

# 22c:181 / 55:181

# Formal Methods in Software Engineering

## Alloy Modules

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# Alloy Modules

- Alloys 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
```

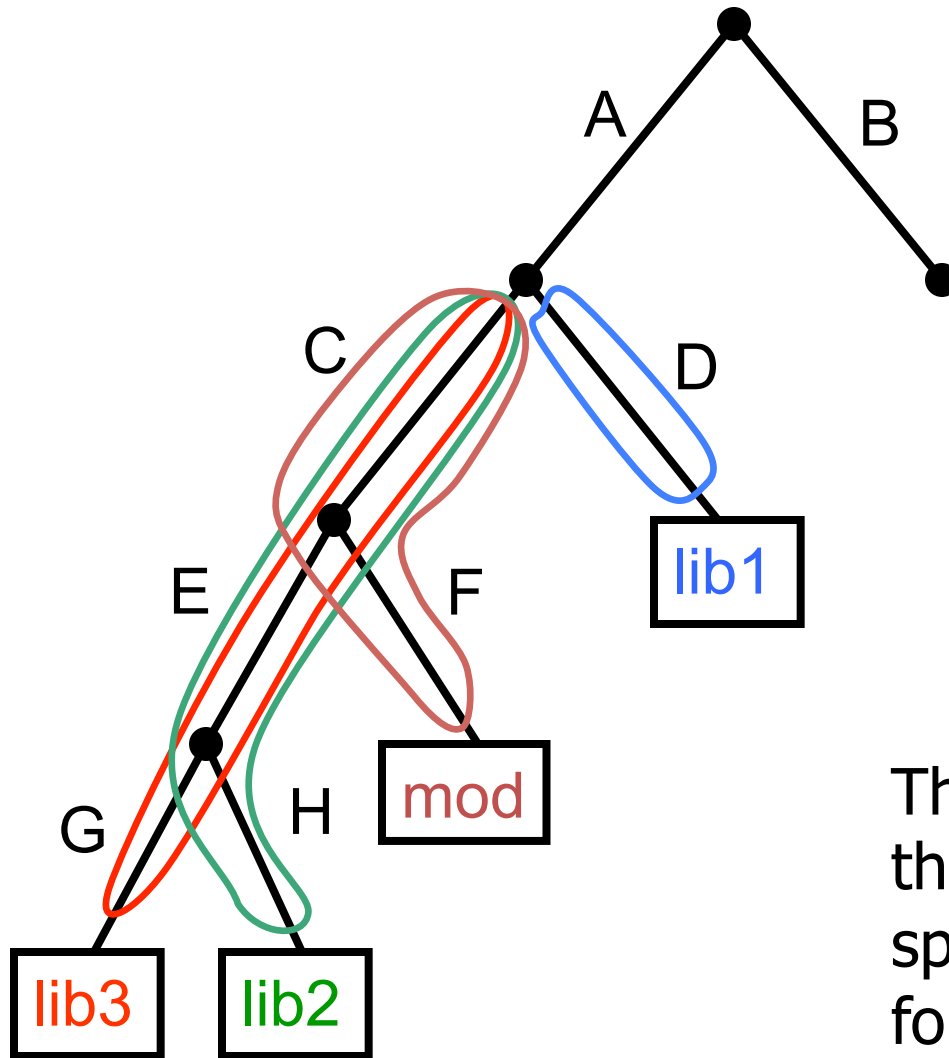
# Module Definition

- A module A can import a module B that 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

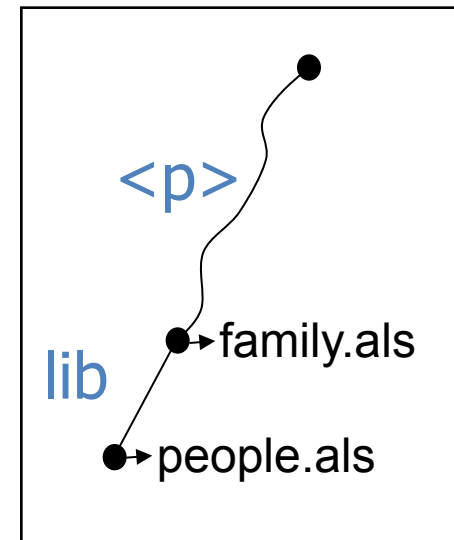
The moduleName in the module header just specifies the root directory for every imported file



# ModulePathName definition

- Example:

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

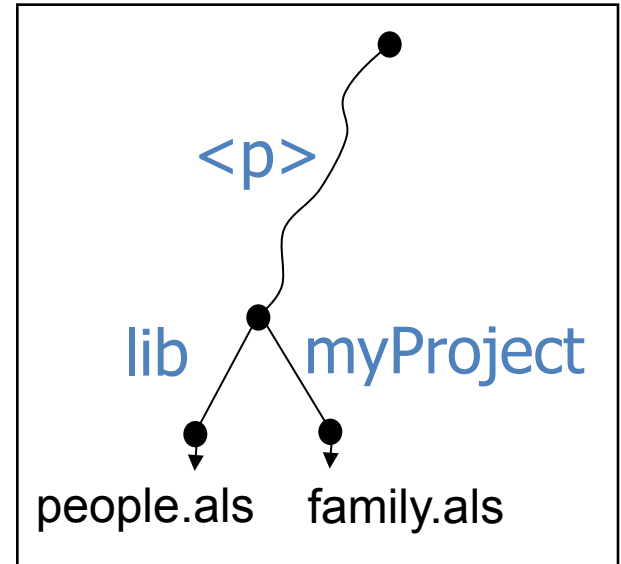


- If the path of `family.als` is `<p>` in the file system then the Alloy Analyzer will search `people.als` in `<p>/lib/`

# 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  $[x_1, \dots, x_n]$
- Any importing module must instantiate each parameter with a signature name
- The effect of opening  $m[s_1, \dots, s_n]$  is that of importing a copy of  $m$  with each signature parameter  $x_i$  replaced by the signature name  $s_i$

# 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 `elem`.
  - 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
one Ord.Last
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]: !one S { e.(Ord.Prev) }  
  
//  
//  
fun next [e: S]: !one 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) }
```