Knowledge Realization Momentum

The Subtle Trap of Unidirectional Innovation

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Abstract – *When a certain innovation effort proves productive, it generates momentum in its established direction. Innovators look for a repeat performance. This 'directional commitment' is likely to suppress 'sideways' innovation without which the project will not be accomplished. That 'sideways' may hide an intractable innovation challenge, which remains unattended because of the enthusiasm and success in the directional innovation. When the intractable challenge finally bursts on the scene, it may generate a daunting cost and time outlook, well beyond the prevailing timeline and budget. This article helps identify and quantify the knowledge realization momentum, (KRM), and it suggests effective ways to escape its fate. The risk of premature termination looms strong for goal-inflexible innovation projects. This methodology is therefore especially helpful for industrial R&D. KRM also generates insight with respect to open-ended scientific efforts, and with respect to the unceasing quest to understand reality. This article proposes a regressive methodology for in-depth research, and suggests that KRM may lead to accidental pattern perception of random data.*

Keywords: Knowledge Realization Momentum, Learning, Innovation Management, Innovation Productivity

1 Introduction

While knowledge has been a topic of discussion since the beginning of science, we still don't have a clear definition, not to speak of a clear metric, for its nature and quantity. And hence, we find it hard to rationally gauge an R&D or innovation effort. These efforts are essentially a knowledge realization process. Since we can't measure knowledge, we can't ascertain whether a knowledge realization session was productive or not. This author has circumvented the challenge of quantifying knowledge per se, by defining '*useful knowledge'* as the knowledge needed for an innovator to achieve his or her well specified innovation goal. To the extent that the innovator lacks a given measure of needed (useful) knowledge, his or her estimate of cost-to-complete, and time-to-finish is less credible. Samid then used the credibility metric of an estimate as the measurement of the missing useful knowledge. As the innovator realizes more useful knowledge, the credibility of his or her estimate increases. By measuring this credibility increase Samid measures the intrinsic innovation progress. This allowed him to spot research and development projects that spend a lot of time and money but don't realize much new knowledge. [15,16].

This new metric also allowed Samid to spot the phenomenon of knowledge realization momentum: the tendency to invest effort in the direction that proved productive before. This investment may deprive another innovation challenge from its due attention. If the project as a whole needs the two innovation challenges to be completed, then by not paying due attention to the 'other issue' one risks a total project failure. This is because a poor credibility estimate of cost-to-complete means that the actual cost may be much higher than what is presently computed as the most probable cost. In other words, every innovation issue that is estimated with poor credibility may become a 'cost mine': eventually 'explode' with a very high price tag in terms of dollars or duration. The price tag may render the entire project infeasible. If one succumbs to innovation momentum then the project will look very promising to begin with, because the first innovation topic is moving along very nicely while the 'cost mine' of the other innovation issue is left latent. This means that the innovator and the people who fund him celebrate a false sense of progress, and only find out about the 'cost explosion' at a much later date.

The above description fits the majority of creative innovative projects that end up doomed, and the methodology offered here is a means to avoid this pitfall.

1.1 Related Prior Work

Knowledge has been a target of human investigation for several millennia. The Stoics developed a 'theory of knowledge' [Watson 96, Russell 72], Kant founded the modern version of the same [Kant 29], and 20th century quantum mechanics totally convoluted any sense of general agreement as to the essential nature of human knowledge. Einstein in his famous thought experiment (EPR), argued that the strangeness of quantum mechanics suggests deeper knowledge, not yet revealed. Niels Bohr, and most physicists today (The Copenhagen School), argued that Einstein's box of hidden knowledge is essentially empty - there is no knowledge there to be discovered. This philosophical dimension of knowledge remains unresolved until today [Wheeler 83, Penrose 04]. It was only in the late decades of the 19th century that scientists and industrialists in Germany reframed the generic notion of knowledge [Rosenblum 96, Cornwell 03]. The association of knowledge with the ultimate truth, and non-subjective reality was downplayed.

Knowledge was increasingly regarded as means to resolve intractable technological challenges, [Rosenblum 96]. Organizational entities dedicated to the accumulation of intractability-resolution knowledge came into being. This reframing of knowledge was quickly picked up in the United States which took the lead, and throughout the 20th century became the powerhouse for intractability-resolution knowledge generation.

When artificial intelligence rose to prominence it inspired a fertile thrust of knowledge taxonomy. Notions like rehmatic knowledge, dicent knowledge, designative knowledge, appraisive knowledge, prescriptive knowledge, argumentative knowledge were introduced [Gudwin 1989]. Various knowledge generation operators were developed for the purpose of processing rich databases and extracting rules from facts, discerning similarities and dissimilarities between bodies of data, extracting equations, even conceptual classifications [Kauffman 1991].

