System Dynamics Endogenous Mental Models

Warren Tignor

(wtignor@ieee.org)

SCITOR

Introduction and Purpose

This article examines System Dynamics endogenous mental models from Kahneman's (2011) System 1 and System 2 thinking perspective. Mental models have evolved from a System Dynamics point of view of stocks and flows (Forrester, 1961; Sterman, 2000), multidimensional collections of images (Richmond, 1994; Senge, 1990), and an endogenous boundary (Richardson, 2011). The purpose of this article is to introduce Kahneman's (2011) System 1 and System 2 behavioral economics vocabulary to enrich the discussion of mental models as endogenous to System Dynamics models. In this article the "modeler" is a System Dynamics person and the "decision-maker" is a user of a System Dynamics model.

System Dynamics Practical Components

The question of what to include in a model is based on the fact that the all-inclusive model is unlikely to be achieved (Forrester, 1961, p. 60). According to Forrester, it is the skill of the modeler to determine the pertinent questions to ask that defines the model boundaries (1961, p. 61). He acknowledges that the objective to include those factors that influence the answers sought cannot be limited to any one narrow intellectual discipline, e.g., technical, legal, and psychological, leaving open the possibility that behavioral economics from Kahneman's perspective may contribute to System Dynamics.

Forrester says that the physical and institutional structure of a system is relatively straightforward. In contrast, discovering and representing the decision rules of the decision-maker is subtle and challenging (Sterman, 2000, p. 514). To be useful, simulation models need to include the decision-making behavior of the user as they affect the decision rules. Modelers need to detect and represent "the guiding policy" behind the decision-makers thoughts, i.e., their mental models.

The inputs to the decision processes are various types of information, or cues (Sterman, 2000, p. 515), see Figure 1. Decision rules do not necessarily utilize all available or potentially

relevant information. The mental models of the decision-makers, as well as organizational, political, personal, and other factors, may influence the selection of cues from the set of available information. Sterman quotes Forrester (2000, p. 513): "No plea about inadequacy of our understanding of the decision-making processes can excuse us from estimating decision making criteria. To omit a decision point is to deny its presence – a mistake of far greater magnitude than any errors in our best estimate of the process." The decision rules may not include all available or possibly relevant information; however, they imply that they may include the mental models of the decision makers as other sectors (Sterman, 2000, p. 515), see Figure 1.

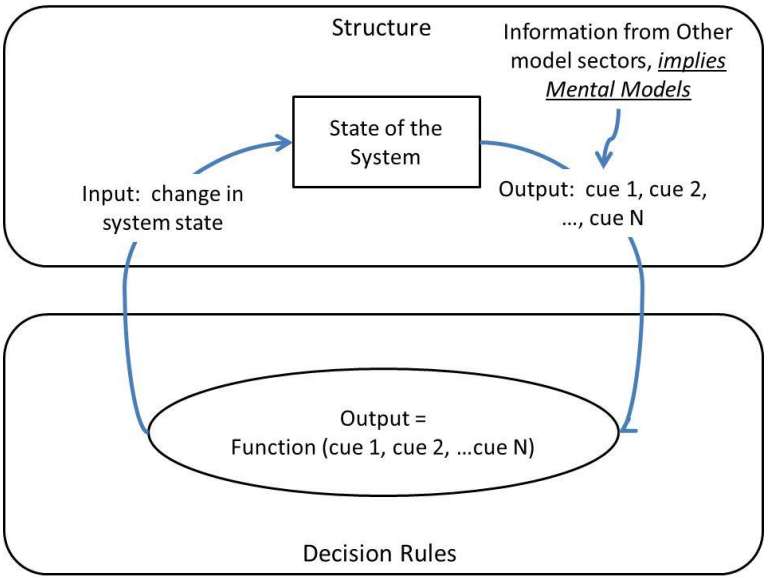


Figure 1 An illustration of a generic model implying Mental Models inspired by Sterman (2000)

Mental Models

Barry Richmond (1994, p.1) wrote, "The world's problems haven't shrunk much, if at all, since 1961, when Jay Forrester penned Industrial Dynamics. In fact, one could make a pretty convincing case that things are going to hell in a hand basket pretty quickly". Richmond opined that the system dynamics community has something very powerful to offer to our increasingly troubled world: "We can offer a way of thinking, doing, and being that can help the planet's citizenry to achieve a much saner day-to-day existence as well as a more promising longer-term future (1994, p. 1350)". Approximately 20 years later, the same thought holds.

Richmond said that system-as-cause thinking is what George Richardson (1991) referred to as "the endogenous viewpoint", i.e., the notion that it is useful to view the structure of a system as the cause of problem behaviors rather than seeing these behaviors as caused by outside agents (Richmond, 1994, p. 140). It is not "them", but "us"!

Richmond's number one challenge was the "abyss between a mental model" and the associated stock, flow and connectors (1994, p. 144). To him the gap between the mental model and the physical structural model constituted the "…fundamental problems inherent in our modeling approach (p145)…". He described mental models as consisting of complex, multidimensional collections of images and recollected experiences that served as the basis for stock and flow models. He identified the need to augment the transition from images of systems that constitute people's mental models to stock and flow models. He predicted that without support, the gap between mental models and stock and flow models would remain an abyss (1994, p145).

Senge (1990, p. 8) wrote, "'Mental Models' are deeply ingrained assumptions, generalizations, or even pictures or images that influence how we understand the world and how we take action. Normally, we are not consciously aware of our mental models or the effects they have on our behavior. Many insights into new markets or outmoded organizational practices fail to get into practice because they conflict with powerful, tacit mental models."

Per Senge, (1990, p. 9), "The discipline of working with mental models starts with turning the mirror inward: learning to unearth our internal pictures of the world, to bring them to the surface and hold them rigorously to scrutiny. It also includes the ability to carry on 'learningful' conversations that balance inquiry and advocacy, where people expose their own thinking effectively and make that thinking open to the influence of others." It was the best that was known about mental models at the time, see Figure 2.

