“Hard” and “Soft” Methods in Complex Adaptive Systems (CAS)

Agent Based Modeling (ABM) and the Agent Based Approach (ABA)

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Abstract: In this chapter, we provide the basis for why a Complex Adaptive Systems (CAS) approach is critically important to solving problems. As a naturalistic reality, a theoretical framework, or a heuristic device, CAS is a powerful tool. Agent Based Modeling (ABM), too, can be a powerful way to discreetly model a CAS understanding of phenomena. When ABM can be used, it is a powerful tool. However, ABM has drawbacks that make it an infeasible method the majority of the time. These drawbacks should not preclude us from using CAS as an alternative, “mixed,” “qualitative,” or “heuristic” method. For this reason, we have outlined a new approach—the Agent Based Approach or ABA—which can be used the majority of the time when CAS analysis is indicated. ABA was developed by Drs. Derek and Laura Cabrera at Cornell University with an expressed focus on the analyses of CASs leading to specific policy recommendations, although it is quite possible that many aspects of ABA can be applied outside of a policy context. This is especially true in light of more nuanced and expanded definitions of “policy” and/or “policy analyst.” Where one might think of “a policy” as a statement or document presented in a legislative, legal, or bureaucratic context, we promote that an understanding of CAS means that a “policy” is simply a set of guidelines for understanding how agent action (the following of simple rules) will affect emergent properties. In other words, policy can be defined as “a statement of the simple interaction rules that one predicts will lead to desired systemic change.” In this regard, “a policy” is something any person might utilize anywhere, not merely something a policy analyst in the halls of Congress might use. To understand and effect change on any CAS—even if the CAS is your family, your classroom, your team, your organization, the state or federal system, or a global crisis—requires you understand the system, to identify the types of actions that can be taken to alter it, and then codify those generalizable actions into specific recommendations. The steps to doing this are the same regardless of the venue or scale. The degree, scale, resources available, timeline, stakeholders, and relative complexity may change, but the basic process does not. In other words, policy analysis is a fractal pattern and “the analysis of policy” is for everyone (i.e., not limited to legislative personnel). Therefore, ABA is a tool that anyone can use, and is well-suited for the formally trained policy analyst. ABA provides another tool in the systems scientist’s tool belt and is an invaluable means by which policy students or scientists can better understand and effect complex adaptive systems.

Complex Adaptive Systems (CAS) | Agent Based Modeling (ABM) | Agent Based Approach (ABA) | DSRP | Policy analysis methods

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1. Historical Background of CAS and ABM

A. What is a Complex Adaptive System (CAS)?. When Adam Smith wrote Wealth of Nations 250 years ago, he examined the complex social phenomena of an economy in which the invisible hand organizes the decisions of many self-interested individuals without any consideration of the whole system to the collective results (1).

In 1948, Warren Weaver identified a class of scientific problems in a "great middle region" made up of "organized complexity" which he posited sat in between the simplicity of physical sciences and the chaos of unorganized complexity (2). In 1975, Nobel laureate Ilya Prigogine examined the self-organizing systems and their role in nonequilibrium thermodynamics (3). His dissipative structure theory offered the tools for studying complex systems. In the 1980's the Santa Fe Institute (SFI) built on this work to focus entirely on the study of complexity and complex adaptive systems (CAS) (4)(5)(6)(7)(8)(9)(10)(11)(12)(13)xxxx.

What makes a CAS? To understand that question, consider an example that differentiates between something that is merely complicated from something that is truly complex and adaptive. If we think of three standardized kicks as a stimulus we can see something interesting emerge when we kick a rock versus kicking a dog. The effect of the kick on the rock is consistent in each instance and therefore, the rock, governed by the laws of physics, responds the same way each time. What occurs is certainly complicated, but it is not complex and it is not adaptive. We can say that both the stimulus and the response are the same each time. But if we kick a dog three times we can say that the stimulus remains the same, but we almost certainly will get three different responses: perhaps the first kick causes the dog to cower; the second kick causes the dog to stand its ground and growl; and finally, the dog lunges and bites upon the third kick. Adaptive systems have different responses to the same stimulus.

CASs are important because so many of the systems that humans care about, want to understand, and hope to effect are CASs. Your family, your problems, your team, your organization, your customer, your country, all are CASs. Cities, languages, tand raffic are CASs. Fireflies, ant colonies, bird flocks, and schools of fish are CASs. The list is endless. But for over 2500 years we have not fully understood CASs. We have seen them, lived among them, and wondered about them, but always had the impression that there was some remarkable leader bird or agent who was instrumental in governing the system behavior. We did not fully realize that these systems self-organize and are mostly, if not entirely, leaderless.

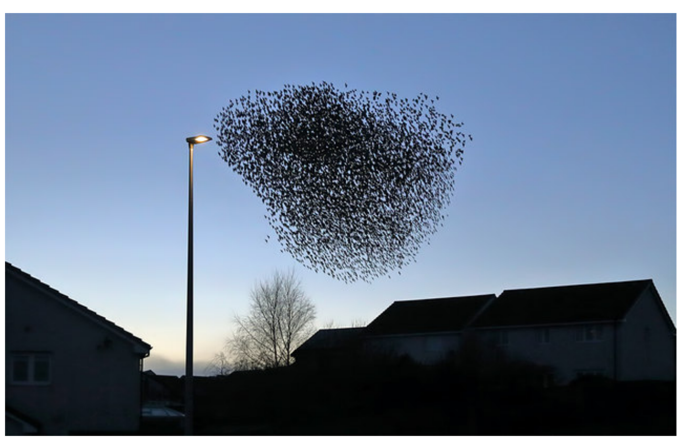

Fig. 1. Murmuration of a Superorganism based on Simple, Local, Interaction Rules

Take a look (in Figure 1) at the flocking behavior of what amounts to millions of starlings. Look at how quickly millions of birds pivot from all moving left to all moving right. It's called a superorganism, a bunch of individual organisms that act like a single organism. When scientists first began studying such systems we thought they must have exceptionally good leaders! These types of systems [seen across the physical, natural and social sciences in flocks, schools of fish, traffic patterns, ant colonies and across the spectrum of nature land human society] baffled scientists because it was unclear how the group behavior occurred in the absence of a leader. But there's simply not enough time for communication to occur between the leader and the follower, nor enough time for the signal to spread. What then causes this behavior?

It turns out there were no leaders, only followers. What were they following? They followed simple rules that brought about this remarkable, adaptive, and complex behavior. These types of systems are based on simple, local rules. Iain Couzin (14)(15), who studies collective animal behavior at Princeton University, did a simulation to show exactly what rules these flocks were following and found just three:

- Rule 1: maintain distance x (locally to nearest neighbors);
- Rule 2: adjust direction (locally to nearest neighbors); and
- Rule 3: avoid predators.

The simulation shows that the simple rules perturbate through the system as predatory hawks attempt to catch the birds. The birds at the bottom of the column are following rules one and two but have no idea that rule three (avoid predators) was followed above.

Fig. 2. Example of CAS

Humans do this, too. The largest human stadium wave consists of 80,000 people acting as a single superorganism with no leadership, all following one simple rule: do what the person to your left does: when they stand, you stand. When they sit, you sit. Remarkable. Other schema (mental models) like ordering in a restaurant, driving in traffic, clapping at a concert, playing sports and games, taking a class, and walking on the street are good examples of how humans are agents in CASs everyday.

There's a relatively simple formula that explicates these complex adaptive systems: *autonomous agents follow simple, interaction rules based on what's happening locally around them, the collective dynamics of which lead to the emergence of the complex behavior we see.* Or,

$$\textbf{CAS} = \textbf{agents } x \textbf{ local interaction rules} \rightarrow \textbf{self-organization/collective dynamics} \rightarrow \textbf{emergent properties}$$

Our old mindset about systems and their behavior puts us in the mind of the *field general*, perched on a hill, sending radio signals to his lieutenants and orchestrating everything from up high. When we take a CAS perspective it takes us into the mind of the *individual soldier* and we see the simple rules use to interact with their small, local band of brothers, that manifest complex collective dynamics that result in the emergent properties we see (e.g., things like self-organization, adaptivity, robustness, complexity, intelligence, and other surprising behaviors, etc.). Figures 1 and 2 depict typical examples of the surprising emerging patterns of behavior that we see—what we don't see are the simple interaction rules that bring it about. Figure 3 depicts the basic features of complex adaptive systems (CAS).

