TRANSPARENT PROXIES FOR JAVA FUTURES

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Concurrent Programming

- Threads of execution: `Thread` objects running in parallel
- Asynchronous method invocations: Methods can be called asynchronously
- e.g:

  Main thread:

  ```
  o = new O();
  o.m(); //async
  ```

Concurrent Programming

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Main thread:		Child thread:
`o = new O();`		
`o.m(); //async`	⇒	`o.m();`

Concurrent Programming

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- Asynchronous method invocations: Methods can be called asynchronously
- e.g:

Main thread:		Child thread:
`o = new O();`		
`o.m(); //async`	⇒	`o.m();`
`...`		

Futures

- What happens with returned value?
- “Future” or “promise”: a placeholder for the result
- “Claim” a future:
  If the result is not available, wait for it
- Futures are *proxies*. Other examples:
  - Suspensions (lazy invocation)
  - Remote objects
  - Other wrappers

Java Transparent Proxy Framework

- Static analysis and program transformation
  - Based on *qualifier inference* system
  - Formalization and proof of soundness
- Implementation of Futures via async methods
  - Also lazy invocations, other applications
- Benefits
  - Simple programming model
  - Can improve application performance

MultiLISP futures

- `(future` *e*`)` means *e* executes in parallel
- Lisp is functional and dynamically typed
- No need for the programmer to insert claims:
  The runtime system checks every access.
  If it is a future, claim before access
- Programmer only inserts `future` notations
- Futures are transparent

Java Futures not Transparent

- Java is statically typed
- Futures in JSR166 must be claimed explicitly:

```
public interface Future<V> {
  V get();
  V get(long timeout, TimeUnit unit);
  ...
}
```

Programming Overhead

To convert a method invocation to asynchronous:

- Change the call site to be asynchronous
- Change the type of the result to `Future`
- Change the type of variables to which the result flows
- Insert claims

It is usual to claim early to avoid rewriting a lot of code

Question: can we do this automatically?

Type Qualifiers

- Qualifiers refine the meaning of types
- `final Integer` is to `Integer` like `Future<String>` is to `String`
- "Proxyness" is a type qualifier: `proxy` or `nonproxy`.
  If `x` has type
  - `proxy String` then `x` *could* be a proxy
  - `nonproxy String` then `x` is *not* a proxy
- `nonproxy` $\leq$ `proxy`

Automatic Transformation

- Use qualifier inference to determine where proxies flow
- Transform program based on results
  - Rewrite `proxy` types
  - Insert claims whenever a proxy is used concretely

Example: Initial Program

```
procRequest(Socket sock) {
  Buffer in = readBuf(sock);

  Request req = translate(in);

  Buffer out = process(req);

  writeBuf(sock,out);
}
Request translate(Buffer in) {
  Request result;
  ... in.foo() ...
  return result;
}
```

