Information Flow Control For Standard OS Abstractions

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Outline

- Motivation
- Flume Model
- Flume System
- Evaluation
- Conclusion

Motivation

- Protecting confidential data in computing environments
- Access controls are insufficient to regulate the propagation of information after it has been released for processing by a program

Information Flow Security

- Track and regulate the information flows of the system
  - Prevent secret data from leaking to unauthorized processes (secrecy)
  - Prevent untrusted software to be compromised through malicious inputs (integrity)

Decentralized Information Flow Control (DIFC)

- Share information with untrusted code
- Control how untrusted code disseminates the shared information to others
- Support for declassification of information in a decentralized way
- Improves the security of complex applications even in the presence of potential exploits

Previous Work

- Programming language abstractions
  - Jif: provide more fine-grained control at the granularity of functions in processes
  - But requires applications to be rewritten
- Integrated into communication primitives in OS kernel
  - Asbestos and HiStar Operating Systems
  - Granularity of unreliable messages between processes (Asbestos) or segments (HiStar)

Flume

- Implements a user-level reference monitor
- Provides DIFC at the granularity of processes
- Integrates DIFC controls with standard communication channels like pipe, sockets, file descriptors
- Simple label system

Flume Model - Tags and Labels

- Flume model closely follow IFC, add new representation
- Each tag is associated with some category of secrecy or integrity
- Labels are subsets of Tags
  - Form a lattice under partial order of subset relation
- Used for tracking

Flume Model - Secrecy and Integrity

- Each Flume process p has two labels
  - S_p for secrecy
  - I_p for integrity
- If tag $t \in S_p$, then it is assumed that process p has seen private data tagged with t
- If $t \in I_p$, then every input to p has been endorsed as having integrity for t
- Files and objects also have secrecy and integrity labels

Decentralized Priviledge

- Any process can create new tags
  - Gets the privilege to declassify and/or endorse information for those tags
- Two capabilities per tag
  - *t*+ : Ability to add *t* to the label
  - *t*- : Ability to remove *t* from the label
- Each process *p* owns a set of capabilities O_p

Capabilities

- Dual privilege
  - $D_p = \{t \mid t+ \in O_p \text{ and } t- \in O_p\}$
- A process *p* allocating a new tag *t*
  - $O_p = O_p \cup \{t+, t-\}$
- Global capability set *O*
  - System enforces that $O \subseteq O_p$ for all *p*
  - Only tag allocation can change *O*