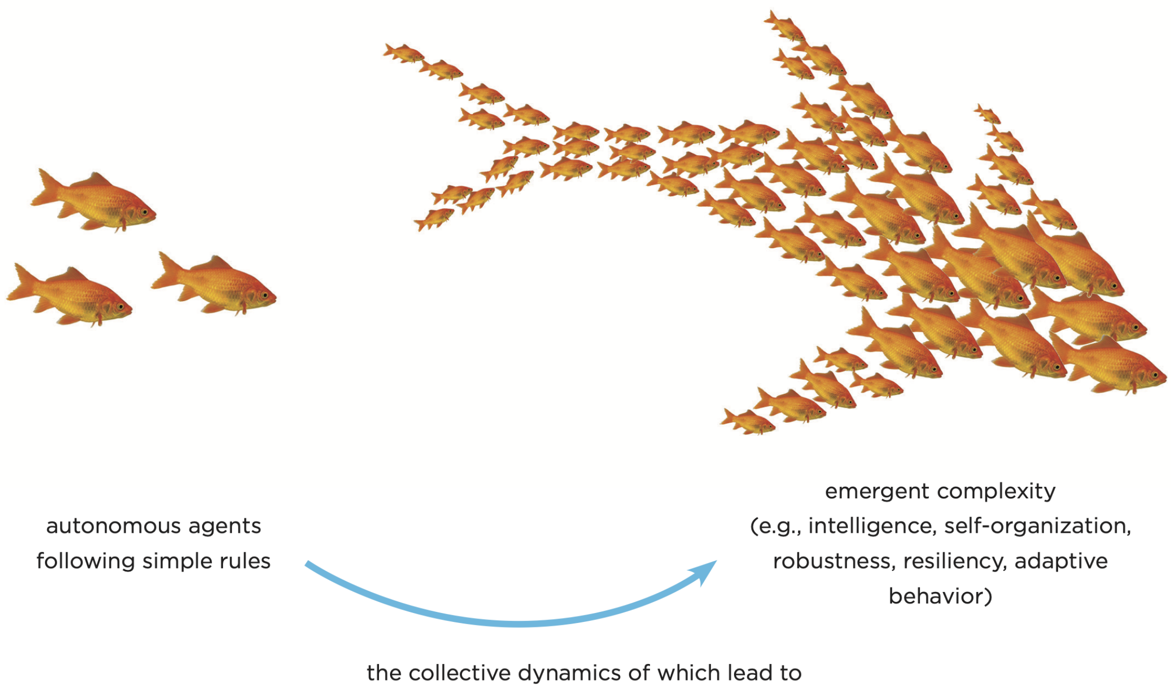

Fig. 3. The Basic Features of a Complex Adaptive System (CAS)

Simply put, agents x simple rules = emergent behavior. This is the basic CAS Formula. In other words, *in CASs, the micro begets the macro.*

A complex adaptive system (CAS) is a system that has parts simultaneously interacting, called agents. The term "agents" can apply to many entities including: ants, birds, fish, humans; groups of individuals such as teams, companies, countries; socio-technical combinations of things such as driver-and-car; and inanimate objects such as bits, atoms, molecules, etc. The agents (or actors) in a CAS have three characteristics: evolution, aggregate behavior, and anticipation.

The system is complex because it has many different agents acting simultaneously according to simple rules in the system. Of equal importance is that (surprisingly) there is little or no central control driving the behavior of the agents. And, the system is adaptive because the agents often modify the rule in order to survive and anticipate future threats. This is why we say that CASs are evolutionary. The result of the agents following the local rules leads to an outcome or aggregate behavior to adapt to the environment. Thus, a Complex Adaptive System in its most basic definition is a set of agents following local simple rules to lead to collective behavior that yields an emergent property or behavior (16).

The simple rules are not just any rules, they are rules that have been refined and encoded (sometimes through DNA and other times through Culture) over evolutionary time. Changing the rules will change the system. Indeed, if we were to try to identify that "leadership function" that we once believed was internal to CASs, it would be found in the rules themselves. It is the rules that lead to the interactions among agents and it is the collective dynamics of these interactions that lead to surprising emergent properties that appear to be organized, coordinated, remarkable, inspiring, intelligent, etc.

Figure 4 illustrates where we can most effect a CAS or CAS behavior. Note that our influence occurs *below the line* with agents and simple, local, interaction rules. Whereas we have significantly less influence *above the line* within the collective dynamics and emergent properties.

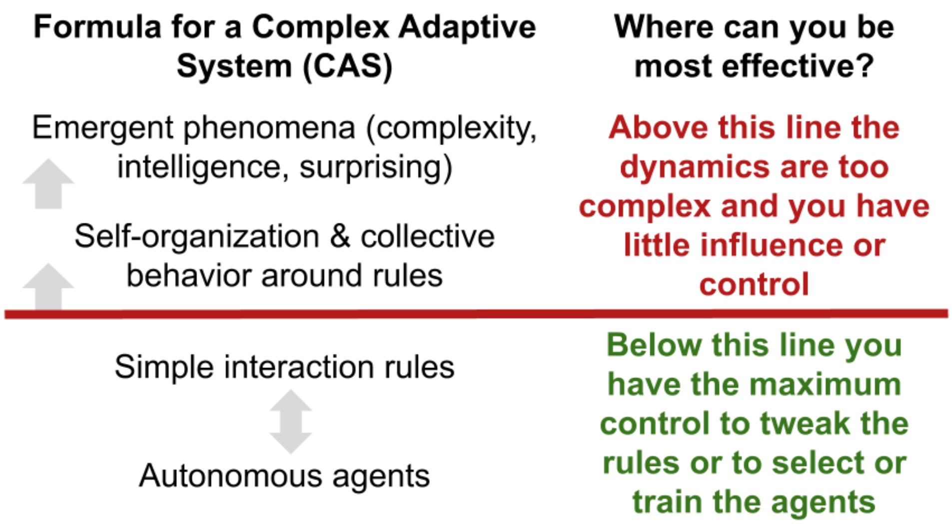

Fig. 4. Effecting CASs

A.1. COVID-19 as a CAS. The COVID-19 Crisis is a germane, example of the importance of CAS (and ABM). The palpable devastation that it has caused warrants global attention. Note that the virus itself, our collective response to it, *and* our individual [agent level] mental models of it, are *all* complex adaptive systems (CAS). Thus, the COVID Crisis provides a simple example of how CASs can be nested inside of CASs, forming larger CASs. Figure 5 illustrates [with red text] a few of the many CASs that are involved in the COVID Crisis and illustrates how CASs can be nesting inside of other CASs and even relating to form larger CASs.

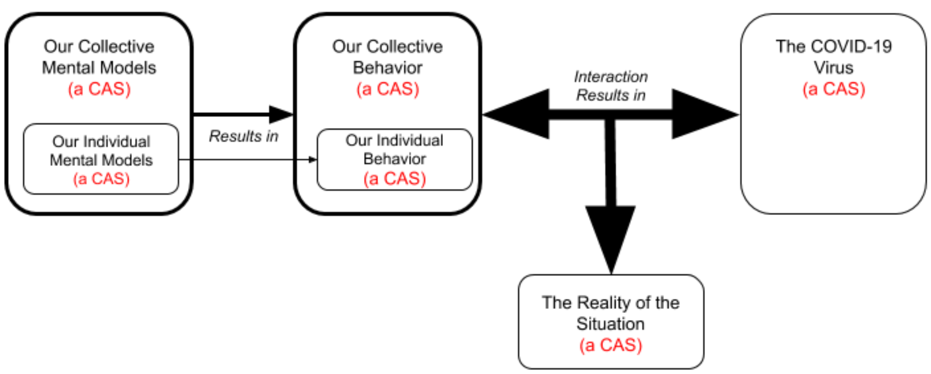

Fig. 5. The multiple CASs nested within the COVID Crisis CAS

Each of these items framed by boxes is a CAS in and of itself, collectively leading the mother of all CASs–the reality of millions of cases of COVID, hundreds of thousands dead, and untold knock-on effects to individual physical and mental health, the economy, and beyond. In Table 1 we [conceptually] walk through just a few of the agent-based scenarios using our "CAS Recipe" as a guide.

Scenario	Agents	Simple Rules	Collective Dynamics	Emergent Properties
COVID Scenario 1	People	(1) Wear Mask (2) Socially Distance (3) Essential Activities only (i.e., Quarantine) (4) Recognize delay	Very few interaction; protected when they occur; wait for delay	COVID spread minimal, curve flattens; health care system not overburdened so death rate decline; not surprised by delay
COVID Scenario 2	People	(1) Masks optional; politically charged (2) Minimal social distancing (3) Any Activities (i.e., party like it's 1999) (4) Only isolate if you have COVID	Many unprotected interactions; when they occur little can be done	COVID spread massive; delay is "surprising", curve spikes; health care system overburdened so death rate rises
COVID Scenario 3	Agencies (federal and state)	(1) Test (2) Contact trace (3) Transparent Reporting	Lot's of feedback interactions	COVID spread understood; informed individuals make better decisions; curve flattens; health care system not overburdened so death rate declines
COVID Scenario 4	Agencies (federal and state)	(1) ignore data (2) Eschew tests (3) Ignore spread (4) Subvert data	Very little situational awareness of interactions; must wait and see what happens	COVID spread massive; delay is "surprising", curve spikes; health care system overburdened so death rate rises

Table 1. A Few Examples of CAS Utilizing the Elements of the "CAS Recipe"

B. What is Agent-Based Modeling (ABM)?. It is best to understand Agent-Based Modeling (ABM) in comparing and contrasting it to CAS. The purpose of ABM as a *method* to *model* CASs. So, ABM is a derivative of CAS concepts, theoretical structures, and assumptions. Where ABM differs is that it provides a methodology (usually a computer program) for creating a "run-time" model of some given CAS phenomena. In other words, in an ABM, you define the agents, simple interaction rules, and the environment (usually a grid of some type with certain parameters) and then pres "run" in order to see how the model plays out in time. The power of ABM is that it allows you to see what happens, quickly "tweak" the rules, agents, or environment, and then run the model again to see how the system behavior will change. In addition, while an ABM's run-time can be quite significant (days, months, years, decades) it can play out in a matters of seconds or minutes, allowing the modeler to see immediately what the emergent properties of given agents and rules will be. The power of ABM is that it can be specific and predictive about CAS. The downside of ABM is that one must be very specific in order to be predictive. Thus, ABM models are only as good as the specificity of the assumptions that are coded into them. There are some essential features of ABM which include: a) an agent's structure; b) agents and the program that represents them; c) and the main program, which is not an agent, but is a description of the systems in which agents can influence its dynamic environment (17). The objective of an ABM is to provide a rationality for the collective behaviors of agents that are following simple rules, especially in natural systems. Under the scope of ABM, a system "is modeled as a collection of autonomous decision-making entities called agents" (18). Most notably, in complex adaptive systems, each agent individually analyzes its situation and makes decisions by following a set of rules; and ABM is a tool used to model these interactions. ABM is used across many disciplines and is also well-known as an effective problem-solving tool in the business area.

