Road Map Presentation*

Extensive-Form Games

(and Some Writing Advice)

Sungmin Park

The Ohio State University
Theory/Experimental Reading Group

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* "These are presentations given by outgoing (or already-graduated) reading group students. The goal is to provide a 'road map' of the literature they've been working in, to help younger students gain perspective on what's known in that literature." – PJ's website

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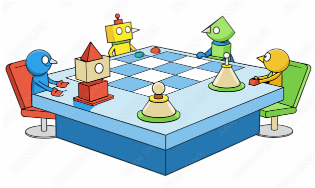
Why learn about extensive-form games?

I'm biased by my work on them

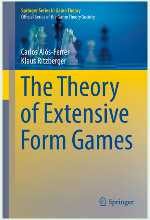
Games in Extensive Form

1. have a fun intellectual history,
2. require a careful application, and
3. have an active research frontier!



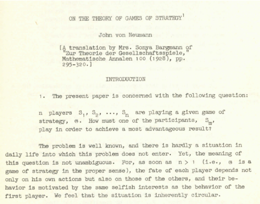
Brief Intellectual History

Loosely based on Alós-Ferrer and Ritzberger (2016)



Origin: "Games of Strategy"

- In his foundational paper, Von Neumann (1928) already has an extensive-form-like structure in mind. He asks:
    - "n players $S_1, S_2, \ldots, S_n$ are playing a given game of strategy, $\mathfrak{G}$. How must one of the participants, S_m, play in order to achieve a most advantageous result?"
- He defines "game of strategy" with "draws"(moves by Nature) and "steps"(moves by Players) which can depend on earlier moves
- He proves the "minimax theorem": In a two-person zero-sum game, $$\max_{x \in X} \min_{y \in Y} u(x,y) = \min_{y \in Y} \max_{x \in X} u(x,y),$$ where (x,y) is a mixed strategy profile and $u(x,y)$ is P1's payoff



ON THE THEORY OF GAMES OF STRATEGY[1]

John von Neumann

[A translation by Mrs. Sonya Bargmann of "Zur Theorie der Gesellschaftsspiele," Mathematische Annalen 100 (1928), pp. 295-320.]

INTRODUCTION

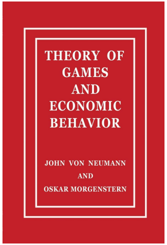
1. The present paper is concerned with the following question:

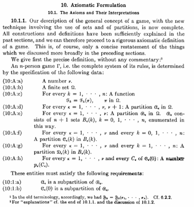
n players $S_1, S_2, \ldots, S_n$ are playing a given game of strategy, $\mathfrak{G}$. How must one of the participants, S_m, play in order to achieve a most advantageous result?

The problem is well known, and there is hardly a situation in daily life into which this problem does not enter. Yet, the meaning of this question is not unambiguous. For, as soon as $n > 1$ (i.e., $\mathfrak{G}$ is a game of strategy in the proper sense), the fate of each player depends not only on his own actions but also on those of the others, and their behavior is motivated by the same selfish interests as the behavior of the first player. We feel that the situation is inherently circular.

Von Neumann (1928) "On the theory of games of strategy"

How to represent a game: (a) Sets and partitions





10. Axiomatic Formulation

10.1. The Axioms and Their Interpretations

10.1.1. Our description of the general concept of a game, with the new technique involving the use of sets and of partitions, is now complete. All constructions and definitions have been sufficiently explained in the past sections, and we can therefore proceed to a rigorous axiomatic definition of a game. This is, of course, only a concise restatement of the things which we discussed more broadly in the preceding sections.

We give first the precise definition, without any commentary:[2]

An n-person game Γ, i.e. the complete system of its rules, is determined by the specification of the following data:

(10:A:a) A number ν.

(10:A:b) A finite set Ω.

(10:A:c) For every $k = 1, \cdots, n$: A function $\mathfrak{F}_k = \mathfrak{F}_k(\pi)$, π in Ω.

(10:A:d) For every $\kappa = 1, \cdots, \nu, \nu + 1$: A partition $\mathfrak{A}_\kappa$ in Ω.

