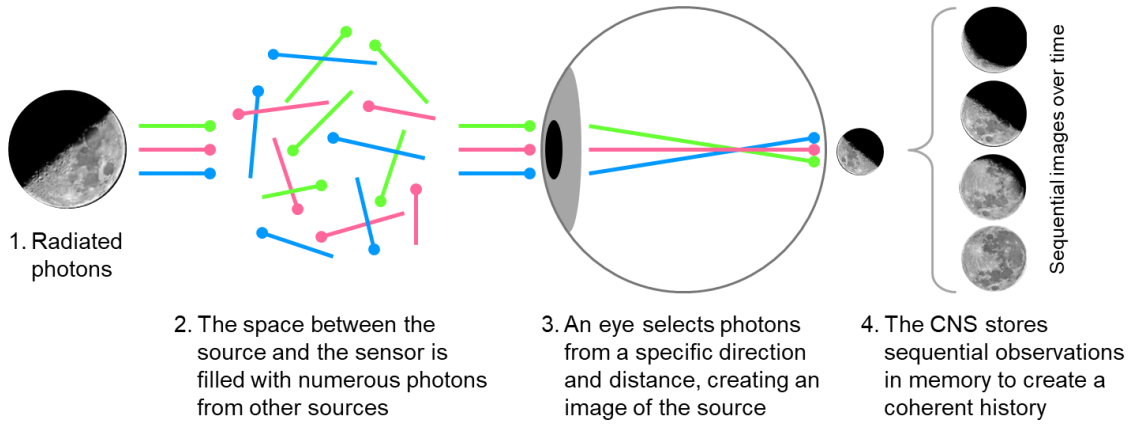

Figure 2 – A human eye collects and process separate packets of information (photons) to form registers of information in the CNS, which can be correlated across space and time

As shown in Figure 2 above:

1. An astronomical body radiates photons into space.
2. Space is filled with photons from numerous other sources but in most cases each photon is an independent packet of information and has no correlation to any other photon.
3. The human eye is bombarded by photons from these many sources but selects specific photons by the relative direction and distance to the object of interest, producing an image on the retina *having a direct spatial correlation to the astronomical body*.
4. The CNS can create memories of the images, and can recall those memories in sequence, thereby creating a *coherent history* of the astronomical object.

While this description of visual perception is rudimentary, it is meant to illustrate several key concepts regarding correlated information.

- Individual photons emanating from a source do not form a coherent representation of the source until a suitable sensor filters out any extraneous photons flying through the same volume of space. Once collected, the sensor arranges the photons into a coherent register of information, e.g. the image on a retina or a memory in the CNS.
- Lacking a sensor, the individual photons emitted by an object are not correlated with each other, i.e. there is no interaction or process that connects or associates different photons as they fly through space, even if they were emitted by the same source.
- Individual photons do not carry a record of where or how they were formed, i.e. they carry no history. It is only through centuries of scientific endeavor that humans are able to describe in detail how photons are created and how they move through space—but this is all human knowledge, and is not inherent in the photons themselves.

- Thus, the universe is filled with a blizzard of information in the form of individual uncorrelated photons. As far as we know, correlation only takes place in biological sensors and human technical systems.

Human Systems

For this essay *human systems* are defined as comprising humans and/or machines built by humans. An example of a human system could be a person using a telescope and a digital image processor to view stars in wavelengths not visible to the naked eye. While humans and machines are clearly distinct entities, they can be considered elements of an integrated system having the ability to precisely exchange and process large quantities of correlated information. The remainder of this essay will focus on human systems because there are no other known systems that sense and process a similar scope of correlated information from across the universe.

Over many centuries Human Systems have advanced well beyond the individual biological capabilities to include technical systems such as telescopes, particle detectors, gravity wave detectors, etc. These technologies are able to sense across sub-atomic and astronomic scales, extending our capabilities well be beyond our purely biological sensors.

Humans not only excel at building sensors and information systems, but also at collaborating with each other to further share and cross-correlate information. By cross-correlating information from many different individuals and organizations, humans can effectively weed out incorrect information, thereby creating more comprehensive and more accurate *Information Models* of the world and universe in which we live.

