Explicit Information Flow in the HiStar OS

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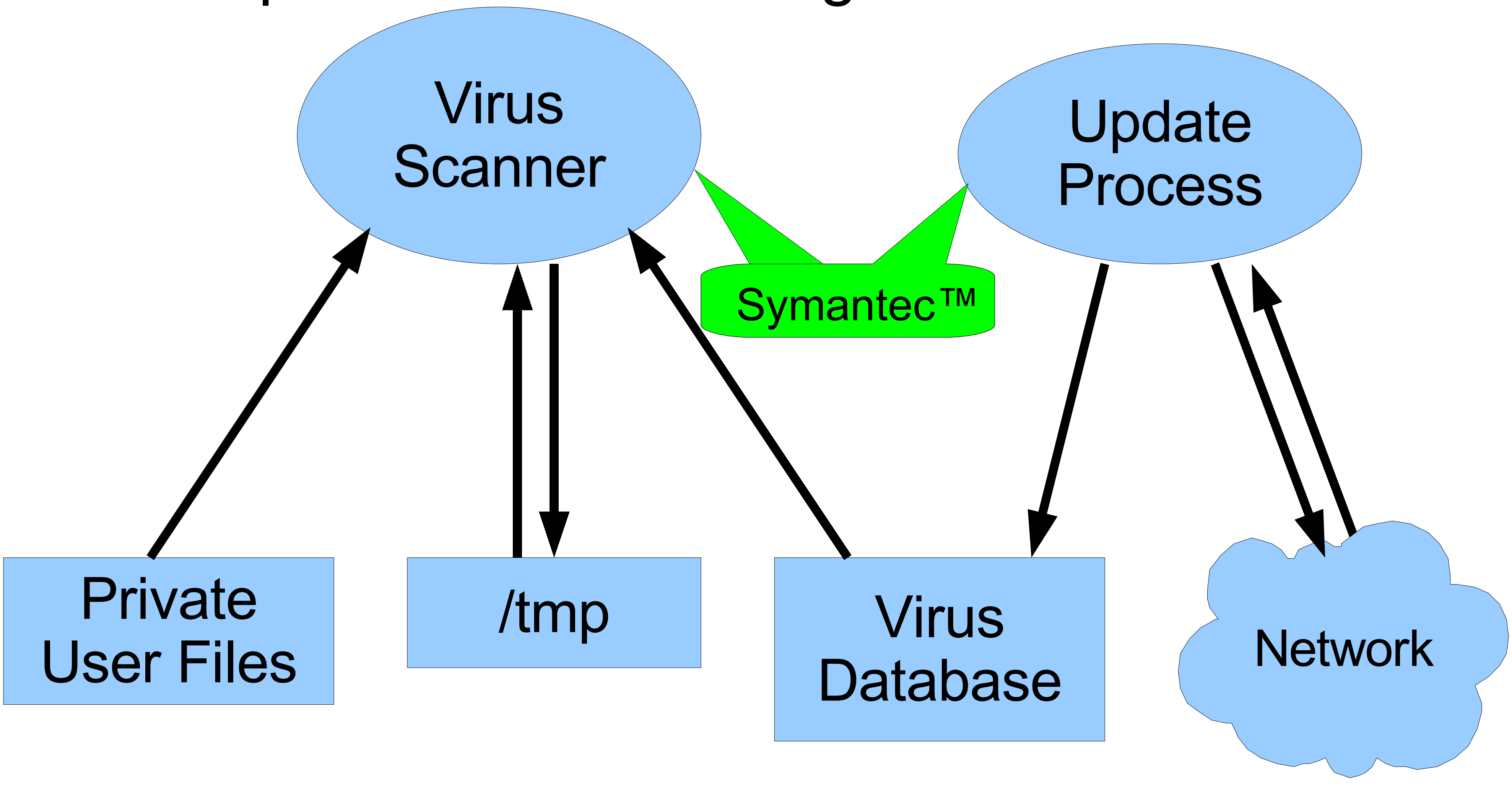
Too much trusted software

- Untrustworthy code a huge problem
- Users willingly run malicious software
  - Malware, spyware, ...
- Even legitimate software is often vulnerable
  - Symantec remote vulnerability
- No sign that this problem is going away
- Can an OS make untrustworthy code secure?

Example: Virus Scanner

- Goal: private files cannot go onto the network



Information Flow Control

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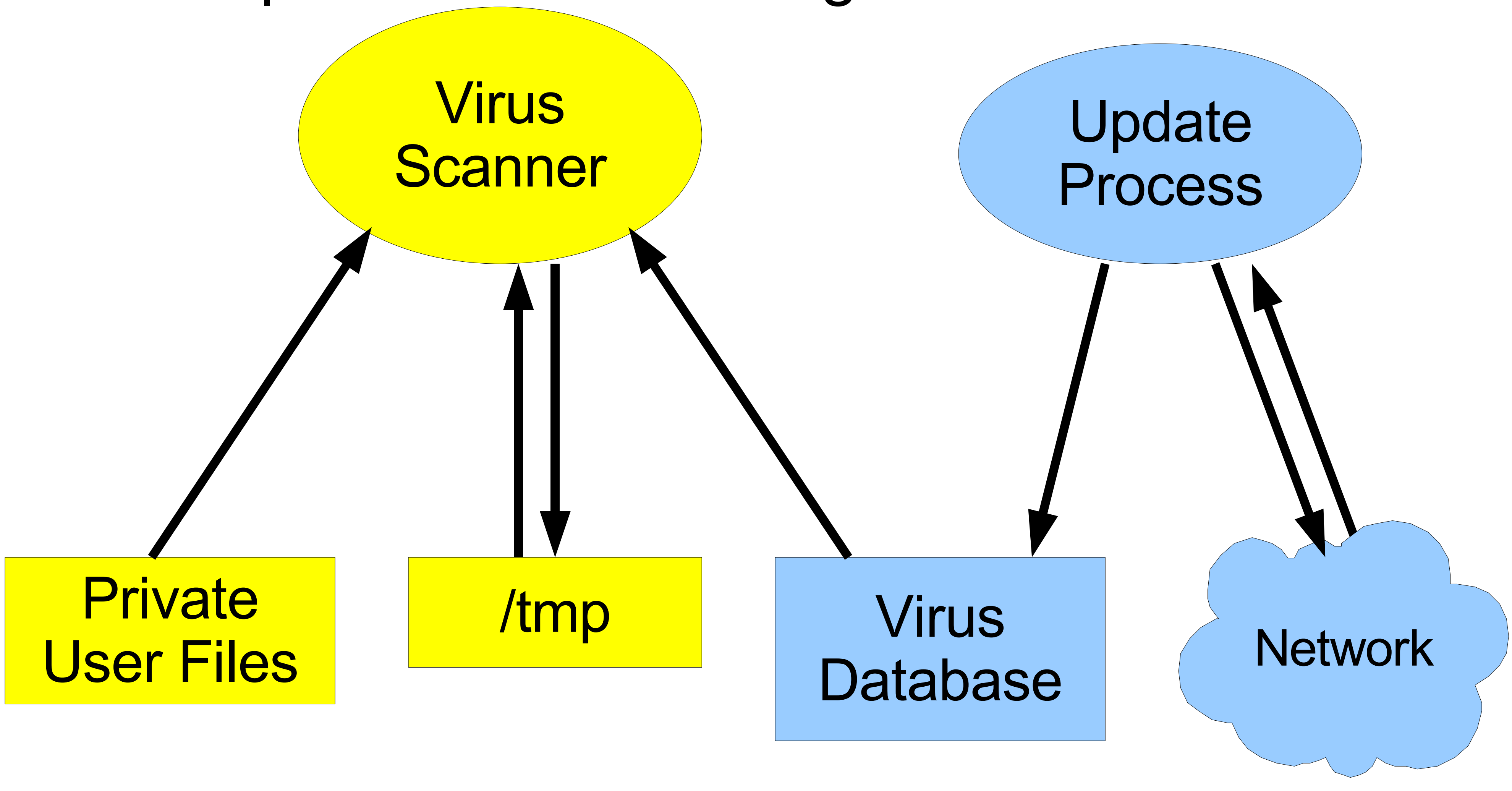
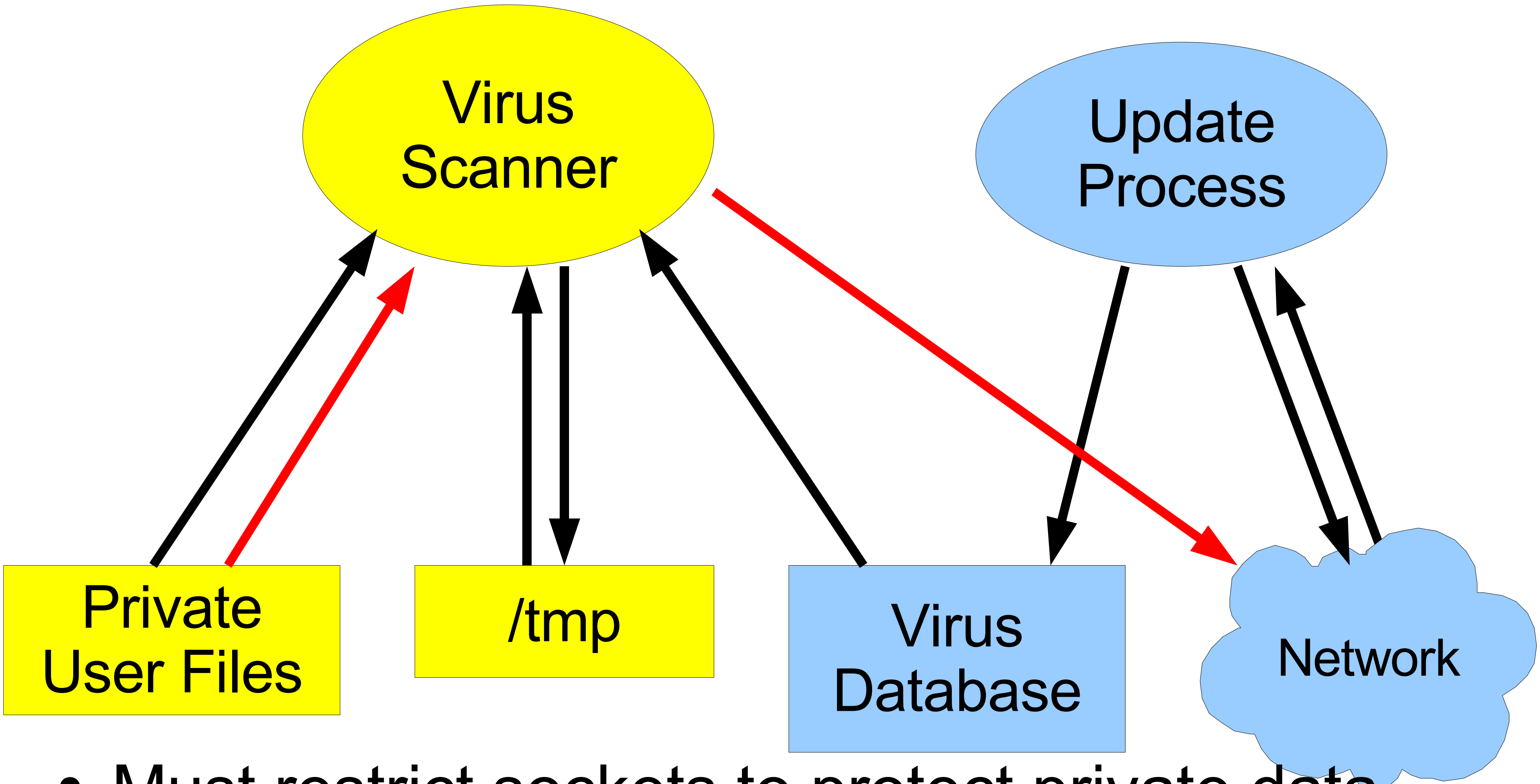


Buggy scanner leaks private data



- Must restrict sockets to protect private data

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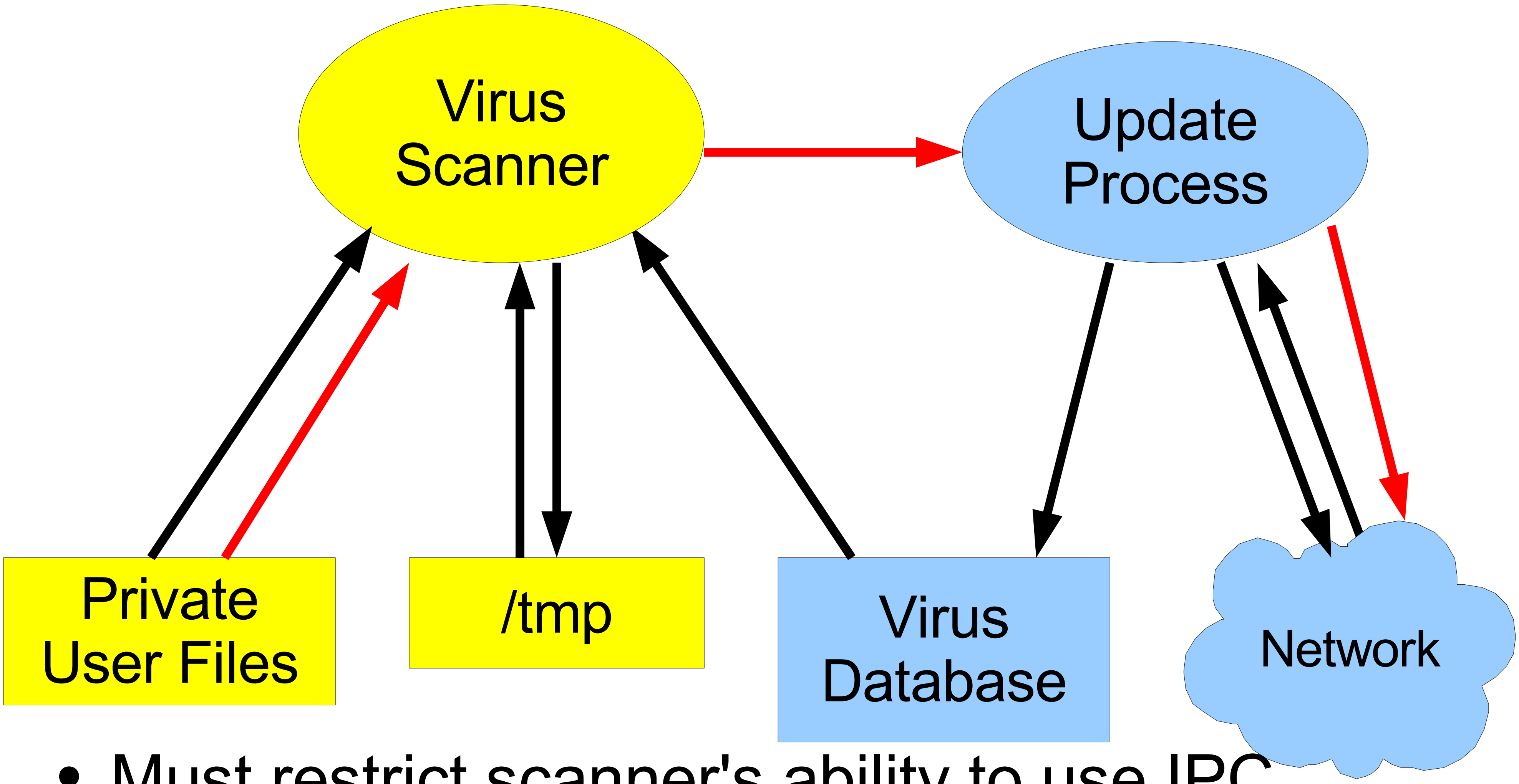

- Must restrict scanner's ability to use IPC

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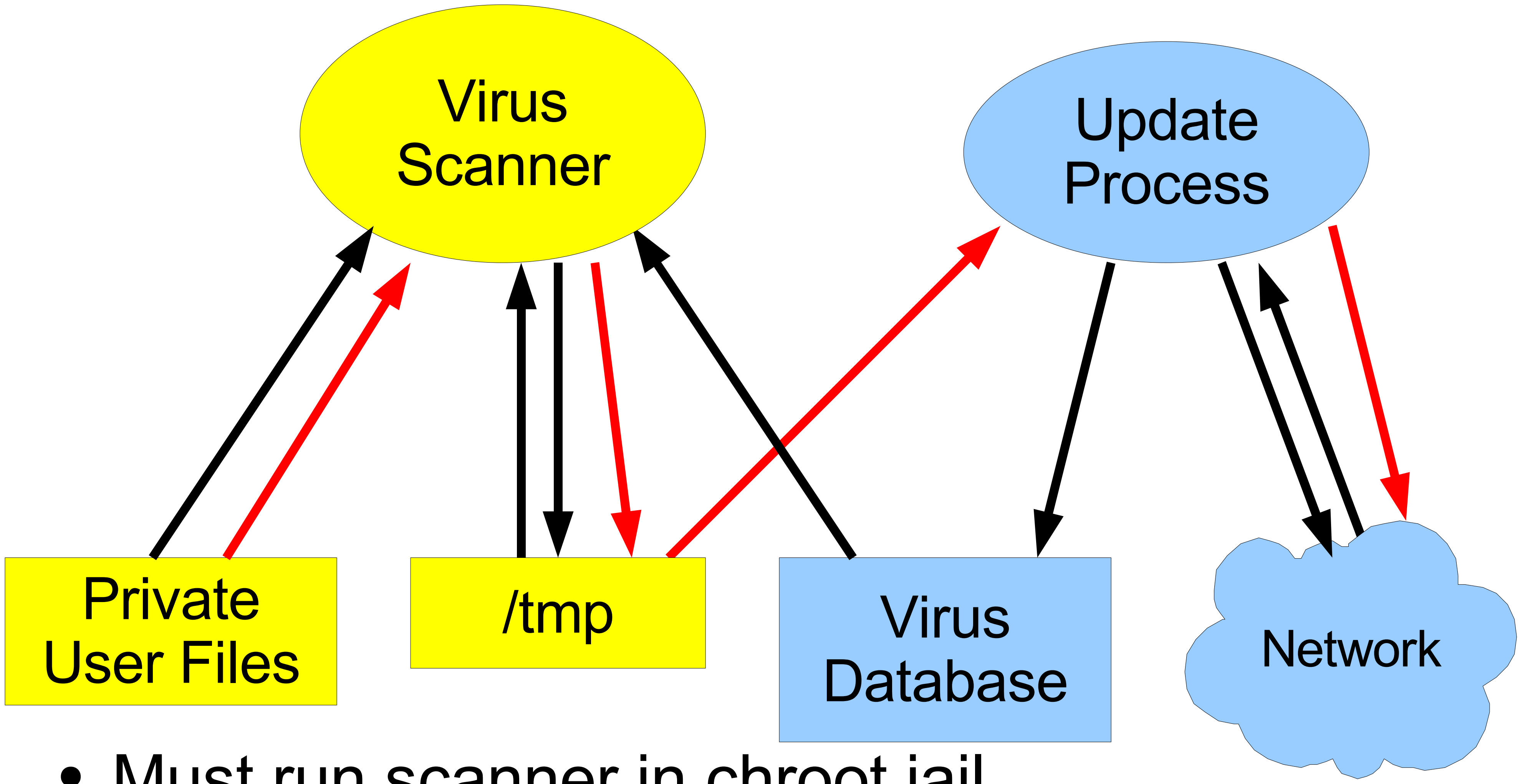
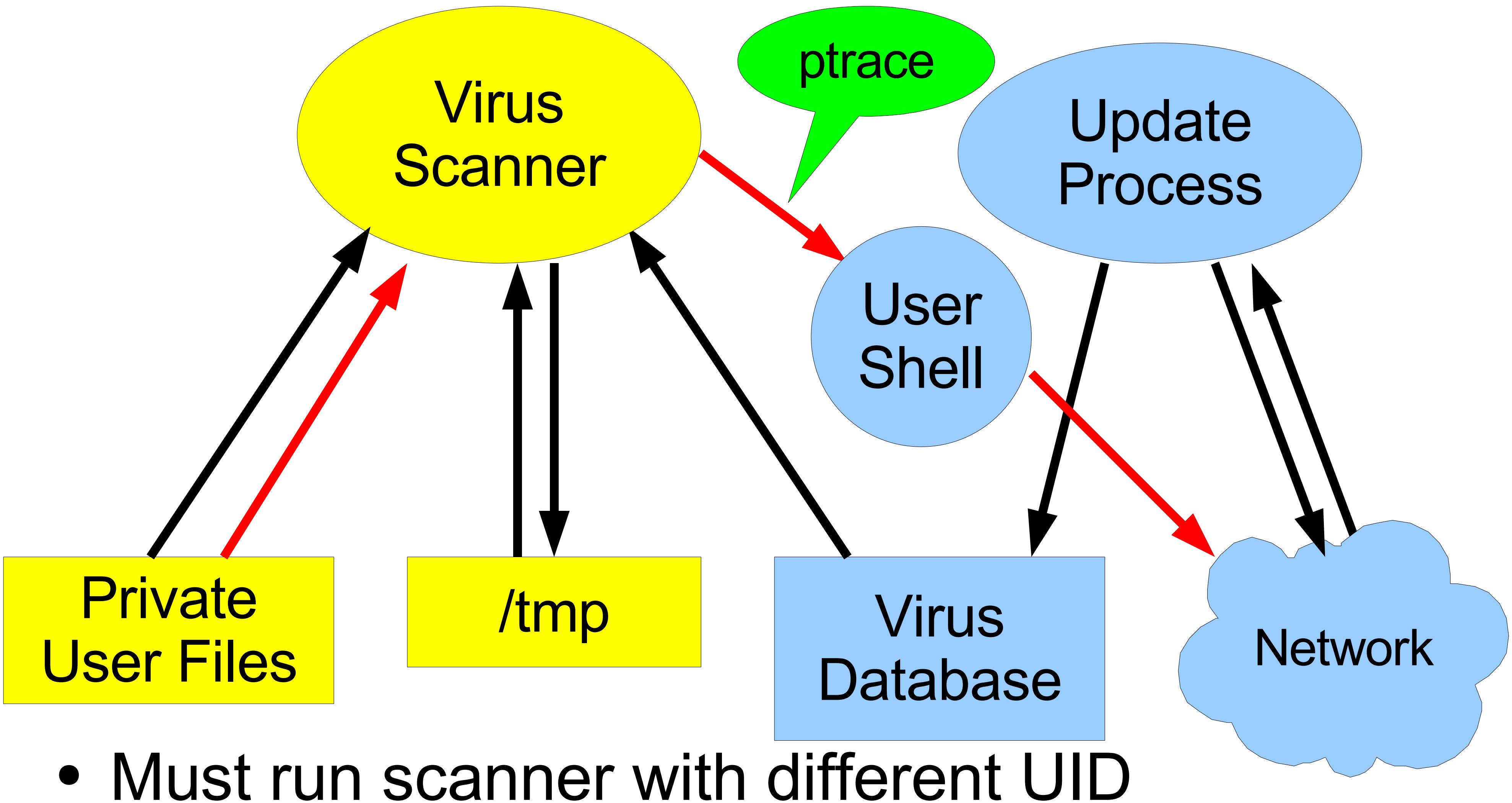


