Knowledge Inference with First-Order Logic

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We will show how apply inference processes to First-order logic (FOL) to infer new sentences from the KB.

FOL Inference Methods

- Converting a FOL KB to a Propositional KB & Use Propositional Inference.
- Forward Chaining
- Backward Chaining
- Other methods!

FOL Inference by Reduction to Propositional Logic

Rules in a FOL KB are similar to rules in a Propositional KB; except for the **universal** ∀ and **existential** ∃ quantifiers**.**

Rules that contain a universal quantifier ∀ can undergo **Universal Instantiation** to generate all possible cases based on the KB objects.

$$\forall p, c \; Parent(p, c) \iff Child(c, p)$$

Apply rule to all people in the KB to obtain all parent-child instances. There could be millions of such cases in large KB's *(Ancestry)*!

Rules that contain an existential quantifier ∃ can undergo **Existential Instantiation** to replace the existential variable with a constant symbol.

Once replacements are complete, propositional inference methods can be applied.

This may not be efficient because universal instantiation can result in so many rules.

FOL Inference with Forward Chaining

> The law says that it is a crime for an American to sell weapons to hostile nations. The country Nono, an enemy of America, has some missiles, and all of its missiles were sold to it by Colonel West, who is American.

Chapter 9, Russell & Norvig's Textbook

We would like to

1. **Construct the KB** for this domain and then
2. **Infer that Colonel West has committed a crime** (is a criminal).

"$\cdots$ it is a crime for an American to sell weapons to hostile nations":

(9.3)

$$American(x) \land Weapon(y) \land Sells(x, y, z) \land Hostile(z) \Rightarrow Criminal(x).$$

Chapter 9, Russell & Norvig's Textbook

"Nono . . . has some missiles." The sentence $\exists x\ Owns(Nono, x) \wedge Missile(x)$ is transformed into two definite clauses by Existential Instantiation, introducing a new constant M_1:

(9.4)

$$Owns(Nono, M_1)$$

(9.5)

$$Missile(M_1).$$

Chapter 9, Russell & Norvig's Textbook

"All of its missiles were sold to it by Colonel West":

(9.6)

$$Missile(x) \wedge Owns(Nono, x) \Rightarrow Sells(West, x, Nono).$$

We will also need to know that missiles are weapons:

(9.7)

$$Missile(x) \Rightarrow Weapon(x)$$

Chapter 9, Russell & Norvig's Textbook

and we must know that an enemy of America counts as "hostile":

(9.8)

$$Enemy(x, America) \Rightarrow Hostile(x).$$

Chapter 9, Russell & Norvig's Textbook

"West, who is American . . .":

(9.9)

$$American(West).$$

Chapter 9, Russell & Norvig's Textbook

"The country Nono, an enemy of America . . .":

(9.10)

$$Enemy(Nono, America).$$

Chapter 9, Russell & Norvig's Textbook

Forward Chaining starts from known facts (symbols whose values are known), **fires all relevant rules**, repeats until a conclusion is reached, or no more rules to fire.

Facts:

$$Owns(Nono, M_1)$$

$$Missile(M_1)$$

$$American(West)$$

$$Enemy(Nono, America).$$

Round 1:

$$Missile(x) \wedge Owns(Nono, x) \Rightarrow Sells(West, x, Nono)$$

$$Missile(x) \Rightarrow Weapon(x)$$

$$Enemy(x, America) \Rightarrow Hostile(x)$$

Facts:

$Owns(Nono, M_1)$

$Missile(M_1)$

$American(West)$

$Enemy(Nono, America).$

Round 1:

x=M1

$Missile(x) \wedge Owns(Nono, x) \Rightarrow Sells(West, x, Nono)$

$Missile(x) \Rightarrow Weapon(x)$ *x=M1*

$Enemy(x, America) \Rightarrow Hostile(x)$ *x=Nono*

Round 2:

x = West, y = M1, z = Nono

$American(x) \wedge Weapon(y) \wedge Sells(x, y, z) \wedge Hostile(z) \Rightarrow Criminal(x)$

