Programming with Logic and Objects

Michael Kifer

Stony Brook University

Outline

- Introduction: About FLORA-2
- F-logic
- HiLog
- Example of an application of FLORA-2
- Transaction Logic (*if time permits*)

Introduction

What's Wrong with Classical Programming with Logic?

- Precisely that it is based on *classical* logic:
  - Essentially flat data structures (relations with `struct`s)
  - Awkward meta-programming
  - Ill-suited for modeling side effects (state changes, I/O)

What is FLORA-2?

- **F**-**L**ogic t**RA**nslator (the next generation)
  - FLORA-2 programs are translated into XSB & executed by the XSB tabling inference engine
- Language for knowledge-based applications
  - *Declarative* – much more so than Prolog
  - *Object-oriented* (frame based)
- Overcomes most of the usability problems with Prolog
- *Practical* & *usable* programming environment based on
  - *F-logic* (Frame Logic) ≡ objects + logic (+ extensions)
  - *HiLog* – high degree of *truly declarative* meta-programming
  - *Transaction Logic* – database updates + logic
- Builds on earlier experience with implementations of F-logic: FLORID, FLIP, FLORA-1 (which don't support HiLog & Transaction Logic)
- http://flora.sourceforge.net

Applications of FLORA-2

- Ontology management (Semantic Web)
- Information integration
- Software engineering
- Agents
- Anything that requires manipulation of complex structured (especially semi-structured) data

Other F-logic Based Systems

- *No-name system* (U. Melbourne – M. Lawley) – early 90's; first Prolog-based implementation
- *FLORID* (U. Freiburg – Lausen et al.) – mid-late 90's; the only C++ based implementation
- *FLIP* (U. Freiburg – Ludaescher) – mid 90's; first XSB based implementation. Inspired the FLORA effort
- *TFL* (U. Valencia – Carsi) – mid 90's; first attempt at F-logic + Transaction Logic
- *SILRI* (Karlsruhe – Decker et al.) – late 90's; Java based
- *TRIPLE* (Stanford – Decker et al.) – early 2000's; Java

✓ *FLORA-2 – most comprehensive and general purpose of all these*

F-Logic

Usability Problems with Flat Data Representation

Typical result of translation from the E-R diagram:

Person

SSN	*Name*	*PhoneN*	*Child*
111-22-3333	Joe Public	516-123-4567	222-33-4444
111-22-3333	Joe Public	516-345-6789	222-33-4444
111-22-3333	Joe Public	516-123-4567	333-44-5555
111-22-3333	Joe Public	516-345-6789	333-44-5555
222-33-4444	Bob Public	212-987-6543	444-55-6666
222-33-4444	Bob Public	212-987-1111	555-66-7777
222-33-4444	Bob Public	212-987-6543	555-66-7777
222-33-4444	Bob Public	212-987-1111	444-55-6666

Problem: redundancy due to dependencies

$$\textbf{Person} = (SSN, Name, PhoneN) \bowtie (SSN, Name, Child)$$

$$SSN \;—\; Name$$

Normalization That Removes Redundancy

Person1

SSN	Name
111-22-3333	Joe Public
222-33-4444	Bob Public

Phone

SSN	PhoneN
111-22-3333	516-345-6789
111-22-3333	516-123-4567
222-33-4444	212-987-6543
222-33-4444	212-135-7924

ChildOf

SSN	Child
111-22-3333	222-33-4444
111-22-3333	333-44-5555
222-33-4444	444-55-6666
222-33-4444	555-66-7777

But querying is still cumbersome:

Get the phone#'s of Joe's grandchildren.