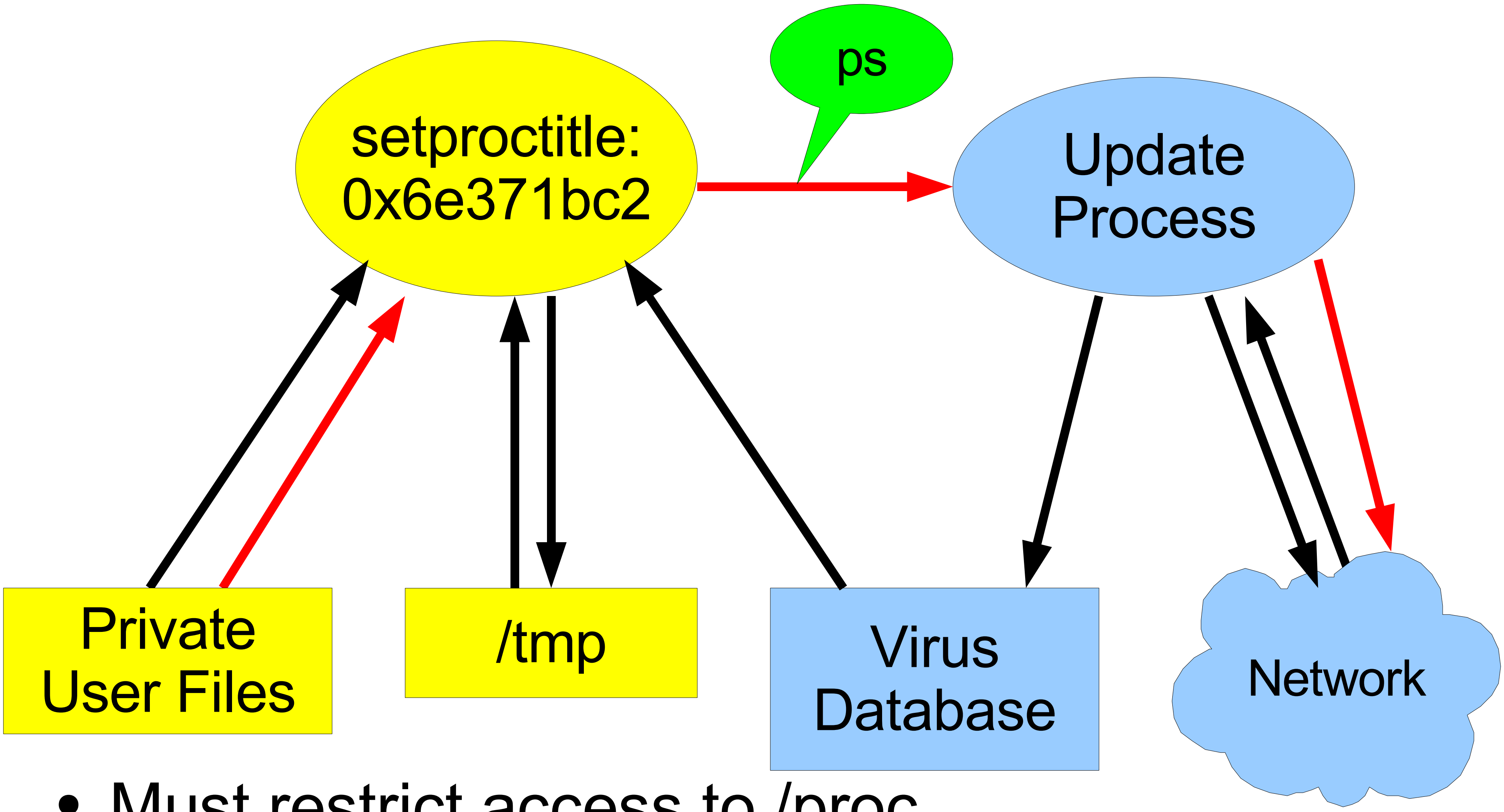
- Must run scanner in chroot jail

Buggy scanner leaks private data



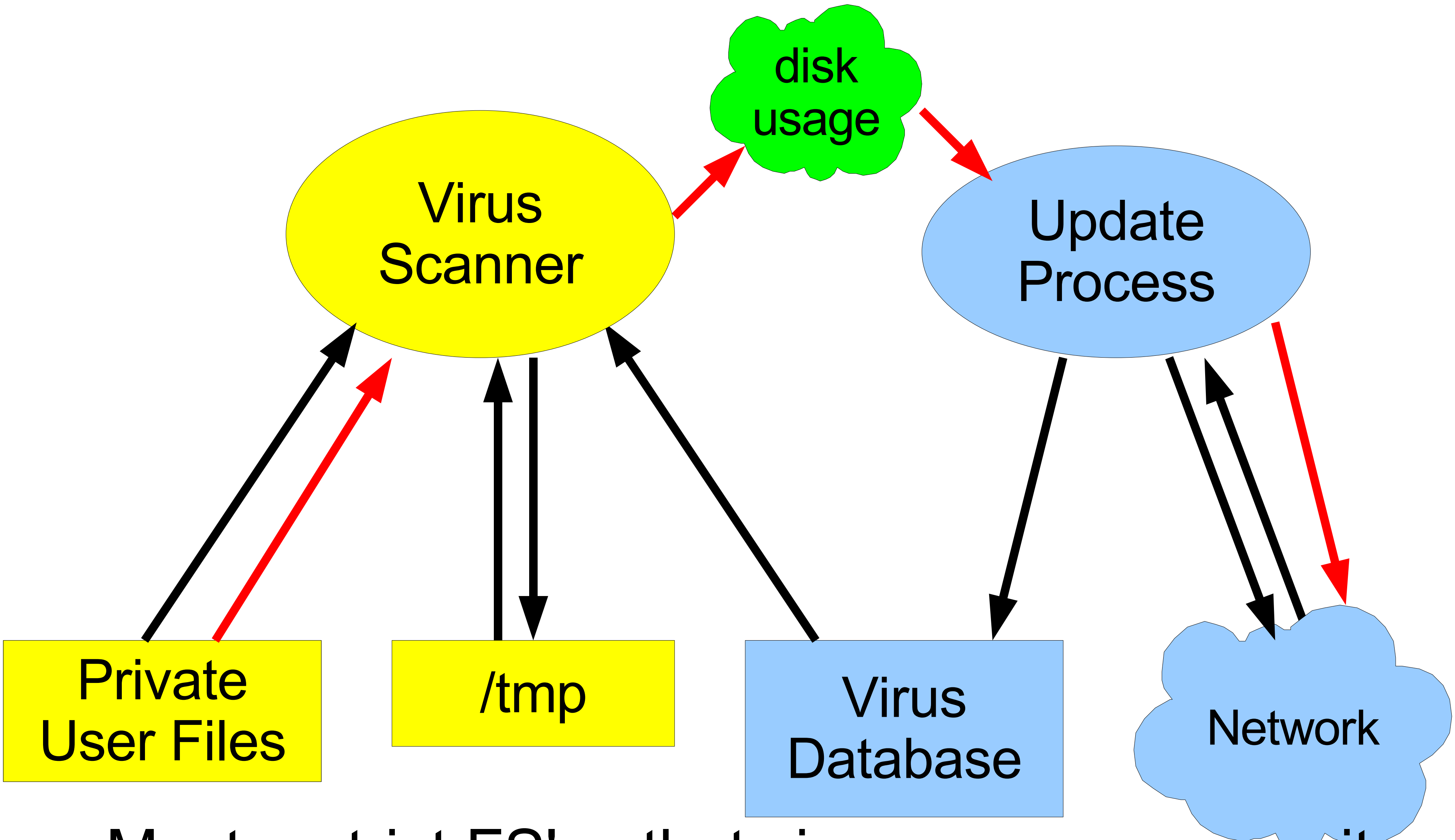
- Must run scanner with different UID

Buggy scanner leaks private data



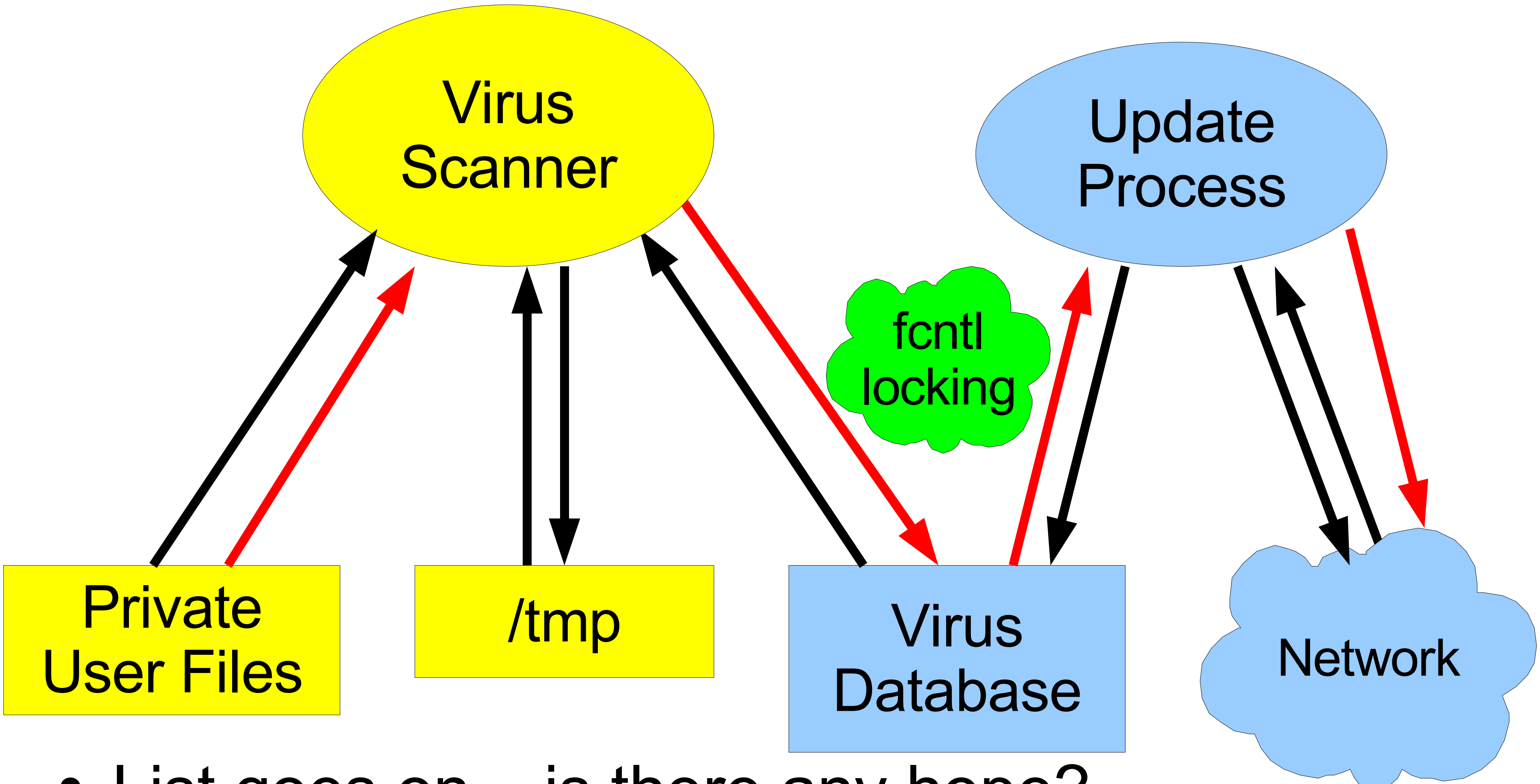
- Must restrict access to /proc, ...

Buggy scanner leaks private data



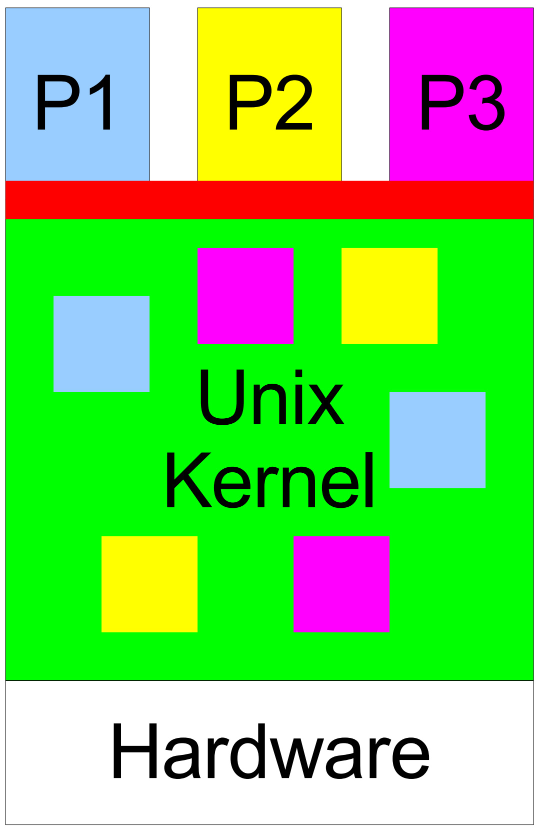
- Must restrict FS'es that virus scanner can write

Buggy scanner leaks private data



- List goes on – is there any hope?

What's going on?



Unix

- Kernel not designed to enforce these policies
- Retrofitting difficult
  - Need to track potentially any memory observed or modified by a system call!
  - Hard to even enumerate

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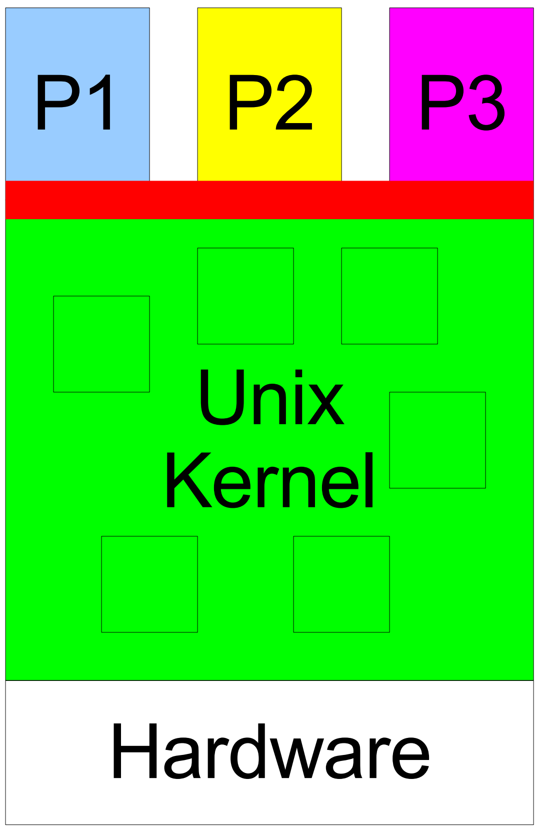

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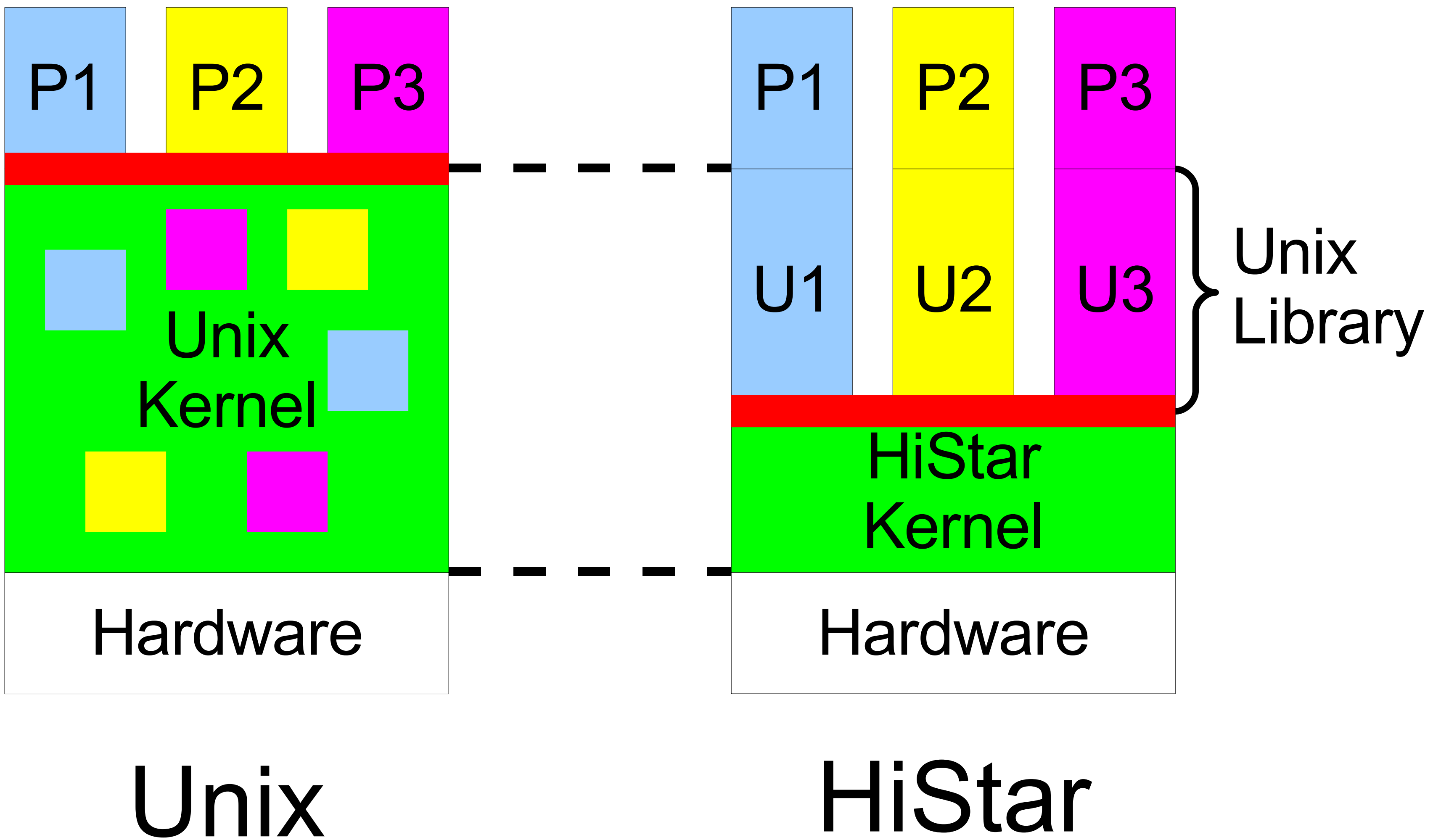
HiStar Solution

- Make all state explicit, track all communication

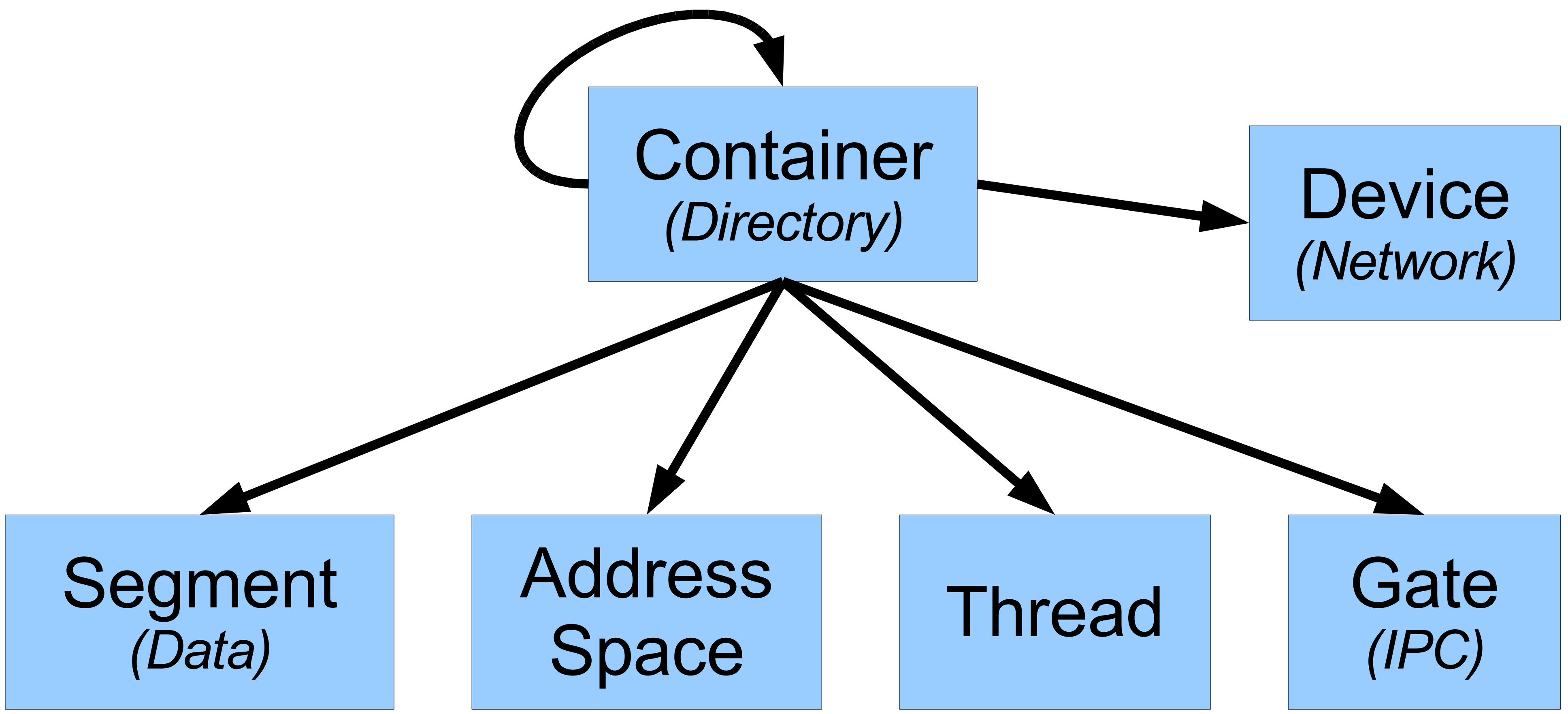


HiStar: Contributions

- Narrow kernel interface, few comm. channels
  - Minimal mechanism: enough for a Unix library
  - Strong control over information flow

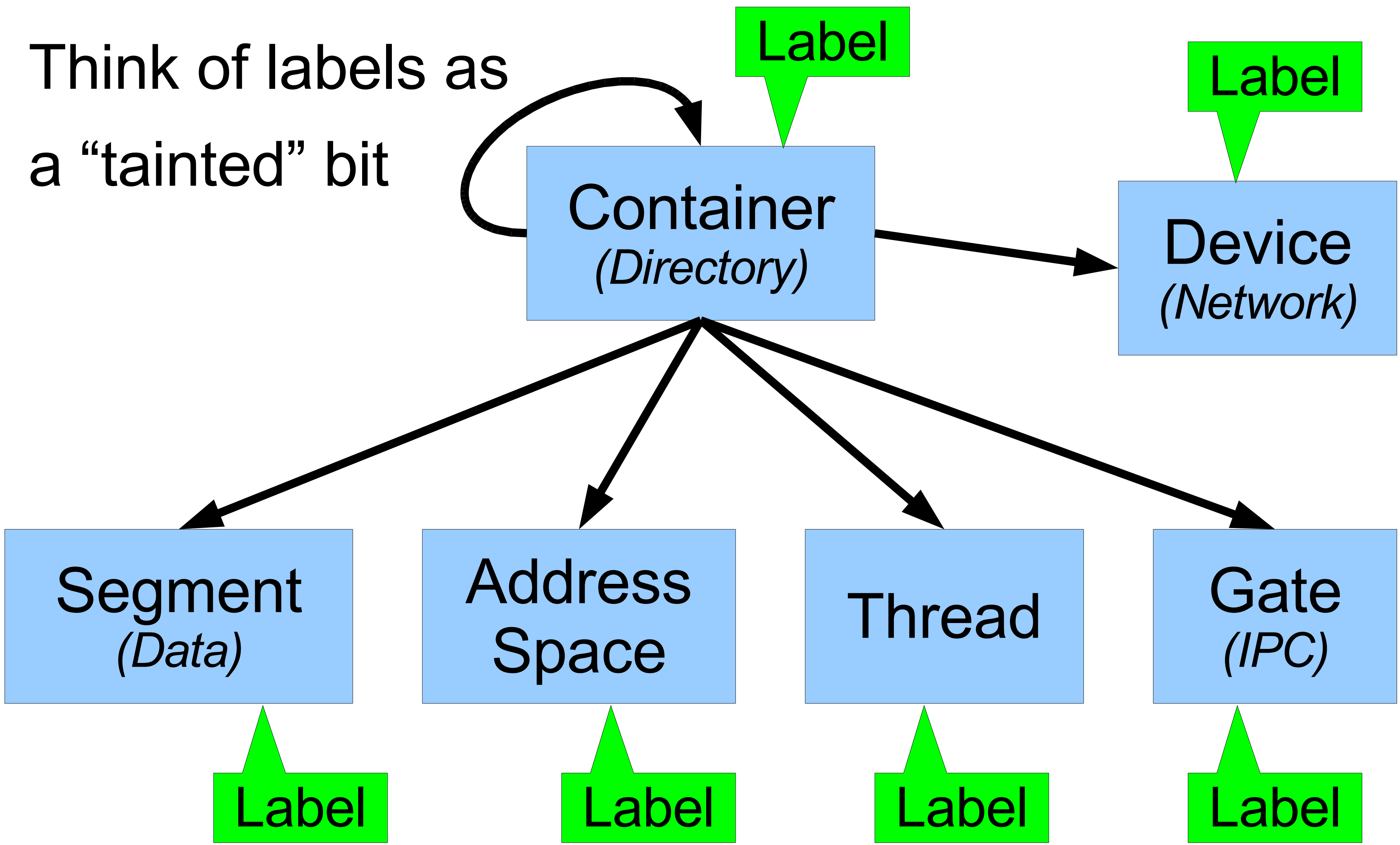
- Unix support implemented as user-level library
  - Unix communication channels are made explicit, in terms of HiStar's mechanisms
  - Provides control over the gamut of Unix channels

