TOMASZ PAWLAK, PHD
MARCIN SZUBERT, PHD

WEB FUNDAMENTALS

HYPERTEXT TRANSFER PROTOCOL

PRESENTATION OUTLINE

- Evolution of the Web
- Building blocks of the Web
- HTTP — Hypertext Transfer Protocol
  - Messages: verbs, status codes, headers
  - Connections: performance, security, proxies
- HTTP extensions: SPDY, HTTP/2

MOTIVATION

- *HTTP: the protocol every web developer must know.*
- HTTP is the foundation of the most successful distributed system ever built — the World Wide Web.
- Understanding HTTP is critical to:
  - designing a clean, simple and RESTful Web API,
  - implementing efficient and scalable web applications,
  - debugging web application.

SCALABILITY

- "*Scalability* is the capability of a system, network, or process to handle a growing amount of work, or its potential to be enlarged in order to accommodate that growth.", Wikipedia

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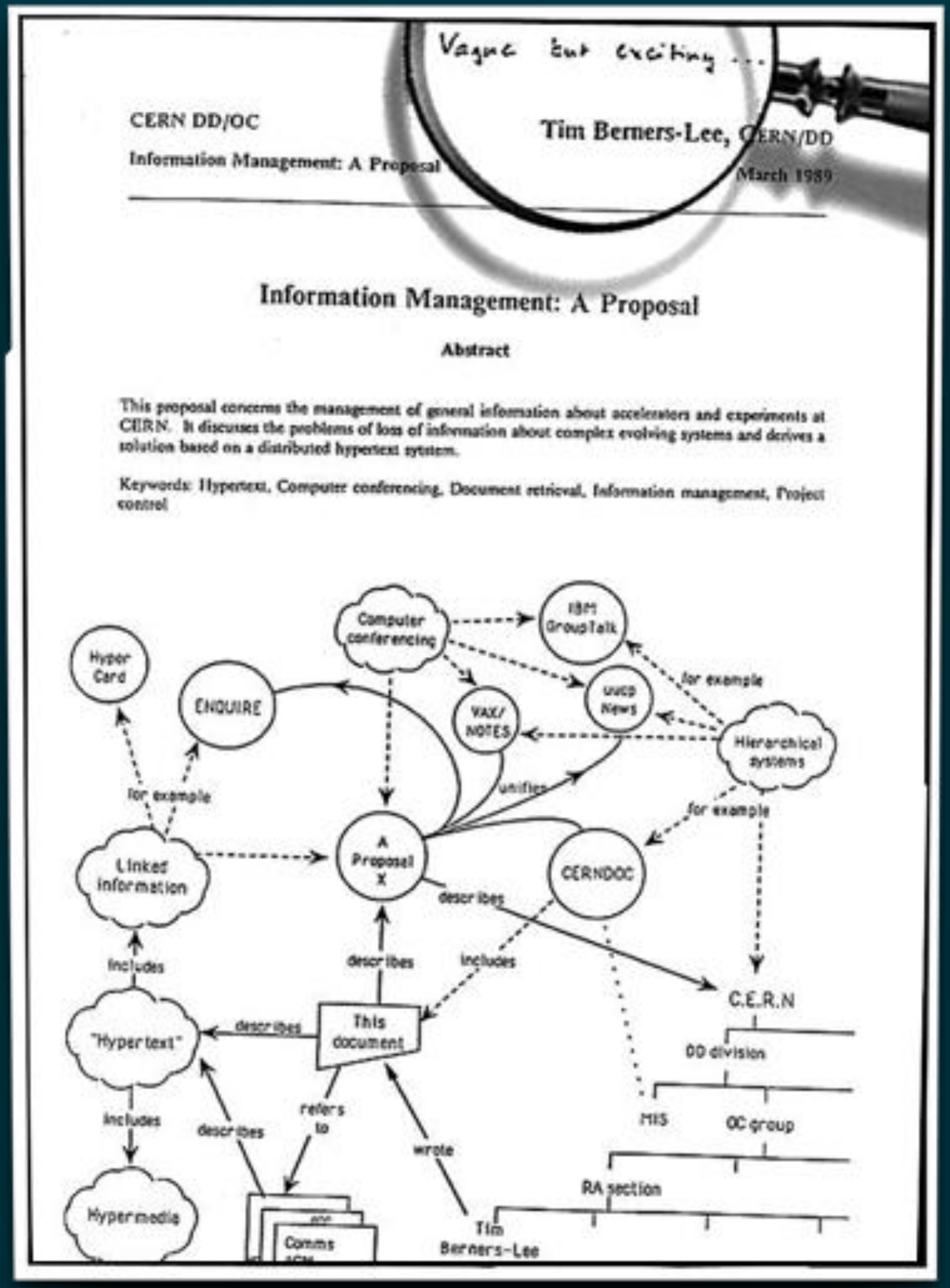
Vague but exciting ...

CERN DD/OC

Information Management: A Proposal

Tim Berners-Lee, CERN/DD

March 1989

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Abstract

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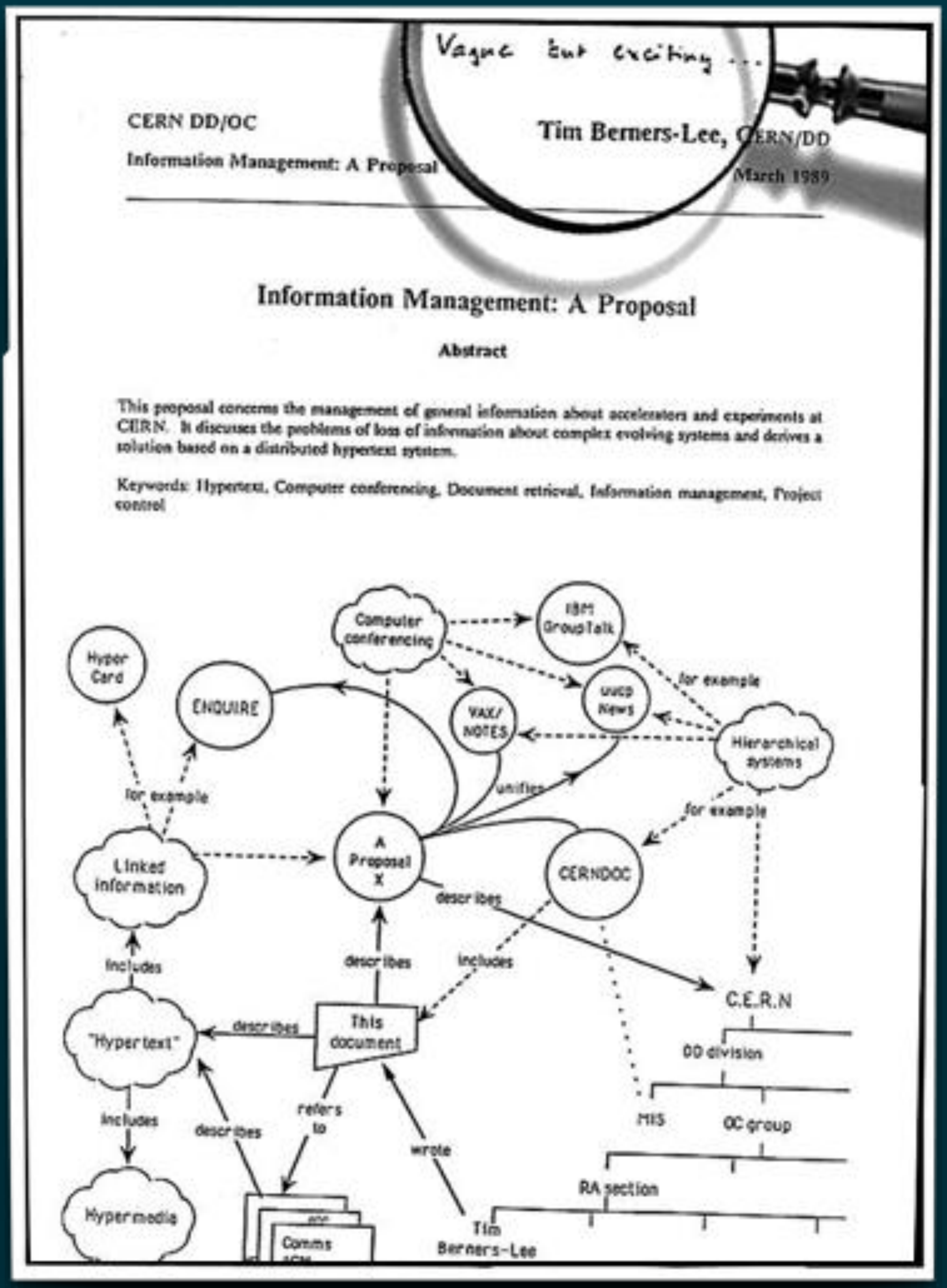

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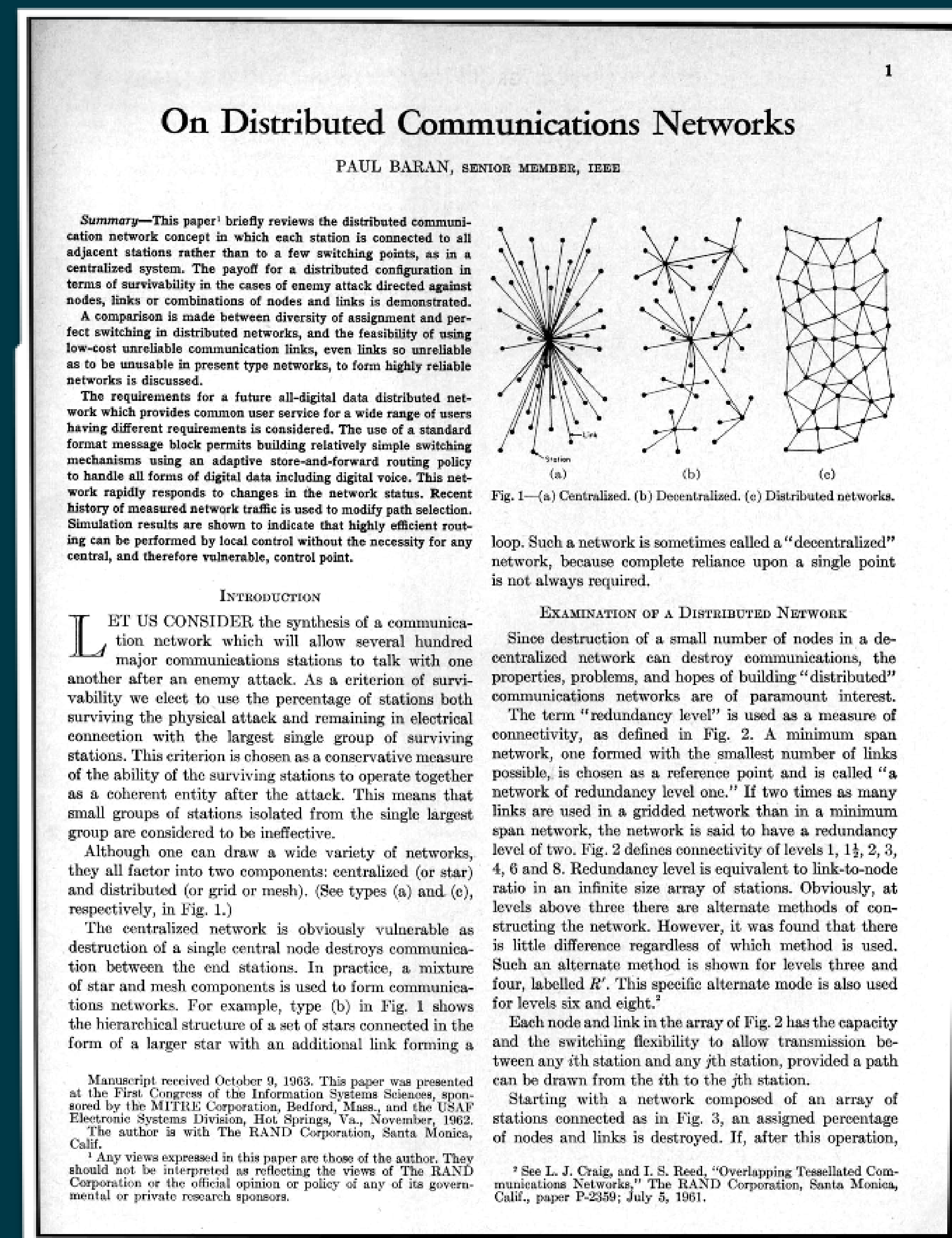

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On Distributed Communications Networks

PAUL BARAN, SENIOR MEMBER, IEEE

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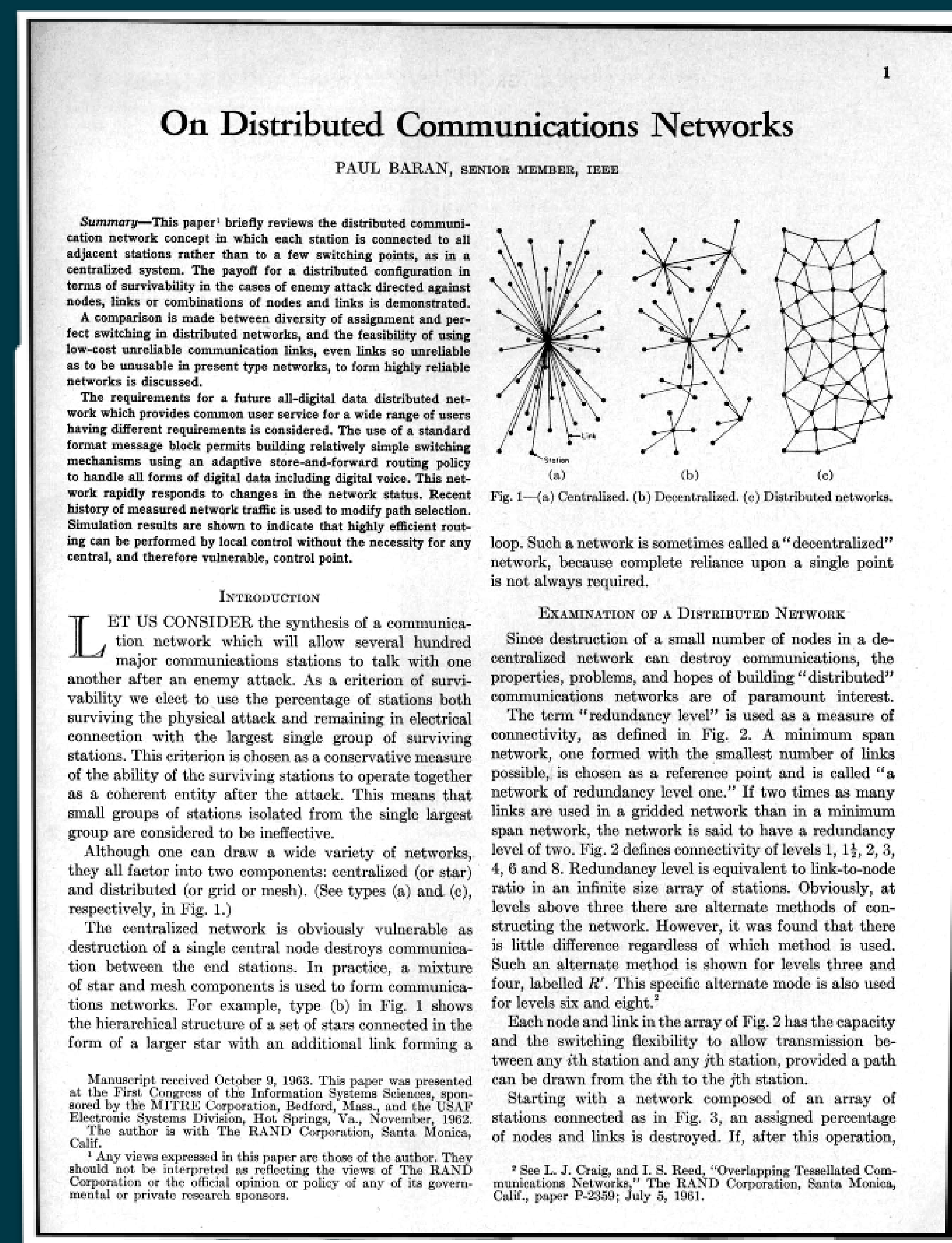

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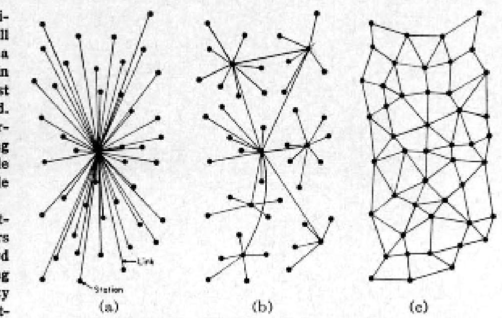

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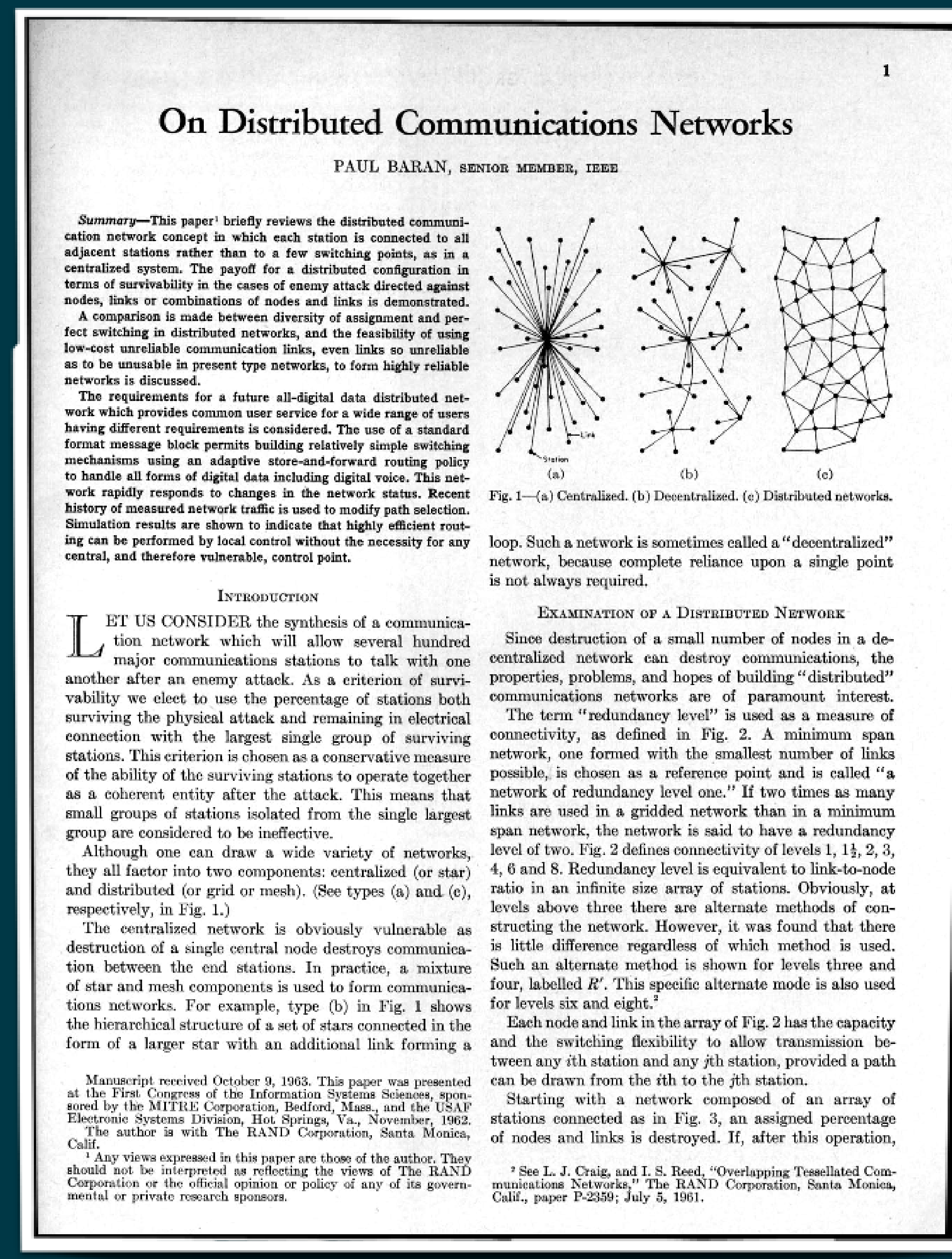

