# Satisficing, Optimization, and Adaptive Systems

# JASON BROWNLEE

Technical Report 070305A

Complex Intelligent Systems Laboratory, Centre for Information Technology Research, Faculty of Information Communication Technology, Swinburne University of Technology Melbourne, Australia jbrownlee@ict.swin.edu.au

Abstract- An aspect of complex adaptive systems is an observation that they typically operate far from equilibrium and optimality. This provokes investigation into frameworks into such decision-making processes. Satisficing describes a rational decision making process in economics where deciding agents accept solutions that achieve a minimum level of satisfaction. This theory differs from previously traditional rational decision-making in which the agent seeks to maximise or optimize utility from the choices faced. This work investigates some of the impact this altered perspective on the decision making process has had in economics, game theory, control theory, and evolutionary biology. We see it is the latter case that that may be most interesting to the study of complex adaptive systems and resultant models, such as those used in biologically inspired computation.

Keywords- Satisficing, Adaptation, Optimization, Evolution, Algorithms, Complex Adaptive Systems

# I. INTRODUCTION

Consider Complex Adaptive Systems (CAS) [14] as systems of collectives of adaptive agents whose local interactions result in dynamical non-linear effects and emergent behaviours. According to Holland [14,15], and others [35,36,38], such systems operate far from equilibrium and optimality. This is an intriguing notion given the ubiquitous adaptationist model of evolutionary biology (a popular example of a CAS) as an optimization process. That is, organisms are optimized by evolution for their environment.

This work softly explores this theme by providing background on the decision theory of 'good enough' solutions known as *satisficing* and a number of interesting and notable works interpreting this notion in the context of game theory, control theory, ecology, and search. Satisficing is a notion suitable to describe the 'operating far from optimality' description of CAS, and a final discussion considers a few implications of satisficing in designing future artificial evolutionary and immune system algorithms.

# II. SATISFICING

The Nobel Prize laureate Herbert A. Simon coined the term 'satisficing' to describe the selection of a 'good enough' solution, the selection of a decision that meets a minimum threshold or aspiration level, the selection of which occurs in the context of incomplete information or limited computation [7,8]. This formalism came out of his work on "bounded rationality", the idea of agents

acting approximately rational, rather economically rational in terms of utility. Simon had a problem with the idea of the traditional "economic" and "rational" agent, because in reality, agents do not always optimize their decision making process. He drew from the field of psychology to describe a 'characteristic decision maker'. In so doing, he outlined a scenario of rational choice:

- (1) There are set of alternatives open to choice
- (2) The relationships that determine payoffs (satisfaction or attainment) are a function of the alternatives that are chosen
- (3) There is preference orderings among payoffs (ordinal)

In this generalised scenario, the decision maker must apply a strategy. Traditional economic strategies of the time include: the max-min rule, the probabilistic rule, and the certainty rule. Simon's problem was that these strategies required information or computation that no human could possess, and hence were unrealistic.

Satisficing: The selection of an 'acceptable' or 'satisfactory' solution that meet an agents minimum 'aspiration-level' or 'threshold', a threshold, under which solutions are deemed 'unacceptable'. A satisficing solution may or may not be an optimal economic solution.

Figure 1 - Canonical definition of the term 'satisficing'

Satisficing differs from a traditional rational decision-making process in economics in which the agent assigns a utility to each choice, and then makes a decision based on the probability that each choice would occur — maximising utility. In contrast, satisficing solutions are deemed either satisfactory (above the agents aspiration level) or unsatisfactory (below the agents aspiration level). An agent may decide on the first, or any satisficing choice, the outcome being that the agent is always satisfied, although the solution may or may not be economically optimal. Such a strategy is simple, computationally tractable, and a rational strategy, although always selecting a satisficing strategy may not be rational.

Simons 'satisficing decision-making' and 'bounded rationality' have had a profound effect in many fields, not limited to economics, game theory, management theory, psychology, artificial intelligence and evolutionary biology. Some interesting and notable works follow.

