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From Access Control to Information Flow

Security Model and Static Analysis for Programs Consist of Trusted and Untrusted Code

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Introduction

- Modern programming languages are designed for internet applications and extensible systems
- Untrusted code may run in the same process as trusted code
- Fine-grained access control is needed to manage the security requirements of program code

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Stack Inspection

- A permission-based mechanism for controlling code access
  - E.g., sandboxing in Java and C#

- Code attempting sensitive operations may be privileged with permissions
  - Permissions are granted to classes by policy files
  - An implementation of *the principle of least privilege*

- **All code on the call stack** must have sufficient privilege to perform certain sensitive operation
  - Tested by a permission check at runtime

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Stack Inspection Example

```
public class A {
   public static void main(String[] args) throws Exception {
      L l = ...;
      …
      l.createResource(name);
      ...
   }
}
```

```
public class L {
   private Resource resource;

   private native Resource create(String name);

   public void createResource(String name) {
      AccessController.checkPermission(
         new ResourcePermission(name, "create"));
      resource = create(name);
   }
}
```

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Stack Inspection Example

```
public class A {
    public static void main(String[] args) throws Exception {
        L l = ...;
        …
        l.createResource(name);
        ...
    }
}
```

AC.checkPermission	AllPermission
L.createResource	AllPermission
A.main	ResourcePermission("*", "create")

```
public class L {
    private Resource resource;

    private native Resource create(String name);

    public void createResource(String name) {
        AccessController.checkPermission(
            new ResourcePermission(name, "create"));
        resource = create(name);
    }
}
```

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Stack Inspection Successful

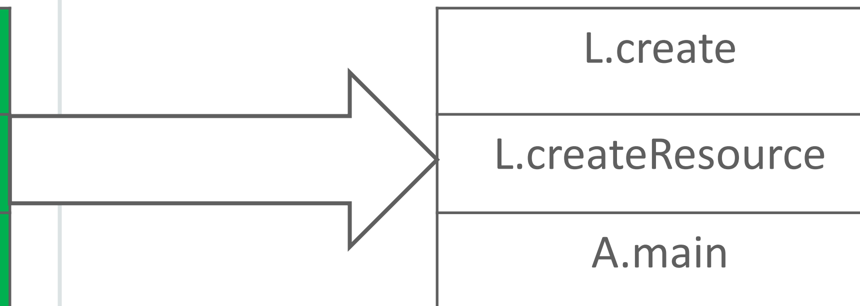
```
public class A {
   public static void main(String[] args) throws Exception {
      L l = ...;
      …
      l.createResource(name);
      ...
   }
}
```

```
public class L {
   private Resource resource;

   private native Resource create(String name);

   public void createResource(String name) {
      AccessController.checkPermission(
         new ResourcePermission(name, "create"));
      resource = create(name);
   }
}
```

AC.checkPermission	AllPermission
L.createResource	AllPermission
A.main	ResourcePermission("*", "create")



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Stack Inspection Unsuccessful: Exception Thrown

```
public class A {
   public static void main(String[] args) throws Exception {
      L l = ...;
      …
      l.createResource(name);
      ...
   }
}
```

```
public class L {
   private Resource resource;

   private native Resource create(String name);

   public void createResource(String name) {
      AccessController.checkPermission(
         new ResourcePermission(name, "create"));
      resource = create(name);
   }
}
```

AC.checkPermission	AllPermission
L.createResource	AllPermission
A.main	ϕ

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Tainted Information Used in Sensitive Operation

```
public class A {
   public static void main(String[] args) throws Exception {
      L l = ...; B b = ...;
      String name = b.getName();
      l.createResource(name);
      ...
   }
}

public class B {
   public String getName() {
      return "password";
   }
   ...
}
```

```
public class L {
   private Resource resource;

   private native Resource create(String name);

   public void createResource(String name) {
      AccessController.checkPermission(
         new ResourcePermission(name, "create"));
      resource = create(name);
   }
}
```

B.getName	ϕ
A.main	ResourcePermission("*", "create")

