Principles for secure implementation

Some of the slides and content are from Mike Hicks' Coursera course

Trusted computing bases

Every system has a TCB

- Your reference monitor
- Compiler
- OS
- CPU
- Memory
- Keyboard…..

Security requires the TCB be

- Correct
- Complete
- Secure

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Two principles behind a good TCB:

KISS Privilege Separation

KISS: Small TCB

- Keep the **TCB small** (and simple) to **reduce overall susceptibility to compromise**
  - The trusted computing base (TCB) comprises the system components that *must* work correctly to ensure security

- **Example**: **Operating system kernels**
  - Kernels enforce security policies, but are often millions of lines of code
    - Compromise in a device driver compromises security overall
  - Better: **Minimize size of kernel** to reduce trusted components
    - Device drivers moved outside of kernel in micro-kernel designs

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- **Security software** is part of the TCB
- But as it grows in size and complexity, it becomes vulnerable itself, and can be bypassed

DARPA Additional security layers often create vulnerabilities…

October 2010 vulnerability watchlist

Vulnerability Title	Fix Avail?	Date Added
XXXXXXXXXXXX XXXXXXXXXXXX Local Privilege Escalation Vulnerability	No	8/25/2010
XXXXXXXXXXXX XXXXXXXXXXXX Denial of Service Vulnerability	Yes	8/24/2010
XXXXXXXXXXXX XXXXXXXXXXXX Buffer Overflow Vulnerability	No	8/20/2010
XXXXXXXXXXXX XXXXXXXXXXXX Sanitization Bypass Weakness	No	8/18/2010
XXXXXXXXXXXX XXXXXXXXXXXX Security Bypass Vulnerability	No	8/17/2010
XXXXXXXXXXXX XXXXXXXXXXXX Multiple Security Vulnerabilities	Yes	8/16/2010
XXXXXXXXXXXX XXXXXXXXXXXX Remote Code Execution Vulnerability	No	8/16/2010
XXXXXXXXXXXX XXXXXXXXXXXX Use-After-Free Memory Corruption Vulnerability	No	8/12/2010
XXXXXXXXXXXX XXXXXXXXXXXX Remote Code Execution Vulnerability	No	8/10/2010
XXXXXXXXXXXX XXXXXXXXXXXX Multiple Buffer Overflow Vulnerabilities	No	8
XXXXXXXXXXXX XXXXXXXXXXXX Stack Buffer Overflow Vulnerability	Yes	8
XXXXXXXXXXXX XXXXXXXXXXXX Security-Bypass Vulnerability	No	8
XXXXXXXXXXXX XXXXXXXXXXXX Multiple Security Vulnerabilities	No	8
XXXXXXXXXXXX XXXXXXXXXXXX Buffer Overflow Vulnerability	No	7/29/2010
XXXXXXXXXXXX XXXXXXXXXXXX Remote Privilege Escalation Vulnerability	No	7/28/2010
XXXXXXXXXXXX XXXXXXXXXXXX Cross Site Request Forgery Vulnerability	No	7/26/2010
XXXXXXXXXXXX XXXXXXXXXXXX Multiple Denial Of Service Vulnerabilities	No	7/22/2010

6 of the vulnerabilities are in security software

Color Code Key: Vendor Replied – Fix in development | Awaiting Vendor Reply/Confirmation | Awaiting CC/S/A use validation

http://www.darpa.mil/WorkArea/DownloadAsset.aspx?id=2147484449

TCB: Privilege Separation

Isolate privileged operations to as small a module as possible

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- **Example**: Email apps often drop you into an editor
  - vi, emacs
  - But these editors often permit dropping you into a shell

Lesson: Trust is Transitive

- **If you trust something, you trust what it trusts**
  - *This trust can be misplaced*

- **Previous e-mail client example**
  - Mailer delegates to an arbitrary editor
  - The editor permits running arbitrary code
  - Hence the mailer permits running arbitrary code

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    - Policy akin to *Berkeley Packet Filters (BPF)*
  - Used by *Chrome*, *OpenSSH*, *vsftpd*, and others

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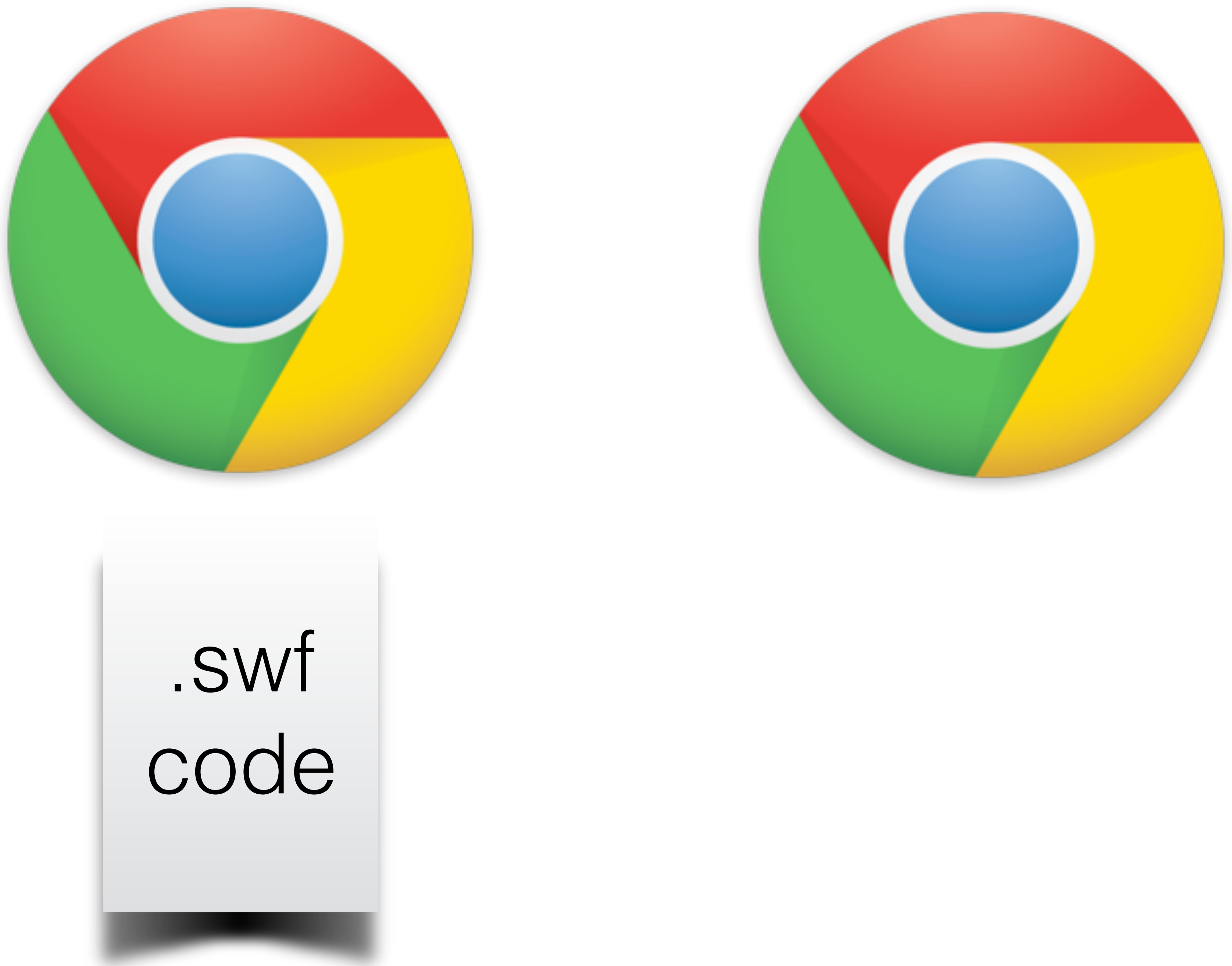

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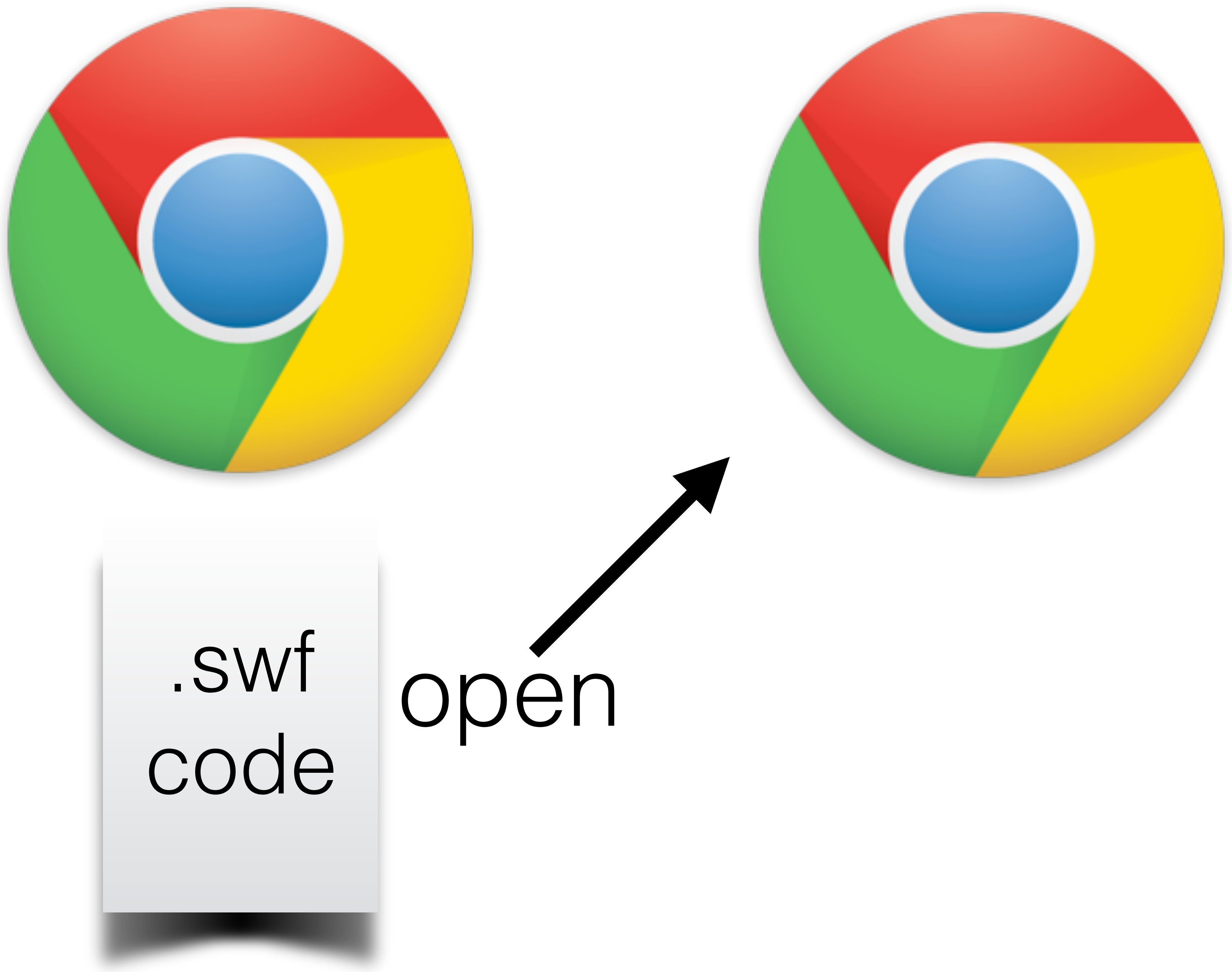

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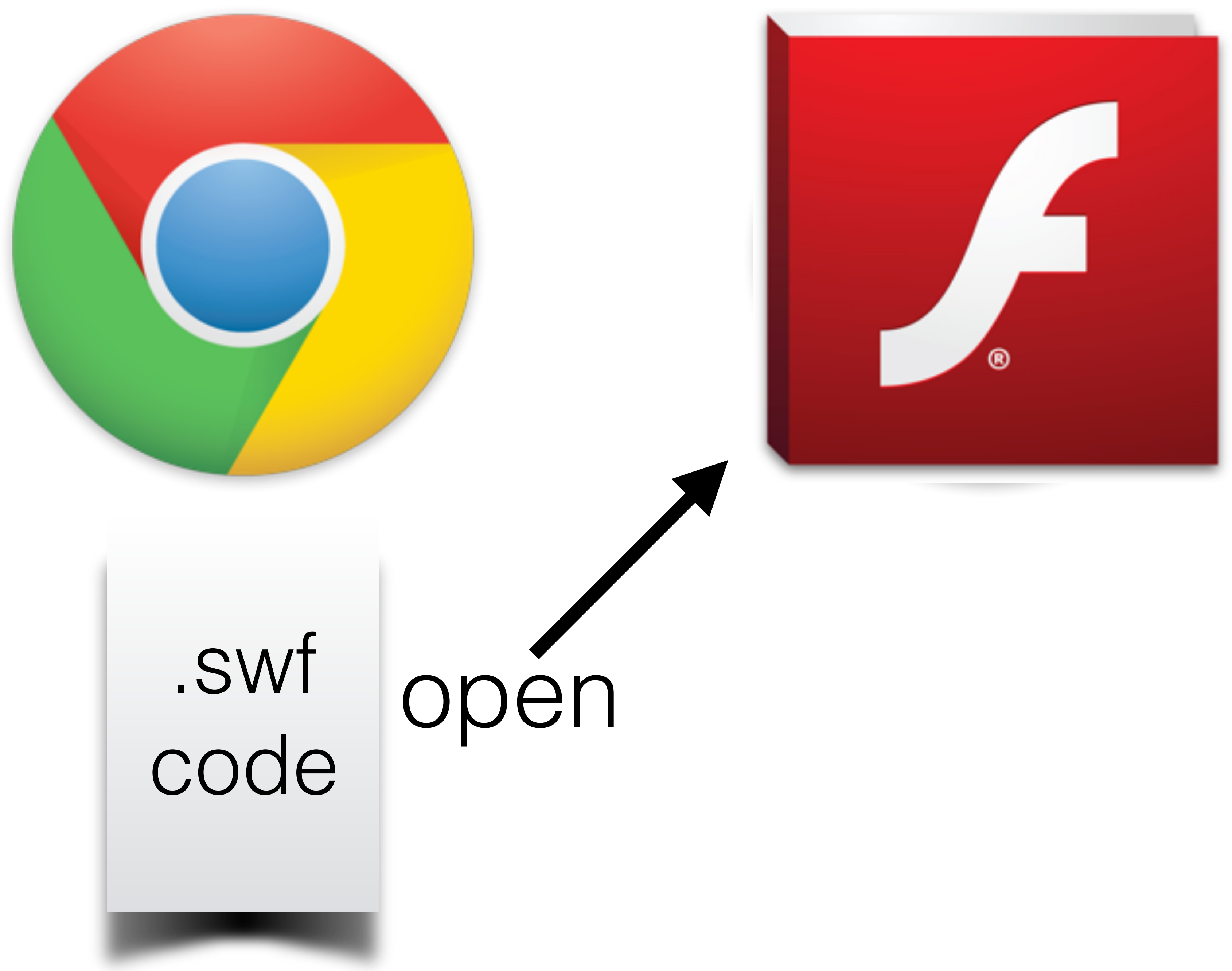

