Trusted computing base and Code safety

Slides from Dave Levin 414-spring2016

Trusted computing bases

Every system has a TCB

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

What is trustworthy here?

What is not trustworthy here?


Bradesco
Tarifas de
Serviços Bancários


widelec.org


Lutujeme, ale bankomat je

Security requires the TCB be

- Correct
- Complete
- Secure

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Two key 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

Failure: Large TCB

- **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

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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

SecComp

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  - Affected process can subsequently **only perform `read`, `write`, `exit`, and `sigreturn` system calls**
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- Follow-on work produced **seccomp-bpf**
  - **Limit process to policy-specific set of system calls**, subject to a policy handled by the kernel
    - Policy akin to *Berkeley Packet Filters (BPF)*
  - Used by *Chrome*, *OpenSSH*, *vsftpd*, and others

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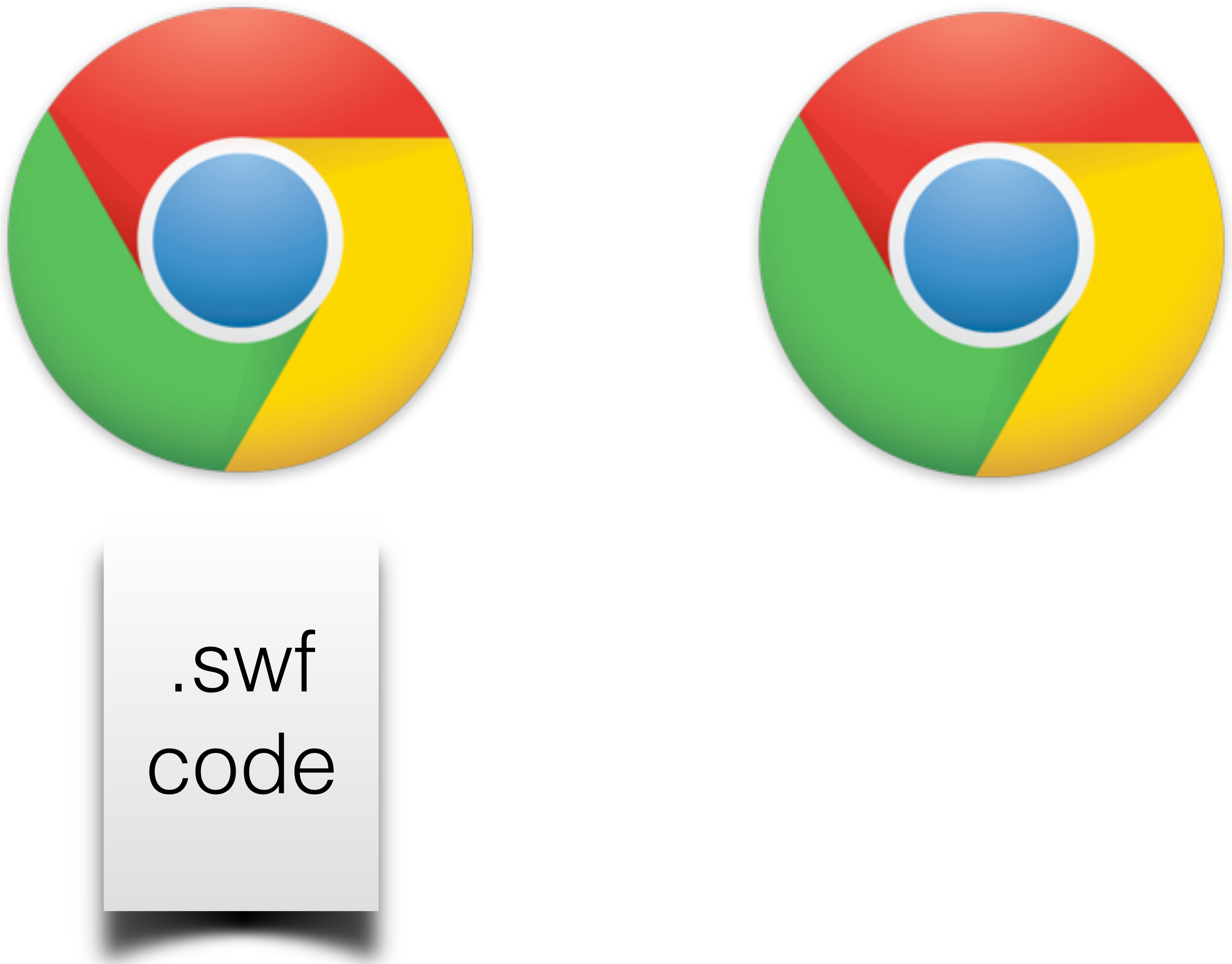

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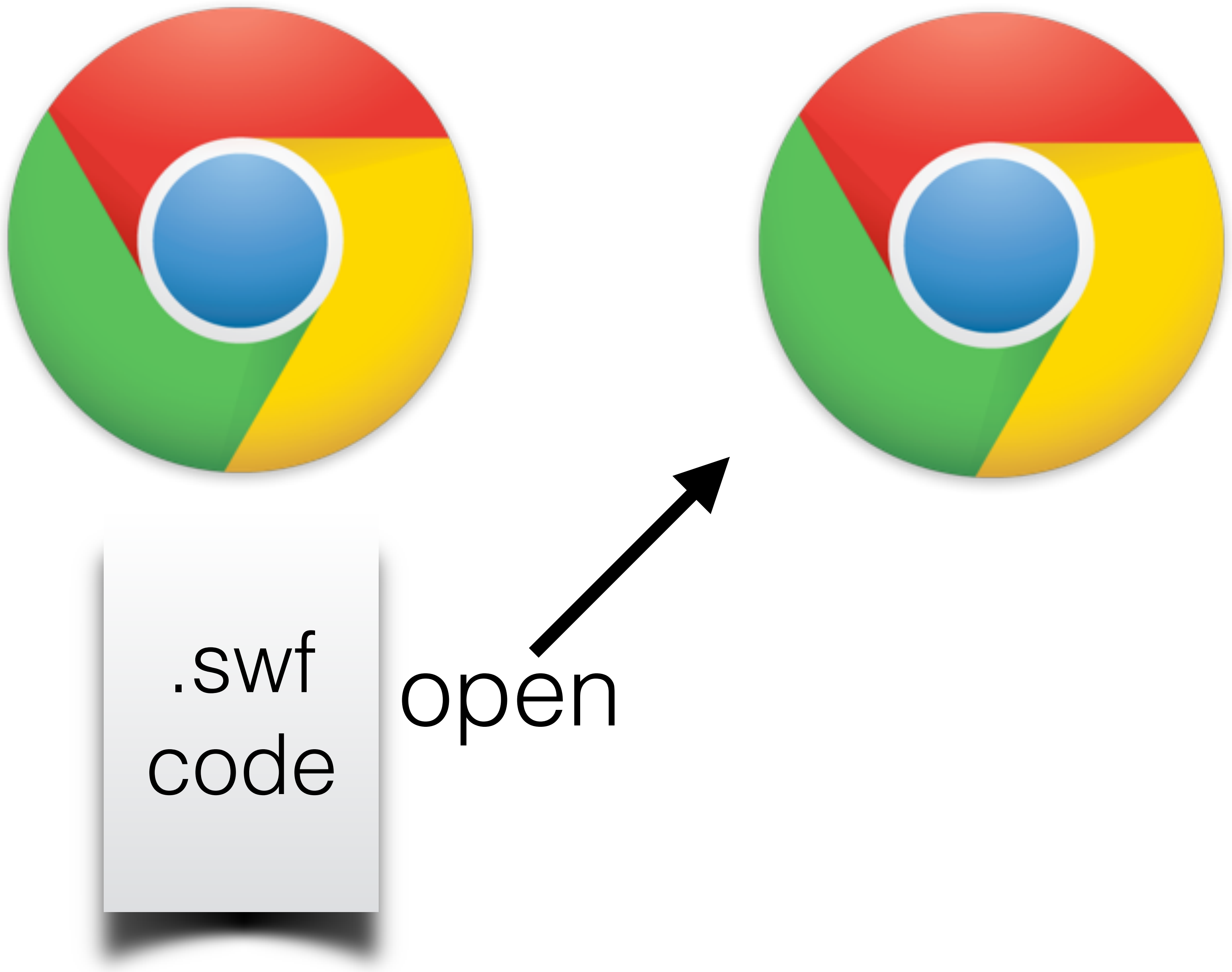

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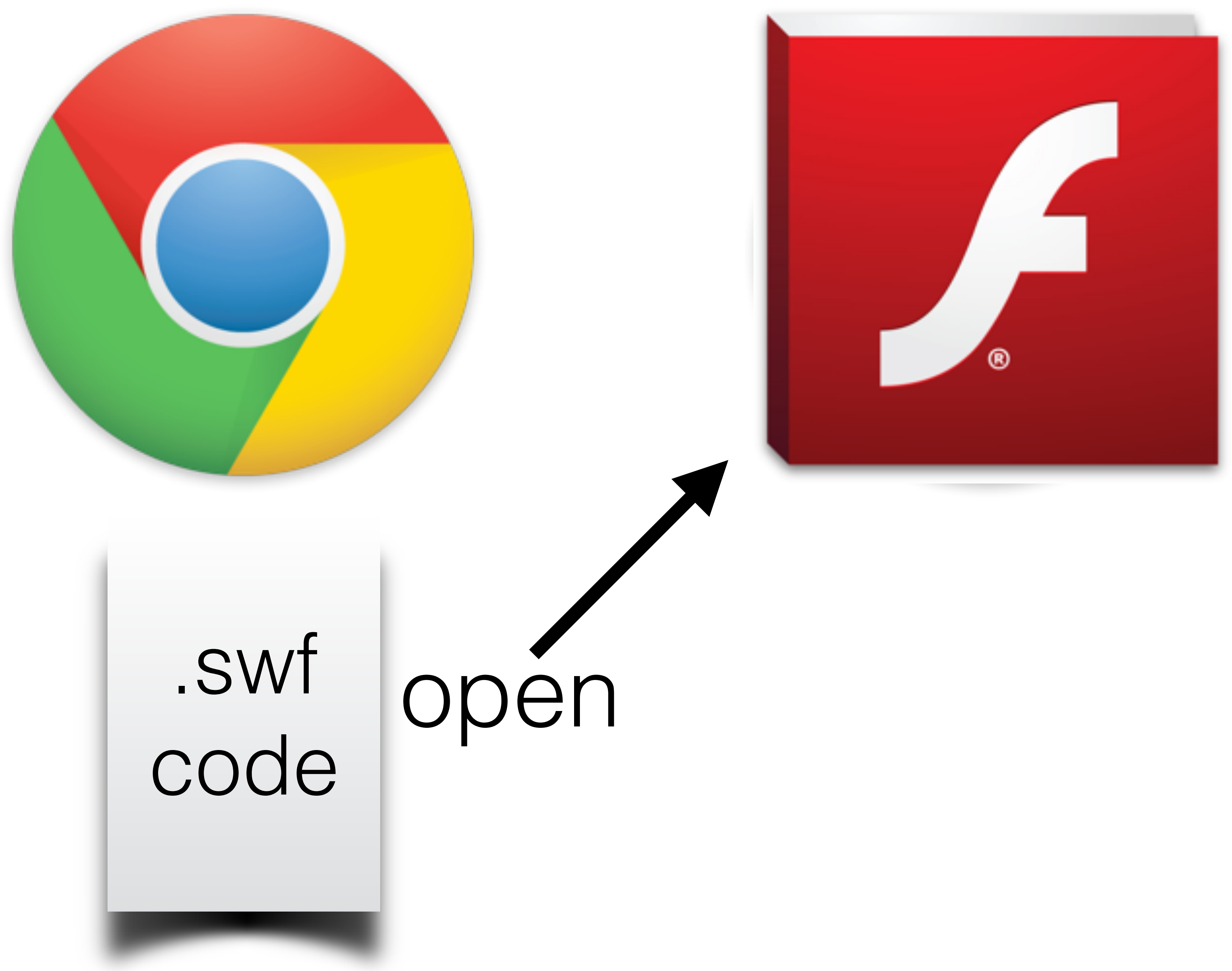