Information Models

An Information Model (IM) is a correlated representation of a system, used to predict the behavior of the system, or to infer its history. Humans use all sorts of IMs in their daily lives (e.g. weather forecasts and fantasy sports teams) but notable early scientific examples include Kepler's laws of planetary motion, and Newton's laws of motion and universal gravitation.

For centuries people have observed and recorded the motions of the sun, moon, planets and stars, the changing of the seasons and rise and fall of tides. Humans have refined and correlated numerous independent observations to create highly accurate models of planetary motion. Humans have sent probes to the moon and planets to gather and analyze their composition. We have compared the material composition of the Moon and Earth and found their chemical signatures quite similar, allowing us to conclude the Moon was once part of the Earth. We also use precise IMs of the Sun and stars to set our clocks and calendars and to navigate around the Earth.

Figure 3 shows how these many observations have gathered sufficient information from our solar system to create comprehensive IMs of the solar system's behavior and origins.

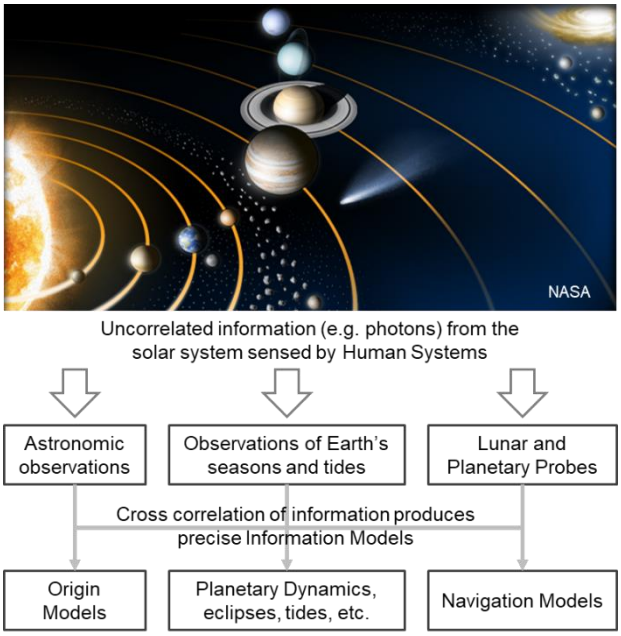

Figure 3 – Information Models of the Solar System

In modern times the extent and accuracy of human of Information Models of the overall universe have increased rapidly as we have advanced our technology to look deep into space and to manipulate matter at subatomic scales. We have combined our knowledge of high-energy particle physics with our observations of deep space phenomena to determine the history of the universe, including its age, its early development following the big bang, and its likely accelerated expansion into the far future.

Thus, over centuries, humans have gathered numerous uncorrelated packets of information from across the universe, and have transformed that information into a highly correlated representation of the universe's behavior.

Confirming Correlation

At this point in the discussion, the question could be raised as to whether or not these human created IMs actually correlate to the real world—or, are human IMs simply self-referential constructs of the mind with no relationship to the real universe.

The correlation between IMs and the real-world can be confirmed by the example of designing, building, and then sending a probe to Mars to collect data. The process of developing a spacecraft and planning for its trajectory to Mars must cross-correlate numerous sets of information including orbital mechanics, computer simulations, engineering disciplines, scientific experiments, and launch vehicle integration. Once the spacecraft is launched, reaches its destination, and successfully conducts the scientific experiments, then all the human IMs used to plan and execute the mission are validated. This demonstrates the IMs are in fact precisely correlated with the actual behaviors of Earth and Mars, and their orbits through the Solar System.

Part 2 – Agency

Part 2 of this essays builds on the previous descriptions of Information, Intelligence, and IMs to develop a functional description of Agency. The relationship between intelligence and agency is that agency applies intelligence to intervene in processes that are of interest to the agent.

For background, one of the Merriam Webster definitions for agency is: *the capacity, condition, or state of acting or of exerting power.* This definition can be applied to simple cause and effect scenarios such as gravity causing a comet to fall towards the sun.

