Modeling Uncertainty using Accept & Reject Statements

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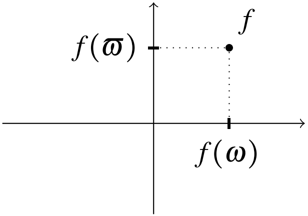
The setup

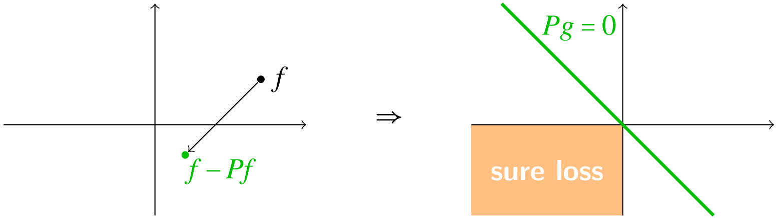
- Experiment with outcomes in some possibility space Ω.
- Agent uncertain about the experiment's outcome.
- Linear space $\mathcal{L}$ of real-valued gambles on Ω.



- Agent expresses uncertainty by making statements about gambles, forming an assessment.
- Agent wishes to rationally deduce inferences and draw conclusions from this assessment.

The work we build on

- De Finetti: previsions P.



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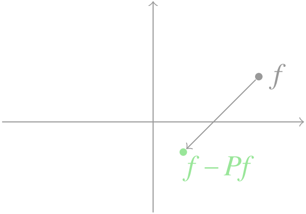

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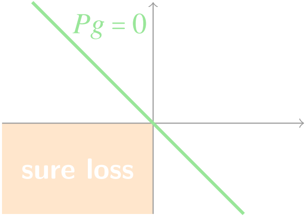
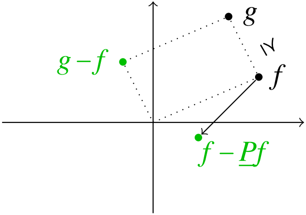


- Williams, Seidenfeld et al., Walley:
  - lower previsions $\underline{P}$,
  - sets of acceptable/favorable/desirable gambles,
  - partial preference orders $\geq$.



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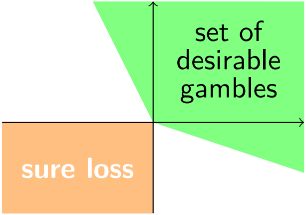

Accepting & Rejecting Gambles

Accepting a gamble f implies a commitment to engage in the following transaction:

(i) the experiment's outcome $\omega \in \Omega$ is determined,

(ii) the agent gets the—possibly negative—payoff $f(\omega)$.

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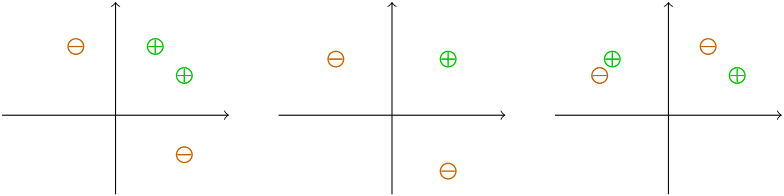
Assessment A pair $\mathcal{A} \coloneqq \langle \mathcal{A}_{\geq} ; \mathcal{A}_{\prec} \rangle$ of sets of accepted and rejected gambles.



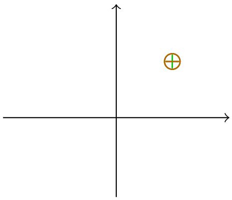
Gamble Categorization

Accepted $\mathcal{A}_{\geq}$.

Rejected $\mathcal{A}_{\prec}$.

Unresolved Neither accepted nor rejected; $\mathcal{A}_{\smile} \coloneqq \mathcal{L} \setminus (\mathcal{A}_{\geq} \cup \mathcal{A}_{\prec})$.

Confusing Both accepted and rejected; $\mathcal{A}_{\geq,\prec} \coloneqq \mathcal{A}_{\geq} \cap \mathcal{A}_{\prec}$.



