Module 13
Decision Field Theory

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Decision Making in Engineering Design

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Module Outline

1. Motivation for Decision Field Theory

2. Details of Decision Field Theory

Busemeyer, J. R., Townsend, J. T., 1993, “Decision Field Theory: A Dynamic-Cognitive Approach to Decision Making in an Uncertain Environment”, *Psychological Review*, Vol. 100, No. 3, pp. 432-459.

Motivation for Decision Field Theory

A Classification of Decision Theories

	Static	**Dynamic**
Deterministic	Expected Utility	Dynamics of action
Probabilistic	Random Utility	Decision Field Theory

Deterministic vs. **Probabilistic** Theories:

- Deterministic: Postulate binary relations between alternatives (e.g., $(A_1 \succ A_2)$).
- Probabilistic: postulate a probability function that maps pairs of actions to $[0, 1]$, e.g., $P(A_1 \succ A_2) = p$.

Static vs. **Dynamic**:

- Static: Assume that preference relations are independent of deliberation time.
- Dynamic: specify how preference relations change as a function of deliberation time.

Note: difference between dynamic decisions and dynamic theories of decisions.

Role of Deliberation Process in Decision Making

Deliberation process affects:

- Indecisiveness
- Vacillation (inability to take a stand)
- Inconsistency
- Lengthy deliberation
- Distress

Why do preferences waver over time?
How long does deliberation last?

Fundamental Properties of Human Decision Making Behavior

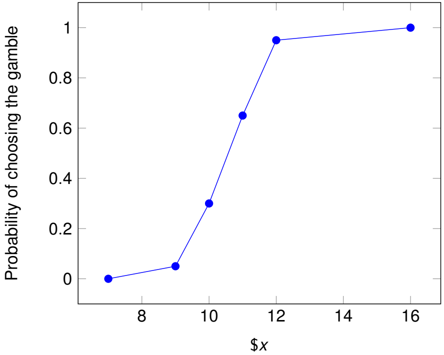
1. Variability of preferences: Preferences are inconsistent.
2. Violation of Independence between alternatives.
3. Deliberation time affects decisions.

Fundamental Properties of Human Decision Making Behavior

1. Variability of Preferences

Experiment

- Decision: Reject or accept the lottery $\langle \$x, 1/3, -\$0.05 \rangle$
- Control: Varied x
- Results: probability of choosing the gamble gradually increased with x



Conclusion

"Subjects are not so consistent about preference and indifference."

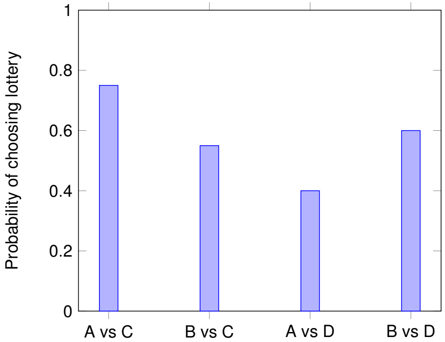
Fundamental Properties of Human Decision Making Behavior

2. Violation of Independence between Alternatives

Violation of Independence between Alternatives

Lotteries:

- **A**: $\langle 5, 0.5, -5 \rangle$
- **B**: $\langle 50, 0.5, -50 \rangle$
- **C**: $\langle 0, 0, -1 \rangle$
- **D**: $\langle 1, 1, 0 \rangle$



Proposal

Inconsistency arises from changes in preference over time.

Fundamental Properties of Human Decision Making Behavior

3. Preference Strength and Deliberation Time

Observations from experiments:

- Choice time is a decreasing function of preference strength
- Choice time systematically decreases as the probability of choosing the gamble increases
- Probability of choosing an action can be moved up or down simply by manipulating time pressure.

Conclusion

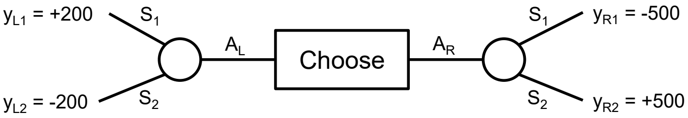
Decisions take time, and the amount of time spent making decisions influence the final choice.

Details of Decision Field Theory

Prototype Choice Problem

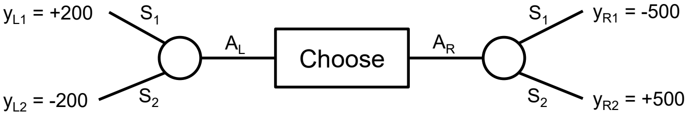
Set up:

- Alternatives: A_L and A_R
- Uncertain events: S_1 and S_2
- Possible payoffs: $y_{L1}, y_{L2}, y_{R1}, y_{R1}$



Example: A_L and A_R as alternate treatments, and S_1 and S_2 as alternate diseases present.

Stage 1: Deterministic Subjective Expected Utility (SEU)

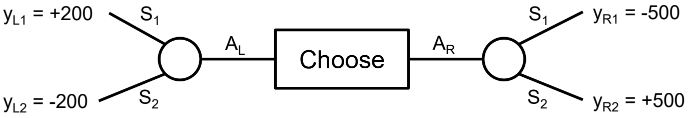


Subjective probability weights, $w(S_j)$, are assigned to each uncertain event. Cognitively, it can be viewed as the **amount of attention** given to the uncertain event.

