Formal Methods for Java

Lecture 10: Ownership and Friendship

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- The following invariant should always hold:
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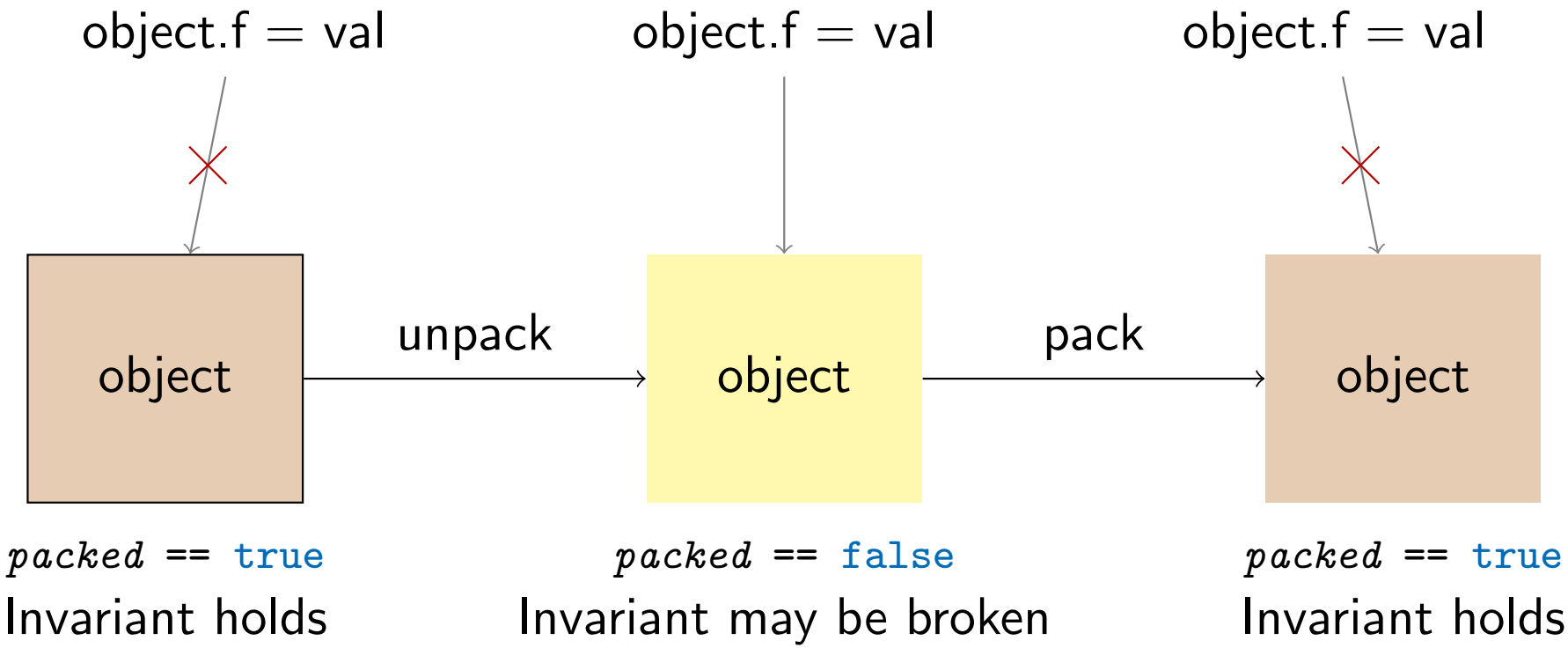
- The caller has to ensure that the objects he uses are packed.

