Browser Internals

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https://programmerhumor.io/programming-memes/the-best-browser-at/

Background: Overall Outline

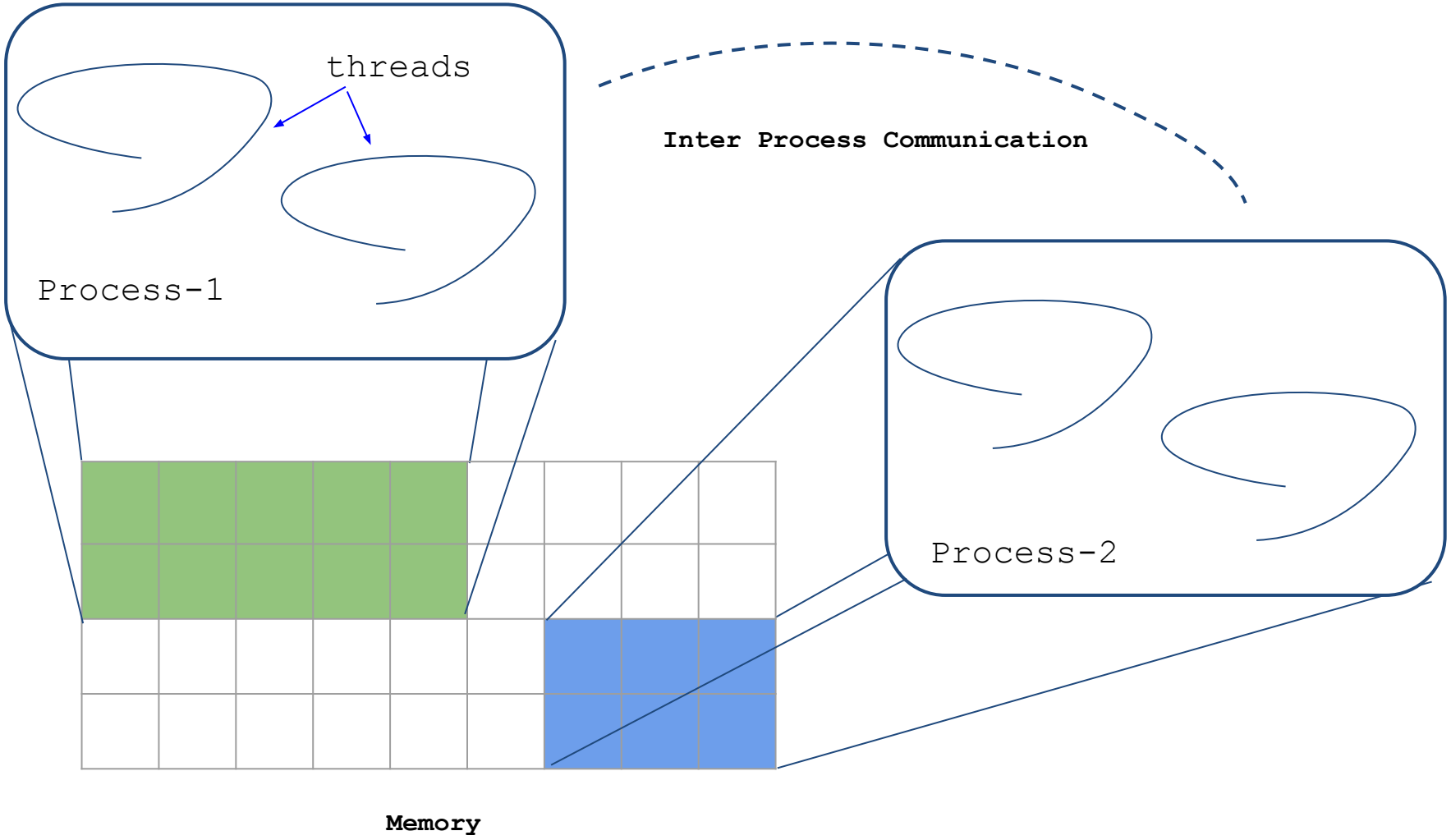
- ~~What constitutes a webpage?~~
- **What goes on inside a Browser?**
  - **What standard security mechanisms implemented?**
- How do client and server communicate?
  - HTTP/HTTPs protocol
  - Session Management via cookies and tokens
- How does a web server process requests and generate responses?
  - Static vs Dynamic content

Browser

- A software application that helps users to “browse” the Web
  - Provide a rich user interface
    - address bar, navigation buttons, bookmarks etc
  - Support extensions or add-ons to enhance functionality
- Popular web browsers: Google Chrome, Mozilla Firefox, Microsoft Edge, Safari, and Opera
- Lot happens inside the Browser!

