Systems and Internet Infrastructure Security

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Advanced Systems Security
Retrofitting for Security

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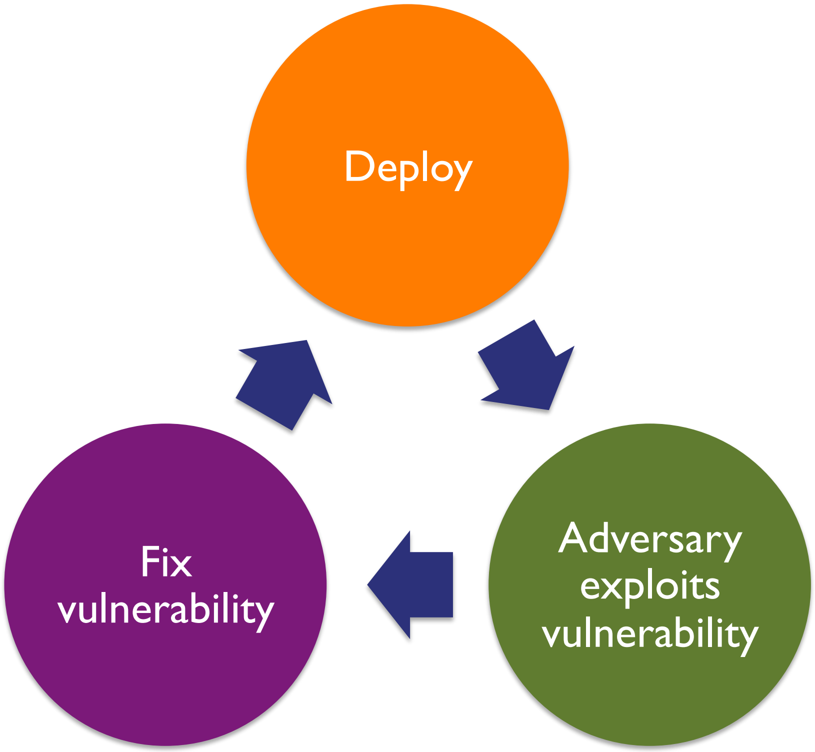
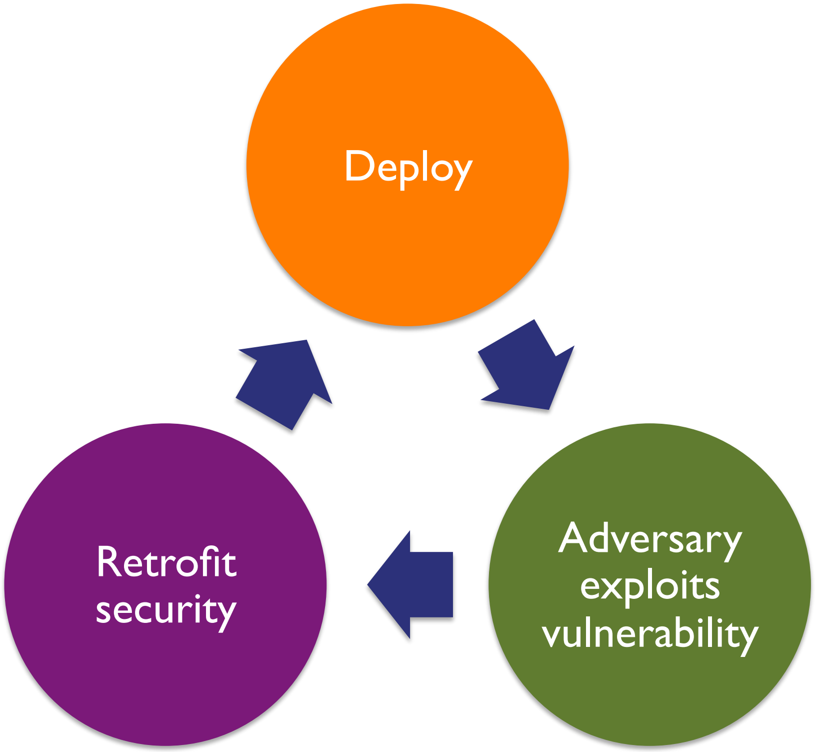
Retroactive Security