(10:A:e) For every $\kappa = 1, \cdots, \nu$: A partition $\mathfrak{B}_\kappa$ in Ω. $\mathfrak{B}_\kappa$ consists of $n + 1$ sets $B_\kappa(k)$, $k = 0, 1, \cdots, n$, enumerated in this way.

(10:A:f) For every $\kappa = 1, \cdots, \nu$ and every $k = 0, 1, \cdots, n$: A partition $\mathfrak{C}_\kappa(k)$ in $B_\kappa(k)$.

(10:A:g) For every $\kappa = 1, \cdots, \nu$ and every $k = 1, \cdots, n$: A partition $\mathfrak{D}_\kappa(k)$ in $B_\kappa(k)$.

(10:A:h) For every $\kappa = 1, \cdots, \nu$ and every C_κ of $\mathfrak{C}_\kappa(0)$: A number $p_\kappa(C_\kappa)$.

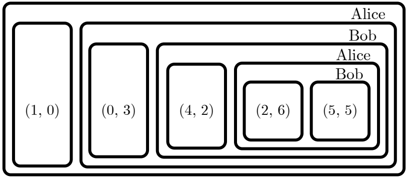
These entities must satisfy the following requirements:

(10:1:a) $\mathfrak{A}_\kappa$ is a subpartition of $\mathfrak{B}_\kappa$.

(10:1:b) $\mathfrak{C}_\kappa(0)$ is a subpartition of $\mathfrak{A}_\kappa$.

[1] In the old terminology, accordingly, we had $\mathfrak{F}_k = \mathfrak{F}_k(\sigma_1, \cdots, \sigma_\nu)$. Cf. 6.2.2.
[2] For "explanations" cf. the end of 10.1.1. and the discussion of 10.1.2.

A Simple Example (not from the book)



Von Neumann and Morgenstern (1944) use sets and partitions to define $\Gamma = (T, \Omega, \mathcal{A}, \mathcal{B}, \mathcal{C}, \mathcal{D}, p, u)$, where

- T is the total number of stages,
- Ω is the set of all outcomes,
- $\mathcal{A}_t$ represents Umpire's infomation at stage t,
- $\mathcal{B}_t$ represents assignment of players at stage t
- $\mathcal{C}_t(i)$ represents player i's actions at stage t,
- $\mathcal{D}_t(i)$ represents player i's information,
- $p_t(\cdot)$ are probabilities of Umpire's actions at stage t, and
- $u_i(\omega)$ is player i's payoff at outcome ω.

$\Rightarrow$ Although lengthy ($\sim$30 pages) and somewhat clunky, the above contains all crucial elements of extensive-form games

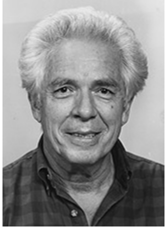
(b) Game trees

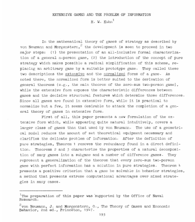
The innovation that became the textbook representation

Kuhn (1953) defines $\Gamma = (N, H, \iota, \mathcal{I}, \pi, u)$ where

- N is the set of players,
- H is a game tree (finite rooted tree), where each edge represents an action $a \in A$,
- ι assigns each non-terminal node $h \in H$ to a player i,
- $\mathcal{I}$ is the collection of information sets, such that players have perfect recall (not forgetting own action),
- π is the prob distribution over Nature's actions, and
- u is the payoff function.

$\Rightarrow$ This representation removes restrictions on stages, allows general information structures, and introduces perfect recall





EXTENSIVE GAMES AND THE PROBLEM OF INFORMATION

H. W. Kuhn[1]

In the mathematical theory of games of strategy as described by von Neumann and Morgenstern,[2] the development is seen to proceed in two major steps: (1) the presentation of an all-inclusive formal characterization of a general n-person game, (2) the introduction of the concept of pure strategy which makes possible a radical simplification of this scheme, replacing an arbitrary game by a suitable prototype game. They called these two descriptions the extensive and the normalized forms of a game. As noted there, the normalized form is better suited to the derivation of general theorems (e.g., the main theorem of the zero-sum two-person game), while the extensive form exposes the characteristic differences between games and the decisive structural features which determine those differences. Since all games are found in extensive form, while it is practical to normalize but a few, it seems desirable to attack the completion of a general theory of games in extensive form.