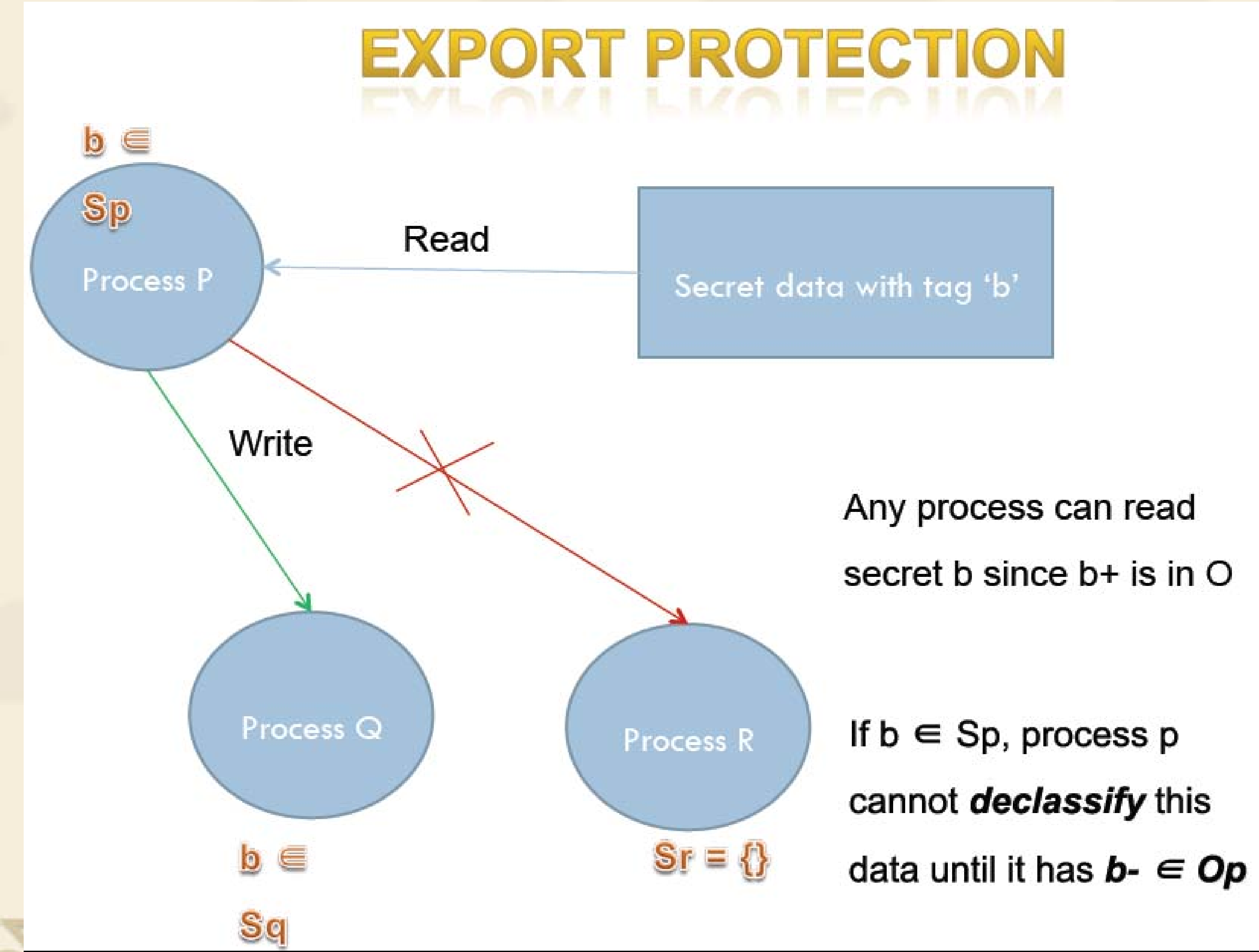
Flume Model: Security – Safe Messages

- Restriction of process communication to prevent data leaks
- *p* can send a message to *q* only if,
  - $S_p \subseteq S_q$ (less secret to more secret ->allow)
  - $I_q \subseteq I_p$ (more integrity to less integrity ->allow)
- A message from *p* to *q* is safe iff,
  - $S_p - D_p \subseteq S_q \cup D_q$ and
  - $I_q - D_q \subseteq I_p \cup D_p$