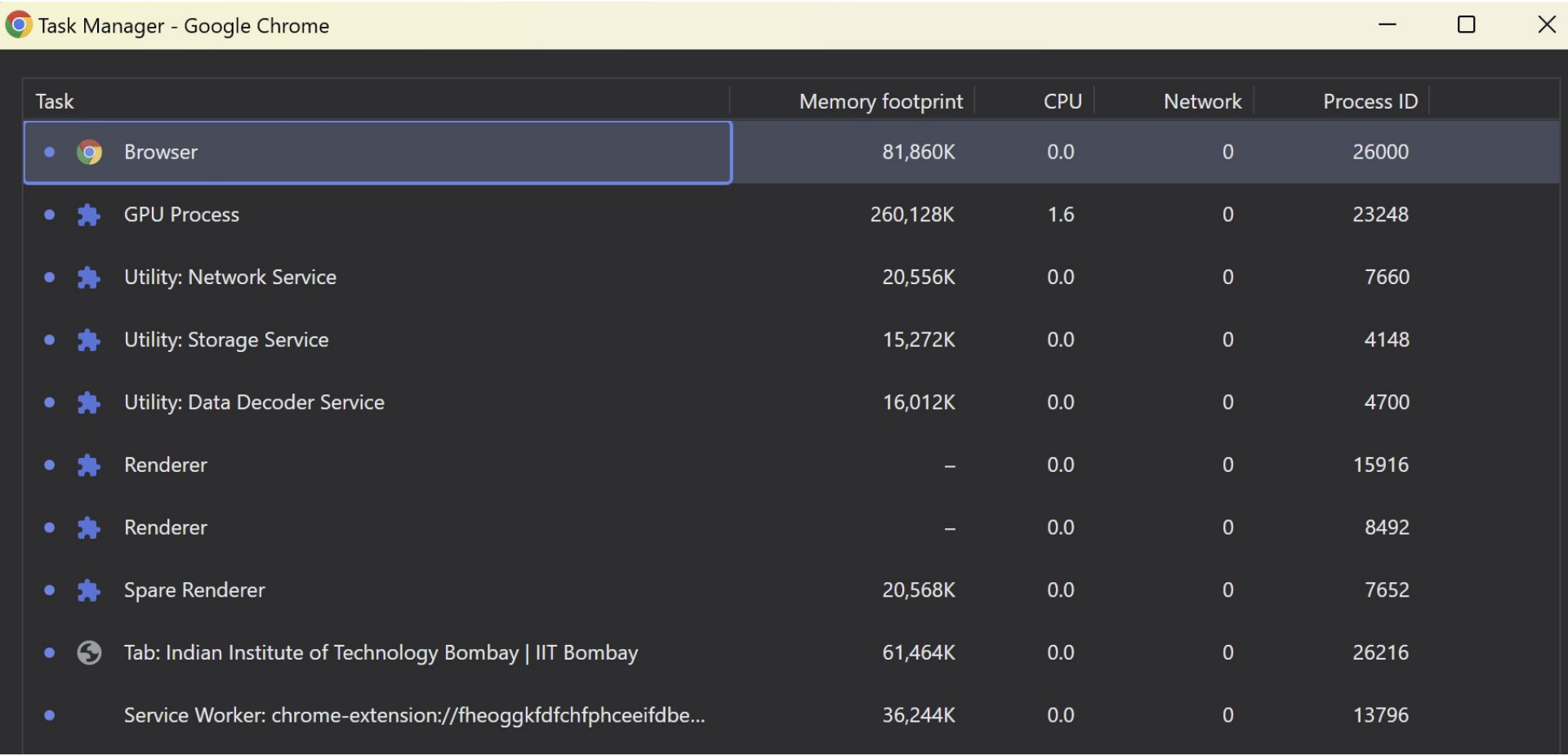
Background: Processes and Threads

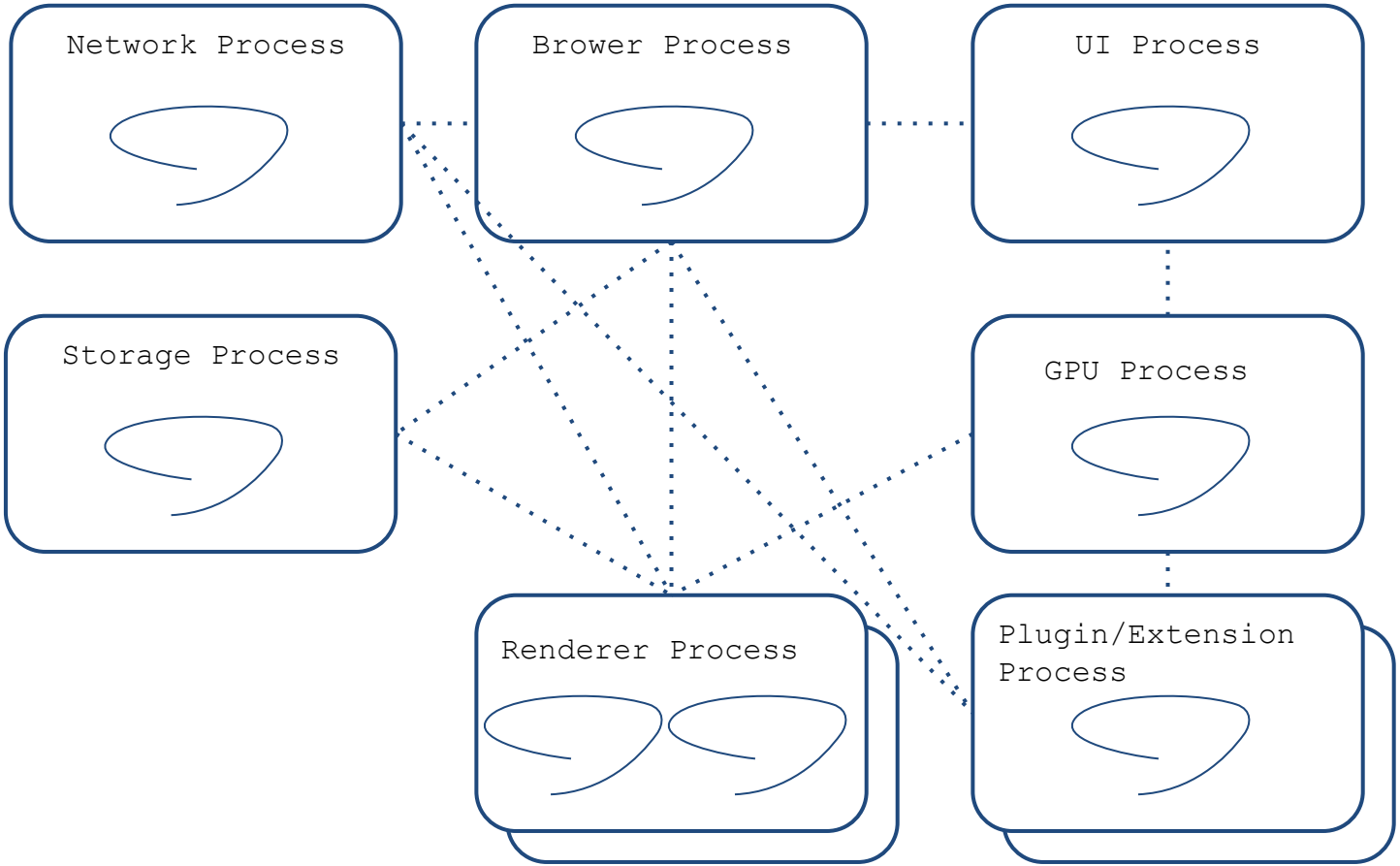
- Process: a running program
- Thread: lives inside a process and executes part of the program
- When a process starts, OS gives it a chunk of memory
  - Close application, processes stopped and memory freed by OS
- Process can fork other processes
  - These worker processes run different tasks of an application
    - They talk via Inter Process Communication (IPC)
    - Each process has its own “disjoint” chunk of memory
  - One worker unresponsive, can be restarted independent of others → better fault tolerance