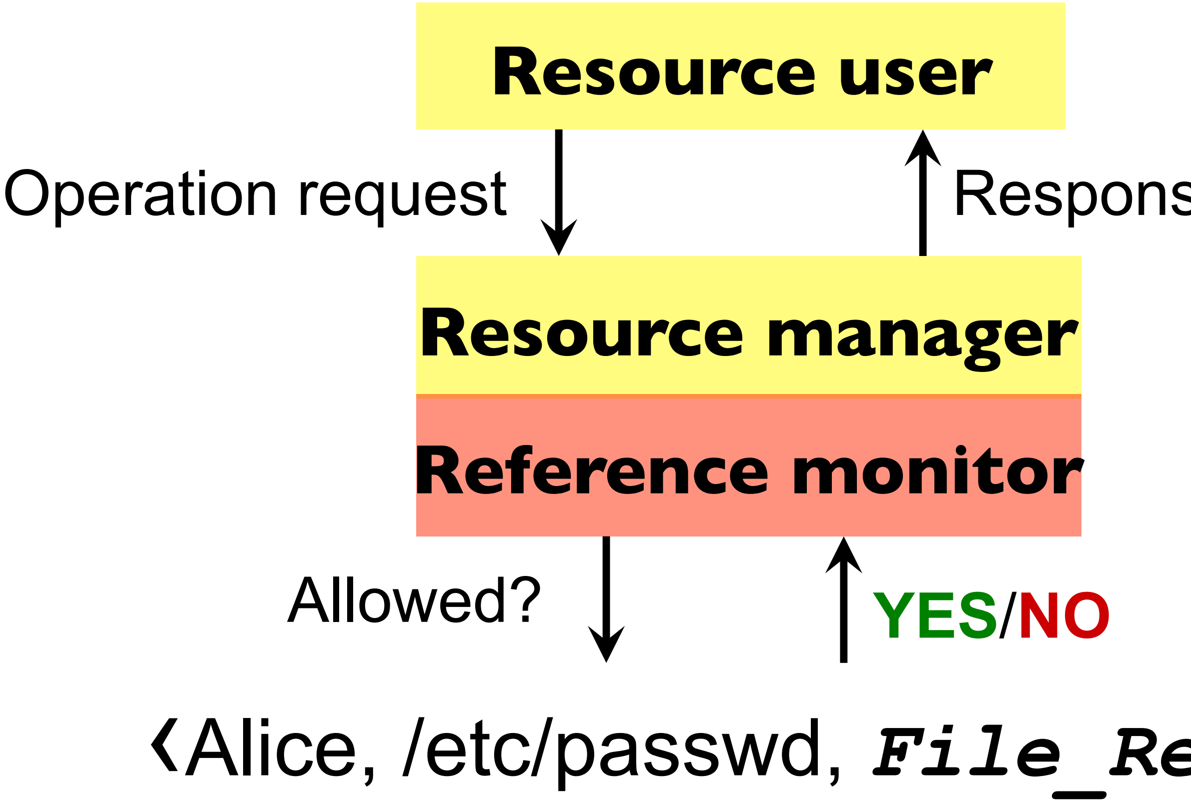
- “Penetrate and patch” as flaws are exposed as vulnerabilities

Retroactive Security



- Several codebases have been extended with security features retroactively
  - X Server, postgres, Apache, OpenSSH, Linux Kernel, browsers, etc.
- With a variety of security controls:
  - Privilege separation, Authentication, Auditing, Authorization, etc.

Authorizing Access



Resource user

Operation request

Response

Resource manager

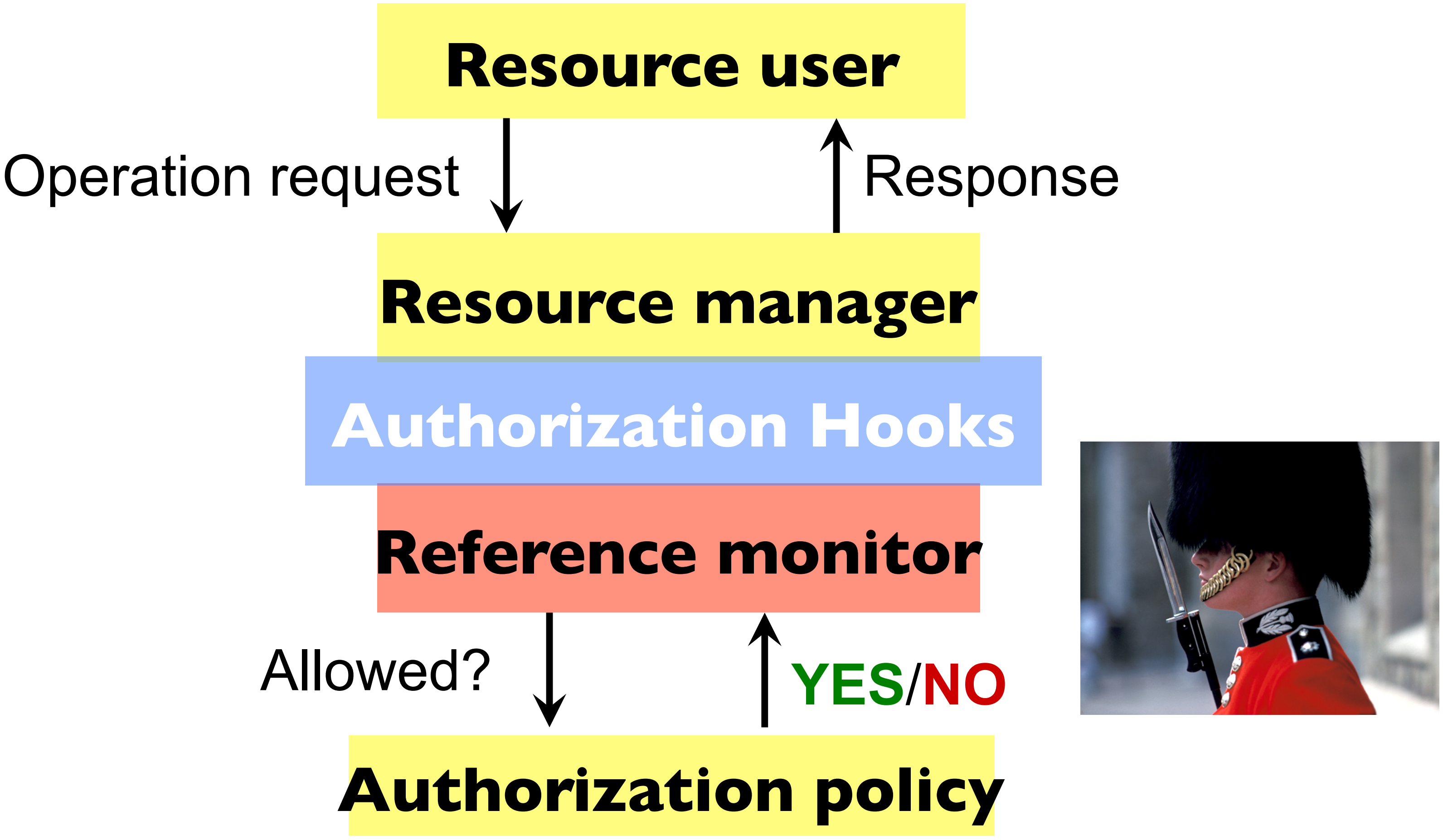
Reference monitor

Allowed?

