

# JavaD: Bringing Ownership Domains to Mainstream Java

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Some slides adapted from a talk by  
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# Why Ownership Domains?

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- “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

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- 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

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- “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

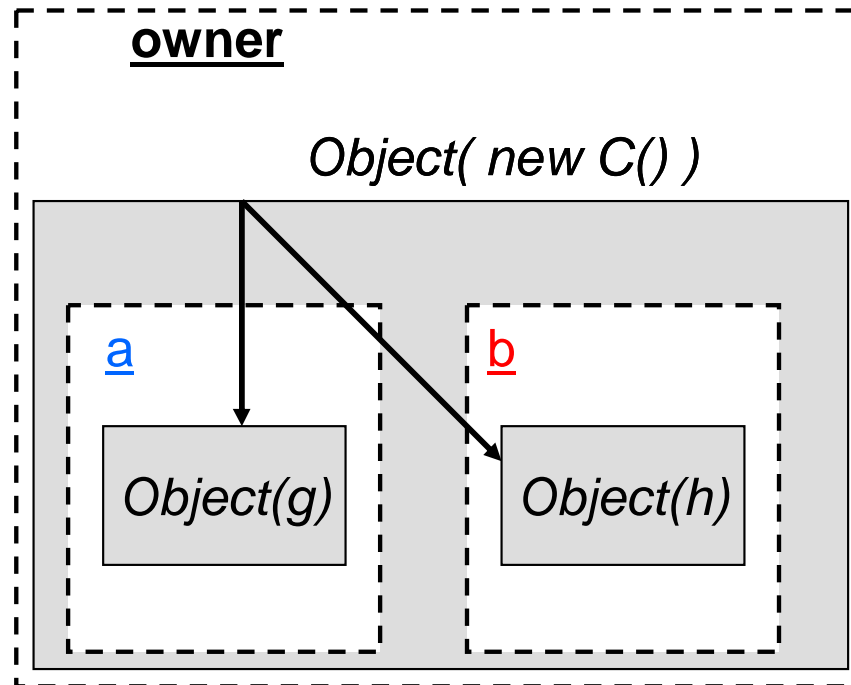
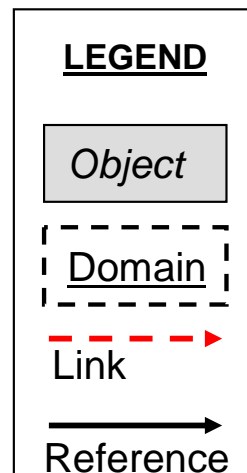
class C

domain a, b;

Object< a > g;

Object< b > h;

}



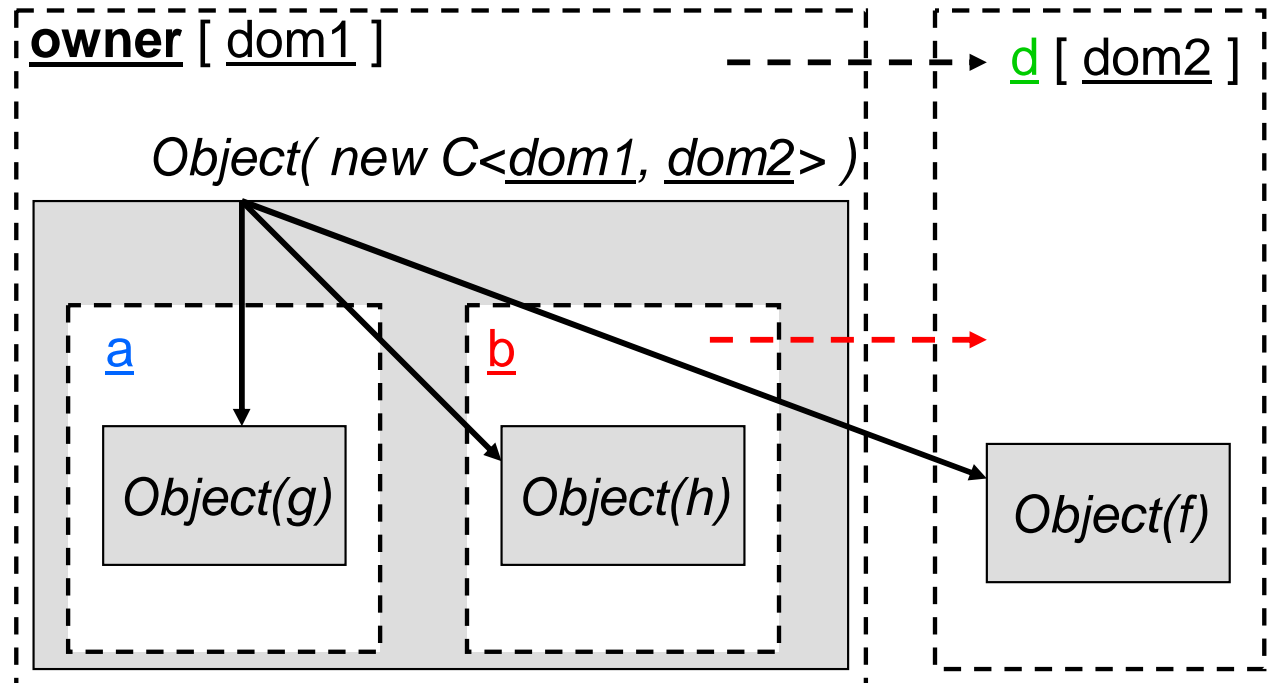
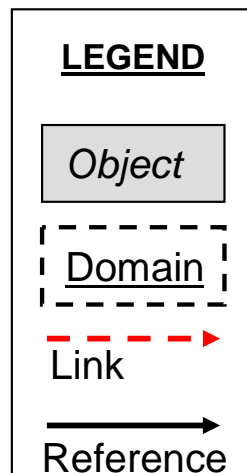
- Every object is in exactly one domain
- Every object can have one or more domains
  - Domains a and b are declared in class C
  - Object< a > g means object g is in domain a



# Ownership domain parameters

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

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



- 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.)