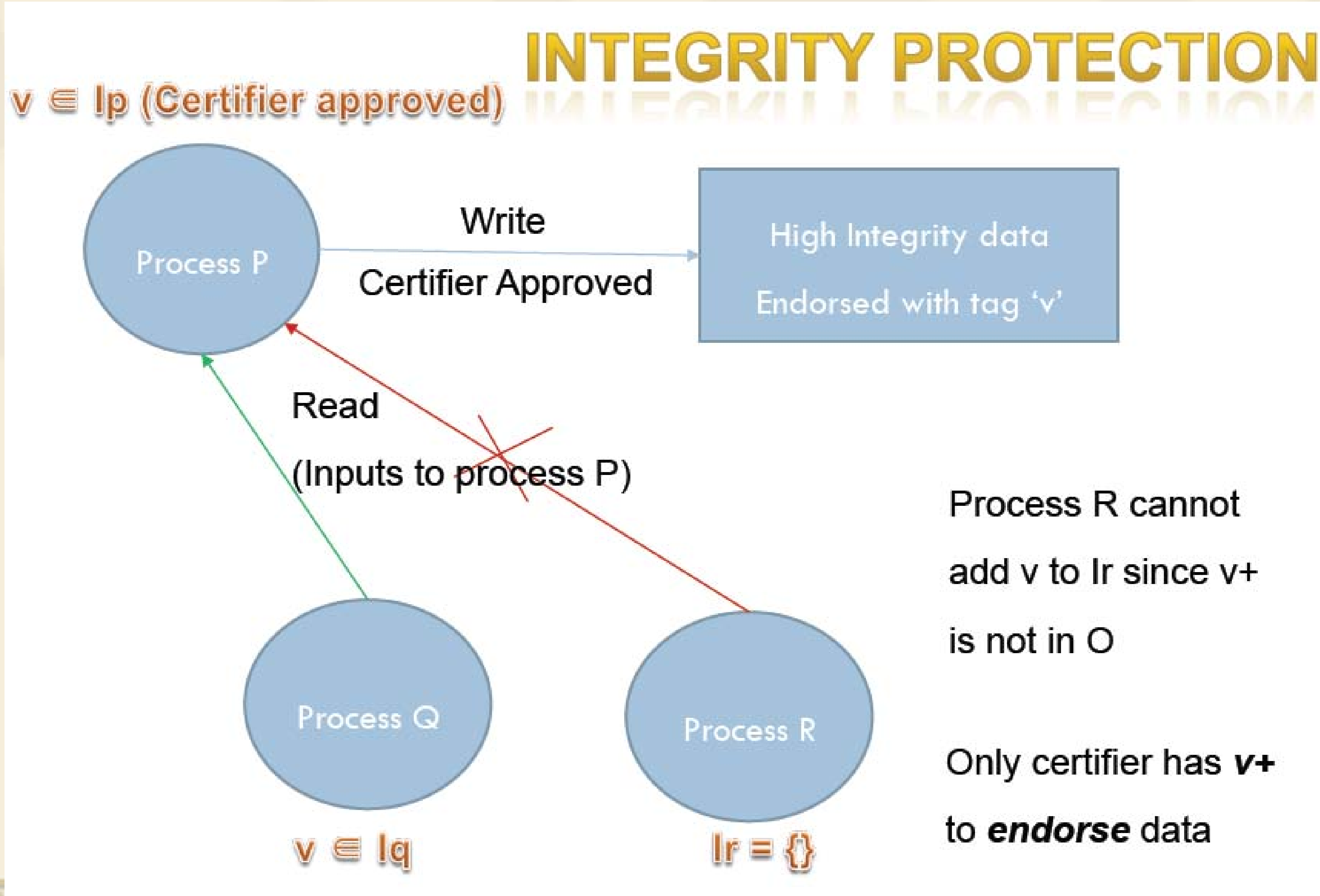
Secrecy and Integrity Protections

- Export protection
  - Secrecy tag *t*+ is added to **O**
  - Only process with ***t-*** can *'declassify'*
- Read protection
  - Controlling *t*+, thereby limiting the processes
- Integrity protection
  - integrity tag *v*- is added to O
  - Only a certifier who has *v*+ can 'endorse'

Secrecy - Illustrated



Integrity - Illustrated



Security – Safe Label Changes

- External Sinks and Sources
  - Remote host, terminal, sockets…
  - $S_x = I_x = \{\}$
- Objects
  - Assigned immutable secrecy and integrity labels
  - Creating process specifies these labels

Security – Safe Label Changes

- In Flume, only process *p* can change S_p or I_p and must request such a change explicitly
- For a process *p*, *L* be S_p or I_p, *L'* be the new label
- Change from *L* to *L'* is safe iff,
  - $\{L' - L\}^{+} \cup \{L - L'\}^{-} \subseteq O_p$

Flume System: Endpoint abstraction

- Need to apply DIFC controls to existing APIs
- Glue between flume and standard communication abstractions like sockets, file descriptors
- Flume assigns an *endpoint* to each Unix file descriptor
- A process can potentially adjust the labels on an endpoint
- All IPC happens between two endpoints

Flume System: Endpoints

- A process owns readable/writable/both endpoints for each of its resource
- A readable endpoint is safe iff
  - $(S_e - S_p) \cup (I_p - I_e) \subseteq D_p$
- A writable endpoint is safe iff
  - $(S_p - S_e) \cup (I_e - I_p) \subseteq D_p$
- Safe flow between endpoints ensures safe flow between processes