The pack/unpack Mechanism

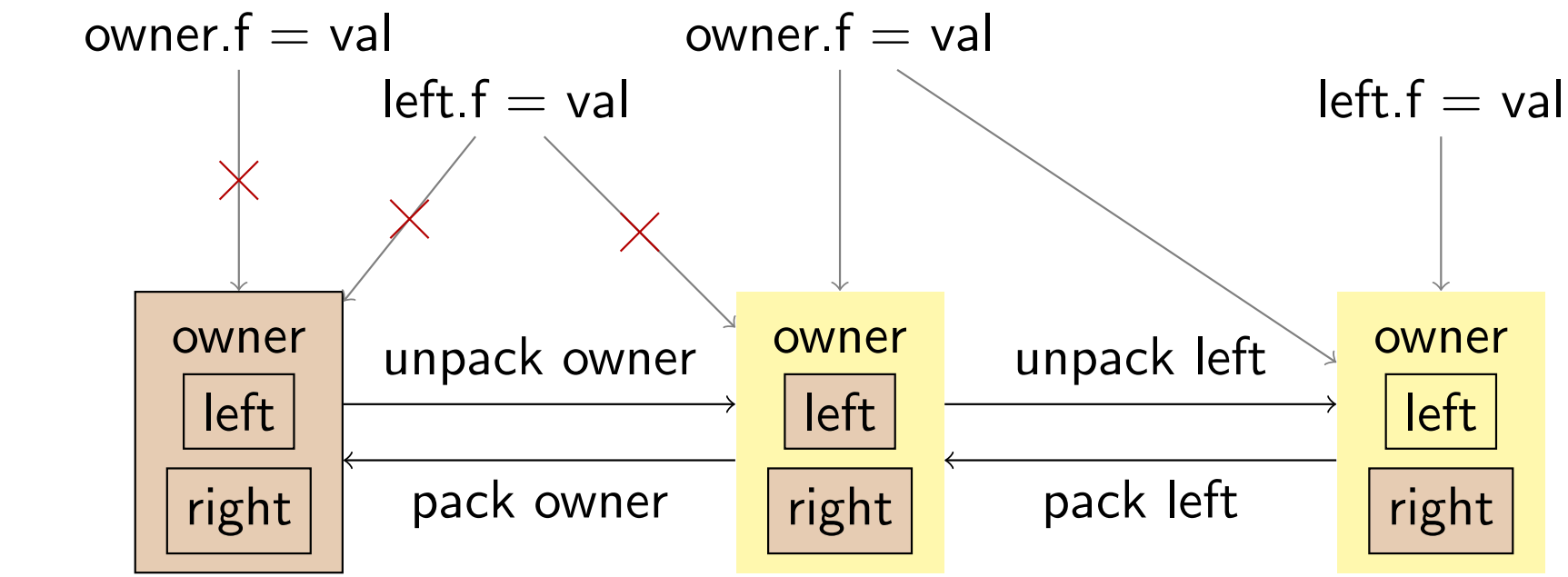


- An object must be unpacked before fields may be accessed.
- The invariant has to hold only while object is packed.
- The invariant may only depend on fields of the object.

Adding Ownership

- The invariant may also depends on fields of other classes.
- The class must own a class to depend on its fields.
- A class can only be unpacked and changed if the owner is unpacked.

Ownership and pack/unpack



- The owner must be unpacked before an owned object can be unpacked.
- The invariant of owner may depend on owned objects.

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- An invariant of a friend can depend on fields of granters.
- The friend class must define update guards for the fields it depends on.
- The granter class has a list of friends that depend on fields.
- A field may be changed if the update guards of all friends holds.

Friendship

Friendship is not symmetric. The allies are:

- Granter G that gives rights to depend on a field.

```
class G {
   int f;
   friend C reads f
}
```

- Friend C whose invariant depends on a field.

```
class C {
  invariant packed ==> ... g.deps.has(this) && g.f == ...
  guard g.f := val by ...
}
```

Every class that changes a field of G has to check the friend's guard.