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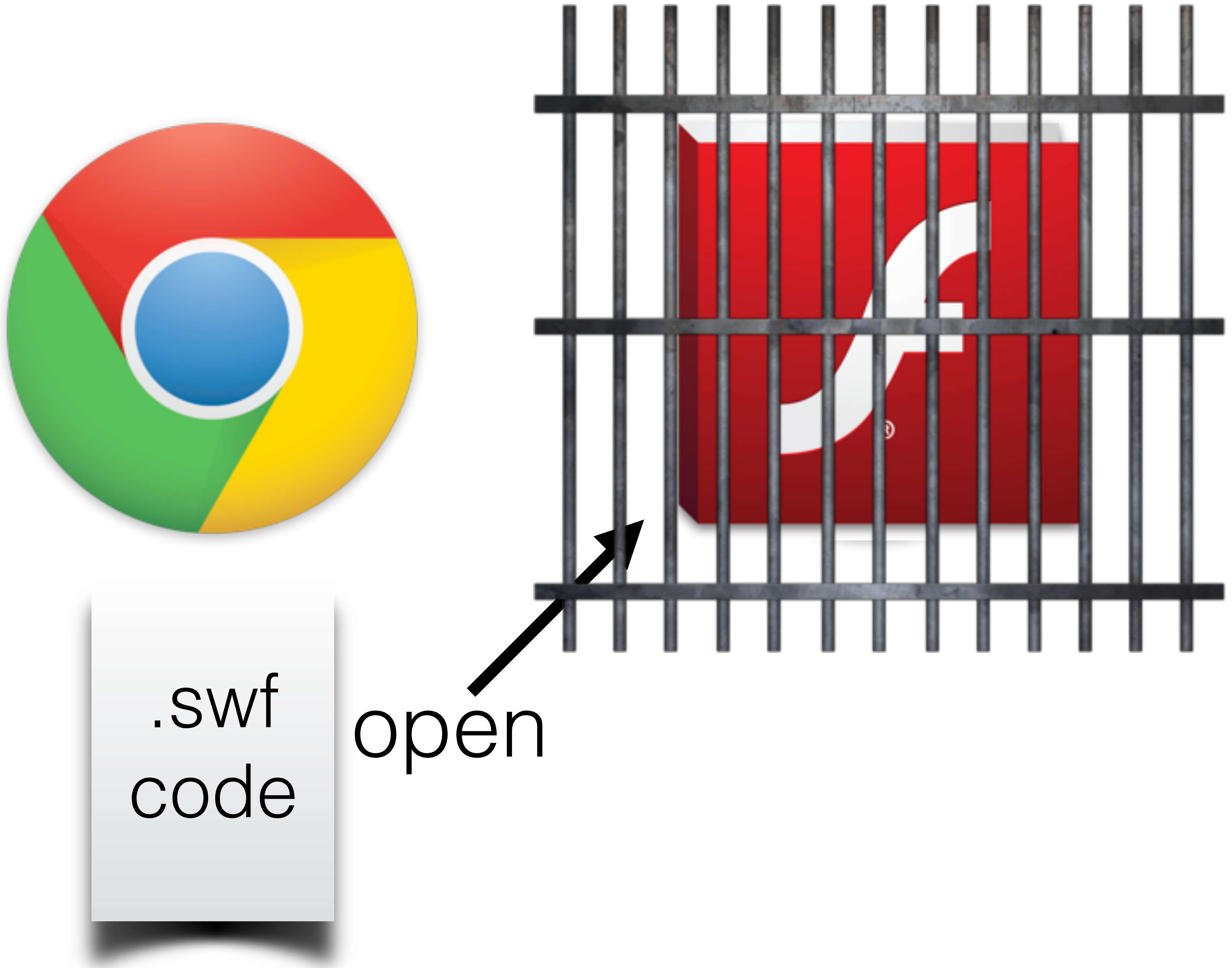
- Call **`seccomp-bpf`** to compartmentalize



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;
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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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};
```

```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`

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void
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  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?
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  - What if returned value is NULL?
    - Oftentimes, a de-reference 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)
  {
    die("malloc");
  }
  return p_ret;
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fails if it receives malformed argument or runs out of memory

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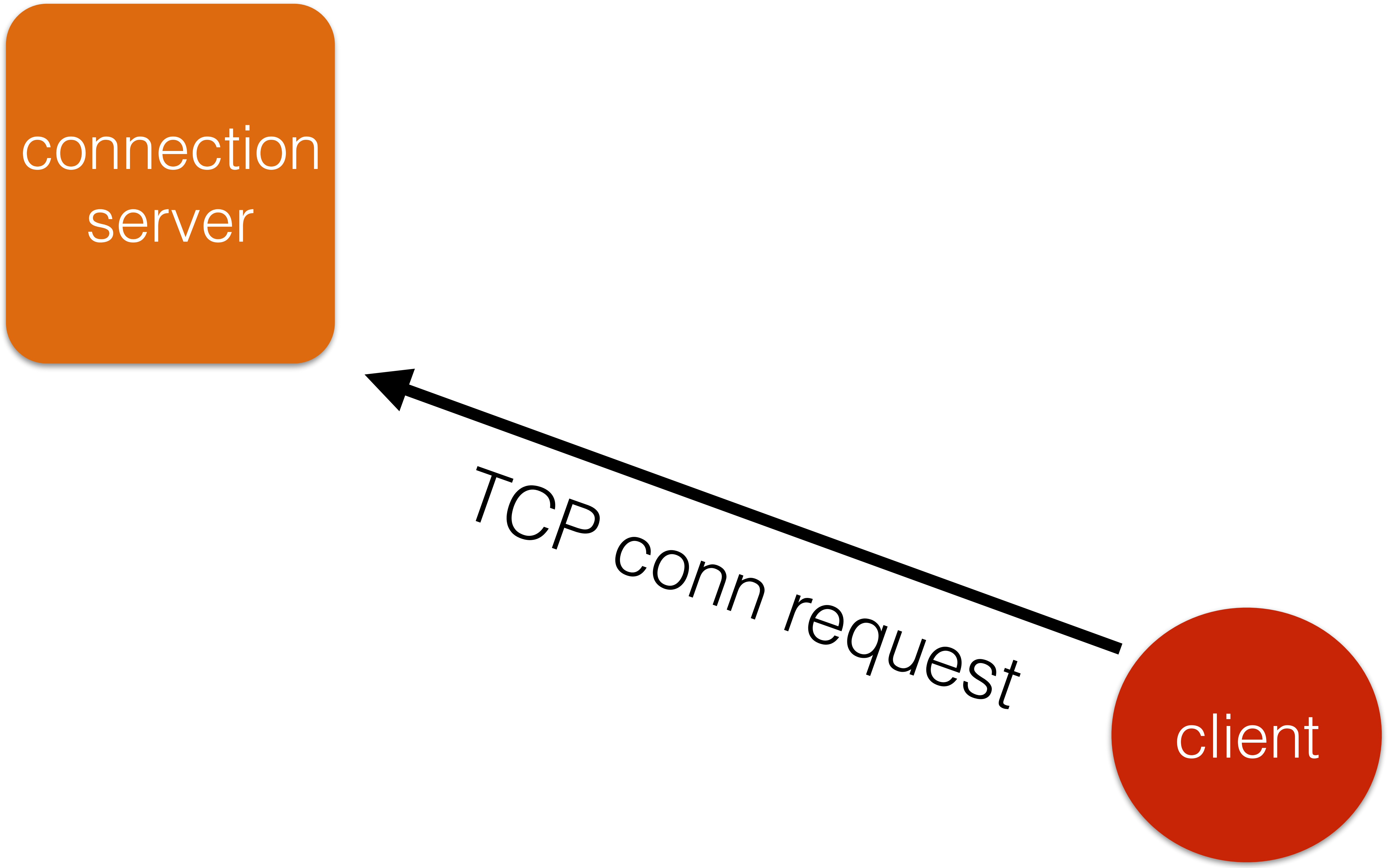

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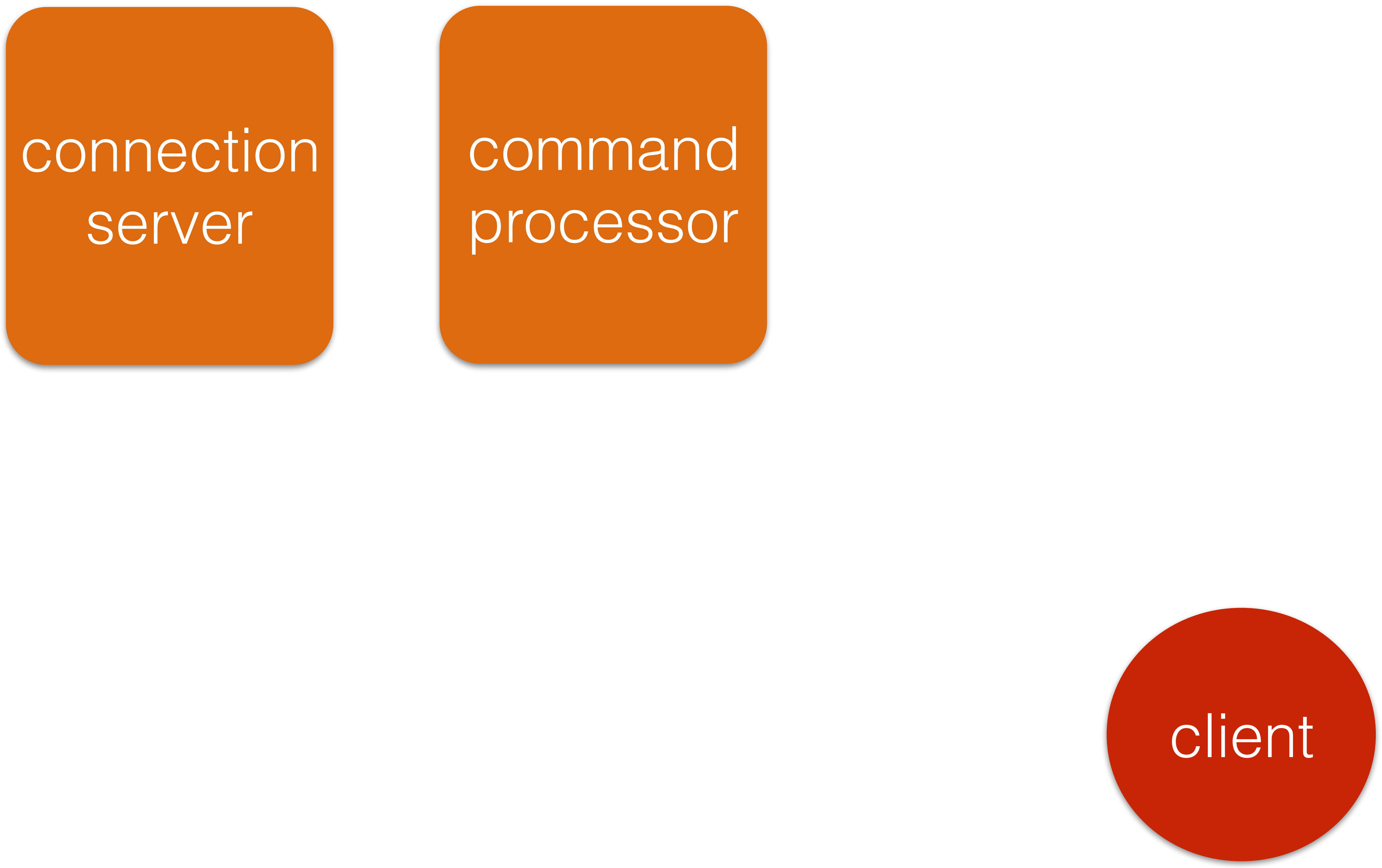

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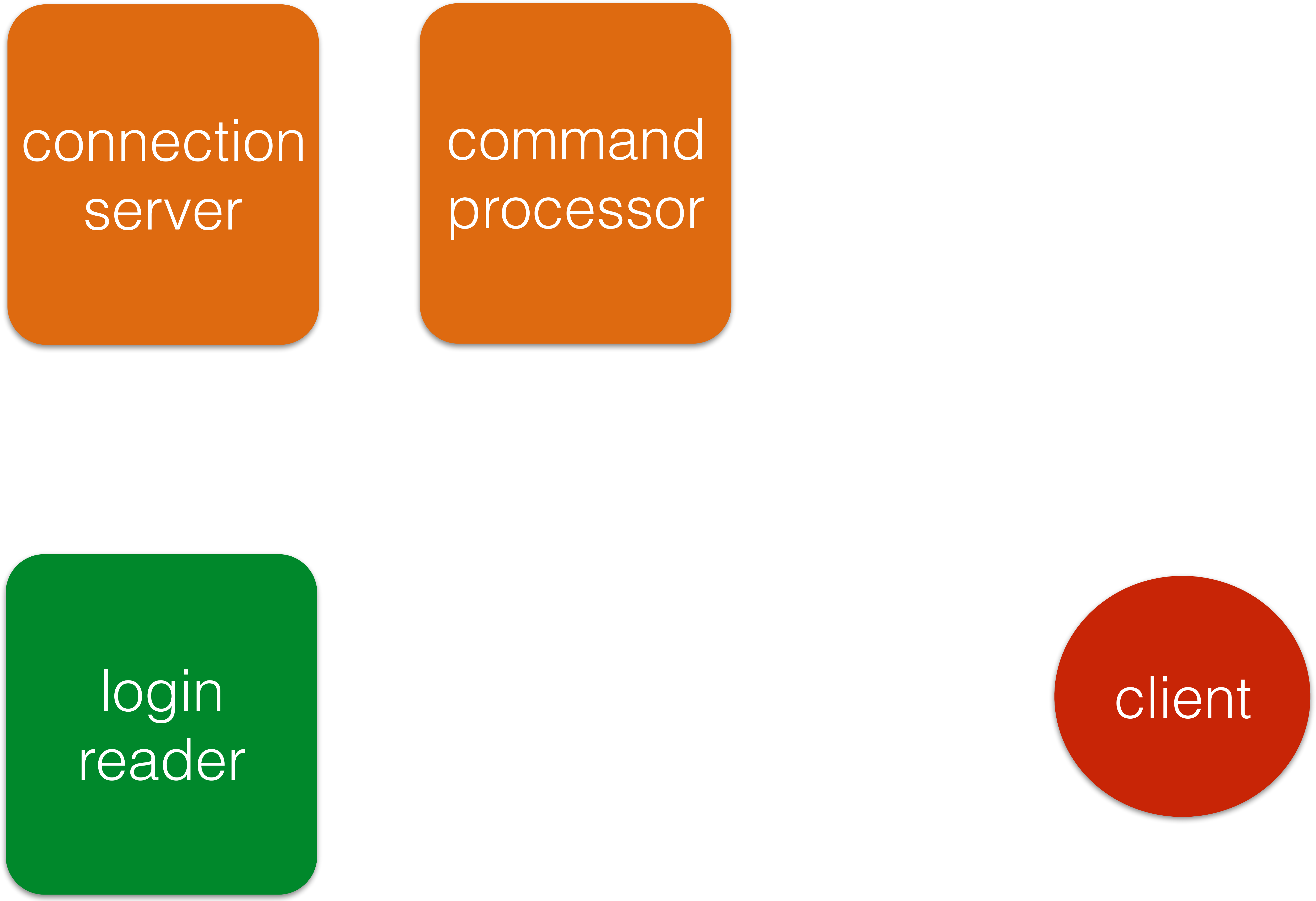