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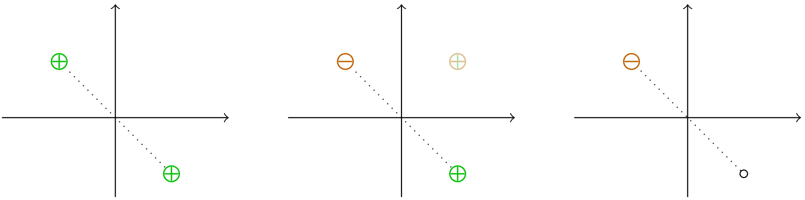

Indifferent Both it and its negation accepted; $\mathcal{A}_{\simeq} \coloneqq \mathcal{A}_{\geq} \cap -\mathcal{A}_{\geq}$.

Favorable Accepted with a rejected negation; $\mathcal{A}_{\succ} \coloneqq \mathcal{A}_{\geq} \cap -\mathcal{A}_{\prec}$.

Indeterminate Both it and its negation not acceptable; $\mathcal{A}_{\parallel} \coloneqq (\mathcal{A}_{\geq} \cup -\mathcal{A}_{\geq})^c$.

Axiom: **No Confusion**

Because of the interpretation attached to acceptance and rejection statements, we consider confusion irrational.

So we require assessments $\mathcal{A}$ to not contain confusion:

$$\mathcal{A}_{\geq,\prec} = \mathcal{A}_{\geq} \cap \mathcal{A}_{\prec} = \emptyset$$

Axiom *template*: **Background Model**

Problem domain specific set of acceptable gambles $\mathcal{S}_{\geq}$ and set of rejected gambles $\mathcal{S}_{<}$. To be combined with the agent's own assessment.

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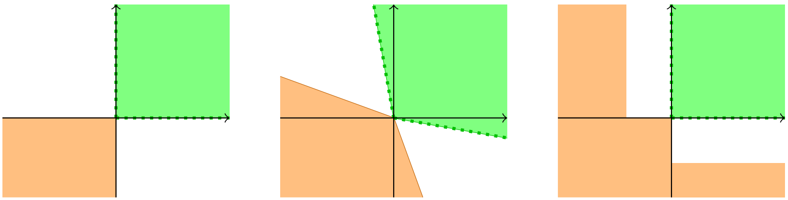

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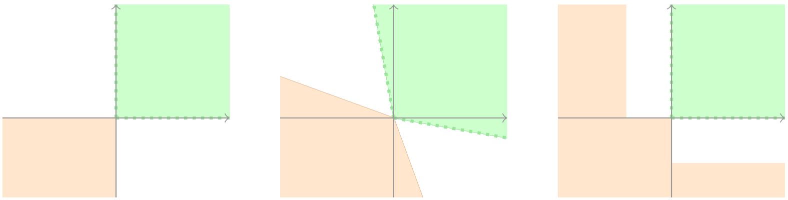

For convenience, assume Indifference to Status Quo: $0 \in \mathcal{S}_{\geq}$.

Deductive extension

The nature of the gamble payoffs (utility considerations) determines a deductive extension rule for acceptable gambles: given a set of acceptable gambles, which other gambles should be acceptable to the agent.

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1. Positive linear combinations (assumption of linear precise utility):
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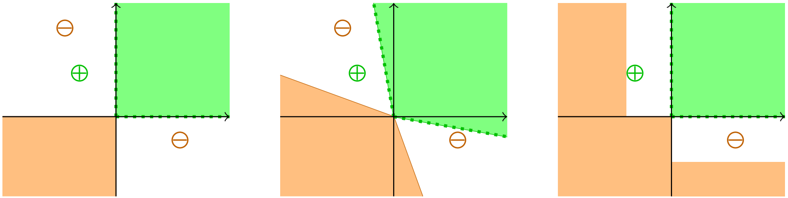

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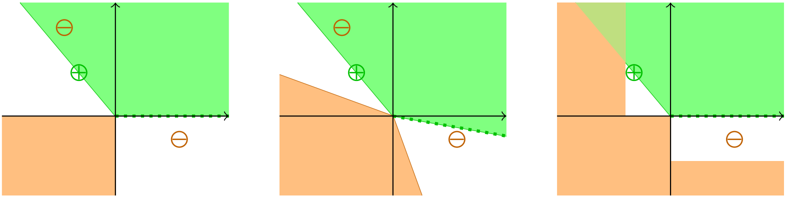
The positive linear hull operator posi combines both operations; it generates convex cones.