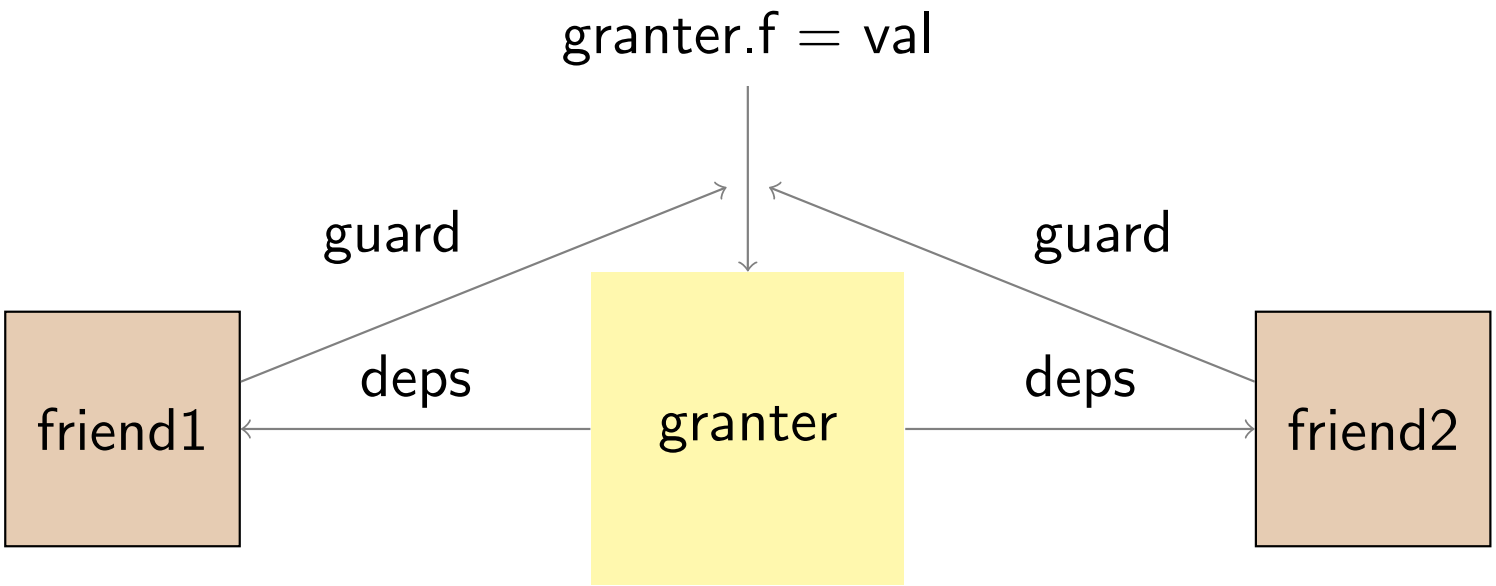
Update Guard and Invariant

```
class FriendClass {
  //@ invariant packed ==> friendInvariant(granter.field)
  //@ guard granter.field := val by updateGuardForField(granter, val);
}
```

The update guard must guarantee that the invariant is not invalidated:

```
friends.packed && friendInvariant(granter.field)
  && updateGuardForField(granter, val) ==> friendInvariant(val)
```

Field update on Friends



- Friend's invariant can depend on granted fields.
- Access to granted fields is checked against update guards.
- A granter can have many friends.
- All current friends must be checked.
- The friend objects can be packed or unpacked.