Against the <u>original</u> relation – complex:

```
SELECT  G.PhoneN
FROM    Person  P,  Person  C,  Person  G
WHERE   P.Name = 'Joe Public'   AND
        P.Child = C.SSN   AND  C.Child = G.SSN
```

Against the <u>decomposed</u> relations – even more so:

```
SELECT   N.PhoneN
FROM     ChildOf  C,  ChildOf  G,  Person1  P,  Phone  N
WHERE    P.Name = 'Joe Public'  AND  P.SSN = C.SSN  AND
         C.Child = G.SSN  AND  G.SSN = N.SSN
```

O-O approach: rich types and better query language

Schema:

Person(SSN: String,
  Name: String,
  PhoneN: {String},
  Child: {Person})

Set data types

- *No need to decompose in order to eliminate redundancy*

Query:

Path expressions

```
SELECT   P.Child.Child.PhoneN
FROM     Person P
WHERE    P.Name = 'Joe Public'
```

– *Much simpler query formulation*

Basic Ideas Behind F-Logic

- Take complex data types as in object-oriented databases
- Combine them with logic
- Keep it clean – no ad hoc stuff
- Use the result as a programming/query language

F-Logic Features

- Objects with complex internal structure
- Class hierarchies and inheritance
- Typing
- Encapsulation
- Background:
  - Basic theory: [Kifer & Lausen SIGMOD-89], [Kifer,Lausen,Wu JACM-95]
  - Powerful path expression syntax: [Frohn, Lausen, Uphoff VLDB-84]
  - Semantics for non-monotonic inheritance: [Yang & Kifer, ODBASE 2002]
  - Meta-programming + other extensions: [Yang & Kifer, ODBASE 2002]

F-logic: simple examples

Object Id

Single-valued attribute

Object description:

john[*name*→‘John Doe’, *phones*->>{6313214567, 6313214566},
children->>{bob, mary}]

mary[*name*→’Mary Doe’, *phones*->>{2121234567, 2121237645},
children->>{anne, alice}]

Set-valued attribute

Structure can be nested:

sally[spouse -> john[address -> ‘123 Main St.’]]

Examples (contd.)

ISA hierarchy:

john **:** person - *class membership*
mary **:** person
alice **:** student

student **::** person - *subclass relationship*

Examples (Contd.)

Methods: like attributes, but take arguments

```
P[ageAsOf(Year)→Age] :--
      P:person, P[born→B], Age is Year–B.
```

Queries:

```
?-- john[born→Y, children->>C],
    C[born→B], Z is Y+30, B>Z.
```

John's children who were born when he was over 30.

Examples (Contd.)

Type signatures:

person[*born* => integer,
ageAsOf(integer) => integer,
name => string,
children =>> person].

Can define signatures as facts or via deductive rules;
Signatures can be <u>queried</u>.
Type correctness has logical meaning (as "runtime" constraints).

Syntax

- ISA hierarchy:
  - O:C -- object O is a *member* of class C
  - C::S -- C is a *subclass* of S
- Structure:
  - O[*M*→S] – *scalar* (single-valued) invocation of method
  - O[*M*->>S] – *set*-valued invocation of method
- Type (signatures):
  - Typeobj[*Meth* => Resulttype] – a scalar method signature
  - Typeobj[*Meth* =>> Resulttype] – signature for a set-valued method
- Combinations of the above: ∨, ∧, negation, quantifiers

- O,C,M,Typeobj, ... – usual first order function terms, e.g., *john*, *AsOf(Y)*, *foo(bar,X)*.

More Examples

Browsing ISA hierarchy:

?- john : X.

?- student ::Y

Virtual (view) class:

X : redcar :- X:car, X[color -> red].

Schema browsing:

O[attrs(Class) ->> A] :-

(O[A -> V; A ->> V]), V:Class.

Rule defines method, which returns attributes whose range is class Class

Parameterized classes:

[]:list(T).

[X|L]:list(T) :- X:T, L:list(T).

E.g., list(integer), list(student)

