Information Theory—part 4: fundamental theorems of Coded Information Systems Theory

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In parts 1 and 2 of this series the work of various information theoreticians was outlined, and reasons were identified for needing to ask the same questions in a different manner. In Part 3 we saw that information often refers to many valid ideas but that the statements reflect we are not thinking of a single *entity*, but a *system* of discrete parts which produce an intended outcome by using different kinds of resources.

We introduced in Part 3 the model for a new approach, i.e. that we are dealing with Coded Information Systems (CIS). Here in Part 4 the fundamental theories for CIS Theory are presented and we show that novel conclusions are reached.

In Part 3 of this series[1] we emphasized that the word *information*, although singular, often refers to separate entities. This led to the notion that we are often describing a *system*, parts of which involve coded messages.

> *Definition*. A Coded Information System (CIS) consists of linked tools and machines designed to refine outcomes to attain a specific goal. A coded message plays a prominent role between at least two members of this linked series.

Theorems to explain CISs

A series of theorems are presented next, to clarify what a Coded Information System (CIS) is. These are based on observation and analysis of all coded information systems known to us.

Theorem 1. A CIS is used to organize matter and energy to satisfy an intended goal. All components of the system which guide towards the final outcome, including timing and location, are part of a CIS.

The resulting organization of portions of the material world reflect intended goals. All the components involved in a series of refinements to attain the final state are part of the CIS, and their effect must be quantitatively measurable, at least in principle.[2]

Theorem 2. A CIS can be used to achieve a mental goal.

In the absence of wilful input, the organization of matter can be explained by deterministic laws of nature and statistical principles of randomness. Mental processes, however, are not controlled deterministically or by randomness, and include: making choices; seeking to understand; and developing a strategy.

Suppose you are learning German, and are reflecting on what *Unsinn* might mean. The intention to translate is surely not deterministic, nor explained by randomness. Perhaps the intention is stored temporarily (physically?) in the brain, with which an immaterial *you* interacts almost instantly. You know what you wish to do and can easily communicate this to others. This intention is converted somehow into a physical search through the data stored in your neurons. This requires very special mental equipment, since a multitude of kinds of searches are possible: for a discrete telephone number; for how a face looks; for a melody. The list is near endless. In this case we're searching for a concept which we believe reflects the meaning of *Unsinn*.

The concept we seek to translate must be encoded in some manner, and the searches directed efficiently. Suitable data must somehow be extracted from the neurons, requiring further mental machinery, and the results must be encoded and transferred somewhere for the mind to evaluate. Another tool then compares a candidate English word, the associations of which get compared with those of *Unsinn*. It is absurd to argue neurotransmitter concentrations or electrical signals are being 'compared' across billions of neurons. The logical processing must involve some kind of compression and high-performance language. Eventually the mind decides whether a potential translation of *Unsinn*, like *nonsense*, is correct or not.

All the resources involved in mental processes like these are part of a CIS, and *some are not physical*. Various resources narrow the range of possibilities, including when the translation is to occur and where.

Theorem 3. Coded messages do not arise from the properties of the physical carrier medium.

An implication which results is that the symbols used by the coding alphabet can appear in any order and combination, whether the resulting messages serve a purpose or not. Ideally the carrier must not place any constraints on the potential messages which could be created.[3]

By our definition, a CIS must use a coded message at some point. Otherwise we'll treat the phenomenon as a tool. Some coded messages provide step-by-step instructions on how to accomplish something. Examples include computer programs and algorithms. These messages must be supplemented with hardware able to carry out the instructions.

Another class of coded messages only specify specific outcomes or choices, without any instructions on how to attain them. A communication convention must be established *a priori*. The message '*01101*' might mean 'bring me menu number thirty one', or 'pitch a curve ball'.

Combinations of these two extremes are possible, such as when a computer program invokes a subroutine (or method or function) using parameter values.

Coded messages permit intended outcomes to be communicated between flexible tools and machines, which have been designed to solve a class of problems. This is an efficient manner to use resources to solve problems. The alternative would be to build assembly lines of machines to solve each individual problem and then to communicate which ensemble is required for each problem.

Instead, to illustrate, billions of dollars of complex logistics components of an overnight delivery service can be put to use flexibly by only associating a coded delivery address to the object to be transported.