The difficulties facing artificial intelligence bear testimony to the intractability of the step that crosses from data to knowledge. While the former was rigorously analyzed by Claude Shannon, Kolmogorov and their followers, making a fully compressed, random look-alike bit string the metric for quantity of data, corresponding metrics for knowledge remained elusive. In a recent work knowledge was quantified in terms of what one needs to know in order to resolve a well defined intractable challenge [Samid 09]. Alas, it is exactly this vagueness with respect to the process of realizing more knowledge that makes one apprehensive on whether the very process of knowledge realization has an impact on the goal of resolving the challenge at hand.

1.2 Unbounded Innovation.

The definition of useful knowledge applies to knowledge needed to accomplish a well specified goal. It does not apply to open-ended research, or to what we shall call 'Unbounded Innovation'. When one aims to 'understand an issue' then at any point of his or her understanding it is hard to say whether all the significant knowledge is known. This is different from a research designed to accomplish a testable goal. Much of the academic research or the research conducted by long-range institutions (e.g. DARPA) may be categorized as Unbounded Innovation where the knowledge metric discussed above does not apply. And hence the notion of knowledge realization momentum is reduced to a conjecture only. It says: human researchers will develop a directional commitment (momentum) to pursue their research in the direction that proved productive before. This practice leaves sideways knowledge untouched, and its benefit unrealized. It further skews the view of reality because so much of reality is left unresearched. Today, when cutting edge research requires considerable funding, this blinding phenomenon only becomes worse. Fund managers tend to increase their return by betting on established directions.

To illustrate, consider two people approaching a library with the intent to describe what is in it. One person is a professional librarian. She will first catalogue all the books on the shelves, familiarize herself with their subjects, and their main message. The other person is a typical reader. He will browse the books until he would hit a book that holds a great deal of personal interest for him. He will consume this book cover to cover, and then read likewise books. When later on these two people will describe what the library is about, their descriptions will be very different from each other. Intuitively we will say that the librarian has a more accurate take on what the library is about, and she will be more useful when a need arises to find knowledge for some unexpected topic.

The implications for science in general are that our fast moving innovation train in bioinformatics, digital technology, and green energy may deprive us from some wonderful revelations in areas where no momentum has yet been established. The only way to rectify this is by being aware of the situation, which is another reason for publishing this work.

2 The KRM Model

In 2002 Samid introduced an objective metric to gauge the progress of a research and development project. Accordingly, the validities of the quantitative estimates of the project resources measure the unknown that still needs to be discovered before the project is declared a success. The KRM model builds on this metric to measure the balance among the various estimates: are they all becoming more valid, or is one resource, one aspect of the project receiving the lion share of innovative attention. The latter is what happens when knowledge realization momentum drives the innovation efforts. And so here we propose a mathematical expression that tracks the knowledge realization momentum. This model will also help countering its deficiencies. We then take a leap of faith towards open-ended innovation projects where the validity metrics don't apply.

2.1 Measuring Knowledge Momentum

Consider an innovation project, namely an a project where a measure of innovation is needed to accomplish its goal. This means that at present one cannot specify a well defined procedure, or algorithm to achieve the stated goal. And hence one is somewhat ambiguous as to the quantities of resources that would be required to accomplish the same. Once the exact procedure, or algorithm, are specified, so would be the measure of resources. Let it be known that some r resources participate in the solution procedure. At any given point we may estimate the required quantity of resource i with a credibility or validity marked as V_i such that Vi=0 indicates zero validity, and Vi=1 indicates zero uncertainty. Once innovation is done, all is clear and the validity of the estimate for each required resource i is Vi=1 for i=*1,2,…,*r. At any point p' before that, the validities will be $V'_1, V'_2, \ldots V'_r \leq 1.00$, and hence the project history could be marked as a path on an r-dimensional metric space where the path starts at p' and ends at [1,1,1,…1], where each dimension reflects a validity measure of resource i *(i=1,2,…r).*

One could use the Samid validity metrics for the r resources, or any other metric, to construct this r-dimensional construct.