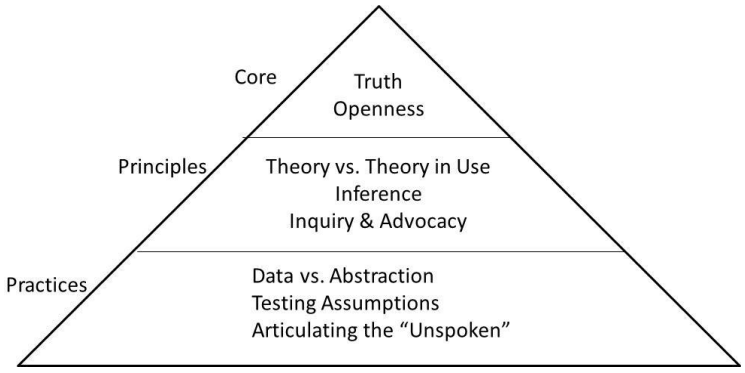


Figure 2 Mental Model Components adapted from Senge (1990, p. 376)

In fact, there seemed to be more evidence about the negative impact of mental models than examples of their role in models to support the decision-maker. Senge wrote (1990, p. 174):

- Many of the best ideas never get put into practice. Brilliant strategies fail to get translated into action. Systemic insights never find their way into operating policies. Successful pilots do not result in widespread adoption of the new approach.

- The new approaches were not discarded due to weak intentions, wavering will, or even non-systemic understanding, but from *mental models.*
- The discipline of managing mental models (surfacing, testing, and improving our internal pictures of how the world works) promises to be a major breakthrough for building learning organizations.
- "The inertia of deeply held entrenched mental models can overwhelm even the best systemic insights" (1990, p.177).

However, Senge offered (1990, p. 178), "But if mental models can *impede* learning-freezing companies and industries in outmoded practices-why can't they also help *accelerate* learning?" This is why a better vocabulary is needed to describe mental models; what is proposed is available from Kahneman (2011).

Moving forward with the thought that mental models need to be part of system dynamic models, George Richardson (2011, p. 219) explains that the scope of System Dynamics has progressed from the foundational fundamentals (computing technology, computer simulation, strategic decision making, and the role of feedback in complex systems) and beyond dynamic thinking, stock and flow thinking, and operational thinking to a deeper foundation – the "endogenous point of view". He says (2011, p. 221) that the endogenous point of view exists in some form in all purposeful decisions- making; this opens wider the door to include mental models within the endogenous boundary (see Figure 3), for example:

- Building models that are capable of deriving the dynamic behavior of interest solely from variables and interactions within an appropriately chosen system boundary.
- Being independent of exogenous forces to produce the dynamics of interest.
- Trying to understand system dynamics as generated from within some conceptual, mental boundary.

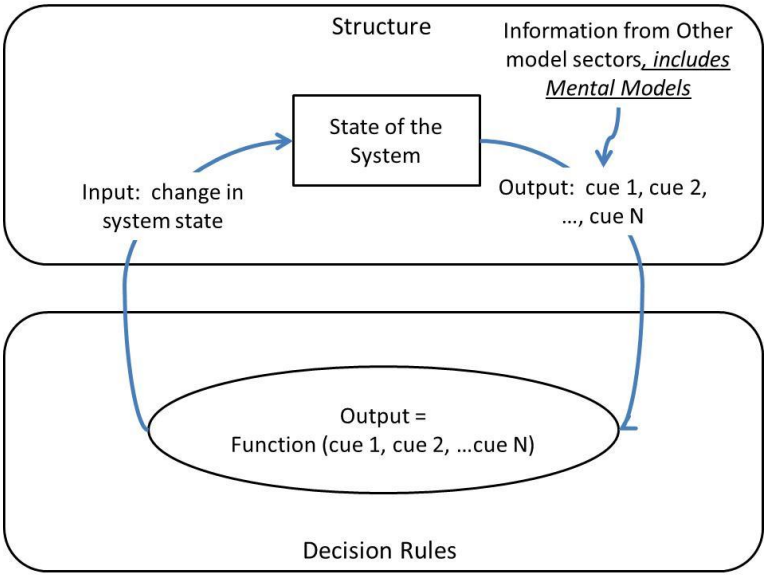


Figure 3 An illustration of a generic model <u>including</u> Mental Models inspired by Sterman (2000)

He cites Forrester's graphic, Figure 4, explaining, "The closed-boundary concept implies that the system behavior of interest is not imposed from the outside but created within the boundary" (Forrester, 1969, p. 12).

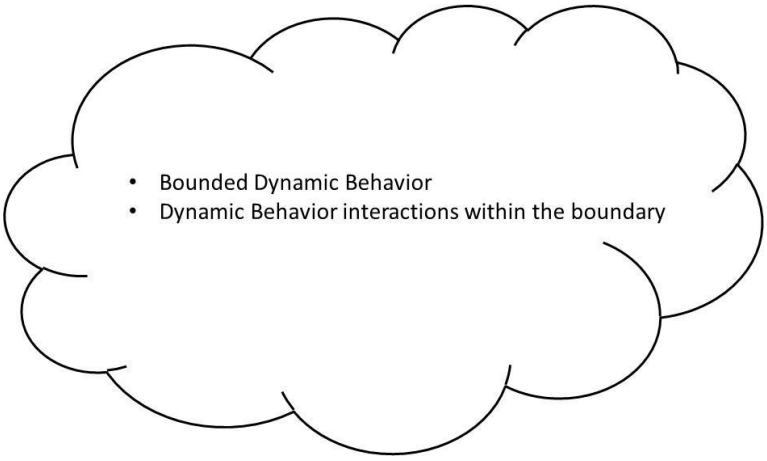


Figure 4 Envisioned System Dynamic Boundary based on Forrester (1969, p. 13)

Richardson (2011, p.229) quoted Forrester, "Perhaps it is time to reintroduce system dynamics into world modeling: it lends itself to communicating with the public, dealing with long time horizons, choosing the appropriate level of aggregation, emphasizing policy choices, making all the variables endogenous, joining the arena of political controversy, and drawing on the rich and diversified mental database". Following this quote, Richardson poses some questions relevant to this article (2011, p. 229):

- Who are the decision-makers in the dynamics of a complex system and how do their perceptions, pressures and policies interact?
- Are modelers and the groups they represent part of the endogenous system structure responsible for the system behavior?
- Are modelers part of the problem, or part of the solution, or bystanders watching model dynamics?

