CMPSC 447
Privilege Separation

Trent Jaeger
Systems and Internet Infrastructure Security (SIIS) Lab
Computer Science and Engineering Department
Pennsylvania State University

Our Goal

- In this course, we want to develop techniques to prevent vulnerabilities from being created
  - Prevent flaws
  - Prevent access or exploitation of flaws
    - Privilege separation prevents access and exploitation, but moving sensitive data to another address space

OpenSSH

- Secure remote login software
- Client and server architecture

- Client and server establish secure channel using private key stored on server
- Enabling client to login using password without fear of password sniffing

OpenSSH

- Is security-critical software
  - Runs as root – needs to be able to login users
  - Stores and uses a private key that if lost could enable machine spoofing
  - Has access to user passwords that may apply to any machine in the domain
  - Launches user processes under the authenticated user ID, which requires root privilege
- That is OK, OpenSSH is written in C, so I am sure there are no problems

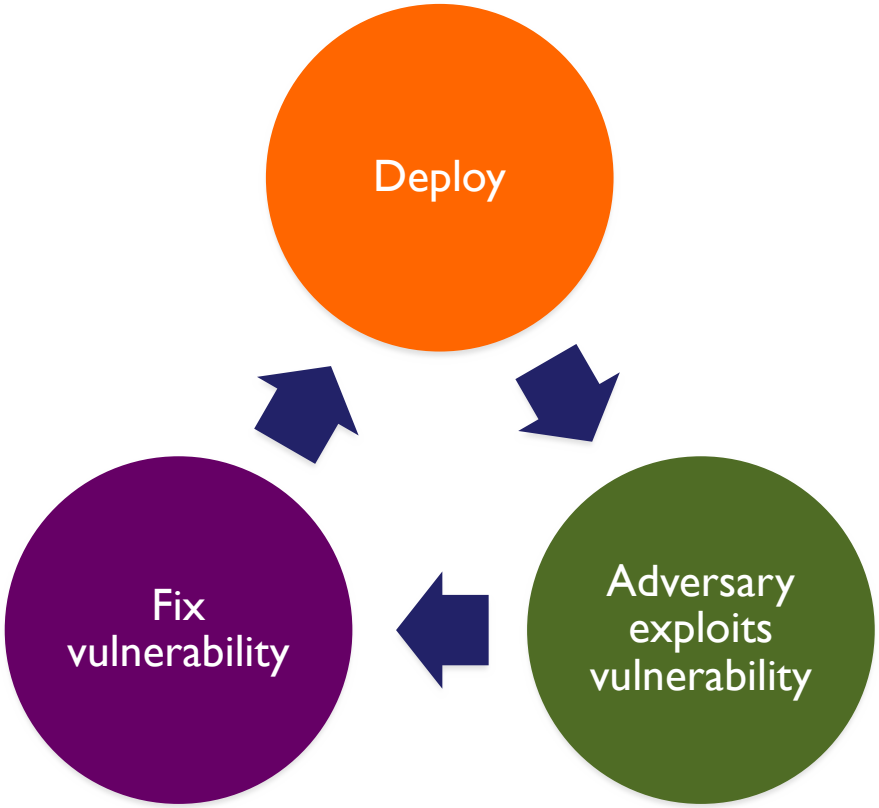
OpenSSH

- Is secure-critical software
  - Runs as root – needs to be login users
  - Stores and uses a private key that if lost could enable machine spoofing
  - Has access to user passwords that may apply to any machine in the domain
  - Launches user processes under the authenticated user ID, which requires root privilege
- That is OK, OpenSSH is written in C, so I am sure there are no problems
  - That was a joke…

OpenSSH Vulnerabilities

- Circa 2002
  - CVE-2000-0525 – does not properly drop privileges, allowing local users to execute arbitrary commands
  - CVE-2001-0872 – does not properly cleanse critical environment variables, allowing local users to gain root
  - CVE-2001-1029 – does not drop privileges before reading the copyright files, allows local users to read arbitrary files
  - CVE-2002-0059 – releases certain memory more than once ("double free"), allowing remote attackers to execute arbitrary code
  - CVE-2002-0083 – Off-by-one error allows remote malicious servers to gain privileges.