→

AC.checkPermission	AllPermission
L.createResource	AllPermission
A.main	ResourcePermission("*", "create")

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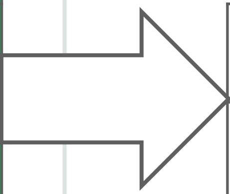
Leaked Sensitive Information

```
public class A {
   public static void main(String[] args) throws Exception {
      L l = ...; B b = ...;
      ...
      Resource r = l.getResource();
      b.useResource(r);
   }
}

public class B {
   ...
   public void useResource(Resource res) { ... }
}
```

```
public class L {
   private Resource resource;

   ...

   public Resource getResource() {
      AccessController.checkPermission(
         new ResourcePermission("*", "get"));
      return resource;
   }
}
```

AC.checkPermission	AllPermission
L.getResource	AllPermission
A.main	ResourcePermission("*", "create") ResourcePermission("*", "get")



B.useResource	ϕ
A.main	ResourcePermission("*", "create") ResourcePermission("*", "get")

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Forbid Desired Operation

```
public class A {
   public static void main(String[] args) throws Exception {
      L l = ...;
      …
      l.initResource();
      ...
   }
}
```

```
public class L {
   private Resource resource;

   private native Resource create(String name);

   public void createResource(String name) {
      AccessController.checkPermission(
         new ResourcePermission(name, "create"));
      resource = create(name);
   }

   public void initResource() {
      final String name = "initial";
      createResource(name);
   }
}
```

AC.checkPermission	AllPermission
L.createResource	AllPermission
L.initResource	AllPermission
A.main	ϕ

Security Exception

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Elevate Privilege in Java

```
public class A {
   public static void main(String[] args) throws Exception {
      L l = ...;
      …
      l.initResource();
      ...
   }
}
```

AC.checkPermission	AllPermission
L.createResource	AllPermission
PrivilegedAction.run	AllPermission
AC.doPrivileged	AllPermission
L.initResource	AllPermission
A.main	ϕ

```
public class L {
   private Resource resource;

   private native Resource create(String name);

   public void createResource(String name) {
      AccessController.checkPermission(
         new ResourcePermission(name, "create"));
      resource = create(name);
   }

   public void initResource() {
      final String name = "initial";
      AccessController.doPrivileged(
         new PrivilegedAction<Object>() {
            public Object run() {
               createResource(name);
            }
         });
   }
}
```

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Limitations of Stack Inspection

- Too weak against information flow attacks
  - E.g. *the confused deputy problem*
    - Untrusted code may inject data to be used by trusted code to perform sensitive operations
    - Data generated from sensitive operations by trusted code may be received by untrusted code

- Too strong to allow desired information flows
  - Often have to elevate code privilege at runtime

- Rely on programmer discipline
  - No enforceable security model or policy

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Related Work

- Stack-based access control
  - Wallach and Felten, S&P'98
  - Fournet and Gordon, POPL'02
- History-based access control
  - Abadi and Fournet, NDSS'03
- Information-based access control
  - Pistoia, Banerjee and Naumann, S&P'07

- *It is surprisingly hard to state a useful security goal that captures the intent for a general class of trusted and untrusted code*

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A New Security Model

- Answer the questions:
  - What is the desired security goal for programs consist of trusted and untrusted code?
  - Can the security goal be enforced statically?

- Control information flow between code according to their privileges
  - Prevent undesired influences between sensitive code and unprivileged code
  - Allowing desired influences between sensitive code and privileged code

- Provide a simple and general security policy to support both confidentiality and integrity

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Connecting Information Flow to Code Access Control

- Each code is associated with a dual access control specification
  - Governing how information may flow between code

- **Capability** determines privilege/trust of code
  - i.e. the privilege granted to untrusted code

- **Accessibility** determines secrecy/sensitivity of code
  - i.e. the privilege required by sensitive code