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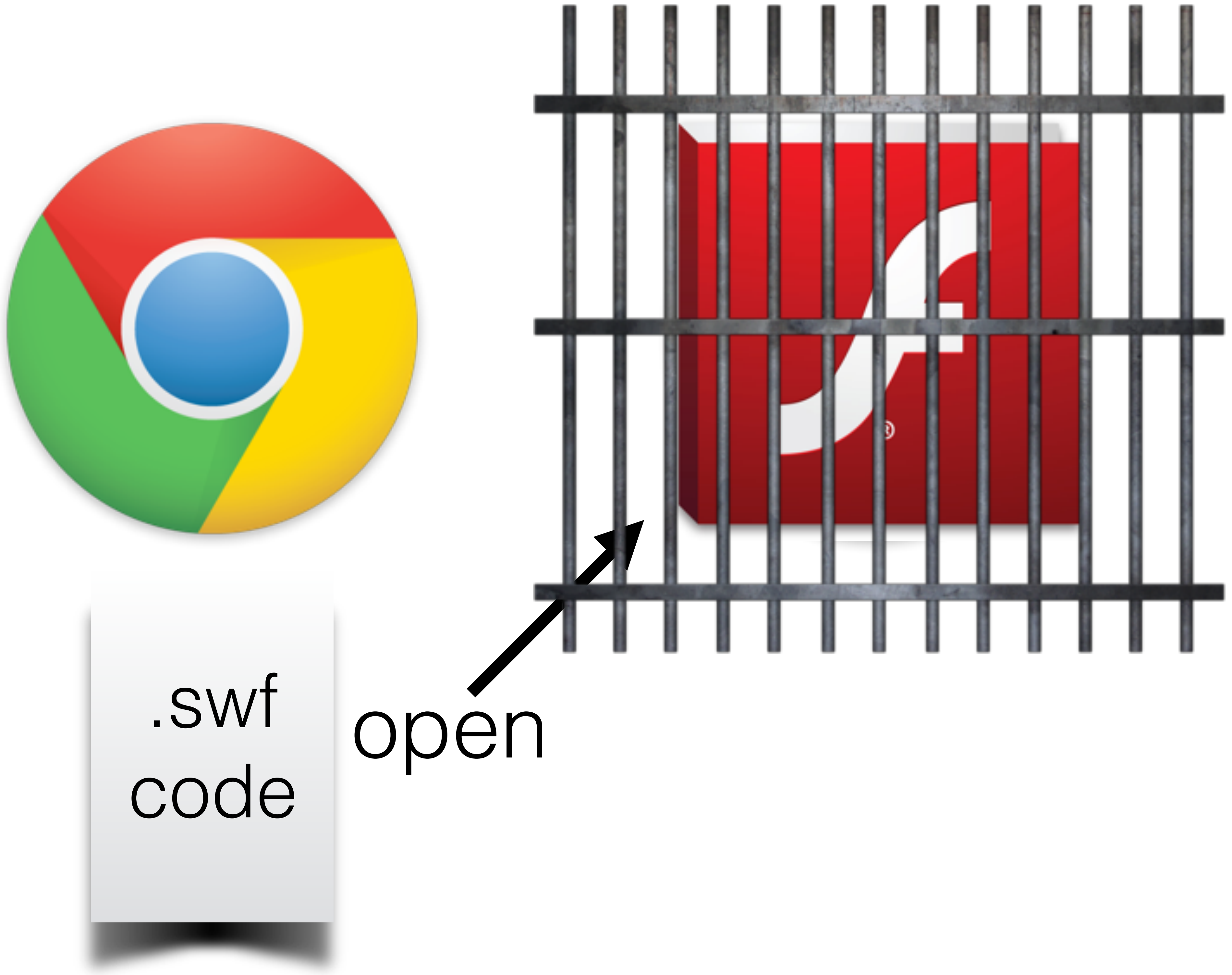
- Call `seccomp-bpf` to compartmentalize



Case study: VSFTPD

Very Secure FTPD

- **FTP**: File Transfer Protocol
  - More popular before the rise of HTTP, but still in use
  - 90's and 00's: **FTP daemon compromises were frequent and costly**, e.g., in Wu-FTPD, ProFTPd, …

- **Very thoughtful design** aimed to **prevent** and **mitigate security defects**

- But also to **achieve good performance**
  - Written in C

- Written and maintained by Chris Evans since 2002
  - **No security breaches that I know of**

https://security.appspot.com/vsftpd.html

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- Circumstances:
  - **Client attacks server**
  - **Client attacks** another **client**

Defense: Secure Strings

```
struct mystr
{
  char* PRIVATE_HANDS_OFF_p_buf;
  unsigned int PRIVATE_HANDS_OFF_len;
  unsigned int PRIVATE_HANDS_OFF_alloc_bytes;
};
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void
private_str_alloc_memchunk(struct mystr* p_str, const char* p_src,
                           unsigned int len)
{
  ...
}
```

```c
struct mystr
{
  char* p_buf;
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  unsigned int alloc_bytes;
};
```

```c
void
str_copy(struct mystr* p_dest, const struct mystr* p_src)
{
  private_str_alloc_memchunk(p_dest, p_src->p_buf, p_src->len);
}
```

replace uses of `char*` with `struct mystr*`
and uses of `strcpy` with `str_copy`

```c
void
private_str_alloc_memchunk(struct mystr* p_str, const char* p_src,
                           unsigned int len)
{
  /* Make sure this will fit in the buffer */
  unsigned int buf_needed;
  if (len + 1 < len)
  {
    bug("integer overflow");
  }
  buf_needed = len + 1;
  if (buf_needed > p_str->alloc_bytes)
  {
    str_free(p_str);
    s_setbuf(p_str, vsf_sysutil_malloc(buf_needed));
    p_str->alloc_bytes = buf_needed;
  }
  vsf_sysutil_memcpy(p_str->p_buf, p_src, len);
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  - What if argument is non-positive?
    - We saw earlier that integer overflows can induce this behavior
    - Leads to buffer overruns
  - What if returned value is NULL?
    - Oftentimes, a deference means a crash
    - On platforms without memory protection, a dereference can cause corruption

```c
void*
vsf_sysutil_malloc(unsigned int size)
{
  void* p_ret;
  /* Paranoia - what if we got an integer overflow/underflow? */
  if (size == 0 || size > INT_MAX)
  {
    bug("zero or big size in vsf_sysutil_malloc");
  }
  p_ret = malloc(size);
  if (p_ret == NULL)
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fails if it receives malformed argument or runs out of memory

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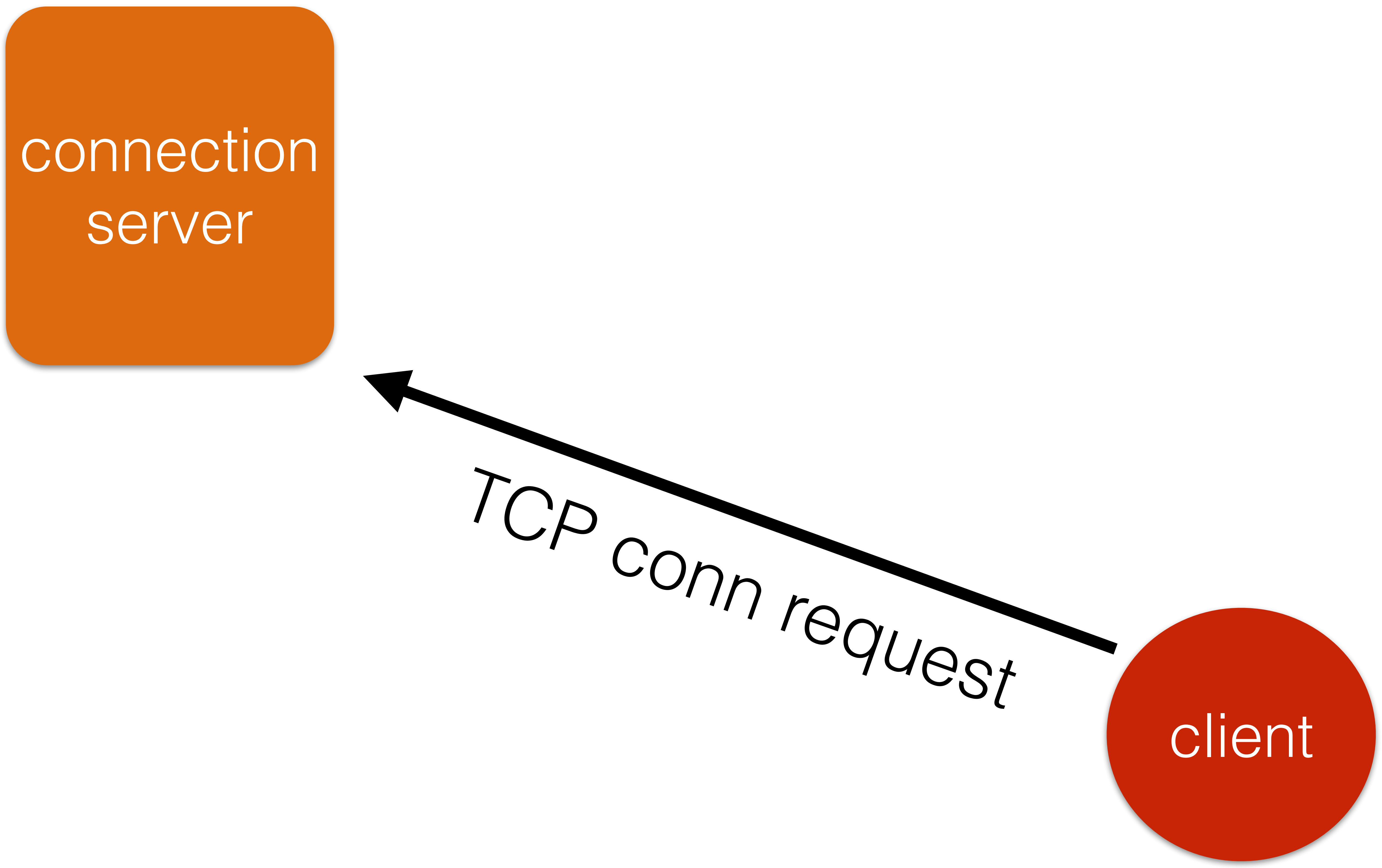

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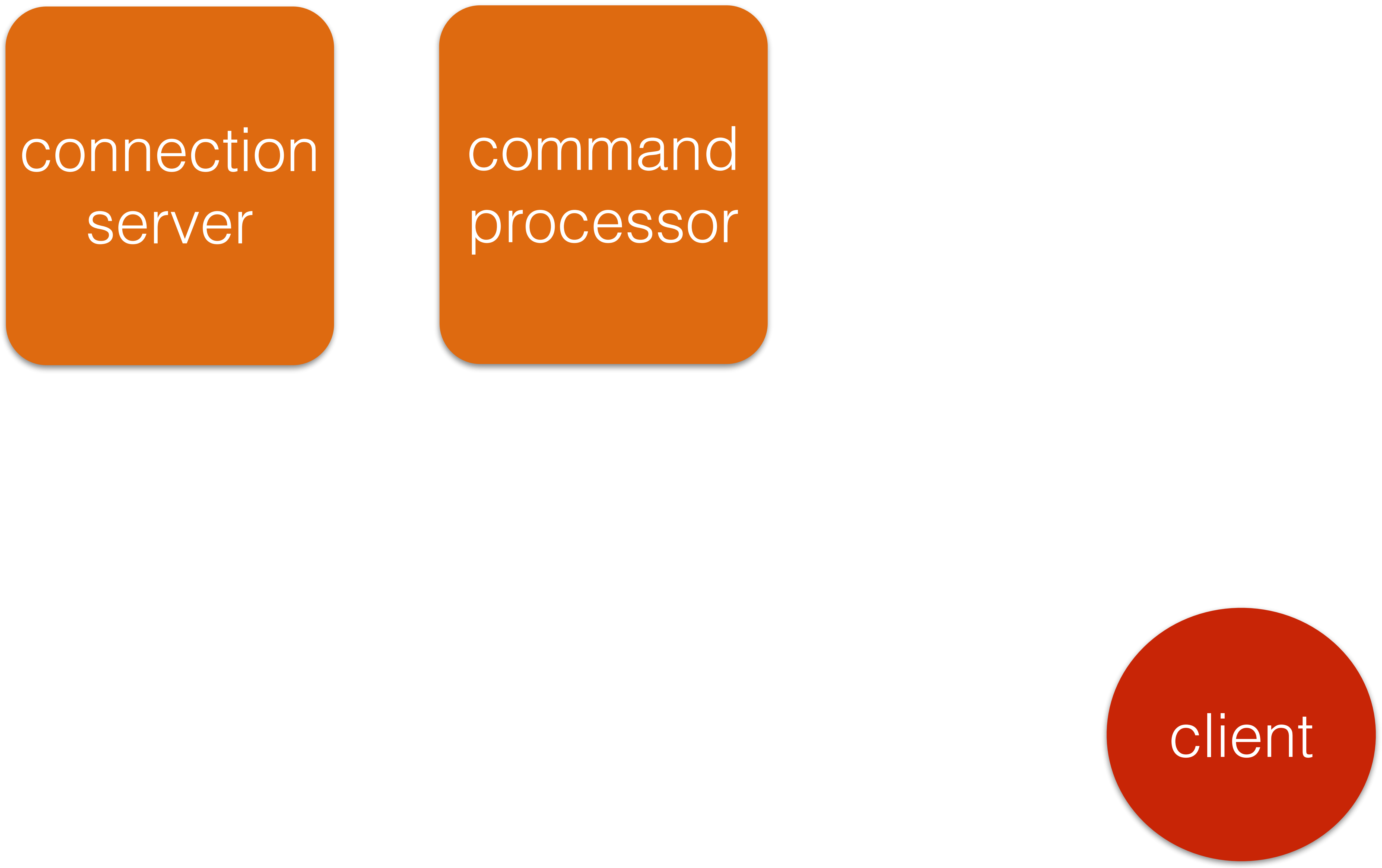