We may now rigorously define the Knowledge Realization Space (KRS) as follows: Let the accomplishment of a certain innovation goal be carried out through a procedure that refers to r resources, each needed in a definite measure, R_i, $i=1,2,\ldots r$. At any given state of progress the best estimate for resource i is S_i. S_i is estimated with credibility, or validity V_i where $0 \leq V_i \leq 1.00$, such that $V_i=0$ is zero validity (zero credibility, a wild baseless guess), and $V_i=1$ indicates zero uncertainty, a maximum validity estimate. This innovation project will be associated with a Knowledge Realization Space (KRS) – a metric space of r dimensions where each dimension i *(i=1,2,…r)* is associated with one project resource i, and such that $V_i=0$ will be at the origin, and $V_i=1$ will be at the end stretch of the dimension. The r dimensions will be mutually scaled to reflect the best estimate S_i values for the various i values. So the length of dimension i will be S_i.

Since the state of $V_i=1$ for $i=1,2,\ldots r$ represents the state of project complete (no more uncertainty with respect to any resource), then the most efficient pathway from any given point q to the final point [1,1,..1],will be the straight line between these two points on the knowledge realization space. This straight line can be described using vector notation as (Eq-1):

$$\vec{O} = \sum_{i=1}^{i=r} S_i (1 - V_i) \overrightarrow{U_i}$$

where $\vec{O}$ is the vector that starts at point q on the KRS, and ends at the end-point [1,1,….1] there, and $\overrightarrow{U_i}$ represents the unit vector in direction i. The actual move from point q to point q' on the KRS can be expressed using vector noation as follows (Eq-2):

$$\overrightarrow{qq'} = \sum_{i=1}^{i=r} \left[\!\left[\int_q^{q'} \left(\frac{\partial V_i}{\partial e} \right) de \right]\!\right] \overrightarrow{U_i}$$

where *e* is the innovation effort leading from state *q* to state *q'*. e can be measured in dollars, time or otherwise. The knowledge momentum effect will be measured by the scalar product of these two vectors (Eq-3):

$$KRM = \frac{|\vec{O}||\overrightarrow{qq'}|}{\vec{O} \bullet \overrightarrow{qq'}} - 1$$

such that a well balanced innovation path will compute to KRM=0 (no momentum distraction), and the greater the knowledge realization momentum effect the higher the value of KRM.

One can use Eq-3 both in order to appraise a planned innovation move, and as a way to measure how focused on the project goal (and not distracted by knowledge momentum) have we been.

Projects that show chronic distraction (persistent high KRM values) warrant special attention. Perhaps a leadership change, or even defunding.

2.2 Choice of Resources

It is practically impossible to list and manage all the various resources used in accomplishing an innovation goal. One must pick a good representation of the required resources. A good representation will be such that when (i) the required measures of all the listed resources is well known, the innovation goal can be readily accomplished, and (ii) when the innovation progress cannot be properly managed using a subset of the listed resources. The latter requirement prevents one from amassing secondary resources of no much meaning for the project. For instance, the number of test tubes needed to synthesize a desired chemical. The first requirement is designed to insure that all the resources that are essential for the project are accounted for. For instance: innovation efforts to make oil from coal may need to measure the required coal per a barrel of oil, the required quantities of the non-coal ingredients, and the required energy for this transformation. As long as either one of these quantities is not known with high validity – the innovation load is still looming.

2.3 Capabilities as Resources

Any component of an innovation project can be measured by its required resources, or by the estimate of the effort needed to make it work as required. In the first option the credibility of the estimate of the required resources will be tracked, and in the second case the credibility of the estimate of the effort to complete will be tracked. For example, to innovate a cancer killing drug one needs to have a high credibility estimate of the effort to engineer a drug that will kill the cancer cell once there, and also to have a high credibility estimate of the required effort to innovate an effective way to lead the drug to the site of the cancer. In this case the resources can be viewed as a service for the goal. Clearly when one has a good estimate as to what will it take to synthesize the cancer killing drug, and what will it take to haul it there – then the original project can also be estimated in very good credibility. One can also mix a project component with some nominal resources to build the project management resource list.

Using a project component in appraising and managing an innovation project may lead to a cascade in which the progress of the original project is estimated from the credibility of the estimates of some derived projects. The derived projects are not necessarily components of the original project, but rather associated projects such that when they are accomplished they make the accomplishment of the deriving goal easier. Such relationship is described in Samid 06. Accordingly, if the effort to accomplish an innovation goal is *P*, then one could search for an associated innovation challenge for which the accomplishment effort is *P'* and such that the following inequality will hold, (Eq-4):

$$P > P' + P|P'$$

where *P|P'* is the effort to resolve the original challenge after having resolved the associated challenge *P*'. Eq-4 can be cascaded indefinitely (Eq-5):

$$P > P|P' + P'|P" + P"|P'" + ...$$

and where the associated projects are either a breakdown project, an extension project, or an abstraction project as described in Samid-06.

