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Quantum Probability Models for Decision Making

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Introduction

- Research has verified human experience that judgment and decision making is commonly enigmatic; that is, there are situations in which human decision making deviates from classical probability and utility models.
  - Examples include: sunk cost fallacies, anchoring, availability heuristics, Halo effects, group think, bandwagon effects, etc.
- Not only do our own decisions suffer from this condition, but more importantly, the actions of other actors are often hard to predict or interpret.
- There is a need for new models to accurate predict decisions and attitudes of various actors
  - Particularly in an atmosphere of uncertainty and lack of consensus, decisions by the various actors in a situation may seem irrational and ambiguous.

"Linda" is 31 years old, single, outspoken, and very bright. She majored in philosophy. As a student, she was deeply concerned with issues of discrimination and social justice, and also participated in anti-nuclear demonstrations. An individual is asked to estimate which of the following was more likely:

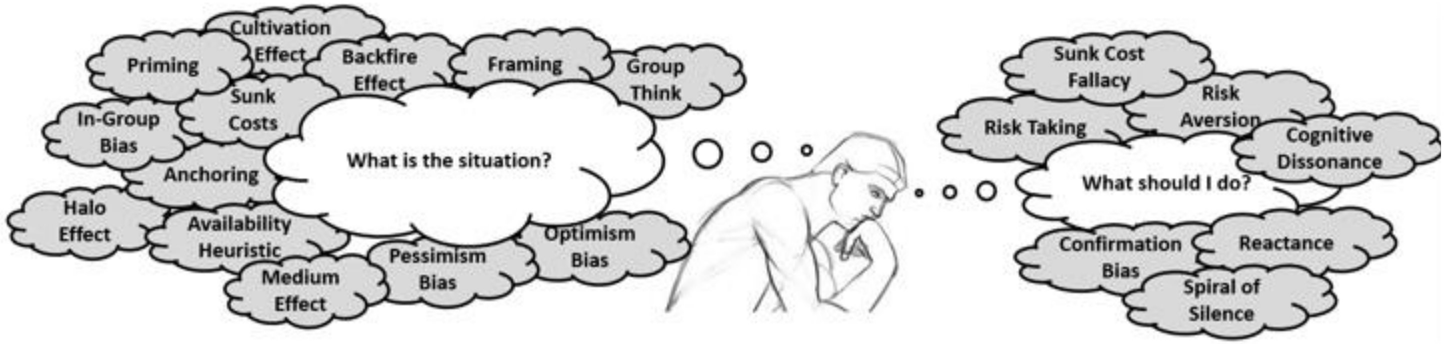
(i) "Linda" is a bank teller;

(ii) "Linda" is a bank teller and is active in the feminist movement;

People judge (ii) more likely than (i) – a violation of classic probability laws!

Introduction

- AI agent research is generally focused on developing "intelligent" agents that can perform as well (or even outperform) human agents on decision-making tasks.
- To achieve this, researchers have employed well-studied "classical" methods for reasoning and decision making in order to forecast situation assessment and ultimate decision making.
- In some sense, these agents will make the rational or optimal choice in a given situation

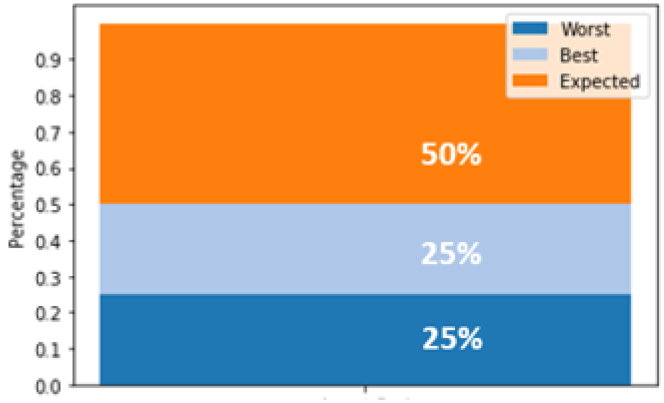


People are not "econs"

- Our approach is focused on developing agents that perform as humans do on decision-making tasks, with all the contextual biases of a particular situation.
- When doing the situation assessment, humans are influence by a variety of biases.
- This assessment then influences the decision of what to do (or not).