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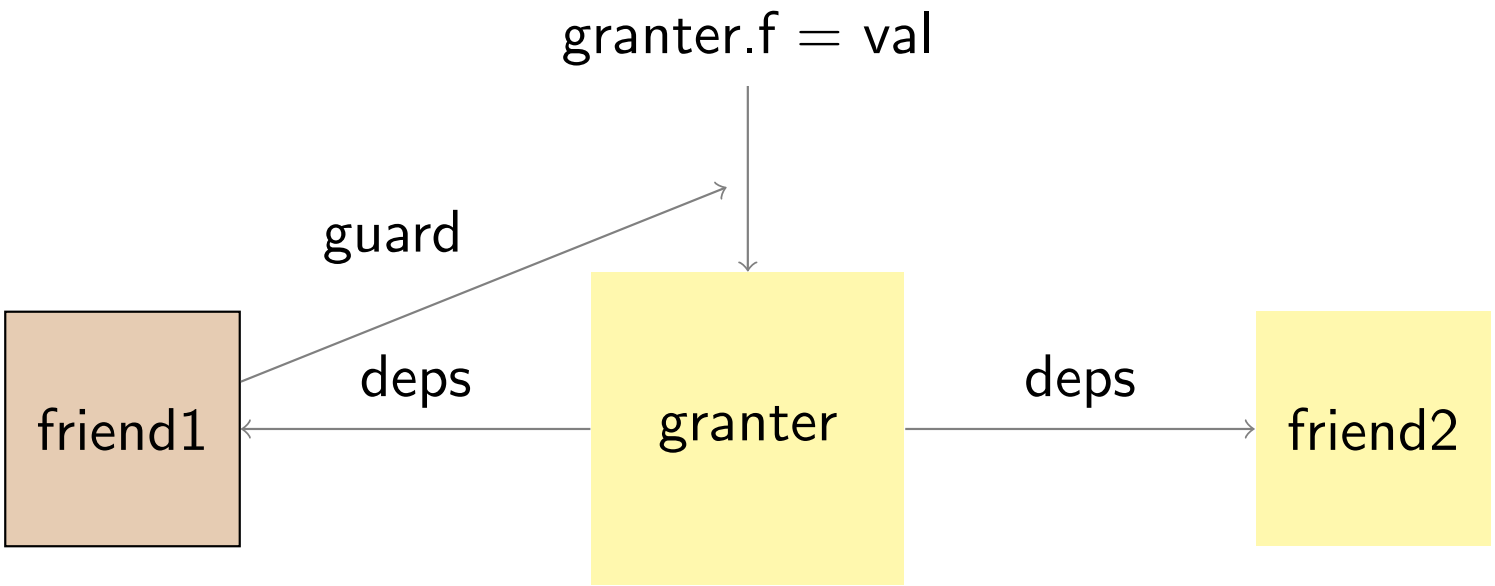

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- A granter can have many friends.
- All current friends must be checked.
- The friend objects can be packed or unpacked.
- Guard is not checked for unpacked friends.

Friendship Example

```
static class Node {
  Node next, prev;
  Object value;
  //friend Node reads next,prev,deps

  //guard next.next = val by next != prev;
  //guard prev.prev = val by prev != next;

  /*@invariant packed ==>
      (next != null && prev != null &&
      deps.equals(new JMLObjectSet().insert(next).insert(prev)) &&
      next.deps.has(this) && next.prev == this &&
      prev.deps.has(this) && prev.next == this);
  */
}
```

Friendship Example (continued)

```
static class Node {
  //@requires n.prev == n.next == n;
  public void add(/*@non_null*/ Node n) {
    //@unpack n
    //@unpack this
    //@unpack this.prev
    n.prev = this.prev;
    n.next = this;
    this.prev.next = n;
    this.prev = n;
    //@set n.deps = new JMLObjectSet().insert(this).insert(this.prev);
    //@set this.deps = this.deps.remove(prev).add(n);
    //@set prev.deps = prev.deps.remove(this).add(n);
    //@pack this.prev
    //@pack this
    //@pack n
  }
}
```

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  x`.`*field* if *x*`.`*owner*`...`*owner* `==` `this` can be proven.

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Only the following field accesses are allowed in an invariant:

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  `this.`*`field`* for all fields.
- A field of a (transitively) owned class:
  `x.field` if *`x.owner...owner`* == `this` can be proven.
- A field of a granter class:
  `x.field` if *`x.deps.has(`*`this`*`)`* can be proven.

Why Is This Sound?

We need to show the following invariant holds for each instance `this` at every time:

$$\texttt{this}.\mathit{packed} \texttt{ ==> this.invariant}$$

A field access $\mathit{obj}.f{=}\mathit{val}$ can change the truth of invariant if:

- obj == `this` is the current class:
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$$\texttt{this}.\mathit{packed} \implies \texttt{this}.\texttt{invariant}$$

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- $\mathit{obj}.\mathit{owner}...\mathit{owner}$ == `this` (a field of an owned class):
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- $\mathit{obj}.\mathit{deps}.\mathit{has}(\texttt{this})$ (a field of a granter class):
  Then the update guard $\mathit{this}.\mathit{guard}(f, \mathit{val})$ is true. If $\mathit{this}.\mathit{packed}$ is true, the invariant held before. Hence it must hold afterwards.