ECE590-03
Enterprise Storage Architecture

Fall 2016

Security

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What this lecture contains

- Included:
  - Basic definitions
  - Fundamental cryptography primitives
  - Where cryptography can be used in enterprise storage
  - Access control models applicable to storage
  - Secure deletion
- Not included:
  - Cryptography internals
  - How to program using cryptography primitives (it's easy to screw up!)
  - The many other uses of cryptography
  - Database security (e.g. SQL injection attacks)
  - Intrusion detection and prevention systems
  - Software security (bugs and exploits, e.g. buffer overflow)
  - Denial of service attacks
  - Too many other things to ever possibly list

Key Security Concepts

Confidentiality

- Preserving authorized restrictions on information access and disclosure, including means for protecting personal privacy and proprietary information

Availability

- Ensuring timely and reliable access to and use of information

Integrity

- Guarding against improper information modification or destruction, including ensuring information nonrepudiation and authenticity

Threat model

- Security is boolean:
  - If (ANY exploitable flaw exists): system can be compromised
    else: system cannot be compromised
- Can easily *prove* condition (existence proof);
  cannot easily *disprove* condition
- Result: Cannot determine if a system is secure
  - Scary/sad result

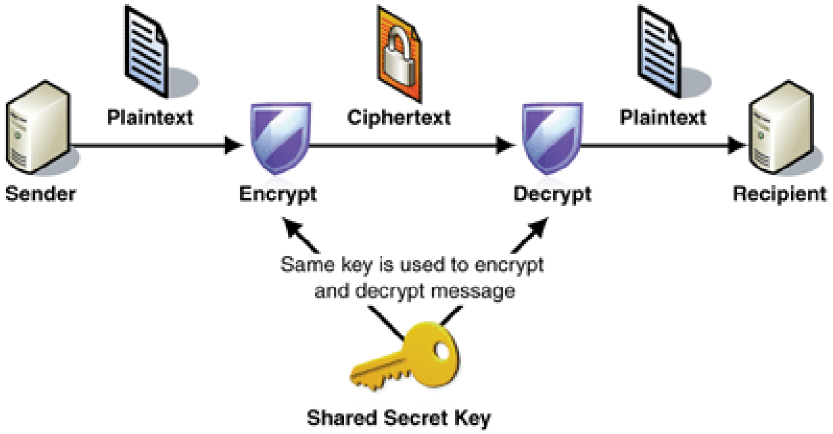
- To reason about security, need to identify **threat model**
  - What do we assume potential attacker can do?
  - Then, in that situation, what consequences can we prevent?
- Example: "Assume attacker can listen on this wire. Normally, they can intercept user data, but we if we use encryption, then they cannot."

Cryptography primitives

Cryptography basics: Symmetric encryption

(Also called shared-key encryption or secret-key encryption)

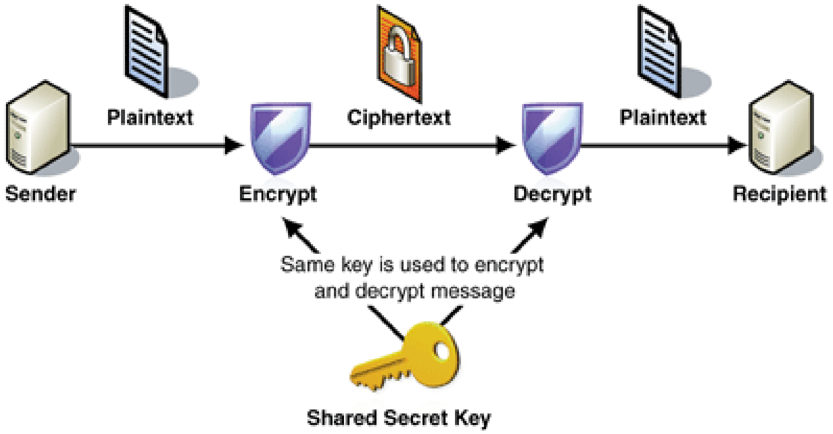
- Given:
  - Plaintext **p** (arbitrary size)
  - Secret key **k** (fixed size)
  - Encryption function **E**
  - Decryption function **D**
- Can produce ciphertext **c**:
  - **c = E(p,k)**
- Can recover plaintext:
  - **p = D(c,k)**



Cryptography basics: Symmetric encryption

- Ciphertext indistinguishable from random noise
- For a “good” algorithm, message cannot be recovered without key; attacker would need to try all possible keys
  - If k is big, that would take too long (longer than life of universe)
- Making a “good” algorithm is hard... a whole field of study
  - Never, ever make your own algorithm!
- Common algorithms: AES, Twofish, Serpent, Blowfish
  - If you’re unsure, AES is a fine choice
    (unless these slides are old, then google it first...)

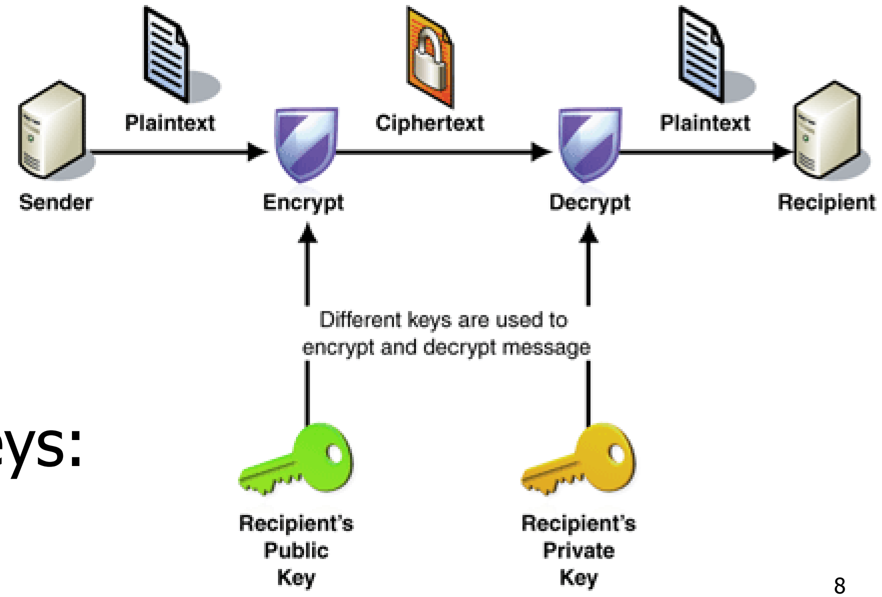
- **Problem with this?**
  - Need to pre-share the key!



Cryptography basics: Asymmetric encryption

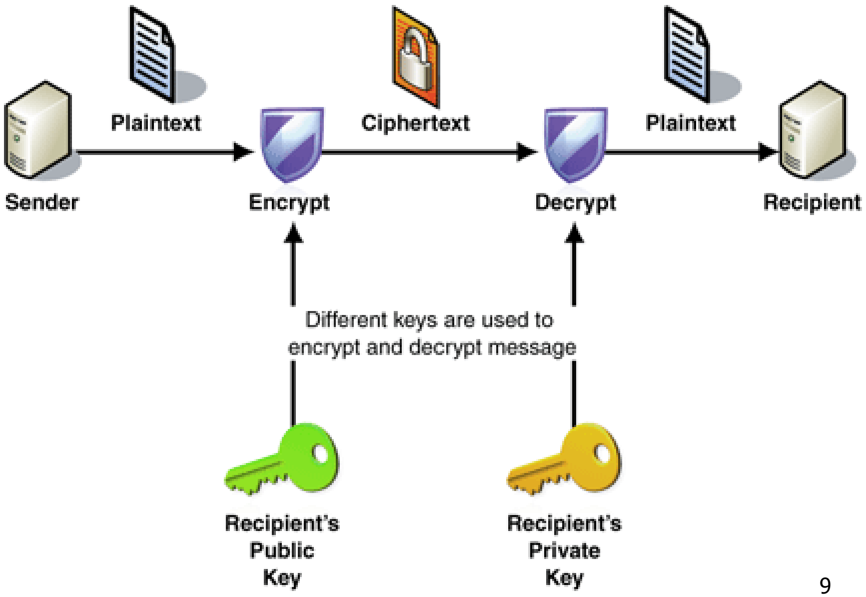
(Also called public-key encryption)

- Sender has:
  - Plaintext **p** (arbitrary size)
  - Recipient's public $\mathbf{k_{pub}}$ (fixed size)
    - Recipient makes this freely available (hence the name "public")
  - Encryption function **E**
  - Decryption function **D**
- Can produce ciphertext **c**:
  - $\mathbf{c = E(p, k_{pub})}$
- Can recover plaintext:
  - Need recipient private key $\mathbf{k_{priv}}$
    - Recipient keeps this hidden at all costs (hence the name "private")
  - $\mathbf{p = D(c, k_{priv})}$
- Also works if you reverse the keys:
  - $\mathbf{D(E(p, k_{priv}), k_{pub}) == p}$



Cryptography basics: Asymmetric encryption

- Public and private keys mathematically related, but one cannot be determined from the other
- Far slower than symmetric encryption
  - Common trick: Use asymmetric to send a secret key, then use symmetric with that key
- Common algorithms: RSA, Diffie-Hellman key exchange
  - If you're developing something with asymmetric encryption and you're using these slides as your reference, **stop**. You're doing it wrong.



