

Enlivened Trees and Other Challenges in Decisions, Games and Statistics

Peter J. Hammond (U. of Warwick)

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Introduction

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Seminar Outline

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Research Challenges in Game Theory

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Motivation:

mismatch between theory, experiment, and observation.

Plenty of evidence from recent studies.

We need not only a more realistic theory,
but sometimes a better understanding
of how to interpret experimental results theoretically.

Normal Form Invariance and Beyond

Von Neumann (1928) hypothesized that only the normal form of a game is relevant to rational play.

Yet even in Battle of the Sexes, this hypothesis seems contradicted by players' actual behaviour in experiments. Here a refined Nash equilibrium is proposed for games where one player moves first, and the only other player moves second without knowing the first move.

The refinement relies on a tacit understanding of the only straightforward perfect Bayesian equilibrium which is credible in a corresponding game allowing a predictable direct form of cheap talk.

Normal Form Strategies

Von Neumann and Morgenstern (1953), p. 79:

“Imagine now that each player . . . , instead of making each decision as the necessity for it arises, makes up his mind in advance for all possible contingencies; i.e., that the player . . . begins to play with a complete plan: a plan which specifies what choices he will make in every possible situation, for every possible actual information which he may possess at that moment in conformity with the pattern of information which the rules of the game provide for him for that case. We call such a plan a strategy.”

Playing the Normal Form

Von Neumann and Morgenstern (1953), p. 84:

“Each player must make his choice [of strategy] in absolute ignorance of the choices of the others. After all choices have been made, they are submitted to an umpire who determines . . . the outcome of the play for [each] player.

Observe that in this scheme no space is left for any kind of further ‘strategy.’ Each player has one move, and one move only; and he must make it in absolute ignorance of everything else.”

Normal Form Invariance, I

Von Neumann and Morgenstern (1953), p. 85:

“ . . . we obtained an all-inclusive formal characterization of the general game of n persons We followed up by developing an exact concept of strategy which permitted us to replace the rather complicated general scheme of a game by a much more simple special one, which was nevertheless shown to be fully equivalent to the former In the discussion which follows it will sometimes be more convenient to use one form, sometimes the other. It is therefore desirable to give them specific technical names. We will accordingly call them the extensive and the normalized form of the game, respectively.

Normal Form Invariance, II

Von Neumann and Morgenstern (1953), p. 85, continued:

Since these two forms are strictly equivalent, it is entirely within our province to use in each particular case whichever is technically more convenient at that moment. We propose, indeed, to make full use of this possibility, and must therefore re-emphasize that this does not in the least affect the absolute general validity of all our considerations."

Game Theorists' Dead Trees

Not just the trees killed
so that papers and books on game theory can be printed.
Nor the trees described
by computer scientists and graph theorists
that have only one “root”, unlike any living tree.

Botanically incorrect!

Rather, the tree structure used in the extensive form model
of the game, which is fixed once and for all.

Following Zermelo, von Neumann, even Kolmogorov (ZNK),
game theorists and others
use a model of a game (or a stochastic process)
that fails to recognize the possibility, even virtual certainty,
that the tree model will be modified
in the light of later circumstances.

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Enlivened Trees? Or Decision Jungles?

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Mephistopheles in Goethe's *Faust*, Part I:

“Grau, teurer Freund, ist alle Theorie
und grün des Lebens goldner Baum.”

with the (obviously incomplete) translation:

“Grey is all theory and green the golden tree of life.”

Shackle's Unexpected Events

Shackle, G.L.S. (1953) "The Logic of Surprise"
Economica, New Series, **20**, 112–117.

On p. 113 he defines a "counter-expected hypothesis"
as what we might now call a "counterfactual"
— i.e., "a hypothesis that has been looked at and rejected."
Then, on the same page:

"In contrast with this I define an unexpected event as one which has never been formulated in the individual's imagination, which has never entered his mind or been in any way envisaged."

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Zermelo, E. (1912) “Über eine Anwendung der Mengenlehre auf die Theorie des Schachspiels”

Proceedings of the Fifth International Congress of Mathematicians, Vol. II, pp. 501–504.

Zermelo used backward induction to prove formally that Chess, starting from any (legal) position, has a definite result with best play:
either White can force a win; or Black can;
or the game should be drawn.

Zermelo's proof works even though exhaustive analysis of all the possibilities in chess.

This remains completely impossible to this day.
Except in greatly simplified “endgame” positions with only a few (≤ 6) pieces remaining on the board.

Von Neumann, J. (1928)

“Zur Theorie der Gesellschaftsspiele,”
Mathematische Annalen, **100**, 295–320.