Semantics

Herbrand universe: HB – set of all ground terms

Interpretation: $I = (HB, I_{->}, I_{->>}, \in, <)$

where $<$: partial order on HB

$\in$: binary relationship on HB

$$I_{->} : HB \rightarrow (HB \xrightarrow{partial} HB)$$

$$I_{->>} : HB \rightarrow (HB \xrightarrow{partial} \text{powersetOf}(HB))$$

$I \models o[m\text{->}v]$ if $I_{->}(m)(o) = v$

$I \models o[m\text{->>}v]$ if $v \in I_{->>}(m)(o)$

$I \models o{:}c$ if $o \in c$

$I \models c{::}s$ if $c < s$

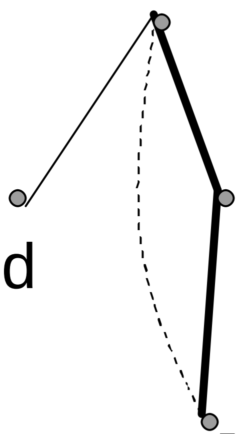
- *Won't discuss typing*

Proof Theory

- Resolution-based
- Sound & complete w.r.t. the semantics

Inheritance in F-logic

`Elephant[`*`color`*`→grey]`



`royalElephant[`*`color`*`→white]`

`fred`

`clyde`

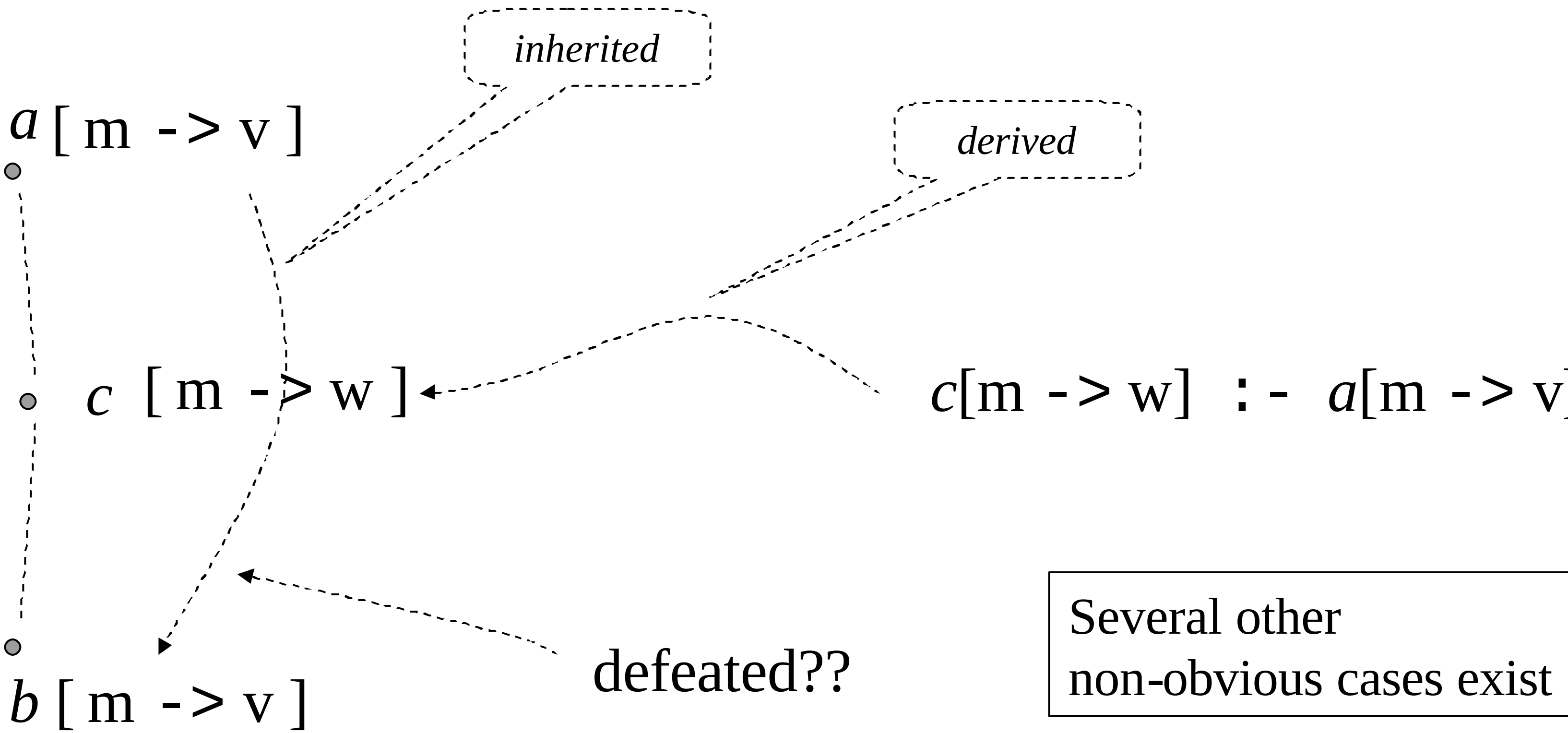
`Overriding`

Should conclude:

`fred[`*`color`*`→grey]`
`clyde[`*`color`*`→white]`

The Problem with Rules

- Inheritance is hard to even define properly in the presence of rules.



