Logic Programming
Datasets

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Datasets

Dataset - collection of simple facts about state of "world"

Facts in dataset are assumed to be true

Facts not in dataset are assumed to be false

i.e. datasets are complete; there are no unknowns

Role #1 - Datasets as (trivial) logic programs

used by themselves as standalone databases

used in combination with rules to define "virtual" relations

Role #2 - Datasets as basis for semantics of logic programs

Basics

Conceptualization

Objects - e.g. people, companies, cities

concrete (*person*) or abstract (*number*, *set*, *justice*)

primitive (*auto wheel*) or composite (*car*)

real (*earth*) or fictitious (*Sherlock Holmes*)

Relationships

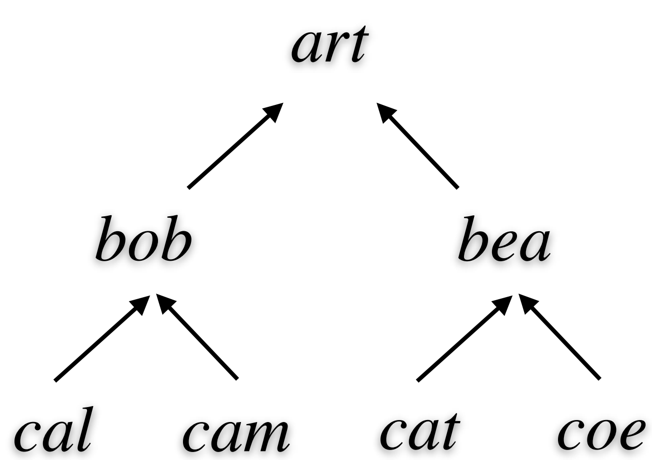
properties of objects or relationships among objects

e.g. Joe *is a person*

e.g. Joe *is the parent of* Bill

e.g. Joe *likes* Bill *more than* Harry

Graphical Representation



Tabular Representation

parent	
art	bob
art	bea
bob	cal
bob	cam
bea	cat
bea	coe

Natural Language Representation

Art is the parent of Bob.
Art is the parent of Bea.
Bob is the parent of Cal.
Bob is the parent of Cam.
Bea is the parent of Cat.
Bea is the parent of Coe.

Mathematical Notation

```
parent(art,bob)
parent(art,bea)
parent(bob,cal)
parent(bob,cam)
parent(bea,cat)
parent(bea,coe)
```

Constants

Constants are strings of lower case letters, digits, underscores, and periods *or* strings of arbitrary ascii characters within double quotes.

Examples:

`joe`, `bill`, `cs151`, `3.14159`

`person`, `worksfor`, `office.occupant`

`the_house_that_jack_built`,

`“Mind your p’s & q’s!”`

Non-examples:

`Art`, `p&q`, `the-house-that-jack-built`

A set of constants is called a **vocabulary**.

Types of Constants

Symbols / object constants represent objects.

`joe`, `bill`, `harry`, `a23`, `3.14159`

`the_house_that_jack_built`

`“Mind your p’s & q’s!”`

Constructors / function constants represent functions.

`cell`, `pair`, `triple`, `set`

Predicates / relation constants represent relations.

`person`, `parent`, `prefers`

Arity

The **arity** of a predicate is the number of arguments that can be associated with the predicate in writing sentences.

Unary predicate (1 argument): `person(joe)`
Binary predicate (2 arguments): `parent(art,bob)`
Ternary predicate (3 arguments): `prefers(art,bob,bea)`

In talking about vocabulary, we sometimes notate the arity of a predicate by annotating with a slash and the arity, e.g. `male/1`, `parent/2`, and `prefers/3`.

Formality and Informality

In some logic programming languages (e.g. Prolog), types and arities determine syntactic legality; and they are enforced by interpreters and compilers.

In other languages (e.g. Epilog), types and arities suggest their intended use. However, they do not determine syntactic legality, and they are not enforced by interpreters and compilers.

In our examples, we use Epilog; but, in this course, we specify types and arities where appropriate and we *try* to adhere to them.

Data / Factoids

A **datum / factoid** is an expression formed from an *n*-ary **predicate** and *n* symbols enclosed in parentheses and separated by commas.

Symbols: `a, b`
Predicate: `p/2, q/1`

Sample Datum: `p(a,a)`
Sample Datum: `p(a,b)`
Sample Datum: `q(a)`
Sample Datum: `q(b)`

Herbrand Base

The **Herbrand base** for a vocabulary is the set of all factoids that can be formed from the vocabulary.