First of all, this paper presents a new formulation of the extensive form which, while appearing quite natural intuitively, covers a larger class of games than that used by von Neumann. The use of a geometrical model reduces the amount of set theoretical equipment necessary and clarifies the delicate problem of information. After the definition of pure strategies, Theorem 1 removes the redundancy found in a direct definition. Theorems 2 and 3 characterize the properties of a natural decomposition of many games into a subgame and a number of difference games. They represent a generalization of the theorem that every zero-sum two-person game with perfect information has a solution in pure strategies. Theorem 4 presents a positive criterion that a game be solvable in behavior strategies, a method that presents extreme computational advantages over mixed strategies in many cases.

[1]The preparation of this paper was supported by the Office of Naval Research.

[2]von Neumann, J. and Morgenstern, O., The Theory of Games and Economic Behavior, 2nd ed., Princeton, 1947.

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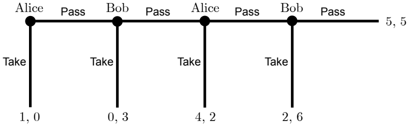
Kuhn (1953) "Extensive games and the problem of information"

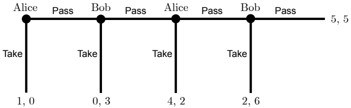


A Game Tree Representation (not from the paper)

(c) Histories

The quiet innovation of Harris, Osborne, and Rubinstein

O&R's textbook, Osborne, Rubinstein, and Harris



- Osborne and Rubinstein (1994) define a game the same way as Kuhn (1953) as $\Gamma = (N, H, \iota, \mathcal{I}, \pi, u)$ except

  H is a set of histories (i.e. sequences) of actions $a \in A$.

- For example, with $A = \{T\text{ake}, P\text{ass}\}$, we may have

  $$H = \{\emptyset, T, P, PT, PP, PPT, PPP, PPPT, PPPP\}.$$

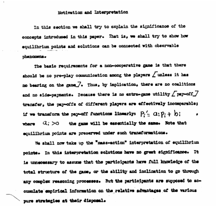
- Harris (1985) uses it for games with perfect information

$\Rightarrow$ This representation removes diagrams, making definitions, proofs, and infinite-game extensions far easier to handle

What is a "solution" of a game?

Mass-action vs. rational interpretations

- A **solution** is a prediction of how players would or should play a game. A **solution concept** is a set of conditions for valid solutions.
- In his PhD thesis, Nash (1950) offers "mass-action" (population behavior) vs. "rational" (correct behavior) interpretations of his solution concept
- Many solution concepts have interpretations somewhere on a spectrum
  1. **Closer to mass-action**: Nash equilibrium, Self-confirming equilibrium, Fictitious play, Evolutionary stable strategies, Level-k reasoning, Quantal response equilibrium (QRE), Reinforcement learning, etc.
  2. **Closer to rational**: Iterated elimination of strongly dominated strategies (IESDS), Rationalizability, Subgame-perfect equilibrium, Perfect Bayesian equilibrium (PBE), Sequential equilibrium, etc.



Motivation and Interpretation

In this section we shall try to explain the significance of the concepts introduced in this paper. That is, we shall try to show how equilibrium points and solutions can be connected with observable phenomena.

The basic requirements for a non-cooperative game is that there should be no pre-play communication among the players [unless it has no bearing on the game]. Thus, by implication, there are no coalitions and no side-payments. Because there is no extra-game utility [pay-off] transfer, the pay-offs of different players are effectively incomparable; if we transform the pay-off functions linearly: $p_i' = a_i p_i + b_i$, where $a_i > 0$ the game will be essentially the same. Note that equilibrium points are preserved under such transformations.

