

CS:5810

Formal Methods in Software Engineering

Alloy Modules

Copyright 2007-14, Laurence Pilard, and Cesare Tinelli.

These notes are copyrighted materials and may not be used in other course settings outside of the University of Iowa in their current form or modified form without the express written permission of one of the copyright holders. During this course, students are prohibited from selling notes to or being paid for taking notes by any person or commercial firm without the express written permission of one of the copyright holders.

Alloy Modules

- Alloy has a module system that allows the **modularization** and **reuse** of models
- A **module** defines a model that can be incorporated as a **submodel** into another one
- To facilitate reuse, modules may be **parametric** in one or more signatures

Examples

```
module util/relation
  -- r is acyclic over the set s
  pred acyclic [r: univ->univ, s: set univ] {
    all x: s | x !in x.^r
  }
```

```
module family
  open util/relation as rel
  sig Person {
    parents: set Person
  }
  fact { acyclic[parents, Person] }
```

Examples

```
module util/relation
  -- r is acyclic over the set s
  pred acyclic [r: univ->univ, s: set univ] {
    all x: s | x !in x.^r
  }
```

```
module fileSystem
  open util/relation as rel
  sig Object {}
  sig Folder extends Object {
    subFolders: set Folder
  }
  fact { acyclic[subFolders, Folder] }
```

Module Declarations

- The first line of every module is a **module header**

```
module modulePathName
```

- The module can **import** another module with an **open** statement immediately following the header

```
open modulePathName
```

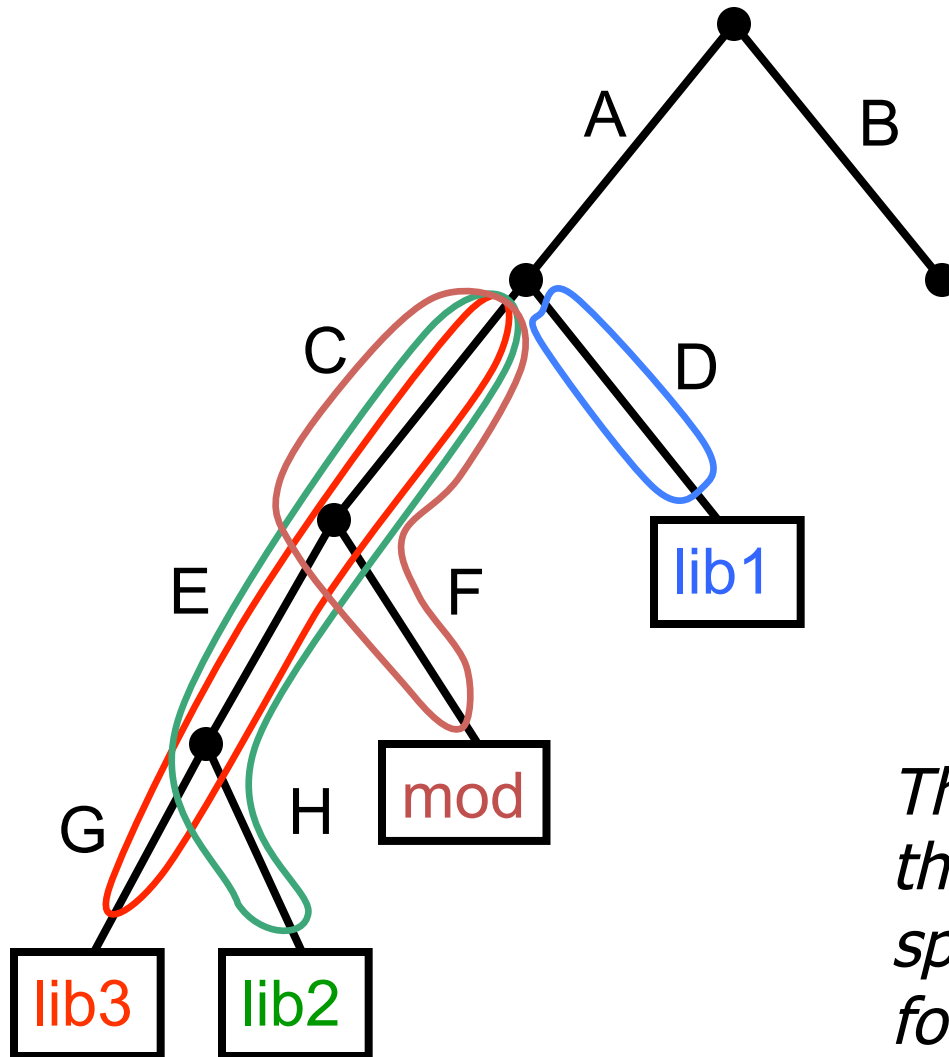
Module Definition

- A module **A** can import a module **B** which can in turn import a module **C**, and so on
- You can understand **open** statements informally as textual inclusion
- No cycles in the import structure are permitted