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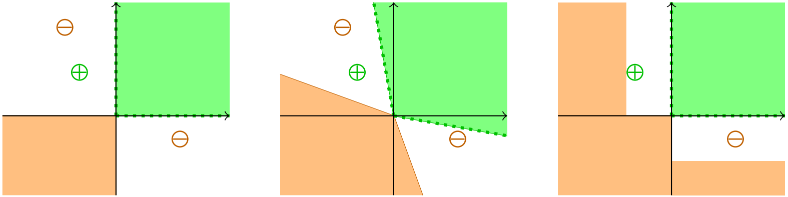

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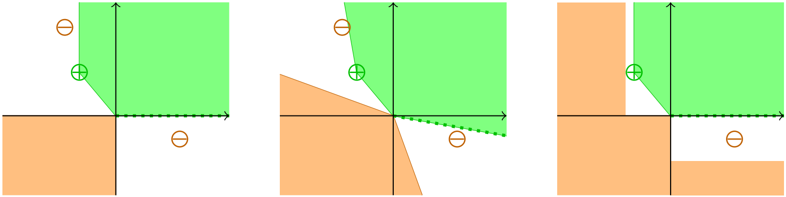

Axiom *template*: **Deductive Closure**

An assessment $\mathcal{A}$ can be deductively extended to a deductively closed assessment $\mathcal{D}$;

1. $\mathcal{D} \coloneqq \langle \operatorname{posi} \mathcal{A}_{\geq} ; \mathcal{A}_{\prec} \rangle$,
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The assumptions underlying the choice of a deductive extension rule lead us to exclusively use deductively closed assessments $\mathcal{D}$ for inference and decision purposes:

1. $\operatorname{posi} \mathcal{D}_{\geq} = \mathcal{D}_{\geq}$
2. $\operatorname{co} \mathcal{D}_{\geq} = \mathcal{D}_{\geq}$

Gambles in limbo & reckoning extension

Deductive Closure interacts with No Confusion:

- Consider a deductively closed assessment $\mathcal{D}$.
- Additionally consider some unresolved gamble f acceptable.
- Apply deductive extension to $\langle \mathcal{D}_{\geq} \cup \{f\}; \mathcal{D}_{\prec} \rangle$.
- For some f, this would lead to an increase in confusion.
- These have the same effect as gambles in $\mathcal{D}_{\prec}$,
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We use reckoning extension to reject gambles in limbo and create a model $\mathcal{M}$.

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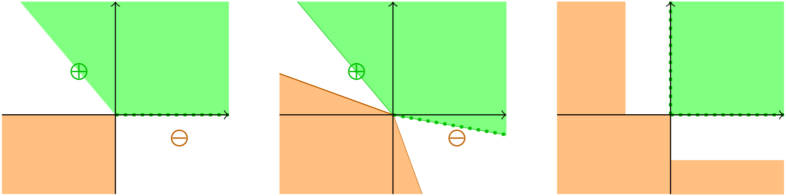

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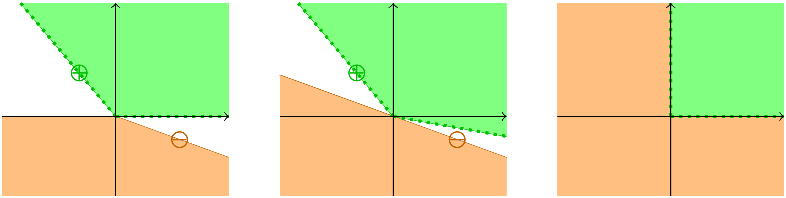

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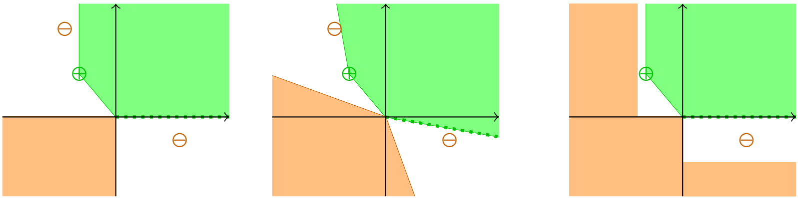

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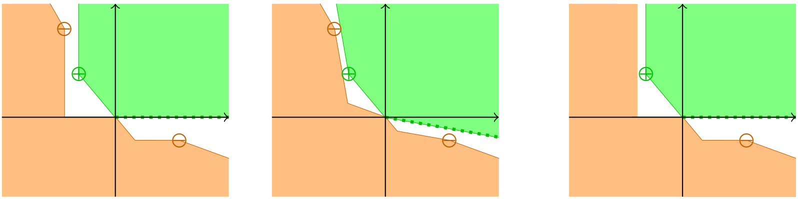