threads
Process-1
Inter Process Communication
Process-2
Memory

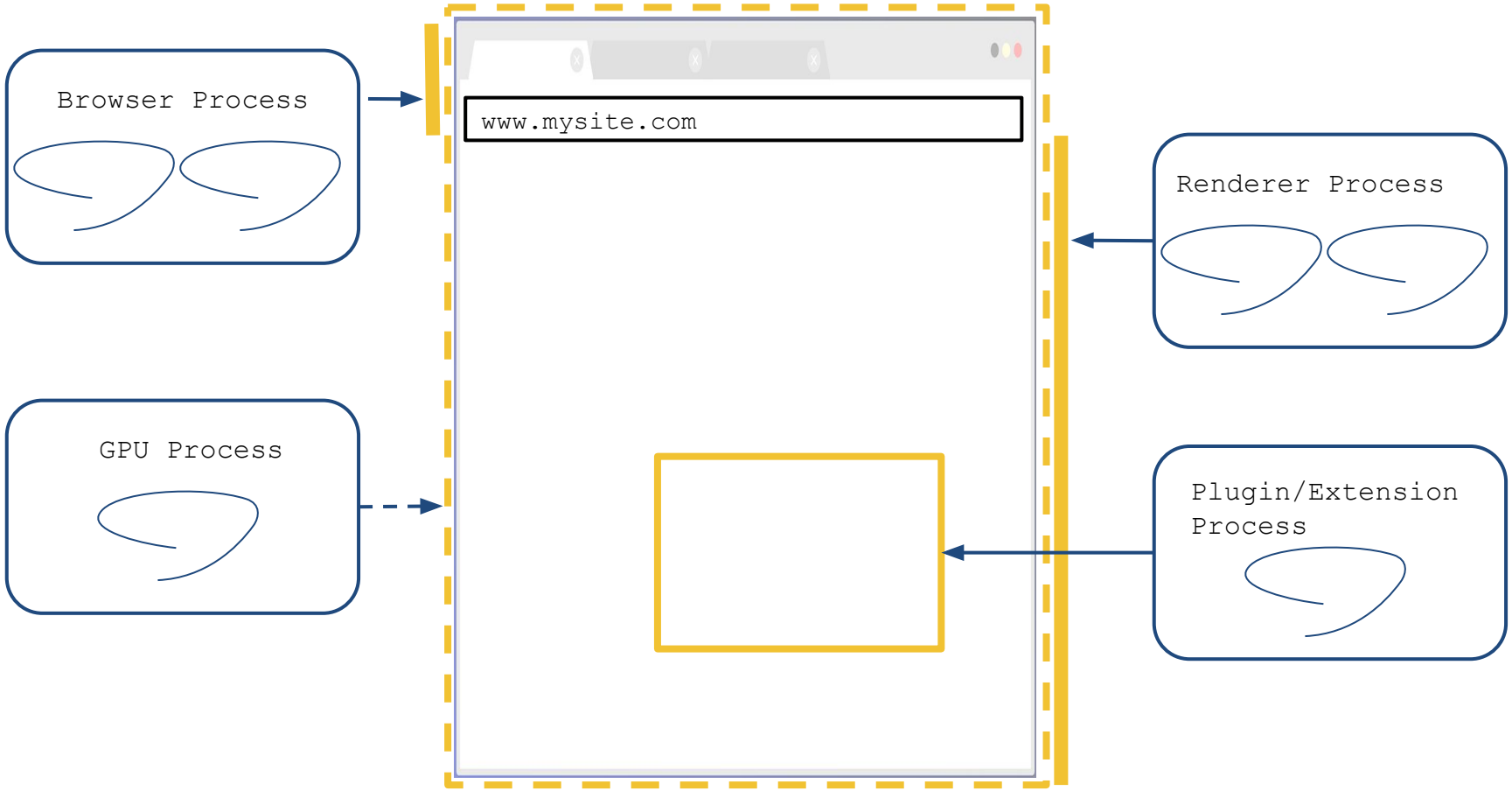
Case Study: Chrome browser

- Start a browser (application)
  - One process with many different threads or many different processes with a few threads?
  - Latter more common
- How many processes are running?
  - Open Chrome, click three dots →More Tools (top right corner)
  - Select Task Manager
  - Shows a list of processes currently running and their CPU/Memory usage


Task Manager - Google Chrome
Task
Memory footprint
CPU
Network
Process ID
Browser 81,860K 0.0 0 26000
GPU Process 260,128K 1.6 0 23248
Utility: Network Service 20,556K 0.0 0 7660
Utility: Storage Service 15,272K 0.0 0 4148
Utility: Data Decoder Service 16,012K 0.0 0 4700
Renderer – 0.0 0 15916
Renderer – 0.0 0 8492
Spare Renderer 20,568K 0.0 0 7652
Tab: Indian Institute of Technology Bombay | IIT Bombay 61,464K 0.0 0 26216
Service Worker: chrome-extension://fheoggkfdfchfphceeifdbe... 36,244K 0.0 0 13796


Network Process
Brower Process
UI Process
Storage Process
GPU Process
Renderer Process
Plugin/Extension
Process

Process	Role
Browser	• Controls address bar, bookmarks, back and forward buttons etc • Underhood, handles privileged stuff such as network requests and file access as threads
Renderer	Controls what happens inside a tab (one tab per website)
Plugin/Extensions	Controls any plugins/extensions (one process per plugin or extension)
GPU	• Handles GPU tasks in isolation from other processes • Responsible for rendering and displaying graphics, images, and multimedia content • Also handles compositing (final image that you see on your screen); ensure smoothness and responsiveness of web page interaction
Storage	Manages different types of storage (cookies, local storage, indexed dB etc) are managed efficiently, securely, and isolated from each other where appropriate