Examples – IPC communication

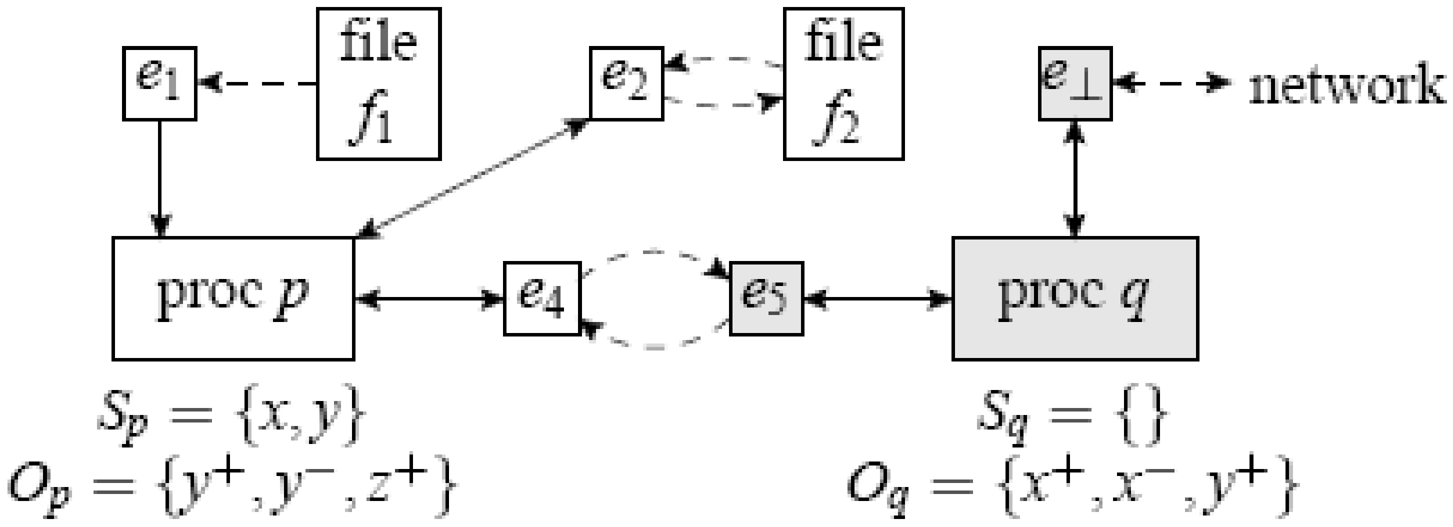


Figure 1: Processes p and q. Assume $\mathbf{O} = \{\}$.

Examples – Shell and Editor

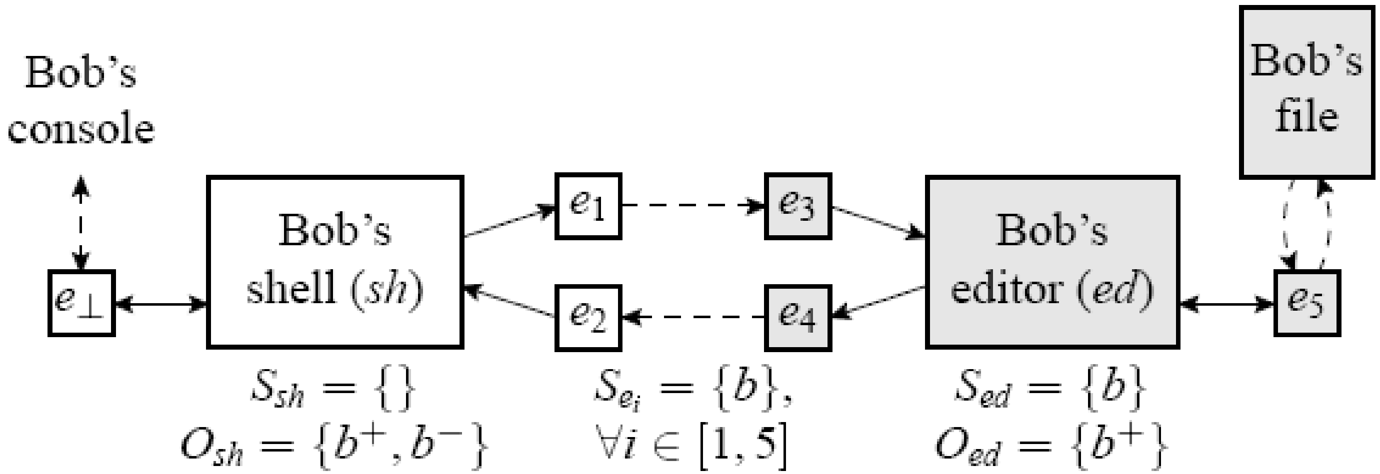


Figure 2: A configuration for Bob's shell and editor. Here, $\mathbf{O} = \{b^+\}$.