YES/NO

〈Alice, /etc/passwd, ***File_Read***〉

Authorizing Access



Retrofitting is Hard

- For authorization
  - X11 ~ proposed 2003, upstreamed 2007, changing to date. [Kilpatrick *et al.*, ‘03]
  - Linux Security Modules ~ 2 years [Wright *et al.*, ’02]

Painstaking, manual procedure

> *At this point, SE-PostgreSQL has taken up a *__lot__* __of community resources__, not to mention an __enormous and doubtless frustrating amount of *the lead developer's* time and effort__, thus far __without a single committed patch, or even a consensus as to what it should (or could) do.__ Rather than continuing to blunder into the future, I think we need to do a reality check*
>
> \- http://archives.postgresql.org/message-id/20090718160600.GE5172@fetter.org

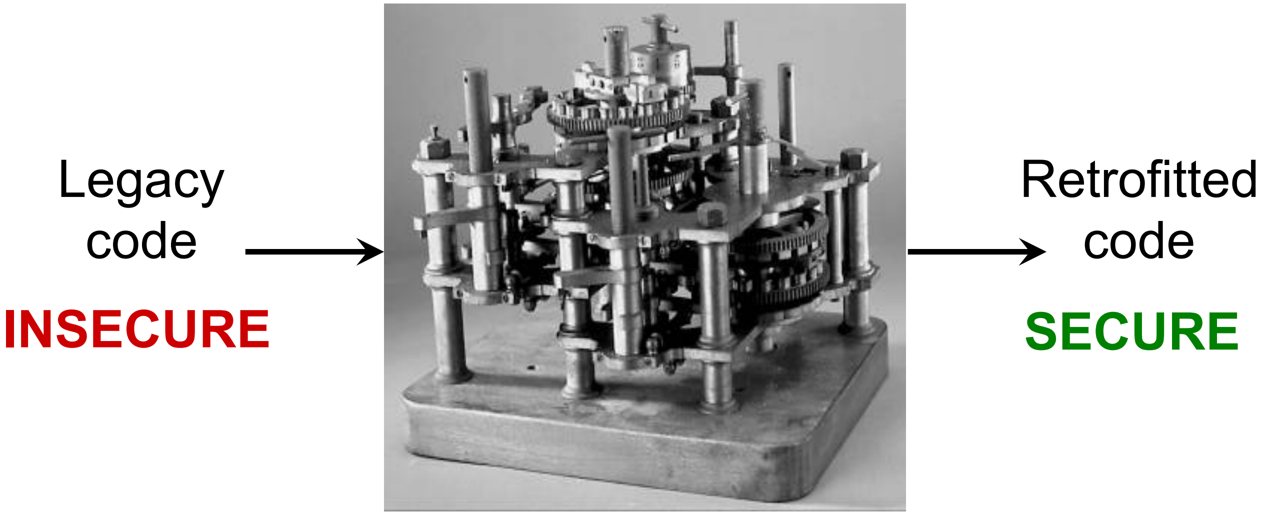
Retrofitting is Common

- Mandatory access control for Linux
  - Linux Security Modules [Wright *et al.*,'02]
- TrustedBSD, SEDarwin, sHype, XSM, …
- Secure windowing systems
  - Trusted X, Compartmented-mode workstation, X11/SELinux [Epstein *et al.*,'90][Berger *et al.*,'90][Kilpatrick *et al.*,'03]
- Java Virtual Machine/SELinux [Fletcher,'06]
- IBM Websphere/SELinux [Hocking *et al.*,'06]
- And more: Apache, PostgreSQL, dbus, gconf, …

Retrofitting Legacy Code

- What if you had to add security controls for a legacy program?

