UNIVERSALITY: OR WHY THERE ARE SEPARATE SCIENCES

The reason is the existence of universality at many levels.

Let's start in the middle, where universality is most familiar.

1. The basic computer components are universal. Whatever can be built from transistors can also be built from vacuum tubes, relays, fluidic elements, McCulloch-Pitts neurons, connectionist neurons, or from any of the other kinds of neuron Marvin Minsky proved universal in his 1954 Princeton PhD dissertation.

2. On the biological level, molecular biology doesn't tell us what kinds of animals exist. There could be six-legged mammals. Apparently DNA could encode for them.

3. Atomic physics is more closely linked to chemistry until you get to organic chemistry. The simple compounds that can exist mostly do exist, and the strengths of a chemical bond is determined by quantum mechanical calculations to the extent that these calculations are feasible. However, the complex organic compounds that exist in nature are only a small subset of those that could exist. Which ones occur in nature depends today on DNA encodings of the enzymes that build them.

4. Quantitatively, chemistry is determined by the nuclear atom with a heavy positive nucleus and lighter electrons. It helps somewhat to know about neutrons and protons, but most isotopes are very similar chemically.

5. The neutrons and protons are built from quarks and gluons, but quantum chromodynamics is apparently not something designers of nuclear power plants needs to know.

   That's going down.

6. I'll make the controversial assertion that intelligence will take essentially the same forms in machines as it takes in humans. The little green men from Arcturus will also have qualitatively similar intelligence.

7. Up another level, economics has most of its content independent of psychology. The little green men will need to trade among themselves and with us, and if their desires conflict among themselves or with us, game theory will be relevant independent of their psychology. Of course, psychology leaks into economics, as economists have recently emphasized.

8. Politics is interesting, because what happens is not just a statistical result of the millions of citizens. Particular individuals get high office, and then their peculiarities matter. People have likened politics to the chaotic weather systems in which a seagull's wing flutters in the Gulf of Alaska can be amplified to affect a big storm in the Eastern US. However, politics resembles electing a chief seagull for a term of four years.

Thus particle physics, though fundamental structurally, is only a small part of science, as is chemistry or economics - to sample various levels.

The opposite intellectual sin to wanting to derive everything from fundamental physics is holism which makes too much of the fact that everything is ultimately connected to everything else. Sure, but scientific progress is made by finding where the connections are weak enough to allow separate theories.

Leakages and amplifiers

1. Neutrons leak into chemistry a little bit, because chemical reactions and equilibria depend slightly on the isotopes involved. This permits small differences in concentrations of isotopes to be used to study the history of a chemical substance in the sea or in life forms.

2. Physics and chemistry leak into biology a lot.

3. The spectacular leaks are in human affairs. Psychology strongly affects sociology, economics and politics. Some of this is at the level of averages, e.g. on the average women buy different things than men do.

4. However, the most important reason individual psychology affects large scale social events is that most organizations require leadership by an individual. The US has a president and so do corporations and universities. Army units require leaders ranging from sergeants to generals. If an organization must make a sequence of actions quickly in a co-ordinated way, an individual has to be in a position to make some of the major decisions. Attempts to avoid this have always failed when the organization has to compete with others. Fortunately, it isn't usually necessary to have a dictator, and the power of the individual can be limited by what American political jargon calls checks and balances.

5. Which people get influential positions depends on competition.

6. Whenever an individual is in charge his peculiarities and his interaction with other individual can affect large scale events.

7. Ideas are also amplified. The formal mechanism for this is publication. Which ideas are amplified also depends on competition.

8. A plant or an animal at the level of a sea anemone or a jellyfish does not require a decision making center. A tree bends toward the light, because the individual branches bend. However, a mobile animal must move as whole in some direction and requires a central mechanism to decide on when and where to move and to make other decisions.

Universality in computer science and mathematical logic

1. All present stored program computers are universal. Any can do any computation that can be done by any other and can simulate any other. We ignore memory limitations. Taking them into account would require a more subtle theory.

2. All general purpose programming languages are universal. A program can be written in any of them to simulate any other. Lisp and Prolog have access to their own abstract syntax, and maybe this constitutes an additional kind of universality.

3. As Goedel showed, Peano arithmetic with axiomatized addition and multiplication is universal in the sense that any recursively enumerable predicate is representable by a first order logical formula with one free variable, where the argument takes on Goedel numbers of formulas as value. With just addition, Peano arithmetic is not universal.

4. The bare theory of *car*, *cdr*, *cons*, and *atom* is not universal. I doubt that adding just *append* would make it universal, but I don't know what would. Adding *eval* would suffice but surely would seem to be overkill.

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Send comments to mccarthy@stanford.edu. I sometimes make changes suggested in them. - John McCarthy