

## Lecture 38: Declarative Programming (Under the Hood)

### Announcements:

- Autograder running. As we fix glitches, expect multiple reports.
- Remember: you still have to provide your own tests!
- Submit your Project 4 contest entries as "proj4-contest." by next Wednesday. Assuming we get entries, we'll ask the class to judge these entries.
- Penultimate homework (13) to be released late tonight(?). Due date to be set appropriately.
- "Homework" 14 will be judging the contest.

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## Review: A "Schemish" Prolog

- A Scheme expression, e.g. `(ordered (0 1 2))` represents a logical assertion.
  - Its top-level operator (e.g., `ordered`) names a *predicate* (true/false function).
  - Its operands are the data for this predicate: unlike Scheme programs, they don't represent function calls—they are the literal data...
  - ...with the exception that *logical variables*, represented as symbols starting with underscore, stand for operands that may be replaced by other expressions.
- To define a predicate, we give rules for it:
  - `(fact CONCLUSION)` means that `CONCLUSION` is to be taken as true, for any replacement of its logical variables.
  - `(fact CONCLUSION HYPOTHESIS ...)` means that `CONCLUSION` is to be taken as true, assuming that the `HYPOTHESES` can all be shown to be true. Again, this is for all replacements of logical variables throughout the rule.

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## Review: Operational and Declarative Meanings

- Thus,  
`(fact (eats _P _F) (hungry _P) (has _P _F) (likes _P _F))`  
means that for any replacement of `_P` (e.g., 'brian') and `_F` (e.g., 'potstickers') throughout the rule:
  - Declarative Meaning** If brian is hungry and has potstickers and likes potstickers, then brian will eat potstickers.
  - Operational Meaning** To show that brian will eat potstickers, show that brian is hungry, then that brian has potstickers, and then that brian likes potstickers.
- The *declarative meaning* allows us to look at our Scheme-Prolog program as a logical specification of a problem for which the system is to find a solution.
- The *operational meaning* allows us to look at our Scheme-Prolog specification as an executable program for searching for a solution.
- **Closed Universe Assumption:** We make only positive statements. The closest we come to saying that something is false is to say that we can't prove it.

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## Review: Relations, not Functions

- We've "logified" functions. Instead of saying  
"the value of `(abs -5)` is 5,"  
we recast the statement as  
"the value 5 stands in the 'absolute value of' relation to -5: `(abs -5 5)`."
  - Given a value, `-5`, we can ask for its absolute value with a logical variable and then use it elsewhere with the help of logical variables:  
`(? (abs -5 _X) (add _X 4 _Y))`  
specifies a replacement for `_Y` that makes it equal to `4+|-5|`.

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## How It's Done (I): Unification

- In general, our system, given a target expression involving a predicate to prove, must find a fact that might assert that target, given a suitable replacement of logical variables.
- To do this, we try to pattern-match the conclusions of all our facts against the target expression.
- The pattern matching is called *unification*, [J. A. Robinson].
- For example, we say that `(likes brian potstickers)` *unifies with* the expression `(likes _P _F)`, if we substitute `brian` for `_P` and `potstickers` for `_F`.
- Might think of this substitution—called a *unifier*—as a Python dictionary mapping logical variables to expressions.

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## Unification (II)

- The substitution has to be uniform:
  - Can unify `(le 0 1)` with `(le _X _Y)`
  - But cannot unify `(le 0 1)` with `(le _X _X)`
- Everything is symmetric: if `A` unifies with `B`, then `B` unifies with `A`. Logical variables can appear in one or both.
- It is possible for logical variables to be unified with each other:  
Unify `(likes _P _F)` with `(likes _Q potstickers)`.
- We substitute `potstickers` for `_F`, and choose either to substitute `_Q` for `_P` or vice-versa.
- The result in either case means that any person likes potstickers.

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## Implementing Unification

A simple tree recursion with side-effects:

```
def unify(E0, E1, env):
    """Returns True iff E0 and E1 can be unified by an extension
    of ENV. ENV is modified to provide a suitable unifier."""
    def unify1(E0, E1):
        E0 = binding(E0, env); E1 = binding(E1, env)
        if scm_eqvp(E0, E1): return True
        if is_logical_var(E0):
            env[E0] = E1
            return True
        elif is_logical_var(E1):
            env[E1] = E0
            return True
        elif E0.atomp() or E1.atomp(): return False
        else:
            return unify1(E0.car, E1.car)
            and unify1(E0.cdr, E1.cdr)

    return unify1(E0, E1)
```

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## Using Unification to Search for Proofs

- The process of attempting to demonstrate an assertion (answer a query) is a systematic depth-first search of facts.

```
def query(targets, env):
    for fact in fact database:
        unify conclusion of fact with first target, \
            extending env
        if this succeeds:
            if query(hypotheses of fact, env) and \
                query(rest of targets, env):
                Success! return resulting env
    if we fail at any point, back up, undo changes to env and \
        try another fact.
```

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## Actual Code

```
def query(clauses, env):
    if scm_nullp(clauses):
        yield env
    else:
        for fact in facts_db:
            fact = fact.freshen({})
            env_head = EnvironFrame(env)
            if unify(fact.car, clauses.car, env_head):
                for env_rule in query(fact.cdr, env_head):
                    for r in query(clauses.cdr, env_rule):
                        yield r
```

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