CSC384: Lecture 3

- Last time
  - DCL: syntax, semantics, proofs
  - bottom-up proof procedure
- Today
  - top-down proof procedure (SLD-resolution)
  - perhaps start on uses of DCL
- Readings:
  - Today: 2.7; 2.8 (details in tutorial),
    - perhaps Ch.3 (excl. 3.7); we'll discuss only part
  - Next week: wrap Ch.3; start on Ch.4: 4.1-4.4/4.6

Top-Down Proof Procedure

- BUPP is data-driven
  - not influenced by query *q*, just facts and rules in *KB*!
  - wasteful: proves things unneeded to prove *q*
- **Top-down proof** procedure is query-driven:
  - focussed on deriving a specific query
- We'll describe a TDPP called *SLD-resolution*
  - Basically, the strategy implemented within Prolog
  - stands for *selected linear, definite-clause* resolution

SLD-Resolution (No vars)

- Basic intuitions:
  - suppose we have query $?q_1 \,\&\, q_2$
  - suppose we have rule $q_1 \leftarrow a \,\&\, b \,\&\, c$.
  - if we prove *subgoal query* $?a \,\&\, b \,\&\, c \,\&\, q_2$ then we know that original query must be true
- SLD a form of backchaining or subgoaling:
  - to prove *q*, we look for a rule with the head *q*, and then attempt to prove the body of that rule; if proven, we know *q* must be a consequence of KB
  - Progress: when subgoals are facts!
- **Defn**: An *answer clause*: $yes \leftarrow q_1 \,\&\, \ldots \,\&\, q_m$
- **Defn**: An *answer*: $yes \leftarrow .$

SLD-Resolution: Algorithm (no vars)

Given query $?q_1 \& \ldots \& q_m$ and a KB

1. Construct answer clause $yes \leftarrow q_1 \& \ldots \& q_m$

2. Until no KB-clause choosable or AC is an answer

   (a) Select an atom a_i from the current AC
   $yes \leftarrow a_1 \& \ldots \& a_k$

   (b) Choose a clause $a_i \leftarrow b_1 \& \ldots \& b_n$ from KB whose head matches selected atom

   (c) Replace a_i in AC with body to obtain new AC
   $yes \leftarrow a_1 \& \ldots a_{i-1} \& b_1 \& \ldots \& b_n \& a_{i+1} \& \ldots \& a_k$

SLD-Resolution

- If we reach an answer, return YES
  - query is a logical consequence of KB
- If we find no choosable clauses, return NO
  - query not a consequence (but not necessarily false)
- A sequence of answer clauses that culminates in an answer is an *SLD-derivation of the query*
- Our algorithm **attempts** to find a derivation:
  - if it chooses incorrectly at Step 2, it may fail
  - see text for distinction between choice and selection
  - we say derivation attempt *fails* if we get stuck
  - how does Prolog deal with failure?

SLD: Example

KB: (1) a <- b & c.
(2) b <- d & e.
(2') b <- c.
(3) b <- g & e.
(4) c <- e.
(5) d.
(6) e.
(7) f <- a & g.

Query: ?a

Derivation Attempt #1

yes <- a.	
yes <- b & c.	Select a; choose (1)
yes <- g & e & c.	Select b; choose (3)
yes <- g & c.	Select e; choose (6)

Select g: FAIL! no choosable clause

SLD: Example

KB:
- (1) a <- b & c.
- (2) b <- d & e.
- (2') b <- c.
- (3) b <- g & e.
- (4) c <- e.
- (5) d.
- (6) e.
- (7) f <- a & g.

