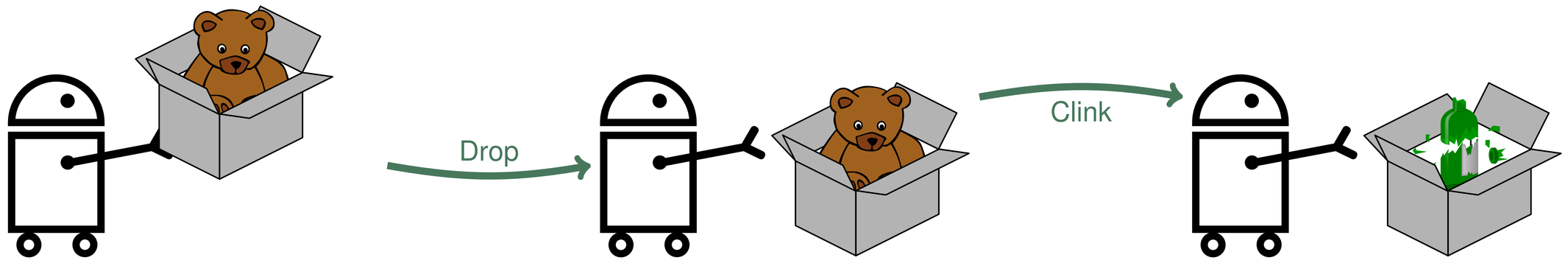
Belief Revision and Progression of KBs in the Epistemic Situation Calculus

Christoph Schwering[1] and Gerhard Lakemeyer[1] and Maurice Pagnucco[2]

Actions and Belief Revision



Believes the object is not fragile

Believes it is unimpaired after dropping it

Believes it is broken after hearing a clink

Belief Progression

All the robot believes is that

1. the object is not fragile and not metallic
2. the object being fragile is more plausible than it being metallic
3. the object is certainly not broken

plus knowledge about dynamics.

- What is all the robot believes after dropping the box?
- What is all the robot believes after hearing the clink?

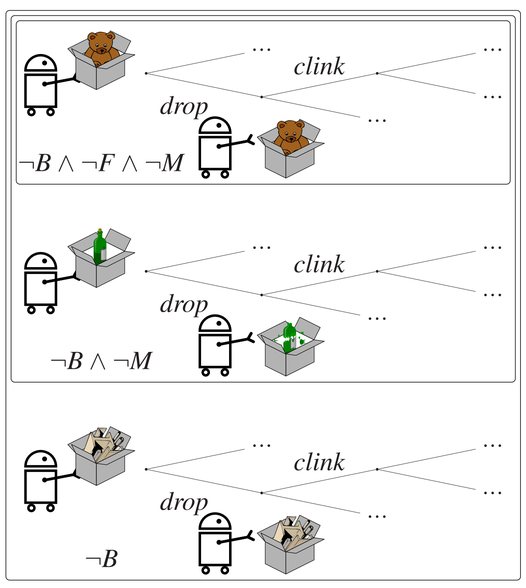
A Logic for Actions and Beliefs

- First-order formulas $P(t_1,...,t_k)$, $(t_1 = t_2)$, $\neg\alpha$, $\forall x.\alpha$, $(\alpha \wedge \beta)$
- α holds after action A $[A]\alpha$
- α holds after any seq. of actions $\Box\alpha$
- If ϕ was true, ψ would also be true $\mathbf{B}(\phi \Rightarrow \psi)$ short: $\mathbf{B}\psi$
- All we believe is $\phi_i \Rightarrow \psi_i$ $\mathbf{O}\{\phi_1 \Rightarrow \psi_1, \ldots, \phi_m \Rightarrow \psi_m\}$
- Before forgetting $\mathcal{P}$, —"— $\mathbf{O}_{\mathcal{P}}\{\text{—"—}\}$

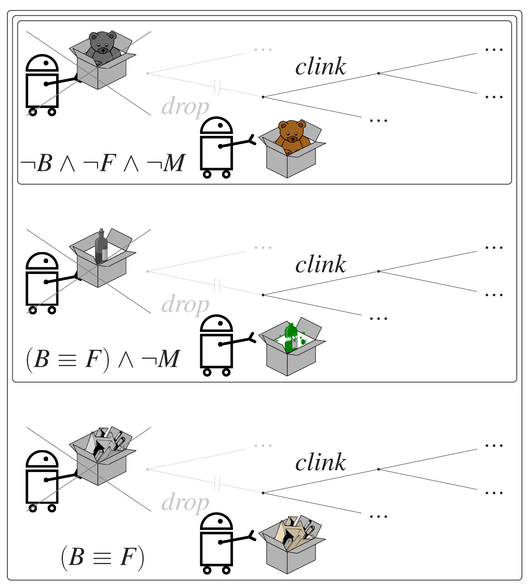
- Possible worlds ranked by plausibility
- Actions A revise by $IF(A)$
- Natural revision: promotes most-plausible $IF(A)$ worlds to the top
- Satisfies AGM and DP (except for inconsistent state), not NPP