Retroactive Security



- "Penetrate and patch" as flaws are exposed as vulnerabilities

OpenSSH

PENNSTATE 1855

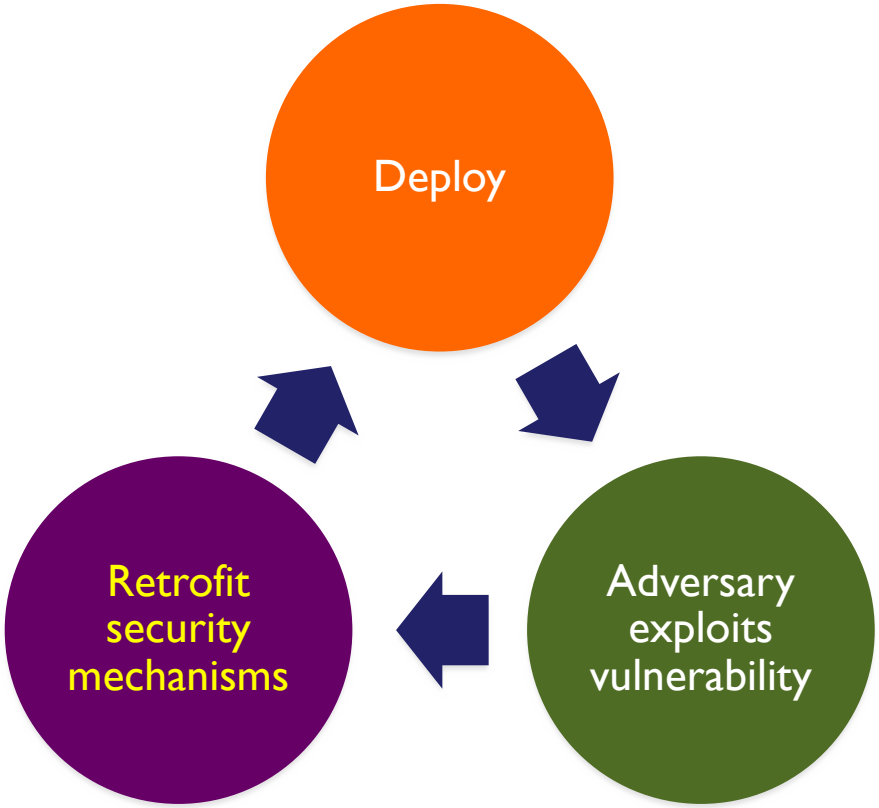
- After patching enough of these and other vulnerabilities, what is the impact on?
  - Preventing privilege escalation (to root)
  - Protecting program secrets

OpenSSH

PENNSTATE 1855

- After patching enough of these and other vulnerabilities, what is the impact on?
  - Preventing privilege escalation (to root)
  - Protecting program secrets
- Not sure whether there are other latent flaws that can be exploited (vulnerabilities)?
- Can we make some change to the design to make such flaws much more difficult to access or exploit?

Retrofit Security Mechanisms



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

Privilege Separation

PENNSTATE 1855

- Isolate parts of a program into separate protection domains each with
  - Access to a subset of the program data
  - Different system privileges (access rights)
- Goals
  - Small amount of code with sensitive data and privileges
  - Rest of code can run with basic (low) data and privileges
- What parts of code need access to sensitive data and privileges in OpenSSH?

Privilege Separation

- What parts of code need access to sensitive data and privileges in OpenSSH?
  - Code that needs access to root privileges
    - to change UID of child process (integrity)
  - Code that needs access to critical secrets
    - For setting up secure channels and password authentication (secrecy)