Cryptography basics: Hashing

- You're already familiar with hashing (right?)
- Usual hash function properties:
  - Produces fixed size output for variable size input quickly (O(n))
  - Statistically, any output is as likely as any other

  ^ Good enough to make a hash table
- Additional requirements for cryptography:
  - **Irreversibility:** hash reveals absolutely <u>nothing</u> about input content
  - **Avalanche effect:** small input change will completely alter hash
  - **No collisions:** Big enough hash that collision probability is near-zero

  ^ Result: can't determine input from hash except by brute force
- Given message **p** and hash function **H**, get hash value **h**:
  - **h = H(p)**
- Common choices: SHA-1, SHA-2, SHA-3, RIPEMD-160
  - Most lists include MD5, too, but MD5 was slightly broken in 1996 and badly broken in 2005! There's more detail than that, but to keep it simple: Don't use it!

Cryptography basics: Hashing to verify integrity

- Simple integrity check: send message **p** with **h=H(p)**
  - Recipient verifies that $\mathbf{H(p_{received}) = h}$
- Password verification: instead of password **p**, send **h=H(p)**
  - Receiver verifies that $\mathbf{h_{received}=h_{stored}}$
  - Advantage: Server doesn't store actual passwords, only hashes
  - *HEY YOU: never store passwords in plaintext! NEVER!*
    - *Also, when you hash passwords, salt them! (Look it up!)*
- Encryption by itself doesn't verify that the encrypted message isn't tampered with, so let's add hash verification:
  - Given message p, send **c=E(p,k)** and **h=H(p)**
  - Recipient verifies that **H(D(c,k)) = h**
- Can also combine with asymmetric encryption...

Cryptography basics: Electronic signatures

- Integrity verification mixed with asymmetric encryption

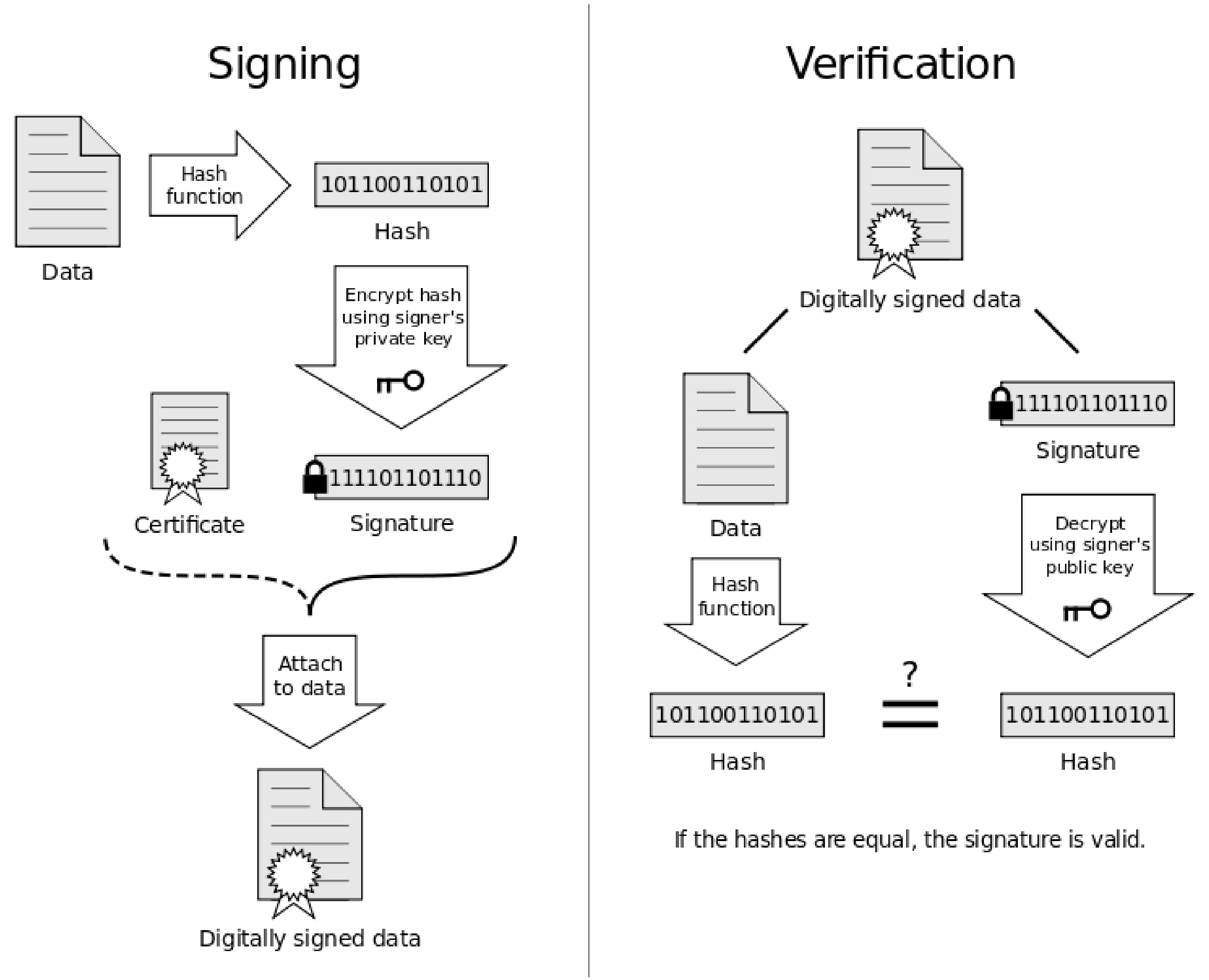
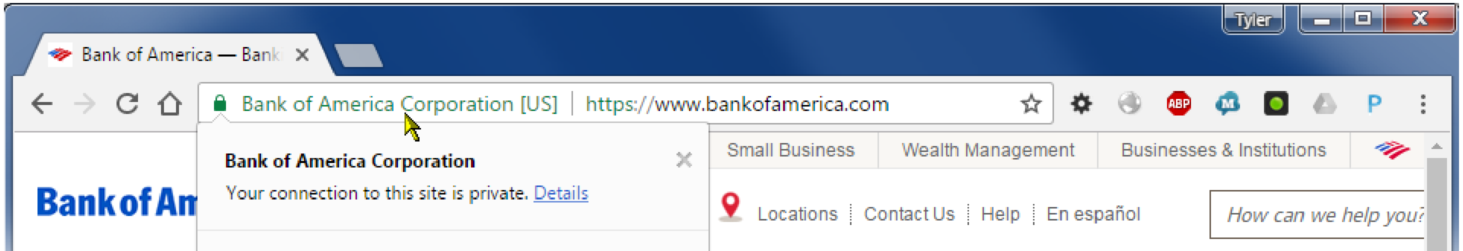


Figure from Wikipedia: Electronic signature

Cryptography basics: Web of trust

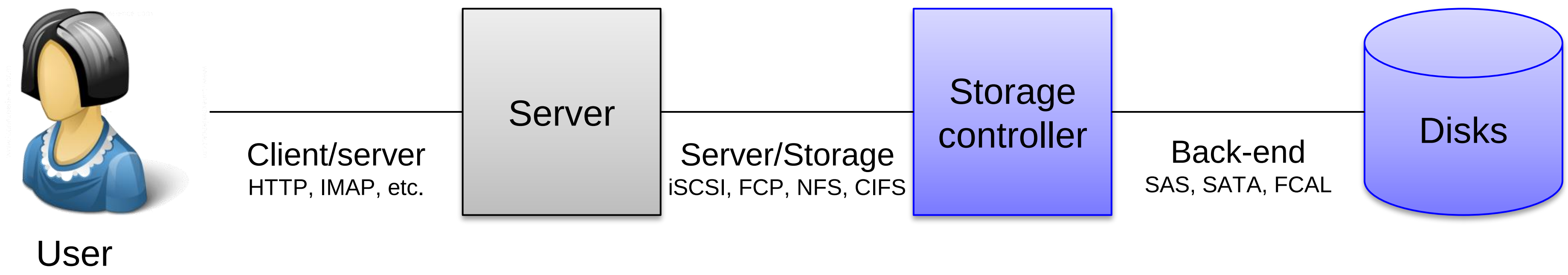
- "Web of trust" is a complex thing, here's the short version
- Using electronic signatures, you can "prove" you are the holder of a given private key
- We assume that a few certain keyholders are "trusted" enough to verify the identity of other keyholders
- The electronic signature that identifies someone in this manner is called a **certificate**.
- Example:
  - I go to Verisign and say (1) I'm Tyler Bletsch and (2) I own tylerbletsch.com.
  - They require documentation to prove this, then they electronically sign a certificate attesting to it.
  - Any browser that connects to tylerbletsch.com will automatically download and verify the certificate.