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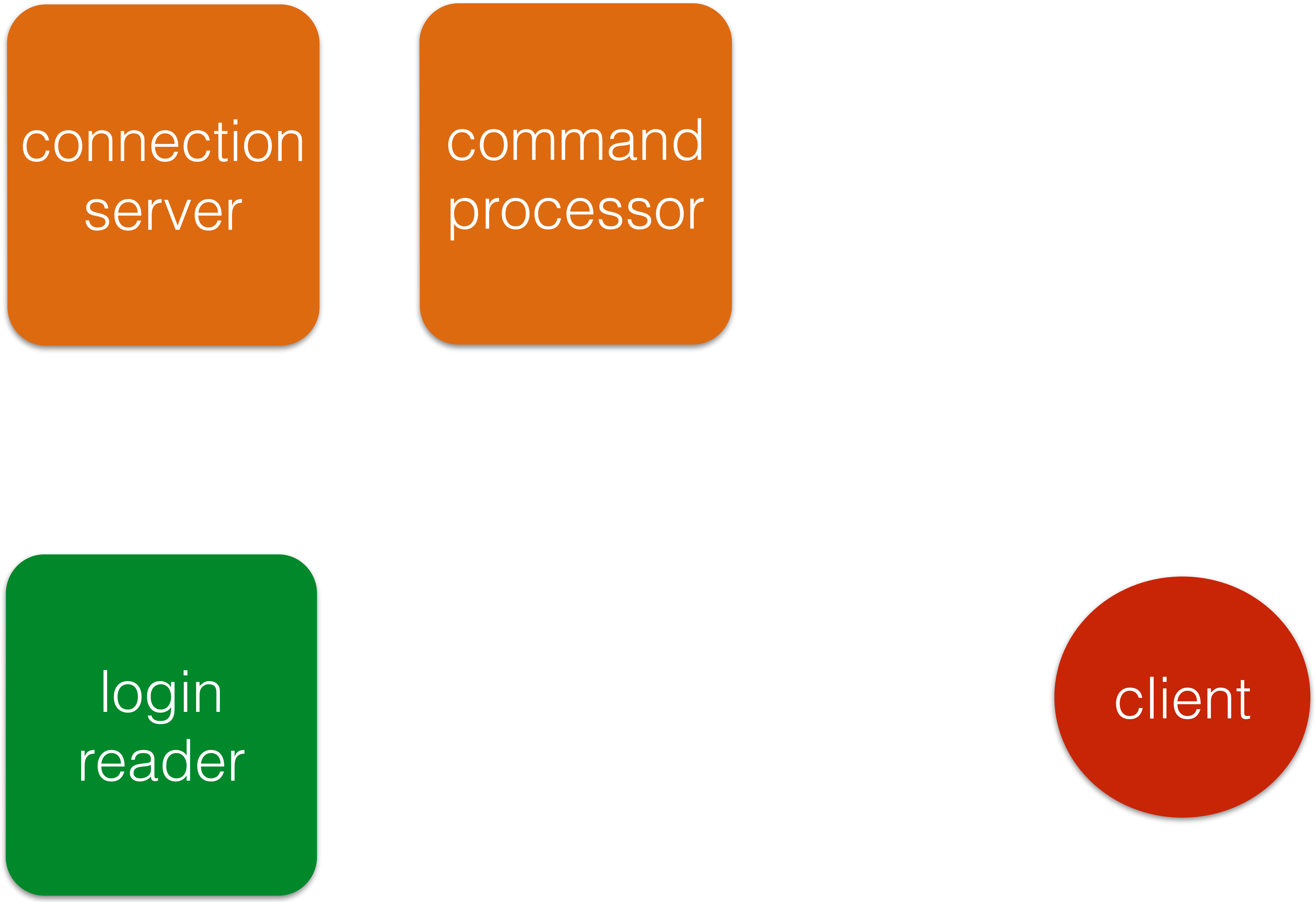

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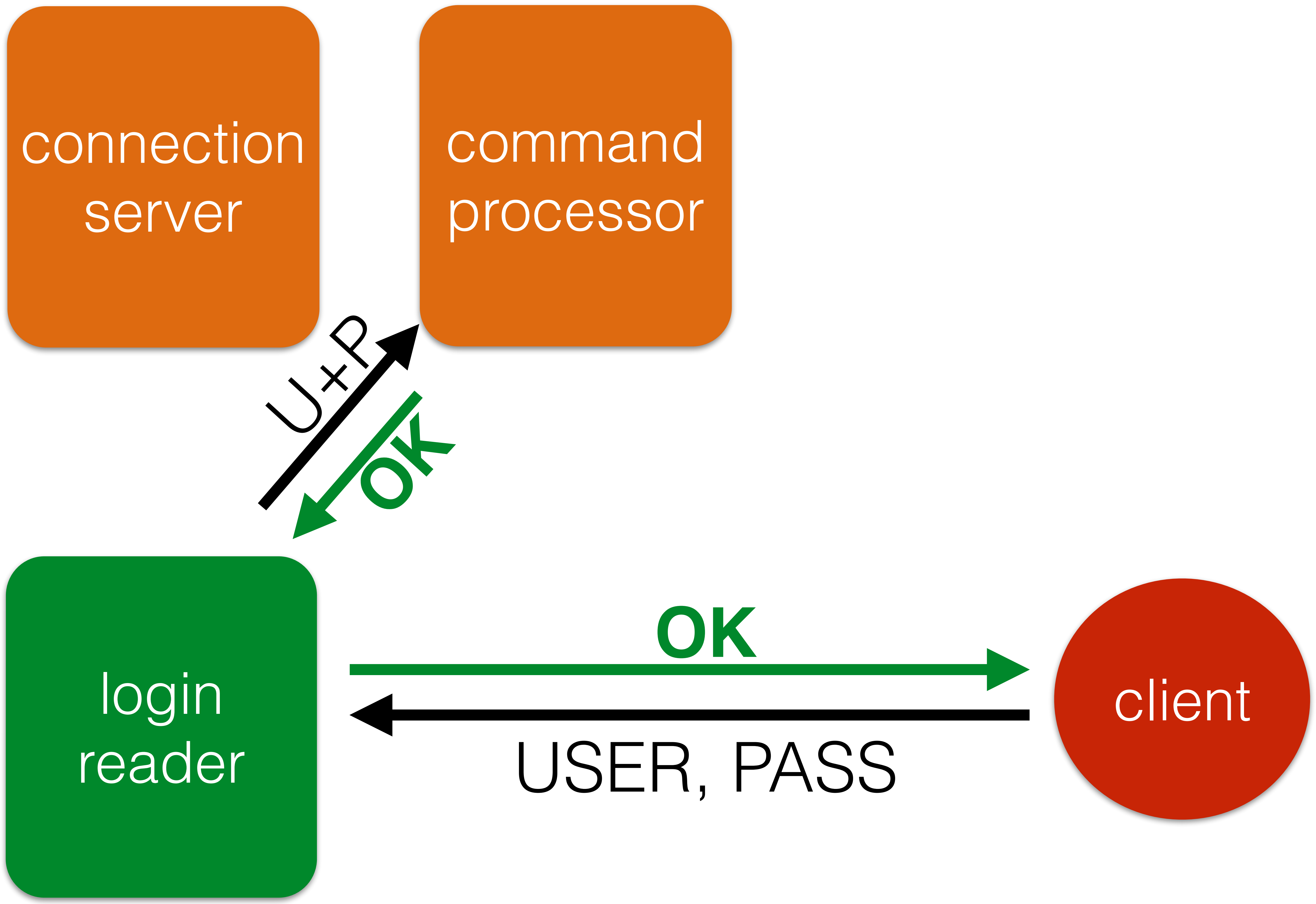

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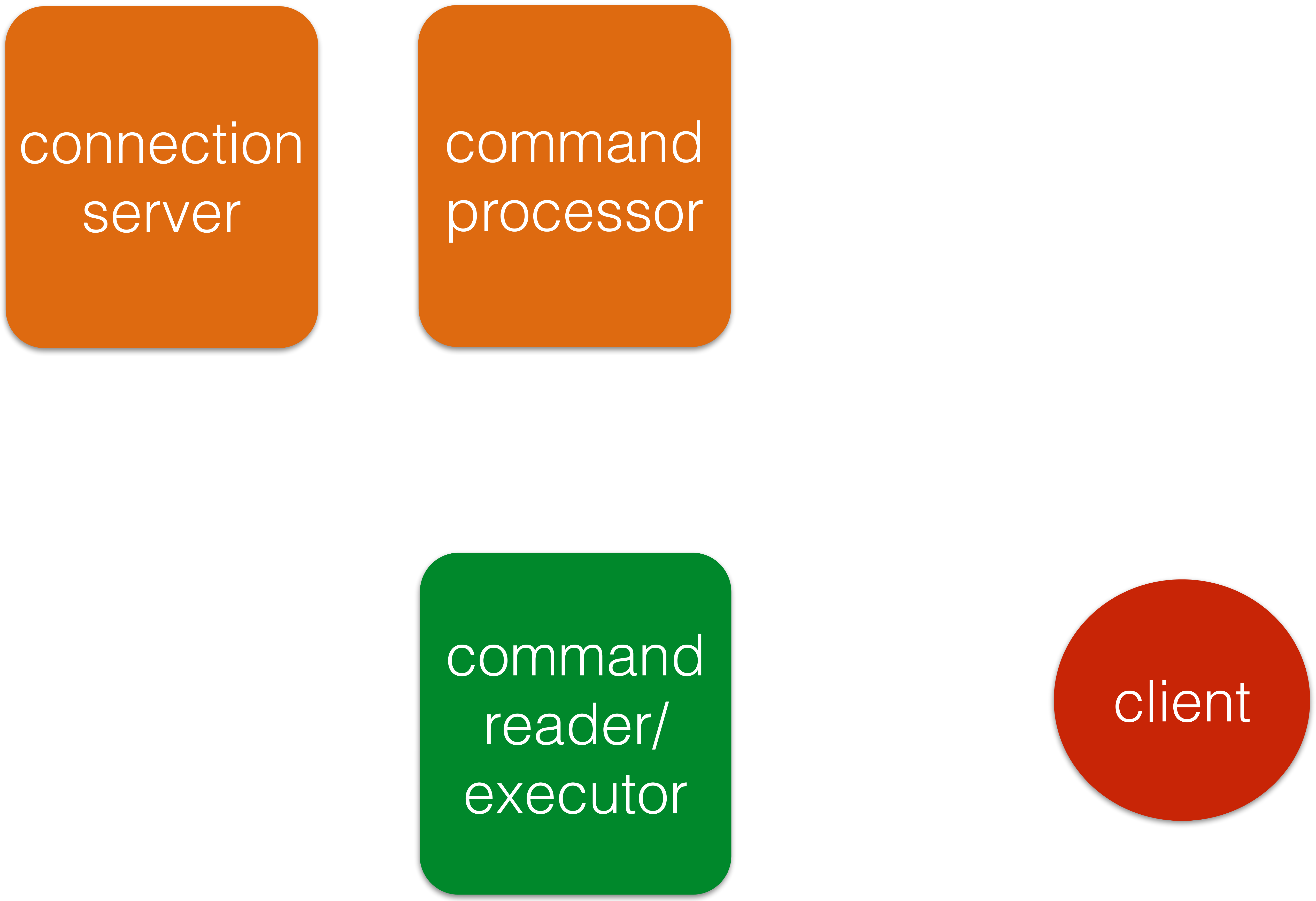