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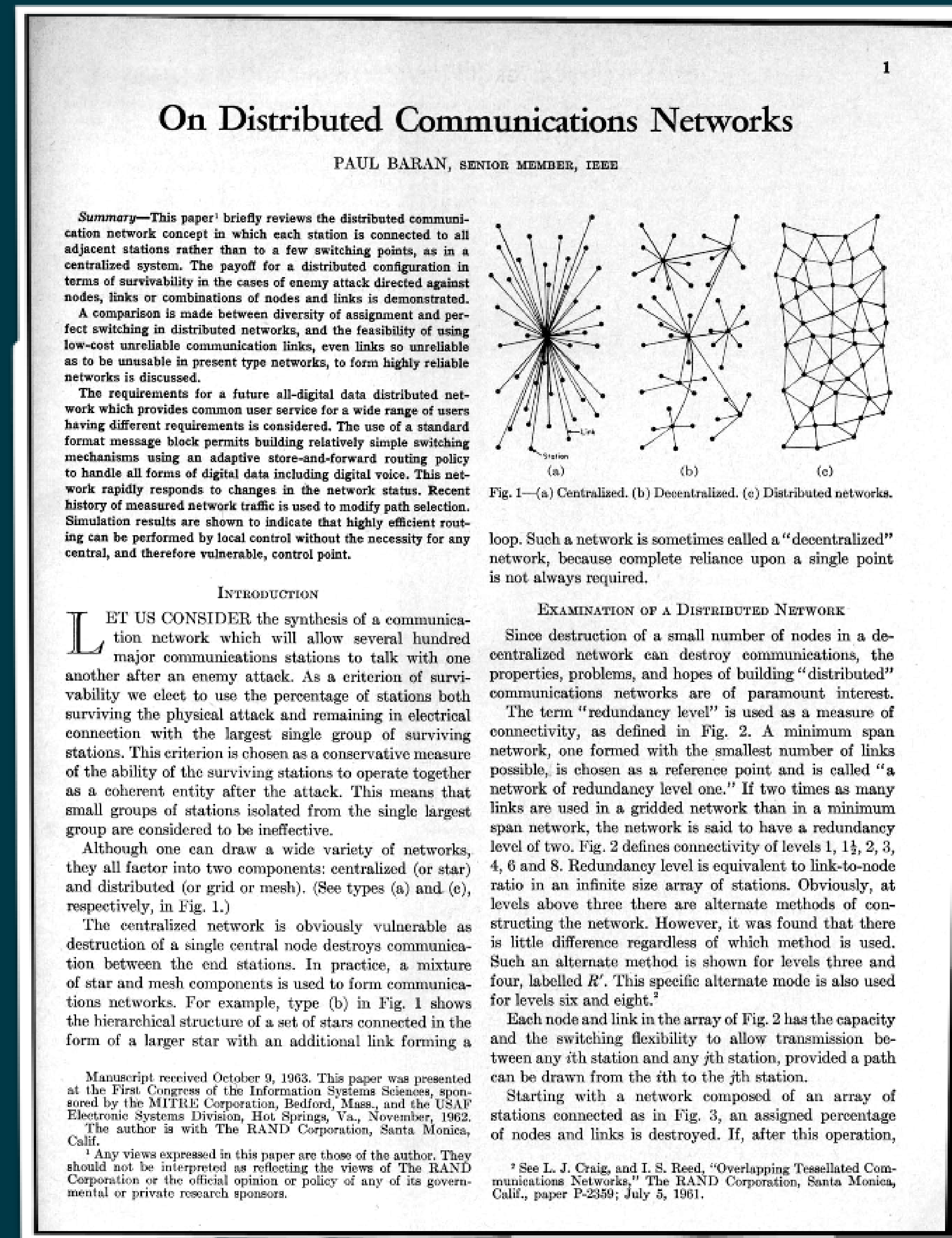
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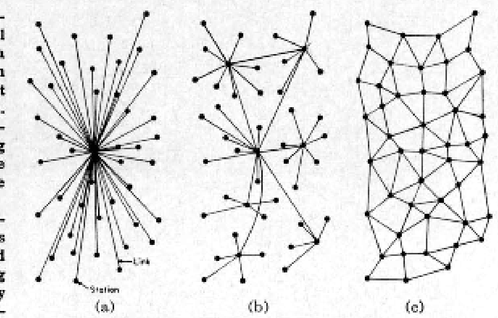

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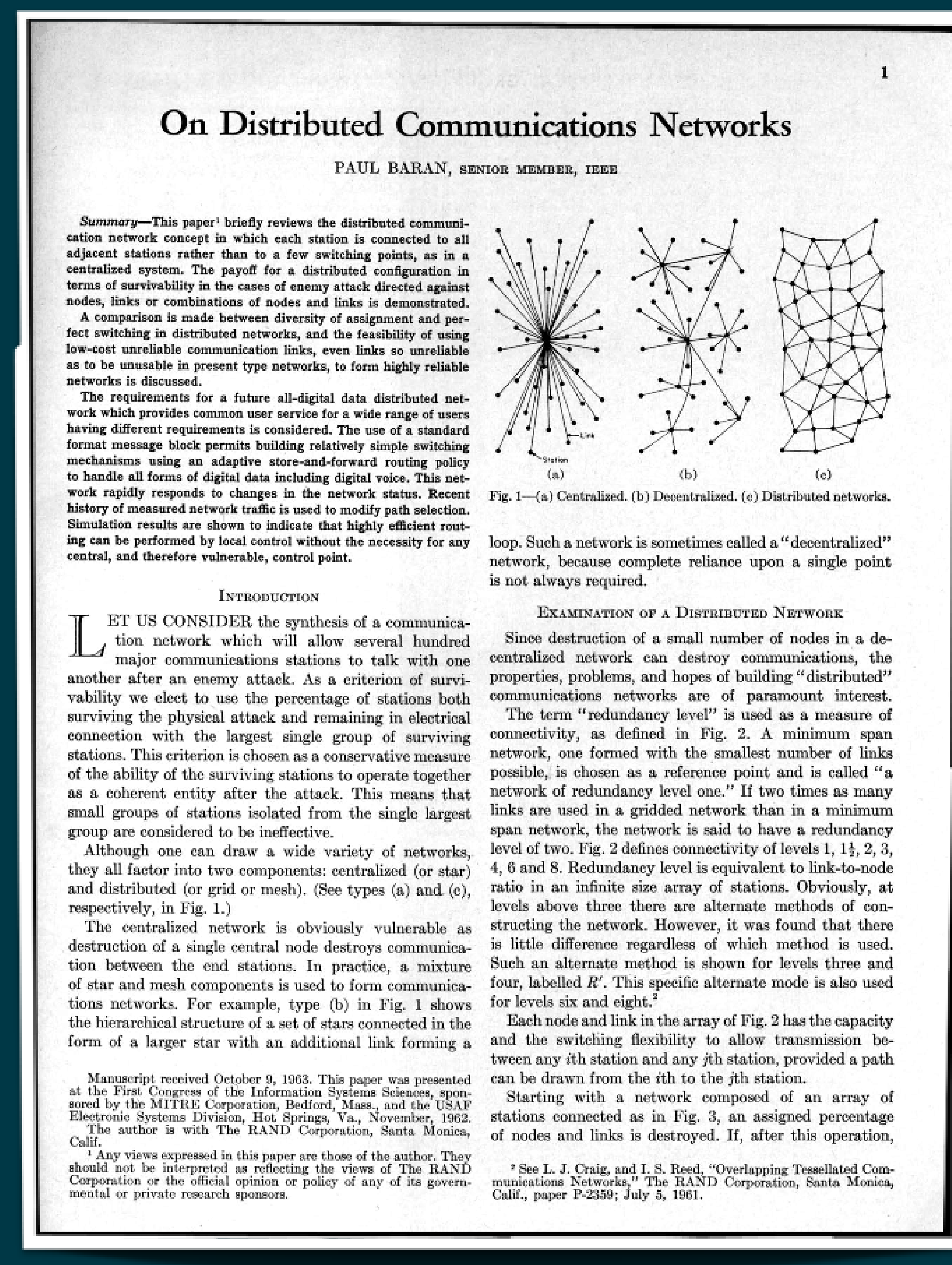
[2] See L. J. Craig, and I. S. Reed, "Overlapping Tessellated Communications Networks," The RAND Corporation, Santa Monica, Calif., paper P-2359; July 5, 1961.

HISTORICAL PERSPECTIVE

- 1989 — **Tim Berners-Lee** presented a proposal for an information management system that would enable sharing of resources over a **computer network**.
- **ARPANET** — open **decentralized** computer network architecture.
  - 1969: First message sent
  - 1971: First e-mail sent
  - 1973: File Transfer Protocol (RFC 354)
  - 1977: Network Voice Protocol (RFC 741)
  - 1981: Internet Protocol v4
  - 1987: number of hosts > 10 000



1

On Distributed Communications Networks

PAUL BARAN, SENIOR MEMBER, IEEE

Summary—This paper[1] briefly reviews the distributed communication network concept in which each station is connected to all adjacent stations rather than to a few switching points, as in a centralized system. The payoff for a distributed configuration in terms of survivability in the cases of enemy attack directed against nodes, links or combinations of nodes and links is demonstrated.

A comparison is made between diversity of assignment and perfect switching in distributed networks, and the feasibility of using low-cost unreliable communication links, even links so unreliable as to be unusable in present type networks, to form highly reliable networks is discussed.

The requirements for a future all-digital data distributed network which provides common user service for a wide range of users having different requirements is considered. The use of a standard format message block permits building relatively simple switching mechanisms using an adaptive store-and-forward routing policy to handle all forms of digital data including digital voice. This network rapidly responds to changes in the network status. Recent history of measured network traffic is used to modify path selection. Simulation results are shown to indicate that highly efficient routing can be performed by local control without the necessity for any central, and therefore vulnerable, control point.

INTRODUCTION

LET US CONSIDER the synthesis of a communication network which will allow several hundred major communications stations to talk with one another after an enemy attack. As a criterion of survivability we elect to use the percentage of stations both surviving the physical attack and remaining in electrical connection with the largest single group of surviving stations. This criterion is chosen as a conservative measure of the ability of the surviving stations to operate together as a coherent entity after the attack. This means that small groups of stations isolated from the single largest group are considered to be ineffective.

Although one can draw a wide variety of networks, they all factor into two components: centralized (or star) and distributed (or grid or mesh). (See types (a) and (c), respectively, in Fig. 1.)

The centralized network is obviously vulnerable as destruction of a single central node destroys communication between the end stations. In practice, a mixture of star and mesh components is used to form communications networks. For example, type (b) in Fig. 1 shows the hierarchical structure of a set of stars connected in the form of a larger star with an additional link forming a

Link

Station

(a) (b) (c)

Fig. 1—(a) Centralized. (b) Decentralized. (c) Distributed networks.

loop. Such a network is sometimes called a "decentralized" network, because complete reliance upon a single point is not always required.

EXAMINATION OF A DISTRIBUTED NETWORK

Since destruction of a small number of nodes in a decentralized network can destroy communications, the properties, problems, and hopes of building "distributed" communications networks are of paramount interest.

The term "redundancy level" is used as a measure of connectivity, as defined in Fig. 2. A minimum span network, one formed with the smallest number of links possible, is chosen as a reference point and is called "a network of redundancy level one." If two times as many links are used in a gridded network than in a minimum span network, the network is said to have a redundancy level of two. Fig. 2 defines connectivity of levels 1, $1\frac{1}{2}$, 2, 3, 4, 6 and 8. Redundancy level is equivalent to link-to-node ratio in an infinite size array of stations. Obviously, at levels above three there are alternate methods of constructing the network. However, it was found that there is little difference regardless of which method is used. Such an alternate method is shown for levels three and four, labelled R'. This specific alternate mode is also used for levels six and eight.[2]

Each node and link in the array of Fig. 2 has the capacity and the switching flexibility to allow transmission between any ith station and any jth station, provided a path can be drawn from the ith to the jth station.

Starting with a network composed of an array of stations connected as in Fig. 3, an assigned percentage of nodes and links is destroyed. If, after this operation,

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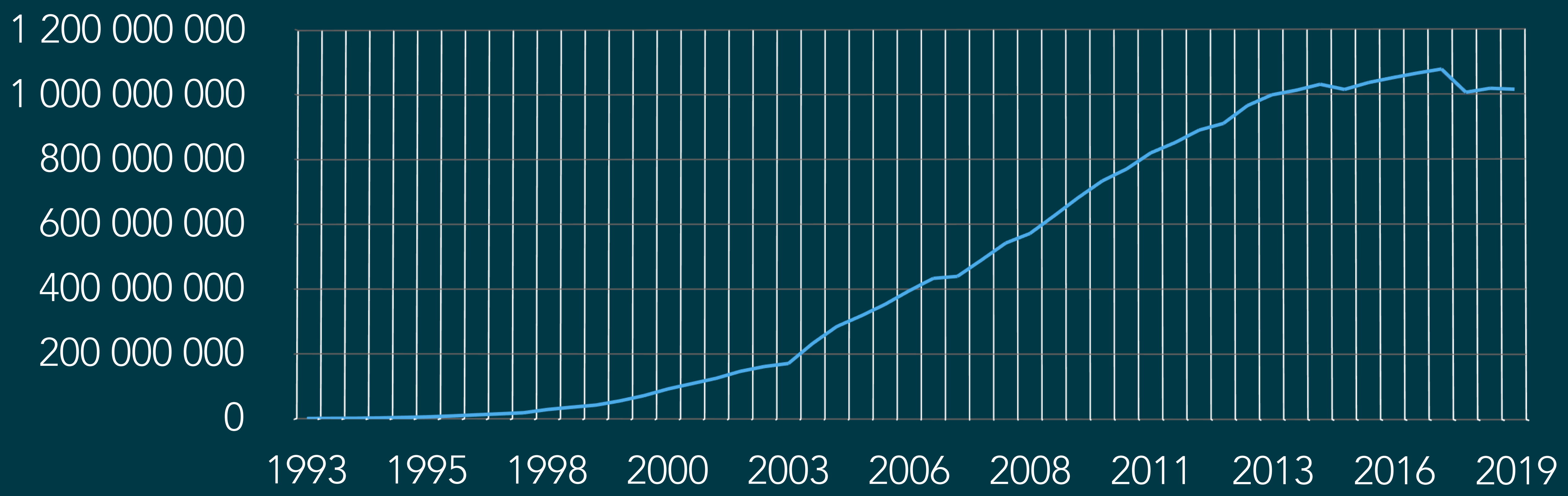
NUMBER OF INTERNET HOSTS

INTERNET DOMAIN SURVEY
HTTPS://WWW.ISC.ORG/NETWORK/SURVEY/

NUMBER OF INTERNET HOSTS



INTERNET DOMAIN SURVEY

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HISTORICAL PERSPECTIVE WHAT HAS BEEN CHANGING?