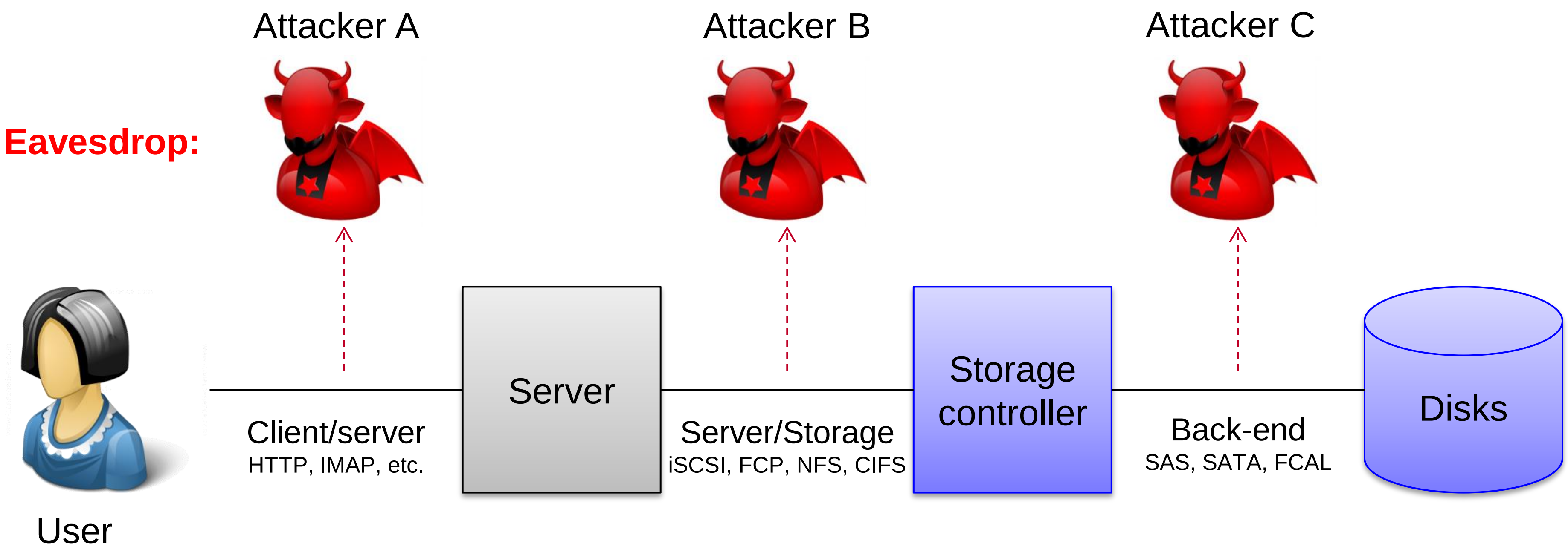
Applying cryptography to storage

Common threat models in storage

- A basic enterprise storage deployment.

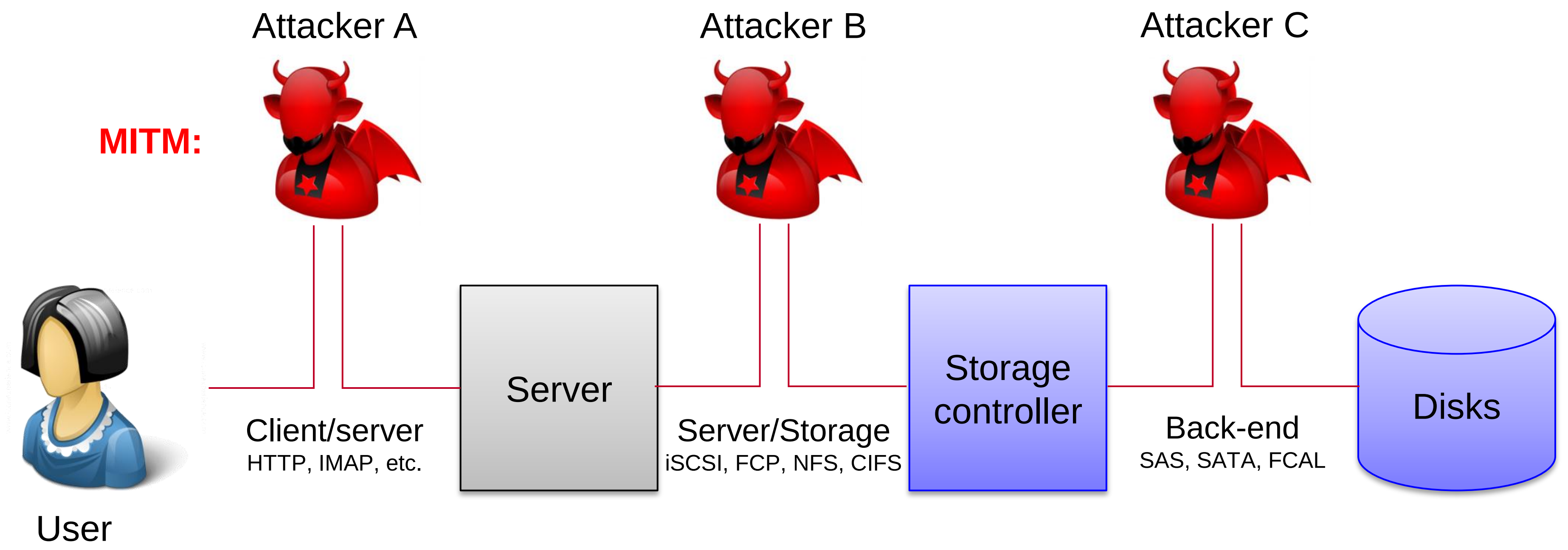


Common threat models in storage: Eavesdropping



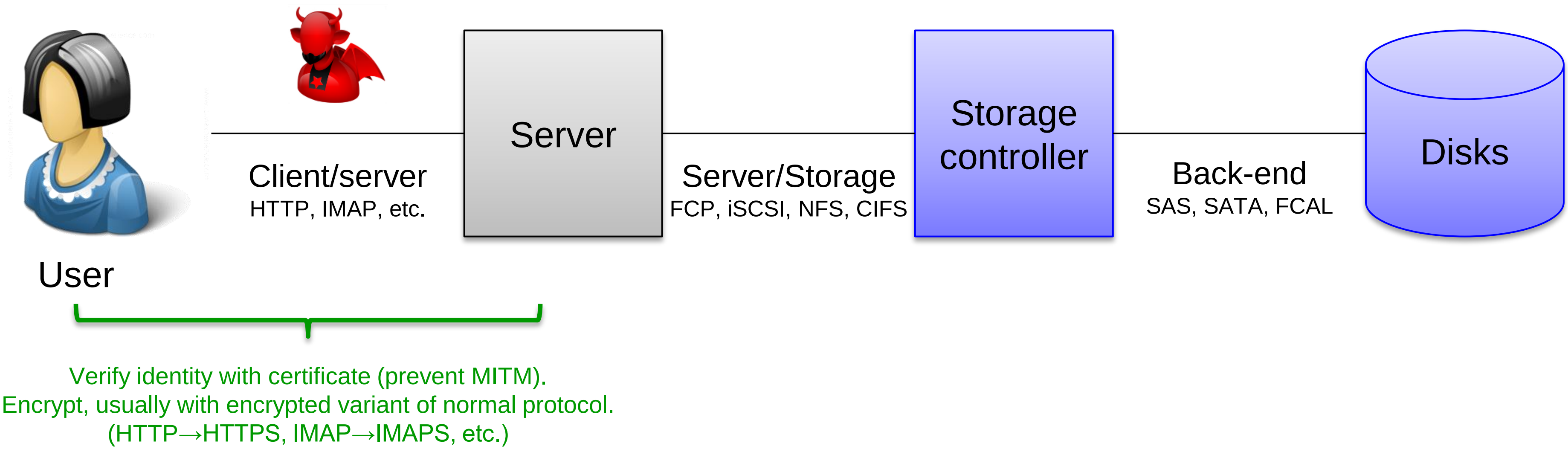
- **Eavesdrop**: attacker has a read-only tap on the wire. E.g.:
  - Physical access
  - Compromised user machine or maybe even server
    (in the case of compromised storage controller, we're dead no matter what, so we omit consideration of this case)
  - Network spoofing or compromised switch; configured to forward traffic