Axiom: **No Limbo**

We consider accepting gambles in limbo unreasonable and therefore further restrict attention to models $\mathcal{M}$ for inference and decision purposes:

1. $\overline{\mathcal{M}_{\prec}} - \mathcal{M}_{\geq} \subseteq \mathcal{M}_{\prec}$
2. $\bigcup_{\mu>0} (\mu+1)\mathcal{M}_{\prec} - \mu\mathcal{M}_{\geq} \subseteq \mathcal{M}_{\prec}$

Order-theoretic considerations

'not less resolved' $\mathcal{A} \subseteq \mathcal{B}$ ($\mathcal{A}_{\geq} \subseteq \mathcal{B}_{\geq}$ and $\mathcal{A}_{\prec} \subseteq \mathcal{B}_{\prec}$)

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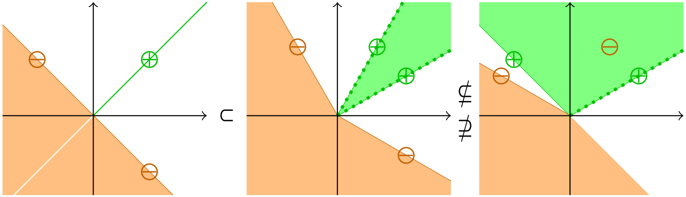

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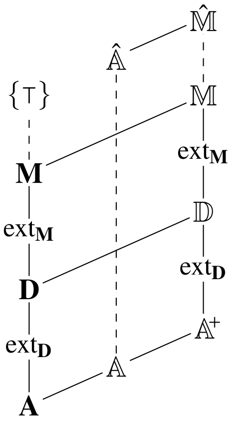

Natural extension, Respect, Coherence

Background model $\mathcal{S}$ Captures any (structural) a priori assumptions about the gambles; replaces trivial model $\langle\varnothing;\varnothing\rangle$.

Respect An assessments respects a background model if they share a common maximal model, or $\mathcal{A} \cup \mathcal{S} \in \mathbb{A}^+$.

Natural extension Reckoning extension of an assessment with a background model: $\mathcal{A} \boxplus \mathcal{S}$.

Coherence An assessment is coherent iff it coincides with its natural extension.

Main characterization result (posi)

An assessment $\mathcal{M}$ is a model that satisfies
No Confusion and Indifference to Status Quo iff

(i) $0 \in \mathcal{M}_{\succeq}$,

(ii) $0 \notin \mathcal{M}_{\prec}$,

(iii) $\operatorname{posi} \mathcal{M}_{\succeq} = \mathcal{M}_{\succeq}$,

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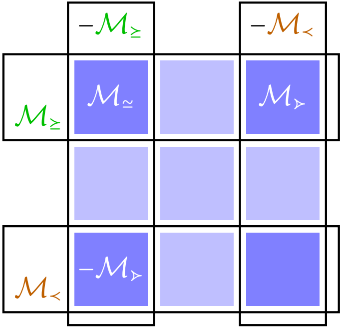

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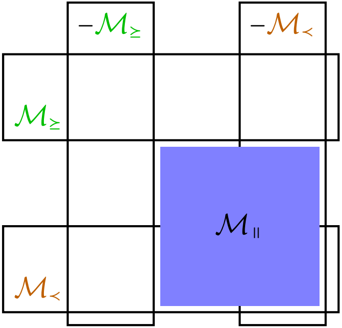

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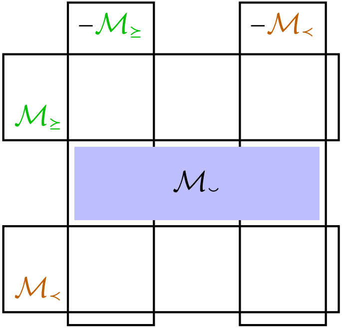

Gamble relations (posi)

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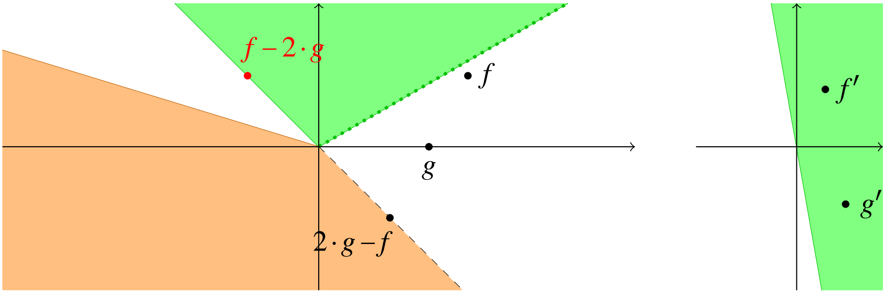