Example: Async Calls

```
procRequest(Socket sock) {
  Buffer in = @readBuf(sock);

  Request req = @translate(in);

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Example: Qualified Types

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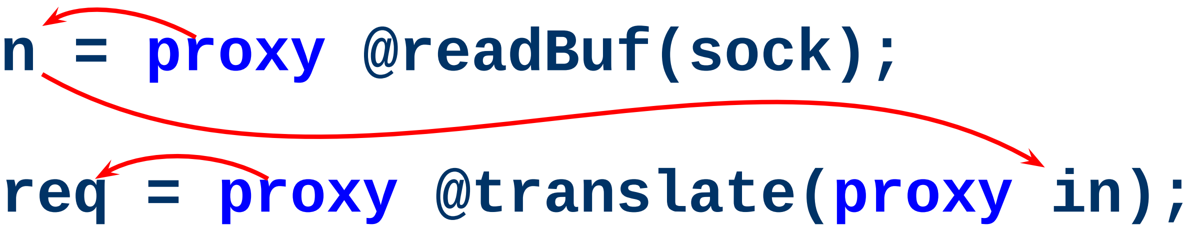

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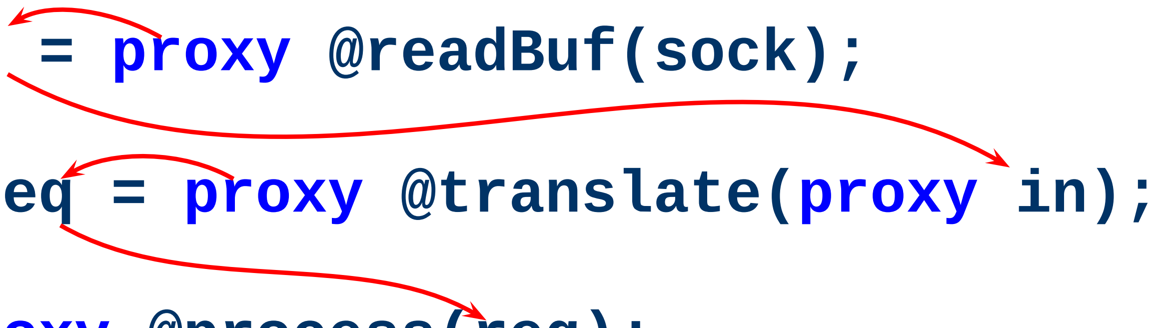