Symbols: `a`, `b`
Predicate: `p/2`, `q/1`

Herbrand Base:

{`p(a,a), p(a,b), p(b,a), p(b,b), q(a), q(b)`}

Datasets

A **dataset** is any *set of factoids* that can be formed from a vocabulary, i.e. a subset of the Herbrand base.

Symbols: `a`, `b`
Predicates: `p/2`, `q/1`
Herbrand Base:

{`p(a,a)`, `p(a,b)`, `p(b,a)`, `p(b,b)`, `q(a)`, `q(b)`}

Dataset: {`p(a,b)`, `p(b,a)`, `q(a)`}
Dataset: {}
Dataset: {`p(a,a)`, `p(a,b)`, `p(b,a)`, `p(b,b)`, `q(a)`, `q(b)`}

We use datasets to characterize states of the world. The *facts in a dataset are assumed to be true* and those that are *not in the dataset are assumed to be false*.

Exercise

Vocabulary

Symbols: `a`, `b`

Predicates: `p/2`, `q/1`

Questions

How many symbols in our vocabulary?

How many elements in the Herbrand base?

How many possible datasets?

Note on Spelling

Spelling carries no meaning in logic programming (except as informal documentation for programmers).

```
parent(art,bob)
parent(bob,cal)
```

```
p(a,b)
p(b,c)
```

```
coulish(widget,gadget)
coulish(gadget,framis)
```

The meaning of a constant in logic programming is determined solely by the sentences that mention it. Exception: numbers (23) and strings ("Like this!").

Note on Order of Arguments

The order of arguments in an instance of a relation is determined by one's understanding of the relation.

