3. Expressing Knowledge

Knowledge engineering

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, marriages, divorces, hanky-panky, deaths, kidnappings, crimes, ...

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, sleezyTown, faultyInsuranceCorp, fic, johnQsmith, ...

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

attributes
Rich, Beautiful, Unscrupulous, ...

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

functions
fatherOf, ceoOf, bestFriendOf, ...

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**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 (can store in a table)
Complex facts

Universal abbreviations

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

Incomplete knowledge

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

Closure axioms

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

also useful to have \text{jane} \neq \text{john} \ldots

Terminological facts

General relationships among predicates. For example:

- **disjoint** \[ \forall x [\text{Man}(x) \supset \neg \text{Woman}(x)] \]
- **subtype** \[ \forall x [\text{Senator}(x) \supset \text{Legislator}(x)] \]
- **exhaustive** \[ \forall x [\text{Adult}(x) \supset \text{Man}(x) \lor \text{Woman}(x)] \]
- **symmetry** \[ \forall x \forall y [\text{MarriedTo}(x, y) \supset \text{MarriedTo}(y, x)] \]
- **inverse** \[ \forall x \forall y [\text{ChildOf}(x, y) \supset \text{ParentOf}(y, x)] \]
- **type restriction** \[ \forall x \forall y [\text{MarriedTo}(x, y) \supset \text{Person}(x) \land \text{Person}(y) \land \text{OppSex}(x, y)] \]

Usually universally quantified conditionals or biconditionals
**Entailments: 1**

Is there a company whose CEO loves Jane?

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

Suppose \( \mathcal{I} \models \text{KB} \).

Then \( \mathcal{I} \models \text{Rich}(\text{john}), \text{Man}(\text{john}) \),

and \( \mathcal{I} \models \forall y[\text{Rich}(y) \land \text{Man}(y) \supset \text{Loves}(y,\text{jane})] \)

so \( \mathcal{I} \models \text{Loves}(\text{john},\text{jane}) \).

Also \( \mathcal{I} \models \text{john} = \text{ceoOf}(\text{fic}) \),

so \( \mathcal{I} \models \text{Loves( ceoOf}(\text{fic}),\text{jane}) \).

Finally \( \mathcal{I} \models \text{Company}(\text{faultyInsuranceCorp}) \),

and \( \mathcal{I} \models \text{fic} = \text{faultyInsuranceCorp} \),

so \( \mathcal{I} \models \text{Company}(\text{fic}) \).

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

and so

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

Can extract identity of company from this proof

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**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 \( \text{KB} \cup \{\alpha\} \models \beta \)

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

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

Have: \( \exists x[\text{Adult}(x) \land \text{Blackmails}(x,\text{john})] \) and \( \forall x[\text{Adult}(x) \supset \text{Man}(x) \lor \text{Woman}(x)] \)

so \( \exists x[\text{Woman}(x) \land \text{Blackmails}(x,\text{john})] \).

Then: \( \forall y[\text{Rich}(y) \land \text{Man}(y) \supset \text{Loves}(y,\text{jane})] \) and \( \text{Rich}(\text{john}) \land \text{Man}(\text{john}) \)

so \( \text{Loves(\text{john},\text{jane})} \).

But: \( \forall y[\text{Woman}(y) \land y \neq \text{jane} \supset \text{Loves}(y,\text{john})] \)

and \( \forall x \forall y[\text{Loves}(x,y) \supset \neg \text{Blackmails}(x,y)] \)

so \( \forall y[\text{Woman}(y) \land y \neq \text{jane} \supset \neg \text{Blackmails}(y,\text{john})] \) and \( \text{Blackmails}(\text{jane},\text{john})!! \)

Finally: \( \text{Loves(\text{john},\text{jane}) \land \text{Blackmails}(\text{jane},\text{john})} \)

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

Flexibility in terms of arity:

```
Purchases(john,sears,bike) or
Purchases(john,sears,bike,feb14) or
Purchases(john,sears,bike,feb14,$100)
```

Instead: introduce purchase objects

```
Purchase(p) ∧ agent(p)=john ∧ obj(p)=bike ∧ source(p)=sears ∧ ...
```

allows purchase to be described at various levels of detail

Complex relationships: MarriedTo(x,y) vs. ReMarriedTo(x,y) vs. ...

Instead define marital status in terms of existence of marriage and divorce events.

```
Marriage(m) ∧ husband(m)=x ∧ wife(m)=y ∧ date(m)=... ∧...
```

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 2006 4:47:03EST"
can use
time(m)=t ∧ year(t)=2006 ∧ ...
```
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 ...