In contrast to the Merriam Webster definition, this essay identifies a more specific form of Agency – *Informed Agency* – which requires an *agent* with intelligence to form a *information model* of a real-world process, and then apply the IM to intervene in the real-world process. The IM must include several distinct elements including an *agent*, an *objective*, and an *intervention*.

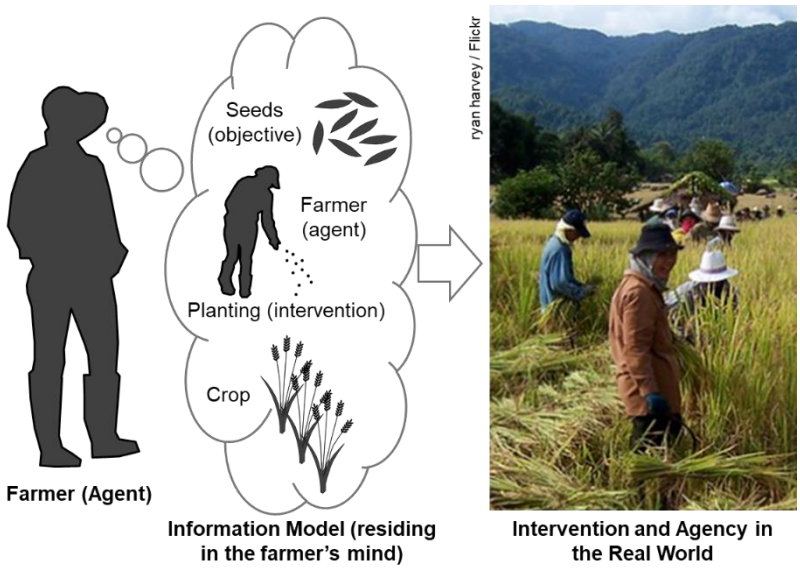

Figure 4 – Informed Agency: Sowing Crops

To illustrate Agency, we will start with a farmer sowing crops. Figure 4 shows a farmer using her intelligence to form a coherent IM, which includes the seeds (the objective), the farmer herself (the agent), and the farmer planting the seeds (the intervention). The famer then applies this IM to the real world, and if successful, produces the desired crop.

By contrast, seeds that naturally fall to the ground and start new plants are not an example of Informed Agency, because the plants and seeds do not possess a coherent IM of the objective, agent, or intervention. While plants do contain genetic information, which determines how they will grow, they do not determine when or where they will grow. In contrast, a farmer who wants to increase crop production will plant crops in rows, in a suitable field, at a specific time, thus exercising agency by intervening in the natural growth cycle.

This Informed Agency concept can also be applied to technical scenarios as shown in Figure 5 below. Here a scientist envisions and plans for a test in the Large Hadron Collider (LHC). One of her objectives is to collide high-energy hadrons (the objective) to produce a shower of sub-atomic particles. She also assembles a team of scientists (the agent) to prepare and conduct the experiments (the intervention). Otherwise stated, the scientist creates a mental IM of how to intervene in the hadrons' normal behavior to produced desired results in the real world.