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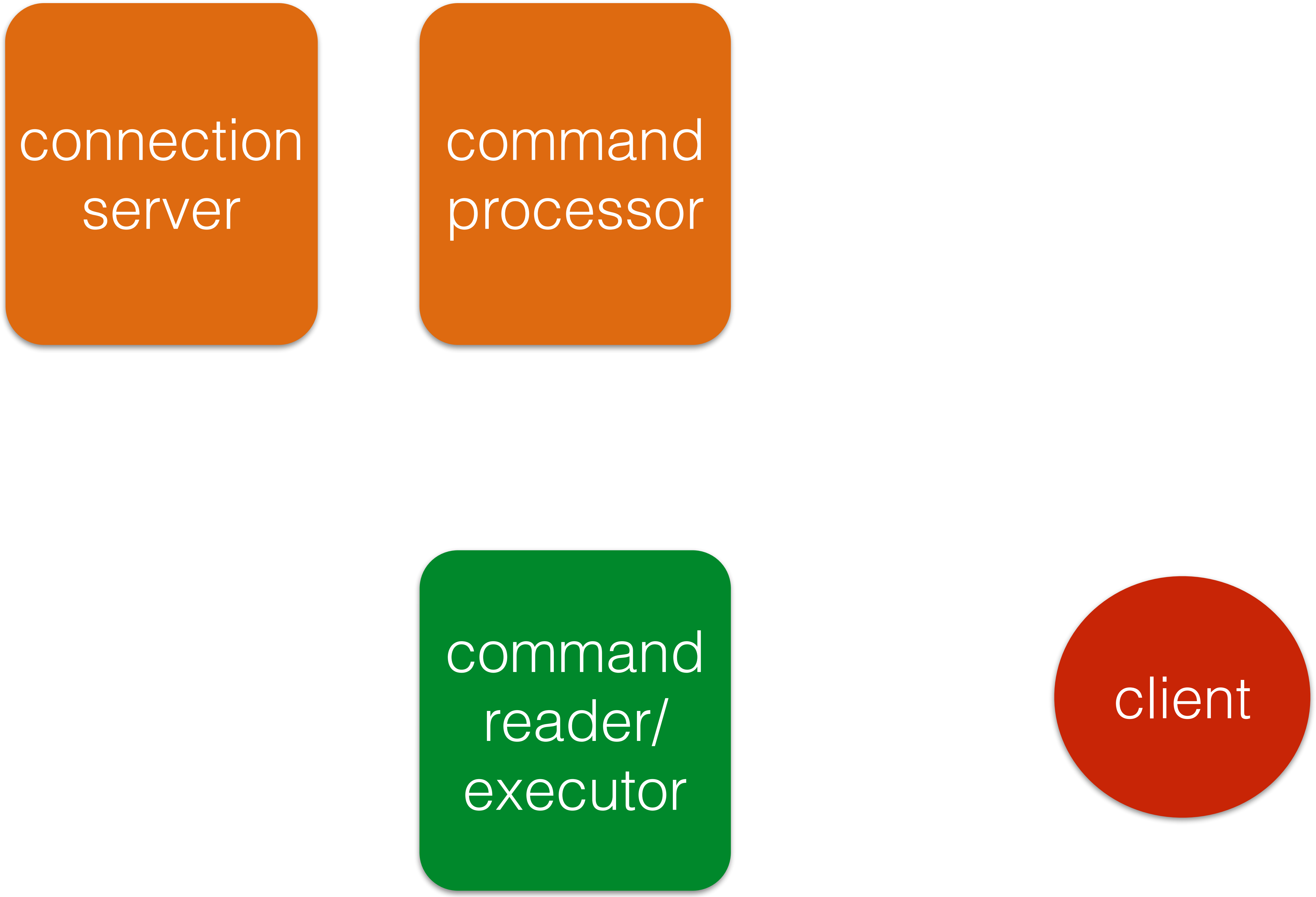

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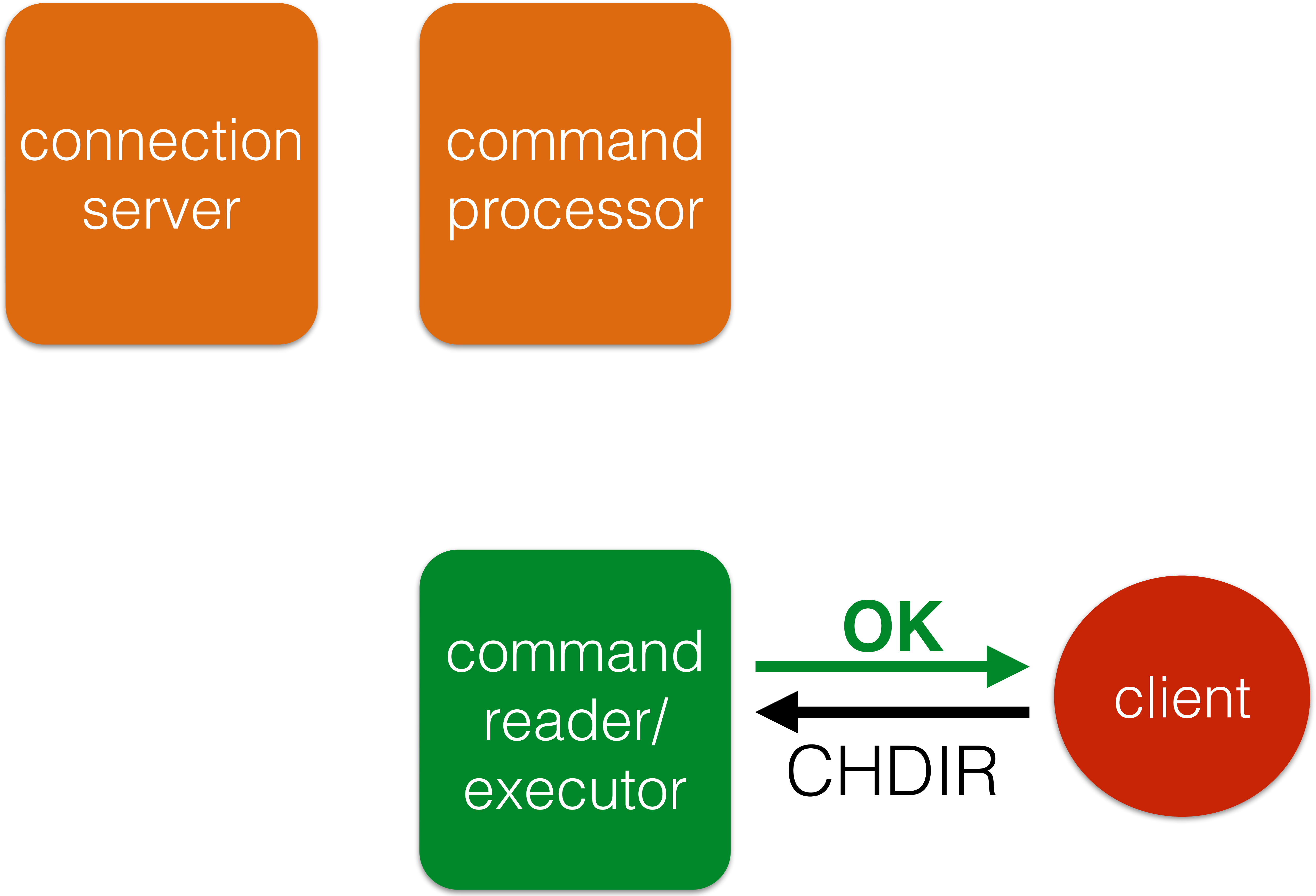

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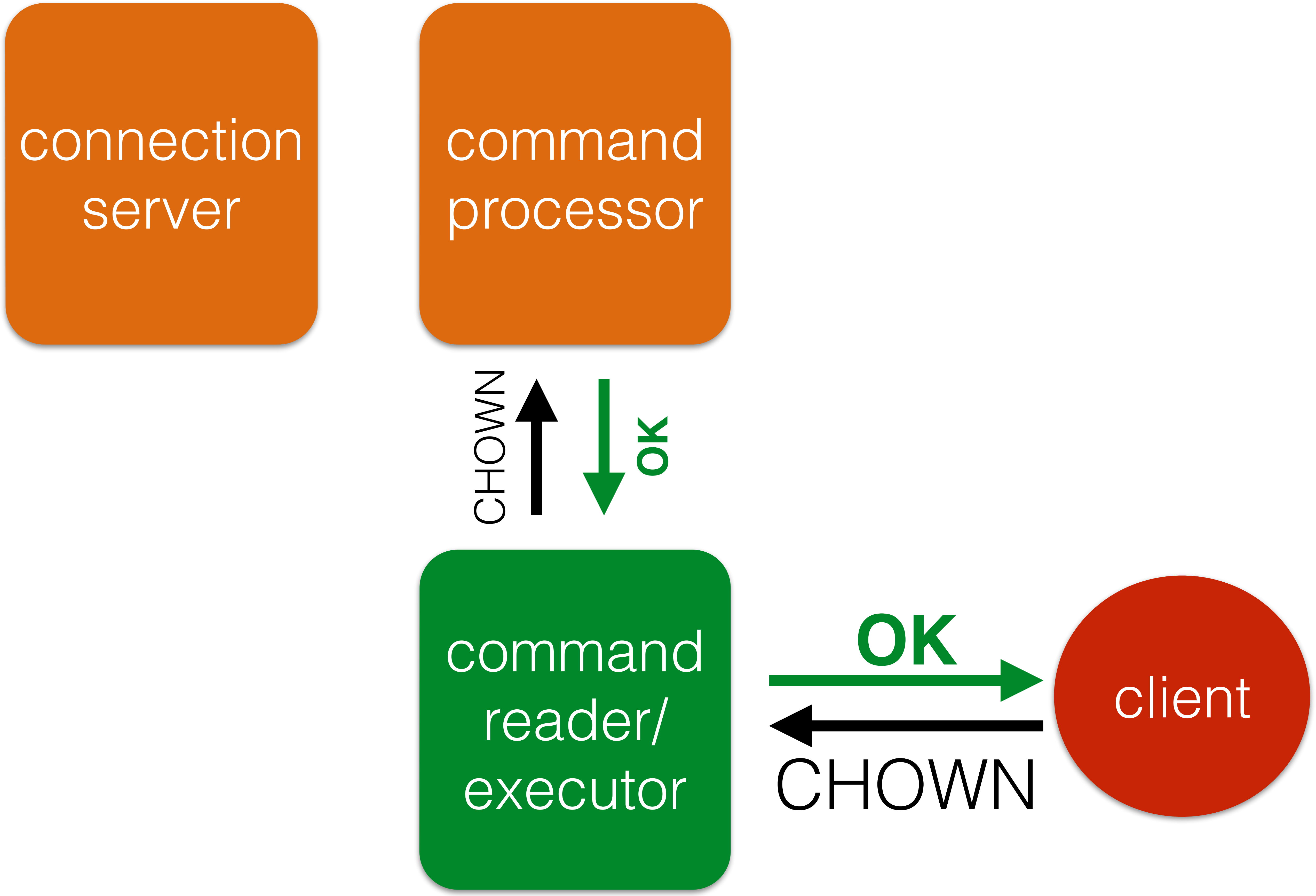
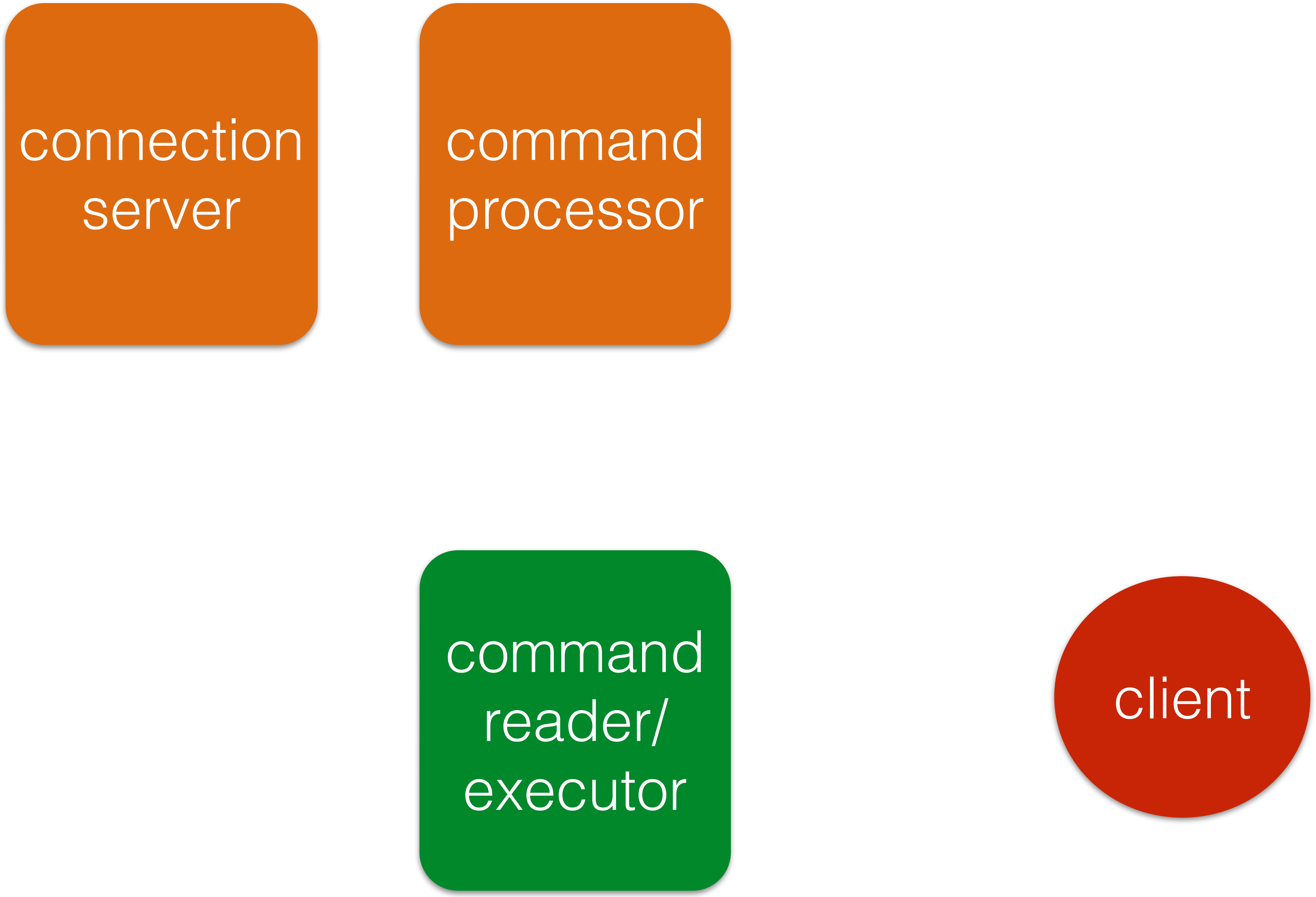
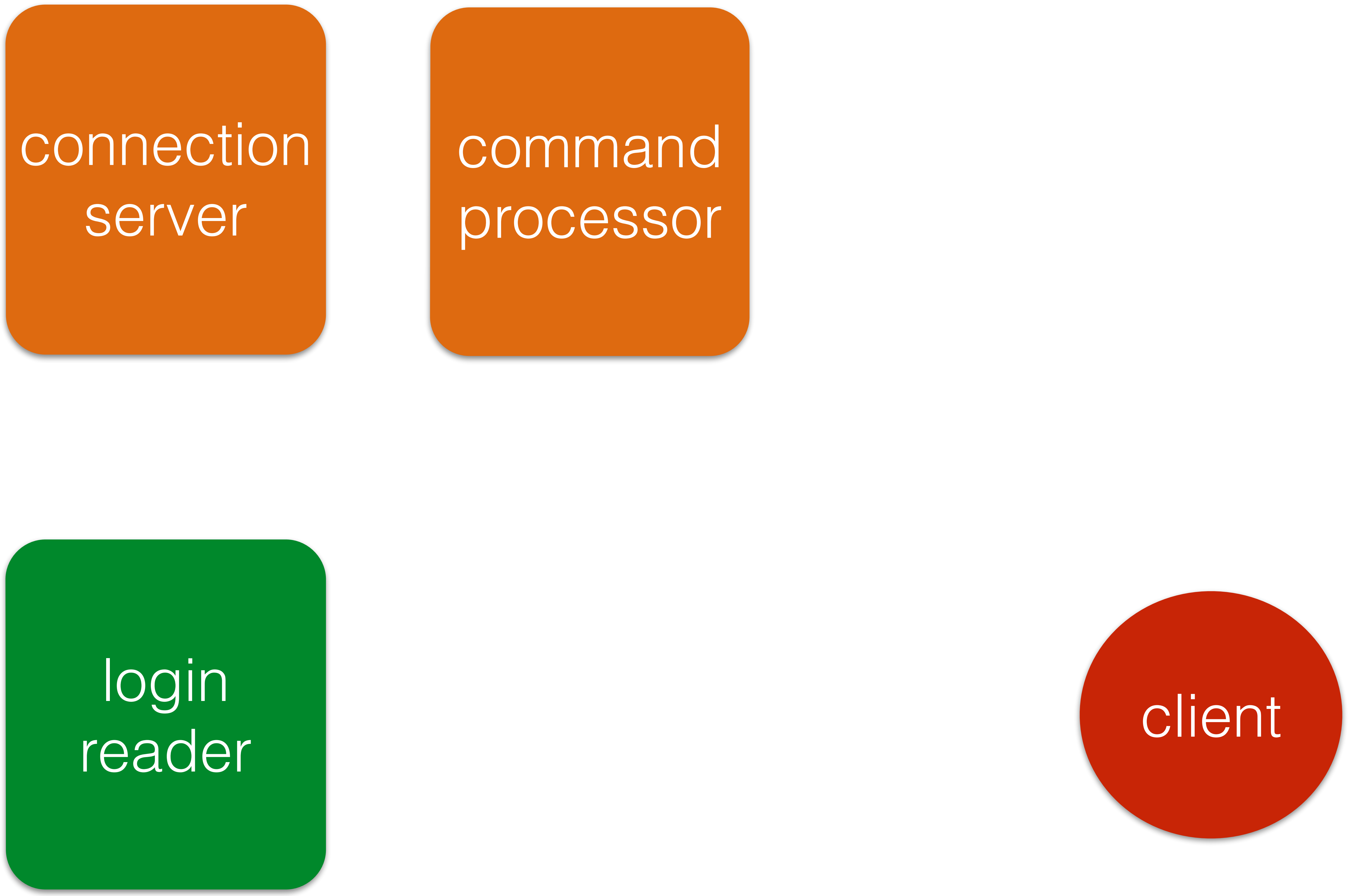


