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EVIDENTIAL DECISION THEORY VIA PARTIAL MARKOV CATEGORIES

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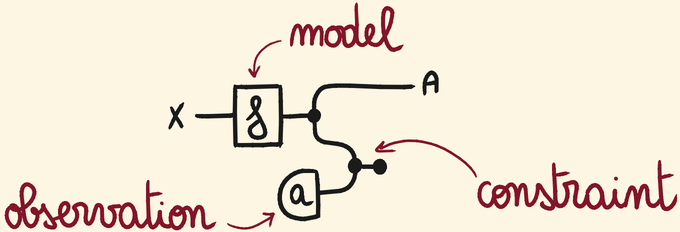
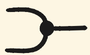
PARTIALITY FOR OBSERVATIONS

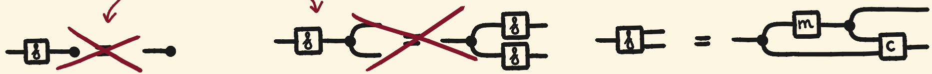
Updating a model on an observation means restricting the model to scenarios that are compatible with this observation.



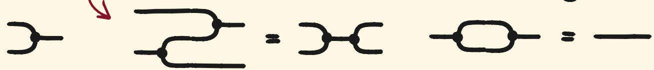
constraints  cannot be total computations
because  $\neq$  .

OVERVIEW

Combine Markov and cartesian restriction categories to express partial stochastic processes.



Add the discrete structure to express equality checking.



Morphisms X —$\boxed{f}$— A are partial stochastic channels

$f(a|x)$ = "probability of a given x"

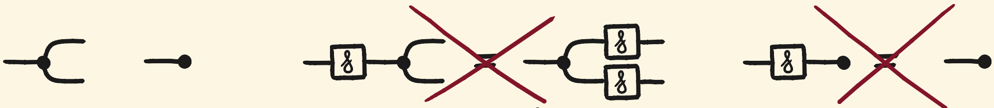
$f(\perp|x)$ = "probability of failure"

[Fritz 2020, Cockett & Lack 2007, Cockett, Guo & Hofstra 2012, Cho & Jacobs 2019]

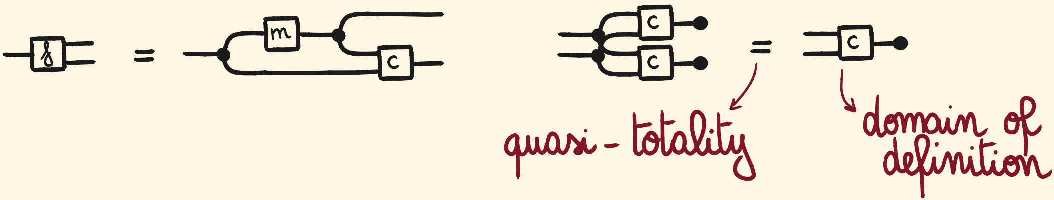
PARTIAL MARKOV CATEGORIES

A partial Markov category is a copy-discard category with quasi-total conditionals.

COPY - DISCARD STRUCTURE



CONDITIONALS



EXAMPLES : PARTIAL STOCHASTIC PROCESSES

Partial stochastic processes form a partial Markov category.

maybe monad on a Markov category

THEOREM

$\left\{\begin{array}{l}\mathcal{C} \text{ Markov category with conditionals and coproducts} \\ \text{Some ugly technical conditions}\end{array}\right.$

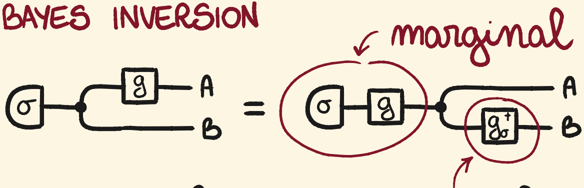
$\Rightarrow \mathrm{Kl}(\cdot + 1)$ is a partial Markov category.