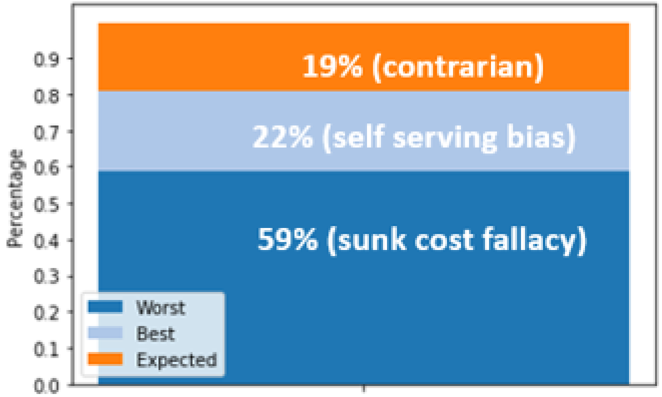
A practical application – Enemy Course-of-Action Analysis

Classic Methods



- Classical methods - likelihood estimates made using SME expertise, game theory, classical Bayesian methods, etc.
- Possible shortcomings include estimates that are
  - inconsistent with realistic decision making tendencies, or
  - might result in situation understanding that is not prepared for the most likely outcomes.

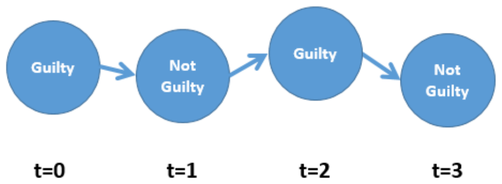
Proposed Methods



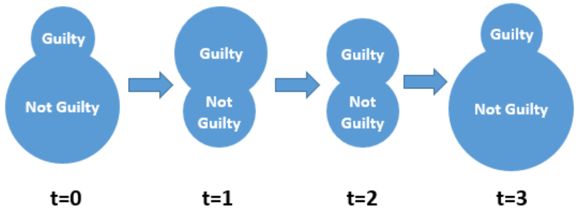
- Proposed methods – likelihood estimates made using models that are more consistent with actual enemy decision making tendencies.
- Models enable deeper "what if" analysis to explore the impacts of a variety of human decision making tendencies.
- Expected advantages include
  - Forecasts that are consistent with realistic decision making tendencies,
  - Situation understanding that is more prepared for the most likely outcomes,
  - Provides a possible "why" behind the specific decisions.
    - If the enemy is operating under a sunk cost bias, then there are ways that that outcome can be mitigated; for example, by reducing the enemy assessment of sunk costs.

Foundational Concepts

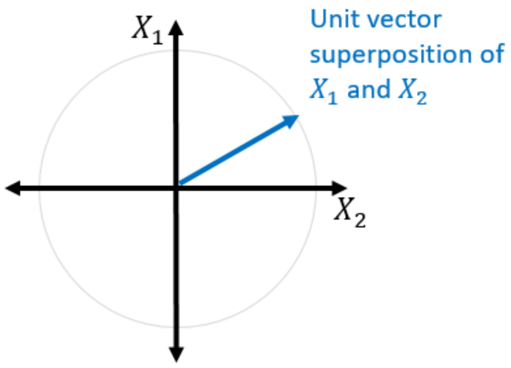
In classical models, there is a trajectory through states. At each moment, there is a specific state in mind



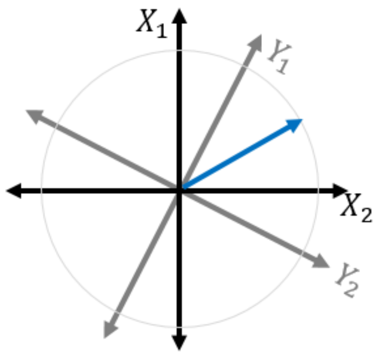
In quantum models, states are in superposition. At each moment, there is a "superposition" of states, defined probabilistically