Need systematic techniques to retrofit legacy code for security



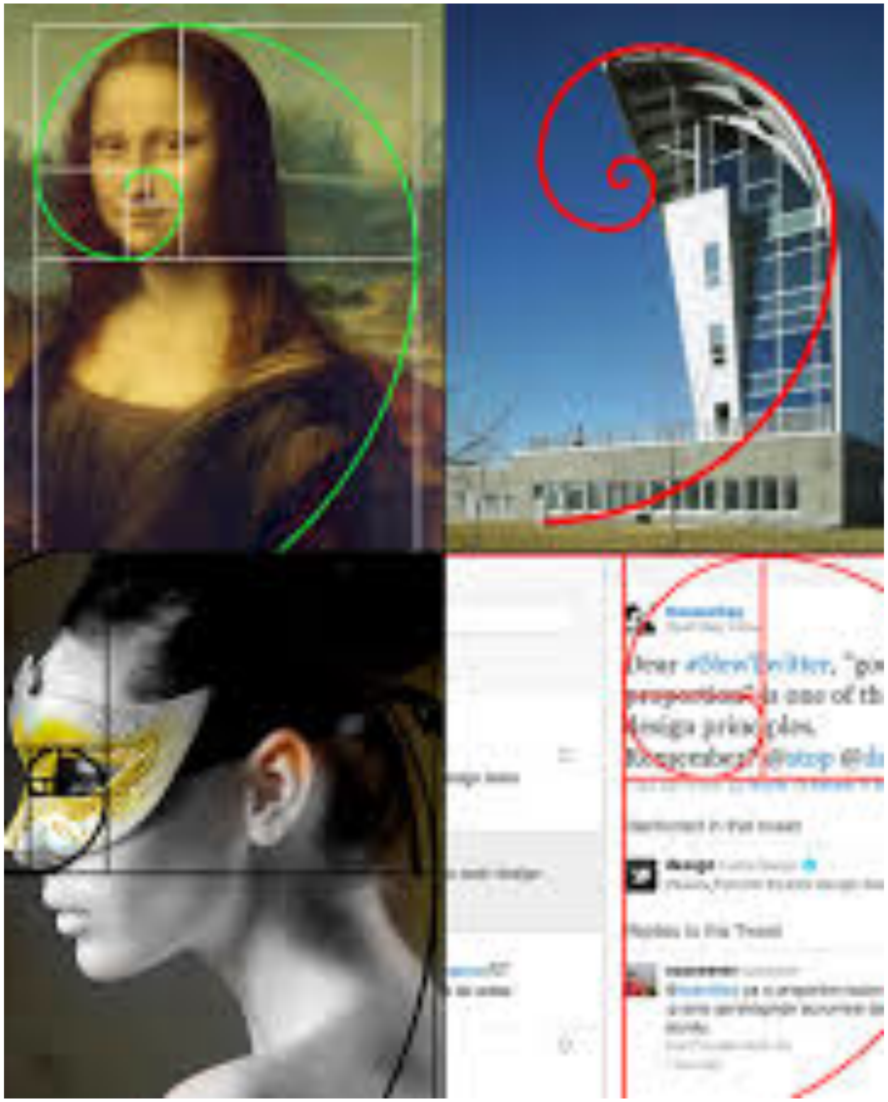
Legacy code

INSECURE

Retrofitted code

SECURE

Design for Security



- Perhaps retroactive security is the wrong approach
  - Too late to get right
- "Design for security" from the outset is the goal
  - But, how do we teach programmers to do that?
  - In a practical and time-effective manner
- Design methodologies may vary widely

What is Needed?

- Programs need multiple security controls

```
request_loop (client_data, private_data) {
  read(client_passwd, client_req );
  if (necessary ||
      compare_client(client_passwd,
                     private_data))
    access_object(client_req, client_data);
}
```

- Program reads `client_passwd` and `client_req`
- Don’t leak `private_data` used to check passwords
- Control client request’s access to `client_data`

What is Needed?

