CS Lunch today in Frary South

Lecture 19: Modules

CSC 131
Spring, 2019

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Specification

- Definitions should not depend on implementation details.
- Constants, types, variables, and operations
  - Behavior must be specified abstractly
    - pre- and postconditions
    - Axioms and rules: pop(push(S,x)) = S,
      if not empty(S) then push(pop(S), top(S)) = S
  - Details of implementation provided elsewhere
  - Data + Operations (+ equations) = Algebra

Implementation

- Details of representation and implementation of operations.
- Details not accessible outside unit.

Modules

- Reusable modules:
  - Separate, but not independent compilation
  - Maintain type checking
  - Control over export and import of names

Representation Independence & Information Hiding

- Choice of representation doesn't affect computation. E.g., rationals.
- If represent new type in terms of old:
  - Rep may have values not corresponding to new type. E.g., (3,0)
  - Rep may have several values corresponding to same abstract value. E.g., (1,2) and (2,4).
  - Values of new type can be confused w/values of rep type.

Last Time

- Simula 67
- Clu
- Ada

Modula 2

- Similar to Ada except
  - no generics
  - no "private" section
- Require all private types to take same amount of space -- a pointer

```
DEFINITION MODULE stackMod;
IMPORT element FROM elementMod;
    TYPE stack;
    PROCEDURE make_empty (VAR S : stack);
    PROCEDURE push (VAR S : stack; X : element);
    PROCEDURE pop (VAR S : stack; X: element);
    PROCEDURE empty (S : stack): BOOLEAN;

END stackMod.

IMPLEMENTATION MODULE stackMod;
    TYPE stack = POINTER TO RECORD
        space   : array[1..length] of element;
        top     : INTEGER;
    END;

    PROCEDURE make_empty (VAR S : stack);
    BEGIN
        S^.top := 0;
    END make_empty ;

    ...  (* can be start-up code too to initialize *)
END stackMod;
```

Ada vs. Modula 2

- Representations fairly similar
  - can import from other units (modules or packages) and export items to other units.
- For external representations not much difference.
- Private types in Ada vs opaque types in Modula.

Ada vs. Modula 2

- Use of opaque types require Pointer types
- Representation changes
  - in Ada forces recompilation of user programs
  - Not in Modula 2
- Internal reps of ADT's almost identical.
- Ada more flexible via generic routines -
  - can parameterize on types and sizes
  - Create new instances of packages

Easier if Uniform Reps

- LISP, Scheme, ML, Haskell, Clu, Eiffel, and Java have uniform reps for values so can share same code.
- Non-uniform representations:
  - Ada requires different implementation, but still type-checks statically.
  - C++ type-checks only when instantiated
- Automatic boxing and unboxing now helps with primitive types in Java and C#.

Modules in Haskell

- Module:
  - Control namespace
  - define abstract data types.
  - No nesting of modules
- Examples: PcfLexer.hs, ParsePCF.hs
  - Name starts with cap
  - list functions and types (including constructors) to be exported.
  - Make more abstract by leaving off constructors
  - if no export list, then all exported

Importing

- Module must be explicitly imported
  - Can narrow more by listing items to be imported
    - import PcfLexer(getTokens, Token(ID,NUM))
  - If name conflicts, can "import qualified" and access:
    - PcfLexer.getTokens
  - "hiding" clause can hide imported items.
  - "as" clause can rename imported features

ML

- datatype like Haskell data declaration.
- No information hiding

ML Modules

- SML has two sub-languages:
  - Core -- programming in the small
    - details of types and expressions
  - Modules -- programming in the large -- architecture.
    - group defs of types & expressions into units w/interfaces
- Separate interfaces (signatures) from implementations (structures)
  - Explicitly typed!
  - Can reveal implementations if want.

Signature

```
signature INTSTACKSIG =
  sig
    type intstack;
    exception stackUnderflow;
    val emptyStk: intstack;
    val push: int -> intstack -> intstack;
    val pop: intstack -> intstack;
    val top: intstack -> int;
    val IsEmpty: intstack -> bool;
  end;
```

Structure

optional

```
structure IntStack: INTSTACKSIG =
  struct
    type intstack = int list;
    exception stackUnderflow;

    val emptyStk = [];

    fun push (e:int) (s:intstack) = (e::s);

    fun pop [] = raise stackUnderflow
      | pop (e::s) = s;
     ...

     fun extra ...  (* not visible outside *)
   end;
```

Accessing Structure

- IntStack.push 12 IntStack.emptyStk
- open IntStack;
  push 12 emptyStk;
- Considered bad style to open outside structure.
- Rather than open, rename:
  - val push = IntStack.push;
    val emptyStk = IntStack.emptyStk;