Von Neumann devised what has become the standard paradigm in decision and game theory, which assumes that all possible future eventualities are included in an extensive game form. Thus, there must be a fixed state space large enough to include all possible future eventualities. Similarly for the Arrow–Debreu “complete markets” hypothesis in General Equilibrium Theory.

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Kolmogorov, A.N. (1933, 1956)

Grundbegriffe der Wahrscheinlichkeitsrechnung;
translated as *Foundations of Probability*.

For the particular case of a single-person decision problem, the paradigm allows it to be represented as a decision tree, in which nature also has a once-and-for-all strategy represented by a member of a fixed state space, as in Kolmogorov's (1933) standard model of a stochastic process.

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Limitations of the ZNK Paradigm

The standard ZNK paradigm is too limited to serve as a realistic model of actual economic behaviour in complex settings.

It reduces decision trees and extensive games to their normal form,

in which each agent or player makes a single once and for all choice of strategy.

This imposes unrealistic demands on real decision makers' modelling and planning abilities, and on their imagination of what events could occur.

In particular, for the games of Chess and Go, there is no possibility of either player "outwitting" the other, since both are assumed to make perfect moves all the time.

Think why Tic-Tac-Toe (or Noughts and Crosses) is not a very interesting game.

Beyond ZNK

The ZNK paradigm also rules out unforeseen contingencies. It is a tautology that any extensive form game model can only include contingencies that the model, at least, takes into account.

Anything else, such as an earthquake (or a young child's temper tantrum) upsetting the Chess board and pieces, is not foreseen.

No fixed model will do

— not even models as rich as von Neumann's (or Kuhn's), or Kolmogorov's very general model of a stochastic process. This is obvious if something unforeseen actually occurs.

But it is also true if models which have been developed to respect practical limitations are then subsequently revised to include more detail concerning proximate possibilities.

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Meta Stochastic Processes

Could one define a “meta” stochastic process on the space of all possible stochastic process models? The result would be a sequence of stochastic processes in which the state space is continually being enriched **unpredictably**.

The stochastic process model is based on Kolmogorov’s extension theorem in probability. This theorem demonstrates that any “consistent” family of probability laws on finite Cartesian subproducts of an arbitrary collection of measurable spaces can be extended to a probability law on the whole Cartesian product.

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Meta Stochastic Processes: A Challenge

The theorem, however, depends on a significant assumption: for example, that the probability distribution on each single measurable space is *tight* — i.e., the probability of any measurable set must equal the supremum of the probabilities of all its compact subsets. (See Aliprantis and Border (1999), which also includes a significant generalization due to Neveu (1965).) It seems difficult to find a suitable topology on the class of all potentially relevant sequences of stochastic process models which allows an interesting probability measure to exist.

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Alephs ...

Jorge Luis Borges *El Aleph* (1945),
begins with quotations from *Hamlet* II, 2

*O God! I could be bounded in a nutshell,
and count myself a King of infinite space ...*

and from Thomas Hobbes' *Leviathan*, IV, 46

*But they will teach us that Eternity is the
Standing still of the Present Time, a Nunc-stans
(as the schools call it); which neither they, nor any
else understand, no more than they would a
Hic-stans for an Infinite greatness of Place.*

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Borges' Aleph I

Translation by Norman Thomas Di Giovanni
in collaboration with the author.

When I opened my eyes, I saw the Aleph . . . the only place on earth where all places are — seen from every angle, each standing clear, without any confusion or blending.

The Aleph's diameter was probably little more than an inch, but all space was there, actual and undiminished. Each thing (a mirror's face, let us say) was infinite things, since I distinctly saw it from every angle of the universe.

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Borges' Aleph II

I saw the Aleph from every point and angle, and in the Aleph I saw the earth and in the earth the Aleph and in the Aleph the earth; I saw my own face and my own bowels; I saw your face; and I felt dizzy and wept, for my eyes had seen that secret and conjectured object whose name is common to all men but which no man has looked upon — the unimaginable universe.

I felt infinite wonder, infinite pity.

... for Cantor's Mengenlehre, [Aleph, or \aleph] is the symbol of transfinite numbers, of which any part is as great as the whole.

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... and Universes

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Indeed, is the class of all potentially relevant sequences of stochastic process models a “proper class”, beyond the realm of set theory?
Even if it can be made a set, or “von Neumann universe” with a hierarchy of sets, can we assign it a meaningful σ -algebra of measurable sets and a meaningful probability measure?

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Beyond Meta Stochastic Processes

Suppose one could define a meta stochastic process on the space of all potentially relevant stochastic processes. Even so, it would surely be vastly too complex for practical use.