Query: ?a

Derivation Attempt #2

yes <- a.	
yes <- b & c.	Select a; choose (1)
yes <- d & e & c.	Select b; choose (2)
yes <- e & c.	Select d; choose (5)
yes <- c.	Select e; choose (6)
yes <- e.	Select c; choose (4)
yes <- .	Select e; choose (6)

QUERY IS TRUE: obtained answer

SLD Notes

- Does atom selected to resolve away matter?
  - No: all must be “proven” eventually
- Does KB clause chosen to resolve with matter?
  - Yes: wrong choice can lead to failure
  - We’ll talk later about backtracking/search for a proof
- **Soundness**: should be fairly obvious
  - Exercise: prove that if any body in any answer clause is a consequence of KB, then so is query (soundness follows: if we derive an answer, query holds)
- **Completeness**: if $KB \models q$, there is a derivation
  - can we find it? Yes, if we make correct choices
  - How? Might have to try all options (watch for cycles)

Aside: Resolution

$$\frac{a \vee b, \quad \neg b \vee c}{a \vee c}$$

Resolution Proof Rule

Query $yes \leftarrow g \,\&\, h$ equivalent to $\neg g \vee \neg h \vee yes$

Rule $h \leftarrow a \,\&\, b \,\&\, c$ equivalent to $h \vee \neg a \vee \neg b \vee \neg c$

$$\frac{\neg g \vee \neg h \vee yes, \quad h \vee \neg a \vee \neg b \vee \neg c}{\neg g \vee \neg a \vee \neg b \vee \neg c \vee yes}$$

Resolvent $\neg g \vee \neg a \vee \neg b \vee \neg c \vee yes$

equiv. to $yes \leftarrow g \,\&\, a \,\&\, b \,\&\, c$

Variables in SLD (no functions)

- Recall query *q(X)* is interpreted existentially:
  - is there some *X* s.t. *q(X)* is a consequence?
  - return a ground instance/term *t* (or **all** *t*) s.t. *q(t)* holds
  - with no functions, terms are just constants

Example:
(1) rich(joan).
(2) mother(linda,joan).
(3) mother(mary,linda).
(4) rich(X) <- mother(X,Y)
& rich(Y).

Query:
? rich(linda).
yes
? rich(X).
joan, linda, mary

SLD: Queries with no vars

- Query: *?rich(linda)*
  - set up answer clause: *yes* $\leftarrow$ *rich(linda)*
  - but body matches no heads in KB! How to start??
- Intuitively, *rich(linda)* **does** match the head of the rule *rich(X)* $\leftarrow$ *mother(X,Y) & rich(Y).*
  - just need to substitute constant *linda* for var *X*
  - result: *yes* $\leftarrow$ *mother(linda,Y) & rich(Y).*
- Applying constant substituition {X/linda} to rule (4) gives us an *instance* of rule (4):
  - *rich(linda)* $\leftarrow$ *mother(linda,Y) & rich(Y).*
  - Note: this instance is clearly entailed by KB

Example: SLD with vars in KB

KB:

(1) rich(joan).
(2) mother(linda,joan).
(3) mother(mary,linda).
(4) rich(X) <- mother(X,Y) & rich(Y).

Query:

? rich(linda).

Derivation:

yes <- rich(linda).
yes <- mother(linda,Y) & rich(Y).

How: Select rich(linda); resolve with (4) using {X/linda}

yes <- rich(joan).

How: Select mother(linda,Y) ; resolve with (2) using {Y/joan}

yes <- .

How: Select rich(joan); resolve with (1) using { }

SLD: Queries with vars

- Query: *?rich(Z)*
  - set up answer clause: *yes(Z)* $\leftarrow$ *rich(Z)*
  - once derivation reaches an answer, this allows us to extract an “individual” for which query holds
  - can’t just say yes: must say “for who”
- Intuitively, *rich(Z)* **does** match the head of the rule *rich(X)* $\leftarrow$ *mother(X,Y) & rich(Y).*
  - just need to substitute var *Z* for var *X*
  - result: *yes(Z)* $\leftarrow$ *mother(Z,Y) & rich(Z).*
- Applying substitution {X/Z} to rule (4) gives:
  - *rich(Z)* $\leftarrow$ *mother(Z,Y) & rich(Y).*

Example: SLD with vars in query

KB:

(1) rich(joan).
(2) mother(linda,joan).
(3) mother(mary,linda).
(4) rich(X) <- mother(X,Y) & rich(Y).