We shall now take up the "mass-action" interpretation of equilibrium points. In this interpretation solutions have no great significance. It is unnecessary to assume that the participants have full knowledge of the total structure of the game, or the ability and inclination to go through any complex reasoning processes. But the participants are supposed to accumulate empirical information on the relative advantages of the various pure strategies at their disposal.

Nash (1950) PhD thesis, final section

Perfect Bayesian Equilibrium (Fudenberg and Tirole, 1991)

A standard solution concept allowing any off-path beliefs

Notation

- A **strategy** σ_i assigns a probability distribution over actions at each of Player i's information sets.
- A **belief** μ_i assigns a probability distribution over histories within each of Player i's information sets

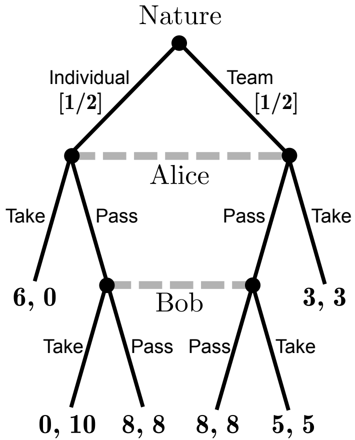
Definition

A pair (σ, μ) of strategy and belief profiles is a **perfect Bayesian equilibrium (PBE)** if, for every player i,

1. σ_i is sequentially rational* given (σ_{-i}, μ_i), and
2. μ_i satisfies Bayes rule on the path** of σ.

* maximizes one's expected utility at each information set
** information sets reached with positive probability.

Modified Trust Game



Sequential Equilibrium (Kreps and Wilson, 1982)

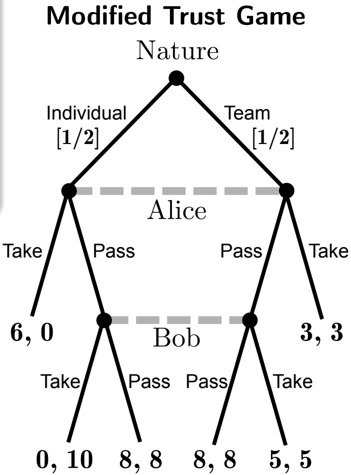
PBE with a soft restriction on off-path beliefs

Definition

A PBE (σ, μ) is a **sequential equilibrium (SE)** if there exists

- a sequence $\{\sigma^k\}$ of totally mixed strategy profiles, and
- a sequence $\{\mu^k\}$ of belief profiles satisfying Bayes rule with σ^k

such that $(\sigma^k, \mu^k) \to (\sigma, \mu)$.



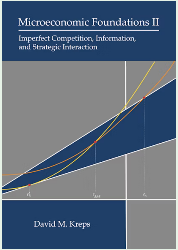
Meaning

- SE rules out unreasonable beliefs, by requiring them to be derived from nearby trembled strategies

$\Rightarrow$ In contrast to PBEs, the SE is unique in the Modified Trust Game example

Seven Practical Issues for (Applied) Theorists

Loosely based on Kreps (2023)



1. Perfect Bayesian Equilibrium vs. Sequential Equilibrium

Both are standard concepts

Use PBE or SE? It depends on the application

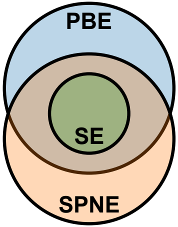
- In many economic applications, $\{\text{PBE}\} = \{\text{SE}\}$.
- When $\{\text{PBE}\} \supsetneq \{\text{SE}\}$, it's fine to use PBE while explicitly ruling out unreasonable off-path beliefs.
- Fudenberg and Tirole (1991): For games with incomplete information and observable actions,

$$\{\text{PBE}\} \cap \{\text{“no signalling what you don't know”}\} = \{\text{SE}\}$$

- In general,

$$\{\text{SE}\} \subset \{\text{SPNE}^*\}, \quad \text{but} \quad \text{PBE} \not\subset \text{SPNE}^*.$$

$*$ Subgame-perfect Nash Equilibrium



2. Sequential Rationality

When is sequential rationality reasonable?