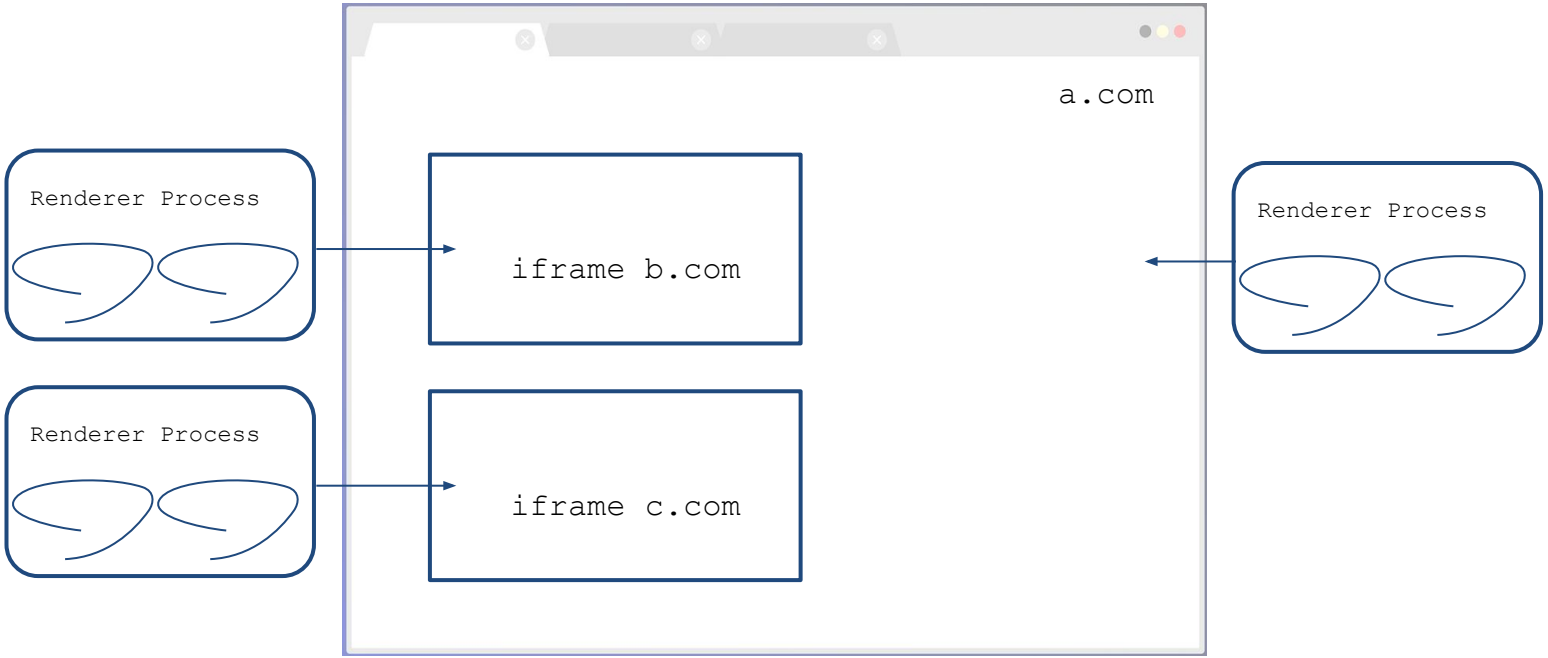

Browser Process
www.mysite.com
Renderer Process
GPU Process
Plugin/Extension Process

A few points to note

- Browser Process:
  - Running on powerful hardware → Splits into different processes giving more stability (saw earlier under Chrome task manager)
  - Less powerful hardware → Runs as single process saving memory
- Renderer Process:
  - One process per tab. Why?
    - If one tab unresponsive, other tabs still active
    - More important reason: Security
      - OS protects one process from accessing another process memory

- iframe (inline frame) allows you to embed content from another website within your webpage
  - <iframe src="https://www.example.com" width="600" height="400" frameborder="0"></iframe>
  - src attribute specifies the URL of the external site to be displayed in the iframe

- Each cross-site iframe in the same tab gets a separate renderer process (security reasons, SOP policy)
  - Not easy to implement
  - E.g. Ctrl+F to find a word in a page → searching across different renderer processes



Security Mechanisms

- Browsers implement many mechanisms to protect users from various threats
  - Many will be covered over time as we cover attacks and corresponding defenses!
- Some basic mechanisms important to know:
  - Sandboxing
  - Same Origin Policy
  - HTTPS (SSL/TLS) – covered under protocols

SandBoxing

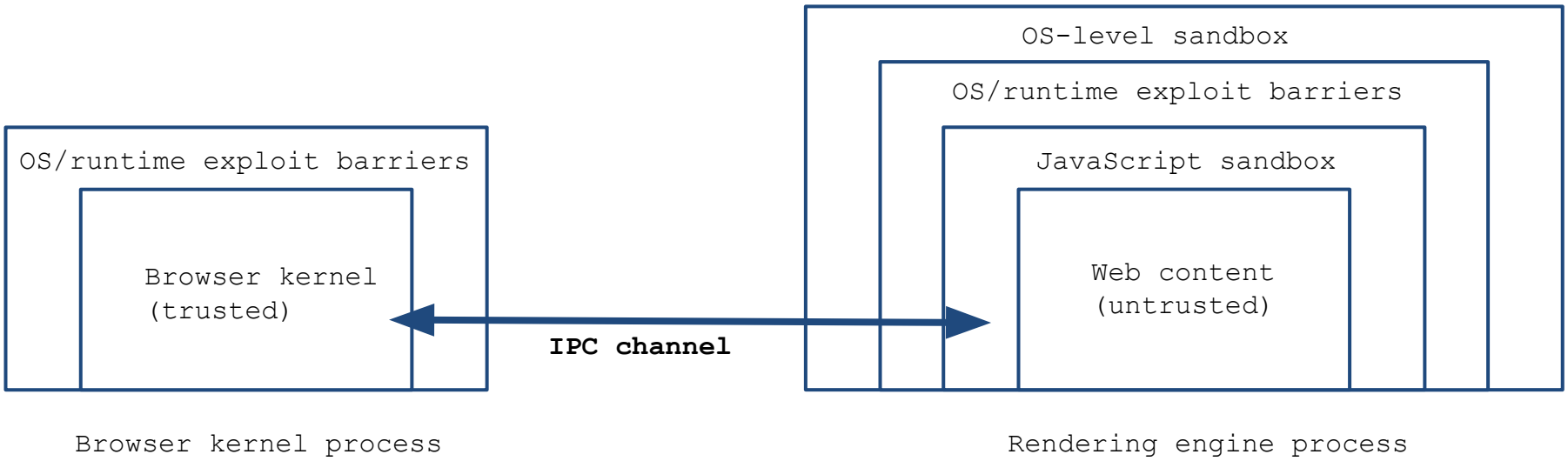
- What is a sandbox?
  - A safe and isolated environment for executing untrusted programs
    - Prevents a bad process from compromising the system
  - Achieved by restricting a process from accessing system resources
    - E.g. limit access to files outside of designated directory
- In Linux: chroot, Linux namespaces, seccomp etc establish a sandbox environment