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```
request_loop (client_data, private_data) {
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}
```

- Privilege separation between `compare_client` and `access_object`
- Authorization of `access_object`
- Auditing of execution of unsafe `client_req`

Past Efforts

- Automated Hook Placement:
  - Assumptions: **Training wheels**
    - (sensitive data types, hook code)

  [Ganapathy et al., 2005, 2006, 2007]

  [Sun et al., 2011, RoleCast 2011]

- Automated Hook Placement 2:
  - Assumptions: **Training wheels**
    - (constraint models of function and security)

  [Harris et al., 2010, 2013]

Security Goals

- Retrofit security controls automatically
  - From "security programs"
- Assist programmers in producing such security programs
  - From code analyses
- Compile such security programs into minimal cost code for enforcing the expected security goals correctly
  - Across security controls

Outline

- Let’s examine the problem of retrofitting for security
  - For authorization
- Then explore other security controls
  - For privilege separation and auditing
- Then, discuss how to retrofit across security controls
  - Step two

Retrofit for Authorization

We want to generate complete and minimal authorization hook placements mostly-automatically for legacy code

[CCS 2012] Divya Muthukumaran, Trent Jaeger, Vinod Ganapathy. Leveraging "choice" to automate authorization hook placement. In *Proceedings of the 19th ACM Conference on Computer and Communications Security (ACM CCS)*, October 2012.

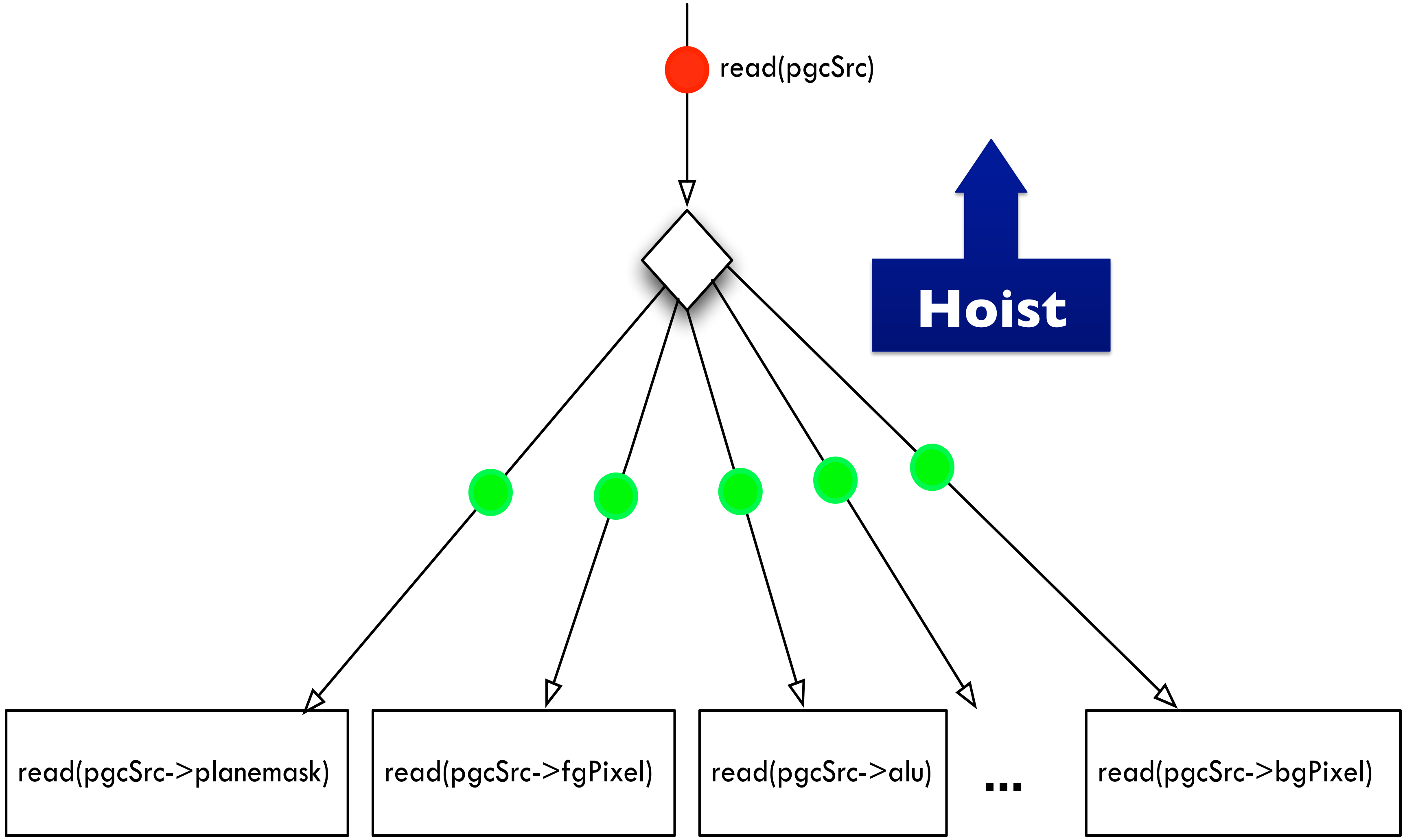
[ESSoS 2015] Divya Muthukumaran, Nirupama Talele, Trent Jaeger, Gang Tan. Producing hook placements to enforce expected access control policies. In *Proceedings of the 2015 International Symposium on Engineering Secure Software and Systems (ESSoS)*, March 2015.