The use of coded messages characterizes living organisms, to control their development and response to novel situations; and to interact among each other. Humans devise coding conventions with so little effort that few realize what an extraordinary feature this is. Being so fundamental to a wide class of life-related observations, the presence of a coded message is a requirement for a system to be considered a CIS.

Theorem 4. The coded message does not provide the energy which causes the intended changes.

The outcomes produced by messages must not be caused only by the carrier medium, to distinguish from mere mechanical effects. The symbols in a coding alphabet could indeed require different amounts of energy to be generated or processed. For example, in alphabet $\{0, 1\}$ the *0* could be communicated by lifting one arm, and the *1* by lifting both arms. But the energy to produce the symbols must not lead to the resulting changes upon processing the message (e.g. by providing different levels of force, or resulting momentum in a specific direction, caused directly by the symbol). Theorem 4 draws attention to the need for independent components to be engineered for a CIS to work. Energy in the right form, time, and place must work with the intent expressed by the message.

Theorem 5. Outcomes improved beyond what coded messages alone convey imply additional refining components are involved. The additional contributions can be expressed quantitatively.

An example in Part 3 of this series[1] revealed this principle. The coded message communicated only four possible choices (two bits of information), but an internal clock revealed in addition whether a race had been carried out during odd or even hours, thereby indicating the gender of the winner. Therefore, the correct one out of eight choices was able to be determined with the help of the clock.

Example 1. Assume the jets on an aircraft carrier are only told whether to fly off in one of four quadrants, figure 1. Suppose careful observation shows that the pilots begin search manoeuvres only once beyond a certain distance from the ship (therefore, the central square in figure 1 was excluded).

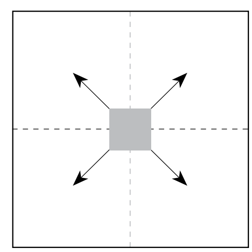

Figure 1. A jet interceptor is instructed to fly off in one of four possible directions. This provides $\log_2(4)$ = 2 bits of information.

Although $\log_2(4)$ = 2 bits of information can only communicate the correct quadrant, we observe that the target is usually identified, although located within a small portion within a quadrant. How is this possible? Clearly additional refining components were available. Repeated observation would allow the scientist to identify at least three sequentially refining components (without knowing anything *a priori* about the details of the coded message): a) a coded message directs into one of four directions; b) searching begins some distance from the carrier (there is prior knowledge that an alarm will occur when the enemy is still far away); c) there are specific kinds of targets to search for, plus logic and special equipment to perform the searches.

Example 2. Protein-coding portions of DNA are the messages which communicate the order in which each of twenty possible amino acids are linked. But notice that almost always only *l*-form amino acids appear in the proteins. The choice of isomer was not communicated by the mRNA messages, but optically pure amino acids were independently manufactured as feedstock. We also observe that undesired chemical reactions amino acids normally undergo are prevented when forming the proteins. For example, the side-chains of amino acids don't react together, nor do short five- to seven-membered chains form.[4] This is true because outcome-guiding equipment was deliberately included in the design.

Other illustrations (examples A1–A6) are offered online. Figure 2 is explained in example A4 on-line.

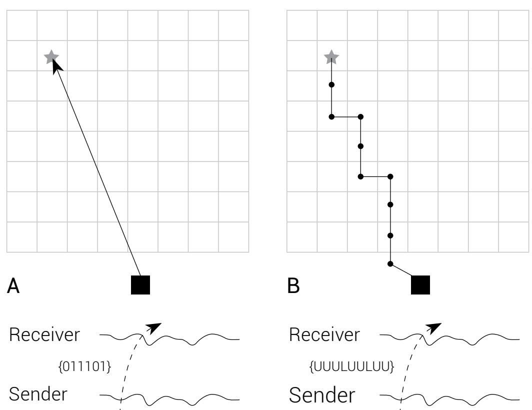

Figure 2. Trade-offs between message complexity and engineering design. A) The message communicates only the final destination. Resources receiving the message must interpret it and have the means to act upon the communicated intention. B) The message communicates step-wise what is to be done. *U = 'Up'; L = 'Left'* one unit. Now the messages are more complex but the equipment can be simplified.

Theorem 6. Receipt of a message often communicates more than just the coded content.