This article does not try to answer these questions, but poses a vocabulary to better focus their discussion. If we think of System Dynamics as the use of informal maps and formal models with computer simulation to uncover and understand endogenous sources of system behavior, as Richardson proposes; then Kahneman's language of behavioral economics may be key to identifying mental models as endogenous to System Dynamics. The next section will explore this possibility.

System 1 and 2 Thinking

Kahneman says, see Figure 5, that System 1 operates automatically and quickly, with little or no effort and no sense of voluntary control (2011, p. 20). System 2 allocates attention to the effortful mental activities that demand it, including complex computations, see Figure 6. The operations of System 2 are often associated with the subjective experience of agency, choice, and concentration. System Dynamics has the opportunity to recognize these two types of thinking as endogenous to decision-makers. Each thinking type has different abilities and limitations, endogenous to every model, as part of the mental model of the decision-maker.

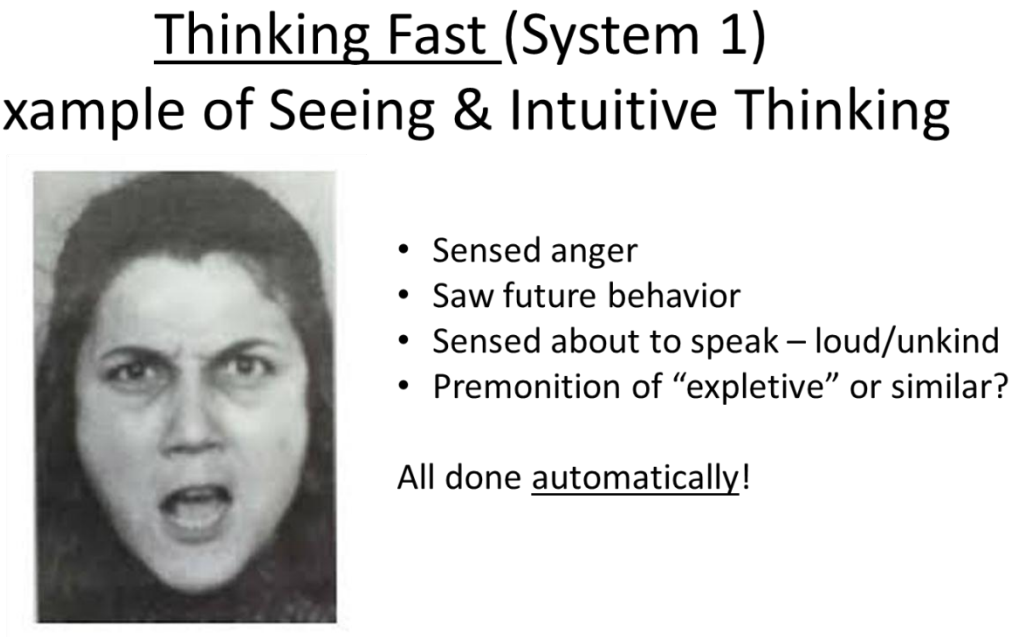


Figure 5 Visual Example of System 1 Thinking based on Kahneman (2011, p19) (https://www.google.com/search?q=kahneman+system+1+images&oq=kahneman+system+1+images&aqs=chrome.0.57j62l3.13726j0&sourceid=chrome&ie=UTF-8,183b13104df0a31aed4e776a38ab08d0_LARGE.png grin.comShare accessed 15Jun2013)

Thinking Slow (System 2)
Example of effortful, & orderly mental work

17 X 24

- Knew immediately this is multiplication problem
- Probably knew it was solvable w/paper & pencil
- Vague sense of solution magnitude
- Recognize the implausible – 12,609 or 128
- Not certain the answer is not 568

Precise solution does not come to mind.

Figure 6 Visual Example of system 2 Thinking based on Kahneman (2011, p20)

Kahneman says that System 1 continuously generates suggestions for System 2 via impressions, intuitions, intentions, and feelings. If accepted by System 2, impressions and intuitions turn into beliefs, and impulses that become voluntary actions. Generally, System 2 adopts the suggestions of System 1 with little or no modification. If System 1 runs into difficulty, it invokes System 2 for more detailed and specific processing to try to solve the problem at hand. System 1 operates automatically and quickly to generate complex patterns of ideas. System 2 operates slowly to construct thoughts in an orderly series of steps (Kahneman, 20211, pp. 24-29).

To become conversant with System 1 and 2 thinking, modelers will need to apply Kahneman's behavioral economics vocabulary to decision-maker mental models. There are characteristics of System 1 and 2 thinking that will support modelers to account for the "marvels as well as the flaws of intuitive thinking" (Kahneman, 2011, p. 10). However, there are two exceptions that should not be overlooked. There are accurate expert intuitions based on extensive practice and cues; and there is the ever present role that luck plays (Kahneman, 2011, pp. 9-11); this article will not address these exceptions.

When exploring the possibility of applying the characteristics of System 1 and 2 thinking to System Dynamics, it is important to keep in mind the difference between decision rules and the decisions they generate (Sterman, 2000, p. 514). Decision rules are policies and protocols regarding how the decision-maker processes information (mental model) and decisions are the outcome of the process. As Forrester wrote (1961, pp. 93-108), modelers must model the guiding policy decision rule(s), not the decision itself. It is the decision-making process that concerns System 1 and System2 thinking as endogenous to System Dynamics modeling, see Figure 7.

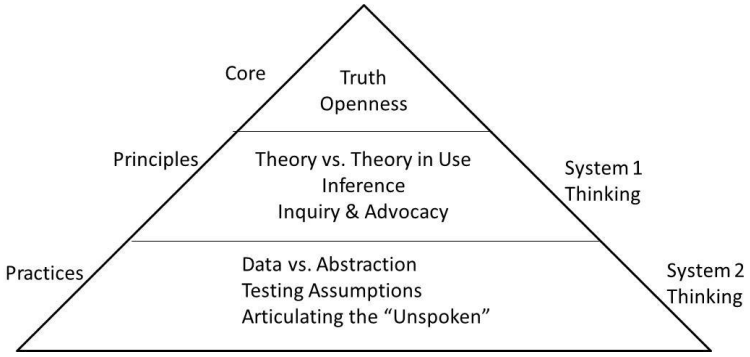


Figure 7 Mental Models adapted from Senge with System 1 and System 2 (1990, p. 376)

With knowledge of how the decision-maker is thinking, the modeler will have the opportunity to adjust the model or discuss the mental model with the decision-maker to close any gap between the model and the decision-maker's mental model.