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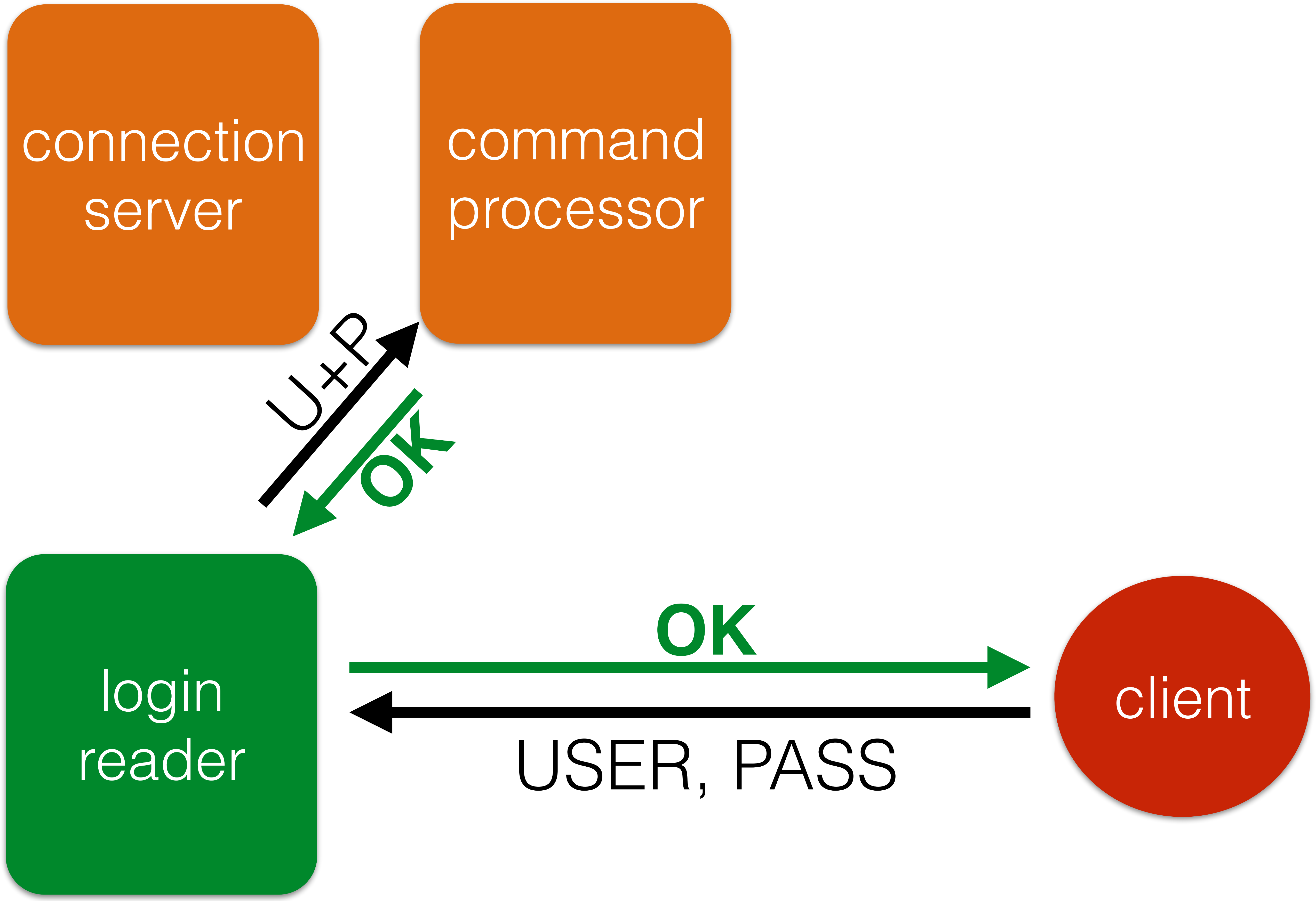

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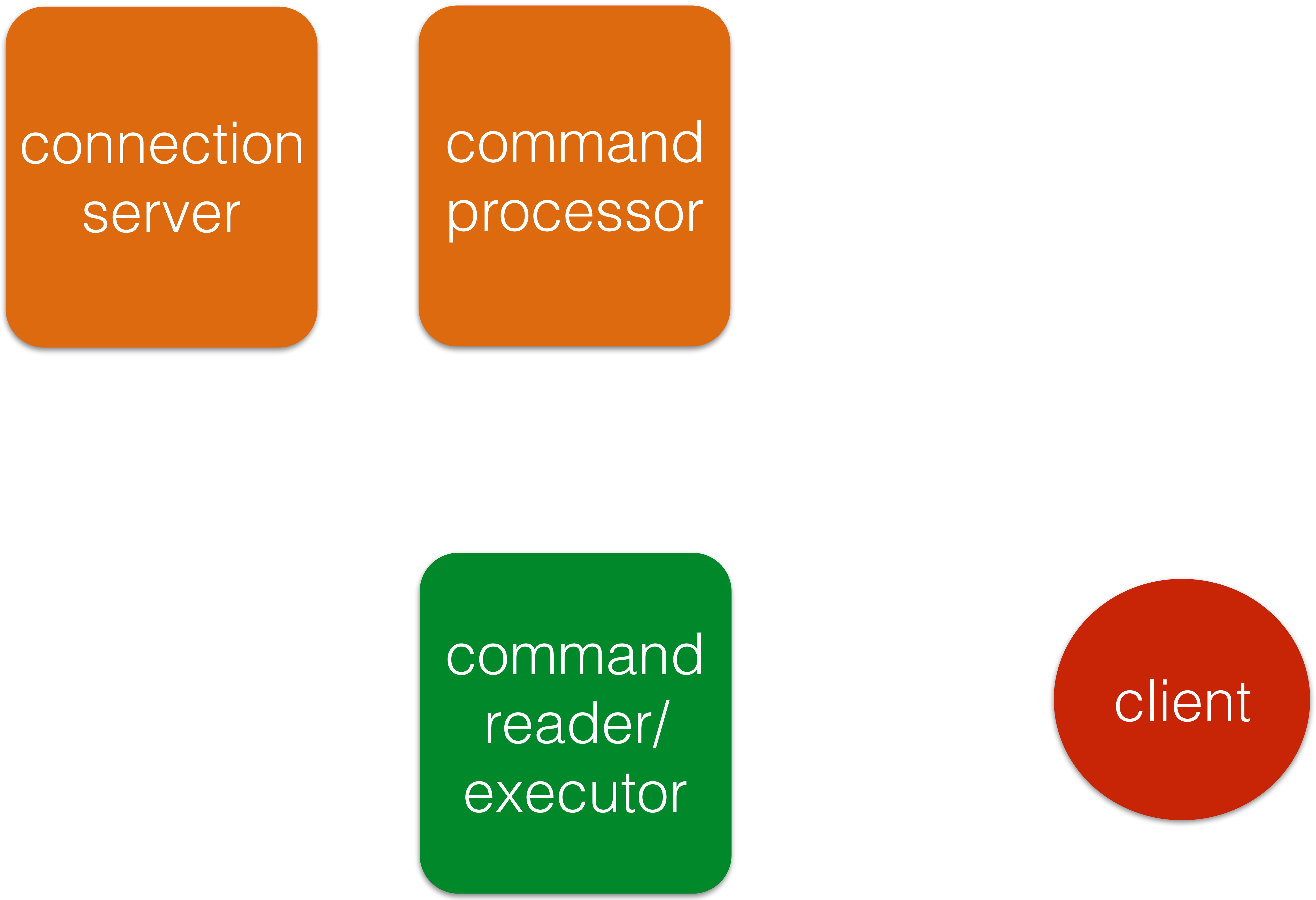

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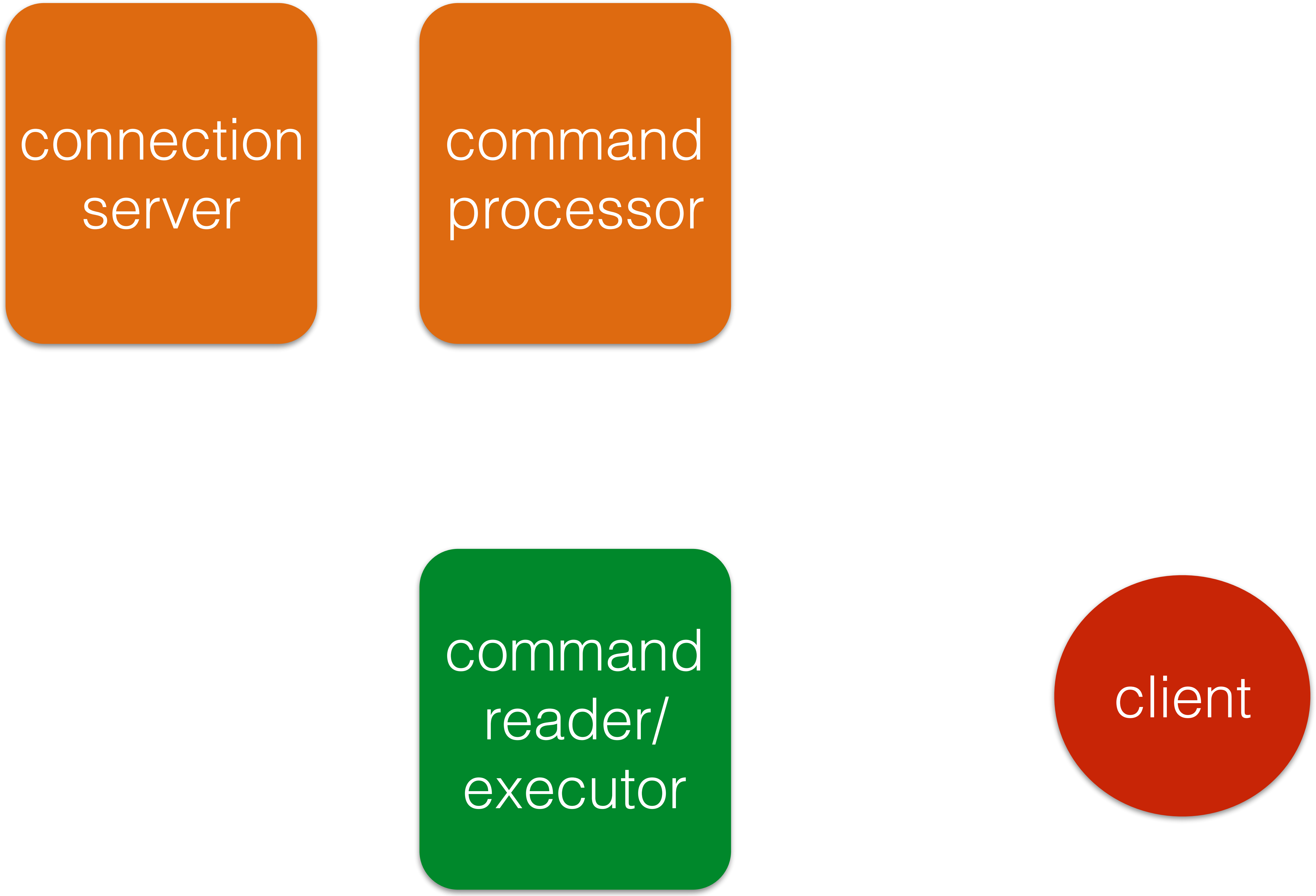