Privilege Separation

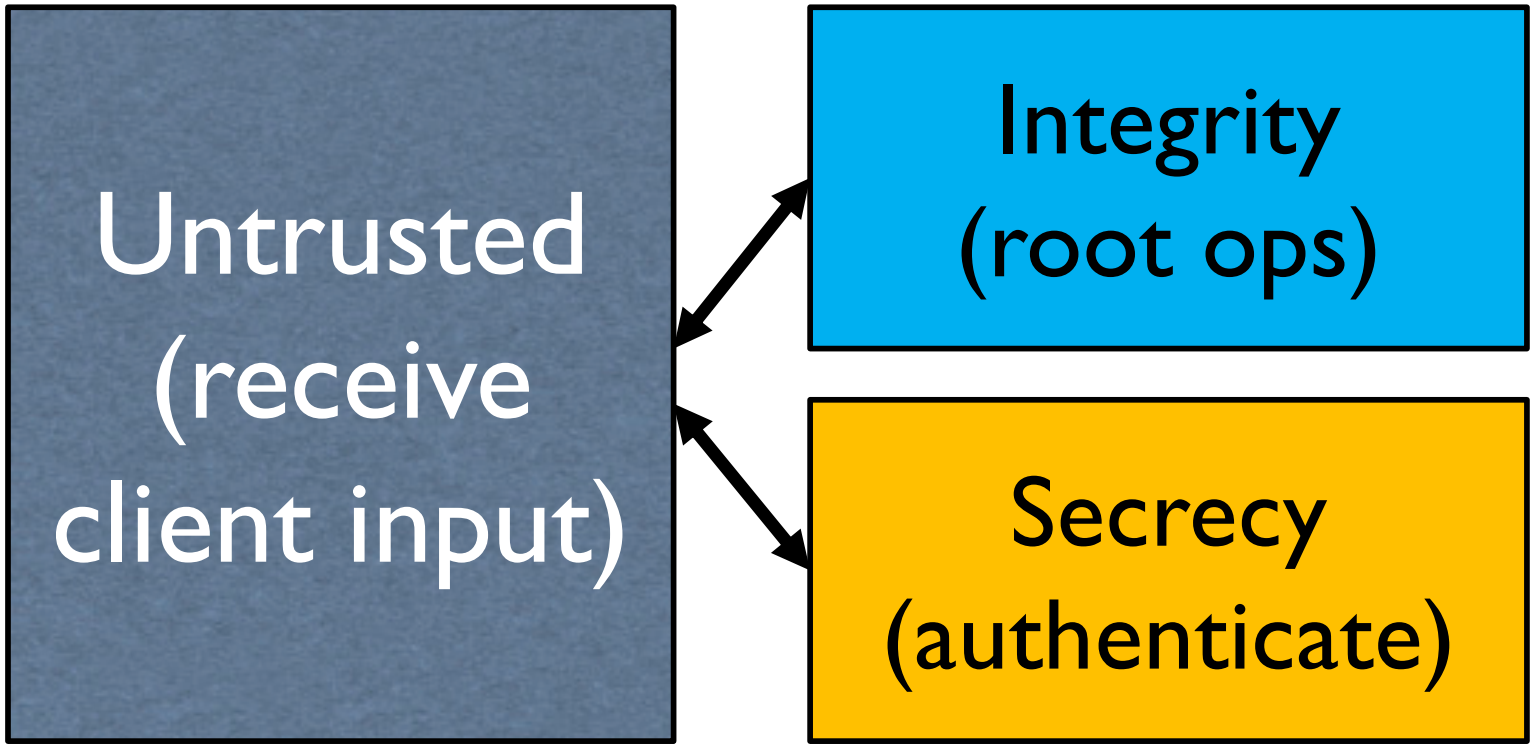
- How do we take a monolithic program and create one or more privilege-separated components?

Privilege Separation

- How do we take a monolithic program and create one or more privilege-separated components?
  - Need to identify privileged data in your program
  - Integrity
    - Must not be impacted by adversary inputs
    - E.g., Data used in operations that require 'root' privileges
  - Secrecy
    - Must never be leaked to adversaries
    - SSH private keys
- Then, you need to determine code (functions) that operate on such data

Privilege Separation

- How do we take a monolithic program and create one or more privilege separated components?