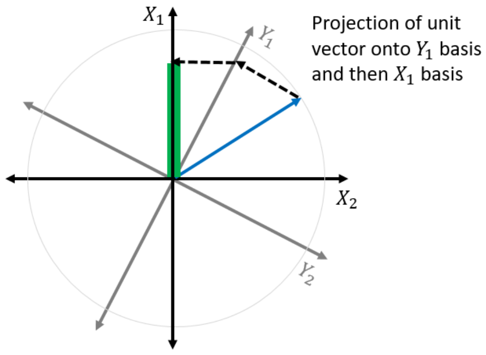
Decision Making



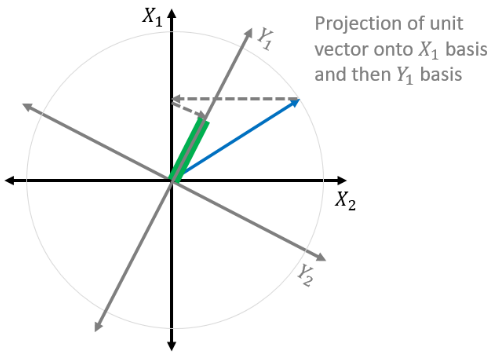
(a) Single basis with state unit vector



(b) Multiple bases

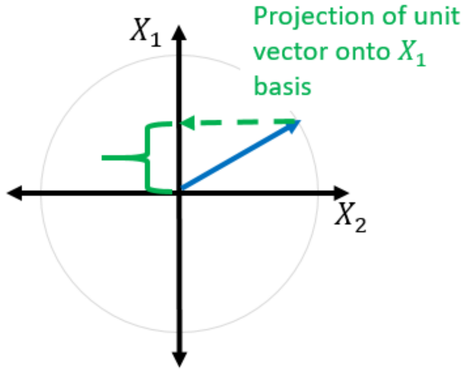


(a) $p(Y_1 \cap X_1)$



(b) $p(X_1 \cap Y_1)$

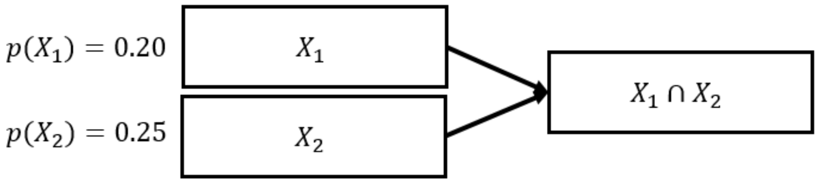
Order Effects



(c) State vector projection

Superposition State

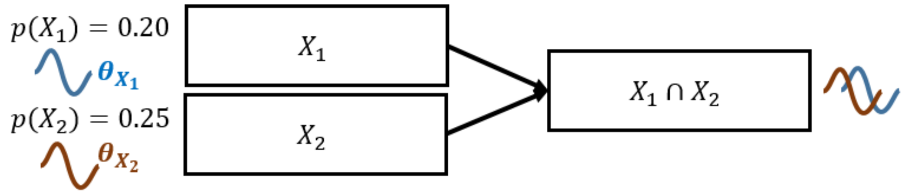
Interference in Situation Assessment



From Classic Axioms

$p(X_1 \cap X_2) = p(X_1) \cdot p(X_2)$

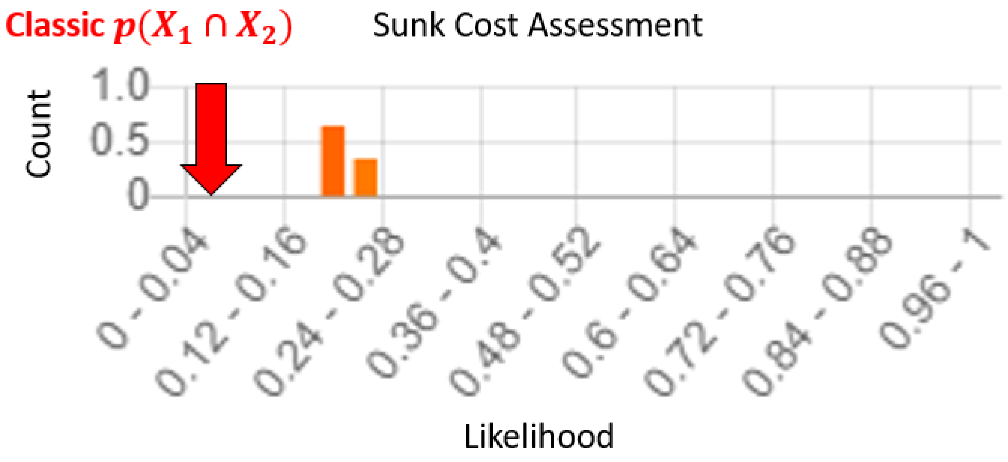
$p(X_1 \cap X_2) = 0.20 \cdot 0.25 = 0.05$



From Classic Axioms

$p(X_1 \cap X_2) = p(X_1) \cdot p(X_2) + Int_{X_1,X_2}$

$p(X_1 \cap X_2) = 0.20 \cdot 0.25 = 0.05 + Int_{X_1,X_2}$



Example – sunk cost assessment

