System Structure
Designing a System

- We have lots of tools
- Tools are rarely interesting by themselves
- Let’s design a system...
Some of Our Tools

- Encryption
- Authentication mechanisms
- Access control mechanisms
- Confinement mechanisms
- Lots of computers—hardware is relatively cheap
What Should We Build?

- Let’s build a large e-commerce site
- Lots of machines
- Lots of processes
What Are the Pieces?

- Web server itself
- A *replicated* web server, for load-sharing and reliability
- Databases
- Firewalls (well, we haven’t covered those)
More Pieces

- Customer care
- Mail servers
- Links to suppliers, banks, shipping companies, etc.
- NOC
- System administrators
- Webmasters
- Development machines
Even More Pieces

- Developer access
- Tier N customer care—often your top developers
- Backup servers
- Geographically diverse machines?
- Environmental control systems – air conditioning, power, backup generators
- Console servers
- Personnel machines (stay tuned)
- DNS servers
- KDC and/or CA
- Probably a lot more
How Do We Connect These?

- First—which pieces go on separate machines?
- Does that even matter?
- Yes…
A Real-World Example

- I looked at the internal documentation for a billing system
- Four different databases
- 18 other processing elements
- Transaction and web inputs; external link to credit card processor
The Web Server Complex

ISP

Router

Inverse Proxy/Load Balancer

Router

Inverse Proxy/Load Balancer

Router

ISP

Web Server

Web Server

Web Server

Database

Database

Database

Database

To Back Ends
Why So Complex?

- Availability—primarily against ordinary failures
- *Everything* is replicated: routers, links, Ethernets, servers, etc.
- The only security feature of the redundancy is some protection against DDoS attacks if your two routers connect to different ISPs
Other Security Functionality

- The inverse proxies are effectively firewalls – they only pass ports 80 and 443
- The database servers are not accessible from the outside—you have to hack through a web server to get any access at all
What are the Danger Points?

- How are these devices *managed*?
- How does the NOC talk to the routers? How is software upgraded on the Web servers?
- *Something* is missing
- The link to the back-end systems—how is that protected?
Managing the Network Elements

• Some NOC machine has to be able to talk to the network elements
• The top ("north") routers and the inverse proxies are exposed to the public Internet
• Must use strong cryptographic authentication
• Add network access control to limit sites that can talk to them
• What about the middle routers?
• Does the inverse proxy permit access to them? That’s a slight weakening of the firewall functionality
• Are they reached from the north LANs? Does that weaken the protection of the database servers?
**How Many NOCs?**

- The NOC really needs to see all network elements
- To talk to the south and middle routers, it has to be on the inside
- To talk to the north routers, it has to be able to reach the outside
- Some problems are most easily diagnosed if you have the ability to connect to all of the elements
- Conclusion: we need a special firewall for the NOC machines
What are Our Goals?

• The usual trilogy: confidentiality, integrity, availability

• Ah—but what resources need what type of security?

• What are the consequences of failures?
If the Web Server is Hacked...

- Embarrassment—see, for example, [http://www.zone-h.org/archive](http://www.zone-h.org/archive)
- Passwords from active users
- Access to the database machines?
- Passwords for your userbase are stored in a database
How to Protect Web Servers?

- Use strategies already discussed
- Major advantage—these are dedicated machines, with no ordinary users
- Can we use separate UIDs?
Separate UIDs on the Web Server

- In general, it’s a good idea
- Principle of least privilege—protect different functions from each other
- Example: login CGI script runs as a different user than the browsing CGIs, to protect the user password database
- Often harder than it seems—functions interact a lot
Should We Chroot the Web Server?

- What do we protect if we do that?
- The rest of the system? Maybe—but there’s nothing else on the system
- It doesn’t hurt, but it isn’t that big a help
- This machine is a web server appliance
The Database Machines

- These are the crown jewels of the company
- If the database is tampered with, very bad things can happen, including loss of lots of money
- How are the database machines attacked?
  - Hacking attack—first the web server falls, then the database machine
  - Database queries and changes—the web servers have access to the database; therefore, the hackers on that machine do, too
  - SQL injection attacks through the web server
Databases for a Simple Configuration

- User information: login, password, credit card numbers, shipping and billing addresses, etc.
- Orders: active orders, past orders, etc.
- Inventory: stock on hand, prices, etc.
Hacking Attacks

- This is nothing special—it’s just another machine to lock down
- The database machine runs very different software than the web server does; probably no common mode failures
- Not a major threat—but don’t forget to lock it down
Database Query Attacks

• The web server can perform lots of database operations
• How do we stop the hacker from doing them?
• Answer: have the customer log in to the database!
• That is, all customer-type operations must be accompanied by a customer-specific authenticator
• A compromised web server machine can only modify database records for active users
More Generally

- Let’s adjust the control and information flow
- Only let the web server write what it has to
- Thus: the user database creates the order, not the web server
- Why? Because the web server is much more exposed and hence vulnerable
What About the Inventory Database?