The bits of information provided in a message provide an incomplete picture from the point of view of resulting outcomes. Although choices between alternatives can be communicated, the changes which result occur in narrow time and location ranges. The equipment receiving the message could be used more than once, and the correct Receiver could be targeted, at the correct time and location.

Example 3. A zip code can communicate where to deliver a package, but *when* it is generated and on *which* object make a difference! The intended goal must be taken into account.

Theorem 7. Refinement components are integrated into a sequence to produce the intended outcome.

Refinement components, designed to refine towards a goal, include:

- received coded messages
- engineered constraints or guidance
- external cues
- preloaded algorithms or reasoning resources.

The state of affairs achieved from one component of the CIS becomes the starting point for additional improvement by other components.

Theorem 8. The quantitative contribution of Refining Components can be calculated by comparing ranges of behaviour before and after the goal-directing activity.

A fundamental notion in CIS Theory is to identify the contribution provided by each discrete component in the processing chain, by identifying the range of behaviour before the refinement and afterward. The theory applies to any kind of behaviour in time and space. And the improvement can be due to receipt of a coded message and/ or of other factors.

The range of possible outcomes will be represented by a discrete number *n*; the entropy *H*; L or a probability distribution function. We will use some mathematical ideas developed by Shannon, as discussed in Part 3,[1] to define the *Refinement Improvement*[5] as $H_{before} – H_{after}$, which is measured in bits. This permits the improvement by each member of the chain, expressed in bits, to be additive.

Theorem 9. Quantifying the contribution from a received message may require analysis of a single final state or of intermediate ones along the way. It is necessary to evaluate what the intention is.

Example 4. In the CIS methodology we focus on behaviour which results from refining factors, and not the statistical details of coded messages (which is Shannon's methodology). Unlike Example A4 online, suppose the intention of a message was to provide an itinerary, figure 3. Comparing one final destination with all possible outcomes (1/64) would be wrong if the intention was a 'milk run',[6] like a parcel service delivering packages, or a path to transverse a mine field, or to avoid incoming missiles. Then the result of *each* successful decision would need to be compared to the relevant reference state and not the one-time final destination.

If the intention was a one-time delivery of a package to a final destination, then the space of random possibilities around the starting point would be the 'message-less' state and would define the possible outcomes.

Alternatively, if the intention was to avoid in-coming missiles again and again, the random behaviour around each decision point would define the reference state. Note that in these kinds of analysis another resource is at play. In the random reference state, the vehicle has no reason to move at all. Independent of the message's content, its receipt communicates that something is to be done.[7]

Often a message communicates more than necessary. This could be due to incompetence; or to refine or to correct instructions already sent. It is also possible that other resources (logic, stored data) available to the Receiver indicate that messages, or parts of them, are to be discarded. For example, the message to print a page with various colours could be corrected by software which is 'aware' that a colour cartridge is missing and only black and white outputs can be generated.

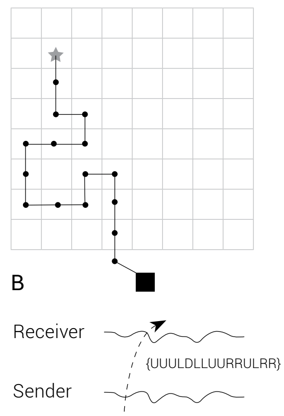

Figure 3. Convoluted messages could reveal incompetence or deliberate intention. Upon processing the message, the vehicle here ends at the same place as shown in figure 2, although the message and trajectory is now more complex. If the intention was only to deliver to a specific location, then the message 'select one out of 64 possibilities', or 6 bits of information, would suffice. But if the trajectory had a deliberate purpose, the outcome would have to be compared to the relevant reference alternatives, taking each subgoal into account.

Theorem 10. Part of a CIS may permit behaviour to occur which otherwise wouldn't be observed. To quantify the improvement provided by one of the CIS resources, a realistic hypothetical reference system behaviour needs to be defined.

Example 5. DNA encodes the order in which amino acids link to form proteins. For this to occur, the carboxyl group *at the end* of one amino acid must react with the amino group at the *other end* of another amino acid, to form peptides bonds. But amino acids in free nature or a laboratory undergo a variety of other chemical reactions. As an example, amino and carboxyl groups that are present on side-chains can also react. In addition, the carboxyl and amino acid ends of a growing polypeptide will react in an intra-molecular fashion, creating cyclic rings; and other reactions also occur.