More from Borges' *Aleph*:

Out on the street, going down the stairways inside Constitution Station, riding the subway, every one of the faces seemed familiar to me. I was afraid that not a single thing on earth would ever again surprise me; I was afraid I would never again be free of all I had seen. Happily, after a few sleepless nights, I was visited once more by oblivion.

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Savage's Small Worlds and Microcosms, I

Savage (*Foundations of Statistics*, pp. 16–17)

discusses the need for a sequence of decision models:

“The point of view under discussion may be symbolized by the proverb, ‘Look before you leap,’ and the one to which it is opposed by the proverb, ‘You can cross that bridge when you come to it.’ When two proverbs conflict in this way, it is proverbially true that there is some common truth in both of them, but rarely, if ever, can their common truth be captured by a single pat proverb. One must indeed look before he leaps, in so far as the looking is not unreasonably time-consuming and expensive; but there are innumerable bridges one cannot afford to cross, unless he happens to come to them.”

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Savage's Small Worlds and Microcosms, II

“Though the ‘Look before you leap’ principle is preposterous if carried to extremes, I would none the less argue that is the proper subject of our further discussion, because to cross one’s bridges when one comes to them means to attack relatively simple problems of decision by artificially confining attention to so small a world that the ‘Look before you leap’ principle can be applied there.”

...

“In view of the ‘Look before you leap’ principle, acts and decisions, like events, are timeless. The person decides ‘now’ once and for all; there is nothing for him to wait for, because his one decision provides for all contingencies.”

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Savage's Small Worlds and Microcosms, III

Eventually (p. 83) Savage does recognise that a person over his or her lifetime is bound to consider nothing richer than a series of small world decision problems:

“Making an extreme idealization, which has in principle guided the whole argument of the book thus far, a person has only one decision to make in his whole life. He must, namely, decide how to live, and this he might in principle do once and for all. . . . Any claim to realism made by this book—or indeed by almost any theory of personal decision of which I know—is predicated on the idea that some of the individual decision situations into which actual people tend to subdivide the single grand decision do recapitulate in microcosm the mechanism of the idealized grand decision.”

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Savage: Conclusion

Yet nowhere does Savage seek to explore systematically the implications of a decision-maker using an evolving sequence of small models.

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Yasunari Kawabata (1954) *The Master of Go*

The Japanese game of Go

is a two-person zero sum game of perfect information.

Orthodox game theory predicts it should be played perfectly, and so perfectly predictably. But, at the end of chapter 37:

“‘This is what war must be like,’ said Iwamoto gravely. He meant of course that in actual battle the unforeseeable occurs and fates are sealed in an instant. Such were the implications of White 130. All the plans and studies of the players, all the predictions of us amateurs and of the professionals as well had been sent flying.

As an amateur, I did not immediately see that White 130 assured the defeat of the ‘invincible Master.’”

Translated from the author’s own shortened version by Edward G. Seidensticker (New York: Alfred A. Knopf, 1972).

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Herbert Simon and Bounded Rationality

The games of Chess and Go are so complicated that playing them perfectly is humanly impossible, and even computationally infeasible.

Currently the best computer Chess programs are worthy of being challenged by the very best humans in sponsored matches;

in Go, the computer programs remain significantly worse.

All competent Chess and Go players know this already.

So should all economists, especially after Herbert Simon (who himself devised an early computer chess program).

Indeed, when it comes to describing actual behaviour, many decision models in social science do feature “bounded rationality”, or “procedural rationality”.

Usually, however, this involves what Simon (1955, 1957) called “satisficing” — making a decision that seems “good enough” rather than optimal.

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Rationally Bounded Models

The kind of normative model proposed here suggests that satisficing behaviour should occur, not within a given decision model, but in how much detail to include within the model. This is along the lines suggested in Behn and Vaupel (1982) and Vaupel (1986), who described a theory in which the choice of whether to complicate a bounded model emerges from comparing the expected benefits of possibly changing the original decision with the costs of the extra analysis. See also Bolton and Faure-Grimaud (2005) for a related idea.

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Sequences of Bounded Models

Real agents, insofar as they are conscious of anything that can be reasonably described as a (bounded) decision model,

may be forced to adapt these models to accommodate unpredicted events that have actually occurred.

By contrast, very little existing work, even on bounded rationality or in economic psychology, recognizes that decision-makers must actually use a sequence of bounded models which gradually respond to evolving events, especially major events that were never predicted.

Evaluating Consequences: A Preference for Flexibility

According to the ZNK standard paradigm, any decision strategy results in a “Bayesian” consequence pattern. This becomes successively refined as one proceeds through the tree and excludes decisions and events that are no longer possible. In an enlivened decision tree, however, the usual Bayesian approach to decision-making is inadequate, even with subjective or personal probabilities. Then the best current action at the start of an arbitrarily long sequence of successive decisions may not have the best pattern of uncertain consequences in the usual sense. In a static choice setting, Koopmans (1964) and Kreps (1992) explain why a “preference for flexibility” might result when there could be “unforeseen contingencies”.