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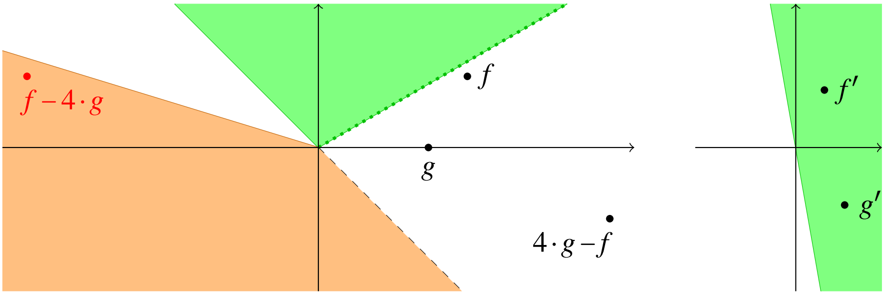

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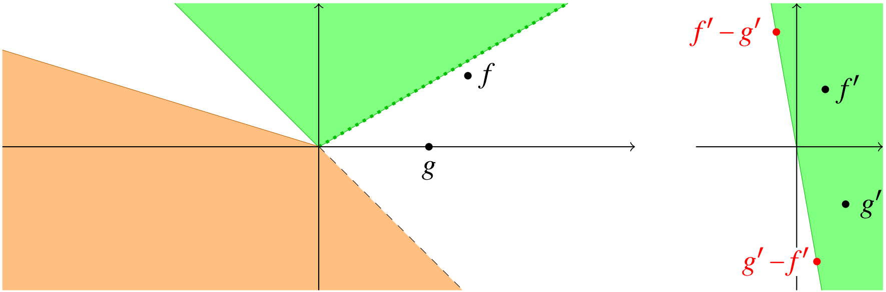

- indifference between f and h: $f \simeq h \Leftrightarrow f \succeq h \wedge h \succeq f \Leftrightarrow f - h \in \mathcal{M}_{\simeq}$.

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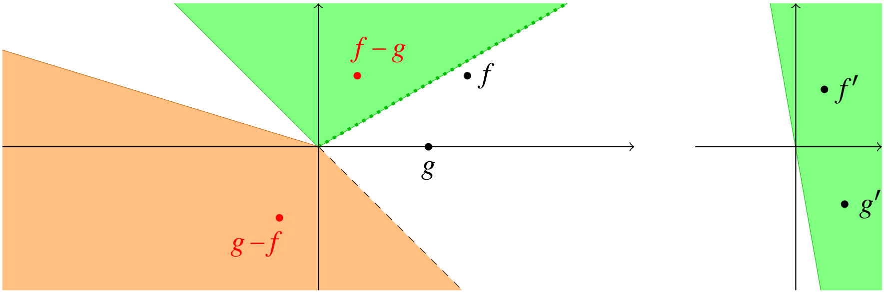

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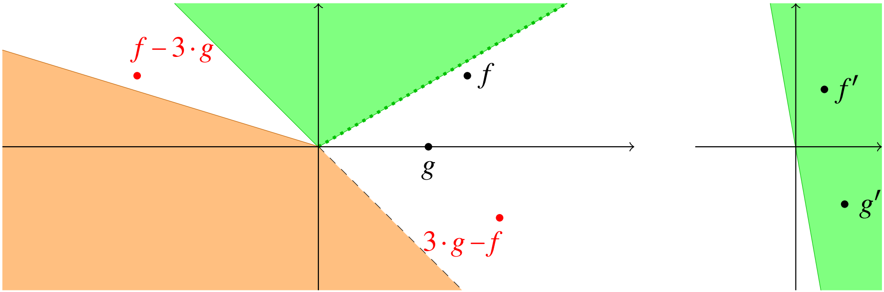

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- f is preferred over h: $f \succ h \Leftrightarrow f \geq h \wedge h \prec f \Leftrightarrow f - h \in \mathcal{M}_{\succ}$.
- f and h are uncomparable: $f \parallel h \Leftrightarrow f - h \in \mathcal{M}_{\parallel}$.