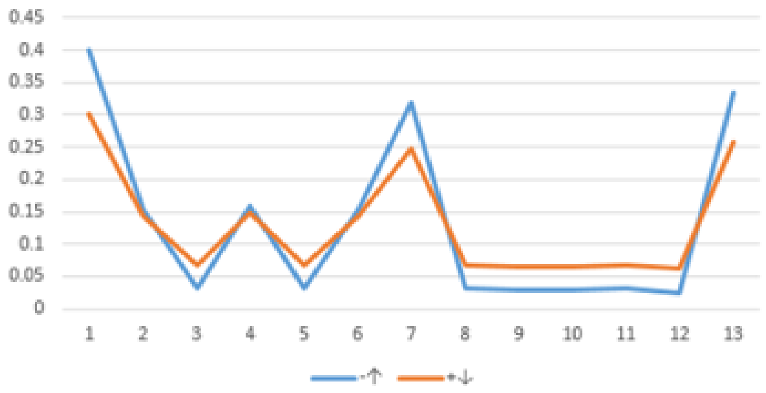
- The factors that can influence a sunk cost assessment includes things such as: amount of resources expended in a battlefield (X_1), the number and severity of losses towards a goal in a battlefield (X_2), etc.
  - The assessment might be expected to result in a course of action that is more aggressive or risky than a normative course of action in order to recover the perceived sunk costs.
- To incorporate interference between the factors, we include a *phase* associated with each factor. Mathematically, the factors are *wave functions* and the interference is represented as differences in phase (θ) between factors.
- The phase is a function of the factors, current situation, attitudes of the decision maker, and other contextual elements.