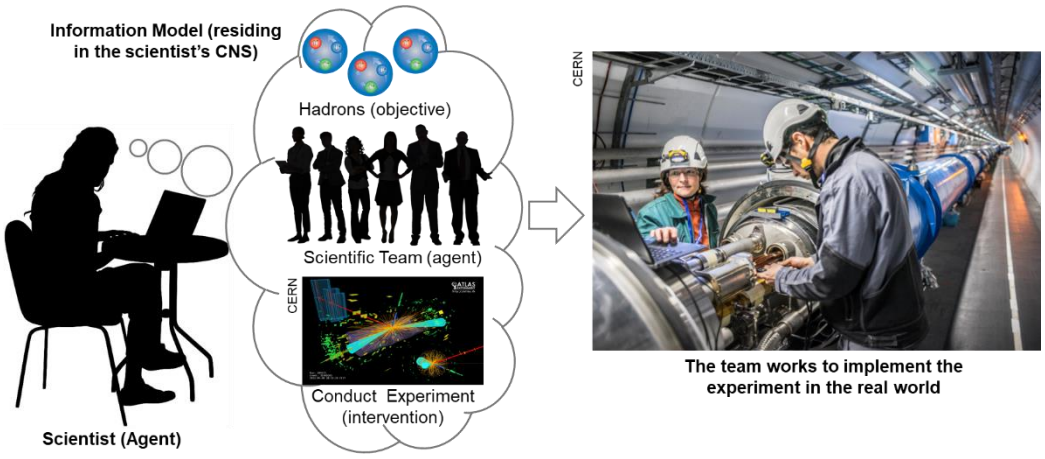

Figure 5 – Informed Agency: Preparing for a Test in the LHC

Human Scale of Intelligence and Agency

The scale of human intelligence and agency in the universe is summarized in Figure 6 below. The chart shows a historical summary of human discovery covering—on the vertical axis—both large (astronomic) and small (particle) scales. The events marked on the horizontal timeline roughly correlate to the growing scale of humanity's Information Model of the universe.

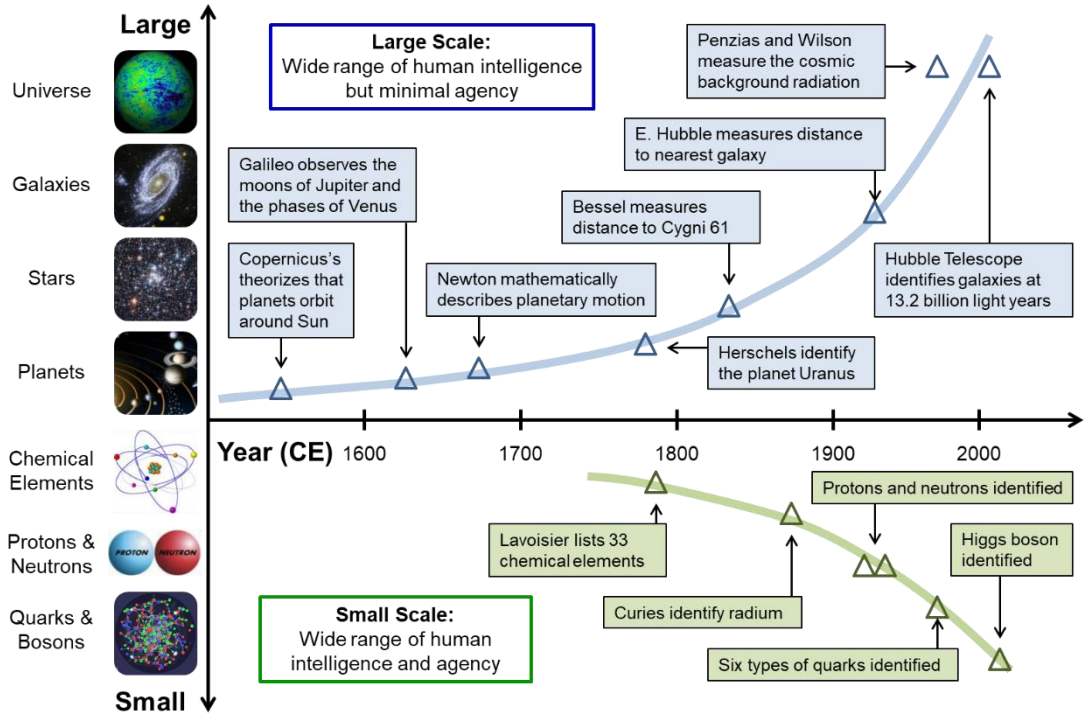

Figure 6 – Timeline of Expanding Information Model of the Universe for Large and Small Scales

From this diagram we can draw the following high level findings, which distinguish between large and small scales, and between intelligence and agency.

