TOWARDS A GENERAL THEORY OF ADAPTIVE SYSTEMS

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ABSTRACT

A generic model of adaptive systems behavior is developed in causal loop form. Examples from many different living systems are given.

Living systems do adapt: plants turn towards the light; birds fly south in the winter; people acquire a taste for champagne; revolutionaries become government bureaucrats; and cultures have dealt with horseless carriages and jet travel.

Living systems also collapse: lakes get polluted and die; dinosaurs are no more; people commit suicide; there is no more Federalist party; and the Indian nations of North America have all disappeared.

As a system dynamist I am interested in the attribute or, more exactly, the minimal set of attributes of all these systems that can explain the capability to adapt and also the obvious limits to that same capability.

For a start, adapting can be viewed as the successful maintenance of the systems integrity in the face of changes. The cell maintains it's chemical integrity inside the cell wall, and the church rids itself of those it calls heretics. Successful adapting, then, is possible because of systems skills to cope with assaults on its integrity.

Therefore, coping skills must be an integral part of every system. Some are imparted at birth by genetics, others are learned and acquired throughout the systems lifetime; all of them, however, atrophy. An older person is much less likely to recover from viral infections than a young and healthy person. Genetically transmitted coping skills only are unidirectionally getting worse. The system may engage in behavior designed to let them act at its full potential - a well fed organism can cope better with illness than a malnourished one - but the upper level is given in every single system. Learned coping skills, on the other hand, have generally a shorter decaying time constant, but they can also be increased within the lifespan of an individual system. As people grow more toward adulthood they learn to cope with marriage, job, children, and responsibility that would overwhelm a child; a mature relationship can weather more storms than a fleeting romance; and well established legal principles are harder to challenge than new interpretations.

As far as we know, learned coping skills are only found in systems that use abstract reasoning. A plant does not learn to turn to the light whereas a monkey learns to stand on a box to reach a banana.

But does an algae learn to control its vertical position in a lake? The line is certainly far from being clear.

Learning to cope requires the systems ability to interpret stimuli, stress, and input and anticipate it in similar occasions in the future: even folk wisdom acknowledges that we (may) learn from mistakes.

Learning has, in the context of this paper, one other function besides increasing our level of coping skills: it is used to generate a reference world view against which system input is compared. The first time a child crosses a busy street releases more adrenalin than the tenth or hundredth time; the first incidence of chicken pox is enough to immunize the person; and the first driving lesson is more nerve racking than the daily drive to work ten years later.

The world view is a necessary reference point against which the vast majority of inputs are checked and instantaneously and safely neglected. It has in fact been shown experimentally that neurons adapt, i.e. reduce their response, if the intensity and the rate of change of stimuli that they are exposed to is constant. They form an image of expected stimuli; if either the intensity or the rate of change or both changes, then a full response is seen, only to be reduced again as the new expected stimuli replace the old one. Incidentally, removing the stimulus entirely, will call forth another full response.

We have now talked about enough hypotheses to put down a possible causal loop for systems adapting.

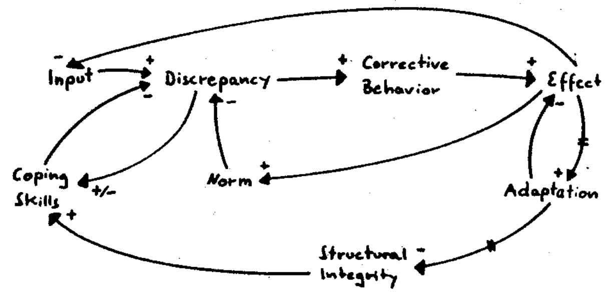

Figure 1: System Adaptation and Collapse

The little diagram says that if there is no discrepancy, coping skills atrophy. As the discrepancy increases the system learns and as it goes beyond a threshhold specific to each single system, it stops learning and eventually collapses. Note here that the optimal discrepancy is probably a function of coping skills, so it will not remain static.

This formulation explains many real phenomena: people forget what they know unless they exercise their knowledge, be that physical or mental; some can tolerate more problems than others; given enought stress, we all crumble.

What is the threshhold that determines our capacity to deal with discrepancy? If we look at algea, which do not have personality, psychology or culture, as far as we know, we can point to the energy balance. So much energy is contained in the cell which can be allocated to maintenance, growth, reproduction, and defense energy. It may even be stored in various forms that can easily be converted to useful energy when needed. When energy is low, the reproductive energy expenditure goes, then growth, then defense, then maintenance of integrity, then comes death. For an algea, we can pretty much equate energy with coping skills.