Assess → Decide → Act Model

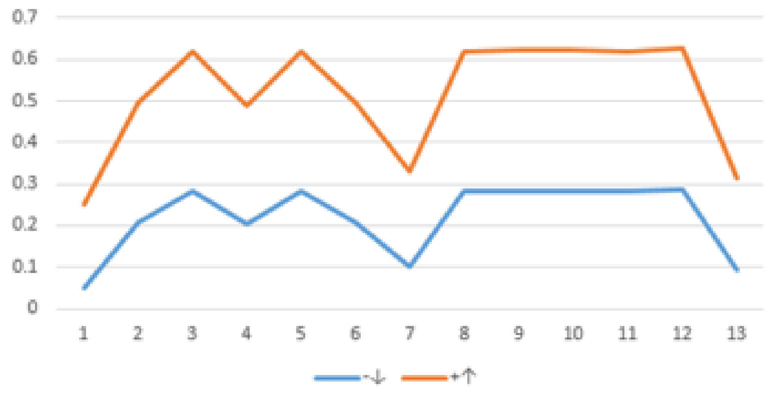
- Our model of how decision makers act is based on theories of how they form beliefs about a state of the world and make decisions about which actions to take in the context of those beliefs.
- In this model, beliefs (situation assessment) *interferes* with action options (selecting the right action for the situation) to make forecasts about what to do.
  - *In a "rational actor", the actions are consistent with beliefs*; violation of this is called *cognitive dissonance*.
- The dynamics of the decision making process is governed by a Schrödinger equation, with parameters for consistency, rewards and penalties, and ambiguity or randomness
- In military applications, this model can apply when the decision maker (own force or enemy force) must make an assessment prior to making a decision to act, as in the OODA loop context.

Assess → Decide → Act Model

- Our model amplifies the "correct decision" (actions are consistent with beliefs) and attenuates the "incorrect decision" (actions are inconsistent with beliefs).
  - In this model, the assessment basis (denoted as the +/- basis) interferes with the action basis (denoted as the ↑/↓ basis).
- In quantum modeling terms, the assessment basis is *entangled* with the action basis such that $P(+/- \cap \uparrow/\downarrow) \neq P(+/-) \cdot P(\uparrow/\downarrow)$.
  - The deviation from the classic axiom is the interference effect.



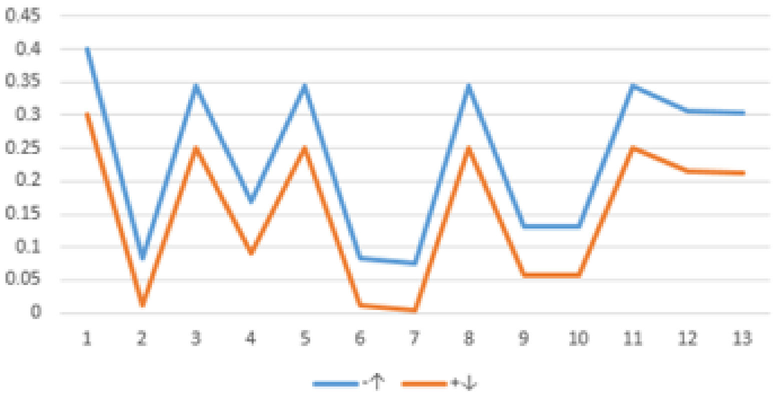
Entanglement Attenuation for States $-\uparrow$ and $+\downarrow$



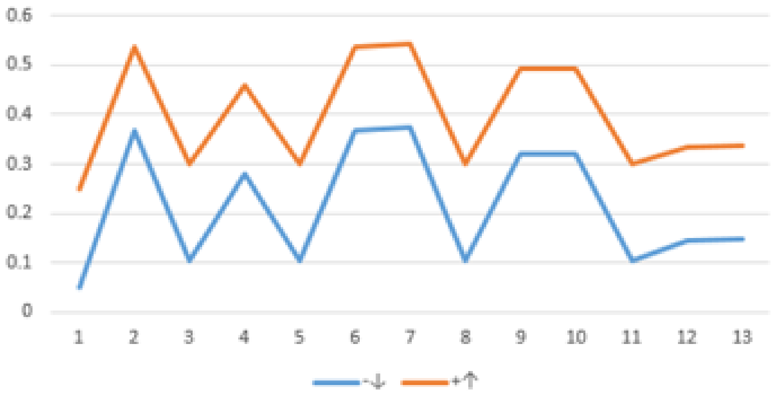
Entanglement Amplification for States $-\downarrow$ and $+\uparrow$

Assess → Decide → Act Model

- Our model amplifies acting when the assessment indicates that the action should be taken (a reward) and attenuates acting when the assessment indicates no action should be taken (a penalty).