- The Internet of Things (IoT)
  - The first **thing** (non-computer) connected to the Internet ever: the Toaster
    - It was connected to the Internet with TCP/IP networking and controlled with SNMP http://www.livinginternet.com/i/ia_myths_toast.htm
  - In 2008 the number of **things** connected to the Internet exceeded the number of people on earth.
    - Dave Evans, Cisco, The Internet of Things, http://www.cisco.com/c/dam/en_us/about/ac79/docs/innov/IoT_IBSG_0411FINAL.pdf
- Web users and their expectations:
  - multiple platforms, simultaneous screening
  - consistent user experience — **responsive web design**
  - little or no latency — impatience of web users
    - Note: an average attention span of an Internet user shortened from 12sec in 2000 to 8sec in 2015
    - Less than a goldfish (9sec)!
    - http://time.com/3858309/attention-spans-goldfish/
- Technology:
  - shift of responsibility from the server to the client
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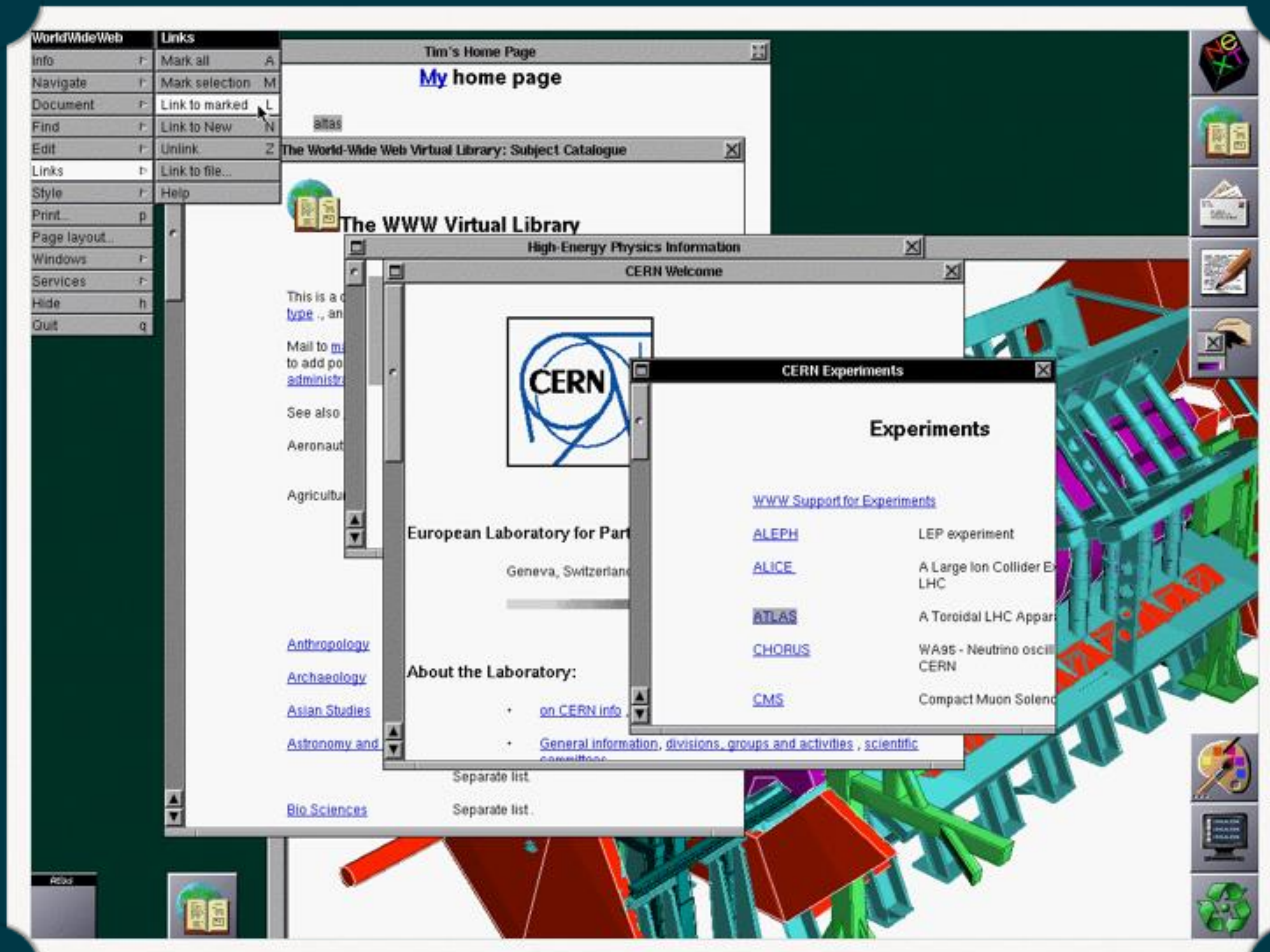
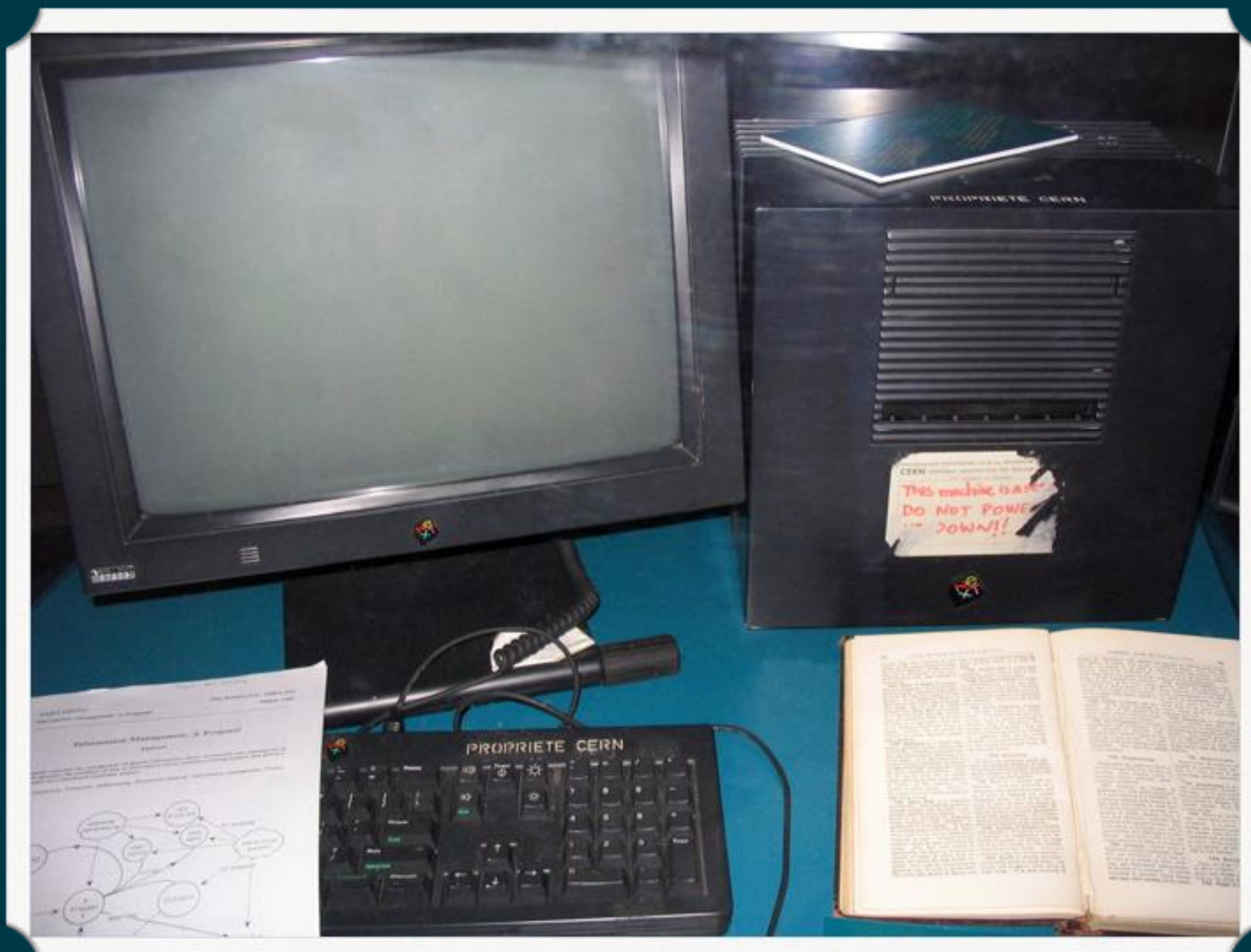
2. **URL** — a uniform notation scheme for uniquely identifying accessible **resources** over the network.

3. **HTTP** — a protocol for **transporting** messages (requests and responses) over the network.

BUILDING BLOCKS OF THE WEB
WORLDWIDEWEB BROWSER



BUILDING BLOCKS OF THE WEB
HTTPD WEB SERVER



HYPERTEXT MARKUP LANGUAGE

- HTML was defined by Tim Berners-Lee as an application of the Standard Generalized Markup Language (SGML).
- HTML is used for describing both the content and the structure of web pages.
- HTML is a markup language that web browsers use to interpret and compose text, images and other material into web pages.

HYPERTEXT MARKUP LANGUAGE

- Elements of HTML structure
  - Headings, paragraphs, tables, lists, photos, etc.
  - **Hyperlinks**
  - **Design forms** for conducting transactions with remote services, for use in searching for information, making reservations, ordering products.

—HTTP://WWW.W3.ORG/STANDARDS/WEBDESIGN/HTMLCSS

UNIFORM RESOURCE **IDENTIFIER**

- *A Uniform Resource Identifier (URI) is a compact sequence of characters that identifies an **abstract** or **physical** resource.*

- *A Uniform Resource Identifier (URI) provides a simple and extensible means for identifying a resource.*

- *The term "Uniform Resource Locator" (URL) refers to the subset of URIs that, in addition to identifying a resource, provide a means of locating the resource by describing its primary access mechanis (e.g., its network "location").*

—UNIFORM RESOURCE IDENTIFIER (URI): GENERIC SYNTAX (RFC 3986)

UNIFORM RESOURCE **LOCATOR**

```
scheme://[user:password@]host[:port]/path/…/[?query-string][#fragment]
```

- **scheme** — protocol used to connect to the server
  - // are optional in some protocols and compulsory in others
- **user:password** – optional user name and password for authentication
- **host** — IP address of the server (or its domain name)
- **port** — optional port number to which the target server listens
- **path** — path to the desired resource on the server
- **query-string** — key=value dynamic parameters separated by &
- **fragment** — positional marker within the requested document

UNIFORM RESOURCE LOCATOR

- Schemes
  - Case insensitive
  - By convention lowercase
  - May use +, ., -
- Path
  - Must begin with a single slash (/) if host is present
  - Must not begin with two slashes (//)
- Permitted characters in variable parts
  - Lowercase and uppercase letters
  - Arabic numbers
  - ASCII encoding
  - Other symbols must be octet-encoded (e.g., %26 instead of &)

HYPERTEXT TRANSFER PROTOCOL

- The Hypertext Transfer Protocol (HTTP)
  - Application-level
  - Textual
  - Stateless & sessionless
    - No requirement for persistent connection
    - Source of troubles for software developers
  - For distributed, collaborative, hypermedia information systems
  - Can be used for many tasks beyond its use for hypertext
- HTTP has been in use by the World-Wide Web global information initiative since 1990. HTTP/1.1 (RFC 2616) in wide use since 1999. HTTP/2.0 (RFC 7540) was introduced in 2015.

HYPERTEXT TRANSFER PROTOCOL

- In the following I will describe HTTP/1.1
- Then show what changed in HTTP/2.0

THE CLIENT—SERVER ARCHITECTURE

- The HTTP protocol uses the **request-response paradigm**.
- An **HTTP transaction** consists of a single request from a client, followed by a single response from the server.

SERVER

CLIENT

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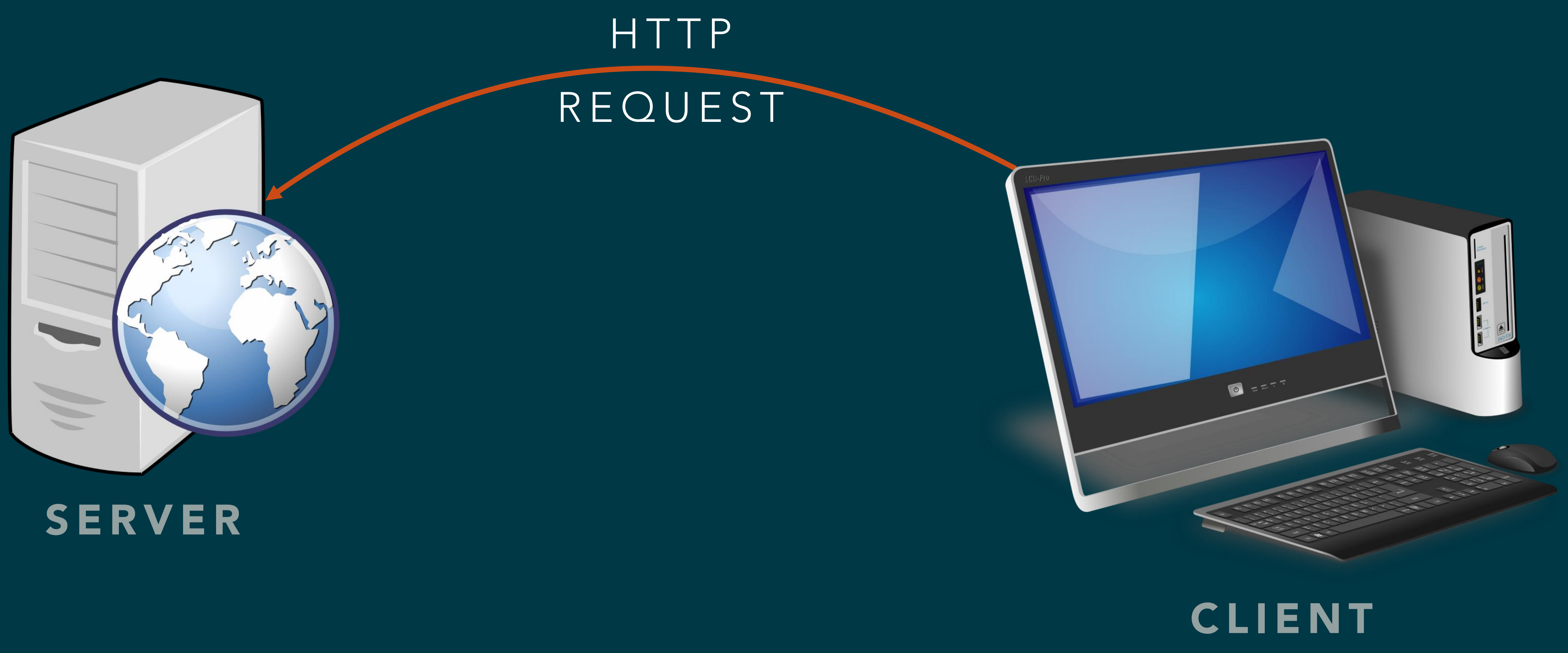

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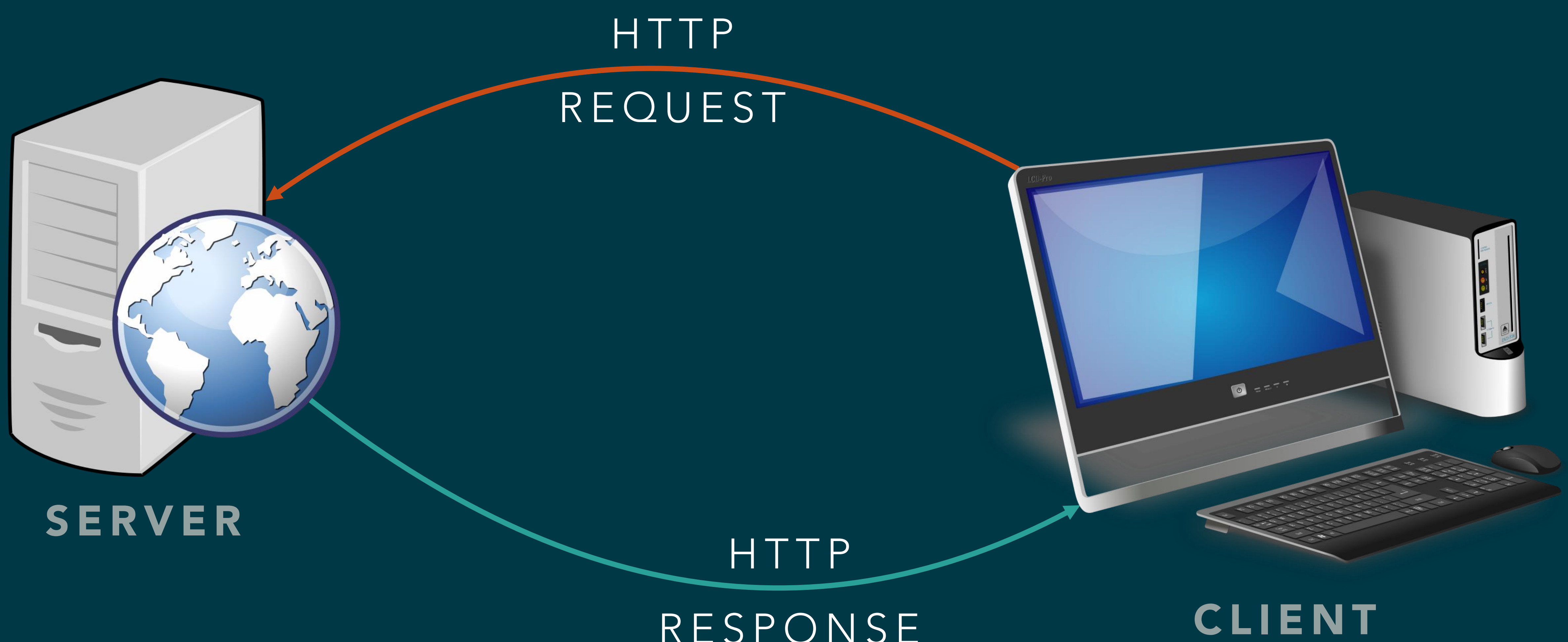

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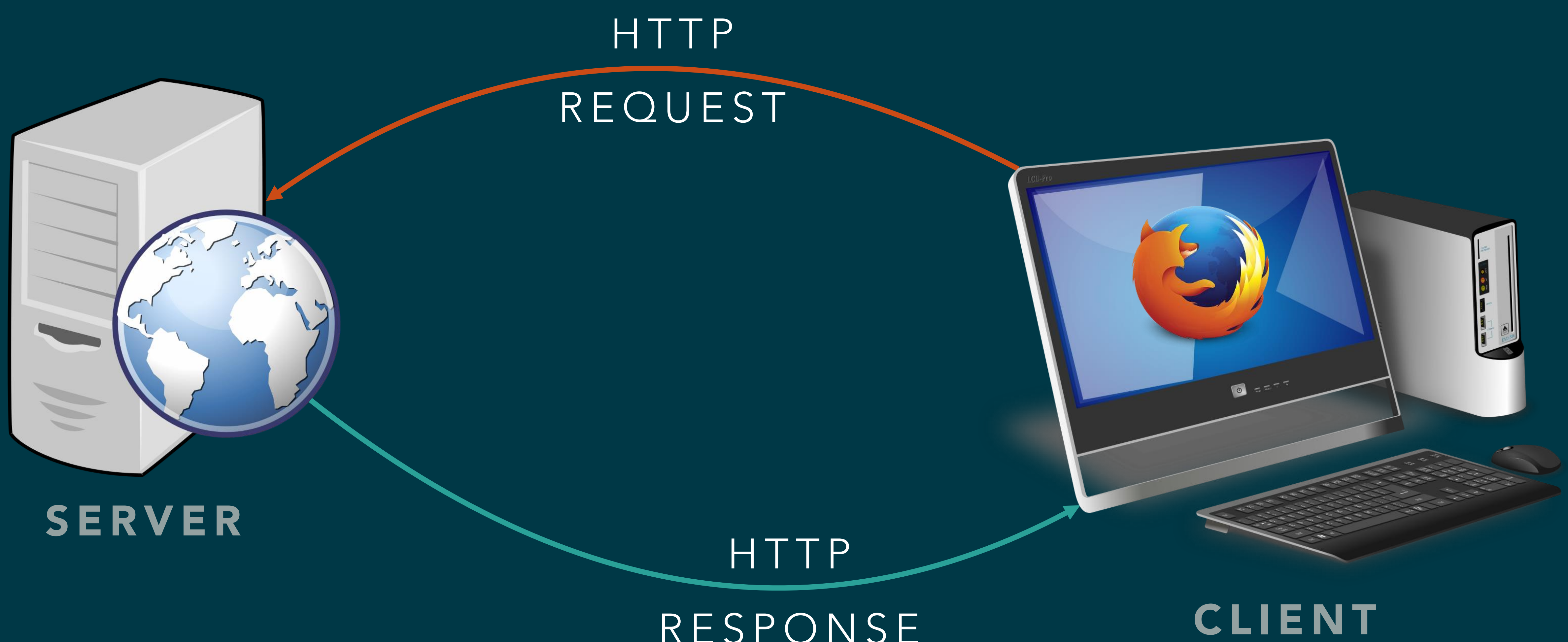


HTTP MESSAGES STRUCTURE

- HTTP messages are simple, formatted blocks of data.
- Requests and response have a similar structure:

```
message = {start-line}\r\n
          ({message-header}\r\n)*
          \r\n
          {message-body}

{start-line} = {Request-Line} | {Status-Line}
{message-header} = Field-Name ':' Field-Value

{Request-Line} = {method} {URI} HTTP/{version}
{Status-Line} = HTTP/{version} {status} {explanation}
```

HTTP REQUEST METHODS (VERBS)

- **GET** — retrieves the specified resource. GET does not have a body and, until HTTP 1.1, was not required to have headers.

```
GET /standards/ HTTP/1.1
Host: www.w3.org
User-Agent: Mozilla/5.0 (Macintosh; Intel Mac OS X 10.9; rv:35.0)
```

- **POST** — requests that the target resource processes the data enclosed in the message body according to specific semantics.
- **PUT** — requests that the state of the resource be created or replaced with the state enclosed in the message body.
- **DELETE** — deletes the specified resource.

HTTP REQUEST METHODS (VERBS)

- **HEAD** — functionally similar to **GET**, except that the server responds without message body. It's used to retrieve the server headers for a particular resource, generally to check if the resource has changed, via timestamps.

- **OPTIONS** — Returns the HTTP methods that the server supports for the specified URL.

- **TRACE** — Echoes back the received request so that a client can see what (if any) changes or additions have been made by intermediate servers. Each intermediate proxy or gateway would inject its IP or DNS name into the `Via` header field. This can be used for diagnostic purposes.