In cells, clever design prevents the wrong reactions from occurring. Computer simulations could be built to estimate the proportion of protein-like chains which amino acids would form compared to all possible reactions, based on *d* and *l* racemic mixtures.[8]

Example 6. In water, peptides hydrolyze instead of forming long chains. For even a very short protein with 100 peptide bonds (101 amino acids), the equilibrium concentration would be about 3×10^{-216}.[9] So how can proteins form at all in cells? It is because water is excluded from the interior of the ribosomes, and energy is provided by ATP to drive the polymerization reaction forward.

These examples show it is impractical (and unnecessary) to always perform empirical studies on how nature would react in the absence of a CIS. But a reasonable estimate is still useful, and the probabilities can easily be converted into bits of information.[10] It is usually sufficient to determine when a probability is so miniscule that nobody will ever see the event unless something, like intelligence, provides a new pathway for it to occur.

Theorem 11. Individual Refinement Components can contain multiple improvement steps.

We saw in Examples 5 and 6 that specialized machinery like ribosomes can make multiple contributions. One can combine contributions to simplify the analysis if one wishes.

Theorem 12. Accumulated goal refinements, defined by CIS in bits, reveal far more about what is accomplished than Shannon Information Theory implies.

Molecular machines are built to solve thousands of kinds of problems such as catalyzing metabolic reactions, transporting bio-chemicals, and replicating chromosomes. The quantitative CIS theory seeks to explain how so much more is accomplished than is implied by the statistical studies of coded messages, such as of gene sequences.

Example 7. In the brain there are special kinds of cells called neurons, organized into specialized signal-processing subsystems.[11] These come in many sizes and shapes with very different designs and functions. There are about 10^{11} neurons in the human brain and about 10^{14} synapses,[12] which must be placed at the right locations, and interconnected correctly. As an example, the Purkinje cells of the cerebellar cortex have about 200,000 synaptic contacts each.[13] The first question is, where do the instructions come from to physically build such complex brains? And second, where does the input come from which permits brains to make thousands of multimedia decisions each second?

These requirements cannot be explained by the bits of Shannon information implied on the chromosomes of the fertilized egg. The coded information is embedded in a context which provides additional refinements, and the neurons are refined by their ability to learn.

Theorem 13. There can be trade-offs in how a CIS can be designed. The contributions towards the goal, expressed in bits, can be distributed between the message and the hardware equipment.

Examples A4 and A5 online illustrate this principle.

Example 8. Suppose 20 copies of five books are to be printed out. One solution would be for the message to transmit the relevant text each time for every book, which flexible printing equipment must then process. Another solution would be to build five machines, each of which mechanically prints out a single book. Now one only needs to send a signal to the appropriate machine, 20 times, communicating to start printing. The final outcome is the same, but the effort, expressed in bits according to resulting outcome, are distributed over different refining components.

Example 9. Printers can often handle papers of different standard formats. The content to be printed, plus instructions on how to manipulate all the physical parts to position the paper and ink in the right position, could be part of a huge coded message. A better design would be to engineer the printer to always position the paper for each standard size in the same manner, so that the message only needs to communicate the content and paper size.

Example 10. Many business presentations benefit from the use of colour. The background colour and display for PowerPoint presentations are communicated along with the content to be presented. This is a better design than to send content to a large number of differently designed printers, each filled with paper prepared with a specific kind of coloured background.

Theorem 14. The hardware components found in an integrated CIS do not arise from the properties of the physical carrier medium.

For example, many kinds of media can be used to store the same computer data. These materials could be made into memory sticks, DVDs, hard disks, archival systems, etc. The origin of these engineered parts, as also for biological parts, are not simple extrapolations of atomic properties. They have to be wilfully organized.

Theorem 15. The contribution towards a goal provided by a particular refinement component cannot be more than the improvement observed, expressed in bits.

This is related to Theorem 5.