Several other
non-obvious cases exist

Inheritance (Contd.)

- Hard to define semantics to multiple inheritance + overriding + deduction; several semantics might be "reasonable"
- The original semantics in [Kifer,Lausen,Wu JACM-95] was quite problematic
- Problem solved in [Yang&Kifer ODBASE 2002]

HiLog

HiLog

- Allows certain forms of logically clean meta-programming
- Syntactically appears to be higher-order, but semantically is first-order and tractable
- Has sound and complete proof theory
- [Chen,Kifer,Warren JLP-93]

Examples of HiLog

Variables over predicates and function symbols:

p(X,Y) :- X(a,Z), Y(Z(b)).

Variables over atomic formulas:

call(X) :- X.

HiLog in FLORA-2 (e.g., method browsing**):**

O[*unaryMethods*(Class) ->> M] **:--**

O[*M*(_) -> V; *M*(_) ->>V], V**:**Class.

Reification
[Yang&Kifer ODBASE 2002]

Meta-variables

john[*believes* ->> ${mary[*likes* ->> bob]}]

Applications

Applications

- Web information extraction agents (XSB, Inc.'s prototype; FLORA-1)
- Info integration in Neurosciences (San Diego Supercomputing Institute; FLORA-1)
- Ontology management (Daimler-Chrysler; FLORA-2)
- CASE tool (U. Valencia; FLORA-2)
- Stony Brook CS Grad Program Manager (FLORA-2)

SBCS Graduate Program Manager

- Need to keep track of lots of special cases
    - MS, PhD status over time; with/without support
    - Types of support over time (RA/TA/fellowships, permanent/temporary)
    - PhD examinations (with history of failures, conditions); N/A to MS
    - Teaching history
    - Advisors over time
- TA assignments
    - 35+ courses
    - 70 TAs; ~50 guaranteed, ~50 wannabees (waitlist)
        - Preferences/skills
        - English proficiency test results, etc., etc.
- Need complex aggregate reports
- *Very complicated*
    - Hard to figure out the right database schema (still evolving)
    - Data *highly semistructured*

SBCS Grad Manager (Contd.)

- Was hard-pressed: didn't have the time to do it in Java/JDBC (also: maintenance would have been a serious problem afterwards)
- FLORA-2 was ideal for this:
    - Objects don't need to have exactly the same structure
    - Changes of object schema (usually) don't require changes to old rules/queries – low maintenance overhead
- Took only 2 weeks for initial version *including* data entry and debugging FLORA-2 itself!
  – Had some fun doing the otherwise boring job

Student Data – Highly Semi-structured

Anonymous oid

```
_#1 : student
 [ last      -> 'Doe',   first  -> 'Mary',   email  -> 'marydoe@yahoo.com',
   joined    -> fall(1999),  graduated -> futuredate,
   advisor   ->> _#(_#1)[who -> johndoe, since -> fall(1999)],
   support   ->> {_#(_#1)[type ->ra, since -> fall(2001)],
                   _#(_#1)[type -> ta, until -> spring(2001)] },
   status    ->> {_#(_#1)[type->phd, since->spring(2002), remarks->'part time'],
                  _#(_#1)[type->phd, until->summer2(2000)],
                  _#(_#1)[type->ms, since->fall(2000), until->fall(2001)] },
   quals     ->  _#(_#1)[passed     ->  date(2000,10), history ->>  data(2000,5) ],
   defense   ->  _#(_#1)[passed    ->  futuredate],
   female,
   domestic,
   taught    ->> {  _#(_#1)[course->cse529, semester->fall(2000), load -> 0.5],
                  _#(_#1)[course->cse310, semester->fall(2000), load -> 0.5],
                  _#(_#1)[course->cse305, semester->spring(2001)]  },
  canteach  ->> {cse332,cse336,cse333,cse230,cse528}
 ].
```