HTTP REQUEST METHODS (VERBS)

- **PATCH** — Updates portion of resource at the given URL (RFC 5789)
- **CONNECT** — Establish a tunnel to the server identified by the target resource. It is intended only for use in requests to a proxy (RFC 2817)

HTTP METHOD PROPERTIES

- A method is **"safe"** if its defined semantics is essentially **read-only**. Safe methods **does not** change the state of the server:
  - **GET**
  - **HEAD**
  - **OPTIONS**
  - **TRACE**
  - **CONNECT**

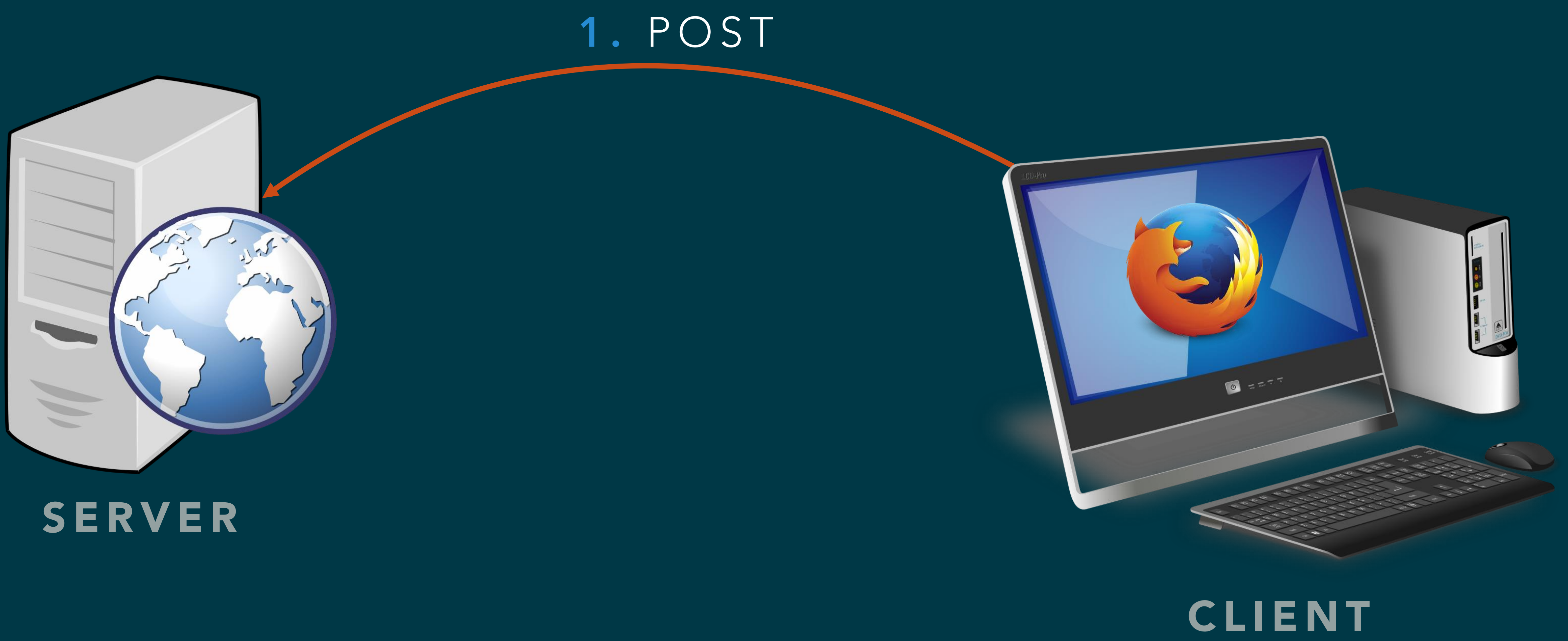
- A method is considered **"idempotent"** if the effect of multiple identical requests with that method is the same as the effect for a single such request:
  - safe methods
  - **PUT**
  - **DELETE**
  - **PATCH** (optionally, in conjunction with ETag, see RFC 5789 for details)

POST IS NOT SAFE, NOR IDEMPOTENT

SERVER

CLIENT

POST IS NOT SAFE, NOR IDEMPOTENT



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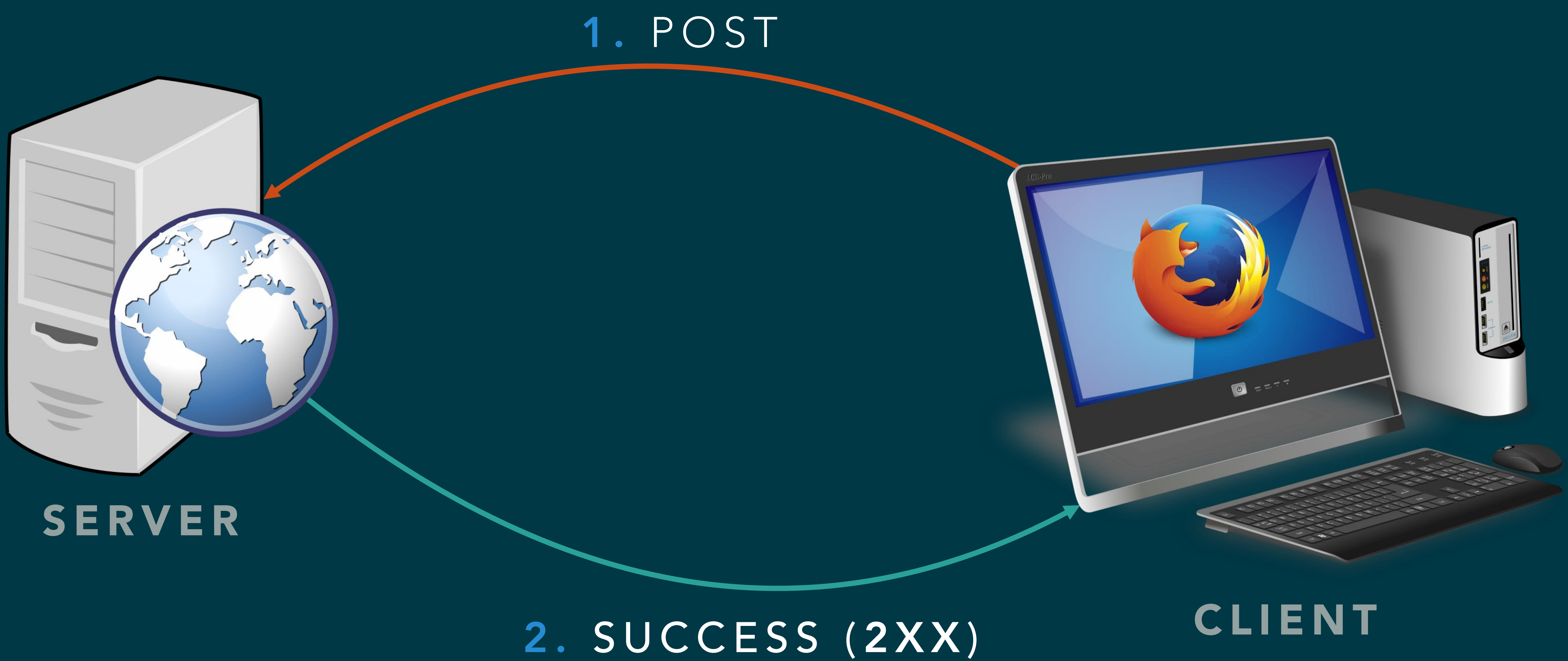

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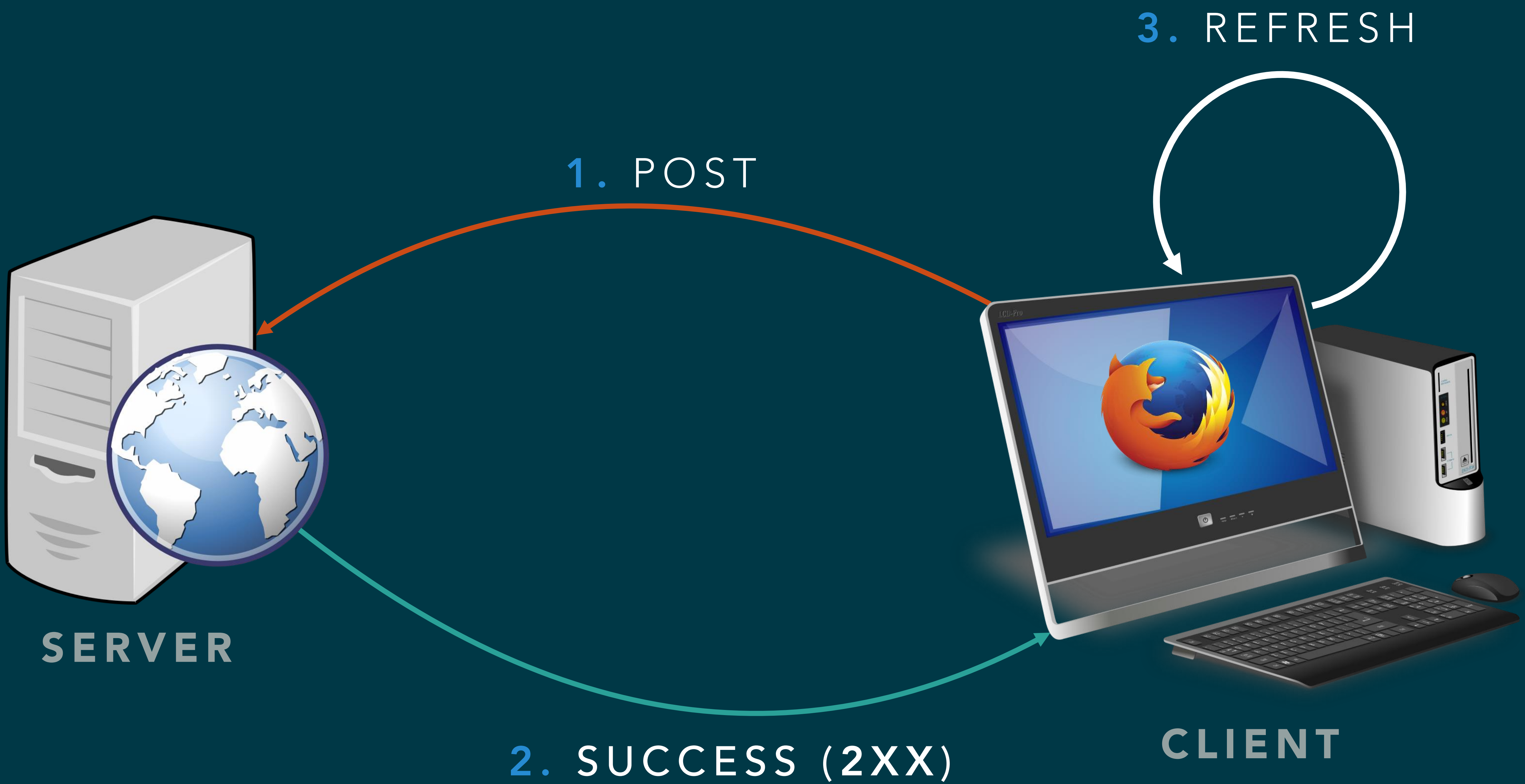

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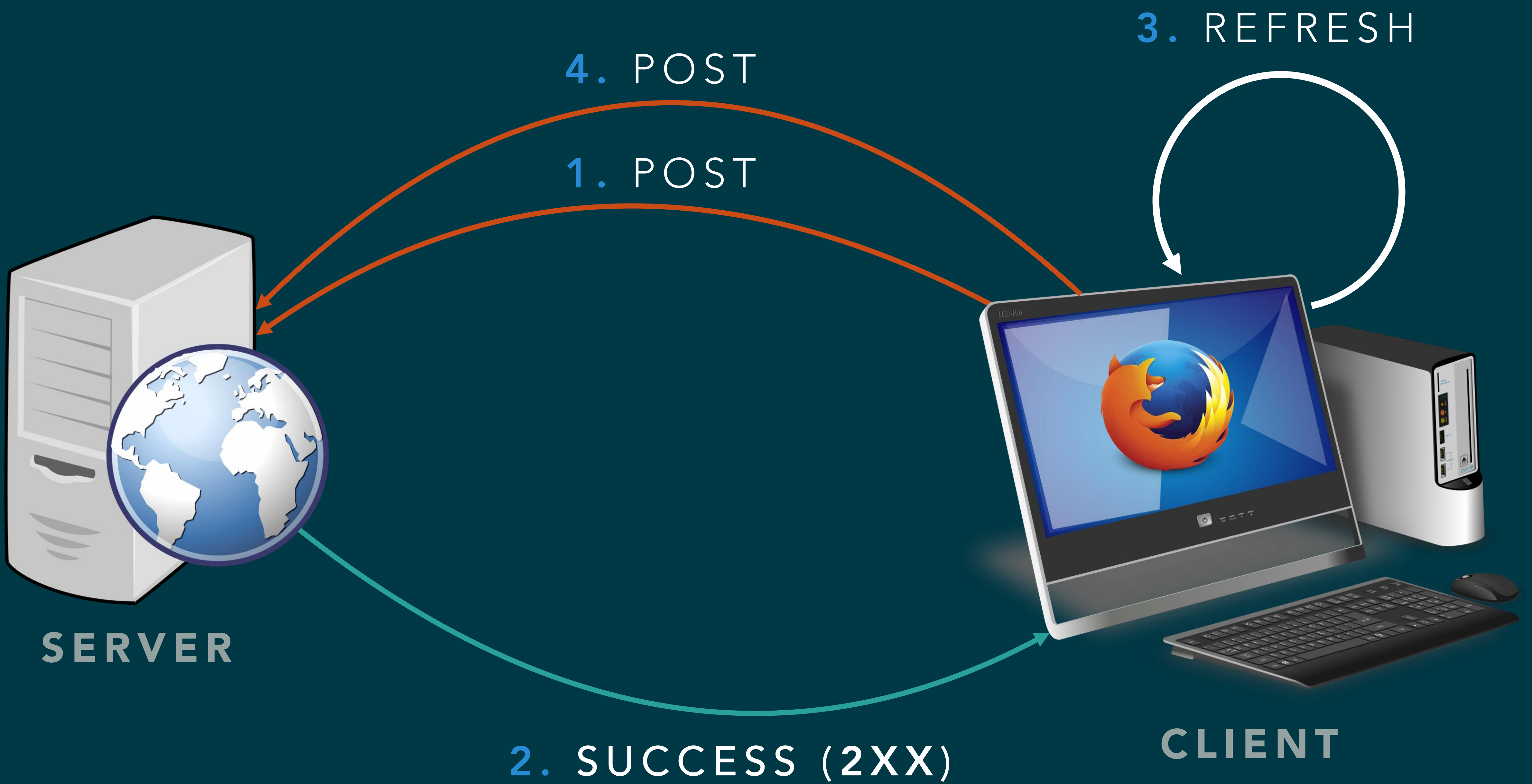

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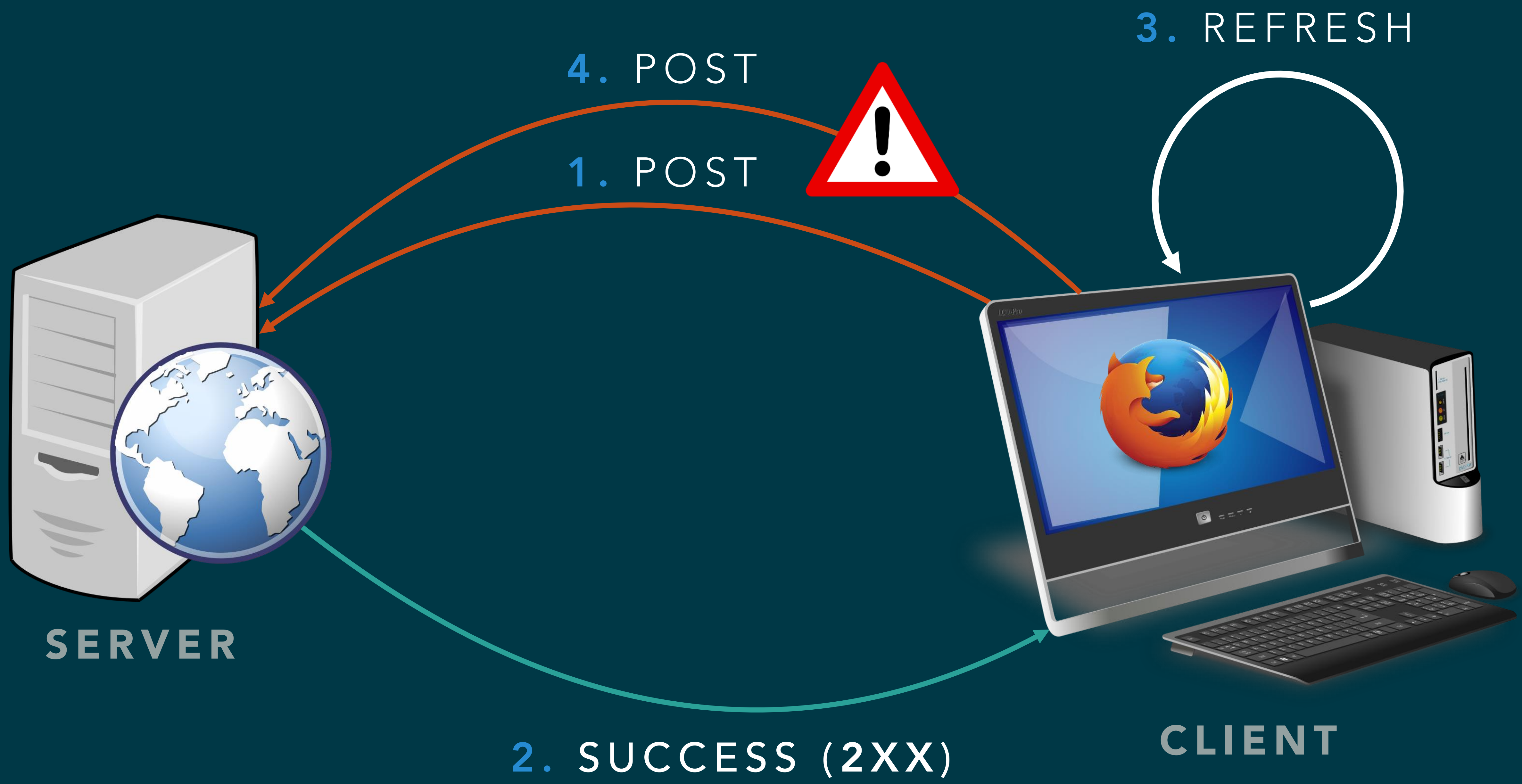

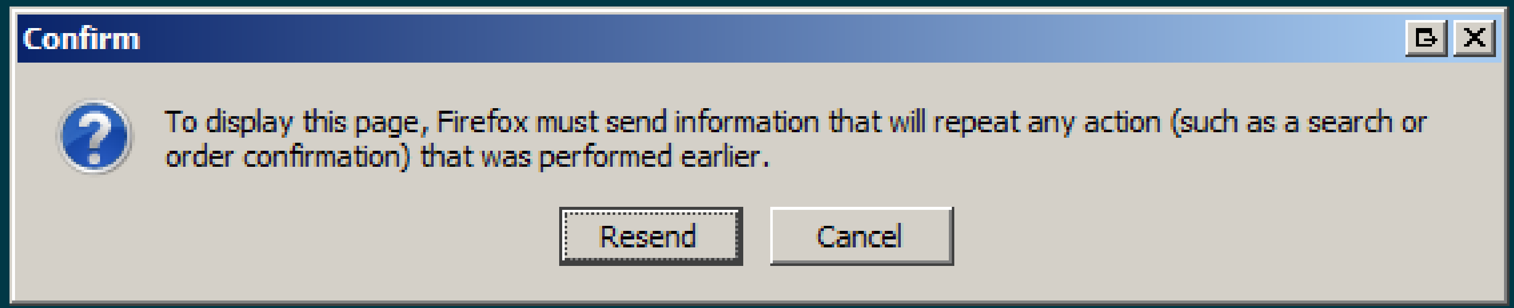

HTTP RESPONSE STATUS CODES

- **1xx** — Informational — does not include message body.
  - **100** — Continue
  - **101** — Switching protocols