ModulePathName Definition

- Every module has a path name that must match the path of its corresponding file in the file system
- The module's path name can range
 - from just the name of the file (without the .als extension)
 - to the whole path from the root
- The root of the path in the importing module header is the root of the path of every import

Examples



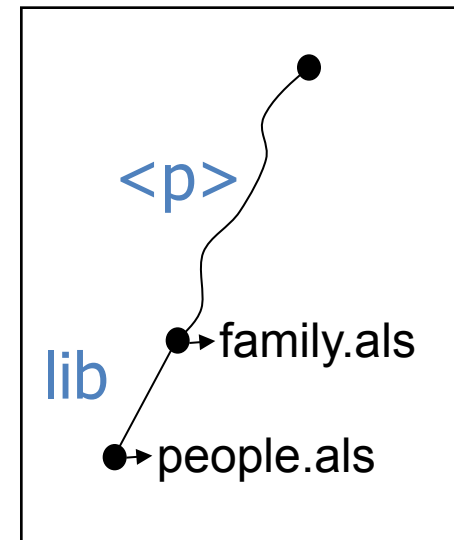
model C/F/mod
open D/lib1
open C/E/H/lib2
open C/E/G/lib3

The modulePathName in the module header just specifies the root directory for every imported file

ModulePathName definition

- Example:

```
module family
  open lib/people
```

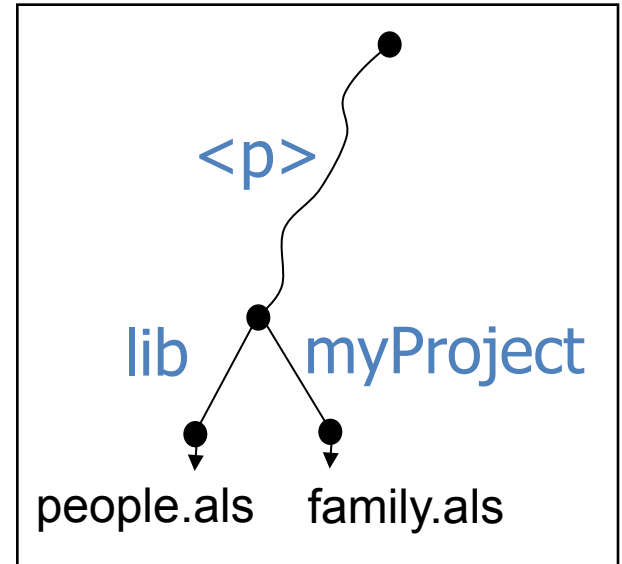


- If the path of `family.als` is `<p>` in the file system then the Alloy Analyzer will search `people.als` in `<p>/lib/`

ModulePathName definition

- Example:

```
module myProject/family
open lib/people
```



- If the path of `myProject` is `<p>` in the file system then AA will search `people.als` in `<p>/lib/`

Predefined Modules

- Alloy 4 comes with a library of predefined modules
- Any imported module will actually be **searched first** among those modules
 - Examples:
 - `book/chapter2/addressBook1a`
 - `util/relation`
 - `examples/puzzles/farmer`
- Failing that, the rules in the previous slides apply

As

- When the path name of an import include / (*i.e.* it is not just the name of a file but also a path)
- Then you **must** give a shorter name to the module with **as**

```
open util/relation as rel
```

Name Clashes

- Modules have their own **namespaces**
- To avoid name clashes between components of different modules, we use **qualified names**

```
module family
  open util/relation as rel
  sig Person { parents: set Person }
  fact { rel/acyclic [parents] }
```

Parametric Modules

- A model `m` can be **parametrized** by one or more signature parameters `[x1, ..., xn]`
- Any importing module must instantiate each parameter with a signature name
- The effect of opening `m[S1, ..., Sn]` is that of importing a copy of `m` with each signature parameter `xi` replaced by the signature name `Si`