Logging out


connection server
command processor
command reader/ executor
client

Logging out

Attack: Login



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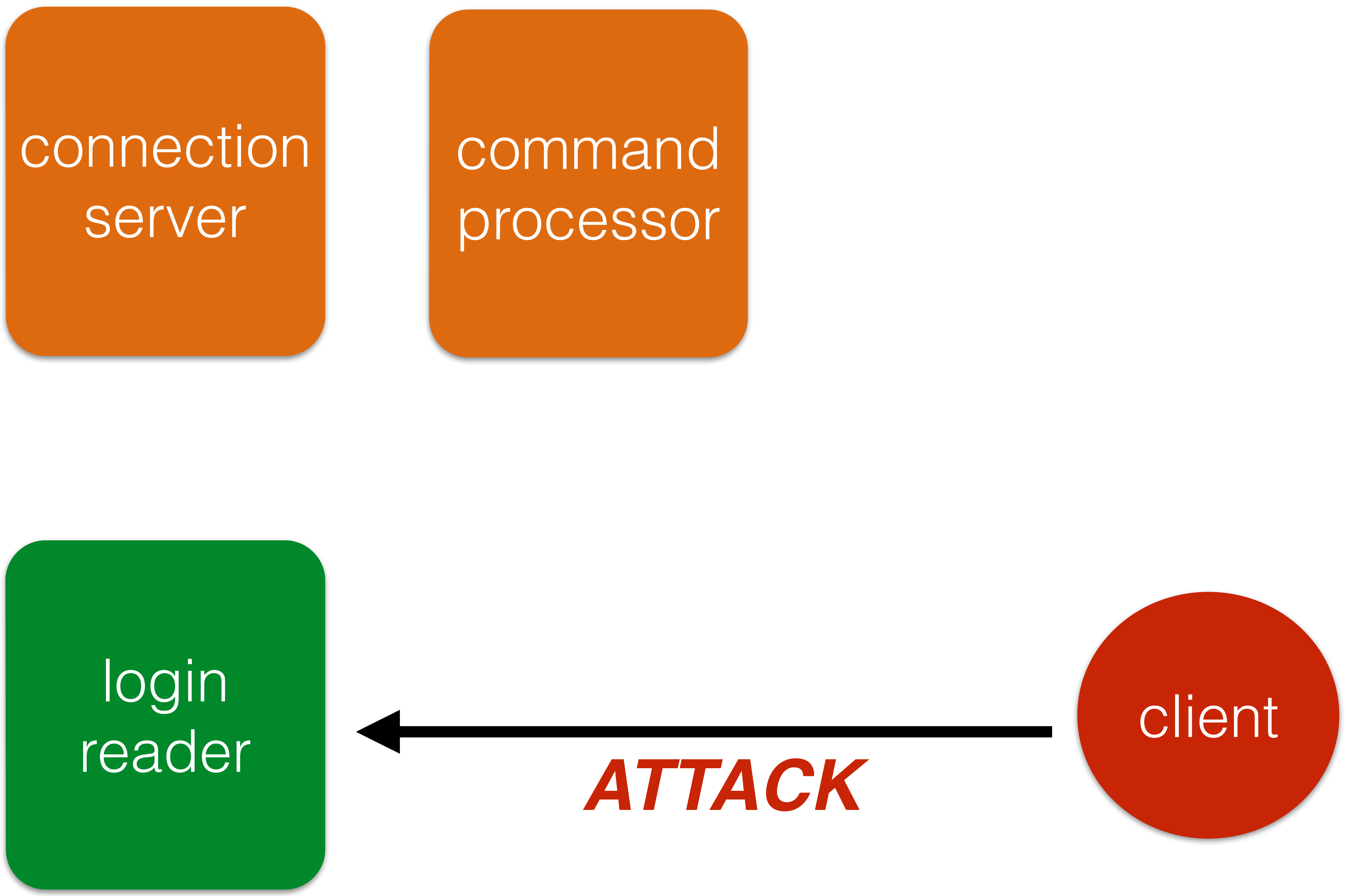
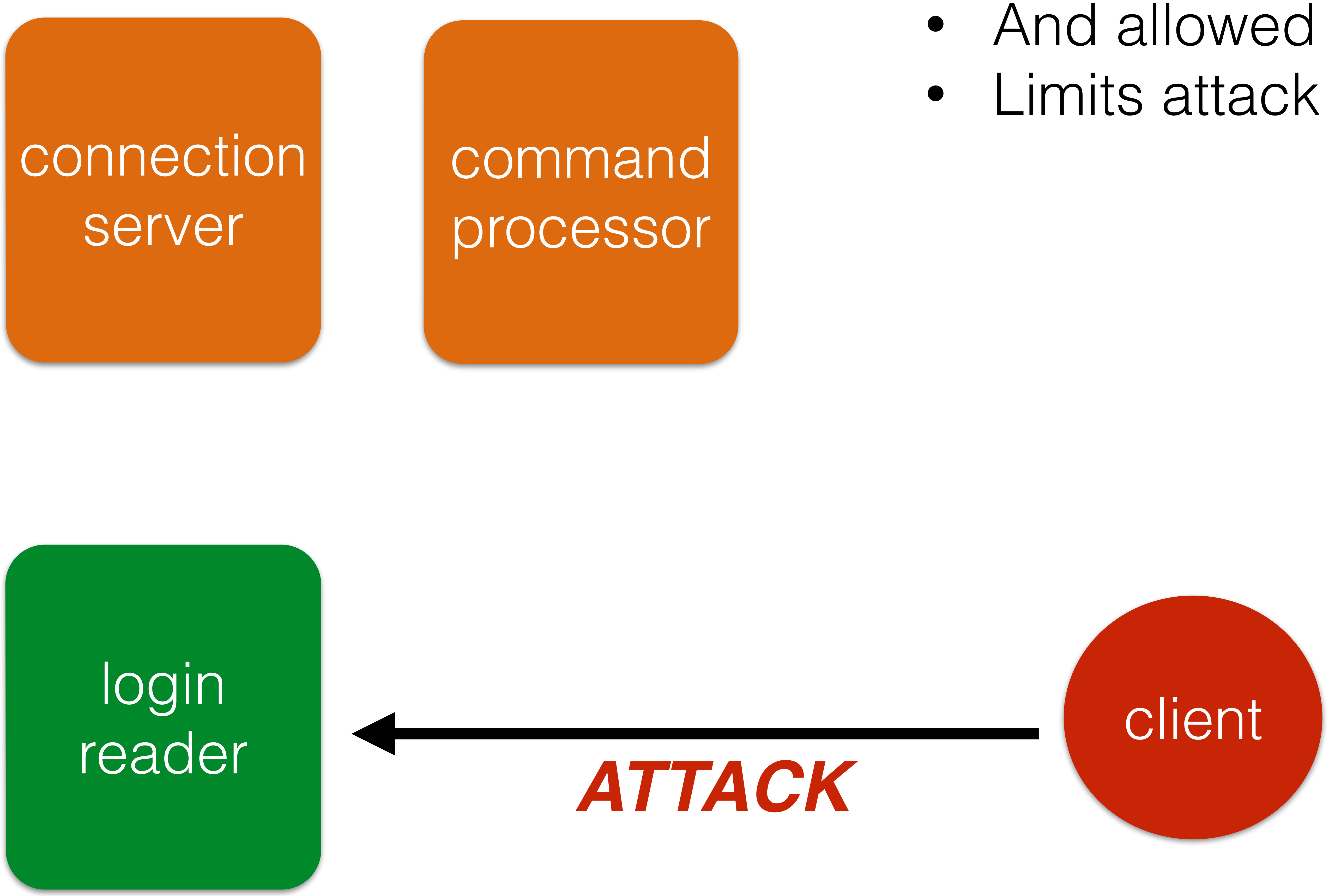


Attack: Login

- **Login reader white-lists input**
  - And allowed input very limited
  - Limits attack surface



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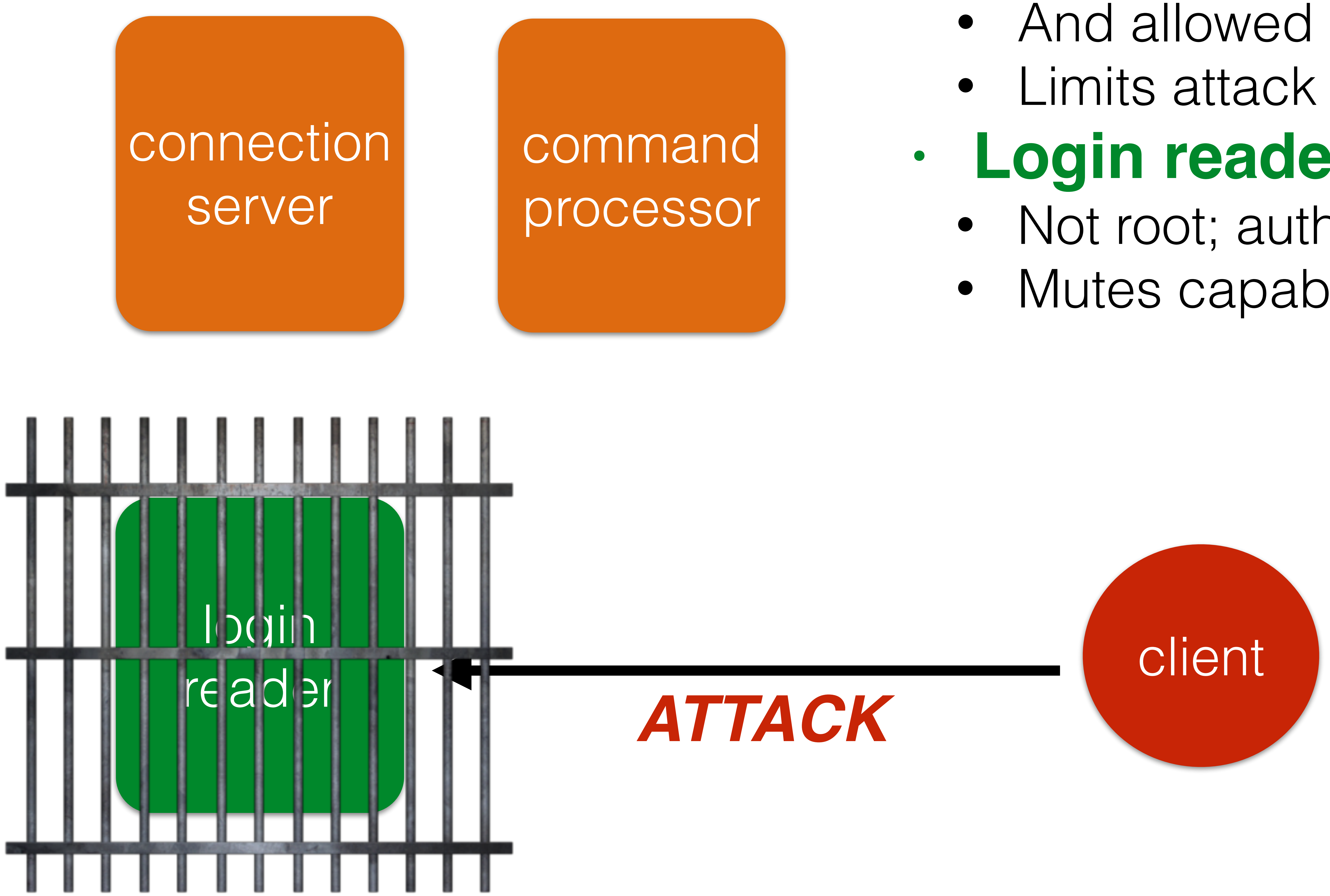