A brief list of System 1 characteristics is as follows (Kahneman, 2011, p. 105):

- Operates automatically and quickly, with little or no effort, or voluntary control
- Infers and invents causes and intentions.
- Neglects ambiguity and suppresses doubt.
- Focuses on existing evidence and ignores absent evidence.
- Is biased to believe and confirm.
- Generates a limited set of basic assessments.
- Represents sets by norms and prototypes, does not integrate.
- Creates a coherent pattern of activated ideas in associative memory.
- Generates impressions, feelings, and inclinations.
- Exaggerates emotional consistency.
- Distinguishes the surprising from the normal.
- Sometimes substitutes an easier question for a difficult one.
- Can pay attention to a particular pattern when "programmed" by System 2.
- Executes skilled responses and generates skilled intuitions, after adequate training.

Characteristics that involve both System 2 and System 1 interaction are as follow:

- Attention and Effort
- Self-Control
- Associative Machine
- Cognitive Ease
- Norms, Surprises, and Causes
- Jumping to Conclusions, and
- Answering an Easier Question.

The following paragraphs offer some details about these characteristics.

Attention and Effort

System 2 thinking is effortful. One of System 2's main characteristics is laziness. As a consequence, the thoughts and actions that System 2 believes it has chosen are often guided by System 1. However, there are vital tasks that only System 2 can perform because they require effort and acts of self-control in which the intuitions and impulses of System 1 are overcome (Kahneman, 2011, p. 31).

According to Kahneman, (2011, p.35) the general "law of least effort" applies to cognitive as well as physical exertion. If the decision-maker has several ways of achieving the same goal, they will eventually gravitate to the least demanding course of action. To test for or initiate System 2 thinking, look for decision-making that follows rules; compares objects on several attributes; and makes deliberate choices between options. The automatic System 1 does not have these capabilities. However, System 1 detects simple relations and excels at integrating information about one thing; it does not deal with multiple distinct topics at once. System 1 is not adept at using purely statistical information (Kahneman, 2011, p. 36). Overlooking the potential impact of the general "law of least effort" may mean that the decision-maker, due to time pressures or switching attention among tasks, unconsciously uses System 1 thinking when System 2 effortful thinking is required to understand and apply model results.

Self-Control

Self-control, and cognitive attention and effort are forms of mental work (Kahneman, 2011, p. 41). When decision-makers are cognitively busy, they are more likely to make superficial judgments; the effort of self-control is tiring. Activities that impose high demands on System 2 require self-control, and the exertion of self-control is depleting and unpleasant (Kahneman, 2011, p. 42). The System Dynamics modeler will need to be conscious of modeling activities or results that place high demands on the decision-maker's self-control.

One of the main functions of System 2 is to monitor and control thoughts and actions "suggested" by System 1, allowing some to be expressed directly in behavior and suppressing,

or modifying others (Kahneman, 2011, p. 44). The modeler should not assume that the decision-makers will apply System 2 reasoning regarding modeling results. Kahneman suggests that when people believe a conclusion is true, they are also very likely to believe arguments that appear to support it, even when these arguments are unsound. "If System 1 is involved, the conclusion comes first and the arguments follow (Kahneman, 2011, p. 45)."

Associative Machine

System 1 is an associative machine that is not willed and is not stoppable. For example, seeing the words "blood and gun" will trigger a process called associative activation; ideas that have been evoked trigger many other ideas in a spreading cascade of activity in our brains (Kahneman, 2001, p. 50). Each associative element is coherently connected, and supports and strengthens the others. This results in a self-reinforcing pattern of cognitive, emotional, and physical responses that is both diverse and integrated (Kahneman, 2011, p.51).

Additionally, associative memory can be "primed"; the priming effect could be based on ideas, words, emotions, and events without conscious awareness. This may be significant when trying to create or explain a system dynamic model, e.g., the implications of global warming is already formed in the decision-makers mind regardless of the model results. Overcoming the decision-maker's endogenous mental model resistance to model results requires the modeler to be aware of this phenomenon and engage System 2 thinking. Assuming that System 2 is in charge and that it knows the reasons for decisions will only lead to problems. Priming studies confirm that it is System 1 that contains the model of the world that instantly evaluates events as normal or not (Kahneman, 2011, p. 58).

Cognitive Ease

How would you characterize the ease with which the results of a model are understandable by the decision-maker – easy or strained, or somewhere in between? -Cognitive ease means that there are no threats, no major news, no need to redirect attention or mobilize effort by the decision-maker. Cognitive strain indicates a problem requires increased mobilization of System 2; an action that requires effort by the decision-maker.

The various causes of ease or strain will have interchangeable effects on the decision-maker (Kahneman, 2011, p. 60). For instance, when in a state of cognitive ease, one's mood is good, which results in liking what is seen, believing what is heard, trusting intuitions, and feeling that the current situation is familiar. This typically will result in System 1 being relatively casual and superficial. However, if the decision-maker is feeling strained, they are more likely to be vigilant and suspicious, investing more effort in the activity, feeling less comfortable, and make fewer errors (Kahneman, 2011, p.60). The modeler may have to challenge the decision-maker to encourage System 2 thinking. What follows are some examples that illustrate cognitive ease and strain:

- Illusions of Remembering – There are memory illusions that ease decisions just like there are visual illusions, (Kahneman, 2011, p. 60).
- Illusions of Truth – It is general knowledge that a reliable way to make people believe in falsehoods is frequent repetition. Without the source of a statement, a decision-maker will have no option but to go with the sense of cognitive ease says Kahneman (2011, p. 62).
- Persuasive Message - Cognitive ease can be used to a modeler's benefit by making the model clearly understandable (Kahneman, 2011, p. 62).
- Strain and Effort - Conversely, cognitive strain can mobilize System 2 to shift a decision-maker's problem solving approach from a casual intuitive mode to an engaged analytic mode (Kahneman, 2011, p. 65).