Some general works include; a recent collection of

essays on satisficing decision making [25], satisficing in economics and firms [33], decision theory on deciding when a selected capacity has been learned and overt learning should cease [34], and a philosophical treatment of satisficing verses optimization [24].

Much work has been done to extend satisficing and 'comparative rationality' in game theory by Stirling, et al. not limited to satisficing in games such as the prisoners dilemma and battle of the sexes [41]. There is a recent book dedicated to the topic of 'satisficing games' [40] including computer models and algorithms. Stirling has also done work on decision-making with regard to appropriate skill selection, as opposed to selecting the single best skill [23], and so called 'satisficing equilibria' [39]. There has also been work by others on the evolution of cooperation with regard to satisficing strategies in [42], and resultant cooperation given satisficing strategies in mutual interest games [3].

Satisficing has also proven a useful inspiration for decision making in control systems. In particular is the development of the so called 'satisficing control theory' for nonlinear systems controllers [18-20]. The satisficing threshold was paired with 'epistemic utility theory' as a multi-objective approach to accepting and rejecting propositions.

Satisficing controllers have been used in robot soccer simulations [13], and so called 'action selection' in robot theory [27]. Sen [32] provides a collection of essays on satisficing models of control when dealing with uncertainty. Finally, satisficing has been applied to 'design-to-criteria' [37] as a multiobjective approach to meeting the needs of clients, and in [17] as a theory to describe the problem of human designers latching onto one design (even if the design is sub-optimal), not considering other designs.

#### ADAPTATION AND OPTIMIZATION

Thus far, satisficing has been superficially demonstrated to be an interesting little pocket of decision theory, it isn't until it is considered in the context of ecology and evolutionary biology that the interesting link to adaptive systems becomes apparent.

"Bracketing satisficing with Darwinian [evolution] may appear contradictory, for evolutionists sometimes talk about survival of the fittest. But, in fact, natural selection only predicts that survivors will be fit enough, that is, fitter than their loosing competitors; it postulates satisficing, not optimization"

From [11] (pg 192) quoting Simon and Newell.

Adaptation by Darwinian evolution by natural selection and is often phrased 'survival of the fittest', as the optimization of the 'best' or 'fittest' organisms to their environment. A well-known problem to ecologists and evolutionary biologists is that there is no clear fitness for natural selection to maximise. As Simon and Newell point out in the above quote, perhaps rather than the conventional optimizing adaptationist discussion of evolution, a satisficing perspective may be more insightful. Evolution phrased in this way would perhaps be 'survival of the comparatively fit' not the most fit, where evolutionary fitness is measured as the trade-off

of many different local and relative considerations.

A popular quote from Dennett from his work on intention theory [4]:

"...poor old Mother Nature makes do, opportunistically and short-sightedly exploiting whatever is in hand-until we add: she isn't perfect, but she does the best she can. Satisficing itself can often be shown to be the optimal strategy when 'costs of searching' are added as a constraint".

Richardson considers the question of optimization in the context of evolution ecology [30], and the tradition of considering evolution as maximising adaptiveness of an agent. In his treatment, he shifts the focus from evolution as an optimizing process, to that of the decision making component 'natural selection'.

He contends that optimization models are simpler than satisficing models and easier to assess. He further that satisficing may be optimization, although a more complex optimization in many dimensions. Richardson discusses two points in which optimization and satisficing differ: 1. 'Whether the constraints defining an optimal solution are dynamically significant', and 2. 'Structure of the environment'. Here he is referring to the consideration of a sequential decision making process of satisficing where unlike optimization, evolution is working with what it has based on the organisms history, that alternatives for the organism are not presented in parallel. He does not propose that satisficing presents a major shift in thinking about evolutionary ecology from optimization, rather a minor change in perspective.

Satisficing Evolution: Satisficing provides decision making mechanism in which to consider evolution by natural selection not as a process of seeking 'maximal adaptiveness' of an agent to its environment, but rather 'sufficient adaptiveness'. Such adaptation may or may not be optimal in the consideration of all the constraints of the agent.