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- **Login reader has limited privilege**
  - Not root; authentication in separate process
  - Mutes capabilities of injected code

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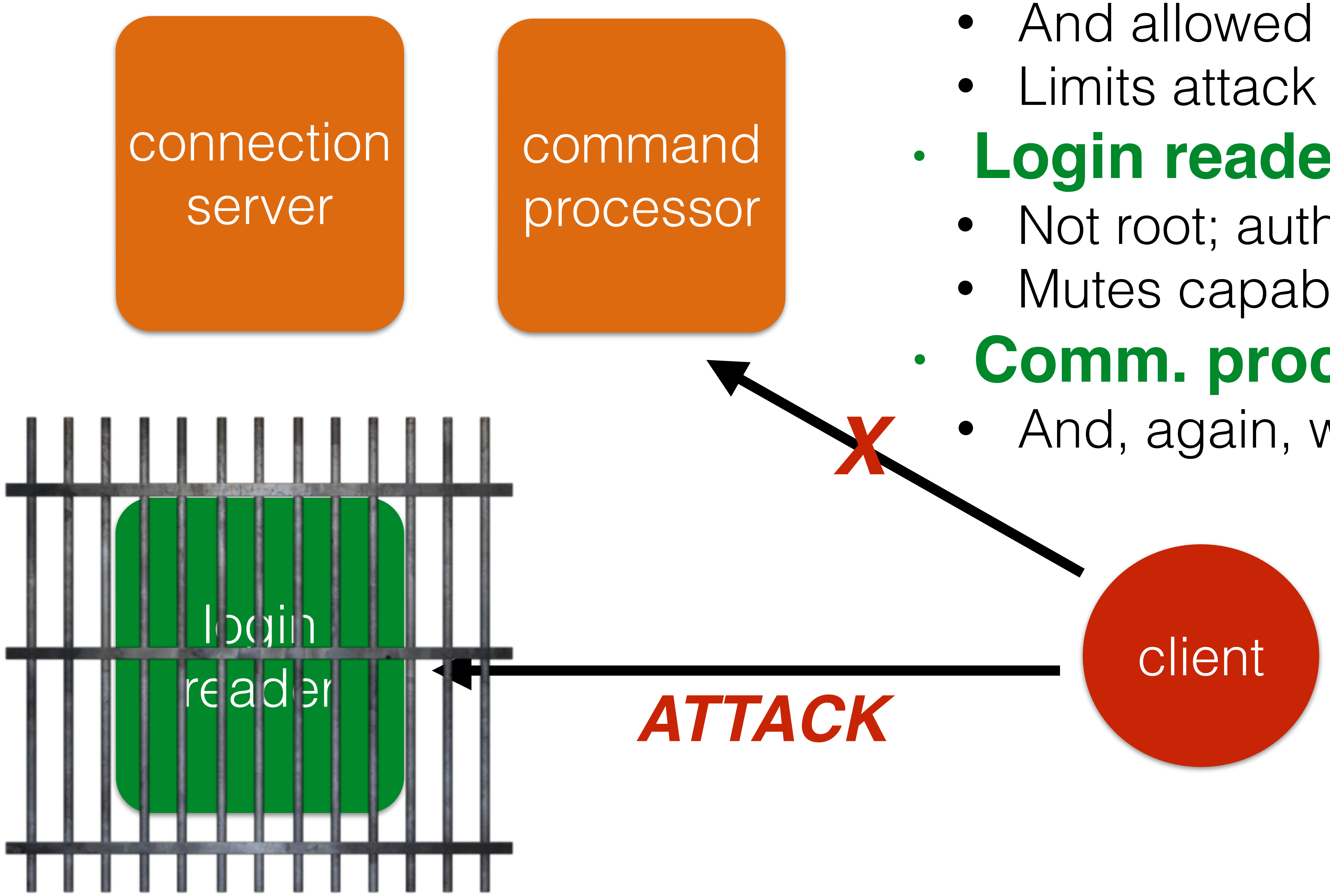
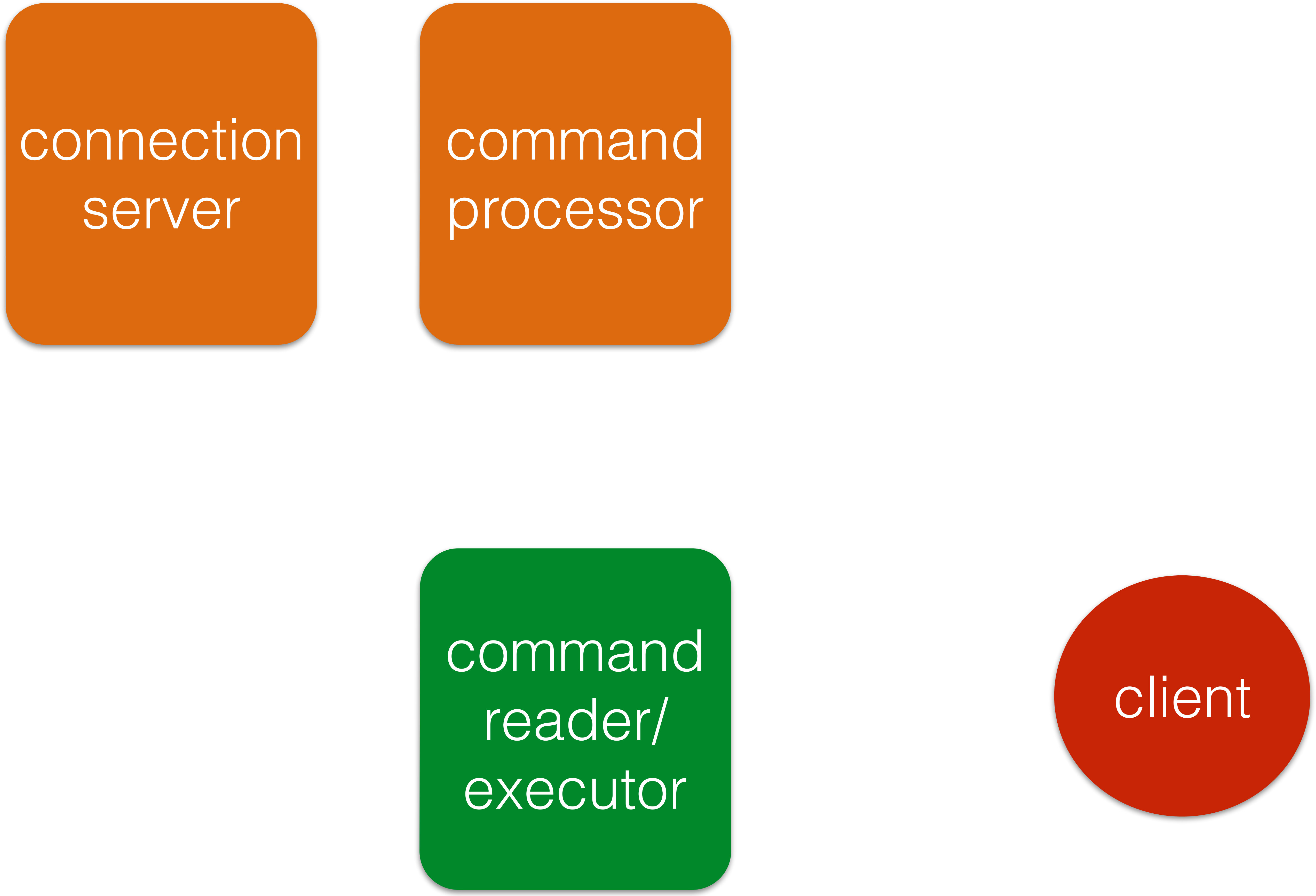


- **Login reader white-lists input**
  - And allowed input very limited
  - Limits attack surface
- **Login reader has limited privilege**
  - Not root; authentication in separate process
  - Mutes capabilities of injected code
- **Comm. proc. only talks to reader**
  - And, again, white-lists its limited input

Attack: Commands



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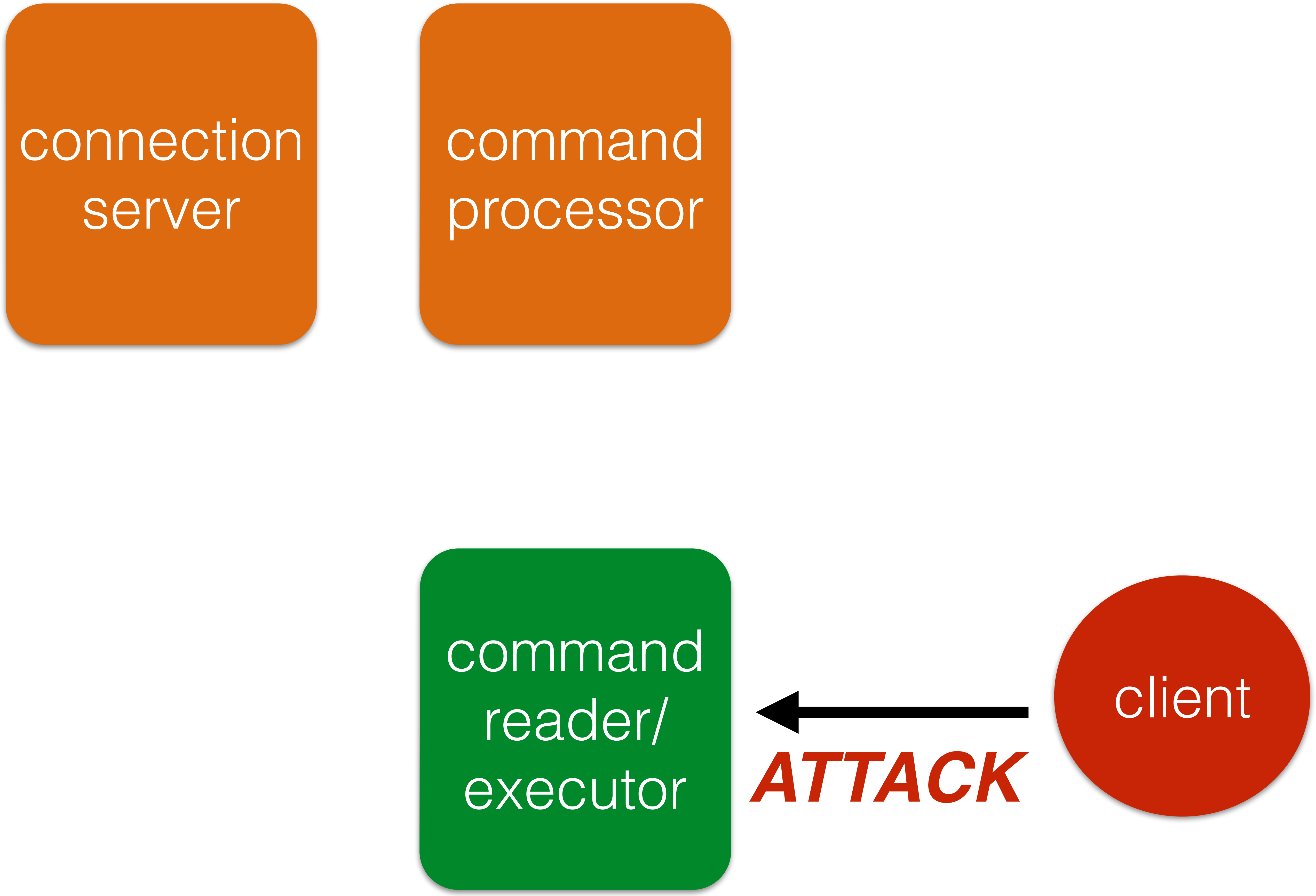

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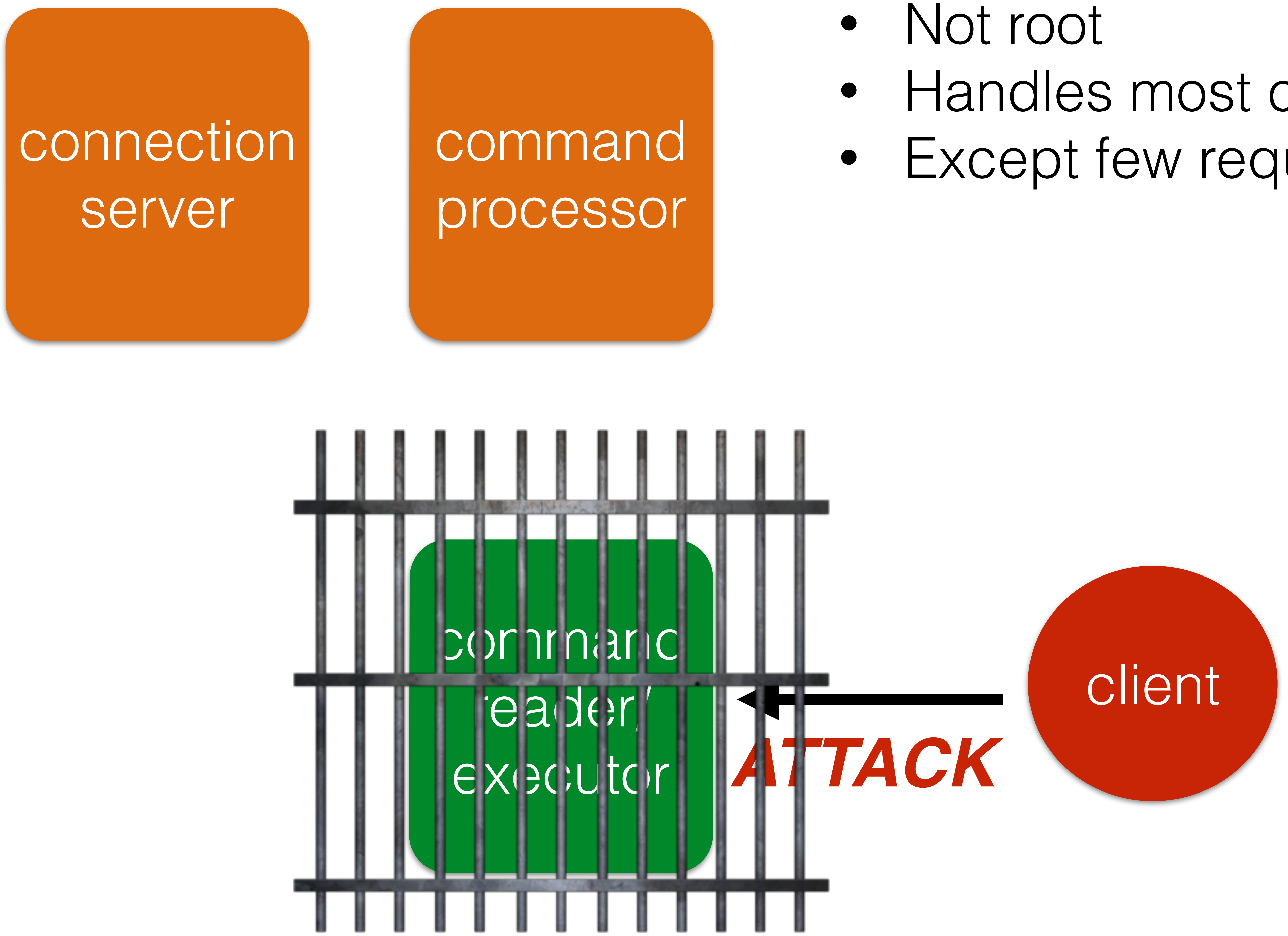