C. The relationship between CAS and ABM. Both ABM and CAS provide theoretical and empirical tools that increase our ability to form expectations, make predictions, or anticipate the future (19). In particular, both the adaptivity that is borne of simple rules and the longer-term adaptation of underlying rules as an adjustment to the wider environment are features that distinguish CAS and ABM from the deterministic systems such as a power grid or the motherboard of a computer. Within this relationship, there are many ongoing debates including: the range of complexity approaches; tensions between theoretical and empirical research; calibration, verification, and validation; scale; equilibrium and change; and decision making.

ABM is not only used to study the complex systems but also provides tools to represent complex phenomena. ABM is useful for theoretical and empirical research of complex systems because it defines the system agents, rules they follow, environmental factors, and their relationship to collective behavior and emergent outcomes. Notably, ABM provides observable models of CASs. In short, ABM is a computational model that enables us to understand the properties of CAS and to simulate changes in outcomes that may result from modeling changes in local behaviors of the agents.

D. Applications of CAS and ABM. ABM has been used in various fields(1). Dooley applied CAS principles in his organization change theory and emphasized that the paradigm shift in science must also be embraced in management science (20). In biology, Bonabeau found that the foraging behavior of various species of ants shows the adaptation to the edge of chaos (21). This means whenever the ant colony faces instability (at the edge of chaos) caused by environmental change, the ants change the behavioral parameters such as the number of foragers, the location of harvesting. The emergent property is a form of collective intelligence and the survival of the colony. In anthropology, Gumerman studied sociocultural phenomena such as trade, warfare, and class structures formed by simple interactions of adaptive agents in prehistoric times and offered new perspectives (22). The following are examples of ABM models and their use areas:

1. Health (23): Barbrook (2017) applied ABM models to the public health sector. His research analyzed communication patterns using the TELL ME agent-based model developed in NetLogo software. These models allows researchers to change the parameters of communication in the model. Communication plans are compared to understand the complex relationship between communication and behavior in response to a pandemic. Key findings from this research showed that this model was useful: a) as a teaching tool; b) as a formal thought experiment to test the theory; and c) to inform data collection. Thus, the TELL ME ABM model was applied epidemiologically as it could simulate populations over time to promote population-level inference from explicitly programmed micro-level rules. This ABM model can also can explore the feedback and reciprocity between exposures and outcomes in the etiology of complex diseases (24). The TELL ME model was the first to successfully combine five requirements:
   - It includes the effects of communication on behavior;
   - It considers a two-way influence between the simulated epidemic and personal behavior;
   - Decisions to adopt protective behavior are based on appropriate psychological models;
   - Simulated individuals have different characteristics (such as attitude and media access) and react differently to the same situation, and perceive their environment (such as proximity to the epidemic), reacting differently to different situations; and
   - The model has been parameterized with available empirical data.
2. Economy (17): ABM has also been applied to economic phenomenon and in many cases has replaced econometric approaches because it is more predictive. Farmer and Foley examined the use of econometrics and Dynamic Stochastic General Equilibrium (DSGE) that had been used by Obama's economic team to face the economic crisis. Both methods had a fatal flaw. Econometrics could forecast the data but failed when major changes occurred. A DSGE model falsely assumed a perfect world and therefore removed the crisis from the model, rendering it useless. The authors proposed that ABM was a better methodology, because it can analyze a wider range of linear behaviors than DSGE. In addition, policymakers can apply ABM in different policy settings to explore the consequences quantitatively. Thus, ABM had the potential to model the whole economy, and also to accurately forecast conditions of the real economy, integrating models of financial interaction, real estate, government expenditure, government revenue, business, foreign trade, and investment with consumer behavior. The result of this simulation could then be used to evaluate economic stimulus and it's correlated effects.
3. Tourism (25): ABM has also been applied by tourism researchers. Tourism is a complex system. In tourism, there are advantages to using ABM including: (a) the ability to capture agents behavior, (b) it is more intuitive than statistical methods in describing and simulating systems, and (c) the ability to "map up" from the small scale level of the individual to a large scale of the system, and contrast this with the existing data. In Nichols, et. al (2017) (25) ABM was used to: (a) explore the potential economic spread and benefits across clusters which could increase awareness, through advertising, of other destinations; (b) study tourist decision making when choosing a destination; (3) allow Italy, which was interested in expanding its winter tourism, to evaluate the robustness of adaptive strategies for climate change and demand and competition. Perhaps one of the most valuable benefits of ABM is that it can test theories and explore their implications. Future uses of ABM in tourism include: exploring tourist motivation and behavior, management of visitors flows, tourism development planning, tourism marketing, and tourism policy.
4. Public Policy (26): ABM is ubiquitous in its use to simulate social systems because it can represent complex phenomena that are not easily captured in other mathematical or more traditional methodologies. ABM can show the heterogeneous behavior of agents with different information, rules, and situations to the macro behavior within the system. It can describe the behavior of inherently unpredictable systems and identify which model is more useful under uncertain conditions. When the variables can be well-defined, ABM simulation can play an important role in supporting the development of social processes, such as policy making, when the standard methods of policy analysis are least effective and prediction is not available.

In general, use patterns and research across disciplines shows that ABM is best used when: (a) interactions between agents are complex, (b) agent's positions are not fixed, (c) the population is heterogeneous, (d) the topology of the interactions is complex, and (d) agents have complex behavior (18). ABM can help us to trace how agents' (individual) rules generate macroscopic regularities and also to separate individual rationality from macroscopic equilibrium and decision science from social science in general(27). ABM is useful for theoretical and empirical research of complex systems because, if/when the system entities and their relationships can be defined, this definition can be used to determine or observe observed the emergent system-level behaviors and to explore different scenarios that could or will occur in the future (28).

E. Pros and cons of CAS and ABM. Many social and natural systems are CAS. Because CASs may result in far-from-optimal aggregate behavior, often the standard theories of economics or physics—rely on optimization—are limited (19). A majority of economic models rely on equilibrium, for example, despite that fact that all economic systems are CASs and there may not be equilibrium in a CAS, because CASs have heterogeneous, dynamic agents interacting in nonlinear ways. Because ABM uses individual agents as a modeling unit and uses computer simulation instead of linear optimization, ABM can be an effective modeling tool for solving potential problems arising from the CAS environment. In addition, modern advancement of information technology makes simple ABM modeling tools available on the desktop to any user with relatively low programming needs. And, super-computing has made it possible for parallel computers to work together to run simulations mimicking real-life CAS. This offers ample opportunities to deal with complex adaptive systems (19). All of these facotrs point to the relative benefits of ABM over other modeling techniques, especially (18):

- ABM captures emergent phenomena;
- ABM simulates the behavior of the system, the agents, and its interactions, capturing emergence from the bottom up when the simulation is run;
- ABM provides a natural description of a system;
- ABM describes and simulates the behavior of the system; and
- ABM is flexible. It can be observed along multiple dimensions, with the ability to add more agents. It also provides a framework for modeling many facets of complexity including: agents, behavior, degree of rationality, ability to learn, and rules of interaction.

There are several recommendations for the improved use of ABM in the future. It is important to choose a topic that is close enough to its environment to allow for an independent consideration of its internal dynamics. It is then important to identify and consider agents at every level within the scope of the model. At least one of these agents must have a goal variable and an instrument variable. Then, the internal model must be constructed which must consist of a suggested relationship between its single instrument and its goal variable. Empirical data for all used variables then has to be found. Then comes the econometric estimation and calibration of the suggested relationship. The estimation quality will vary according to the quality of available data. The quality of this estimation will vary according to the quality of the available data. In some cases we can estimate certain parameters that have to be used, and the quantitative result will be the blueprint of the ABM. (29)

ABM is a useful tool, but there are still some issues regarding its use, especially in the areas of psychological, social, political, and economic phenomena (18):

1. *Specificity*: ABMs tend to be very specific. ABMs often cannot be generalized. They require specific parameters detailing specific purposes;
2. *Construct validity*: Generally speaking, all aggregate results of an ABM are only as good as the construct validity of the agent and rule inputs. Sometimes it is difficult to define the variables that must be defined. ABMs involving human or animate agents may have difficulty capturing irrational behavior, subjectivity, and complex psychology because these "soft factors" are difficult to quantify, calibrate, or justify. ; and
3. *Practicality*: ABM analyzes the system at the level of its constituent agents and rules, not at the aggregate level. To *develop* a simulation of all the heterogeneous agents can be extremely time, skill, and/or resource intensive. The human costs in variable specification, construct validity, and programming is often prohibitive. Although technology has significantly lessened the computational costs, the high computational requirements of ABM when modeling large systems are still a serious issue.