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Example Revisited

```
@requires{} @holds{ResourcePermission("*", "create")}
public class A {
    public static void main(String[] args) throws Exception {
        L l = ...; B b = ...;
        String name = b.getName();
        l.createResource(name);
        ...
    }
}

@requires{} @holds{}
public class B {
    public String getName() {
        return "password";
    }
    ...
}
```

```
@requires{} @holds{AllPermission}
public class L {
    private Resource resource;

    @requires{ResourcePermission(name, "create")}
    private native Resource create(String name);

    public void createResource(String name) {
        AccessController.checkPermission(
            new ResourcePermission(name, "create"));
        resource = create(name);
    }
}
```

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Security Policy

$$x \to y \implies acc(x) \le cap(y) \wedge acc(y) \le cap(x)$$

- $x \to y$: information may flow from x to y
- $acc(x)$: the accessibility of the code defining x
- $cap(y)$: the capability of the code defining y
- A ≤ B iff B is more privileged than A

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Security Policy

$$x \to y \implies acc(x) \leq cap(y) \wedge acc(y) \leq cap(x)$$

- Privilege-dependent confidentiality
  - The receiver must have sufficient privilege to receive the information
- Privilege-dependent integrity
  - The sender must have sufficient privilege to send the information
- Mutual information flows are supported (often desired)

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Tainted Information Used in Sensitive Operation Revisited

```
@requires{} @holds{ResourcePermission("*", "create")}
public class A {
   public static void main(String[] args) throws Exception {
      L l = ...; B b = ...;
      String name = b.getName();
      l.createResource(name);
      ...
   }
}

@requires{} @holds{}
public class B {
   public String getName() {
      return "password";
   }
   ...
}
```

```
@requires{} @holds{AllPermission}
public class L {
   private Resource resource;

   @requires{ResourcePermission(name, "create")}
   private native Resource create(String name);

   public void createResource(String name) {
      AccessController.checkPermission(
         new ResourcePermission(name, "create"));
      resource = create(name);
   }
}
```

"password" $\rightarrow$ name $\Longrightarrow$ {} $\leq$ {AllPermission} $\wedge$ {ResourcePermission(name,"create")} $\leq$ {}

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Forbid Desired Operation Revisited

```
@requires{} @holds{}
public class A {
   public static void main(String[] args) throws Exception {
      L l = ...;
      ...
      l.initResource();
      ...
   }
}
```

```
@requires{} @holds{AllPermission}
public class L {
   private Resource resource;

   @requires{ResourcePermission(name, "create")}
   private native Resource create(String name);

   public void createResource(String name) {
      AccessController.checkPermission(
         new ResourcePermission(name, "create"));
      resource = create(name);
   }

   public void initResource() {
      final String name = "initial";
      createResource(name);
   }
}
```

$\text{"initial"} \rightarrow \text{name} \Longrightarrow \{\} \leq \{\text{AllPermission}\} \wedge \{\text{ResourcePermission(name,"create")}\} \leq \{\text{AllPermission}\}$

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Leaked Sensitive Information Revisited

```
@requires{} @holds{ResourcePermission("*", "get")}
public class A {
   public static void main(String[] args) throws Exception {
      L l = ...; B b = ...;
      ...
      Resource r = l.getResource();
      b.useResource(r);
   }
}

@requires{} @holds{}
public class B {
   ...
   public void useResource(Resource res) { ... }
}
```

```
@requires{} @holds{AllPermission}
public class L {
   @requires{ResourcePermission("*", "get")}
   private Resource resource;

   ...

   public Resource getResource() {
      AccessController.checkPermission(
         new ResourcePermission("*", "get"));
      return resource;
   }
}
```

$\text{"resource"} \rightarrow \text{res} \Longrightarrow \{\text{ResourcePermission}(\text{"}*\text{"},\text{"get"})\} \leq \{\} \wedge \{\} \leq \{\text{AllPermission}\}$