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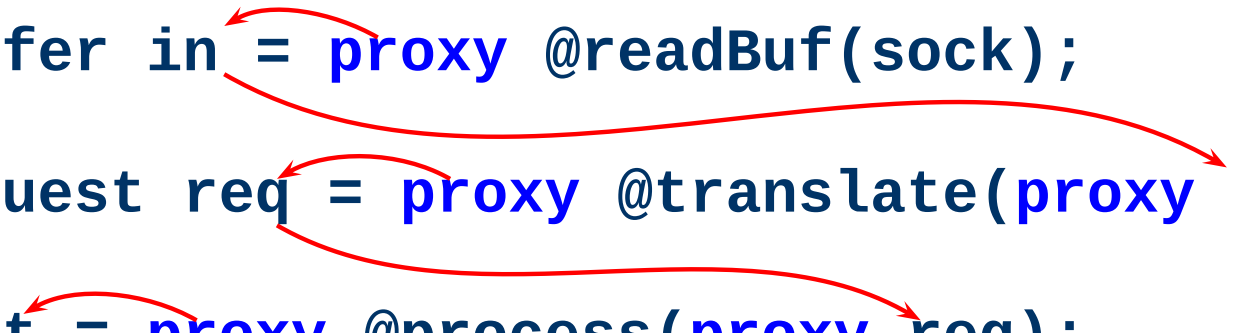

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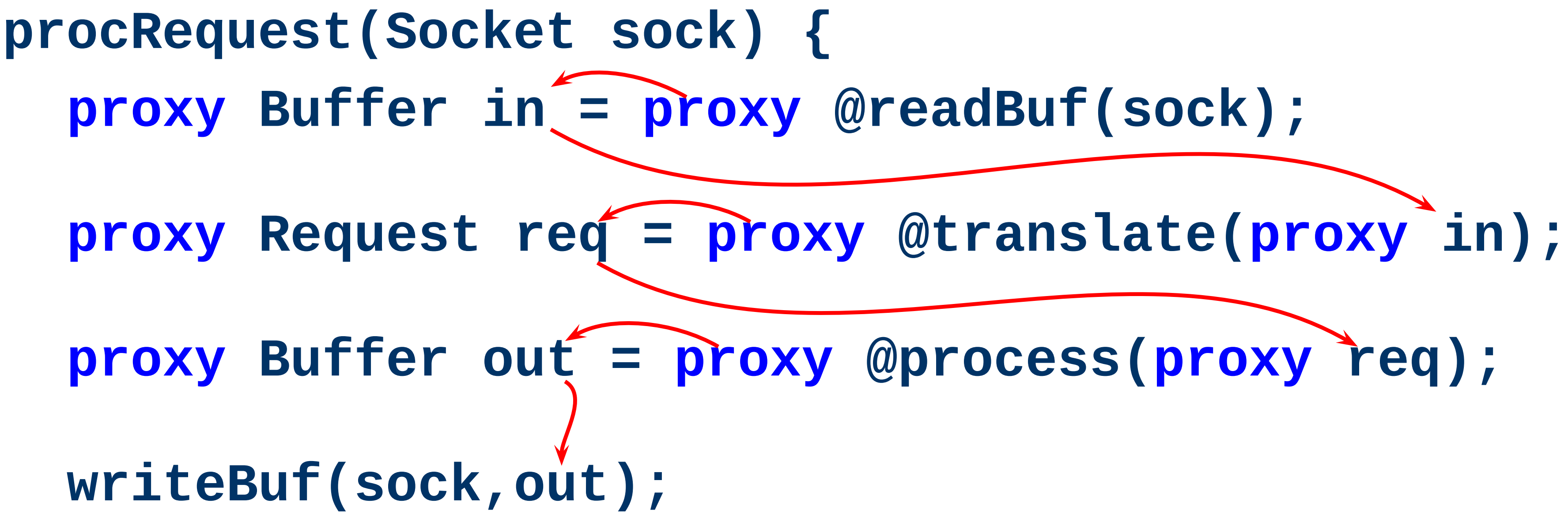

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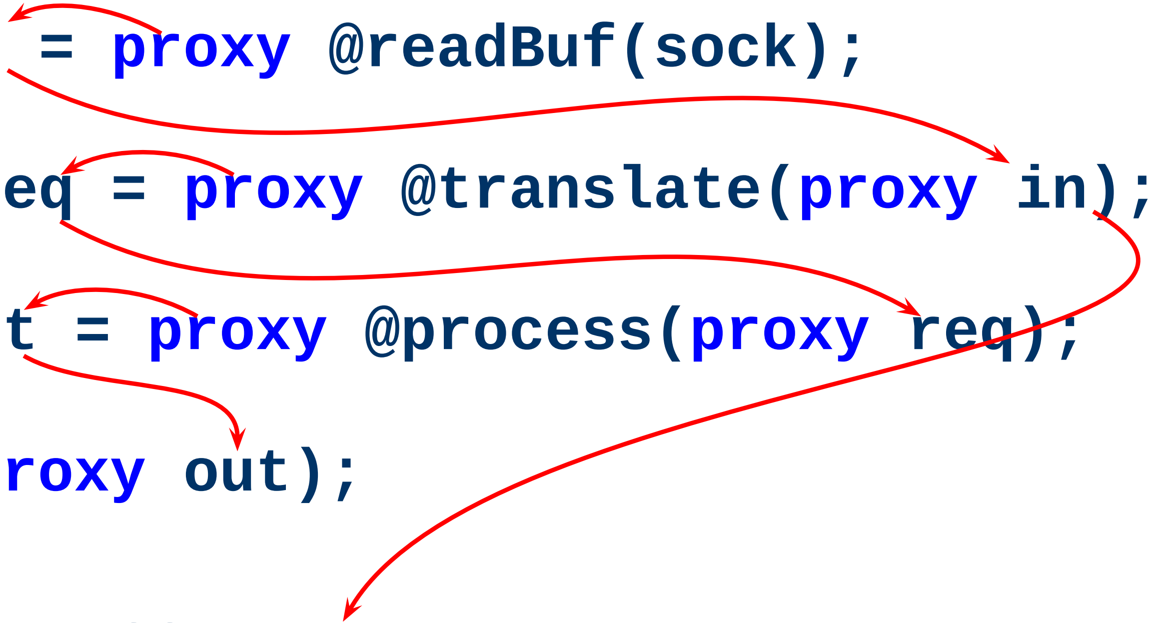

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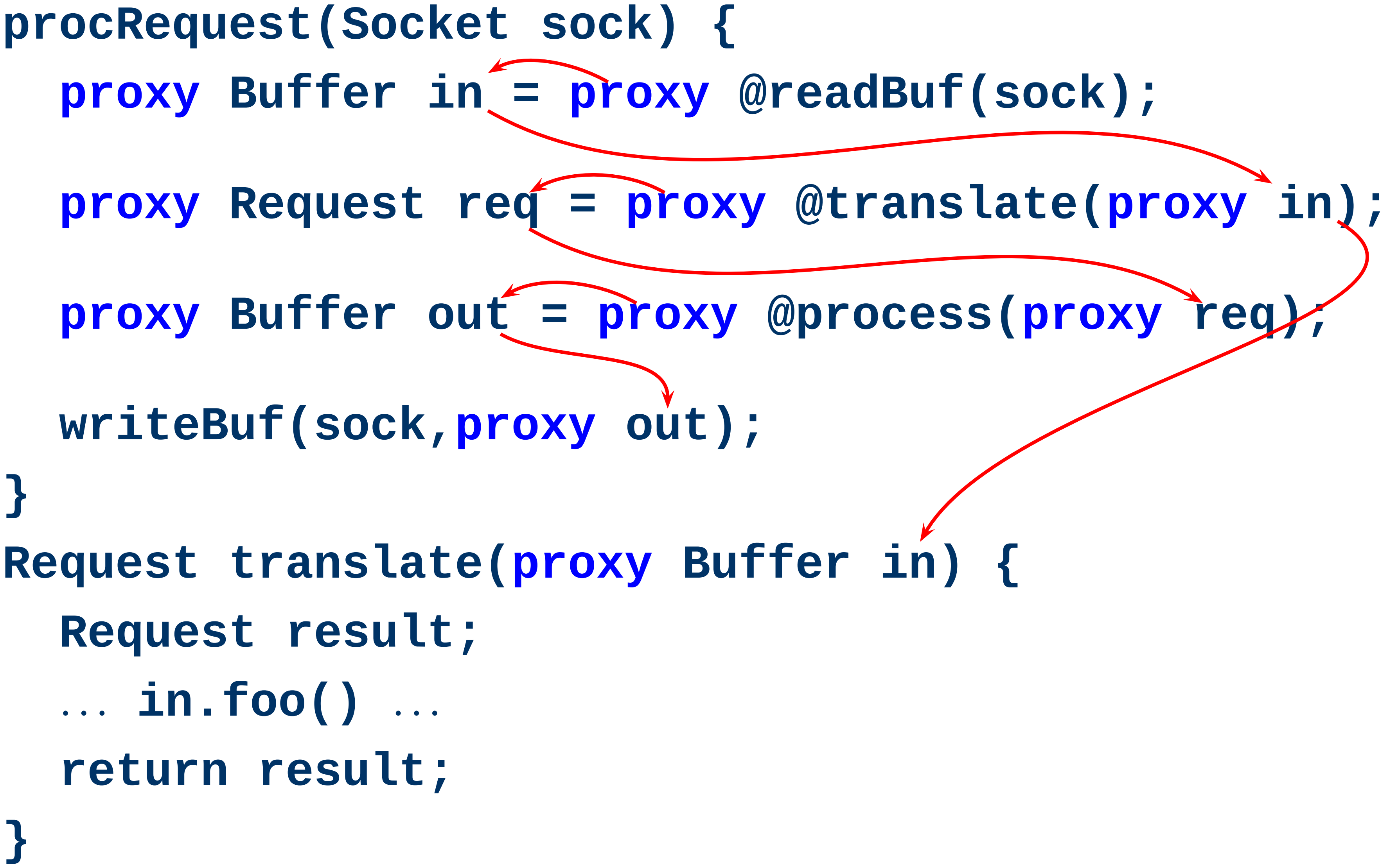

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Example: Future Transformation