Placement Comparison

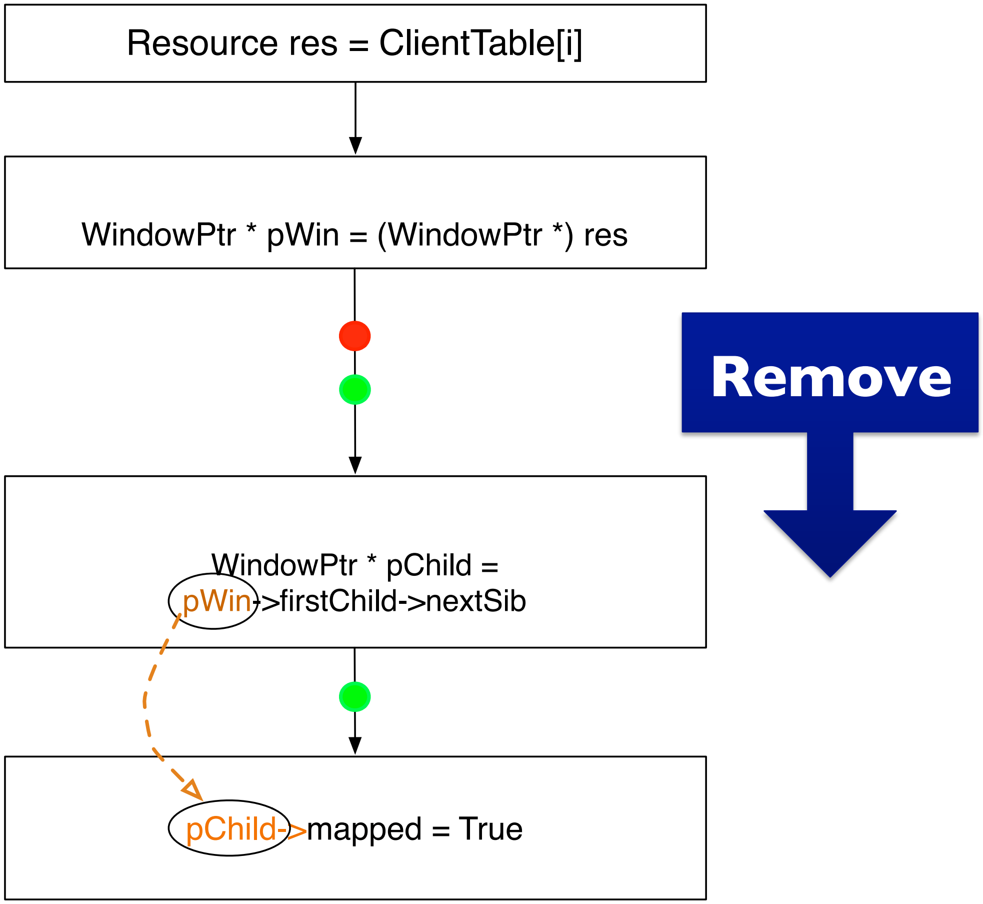
- Based on CCS 2012 Method
- X Server:
  - Manual: 201 hooks
  - Automated: 532 hooks
- Postgres:
  - Manual: ~370
  - Automated: 579

What does this mean?

Hook Hoisting



Hook Removal



Resource res = ClientTable[i]

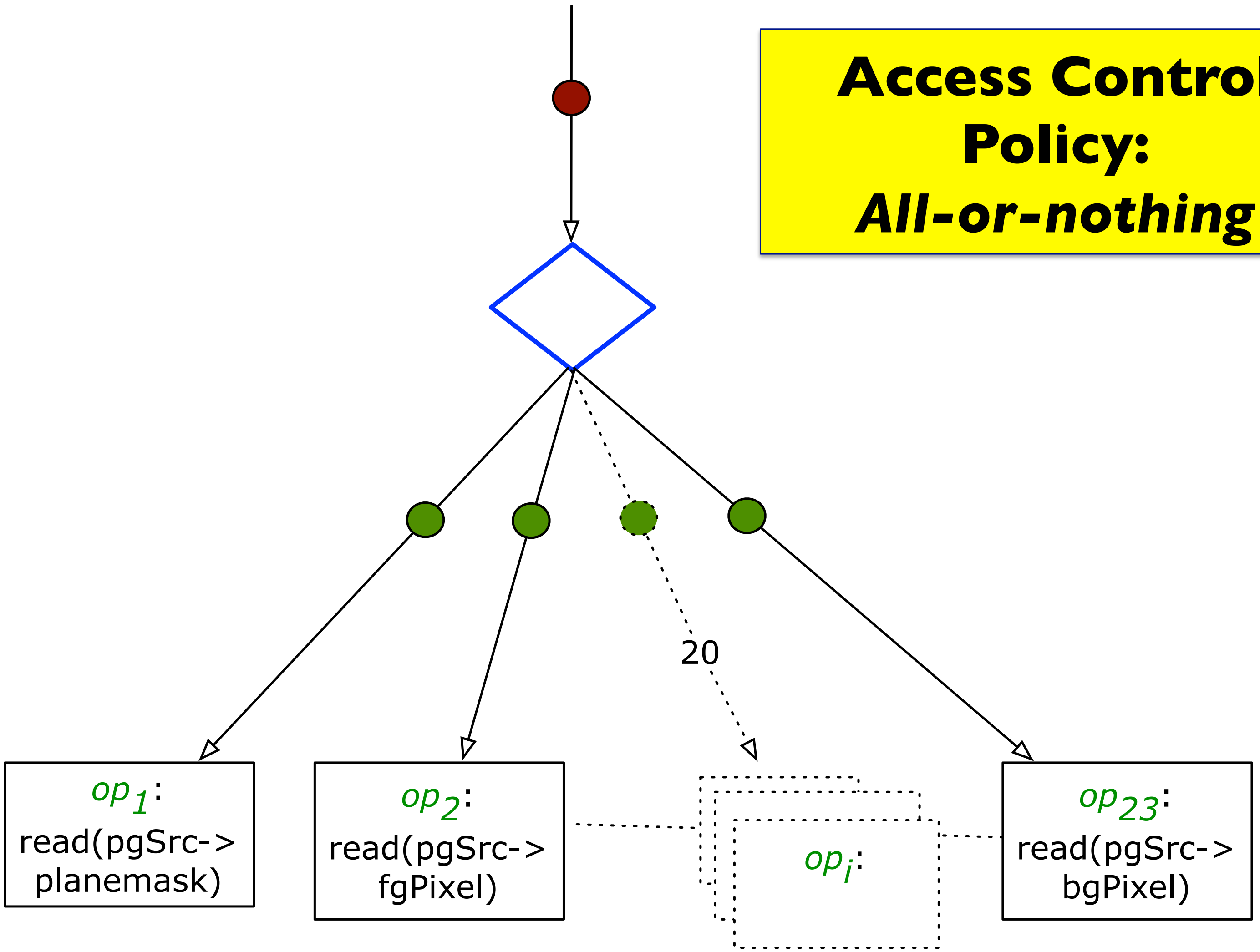
WindowPtr * pWin = (WindowPtr *) res

WindowPtr * pChild = pWin->firstChild->nextSib

pChild->mapped = True

Remove

Relate to Access Control


20
op_1: read(pgSrc-> planemask)
op_2: read(pgSrc-> fgPixel)
op_i:
op_{23}: read(pgSrc-> bgPixel)

Access Control Policy: ***All-or-nothing***

Authorization Constraints

- *Allowed(o)*: Subset of subjects in *U* that are allowed to perform operation *o*.
- Constraint 1:
  - *Allowed(o1) = Allowed(o2)*, then ***o1 equals o2***
- Constraint 2:
  - *Allowed(o1)* ⊂ *Allowed(o2)*, then ***o1 subsumes o2***

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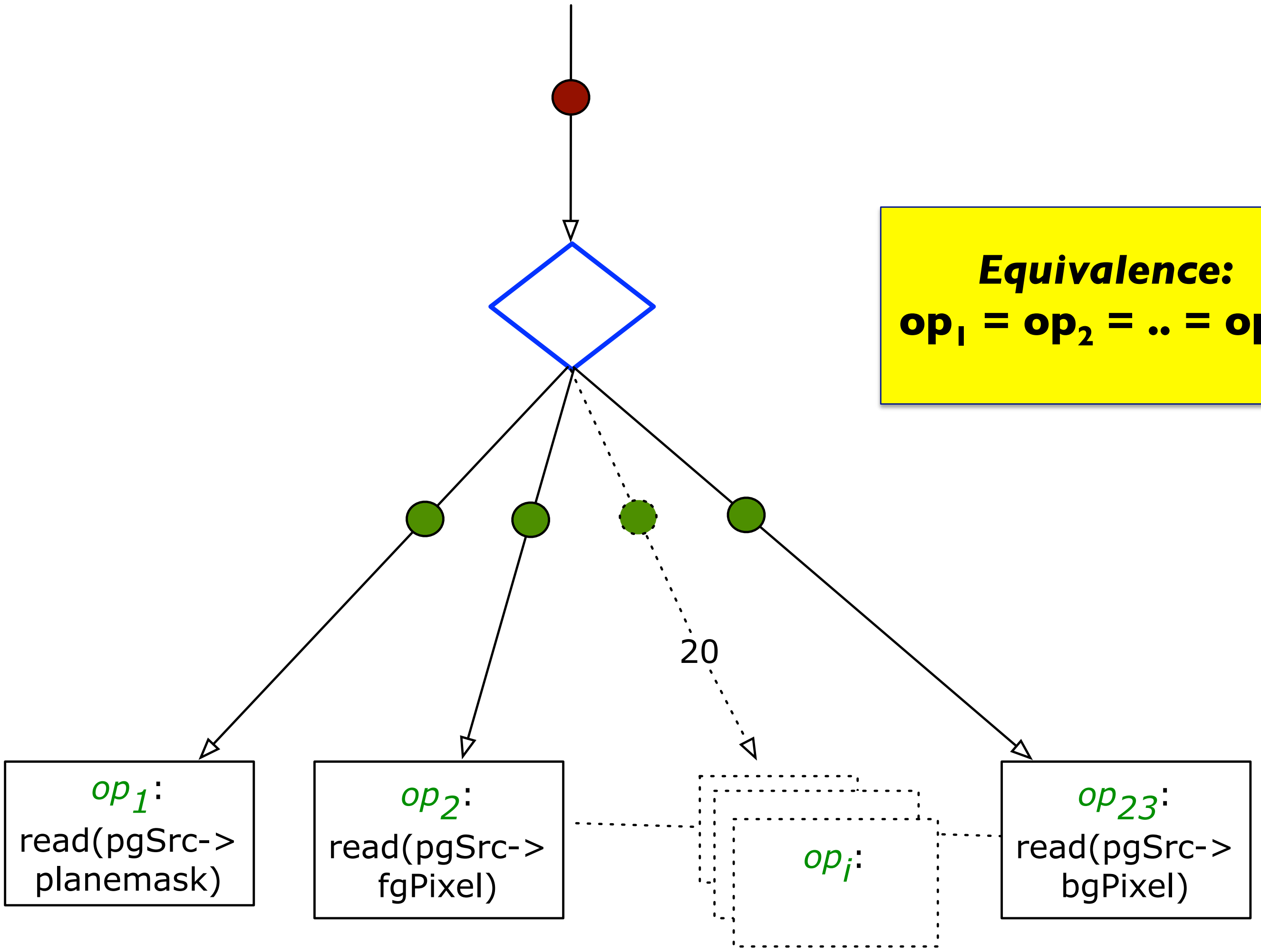
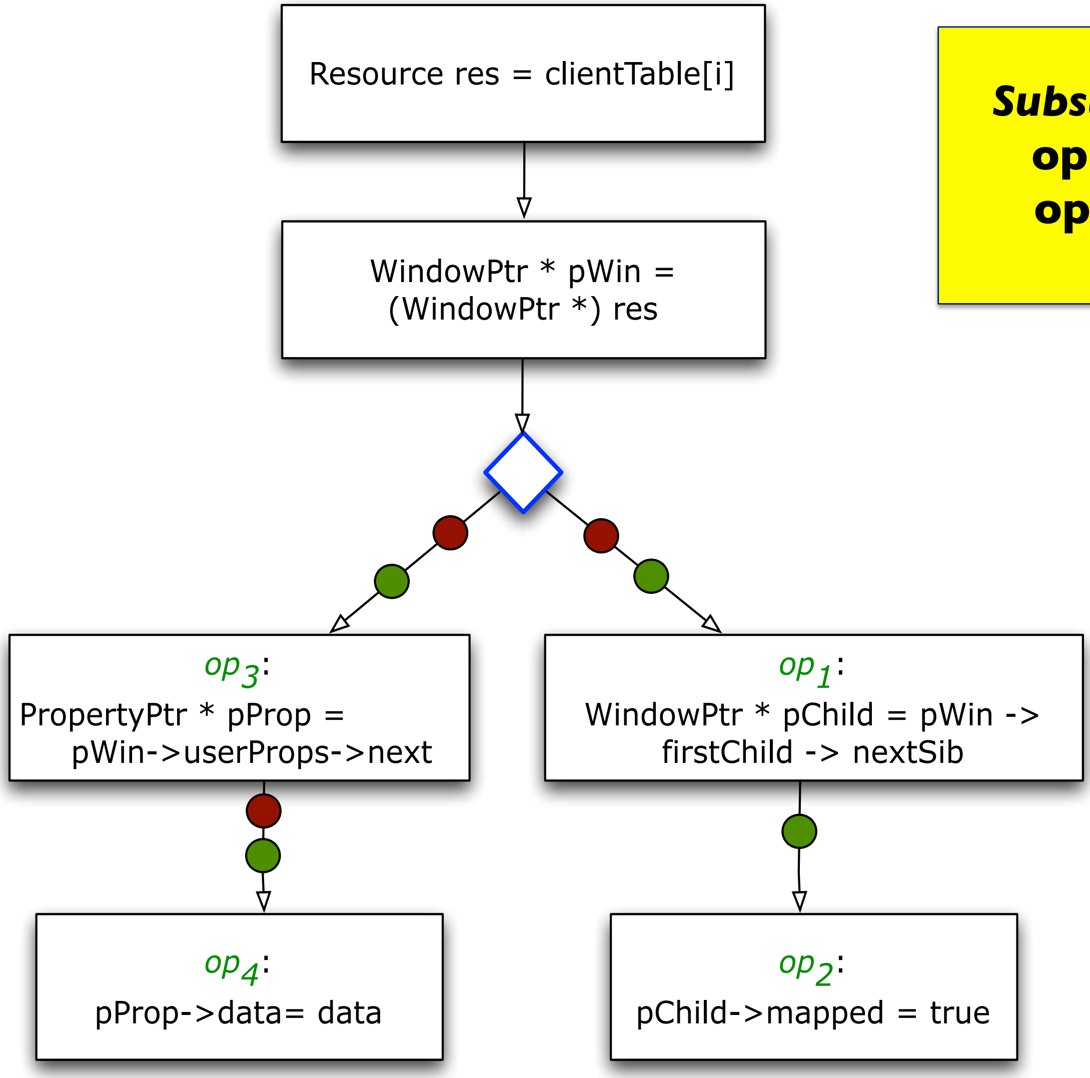
Set of Authorization Constraints limit the access control policies that can be enforced

Equivalence


20
op_1: read(pgSrc->planemask)
op_2: read(pgSrc->fgPixel)
op_i:
op_{23}: read(pgSrc->bgPixel)

Equivalence:
$op_1 = op_2 = .. = op_{23}$

Subsumption



Resource res = clientTable[i]

WindowPtr * pWin = (WindowPtr *) res

op$_3$: PropertyPtr * pProp = pWin->userProps->next

op$_1$: WindowPtr * pChild = pWin -> firstChild -> nextSib

op$_4$: pProp->data= data

op$_2$: pChild->mapped = true

Subsumption:

$op_1 > op_2$

$op_3 \not> op_4$

Build Retrofitting Policies

- How do programmers build retrofitting policies?
  - Hundreds of hooks could be removed
-

Build Retrofitting Policies