HiStar kernel objects

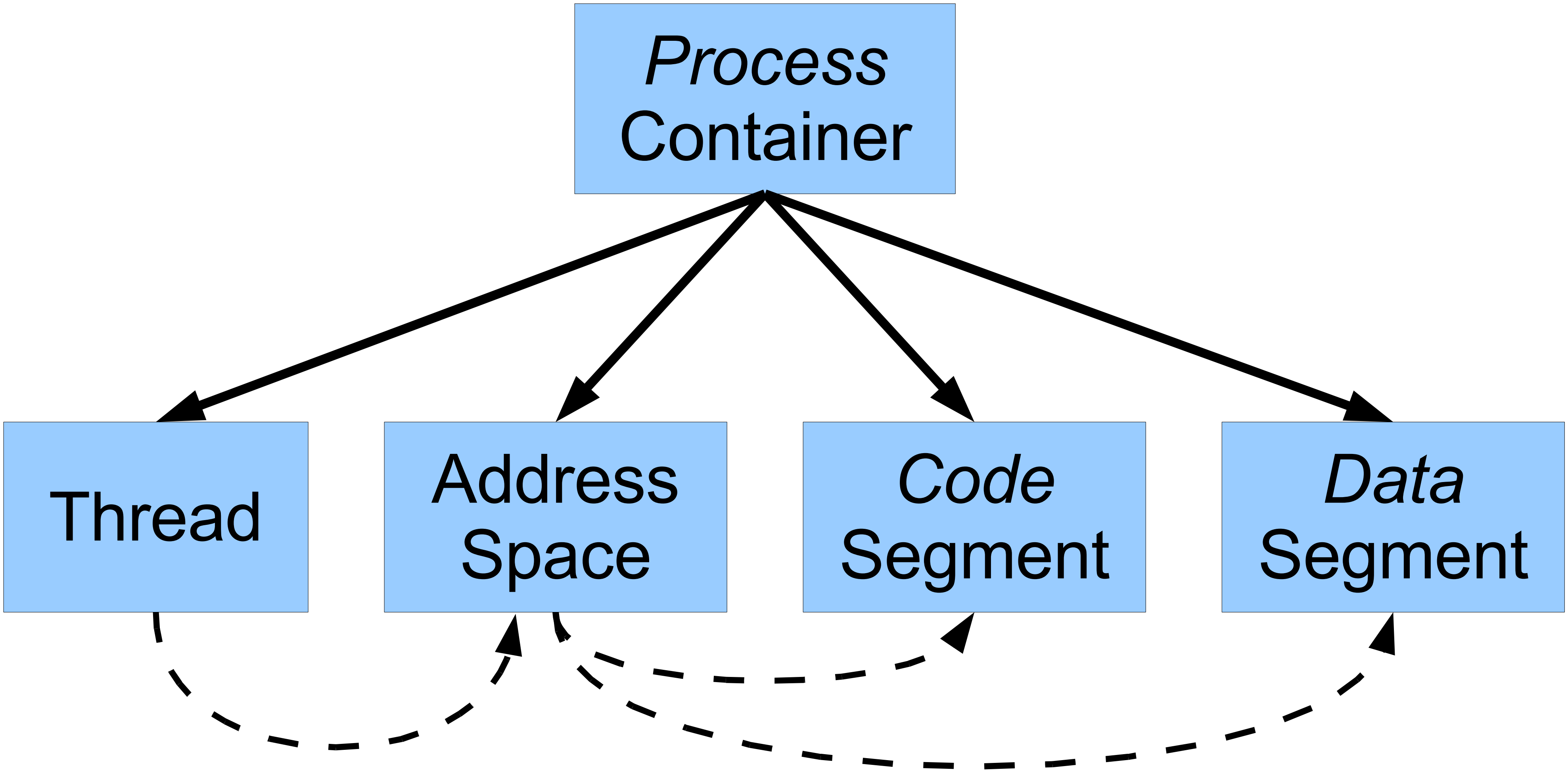


HiStar kernel objects

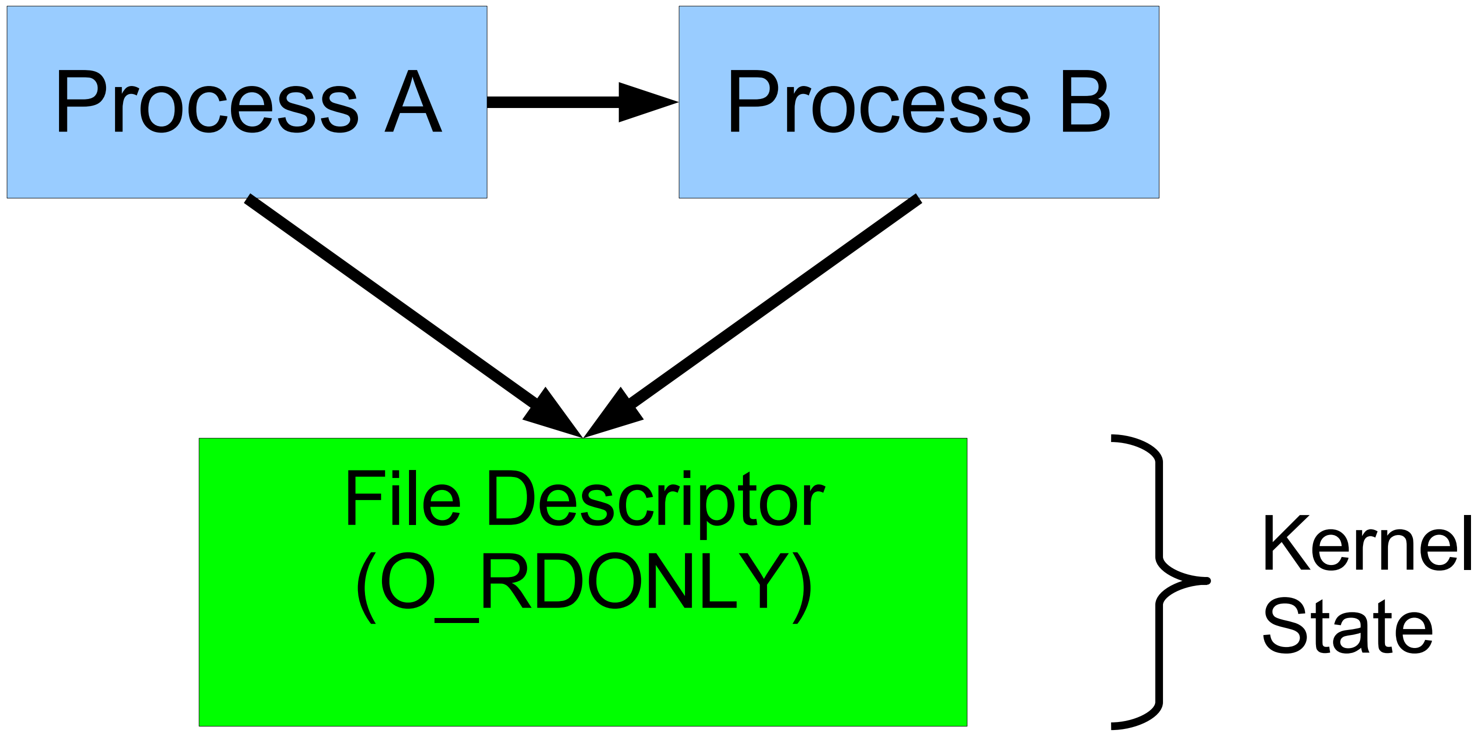
Think of labels as a “tainted” bit



HiStar: Unix process

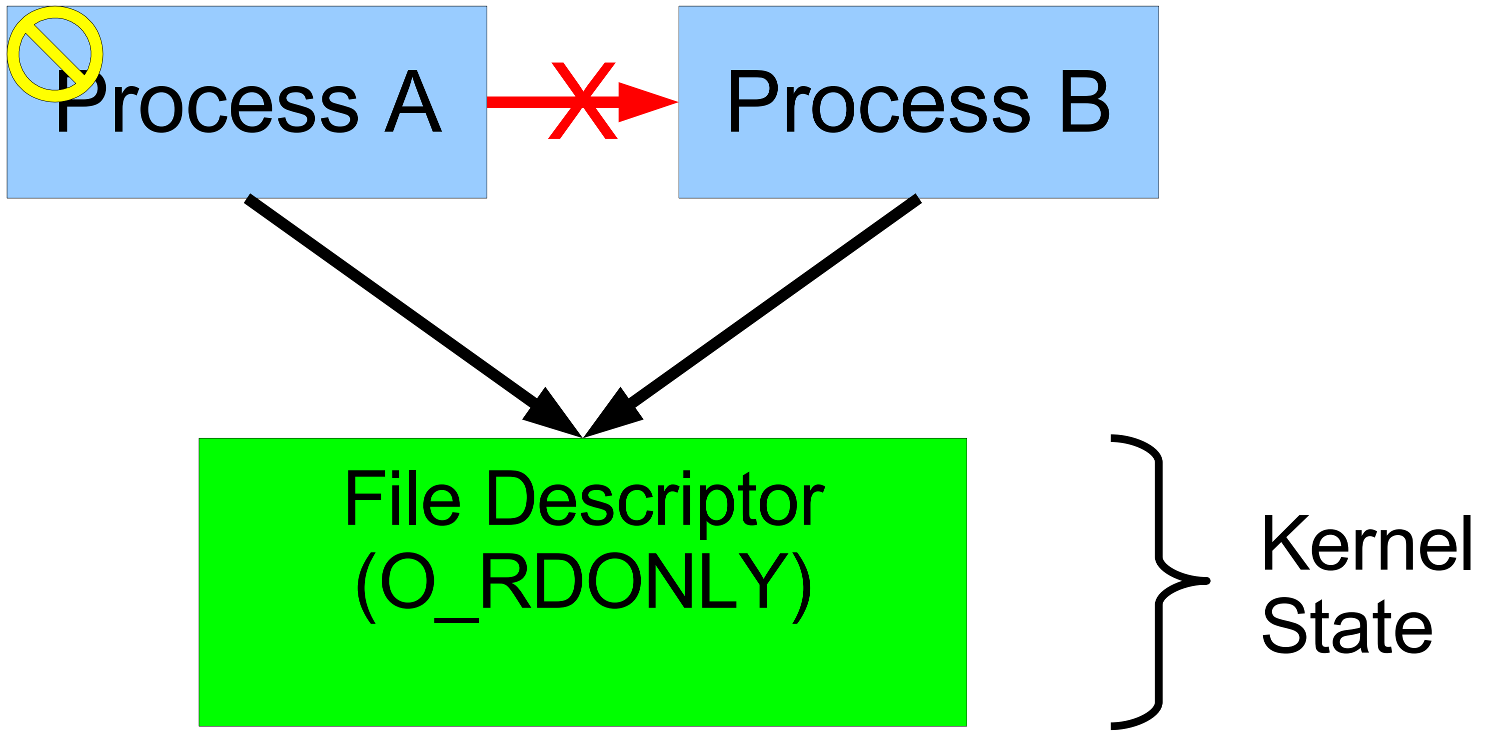


Unix File Descriptors



Unix File Descriptors

- Tainted process only talks to other tainted procs



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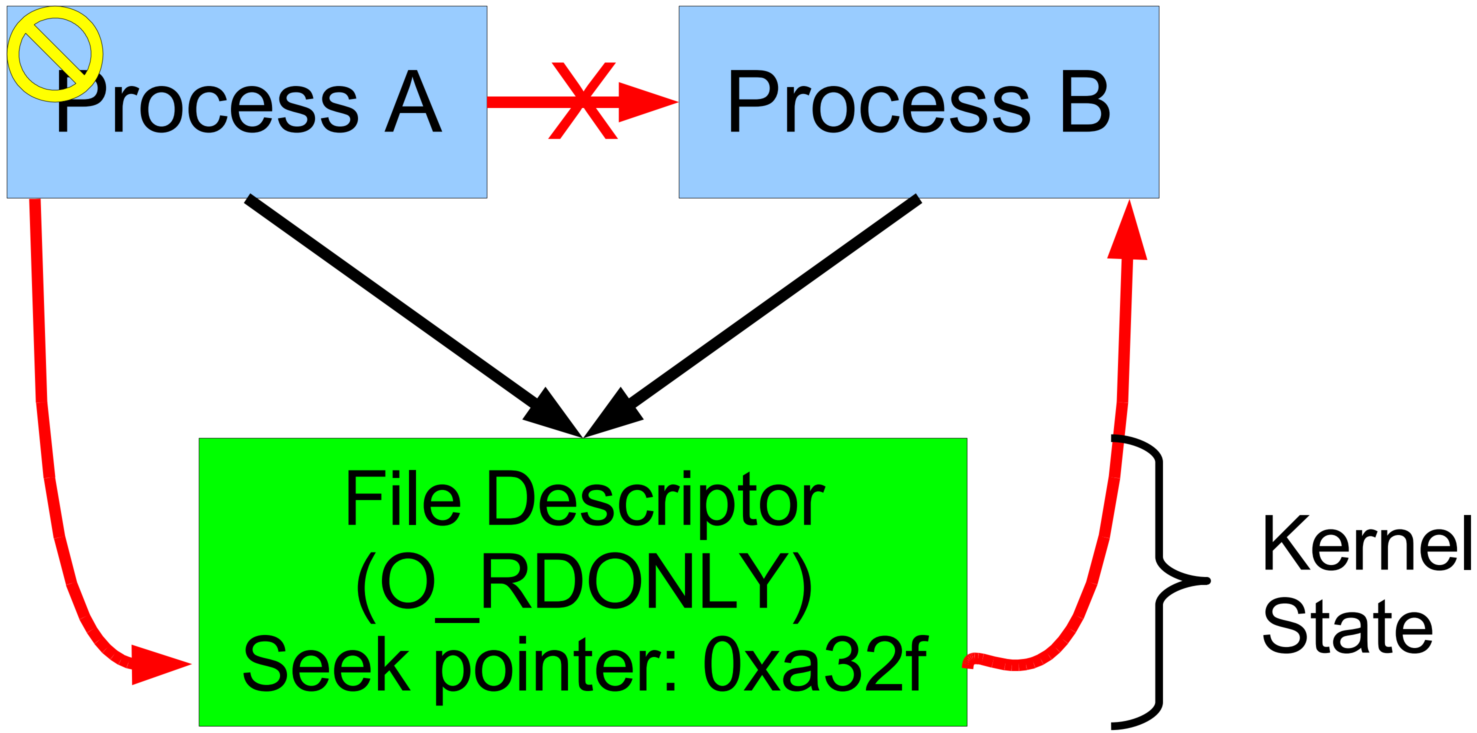
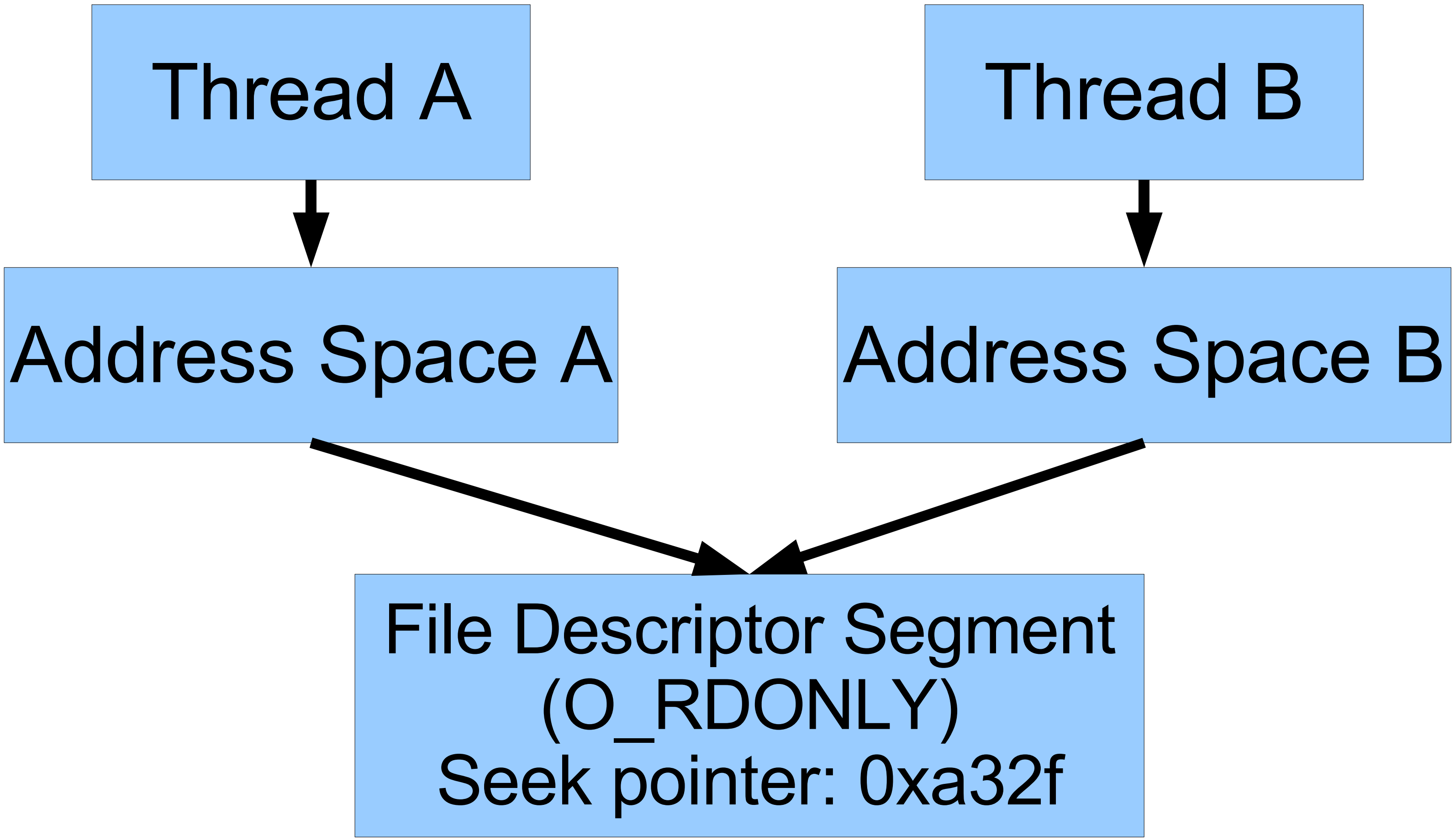


- Lots of shared state in kernel, easy to miss

HiStar File Descriptors



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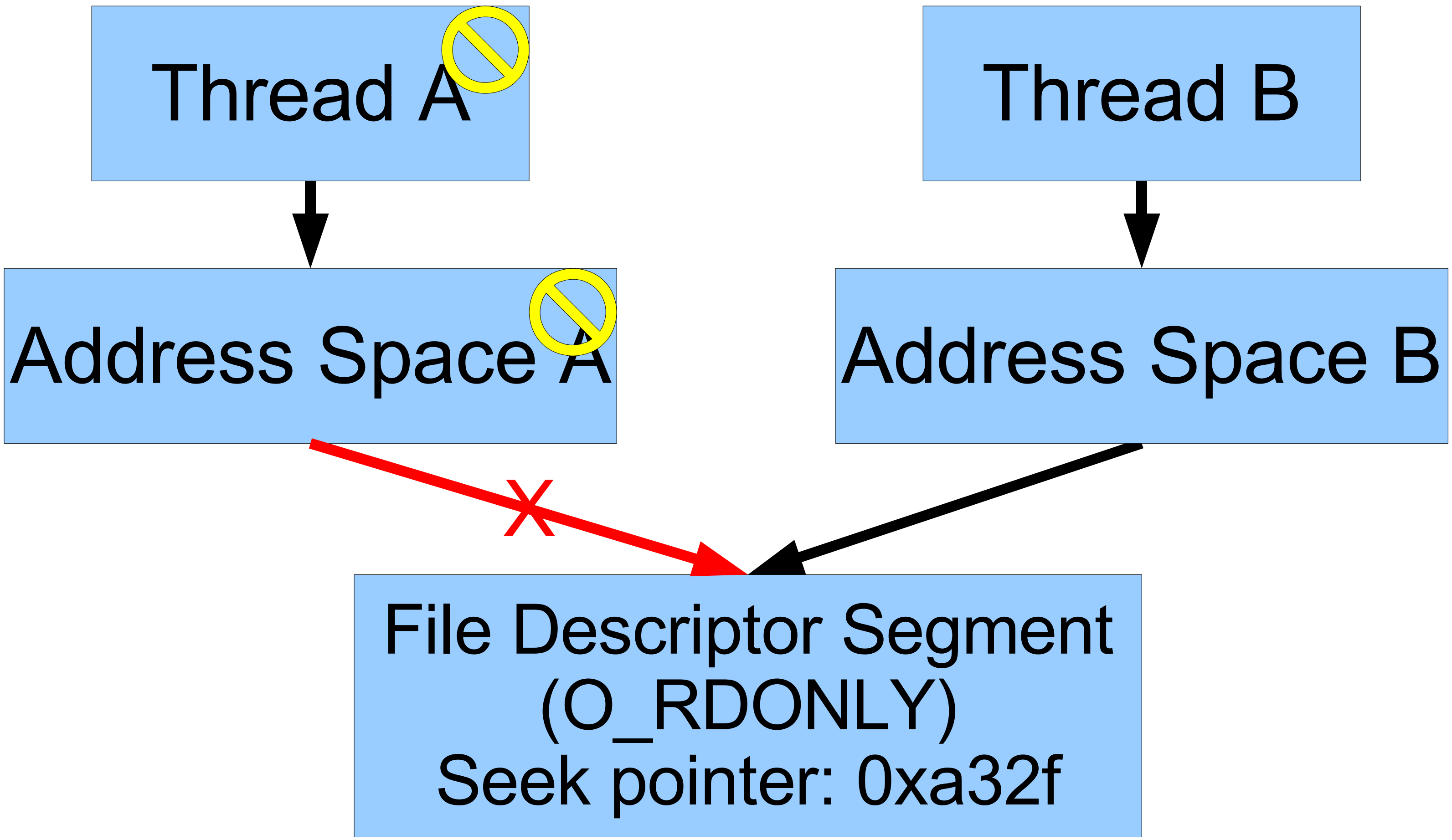
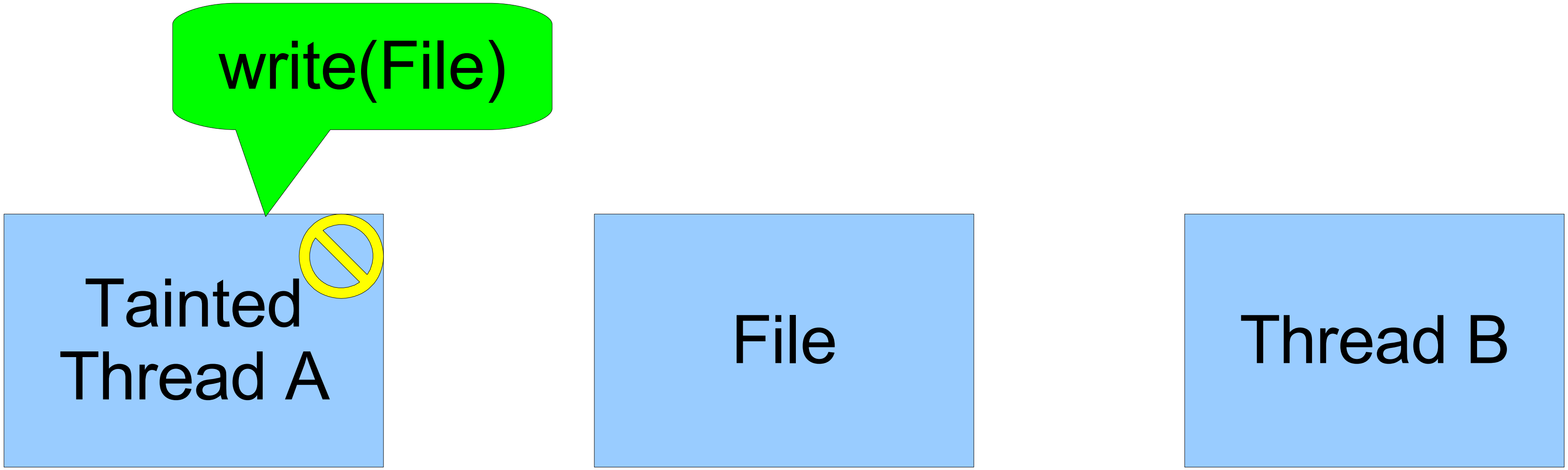


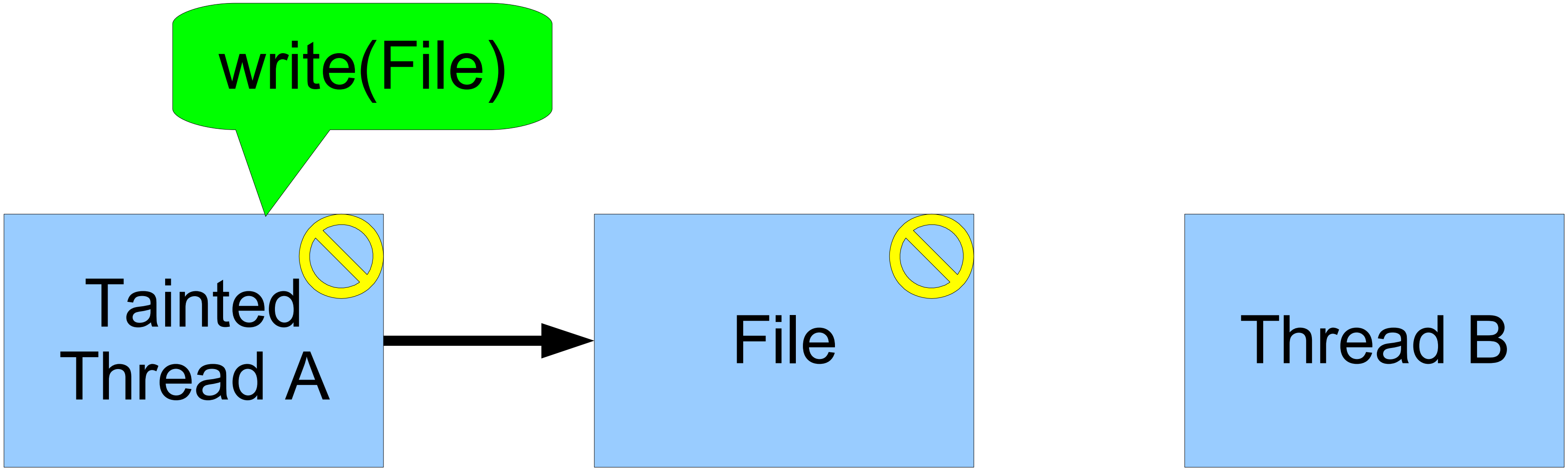
- All shared state is now explicitly labeled
- Just need segment read/write checks

Taint Tracking Strawman



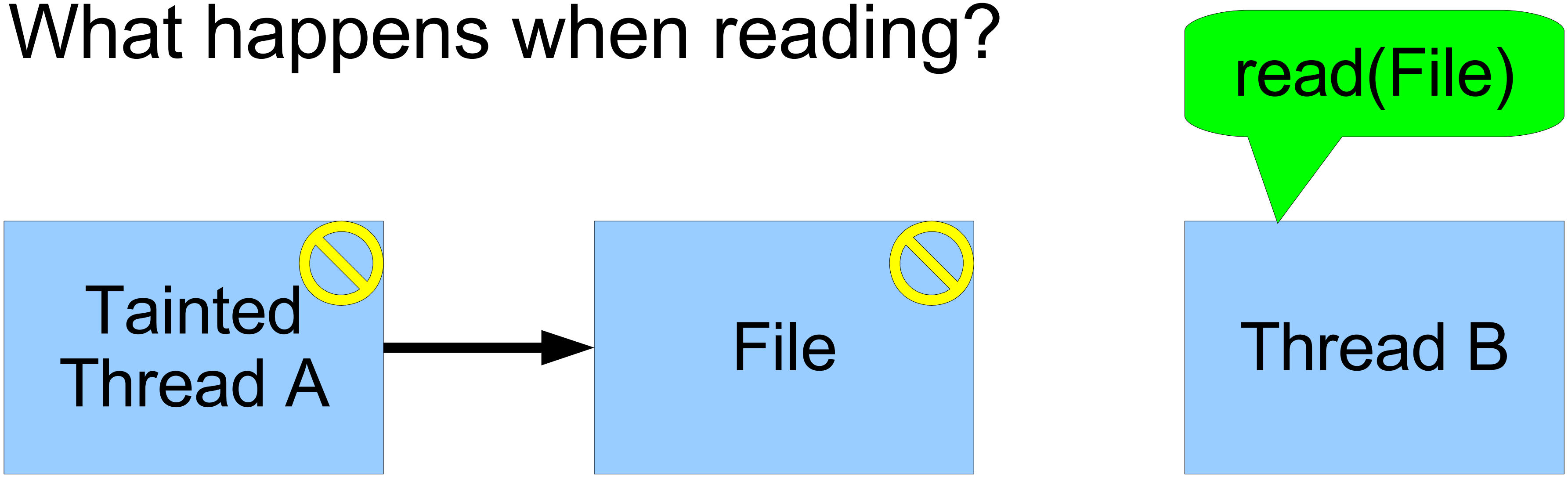
Taint Tracking Strawman

- Propagate taint when writing to file



Taint Tracking Strawman

- Propagate taint when writing to file
- What happens when reading?



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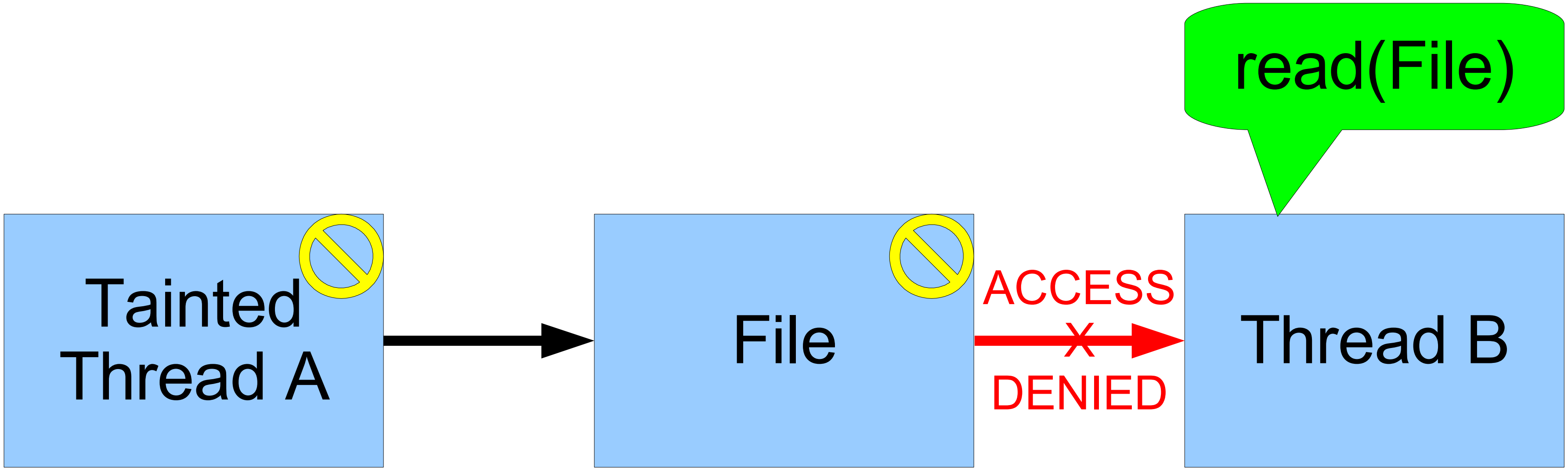
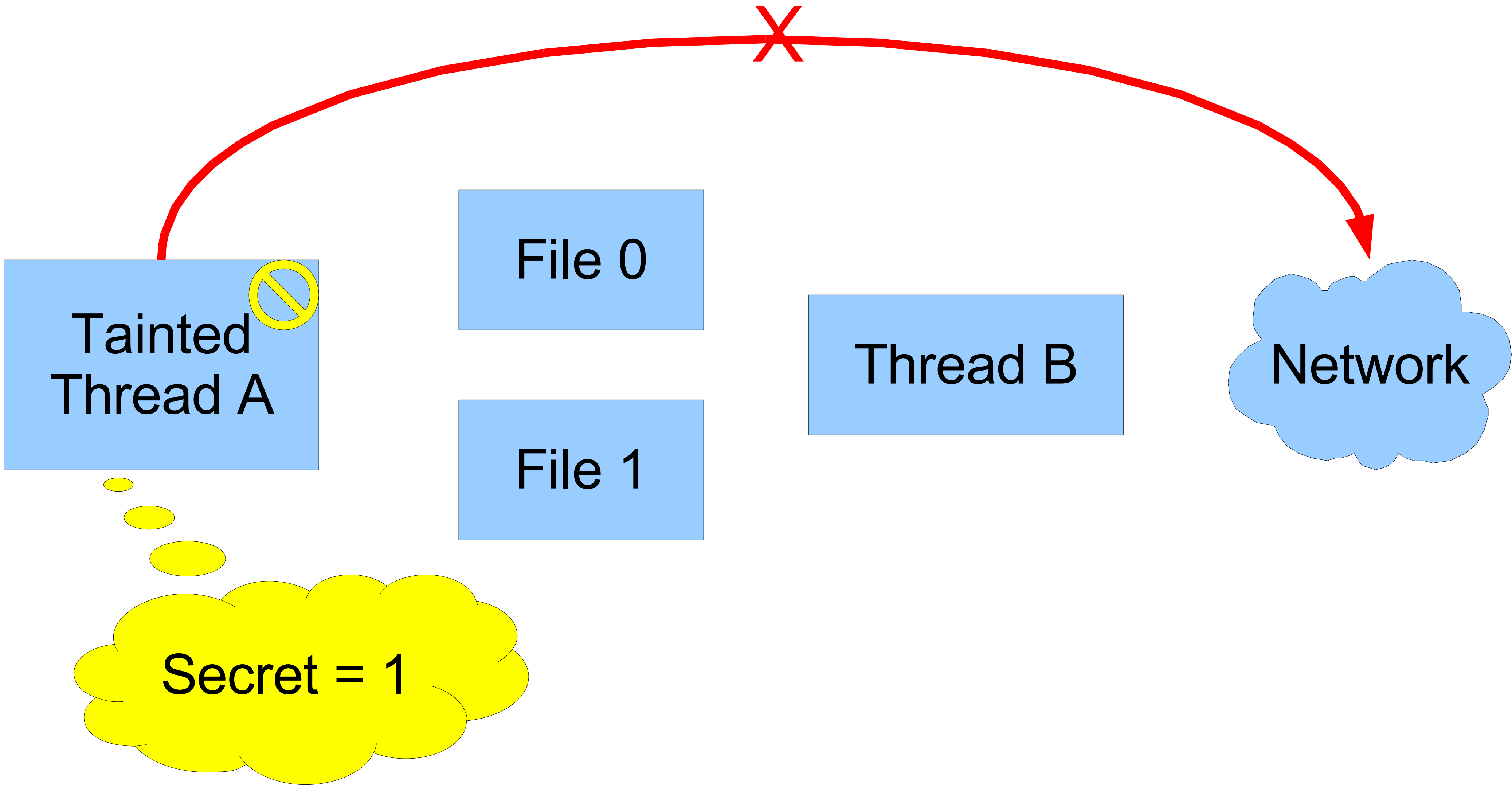


Strawman has Covert Channel



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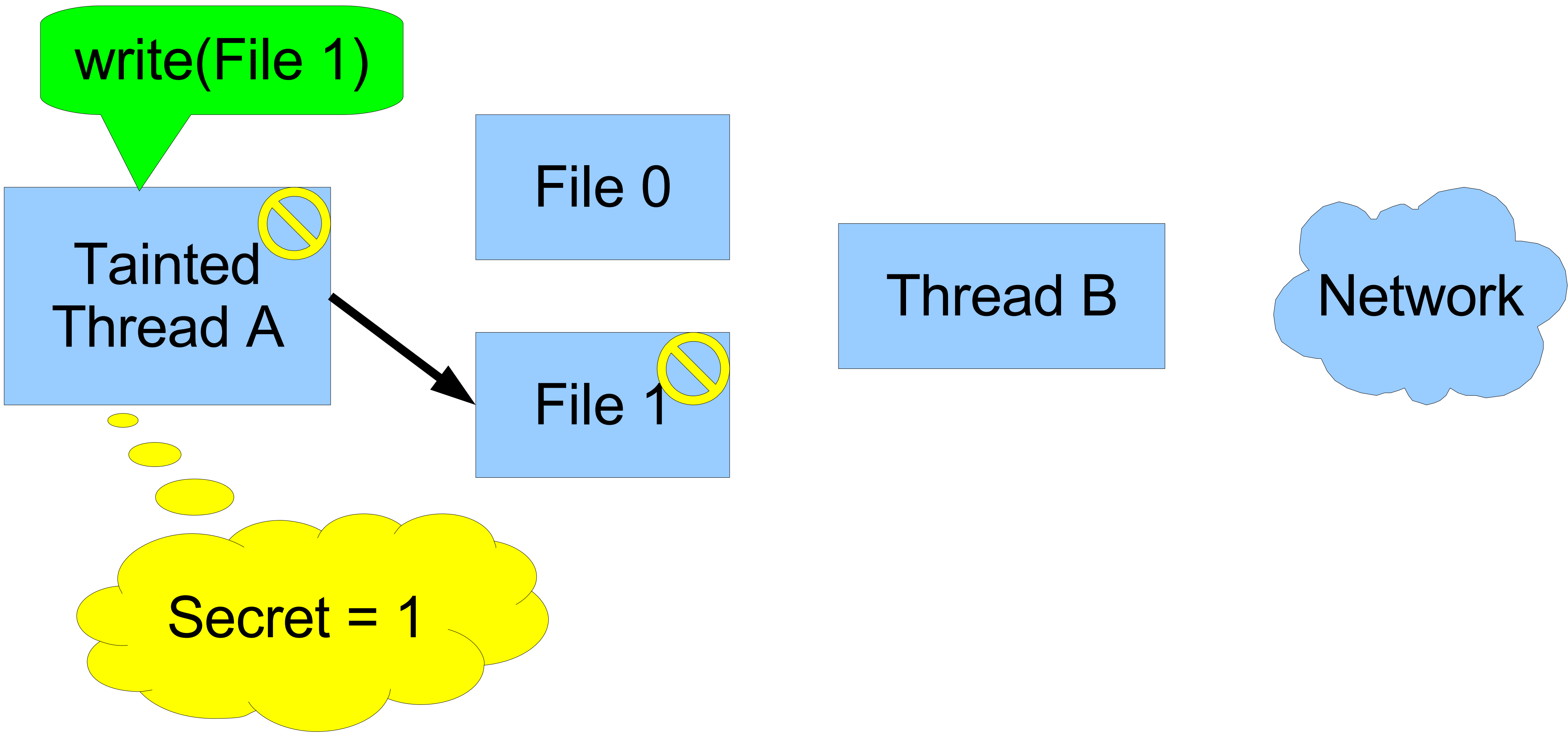