3 KRM v. The Gantt Chart

Many innovation projects are based on nominal projects and hence are designed as a Gantt chart where a series of project components follow each other based on their logical sequence. The innovator who would follow the Gantt sequence will show a poor showing on his KRM score. The question arises: *should one adhere to the logical sequence expressed in Gantt, or vie for the KRM strategy*? The answer depends on the innovation content of the project at hand. If the innovation is low to moderate, then the Gantt sequence offers order and manageability, but if the innovation content is high, it would make sense to give priority to KRM consideration. It is not always possible, many projects are so structured that task B must follow task A, but to the extent possible KRM should have priority.

3.1 Illustration: New Drug Administration

A certain pharmaceutical company experimented with a new molecule for its target disorder. It was clear upfront that the new drug would have to be administered as a skin patch. Alas, due to the large size of the molecule it was not clear whether the prevailing patch will be effective. The Gantt chart logic called to first develop the drug, be sure of exactly what molecular structure it is, and only then worry about how to get it into the body. The KRM approach called for dividing the research attention between the two parts because it does not make sense to resolve the uncertainty in only one part, allowing the other part to doom the project. By shifting to the KRM strategy the company researched the drug administration with a like-size molecule. It discovered some insurmountable difficulties and changed the project.

3.2 Illustration: Using Car Traffic to Clean the Air

An academic research group has developed a concept whereby an ingenious powerful adsorber will be installed in front of a typical car radiator fan, and the drawn air will be scrubbed from air pollutants. Once the adsorption contraption becomes mandatory, so the idea went, the urban air will be spot clean! The group worked on the adsorption chemistry with a lot of enthusiasm, neglecting the uncertainty with respect to the expected impact on the air pollution. It was late into the research when one computed the figures to show that even if all the cars in America would have been fitted with this device, and even if it would have functioned in top performance – the impact on the urban air would have been minimal. A level headed KRM approach would have attended to this computation much earlier.

4 KRM and Result Flexibility

The KRM methodology is critical for innovation projects with poor result flexibility. Namely projects where the goal is dictated from above, and is not subject to change. This is the case when the R&D effort is an attempt to solve a problem that showed up, and needs a solution. The researcher in that case does not have the freedom to say, I will solve a different problem. In most industrial and military contexts, the innovation goal is fixed and nonnegotiable, and in such cases, it is crucial to implement KRM. It is a different case when the R&D is academic. In that case the research team could say, *yes we set out to discover A, but, guess what, we have discovered B – so be it, we will report the unexpected discovery of B*. If the goal, the result, is flexible the innovator could say *I will develop something else*. In fact a large majority of start-up companies set out to develop one product but end up developing quite another.

5 KRM and Funding Philosophy

Fund managers are naturally apprehensive of research directors reporting high percentage of progress along the way. They suspect that bad news are suppressed to the last moment, and this apprehension halts their funding. By implementing KRM, a research director is communicating to the funding authority that the residual project uncertainty will be reduced as fast as possible, and if indeed the project hides a latent ‘cost mine’ – it will be flashed out much earlier than otherwise. This attitude will increase the fund manager inclination to invest in that innovation project.

6 KRM v. Knowledge Per Se

The KRM methodology as defined here is applicable only to situations where a fixed innovation goal guides the action and measures its efficiency. This is not the case in a ‘general learning’ environment where one tries to learn what there is, as opposed to achieving a well stated goal. However, we may define our research goal as learning all that there is to learn, regardless of utility. The difficulty with such a goal is, of course, that at any point we are not sure whether there is more that is still hidden, so we can’t use this goal the way we use a regular R&D objective. Albeit, being aware of the knowledge

Realization Momentum, we may reasonably suspect that our learning path is skewed in the direction of our learning momentum, and as a result large knowledge zones are left untouched, and unrecognized. This conjecture brings forth the question, how can we reach out to this unchartered territory. In this open case we don't have the estimate credibility metric to guide us. One possible approach is herewith outlined:

The process of science may be described as a series of conclusions drawn from a body of data. So we have body of data D_1 leading to conclusion C_1, body of data D_2 along with C_1 leading to conclusion C_2, etc. Given our KRM tendency we should suspect that every conclusion we have drawn from a body of data is not exhaustive, namely there are more conclusions that may be drawn from the same data. We missed them originally because we acted under the influence of the knowledge realization momentum. Yet, upon revisiting the same body of data we may discover formerly overlooked conclusions. Once we have found such a new conclusion, we may regard it as the starting point of another conclusion sequence. In other words, we are calling here for a regressive approach: revisiting past conclusions, searching for additional conclusions we missed before. To be productive we may focus on bodies of data that led to conclusions that were part of an enthusiastic discovery drive. These bodies of data, in particular, might hide some important latent conclusions that were passed over as the knowledge realization momentum directed the research attention into its unidirectional way.