Common threat models in storage: Man-in-the-middle



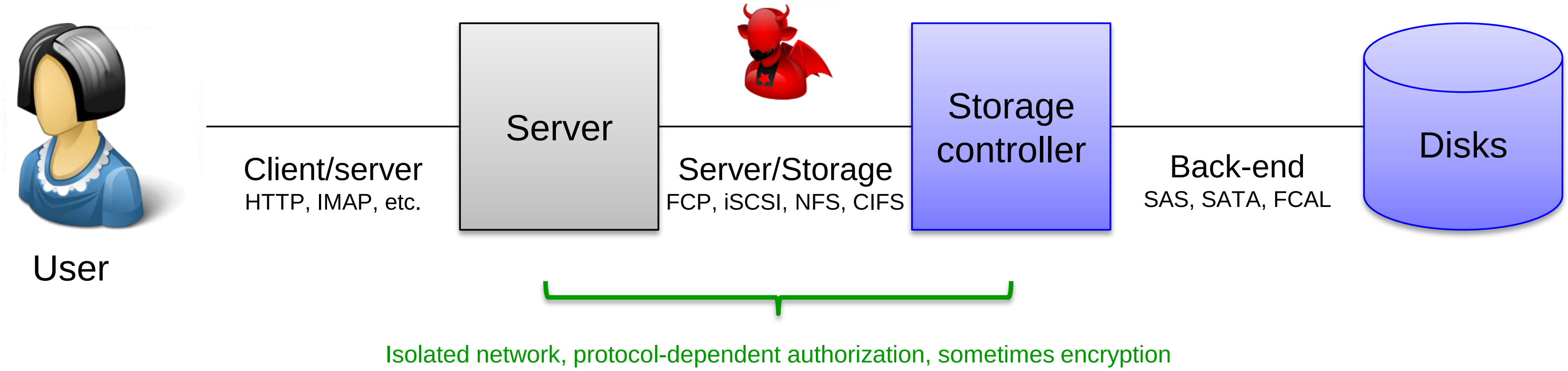
- **Man-in-the-middle**: attacker intercepts, can drop and spoof packets.
  - Similar attacks to gain this access; more visible to detection schemes

Securing the stack: client/server



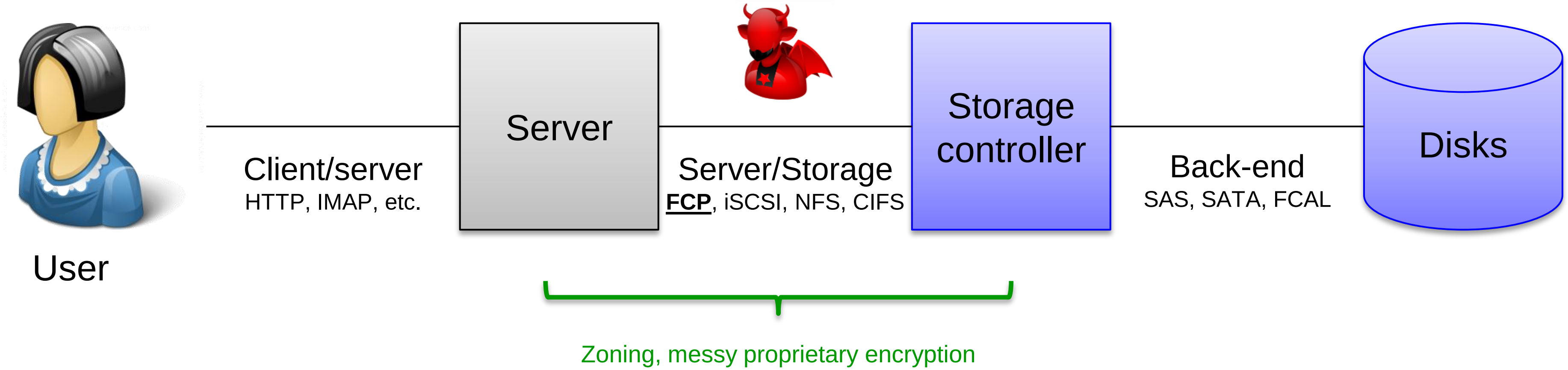
- Client/server security
  - A bit out of scope of this class
  - Basically, it's web-of-trust to verify identity, asymmetric key exchange to get a shared key, then symmetric crypto on the payload

Securing the stack: storage controller



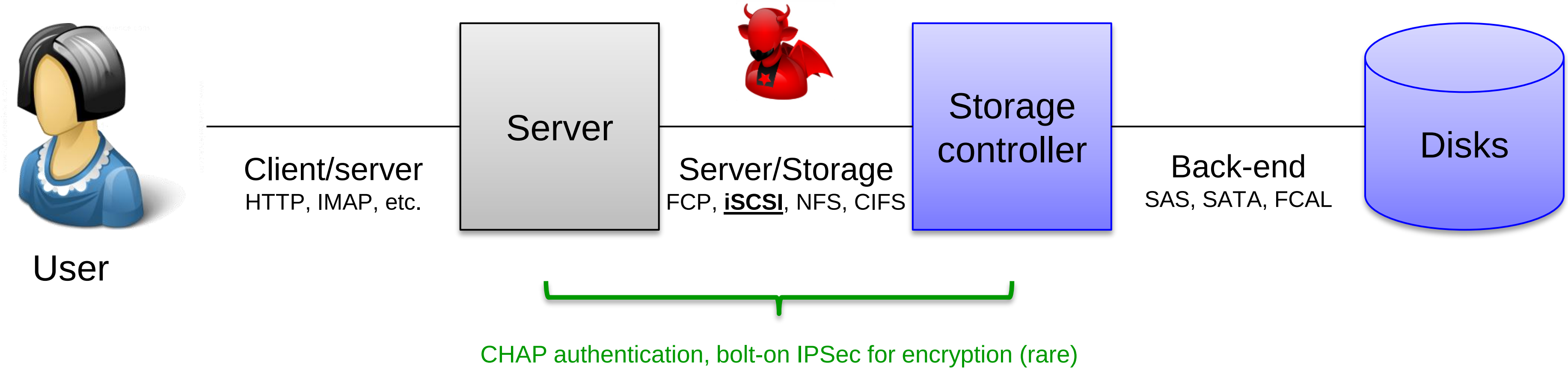
- Storage controller security in general
  - Sadly, it's kind of worse than the client/server link...
  - Primary defense: **isolated network**
    - Physical isolation (separate switches, "air gap") – expensive
    - Virtual isolation (VLANs) – cheaper, but configuration mistakes can break isolation
  - Other defenses are protocol-specific and...not...really.....good........

Securing the stack: storage controller



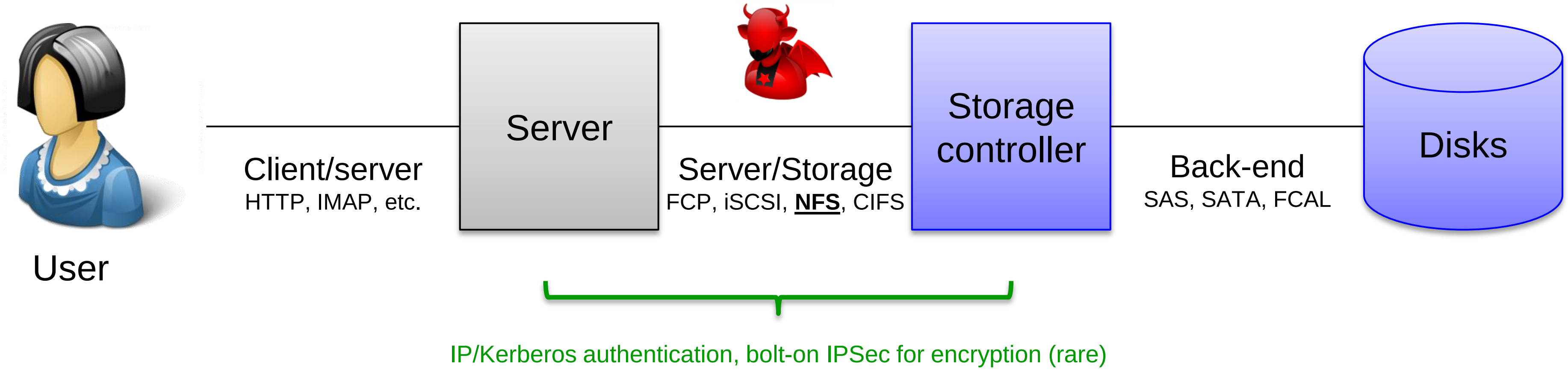
- Storage controller security: FCP
  - Identity verification: **Zoning and world-wide names**
    - Switch limits access based on names (no actual secrets)
    - If switch is secure and configured correctly, okay
    - If not, well, there are no secrets, so no security… (bad)
  - Encryption: **hahahahaha what a mess, good lord**
    - Lots of proprietary bolt-on products that claim FCP encryption
    - All are black-box mystery machines, leave a gap between the box and your controller