Ascription

- `structure IntStack: INTSTACKSIG = ...`
  - lets type definitions escape - transparent
  - hides extra features
- `structure IntStack:> INTSTACKSIG = ...`
  - also hides type definitions - opaque
- Can further restrict structure to create "views" by giving new name and signature
  - `structure ResStack:> RESSTACKSIG = IntStack`

More ML Modules

- Modules may be nested -- helping modules
- Functors: Modules parameterized by other modules.
- Supports code reuse -- apply to many different structures

Functor Examples

```
signature EQ =
   sig
      type t
      val eq : t * t -> bool
   end;

functor PairEQ(P : EQ) : EQ = struct
  type t = P.t * P.t
  fun eq((x,y),(u,v)) = P.eq(x,u) andalso P.eq(y,v)
end;

structure IntEQ : EQ = struct
      type t = int
      val eq : t*t->bool = (op =)
    end;

structure IntPairEQ : EQ = PairEQ(IntEQ);
```

What is this like in Haskell?

Module Languages

- Signatures like types
  - Describe families of structures
  - Make functor argument specification possible
  - But ... components can themselves be types
- Structures like records
  - But ... can contain types
- Complications:
  - Opacity sometimes requires "sharing constraints"
  - force types in parameters to match up -- omit details

Evaluating ML Modules

- Limitations:
  - Functors are first-order only
    - can't be applied to or return functor
  - Structures & functors are second-class values
    - Compile-time structures, can't be constructed or stored at run-time.

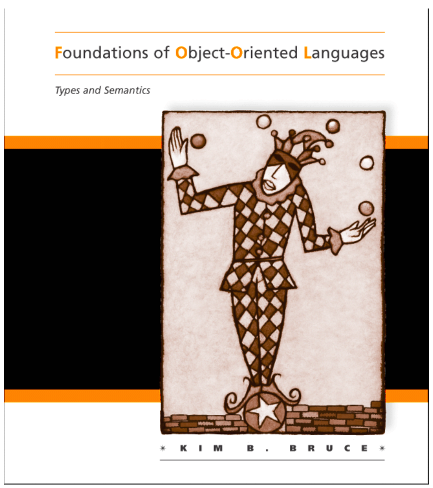
Key Features of ADT's

- Encapsulation of all features in one place
- Information hiding -- explicit control over what imported and exported.
- Generally separate specification and implementation (except in Clu)
  - Separately compiled (except in ML)
- Ada, Clu, and ML provide parameterized modules.

Subtyping: Making it easier to reuse code!

Subtyping

- Can be added to non-OO languages
- Matching structures and signatures similar
  - but more restricted.
- Provides support for using values from new types in old (unexpected) contexts



- Read Chapter 5, Understanding Subtypes, from Foundations of Object-Oriented Languages: Types and Semantics, Bruce (MIT Press, 2002). *Available on course "links" page.* On-line at:
  - http://www.cs.pomona.edu/~kim/FOOPL/chap5.pdf

Subtype Polymorphism

S is a *subtype* of T, written S <: T,

iff

a value of type S can be used in any context expecting a value of type T,

i.e., S can masquerade as a T.

Subsumption: e: S & S <: T ⇒ e: T.

Immutable Records

Records without field update (like Haskell/ML):

Sandwich = { bread: BreadType;
filling: FoodType }

s: Sandwich = { bread = rye;
filling = pastrami }

Only operation is extracting field:

… s.filling …

Specializing Record Types

CheeseSandwich = {bread: BreadType;
filling: CheeseType;
sauce: SauceType}

c_s: CheeseSandwich = {bread = white;
filling = cheddar;
sauce = mustard}

Subtyping Immutable Records

If r: $\{ l_i : T_i \}_{1 \le i \le k}$ then expect r. $l_i : T_i$.

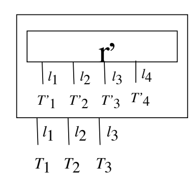
When is $\{ l_i : T'_i \}_{1 \le i \le n} <: \{ l_i : T_i \}_{1 \le i \le k}$?

Suppose r': $\{ l_i : T'_i \}_{1 \le i \le n}$

When can r' *masquerade* as elt of $\{ l_i : T_i \}_{1 \le i \le k}$?

Need $r'.l_i : T_i$.

Masquerading



$\{ l_i : T'_i \}_{1 \le i \le n} <: \{ l_i : T_i \}_{1 \le i \le k}$

iff

$k \le n$ and for all $1 \le i \le k$, $T'_i <: T_i$.