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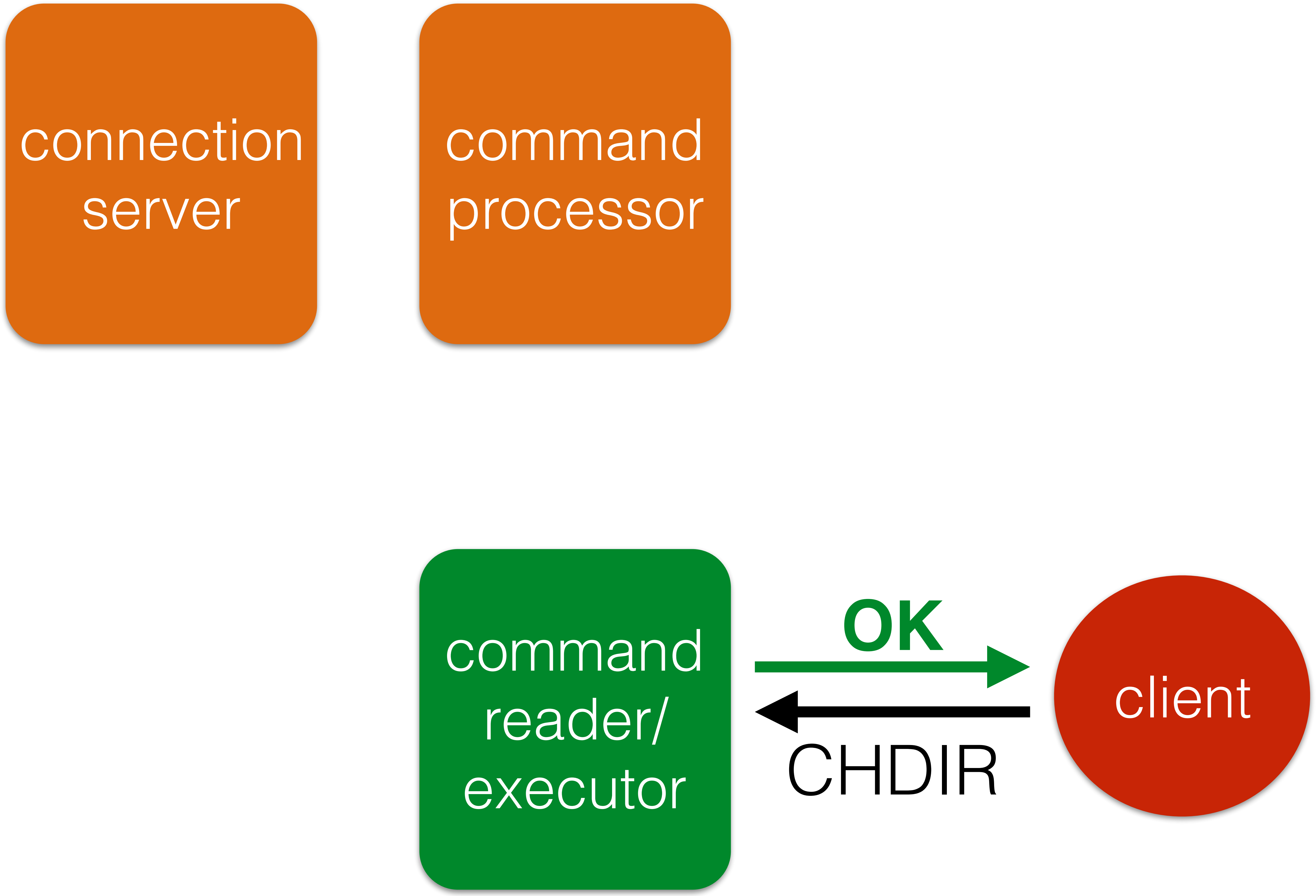

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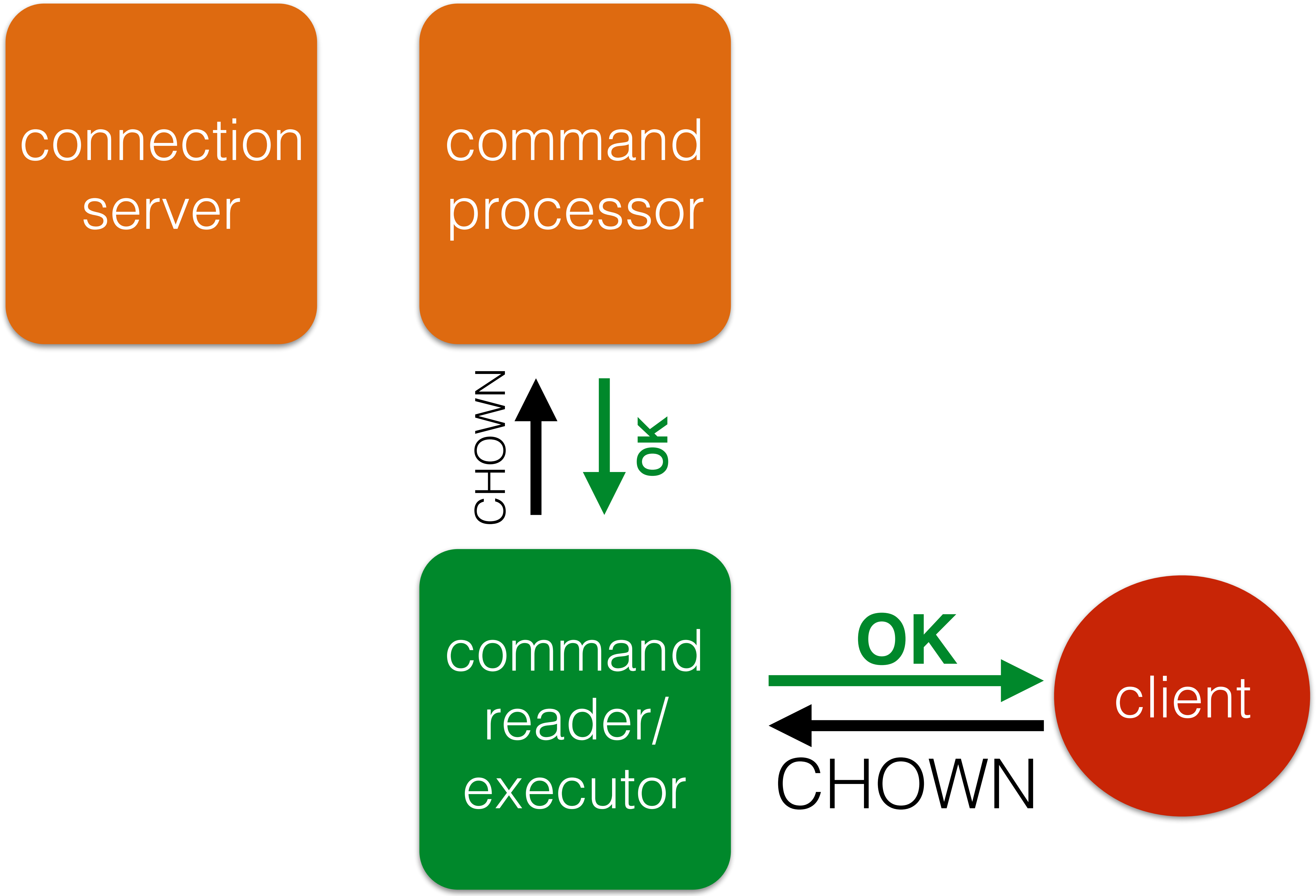
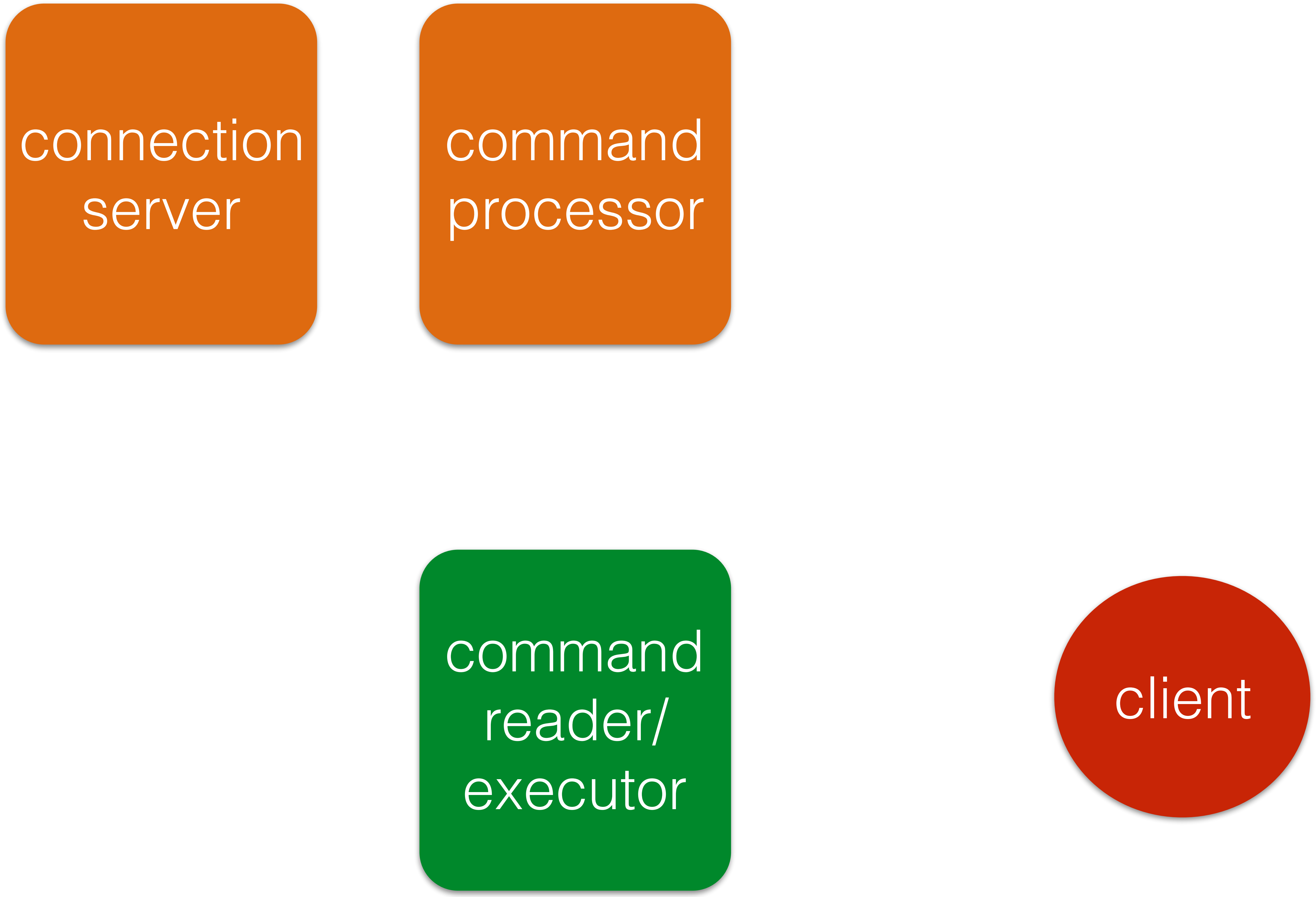


Logging out


connection server
command processor
command reader/ executor
client

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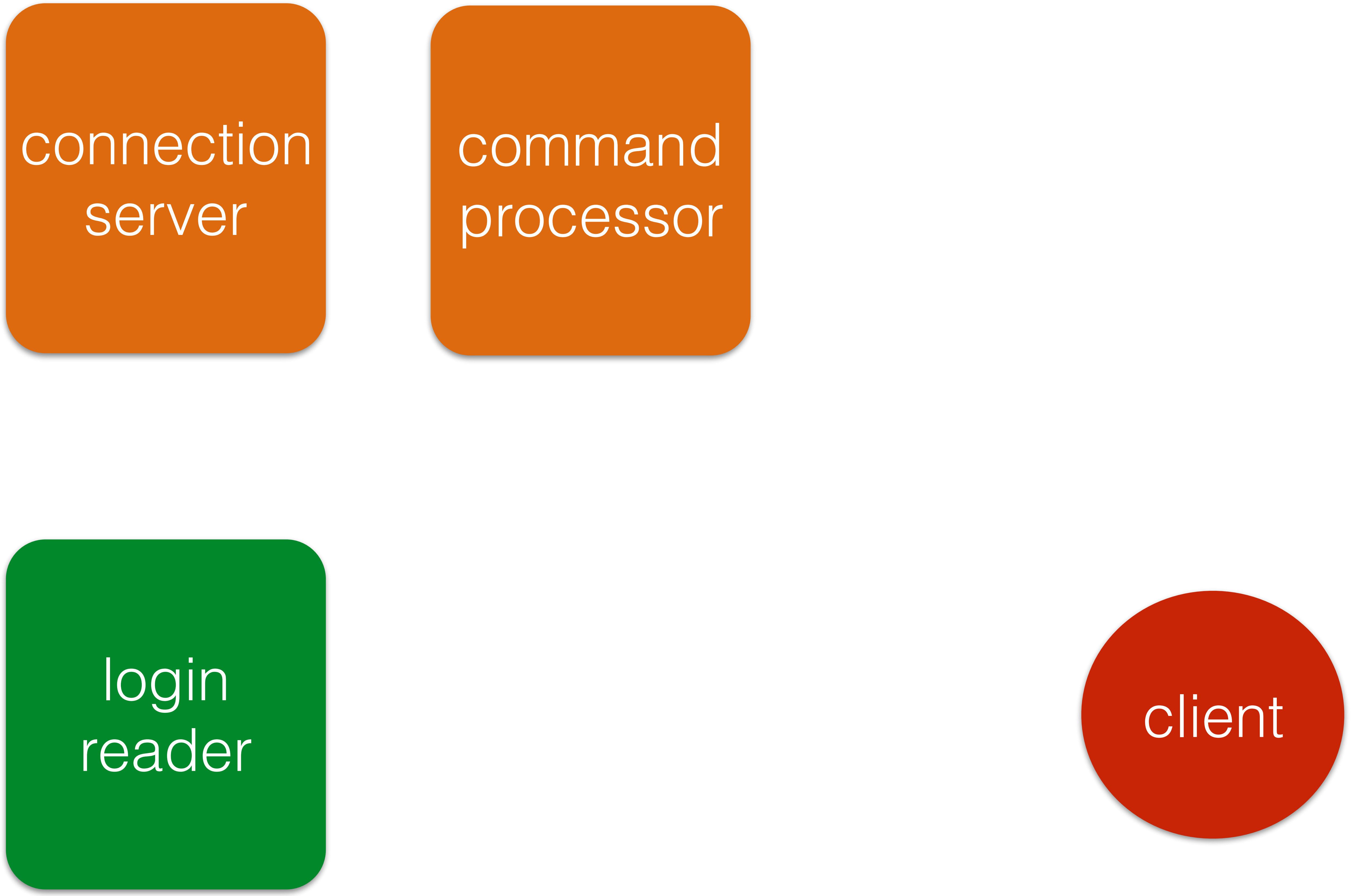
Attack: Login