Characterization result for gamble relations (posi)

Gamble relations $\succeq$ and $\prec$ are equivalent to a model that satisfies No Confusion and Indifference to Status Quo iff

(i) Accept Reflexivity: $f \succeq f$,

(ii) Reject Irreflexivity: $f \not\prec f$,

(iii) Accept Transitivity: $f \succeq g \wedge g \succeq h \Rightarrow f \succeq h$.

(iv) Mixed Transitivity: $f \prec g \wedge h \succeq g \Rightarrow f \prec h$,

(v) Accept Mixture Independence:
$f \succeq g \Leftrightarrow \mu \cdot f + (1-\mu) \cdot h \succeq \mu \cdot g + (1-\mu) \cdot h$.

(vi) Reject Mixture Independence:
$f \prec g \Leftrightarrow \mu \cdot f + (1-\mu) \cdot h \prec \mu \cdot g + (1-\mu) \cdot h$.

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(iv) Mixed Transitivity: $f \prec g \wedge h \succeq g \Rightarrow f \prec h$,

(v) Accept Mixture Independence:
$f \succeq g \Leftrightarrow \mu \cdot f + (1-\mu) \cdot h \succeq \mu \cdot g + (1-\mu) \cdot h$.

(vi) Reject Mixture Independence:
$f \prec g \Leftrightarrow \mu \cdot f + (1-\mu) \cdot h \prec \mu \cdot g + (1-\mu) \cdot h$.

- Acceptability $\succeq$ is a non-strict pre-order (a vector ordering).
- Indifference $\simeq$ is an equivalence relation.
- Preference $\succ$ is a strict partial order.

A simplification: The Accept-Favor Framework

A simplification, restrict reject statements to negated acceptable gambles:

$$-\mathcal{A}_{\prec} \subseteq \mathcal{A}_{\succeq}$$

A simplification: The Accept-Favor Framework

An assessment $\mathcal{M}$ is a model that satisfies No Confusion and Indifference to Status Quo iff

(i) $0 \in \mathcal{M}_{\succeq}$,

(ii) $0 \notin \mathcal{M}_{\prec}$,

(iii) $\operatorname{posi} \mathcal{M}_{\succeq} = \mathcal{M}_{\succeq}$ and $\operatorname{posi} \mathcal{M}_{\succ} = \mathcal{M}_{\succ}$,

(iv) $\mathcal{M}_{\succeq} + \mathcal{M}_{\succ} \subseteq \mathcal{M}_{\succ}$.

A simplification: The Accept-Favor Framework

An assessment $\mathcal{M}$ is a model that satisfies
No Confusion and Indifference to Status Quo iff

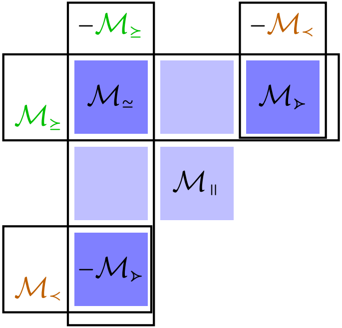
(i) $0 \in \mathcal{M}_{\geq}$,

(ii) $0 \notin \mathcal{M}_{\prec}$,

(iii) $\operatorname{posi} \mathcal{M}_{\geq} = \mathcal{M}_{\geq}$ and $\operatorname{posi} \mathcal{M}_{\succ} = \mathcal{M}_{\succ}$,

(iv) $\mathcal{M}_{\geq} + \mathcal{M}_{\succ} \subseteq \mathcal{M}_{\succ}$.

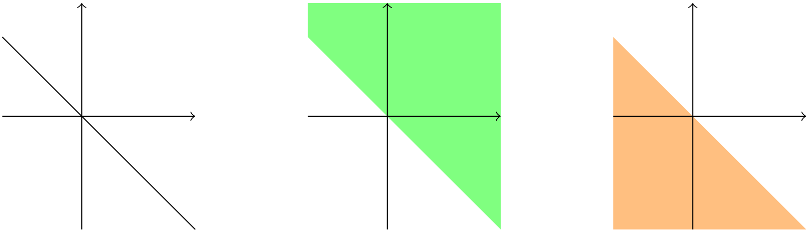
Gamble space partitioning:



Linear Previsions

Real linear gamble functionals P that satisfy $\inf f \leq Pf \leq \sup f$.
They specify *fair* prices.