- Sequential rationality means that each player best responds to others' actual strategies at every contingency of the game, given their beliefs

- It's a strong assumption, even if players know the game correctly.

- It's difficult to optimize how to play or predict how others will play if the game is too complex or too artificial (or unfamiliar).

  e.g. Texas Hold'em Poker (too complex) or Centipede game (too artificial).

- Sequential rationality may still be reasonable in models that are:
  - simple: having only a few stages of actions, or
  - realistic: capturing features of real strategic interaction

3. Multiple Equilibria

- Games often have multiple equilibria due to strategic complementarity (e.g. Battle of Sexes), asymmetric information (e.g. Signalling), dynamic interaction (e.g. repeated Prisoners' Dilemma), or other reasons.

- There are three common views, not mutually exclusive, on what to do:
  1. Find a better-specified model.
  2. Use an equilibrium refinement or selection criterion.
  3. Accept them, as they reflect the richness of strategic behavior.

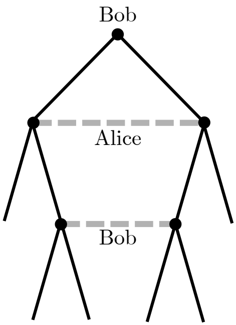
- In applied work, ③ is rarely acceptable, so people do ① & ②

  e.g. Modifying the model; Equilibrium refinement using forward induction or trembling-hand perfection; Selection using Pareto or risk dominance; Robust mechanism design or dominant strategy-implementation

Image from Flaticon.com

4. Perfect or Imperfect Recall

It's fine to keep assuming perfect recall

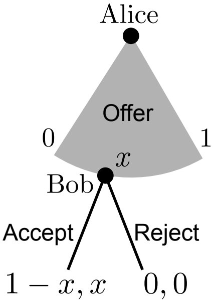


Bob forgets what he did

- Perfect recall* means that players don't forget what they did or what they knew before.
  - * A game has **perfect recall** if for two histories h and h' in the same information set of Player i, the sequences of i's information sets up to h and h' are equal.
- Games with perfect recall are nice: Every mixed strategy has an equivalent behavioral strategy and vice versa (Kuhn, 1953).
- Is imperfect recall ever useful? There are a few theoretical papers* but no serious application yet
  - * Piccione and Rubinstein (1997) introduce "multiselves equilibrium"
- It's difficult to interpret predictions for imperfect-recall games as either "mass-action" or "rational" outcomes

5. Beyond finite games

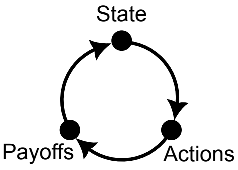
- Many classic results like the existence of sequential equilibrium are for games with finite players, actions, and time-horizons (histories).
- In many models, these are on a continuum or infinite
  - e.g. market with a continuum of firms, pricing decisions in oligopolies, Rubinstein Bargaining model, etc.
- Myerson and Reny (2020): SEs of nearby finite games may not converge to SE of an infinite-action game.
- In practice, this is rarely a problem. We can show an equilibrium exists or explicitly solve for one for the specific application.



Action on a continuum

6. Stochastic Games

A tractable class of infinite-horizon games; very common in Industrial Organization



Timing in a stochastic game

- A **stochastic game (or Markov game)** is an extensive-form game derived from $(N, S, A, \pi, u, \delta)$, with
  - N, the set of players
  - S, the set of states where $s_0 \in S$ is the initial state,
  - $A_i(s)$, the set of available actions a_i for Player i in state s,
  - $\pi(s'|s, a)$, the transition probability to next state s' given current state s and action profile a,
  - $u_i(s, a)$, the periodic payoff function for i given (s, a), and
  - $\delta \in (0, 1)$, the discount factor.
- Cole and Kocherlakota (2001) extend this framework to include hidden states and hidden actions
- A common solution concept is Markov Perfect Equilibrium (MPE), which refines SPNE

7. Art of Economic Model-Building

Varian (2016) "How to Build an Economic Model in Your Spare Time"

1. "Look for ideas in the world, not in the journals."
2. "First make your model as simple as possible, then generalize it."
3. "Look at the literature later, not sooner."
4. "Model your paper after your seminar."
5. "Stop when you've made your point."