EXAMPLES

- $\mathrm{Kl}(\mathcal{D}(\cdot + 1))$ $\rightsquigarrow$ finitary subdistributions
- $\mathrm{Kl}(\mathrm{Giry}_B(\cdot + 1))$ $\rightsquigarrow$ subdistributions on standard Borel spaces

BAYES INVERSION & NORMALISATION

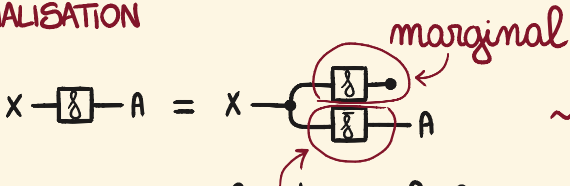
BAYES INVERSION



$$\rightsquigarrow \quad g_\sigma^\dagger(b|a) := \frac{g(a|b)\,\sigma(b)}{\sum_{b'\in B} g(a|b')\,\sigma(b')}$$

$g_\sigma^\dagger$ is a Bayes inversion of g w.r.t. σ

NORMALISATION



$$\rightsquigarrow \quad \bar{f}(a|x) := \frac{f(x|a)}{1-f(\perp|a)}$$

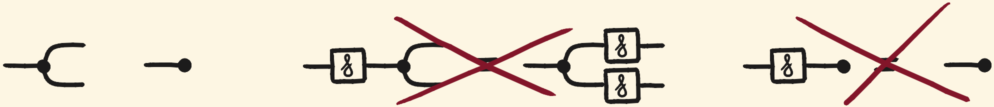
$\bar{f}$ is a normalisation of f

→ Both are particular cases of quasi-total conditionals.

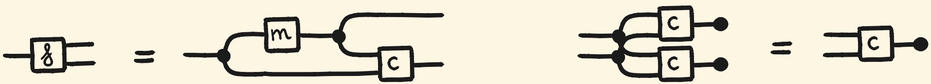
DISCRETE PARTIAL MARKOV CATEGORIES

A discrete partial Markov category is a copy-discard category with quasi-total conditionals and comparators.

COPY-DISCARD STRUCTURE



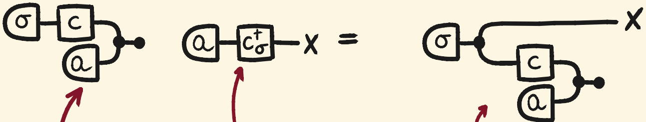
CONDITIONALS



PARTIAL FROBENIUS STRUCTURE

SYNTHETIC BAYES THEOREM

A deterministic observation $a : I \to A$ from a prior $\sigma : I \to X$ through a channel $c : X \to A$ determines an update proportional to the Bayes inversion $c^{\dagger}_{\sigma}$ evaluated on a.

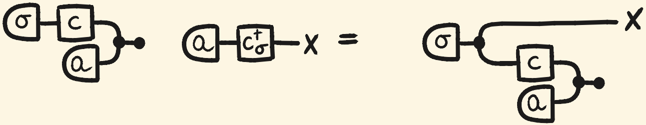


$$P(X{=}x \mid A{=}a) = \frac{P(A{=}a \mid X{=}x)\cdot P(X{=}x)}{\sum_{y\in X} P(A{=}a \mid X{=}y)\cdot P(X{=}y)}$$

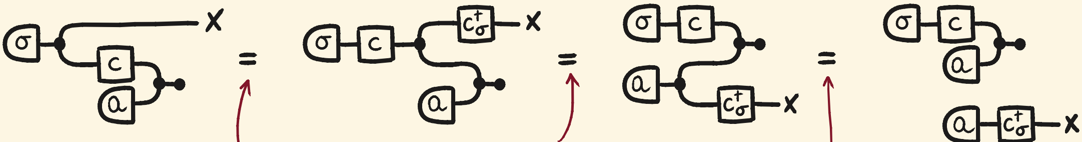
classical formula for Bayes theorem

SYNTHETIC BAYES THEOREM

A deterministic observation $a : I \to A$ from a prior $\sigma : I \to X$ through a channel $c : X \to A$ determines an update proportional to the Bayes inversion $c^{\dagger}_{\sigma}$ evaluated on a.



PROOF

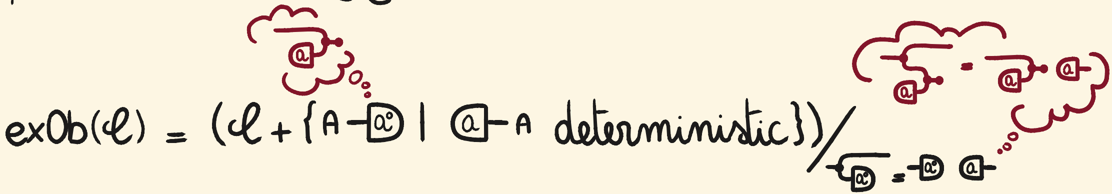


conditionals Frobenius determinism

□

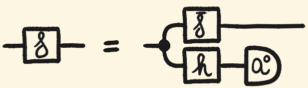
PROCESSES WITH EXACT OBSERVATIONS

For a Markov category $\mathscr{C}$ with conditionals, we construct a partial Markov category $\mathrm{exOb}(\mathscr{C})$:

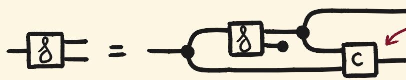


Conditionals and normalisations are computed in $\mathscr{C}$

normalisation of f

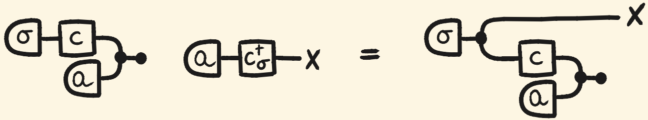


conditional of $\bar{f}$



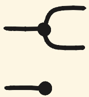
SUMMARY

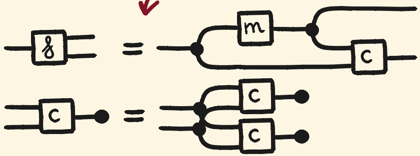
Discrete partial Markov categories express stochastic processes with observations and updates.

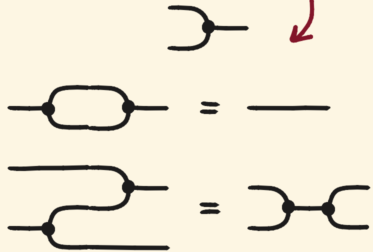


Synthetic Bayes theorem

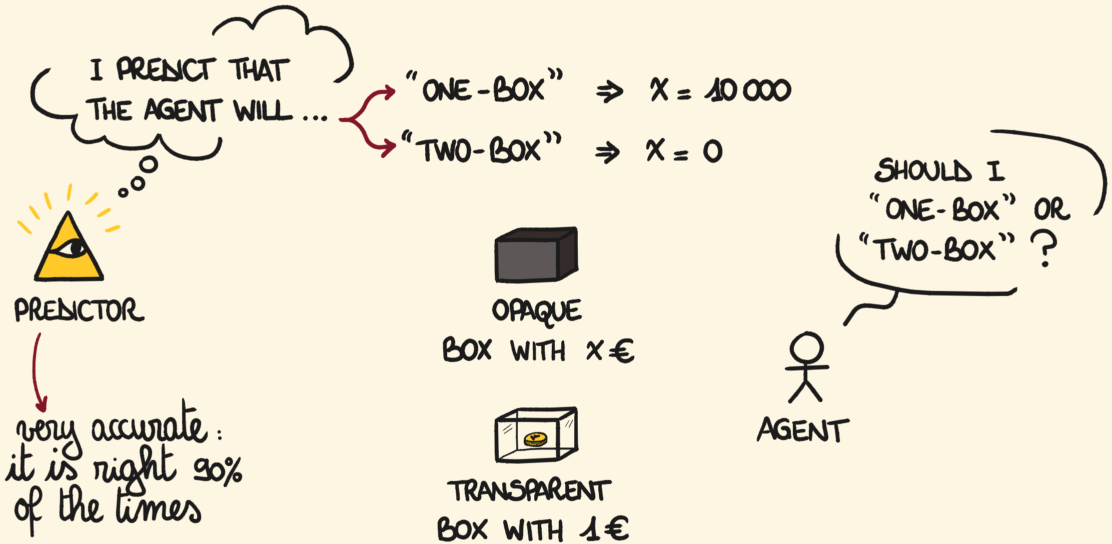
They are copy-discard categories with conditionals and comparators.







NEWCOMB'S PROBLEM



EVIDENTIAL DECISION THEORY

Evidential decision theory answers :

"Which action would be evidence for the best-case scenario ?"

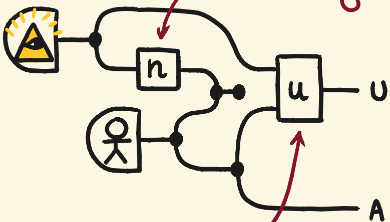
My action is evidence for the prediction :
if I one-box I expect 10 000 €,
if I two-box I expect 1 € .
⇒ I will one-box

PREDICTOR \ AGENT	ONE-BOX	TWO-BOX
ONE-BOX	10 000 €	10 001 €
TWO-BOX	0 €	1 €

MOST LIKELY

NEWCOMB'S PROBLEM CATEGORICALLY

noise: the predictor
is right 90% of the times



utility function

PREDICTOR \ AGENT	ONE-BOX	TWO-BOX
ONE-BOX	10 000 €	10 001 €
TWO-BOX	0 €	1 €

SOLVING NEWCOMB'S PROBLEM

Evidential decision theory asks:
"Which action would be evidence for the best-case scenario?"
i.e. "Which action maximises the average of the state below?"