Inference with Forward Chaining

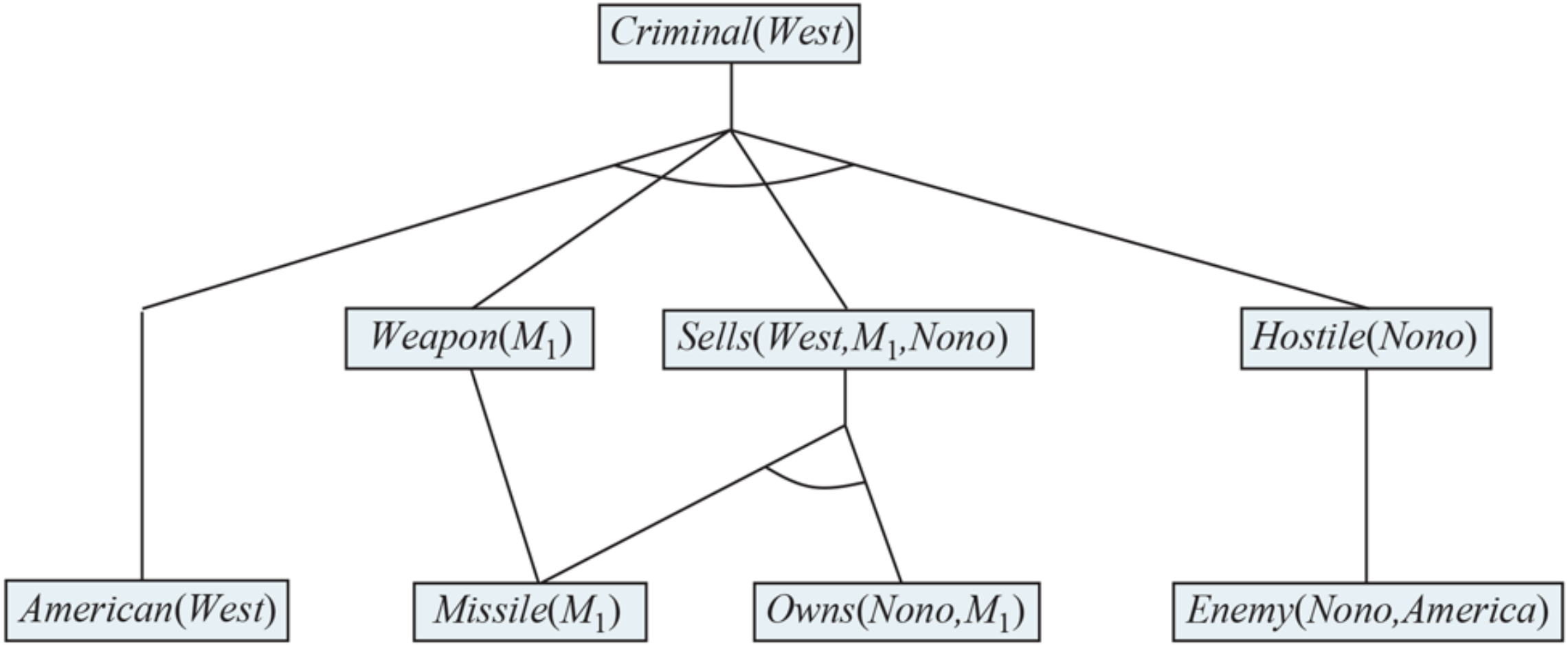

Fig 9.4, Russell & Norvig's Textbook

FOL Inference with Backward Chaining

Unlike Forward Chaining, Backward Chaining starts from the goal and works backward until it reaches the known facts.