Securing the stack: storage controller



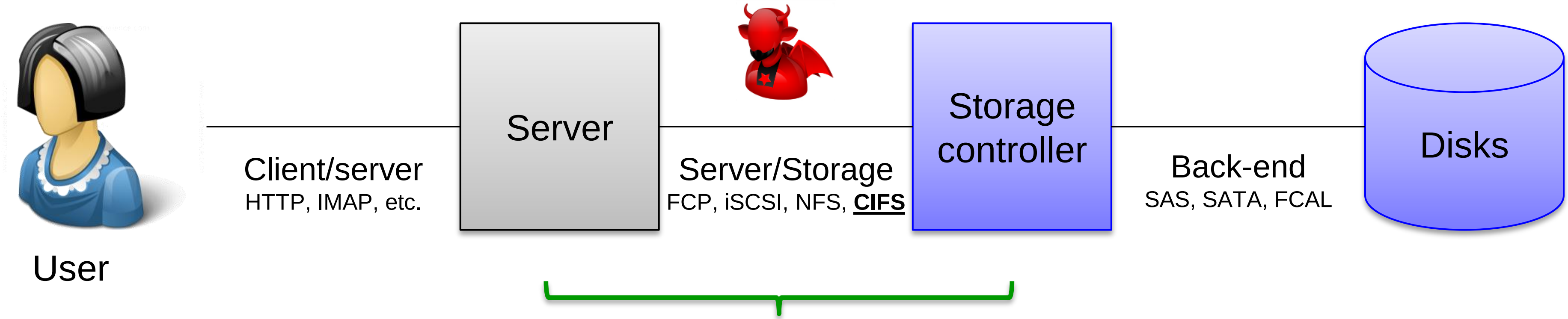
- Storage controller security: iSCSI
  - Identity verification: **CHAP protocol**
    - Basically it's hash-based password checking; fairly weak
  - Encryption (and also enhanced identity verification): **IPSec**
    - IPSec is a generic encryption layer on IP
    - Storage controller may do IPSec directly, or could add a tunnel device
      - (But if you have to add a tunnel, what about network between tunnel and storage controller...)

Securing the stack: storage controller



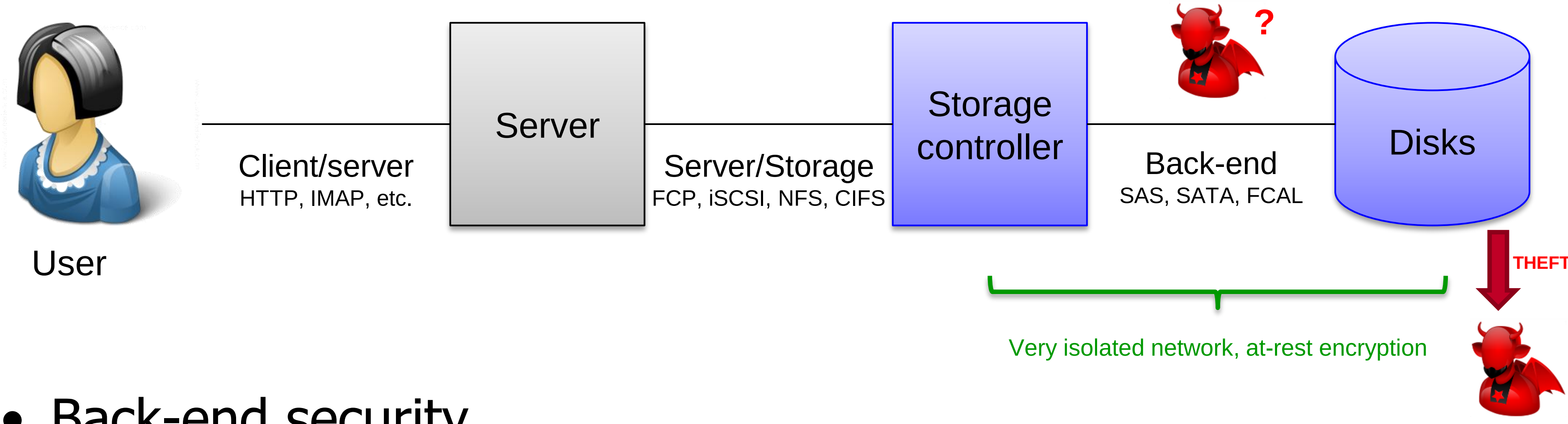
- Storage controller security: NFS
  - Identity verification: **IP-based check** or **Kerberos**
    - IP-based check: garbage
    - Kerberos: server authenticates with central login authority; basically equivalent to hash-based password verification
  - Encryption: **IPSec**
    - No built-in encryption standard (or even cert verification)
    - Instead we use generic IPSec again; similar tradeoffs as with iSCSI

Securing the stack: storage controller



- Storage controller security: <u>CIFS</u>
  - Identity verification: **Windows certificates**
    - Similar certificate system to the client/server side, nice
  - Encryption: **CIFS encryption** (new) or **IPSec**
    - Historically had to do IPSec (similar to iSCSI/NFS)
    - Windows server 2012+ and Windows 8+ can do CIFS-level encryption

Securing the stack: at-rest encryption



- Back-end security
  - Not usually concerned with data "in-flight" from controller to disk
    - If attacker has attached a wire to your SAS bus, game over
  - More common concern: disk theft or inspection
  - **"At-rest" encryption**: controller encrypts on way to physical media
  - Typically symmetric encryption

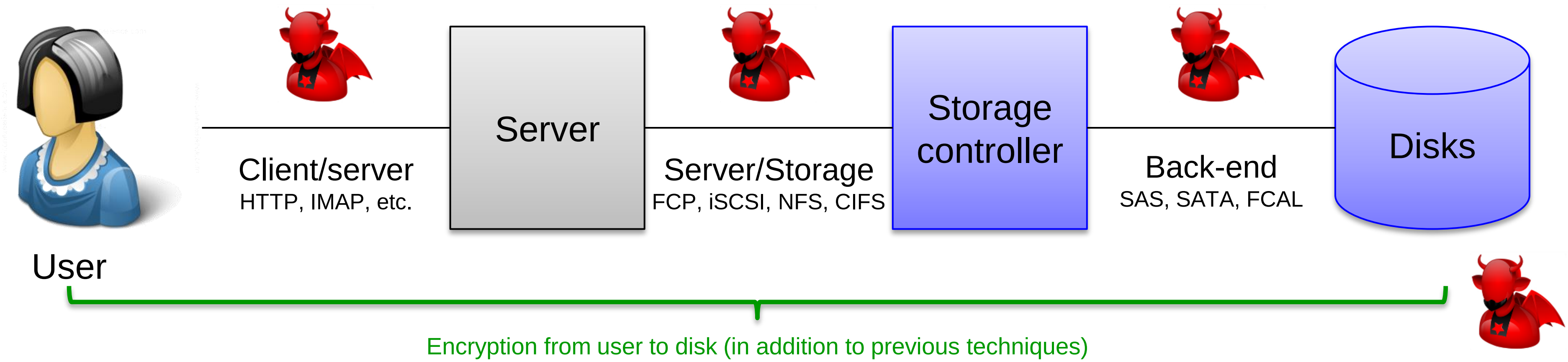
  - Question: Where does the key live???

Key management

- Fundamental problem with at-rest encryption: Where does the key live?
  - In RAM?
    - How did it get there?
    - How do I get it back after an outage?
  - One solution: boot-time key storage (admin must insert cart to provide key, key copied to RAM, admin takes card out and secures it)

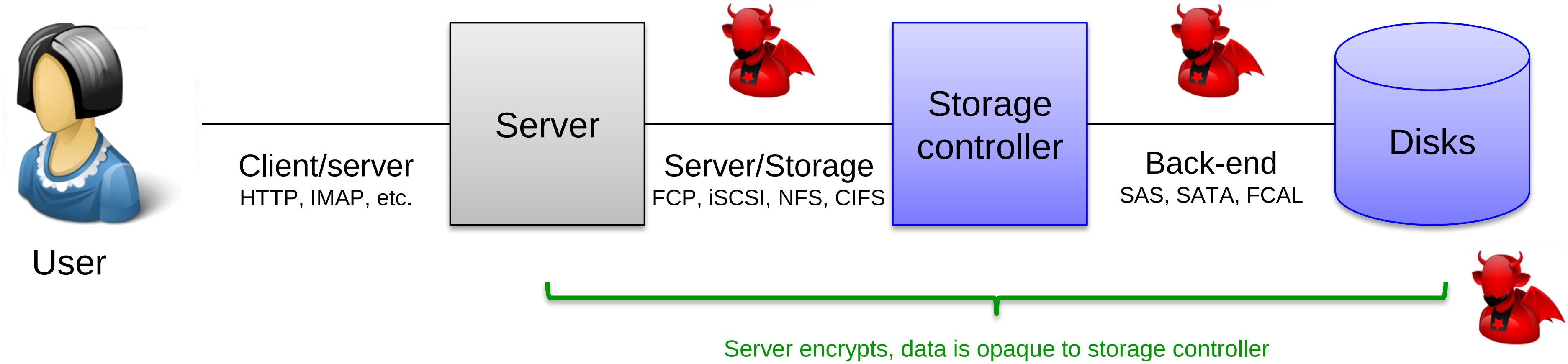
- The “LOL DRM” issue:
  - Systems that store key with encrypted data