SEU for the two alternatives are:

$$v_L = w(S_1)u(+200) + w(S_2)u(-200)$$
$$v_R = w(S_1)u(-500) + w(S_2)u(+500)$$

Stage 1: Deterministic Subjective Expected Utility (SEU)



Decision is made based on the difference between the SEUs,

$$d = v_R - v_L$$

d determines the direction of preference. If $d > 0$, choose A_R. If $d < 0$, choose A_L.

Limitation: Deterministic SEU does not account for the fundamental variability of human preference. It predicts the same decision across trials.

Stage 2: Random SEU

Random SEU Theory allows the decision maker's attention to switch from one event to another **across choice trials**. Variability in subjective probability weights, $w(S_j)$ results in variability in $d(= v_R - v_L)$ across trials, resulting in different decisions.

In Random SEU, the attention weight is a random variable $W(S_j)$.

Define **valence** of an alternative as

$$V_L = W(S_1)u(+200) + W(S_2)u(-200)$$
$$V_R = W(S_1)u(-500) + W(S_2)u(+500)$$

Define **preference state** P on any trial as

$$P = V_R - V_L$$

Decision: Choose A_R whenever $P > 0$.

Relationship between Stage 1 and Stage 2

The attention weights $w(S_j)$ in Stage 1 can be evaluated from Random SEU:

$$w(S_j) = E[W(S_j)]$$

Using this,

$$d = E[V_R - V_L] = E[V_R] - E[V_L] = v_R - v_L$$

The preference state on any trial can be expressed as a random variable (with variance σ^2):

$$P = V_R - V_L = (d + \epsilon)$$

Probability of choosing A_R:

$$Pr[P > 0] = Pr[d + \epsilon > 0] = Pr[\epsilon > -d]$$

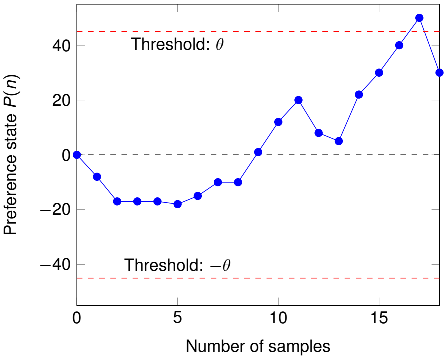
Limitation: The theory does not provide any mechanism to explain the relation between choice probability and decision time.

Stage 3: Sequential SEU

Within SEU, the attention may shift from one event to another **within** a single choice trial. The preference state (P) changes with time.

$$P(1) = [V_R(1) - V_L(1)]$$
$$P(2) = P(1) + [V_R(2) - V_L(2)]$$
$$\dots$$
$$P(n) = P(n-1) + [V_R(n) - V_L(n)]$$
$$= \sum_k [V_R(k) - V_L(k)],$$
$$k = 1, 2, \dots, n$$

Decision: when $P(n)$ exceeds an **inhibitory threshold**, θ



The total number of samples needed to reach the threshold is a random variable, N.

Stage 3: Sequential SEU: Sequential Sampling Process

Speed-accuracy tradeoff

Increasing the threshold increases the probability of choosing the correct action, but it also increases the time required to reach a decision.

- The decision time is an increasing function of N.
- The sequential sampling theory allows choice probability to depend on the threshold criterion, θ.
- The mean number of samples to reach the threshold is:

$$E(N) = \frac{\theta}{d}[2Pr(A_R, A_L) - 1]$$

Limitation of Sequential SEU

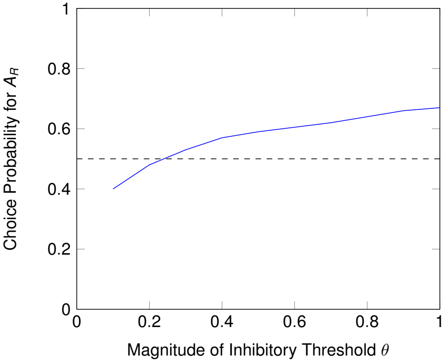
If $d > 0$, then the probability of choosing A_R over A_L is always predicted to be greater than 0.5 for all θ.

Stage 4: Random Walk SEU Theory

Generalizes sequential SEU theory by allowing the initial preference state, $P(0)$, to start at some **anchor point**, z biased by previous knowledge or past experience.

$$P(0) = z$$
$$P(1) = z + [V_R(1) - V_L(1)]$$
$$\dots$$
$$P(n) = P(n-1) + [V_R(n) - V_L(n)]$$
$$= z + \sum_k [V_R(k) - V_L(k)],$$
$$k = 1, 2, \dots, n$$

A_L is a highly familiar brand,
A_R is a new brand.
$d > 0, z < 0$



Stage 4: Random Walk SEU Theory

Summary of parameters in the model:

- Mean valence difference, d: to explain the direction of preference
- Variance of valence difference, σ^2: to explain strength of preference
- Threshold criterion, θ: to explain the speed-accuracy tradeoffs
- Initial anchor point, z: to explain reversals in the direction of preference as a function of time pressure

Stage 4: Random Walk SEU Theory

Characteristics:

- The choice probability can now change from below 0.50 to above 0.50.
- The further the initial state is from the threshold, the longer it takes to reach the threshold.
- Captures the inverse relationship between choice probability and decision time.