Query:

? rich(Z).

Derivation:

yes(Z) <- rich(Z).

yes(Z) <- mother(Z,Y) & rich(Y).

Select rich(Z); resolve with (4) using {X/Z}

yes(Z) <-mother(Z,joan).

Select rich(Y); resolve with (1) using {Y/joan}

yes(linda) <- .

Select mother(Z,joan) ; resolve with (2) using {Z/linda}

Example: SLD with vars in query

KB:

(1) rich(joan).
(2) mother(linda,joan).
(3) mother(mary,linda).
(4) rich(X) <- mother(X,Y) & rich(Y).

Query:

? rich(Z).

A Different Derivation:

yes(Z) <- rich(Z).
yes(joan) <- .

Select rich(Z); resolve with (1) using {Z/joan}

Different derivations can give different answers;
Exercise: construct derivation that gives the answer "mary".

SLD with Variables

- To recap, we've seen SLD with:
  - variables in KB, but ground queries
  - variables in KR and variables in query
- *Basic idea: we need to make appropriate substitutions of our variables in order to make atoms in answer clause match heads of KB rules*
- Let's look at one more example, sticking with the "intuitive" definition of a substitution
- Then we'll formalize unifiers and MGUs

Example Derivation #1

KB:
1. busy(Z) <- teaches(Z,X) &
   teaches(Z,Y) & distinct(X,Y).
2. busy(Z) <- teaches(Z,148).
3. teaches(craig, 384).
4. teaches(craig, 2534).
5. teaches(kyros, 384).
6. teaches(kyros, 2501).
7. teaches(suzanne, 148).
8. distinct(2534,384).
9. distinct(2501,384).
   distinct…

Could have used {Z/P} instead; as long as vars match

Query:
?busy(P).

Answer Clause:
yes(P) <- busy(P).

Derivation:
yes(P) <- busy(P).
yes(P) <- teaches(P,148).
  Select busy(P); resolve with (2) using {P/Z}
yes(suzanne) <- .
  Select t(Z,148); resolve with (2) using {Z/P}

Answer: suzanne
(others: craig, kyros… show!)

SLD-Resolution: Algorithm (w/ vars)

Given query $?q_1 \,\&\, \ldots \,\&\, q_m$ with vars $x_1 \ldots x_n$ and a KB

1. Construct answer clause $yes(x_1 \ldots x_n) \leftarrow q_1 \,\&\, \ldots \,\&\, q_m$.

2. Until no KB-clause choosable or AC is an answer

(a) Select an atom a_i from the current AC $yes \leftarrow a_1 \,\&\, \ldots \,\&\, a_k$

(b) Choose a clause $h_i \leftarrow b_1 \,\&\, \ldots \,\&\, b_n$ from KB

and a **substitution** σ that **unifies** the head h_i of the KB clause with the selected atom a_i (i.e., that when applied to h_i and a_i makes them the same)

(c) apply σ to AC and KB clause to obtain ACσ, KBσ

(d) Replace $a_i\sigma$ in ACσ with body of KBσ to obtain new AC

$$(yes(x_1 \ldots x_n) \leftarrow a_1 \,\&\, \ldots\, a_{i-1} \,\&\, b_1 \,\&\, \ldots \,\&\, b_n \,\&\, a_{i+1} \,\&\ldots\&\, a_k)\,\sigma$$

Example Derivation #2

KB:
1. busy(Z) <- teaches(Z,X) &
   teaches(Z,Y) & distinct(X,Y).
2. busy(Z) <- teaches(Z,148).
3. teaches(craig, 384).
4. teaches(craig, 2534).
5. teaches(kyros, 384).
6. teaches(kyros, 2501).
7. teaches(suzanne, 148).
8. distinct(2534,384).
9. distinct(2501,384).
10. d(148,384). d(2534, 2501).
    d(2534,148). d(2501,148).