Browser: Layers of defense

- Every large piece of software (including browser) contains bugs
- As users browse, websites can be malicious
- How to protect users?

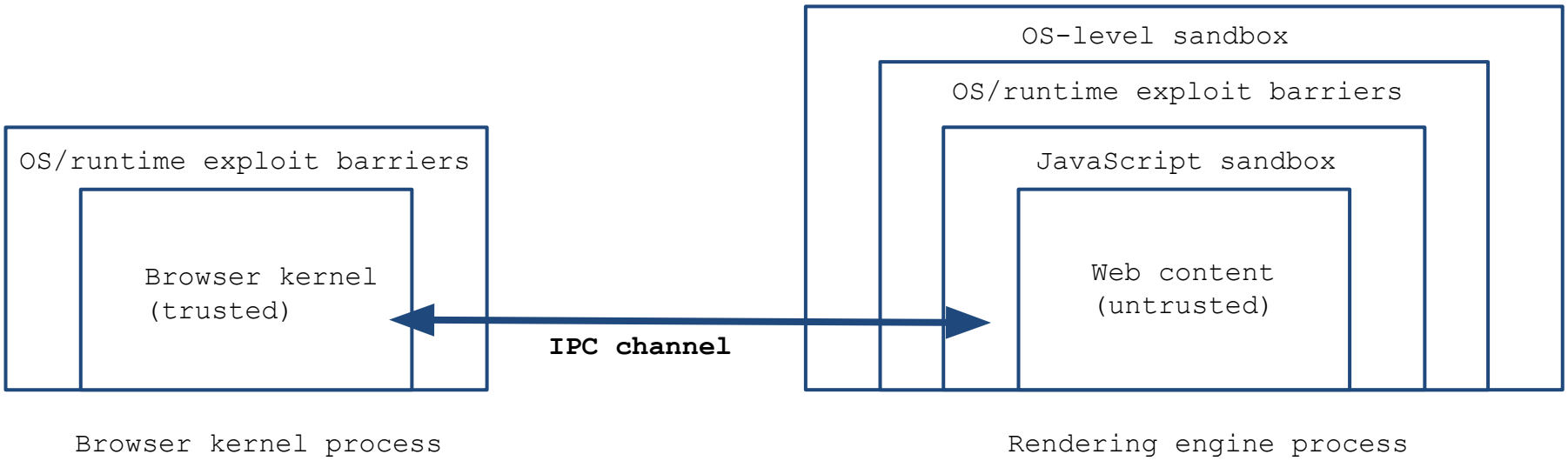
- Already saw process isolation (OS manages)!
  - Browser, Renderer (per tab), GPU etc are all different processes
- Browser process runs with high-privilege
  - Acts with user's authority
  - Responsible for UI, storing cookies (of various websites), history and network access

Layer of Defense around Google Chrome's Rendering Engine



- Rendering process runs at low privilege in a sandbox environment
  - JavaScript engine runs javascript in a sandbox
    - Prevents it from accessing sensitive resources on user's device
  - Each render process also runs in an OS-level sandbox
    - Prevents rendering process from interacting with other processes, file system etc
      - Can only exchange messages with browser process via IPC
      - Malicious code could still send messages to browser process via IPC but interface is simple and restricted to do damage!