Inference with Backward Chaining

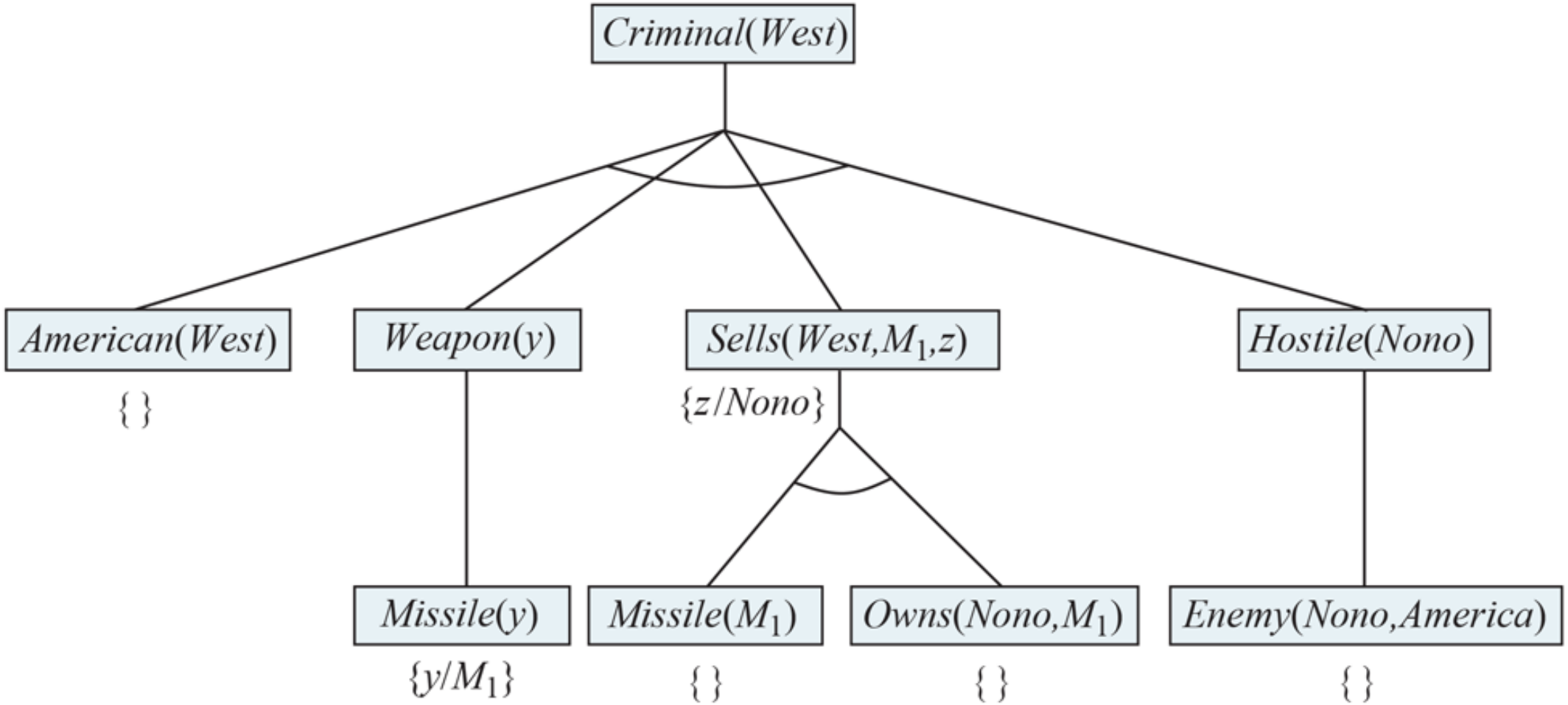

Fig 9.7, Russell & Norvig's Textbook

Backward Chaining conducts a depth-first search on the KB until the facts are reached, or no solution is found.

First-Order Logic can **represent** a domain as **objects** with **properties** and **relations**, **rules** that apply to objects, and provides reasoning mechanisms for **inferring** new knowledge.