Hal Varian

Research Frontier

Strategic interaction with biased beliefs

Warning: This is a rough summary.
See original papers for precise definitions

Conjectural Equilibrium and Self-Confirming Equilibrium

Battigalli and Guaitoli (1988); Azrieli (2009); Fudenberg and Levine (1993)

- Player i's **strategy** is $\sigma_i \in \mathcal{S}_i$. Player i's **conjecture** is $\beta_i \in \mathcal{S}_{-i}$.
- Player i's **(terminal) information structure** is (τ_i, M) where $\tau_i : \Omega \to M$ that maps each terminal node $\omega \in \Omega$ to a message $m \in M$.

Definition

A pair (σ, β) of strategy and conjecture profiles is a **conjectural equilibrium (CE)** if, for every player i,

- the strategy σ_i best responds to β_i, and
- the conjecture β_i is τ_i-consistent with σ.

A **self-confirming equilibrium** is a CE with a perfect info structure (id, Ω).

Meaning. In a SCE, players may have wrong conjectures off the equilibrium path, but not on the path.

Analogy-Based Expectation Equilibrium

Jehiel (2005); Jehiel and Koessler (2008); Jehiel (2022)

Notation

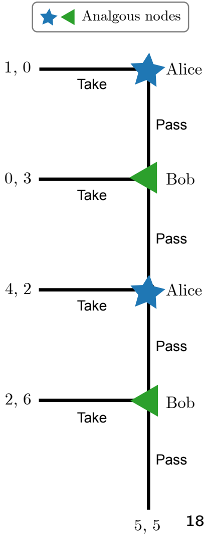
- Player i's **strategy** is $\sigma_i \in \mathcal{S}_i$. Player i's **conjecture** is $\beta_i \in \mathcal{S}_{-i}$.
- An **analogy grouping** $\{\alpha_i\}$ is a partition of player i's decision nodes.

Definition

A pair (σ, β) is an **analogy-based expectation eq. (ABEE)** if

- the strategy σ_i is sequentially rational given β_i,
- the conjecture β_i has the same values for all nodes in the analogy group α_i and is otherwise consistent with σ

Meaning. Players think others behave the same in analogous situations.



Cursed Equilibrium and Cursed Sequential Equilibrium

Eyster and Rabin (2005); Fong et al. (2023)

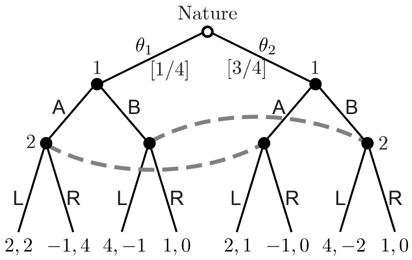
Setting. Consider a game of incomplete information and observable actions. Each player's private type is θ_i.

Definition

A pair (σ, β) is a **cursed equilibrium** if, for every player i and another player j,

- the strategy σ_i best responds to β_i, and
- the conjecture β_i has the same value across the types θ_j and is otherwise consistent with σ.

A **cursed sequential equilibrium** is a cursed equilibrium whose strategies σ_i are sequentially rational given β_i.



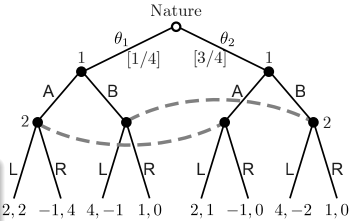
Meaning. Players think others behave the same across types.

Sequential Cursed Equilibrium

Cohen and Li (2022)

Setting. Any extensive-form game with perfect recall.

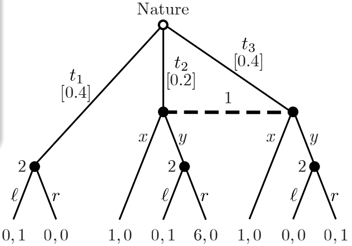
Notation. The **coarse set** $F(h)$ of a node h is the largest set of nodes that could form an information set without violating perfect recall.