When we look at worms, the equation probably still holds. But does it really? What then of birds, us, the system dynamics society, our host country, humankind? What are their threshholds, their coping skills, their reaction repertoire to stress? I do not know. We learn about psychology, about a sound mind in a sound body, about sociology, group cohesion, team spirit, and so on. They all have something to do with coping but we just do not know enough to say once and for all, what exactly it is.

To recapitulate, I have said that a living system has norms. At any given time they are collectively its's view of the world, of how things should be: a meal three times a day, temperature between 10 and 30 degrees C, a certain rate of potassium intake, a certain amount of water per week, a certain income, a positive cash flow, a certain return of investment, and a certain percentage of the vote. The system also receives a continuous stream of input, most of which is ignored to avoid information overload. The ones the systems pays

attention to are the ones that carry information that differ from the norm: no food, -60 C, no potassium, too much potassium, a drought, a flood. The system recognizes these discrepancies and marshalls it's resources, consciously or not, to bring the input in line with the norm, and for the norm in line with the input. This happens at various levels: people in the desert learn to conserve water, to dress and act so as to minimize the need for water, and camels evolve to retain 90% of the moisture of their breath in their nostrils while they exhale.

The time constants are widely different from system to system: the pupil reacts almost instantaneously to changes in light intensity; the blood clots within minutes of the skin being cut; the social drinker recovers within hours from a hangover; a bent grass stem recovers within days; a broken bone heals in weeks; a firm can take years to recover from a severe marketing mistake; the Catholic Church took centuries to recover from the Reformation; and the Sahara Desert may take even longer to become the corn supplier it once was in Roman times.

Each system can cope with discrepancies that do not go beyond it's skills to cope with them. The discrepancy may come from one traumatic event or many little irritations. Once it is too big, coping skills not only do not suffice, but actually deteriorate: a person panics; a firm goes bankrupt, a nation employs desperate weapons.

Usually collapse is not that swift. A forest assaulted by acid rain must wait for further research before it is allowed to die; a cancer victim may suffer for years before death comes; the British Empire has been on the decline for decades. As sytems deal with such severe assaults on their integrity we can observe the last chapters of a system's lifecycle. Schooled in the habit of reducing stress to tolerable levels, a system may, for short-term relief, engage in behavior that ultimately hastens it's own demise: It is common practice for meat farmers to feed subtherapeutic doses of antibiotics to their animals to counter the increased likelihood of disease of modern methods of husbandry. When serious illness strikes, the animals are often immune to antibiotic treatment and die. Legend has it that the thorn bird in its quest for nectar seeks out the thorn tree, gets trapped inside and pays with its life for the sweet taste. Humans often use chemical substances to alter their perception of reality, only to become addicted and enslaved to the substance. Wars that solve differences of opinion by inflicting as much damage as possible may have been useful at some early time in history. Nowadays, they carry only the promise of the complete destruction of life on earth.

The list of examples can be extended at will. Suffice it to say that behaviors useful at some time for a short period may cause consequences that far overshadow the initial event that was the cause of their invocation. In biological terms, these are the diseases of adaptation that are powerful, destructive positive loops. Dealing

with them may eventually take up all the resources the system has and making it extremely vulnerable to the slightest assault on its integrity.

At this point, I am sure many of you are asking what all this has to do with a conference that has a theme of modelling for decision making and management.

For one, if you have a simple model of the aglae, you already know a great deal about a firm, an economy, and even the church or a political party. All you need to do is change your labels, your data, and especially your time constants, but you can leave your structure largely intact.

Secondly, and more specifically with respect to economic modeling: we all know that rational man who has perfect information about the market would be paralyzed into inaction by information overload. We also know that the optimizer that our competitors have created is not for real. But is man really the discrepancy reducer that we have postulated, the one that feverishly tries to bring inventory to the desired level, the one that does not sleep well until the order backlog is right, the one that continuously trades off capital cost, fuel price, and energy efficiency when buying a furnace, insulating a house, or simply paying the utility bill?

Maybe he is, but I have tried to show that he is more of a throughmuddler, on an individual level, an organizational level, a regional, national and even cultural level. Rather than look for a desired capacity utilization, we may learn more about the economy if we tried to identify the ability of an economy to withstand stress and how it abandons norms under pressure, the way the labor force tries to keep it's coping skills from becoming irrelevant , as the economy undergoes structural changes, and what it takes to push the financial system past it's threshhold of coping adequately before it collapses, like it did in 1929.