- However, there are common policy assumptions
  - E.g., object flows – if two operations produce the same data flow, such as from the object to the client (read), then they may be assumed to be equivalent
  - Under this constraint, we could still enforce MLS
- Apply "constraint selectors" to collect such authorization constraints from code
  - Removes up to 2/3 of the unnecessary hooks

Retrofitting for Authorization

- (1) Identify security-sensitive operations
  - Mostly-automated identification of operations [CCS 2012]
- (2) Produce retrofitting policy
  - Produce default authorization hook placement for SSOs
  - Apply constraint selectors for high-level policy constraints
  - Interactive selection of other authorization constraints
- (3) Generate minimal* authorization hook placement
  - Based on retrofitting policy (* modulo assumptions)
- (4) Validate reference monitor concept relative to retrofitting policies and correct transformation

Other Security Controls

- Retrofitting for Privilege Separation and Auditing

Shen Liu, Gang Tan, Trent Jaeger. PtrSplit: Supporting General Pointers in Automatic Program Partitioning. In Proceedings of the 24th ACM Conference on Computer and Communications Security (ACM CCS), October 2017.

Sepehr Amir-Mohammadian, Stephen Chong, Christian Skalka. Correct Audit Logging: Theory and Practice. In Proceedings of the 5th International Conference on Principles of Security and Trust, 2016.

Retrofitting for Auditing

Retrofitting for Auditing

- *Audit logs* are intended to provide information about programs to support:
  - Accountability and proof of authorization.
  - Surveillance and intrusion detection.
  - Dynamic analysis for performance/security evaluation.
- Current practice missing crucial foundational elements:
  - What is the *formal relation* between a program and its audit log?
  - What *policy* specifies audit log generation?

Retrofitting for Auditing

- We propose an information algebraic semantics of auditing that takes as input:
  - An arbitrary program p in a given language.
  - A *logging policy LP* that specifies conditions for logging particular events. (i.e., retrofitting policy)
- This semantics, written *genlog*(p, *LP*) denotes a set of *information*. An audit log L is *sound* (resp. *complete*) with respect to the policy iff:
  - $L \leq \mathit{genlog}(p, \mathit{LP})$ (resp. $\mathit{genlog}(p, \mathit{LP}) \leq L$) where $\leq$ is an *information containment relation.*

Putting it all together

- Retrofit for multiple security controls
  - Claim: reasoning about retrofitting policies across security controls enables benefits

Retrofitting for All

- Benefits of retrofitting policies
  - Separate security program from functional program
    - Prevent errors in integration of the two – even for updates
    - Make policy enforcement expectations explicit
  - Leverage the relationships between security controls
    - Remove redundant security controls
    - Use security controls to improve retrofitting policies
- Bottom line: there is no silver bullet - programmers will need to add such security controls

Summary

- Problem: Place Security Controls in Legacy Code
  - Hard to do manually
- Insights:
  - Program expectations of security controls into "retrofitting policies" or "security programs"
  - Retrofit programs automatically to minimize cost, validate correctness of security and function
  - Apply across a set of security controls for coherent "Defense in Depth"
- Targets: Authorization, Privilege Separation, and Auditing
- Future: How shall programmers "Design/program for security" ?