Definition

A pair (σ, β) is a **sequential cursed equilibrium** if, for every player i and another player j,

- the strategy is σ_i sequentially rational given β_i, and
- the conjecture β_i has the same value across all nodes within each coarse set and is otherwise consistent with σ.



Meaning. Players think others behave the same within "coarse sets"

Causal Misperception with DAGs

Setting. One decision maker (DM)

Notation. Variables $x_1, \ldots, x_n$. Objective probabilities $p(x_1, \ldots, x_n)$.

A "causal model": A directed acyclic graph G with nodes $i \in \{1, \ldots, n\}$ and set R of directed links. $R(i)$ is the set of nodes preceding i.

Definition

A pair (σ, p_G) is a **personal equilibrium** if

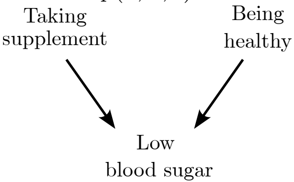
- the strategy σ is a best response to p_G
- the conjecture p_G is consistent with σ and takes values

$$p_G(x_1, \ldots, x_n) = \prod_i p(x_i | x_{R(i)}).$$

Meaning. DM has misperception about the directions of causality

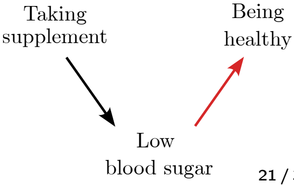
True

$p(a, h, c)$



Misperception

$p_G(a, h, c) =$
$p(a) \cdot p(c|a) \cdot p(h|c)$



Misspecified models: Berk-Nash Equilibrium

Esponda and Pouzo (2016)

- $\theta \in \Theta$ is the true parameter of the game.
- $\Theta_i \subset \Theta$ is Player i's subjective set of parameters.
- A **conjecture** is $\beta_i \in \Delta(\Theta_i)$.

Definition

A pair (σ, β) is a **Berk-Nash equilibrium** if

- the strategy σ_i is a best response to (σ_{-i}, β_i)
- the conjecture β_i is consistent with σ and minimizes the distance* from the true parameter θ.

$*$ weighted Kullbeck-Leibler divergence.

Meaning. Players believe in a model closest to the truth among the set of misspecified models.

Writing Advice for Graduate School

Main idea

Question How can we write many papers in graduate school?

Answer Get Minimum Viable Papers (MVPs) out quickly.

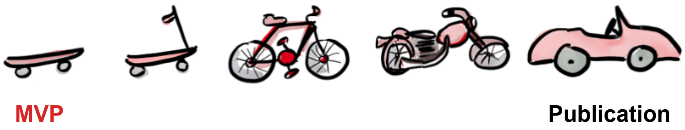


Image from Kniberg (2016)

Motivation

Healy (2019) "The Backwards Induction Approach to Grad School... and other random advice"

PJ's advice: Focus on paper quantity

- Quantity is much easier to choose and signal than quality
- To stand out, have 4+ complete downloadable papers
- Get 1+ revise & resubmit (R&R) or publication
- Do a mix of coauthored and solo work

My similar take

- The speed of learning-by-doing is proportional to quantity
- So higher quantity early on leads to higher quality later

PJ Healy "Self Portrait by Mountain Lake" (c. 2013)

⇒ **Question:** How do you write 4+ papers?

Example: My PhD Journey

Following PJ's advice

	PhD Year					
Semester	1	2	3	4	5	6
Fall		Submit **P1**	Start **P4**	Submit **P2**	Submit **P4**	
		Start **P2**		Start **P6**		
Spring		Start **P3**	Start **P5**			(Submit **P5**)
Summer	Start **P1**			Submit **P3**		(Submit **P6**)

Paper 1. Short coauthored empirical paper. Published after 1st attempt
Paper 2. Short theory paper. Published after 5th attempt
Paper 3. Short coauthored macro paper. Unpublished with 4 attempts
Paper 4. More serious coauthored theory paper. R&R after 2nd attempt
Paper 5. More serious coauthored empirical paper. Working to submit
Paper 6. Most ambitious theory paper and Job Market Paper (JMP). Working to submit

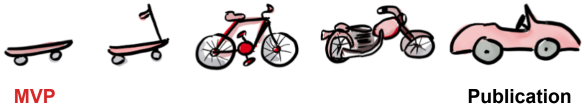
Minimum Viable Paper

Inspired by "minimum viable product" in entrepreneurship (Ries, 2011)

Definition

A **Minimum Viable Paper (MVP)** is a complete draft with just enough content to be readable and discussable, enabling early feedback on its future direction.