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Distinct Integral/Confidential Requirements

```
@requires{} @holds{AllPermission}
public class A {
   public static void main(String[] args) throws Exception {
      L l = ...; B b = ...; C c = ...;
      l.setResource(b.get());
      Resource r = l.getResource();
      c.use(r);
   }
}

@requires{} @holds{ResourcePermission("*", "set")}
public class B {
   public Resource get() { return new Resource("password"); }

}
@requires{} @holds{ResourcePermission("*", "get")}
public class C {
   public void use(Resource res) { ... }
}
```

```
@requires{} @holds{AllPermission}
public class L {
   @requires_conf{ResourcePermission("*", "get")}
   @requires_inte{ResourcePermission("*", "set")}
   private Resource resource;

   …
   public Resource getResource() {
      AccessController.checkPermission(
         new ResourcePermission("*", "get"));
      return resource;
   }
   public Resource setResource(Resource r) {
      AccessController.checkPermission(
         new ResourcePermission("*", "set"));
      resource = r;
   }
}
```

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Security Policy for Distinct Integrity/Confidentiality

$$x \to y \implies conf(x) \leq cap(y) \wedge inte(y) \leq cap(x)$$

- The receiver must satisfy the **confidential requirement** of the sender
- The sender must satisfy the **integral requirement** of the receiver

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Distinct Integral/Confidential Requirements

```
@requires{} @holds{AllPermission}
public class A {
   public static void main(String[] args) throws Exception {
      L l = ...; B b = ...; C c = ...;
      l.setResource(b.get());
      Resource r = l.getResource();
      c.use(r);
   }
}

@requires{} @holds{ResourcePermission("*", "set")}
public class B {
   public Resource get() { return new Resource("password"); }

}
@requires{} @holds{ResourcePermission("*", "get")}
public class C {
   public void use(Resource res) { ... }
}
```

```
@requires{} @holds{AllPermission}
public class L {
   @requires_conf{ResourcePermission("*", "get")}
   @requires_inte{ResourcePermission("*", "set")}
   private Resource resource;

   ...
   public Resource getResource() {
      AccessController.checkPermission(
         new ResourcePermission("*", "get"));
      return resource;
   }
   public Resource setResource(Resource r) {
      AccessController.checkPermission(
         new ResourcePermission("*", "set"));
      resource = r;
   }
}
```

$$\text{new Resource("password")} \rightarrow \text{resource} \Longrightarrow \{\} \leq \{\text{AllPermission}\}$$
$$\wedge \{\text{ResourcePermission("}*\text{","set")}\} \leq \{\text{ResourcePermission("}*\text{","set")}\}$$

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Distinct Integral/Confidential Requirements

```
@requires{} @holds{AllPermission}
public class A {
   public static void main(String[] args) throws Exception {
      L l = ...; B b = ...; C c = ...;
      l.setResource(b.get());
      Resource r = l.getResource();
      c.use(r);
   }
}

@requires{} @holds{ResourcePermission("*", "set")}
public class B {
   public Resource get() { return new Resource("password"); }

}
@requires{} @holds{ResourcePermission("*", "get")}
public class C {
   public void use(Resource res) { ... }
}
```

```
@requires{} @holds{AllPermission}
public class L {
   @requires_conf{ResourcePermission("*", "get")}
   @requires_inte{ResourcePermission("*", "set")}
   private Resource resource;

   ...
   public Resource getResource() {
      AccessController.checkPermission(
         new ResourcePermission("*", "get"));
      return resource;
   }
   public Resource setResource(Resource r) {
      AccessController.checkPermission(
         new ResourcePermission("*", "set"));
      resource = r;
   }
}
```

$$\text{resource} \rightarrow \text{res} \Longrightarrow \{\text{ResourcePermission}(\text{"}*\text{","get"})\} \leq \{\text{ResourcePermission}(\text{"}*\text{","get"})\}$$
$$\wedge \{\} \leq \{\text{AllPermission}\}$$

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Summary

- Stack inspection is inherently limited for secure information flow in programs consist of trusted and untrusted code
- We propose a security model to capture the intent for a general class of trusted and untrusted code
- Our security policy can be enforced by static program analysis

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