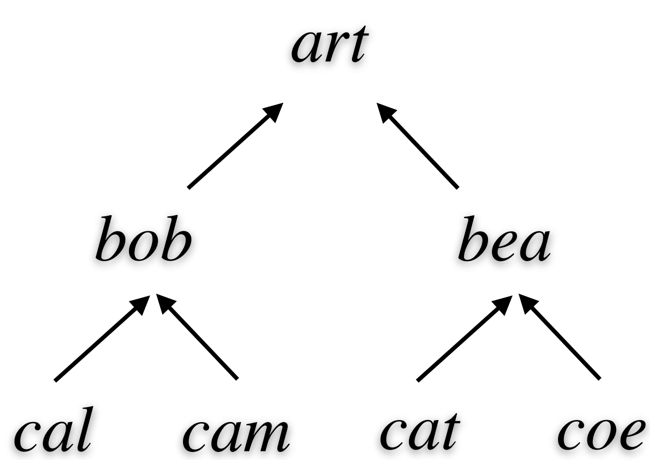
Example:

```
prefers(art,bea,bob)
```

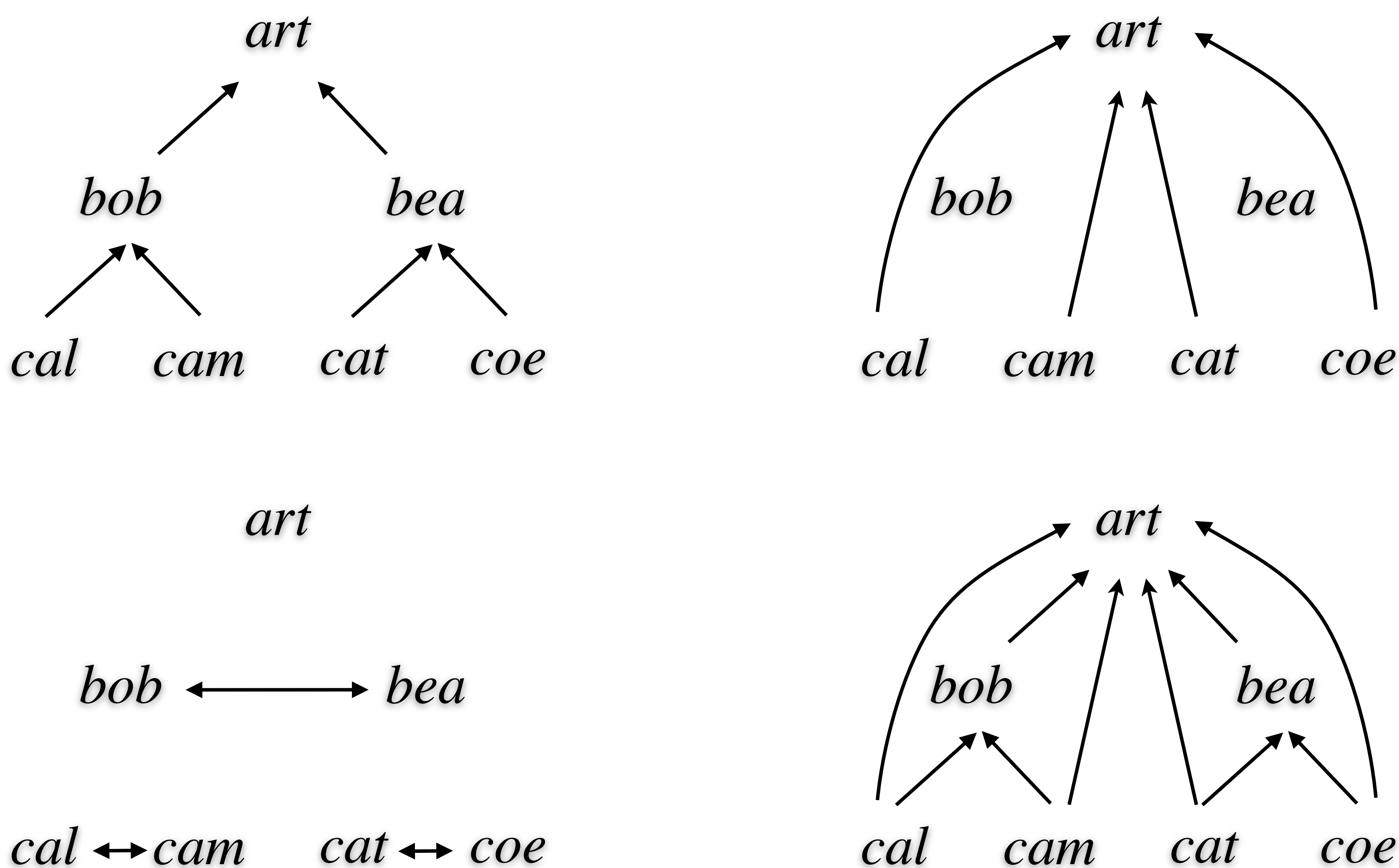
For me, this sentence means that Art prefers Bea to Bob. Other interpretations are possible; the important thing is to be consistent - once you choose, stick with it.