Flume Implementation

- Linux Security Model implements Flume’s system call interposition
- Reference Monitor keeps track of each process’s labels, authorizes or denies its requests to change labels and handles system calls on its behalf
- RM has the following components
  - Spawner process
  - Remote tag registry
  - User space file servers
- Flume aware libc does system call interposition

Flume Architecture

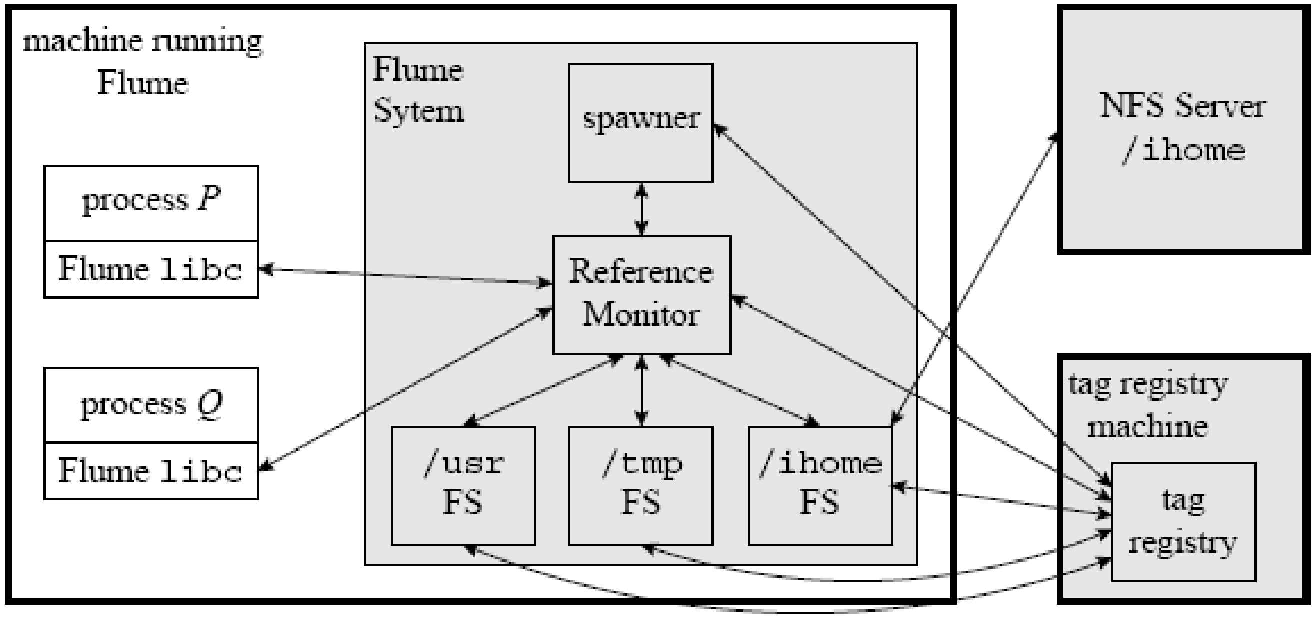


Figure 3: High-level design of the Flume implementation. The shaded boxes represent Flume's trusted computing base.

Spawner process

- The reference monitor calls spawner which calls fork
- In the child process, the spawner
  - Enables the Flume LSM policy
  - Performs any *setlabel* label manipulations if the file to execute is *setlabel*
  - Opens the requested executable (e.g. foo.sh), interpreter (e.g. /bin/sh) and dynamic linker (e.g., /lib/ld.so) via standard Flume open calls, invoking all of Flume's permission checks;
  - Closes all open file descriptors except for its control socket and those opened in the previous step
  - Claims any file descriptors by token
  - Calls exec

Limitations

- Bigger TCB
  - Linux stack (Kernel + glibc + linker)
  - Reference monitor (~21 kLOC)
- Confined processes like MoinMoin don't get full POSIX API.
  - `spawn()` instead of `fork()` & `exec()`
  - `flume_pipe()` instead of `pipe()`

Case Study – Moin Moin Wiki

- Python based web publishing system
- Designed to share documents
- Each page can have an ACL
- 91 K LOC!