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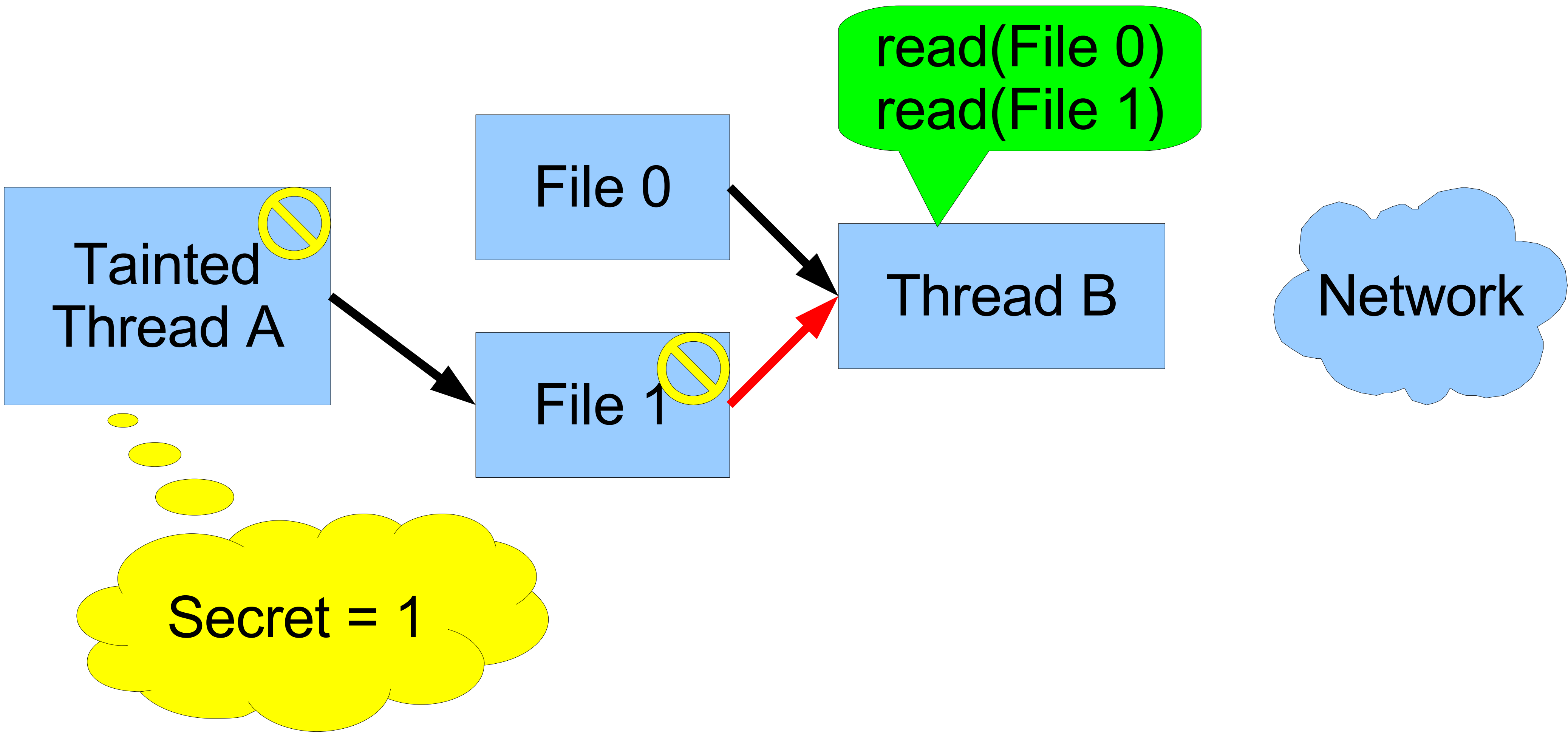

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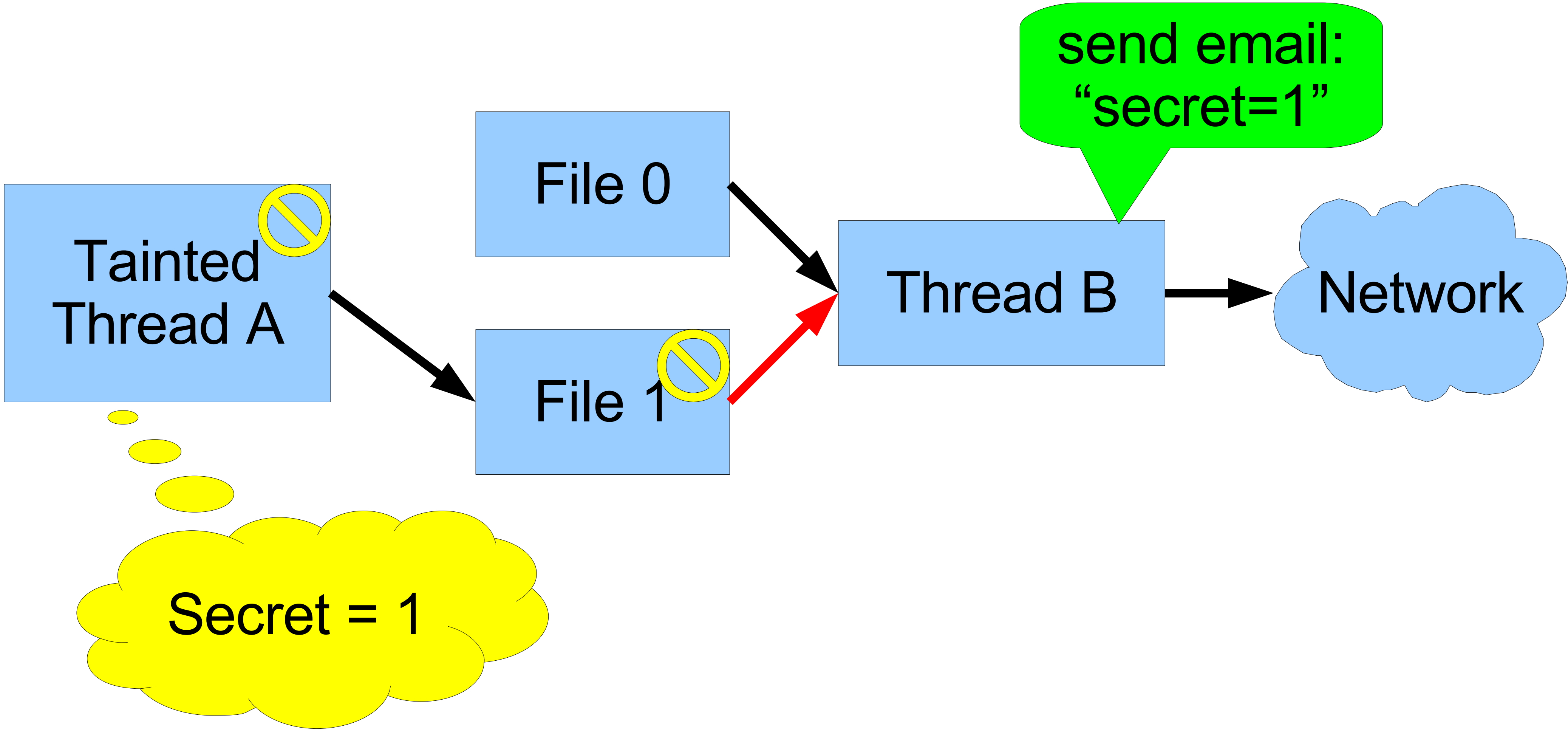
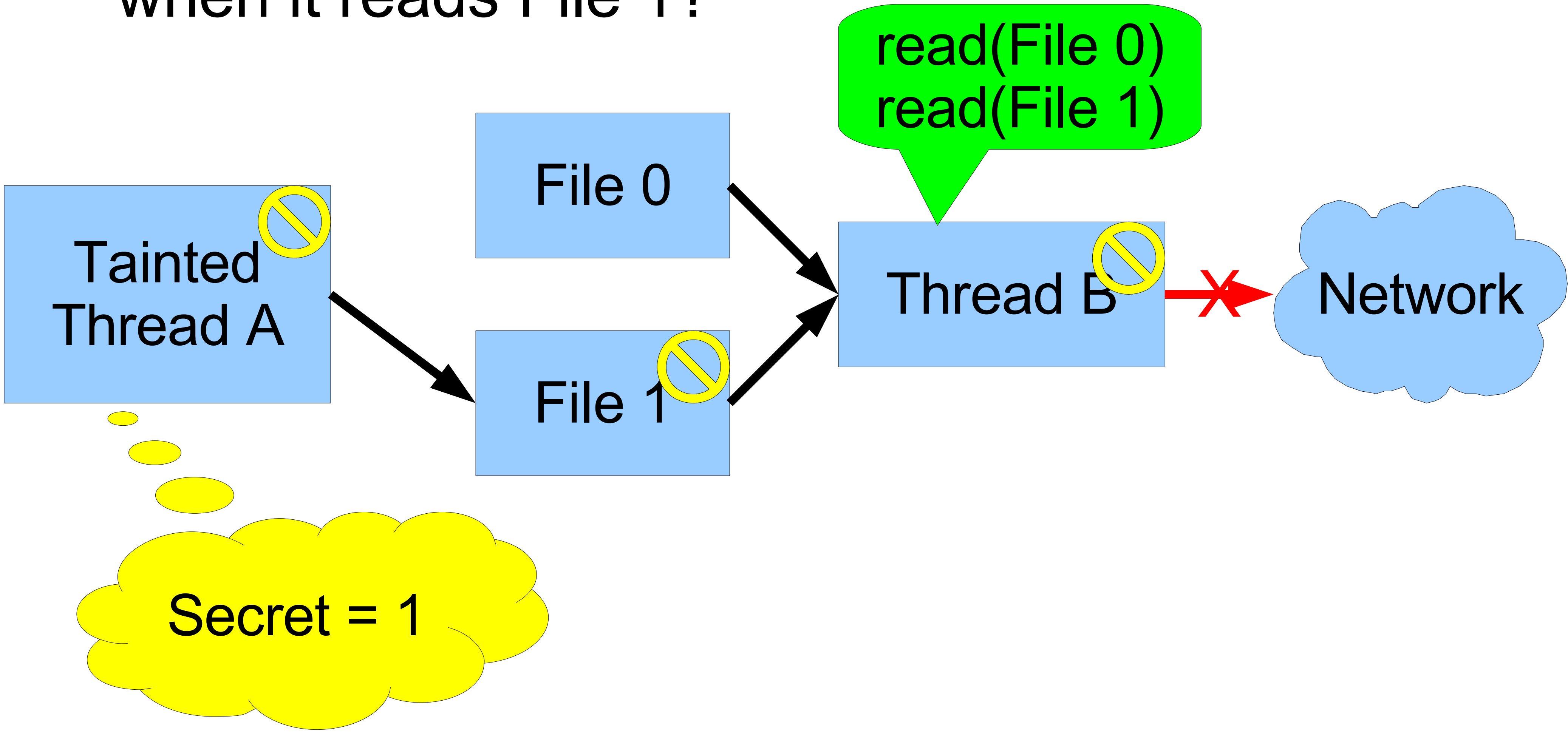


Strawman has Covert Channel

- What if we taint B when it reads File 1?



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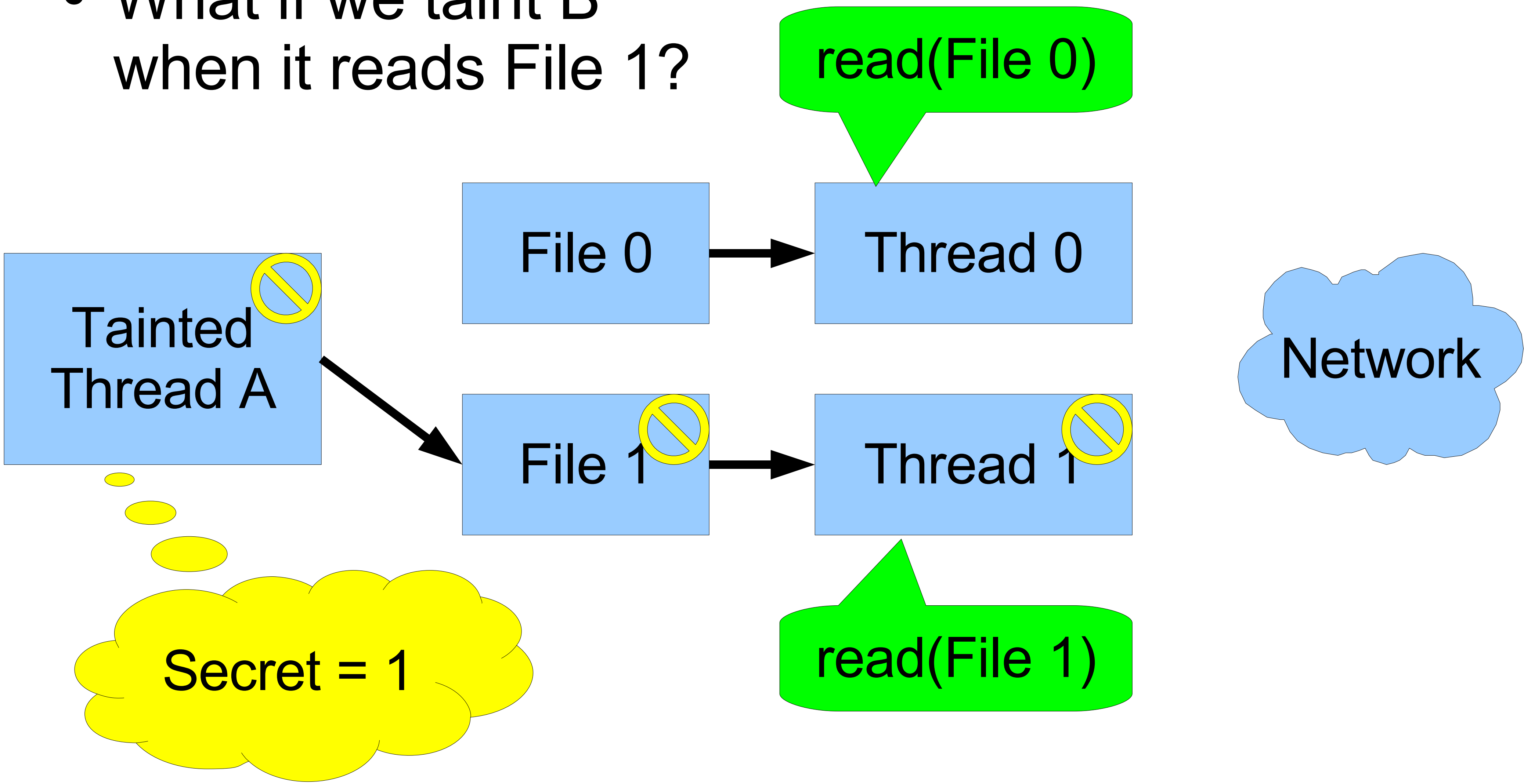

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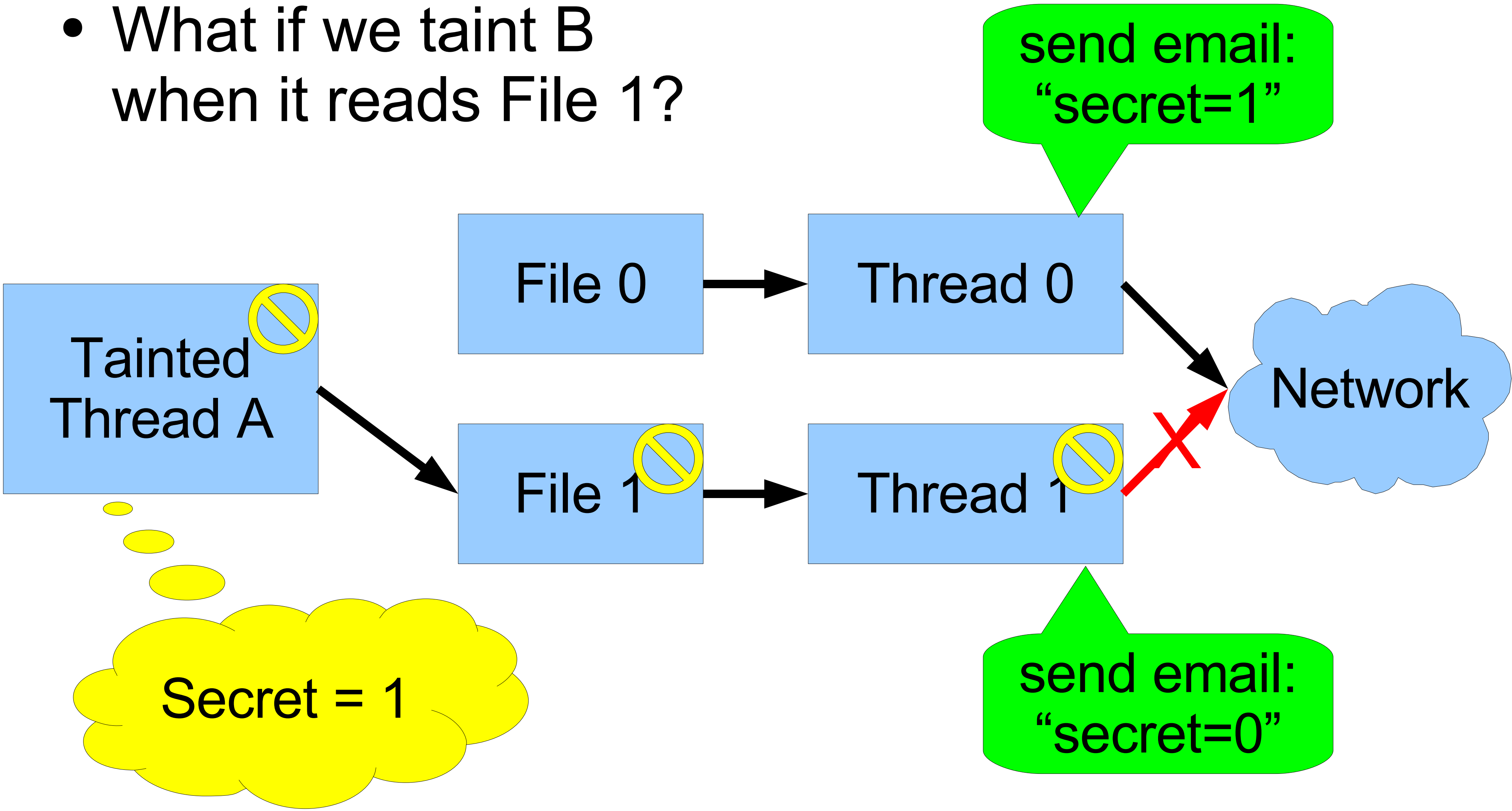
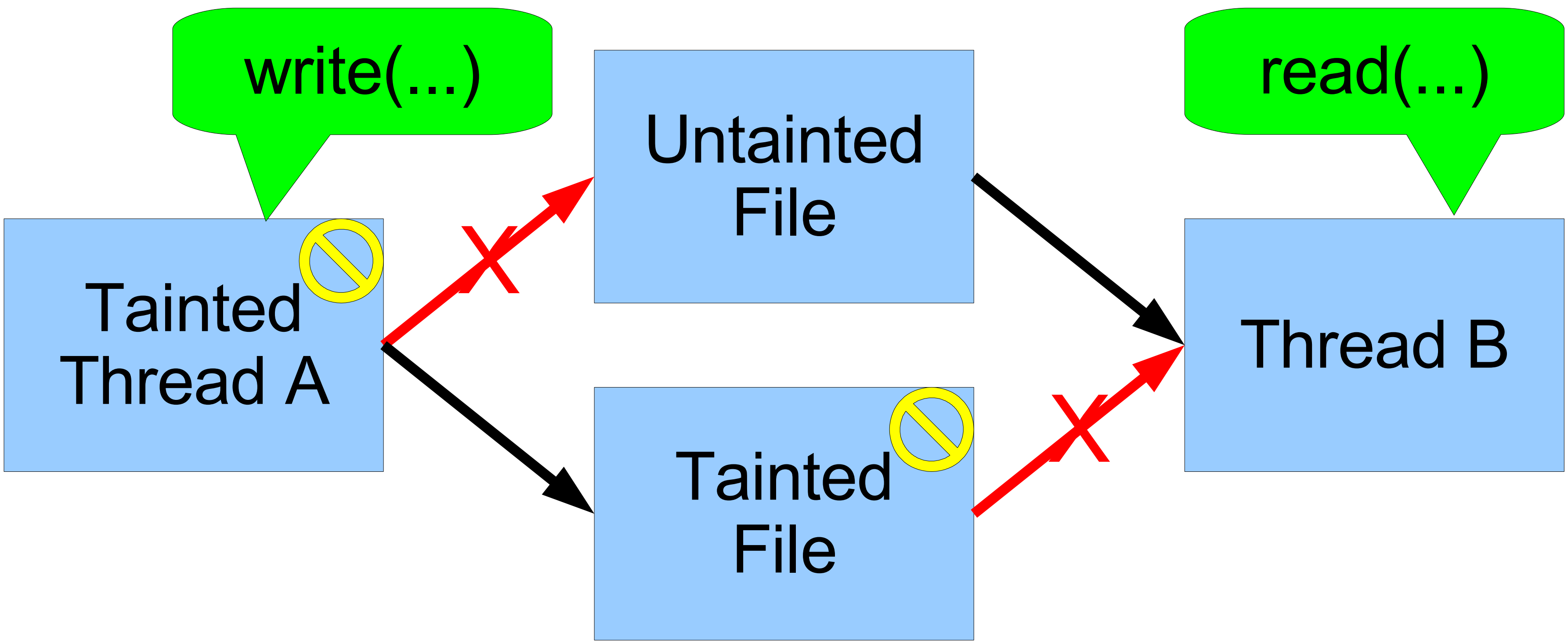


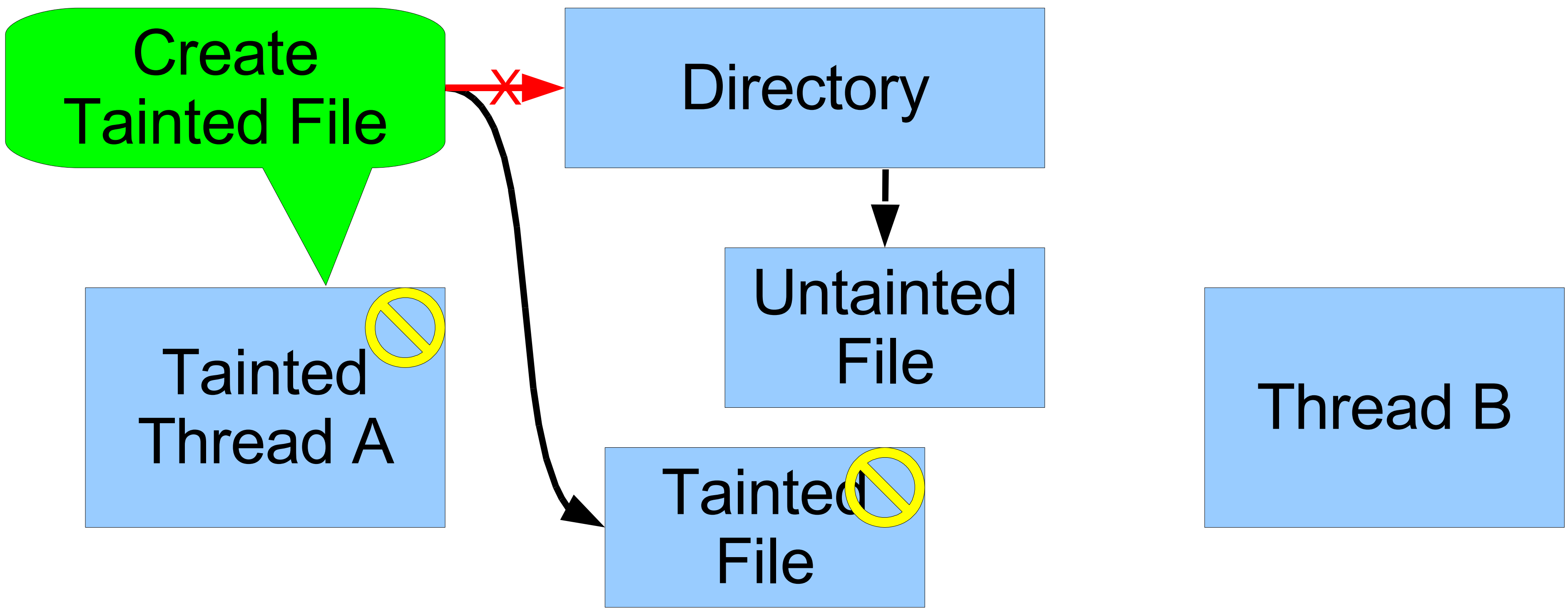
HiStar: Immutable File Labels

- Label (taint level) is state that must be tracked
- Immutable labels solve this problem!



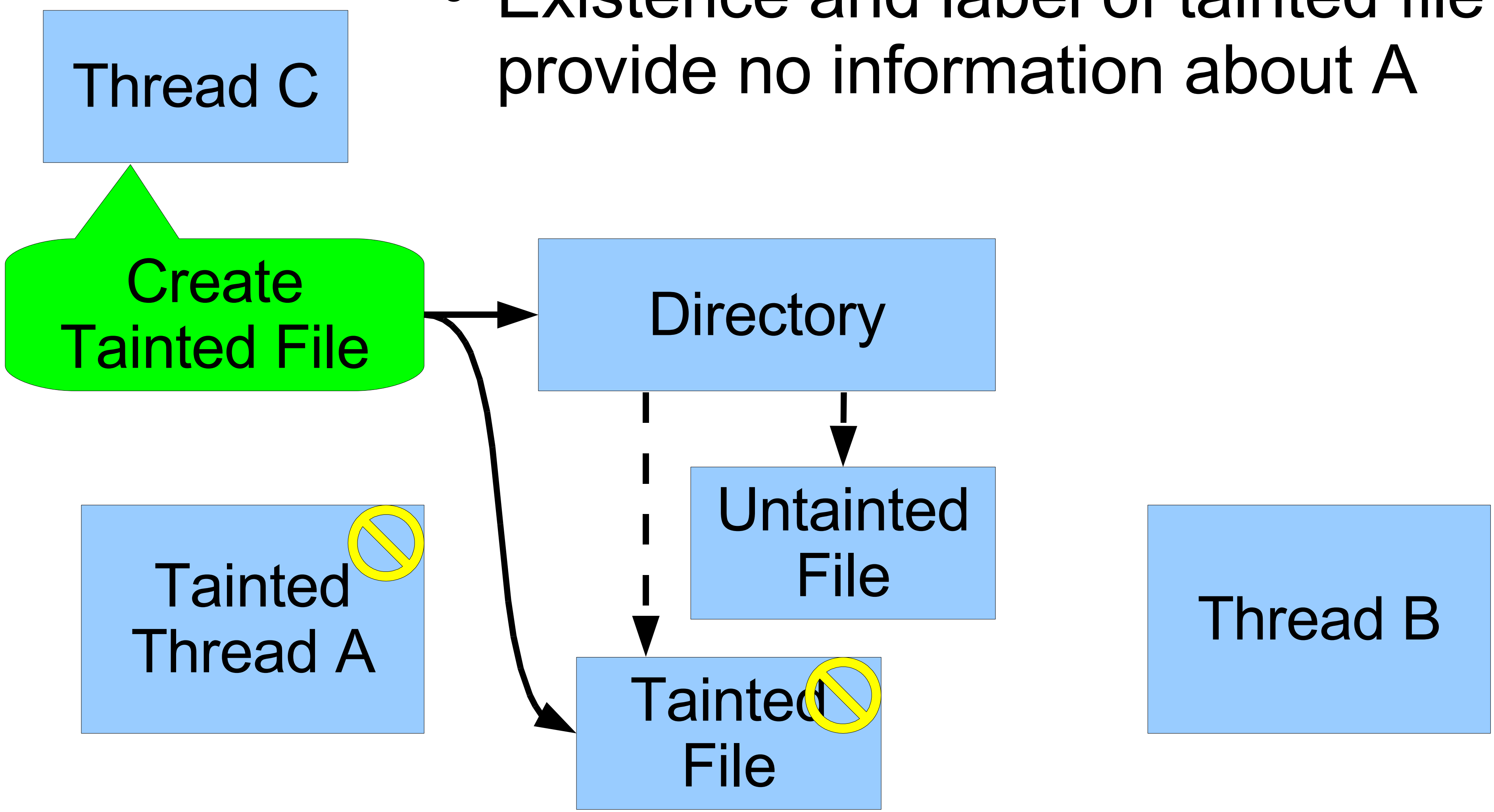
Who creates tainted files?

- Tainted thread can't modify untainted directory to place the new file there...