Parametric Modules Example

```
module graph[node] // 1 signature param
  open util/relation as rel
```

```
  pred dag[r: node -> node] {
    rel/acyclic[r, node]
  }
```

```
module family
  open util/graph[Person] as g
  sig Person { parents: set Person }
  fact { dag[parents] }
```

The Predefined Module `Ordering`

- Creates a single linear ordering over the atoms in `S`

```
module util/ordering[S]
```

- It also constrains all the atoms to exist that are permitted by the scope on `S`
 - If the scope on a signature `S` is 5, opening `ordering[S]` will force `S` to have 5 elements and create a linear ordering over those five elements

The Module Ordering

```
module util/ordering[S]
private one sig Ord {
  First, Last: S,
  Next, Prev: S -> !one S
}
fact {
  // all elements of S are totally ordered
  S in Ord.First.*Next
  ...
}
```

The Module Ordering

```
// constraints that actually define the
// total order
Ord.Prev = ~(Ord.Next)
one Ord.First // redundant with signature decl.
one Ord.Last // redundant with signature decl.
no Ord.First.Prev
no Ord.Last.Next
```

The Module Ordering

```
//  
//  
(one S and no S.(Ord.Prev) and no S.(Ord.Next))  
or  
//  
all e: S |  
  //  
  //  
  (e = Ord.First or one e.(Ord.Prev)) and  
  
  //  
  //  
  (e = Ord.Last or one e.(Ord.Next)) and  
  
  //  
  (e !in e.^ (Ord.Next))
```

The Module Ordering

```
// either S has exactly one atom,  
// which has no predecessors or successors ...  
(one S and no S.(Ord.Prev) and no S.(Ord.Next))  
or  
// or ...  
all e: S |  
  // ... every element except the first has one  
  // predecessor, and ...  
  (e = Ord.First or one e.(Ord.Prev)) and  
  
  // ... every element except the last has one  
  // successor, and ...  
  (e = Ord.Last or one e.(Ord.Next)) and  
  
  // ... there are no cycles  
  (e !in e.^(Ord.Next))
```

The Module Ordering

```
//  
fun first: one S { Ord.First }  
//  
fun last: one S { Ord.Last }  
//  
//  
fun prev [e: S]: 1one S { e.(Ord.Prev) }  
//  
//  
fun next [e: S]: 1one S { e.(Ord.Next) }  
//  
fun prevs [e: S]: set S { e.^(Ord.Prev) }  
//  
fun nexts [e: S]: set S { e.^(Ord.Next) }
```

The Module Ordering

```
// first
fun first: one S { Ord.First }

// last
fun last: one S { Ord.Last }

// return the predecessor of e, or empty set if e is
// the first element
fun prev [e: S]: lone S { e.(Ord.Prev) }

// return the successor of e, or empty set of e is
// the last element
fun next [e: S]: lone S { e.(Ord.Next) }

// return elements prior to e in the ordering
fun prevs [e: S]: set S { e.^(Ord.Prev) }

// return elements following e in the ordering
fun nexts [e: S]: set S { e.^(Ord.Next) }
```

The Module Ordering

```
// e1 is before e2 in the ordering  
pred lt [e1, e2: S] { e1 in prevs[e2] }
```

```
// e1 is after than e2 in the ordering  
pred gt [e1, e2: S] { e1 in nexts[e2] }
```

```
// e1 is before or equal to e2 in the ordering  
pred lte [e1, e2: S] { e1=e2 || lt [e1,e2] }
```

```
// e1 is after or equal to e2 in the ordering  
pred gte [e1, e2: S] { e1=e2 || gt [e1,e2] }
```

The Module Ordering

```
// returns the larger of the two elements in the  
// ordering
```

```
fun larger [e1, e2: S]: S  
    { !t[e1,e2] => e2 else e1 }
```

```
// returns the smaller of the two elements in the  
// ordering
```

```
fun smaller [e1, e2: S]: S  
    { !t[e1,e2] => e1 else e2 }
```

```
// returns the largest element in es  
// or the empty set if es is empty
```

```
fun max [es: set S]: !one S  
    { es - es.^(Ord.Prev) }
```

```
// returns the smallest element in es  
// or the empty set if es is empty
```

```
fun min [es: set S]: !one S  
    { es - es.^(Ord.Next) }
```