These three issues of ABM do not take away from its power as a methodological tool. They simply lessen the number of situations where ABM will be, can be, or is the tool of choice. All three of these significant problems mentioned above result in a single important discrepancy: the discrepancy between the sheer number of situations where CAS is relevant versus the number of those situations where ABM will be feasible. This leads us to a significant problem where the *Feasibility of ABM* (F) is *significantly less* than *Applicability of CAS* (A)

$$\frac{\text{number of cases where ABM is feasible } (F)}{\text{number of cases where CAS is applicable } (A)} = F << A$$

We posit that the biggest problem with ABM is what we will call the "$F<<A$ Problem." For those scenarios where ABM is feasible, then an ABM solution is a great option. But for the significant number of cases where an ABM approach is simply infeasible but for which a CAS approach is applicable, there is, simply put, a methodological chasm.

2. Introducing ABA as an alternative to ABM

We have shown that CAS provides a powerful theoretical framework for understanding systems, and ABM (as well as cellular automata, or CA), a derivative method of CAS, can also be a powerful methodological tool for running simulations. However, the problems associated with ABM are not unlike the historical problems faced by other disciplines in the systems thinking field. System Dynamics (SD), for example, which Forrester called "Industrial Dynamics," provides a powerful set of theoretical tools for understanding systems and System Dynamics Modeling (SDM) (and softwares such as STELLA Vensim, and Loopy). Historically speaking one can see clear parallels between the power and problems of SD and SDM with CAS and ABM. Where historically SD is akin to CAS (both are powerful theoretical concepts and heuristics) and SDM is analogous to ABM and ABM softwares(like NetLogo) in that they provided a means for people to apply the theoretical insights gained by, respectively, SD and CAS, to the modeling environment. However, like SDM software, ABM modeling software suffers from a number of problems that cause a great mismatch between situations where a CAS approach can be utilized and the small minority of those that can utilize ABM. This is akin historically to the many situations where insights from SD could be used despite the relative small minority of times SDM could be used. Some of these limitations in [both SDM and] ABM are listed below:

1. **Lack of data**: Unavailability of the necessary data. Either there is not enough, or not the right data available. If it is available, it may not be readily available to the particular person or team of people who desire to do the modeling. If the data that populates the model is faulty, so to will be the results.

2. **Vague variables**: The system is too complex and knowledge about the system is too vague/nascent for variable specificity and definition.

3. **Coding Competency**: The simple fact is that many of the people trying to solve complex problems either don't have the computational skills or the resources to garner the coding needed to make models work.

4. **Shoehorning Complexity**: The reality is that either the modelling paradigm or the specific modelling application forces the problem solver to shoehorn real-world complexities into tightly-defined, discrete variables in order for the model to work. This is often difficult for the reasons above and for various other reasons having to do with complexity.

The result of these problems is that while modeling (SD or ABM) is a remarkably powerful tool in many situations it is infeasible. Even in situations where ABM (or SD) modeling would be ideal, it is not realistic due to some combination of the problems mentioned above. In short, when "hard" modeling approaches are infeasible, a "soft" modeling alternative is needed (that is founded on the useful theoretical construct of CAS).

Again, the CAS field can learn from the similar history of System Dynamics (SD) and its derivative "hard" and "soft" modeling applications called System Dynamics Modeling (SDM) and Qualitative System Dynamics Modeling (QSDM). we see that historically what has occurred in the vast majority of cases in SDM/QSDM is that people take up the "soft" aspects of these frameworks and methods far more often than they are able to adopt the "hard" modeling. In other words, we are making an analogy between the fields of SD and CAS and subsequently between their modeling derivatives (i.e., the analogy is CAS is to SD as SDM is to ABM and QSDM is to ABA). SD has SDM and QSDM, the latter being far more popular and useful because the former is often infeasible for similar reasons to those stated above. CAS has a "hard" modeling called ABM, but no "soft" alternative.

What we are proposing herein, is that ABA is a "soft" alternative to ABM in cases where ABM is not applicable or infeasible. It is an alternative born of the same powerful theoretical insights of CAS. We propose this with the explicit recognition of having learned from historically similar examples like that of SD. Today, despite significant investment (in time and money) and public acceptance of "hard" SDM, the "soft" QSDM qualitative feedback loop diagrams are far more popular and prevalent and make up the vast majority of "SD" use in the real-world. Only a tiny fraction of folks have the training, skill, data, and problem specifications required to do true SDM. We offer that the same is true of CAS and ABM, ergo the need for a "soft" approach that we call ABA. Table 2 summarizes the discussion above and the analogical reasoning based on this historical similarity.

	Complex Adaptive Systems (CAS)	System Dynamics (SD)	Notes
Underlying theoretical construct	Autonomous agents x simple rules lead to collective dynamics and [surprising] emergent properties. Knowledge of these can be leveraged to alter the system behavior.	Balancing and Reinforcing Feedback loops, Rates, Stocks and Flows lead to System Dynamics. Knowledge of these can be leveraged to alter the system and avoid unintended consequences.	Both SD and CAS are globally applicable to many problems. CAS, provides deep insight into complex systems and problems.
"Hard" Modeling Option	Agent Based Modeling (ABM)	System Dynamics Modeling (SDM)	Pros: Excellent tool for appropriate problems. Cons: Can be hard-to-implement or infeasible for the same reasons as ABM.
Problems with "Hard" Modeling Derivative	Lack of data, Vague variables, Coding Competency, Shoehorning Complexity (i.e., "$F<<A$ Problem").	Not all problems are "population dynamics" problems; Lack of data, Vague variables, Coding Competency, Shoehorning Complexity (i.e., "$F<<A$ Problem").	When "hard" modeling is infeasible, "soft" modeling can be used. (i.e., problem solvers shouldn't have to forgo the benefits of the theoretical framework but still need some methodological guardrails.)
Need for an Alternative "Soft" Modeling Option	Agent Based Approach (ABA) provides an alternative when ABM is infeasible (which is majority of time).	Qualitative System Dynamics Modeling (QSDM) was "invented" by users over time because SDM was so often inapplicable or infeasible (i.e., the majority of time). Mostly consists feedback diagrams and balancing and reinforcing loops.	Following a kind of 80/20 rule; most of the time, in the majority of cases, a hard approach is infeasible and a soft approach will satisfice (i.e., "$F<<A$ Problem").

Table 2. Analogous Problems of SD/SDM to CAS/ABM

As a result of (1) the ubiquity of CAS, (2) the power of the CAS concept as a heuristic device, (3) the various problems, challenges, and limitations associated with ABM, (4) the relatively large majority of cases where CAS applies compared to the relatively small minority of cases where ABM applies, and (5) the need for more robust policy-level models or heuristics based on the CAS approach, Drs. Derek and Laura Cabrera at Cornell University developed the Agent Based Approach (ABA) to be something akin to ABM but in situations where ABM was not feasible but a CAS approach was still desirable. Also, although ABA could be used in many disciplines and domains, its expressed focus is in the area of policy analysis or systems analyses with the intention of making recommendations for change or attempting to alter or "better" the system in some way. Analyzing any system is involved, not to mention a complex and adaptive system. No stepwise process will ever fully account for the many organic and dynamic things the user must do when adapting to new information. However, it is often heuristically useful to delineate a stepwise process as a form of "training wheels" for users to get started. As such, the ABA process is detailed below in discrete, linear steps, with the full awareness that nothing truly occurs in such a neat stepwise fashion.

3. The Steps of an Agent Based Approach (ABA)

An ABA Approach is a stepwise approach to thinking about complex adaptive systems (CAS) with the end goal of coming to some recommendations (and recommendation principles) that will help to change the system from its current undesirable state to some future [more desirable] state. In short, ABA is a problem solving method. Yet, we resist referencing problem solving because the term can introduce significant bias into the process. Instead, we use the term "understanding the system" as an alternative to "solving the problem" because the former is the natural predecessor to the latter. Before laying out the steps of ABA, there are two prerequisites to utilizing ABA as a technique or method. First, you must understand DSRP as the root theoretical construct of Systems Thinking (See Table 3).

Patterns	Elements		
Distinctions (D)	identity (i)	$\leftrightarrow$	other (o)
Systems (S)	part (p)	$\leftrightarrow$	whole (w)
Relationships (R)	action (a)	$\leftrightarrow$	reaction (r)
Perspectives (P)	point (ρ)	$\leftrightarrow$	view (v)

Table 3. Basic Structures

DSRP provides the theoretical basis for the analytical and synthetic skills required for understanding and cognitively mapping complex systems. It may also be useful to understand the derivative of DSRP Systems Thinking, Systems Mapping. Understanding that DSRP provides simple rules for systems thinking, that mental models are comprised of information and DSRP structure, and that one must constantly iterate mental models by exposing them to the real-world in order to receive feedback and consequently adjust mental models. A thorough review of DSRP is provided by other resources (30)(16)(31)(32)(33)(34)(35)(36)(37). However, we offer the following executive primer of the ST/DSRP Loop.