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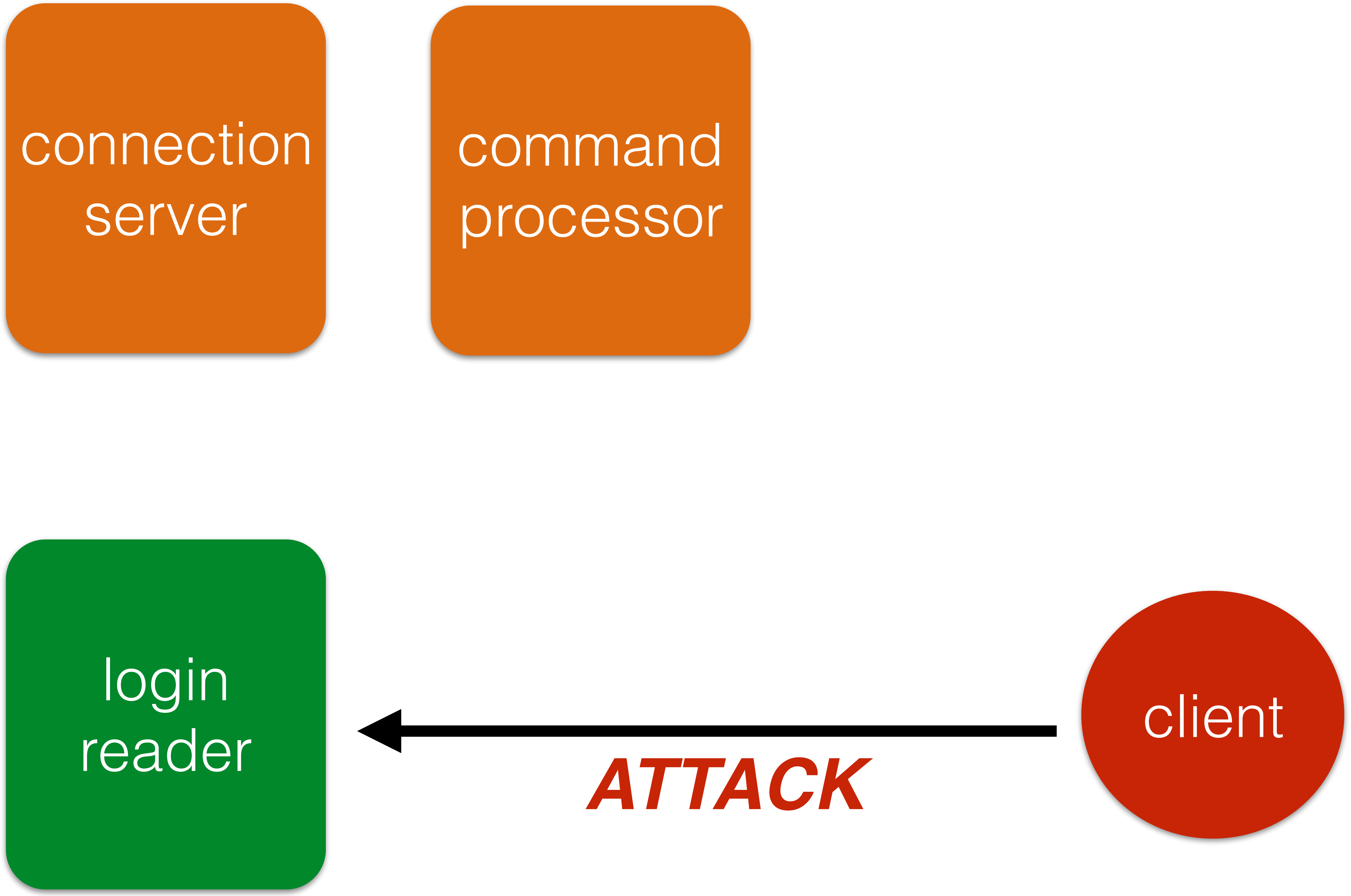

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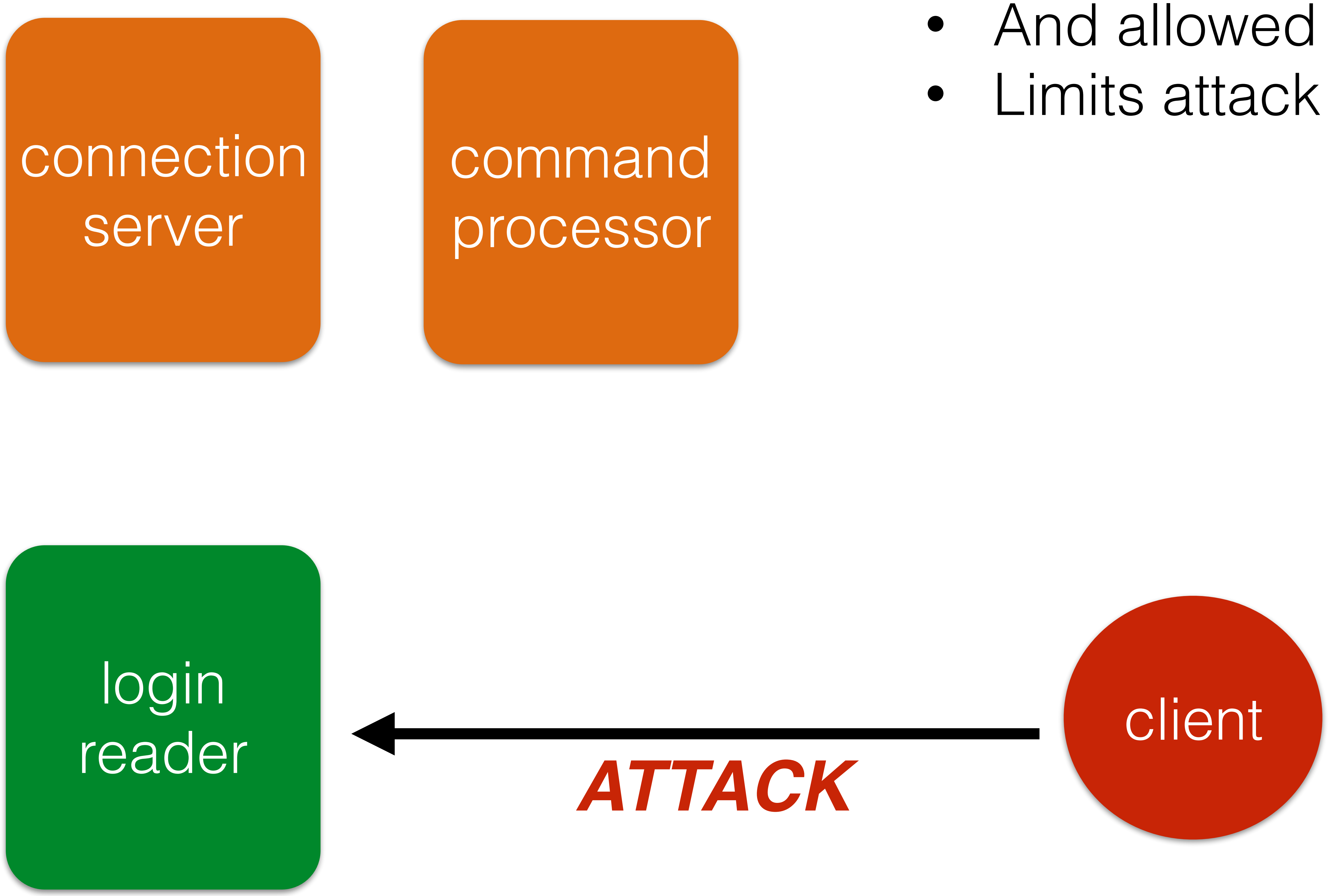

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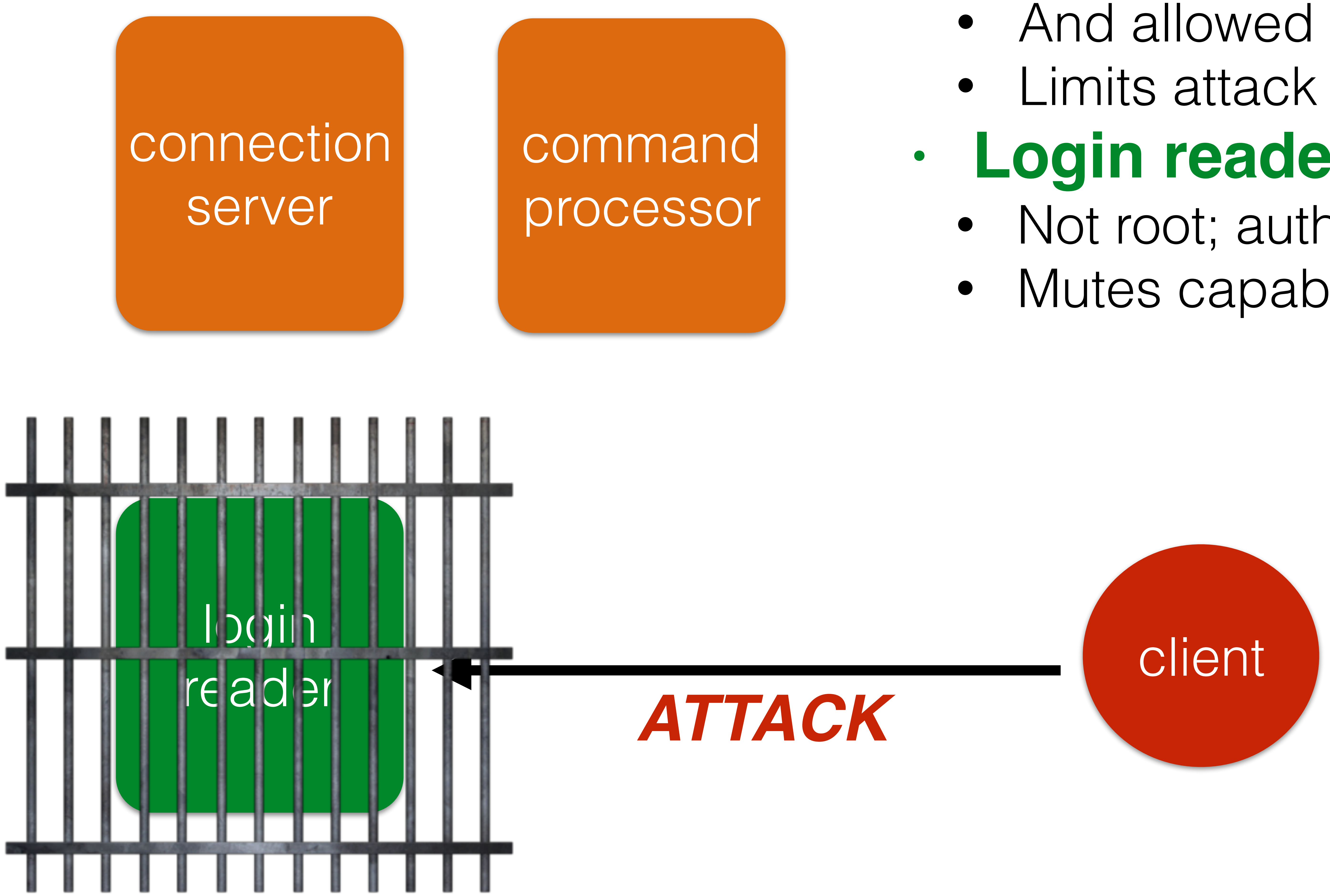