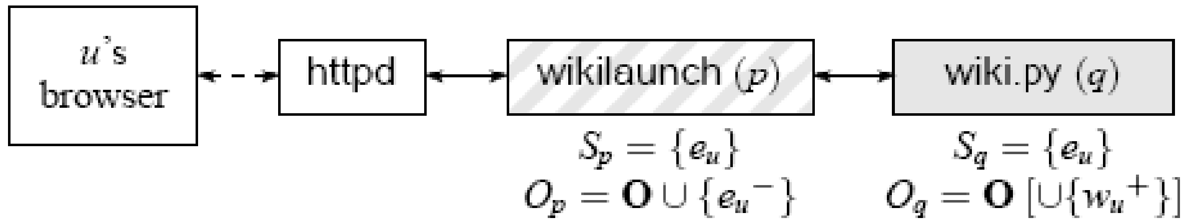


Figure 7: Label setup for a *read* or *write* request in FlumeWiki. wiki.py only gets capability w_u^+ if writing. The target page is export- and write-protected by user u.

Case Study – Overhead

- 1000 LOC launcher/declassifier
- 1000 out of 100K LOC in MoinMoin changed
- Python interpreter, Apache unchanged
- Two ACL bugs are not exploitable in Flume
- Performs within a factor of 2 of the original on read and write tests
- Latency and throughput within 45% and 35% of the unmodified MoinMoin wiki, respectively

Case Study – Interposition Overhead

- For most system calls, Flume adds 35–286ms per system call which results in latency overhead of a factor of 4–35
- Additional 2 system calls
  - accounts for approximately 40ms of Flume's additional latency
- An IPC round trip takes 12 system calls on Flume, incurring the three-fold performance penalty for additional system calls

Performance – System calls

Operation	Linux	Flume	diff.	mult.
mkdir	86.0	371.1	285.2	4.3
rmdir	13.8	106.8	93.0	7.7
open				
— create	12.5	200.2	187.7	16.0
— exists	3.2	110.3	107.1	34.5
— exists, inlined	3.3	41.0	37.7	12.5
— does not exist	4.3	101.4	97.1	23.6
— does not exist, inlined	4.2	39.8	35.6	9.5
stat	2.8	98.1	95.3	34.5
— inlined	2.8	38.7	35.9	13.7
close	0.6	0.9	0.2	1.3
unlink	15.4	110.0	94.6	7.2
symlink	9.5	106.8	97.3	11.2
readlink	2.7	90.2	87.5	33.0
create_tag		22.6		
change_label		55.0		
flumenull		20.1		
IPC round trip latency	4.1	33.8	29.8	8.2
IPC bandwidth	2945	937	2008	3.1

Performance – FlumeWiki

	Throughput (req/sec)		Latency (ms/req)	
	MoinMoin	FlumeWiki	MoinMoin	FlumeWiki
Read	33.2	18.8	117	156
Write	16.9	11.1	237	278

Figure 9: Latency and throughput for FlumeWiki and unmodified MoinMoin averaged over 10,000 requests.

Results

- Does Flume allow adoption of Unix software?
  - 1,000 LOC launcher/declassifier
  - 1,000 out of 100,000 LOC in MoinMoin changed
  - Python interpreter, Apache, unchanged
- Does Flume solve security vulnerabilities?
  - Without our knowing, we inherited two ACL bypass bugs from MoinMoin
  - Both are not exploitable in Flume's MoinMoin
- Does Flume perform reasonably?
  - Performs within a factor of 2 of the original on read and write benchmarks

Conclusion

- DIFC is a challenge to Programmers
- Flume: DIFC in User-Level
  - Preserves legacy software
  - Complements today's programming techniques
- MoinMoin Wiki: Flume works as promised

Thank you!