Kinship

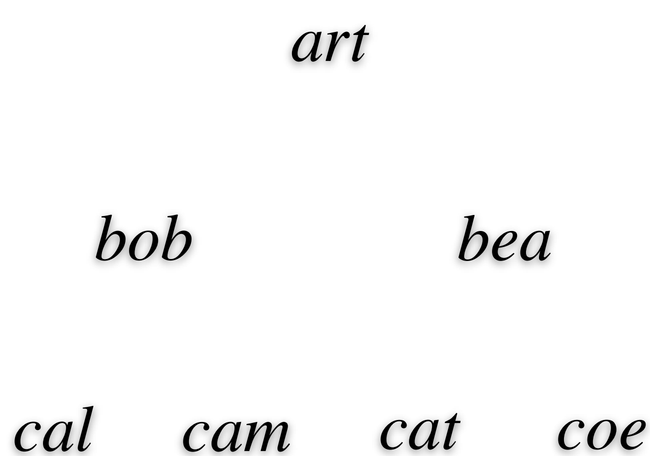
Parentage

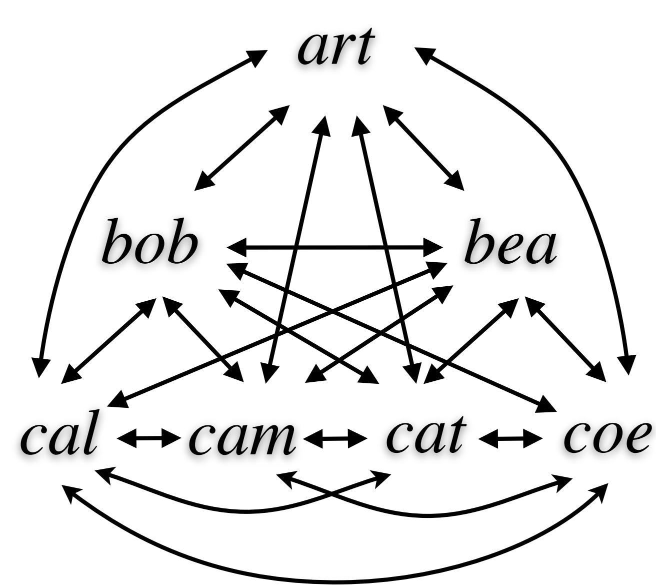


Kinship Relations



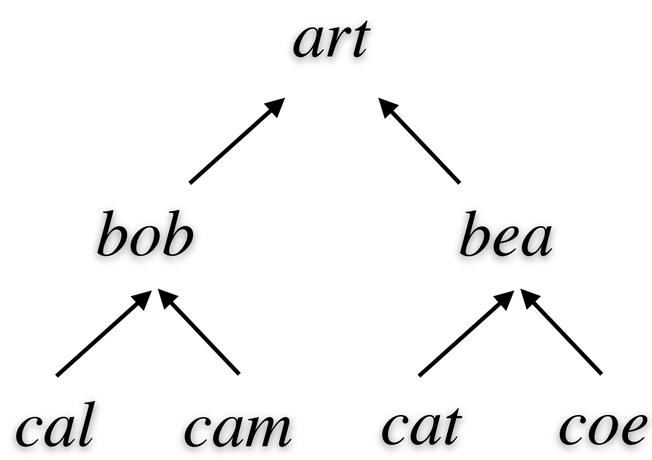
Degenerate Relations





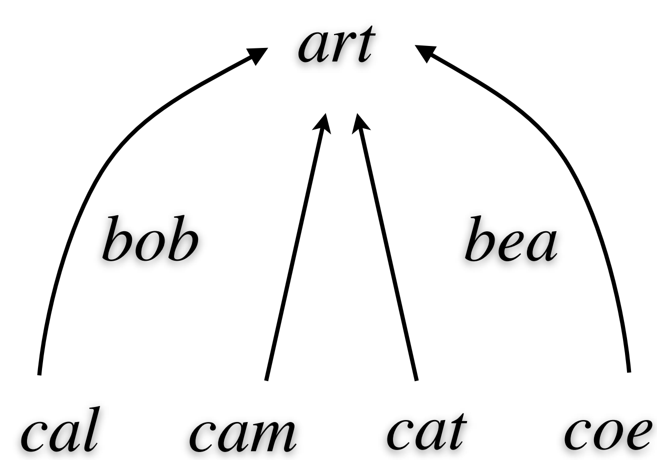
Parent

```
parent(art,bob)
parent(art,bud)
parent(bob,cal)
parent(bob,cam)
parent(bea,cat)
parent(bea,coe)
```



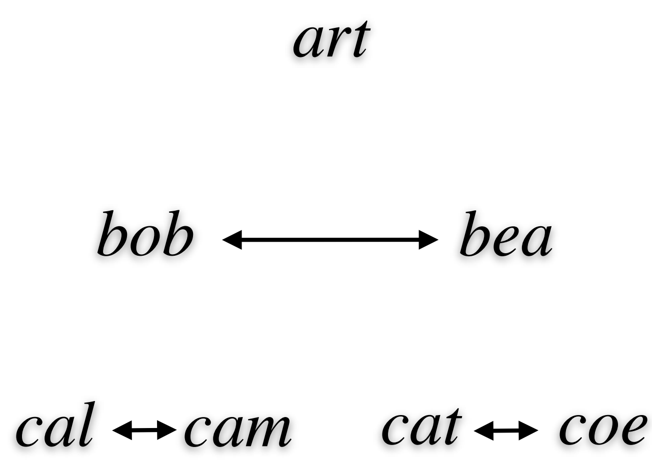
Grandparent

```
grandparent(art,cal)
grandparent(art,cam)
grandparent(art,cat)
grandparent(art,coe)
```



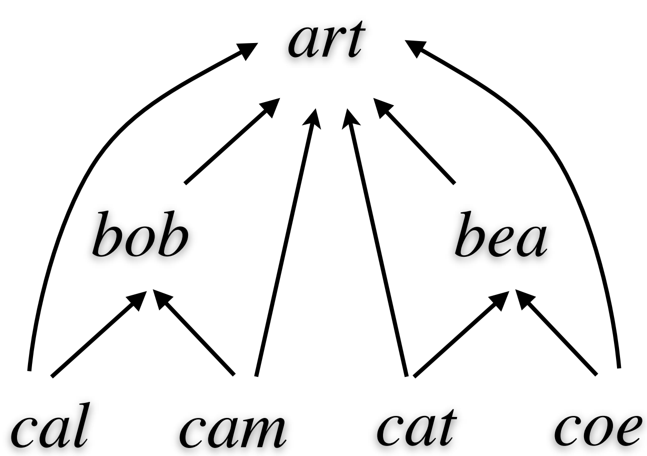
Sibling

```
sibling(bob,bea)
sibling(bea,bob)
sibling(cal,cam)
sibling(cam,cal)
sibling(cat,coe)
sibling(coe,cat)
```