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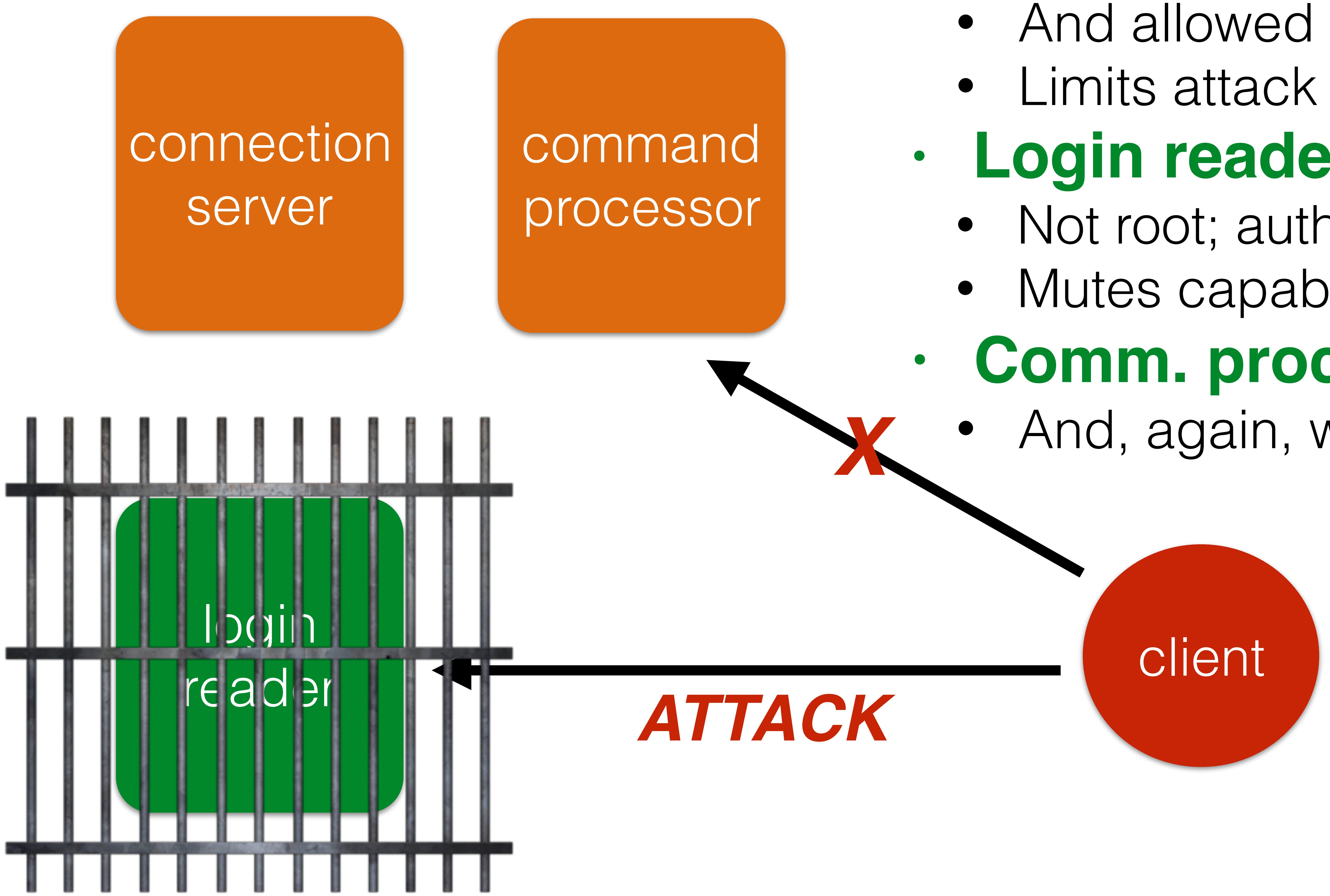

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- **Login reader has limited privilege**
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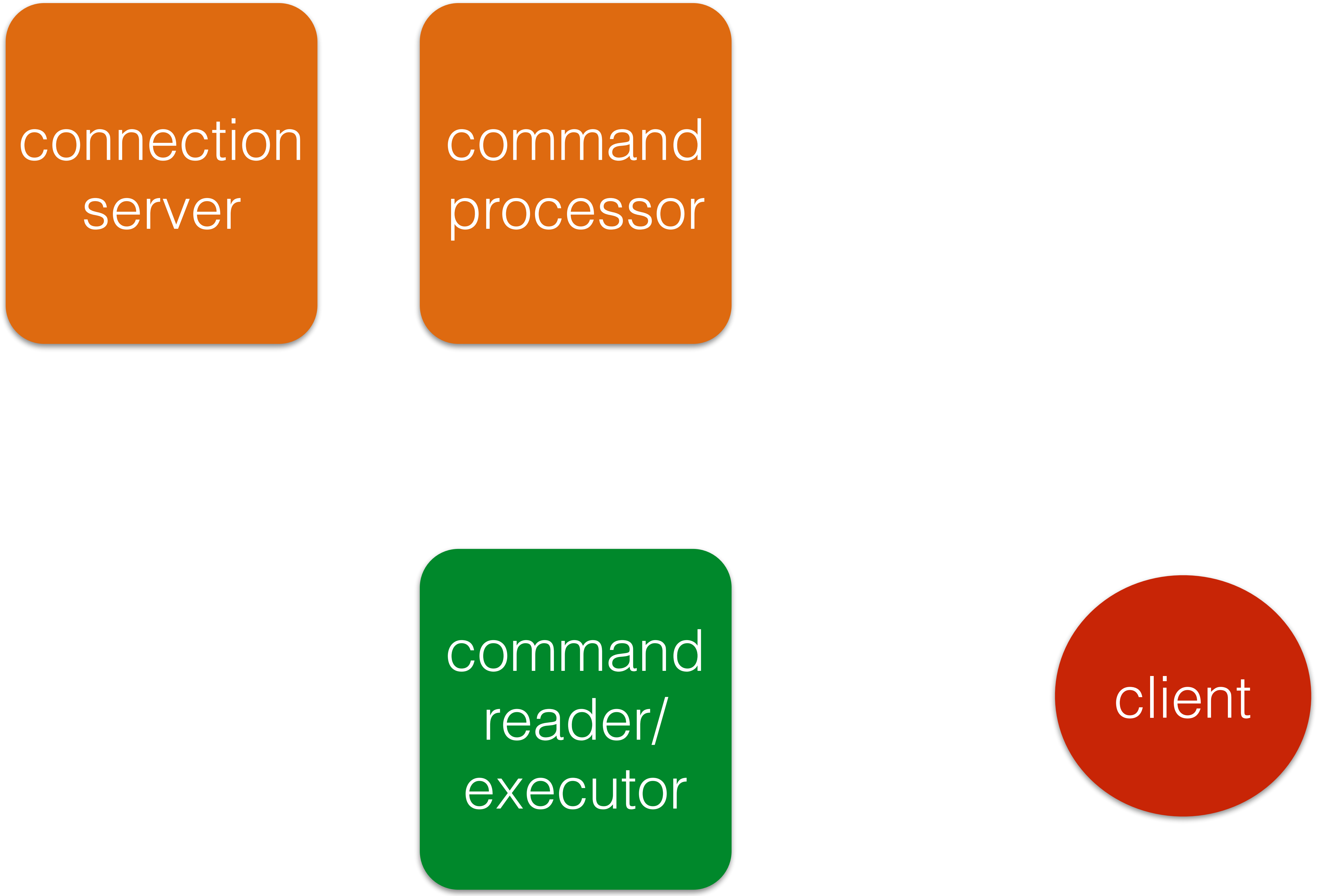
- **Comm. proc. only talks to reader**
  - And, again, white-lists its limited input

Attack: Commands



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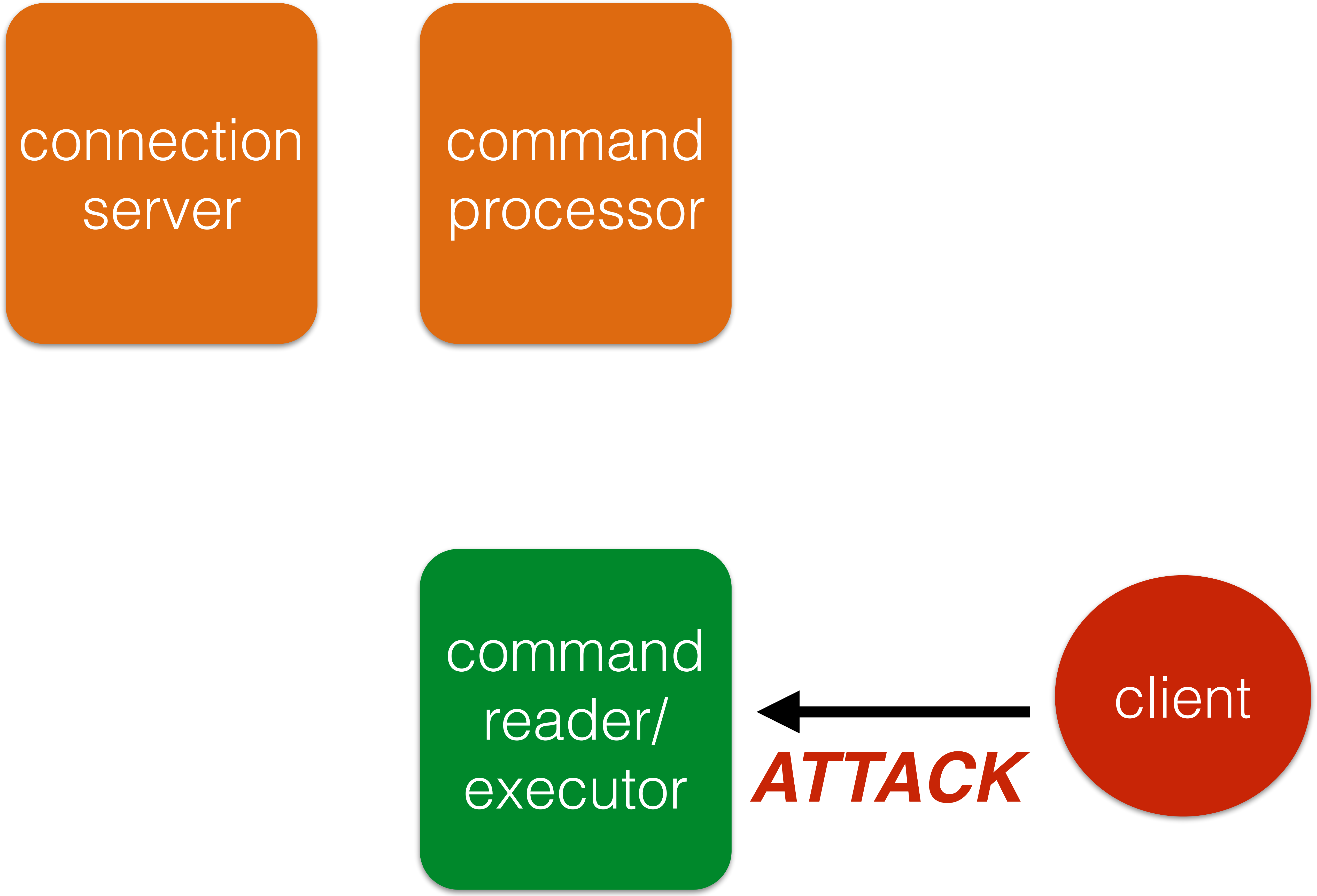

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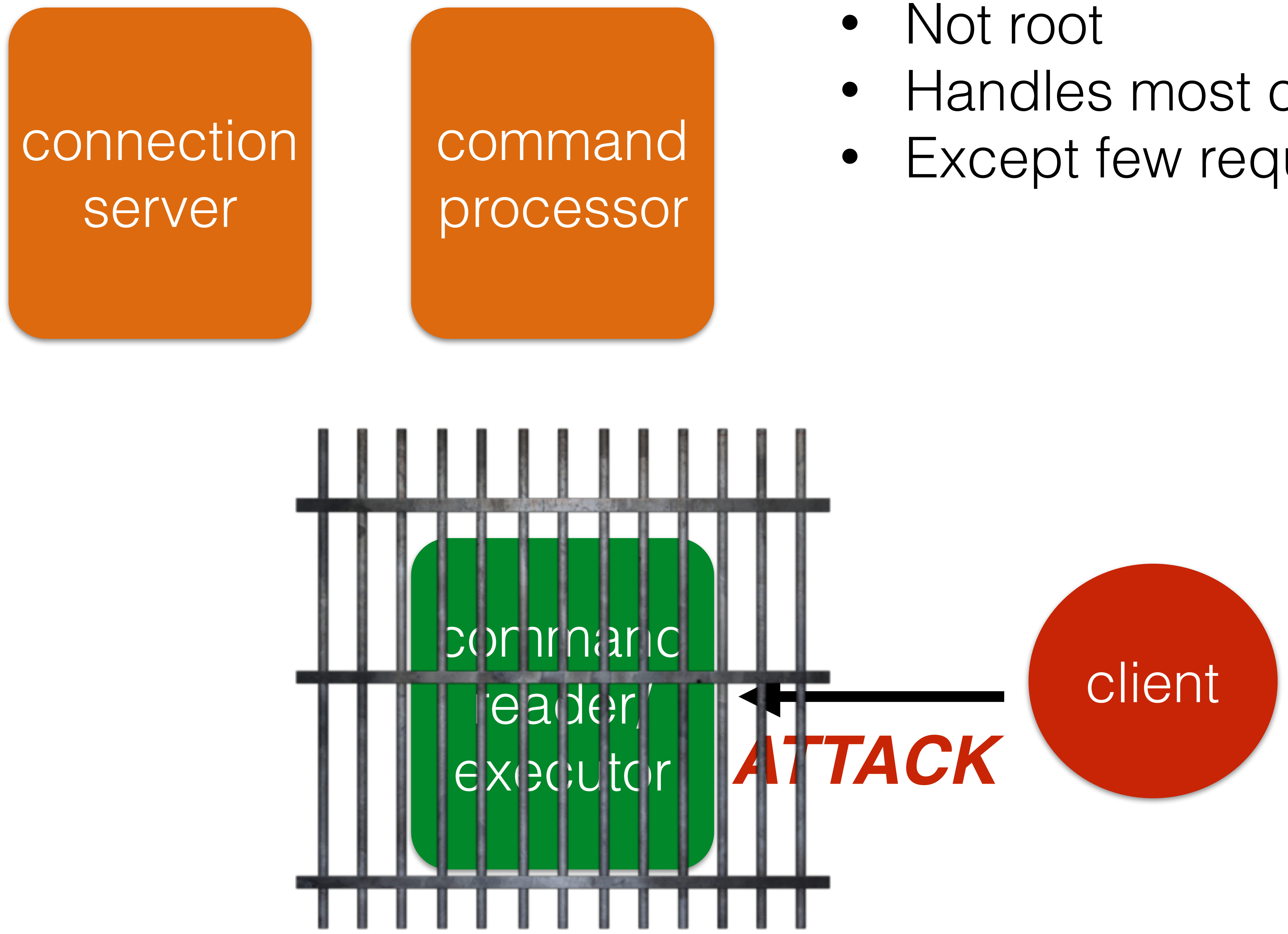