Norms, Surprises, and Causes

The commonly accepted wisdom was that we infer physical causality from repeated observations of correlations among events; however, research indicates this is not the case. According to Kahneman (2011, p. 71), the main function of System 1 is to implement and maintain a model of our personal world. The System 1 model is constructed by associations that link ideas of circumstances, events, actions, and outcomes; not linkage by observations that correlate. The pattern of associated ideas comes to represent the structure of events, and it determines interpretations of the present as well as future expectations.

Recognition of the prominence of causal intuitions is important to System Dynamics because decision-makers are prone to apply causal thinking inappropriately to situations that require statistical reasoning. Statistical thinking derives conclusions about individual cases from its properties. According to Kahneman, System 1 does not have the capability for this mode of reasoning. System 2 can learn to think statistically, but few people receive the necessary training (Kahneman, 2011, p77).

A Machine for Jumping to Conclusions

From a System Dynamics perspective, it is important to realize that a decision-maker who uses System 1 thinking does not keep track of alternatives that are rejected, or even of the fact that there were alternatives. Conscious doubt is not part of System 1. Uncertainty and doubt are the domain of System 2 (Kahneman, 2011, p. 80). A deliberate search for confirming evidence is how System 2 tests a hypothesis (Kahneman, 2011, p. 81). The confirmatory bias of System 1 favors uncritical acceptance of suggestions and exaggeration of the likelihood of extreme and improbable events. System 1 counts on the consistency of information for a good story, not its completeness. For the decision-maker, knowing a little may make it easier to fit everything into a coherent pattern. A coherent story is often close enough to reality to support reasonable action to the detriment of System Dynamic model results.

Answering an Easier Question

If a satisfactory answer to a hard question is not found quickly, System 1 will find a related question that is easier and will answer it. Kahneman calls answering one question in place of another "substitution" (2011, p. 97). The modeler needs vigilance to recognize this mental model tendency, especially with regard to emotions (Kahneman, 2011, p. 104). But, this does not mean that the decision-maker's mind is entirely closed and immune to information and reasoning, Kahneman (2011, p. 103). The "substitution" phenomenon shows System 2 acting in a different mood than acquiescing to System 1. System 2 has the ability to resist the suggestions of System 1; and to slow things down, and impose logical analysis, as well as self-criticize (Kahneman, 2011, p. 103); the modeler may need to recognize the "substitution" phenomenon as endogenous System 1 thinking and decide whether to encourage resistance to its use by the decision-maker

In Summary - System 1 and 2 Thinking, and System Dynamic Mental Models

Forrester (1961), Richardson (2011), Richmond (1994), Senge (1990), and Sterman (2000) have acknowledged that mental models have a role in System Dynamics, see Table 1 for highlights.

Forrester (1961, p. 61)	… it is the skill of the modeler that determines the pertinent questions to be asked that defines the scope of the model and its boundaries…
Sterman (2000, p. 514) cites Forrester	… discovering and representing the decision rules of the decision-maker is subtle and challenging…
Richmond (1994, p. 144)	…number one challenge was the "abyss between a mental model" and the associated stock, flow and connectors…
Senge (1990, p. 8)	'Mental Models' are deeply ingrained assumptions, generalizations, or even pictures or images that influence how we understand the world and how we take action…
George Richardson (2011, pp. 219-221)	…the scope of System Dynamics has progressed from the foundational fundamentals and beyond dynamic thinking, stock and flow thinking, and operational thinking to a deeper foundation – the "endogenous point of view"…to include in some form in all purposeful decisions-making…

Table 1 - System Dynamic Mental Model Highlights

From the 1960's to the present mental models have been generalized and lacking in definition. Seeing mental models as endogenous to System Dynamic models could be a next step in the evolution of System Dynamics. With the vocabulary of behavioral economics provided by Kahneman (2011), there is a substantial foundation to build upon to understand mental model parameters, see Figure 8.

In the lower left cell are models that are primarily influenced exogenously and interpreted by decision-maker exogenous mental-models using System 1 thinking. It is the role of System 1 thinking to make a coherent story about the exogenous influences on the model since they are not causal within the model.

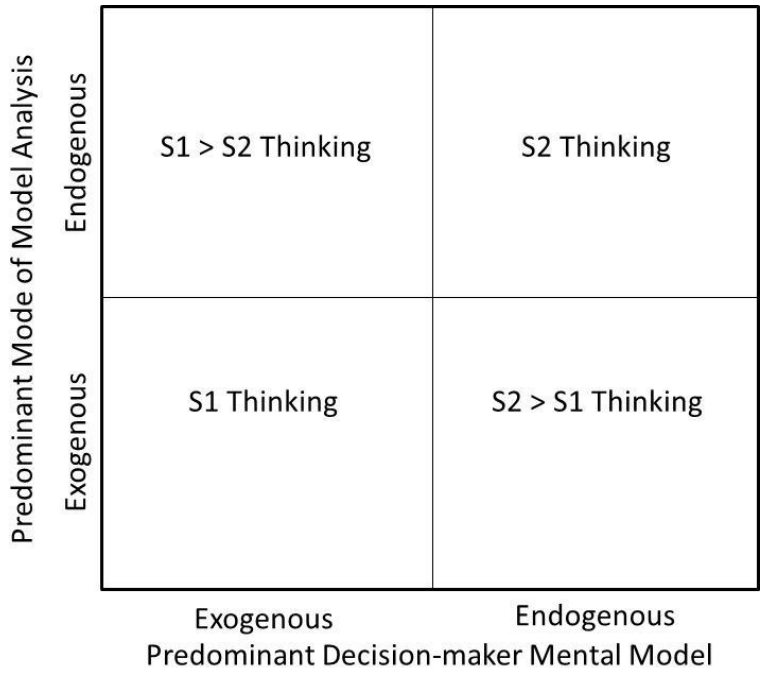


Figure 8 System 1 and System 2 Thinking Matrix, inspired by Richardson (2011, p. 239)

Even though the decision-maker perception may be correct, there is little consolation provided about the future course of events.