Ancestor

```
ancestor(art,bob)
ancestor(art,bea)
ancestor(art,cal)
ancestor(art,cam)
ancestor(art,cat)
ancestor(art,coe)
ancestor(bob,cal)
ancestor(bob,cam)
ancestor(bea,cat)
ancestor(bea,coe)
```

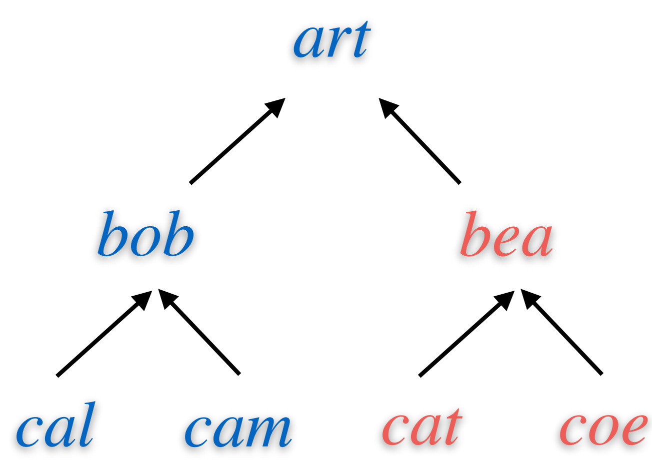


Other Relations

Unary Relations:

```
male(art)
male(bob)
male(cal)
male(cam)

female(bea)
female(cat)
female(coe)
```



Ternary Relations:

```
prefers(art,bob,bea)
prefers(bob,cam,cal)
prefers(bea,cat,coe)
```

?

Comments

Some relations definable in terms of others

e.g. we can define `grandparent` in terms of `parent`

e.g. we can define `sibling` in terms of `parent`

e.g. we can define `ancestor` in terms of `parent`

e.g. we can define `parent` in terms of `ancestor`

See upcoming material on **view definitions**

Some combinations of arguments do not make sense

e.g. `parent(art,art)`

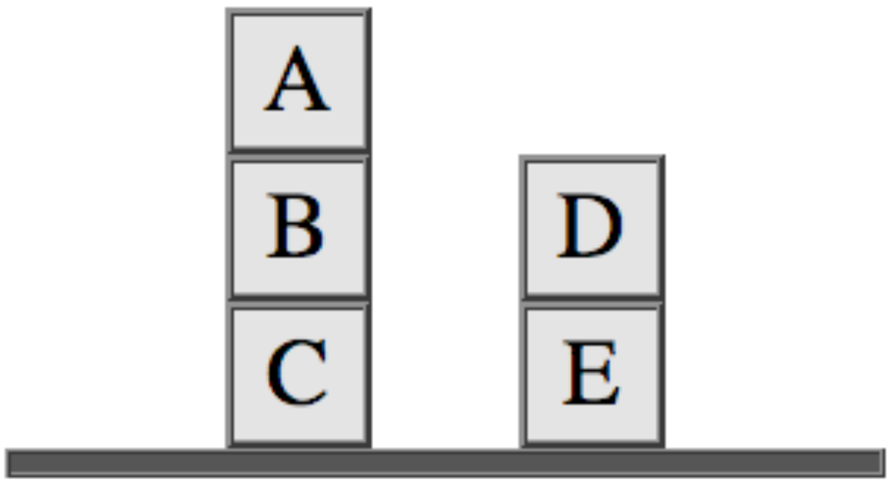
e.g. `parent(art,bob)` and `parent(bob,art)`

e.g. `old(art)` and `young(art)`

See upcoming material on **constraints**

Blocks World

Blocks World



Vocabulary

Symbols: `a`, `b`, `c`, `d`, `e`

Unary Predicates:

`clear` - blocks with no blocks on top.

`table` - blocks on the table.

Binary Predicates:

`on` - pairs of blocks in which first is *on* the second.

`above` - pairs in which first block is *above* the second.

Ternary Predicates:

`stack` - triples of blocks arranged in a stack.