This simply means that guiding towards a goal cannot come for free. If there are eight equally likely outcomes, communicating the correct one each time cannot be done with less than three bits of coded information.[14] These must come from somewhere. This theorem is intuitively obvious but woefully neglected in the evolutionary literature. Bartlett[15] recognized correctly that rapid change can, and does, occur in nature, if the guiding inputs have already been made available and only need to be activated. The notion of preloading of information to ensure future outcomes is also common among Intelligent Design thinkers.

Scientists realize intuitively that purposeful behaviour implies that guidance is coming from somewhere. The fact that the same kinds of proteins always ended up in the same place in cells led researchers to look for special signals guiding this process. And the rapid response of whole populations in short time periods to environmental changes led to the search for, and discovery of, epigenetics.[16] What is overlooked is the fundamental insight that planning and ensuring desired outcomes are characteristics of intelligent agency, and that the methods used to store intent are not found anywhere in inanimate nature.

Theorem 16. There is no direct relationship between goal refinement in bits and importance of the outcome.

Thumbs up or down decided life or death of a Roman gladiator. One mere bit of information, two possible outcomes, but with a dramatic impact!

Theorem 17. Bits in CIS theory are not a direct indicator of difficulty in achieving the goal.

It is true that there is an inverse relationship between many bits in outcome, and likelihood the effect could arise by chance. This is especially clear in CIS theory, where outcomes are compared to what would happen by natural processes. But one must recall (Theorem 13) that there are trade-offs between what the message and the hardware could provide. A simple message to an aircraft carrier flotilla to ‘turn left’ or ‘turn right’ represents only one bit of information because the rest of the details necessary are handled by other parts of the CIS. These one-bit coded messages have a huge lever effect. If the design of two CISs have identical final outcomes, then a comparable number of bits should be calculated. But focusing on the number of bits provided by intermediate CIS ‘services’ can be misleading.

Theorem 18. Wilful, intelligent decision-making occurs during the processing of a CIS; or decision-making has been pre-loaded for it to occur autonomously.

In some CISs, parts can respond mechanically, whereas in other CIS designs, intelligent decision-making is involved. In the mechanical version, intelligence is used to ensure intended outcomes. Complex algorithms can be devised to free active intelligence from having to be present during future execution of a CIS. Examples are techniques used in artificial intelligence. In addition, sensor and queries to the environment can be automated to ensure reliability of the automated portions of a CIS.

Theorem 19. The performance of a CIS will not improve over time in the absence of intelligently provided guidance.

Refinement in the outcome or adjustment to new circumstances requires preloaded facilities in some part of the CIS. One must not overlook, however, that improvement is possible through an algorithmic, iterative process of selection. This occurs for ß-cell maturation[17] and there are many examples in numerical analysis, like Runge-Kutta methods.[18] Natural selection could conceivably be an example, if a small number of organisms, like bacteria, were initially created with the intent of diversifying and specializing. But for this strategy to work, outcomes must be fed back into the causal instructions and an effective method already built in to move in a promising new direction.

Theorem 20. Natural processes are not capable of creating a CIS. Only sentient, intelligent beings able to identify desired goals can create a CIS.

The justification for this is two-fold. First, we notice how easily intelligent beings like humans design a CIS, whereas nothing resembling a CIS occurs in the abiotic universe.

Second, by examining in depth how outcomes are guided, we notice that the resulting bits of improvement are huge. These are calculated by comparing to a reference state which lacks the CIS, which ultimately means comparison to random processes, or to those guided by natural law.

Every bit represents a factor of two change in probability, where two scenarios are being compared: that the initial state migrated into the new one via the natural processes already operating vs via deliberate intervention.

Results from replacing information by CIS

Given the many meanings of *information*, asking where it comes from is too vague and ignores the full picture the Coded Information System approach offers. The issues already introduced in the literature[19,20,1] about information are all subsets of a CIS. For instance, one can always ask what the source of a coding convention is, and coded messages are part of a CIS. Or what guided a particular message to the specific Receiver. CIS goes beyond what Shannon looked into. For example, the decision *when* to send the message is also unique to the CIS approach.

The underlying notions presented in this paper lead to different answers than generally offered about *information*.

1. Gitt and others say that multiple copies of an identical message do not provide 'more information'. Once how to accomplish something has been communicated, extra copies are not considered to offer anything additional. This has been a criticism of Shannon's approach, where if two communication channels transmit the same message, twice as many bits of information are claimed.