Information Flow

PENNSTATE 1855

- One security property for evaluating programs is information flow
- Use information flow to control
  - Secrecy
  - Integrity

Information Flow Secrecy

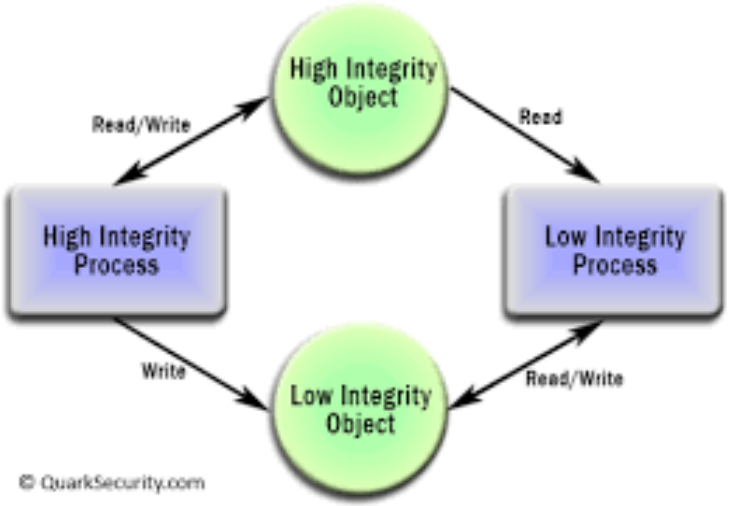
- One security property for evaluating programs is information flow
- Information Flow Secrecy
  - Subjects – Subject Level L_S
  - Objects – Object Level L_O
  - $L_S \geq L_O$ for Subject to read an object
  - $L_S \leq L_O$ for Subject to write an object

Information Flow Secrecy

- One security property for evaluating programs is information flow
- Information Flow Secrecy
  - Subjects – Subject Level L_S
  - Objects – Object Level L_O
  - $L_S \geq L_O$ for Subject to read an object
  - $L_S \leq L_O$ for Subject to write an object