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- **2xx** — Successful — the action requested by the client was received, understood, accepted and processed successfully.
  - **200** — OK
  - **201** — Created
  - **202** — Accepted

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- **2xx** — Successful — the action requested by the client was received, understood, accepted and processed successfully.
  - **200** — OK
  - **201** — Created
  - **202** — Accepted
- **3xx** — Redirection — the client must take additional action to complete the request.
  - **301** — Moved permanently
  - **302** — Found (in HTTP/1.0: Moved temporarily)
  - **303** — See other (changes method to GET)
  - **304** — Not modified
  - **307** — Temporary Redirect (does not change method)
  - **308** — Permanent Redirect (does not change method)
  - 301 & 302 are not implemented consistently: some user agents change method to GET, others do not; the standard says to not change the method

HTTP REDIRECTION PURPOSES

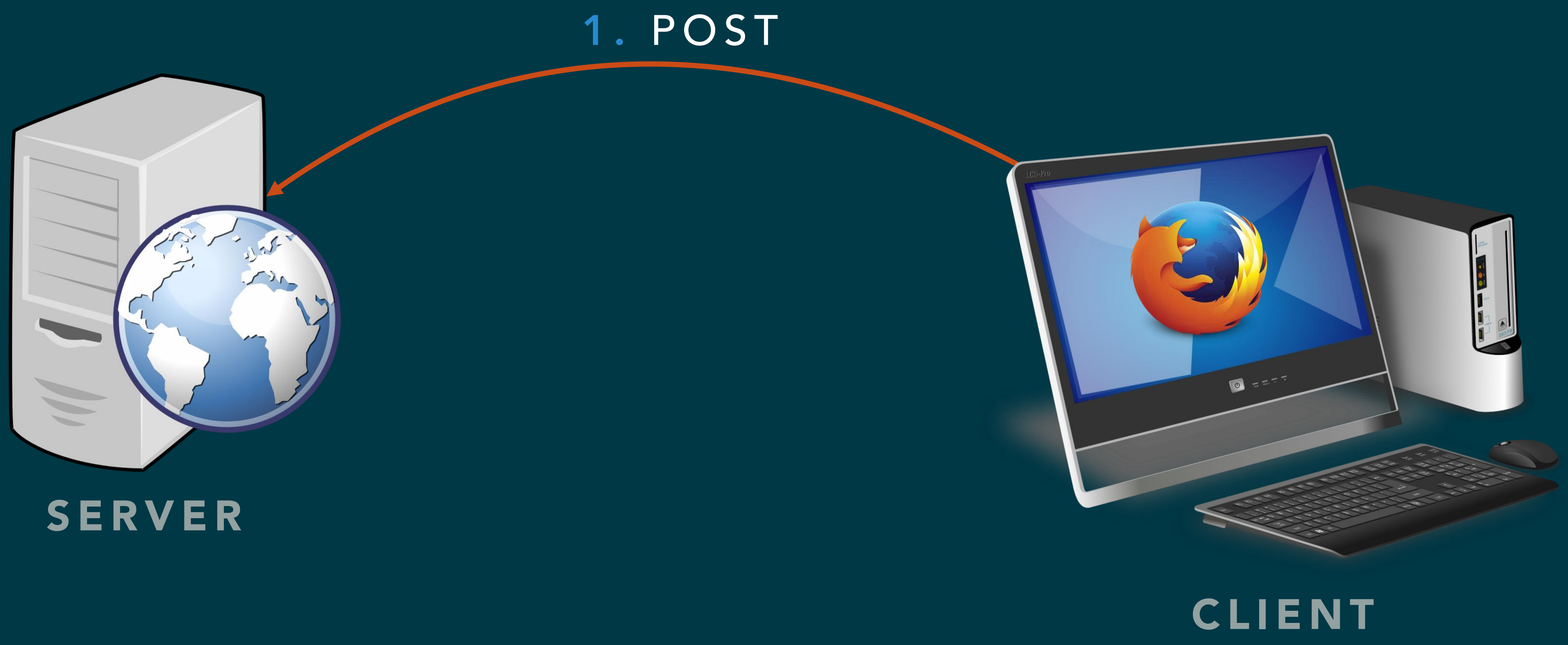
- Similar domain names
  - wikipedia.net, wikipedia.org, wikipedia.com
- URL shortening services
  - http://goo.gl, http://bitly.com
- Request to a directory without terminating slash
  - http://www.cs.put.poznan.pl/mszubert
- Redirecting users to a login page (**301** vs. **302**).
- Post/Redirection/Get

POST / REDIRECT / GET

SERVER

CLIENT

POST / REDIRECT / GET



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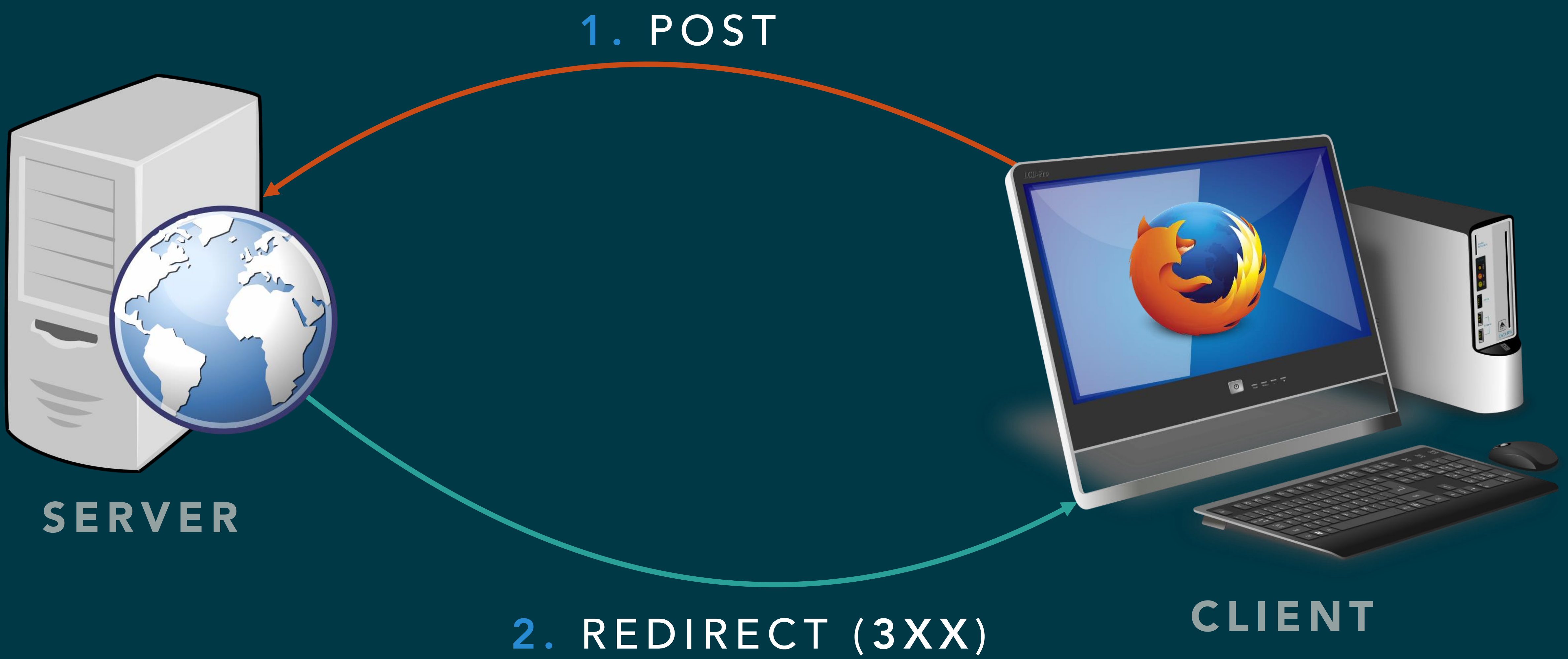

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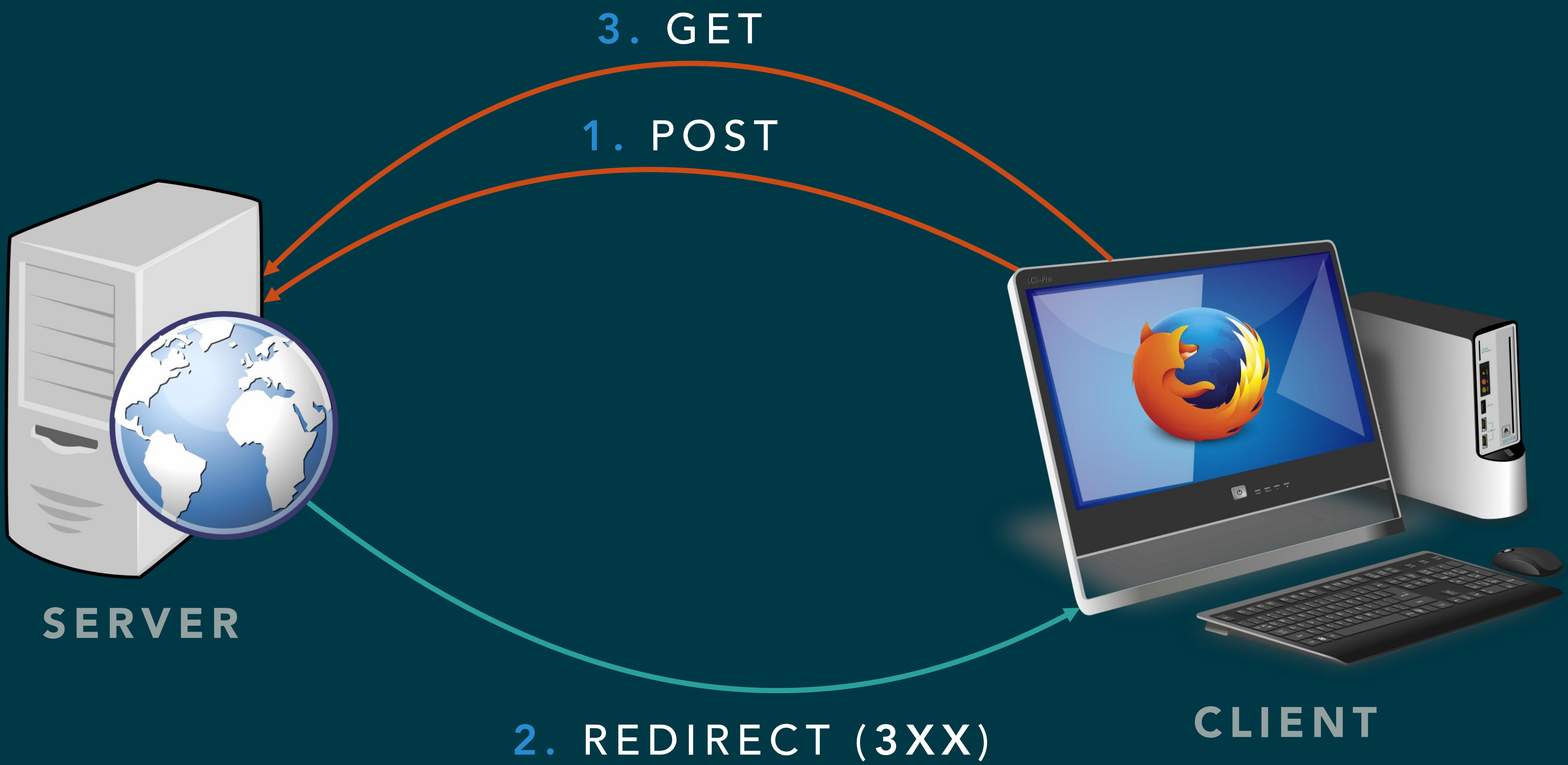

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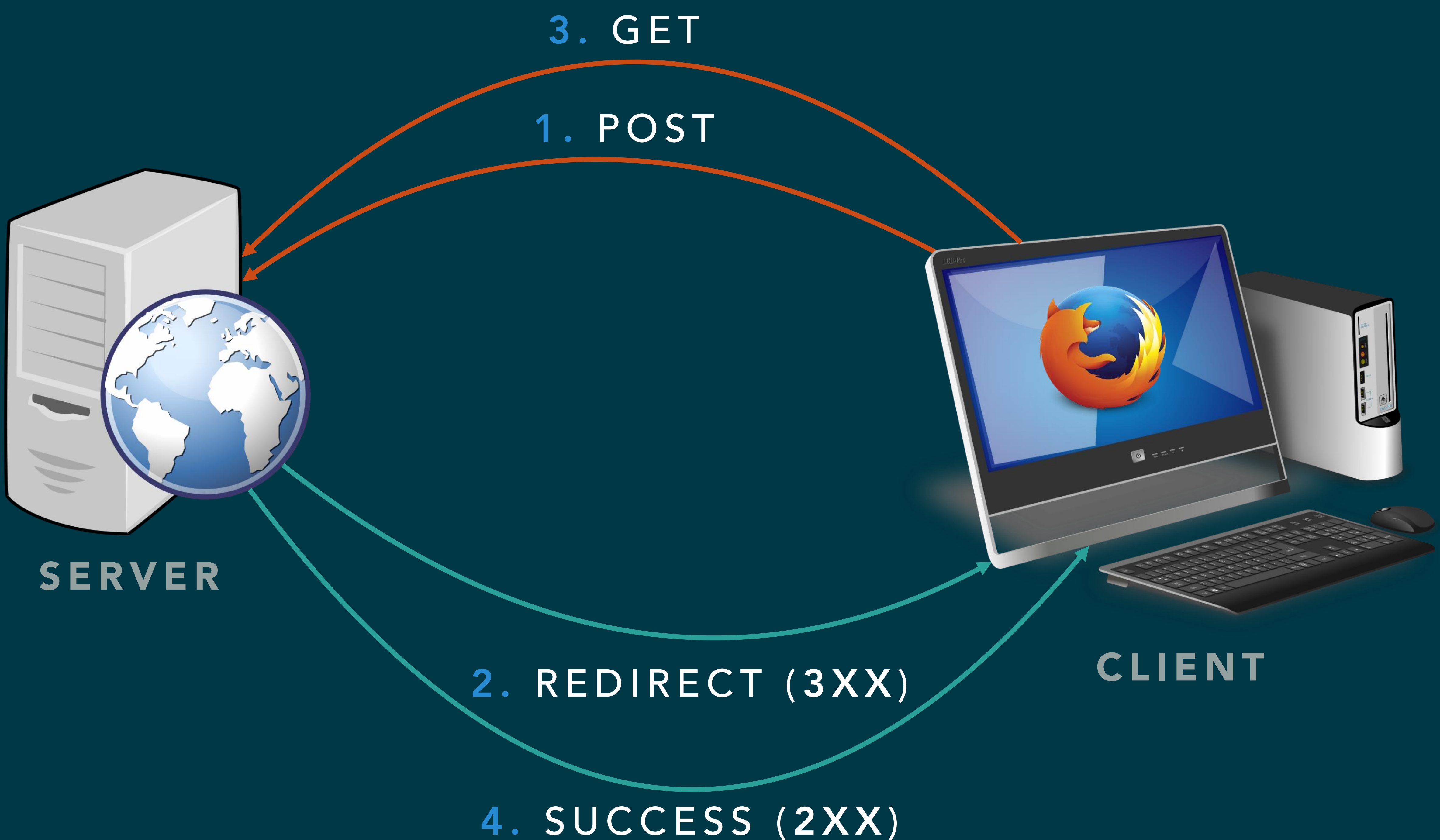

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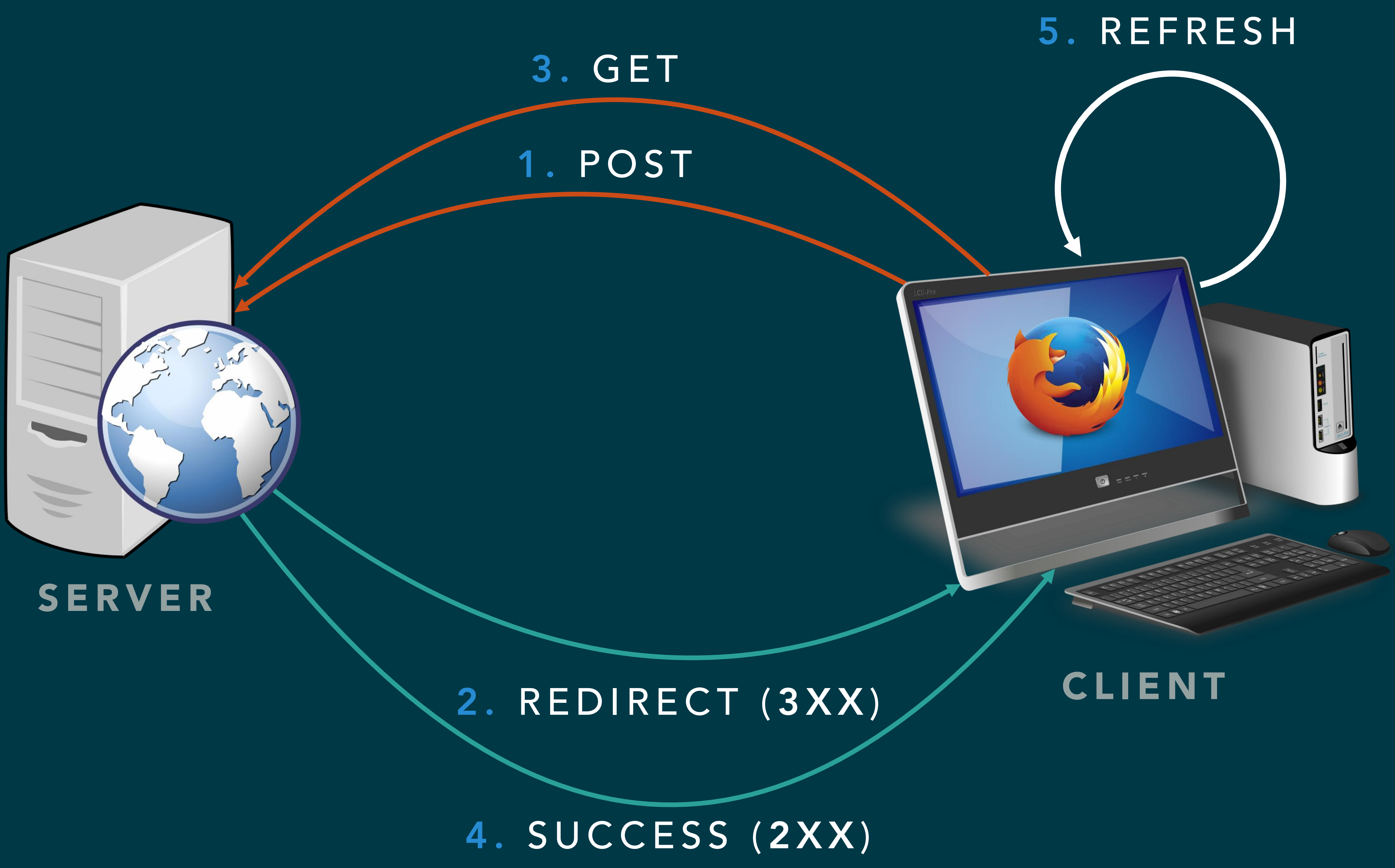