This mechanism is consistent with the anecdotal finding that big leaps of science are discovered and built by unlikely explorers or builders. These innovators, because they are not well learned in the subject, don't suffer from the knowledge realization momentum. They have a fresh look. Thomas Edison said that had he been schooled in electrical engineering he probably would not have experimented so stubbornly with the electrical bulb. The Wright brothers were not highly educated mechanical engineers but rather bicycle repairmen. Paracelsus (1493-1541) revolutionized 16th century medicine despite lacking any formal medical education, concocting specific prescriptions to specific ailments, and ignoring the search for a single 'philosopher stone' as a catch-all generic remedy. He also discredited the vague 'four humors' theory that prevailed among the well educated physicians. In World War II, the German suspected that their Enigma cipher was compromised, but they did not redesign a new cipher – they simply added a fourth wheel to the three wheels cipher they used before – a classic KRM case that shortened the war and saved many lives... Windows – the quintessential operating system for personal computers was developed by two college dropouts, not by learned computer scientists, and ever since it is being patched and repatched for security holes, rather than redesigning a solution from the ground up. Venture capitalists today invest millions in very young innovators because they have not been tainted by KRM.

Because KRM may be rather productive for quite a long time, it effectively hides the fact that more astonishing unknowns are waiting untouched. It's only when an established direction erodes in its productivity that off-shoot directions are being sought.

Modern physics drowns in complexity while it has revolutionized the role of the scientist from a neutral observer to a reality player. This conclusion suggests that we should have a better grasp of physics if we advance our understanding of the human brain and its psychology. Alas, such an interdisciplinary research is unwelcome by most modern physicists, so it is left largely unpracticed. This highlights another aspect of KRM: *expertise*. If an effective research plans calls for work to be done in a discipline which is alien to the researching team, then this conclusion will be de-emphasized, and KRM will reign.

Regarding the off-shoots of conclusion sequences from a given body of data one wonders whether a major scientific conclusion may be drawn through more than one logical path. One may conjecture that much as Feynman's '*sum over histories'* states that moving particles take all possible routes from A to B, so it may be that major conclusions of science can be reached through various logical pathways, and the way to distinguish between theories is not just to what extent they correctly predict the results of a future observation, but to the extent that they suggest creative and un-thought of new experiments and observations.

7 KRM and a Theory of Patterns

Knowledge Realization Momentum can be employed as an explanation for perceived patterns by a generic data reader. Let's consider a random source of data: spewing random bits. These bits are met by a bit reader who has an *a-priori* probability $p_0 < 1$ to read any bit coming its way. The KRM phenomenon is expressed mathematically as follows: the probability of the bit reader to read a given oncoming bit increases with the number of bits of same identity that have been read by the reader before. These two terms would lead the reader to de-randomize the incoming data, and establish a stable pattern based solely on the chance reading of the first bits. A simple exercise using $p_0 = 0.1$, and bit reading probability: $p_0 + (1- p_0)r_b$ where r_b is the bit fraction of same identity bit, will transform a pseudo-random bit series into a clear-pattern series (where one bit appears 60% to 70% of the times). Such pattern-perception may be cascaded upwards, and also may be applied to 2, 3 or more bit sequences. The conclusion here is that if our biological sensors of reality are subjugated to the KRM phenomenon (as Darwinian evolution suggests) then the patterns that we observe in reality are accidental to the history of our reality reading before.

8 Conclusions

Knowledge Realization Momentum (KRM) is identified as a natural human way to conduct research, to innovate, to acquire new knowledge. While KRM may appear very productive to begin with, it may hinder the fulfillment of goal-oriented projects that also require innovation in a different direction. KRM may also distort an open-research aimed at knowledge per-se.

For goal oriented, results-inflexible R&D, we have developed a methodology to measure and correct for KRM and thereby boost the productivity of the innovative effort. For open-ended research we propose a regressive methodology to revisit bodies of data from which earlier conclusions have been drawn under the driving knowledge realization momentum. Such data, upon re-examination, may yield new insight that lay latent as a KRM victim.

This work is consistent with the emerging trend in science: to improve productivity by accounting for common psychological tendencies.

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