They partition gambles space into three parts:



$\mathcal{L}_{=P} \coloneqq \{h \in \mathcal{L} : Ph = 0\}$ $\mathcal{L}_{>P} \coloneqq \{h \in \mathcal{L} : Ph < 0\}$ $\mathcal{L}_{<P} \coloneqq \{h \in \mathcal{L} : Ph > 0\}$

Two possible models:

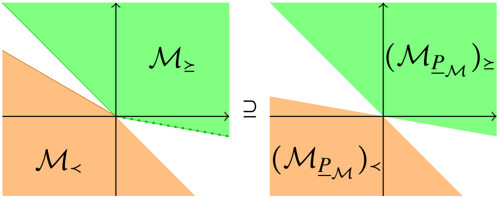
de Finetti $\langle \mathcal{L}_{=P} \cup \mathcal{L}_{>P} ; \mathcal{L}_{<P} \rangle$ (more committal)

Walley $\langle \mathcal{L}_{>P} ; \mathcal{L}_{<P} \rangle$ (less committal)

Lower Previsions

Real *superlinear* gamble functionals $\underline{P}$ that satisfy $\inf f \leq \underline{P}f \leq \sup f$.
They specify supremum acceptable *buying* prices.

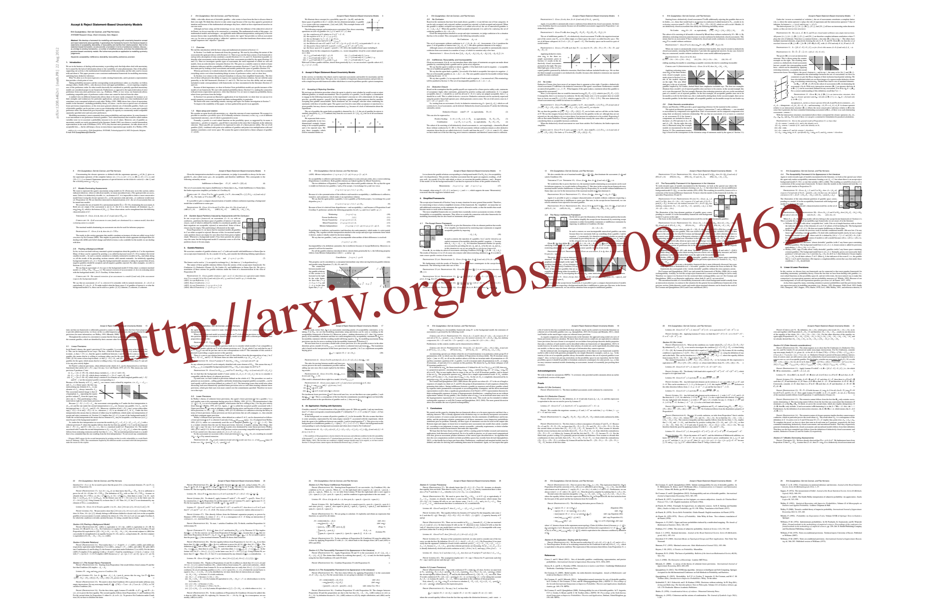
- $\mathcal{G}_{\underline{P}} \coloneqq \{f - \underline{P}f : f \in \mathcal{K}\}$
- $\mathcal{A}_{\underline{P}} \coloneqq \langle \mathcal{G}_{\underline{P}} + \mathbb{R}_{>}; \varnothing \rangle$
- $\mathcal{M}_{\underline{P}} = \langle \operatorname{posi} \mathcal{G}_{\underline{P}} + \mathcal{L}_{\gtrdot}; \mathcal{L}_{\lessdot} - \operatorname{posi} \mathcal{G}_{\underline{P}} \rangle \cup \mathcal{S}.$
- $\underline{P}_{\mathcal{M}} f \coloneqq \sup\{\alpha \in \mathbb{R} : f - \alpha \in \mathcal{M}_{\geq}\}$



Conclusions

- Our framework further generalizes existing generalizations of probability theory.
- The generalization is flexible on input (assessment/elicitation) and output (inference/decisions) side.
- It allows for interesting model types: choose appropriate background models and deductive closure axioms.
- It elegantly combines distinct strict and non-strict preference orders,

Want to know more: read the full paper!



http://arxiv.org/abs/1208.4462