- "complete draft": title, abstract, introduction, body sections, and conclusion
- "just enough content": clear question, simplest method, main result, and contributions to the literature



Minimum Viable Paper (continued)

An **MVP:**

- is "readable and discussable": concise, top-down, and grammatically correct prose; strong topic sentence for each paragraph; intro as the mini-paper; publication-quality figures and tables; footnotes, figure notes, and table notes wherever needed; no secret code or jargon; simplest math notation
- enabling "early feedback": from advisor, committee members, fellow students, talks in the department and at conferences, seminar speakers, authors of closest papers
- for "future direction": more results, comparative statics, robustness checks, extensions, different focus, or even a different question; making the paper publishable

Example: How my Job Market Paper evolved

MVP

January 2024

- 2 main results (A&B)
- shared with Yaron
- presented in reading group

Ext. abstract

March 2024

- 1 more result (C)
- sent to conferences
- continued presenting

“First draft”

May 2024

- 1 more result (D)
- put D&C as main results
- sent to author of closest paper
- present at conferences

Revised draft

October 2024

- added results E, F1, F2, F3, G1, G2, G3, H
- C and F1–3 are main results
- put A in appendix
- removed B

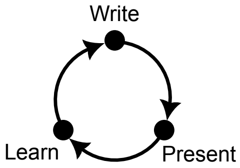
(Submission?)

(August 2025)

- remove A
- move G&H to appendix
- revise thoroughly

What to do: Working to write MVPs

- Working to finish an MVP gives a clear early milestone
- Finishing an MVP forces one to think about every part of the paper early on
    - Title & Abstract: What is the question and the single main result?
    - Intro: Motivation, question, main results, contribution to literature
- Having an MVP allows others to work on my paper
    - They can read and focus on substantive feedback rather than being distracted by how poorly I communicate it
    - Having written an MVP improves my verbal communication
    - I can work on other projects in the meantime
    - I can also happily do the same to others' papers
- With an MVP, I am more open to feedback and can flexibly revise the paper



A virtuous cycle

What not to do: Working without writing

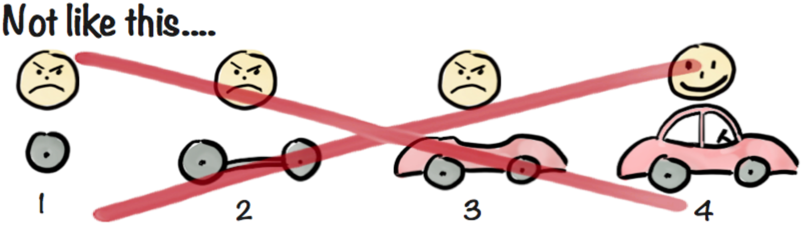


Image from Kniberg (2016)

Other influences on my writing

English

- "Write, not so that people can understand, but so that they cannot misunderstand"
- Strunk and White (1959) say style emerges not by ornament but by restraint

Math

- Halmos (1970) says "write in spirals," by writing sections $1, 2, 1, 2, 3, 1, 2, 3, 4$, etc.
- Tao (2007) recommends "folding arguments into lemmas" and "rapid prototyping"

Economics

- My advisor Yaron says: state Theorem 1 (main result) as early as possible
- Thomson (2001) says: make Theorem statements as short as possible
- Cochrane (2005) says: just use "I" as a sole-author
- Varian (2016) says: economic model-building is like sculpting

Takeaways

To be prolific in graduate school,

- Get MVPs out quickly
- Allow others to work on them while you move onto new MVPs
- Ask for others' drafts and give feedback

Takeaways

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- Get MVPs out quickly
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