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Dekel, Lipman, and Rustichini on Unforeseen Contingencies

Some formal analysis in Dekel *et al.* (1998, 2001, 2005).
However, in (1998, p. 528) they seem to assume there is an analyst who can foresee all possible contingencies:

“[N]o ‘standard state-space model’ can deliver a nontrivial model of unforeseen contingencies. A rough intuition for this result is that in standard state-space models, states play two distinct roles: they are the analyst’s descriptions of ways the world might be and they are also the agent’s descriptions of ways the world might be. If the agent is unaware of some possibility, ‘his’ states should be less complete than the analyst’s. Hence, any model which does not explicitly distinguish between the agent’s descriptions and the analyst’s will fail to capture unforeseen contingencies.”

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Dekel, Lipman, and Rustichini: Discussion

This appears to exclude a model where the agent's and analyst's descriptions match exactly, yet both fail to foresee some contingencies.

Or even a model where the agent foresees some contingencies than no analyst does.

Indeed, the implicit hypothesis seems to be that, even if human Chess and Go players are fallible, there is an analyst who understands everything!

That analyst would know the best move in any given situation, including the start of the game.

He would be a perfect critic of any particular game, as well as a perfect player.

No person and no computer can achieve such perfection (except in especially simple positions, with relatively few ways left before the end of the game).

Really, this work seems to be about “unawareness” rather than “unforeseen contingencies.”

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Develop a Normative
Model

“An agenda for the 21st century”
was a very nice conference subtitle.
But any such agenda is undermined by unpredictable events.
Five-year plans seem long enough.
Here is one, broken down into several different tasks.

Adapting to the Unpredicted

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There is accordingly a need to investigate how a decision maker may be forced to adapt to unpredicted events. In fact, there is a need to go beyond the von Neumann (or ZNK) standard paradigm to examine sequences of successive increasingly refined but bounded decision models. Also, apart from events that really are entirely unpredictable, also inevitable are events that only few agents, if any, manage to incorporate properly in their decision models.

An Evolving State Space

Usually a fixed decision or game model contracts over time as history rules out many possibilities that did not occur.

These possibilities become counterfactual, or what Shackle calls “counter-expected”.

As time passes, one progresses along a branch through a decision tree (or extensive form game), leaving fewer and fewer future possibilities.

In many realistic decision problems, or games, the range of all possible uncertain future eventualities must expand over time to include ex post actual events that were entirely unpredictable ex ante, or at least outside the practical limitations of the ex ante model.

This breaks the standard ZNK paradigm.

We need an **evolving state space** to recognise that any usable model of uncertainty must be incomplete.

Evaluating Consequences Retrospectively

Given that a sequence of decision models will be used, the best current action may no longer have the best pattern of uncertain consequences in the usual sense.

Indeed, Kreps (1990) points how bounded rationality creates a role for retrospective analysis;

how good was that decision I just took

in the light of the unforeseen event that has just occurred?

Accordingly, the normatively relevant consequence patterns emerge in stages from an evolving retrospective analysis applied to a sequence of bounded models.

Each successive model will remove counterfactual decisions and events from earlier models,

but give an increasingly detailed picture of what remains.

Develop a Normative Model

Enlivened Trees
and Other
Challenges
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In a revised decision theory, Kreps' (1992) work for the two-period case leads one to conjecture that evolving consequences can be fitted mathematically within a coherent probabilistic framework which embodies all possible relevant results of retrospective analysis. The construction of this framework may follow ideas used originally to define universal type spaces for Harsanyi's (1967–8) games of “incomplete information”.

Extend “Overture Optimality”

What really matters at any given time is any decision that either cannot be put off, or else should not be because an immediate commitment is best. At any decision node of a decision tree, all that really matters is the next decision; any future plans can be torn up if something unforeseen occurs. “Overture optimal” infinite-horizon plans are those that, for the first few periods would be better than any alternative, provided the horizon is long enough. In an evolving sequence of decision models, this suggests looking for an immediate decision that is somehow robustly optimal when analysed retrospectively from many periods ahead.

Welfare Significance

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Provided that an agent uses some kind of rationally bounded model, perhaps after suitable advice, in principle one can infer revealed preferences concerning the modelled consequences of the decisions that the agent seriously contemplated.

What are the ethical implications of this?

What about psychological or neurological biases?

See Bernheim and Rangel (2005, 2006) for related ideas.

The last hope for revealed preference?