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- 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

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```
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 access `JavaClass`'s **owned** domain
- Clients can only invoke `foo()`





# Signers Example in AliasJava

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```
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

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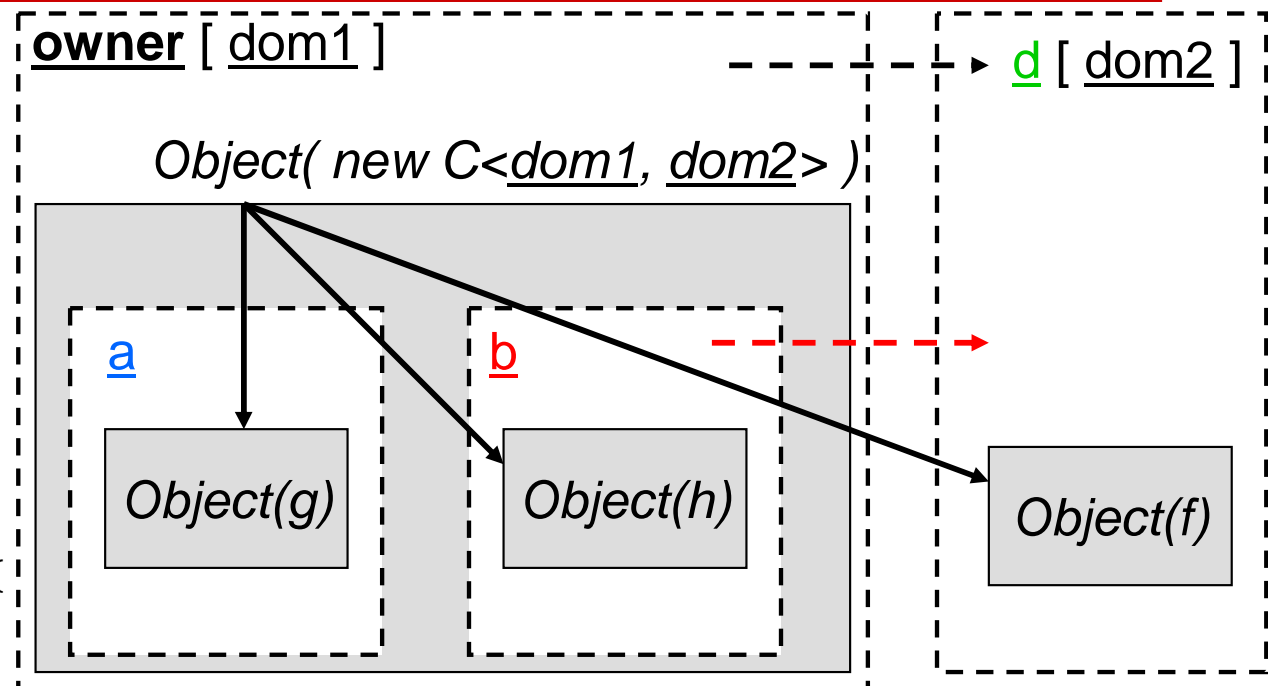
- Use annotation facility in Java 1.5
  - No language extension
- Use Eclipse JDT infrastructure + Crystal
  - Much improved tool support!
  - Debugging, refactoring, syntax highlighting, ...
- Make it easier to add features to the language
  - External uniqueness, read-only references, ...
- Incrementally 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

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- 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

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- 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<sub>i1</sub>, ..., dom<sub>in</sub>> [dom<sub>j1</sub>, ..., dom<sub>jn</sub>]”



# Identify Problematic Patterns

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- 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

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- 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

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- 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





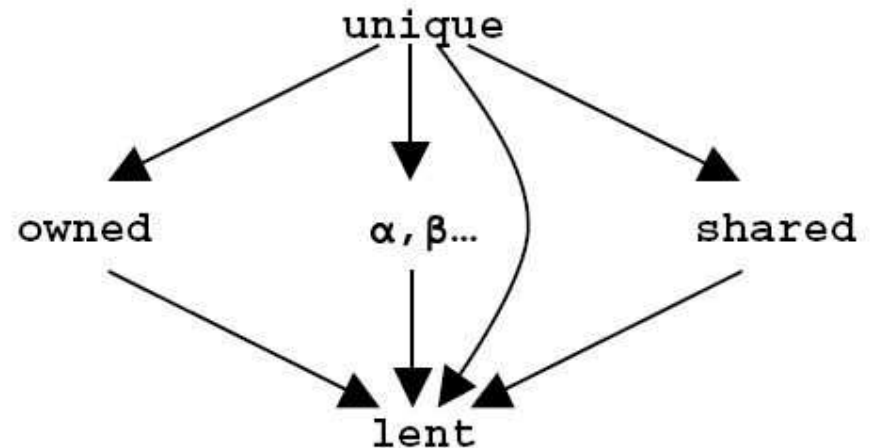
# Check Method Declaration

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- 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

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- 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

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- 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?

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# References

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