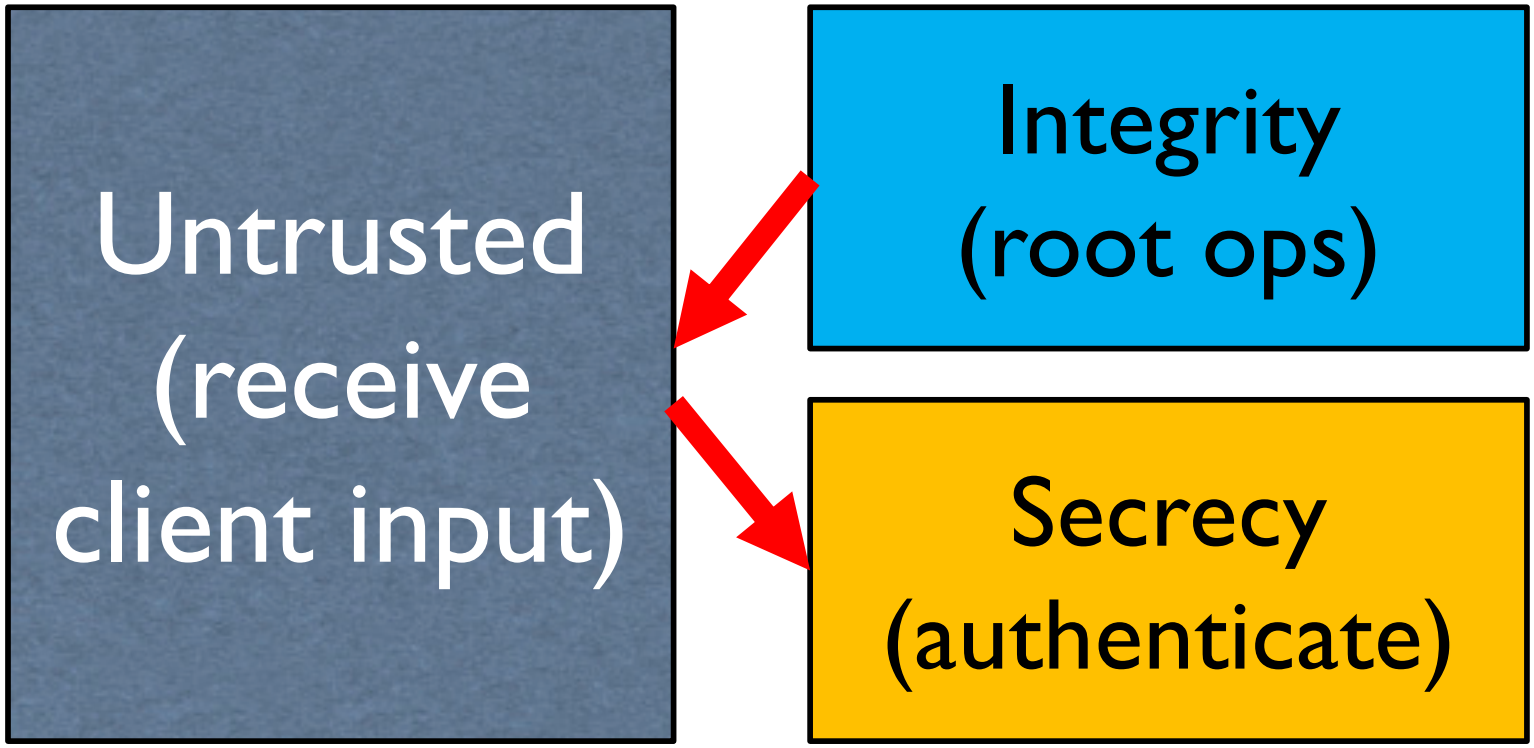
Information Flow Integrity

- One security property for evaluating programs is information flow
- Information Flow Integrity
  - Subjects – Subject Level I_S
  - Objects – Object Level I_O
  - $I_S \leq I_O$ for Subject to read an object
  - $I_S \geq I_O$ for Subject to write an object



Privilege Separation

- How do we take a monolithic program and create one or more privilege separated components?



OpenSSH Privilege Separation

PENNSTATE 1855

- What parts of code need access to sensitive data and privileges in OpenSSH?
  - Code that needs access to root privileges
    - to change UID of child process (integrity)
  - Code that needs access to critical secrets
    - For setting up secure channels and password authentication (secrecy)
- How would you privilege separate these functionalities from the rest of OpenSSH?