```
procRequest(Socket sock) {
  Buffer in = @readBuf(sock);

  Request req = proxy @translate(in);

  Buffer out = proxy @process(req);

  writeBuf(sock,out);
}
Request translate(Buffer in) {
  Request result;
  ... in.foo() ...
  return result;
}
```

Example: Future Transformation

```
procRequest(Socket sock) {
  Object in = new Proxy{
    private Object result;
    public void run() {
      result = readBuf(sock); }
    public synchronized Object get(){
      ...  return result; }
  }();
  Executor.run((Runnable)in);
  Request req = @translate(in);
  Buffer out = @process(req);
  writeBuf(sock,out);
}
```

Example: Future Transformation

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  Object in = new Proxy{
    private Object result;
    public void run() {
      result = readBuf(sock); }
    public synchronized Object get(){
      ... return result; }
  }();
  Executor.run((Runnable)in);
  Object req = new Proxy{... translate(in) ...
  Object out = new Proxy{... process(req) ...
  writeBuf(sock,out);
}
```

Example: Qualified types

```
Request translate(Buffer in) {
  Request result;
  ...
  in.foo();
  ...
  return result;
}
```

Example: Qualified types

```
Request translate(Buffer in) {
  Request result;
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  in.foo();
  ...
  return result;
}
```

concrete use

Example: Qualified types

```
Request translate(Buffer in) {
  Request result;
  ...
  (nonproxy in).foo();
  ...
  return result;
}
```