- When a customer buys something, the inventory needs to be adjusted.
- That isn’t customer-specific—how do we secure that database?
- Use a separate database—and database machine—for orders; the order database can adjust the inventory.
- Put sanity-checking and customer limit enforcement into that machine, too.
- (This is an oversimplification; the shipping database also needs to adjust the inventory in may situations.)
Information Flow Among the Databases

Arrows show direction of information flow
Protecting Information

- The databases will only reveal certain information to certain other machines
- Example: credit card numbers are not readable by the web server or even the order server.
- The web server can tell the user information machine to send a debit message to the bank
What About a Small Site?

- Divide the functions up the same way
- Use chroot() and equivalent to isolate the different components
- We are using chroot() here as a weaker version of separate machines
The Biggest Weakness?
That Link to the Back End

• The link in the southeast to back-end systems is the most dangerous part of the diagram
• What is the protection from the rest of the company?
• What essential functions are there?
Two Major Classes

- Normal operations
- Unusual circumstances
Normal Operations

- Customer care
- Outside links
- Mail servers
- These go on a LAN with reasonable access to the server complex—customer care, for example, has to be able to read and write several databases
Protecting Us from Customer Care

- What do we do about a rogue customer care agent?
- Prevent access to some kinds of information (i.e., credit card numbers)
- Log everything; audit periodically
- Route all requests through a logging proxy
- “This call may be monitored for quality assurance purposes”
Isolating Customer Care

- Customer care is often outsourced or done from home
- How do you protect home computers?
- Supply agents with locked-down laptops
- Use a VPN and firewall that go *only* to the customer care proxy/logging machine
- Be ready to ship replacement machines in case of trouble
Outsourced Functions

- Many other functions might be outsourced
- If there are interconnections, you can be attacked that way
- According to press reports, Target was hacked via their HVAC contractor
- Isolate the networks
- Use enclaves with proxies and logging
Enclaves

- Master Database
- Log File
- Proxy

VPN to Partner
Unusual Circumstances

- Maintenance
- Problem recovery
- Out-of-hours emergencies
- Put a gateway between these functions and the server complex
Maintenance

- On a production system, maintenance is a scheduled activity.
- This means that access controls can be relaxed during that window only.
- Be careful about relaxing the controls only to the extent necessary.
Problem Recovery

- Problem don’t occur on a nice, neat schedule
- Often, development staff has to do the repairs
- How do we mediate access?
Remote Access

• Often, development staff has to do the repairs at night, from home

• Sometimes, the development staff is in another country

• We can’t institute a “physical access only” rule; it’s not realistic
Two Types of Access

- VPN access to the site
- (This may be normal anyway.)
- (Does your answer change if you use an off-site hosting company?)
- Authenticated access to the server complex
Forms of Authentication

• What types of authentication should be used?
• Differs by function
• The NOC can’t use anything that requires access to external servers; they have to talk when the network isn’t working well
• Customer care agents can use more or less anything to log in to their machines—but their machines would have credentials to permit database access
• Scheduled maintenance can use anything, but something secure should be used to relax access controls
• Emergency maintenance personnel need cryptographic keys for the VPN, and something secure—a token?—to get to the server complex. Note, of course, that the server complex may be experiencing connectivity problems...
Revoking Access

- What do you do when an employee leaves?
- This is especially serious for employees with special access rights
- Solution: link the HR database to authentication servers
- Have some other way, driven by the HR database, to revoke access to other resources
- Caution: this means giving the HR machine a lot of access
General Principles

- There’s no one solution; a lot depends on context and budget
- Strive for separation of function
- Reserve your strongest controls for the most valuable pieces
- Log everything (but we talked about that already…)

The Final
The Final

- Wednesday, December 23, 1:10-4:00
- Open book
- Open notes
- No computers
- Same style as the midterm
- *Cumulative*, but a stress on the second half; some questions may span both halves
- Nominally 170 minutes, but I’m going to aim for significantly less