HiStar: Untainted thread pre-creates tainted file

- Existence and label of tainted file provide no information about A



Reading a tainted file

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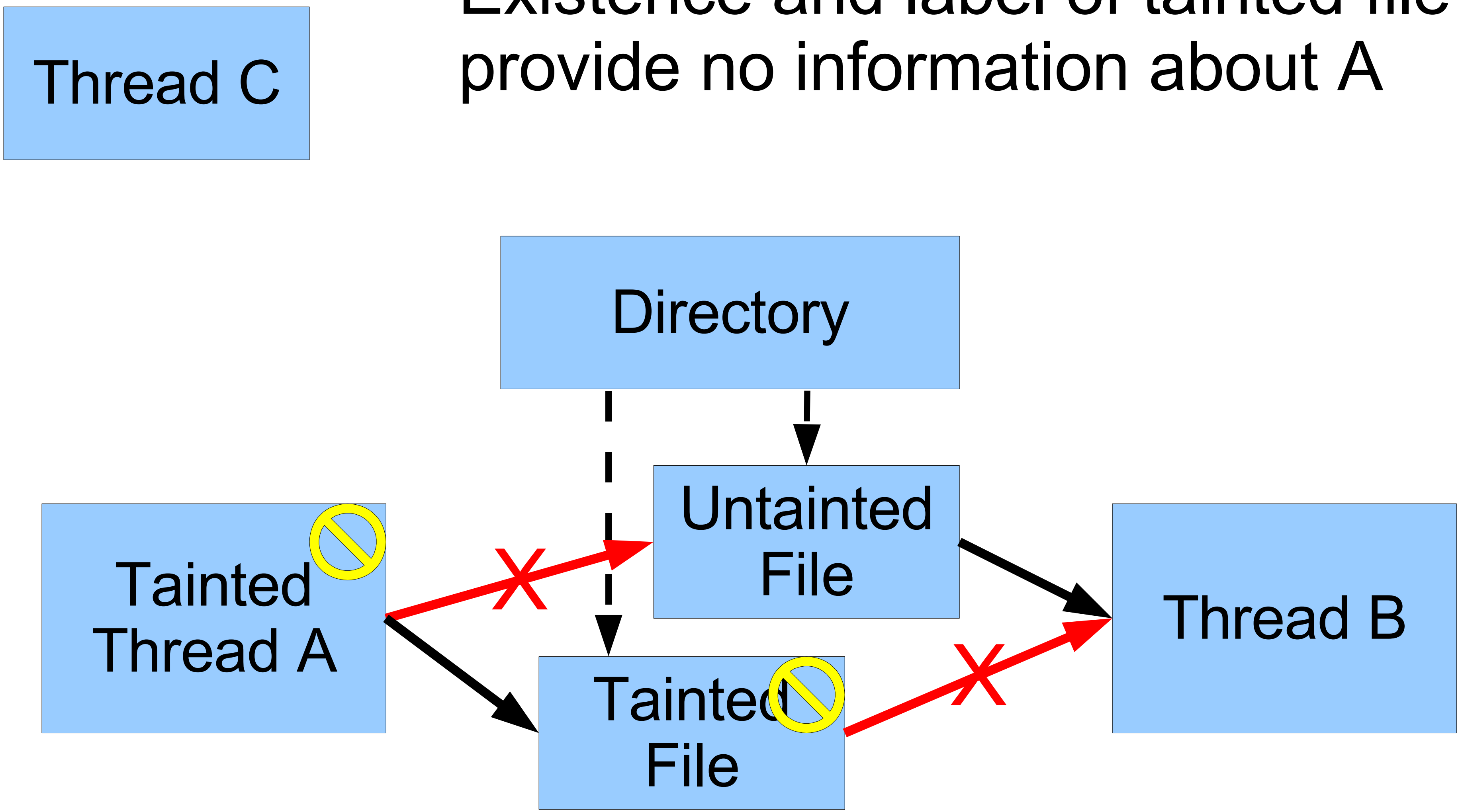

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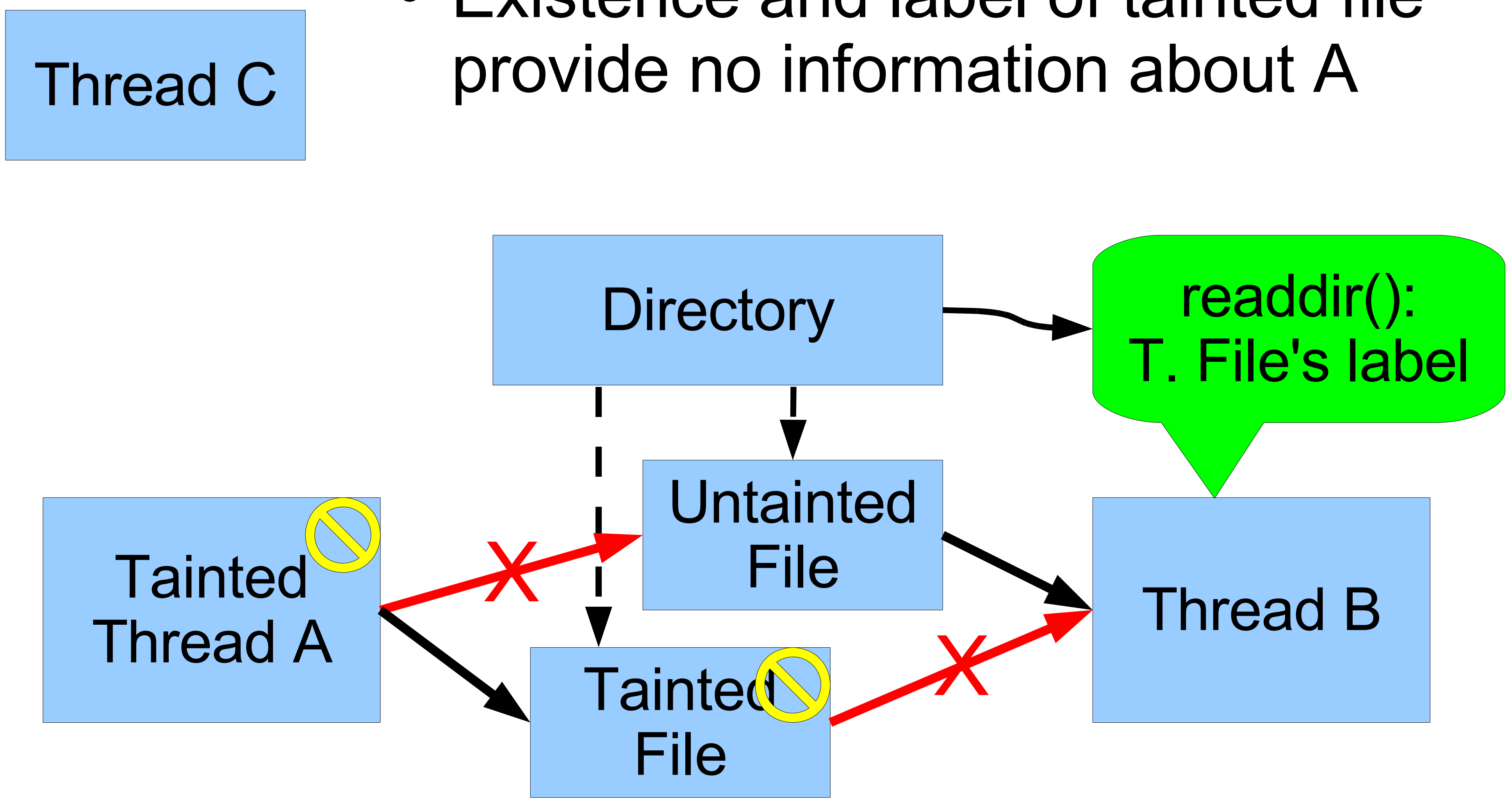
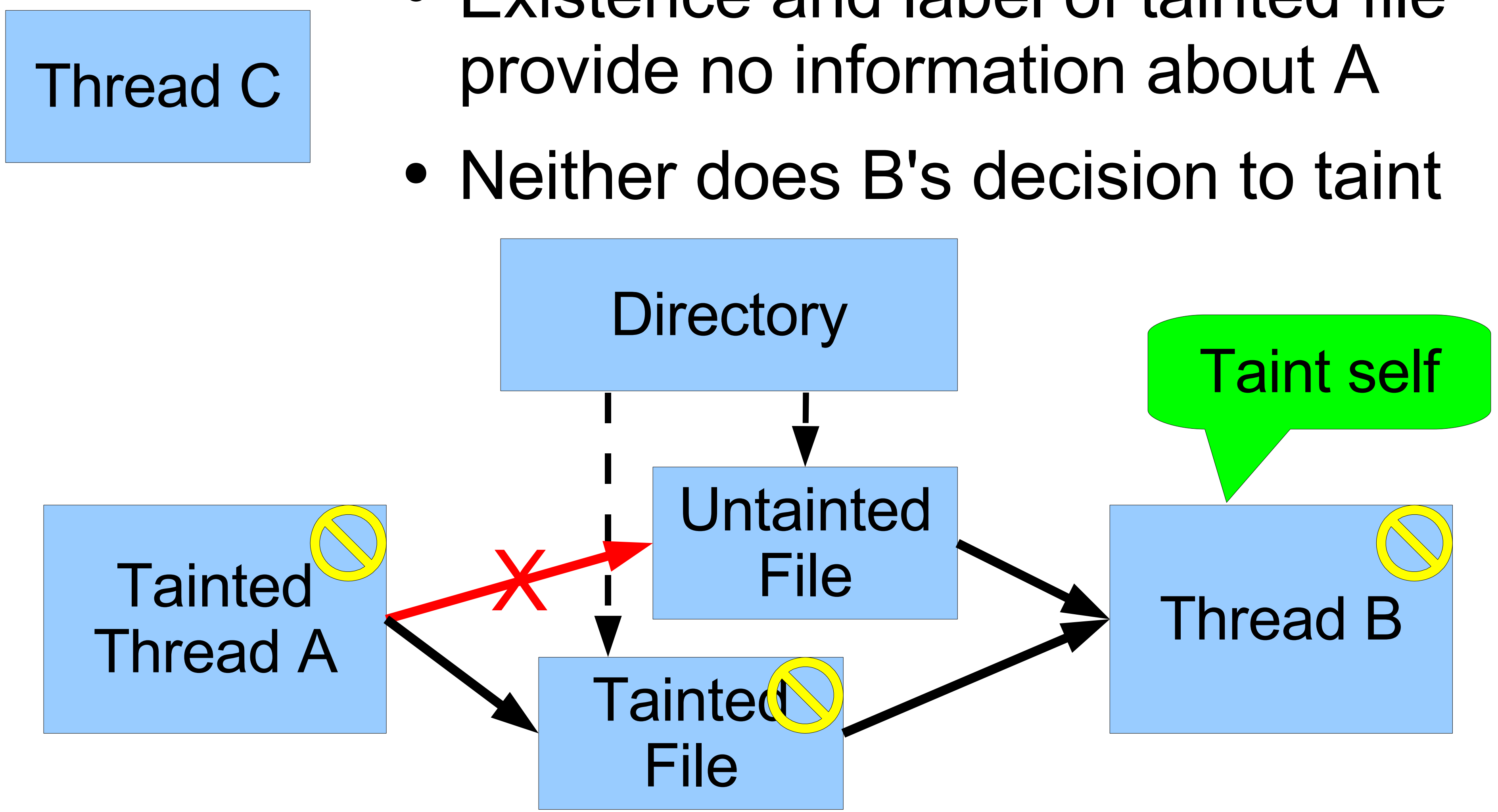


Reading a tainted file

- Existence and label of tainted file provide no information about A
- Neither does B's decision to taint

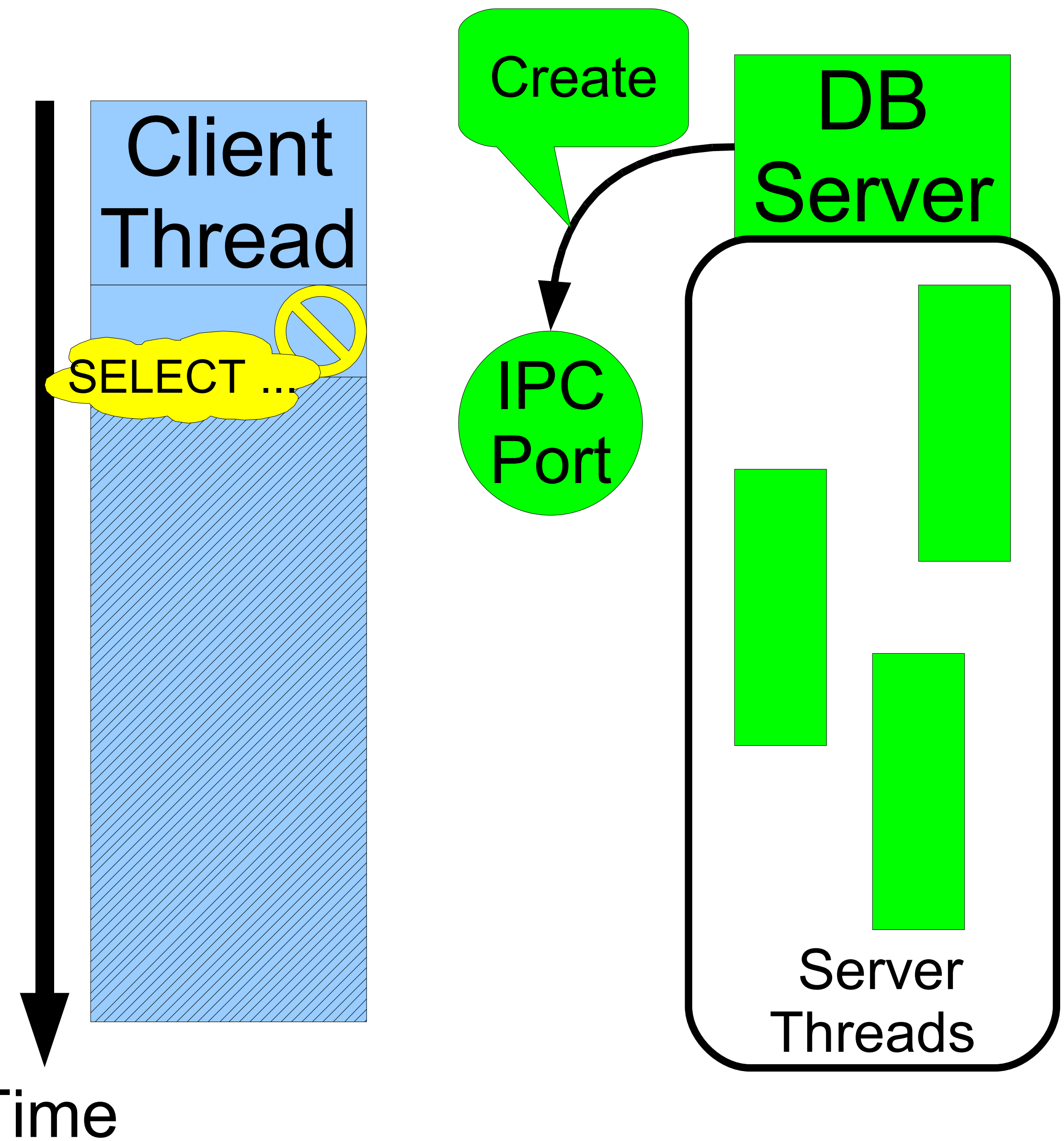


HiStar avoids file covert channels

- Immutable labels prevent covert channels that communicate through label state
- Untainted threads pre-allocate tainted files
  - File existence or label provides no secret information
- Threads taint themselves to read tainted files
  - Tainted file's label accessible via parent directory

Problems with IPC

- IPC with tainted client
  - Taint server thread during request



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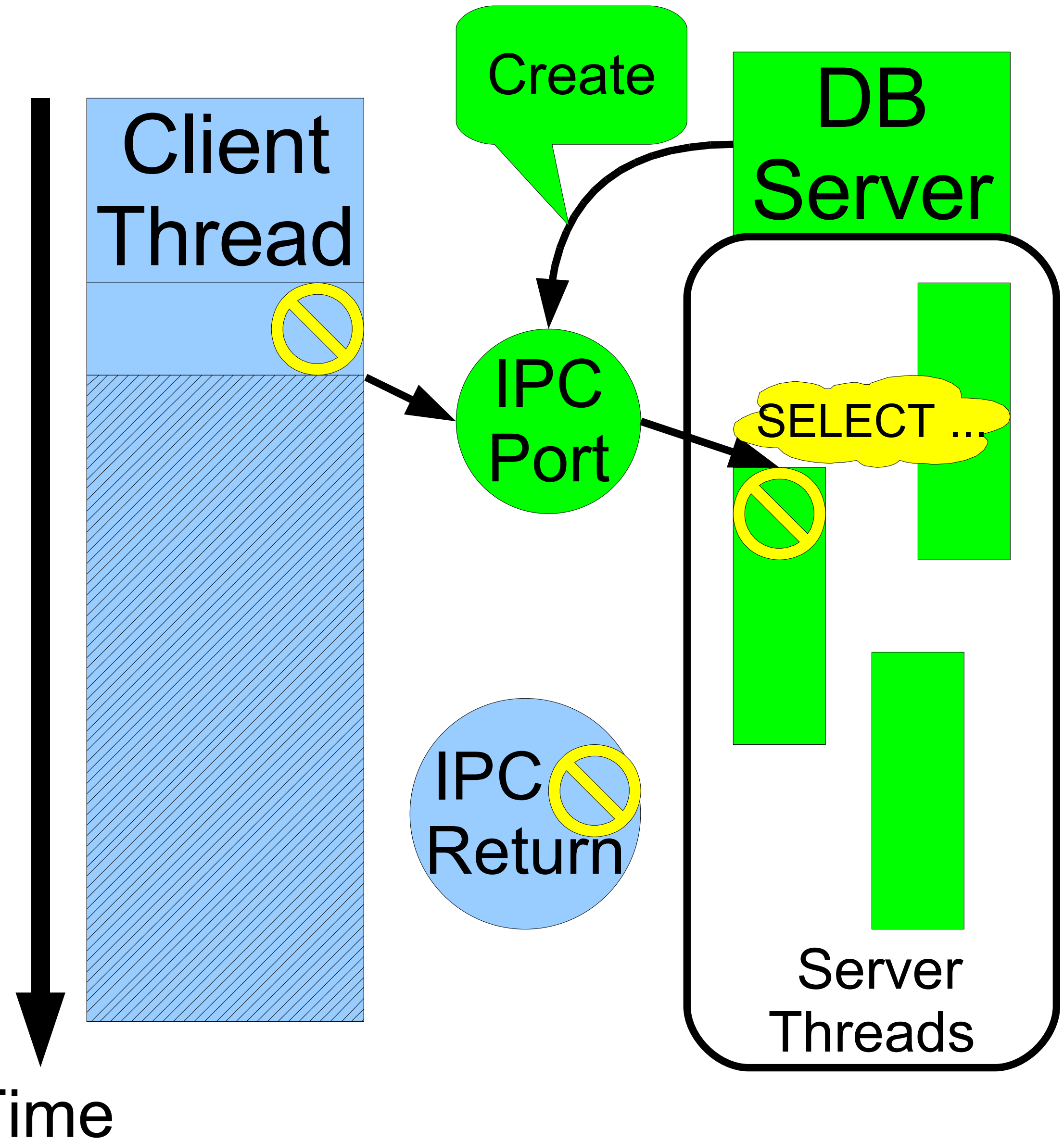

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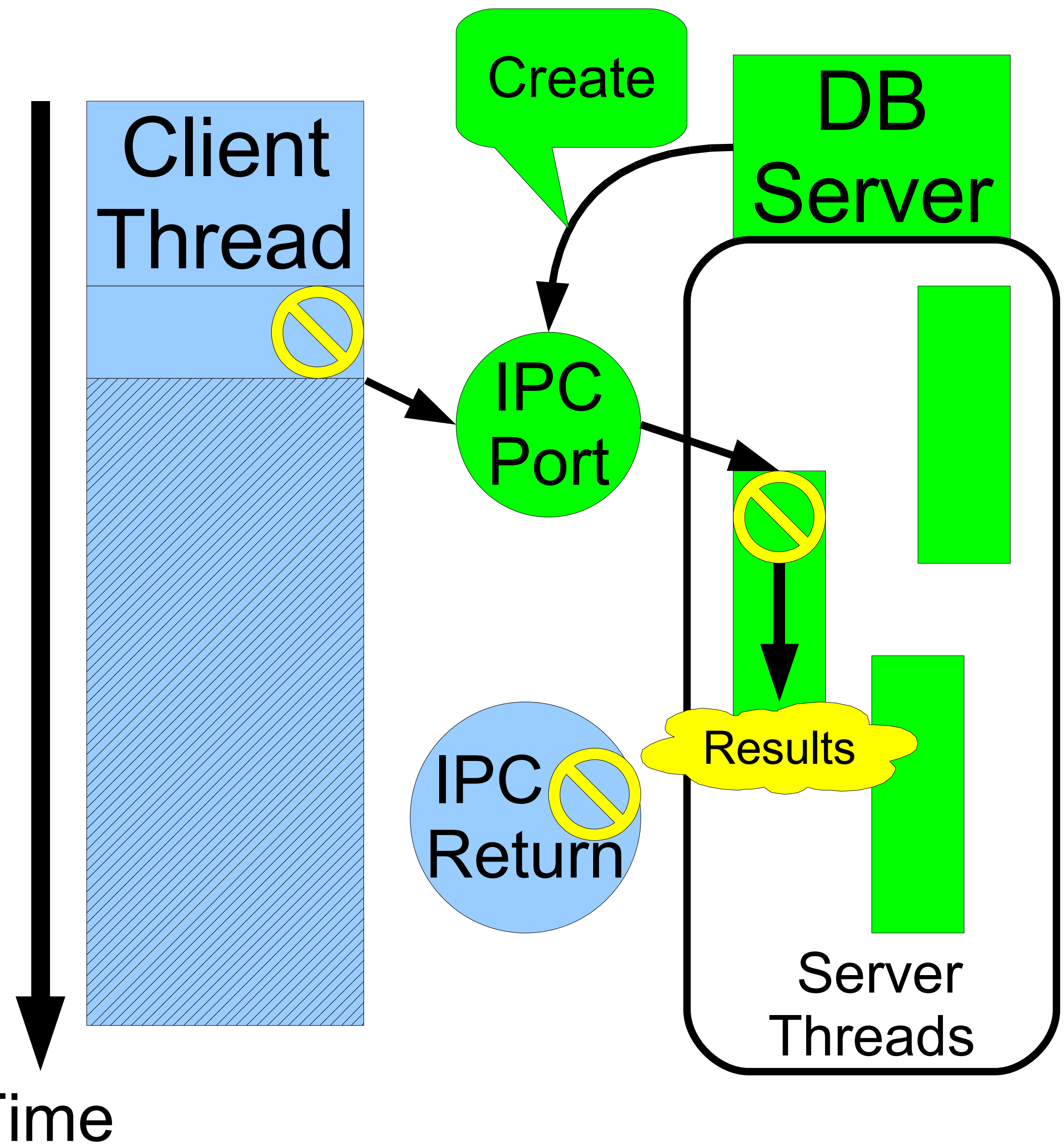

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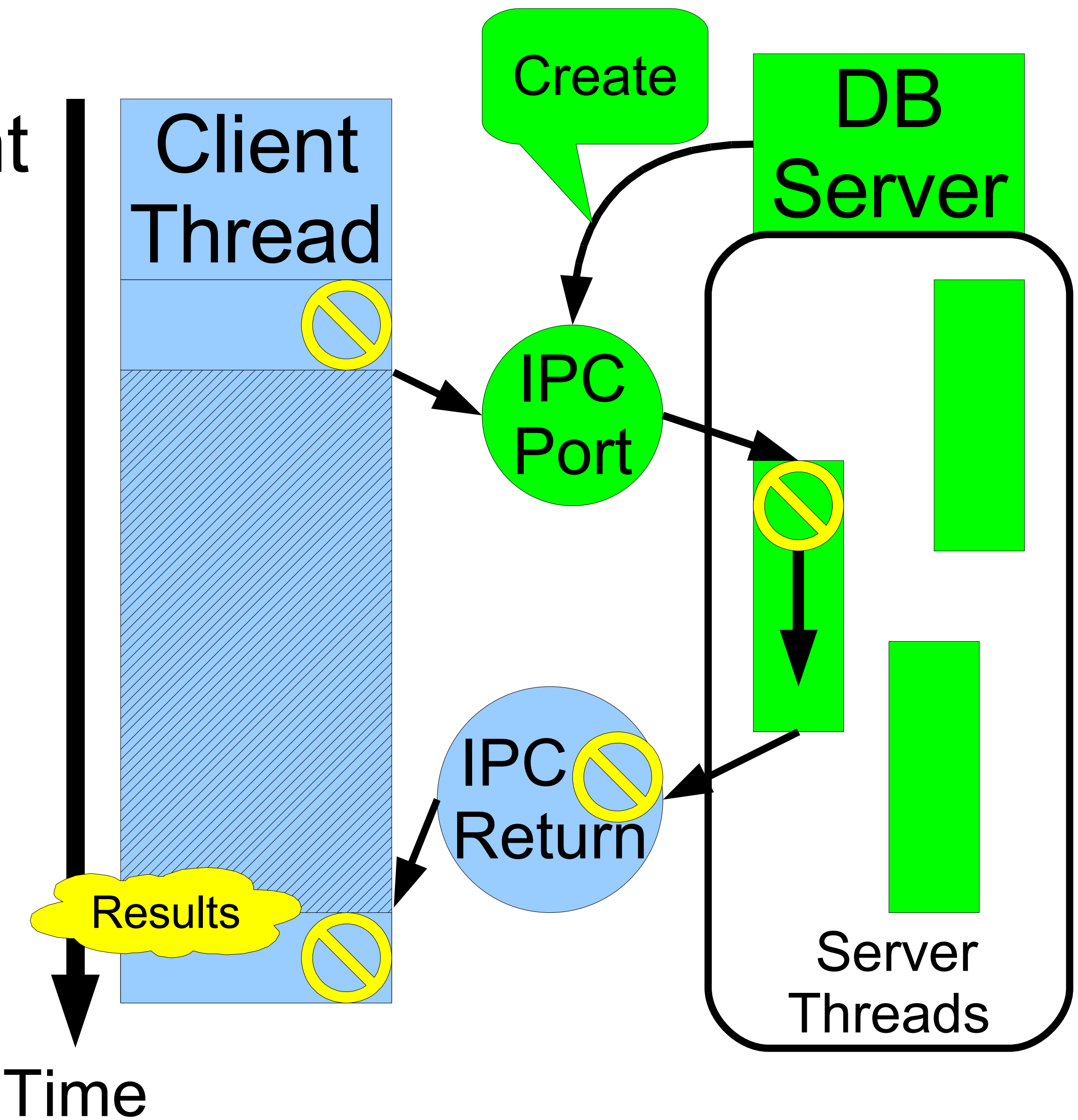
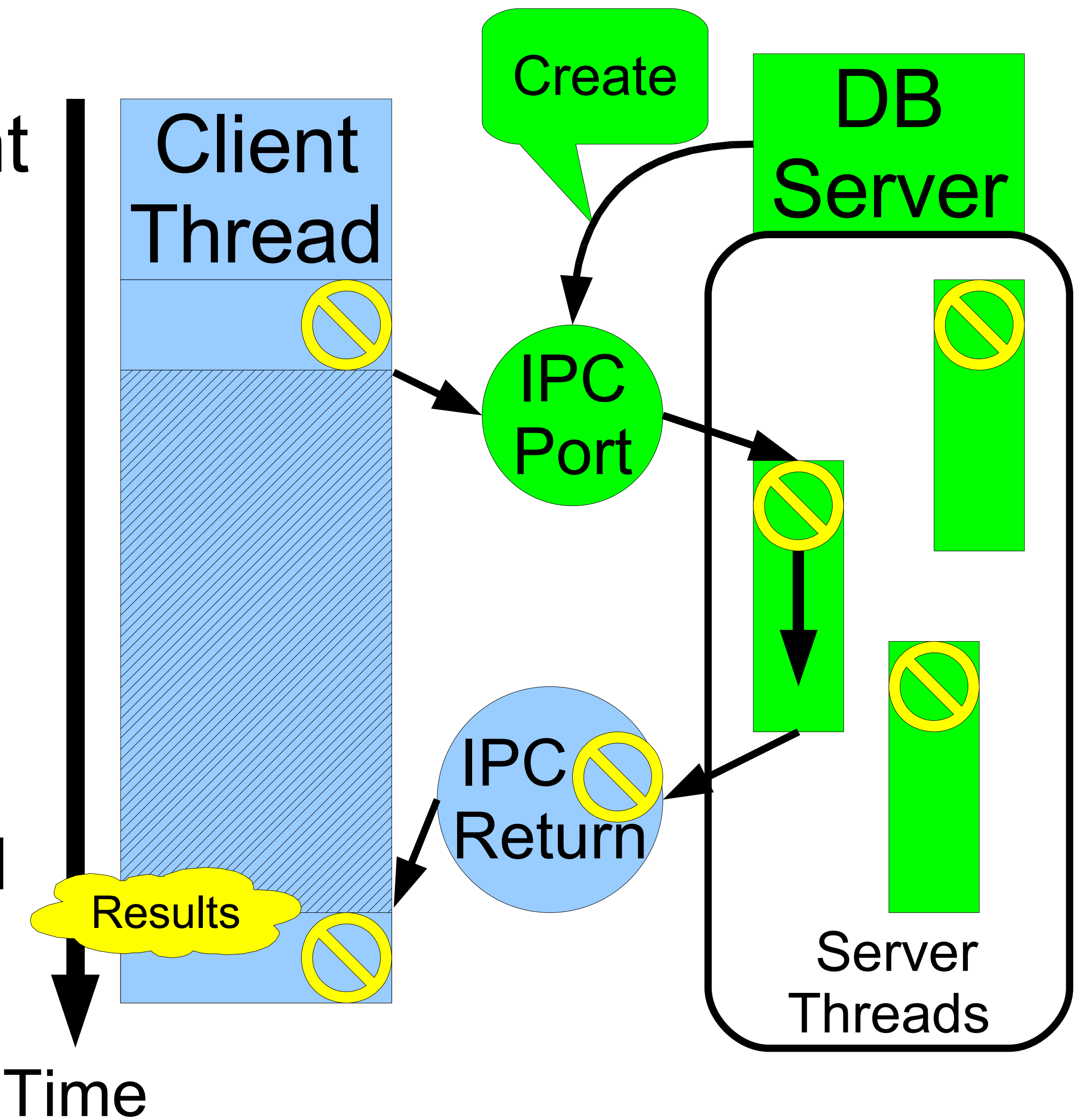