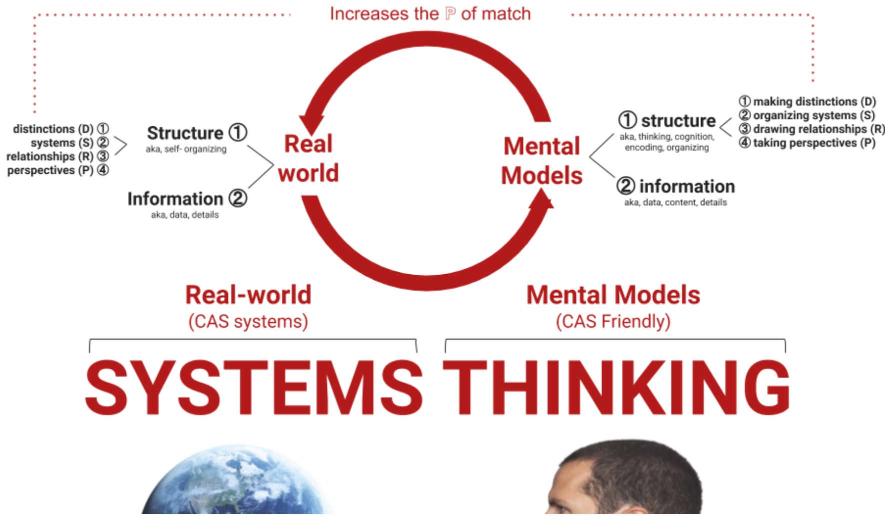

Fig. 6. The ST-DSRP Loop and the basis for Systems Thinking

The ST-DSRP Loop explains that our mental models are approximations of reality that must iteratively be tested against reality in order to engender feedback in the form of information which is then re-incorporated into our mental models using DSRP structuring processes. Doing these processes is called thinking (i.e., cognition, emotion and conation). Being aware of these processes is called metacognition (i.e., awareness of cognitive complexity). It is the combination of cognitive structure and information that results in meaningful mental models. The essential component of DSRP is that its elements provide a bridge between the physical-natural world and the cognitive conceptual-world (both of which are materially formed in DSRP structure). This means that DSRP is a physico-cognitive theory, for which there is meta-analytical evidence.

The DSRP Mapping Method is a stepwise process provided as a heuristic tool for doing DSRP Theory (which is not a stepwise process but a dynamic and organic one). The DSRP Mapping Method illustrates the various things a systems thinker can do at any point in time in the analysis and synthesis of information (there are any number of structural operations that can and do occur simultaneously). It is predicated on the use of "cards" which can be thought of pragmatically as post-it note like objects that can contain any information but can manifest in many analog and digital ways such as: tactile manipulatives (marbles, blocks, or other representational objects), post-it notes, hand drawn shapes, digital or actual cards, or even gestures, etc. The creation of a single card (i.e., a thought containing structure and information) sets off a DSRP set of chain-reactions that can occur in many different ways. Figure 7 provides a map of the various ways these actions and reactions can play out.

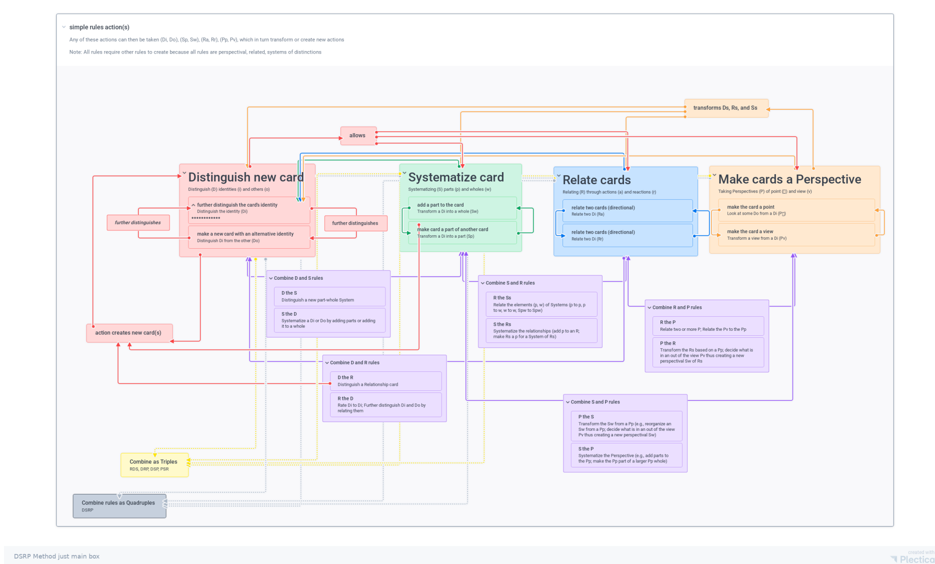

Fig. 7. ST/DSRP Mapping Method

The second prerequisite to using ABA is an understanding of CAS, which we have outlined previously as a relatively simple recipe or "algorithm" as follows:

Autonomous agents x simple, local, interaction rules lead to collective dynamics and [surprising] emergent properties. Knowledge of these can be leveraged to alter the system behavior at the agent and rules level.

These two understandings are the prerequisites to perform an ABA. Here are the Steps to ABA:

- Step 1.0 Understanding the System
  - Step 1.1 ST/DSRP Loop Analysis
  - Step 1.2 POSIWID Differentiation
  - Step 1.3 Root Difference Analysis
  - Step 1.4 List Agents
- Step 2.0 Making Recommendations
  - Step 2.1 CAS Analysis Table
  - Step 2.2 Recommendations Rubric
  - Step 2.3 Specific Recommendations & Backcheck

Visually, ABA illustrates there are some relationships between the two sets of steps (See Figure 8).

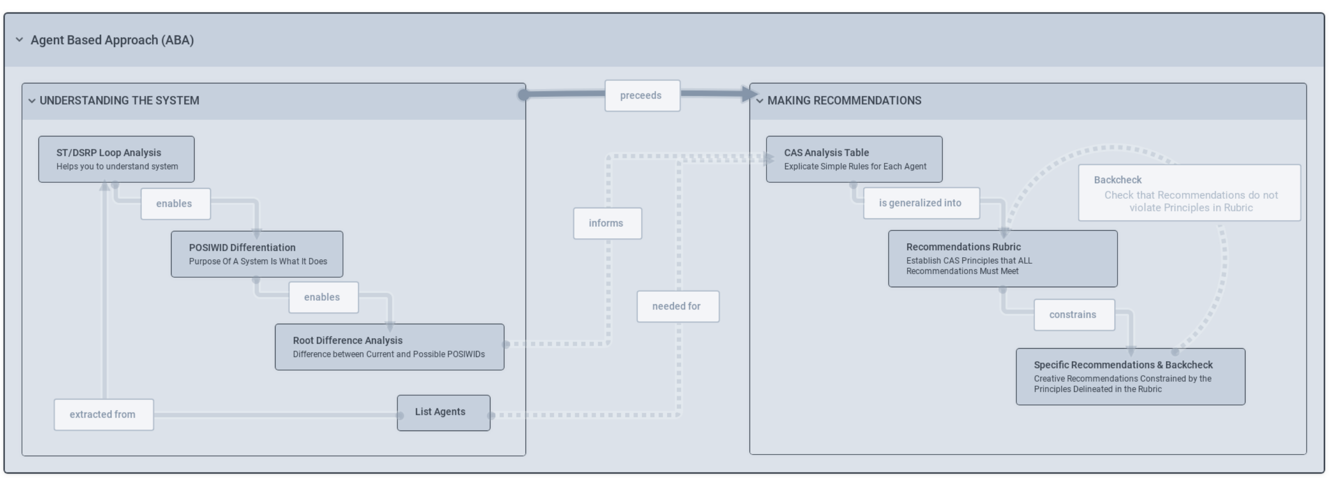

Fig. 8. Steps to an Agent Based Approach (ABA)

Table 4 outlines the steps of a high-level and simple example (women underrepresented in science) to provide a big picture understanding of the ABA steps.

Step	Example
1. Understanding the System	
1.1 ST/DSRP Loop Analysis: Understand your system. Develop a DSRP map of the system and iterate it until it passes "reality-test." (Note: This part of the process is its own process in and of itself, that has to do with understanding how DSRP Mapping works)	Map out all the reasons women are underrepresented in science.
1.2. POSIWID Differentiation: Understand the current POSIWID and desired [future] POSIWID or "goal state" of the system.	A representative number(50%) of female scientists.
1.3 Root Difference Analysis: Identify the difference between the IS and SHOULD BE POSIWID.	Culture of Science for All vs Culture of Science for boys only.
1.4. Agents List: Make a short list (3-10) of the salient agents in system at all levels of scale.	Girls of all ages, parents, teachers, school administrators, schools, grant administrators, granting institutions, policy makers, cultural/political leaders.
2. Making Recommendations	
2.1 CAS Analysis Table: Explicate the simple rules for each agent group. Fill in the "CAS table" for all agents in item 1.4 above checking that no simple rule violates any of your CAS Principles in 2.2 below.	*Girls' rules:* (1) See Self as Scientist (2) Do Science (3) Others See A Scientist; *Supporter's rules:* (1) Do everything you can to support rules (2) Don't do anything to not-support rules.
2.2. Recommendations Rubric: Come up with 3-10 "CAS principles" your and all future recommendations must meet. This list acts as a backcheck on proposed recommendations to see if they pass this litmus.	[These are examples based on the conclusions of systems structure and dynamics in step 1]. Does it disincentivize girls from pursuing science? Does it discriminate against competence in science? Does the act/artifact communicate implicitly or explicitly a difference between males and females in regard to science ability? Does it cost more than what is currently being spent? If so, rethink it.
2.3. Specific Recommendations & Backcheck: Make 3-10 recommendations. Be wildly creative but constrained by the principles. Any recommendation that does adhere to the principles is fair game.	Science Barbie and Priscilla Pal the Science Gal.