Securing the stack: end-to-end encryption



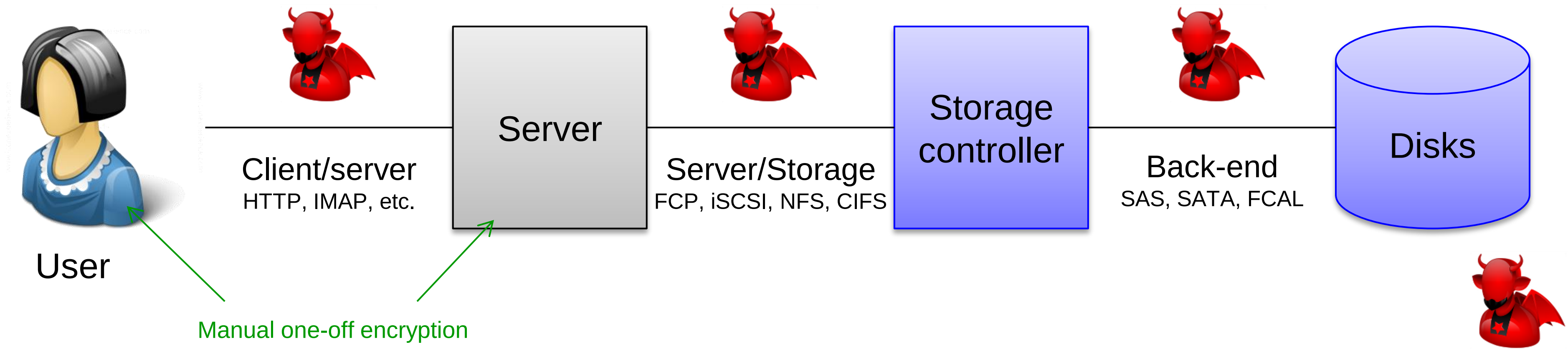
- Special case: end-to-end encryption
  - Client encrypts data in app-specific manner
  - Application on server understands this, doesn't decrypt it (and can't!)
    - Some meta-data is visible
  - Lands on disk with encryption intact
  - Not generalizable – only applicable with app can ignore user content
  - Example: secure email systems, cloud backup

Securing the stack: server encryption



- Special case: server encryption
  - Server runs encryption wrapper over storage controller's NAS/SAN volume
  - Encrypted data is opaque to storage controller
    - Simple to implement
    - Negates storage efficiency features

Securing the stack: "one-off" encryption



- Special case: manual file encryption
  - Can use a simple app to encrypt one or more files
  - Encrypted files are otherwise stored normally
  - With automation, a cheap "bolt on" solution

Encryption side-effects

- Encrypted content cannot be compressed or deduplicated
  - Storage efficiency features have to be applied first

- What about metadata?
  - Filenames, sizes, dates can be valuable information
  - If you're encrypting SAN traffic, you encrypt metadata for free
  - If NAS, though...how to organize file system of encrypted metadata?
    - Would have to add key semantics to file IO, break things, etc.
    - Applying file system encryption above block device is not common

- Encryption makes backup harder
  - Backup the plaintext? Security failure.
  - Backup the ciphertext? Need to back up the key, too...

Access control

Includes content from Computer Security: Principles and Practices by William Stallings and Lawrie Brown (the slate blue slides)

Access control topics

- Core concepts
- Access control policies:
  - Discretionary Access Control (DAC)
    - UNIX file system
    - Access Control Lists (ACLs)
  - Mandatory Access Control (MAC)
  - Role-based Access Control (RBAC)
  - Attribute-based Access Control (ABAC)

Subjects, Objects, Actions, and Rights

Subject (initiator)

- The thing making the request (e.g. the user)

Verb (request)

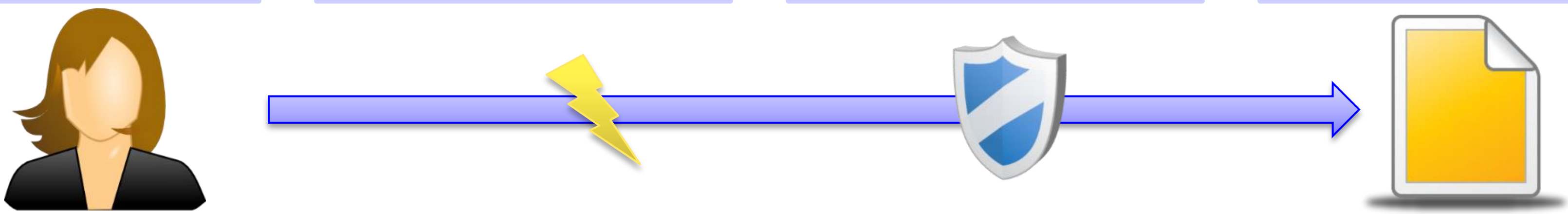
- The operation to perform (e.g., read, delete, etc.)

Right (permission)

- A specific ability for the subject to do the action to the object.

Object (target)

- The thing that's being hit by the request (e.g., a file).



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Access Control (AC) Policies

- **Discretionary AC (DAC)**: There's a list of permissions attached to the subject or object (or possibly a giant heap of global rules).
- **Mandatory AC (MAC)**: Objects have classifications, subjects have clearances, subjects cannot give additional permissions.
  - An overused/abused term
- **Role-based AC (RBAC)**: Subjects belong to roles, and roles have all the permissions.
  - The current Enterprise IT buzzword meaning "good" security
- **Attribute-based AC (ABAC)**: Subjects and objects have attributes, rules engine applies predicates to these to determine access
  - Allows fine-grained expression
  - Usually complex, seldom implemented

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DAC model

```
bool IsActionAllowed(subject, object, action) {
  if (action ∈ get_permissions(subject,object))
    return true
}
```

- Can use various data structures, none of which should surprise you

Matrix

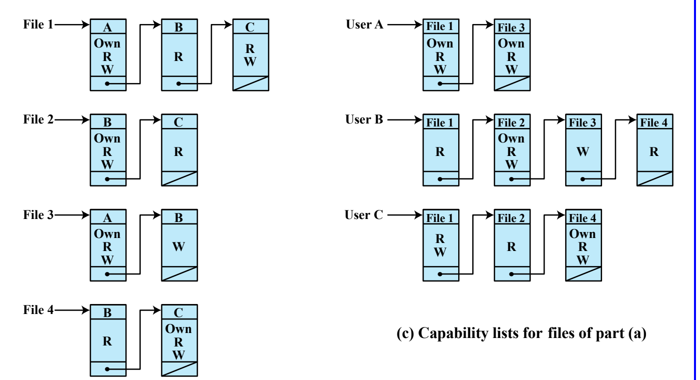
		OBJECTS			
		File 1	File 2	File 3	File 4
SUBJECTS	User A	Own Read Write		Own Read Write	
	User B	Read	Own Read Write	Write	Read
	User C	Read Write	Read		Own Read Write

(a) Access matrix

Flat list

Subject	Access Mode	Object
A	Own	File 1
A	Read	File 1
A	Write	File 1
A	Own	File 3
A	Read	File 3
A	Write	File 3
B	Read	File 1
B	Own	File 2
B	Read	File 2
B	Write	File 2
B	Write	File 3
B	Read	File 4
C	Read	File 1
C	Write	File 1
C	Read	File 2
C	Own	File 4
C	Read	File 4
C	Write	File 4

Linked list



(b) Access control lists for files of part (a)

(c) Capability lists for files of part (a)

Figure 4.2 Example of Access Control Structures

UNIX File Access Control

UNIX files are administered using inodes (index nodes)

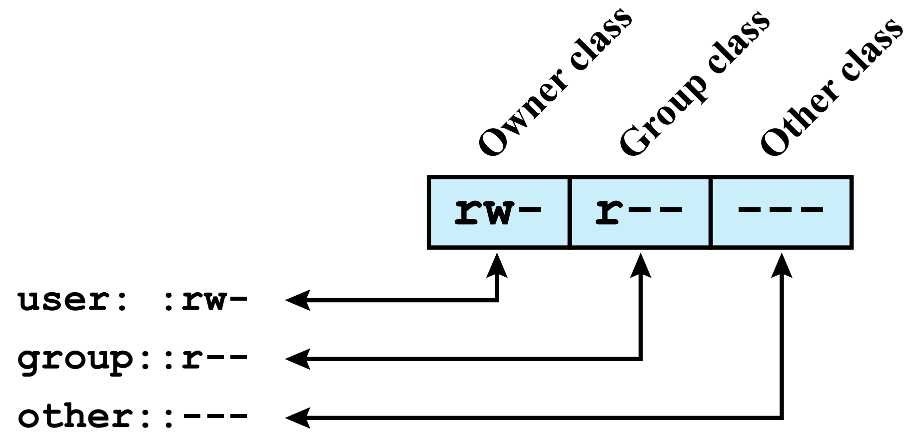
- Control structures with key information needed for a particular file
- Several file names may be associated with a single inode
- An active inode is associated with exactly one file
- File attributes, permissions and control information are sorted in the inode
- On the disk there is an inode table, or inode list, that contains the inodes of all the files in the file system
- When a file is opened its inode is brought into main memory and stored in a memory resident inode table