In the endogenous by exogenous cell (upper left), the model provides an endogenous understanding of a problem, but the decision-maker fails to understand it because the interpretation is predominantly made using exogenous System 1 thinking. The decision-maker understanding of the model is likely misused. The situation is better than in the lower left cell because at least the model has an exogenous basis for interpretation, even though it is overlooked by the decision-maker.

In the upper right endogenous by endogenous cell the model and the decision-maker mental models have corresponding views. The model-based decision-making is logical, rational, and feedback-based. The decision-maker is empowered by the model to make decisions within the scope of the model, e.g., business, climate, and government policy.

The lower right exogenous by endogenous cell is where the model is influenced primarily by exogenous variable that the decision-makers attempts to understand using System 2 thinking. The mismatch of model results and decision-maker System 2 thinking will probably result in interpretations that are confusing and misleading.

A summary of juxtaposed System 1 and System 2 characteristics is as follows (Table 2):

System 1	System 2
Attention & Effort-Used "least effort" to make decision; detected simple relationship; integrated one thing; avoided statistical information	**Attention & Effort**-Followed decision-making rules; compared objects on several attributes; made deliberate choices between options; dealt with multiple distinct topics at once; used statistical information
Self-Control-Reached conclusion first and arguments followed; made superficial judgment	**Self-Control**-Pursued arguments first before reaching conclusion; interrupted cognitive businesses before making judgment
Associative Machine-Unwilled associations triggered by cascading brain activity; self-reinforced pattern of cognitive, emotional and physical response; "primed" without cognitive awareness; enabled coherence of events	**Associative Machine**-Believed, wrongly, that it was in charge; countered by consciously making associations; recognized "priming" activities;
Cognitive Ease-Liked what saw; believed what heard; trusted institutions; felt situation was familiar	**Cognitive Ease**-Mobilized by cognitive strain to be vigilant and suspicious; invested; felt less comfortable; made fewer errors; resulted in less intuitive and creative results
Norms, Surprises, and Causes-Constructed model of personal world from associations that link ideas of circumstances, events, actions, and outcomes, not observations that correlate	**Norms, Surprises, and Causes**-Learned to think statistically to infer physical causality from repeated observations of correlations among events
Machine for Jumping to Conclusions-Didn't recognize alternatives, favored uncritical acceptance of suggestions, exaggerated likelihood of extreme/improbable events, counted on coherence of story, vs. completeness	**Machine for Jumping to Conclusions**-Recognized uncertainty and doubt, searched for confirming evidence of hypothesis, tracked alternatives that are rejected, exercised conscious doubt
Answering an Easier Question-Answered an easier related question if satisfactory answer to harder question is not found quickly (substitution),	**Answering an Easier Question**-Used ability to resist System 1 (e.g., substitution), slowed things down, imposed logical analysis, and performed self-criticism

Table 2 Juxtaposed System 1 and System 2 Thinking Characteristics

System Dynamics Archetypes and Behavioral Economics Examples

This section illustrates System Dynamics archetypes and System 1 and System 2 thinking. The archetypes are from Senge (1990): Success to the Successful (p. 385), Fixes that Fail (p. 388), and Shifting the Burden (p. 380). Each archetype is briefly explained and discussed, including related Behavioral Economics vocabulary.

Success to the Successful Archetype and Halo Effect

The Success to the Successful archetype describes two activities that compete for limited support or resources, see Figure 9 where SD is System Dynamics and BE is Behavioral Economics. The positive, virtuous causal diagram loop, shows that the successful activity gains support or resources to the detriment of the negative, vicious cycle. The more the positive activity gains, the more the negative is starved of resources.

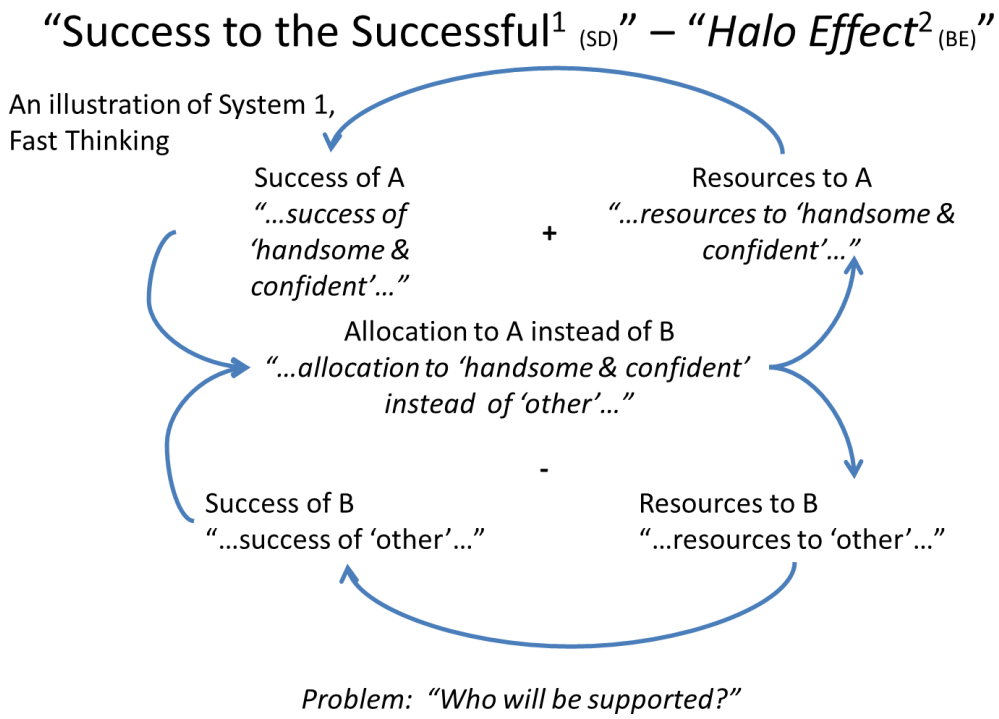


Figure 9 "Success to the Successful (SD)" - "Halo Effect" (BE) inspired by Senge (1990, p385) and Kahneman (2011, p4)

According to Senge (1990), one management principle for this archetype is to look for an overarching goal to achieve a balance for both activities. For example, one could break the

coupling between the two activities so that they no longer complete for the same limited resource.