Table 4. The Steps to an Agent Based Approach (ABA) with Examples

By assembling the components of CAS/ABM and DSRP into a "method" (a stepwise process) we are better able to understand and change complex systems in the real world based on their underlying structure. The artifact of "policy" and the notion of "policy analysis" comes into play here. We see of course that a "policy" is simply a set of guidelines for understanding how agent action (the following of simple rules) will affect emergent properties. We also see that "policy" in this framing of the term is a fractal, general, and abstract concept. That is, "analyzing or establishing policy" isn't something that only a policy expert or government administrator does, but something a parent, team or organizational leader, community organizer, or numerous other roles must do. If the CAS you are attempting to understand and change is a family, a classroom, a team, an organization, a state or federal system, or a global crisis...the steps you must take to understand this CAS, identify the types of actions that can be taken to alter it, and codify those generalizable actions into specific ones (recommendations) is the same. The degree, scale, resources available, timeline, stakeholders, and relative complexity may change but the basic process does not. In other words, policy analysis is a fractal pattern. And, "policy" can be defined less as a legislative, legal, or bureaucratic document and more as "a statement of the simple interaction rules that one predicts will lead to desired systemic change." In this regard, "a policy" is something any person might utilize anywhere, not merely something a policy analyst in the halls of Congress might use. The methodology summarized above, described below, and explicated in the examples provided below are guideposts, for and manifestations of, this idea.

A. Step 1.0 Understanding the System.

A.1. Step 1.1 ST/DSRP Loop Analysis. Notably, while all the steps in ABA are important, it is the first step in the ABA that is the most labor intensive, and itself has some substeps. These substeps are entirely heuristic and/or pedagogical—meaning they are for learning and practicing but are not inherent to the process per se. That is, analyzing, synthesizing, and interrogating one's mental models and testing them against reality using DSRP is not a linear stepwise process as it naturally occurs. Any DSRP process is dynamical— it is massively modular, recursive, and fractal. But because such processes can be confusing to the uninitiated, it is helpful to provide stepwise heuristics as a sort of "training wheels" for practice until the neuronal pathways are fully burned.

The first step of ABA is the ST/DSRP Loop Analysis. This involves the 6 steps outlined in the list below. You can see from Steps 2 and 3 that there are a number of specific substeps that can be followed. If you ask yourself theses DSRP, structural questions, interrogating the system structurally, you'll eventually find the answers.

1. **Stop trying to solve problems and start trying to understand systems!**
2. **Generate your mental model of the system. (use DSRP Questions)**
    - What are the distinctions I am making when I explore this system? (From which perspective?)

- What are the salient parts? (From which perspective?)
- Are there relationships among these parts that I am not seeing?
- What different perspectives could I take to better understand this issue?

3. **Interrogate your mental model of the system with DSRP.**
   - Distinguishing
     - Are my distinctions MECE/NONG (Mutually Exclusive Collectively Exhaustive / No Overlaps, No Gaps)?
     - Are my distinctions necessary/sufficient?
     - From what perspective (set of assumptions) am I making my initial distinctions?
     - Am I othering (Creating a marginalized other)? Could things be distinguished differently?
   - Systematizing
     - How are things organized into part-whole groupings/systems?
     - From what perspective are my groupings being made? Could things be organized differently? Am I locked into categorical thinking?
   - Relating
     - Have the parts of systems and subsystems been sufficiently related?
     - Do any of the current relationships need to be distinguished? Systematized? (RDS)
   - Perspectivizing
     - What perspective is the whole system from? Am I okay with that?
     - Is there anything in the system analysis that should be a perspective on the whole?
     - Are there /missing/important perspectives that would provide insight?
     - Are all of my perspectives "with eyes"?
4. **Test your mental model against reality (get information through feedback).**
5. **Evolve your mental model using DSRP to better fit reality.**
6. **Repeat.**

A.2. Step 1.2. POSIWID Differentiation. The next step in ABA is to understand the current POSIWID and the desired [future] POSIWID. In other words, we POSIWID the system as it IS and also POSIWID the system as it SHOULD be and compare and contrast these two in order to understand the structural difference.

Systems and management scientist Stafford Beer developed an important and popular systems thinking heuristic known by the acronym POSIWID: "The purpose of a system is what it does." Beer regarded POSIWID as "bald fact" and a better starting point for understanding a system than a focus on designers' or users' intention or expectations. Beer states, "The purpose of a system is what it does. There is after all, no point in claiming that the purpose of a system is to do what it constantly fails to do." When assessing a system, we need to focus on what the system actually does rather than its ostensible, original, or ideal purpose (since these often do not match). For example, we need to ask the following questions:

- What is the system's stated (ostensible) purpose?
- What is the system's behavior?
- What does that behavior say about what the system's purpose is?
- Is there alignment between the actual and ostensible purpose?
- If not, what is the system's structure?
- How can we alter the structure to drive new behavior?

In Figure 9 (38), the value of POSIWID thinking is illustrated. It flips the system and its purpose on its head. Instead of looking at the results of a system as problematic, you look at the results of the system by design. The worse the result, the more clear the value of POSIWID thinking. Take, for example, a company that is bleeding cash: you might look at this as a problem (and of course it is), but for a moment consider that everything about that company—all of its internal systems—are actually really good at spending money. This flips the problem on its head. We can now look for processes, cultural morays, and other parts of the system that are good at burning cash. Recasting the system's purpose as POSIWID recasts the problem you are trying to solve.

Identify a system that you think is failing or isn't working well enough	Describe the specific results of the failure	Turn your description on its head with POSIWID*
Example: The U.S. education system	Example: Too many disengaged kids	Example: The U.S. education system is exceptionally well designed and good at its purpose of controlling and boring kids so that they disengage.
Example: Acme's software product	Example: Too much churn	Example: Acme's software product is extremely well designed and effective at its purpose of getting customers interested enough to sign up and then leave.
Add yours here:	Add yours here:	______ is exceptionally well *entry from column 1 (system)* designed and good at its purpose of ______. *entry from column 2 (results)*

Fig. 9. POSIWID activity

Instead of the system being badly designed to serve a good outcome, it is brilliantly designed at bringing about a bad outcome.

A.3. Step 1.3 Root Difference Analysis. So in a POSIWID Differentiation and Root Difference Analysis you must develop a statement of the systems' actual POSIWID and another statement for the systems' "should-be-POSIWID." Remember that this "should-be-POSIWID" may or may not be the same as the current stated Purpose. The "should-be-POSIWID" is what the future system should do based on changes you will make to it. Then, identify the difference as shown in Table 5.

Table 5. Root Difference Analysis Table

Actual "Current-Is-POSIWID"	Difference	Future "Should-be-POSIWID"
School systems are good at disengaging students.	Disengagement and various forms of faux engagement vs. Authentic Engagement	School systems are good at engaging students.

Identifying the difference between the "Current-Is-POSIWID" and the future "Should-be-POSIWID" lays the groundwork for the deeper analysis afforded by the next three steps in the ABA process.

A.4. Step 1.4. Agents List. Making the agents list is an easy step if you've done the ST/DSRP Loop Analysis. Simply make a short list (3-10) of the salient agents in system at all levels of scale. We will utilize this list when we consider recommendations.

B. Step 2.0 Making Recommendations.

B.1. Step 2.1 CAS Analysis Table. The CAS Table is based on the idea that the greatest leverage points in a CAS are the agents and simple rules—so it focuses on the ideas illustrated in Figure 4 above). Explicate the simple rules for each agent group. Fill in the "CAS Table" for all agents in Step 1.4 checking that no simple rule violates any of your CAS Principles in Step 2.2. Table 6 provides a skeleton for how to create a CAS Table to complete this step by identifying the simple rules each agent follows and by backchecking that these simple rules are in alignment with the Recommendations Rubric in Step 2.2..

Table 6. Skeleton Structure of a CAS Analysis Table

Agents from Agents List in step 1.4	Simple Rules for Agent	Backcheck to Step 2.2
Agent Type 1	Simple rules for Agent Type 1	If yes move on, if no fix.
Agent Type 2	Simple rules for Agent Type 2	If yes move on, if no fix.
Agent Type 3	Simple rules for Agent Type 3	If yes move on, if no fix.

B.2. Step 2.2. Recommendations Rubric. Come up with 3-10 "Recommendation Principles" that *all future* recommendations must meet. This list acts as design principles (and as a backcheck) for proposed recommendations to see if they pass this litmus. In other words, there may be a nearly infinite number of creative, specific recommendations that could be made for any given problem, system, or issue. However, This step requires that you look beneath the specific recommendations to identify the "pattern(s) that connects" any and all recommendations (current or future). For example, if the desire is to change a system, one can imagine many specific recommendations. But a recommendation principle would be: "Cannot maintain, reinforce, or engender the status quo." Therefore, if we make a recommendation that violates said principle, it should be rejected. This is a general example but we provide numerous specific examples in the Cases below.