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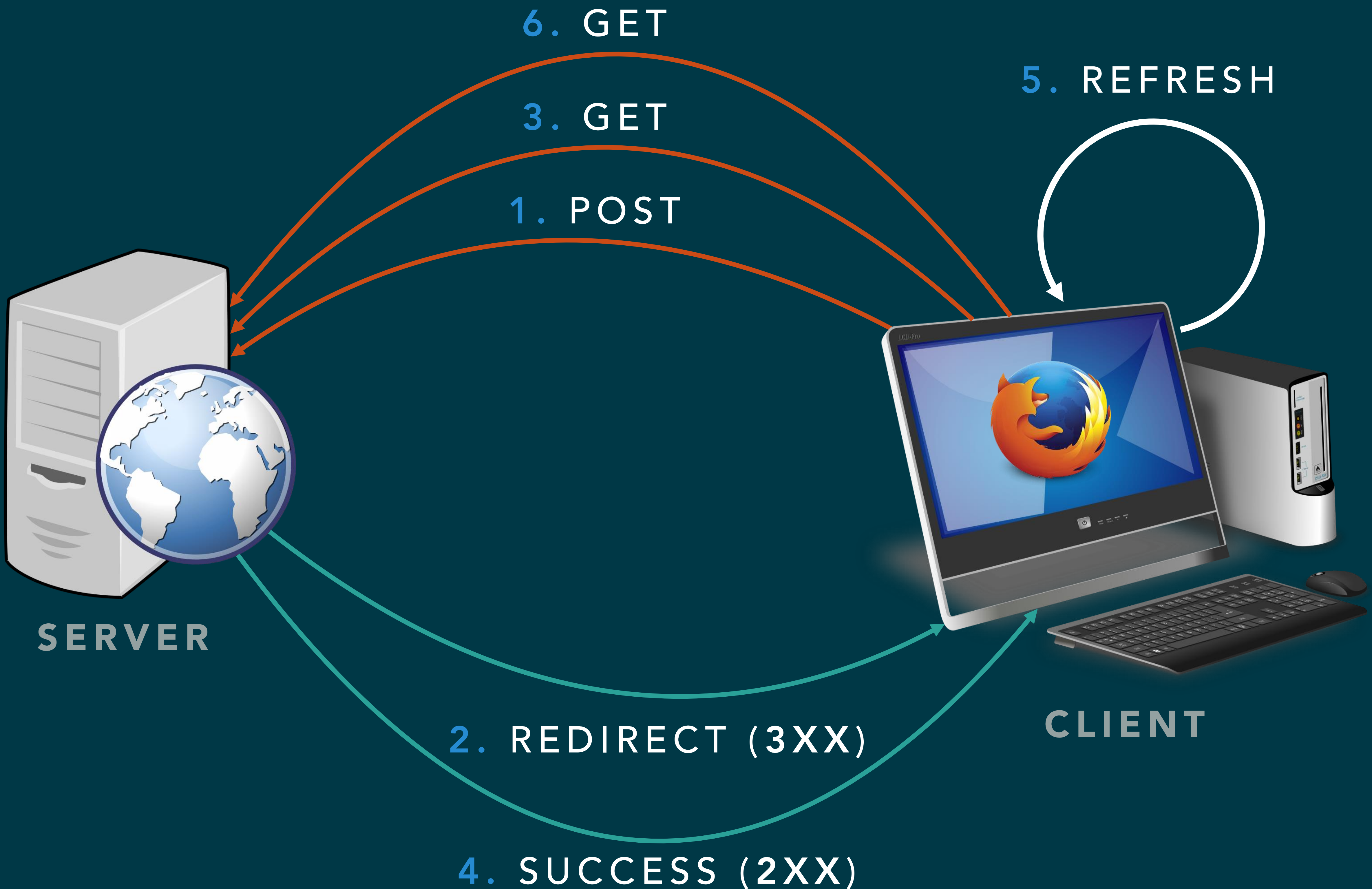

HTTP RESPONSE ERROR CODES

- **4xx** — Client Error — the client failed either by requesting an invalid resource or making a bad request.
  - **400** — Bad request
  - **401** — Not authorized
  - **402** — Payment required
  - **403** — Forbidden
  - **404** — Not found
  - **405** — Method not allowed
  - **406** — Not acceptable
  - **418** — I'm a teapot

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  - **418** — I'm a teapot
- **5xx** — Server Error — the server failed to fulfill a valid request.
  - **500** — Internal server error
  - **501** — Not implemented
  - **503** — Service unavailable

HTTP MESSAGES STRUCTURE

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message = {start-line}\r\n
          ({message-header}\r\n)*
          \r\n
          {message-body}

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- Headers are a form of message **metadata** and are broadly classified into:
  - general headers
  - request-specific headers
  - response-specific headers
  - entity headers

USES OF HEADERS

- Informational
- Virtual hosting
- Content negotiation
- Client identification
- Authentication
- Caching

GENERAL HEADERS

- `Date` — provides a date and time stamp telling when the message was created.
- `Via` — shows what intermediaries (proxies, gateways) the message has gone through.
- `Connection` — allows clients and servers to specify options about the request/response connection.
- `Cache-Control` — used to pass caching directions along with the message.
- `Transfer-Encoding` — used to compress or to break the response into smaller parts (with the `chunked` value).

INFORMATIONAL REQUEST HEADERS

- `Host` — gives the hostname and port to which the request is being sent; introduced to enable a single server to service multiple domains (virtual hosting).
- `Referer` — identifies the address of the webpage that linked to the resource being requested.
- `User-agent` — tells the server the name of the application making the request.
- `From` — the email address of the user making the request.
- `Client-IP` — the IP address of the client’s machine.

INFORMATIONAL RESPONSE HEADERS

- `Server` — identifies the server generating the message.
- `Warning` — stores text for human consumption, something that would be useful when tracing a problem.
- `Location` — contains the new URL when redirecting.
- `Age` — provided by proxies, time in seconds since the message was generated on the server.
- `Allow` — valid actions for a specified resource.

CONTENT NEGOTIATION
REQUEST HEADERS — ACCEPT

- Content negotiation — a mechanism that allows to serve different versions of a document at the same URI, so that user agents can specify which version fit their **capabilities** the best.

```
Accept: text/html, text/plain;q=0.3
Accept-Charset: utf-8, iso-8859-13;q=0.8
Accept-Encoding: gzip;q=1.0, identity;q=0.5, *;q=0
Accept-Language: pl, en-us;q=0.7
```

- `Accept` — accepted Internet media types (MIME). https://www.iana.org/assignments/media-types/media-types.xhtml

- `Accept-Encoding` — used mainly for HTTP compression.

CONTENT NEGOTIATION
RESPONSE ENTITY HEADERS

- Message typing is necessary for both servers and browsers to determine proper actions in **processing** messages.
- Browsers use types and sub-types either to select a proper **content-rendering** module or to invoke a third-party tool.

```
Content-Type: text/html; charset=utf-8
Content-Encoding: gzip
Content-Language: pl
Content-Length: 348
Content-Location: /index.html
```

CLIENT IDENTIFICATION
STATELESS NATURE OF HTTP

- HTTP is stateless and sessionless, each request-response transaction is **independent**.
- Most of the web applications are highly **stateful**, rely on tracking and storing **user sessions**.

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- Most of the web applications are highly **stateful**, rely on tracking and storing **user sessions**.
- How to determine which requests come from **the same** user?
- The server can identify and track users by employing:
  - **HTTP headers** — informational request headers: `From`, `Referer`, `User-Agent`
  - **Client IP address tracking** — identify users by their IP addresses: `Client-IP`
  - Extending **URLs** — generating user-specific URLs by embedding identity
  - **Cookies** — the **most popular** and non-intrusive approach (RFC 6265)
  - **ETag** – unique identifier of resource version
  - **User login** — authentication headers: `WWW-Authenticate`, `Authorization`

CLIENT IDENTIFICATION
IP ADDRESS TRACKING

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CLIENT IDENTIFICATION
IP ADDRESS TRACKING

- The client IP address typically is not present in the HTTP headers, but web servers can find the IP address of the other side of the TCP connection.
- Using the client IP address to identify the user has weaknesses:
  - Client IP addresses describe only the computer being used, not the user.
  - Many ISPs assign IP addresses to users **dynamically**.
  - Users are hidden behind **Network Address Translation** (NAT) devices.
  - HTTP proxies and gateways typically open **new TCP connections** to the origin server. Some proxies add `Client-ip` or `X-Forwarded-For` extension headers to preserve the original IP address.
  - **Anonymous proxies** make tracking IP adress impractical.

CLIENT IDENTIFICATION
EMBEDDING INFORMATION INTO URLS

- Special versions of each URL for each user (also called **fat URLs**).
- Typically, a real URL is extended by adding some state information (e.g. unique session ID) to the end of the URL or to a **query string**, e.g. `http://[host]/edit.jsp;jsessionid=123`

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- Typically, a real URL is extended by adding some state information (e.g. unique session ID) to the end of the URL or to a **query string**, e.g. `http://[host]/edit.jsp;jsessionid=123`
- Problems:
  - Ugly URLs — URLs displayed in the browser are confusing for new users.
  - Can’t share URLs — URLs contain state information about a particular session.
  - Extra server load — the server needs to rewrite HTML to *fatten* the hyperlinks.
  - Not persistent across sessions — all information is lost when the user logs out, unless he **bookmarks** the particular URL.

CLIENT IDENTIFICATION
COOKIES

- **HTTP State Management Mechanism** (RFC 6265)

SERVER

CLIENT

CLIENT IDENTIFICATION
COOKIES

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CLIENT IDENTIFICATION
COOKIES

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```
1 HTTP/1.1 200 OK
2 Content-Type: text/html; charset=utf-8
3 Set-Cookie: ID=494647c; domain=.msn.com; path=/
```

CLIENT IDENTIFICATION
COOKIES

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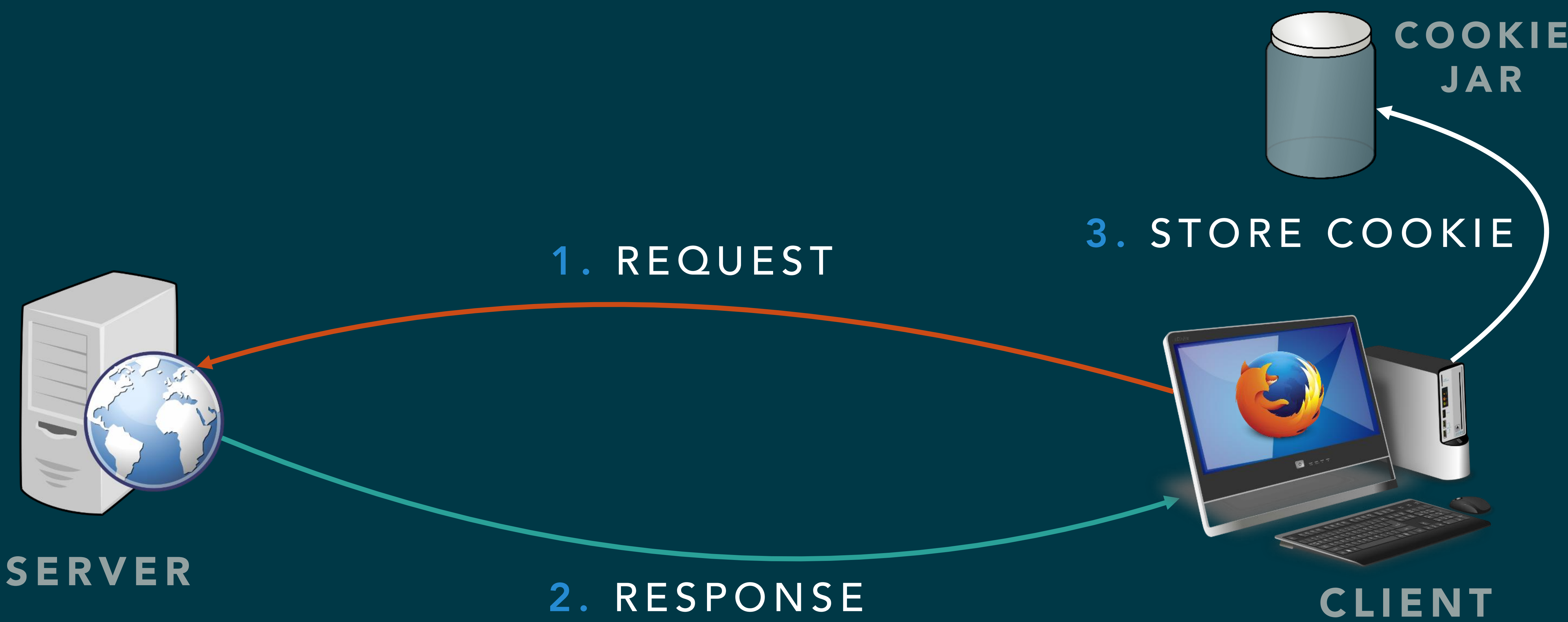


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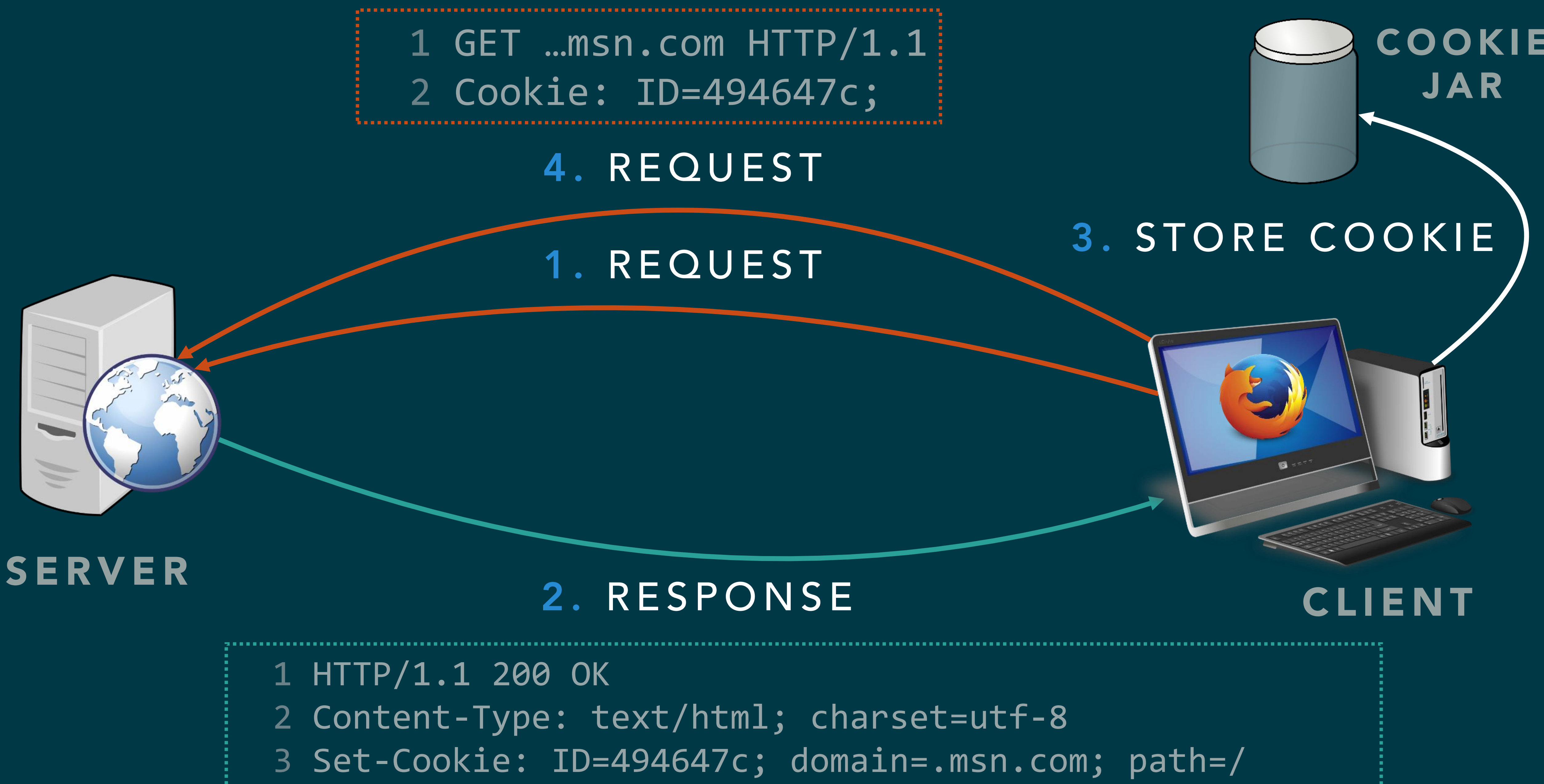

CLIENT IDENTIFICATION
TYPES OF COOKIES

- **Session cookies** — also known as **in-memory** cookies or **transient** cookies. Web browsers normally delete session cookies when the user closes the browser.

- **Persistent cookies** — also referred to as **tracking** cookies. Instead of expiring when the web browser is closed, persistent cookies **expire** at a specific date or after a specific length of time.