Hackery to improve indexing

Variations in structure

Can be missing

Course Data – Also Semistructured

```
cse505 : course[
    name   -> 'Computing with Logic',
    offerings ->> {
                    _#[semester    ->  fall(2001),
                         instructors ->> {cram},
                         enrollment  ->  15,
                      ],
                       _#[semester    ->  fall(2002),
                           instructors ->> {warren},
                           enrollment  ->  25,
                           need_grad_ta   ->  0.5
                         ]

                  }
].
```

Variation in structure

Course Data (Contd.)

```
cse334 : course[
    name   -> 'Introduction to Multimedia Systems',
    crosslisted ->> ise334,
    offerings ->> {
                    _#[semester    ->  fall(2001),
                         instructors ->> {tony, rong},
                         enrollment  ->  182,
                          waiting     ->  0,
                          need_grad_ta   ->  2,
                          need_ug_ta     ->  3,
                          ug_ta       ->> {
                                 'John, Public (jp@aol.com)',
                                 'Blow, Joe (jblow@ic.sunysb.edu)'
                                            }
                      ]
                   }
 ]
```

Variation in structure

Instructor Data

ted:lecturer[*name*->'Ted Teng'].
robkelly:lecturer[*name*->'Rob Kelly'].

ari:faculty[*name* -> 'Ari Kaufman', *section587* -> 19].
skiena:faculty[*name* -> 'Steve Skiena'].
kifer:faculty[*name* -> 'Michael Kifer', *section587* -> 9].

Variation in structure

Main Meta-Query

```
%% Sorted report main entry. Arguments:
%%        PrintMethod (what info about students to print)
%%        SortSpec (how to sort output)
%%        QuerySpec (which students to retrieve)
Class[#sprintquery(PrintMethod,SortSpec,QuerySpec)] :-
        L = collectset{Var | (O:Class)@students,
                            %% Bind Query/SortSpec to the same oid
                            SortSpec = sortSpec(Path,O,Val),
                            QuerySpec = querySpec(O,QueryCond),
                            Path,
                            QueryCond,
                            Var = Val-O
                  },
        keysort(L,SortedL)@prolog(),
        Class[#printlist(PrintMethod,SortedL)],
        length(SortedL,Count)@prolog(basics),
        format('Total ~w count: ~w~w', [Class, Count])@prolog().
```

Call in students module

Use of reification

Call to prolog module

Pragmatics

- Very flexible module system
  - Can load programs into modules on-the-fly
  - Can create modules at run time and put a program into it
  - Prolog environment with its own module system is viewed as a set of “prolog modules”
  - FLORA-2 can call Prolog modules and Prolog can call FLORA-2 modules
- Anonymous OIDs (also useful in RDF and the like)
- Input/Output – use Prolog’s
- Prolog cuts – non-logical, but useful

Transaction Logic

Transaction Logic

- A logic of change
- Unlike temporal/dynamic/process logics, it is also a logic for *programming* (but can be used for *reasoning* as well)
- In the object-oriented context:
  - A logic-based language for programming object behavior (methods that change object state)
- [Bonner&Kifer, TCS 1995 and later]

What’s Wrong with Logics of Change?

- Designed for reasoning, *not* programming
  - E.g., situation calculus, temporal, dynamic, process logics
- Typically lack such basic facility as subroutines
- None became the basis for a reasonably useful programming language

What’s Wrong with Prolog?

- *assert*/*retract* have no logical semantics
- Non-backtrackable
- Prolog programs with updates are the hardest to write, debug, and understand

Example: Stacking a Pyramid

```
stack(0,X).
stack(N,X) :-- N>0, move(Y,X), stack(N-1,Y).

move(X,Y) :-- pickup(X), putdown(X,Y).
pickup(X)   :-- clear(X), on(X,Y), retract(on(X,Y)), assert(clear(Y)).
putdown(X,Y) :-- wider(Y,X), clear(Y), assert(on(X,Y)), retract(clear(Y)).
```

Action:

?– stack(18,block32).   % stack 18-block pyramid on top of block 32

Note:

Prolog *won't* execute this very natural program correctly!