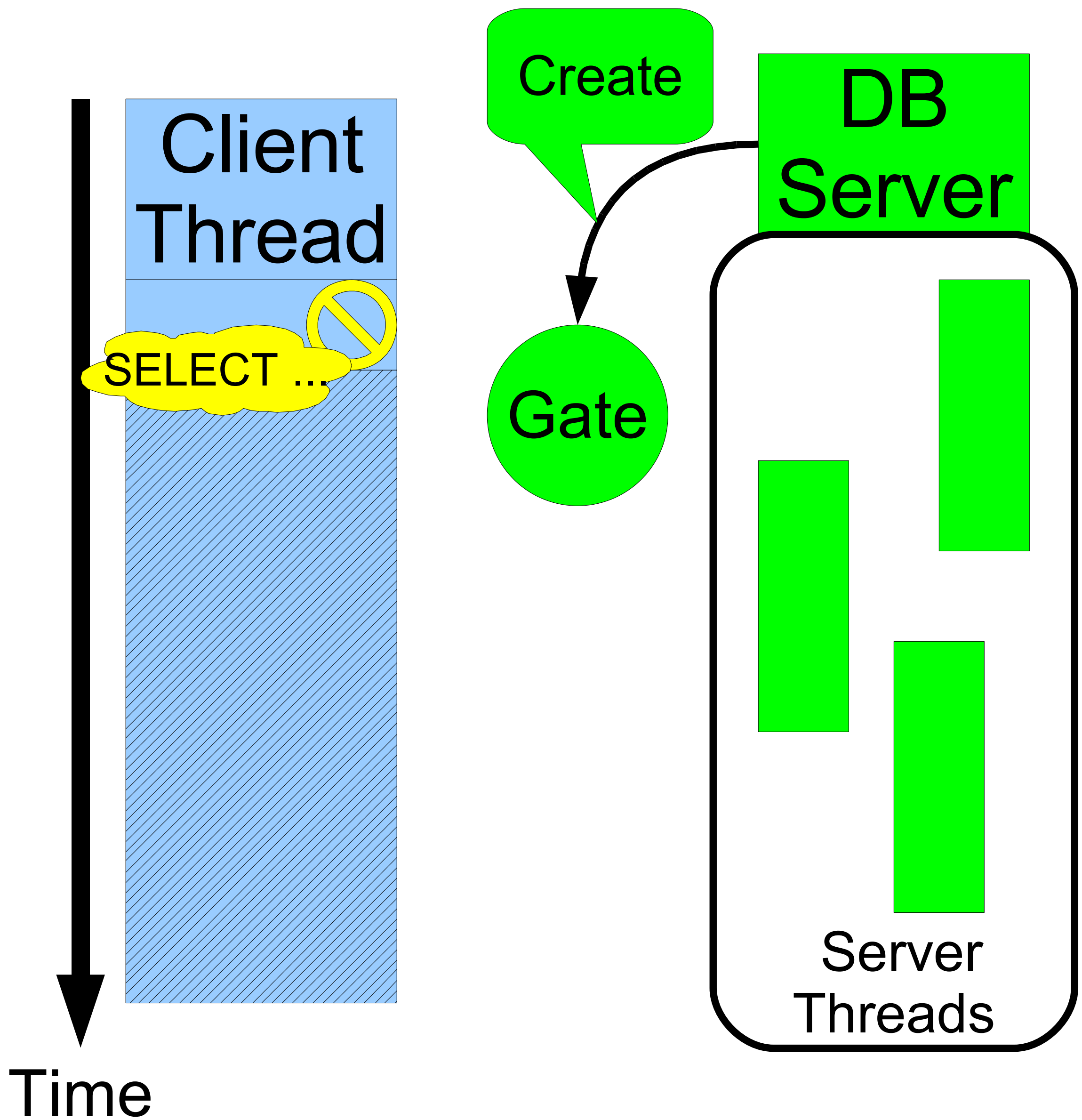
Problems with IPC

- IPC with tainted client
  - Taint server thread during request
  - Secrecy preserved?
- Lots of client calls
  - Limit server threads? Leaks information...
  - Otherwise, no control over resources!



Gates make resources explicit

- Client donates initial resources (thread)



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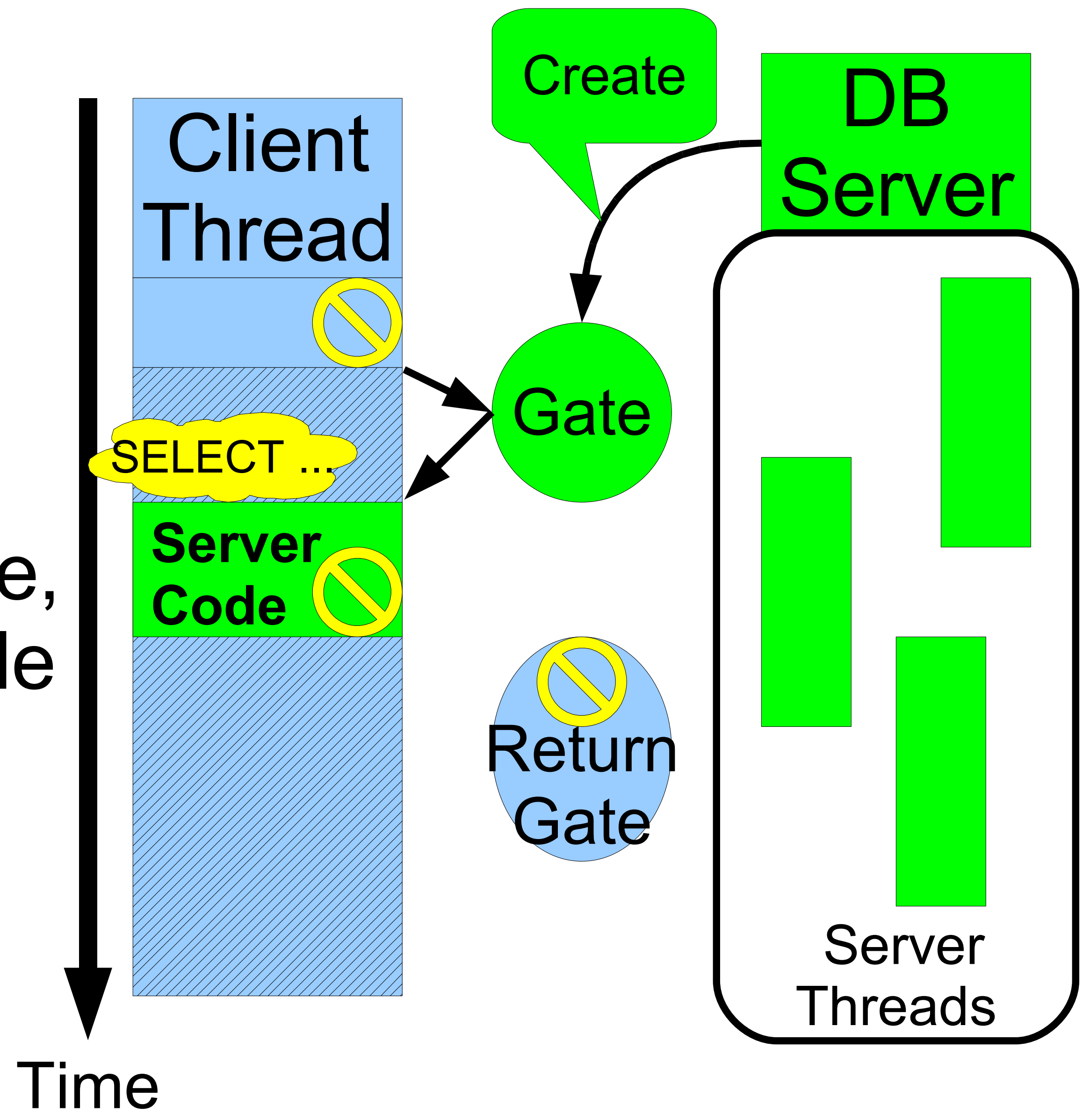

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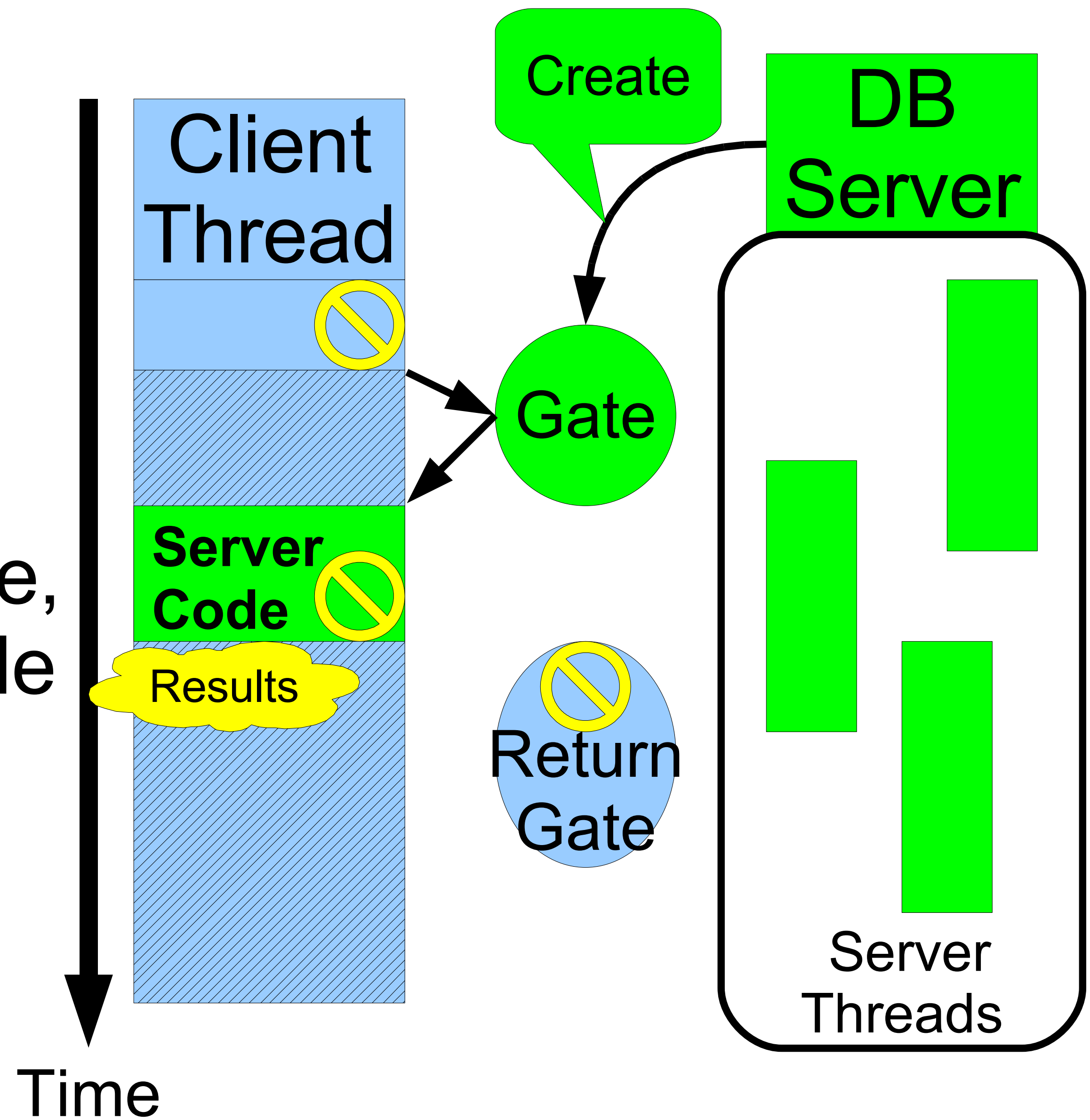
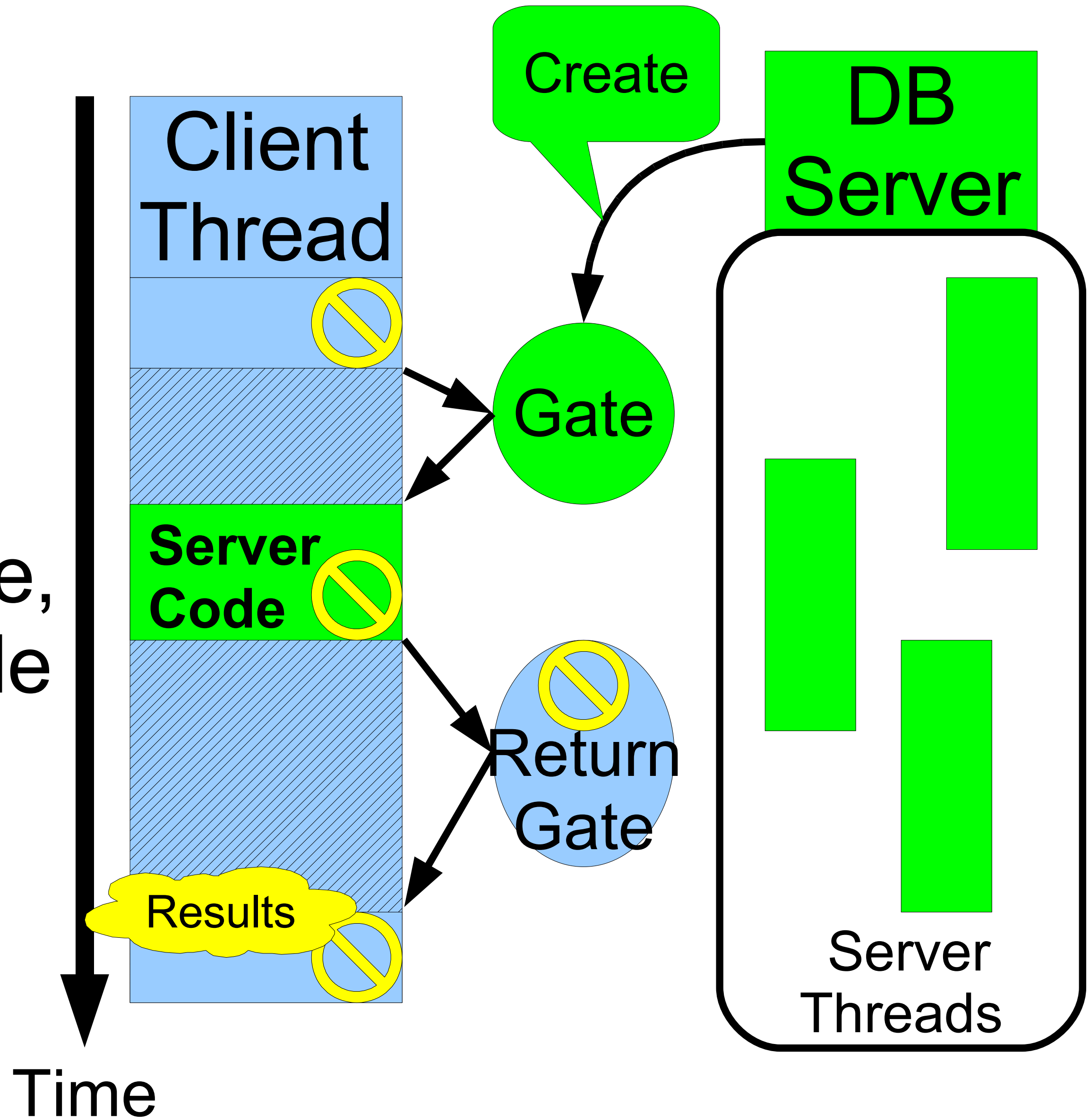
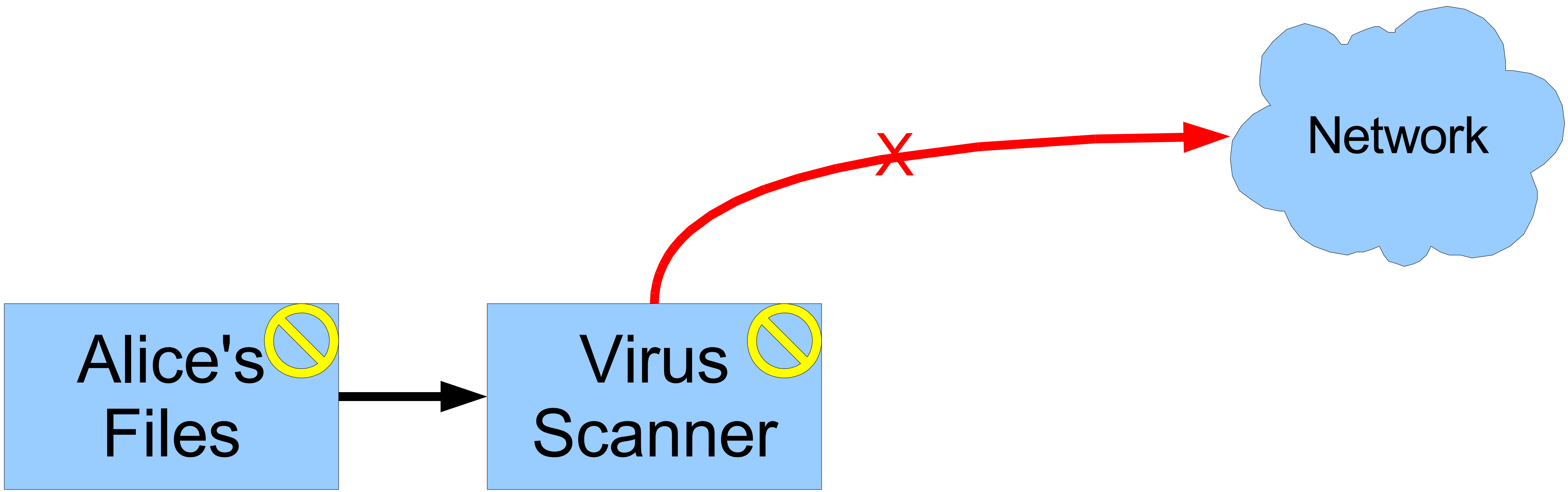


Gates make resources explicit

- Client donates initial resources (thread)
- Client thread runs in server address space, executing server code
- No implicit resource allocation – no leaks

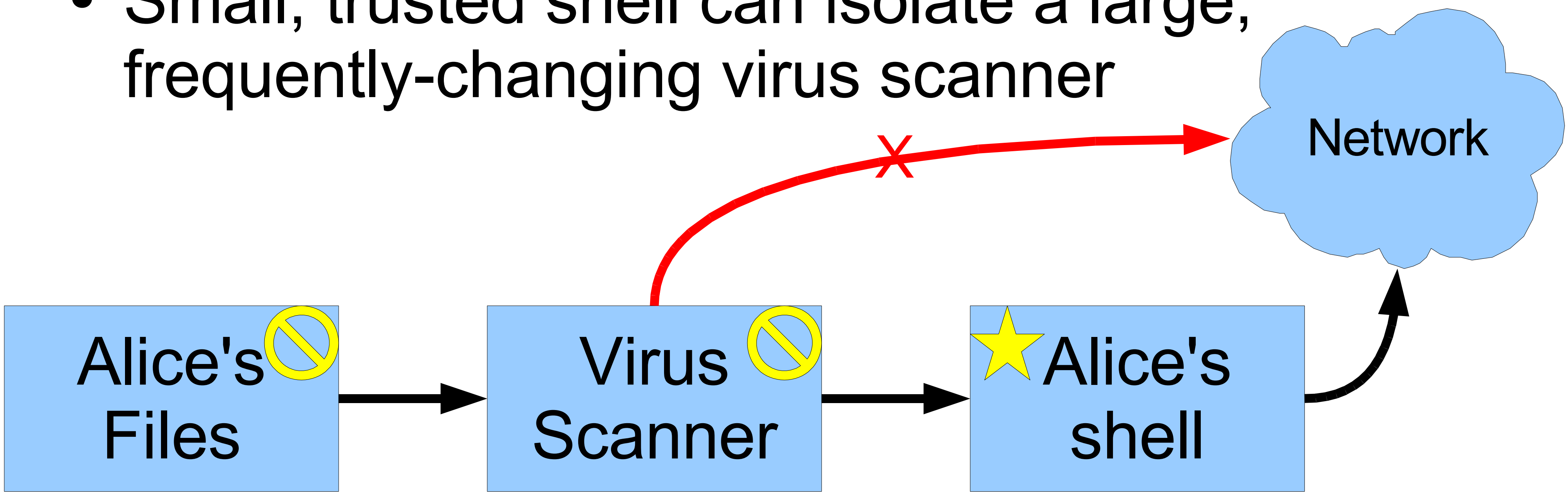


How do we get anything out?

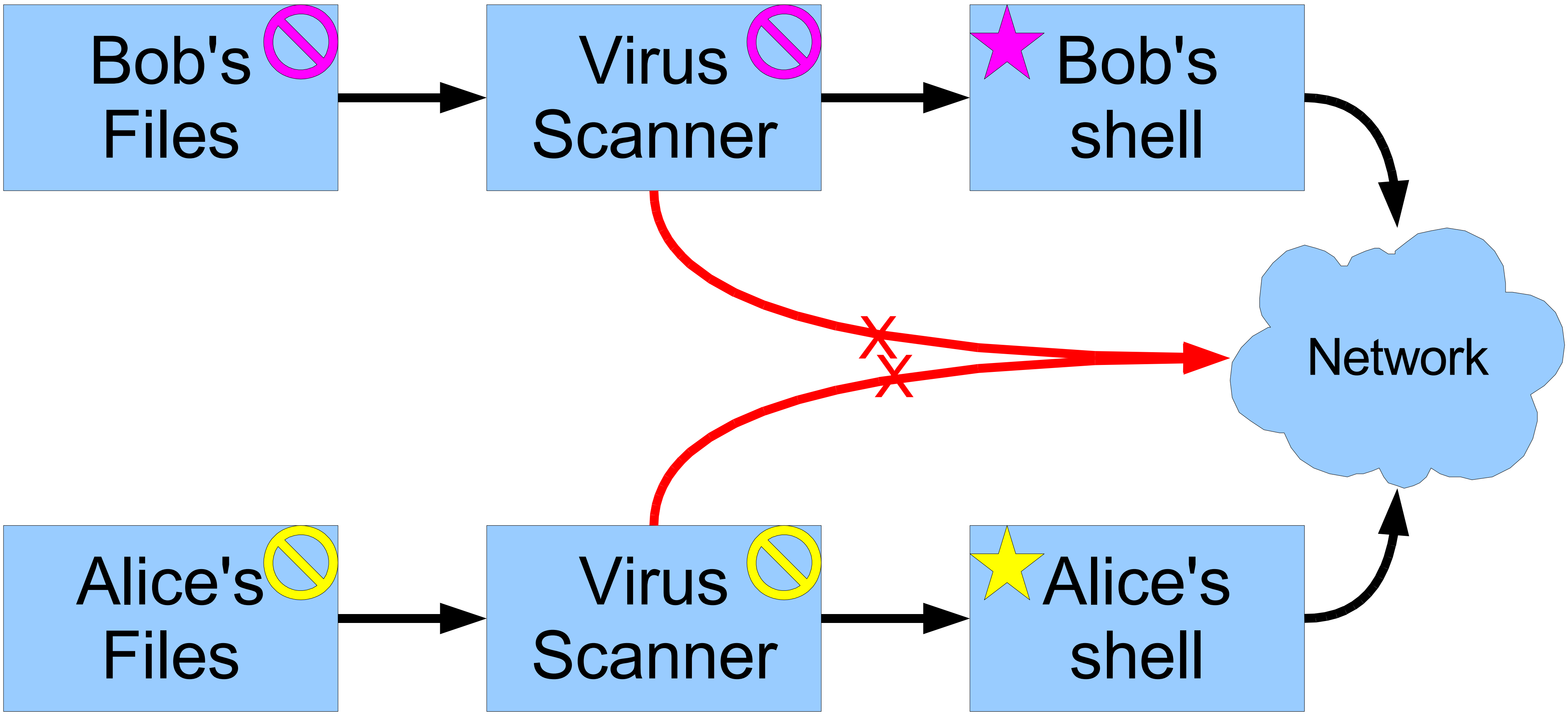


“Owner” privilege

- Yellow objects can only interact with other yellow objects, or objects with yellow star
- Small, trusted shell can isolate a large, frequently-changing virus scanner



Multiple categories of taint



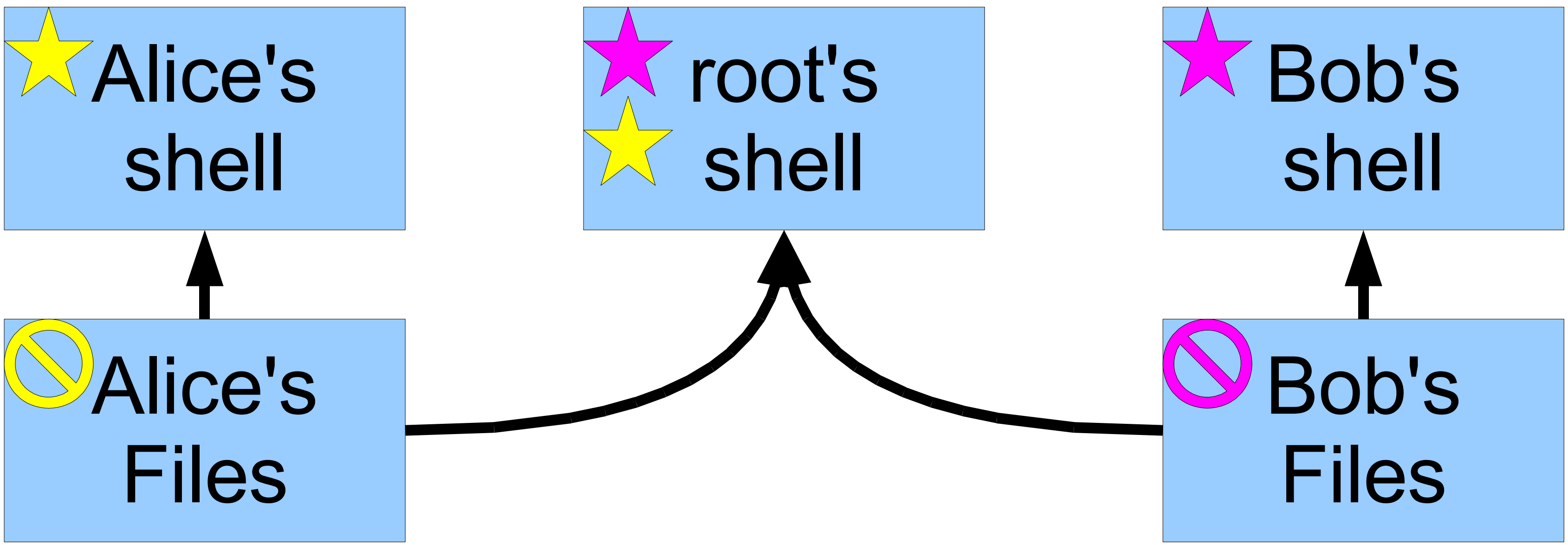
- Owner privilege and information flow control are the only access control mechanism
- Anyone can allocate a new category, gets star

What about “root”?