Kahneman (2011, p4) describes this behavior as the "Halo Effect", e.g., when the handsome and confident speaker bounds onto the stage, one anticipates that the audience will judge his comments more favorably than possibly deserved. The halo effect is a diagnostic label that makes it easier to anticipate, recognize, and understand this bias. The halo effect is a systemic error that recurs predictably in particular circumstances. As a diagnostic label, the halo effect provides a richer vocabulary than is available in everyday language or System Dynamics to understand judgments and choices.

Kahneman says that often one's mind is a machine for jumping to conclusions and the halo effect is an example of exaggerated emotional coherence (2011, p80). The term, halo effect, has been used in psychology for approximately a century. It is one of the ways System 1 thinking represents the world in a simpler and more coherent way than the real thing. In many cases, the halo effect causal relationship is interpreted backwards, e.g., by being prone to believe a firm may fail because the CEO is "rigid", when actually the CEO appears rigid because the firm is failing.

Fixes that Fail and What You See Is All There Is (WYSIATI)

The Fixes that Fail archetype describes a "fix" that is effective in the short term, but has unforeseen long-term consequences, (Senge, 1990). The "fix" will likely be seen as having always worked before, begging the question of why it isn't working currently.

According to Senge (1990), a management principle for this archetype is to maintain focus on the long-term. If feasible, one should disregard the short-term "fix". He says at best one should only use the short-term "fix" to "buy-time" while working on the long-term remedy.

Kahneman (2011, p85) says that the System 1 thinking measures success by the coherence of the story it manages to create. Largely irrelevant is the amount and quality of data. Frequently, information is scarce. System 1 operates as a machine for jumping to conclusions when information is scarce. He concludes that the ease with which instances come to mind is a System 1 heuristic; only if system 2 is engaged will it be replaced by a focus on content (2011, p135). He says that the coherence-seeking System 1 combined with a lazy System 2 implies that System 2 will endorse intuitive beliefs generated by System 1 (2011, p135).

Figure 10 illustrates how a problem, "Will Mrs. X be a good leader? She is intelligent, strong…", addressed by System 1 thinking can jump to a conclusion with untended consequences. For example, if further in the description of Mrs. X that words "corrupt" and "control" are found, the wrong conclusion could be reached based on the incomplete description of Mrs. X.

According to Kahneman, there is an asymmetry between the way our mind treats information that is currently available and information we do not have. System 1 excels at constructing the best possible story from the information at hand and does not allow for information it does not have. System 1 is not inclined to ask, "What would I need to know before forming an opinion about the leadership capability of Mrs.X?". In the end, the consistency of the System 1 story will trump the completeness of the facts.

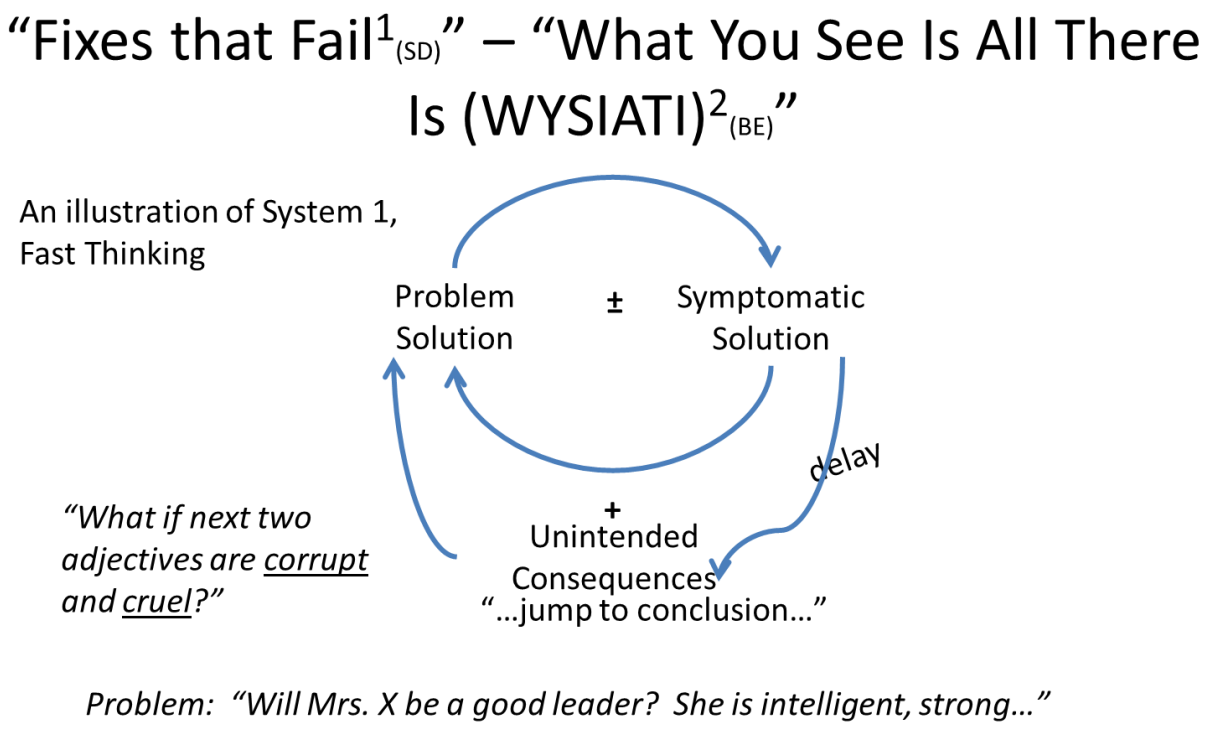


Figure 10 "Fixes that Fail (SD)" - "What You See Is All There Is (WYSIATI) (BE)" inspired by Senge (1990, p388) and Kahneman (2011, p85)