Figure 2 - A phrasing of evolution as a satisficing rather than optimizing

Also in the field of ecology, satisficing has been proposed as a model for predator search (foraging) and parental behaviour [5]. Complaints of such models, when compared to conventional optimizing foraging models is that they are considered both difficult to test and perhaps a subset of optimizing models. Although testable satisficing foraging models have been proposed [26]. So called 'information-gap theory' has been incorporated into satisficing foraging models supporting experimental observations better than conventional models.

# III. SATISFICING IN SEARCH

Satisficing has influenced considerations in computational search and optimization. This section summarises some of the influence satisficing has had in this field of research.

<sup>&</sup>lt;sup>1</sup> Information-Gap Decision Theory: Optimizing robustness to failure or opportunity to windfall rather than conventional decision theory that optimizes utility. The gap refers to what is known, and what needs to be known

Simon, among many other things in his prestigious career, was a founding contribution to the field of artificial intelligence and heuristics. One of his many contributions in this field was his ideas of 'satisficing search' [9]. This involves problems to which the solutions are 'all or nothing', where there is no ordering between solutions, but there are many ways in which to achieve a solution. Thus constraints are placed on the order in which paths are selected to be searched. Such problems can be phrased as and-or trees. Some related and extensions include [6] and [31]. The approach also been used in 'learning while doing' decision making for seeking approximately optimal solutions [28].

Ho [43,44] proposed that satisficing provides an interpretation of optimization of difficult and complex problems where a 'good enough' solution may suffice, promoting the use of heuristic and approximate techniques. That is a solution that is in the top n% of optimal solution. Another satisficing interpretation in the context of search is to that of multiple objective optimization, that is the concurrent optimization of multiple orthogonal objectives, not limited to [10], [12], and [22].

#### Satisficing in Search

**Threshold**: A threshold is imposed with regard to the satisfaction or suitability of a solution. Once a solution meets such a threshold, the search may be considered satisfied.

**Tradeoffs**: More than one consideration (such as fitness or utility) is evaluated when seeking a solution.

**Comparative:** from satisficing evolution, solution utility may be considered comparatively rather than absolutely. This ordinal ranking may further be reduced to the Boolean status of satisfactory and unsatisfactory solutions.

**Presence of Optimality**: also from satisficing evolution, unlike optimization that assumes the presence of a global or locally optimum solution, satisficing makes no such assumptions about the existence of an optimum where one may or may not exist.

Figure 3 - A summary of the major interpretations of satisficing in search

Juric proposes a so called 'anti-adaptationist' genetic algorithm [21] based on satisficing ideas of generating solutions with minimum threshold rather than optimize. He claims that the optimizing adaptive method to search may impede finding solution. He claims satisficing almost as an antonym to 'optimizing adaptation' as a closer match to biology. He lists four main problems he has with the adaptationist approach, claiming that adaptation is the problematic idea that natural selection chooses a particular design for a particular reason (best possible result given the circumstance).

# Juric's problems with 'adaptationist' GA's

- Assumes an optimum exists to which the genotype should be guided
- Assumes continued application beyond a minimum acceptance level seeking the best possible solution
- Assumes that schemata that are currently useful will remain useful, and that those that are useless will remain useless in the future – schemata theorem
- Assume that building blocks that serve a purpose now will continue to serve the same purpose in the future

Figure 4 - The four main problems Juric has with the adaptationist GA

His 'anti-adaptation' approach is claimed to allow for the use of evolved attributes for other purposes. It is not limited to optimization that limits variability, viability, plasticity, flexibility in its drive for an optimum. His approach encourages a minimum standard, robustness. Claiming to encourage the adaptability of the structure, rather than adapting the structure. No implementation is provided of his conceptions.

Channon also investigates the same ideas of what could be called satisficing in genetic algorithms with the goal of novelty [1] and open-ended, persistent evolutionary systems [2]. He claims that genetic algorithms perform 'artificial selection' with explicit fitness function, what he calls 'abiotic selection'. Such systems are unable to perform long-term incremental evolution with continual emergence. He investigates what he calls natural or 'biotic selection' in which there is no explicit specification of what is desired; rather evolution is interpreted as theory of local change and satisficing resulting in continual emergent phenomena. One cannot help but consider such an emergent interpretation of evolution as a strong match to complex adaptive systems theory.