- Huge security hole for information flow control
  - Observe/modify anything – violate any security policy
- Make it explicit
  - Can be controlled as necessary

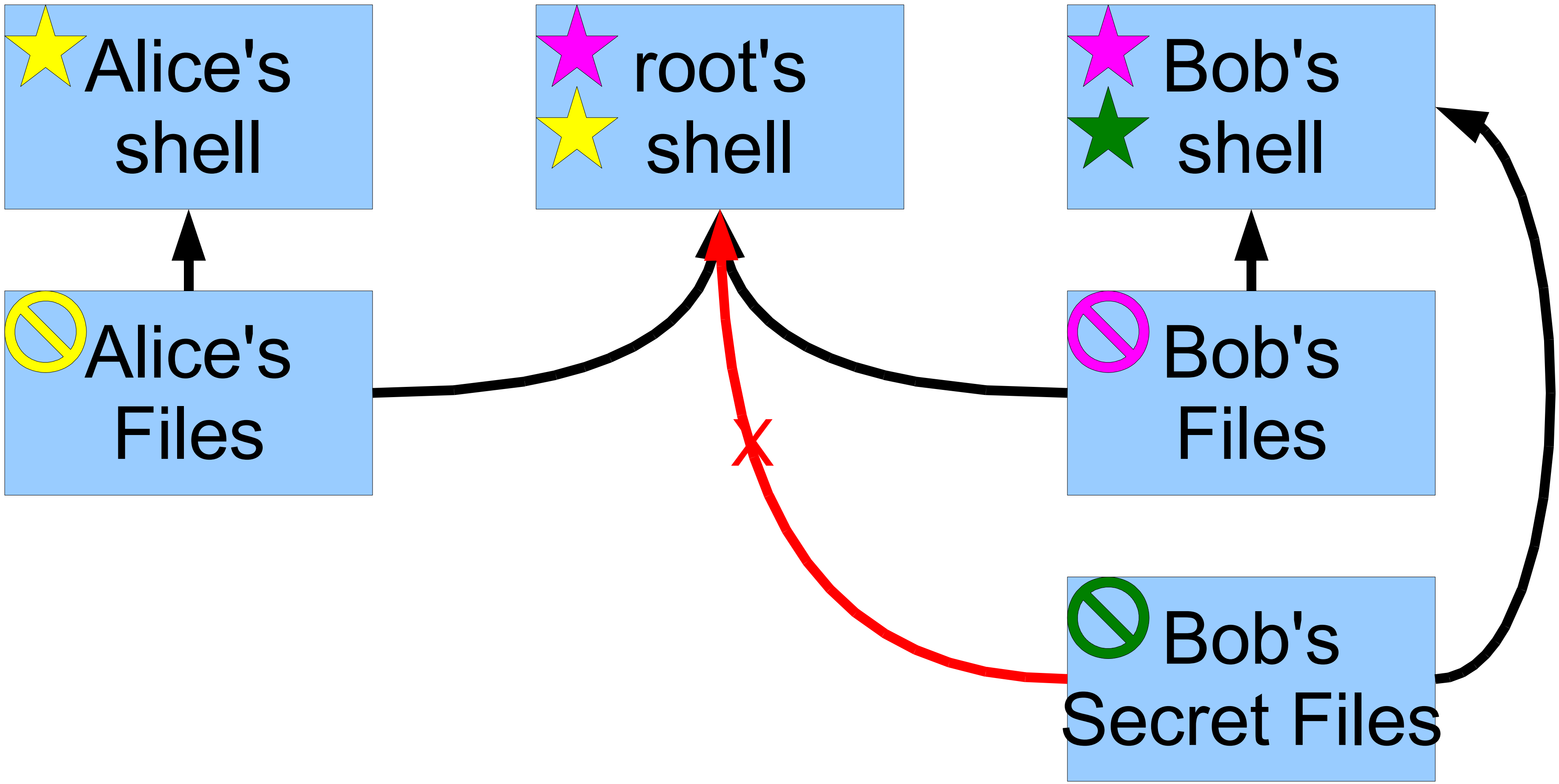
HiStar root privileges are explicit

- Kernel gives no special treatment to root



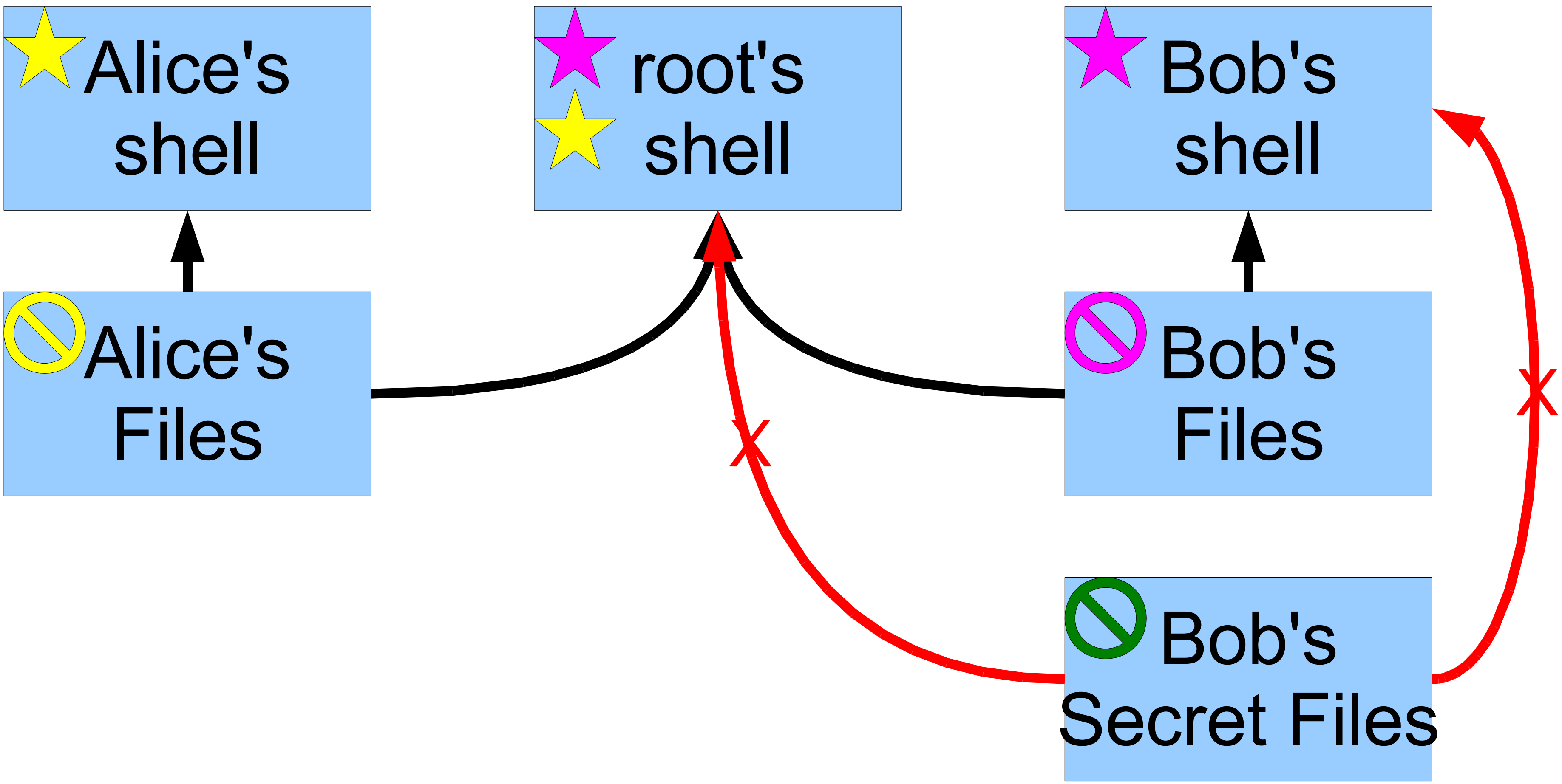
HiStar root privileges are explicit

- Users can keep secret data inaccessible to root

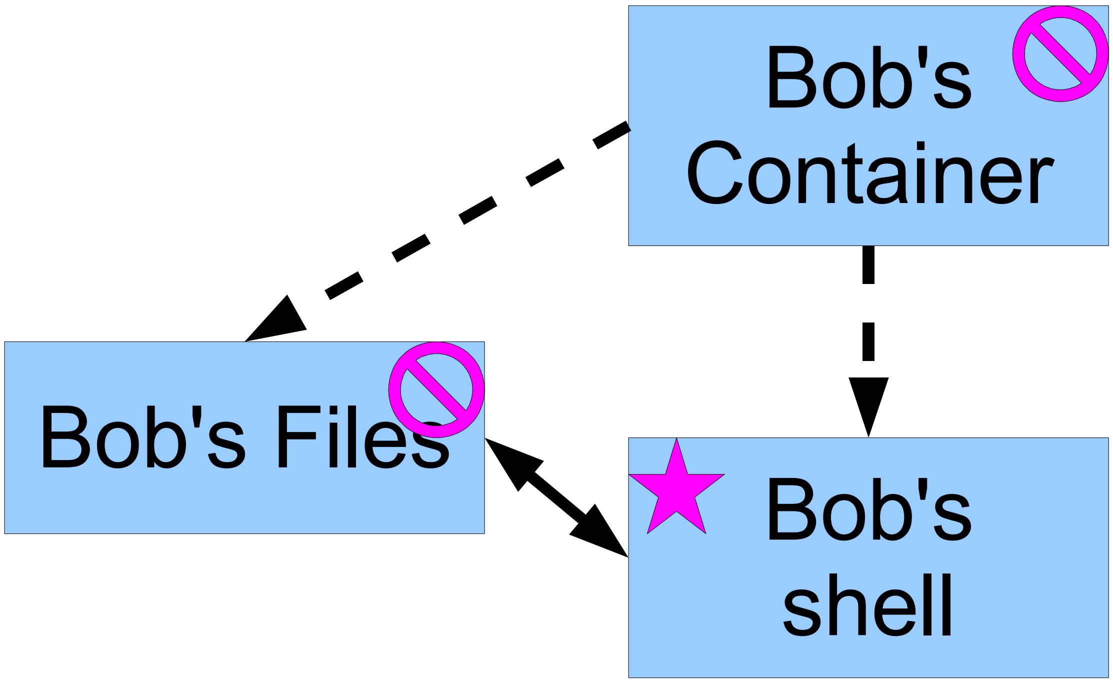


What about inaccessible files?

- Noone has privilege to access Bob's Secret Files

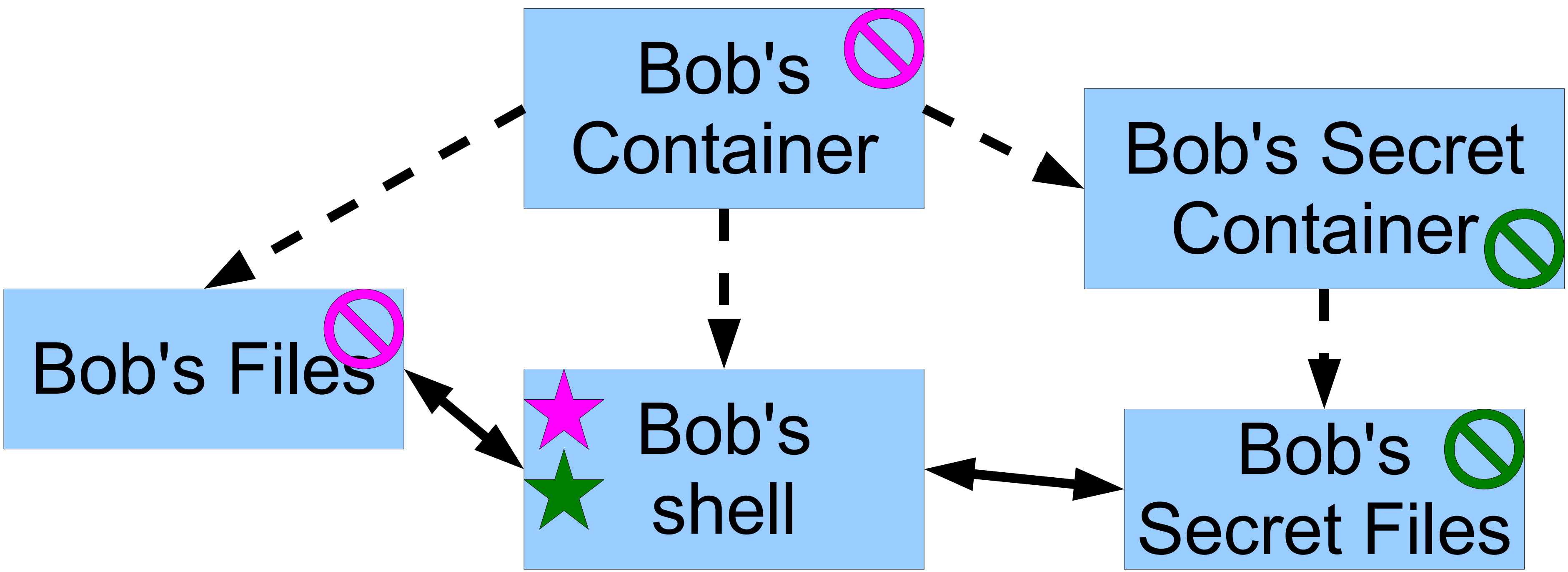


HiStar resource allocation



HiStar resource allocation

- Create a new sub-container for secret files



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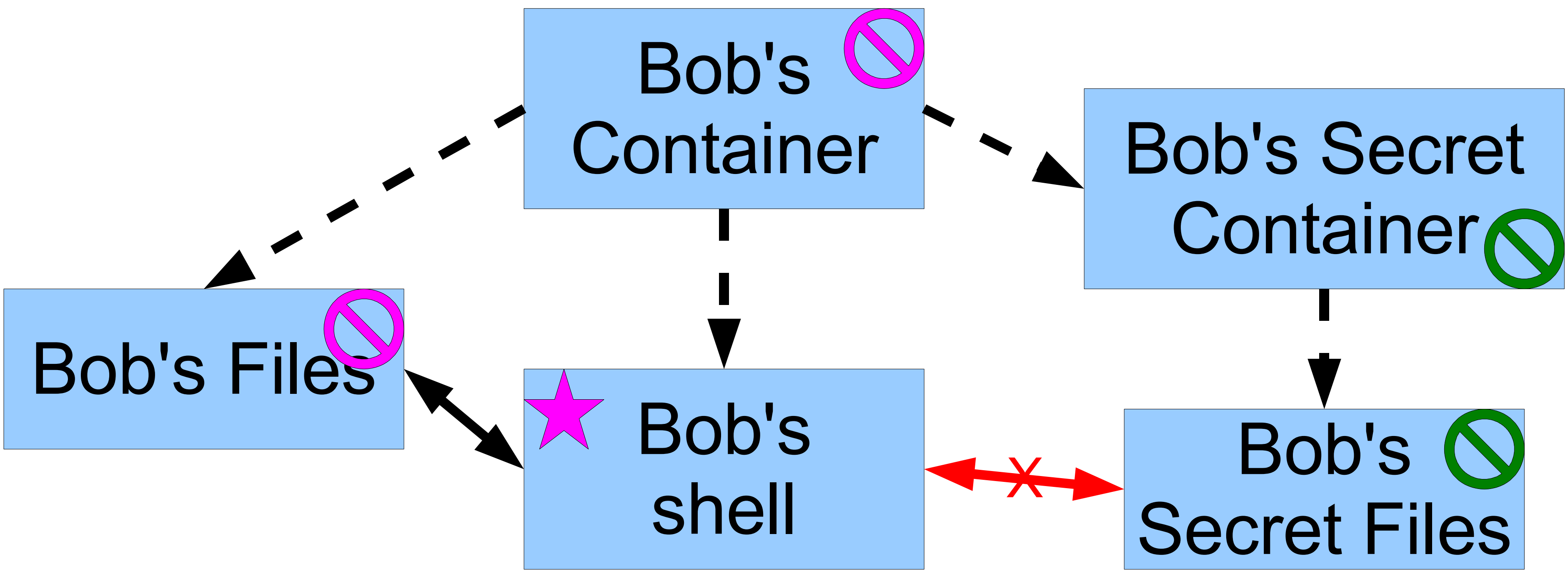
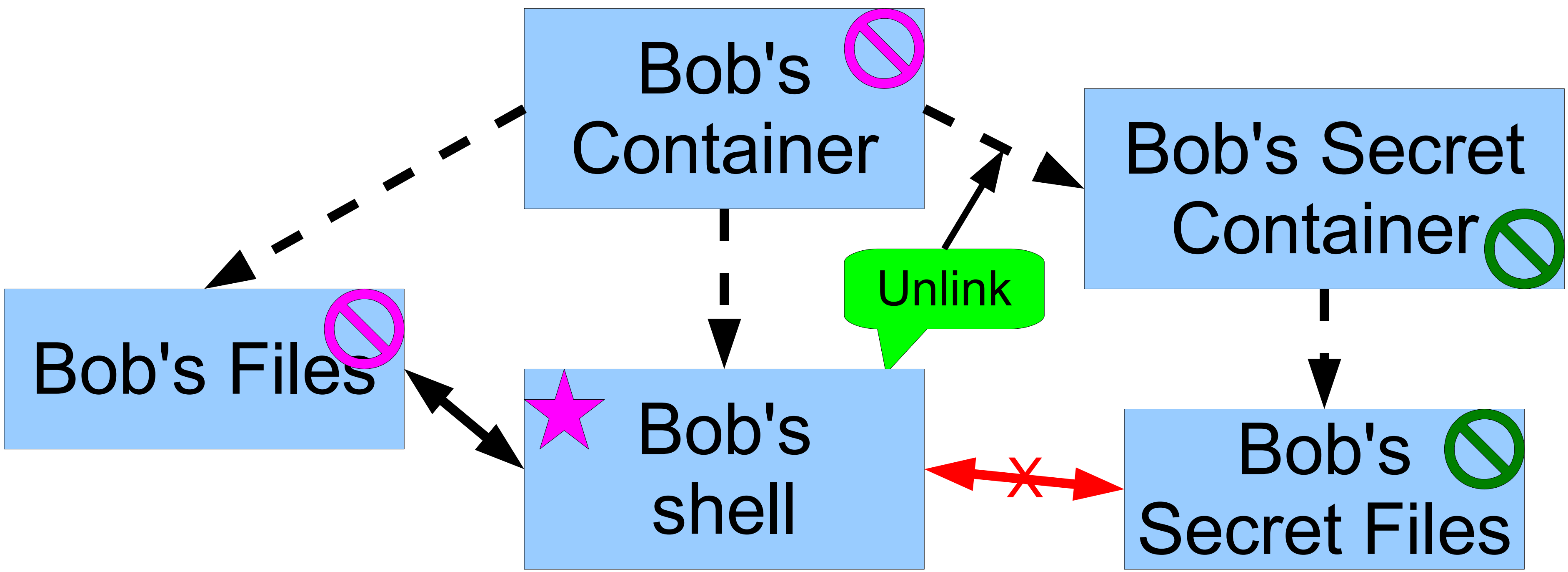


HiStar resource allocation

- Create a new sub-container for secret files
- Bob can delete sub-container even if he cannot otherwise access it!



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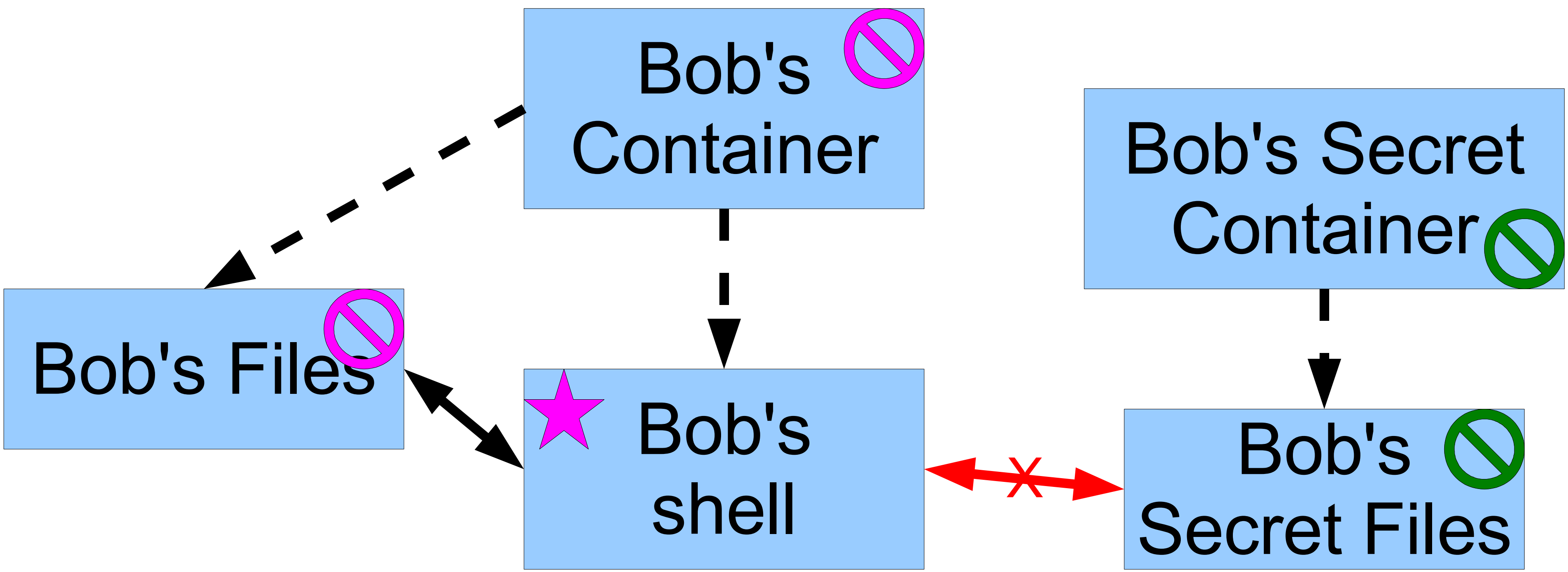

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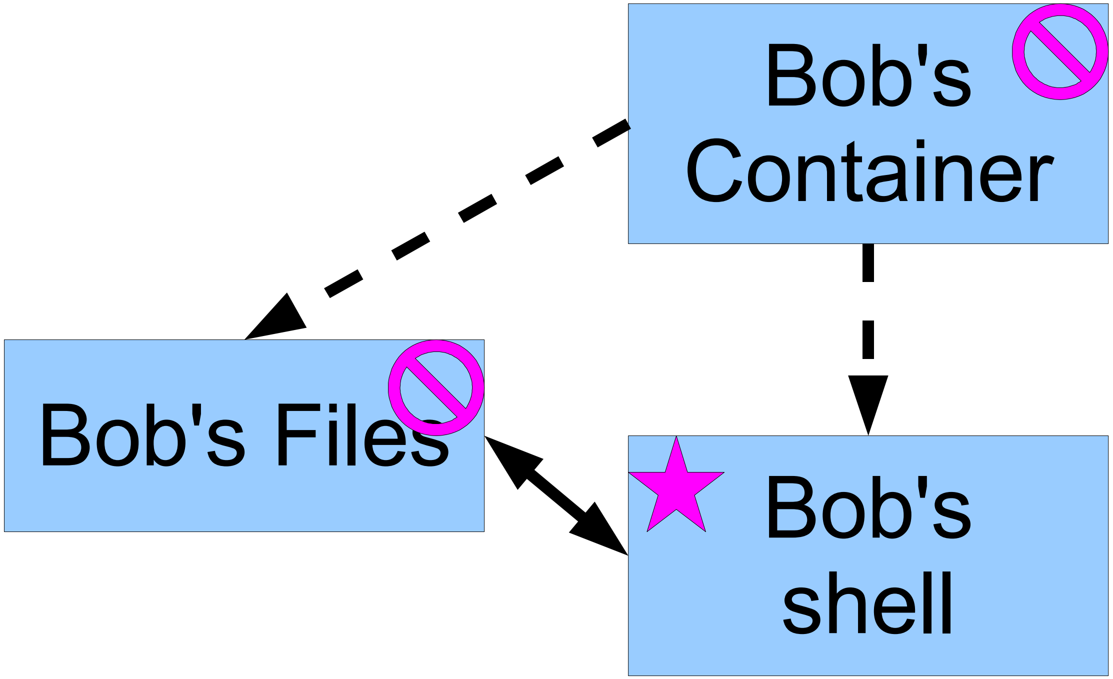
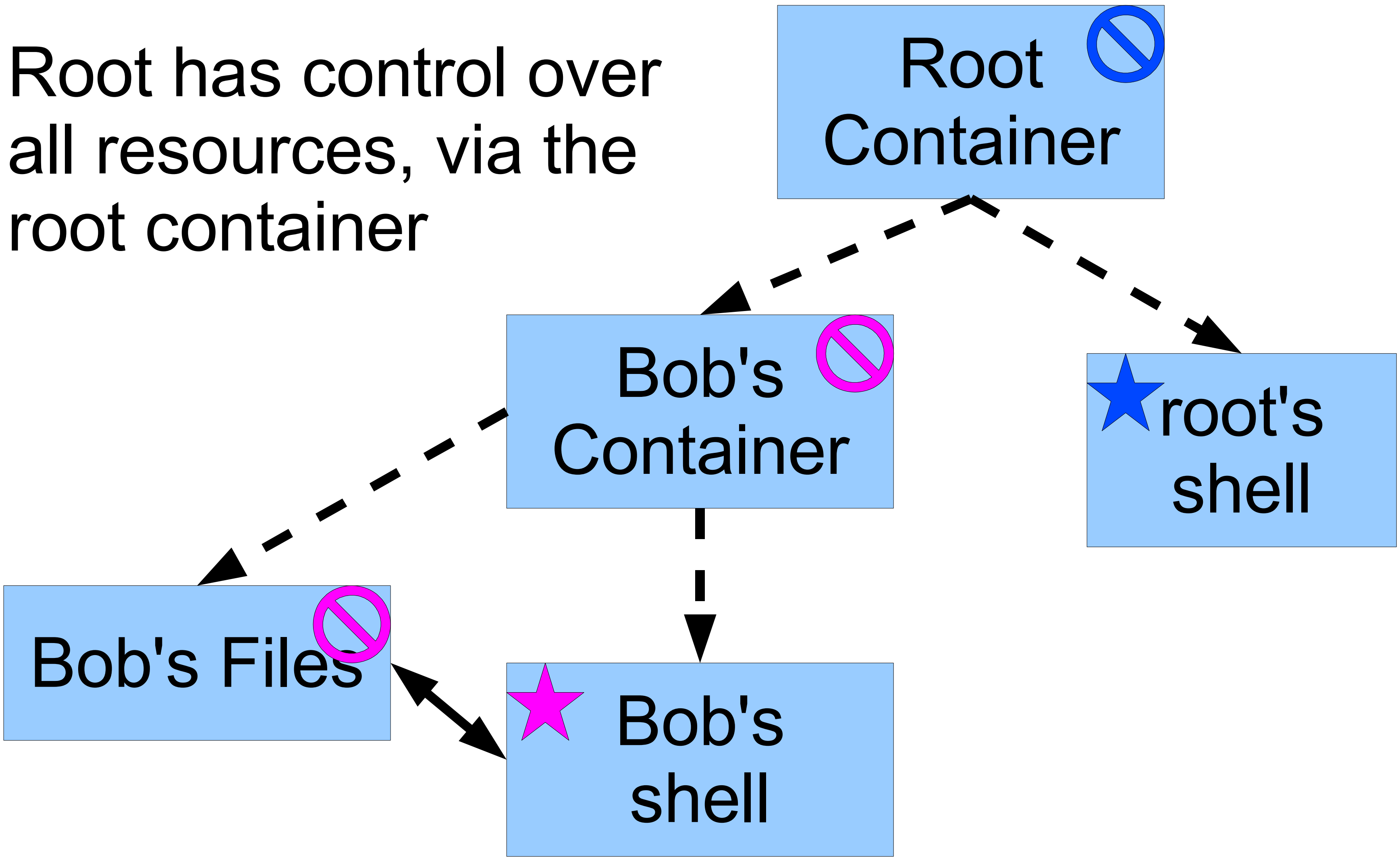


HiStar resource allocation

- Root has control over all resources, via the root container

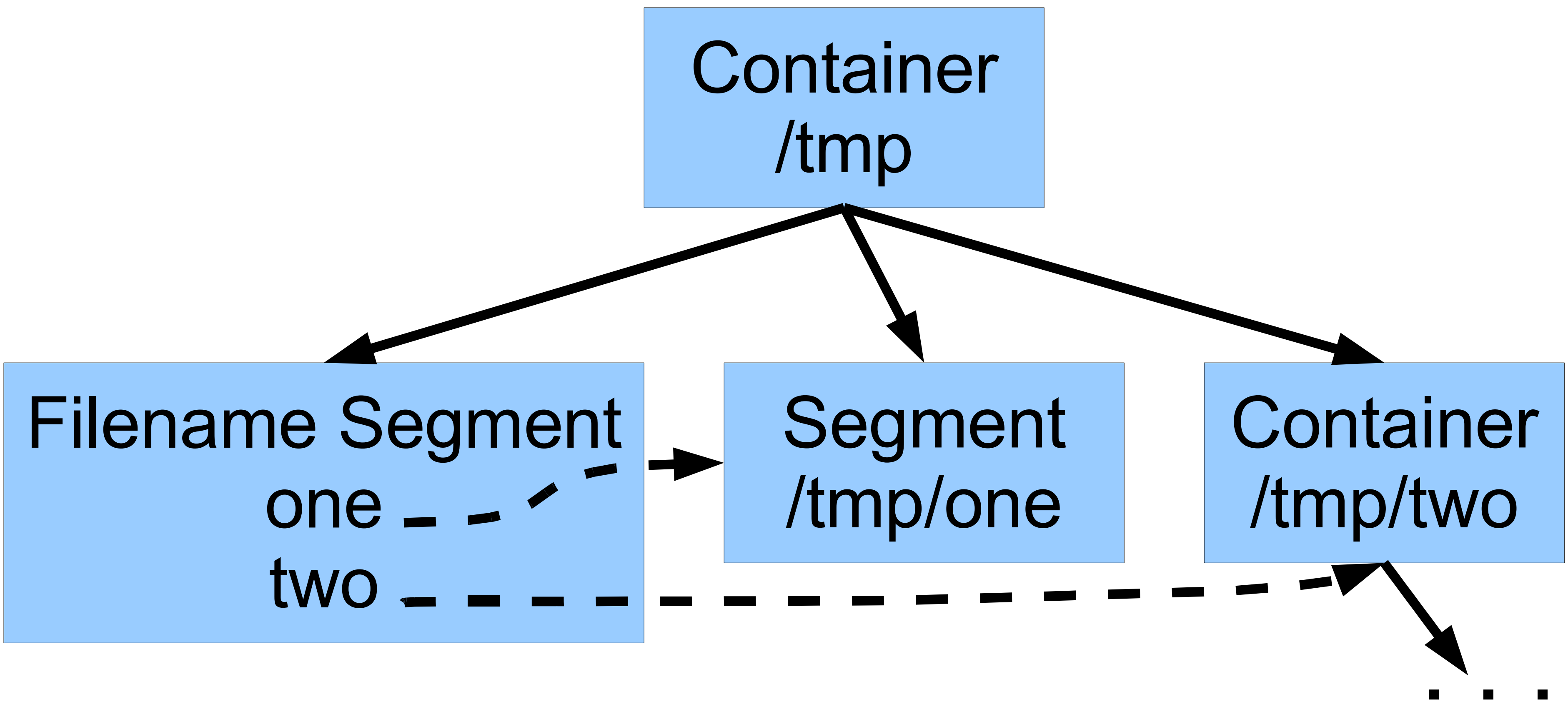


Persistent Storage

- Unix: file system implemented in the kernel
  - Many potential pitfalls leading to covert channels: mtime, atime, link counts, ...
  - Would be great to implement it in user-space as well
- HiStar: Single-level store (ala Multics / EROS)
  - All kernel objects stored on disk – memory is a cache
  - No difference between disk & memory objects