Limitation

The model does not capture **serial position effects** on the final preference, i.e., whether the valence difference occurs early or late in the sequence.

Stage 5: Linear System SEU Theory

Linear System SEU Theory is based on the assumption that the impact of valence difference may vary depending on whether it occurred early or late within the sequence.

Serial position effects:

$$
\begin{aligned}
P(n) &= (1-s)P(n-1) + [V_R(n) - V_L(n)] \\
&= (1-s)^n z + \sum_k (1-s)^{n-k} [V_R(k) - V_L(k)], \quad k = 1, 2, \ldots, n
\end{aligned}
$$

The new preference state is a weighted compromise of the previous preference state and the new valence difference.

Stage 5: Linear System SEU Theory

s: Growth decay parameter

- **Recency effects**: $0 < s < 1$, i.e., recent samples have a greater impact
- **Primacy effects**: $s < 0$, i.e., earlier samples have greater impact

Limitations

It fails to account for the approach-avoidance nature of the conflict (it does not matter whether the valence difference came from two rewards or two punishments).

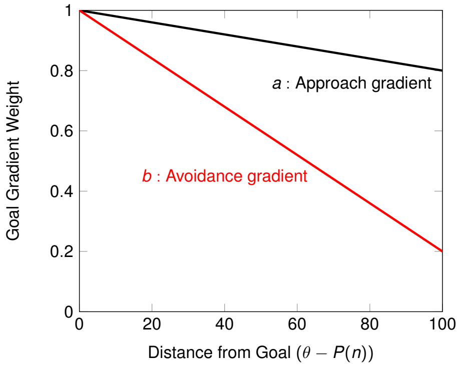
Stage 6: Approach-Avoidance Theory

Basic idea:

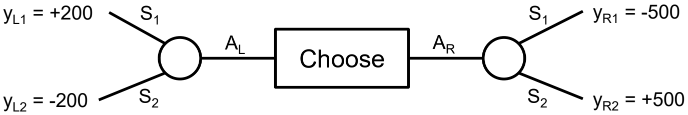
- The attractiveness of a reward or the aversiveness of a punishment is a decreasing function of the distance from the point of commitment to an action.
- If there is little or no possibility of taking an action, then its consequences are ignored; however as the possibility of taking an action increases, then attention to its consequences increases.
- Avoidance-avoidance decisions produce longer mean deliberation times than do approach-approach decisions when the mean differences are held constant.

Stage 6: Approach-Avoidance Theory

Approach-Avoidance Theory introduces **goal gradient**. Gradients for rewards tend to be flatter than for punishments.



Stage 6: Approach-Avoidance Theory



$$v_R(n) = \underbrace{\{1 - b[\theta - P(n)]\}}_{\textbf{Goal Gradient Weight}} w(S_1)u(-500) + \{1 - a[\theta - P(n)]\}w(S_2)u(+500),$$

$$v_L(n) = \{1 - a[\theta + P(n)]\}w(S_1)u(+200) + \{1 - b[\theta + P(n)]\}w(S_2)u(-200),$$

This is analogous to the framing effects in Prospect Theory.

Stage 7: Decision Field Theory

Introducing a time unit h to convert discrete time-steps into continuous time.

$h =$ the amount of time that it takes to retrieve and process one pair of anticipated consequences before shifting attention to another pair of consequences.

Deliberation time, $t = nh$

$$P(t) = (1 - sh)P(t - h) + [V_R(t) - V_L(t)]$$

Stage 7: Decision Field Theory

The decision maker must undergo a slow and time-consuming process of retrieving, comparing, and integrating the comparisons over time.

No action is taken until the preference for one action becomes strong enough to goad the decision maker into action.

Summary of Seven Stages in the Construction of DFT

Stage and Theory	New Parameter	New Phenomenon
1: Deterministic SEU	$d =$ Mean difference	Preference direction
2: Random SEU	$\sigma^2 =$ Variance of difference	Preference strength
3: Sequential SEU	$\theta =$ inhibitory threshold	Speed-accuracy trade-offs
4: Random Walk	$z =$ initial anchor point	Preference reversals with time pressure
5: Linear System	$s =$ growth-decay rate	Serial position effects
6: Approach Avoidance	$c =$ goal gradient	Time to approach is less than time to avoid
7: Decision Field	$h =$ time unit	Real time processing

Decision Field Theory: Advantages

Decision Field Theory can explain...

1. violations of stochastic dominance
2. violations of strong stochastic transitivity
3. violations of independence between alternatives
4. serial positioning effects on preference
5. speed-accuracy tradeoff in decision making
6. inverse relation between choice probability and decision time
7. changes in the direction of preference under time pressure
8. slower decision time for avoidance as compared with approach conflicts
9. preference reversals between choice and selling price measures of preference

Summary

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Reference

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