- **Command reader sandboxed**
  - Not root
  - Handles most commands
  - Except few requiring privilege

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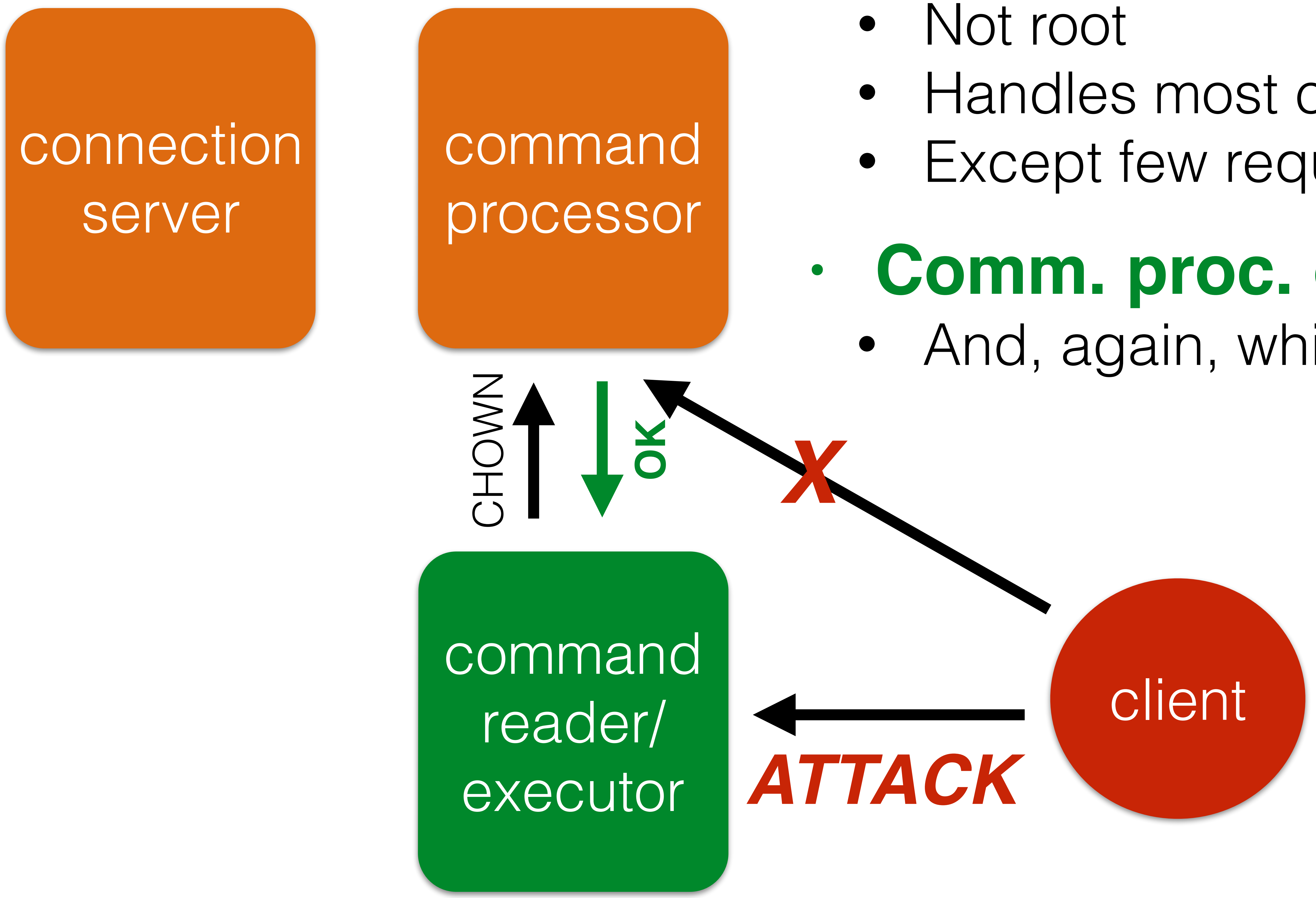

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Attack: Cross-session

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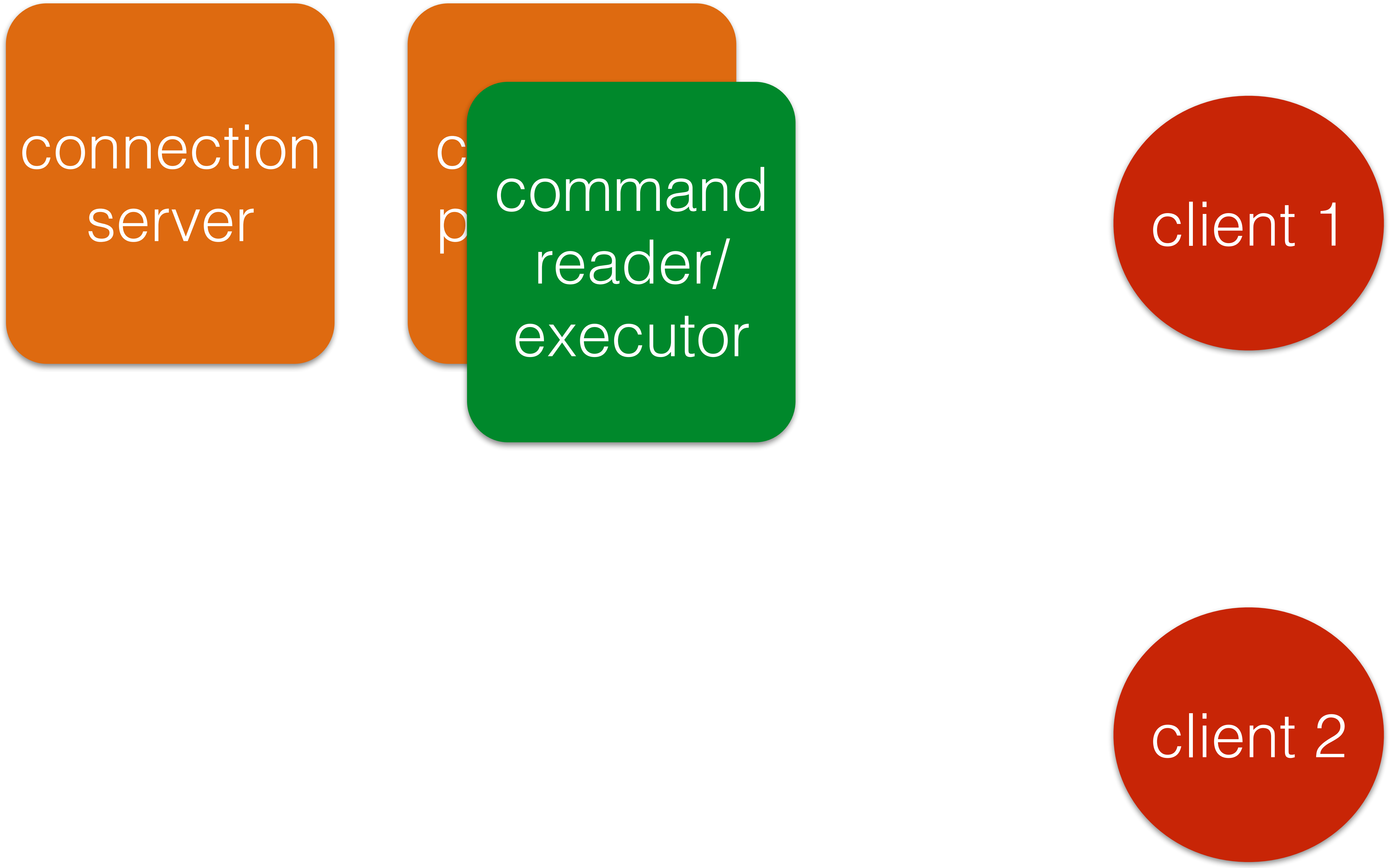

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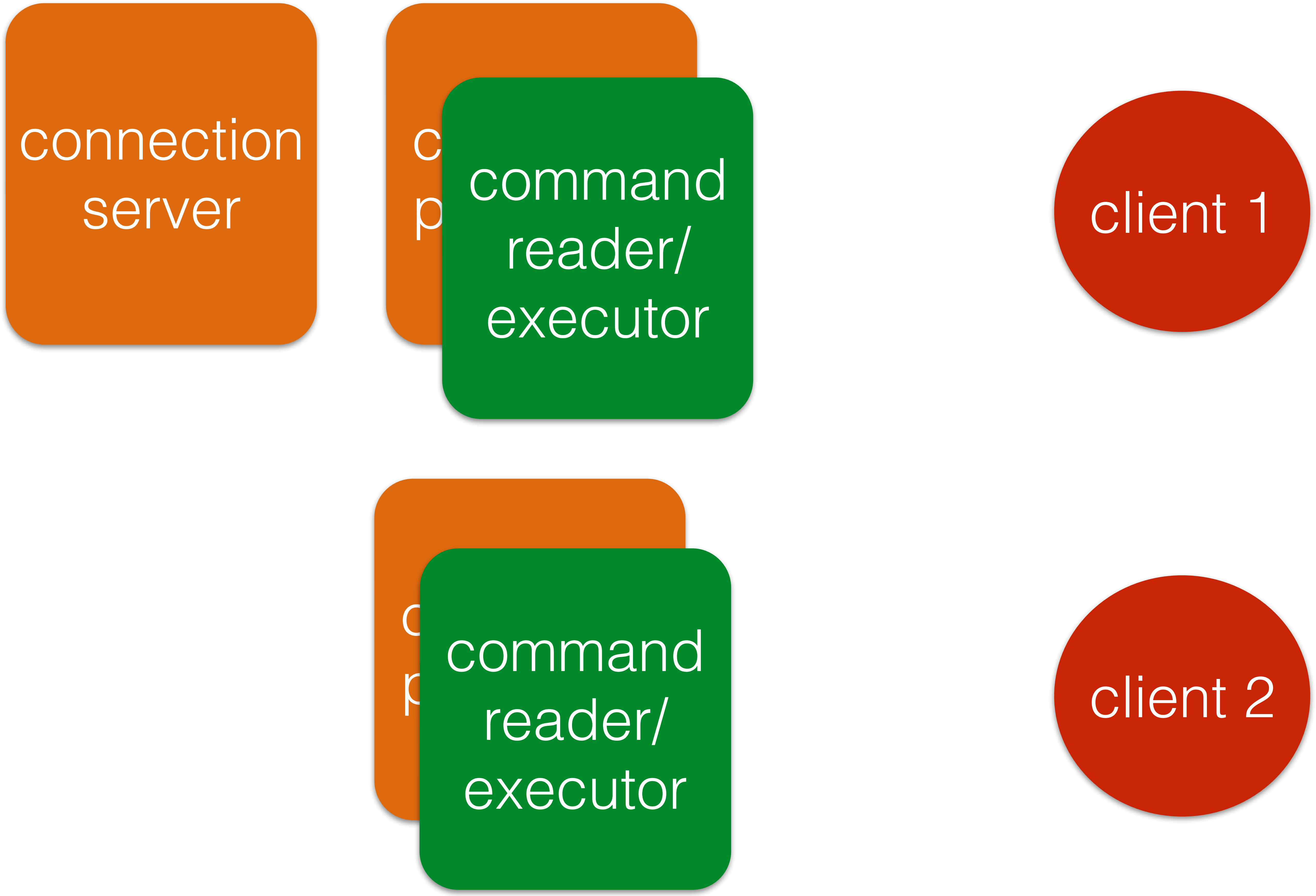