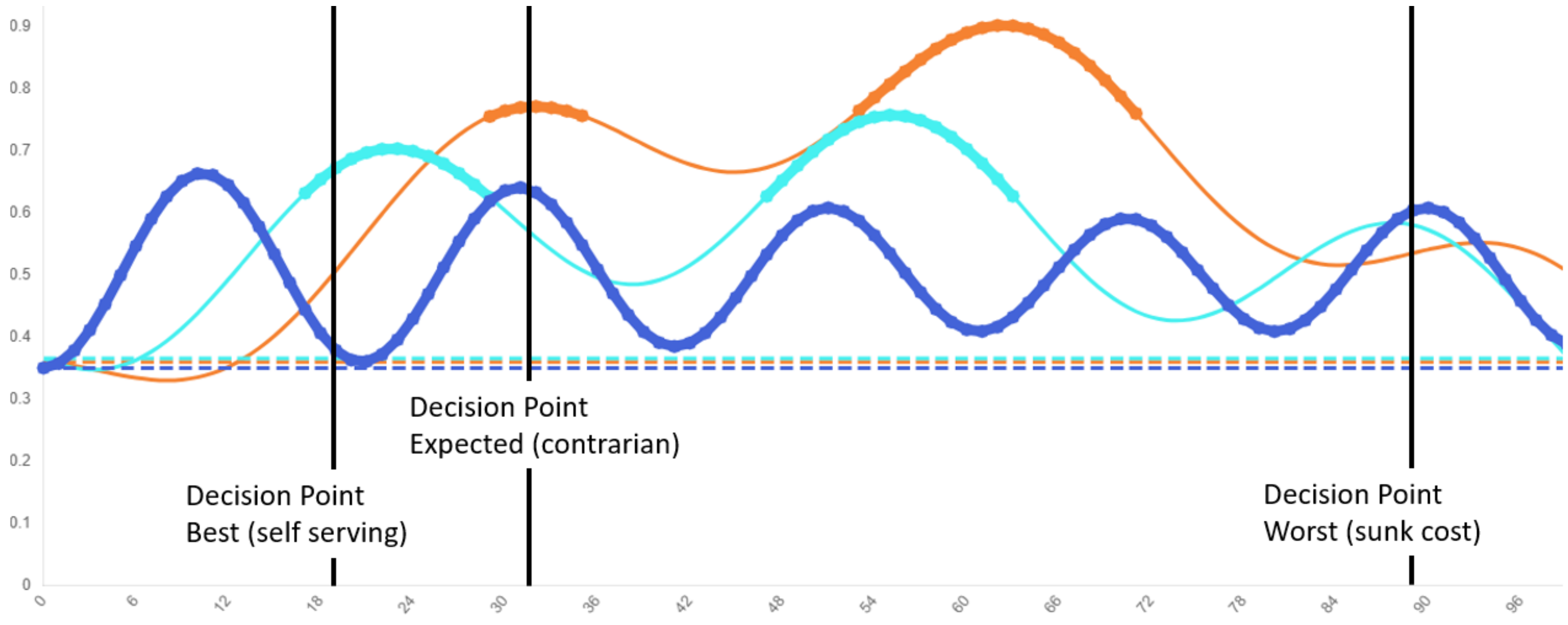


Reward/Penalty Attenuation for States −↑ and +↓



Reward/Penalty Amplification for States −↓ and +↑

Assess → Decide → Act Model



- Monte Carlo simulation using quantum probability for the ECOA assessment example
- The biases (self serving, contrarian and sunk cost) are modeled by selecting specific parameters
- This simulation captures the ambiguity in the decision making process represented as a superposition state over all possible decisions: Best Case (light blue), Expected Case (orange) and Worst Case (dark blue).
- At any given point, the decision maker has some likelihood for selecting each of the three ECOAs.
- We ran the simulation 1000 times by randomly selecting the free parameter representing ambiguity or randomness in the decision-making process.

Discussion / Q & A