```
HTTP/1.0 200 OK
Content-type: text/html
Set-Cookie: ID=494647c; Max-Age=86400
Set-Cookie: ID=abc123; Expires=Wed, 09 Jun 2021 10:18:14 GMT
```

CLIENT IDENTIFICATION ISSUES WITH COOKIES

- Session hijacking and cookie theft:
  - **network sniffing** — resolved by using `Secure` cookies
    - `Secure` cookies are sent back by the browser only if the connection is encrypted
  - **cross-site scripting** — mitigated by using `HttpOnly` cookies
    - `HttpOnly` cookies are not available to scripts in the browser
  - **cross-site request forgery** — mitigated by using `SameSite` cookies
    - `SameSite` cookies are sent back by the browser only if they were created by the same site as the site where the HTTP request originates
    - `SameSite` attribute is implemented inconsistently across browsers as of 03.2020, some of them default to `SameSite=Lax`, while others to `SameSite=None` (see https://caniuse.com/#search=samesite)

CROSS-SITE REQUEST FORGERY

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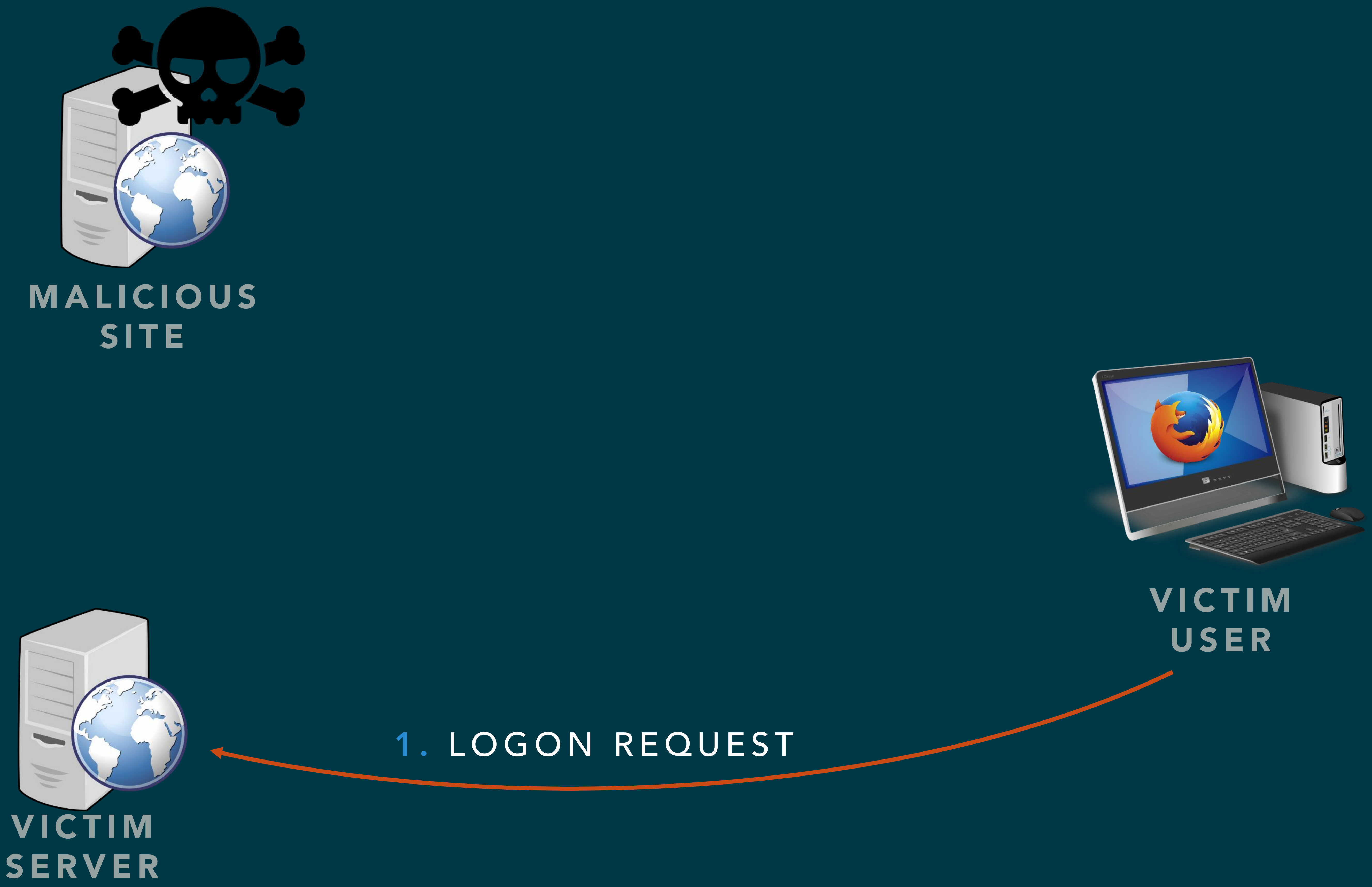

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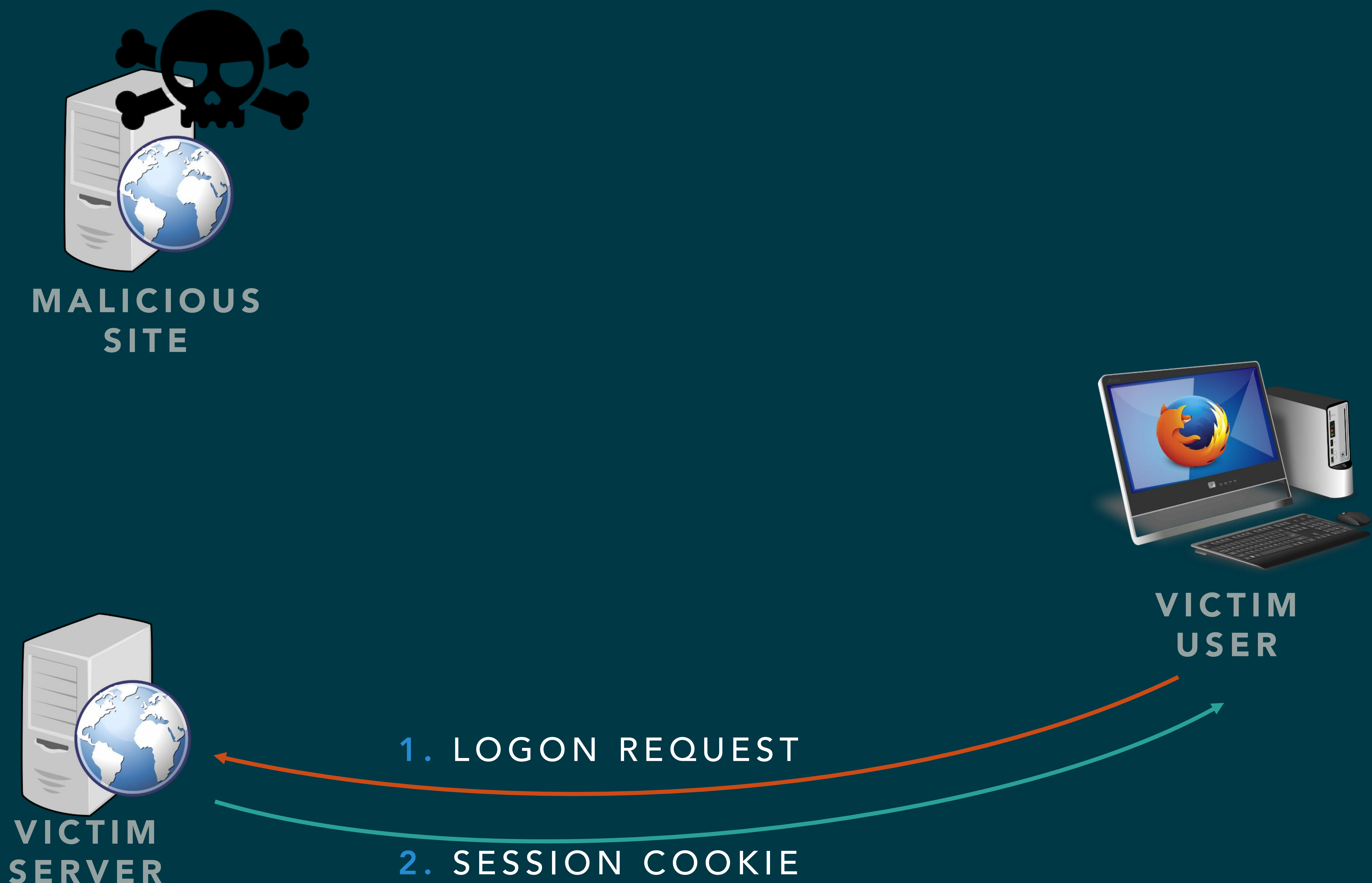

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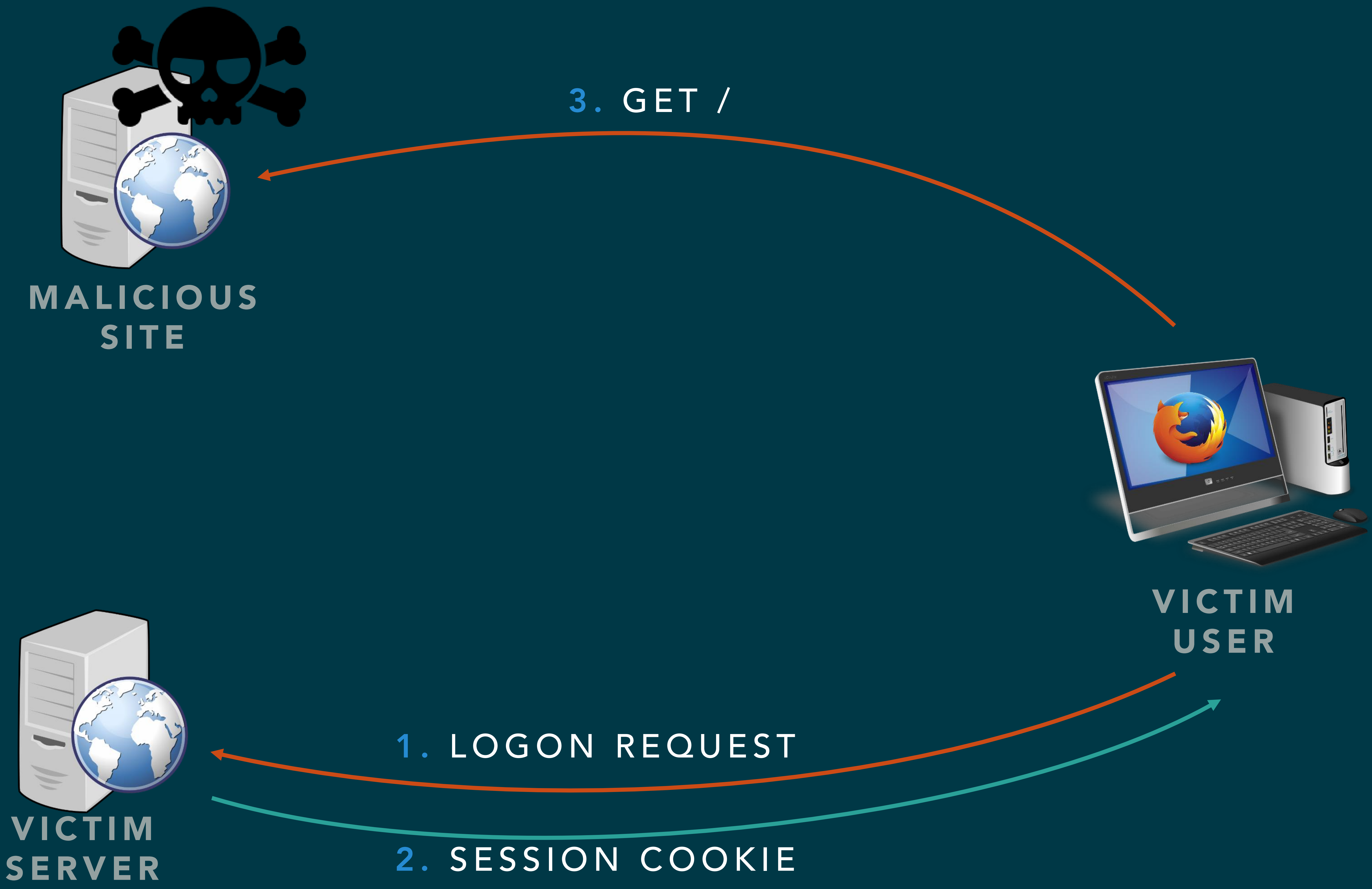

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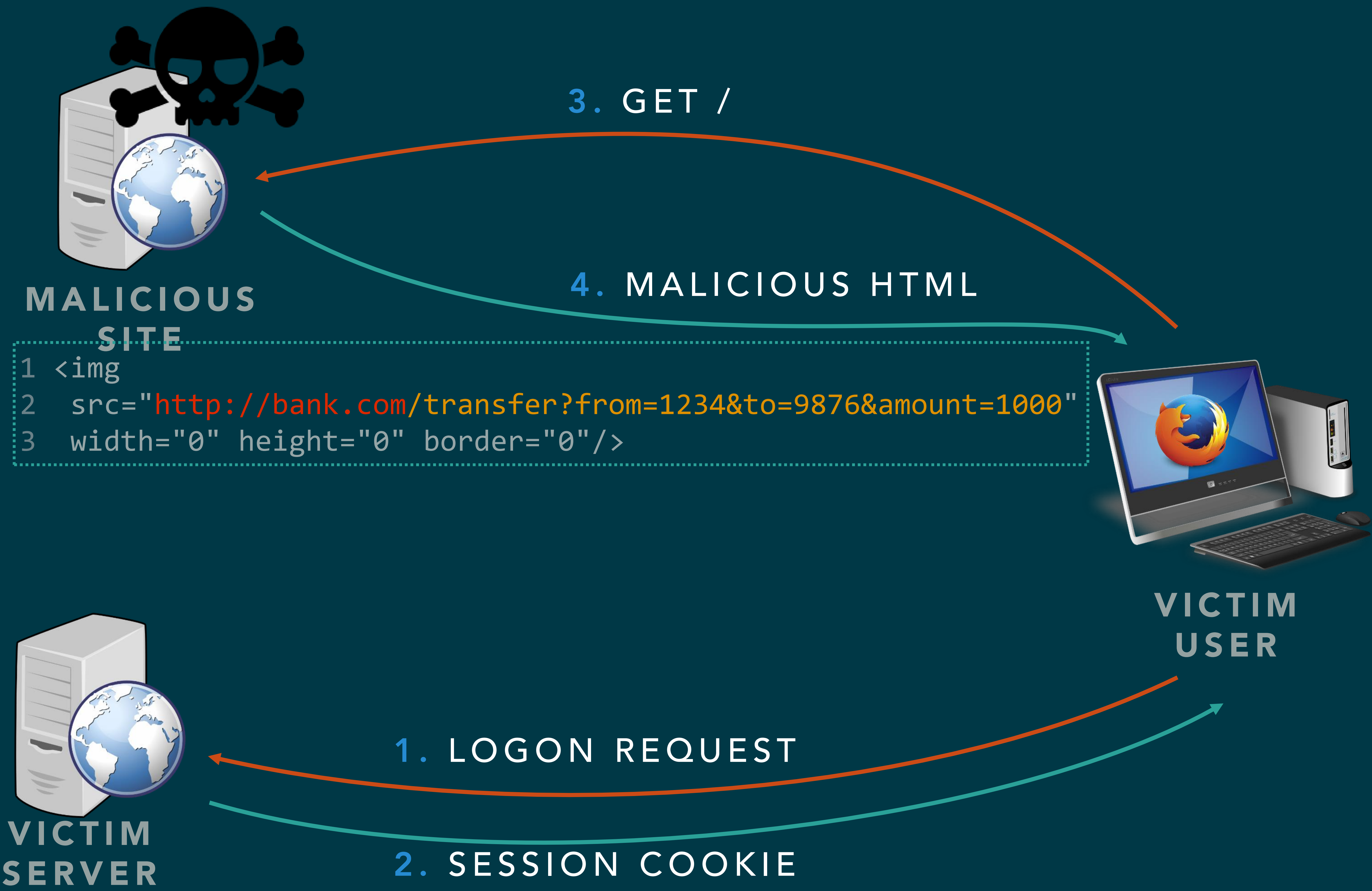
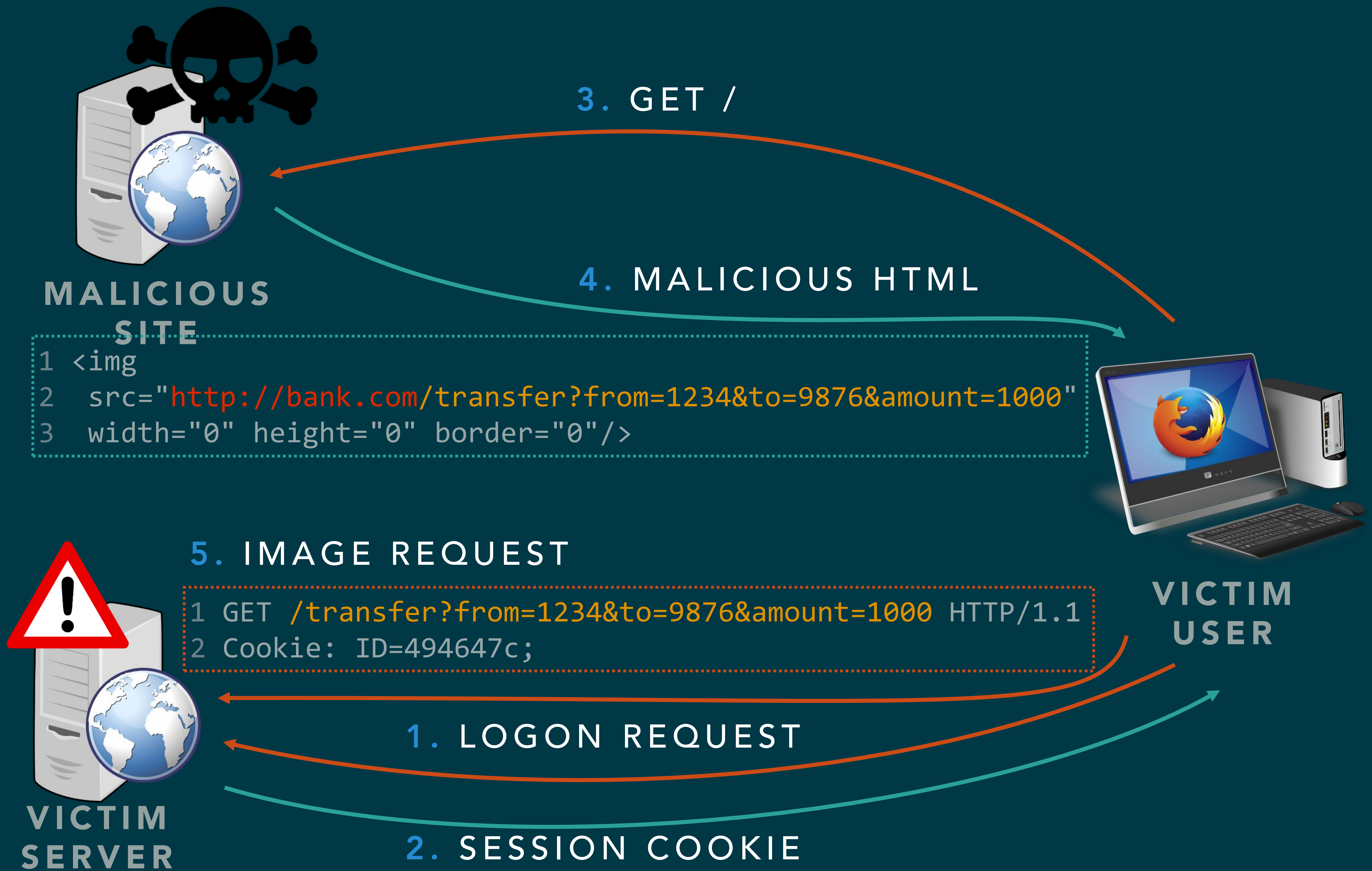