B.3. Step 2.3. Specific Recommendations & Backcheck. Identify 3-10 recommendations. Be wildly creative but constrained by the principles in Step 2.2. Any recommendation that adheres to the principles in Step 2.2 is fair game. The structure of this step is to allow for structured or constrained creativity. Thus, the actual recommendations can be wildly creative and "out of the box" with the one condition that they adhere to the design principles provided by the Recommendations Rubric.

As we have described each step, it is helpful to see these steps in action using real-world case studies. We have provided two such case studies below.

4. Case Examples of ABA

A. Hayden Lake: An ABA Case Study. We use this case to show that the ABA process can be a relatively qualitative and easy process that can be used even in cases where time and resources are short using the same steps:

- Step 1.0 Understanding the System
  - Step 1.1 ST/DSRP Loop Analysis
  - Step 1.2 POSIWID Differentiation
  - Step 1.3 Root Difference Analysis
  - Step 1.4 List Agents
- Step 2.0 Making Recommendations
  - Step 2.1 CAS Analysis Table
  - Step 2.2 Recommendations Rubric
  - Step 2.3 Specific Recommendations & Backcheck

This case occurred as a result of a post on a Facebook group and the ensuing discussion, guided by ABA. The originating request was made by one of the members who we will call the "Client" and Dr. Derek Cabrera who we will call the "Consultant." They wrote the following to describe the situation:

> *"Situation: in North Idaho, we have a lake. Residents want to install buoys to push large wakes toward the center of the lake away from the shoreline. Recreators and County Commissioners don't want buoys, each citing their own reasons. Emotions are high. Opinions are fixed. Nobody is happy and the actors are stalled. I would like to explore this situation using DSRP to see if there are aspects we haven't taken into consideration and to ultimately arrive at a way forward that leaves all parties standing and doors open for future collaborative work. How do we begin?"*

A.1. Step 1.0 Understanding the System. The first four steps revolve around understanding the system.

Step 1.1. ST/DSRP Loop Analysis Using an ABA approach, the process began with the Consultant asking the Client numerous questions. In this case, the Client was not only an interested systems thinker but also a member of the Hayden Lake Community. The Consultant role in this case, assumed the Client was a comprehensive source of information for the purposes of instruction only. In a real-world scenario, the Consultant would obviously interview more than one source. The discussion began with asking questions in order to understand the system. Answers to these questions—along with the initial situation description—yielded a map which evolved using the ST/DSRP Loop in four separate iterations shown in Figure 10.

Fig. 10. The Iterations of the ST/DSRP Loop

In between each iteration, the Consultant asked questions of the Client and shared the current map for feedback (this is a proxy for the kind of on the ground real-world feedback one would seek during an ABA process).

1.2 POSIWID Differentiation The POSIWID Differentiation occurred by looking at a system as it was currently. The current situation could be generally described as conflictual and based on a paradigm of either win-lose or lose-lose. That is, regardless of the internal complexities of the system, the inevitable result was always a zero-sum conflict between one set of stakeholders or another—a conflict that inevitably ended in one side winning and feeling good and another side losing and feeling disenfranchised. The [somewhat obvious] "should-be-POSIWID" was a situation that would result in one of mutual respect and engagement where the various parties involved felt the solution was win-win.

1.3 Root Difference Analysis The main *difference* between these two POSIWID is that one is conflictual and the other is mutual-respect and that one is win-lose or lose-lose and the other is win-win. The main conflict identified was that the boaters purposefully create wakes near the shoreline because they desire to make big wakes that are more fun to surf. Because the best places for creating wakes are the also the places where houses are more likely, a zero-sum conflict arises. Moreover, there is not disagreement with the wake policy, only with the buoy-policy (a proxy for the wake policy). In other words, the disagreement is not about what should be, but more about how to bring it about most effectively through a policy solution. For example, boaters and wake boarders, just want fun wakes to surf. Home owners want peace and to protect the value of their property. The situation leads us to a zero-sum conflict, but there is nothing inherent that require these two desires to be mutually exclusive.

1.4 List Agents From the discussion with the client, the following agents were identified:

- **Boaters and wake riders**: They create wakes for wake riders. Wake riders visit Hayden Lake for recreational purposes. The shallower water makes the steeper the wake, therefore, riders come close to the shore. In steep water areas, they surf even closer to the shore for the lift.
- **Homeowners**: Because the wake causes environmental and property damage (leading to decreased value of property) and safety issues, homeowners want to place buoys so that boaters will know the legally restricted zones along the shoreline that push the creation of large wakes toward the center of the lake away from the shoreline.
- **Fishers and kayakers**: They do not want wakes that threaten their safety because wakes carry and impart energy to other masses in their trajectory.
- **Locals business Restaurants**: They benefit economically from the inward flux of wake riders.
- **Tourists**: Some of the boaters, fishermen, wake boarders, and kayakers are tourists
- **Government agencies**: The Department of Lands is threatening fines for illegal buoys. The County Sheriff does not have the manpower to adequately enforce the law across all of North Idaho's waterways.
- **The Local/Lake authorities**: They consider that less governmental control is better. The commissioners want to improve public education before implementing hard controls like physical barriers.

A.2. Step 2.0 Making Recommendations. The second set of steps involves making recommendations based on understanding the system.

Step 2.1 CAS Analysis Table Hayden Lake is a complex adaptive system where agents follow a set of simple rules resulting in emergent outcomes and thus the ABA process applies. The main stakeholders and agents in the Hayden Lake case are wake riders, homeowners, the lake authorities, and the government agencies. Table 7 describes the Hayden Lake CAS.

Table 7. The Hayden Lake CAS Analysis

Agents	Simple Rules	Emergent Property
Boaters & Wake Riders	(1) Create wake for surfing, (2) Surf for enjoyment, (3) If water is deeper, surf closer to the shore.	Soil erosion along the shore; damage to docks; risk for the safety of the children on the shore; increased water turbidity and sedimentation; and potential decreased value of property on the shore.
Homeowners	Place buoys both legally and illegally.	Surfers do respond to buoys and surf away from the shore.
The lake authorities	(1) Less control on lake, (2) More educational intervention to boaters and wake riders.	Less numbers of legal buoys; more liberal wake riders.
Government agencies	Threatening to fine illegal buoys (but not able fine due to lack of manpower).	More illegal buoys.

Step 2.2 Recommendations Rubric CASs are comprised of agents following local simple rules leading to collective dynamics that yield emergent properties. In the case of Hayden Lake, the CAS analysis led to various Recommendation Principles which will later be used as a litmus test for the veracity of proposed Recommendations. The Recommendation Principles are:

1. Any recommendation must not occlude any stakeholder's perspective (e.g., if it is divisive then it is not a solution);
2. Any recommendation must be borne of individual (agent) action(s) that lead to the desire emergent properties;
3. It is assumed that no single recommendation can yield the desired emergent properties. It is likely that an ecology of solutions is required. It may be that many small things add up to one big solution; and
4. Any recommendation can be iterative and therefore (1) may initially not be "perfect" or "optimal" and (2) will necessitate the solicitation of feedback and additional information to be effective (e.g., the ST Loop).

Step 2.3 Specific Recommendations & Backcheck Table 8 provides specific recommendations for the Hayden Lake stakeholders and performs a backcheck (using the Recommendation Rubric) to ensure that the specific recommendations meet the principled criteria.

Table 8. Recommendations Backcheck to Principles Table

Recommendation	Backcheck
Hackathon: Organize a hackathon event where the community solves its own problems, by collecting creative ideas of solutions directly from stakeholders. The goal is to invite different perspectives, map them out, and come up with creative solutions that meet the Principles of the Recommendation Rubric.	This recommendation does not violate any of the Principles of the Recommendation Rubric because it expressly states that said Rubric is the litmus for any new ideas that come out of the Hackathon.
Wake Park(s): In order to deal with non-zero sum organization of surfing activities, certain shore areas should be designated as a wake park. The community may fortify designated shores for minimizing environmental impacts, and show wake surfers that the goal is not to stop them, but to mitigate their impact on the Lake community.	This recommendation does not violate any of the Principles of the Recommendation Rubric because: (1) it takes everyone's perspective, especially the directly conflicting parties: wake riders and homeowners; (2) Wake riders continue to enjoy the lake, homeowners will not have their shore damaged; and (3) After the solution is implemented, we may need to constantly measure the environmental impact caused by the wake-riders.
"Get Woke to Wakes" campaign: The community should organize a "Get Woke to Wakes" campaign to educate everyone that wakes can be fun if they're done responsibly (i.e., there isn't unwarranted destruction to property, safety issues, or environmental degradation). This includes: (a) educational signs explaining the value of not making wakes in designated areas; (b) buoys paid for by land owners who want them, placed by law enforcement or lake authorities, moving from an authoritative, top-down action to a community bottom-up action; (c) creating a certified campaign logo that can be awarded to local organizations (restaurants, bait and tackle, etc) that support the campaign with educational material, etc; and finally (d) educational brochures that target wave riders and boaters.	This recommendation does not violate any of the Principles of the Recommendation Rubric because: (1) it involves the perspectives of all key stakeholders; (2) it requires each individual to follow simple interaction rules. For example, homeowners will choose if they want buoys but will not put buoys up themselves; and (3) like all marketing campaigns, it will test numerous prototypes to see which configuration resonates with various audiences.

The Hayden Lake Case lends itself to an ABA analysis that yields a set of solutions that are robust recommendations grounded in a thorough understanding of the system itself.