Dataset

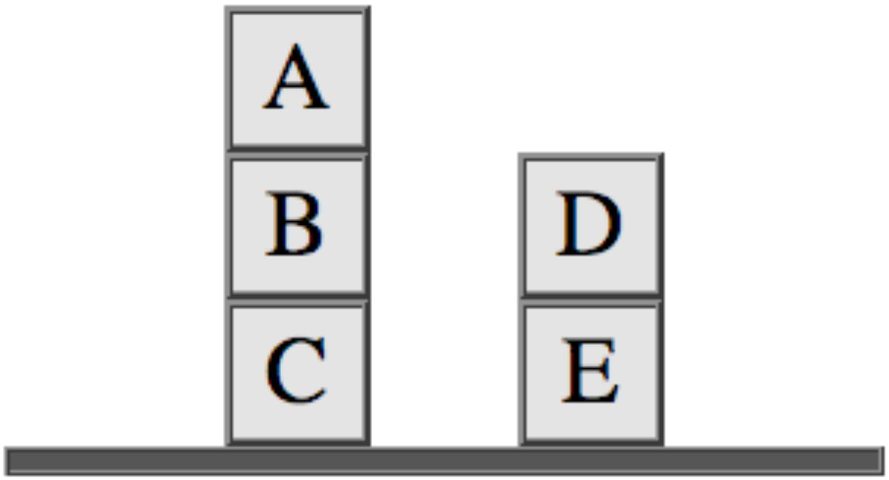
```
clear(a)
clear(d)

table(c)
table(e)

on(a,b)
on(b,c)
on(d,e)

above(a,b)
above(b,c)
above(a,c)
above(d,e)

stack(a,b,c)
```



University

University

Students:	Departments:	Faculty:	Years:
aaron	architecture	alan	freshman
belinda	computers	cathy	sophomore
calvin	english	donna	junior
george	physics	frank	senior

Predicate:

```
student(Student,Department,Advisor,Year)
```

Dataset:

```
student(aaron,architecture,alan,freshman)
student(belinda,computers,cathy,sophomore)
student(calvin,english,donna,junior)
student(george,physics,frank,senior)
```

Missing Values

Suppose a student has not declared a major.
What if a student does not have an advisor?

Leave out fields (syntactically illegal):

```
student(aaron,,,freshman)
```

Add suitable values to vocabulary (new symbol):

```
student(aaron,undeclared,orphan,freshman)
```

Database nulls (new linguistic feature):

```
student(aaron,null,null,freshman)
```

Multiple Values

Suppose a student has *two* majors.

Multiple Rows (storage, update inconsistencies):

```
student(calvin,english,donna,junior)
student(calvin,physics,donna,junior)
```

Multiple fields (storage, extensibility?):

```
student(calvin,english,physics,donna,junior)
student(george,physics,physics,frank,senior)
```

Use compound symbols:

```
student(calvin,english_physics,donna,junior)
```

Triples

Represent wide relations as collections of binary relations.

Wide Relation:

```
student(Student,Department,Advisor,Year)
```

Binary Relations:

```
student.major(Student,Department)
student.advisor(Student,Faculty)
student.year(Student,Year)
```

Always works when there is a field of the wide relation (called the **key**) that uniquely specifies the values of the other elements. If none exists, possible to create one.

Triples

```
student.major(aaron,architecture)
student.advisor(aaron,alan)
student.year(aaron,freshman)

student.year(belinda,sophomore)

student.major(calvin,english)
student.major(calvin,physics)
student.advisor(calvin,donna)
student.year(calvin,senior)

student.major(george,physics)
student.advisor(george,frank)
student.year(george,senior)
```

Terminology

Classes

`student`, `department`, `faculty`, `year`

Attributes (binary relations associated with a class):

```
student.major(Student,Department)
student.advisor(Student,Faculty)
student.year(Student,Year)
```

Properties of Attributes:

domain is class of objects in first position (*arguments*)
codomain is class of objects in second position (*values*)
unique if *at most* one value for each argument
total if *at least* one value for each argument

Subtlety

Missing information

there is a value but we do not know it.

e.g. Aaron has an advisor but we do not know who it is.

Non-existent value

there is no value

e.g. Aaron does not have an advisor.

For now, in talking about datasets, we assume full info.
If a value is missing, it means that there is no value.

Sales

Sales Ledgers

In 2015, Art sold Arborhouse to Bob for $1000000.
In 2016, Bob sold Pelicanpoint to Carl for $2000000.
In 2016, Carl sold Ravenswood to Dan in $2000000.
In 2017, Dan sold Ravenswood to Art for $3000000.

Real Estate Ledger

People:	Properties:	Years:	Money:
art	arborhouse	2015	1000000
bob	pelicanpoint	2016	2000000
carl	ravenswood	2017	3000000
dan	arborhouse		

Relation Constant:

```
sale(Year,Seller,Property,Buyer,Amount)
```

Dataset:

```
sale(2015,art,arborhouse,bob,1000000)
sale(2016,art,pelicanpoint,bob,2000000)
sale(2016,carl,ravenswood,dan,2000000)
sale(2017,dan,arborhouse,art,3000000)
```

Sales Ledgers

In 2015, Art sold Arborhouse to Bob for $1000000.
In 2016, Bob sold Pelicanpoint to Carl for $2000000.
In 2016, Carl sold Ravenswood to Dan in $2000000.
In 2017, Dan sold Ravenswood to Art for $3000000.