Same query: ?busy(P).

Derivation:

yes(P) <- busy(P).

yes(P) <- t(P,X) & t(P,Y) & d(X,Y).
  busy(P); (1); {Z/P}

yes(craig) <- t(craig,Y) & d(384,Y).
  t(P,X); (3); {P/craig, X/384}

yes(craig) <- d(384,2534).
  t(c,Y); (4); {X/2534}

FAILS! Nothing will unify with d(384,2534).

Problem lies in KB. We didn't axiomatize domain correctly.
Add distinct(384,2534), etc…
or add rule: distinct(C,D) <- distinct(D,C).

Example Derivation #3

Assume KB fixed with rule: 12. distinct(C,D) <- distinct(D,C).

Derivation:

yes(P) <- busy(P).

yes(P) <- t(P,X) & t(P,Y) & d(X,Y).

busy(P); (1); {Z/P}

yes(craig) <- t(craig,Y) & d(384,Y).

t(P,X); (3); {P/craig, X/384}

yes(craig) <- d(384,2534).

t(c,Y); (4); {X/2534}

yes(craig) <- d(2534,384).

d(384,2534); (12); {C/384, D/2534}

yes(craig) <- .

d(2534,384); (8); {}

Substitutions

- Defn: A **substitution** σ is any assignment of terms to variables
  - we write it like as σ = *{X/t1, Y/t2, …}*
  - constant substitution is a special case; terms can be any terms (nonground included)
    - without functions, only terms are constants,vars
  - e.g., σ = *{X/craig, Y/father(craig), Z/P, W/father(X)}*
- A substitution is applied to an expression by uniformly and simultaneously substituting each term for the corresponding variable
  - e.g. using subst. above on *related(mother(X),W)* gives *related(mother(craig), father(X))*

Unifiers

- **Defn**: A substitution **unifies** two expressions e_1 and e_2 iff $e_1\sigma$ is identical to $e_2\sigma$
- E.g., *p(X,f(a))* and *p(Y, f(Z))* are unified by:
  - *{X/b, Y/b, Z/a}:* gives *p(b,f(a))* for both expressions
  - *{X/Y, Z/a}:* gives *p(Y,f(a))* for both expressions
  - *{X/Z, Y/Z, Z/a}:* gives *p(Z,f(a))* for both expressions
- Unifier σ is a **most general unifier (MGU)** of e_1 and e_2 iff $e_1\sigma'$ is an *instance of* (unifies with) $e_1\sigma$ for any other unifier σ'
  - An MGU gives the most general instance of an expression; any other unifier gives a result that would unify with that given by the MGU

MGUs: Examples

- Let e_1 = *busy(X)*, e_2 = *busy(Y)*
- Unifier σ_1: {X/kyros, Y/kyros}
  - result: $e_1\sigma_1 = e_2\sigma_1$ = busy(kyros)
- Unifier σ_2: {X/craig, Y/craig}
  - result: $e_1\sigma_2 = e_2\sigma_1$ = busy(craig)
- Unifier σ_3: { Y/X }
  - result: $e_1\sigma_3 = e_2\sigma_3$ = busy(X)
- Unifier σ_3 an MGU of expressions; not σ_1 , σ_2
  - $e_1\sigma_3$ unifies with result of any other unifier
  - $e_1\sigma_1$ = *busy(kyros)* **cannot** (e.g., cannot unify $e_1\sigma_1$ with $e_2\sigma_1$ = *busy(craig)*)

Notes on General SLD Resolution

- Generally insist that you only use *MGUs* in SLD resolution to match a body atom with a KB head
  - ensures we don't make too specific a choice and force us into failure unnecessarily
- To obtain all answers:
  - once we derive an answer, we pretend the derivation failed and backtrack to find other derivations
  - *we only reconsider KB-clause choices*, not atom selections, or unifier choice

