JavaD: Bringing Ownership Domains to Mainstream Java

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Ph.D. Project Presentation
17-754: Analysis of Software Artifacts

Some slides adapted from a talk by Neelakantan Krishnaswami

Why Ownership Domains?

- "The big lie of object-oriented programming is that objects provide encapsulation" (Hogg)
- Aliasing can cause a failure of encapsulation

```
class JavaClass {
    private List signers;

    public List getSigners() {
           return this.signers;
    }
}

// (Malicious) clients can mutate signers field!
class MaliciousClient extends ... {
    public void addTrojanHorse(JavaClass c)
    {
           List signers = c.getSigners();
           signers.add( this );
    }
}
```

Aliasing is a necessary evil

- Aliasing cannot be eliminated
  - Object-oriented design patterns rely on it
- Aliasing can/must be controlled
  - Need for language support for this
- Several solutions proposed
  - Ownership Domains (AliasJava)
- Many paper-only designs
  - AliasJava notable exception
- Few evaluation on large case studies
  - AliasJava, Universes case studies

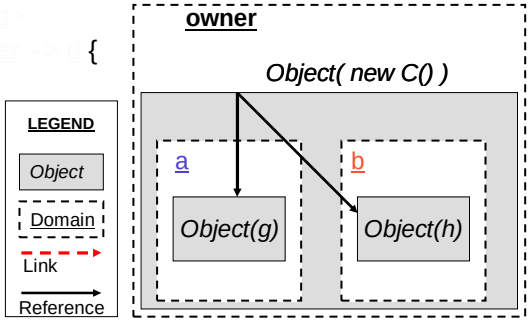
Ownership Domains Defined

- "Object ownership (instance encapsulation) ensures that objects cannot be leaked beyond an object or collection of objects which own them" (Alex Potanin)
- Ownership domain = region of the heap
- How does it control aliasing?
  - Within a given domain, there *can be* aliasing
  - *No* aliasing between two given domains
  - *Explicit* permissions for cross-domain access (creation, reference, etc)

Ownership domains

```
class C <owner, d>
    assume owner -> d {
domain a, b;
link b -> d;

Object< d > f;
Object< a > g;
Object< b > h;
}
```



- Every object is in exactly one domain
- Every object can have one or more domains
  - Domains a and b are declared in class *C*
  - *Object*< a > *g* means object *g* is in domain a

Ownership domain parameters

```
class C <owner, d>
    assume owner -> d {
domain a, b;
link b -> d;

Object< d > f;
Object< a > g;
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```
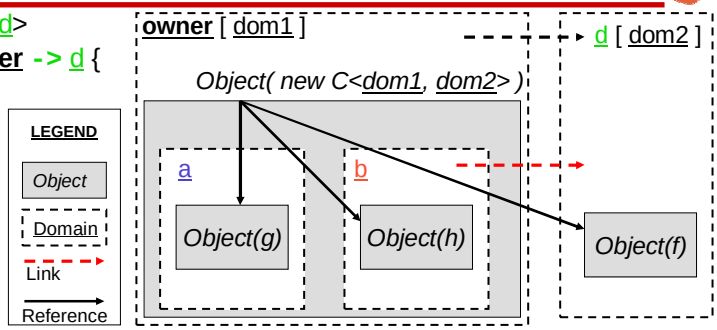



- Domain parameters use syntax similar to type parameters
  - d is a domain parameter
- Link declarations specify that objects in domain b have permission to access objects in domain d

AliasJava (by Aldrich et al.)

- Concrete implementation of Ownership Domains
  - Language extension to Java (Barat infrastructure)
  - Basic tool support (no debugger!)
- Keyword **domain** define ownership domains
- Java 1.5 type parameters syntax to define
  - Domain parameters: `class Sequence<Towner>`
  - Binding actuals to formals: `Sequence<owned> seq;`
- Aliasing annotations describe data:
  - Confined with object ("**owned**") (default domain)
  - Passed linearly from one object to another ("**unique**")
  - Shared temporarily ("**lent**") within method
  - Shared persistently ("**shared**") globally

Signers Example in AliasJava

```
class JavaClass {
    private owned List signers;

    private owned List getSigners() {
      return this.signers; }

    public void foo() {
      lent List x = this.getSigners();
      // do stuff using x
    }
}
```

- **owned** default private domain on each object
- Clients cannot invoke `getSigners()` since objects outside of JavaClass cannot cannot access JavaClass's **owned** domain
- Clients can only invoke `foo()`

Signers Example in AliasJava

```
class JavaClass {
   private owned List signers;

   public shared List getSigners() {
      shared List copy = new List();

      for(int i = 0; I < this.signers.size();i++)
      copy.add(this.signers.get(i));
      return copy;
   }
}
```

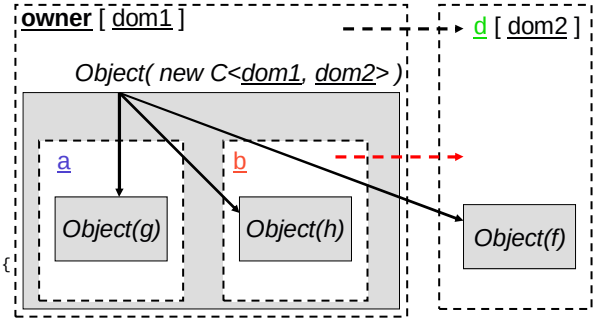
- Making `getSigners()` return a globally shared copy

JavaD: AliasJava with annotations

- Use annotation facility in Java 1.5
  - No language extension
- Use Eclipse JDT infrastructure + Crystal
  - Much improved tool support!
  - Debugging, refactoring, syntax highlighting, …
- Make it easier to add features to the language
  - External uniqueness, read-only references, …
- Incrementally and partially specify annotations
  - Necessary for dealing with large code bases
- Usability
  - Generate **warnings** about inconsistent annotations
  - Supply reasonable defaults

JavaD: ownership domain annotations