- **Command reader sandboxed**
  - Not root
  - Handles most commands
  - Except few requiring privilege

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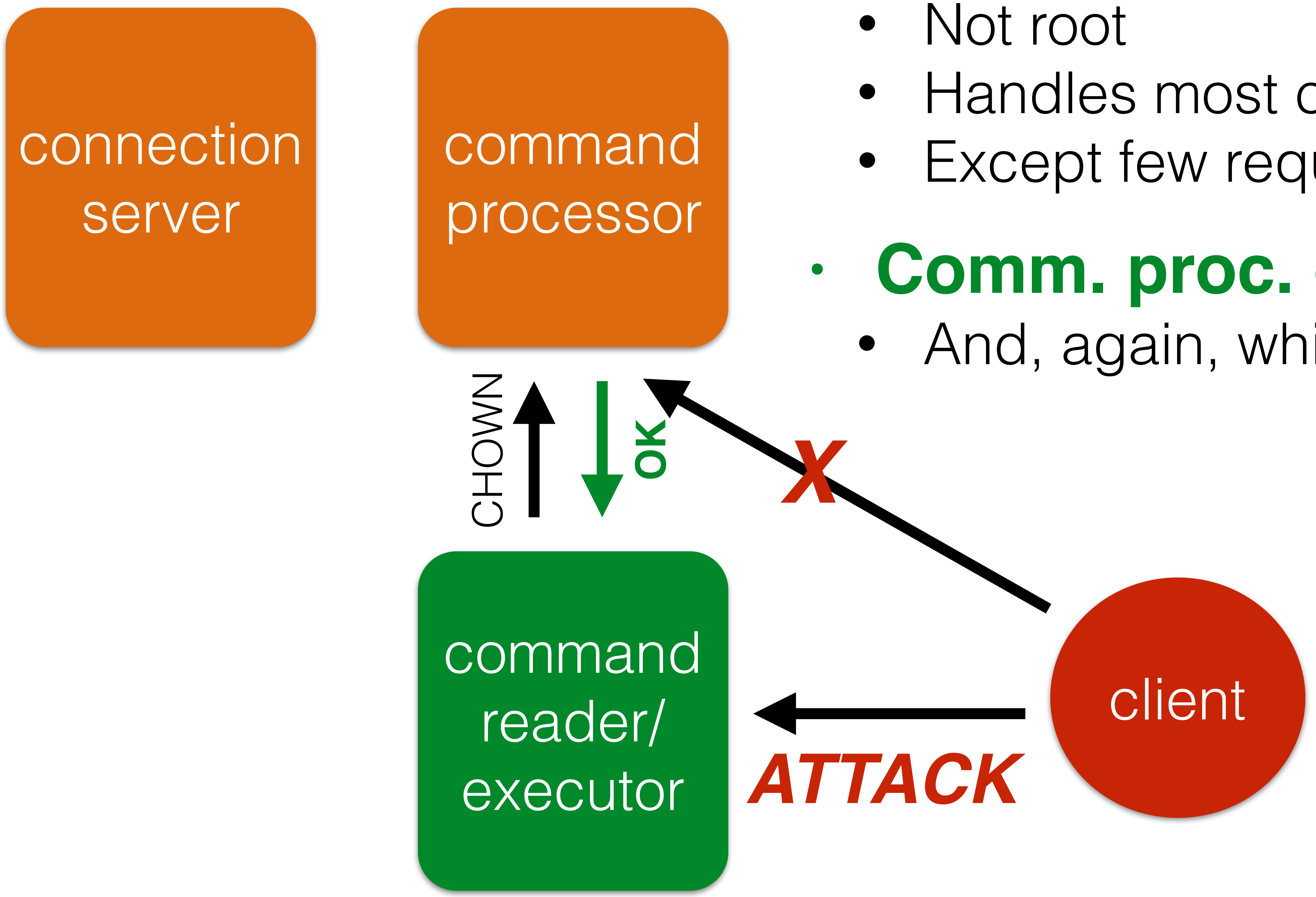

- **Command reader sandboxed**
  - Not root
  - Handles most commands
  - Except few requiring privilege
- **Comm. proc. only talks to reader**
  - And, again, white-lists its limited input

Attack: Cross-session

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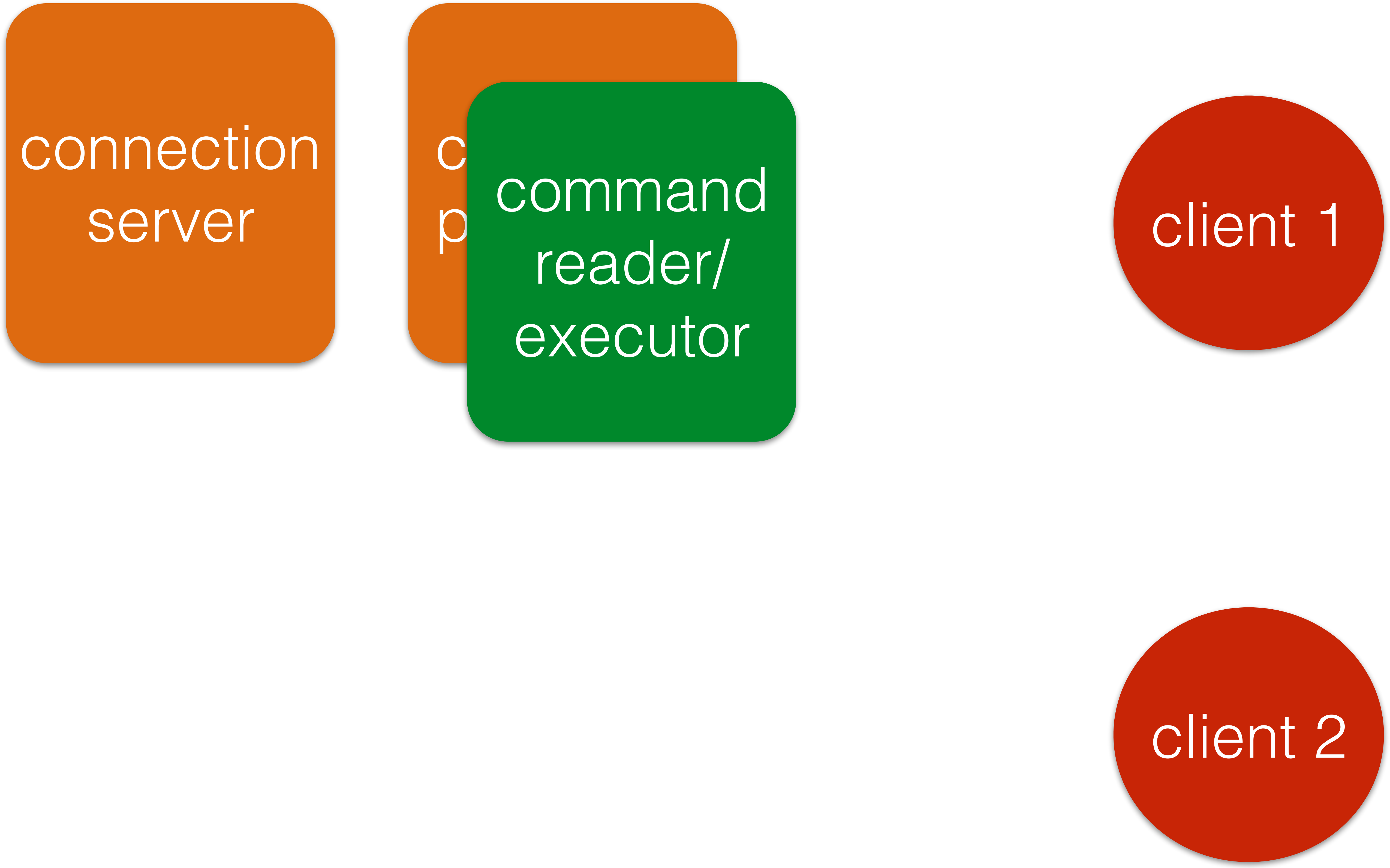

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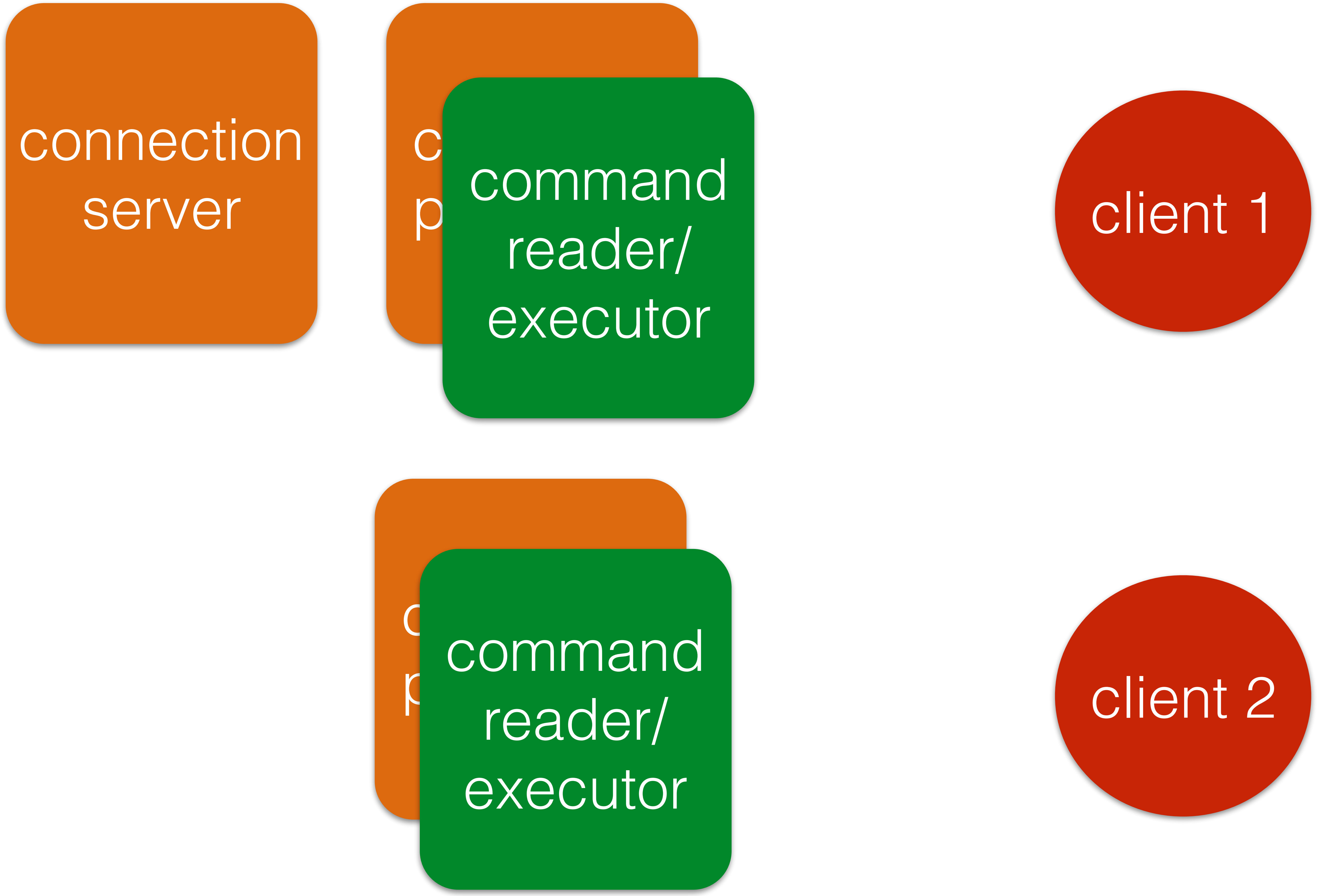