Notes on General SLD Resolution

- Prolog (see Appendix B, Ch3.2, Ch3.3)
  - based on SLD-resolution
  - searches for derivations using a specific strategy: (a) always selects atoms from answer clause in left-to-right order; (b) always chooses KB clauses in top-to-bottom order (using first *unifiable* rule/fact)
  - records choices and tries alternatives if failure (essentially does depth-first search: why?)
  - provides a single answer for nonground queries; but you can force it to search for others (semicolon op)

Renaming of Variables: Example

KB:

(1) rich(joan).
(2) mother(linda,joan).
(3) mother(mary,linda).
(4) rich(X) <- mother(X,Y) & rich(Y).

Query:

? rich(mary).

Derivation:

yes <- rich(mary).

yes <- mother(mary,Y) & rich(Y).

rich(mary); (4); {X/mary}

yes <- mother(mary,X) & mother(X,X) & rich(X).

rich(Y) ; (4) using {Y/X}

Must fail! Nobody (in our KB) is their own mother!

Renaming of Variables

- When we add body of KB clause to answer clause, we may have accidental name conflicts
  - in example, Y in answer clause is not “same person” as Y in KB clause (yet both replaced by X)
- To prevent problems, we always rename vars in KB clause (uniformly) to prevent clashes
  - changing var names in KB clause cannot change meaning
- System: (a) each clause has diff. vars; (b) index KB vars, increase with each use of the clause
  - use rich(X_i) <- mother(X_i,Y_i) & rich(Y_i). *i*-th time you use this clause in a derivation

Renaming of Variables: Example

KB:

(1) rich(joan).
(2) mother(linda,joan).
(3) mother(mary,linda).
(4) rich(X) <- mother(X,Y) & rich(Y).

Query:

? rich(mary).

Derivation:

yes <- rich(mary).

yes <- mother(mary,Y_1) & rich(Y_1).

rich(mary); (4); {X_1/mary}

yes <- mother(mary,X_2) & mother(X_2,Y_2) & rich(Y_2).

rich(Y_1) ; (4) using {Y_1/X_2}

etc… (no conflict now)

DCL: How can we use it?

- Query-answering system:
  - given KB representing a specific domain, use DCL (and suitable proof procedure) to answer questions
- A Deductive Database System
  - much like the above
- A Programming Language
  - Prolog (we've seen) is a dressed up DCL using SLD
  - Important to realize that as a programming language, we are still making logical assertions and proving logical consequences of these assertions

Prolog List Operations

- A distinguishing feature of Prolog is its built-in facilities for *list manipulation*
  - not hacks, but genuine logical assertions/derivations
- Consider the function *cons,* constant *el*:
  - *cons* accepts two args, returns pair containing them
  - e.g, *cons(a,b), cons(a,cons(b,c))*
  - *el* is a constant denoting the empty list
- A proper list is either *el* or a pair whose second element is a proper list
  - *cons(a, cons(b, cons(c, el)))* = (a b c) or [a,b,c]

Prolog List Operations

- Prolog uses a more suggestive notation:
  - [] is a constant symbol (empty list)
  - [|] is a binary function symbol: infix notation (cons)
  - [a,b,c] shorthand for [a | [b | [c | []]]]
- But these are just terms in DCL
- Standard list manipulation operations correspond to logical assertions
  - e.g., the usual definition of append(X,Y,Z) simply defines what it means for Z to be the appending of X and Y

Defining Append

(A1) append([], Z, Z).

(A2) append([E1 | R1], Y, [E1 | Rest]) <-
append(R1, Y, Rest).

Proving the Append Relation #1

Query: ? append([a,b], [c,d], [a,b,c,d]).

(A1) append([], Z, Z).

(A2) append([E1 | R1], Y, [E1 | Rest]) <-
append(R1, Y, Rest).

Derivation:

yes <- append([a,b], [c,d], [a,b,c,d]).

yes <- append([b], [c,d], [b,c,d]).

