3.

Expressing Knowledge

Knowledge engineering

KR is first and foremost about <u>knowledge</u>

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, ...

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

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

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

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

possible to express without quantifiers

Incomplete knowledge

$\text{Loves}(\text{jane},\text{john}) \lor \text{Loves}(\text{jane},\text{jim})$

which?

$\exists x[\text{Adult}(x) \land \text{Blackmails}(x,\text{john})]$

who?

cannot write down a more complete version

Closure axioms

$\forall x[\text{Person}(x) \supset x{=}\text{jane} \lor x{=}\text{john} \lor x{=}\text{jim} \ldots]$

$\forall x \forall y[\text{MarriedTo}(x,y) \supset \ldots]$

$\forall x[x{=}\text{fic} \lor x{=}\text{jane} \lor x{=}\text{john} \lor x{=}\text{jim} \ldots]$

limit the domain of discourse

also useful to have $\text{jane} \neq \text{john}$ ...

Terminological facts

General relationships among predicates. For example:

- disjoint $\forall x[\mathrm{Man}(x) \supset \quad \mathrm{Woman}(x)]$
- subtype $\forall x[\mathrm{Senator}(x) \supset \mathrm{Legislator}(x)]$
- exhaustive $\forall x[\mathrm{Adult}(x) \supset \mathrm{Man}(x) \vee \mathrm{Woman}(x)]$
- symmetry $\forall x \forall y\, [\mathrm{MarriedTo}(x,y) \supset \mathrm{MarriedTo}(y,x)]$
- inverse $\forall x \forall y\, [\mathrm{ChildOf}(x,y) \supset \mathrm{ParentOf}(y,x)]$
- type restriction $\forall x \forall y\, [\mathrm{MarriedTo}(x,y) \supset \mathrm{Person}(x) \wedge \mathrm{Person}(y) \wedge \mathrm{OppSex}(x,y)]$

  sometimes

Usually universally quantified conditionals or biconditionals

Entailments: 1

Is there a company whose CEO loves Jane?

$\exists x\, [\mathrm{Company}(x) \wedge \mathrm{Loves}(\mathrm{ceoOf}(x),\mathrm{jane})]$??

Suppose $\mathfrak{I} \models$ KB.

Then $\mathfrak{I} \models \mathrm{Rich}(\mathrm{john}),\ \mathrm{Man}(\mathrm{john}),$

and $\mathfrak{I} \models \forall y[\mathrm{Rich}(y) \wedge \mathrm{Man}(y) \supset \mathrm{Loves}(y,\mathrm{jane})]$

so $\mathfrak{I} \models \mathrm{Loves}(\mathrm{john},\mathrm{jane}).$

Also $\mathfrak{I} \models \mathrm{john} = \mathrm{ceoOf}(\mathrm{fic}),$

so $\mathfrak{I} \models \mathrm{Loves}(\mathrm{ceoOf}(\mathrm{fic}),\mathrm{jane}).$

Finally $\mathfrak{I} \models \mathrm{Company}(\mathrm{faultyInsuranceCorp}),$

and $\mathfrak{I} \models \mathrm{fic} = \mathrm{faultyInsuranceCorp},$

so $\mathfrak{I} \models \mathrm{Company}(\mathrm{fic}).$

Thus, $\mathfrak{I} \models \mathrm{Company}(\mathrm{fic}) \wedge \mathrm{Loves}(\mathrm{ceoOf}(\mathrm{fic}),\mathrm{jane}),$

and so

$\mathfrak{I} \models \exists x\, [\mathrm{Company}(x) \wedge \mathrm{Loves}(\mathrm{ceoOf}(x),\mathrm{jane})].$

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?

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

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

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

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

Have: $\exists x[\text{Adult}(x) \wedge \text{Blackmails}(x,\text{john})]$ and $\forall x[\text{Adult}(x) \supset \text{Man}(x) \vee \text{Woman}(x)]$
so $\exists x[\text{Woman}(x) \wedge \text{Blackmails}(x,\text{john})]$.

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

But: $\forall y[\text{Woman}(y) \wedge y \neq \text{jane} \supset \text{Loves}(y,\text{john})]$
and $\forall x\forall y[\text{Loves}(x,y) \supset \neg\text{Blackmails}(x,y)]$
so $\forall y[\text{Woman}(y) \wedge y \neq \text{jane} \supset \neg\text{Blackmails}(y,\text{john})]$ and $\text{Blackmails}(\text{jane},\text{john})$!!

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

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) $\wedge$ agent(p)=john $\wedge$ obj(p)=bike $\wedge$ source(p)=sears $\wedge$ ...

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) $\wedge$ husband(m)=x $\wedge$ wife(m)=y $\wedge$ date(m)=... $\wedge$...

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 $\wedge$ year(t)=2006 $\wedge$ ...

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 ...