However, the effect of a CIS is to reorganize matter and energy for some purpose. Therefore, if a coded message is used repeatedly in a CIS at different times and locations, then more matter and energy have been organized. The effect, in bits, is greater from the universe's point of view. This means that if there are identical copies of a bacteria, the effects of each of these CIS would be additive. Is this not reasonable?

We prefer this view than to ask where a gene comes from, and then report the bits from only one copy. Furthermore, reuse of a CIS (including after genetic reproduction) requires the existence of other complex components, which automatically get neglected if one copy and one event only are reported. The total effect of multiple copies and reuse give credit naturally to the additional components which make this possible.

Cellular machines can process similar metabolites, using the exact same genes. But in one microenvironment a nutrient might be present but not in the other. Therefore, the measurable effect of two separate but identical CISs at different times and places can vary!

The earth contains about 6×10^{27} gm of matter.[21] And 12 gm of the isotope carbon-12 contains 6×10^{23} atoms. The number of entities on Earth is very large, whether we mean atoms or molecules, on the order of roughly 10^{50}.[22] Potentially any entity on Earth could be associated with any other: as part of a chemical reaction; as part of a new object; or to modify the properties of other entities. Merely moving an entity during a second changes about $10^{(50)2} = 10^{100}$ pairwise distance relationships, and sometimes multiple other properties besides only their spatial relationships. The organization of all objects on Earth related to living organisms is a vast number, which places great demands on the organizing effects of the available CISs.

Organizing nature on Earth, with its complex ecosystems, means rearranging all this matter and energy in the face of the unimaginably large number of possible distributions. The CIS model credits contribution to this effort to the *multiple copies* and *reuses* of the message-containing information systems.

2. Gitt considers his theorems laws of nature. For example, Scientific Law of Information (SLI) 3C states, "It is impossible to generate UI without an intelligent sender."[23] The justification seems to be that the claimed SLIs should be considered laws until disproved. This seems like a weak argument, since there are many statements which reflect all known experience so far and are difficult to disprove. All facts to date support a claim such as, "It is impossible to build a manned station on another solar system", but is this a law of nature? We certainly agree that UI (Universal Information) cannot arise by natural processes. But by UI we mean the whole package, which is a CIS. Based on known science, we are persuaded that bringing together all the components needed by a CIS, at the right time and location, including a coding convention, is never going to happen. But we believe the CIS justification is sounder, since quantitative and measurable criteria underlie this belief.

A new view of nature

CISs can be embedded hierarchically. A low-level CIS could synthesize an amino acid, which is embedded in a higher CIS to produce proteins. The system analysis would now include all factors involved in reproducing DNA;[24] decoding DNA;[25] regulating location;[26] timing;[27] and number[28] of enzymes (mostly proteins); and formation of the tertiary[29] and quaternary[30] protein structures, including bonding to other bio-chemicals. An example of a higher-level CIS, with embedded subsystems, would be a multi-cellular organism and include all processes to develop into the final, mature state. An example of a still higher order CIS, with a hierarchy of embedded sub-CISs would be an ecological system, consisting of a variety interacting species.

In Part 3 we provided a figure to help visualize how a series of embedded, refining contributors narrow the range of behaviour, using a combination of a) coded messages; b) signals; c) preloaded logic processing and knowledge; and d) engineered components. This is, of course, merely conceptual, and leaves out the exact details used. These four generic classes of refining contributions can be re-invoked to understand the deeper levels of refinement, level by level.

This analysis offers a new way of looking at the world we live in. Vast quantities of matter and energy have been organized within hierarchies of dynamic CISs, leading to a cascade of intermediate goals. And our world itself is embedded in higher CISs as part of ultimate goals.

Conclusion

The CIS model considers the quantitative contribution of all goal-refining components linked by the system. Instead of asking where *information* comes from in nature, we propose to ask where Coded Information Systems come from, which ensures a more complete coverage of all the issues which need to be addressed.

The twenty theorems are based on observation and serve to clarify the key ideas of CIS theory.