File System

- Implemented at user-level, using same objects
- Security checks separate from FS implementation



HiStar kernel design

- Kernel operations make information flow explicit
  - Explicit operation for thread to taint itself
    - Kernel never implicitly changes labels
  - Explicit resource allocation: gates, pre-created files
    - Kernel never implicitly allocates resources

- Kernel has no concept of superuser
  - Users can explicitly grant their privileges to root
  - Root owns the top-level container

Applications

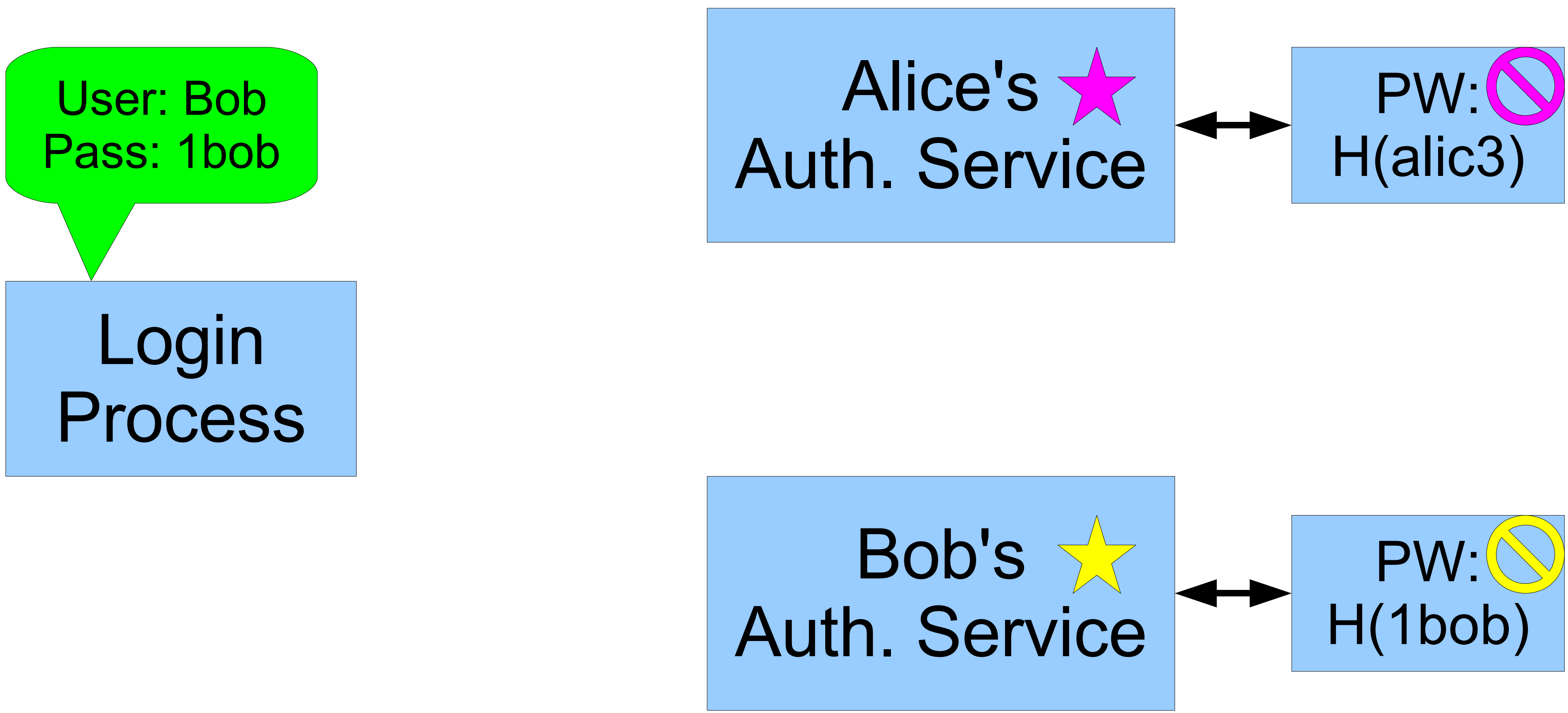
- Many Unix applications
  - gcc, gdb, openssh, ...
- High-security applications alongside with Unix
  - Untrusted virus scanners (already described)
  - VPN/Internet data separation (see paper)
  - login with user-supplied authentication code (next)

Login on Unix

- Login must run as root
  - Only root can setuid() to grant user privileges

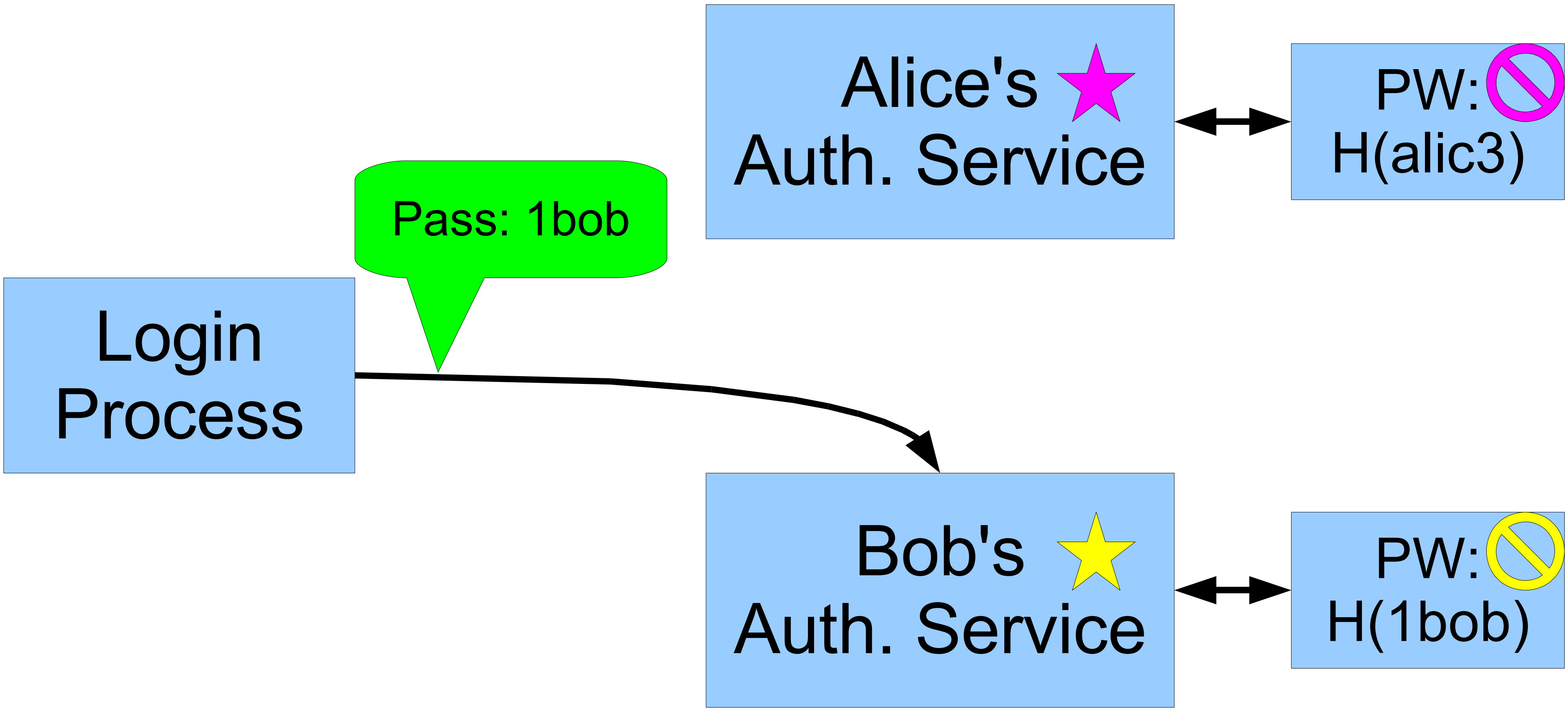
- Why is this bad?
  - Login is complicated (Kerberos, PAM, ...)
  - Bugs lead to complete system compromise

Login on HiStar



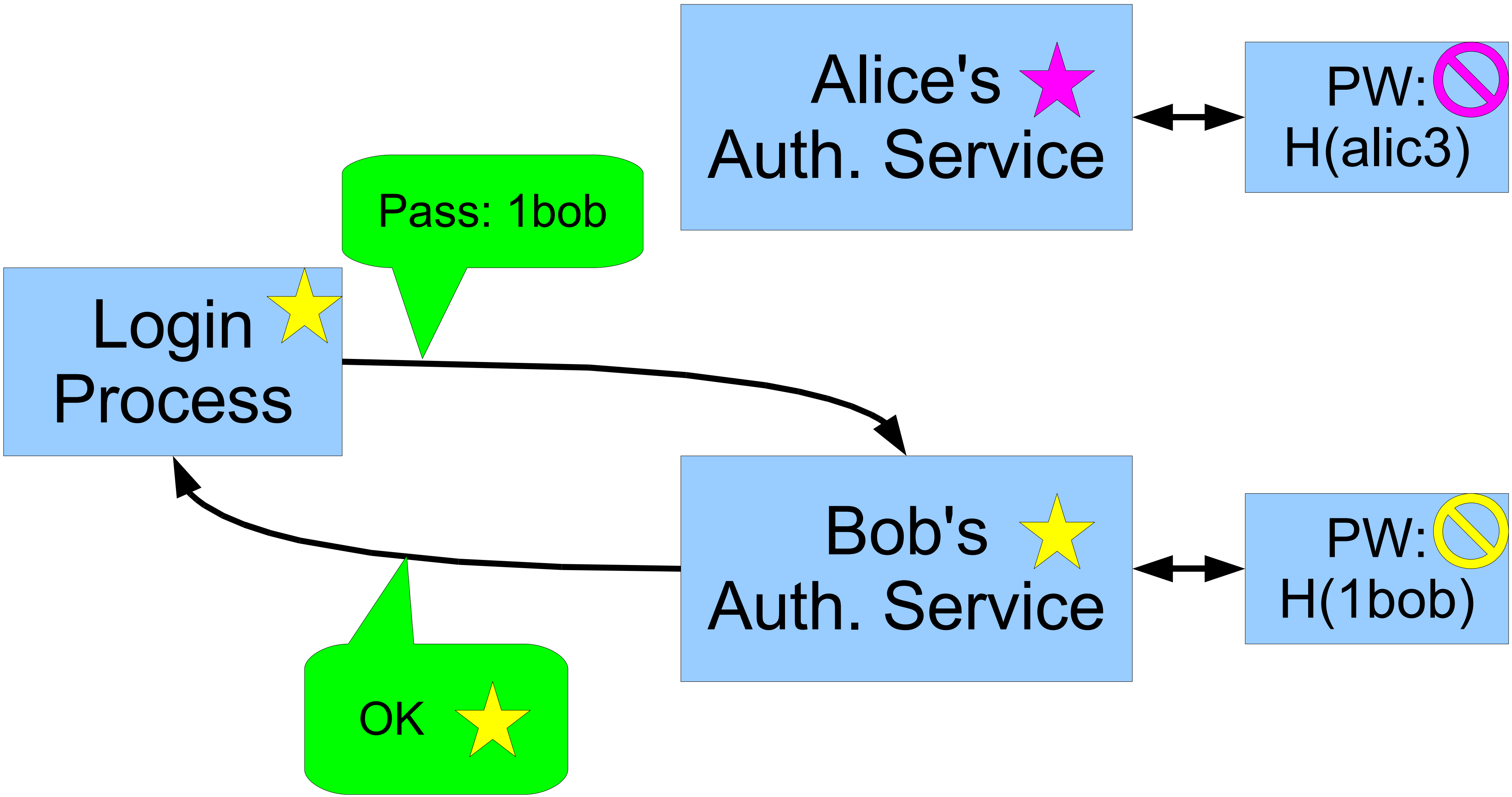
- Each user can provide their own auth. service

Login on HiStar

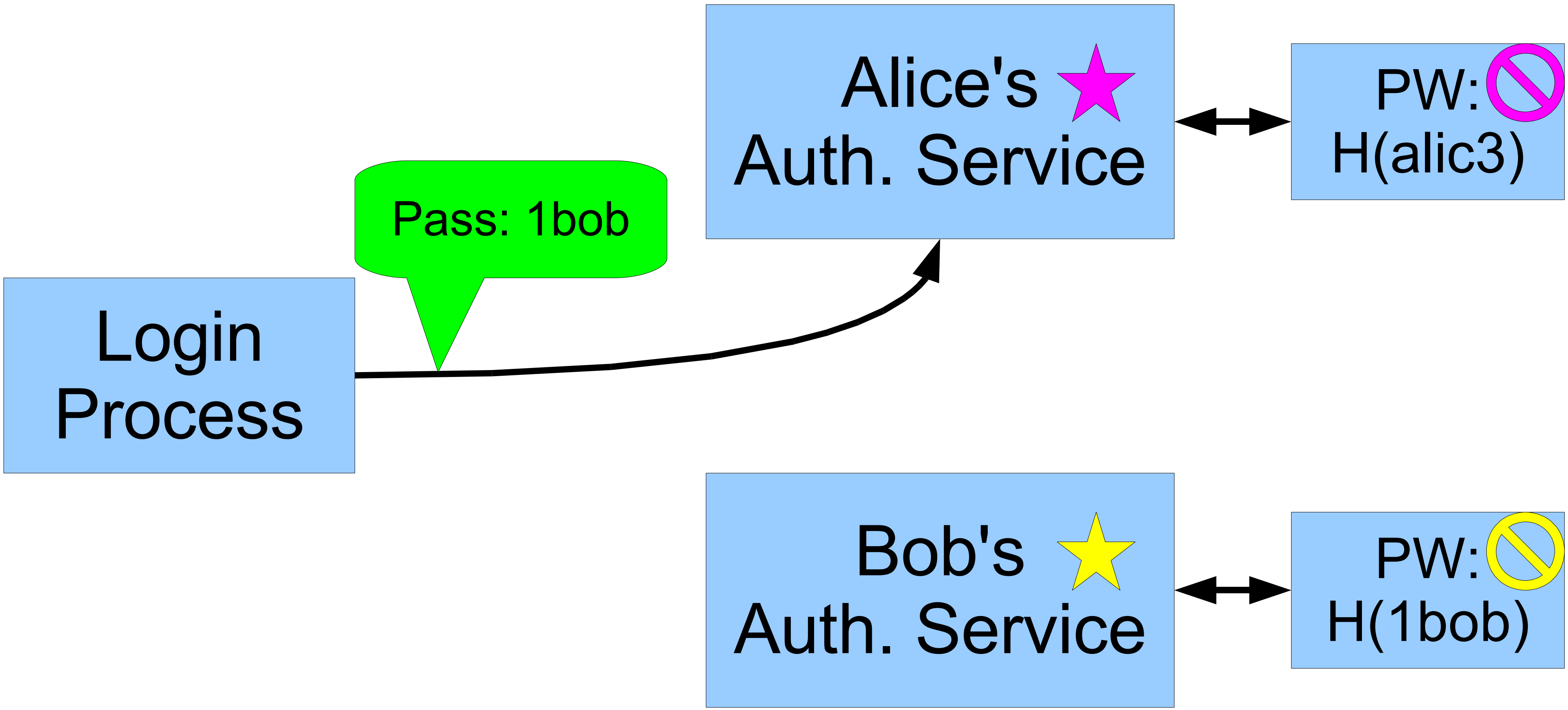


- Each user can provide their own auth. service

Login on HiStar

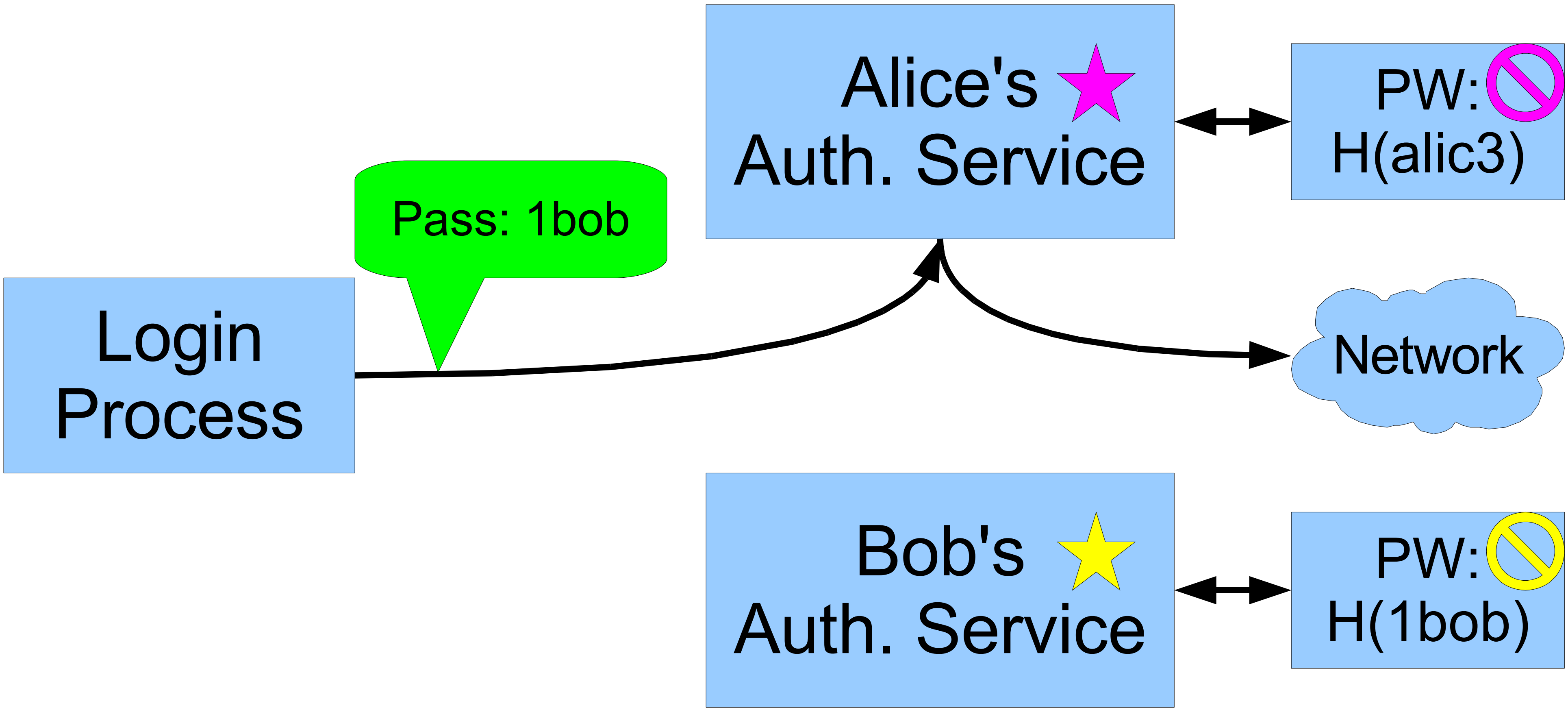


Password disclosure



- What if Bob mistypes his username as “alice”?

Password disclosure



- What if Bob mistypes his username as “alice”?

Avoiding password disclosure

- It's all about information flow
  - HiStar enforces:
  - “Password cannot go out onto the network”

- Details in the paper

Reducing trusted code

- HiStar allows developers to reduce trusted code
  - No code with every user's privilege during login
  - No trusted code needed to initiate authentication
  - 110-line trusted wrapper for complex virus scanner

- Small kernel: 16,000 lines of code

HiStar Conclusion

- HiStar reduces amount of trusted code
  - Enforce security properties on untrusted code using strict information flow control
- Kernel interface eliminates covert channels
  - Make everything explicit: labels, resources
- Unix library makes Unix information flow explicit
  - Superuser by convention, not by design

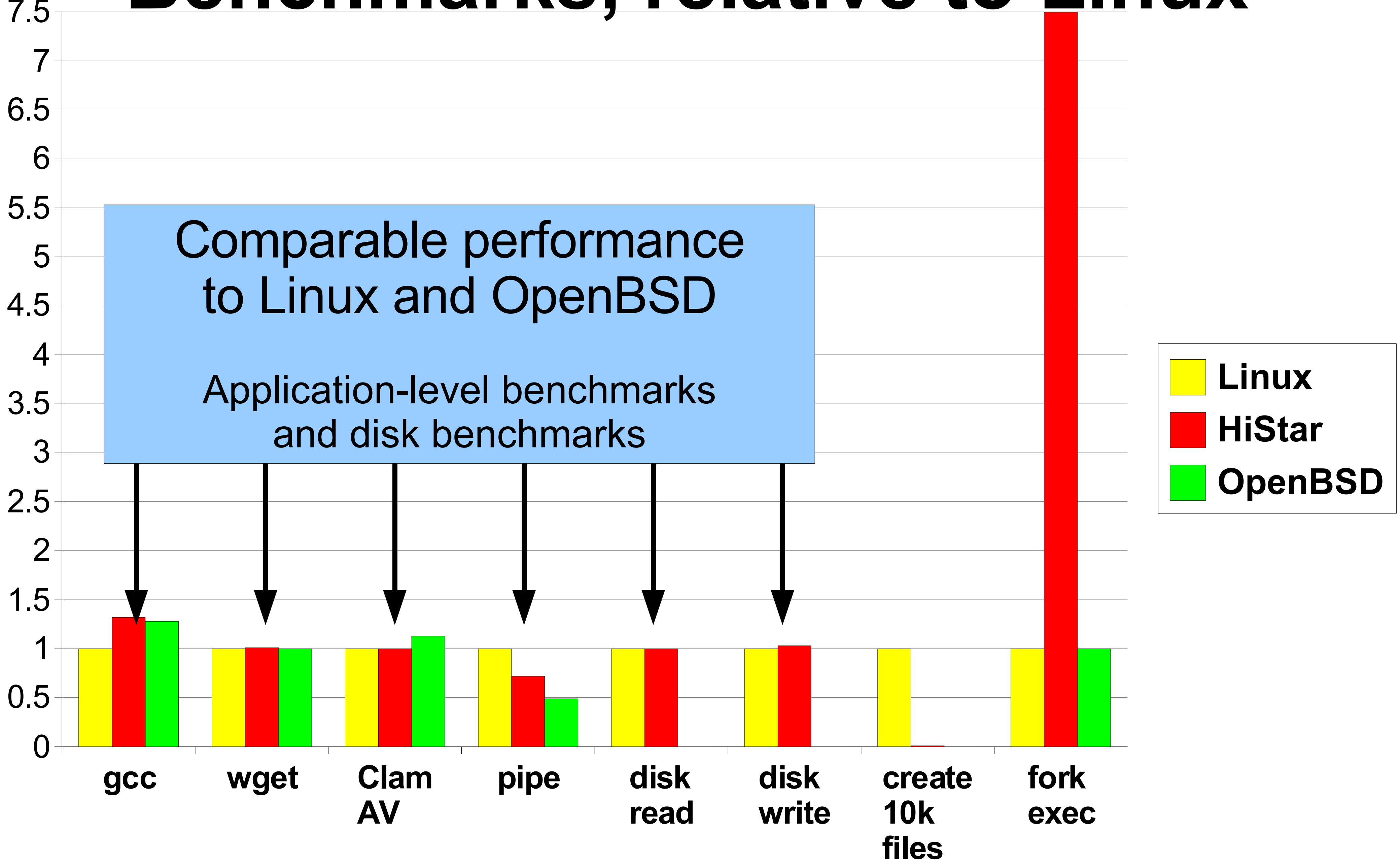
What about Asbestos?

- Different goal: Unix vs. specialized web server
  - HiStar closes covert channels inherent in the Asbestos design (mutable labels, IPC, ...)
  - Lower-level kernel interface
    - Process vs Container+Thread+AS+Segments+Gates
    - 2 times less kernel code than Asbestos
    - Generality shown by the user-space Unix library
  - System-wide support for persistent storage
    - Asbestos uses trusted user-space file server
  - Resources are manageable
    - In Asbestos, reboot to kill runaway process

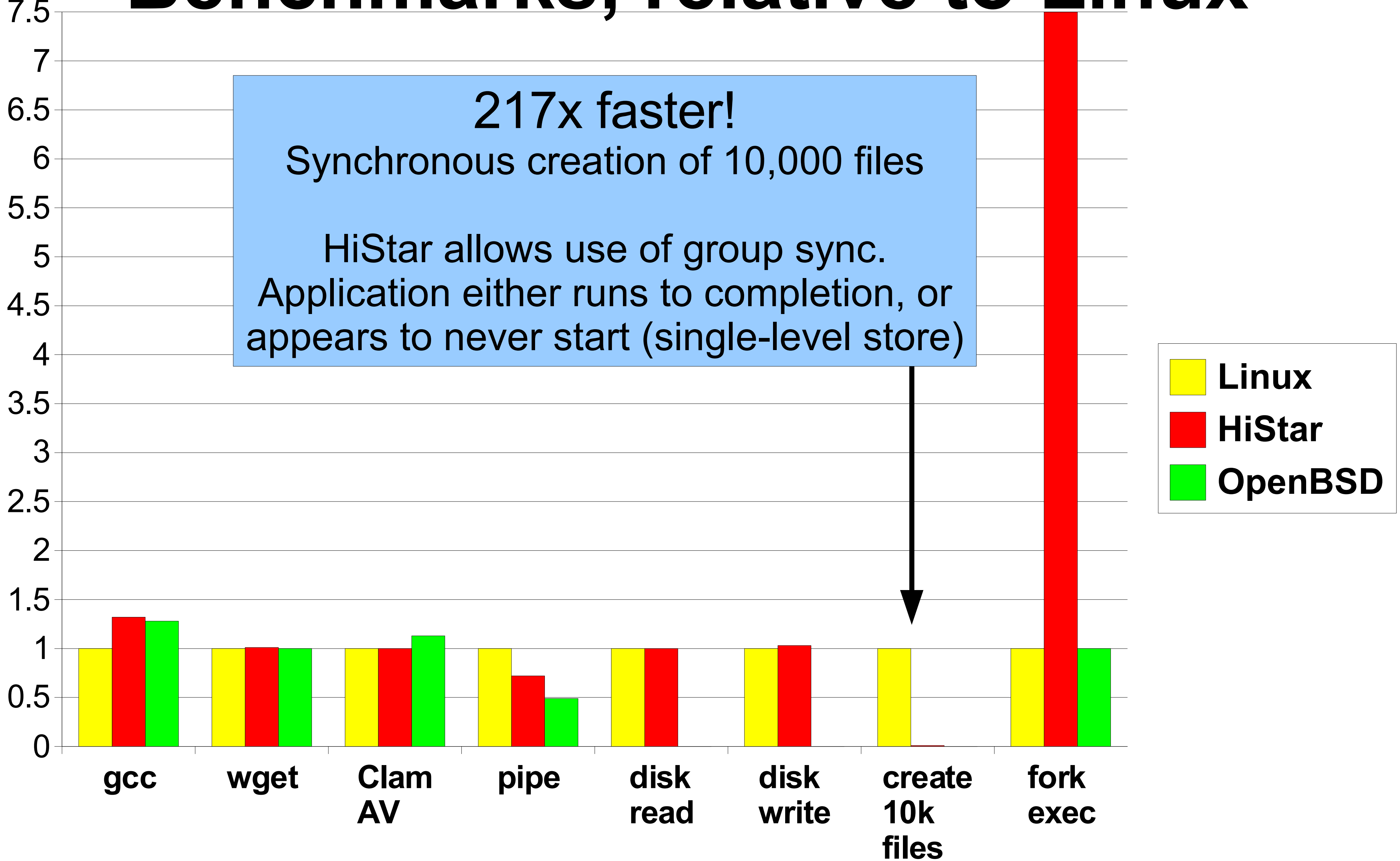
How is this different from EROS?

- To isolate in EROS, must strictly partition the capabilities between isolated applications
- Labels enforce policy without affecting structure
  - Can impose policies on existing code (see paper)

Benchmarks, relative to Linux



Benchmarks, relative to Linux



Benchmarks, relative to Linux