In 2015, Art sold Bob a widget for $10.
In 2016, Art sold Bob a gadget for $20.
In 2016, Art sold Bob a gadget for $20.
In 2017, Art sold Bob a framis for $30.

Different sale!

Sales Ledger

People:	Items:	Years:	Money:
art	widget	2015	10
bob	gadget	2016	20
carl	framis	2017	30
dan			

Relation Constant:

```
sale(Year,Seller,Item,Buyer,Amount)
```

Dataset:

```
sale(2015,art,widget,bob,10)
sale(2016,art,gadget,bob,20)
sale(2016,art,gadget,bob,20)
sale(2017,art,framis,bob,30)
```

Duplicate factoid!?

Sales Ledger

Sales:	People:	Items:	Years:	Money:
`t1`	`art`	`widget`	`2015`	`10`
`t2`	`bob`	`gadget`	`2016`	`20`
`t3`	`carl`	`framis`	`2017`	`30`
`t4`	`dan`			

Relation Constant:

```
sale(Sale,Year,Seller,Item,Buyer,Amount)
```

Dataset:

```
sale(t1,2015,art,widget,bob,10)
sale(t2,2016,art,gadget,bob,20)
sale(t3,2016,art,gadget,bob,20)
sale(t4,2017,art,framis,bob,30)
```

Compound Names

Problem

We sometimes want to talk about complex objects made up of simpler structures.

Examples:

the list of a, b, and c

the cell in row 2 and column 3

Alternative 1: Symbols (structure implicit):

```
the_list_of_a_b_c
cell_2_3
```

Alternative 2: Compound names (structure explicit):

```
[a,b,c]
cell(2,3)
```

Types of Constants

Symbols / object constants represent objects.

`joe`, `bill`, `harry`, `a23`, `3.14159`

`the_house_that_jack_built`

`“Mind your p’s & q’s!”`

Constructors / function constants

`cell`, `pair`, `triple`, `set`

Predicates / relation constants represent relations.

`person`, `parent`, `prefers`

Types of Constants

Symbols / object constants represent objects.

`joe`, `bill`, `harry`, `a23`, `3.14159`

`the_house_that_jack_built`

`"Mind your p's & q's!"`

Constructors / function constants

`cell`, `pair`, `triple`, `set`

Predicates / relation constants represent relations.

`person`, `parent`, `prefers`

Arity

The **arity** of a predicate is the number of arguments that can be associated with the predicate in writing sentences.

Unary predicate (1 argument): `person(joe)`
Binary predicate (2 arguments): `parent(art,bob)`
Ternary predicate (3 arguments): `prefers(art,bob,bea)`

In talking about vocabulary, we sometimes notate the arity of a predicate by annotating with a slash and the arity, e.g. `male/1`, `parent/2`, and `prefers/3`.

Arity

The **arity** of a constructor or a predicate is the number of arguments that can be associated with the constructor or predicate in writing complex expressions in the language.

Unary constructor (1 argument): `successor(1)`
Binary constructor (2 arguments): `pair(1,2)`
Ternary constructor (3 arguments): `triple(1,2,3)`
Unary predicate (1 argument): `person(joe)`
Binary predicate (2 arguments): `parent(art,bob)`
Ternary predicate (3 arguments): `prefers(art,bob,bea)`

In talking about vocabulary, we sometimes notate the arity of a constructor or predicate by annotating with a slash and the arity, e.g. `successor/1`, `pair/2`, `triple/3`, `male/1`, `parent/2`, and `prefers/3`.

Compound Names (version 1)

A **compound name** is an expression formed from an *n*-ary *constructor* and *n symbols* enclosed in parentheses and separated by commas.

Symbols: `a, b`
Constructor: `f/2, g/1`

Compound Names: `f(a,b), f(b,a), g(a), g(b)`

This allows us to refer to complex objects made up of simple objects. How do we refer to complex objects made up of other complex objects?

Compound Names (version 2)

A **compound name** is an expression formed from an *n*-ary *constructor* and *n symbols* **or** *compound names* enclosed in parentheses and separated by commas.

Symbols: `a, b`
Constructor: `f/2, g/1`

Compound Names: `f(a,b), f(b,a), g(a), g(b)`
Compound Names: `f(g(a),b), g(f(a,b))`
Compound Names: `g(g(a)), g(f(g(a),g(b)))`
Compound Names: `g(g(g(a)))`

Ground Terms

A **ground term** is either a *symbol* or a *compound name*.