Directories are structured in a hierarchical tree

- May contain files and/or other directories
- Contains file names plus pointers to associated inodes

UNIX
File Access Control

- Unique user identification number (user ID)
- Member of a primary group identified by a group ID
- Belongs to a specific group
- 12 protection bits
  - Specify read, write, and execute permission for the owner of the file, members of the group and all other users
- The owner ID, group ID, and protection bits are part of the file's inode



(a) Traditional UNIX approach (minimal access control list)

Relevant UNIX commands

`chmod`: Change these bits
`chown`: Change owner
`chgrp`: Change group

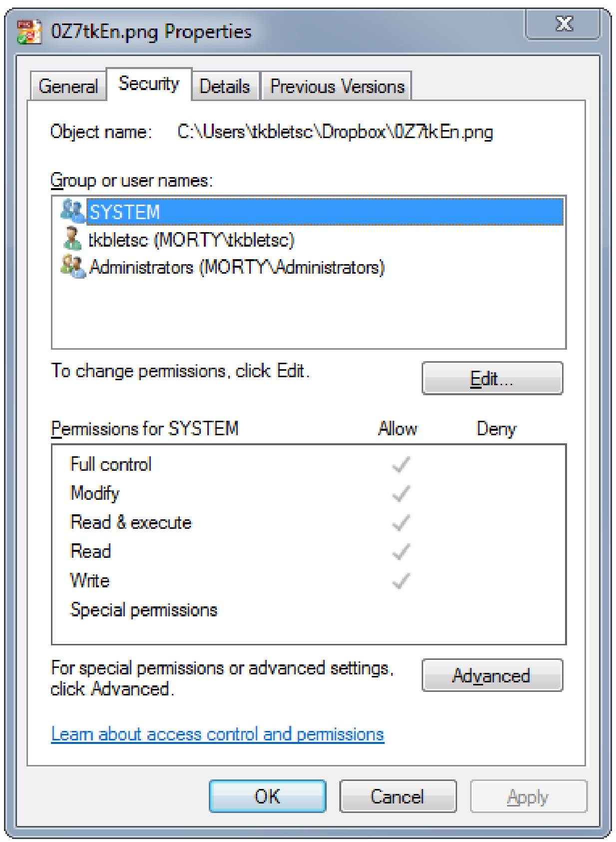
Traditional UNIX File Access Control

- "Set user ID"(SetUID)
- "Set group ID"(SetGID)
  - System temporarily uses rights of the file owner/group in addition to the real user's rights when making access control decisions
  - Enables privileged programs to access files/resources not generally accessible
- Sticky bit
  - When applied to a directory it specifies that only the owner of any file in the directory can rename, move, or delete that file
- Superuser
  - Is exempt from usual access control restrictions
  - Has system-wide access

File system access control lists (ACLs)

- Arbitrary list of rules governing access per-file/directory
- More flexible than classic UNIX permissions, but more metadata to store/check

Windows ACL UI



Examples of Linux ACL commands

Set all permissions for user johny to file named "abc":

```
# setfacl -m "u:johny:rwx" abc
```

Check permissions

```
# getfacl abc

# file: abc
# owner: someone
# group: someone
user::rw-
user:johny:rwx
group::r--
mask::rwx
other::r--
```

Change permissions for user johny:

```
# setfacl -m "u:johny:r-x" abc
```

Check permissions

```
# getfacl abc

# file: abc
# owner: someone
# group: someone
user::rw-
user:johny:r-x
group::r--
mask::r-x
other::r--
```

Remove all extended ACL entries:

```
# setfacl -b abc
```

From Arch Wiki

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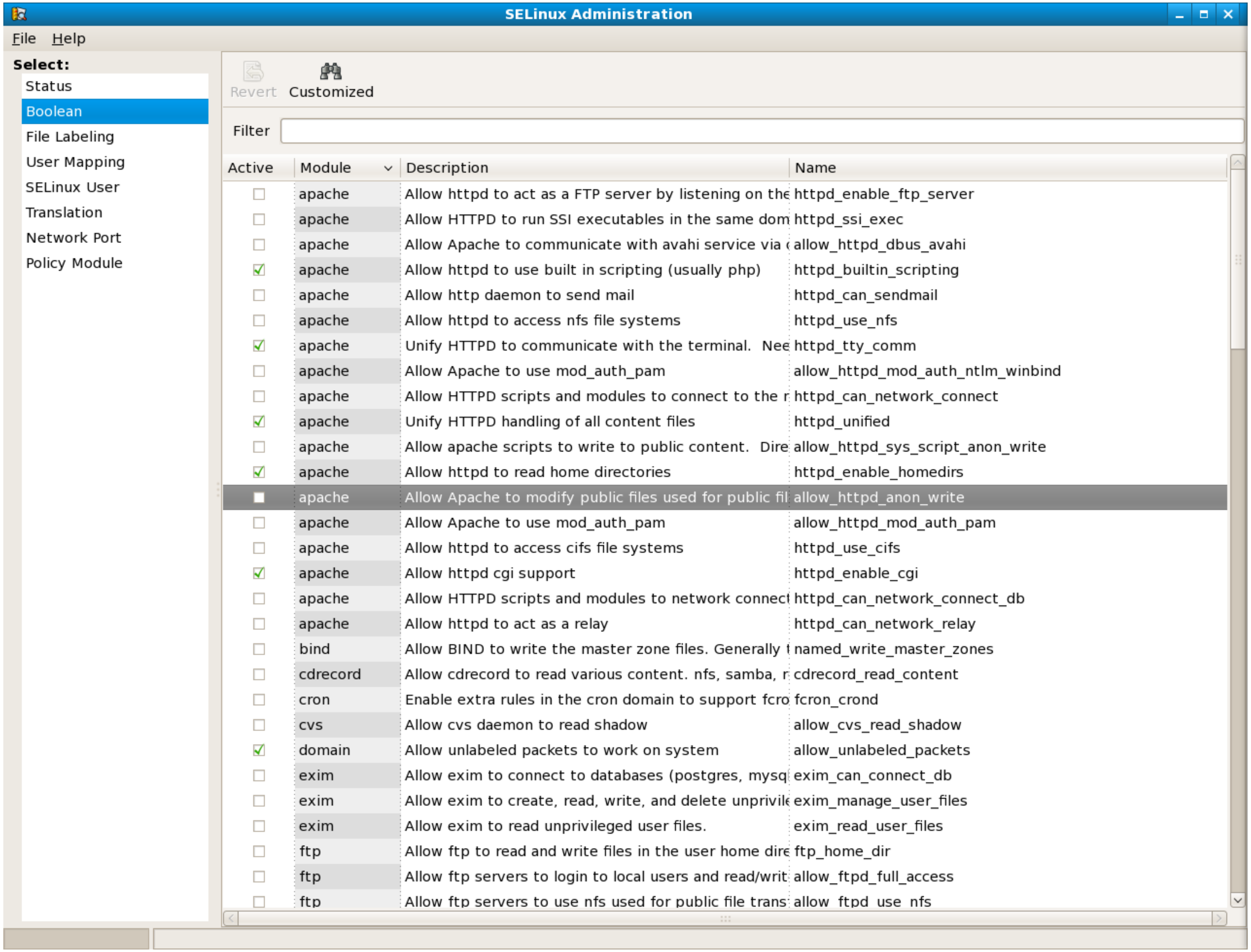
MAC model

```
bool IsActionAllowed(subject, object, action) {
  for each rule in rules:
    if rule allows (subject,object,action) return true
  return false
}
```

MAC example: SELinux

- Developed by U.S. Dept of Defense
- General deployment starting 2003
- Can apply rules to virtually every user/process/hardware pair
- Rules are governed by system administrator only
  - No such thing as “selinux_chmod” for users

MAC example: SELinux



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RBAC: The thing you invent if you spend enough time doing access control

- Scenario:
  - Frank: "Bob just got hired, please given him access."
  - Admin: "What permissions does he need?"
  - Frank : "Same as me."

  - Later, a new system is added
  - Bob: "Why can't I access the new system?!"
  - Admin: "Oh, I didn't know you needed it too…"
  - Bob: "I need everything Frank has!"