Layer of Defense around Google Chrome's Rendering Engine



- Several OS/Runtime level protection also!
  - DEP (data execution prevention)
    - Marks memory pages (e.g. stack, heap etc) as NX (non executable)
  - ASLR (address space layout randomization)
    - Prevents attackers from guessing memory address locations
    - Can upload malicious code and jump to those locations
  - SafeSEH (safe exception handlers)
  - Stack overrun detection (GS) via canary
    - Prevents overwriting of return address
    - Prevents buffer overflow type attacks

All of above help prevent attackers from running malicious code

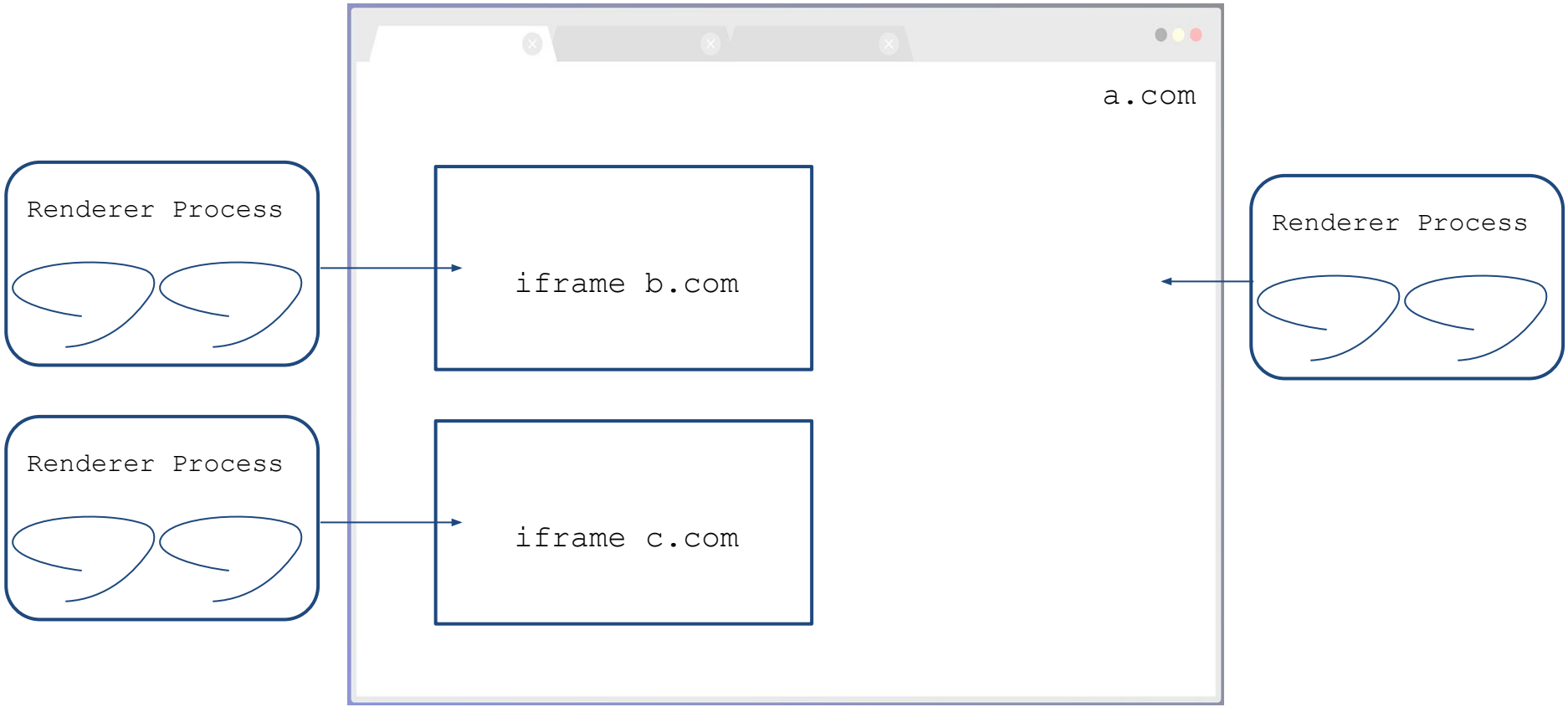
Same Origin Policy (SOP)

- SOP introduced by Netscape in 1995
  - Implemented by all browsers today
  - Result of introduction of JavaScript that manipulates DOM
- Restricts how a document or script loaded by one origin can interact with a resource from another origin
  - What is an origin?
  - Origin: protocol + hostname + port
    - (http) + (www.iitb.ac.in) + (80)