Resolve with (A2) using { E1/a, R1/[b], Y/[c,d], Rest/[b,c,d] }

yes <- append([], [c,d], [c,d]).

Resolve with (A2) using { E1/b, R1/[], Y/[c,d], Rest/[c,d] }

yes <- .

Resolve with (A1) using { Z/[c,d] }

Answer: yes

Proving the Append Relation #2

Query: ? append([a,b], [c,d], [g, b,c,d]).

(A1) append([], Z, Z).

(A2) append([E1 | R1], Y, [E1 | Rest]) <-
append(R1, Y, Rest).

Derivation:

yes <- append([a,b], [c,d], [f,b,c,d]).

No append rule can unify with this atom
(convince yourself: look at E1)

Answer: no

Proving the Append Relation #3

Query: ? append(L, M, [a,b,c,d]).

(A1) append([], Z, Z).

(A2) append([E1 | R1], Y, [E1 | Rest]) <-
    append(R1, Y, Rest).

Derivation:

yes(L,M) <- append(L, M, [a,b,c,d]).

yes([a|R1], M) <- append(R1, M, [b,c,d]).

  Resolve with (A2) using { L/[a|R1], Y/M, E1/a, Rest/[b,c,d] }

yes([a], [b,c,d]) <- .

  Resolve with (A1) using { R1/[], M/[b,c,d], Z/[b, c,d] }

Answer: L = [a], M = [b,c,d]

Proving the Append Relation

- Exercise: Give derivations for at least two other answers for the previous query:
- Query: ? append(L, M, [a,b,c,d]).
  - L = [], M = [a,b,c,d]
  - L = [a], M = [b,c,d]
  - L = [a,b], M = [c,d]
  - L = [a,b,c], M = [d]
  - L = [a,b,c,d], M = []

DCL and Knowledge Representation

- DCL has obvious uses as a question answering system for complex knowledge
  - A key issue: how does one effectively represent knowledge of a specific domain for this purpose?
  - Unfortunately, there are generally many ways to represent a KB: some more useful (compact, natural, efficient) than others
- Let's go through a detailed example to see where choices need to be made, what the difficulties are, etc.

The Herbalist Domain

- Suppose we want to build a KB that answers queries about what sorts of homeopathic remedies we need to treat different symptoms
  - This “expert system” will underly a Web site where users can ask for advice on herbal remedies
- We need to build a KB that represents info we have about different clients, their symptoms, treatments, etc.

What Functionality is Needed?

- Before designing KB, we need to know what types of queries we'll ask; do we want:
  a) **`?treatment(john,T).`**
  b) **`?treatment(`***symptom***`,T).`**
  c) **`?treatment(`***combination-of-symptoms***`,T).`**
  d) **`?safe(`***combination-of-treatments***`).`**
  e) **`?medical_records(john,R).`**
  f) **`?paid_bills(john).`**

- and so on

What Individuals Do We Need?

- What constants/functions will I need?
- Clients (people), other entities:
  - constants: *joan, ming, gabrielle, greenshield*…
  - functions: *insurer(X),* etc.
- Symptoms (constants): *fever, aches, chills,* …
- Treatments:
  - *constants:* echinacea, mudwort, feverfew, …
  - or maybe function: *tmt(feverfew,capsule), tmt(mudwort, tincture),* where we have a treatment requires a substance and a preparation
  - then we need constants for substances, preparations

What Individuals Do We Need?

- Diseases: do we need diseases?
  - why? why not? (our treatment philosophy will be to apply treatments to symptoms: simplicity!)
- Combinations of symptoms? treatments?
- We'll consider combinations:
- symptomList is a list of symptoms:
  - e.g, function: *symList(symptom, SList)*
  - or using Prolog notation: *[aches, fever, chills]*
- treatmentList similar:
  - *[tmt(mudwort,tincture), tmt(echinacea,capsule)]*

What Relations?