  - Later, Frank is promoted to CTO
  - Admin: "Welp, looks like Bob also needs access to our private earnings, since this post-it says he gets everything Frank has…"
  - The admin is later fired amidst allegations of conspiracy to commit insider trading with Bob. He dies in prison. ☹

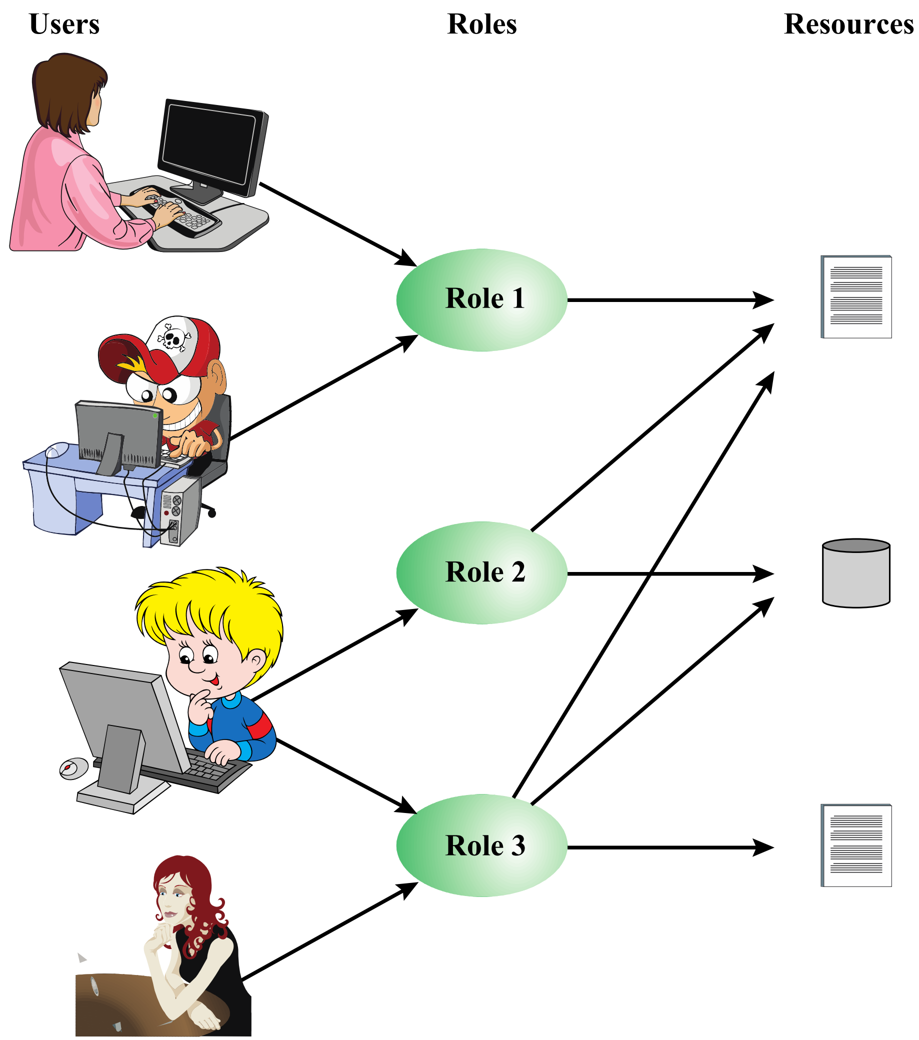

Figure 4.6 Users, Roles, and Resources

RBAC

- Decide what KINDS of users you have (**roles**)
- Assign **permission** to **roles**.
- Assign **users** to **roles**.

- When a role changes, everyone gets the change.
- When a user’s role changes, that user gets a whole new set of permissions.
- No more special unique snowflakes.

- Roles may be partially ordered, e.g. “Production developer” inherits from “Developer” and adds access to the production servers

```
bool IsActionAllowed(subject, object, action) {
  if (action ∈ get_permissions(subject.role,object))
    return true
}
```

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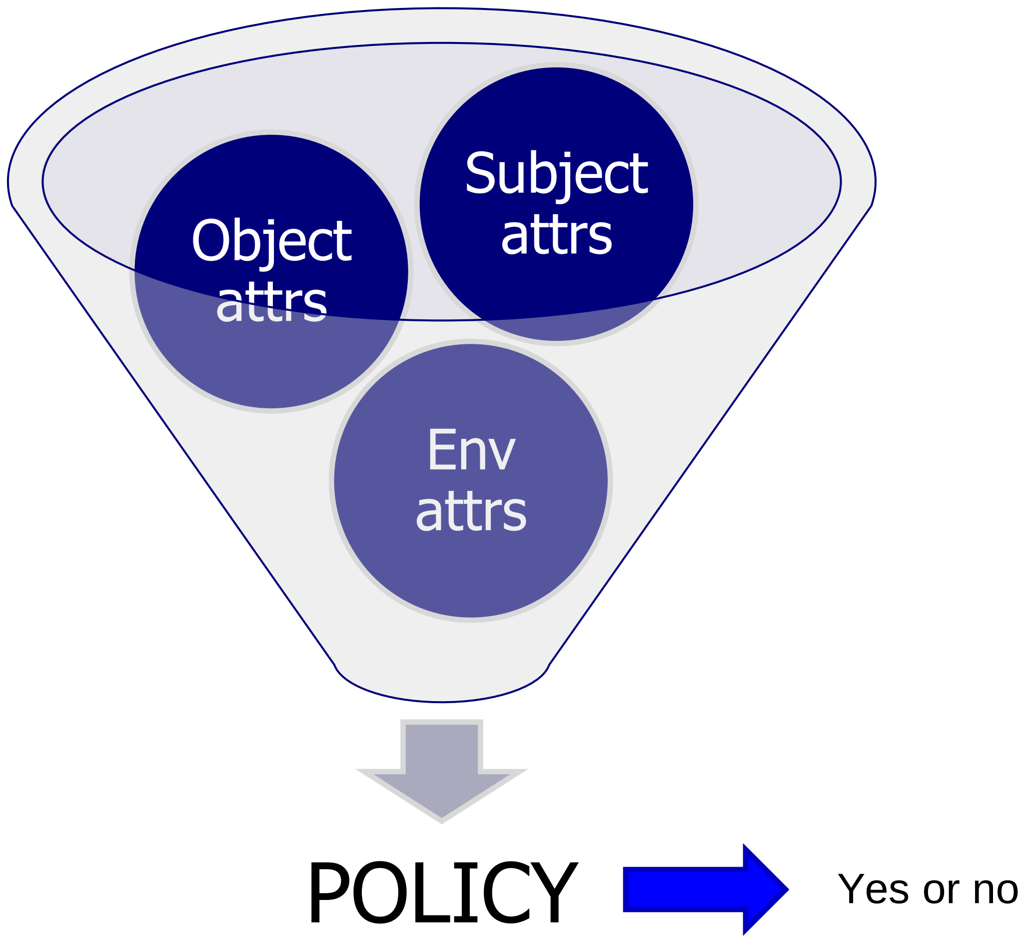
    - Access Control Lists (ACLs)
  - Mandatory Access Control (MAC)
  - Role-based Access Control (RBAC)
  - Attribute-based Access Control (ABAC)

ABAC in a nutshell



ABAC model

```
bool IsActionAllowed(subject, object, action) {
  for each rule in rules {
    The rule is basically code that examines all attributes of subject and object as well as the global environment; the rule is highly expressive, and so could basically do anything.  If it says yes, return true
  }
  return false
}
```

Secure deletion

Secure deletion

- Must destroy data when we need to (e.g. decommissioning a storage system)
- Destroying is easy, right?
  - When you spend all this effort preventing data loss, intentionally losing data can get surprisingly hard.
- Things preventing data destruction:
  - **'Delete' doesn't destroy**: it just updates metadata and marks blocks freed
  - **Journaling**: we keep scraps of written data separate from the actual data blocks; these aren't affected by simple deletion
  - **Failed drives**: If the drive dies enough to replace, we may not be able to tell the drive to overwrite data, but it's still there...
  - **Hardware redundancy**: SSDs redirect blocks internally for wear leveling; disks redirect blocks for bad sector compensation
  - **Snapshots**: their whole purpose was to recover from accidental deletion
  - **Backups**: We've replicated this data across the country...

How to overcome: technical/procedural

- **Block-level IO**: Overwrite raw disk below file system level
  - Traditional: "`dd if=/dev/zero of=/dev/sda`"
    (basically that means "`cat /dev/zero > /dev/sda`")
  - Gets around file system, snapshots, journaling.
- **Procedural**: Documented, automated processes for snapshot deletion, destruction of backups, etc.
- **"Crypto-shredding"**: Do at-rest encryption all along. Then, to destroy data, simply lose the key.

How to overcome: physical

- **Destroy!!!!!!**