B. Galapagos: An ABA Case Study. Another example of ABA analysis is from the case study "Sustainability in the Galapagos Islands: A Systems Thinking Approach Reveals the Need for Environmental and Social Balance" from Cornell Institute for Public Affairs(39). This research paper uses systems thinking generally, and ABA specifically, to analyze the environmental and social-economic systems in the Galapagos Islands. This case follows the steps to ABA outlined below:

- Step 1.0 Understanding the System
  - Step 1.1 ST/DSRP Loop Analysis
  - Step 1.2 POSIWID Differentiation
  - Step 1.3 Root Difference Analysis
  - Step 1.4 List Agents
- Step 2.0 Making Recommendations
  - Step 2.1 CAS Analysis Table
  - Step 2.2 Recommendations Rubric
  - Step 2.3 Specific Recommendations & Backcheck

B.1. Step 1.0 Understanding the System. The following steps were taken to understand the Galapagos as a system.

Step 1.1 ST/DSRP Loop Analysis Before the field visit to Galapagos Islands, researchers did research for four months, including interviews with related stakeholders to formulate a preliminary understanding of the systems in the Galapagos. They also hypothesized an original mental model: that an imbalance existed between social and environmental factors.

A field visit to the Galapagos allowed for more interviews and onsite observations as well as review of salient documentations—all with the purpose of further understanding the system (i.e., the systems understanding paradigm). This is in contrast to determining a problem and then solving for it (i.e., the problem solving paradigm). In the field work they continued to test and evolve their mental model using iterations of the ST-DSRP Loop. In other words, with each opportunity they saught to test their original mental model that there was an imbalance between the social and environmental systems in the Galapagos.

Step 1.2 POSIWID Differentiation The Galapagos researchers used POSIWID Analysis to differentiate between "current-Is-POSIWID" and desired [future] "should-be-POSIWID" to better understand the system. Their understanding of the system achieved in step 1 made the current POSIWID analysis possible. In this case, the current POSIWID appeared to be that the system was designed to maintain the status quo of imbalance between socio-economic and environmental systems (which was financially beneficial for certain stakeholders). The problems that emerged out of this understanding, helped them to develop the [future] desired POSIWID which was that the imbalance that existed needed to be rectified and that the socio-economic and environmental systems needed to be seen as symbiotic in nature.

Step 1.3 Root Difference Analysis After understanding the difference between current and future POSIWID, the authors identified three root difference mental models. These root differences capture how things are currently in the "maintain the status quo of imbalance" paradigm. It is therefore necessary to reverse these same factors in addressing the future POSIWID.

1. *Lack of Connectivity*: There is a "lack of connection" among organizations or groups, that led to weak coordination and lack of communication among agents in the system.
2. *Socio-environmental Imbalance*: A noteable imbalance existed between the social and environmental effort in the Galapagos, as these two systems did not reinforce one another (i.e., they were not thought of as symbionts).
3. *Global and Local Power Dynamics*: In addition to the social-environmental imbalance, a power imbalance between local and global entities was also observed.

Step 1.4 List Agents The understanding of the system gained in step 1, allowed researchers to easily generate a list of the agents involved in the system that included:

1. *Global Interested Parties (GIPs)*: Critical stakeholders in these systems that have the power and ability to shift the status quo. The GIPS include: United Nations Educational Scientific Cultural Organization (UNESCO), World Wildlife Fund (WWF), news outlets, social media, and tourists;
2. *State Interested Parties (SIPs)*: Includes state run entities on mainland Ecuador and on the Galapagos Islands. While the government and non-profit organizations (NGOs) bring influence to the island, they are more focused on maintaining the status quo and protecting species and the environment. The SIPs are: Parque Nacional Galápagos, Galapagos and Ecuadorian Government; and
3. *Local Interested Parties (LIPs)*: Includes local community members and groups in Galapagos islands including: Operators, Park Guides, Restaurant/Hotels, Farmers, "Mafia," Non-governmental organizations (NGOs), Fishermen, and Municipalities.

B.2. Step 2.0 Making Recommendations. The following steps were taken to develop recommendation-principles and specific recommendations for the Galapagos stakeholders.

Step 2.1 CAS Analysis Table CAS happens when agents follow a set of simple rules that lead to emergent properties. The Galapagos Islands is a complex adaptive system, as shown in Table 9.

Table 9. CAS Table for Galapagos Case

Agents	Simple Rules	Emergent Property
Global Interested Parties (GIPs)	(1) Spend money on conservation programs rather than social programs; and (2) Believe relationships among institutions are not essential.	Imbalance between environmental and social systems.
State Interested Parties (SIPs)	(1) Protect the species and environment.	Imbalance between environmental and social systems.
Local Interested Parties (LIPs)	(1) English language skills for locals are not considered important.	Lack of integrated network and cross sector networks.

The existing power structure of the Galapagos relies on international stakeholders (GIPs) and prioritizes the environmental agenda in the Galapagos. There is also a strong connection between the LIPs and SIPs, which is characterized as corrupt by a number of other agents in the system.

Step 2.2 Recommendations Rubric The Galapagos Case was a comprehensive analysis that yielded several important principles used to guide recommendations. These include: the POSIWID Principle; the CAS Principle; and the Symbiont Principle, the Sustainable Conservation Principle; and the Scalar Interest Principle. The Symbiont Principle simply means that the environmental and socio-economic systems must rely on each other rather than compete for resources. The Sustainable Conservation Principle refers to the long-term viability of any recommendations, whereas the Scalar Interests Principle requires a solution that effects stakeholders at the local, state, and global levels. Figure 11 shows how each proposed recommendation passes or do not pass the Recommendation Rubric backcheck based on these principles.

	PRINCIPLES				
	The POSIWID Principle	The CAS Principle	The Symbiont Principle	The Sustainable Conservation Principle	The Scalar Interests Principle
Proposed Recommendations	✓	✓	✓	✓	✓
Start Cuerpo de Conservación de Galápagos (CCG)	✓	✓	✓	✓	✓
Connect Galapagos Guides	✓	✓	✓	✓	✓
Build a "three-legged stool" partnership	✓	✓	✓	✓	✓
Start Farmer Federation	✓	✓	✓	✓	✓
Start "Other" Federation Networks	✓	✓	✓	✓	✓
Start Import = Invasives Campaign	✓	✓	✓	✓	✓
Start "Balance" Campaign	✓	✓	✓	✓	✓
Widely Publish and Disseminate Accessible Report and Collateral	✓	✓	✓	✓	✓
Partner with an Independent Organization to Monitor Transparency	✓	✓	✓	✓	✓
Example Recommendations That Fail Principle Checks					
Reform the Special Law of 1998		✗			✗
Found an English Language School				✗	

Fig. 11. Recommendations Rubric(39)

Step 2.3 Specific Recommendations and Backcheck Based on the guiding principles used, the researchers proposed 9 recommendations including:

1. Start “Cuerpo de Conservación de Galápagos (CCG)”;
2. Connect Galapagos Guides and use them as a valid source of the voice of balance;
3. Build a “three-legged stool” partnership;
4. Start Farmer Federation;
5. Start “Other” Federation Networks;
6. Start Import = Invasive species Campaign;
7. Start a “Balance” Campaign;
8. Widely Publish and Disseminate Accessible Report and Collateral; and
9. Partner with an Independent Organization to Monitor Transparency.

This systemic study included a thorough literature review, a systematic process and methodology to understand the systems, analysis of existing problems, and provides strong recommendations that can be applied in Galapagos to support the balance between socio-economic and environmental systems.

5. The Future of CAS, ABM and ABA

In this chapter, we have provided the basis for a CAS approach to solve critically important problems. As a naturalistic reality, a theoretical framework, or a heuristic device, CAS is a powerful tool. ABM, too, can be a powerful way to test and extend a CAS understanding of the world. When ABM *can* be used, it is a powerful tool. However, ABM has drawbacks that make it an infeasible method the majority of the time. These drawbacks should not preclude the use of CAS when face with seemingly intractable problems. For this reason, a new approach—the Agent Based Approach or ABA— can be used the majority of the time when CAS analysis is indicated. ABA was developed with an expressed focus on the analyses of CASs leading to specific policy recommendations, but many aspects of ABA can be applied outside of a policy context. Especially in light of more nuanced and expanded definitions of “policy” and/or “policy analyst.” Where one might think of “policy” as a legislative, legal, or bureaucratic document we promote that an understanding of CAS means that a “policy” is simply a set of guidelines for understanding how agent action (the following of simple rules) will affect emergent properties. In other words, policy can be defined as “a statement of the simple interaction rules that one predicts will lead to desired systemic change.” In this regard, “a policy” is something any person might utilize anywhere, not merely something a policy analyst in the halls of Congress might use. If the CAS you are attempting to understand and change is a family, a classroom, a team, an organization, a state or federal system, or a global crisis...the steps you must take to understand this CAS, identify the types of actions that can be taken to alter it, and codify those generalizable actions into specific ones (recommendations) is the same. The degree, scale, resources available, timeline, stakeholders, and relative complexity may change but the basic process does not. In other words, policy analysis is a fractal pattern and “the analysis of policy” is for everyone. ABA therefore, is a tool that anyone can use, but especially the formally trained policy analyst. ABA provides another tool in the systems scientist’s tool belt and is invaluable for the policy student or scientist attempting to understand and better complex adaptive systems.

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