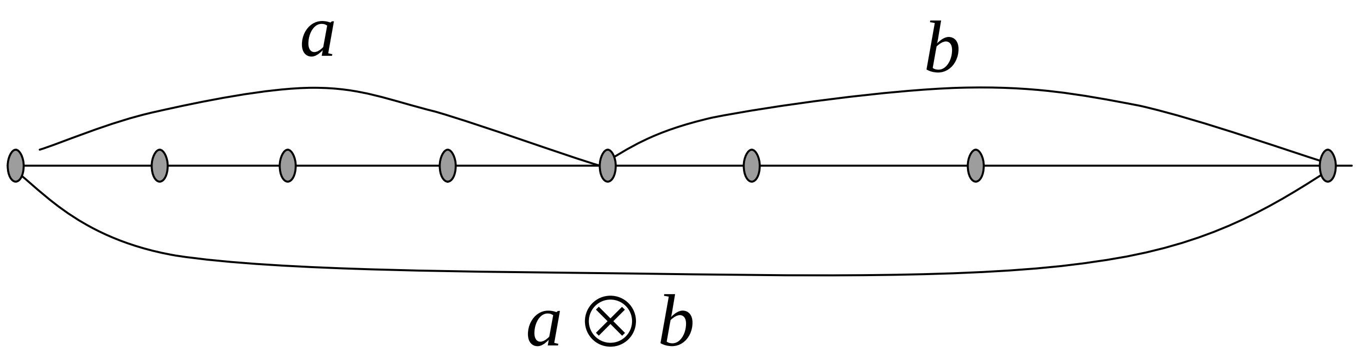
Syntax

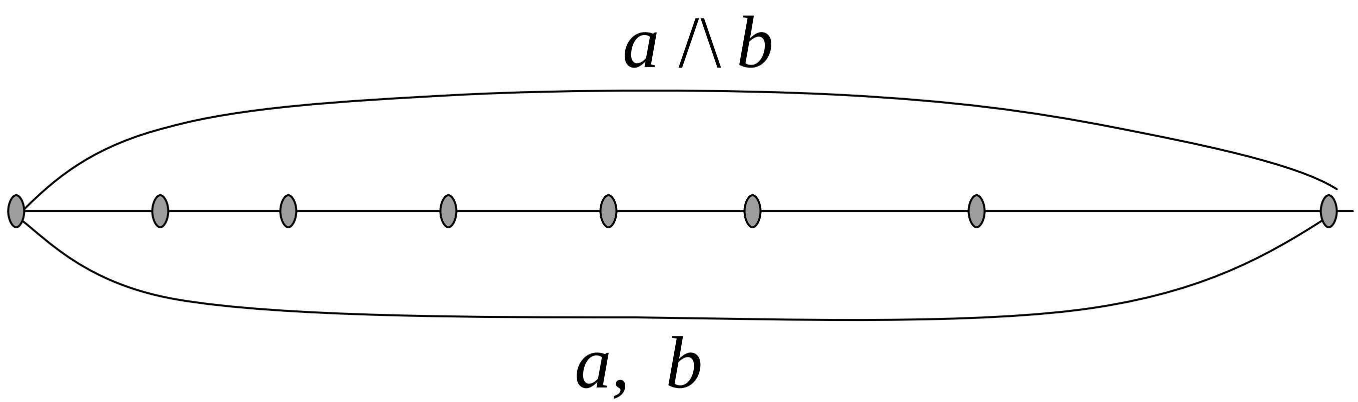
- Serial conjunction, $\otimes$
  - $a \otimes b$ – do a then do b
- The usual $\wedge$, $\vee$, $\neg$, $\forall$, $\exists$ (but with a different semantics)
  - $a \vee (b \otimes c) \wedge (d \vee \neg e)$
- $a \leftarrow b \equiv a \vee \neg b$
  - Means: to execute a must execute b

Semantics

- The basic ideas
  - *Execution path* ≡ sequence of database states
  - Truth values over paths, not over states
  - Truth over a path ≡ *execution* over that path
  - *Elementary state transitions* ≡ propositions that cause a priori defined state transitions