OpenSSH Privilege Separation

- How OpenSSH looks after privilege separation

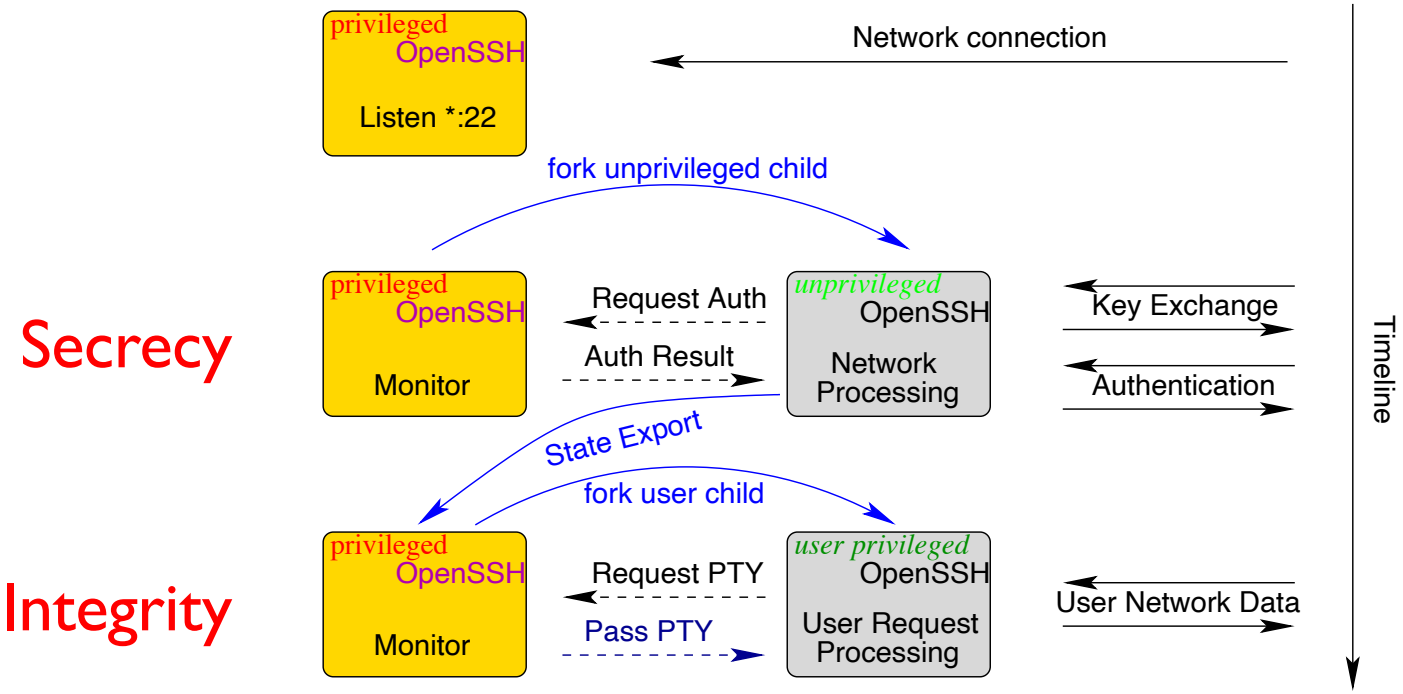


Figure 4: Overview of privilege separation in OpenSSH. An unprivileged slave processes all network communication. It must ask the monitor to perform any operation that requires privileges.

Separation Issues

- Information Flow Issues
  - Secrecy
    - Secret component must return authentication result
    - Filter secrets from the response (declassify)
  - Integrity
    - High integrity component must receive input
    - Validate integrity of untrusted inputs (endorsement)
  - Both
    - In many cases the secret data is also high integrity
    - What then?

Separation Issues

- Information Flow Issues
  - Secrecy
    - Secret component must return authentication result
    - Filter secrets from the response (declassify)
  - Integrity
    - High integrity component must receive input
    - Validate integrity of untrusted inputs (endorsement)
  - Both
    - In many cases the secret data is also high integrity
    - What then? Both declassification and endorsement

Declassification and Endorsement

- Declassification
  - Remove as much impact from the secret as possible
  - Example: Password checking
  - What is the minimal impact of password value of checking result?
- Endorsement
  - Remove influence of untrusted input as much as possible
  - Example: Untrusted request
  - What is the minimal influence of an untrusted input on request processing?

Implementing Privilege Separation

PENNSTATE 1855

- Getting privilege separation to work correctly is non-trivial
  - Need to turn a function call
  - Into a remote procedure call
- One challenge
  - Data in caller and callee are no longer in the same protection domains
  - Example: `int check(char *passwd)`
  - Normally, pass as a pointer to a memory location "passwd"
  - Now, need to copy memory from caller to callee

Implementing Privilege Separation

- Complex task for programmers
- Simplify by specifying as a remote procedure call (RPC)
  - RPC in terms of interface description language (IDL)
    - Marshalling (on caller) and unmarshalling (on callee) input arguments
    - Reverse on return
  - Performance impact
    - What if there are many RPCs to the privilege separated domain?

Implementing Privilege Separation

PENNSTATE 1855

- Some Issues
- Synchronization cost
  - Suppose the original function call passes a reference to a large structure
    - `int fn(struct t1 *t);`
  - But, only uses one field – do we need to copy it all?
- Multithreading
  - What if the two domains (caller and callee) have concurrent access to the same data?