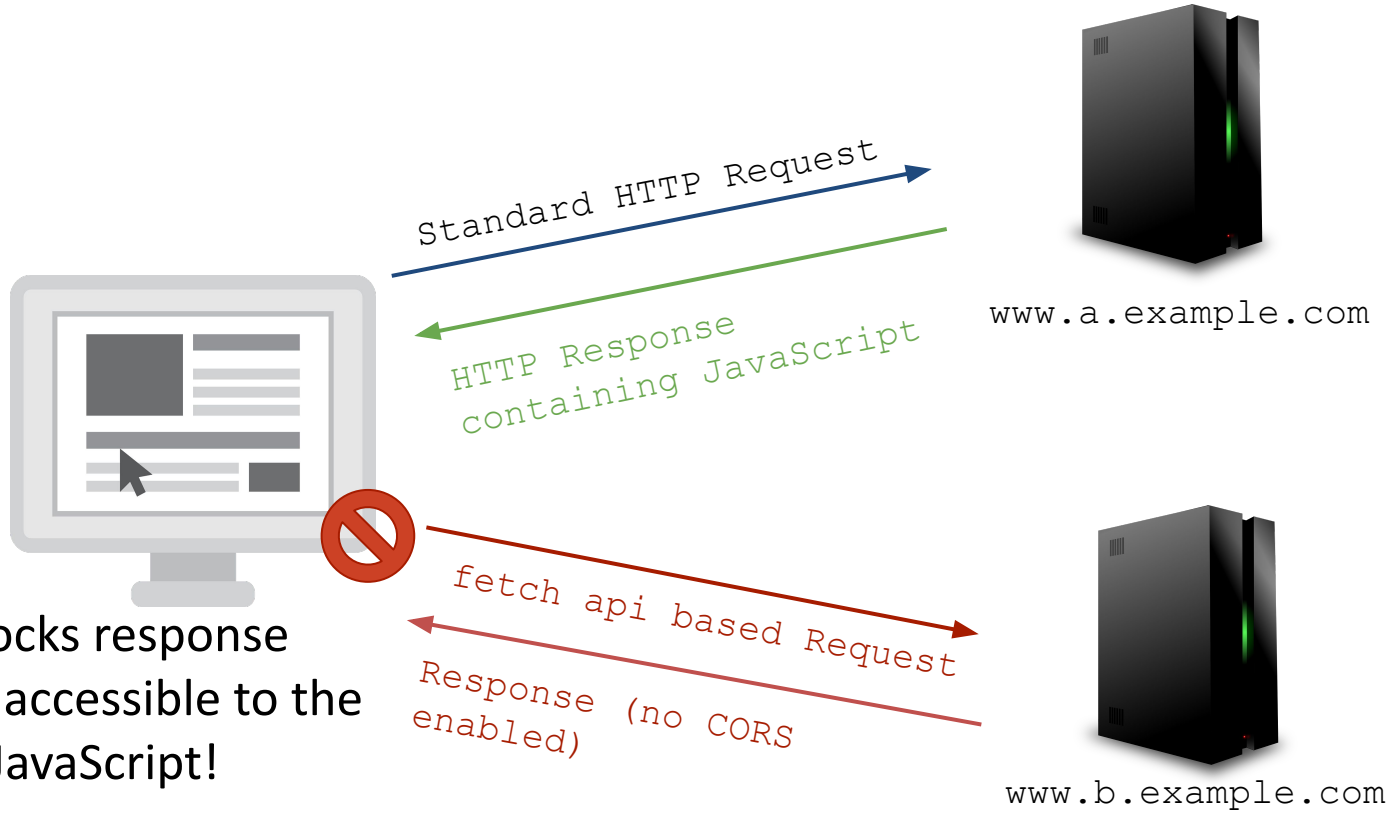
URL1	URL2	Same origin?
http://abc.org/a	http://abc.org/b	
http://abc.org	http://www.abc.org	
http://abc.org	https://abc.org	
http://abc.org:81	http://abc.org:82	

URL1	URL2	Same origin?
http://abc.org/a	http://abc.org/b	Yes
http://abc.org	http://www.abc.org	No (hostname different)
http://abc.org	https://abc.org	No (protocol different)
http://abc.org:81	http://abc.org:82	No (port different)

- Normally, one origin cannot access resources of another origin
  - A malicious script loaded from one origin cannot access **sensitive data** of a page loaded from different origin
    - Sensitive Data: Cookies or response to HTTP request or DOM object


a.com
Renderer Process
iframe b.com
Renderer Process
Renderer Process
iframe c.com

- Cross-origin reads via scripts are disallowed by default
  - Note: Web page can still freely embed cross-origin images, stylesheets, scripts, iframes, and videos etc
  - But “cross-origin” requests, notably Ajax requests via JavaScript are forbidden by default
    - Possible to allow via Cross-Origin Resource Sharing (CORS, will be covered later)



Browser blocks response from being accessible to the client-side JavaScript!

Many more such mechanisms

- Automatic Security Updates
- Secure Credential Management
  - Securely store and manage user credentials
- Phishing and Malware Protection
  - Browsers talk with safe browsing services that maintain databases of known phishing sites and malicious URLs
  - Warn users before navigating to such sites
- Privacy Controls
  - Include features to block or limit third-party tracking cookies
- Many policies implemented via http headers, which browsers execute (more later)

References

- https://developers.google.com/web/updates/2018/09/inside-browser-part1
- https://developer.chrome.com/blog/inside-browser-part2/
- https://developer.chrome.com/blog/inside-browser-part3/
- https://developer.mozilla.org/en-US/docs/Web/Security/Same-origin_policy
- Browser Security: Lessons from Google Chrome: https://queue.acm.org/detail.cfm?id=1556050

Summary

- Lots of action inside a browser
  - We just touched the surface! (see references for depth)
- Basic Security Mechanisms employed by browsers
  - Sandboxing
  - Same Origin Policy (SOP)
  - (more, specifically HTTP headers covered over time)