Additional examples of CIS are discussed in the on-line appendix to illustrate these principles.[31]

References

1. Truman, R., Information Theory—part 3: introduction to Coded Information Systems, *J. Creation* **26**(3):115–119, 2012.
2. Quantitative descriptions are a valuable aspect of modern science and a desirable feature any model of information should satisfy. The components of a CIS may be difficult to quantify to great precision but there should be no doubt quantification is possible. The exact volume of an irregularly shaped balloon or of a distant star may be difficult to measure, but their quantification is not a vacuous notion *per se*.
3. Some authors are mistaken on this point, claiming the message carrier poses no restrictions on which messages could be generated. For example, DNA or mRNA chains which are too long they would solidify. Also, base-paired mRNA substructures can serve as signals for frameshifts in the ribosome, limiting the choice of codons which can be used.
4. Outside the cell, the carboxyl group of one end of a short polypeptide can react with the nearby amino end to form usually six-membered products. Under reaction conditions necessary to link amino acids (absence of water, fairly high temperatures) in nature, the concentration of amino acids will be miniscule, so that the intramolecular peptide bond is far more likely to occur than intermolecular ones.
5. This is equivalent to Kirk Durston's Functional Information; see Part 3.
6. 'Milk runs' are a class of problems studied in computer science and logistics; en.wikipedia.org/wiki/Milk_run.
7. This fact is not relevant to other theories of information, such as Shannon's.
8. Since *d*- and *l*-form amino acids have close to identical reactivities, the probability of obtaining a pure L-based chain 300 amino acids long will be close to $(0.5)^{299} = 10^{-90}$.
9. Sarfati, J., Origin of life: the polymerization problem, creation.com/origin-of-life-the-polymerization-problem.
10. For example, a probabilistic estimate of 10^{-300} implies $-\log_2(10^{-300}) = 996.6$ bits.
11. Gazzaniga, M.S., Ivry, R.B. and Mangun, G.R., *Cognitive Neuroscience: The Biology of the Mind*, W. W. Norton, New York, 3rd edn, 2009.
12. Williams, R.W. and Herrup, K., The control of neuron number, *Annual Review of Neuroscience* **11**:423–453, 1988.
13. Gazzaniga, ref. 11, p. 65.
14. The mathematical reasoning behind Shannon's concepts of Mutual Information and Equivocation are useful here.
15. Bartlett, J., Irreducible Complexity and Relative Irreducible Complexity: foundations and Applications, *Occas. Papers of the BSG* (**15**):1–10, 2010.
16. en.wikipedia.org/wiki/Epigenetics.
17. Truman, R., The Unsuitability of B-Cell Maturation as an Analogy for Neo-Darwinian Theory, www.trueorigin.org/b_cell_maturation.asp, submitted 2001, last modified 14 March 2002.
18. Runge–Kutta methods, en.wikipedia.org/wiki/Runge%E2%80%93Kutta_methods.
19. Truman, R., Information Theory—part 1: overview of key ideas, *J. Creation* **26**(3):101–106, 2012.
20. Truman, R., Information Theory—part 2: weaknesses in current conceptual frameworks, *J. Creation* **26**(3):107–114, 2012.
21. en.wikipedia.org/wiki/Earth_mass.
22. $(6 \times 10^{27}) \times (6 \times 10^{23}) / 12 = 10^{50}$.
23. Gitt, W., Compton, B. and Fernandez, J., *Without Excuse*, Creation Book Publishers, 2011, see p. 143.
24. Duplication DNA requires molecular machines to synthesize the building blocks and many enzymes to duplicate each DNA strand.
25. Each daughter cell resulting from replication must possess a DNA double-strand copy.
26. Cells, in particular eukaryotes, contain many organelles and regions dedicated to specific functions. Usually proteins must be transported to specific locations. For this purpose, many proteins contain short amino acid sequences, special patterns as signals which communicate where they are to go.
27. *When* proteins are to be manufactured is very important. In some cells (in multicellular organisms) various proteins should never be produced. In other cases the production must respond to needs sensed by the cell.
28. The number of protein copies at any time can range from a handful to tens of thousands. A wide range of regulatory components (enhancers, degradation signals, miRNAs …) determine how much protein will be present and when.
29. Tertiary structure refers to the three-dimensional structure needed by many proteins to be functional. Some require help to fold properly, using machines like chaperons.
30. Quaternary structure refers to the interaction between proteins, at specific portions of each protein.
31. Appendix—Examples to illustrate principles of coded Information systems, creation.com/information-theory-part4

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