Progression of an Epistemic State

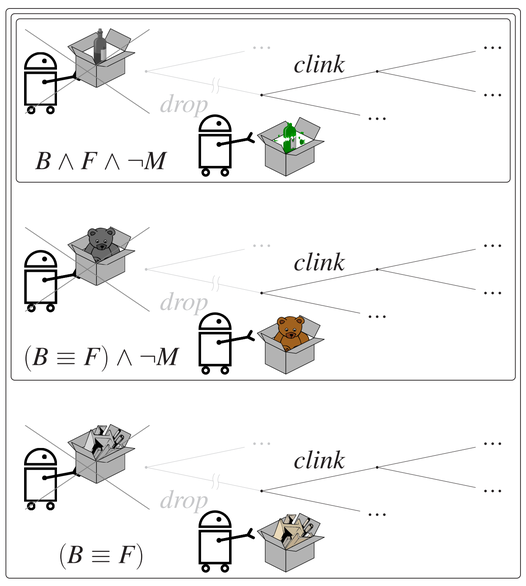
0. Initial state:



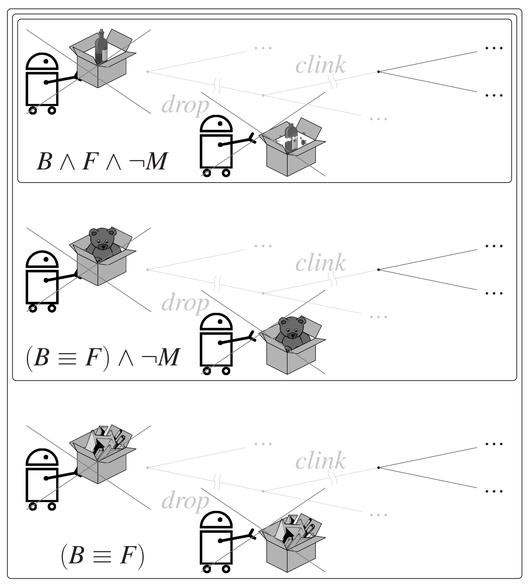
1. Progression by *drop*:



2. Revision by $B \vee M$:



3. Progression by *clink*:



Only-Believing

- Only-believing uniquely determines belief structure
- $\mathbf{O}\{\phi_1 \Rightarrow \psi_1, \ldots, \phi_m \Rightarrow \psi_m\}$ has **unique model** if ϕ_i, ψ_i are objective
- $\mathbf{O}\{\neg\alpha \Rightarrow \bot\}$ is equivalent to Levesque's only-knowing α
- Ranking of $\phi_i \Rightarrow \psi_i$ is equivalent to Pearl's System-Z if ϕ_i, ψ_i "consistent"

Basic Action Theory (BAT)

$$\mathbf{O}\left\{\begin{array}{l}\top \Rightarrow \neg F \wedge \neg M,\\ F \vee M \Rightarrow \neg M,\\ B \Rightarrow \bot,\end{array}\right\} = \Sigma_{\text{bel}}$$
$$\neg\big(\Box[a]B \equiv a = drop \wedge F \vee B\big) \Rightarrow \bot,$$
$$\neg\big(\Box IF(a) \equiv (a = clink \supset B \vee M)\big) \Rightarrow \bot\}$$

Progression of a BAT by a Physical Action

- Similar to Lin and Reiter's progression
- Let $\mathcal{F}$ be fluents of BAT with axioms $\Box[a]F(\vec{x}) \equiv \gamma_F$
- Let $\mathcal{P}$ be new predicates

$$\Sigma_{\text{bel}} \gg A = \Sigma_{\text{bel}}{}^{\mathcal{F}}_{\mathcal{P}} \cup \{\neg(\forall\vec{x}.F(\vec{x}) \equiv \gamma_{F_A}{}^{a}_{\mathcal{P}}{}^{\mathcal{F}}) \Rightarrow \bot \mid F \in \mathcal{F}\}$$

Progression of a BAT by an Epistemic Action

- Let $\Delta = \{\phi \Rightarrow \psi \in \Sigma_{\text{bel}} \mid \mathbf{O}\Sigma_{\text{bel}} \models \mathbf{B}(\alpha \Rightarrow \phi \supset \psi)\}$
- Let P be a new predicate

$$\begin{aligned}\Sigma_{\text{bel}} * \alpha = {} & \{\top \Rightarrow P\} \cup\\ & \{\neg(P \supset \alpha) \Rightarrow \bot\} \cup\\ & \{\neg(\phi \wedge P \supset \psi) \Rightarrow \bot \mid \phi \Rightarrow \psi \in \Delta\} \cup\\ & \{\phi \wedge \neg P \Rightarrow \psi \mid \phi \Rightarrow \psi \in \Sigma_{\text{bel}}\}\end{aligned}$$

$$\Sigma_{\text{bel}} \gg A = \Sigma_{\text{bel}} * IF(A)$$

Correctness of Progression

Let Σ be a BAT, A an action

- $\models \mathbf{O}_{\mathcal{P}}\Sigma \supset [A]\mathbf{O}_{\mathcal{P}\cup\{P\}}(\Sigma \gg A)$
- $\models \mathbf{O}_{\mathcal{P}}\Sigma \supset [A]\alpha$ iff $\models \mathbf{O}_{\mathcal{P}\cup\{P\}}(\Sigma \gg A) \supset \alpha$

Conclusion and Future Work

- Situation calculus plus natural revision
- Only-believing can capture natural revision and progression

Next:

- Other revision schemes, e.g., lexicographic
  - New belief from natural rev. is quickly given up
  - New belief from lexicographic rev. is stronger
- Projection by regression
- Elimination of (nested) beliefs

} similar to our AAAI-15 paper

- Feasible subclass based on Lakemeyer & Levesque, KR-14
- When is progression first-order-definable?
- Implementation

[1] RWTH Aachen University and [2] University of New South Wales

IJCAI 2015, Buenos Aires