KR is first and foremost about **knowledge**

meaning and entailment

find individuals and properties, then encode facts sufficient for entailments

Before implementing, need to understand clearly

• what is to be computed?

• why and where inference is necessary?

Example domain: soap-opera world

people, places, companies, births, marriages, divorces, deaths, events, ...

Task: KB with appropriate entailments

• what vocabulary?

• what facts to represent?
Vocabulary

Domain-dependent predicates and functions

main question:
what are the individuals?
here: people, places, companies, ...

named individuals
john, countryTown, faultyInsuranceCorp, fic,
johnQsmith, ...

basic types
Person, Place, Man, Woman, ...

attributes
Rich, Beautiful, Unscrupulous, ...

relationships
LivesAt, MarriedTo, DaughterOf, HairDresserOf,
HadAnAffairWith, Blackmails, ...

functions
fatherOf, ceoOf, bestFriendOf, ...
Basic facts

Usually atomic sentences and negations

type facts
- Man(john),
- Woman(jane),
- Company(faultyInsuranceCorp)

property facts
- Rich(john),
- ¬HappilyMarried(jim),
- WorksFor(jim, fic)

equality facts
- john = ceoOf(fic),
- fic = faultyInsuranceCorp,
- bestFriendOf(jim) = john

Like a simple database
- could store these facts in relational tables
Complex facts

Universal abbreviations

\[ \forall y [ \text{Woman}(y) \land y \neq \text{jane} \Rightarrow \text{Loves}(y, \text{john})] \]
\[ \forall y [ \text{Rich}(y) \land \text{Man}(y) \Rightarrow \text{Loves}(y, \text{jane})] \]
\[ \forall x \forall y [ \text{Loves}(x, y) \Rightarrow \neg \text{Blackmails}(x, y)] \]

possible to express without quantifiers

Incomplete knowledge

\[ \text{Loves}(\text{jane, john}) \lor \text{Loves}(\text{jane, jim}) \]
which?
\[ \exists x [ \text{Adult}(x) \land \text{Blackmails}(x, \text{john})] \]
who?

cannot write down more complete version

Closure axioms

\[ \forall x [ \text{Person}(x) \Rightarrow x = \text{jane} \lor x = \text{john} \lor x = \text{jim} ...] \]
\[ \forall x \forall y [ \text{MarriedTo}(x, y) \Rightarrow ...] \]
\[ \forall x [ x = \text{fic} \lor x = \text{jane} \lor x = \text{john} \lor x = \text{jim} ...] \]

limits domain of discourse
also useful to have \( \text{jane} \neq \text{john} \) ...
Terminological facts

General relationships among predicates. For example:

**disjoint**
\[ \forall x [\text{Mammal}(x) \supset \neg \text{Reptile}(x)] \]

**subtype**
\[ \forall x [\text{Mammal}(x) \supset \text{Animal}(x)] \]

**exhaustive**
\[ \forall x [\text{Day}(x) \supset \text{Monday}(x) \lor \ldots \lor \text{Sunday}(x)] \]

**symmetry**
\[ \forall x \forall y [\text{RelatedTo}(x,y) \supset \text{RelatedTo}(y,x)] \]

**inverse**
\[ \forall x \forall y [\text{ChildOf}(x,y) \supset \text{ParentOf}(y,x)] \]

**type restriction**
\[ \forall x \forall y [\text{MarriedTo}(x,y) \supset \text{Person}(x) \land \text{Person}(y)] \]

**full definition**
\[ \forall x [\text{RichMan}(x) \equiv \text{Rich}(x) \land \text{Man}(x)] \]

Usually universally quantified conditionals or biconditionals
Is there a company whose CEO loves Jane?

\[ \exists x \ [ \text{Company}(x) \land \text{Loves(ceoOf}(x),jane) ] \]

Suppose \( I \models KB \).

Then \( I \models \text{Rich(john)}, \text{Man(john)} \),
and \( I \models \forall y[\text{Rich}(y) \land \text{Man}(y) \Rightarrow \text{Loves}(y,jane)] \)
so \( I \models \text{Loves(john,jane)} \).

Also \( I \models \text{john = ceoOf(fic)} \),
so \( I \models \text{Loves( ceoOf(fic),jane)} \).

Finally \( I \models \text{Company(faultyInsuranceCorp)} \),
and \( I \models \text{fic = faultyInsuranceCorp} \),
so \( I \models \text{Company(fic)} \).

Thus, \( I \models \text{Company(fic)} \land \text{Loves( ceoOf(fic),jane)} \),
and so

\[ I \models \exists x \ [ \text{Company}(x) \land \text{Loves(ceoOf}(x),jane) ] \].