# IV. DISCUSSION

Satisficing has had an interesting but perhaps still not fully exploited impact on search and optimization theory, and may be an important aspect of complex adaptive systems, and in biologically inspired computation. It is the latter which I will briefly discuss in this section, in particular in the context of evolutionary computation and Artificial Immune Systems (AIS).

The need to consider evolutionary algorithms as complex adaptive systems rather than only as optimizers is known, but infrequently heeded [16]. Such algorithms can be used for optimization tasks with what Channon calls 'artificial selection' (like the artificial selection in the breeding of horses or dogs), although perhaps the satisficing interpretation of evolution (and perhaps other inspirations for CAS and computational models) invites investigation into other aspects of such systems.

This work has highlighted some potentially fruitful avenues for continued and future research. An important one is that of open-ended systems resulting in emergent evolution. The specification of looser objective functions or perhaps no objective functions where solutions are discriminated as satisfactory or unsatisfactory. Such systems promote adaptability rather than perform adaptation, potentially providing future robustness in uncertain environments.

Does satisficing provide a way to reconcile evolutionary algorithms as a model of artificial rather than natural selection, to reconcile approximate (less-than-optimal) optimization?

With regard to the immune system of vertebrates, satisficing points out the obvious, that the system does not provide a perfect defence. If the system were an optimal adaptation, then there would be no disease. Nesse [29] discusses the mal-adaptations that result from evolution, highlighting the immune system and disease as a case study. He questions as to why natural selection left us vulnerable to disease – the evolutionary benefit,

and why bodies were not designed better.

The typical argument from evolutionary biologists is that natural selection is an undirected process whose influence is weak because of the stochastic nature of genetic drift and mutations. We should not expect bodies to be anywhere near optimal. This argument, while good, is insufficient, because while many aspects of say the human are less than optimal, manu others are considered quite close to optimal. He proposes a framework of six reasons why we are vulnerable to disease, grouped into three propositions.

#### Possible reasons why humans are vulnerable to disease

- (1) Selection is slow (time lag), results in:
  - (a) A mismatch between design and environment
  - (b) Competition with a pathogen or other organism
- (2) Selection cannot solve some problems regardless of how much time it has, results in:
  - (a) Tradeoffs
  - (b) Constraints particular to living organisms (path dependence)
- (3) We misunderstand what selection shapes, results in:
  - (a) Traits that increase RS at the cost of disease vulnerability
  - (b) Adverse defences are readily mistaken for diseases

Figure 5 - Nesse's six reasons why humans may be vulnerable to disease

Clearly, the immune system is satisficing rather than optimizing, providing a good solution to detecting and neutralising antigen, not necessarily optimal. These points raise many questions. More importantly, this line of inquiry provokes interesting lines of research in CAS and AIS such as:

What other constraints have evolution considered in its evolution, what has natural selection traded off? What would a perfect immune system look like? Is there a mismatch between the requirements and the implementation of the vertebrate immune system, and if so what is it? Finally, what if rather than use artificial selection and simulate the superficial aspects of the immune system (such as clonal selection), what if we let such a defensive system evolve via artificial emergent evolution? What would a satisficing interpretation of clonal selection theory reveal, given the theories selectionist basis was inspired by Darwin's evolutionary theory?

# ACKNOWLEDGMENTS

Tim Hendtlass for his patience and for providing useful feedback on drafts of this paper

### REFERENCES

- [1] A. D. Channon and R. I. Damper, "Evolving novel behaviors via natural selection," *Proceedings of Artificial Life VI*, Los Angeles, USA, pp. 384-388, 1998.
- [2] Alastair Channon, Evolutionary emergence: the struggle for existence in artificial biota 2001. University of Southampton.
- [3] Amit Pazgal, Satisficing leads to cooperation in mutual interests games *International Journal of Game Theory*, vol. 26, pp. 439-453, Dec, 1997.
- [4] D. Dennett, Intentional Systems in Cognitive Ethology: The Panglossian Paradigm Defended *The Behaviorial and Brain Sciences*, vol. 6, pp. 343-390, 1983.
- [5]  $\,$  D. Ward, The role of satisficing in foraging theory  $\,$  OIKOS , vol. 63, pp. 312-317, 1992.
- [6] Dan Geiger and Jeffrey A. Barnett, Optimal Satisficing Tree Searches National Conference on Artificial Intelligence, vol. pp. 441-445,

1991.