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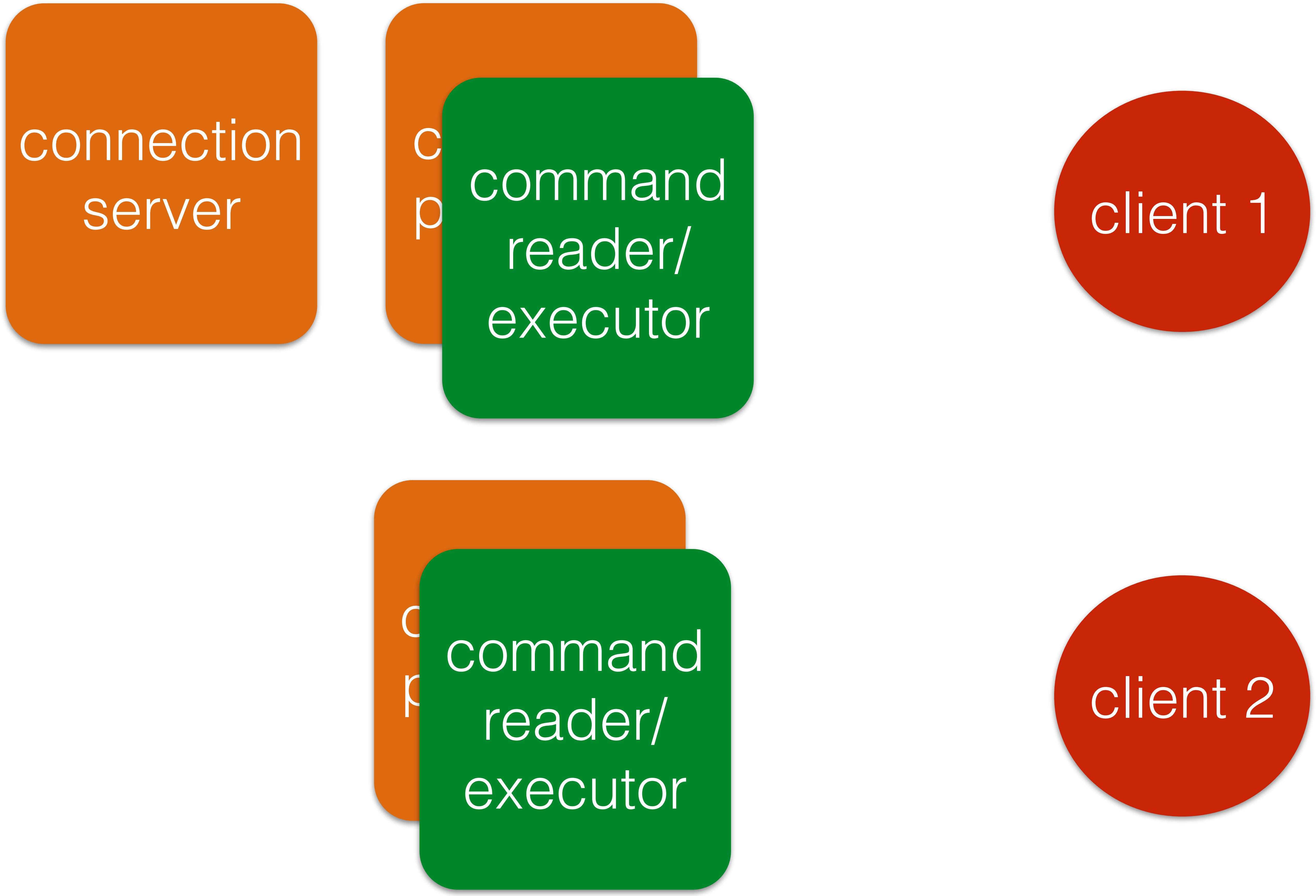

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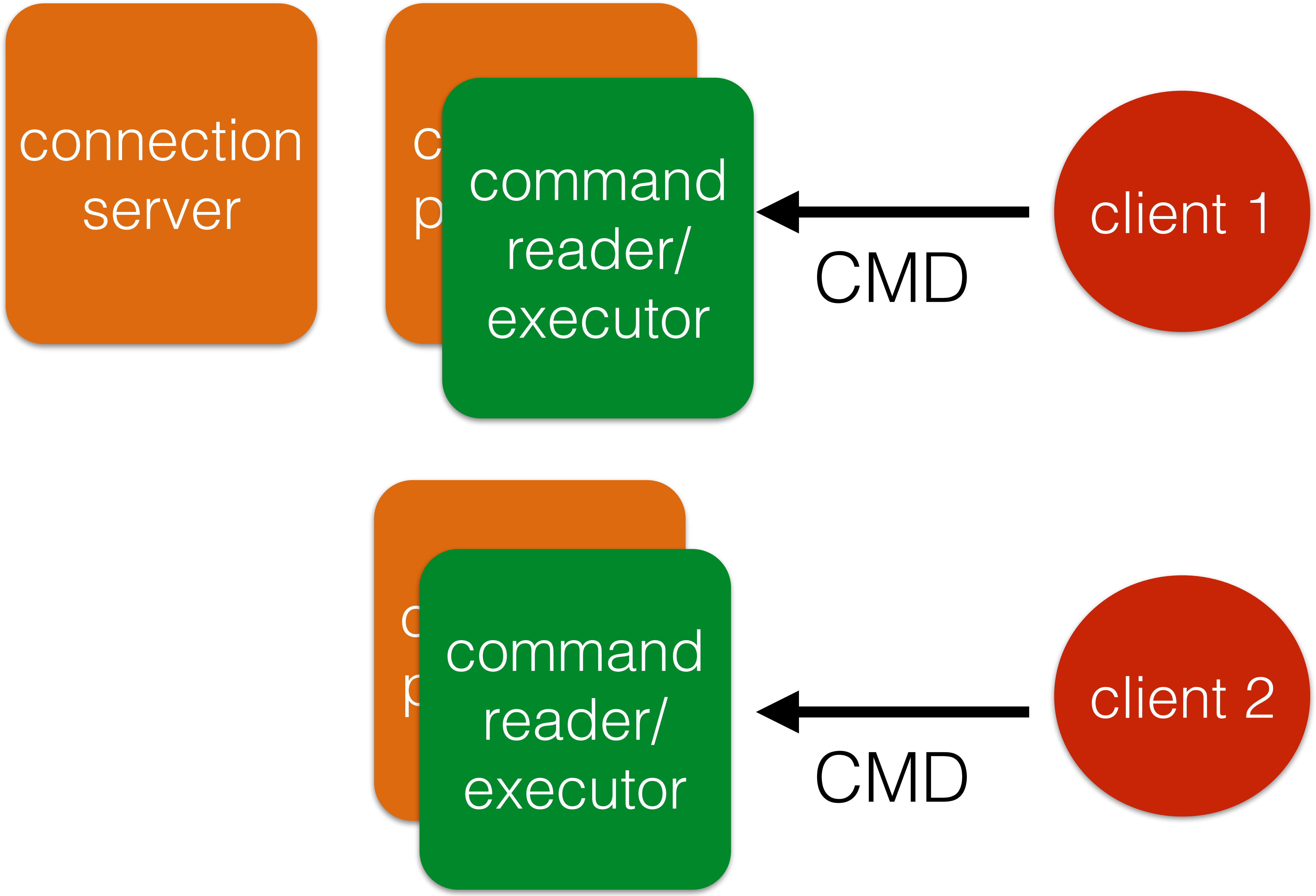

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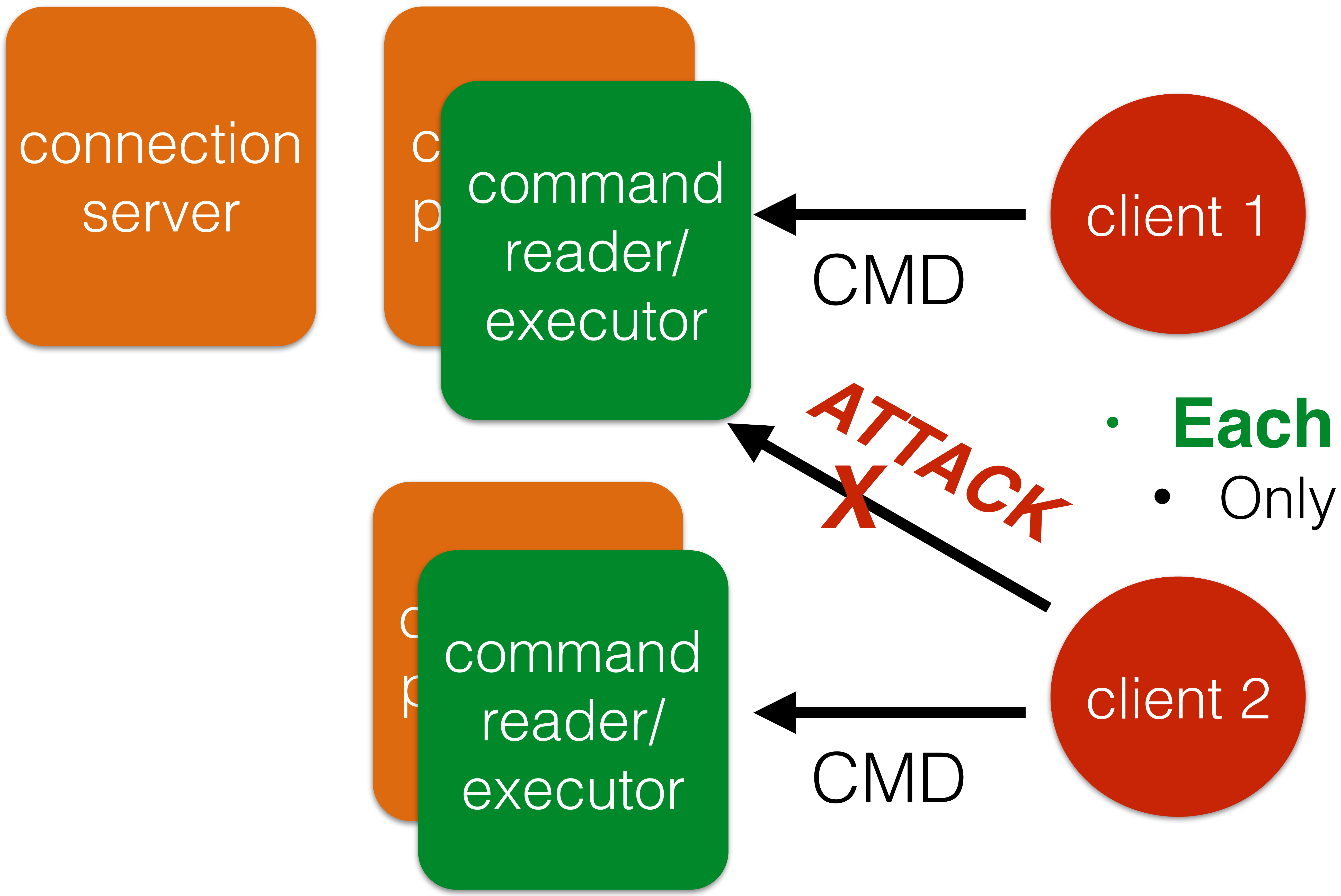

- **Each session isolated**
  - Only can talk to one client

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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 separation, and gets this right.

$\boxed{\text{Comments on this document are welcomed.}}$

Separation of responsibilities

TCB: KISS

TCB: Privilege separation

Principle of least privilege

Kerkhoff’s principle!

```
Presenting vsftpd's secure design
=================================

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Reasoning about code safety

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  - “Statement 1’s postcondition should meet statement 2’s precondition”

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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?

```
/* 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) {
    return *p;
}
```

What are the postconditions to ensure safety?

```
/* ensures:                                          */

void *myalloc(size_t n) {
    void *p = malloc(n);
    if (!p) { perror("malloc"); exit(1); }
    return p;
}
```

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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];
    return total;
}
```

What are the preconditions to ensure safety?

Approach:

1. Identify each memory access
2. Annotate with preconditions it requires
3. Propagate the requirements up

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```c
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Memory access

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/* requires: a != NULL    */
/* requires: 0 <= i       */
/* requires: i < size(a) */
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Memory access

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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/* requires: i < size(a) */
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Memory access

Not guaranteed by above code

```
/* requires: i < size(a) */
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/* requires: n <= size(a) */
```

Memory access

Not guaranteed by above code

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/* requires: i < size(a) */
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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;
}


/* requires:                                  */
bool search(char *s) {
    int i = hash(s);
    return tbl[i] && (strcmp(tbl[i], s)==0);
}
```

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

/* requires: s != NULL and valid, and NULL-terminated        */
/* ensures:                                                   */
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/* requires: s != NULL (and a valid) and 0 <= hash < size(tbl) */
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Does this code meet its postconditions?

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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