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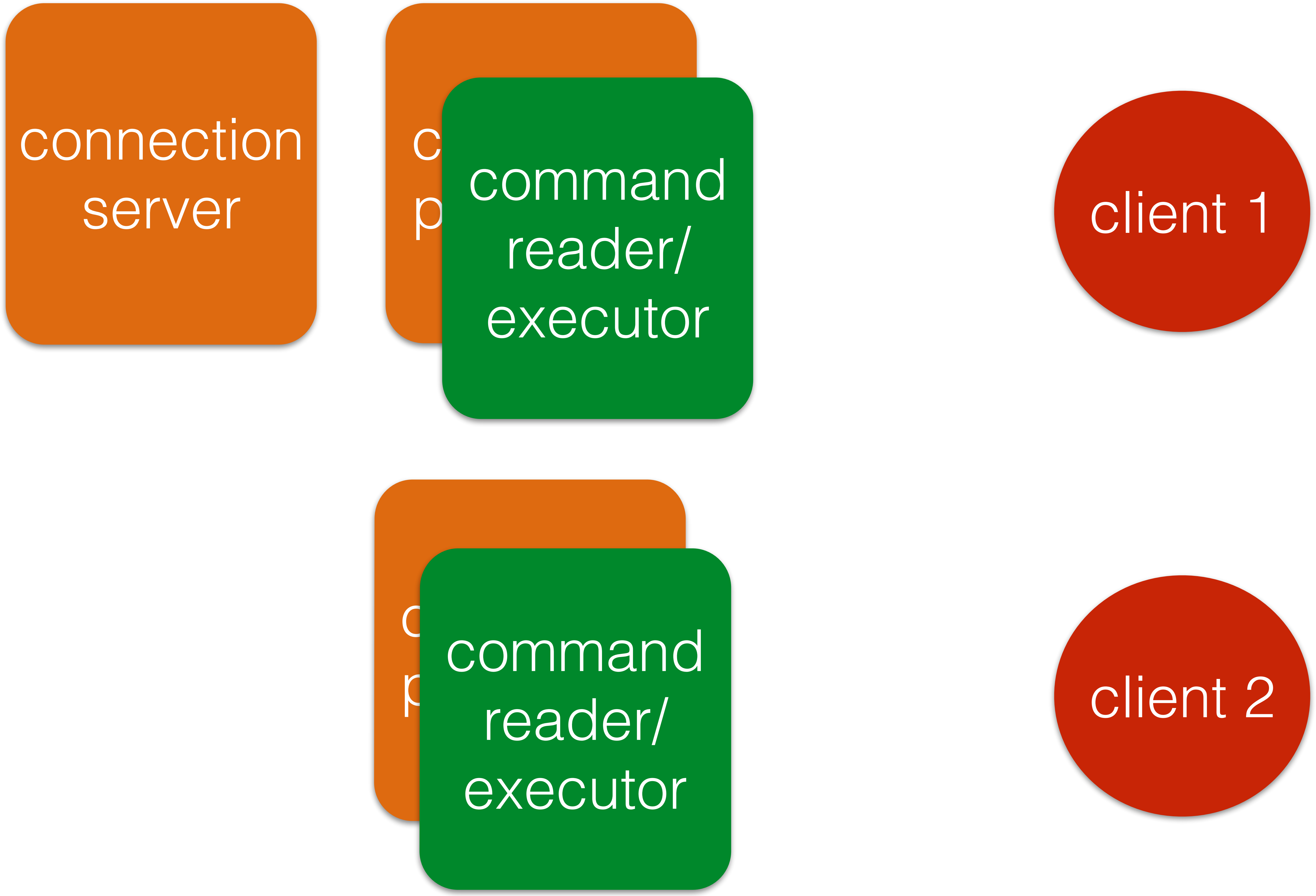

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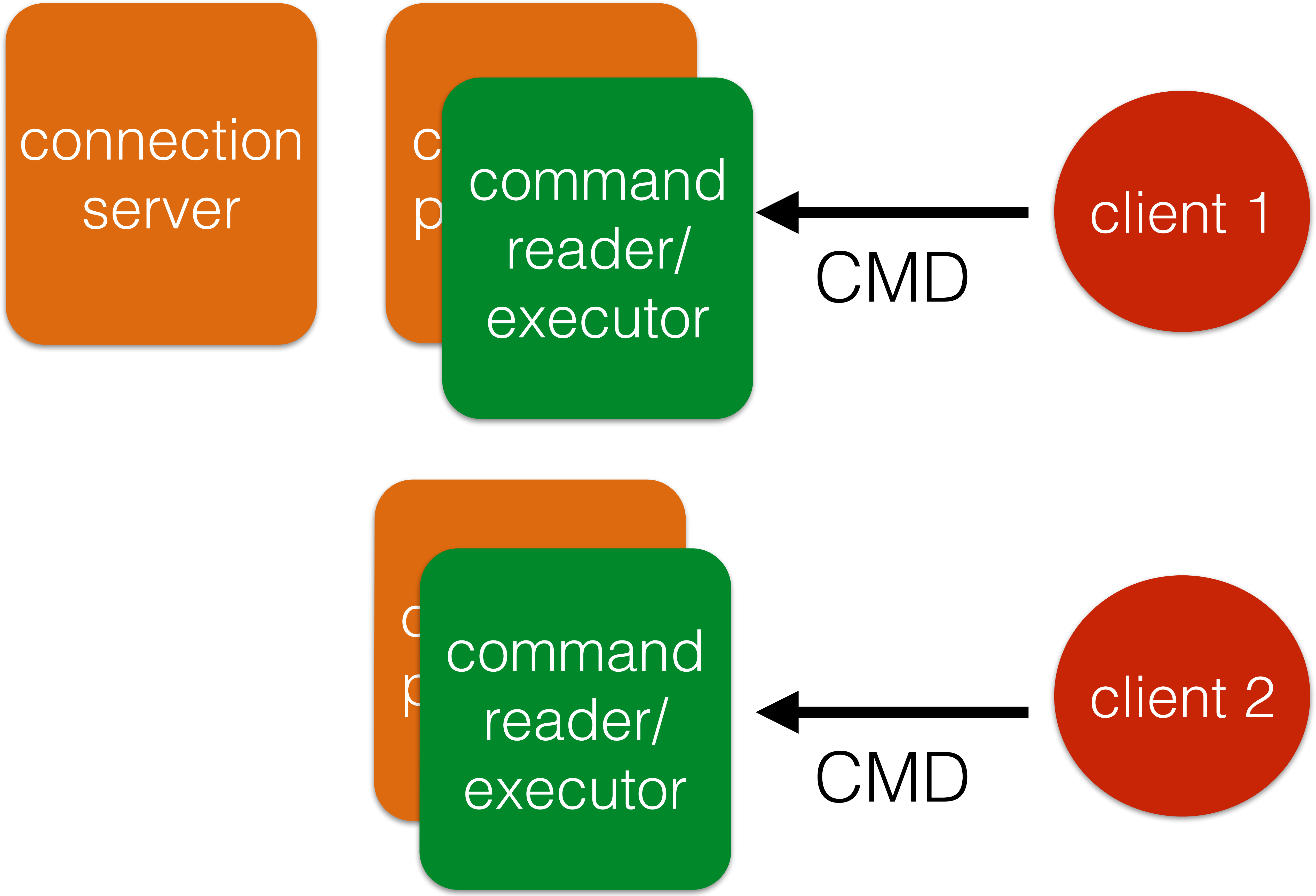

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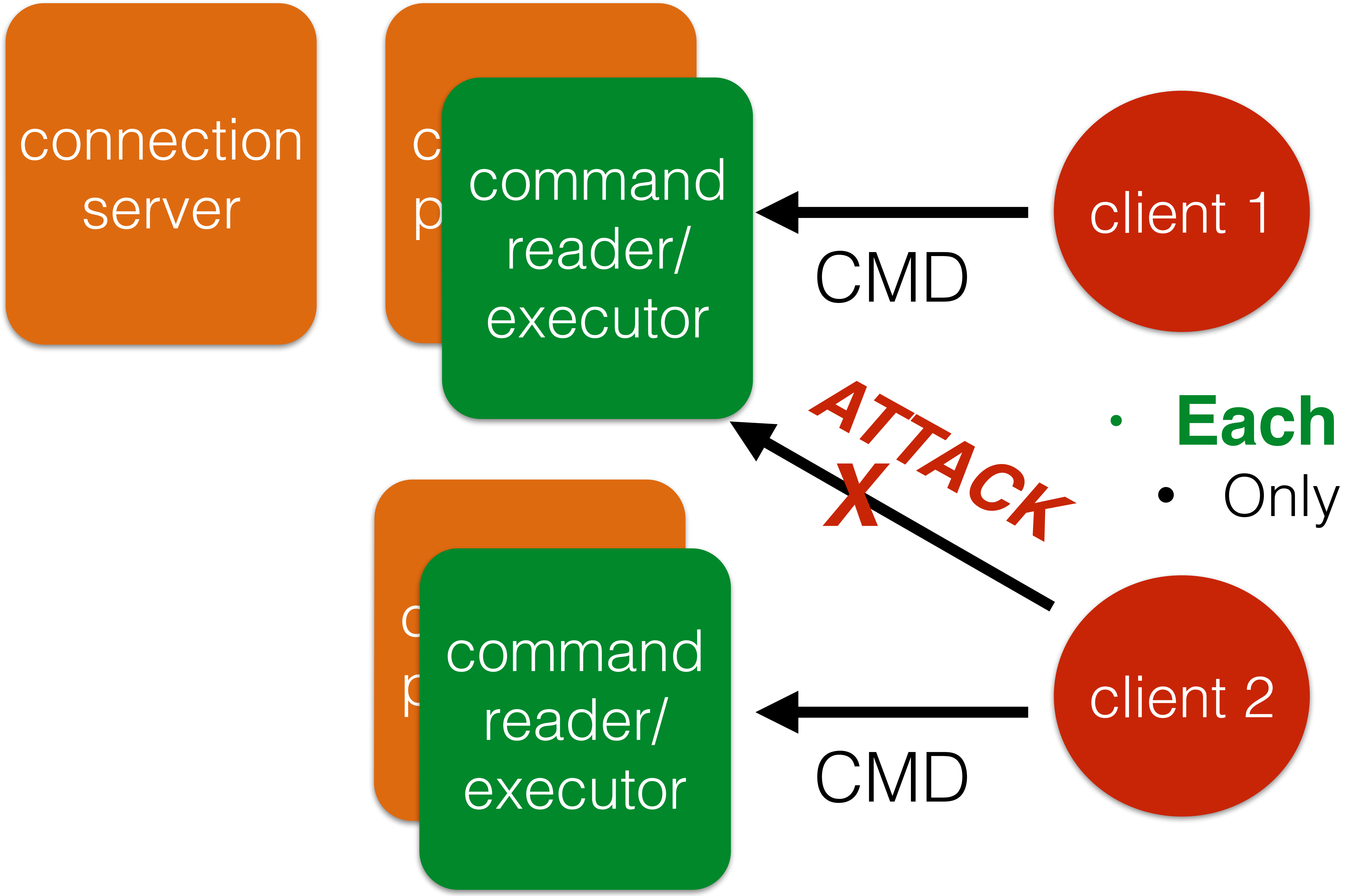

- **Each session isolated**
  - Only can talk to one client

Presenting vsftpd's secure design

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TCB: Privilege separation

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TCB: Privilege separation

Principle of least privilege

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Presenting vsftpd's secure design

vsftpd employs a secure design. The UNIX facilities outlined above are used to good effect. The design decisions taken are as follows:

Separation of responsibilities

1) All parsing and acting on potentially malicious remote network data is done in a process running as an unprivileged user. Furthermore, this process runs in a chroot() jail, ensuring only the ftp files area is accessible.

TCB: KISS

2) Any privileged operations are handled in a privileged parent process. The code for this privileged parent process is as small as possible for safety.

TCB: Privilege separation

3) This same privileged parent process receives requests from the unprivileged child over a socket. All requests are distrusted. Here are example requests:
- Login request. The child sends username and password. Only if the details are correct does the privileged parent launch a new child with the appropriate user credentials.
- chown() request. The child may request a recently uploaded file gets chown'ed() to root for security purposes. The parent is careful to only allow chown() to root, and only from files owned by the ftp user.
- Get privileged socket request. The ftp protocol says we are supposed to emit data connections from port 20. This requires privilege. The privileged parent process creates the privileged socket and passes it to child over the socket.

Principle of least privilege

4) This same privileged parent process makes use of capabilities and chroot(), to run with the least privilege required. After login, depending on what options have been selected, the privileged parent dynamically calculates what privileges it requires. In some cases, this amounts to no privilege, and the privileged parent just exits, leaving no part of vsftpd running with privilege.

5) vsftpd-2.0.0 introduces SSL / TLS support using OpenSSL. ALL OpenSSL protocol parsing is performed in a chroot() jail, running under an unprivileged user. This means both pre-authenticated and post-authenticated OpenSSL protocol parsing; it's actually quite hard to do, but vsftpd manages it in the name of being secure. I'm unaware of any other FTP server which supports both SSL / TLS and privilege separatation, and gets this right.

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Kerkhoff's principle!

Reasoning about code safety

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- Think of it as a **contract** for using the module
  - "Statement 1's postcondition should meet statement 2's precondition"
- **Invariant = Conditions that always hold within some part of a function**

What are the preconditions to ensure safety?

```c
/* requires:                                            */
/* ensures: retval is the first four bytes p pointed to */

int deref(int *p) {
    return *p;
}
```

What are the preconditions to ensure safety?

```
/* requires: p != NULL (and p is a valid pointer)       */
/* ensures: retval is the first four bytes p pointed to */

int deref(int *p) {
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```

What are the postconditions to ensure safety?

```
/* ensures:                                          */

void *myalloc(size_t *n) {
    void *p = malloc(n);
    if (!p) { perror("malloc"); exit(1); }
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int sum(int a[], size_t n) {
    int total = 0;
    for (size_t i=0; i<n; i++)
        total += a[i];
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What are the preconditions to ensure safety?

Approach:

1. Identify each memory access
2. Annotate with preconditions it requires
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No line of code above this guarantees it will hold: so move it up

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Line above it: `size_t i` ensures that `0 <= i` always

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Memory access

Not guaranteed by above code

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Memory access

```c
char *tbl[N];  /* N is of type int */

/* requires:                                                    */
/* ensures:                                                     */
int hash(char *s) {
    int h = 17;
    while (*s)
        h = 257*h + (*s++) + 3;
    return h % N;
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/* requires:                                                    */
bool search(char *s) {
    int i = hash(s);
    return tbl[i] && (strcmp(tbl[i], s)==0);
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char *tbl[N];  /* N is of type int */

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Does this code meet its postconditions?   Need to change `int` to `unsigned int`

Why use pre & postconditions?

- Serves as documentation
- It allows **modular reasoning:** you can verify f() by only looking at
  - The code of f()
  - The annotations on every function that f() calls
- Thus, reasoning about a function's safety becomes an (almost) *purely local activity*
- This is **related to defensive programming**:
  - <u>Ideally</u>: preconditions are the assumptions we make
  - <u>Practically</u>: they're constraints that **honest** clients are expected to follow