- [7] Herbert A. Simon, A Behavioral Model of Rational Choice *Quarterly Journal of Economics*, vol. 69, pp. 99-118, 1955.
- [8] Herbert A. Simon, Rational choice and the structure of the environment *Psychological Review*, vol. 63, pp. 129-138, 1956.
- [9] Herbert A. Simon and Joseph B. Kadane, Optimal problemsolving search: all-or-none solutions *Artificial Intelligence*, vol. 6, pp. 235-247, Autumn, 1975.
- [10] Hiroyuki Tamura, Tomohiro Shibata, and Itsuo Hatono, "Multiobjective combinatorial optimization for performance evaluation by a metaheuristic satisficing tradeoff method," *International conference on Advances in production management systems*, Berlin, Germany, pp. 490-497, 2000
- [11] Hunter Crowther-Heyck. Herbert A. Simon: The Bounds Of Reason In Modern America, John Hopkins University Press, 2005.
- [12] I. Tamura, T. Shibata, S. Tomiyama, and I. Hatono, "A meta-heuristic satisfying tradeoff method for solving multiobjective combinatorial optimization problems-with application to flowshop scheduling," *Proceedings of the IEEE International Conference on Systems, Man, and Cybernetics (IEEE SMC '99 Conference)*, Tokyo, Japan, pp. 539-544, 1999.
- [13] Jay Packard, Satisficing applied to simulated soccer 2003. Electrical and Computer Engineering, Brigham Young University.
- [14] John H. Holland. *Hidden Order: How Adaptation Builds Complexity*, USA: Addison Wesley Publishing Company, 1995.
- [15] John Henry Holland. Adaptation in Natural and Artificial Systems: An Introductory Analysis with Applications to Biology, Control, and Artificial Intelligence, USA: MIT Press, 1975.
- [16] Kenneth A. De Jong, "Genetic Algorithms are NOT Function Optimizers," *Proceedings of the Second Workshop on Foundations of Genetic Algorithms (FOGA)*, Vail, Colorado, USA, pp. 5-17, 1992.
- [17] L. J. Ball, L. Maskill, and T. C. Ormerod, Satisficing in engineering design: causes, consequences and implications for design support *Automation in Construction*, vol. 7, pp. 213-227, Jan, 1998.
- [18] M. A. Goodrich, W. C. Stirling, and R. I. Frost, "A satisficing fuzzy logic controller," *Proceedings of the Fifth IEEE International Conference on Fuzzy Systems*, New Orleans, LA, USA, pp. 272-276, 1996.
- [19] M. A. Goodrich, W. C. Stirling, and R. L. Frost, "A satisficing approach to intelligent control of nonlinear systems," *Proceedings of the 1996 IEEE International Symposium on Intelligent Control, Dearborn, MI, USA, pp. 248-252, 1996.*
- [20] M. A. Goodrich, W. C. Stirling, and R. L. Frost, A theory of satisficing decisions and control *IEEE Transactions on Systems, Man and Cybernetics, Part A*, vol. 28, pp. 1083-4427, Nov, 1998.
- [21] M. Juric, "An anti-adaptationist approach to genetic algorithms," *Proceedings of the First IEEE Conference on Evolutionary Computation*, Orlando, FL, USA, pp. 619-623, 1994.
- [22] M. Sakawa, K. Kato, and T. Shibano, "An interactive fuzzy satisficing method for multiobjective multidimensional 0-1 knapsack problems through genetic algorithms," *Proceedings of IEEE International Conference on Evolutionary Computation*, Nagoya, Japan, pp. 243-246, 1996
- [23] Michael A. Goodrich, Wynn C. Stirling, and Erwin R. Boer, Satisficing Revisited *Minds and Machines*, vol. 10, pp. 79-109, Feb, 2000.
- [24] Michael Byron, Satisficing and Optimality *Ethics*, vol. 109, pp. 67-93, Oct, 1998.
- [25] Michael Byron. Satisficing and Maximizing: Moral Theorists on Practical Reason, USA: Cambridge University Press, 2004.
- [26] P. Nonacs and L. M. Dill, Is satisficing an alternative to optimal foraging theory *Oikos*, vol. 24, pp. 371—3751993.
- [27] Paolo Pirjanian, Satisficing Action Selection Sensor Fusion and Decentralized Control in Robotic Systems (SPIE Conference), vol. 3523, pp. 157-168, 1998.
- [28] R. Greiner and P. Orponen, Probably Approximately Optimal Satisficing Strategies *Artificial Intelligence*, vol. 82, pp. 21-44, Apr, 1996.
- [29] Randolph M. Nesse, Maladaptation and Natural Selection *The Quarterly Review of Biology*, vol. 80, pp. 62–702005.
- [30] Robert C. Richardson, Optimization in Evolutionary Ecology *Philosophy of Science Association (PSA)*, vol. 1, pp. 13-21, 1994.
- [31] Russell Greiner, Ryan Hayward, Magdalena Jankowska, and Michael Molloy, Finding optimal satisficing strategies for and-or trees *Artificial Intelligence*, vol. 170, pp. 19-58, Jan, 2006.