```
@Domains({"a", "b"})
@DomainParams({"d"})
@DomainLinks({"b->d"})
@DomainInherits({"IC<d>"})
public class C implements IC {
     @Domain("d") B f = new B();
     @Domain("a") B g = new B();
     @Domain("b") B h = new B();
}

@DomainParams({"d"})
public interface IC implements IC {
}
```



`@Domains`: declare domains
`@DomainParams`: declare *formal* domain parameters
`@DomainLinks`: declare domain link specifications
`@DomainInherits`: specify parameters for superclass/interfaces
`@Domain`: specify object domain and specify *actual* domain parameters
`@DomainReceiver`: specify annotation for constructor/method receiver

Tool Design and Implementation

- Annotation information management
  - Retrieve annotations from AST
  - Parse annotation values
- First Pass (visitor-based analysis)
  - Identify problematic code patterns
  - Propagate local annotations
  - Map AST nodes to annotations
- Second Pass (visitor-based analysis)
  - Check annotations using AliasJava rules
  - Intra-procedural live variables analysis

Annotation Information

- For each AST node, maintain
  - Annotation (e.g., “lent”)
  - Parameters
  - ArrayParameters
  - Map from Formals to Actuals
- Work around Java annotation limitations
  - Only use @Target({ElementType.PARAMETER, ..}) to specify where annotation is allowed
  - Otherwise, use free form string annotation value
- JavaCC for parsing annotations
  - “parameter <parameter, …> [arrayParameter, …]
  - “obj.dom <dom_{i1}, …, dom_{in}> [dom_{j1}, …, dom_{jn}]”

Identify Problematic Patterns

- Replace with equivalent constructs
  - Declare a local variable (built-in refactoring)
  - Add appropriate annotations
- New Expressions

```
public Iterator getIter() {
    return new SequenceIterator(head);
}
```

- Cast Expressions

```
ArrayList vCourse = objStudent.getRegisteredCourses();
for (int i=0; i<vCourse.size(); i++) {
    if (((Course) vCourse.get(i)).conflicts(objCourse)) {
            lock.releaseLock();
            return "Registration conflicts";
    }
}
```

Propagate Local Annotations

- AST Visitor
- Read annotations from
  - TypeDeclarations
  - Variable/Field Declarations
  - Method Declarations
- Translate Formals to Actuals
- Infer default annotations
  - Unique on NullLiteral, StringLiterals
- Map ASTNode to annotation
  - Used by the second pass

Check annotations

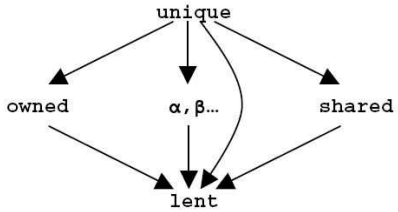
- AST Visitor to implement AliasJava rules
  - TypeDeclaration: inheritance rules
  - FieldDeclaration: declaration rules
  - SingleVariableDeclaration: declaration rules
  - VariableDeclarationFragment: declaration rules
  - MethodDeclaration: check method rules
  - Assignment: check assignment, initializers
  - ClassInstanceCreation: constructor rules
  - MethodInvocation: method call rules
  - ReturnStatement: assignment
  - FieldAccess: assignment

Check Method Declaration

- Check Return Type Annotation
  - If reference type, must have an annotation
  - May not be marked **owned** for public methods
- Check Parameter Annotations
  - If reference type, must have an annotation
  - May not be marked **owned** for public methods
- Check Overriding
  - May not change return type annotation
  - May not change parameter annotation
  - May not change receiver annotation
- Each annotation must have appropriate binding from actuals to formals

Value flow analysis

- Checking assignment
- Value flow analysis
  - Not dataflow analysis
  - Arrow means data can flow between variables with two annotations
- **Live variables analysis** to check "destructive read"
  - Data flow analysis
  - Reused from Crystal



- Variable with any type annotation can be assigned a **unique** value
- **lent** variables can be assigned a value with any type annotation
- Values with type annotations **owned** and **shared**, as well as declared domains kept separate from each other

Lessons Learned

- Java 1.5 annotations too limiting
  - @owned vs. @Domain("owned") or
  - @Domain("owned <owned>")
- Restrictions on certain coding constructs
- Annotations too verbose
  - Combine ownership and generic types (Potanin et al.)
  - Consider for example a box as a kind of object
  - Plain OO: "this is a box"
  - Generics: "this is a box of books"
  - Ownership: "this is my box", "these are library books"
  - Ownership **+** generics: "this is my box of library books"

Limitations and Future Work

- Support adding annotations to JDK and other third-party libraries
  - Place annotations in separate files
- Additional case studies
- Develop new kinds of annotations
  - "**extunique**", "**readonly**", …
  - @Ignore, @Suggest, @Complete
- Make it easier to infer annotations interactively
  - Use Eclipse preview refactoring functionality
  - Annotating existing code difficult
    - Determining ownership parameters
  - Annotating existing code time-consuming
    - Every line of code with a reference type!

Questions?

References

- Aldrich, J. and Chambers, C. Ownership Domains: Separating Aliasing Policy from Mechanism. In ECOOP, 2004.