- Relations depend on functionality desired
- If we ask **`?treatment(john,T).`** we need information about john in KB (e.g., symptoms)
  - e.g.: *symptom(john,fever). symptom(john,chills*).
  - or: *symptoms(john, [fever,chills]).*
  - or maybe symptoms are relations themselves and not individuals: *fever(john). chills(john).*
- Maybe we don't even discuss individual clients:
  - e.g., we only ask: **`?treatment(SList,TList).`**
- Different choices influence how you express your knowledge: some make life easy, or difficult!

Facts and Rules

- Once we’ve decided on suitable relations we need to populate our KB with suitable facts and rules
  - facts/rules should be correct
  - facts/rules should cover all *relevant* cases (which depends on the task at hand)
  - try to keep facts/rule concise (only relevant facts)
- For example: we can often express a zillion facts using one or two simple rules

Some Example Facts/Rules

- Facts about individual patients

Specific Visit Facts (enter into KB during exam):

```
musclepain(mary,shoulders).
slow_digestion(john).
fever(john).
```

Semi-permanent Facts (persist in KB):

```
arthritis(ming).
hypertensive(john).
relaxed_disposition(mary).
```

Some Example Facts/Rules

- Rules relating treatments to symptoms

We can relate treatments to symptoms directly:

remedy(X,echinacea) :- fever(X) & cough(X) & sniffles(X).
remedy(X,echinacea) :- chills(X) & cough(X) & sniffles(X).

Or relate treatments to diseases,
and diseases to symptoms:

remedy(X,echinacea) :- has_cold(X).

has_cold(X) :- fever(X) & cough(X) & sniffles(X).
has_cold(X) :- chills(X) & cough(X) & sniffles(X).

Some Example Facts/Rules

- We might even have more general rules
  - Appropriate level of generality can make KB expression more concise

We might have general problems:

```
general_dig_probs(X) :- slow_digestion(X).
general_dig_probs(X) :- heartburn(X) & relaxed_disposition(X).
general_dig_probs(X) :- gastritis(X).
```

and relate treatments to such classes of problems:

```
remedy(X,cloves) :- general_dig_probs(X).
remedy(X,meadowsweet) :- gastritis(X).
```

Some Example Facts/Rules

- Design choice for relations, individuals can have impact on ability to prove certain things (easily)
- Suppose we want to find a treatment list for *john*:
  - list should cover each symptom john exhibits (in KB)
  - but how do we "collect" all the facts from the KB of the form *fever(john), slow_digestion(john),* etc.
  - (actually Prolog has some hacks, but SLD doesn't)
- Thus we make our lives easier by thinking of symptoms as individuals, and relating patients to a list of all symptoms
  - *symptoms(john, [fever, aches, slow_digestion]).*

Example Facts/Rules

- Let's attempt to define *treatment(S,T):* treatment list T is satisfactory for symptom list S
  - Note: it suggests new relations to specify/define
- Is this definition correct? complete? efficient? for what types of queries will it work?

```
treatment( [], []).
treatment( [S1 | RestS], [T1 | RestT] ) :-
  treats(T1,S1),
  treatment(RestS, RestT),
  safe( [T1 | RestT] ).
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Example Facts/Rules

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```

- *?treatment([aches,fever], T):* is this defn OK?
- *?treatment([aches,fever], [ech,mudwort]):* OK?
  - what if *ech* treats *fever* and *mudwort* treats *aches*?
  - must rewrite to make order-independent
- Final Tlist is safe if no nasty interactions:
  - why is this definition inefficient?
  - why prove for each *sublist*? how would you rewrite it?
  - ***could*** proving it each time make sense (for Prolog)?
  - Exercise: define a version of the *safe* predicate

KB Design: The Moral

- There are many design choices
- The queries you plan to ask influence the way you break the world into individuals and relations
- Even with fixed functionality, there are often several ways to approach the problem
- Different approaches lead to more or less natural, efficient, and compact KBs