Can extract identity of company from this proof.
Entailments: 2

If no man is blackmailing John, then is he being blackmailed by somebody he loves?

$$\forall x[\text{Man}(x) \supset \neg \text{Blackmails}(x,\text{john})] \supset \exists y[\text{Loves}(\text{john},y) \land \text{Blackmails}(y,\text{john})]$$

Note: $\text{KB} \models (\alpha \supset \beta)$ iff $\text{KB} \cup \{\alpha\} \models \beta$

Assume: $I \models \text{KB} \cup \{\forall x[\text{Man}(x) \supset \neg \text{Blackmails}(x,\text{john})]\}$

Show: $I \models \exists y[\text{Loves}(\text{john},y) \land \text{Blackmails}(y,\text{john})]

Have:

- $\exists x[\text{Adult}(x) \land \text{Blackmails}(x,\text{john})]$  
- $\forall x[\text{Adult}(x) \supset \text{Man}(x) \lor \text{Woman}(x)]$  
- $\exists x[\text{Woman}(x) \land \text{Blackmails}(x,\text{john})]$.

Then:

- $\forall y[\text{Rich}(y) \land \text{Man}(y) \supset \text{Loves}(y,\text{jane})]$  
- Rich(\text{john}) \land \text{Man}(\text{john})  
- so Loves(\text{john},\text{jane})!

But:

- $\forall y[\text{Woman}(y) \land y \neq \text{jane} \supset \text{Loves}(y,\text{john})]$  
- $\forall x\forall y[\text{Loves}(x,y) \supset \neg \text{Blackmails}(x,y)]$  
- $\forall y[\text{Woman}(y) \land y \neq \text{jane} \supset \neg \text{Blackmails}(y,\text{john})]$  
- and\ldots  
- Blackmails(\text{jane},\text{john})

Finally:

- Loves(\text{john},\text{jane}) \land \text{Blackmails}(\text{jane},\text{john})  
- so: $\exists y[\text{Loves}(\text{john},y) \land \text{Blackmails}(y,\text{john})]$

Proof as sequence of sentences
What individuals?

Sometimes useful to reduce n-ary predicates to 1-place predicates and 1-place functions

- involves reifying properties: new individuals
- typical of description logics / frame languages

Flexibility in terms of arity:

\[
\text{Purchases}(\text{john}, \text{sears}, \text{bike}) \quad \text{or} \\
\text{Purchases}(\text{john}, \text{sears}, \text{bike}, \text{feb14}) \quad \text{or} \\
\text{Purchases}(\text{john}, \text{sears}, \text{bike}, \text{feb14},$100)
\]

Instead introduce purchase objects

\[
\text{Purchase}(p) \land \text{agent}(p)=\text{john} \land \\
\text{obj}(p)=\text{bike} \land \text{source}(p)=\text{sears} \land \\
\text{amount}(p)=... \land ...
\]

allows purchase to be described at various levels of detail

Complex relationships:

\[
\text{MarriedTo}(x,y) \quad \text{vs.} \\
\text{PreviouslyMarriedTo}(x,y) \quad \text{vs.} \\
\text{ReMarriedTo}(x,y)
\]

Define marital status in terms of existence of marriages and divorces.

\[
\text{Marriage}(m) \land \text{partner1}(m)=x \land \\
\text{partner2}(m)=y \land \text{date}(m)=... \land \\
\text{witness}(m)=... \land ...
\]
Abstract individuals

Also need individuals for numbers, dates, times, addresses, etc.

   objects about which we ask wh-questions

Quantities as individuals

   age(suzy) = 14
   age-in-years(suzy) = 14
   age-in-months(suzy) = 168

   perhaps better to have an object for the age of Suzy, whose value in years is 14

   years(age(suzy)) = 14
   months(x) = 12*years(x)
   centimeters(x) = 100*meters(x)

Similarly with locations and times

   instead of

   time(m)="Jan 5 1992 4:47:03EST"

   can use

   time(m)=t ∧ year(t)=1992 ∧ ...
Other sorts of facts

Statistical / probabilistic facts

- Half of the companies are located on the East Side.
- Most of the employees are restless.
- Almost none of the employees are completely trustworthy.

Default / prototypical facts

- Company presidents typically have secretaries intercepting their phone calls.
- Cars have four wheels.
- Companies generally do not allow employees that work together to be married.

Intentional facts

- John believes that Henry is trying to blackmail him.
- Jane does not want Jim to think that she loves John.

Others ...