- [32] Sandip Sen, "Satisficing Models," Published by The AAAI Press, Menlo Park, California, USA, Technical Report SS-98-05, 1998.
- [33] Sidney G. Winter, Satisficing, Selection, and The Innovating Remnant *Quarterly Journal of Economics*, vol. pp. 237-261, 1971.
- [34] Sidney G. Winter, The Satisficing Principle in Capability Learning *Strategic Management Journal*, vol. 21, pp. 981-996, 2000.
- [35] Simon A. Levin, Ecosystems and the Biosphere as Complex Adaptive Systems *Ecosystems, Biomedical and Life Sciences and Earth and Environmental Science*, vol. 1, pp. 431-436, Sep, 1998.
- [36] Simon A. Levin, Complex adaptive systems: Exploring the known, the unknown and the unknowable *American Mathematical Society*, vol. 40, pp. 3-19, 2003.
- [37] Thomas Wagner, Alan Garvey, and Victor Lesser, "Satisficing evaluation functions: The heart of the new design-to-criteria paradigm," UMASS Department of Computer Science, USA, Technical Report TR-96-82, Nov 1996
- [38] W. Brian Arthur. Introduction: Process and Emergence in the Economy . In: *The Economy as an Evolving Complex System II*, eds. W. Brian Arthur, Steven Durlauf, and David A. Lane. Reading, Mass, USA: Addison-Wesley Pub. Co, 1997.pp. 1-04.
- [39] W. C. Stirling, M. A. Goodrich, and D. J. Packard, Satisficing Equilibria: A Non-Classical Theory of Games and Decisions *Autonomous*

- Agents and Multi-Agent Systems, vol. 5, pp. 305-328, Sep, 2002.
- [40] Wynn C. Stirling. Satisficing Games and Decision Making: with applications to engineering and computer science, USA: Cambridge University Press, 2003.
- [41] Wynn C. Stirling and Michael A. Goodrich, Satisficing games *Information Sciences: an International Journal*, vol. 114, pp. 255-280, Mar, 1999.
- [42] Youngse Kim , Satisficing and Optimality in 2 x 2 Common Interest Games *Economic Theory*, vol. 13, pp. 365-375, Feb, 1999.
- [43] Yu-Chi Ho , Heuristics, rules of thumb, and the 80/20 proposition *IEEE Transactions on Automatic Control*, vol. 39, pp. 1025-1027, May, 1994.
- [44] Yu-Chi Ho, On the numerical solutions of stochastic optimization problem *IEEE Transactions on Automatic Control*, vol. 42, pp. 727-729, 1997