- Human **intelligence** regarding the **large** scale universe is extensive. We are able to observe, measure, and describe many astronomical phenomena including the Cosmic Microwave Background (CMB). However, there are also many phenomena we are still figuring out, including dark matter and dark energy.
- Human **intelligence** regarding **small** scale phenomena is also quite extensive and includes descriptions of the smallest particles of matter and how they interact to progressively build protons and neutrons, chemical elements, molecules, and even living organisms. However, we still have much to learn regarding quantum behaviors.
- Human **agency** on **small** scales is significant. We are able to precisely intervene in chemical and sub-atomic processes (see the LHC example above).
- However, human **agency** on **astronomic** scales is essentially non-existent. While we may be able to observe, we are currently unable to intervene in any astronomical process, other than sending spacecraft around the solar system for planetary exploration.

- While human agency falls short of astronomical scales, we should note that the LHC's high energy particle experiments are specifically designed to simulate the conditions of the big bang and to inform us of the properties of the early universe. This suggests a small degree of human agency with regard to some of universe's early processes.

Part 3 – Information Gaps and their Effects on Humans

Having described intelligence and agency we can now switch our discussion to the gaps in human intelligence, which are quite immense. A short description of some of those gaps is given below.

- Inaccessible information: Human Systems are only able to sense and process a miniscule fraction of the universe's total information content, while the vast majority of information continues to fly through the universe well out of reach of our sensors.
- Uncertainty: As mentioned in the essay contest announcement, there are real barriers to observing and measuring phenomena at quantum scales, and there are real barriers to our ability to compute outcomes on all scales.
- Information Loss: Even after sensors collect information, much of the information is lost through conversion errors or corrupted memory in both biological and machine systems.

Which brings us to the specific questions of this contest which will be answered based on the material previously presented in this essay.

Q: Are there real consequences for physics of undecidability and non-computability?

A: Yes, there are consequences. We do not have the theoretical capability nor the quality of instruments to measure phenomena beyond an inherent level of uncertainty, and we lack the ability to compute outcomes regardless of the quality of the starting data. The result is that many things will remain unknown to us.

Fortunately, humans have a pretty effective technique to mitigate uncertainty: *Estimation*.

Despite humanity's highly restricted access to information, and all its inherent errors, we have used educated guesses and estimations to great effect, expanding the scope of our intelligence when certainty and computability have reached their limits.

Q: Are there implications for our understanding of the relations between agency, intelligence, mind, and the physical world?

A: Yes, there are implications. This essay has described information, intelligence, and agency and has shown how they relate to the physical world. Intelligence and agency are affected by limited or low-quality information. If we do not have sufficient high-quality information then the effectiveness of our agency suffers and we can make bad decisions.

Again, humans have another trait to mitigate this issue: *Humans are Persistent*.

Human endeavors are characterized by repeated failures as we attempt to make progress with limited or low-quality information. However, our preferred response to failure is to learn from our mistakes and to try again. In the case of undecidability, or if there is no clear way forward, humans will flip a coin and see what happens next. Eventually, by chance or by hard-won intelligence, we find a solution to the problem, the question, or the mystery we are trying to solve. These concepts are not some sort of motivational slogans, they are in fact essential elements of humanity's inherent capability to gather and correlate information, and to expand the reach of intelligence and agency in the universe.

Addendum

Additional Examples of Information:

- Gravity represents the existence of mass
- A spectral signature represents a specific type of atom or molecule
- Acoustic waves represent the vibrations of an object
- A messenger RNA molecule represents the gene sequence of a DNA molecule
- In human terms a written language represents a spoken language and vice versa
- In computer terms electrons on a memory chip can represent ones and zeros, which in turn may represent ASCI code, which in turn may represent letters in a text
- Memes represent other memes: http://www.quickmeme.com/Hipster-Cosmology
- Weird Al represents Obi Wan Kenobi: https://www.youtube.com/watch?v=hEcjgJSqSRU

Additional examples of Information Processing

- Assigning metadata including naming and tagging
- Higher-level processing including, categorizing, sorting, searching, matching, and correlating
- Compressing, filtering, etc.
- Logical or mathematical operations
- Note: all processes listed above are ubiquitous in both humans and machine systems

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