Example: Qualified types

```
Request translate(Buffer in) {
  Request result;
  ...
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  ...
  return result;
}
```

proxy

Example: Qualified types

```
Request translate(Buffer in) {
  Request result;
  ...
  (nonproxy in).foo();
  ...
  return result;
}
```

Example: Future Transformation

```
Request translate(Object inF) {
  Request result;
  ...
  Buffer in = (Buffer)
    (inF instanceof Proxy ?
     inF.get() :
     inF);
  in.foo();
  ...
  return result;
}
```

claim

Other Uses of Proxies

- User can define:
  - What is a concrete usage (places where an unwrapping would be necessary)
  - Where proxies are created
  - What is a claim
- E.g. suspensions (lazy proxies):
  - Concrete usage: same as futures
  - Proxy creation: lazy invocations
  - Claim: evaluate the invocation and return its result

Other Uses of Qualifier Inference

- `tainted` / `untainted` qualifiers (for security)
- `null` / `non-null` qualifiers: can be used to enforce stronger interfaces
- `stack` / `heap` allocation for objects:
  Figure out which objects can be stack-allocated, and if/when they need to be moved to the heap

Formalism: Checking System

- FJ_Q: Featherweight Java + Qualifiers: checking system
  - If the programmer annotated every type with a qualifier by hand, would it be correct?
- Proof of soundness for FJ_Q:
  - If the annotated program typechecks, then everything is claimed before used

Formalism: Inference System

- FJ_Q^i: Inference system that produces FJ_Q programs
    - Find the values of the proxy qualifier automatically
- Correctness of inference:
    - If FJ_Q^i finds a solution, the resulting annotated program typechecks in FJ_Q

Formalism: Features

- Use set types to improve precision:

```
class A { ... }
class B extends A { ... }
class C extends A { ... }
...
A var = new B();
```

  Variable `var` has type $\{B\}^A$

- Selective flow-sensitive coercions from `proxy` to `nonproxy`

Implementation

- Uses Soot
  - Jimple: Three-address code SSA-like representation of bytecode
  - Spark: Points-to analysis engine
- Extends Spark's Andersen-style points-to analysis with selective flow-sensitivity
- Bytecode to bytecode transformation
- Handles the full Java language (exceptions, JNI, reflection, etc)

Performance

- RMI peer-to-peer application
- Each peer searches in the network to find service providers

Example

```
Service findService(LocalPeer self,
                    String sName) {
  Service s = self.getService(sName);
  if (s != null) return s;
  else {
    self.forward(
      new FindServiceMessage(sName));
    return getRemoteService(self, sName);
  }
}
```

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    @self.forward(
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    return $getRemoteService(self, sName);
  }
}
```

$ denotes a lazy invocation

Analysis Performance

Analysis	Time	classes			claims
	(s)	analyzed	w/ fut.	changed	claims
FI	73	1324	27	2	7
FS	92	1324	9	2	2
SPARK	66	1320	*n/a*	*n/a*	*n/a*

Related Work

- Futures and async methods
    - MultiLISP (Halstead et al.)
    - Promises (Liskov and Shrira)
    - Touch elimination (Flanagan and Felleisen)
    - Polyphonic C# (Benton et al.)
    - Lazy Task Creation (Halstead, Frigo et al.)
    - SCOOP/Eiffel (Compton)
    - Async RMI (Raje et al, Sysala et al.)

Related Work

- Static Analysis
  - Points-to analysis (many)
  - Qualifier inference (Foster et al.)
  - Value flow analysis (Heintze and Tardieu)

Future Work

- Incorporate into a general framework for qualifiers in Java
    - Arbitrary qualifier partial order
    - Context-sensitive analysis
    - Faster algorithm
- Incremental analysis
    - Only re-run analysis for files affected by local change
    - Don’t reanalyze the library every time

Summary

- Framework for programming with proxies
  - Simplifies programming process
  - Avoids violations of transparency
- Novel static analysis
  - Extends qualifier inference with flow-sensitive coercions
  - Has additional applications (Stack-allocated objects, not-null types, etc)
- Formalization and proof of soundness
- Prototype implementation