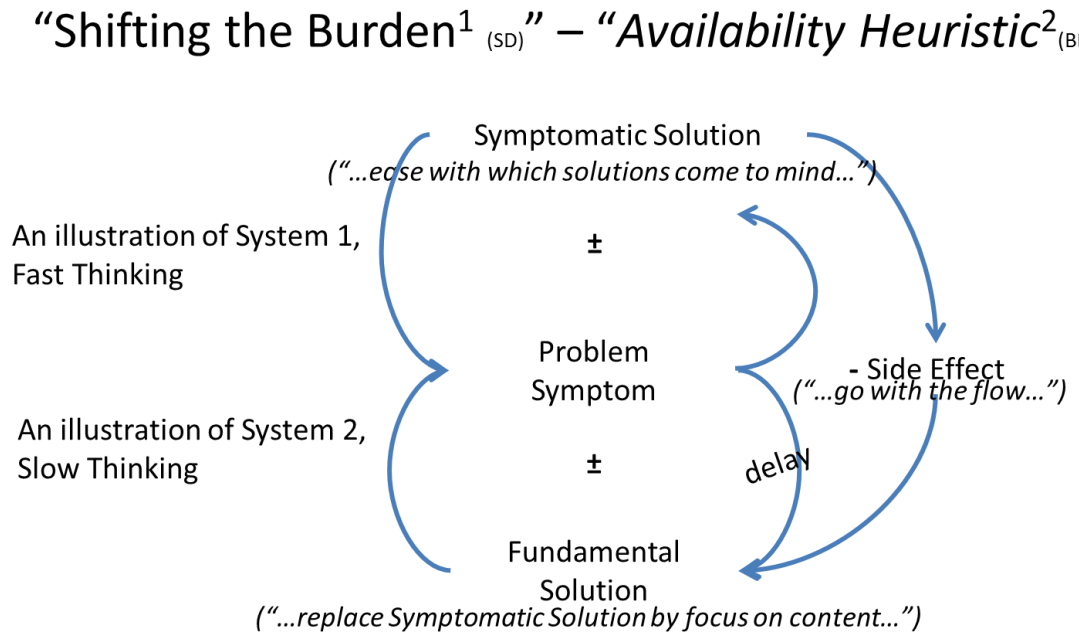
Shifting the Burden and Availability Heuristic

Senge (1990, p380) describes the "Shifting the Burden" archetype as a short-term solution used to correct a problem, with seemingly positive immediate results. However, over the long-term, the capability for corrective measures may atrophy or become disabled, leading to even greater reliance on the short-term solution. Since a solution is working well so far, it is difficult to see that there is trouble down the road.

As a management principle, Senge advises to focus on the fundamental solution. Only use the short-term solution is an interim solution to gain time while working on the fundamental solution.

Kahneman (2011, p7) describes the Availability Heuristic as a judgment bias that relies on the ease of memory search. It is a systematic error in thinking that he traced to the machinery of thinking rather than to corruption of thought by emotion (2011, p8). The ease of retrieval from memory is largely determined by the extent of coverage in the media (Kahneman, 2011, p8). Kahneman says (2011, p135) that people are inclined to "go with the flow" of what is available and retrieved from memory under these circumstances: 1. when engaged in an effortful task at the same time, 2. when they are in a good mood, 3. when they are not depressed, 4. when they are subject matter novices versus experts, 5. when they have an above average faith in intuition, and 6. when they are or made to feel powerful.

Figure 11 is an interesting example as a pattern to examine the case of Hewlett-Packard (HP) and Dell's PC business. According to Mourdoukoutas (2013), HP and Dell destroyed their PC business advantage piece-by-piece through outsourcing, i.e., pursuing the Symptomatic Solution. The article says that the outsourcing continued for a decade, indicating that management was going with the flow to increase return on investment with a significant time delay in terms of its side-effect. This resulted in a loss of competitive advantage for HP and Dell and a side-effect that essentially meant that they could no longer reach a fundamental solution to sustain their business. Consequently, both HP and Dell are experiencing a decline in PC sales and an erosion of profit margins, revenue and profit due to new competitors (Mourdoukoutas, 2013).



Problem: "…HP and DELL PC business case example…"

Figure 11 "Shifting the Burden (SD)" - "Availability Heuristic (BE) inspired by Senge (1990, p380) and Kahneman (2011, p8)

Conclusion

In conclusion, Kahneman's behavioral economics vocabulary will help system dynamics modelers hypothesize, test, and refine decision-maker mental models as endogenous variables. Considering the decision-maker's mental model as endogenous to the model will enable the modeler to better communicate with the decision-maker. Consequently, the modeler will have the opportunity to challenge the decision-maker, invoking System 1 or System2 thinking, as needed.

Works Cited

Forrester, Jay W. *Industrial Dynamics*. Waltham, MA: Pegasus Communications, 1961. Print.

Forrester, Jay W. *Urban Dynamics*. Portland, OR: Productivity Press, 1969. Print.

Kahneman, Daniel. *Thinking, Fast and Slow*. New York: Farrar, Straus, and Giroux, 2011. Web. 6 Oct. 2012.

Mourdoukoutas, Panos. *How Hewlett-Packard And Dell Destroyed Their PC Advantage…Piece-By-Piece*. Forbes. Web 19 Jul. 2013. <http://www.forbes.com/sites/panosmourdoukoutas/2013/04/14/how-hwelwtt-packard-and dell-destroyed-their-pc-advantage-piece-by-piece/>.

Richardson, George P. *Feedback Thought in Social Science and Systems Theory*. [Philadelphia]: University of Pennsylvania, 1991. *Google Books*. Web. 6 Jan. 2013. <http://books.google.com/books?id=Ey58AAAAIAAJ&q=endogenous+viewpoint#search_anchor >.

Richardson, George P. "Reflections on the Foundations of System Dynamics." *System Dynamics Review* July-September 27.3 (2011): 219-43. *Wiley Online Library*. Wileyonlinelibrary.com, 14 July 2011. Web. 7 Oct. 2012. <http://onlinelibrary.wiley.com/advanced/search>.

Richmond, Barry. "Systems Thinking/System Dynamics: Let's Just Get on with It." *System Dynamics Review* Summer-Fall 10.2-3 (1994): 135-57. *Wiley Online Library*. Wileyonlinelibrary.com, 26 Dec. 2006. Web. 7 Oct. 2012. <http://onlinelibrary.wiley.com/advanced/search>.

Senge, Peter M. *The Fifth Discipline*. New York: Currency Doubleday, 1990. Print.

Sterman, John D. *Business Dynamics: Systems Thinking and Modeling for a Complex World*. Boston: McGraw-Hill, 2000. Print.