Privilege Separation

- Complex task for programmers
  - We would like to automate this task (next time)

Privilege Separation In Use

- Browsers

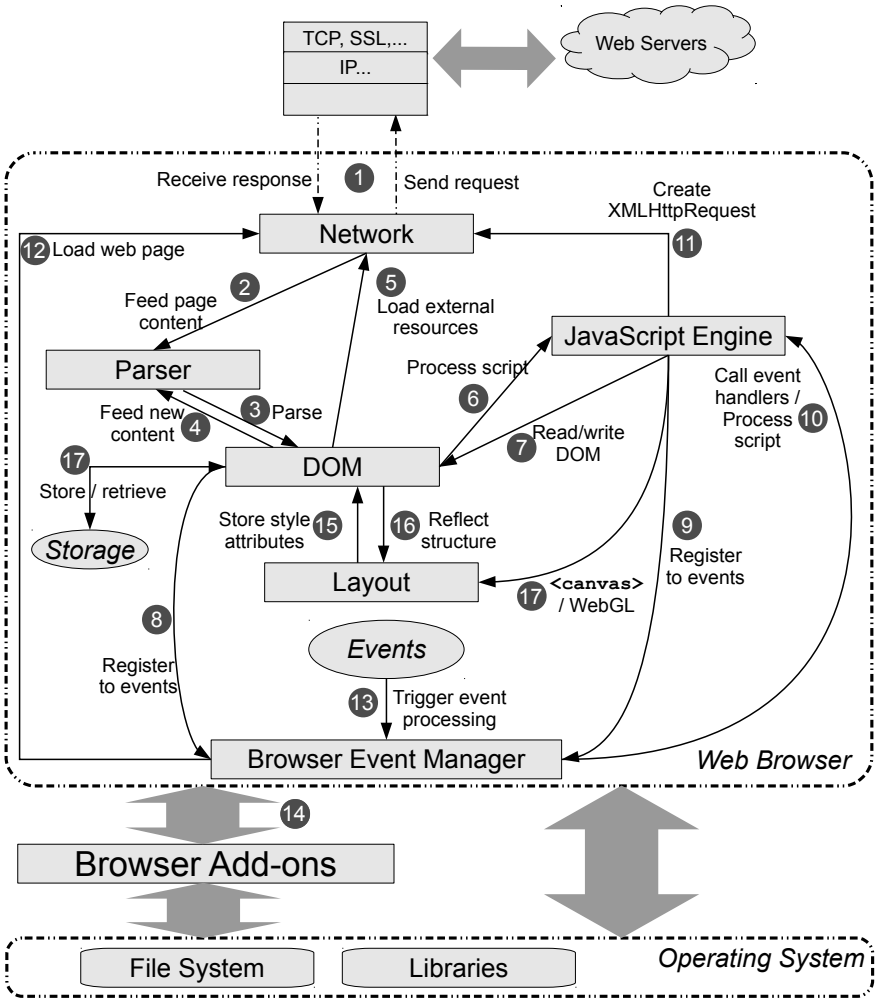


Fig. 1. Browser Blueprint. *It shows typical interactions between browser components in processing a web page.*

Some Browser Goals

PENNSTATE 1855

- Isolate web page processing from network processing
- Isolate browser components that need filesystem access from those that do not
- Isolate the processing of one web page from another
- Isolate the execution of browser processing from the JavaScript engine
- Isolate the execution of browser processing from browser extensions

Browser Separation

- Firefox has 20+ components

Comp#	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
LOC	136	367	74	155	32	3	131	21	77	366	10	269	763	17	223	24	137	478	24	188	53

Table 2. Kilo-lines of Source Code in Firefox Components. *In our experiments, we consider the following components: 0. NETWORK, 1. JS, 2. PARSER, 3. DOM, 4. BROWSER, 5. CHROME, 6. DB, 7. DOCSHELL, 8. EDITOR, 9. LAYOUT, 10. MEMORY, 11. MODULES, 12. SECURITY, 13. STORAGE, 14. TOOLKIT, 15. URILOADER, 16. WIDGET, 17. GFX, 18. SPELLCHECKER, 19. NSPR, 20. XPCONNECT, and 21. OTHERS.*

- That "security" is the largest is not entirely a good sign
- Browsers are as complex as operating systems

Take Away

- Programs may have lots of ad hoc bugs that prevent it from running securely
  - However, there are certain security goals we may want to achieve
    - Focusing on the goals may make the program easier to protect through security mechanisms targeted for those goals
  - One such security mechanism
    - Privilege separation: Isolate code with extra privileges or sensitive resources from rest of the program – call via small API