The adjective *ground* here means that the term does not contain any *variables* (which we discuss in later lessons).

Herbrand Universe

The **Herbrand universe** for a vocabulary is the set of **all** *ground terms* that can be formed from the *symbols* and *constructors* in the vocabulary.

Data / Factoids

A **datum / factoid** is an expression formed from an *n*-ary predicate and *n ground terms* enclosed in parentheses and separated by commas.

Symbols: `a, b`
Constructor: `f/2, g/1`
Predicate: `p/2`

Sample Datum: `p(a,g(a))`
Sample Datum: `p(f(a,b),g(b))`

Other Notions

The **Herbrand universe** for a vocabulary is the set of all *ground terms* that can be formed from the *symbols* and *constructors* in the vocabulary.

The **Herbrand base** for a vocabulary is the set of all factoids that can be formed from the vocabulary.

A **dataset** is any *set of factoids* that can be formed from a vocabulary, i.e. a subset of the Herbrand base.

Exercise

Vocabulary

Symbols: `a`, `b`

Predicates: `p/2`, `q/1`

Questions

How many symbols in the Herbrand universe?

How many elements in the Herbrand base?

How many possible datasets?

Exercise

Vocabulary

Symbols: `a`, `b`

Constructor: `f/1, g/1`

Predicates: `p/2`, `q/1`

Questions

How many elements in the Herbrand universe?

How many elements in the Herbrand base?

How many possible datasets?

Sierra

Sierra

Sierra is browser-based IDE (interactive development environment) for Epilog.

Saving and loading files

Visualization of datasets
Querying datasets
Transforming datasets

Interpreter (for view definitions, action definitions)
Trace capability (useful for debugging rules)
Analysis tools (error checking and optimizing rules)

http://epilog.stanford.edu/sierra/sierra.html

Assignments

Optional Readings

Required:

- Reading - Datasets

Background:

- Reading - Programs with Common Sense
- Reading - Logic Programming

Assignment 1.1 - Sierra

The goal of this exercise is for you to familiarize yourself with the updates mechanism of Sierra. As always, go to http://epilog.stanford.edu and click on the Sierra link.

In a separate window, open the documentation for Sierra. To access the documentation, go to http://epilog.stanford.edu, click on Documentation, and then click on the Sierra item on the resulting drop-down menu.

Read Sections 1-3 of the documentation and reproduce the examples in the Sierra window you opened earlier. Read section 9 and play around with saving and loading data and configurations.

Assignment 1.2 - Movies

Consider a vocabulary that includes the following relations.

`movie.instance(`x`)` means that x is a movie.
`actor.instance(`x`)` means that x is an actor.
`director.instance(`x`)` means that x is a director.
`year.instance(`x`)` means that x is a year.
`title.instance(`x`)` means that x is a title.

`movie.star(`x`,`y`)` means that movie x stars actor y.
`movie.director(`x`,`y`)` means that movie x was directed by y.
`movie.year(`x`,`y`)` means that movie x was released in year y.
`movie.title(`x`,`y`)` means that movie x has the title y.

Choose symbols for a few movies, actors, directors, years, and titles, and encode the relevant data about these entities using this vocabulary.

Assignment 1.3 - Metadata

Consider a vocabulary that includes the following relations.

`type.instance(`x`)` means that x is a type.
`type.predicate(`x`,`y`)` means that type x has predicate y.
`type.attribute(`x`,`y`)` means that type x was attribute y.

`predicate.instance(`x`)` means that x is a predicate.
`predicate.domain(`x`,`y`)` means that predicate x has domain y.

`attribute.instance(`x`)` means that x is an attribute.
`attribute.domain(`x`,`y`)` means that attribute x has domain y.
`attribute.codomain(`x`,`y`)` means that x has codomain y.
`attribute.total(`x`,yes)` whether x has at least one value.
`attribute.unique(`x`,yes)` whether x has at most one value.

Use this vocabulary to encode types and relations in movie vocabulary.

Assignment 1.4 - Escher

Use the vocabulary in Assignment 1.4 to describe itself.

Factoids describing type are shown below. Your job is to do other types, predicates, attributes, and booleans.

```
type.instance(type)
type.predicate(type,type.instance)
type.attribute(type,type.predicate)
type.attribute(type,type.attribute)
             ...
```

Yes, the *predicates* in our vocabulary are *symbols* in this vocabulary as well as *predicates*!