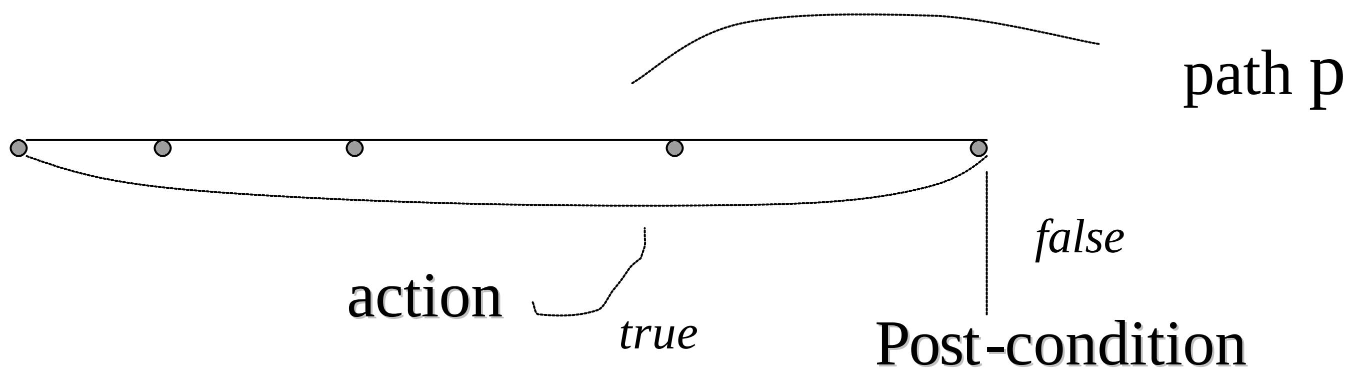
Semantics





Semantics

The semantics makes updates logical



If action is *true*, but postcondition *false*, then
action ⊗ postcondition is *false* on p.

In practical terms: *updates are undone on backtracking*.

Proof Theory

- To prove f, tries to find a path, π, where f is true
- => *executes* f as it proves it (and changes the underlying database state from the initial state of π to the final state of π)

Pyramid Building (again)

stack(0,X).
stack(N,X) :-- N>0 ⊗ move(Y,X) ⊗ stack(N-1,Y).

move(X,Y) :-- pickup(X) ⊗ putdown(X,Y).
pickup(X) :-- clear(X) ⊗ on(X,Y) ⊗ delete(on(X,Y)) ⊗ insert(clear(Y)).
putdown(X,Y) :-- wider(Y,X) ⊗ clear(Y) ⊗ insert(on(X,Y)) ⊗ delete(clear(Y)).

?– stack(18,block32). % stack 18-block pyramid on top of block 32

- Under the Transaction Logic semantics the above program does the right thing

Constraints

- Can express not only execution, but all kinds of sophisticated constraints:

?– stack(10, block43)

$\wedge\ \forall X,Y\ ((move(X,Y) \otimes color(X,red)) \Rightarrow \exists\ Z(color(Z,blue) \otimes move(Z,X)))$

Whenever a red block is stacked, the next block stacked must be blue

- Has been shown useful for process modeling (Davulcu et. al. PODS-97, Thesis 2002, Senkul et. al. VLDB-02)

Reasoning

- Can be used to *reason* about the effects of actions [Bonner&Kifer 1998]

Integration into FLORA-2

- FLORA-2 provides
  - btinsert{Template | Query}
  - btdelete{Template | Query}
  - bterase{Template | Query}
  - And other “elementary” updates that behave according to the semantics of Transaction Logic
- FLORA’s “,” then serves as $\otimes$ and “;” as $\vee$, which allows us to build larger and larger transactions

Pragmatics

- FLORA-2 also provides non-logical updates that are similar, but more powerful to Prolog’s
- Logical updates + Prolog cuts
  - can be used to implement “partial commit” of transactions
  - have perfect sense in databases, but (unfortunately) not in Transaction Logic

Conclusion

- FLORA-2
  - ≡ F-logic + HiLog + Transaction Logic + XSB
  - ≡ Logic + Objects + Meta-programming

    + State changes + Implementation

Future Work

- XSB: has a number of problems that spoil the party
  - Limitations on cuts (will be fixed in the future)
  - Problems with updates
  - Bad interaction between tabling and updates
- FLORA-2:
  - Interfaces to databases, C, Java
  - Additional features: encapsulation, various optimizations