```
<img
 src="http://bank.com/transfer?from=1234&to=9876&amount=1000"
 width="0" height="0" border="0"/>
```

CROSS-SITE REQUEST FORGERY



CLIENT IDENTIFICATION ISSUES WITH COOKIES

- Cookies can be disabled or deleted by users in their browsers

- Privacy concerns:
  - **Third party cookies** may track users across the Internet
    - E.g., Google Analytics
  - **EU: *The Right to be Forgotten***
    Service providers are required to ask users whether they accept use of a tracking mechanism (in Poland from 2013)
    - Penalties up to €1 million or 2% of their sale
    - Replaced in May 2018 by:
  - **EU: *General Data Protection Regulation***
    Service providers are required to ask the users for consent for use of data separately for each purpose
    - Penalties up to €20 million or 4% of their worldwide turnover

CLIENT IDENTIFICATION
ETAG

- ETag
  - Piece of information that uniquely identifies a resource and its version
    - E.g., a cryptographic sum: crc, md5, sha-1, sha-256,…
  - Sent by server in HTTP headers
  - Intended for effective caching
- Browser that supports ETags
  - Sends header in every subsequent request:
  - `If-None-Match: “etag-value”`
- Server responses
  - 304 Not Modified or
  - 200 Ok

CLIENT IDENTIFICATION
ETAG

- To track a user, send different ETag for the same resource each time, a request has no ETag included

SERVER

CLIENT

CLIENT IDENTIFICATION
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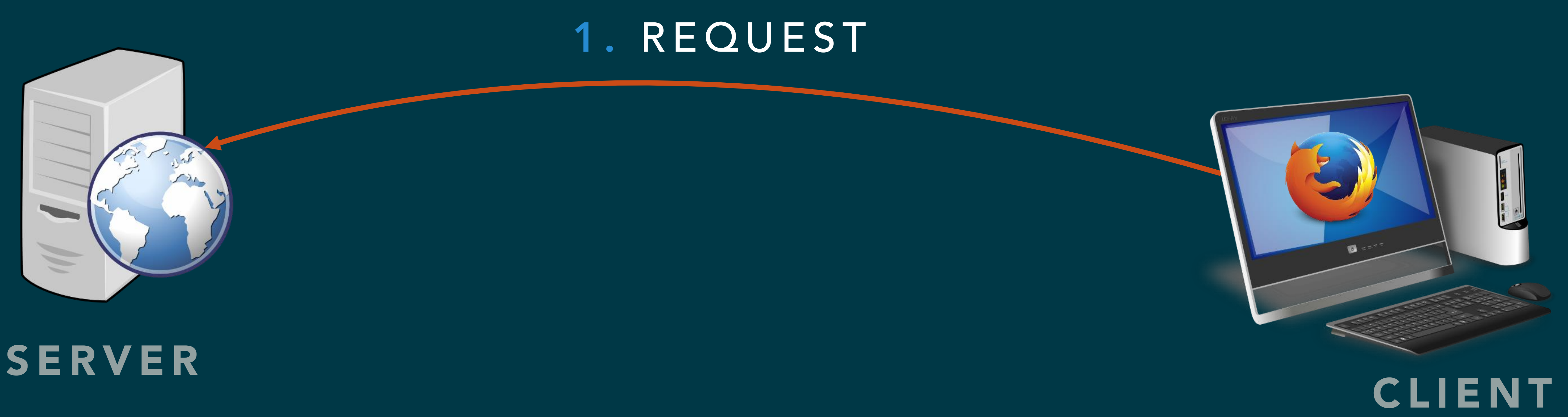

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```
HTTP/1.1 200 OK
Content-Type: text/html; charset=utf-8
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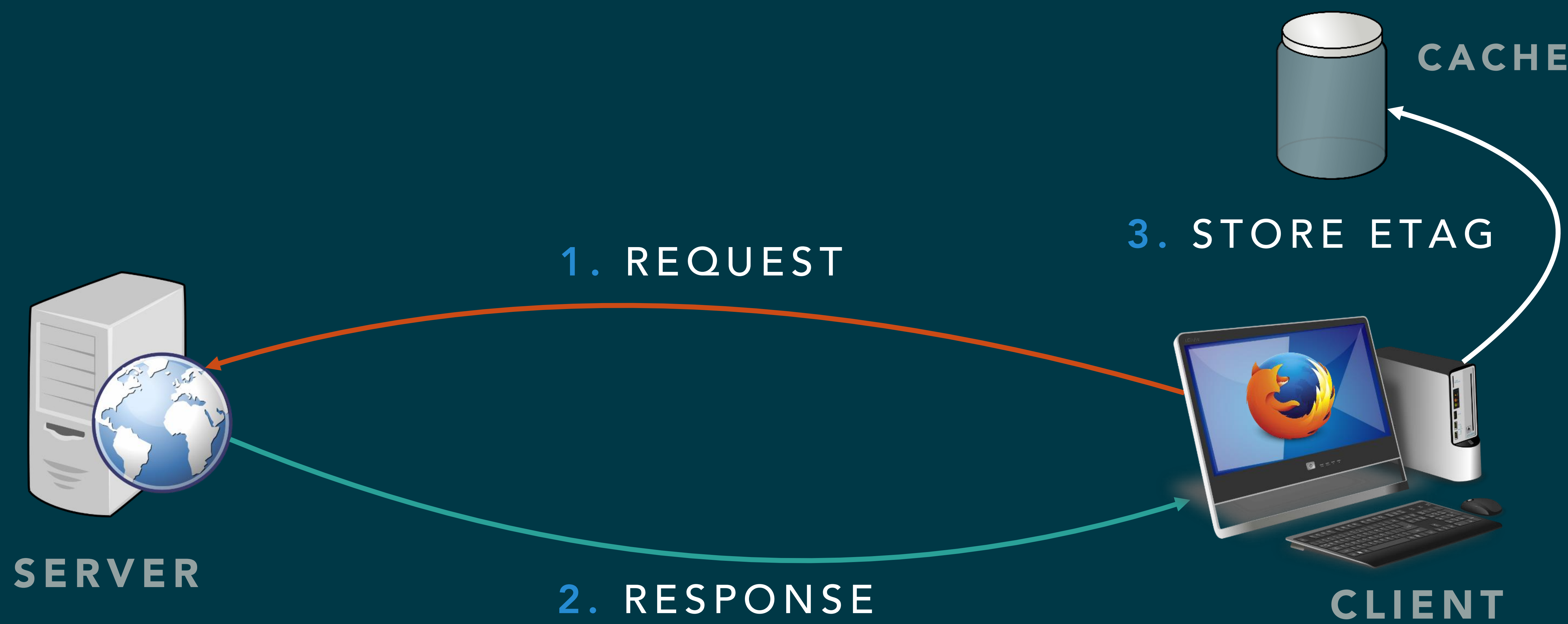


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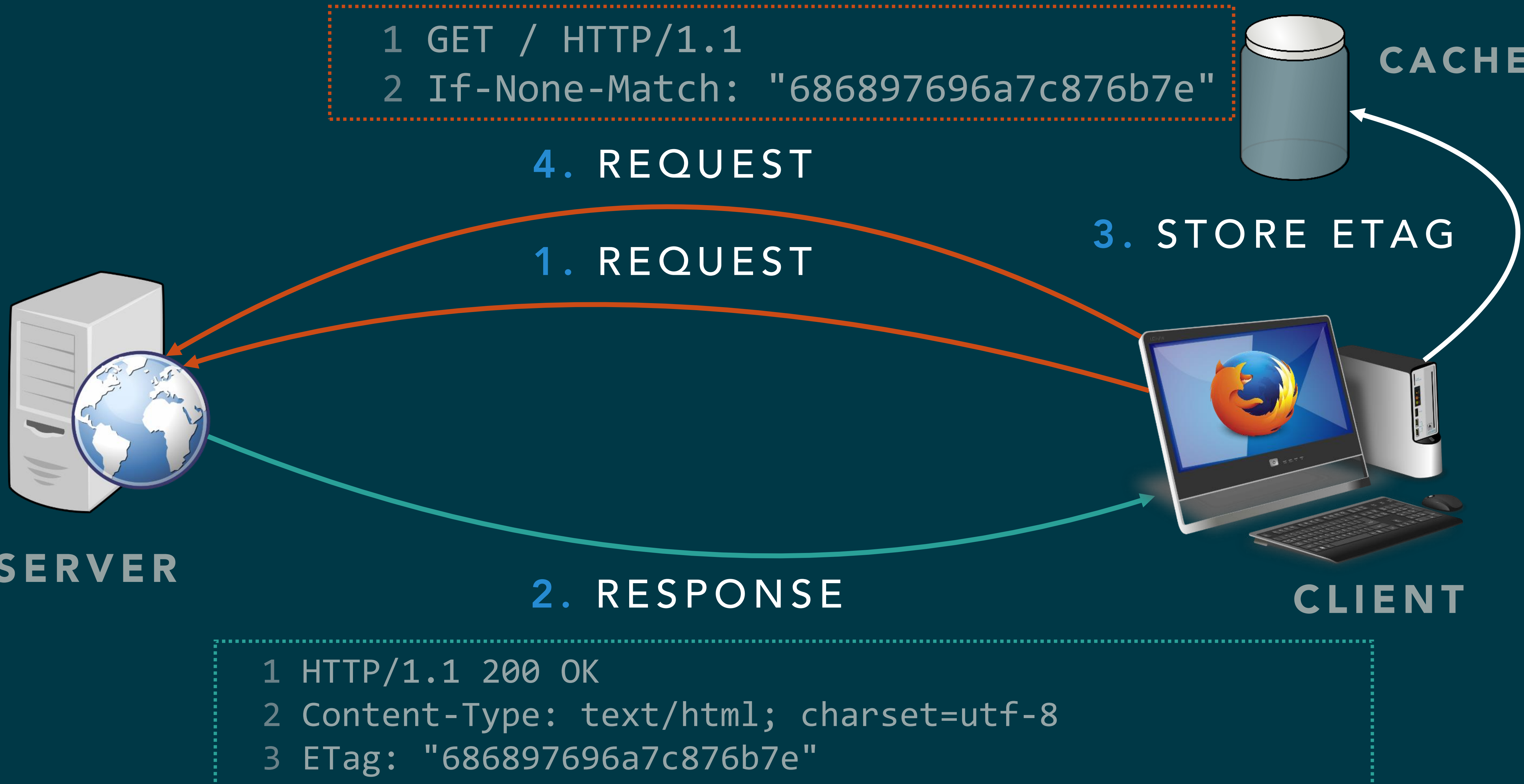

CLIENT IDENTIFICATION
HTTP BASIC AUTHENTICATION

- HTTP provides built-in support for Basic Authentication, where user credentials formatted as `user:password` are transmitted via the `Authorization` header as a **Base64**-encoded string.

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- If the server validates the authorization credentials, browser uses them as the value of the Authorization header in future requests to **dependent URLs**.

- Basic authentication is **insecure by default** — credentials are simply encoded (not encrypted) — rarely used without **HTTPS**.

CLIENT IDENTIFICATION HTTP DIGEST AUTHENTICATION

- Server sends a seed `nonce` and a message `realm` to the client
- Client responds with MD5 of credentials concatenated with `realm`, method, URI, and `nonce`
- Algorithm for calculating response (RFC 2069):

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- Algorithm for calculating response (RFC 2069):

```
HA1=MD5(username:realm:password)
HA2=MD5(method:digestURI)
response=MD5(HA1:nonce:HA2)
```

CLIENT IDENTIFICATION
HTTP DIGEST AUTHENTICATION

CLIENT IDENTIFICATION
HTTP DIGEST AUTHENTICATION

```
HTTP/1.1 401 Unauthorized
Date: Sun, 10 Apr 2014 20:26:47 GMT
WWW-Authenticate: Digest realm="testrealm@host.com",
                  nonce="dcd98b7102dd2f0e8b11d0f600bfb0c093"
```

CLIENT IDENTIFICATION
HTTP DIGEST AUTHENTICATION

```
HTTP/1.1 401 Unauthorized
Date: Sun, 10 Apr 2014 20:26:47 GMT
WWW-Authenticate: Digest realm="testrealm@host.com",
                  nonce="dcd98b7102dd2f0e8b11d0f600bfb0c093"
```

```
GET /dir/index.html HTTP/1.1
Host: localhost
Authorization: Digest username="Mufasa",
                   realm="testrealm@host.com",
                   nonce="dcd98b7102dd2f0e8b11d0f600bfb0c093",
                   uri="/dir/index.html",
                   response="6629fae49393a05397450978507c4ef1"
```

CLIENT IDENTIFICATION
HTTP DIGEST AUTHENTICATION

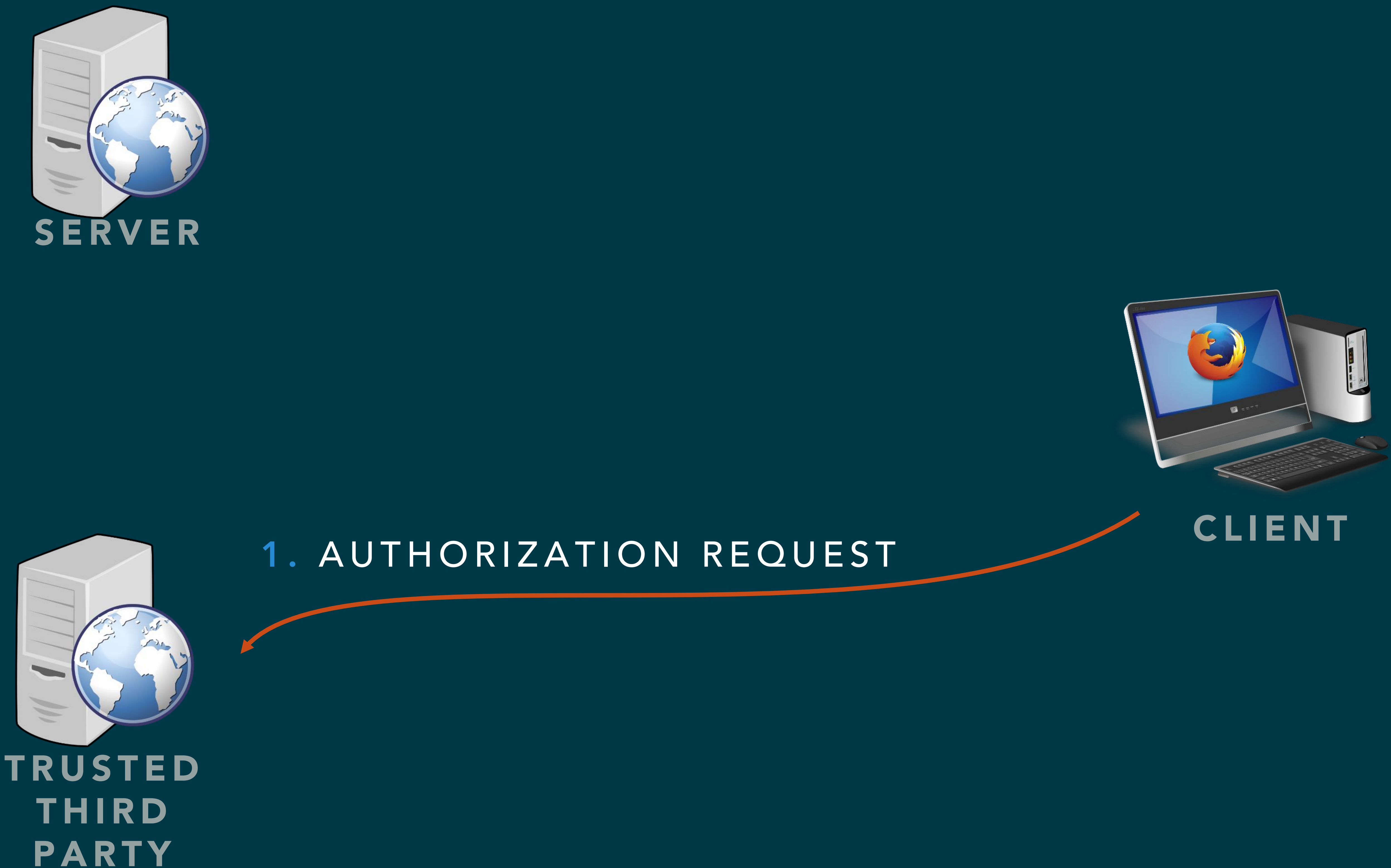
- RFC 2617 defines more secure way to digest authentication
  - Recurrent MD5 hashes
  - A counter of requests incremented by client
  - A client-generated seed
- More secure than basic and RFC 2069 digest authentication, but
  - Passwords must be stored in plain text on server side to calculate MD5s
  - MD5 collisions are easy to generate
- RFC 7616 extends digest authentication by negotiation of checksum algorithm
  - A proposal of standard as of 03.2020
  - Partial implementations in major browsers as of 03.2020

CLIENT IDENTIFICATION
HTTP BEARER AUTHENTICATION

- Involves a trusted third party performing authorization
  - Authorized client receives OAuth 2.0 token
- Client exchanges the token with server
- Server verifies the token with the trusted third party
- RFC 6750
  - A proposal of standard as of 03.2020

CLIENT IDENTIFICATION
HTTP BEARER AUTHENTICATION

CLIENT IDENTIFICATION
HTTP BEARER AUTHENTICATION



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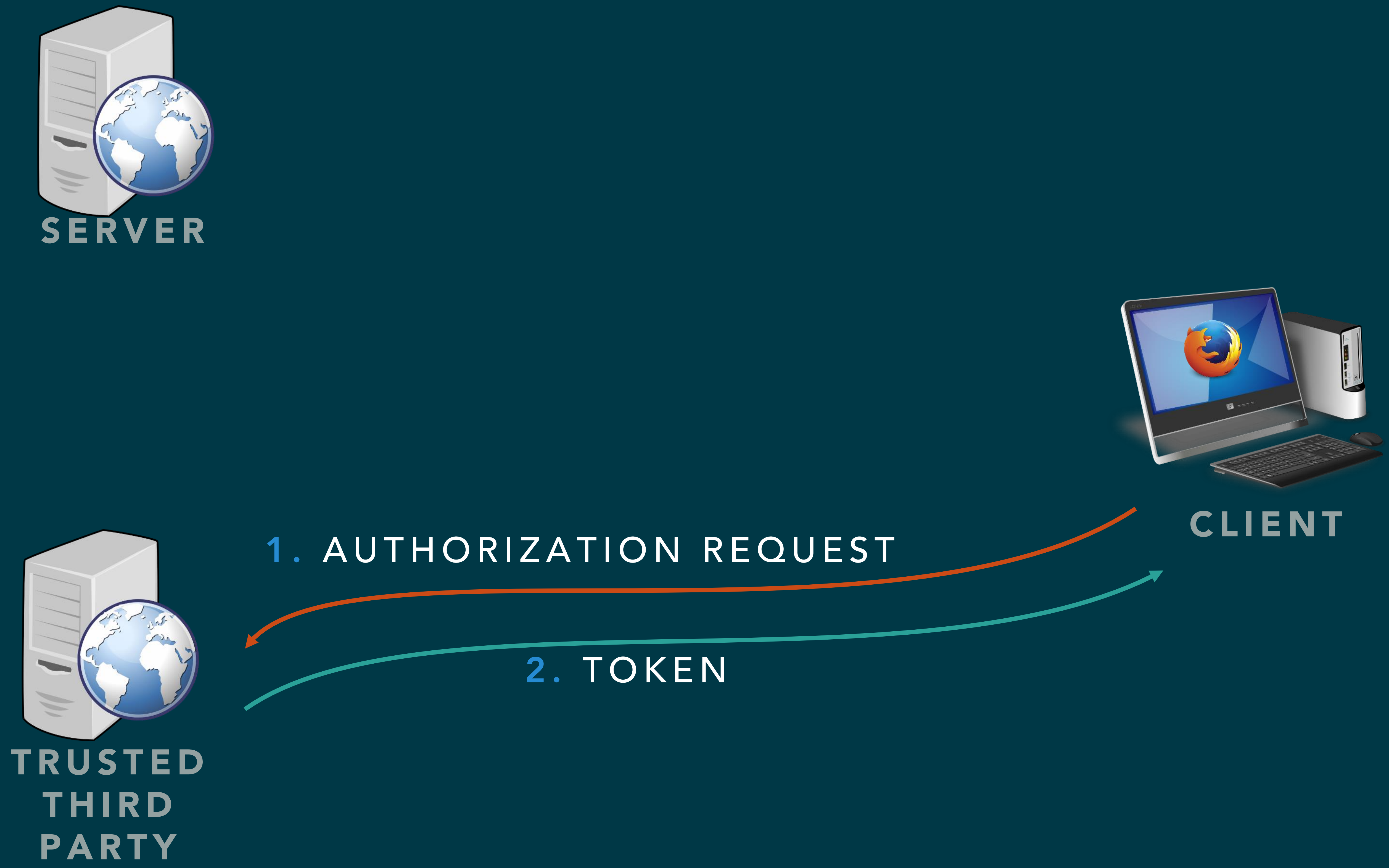

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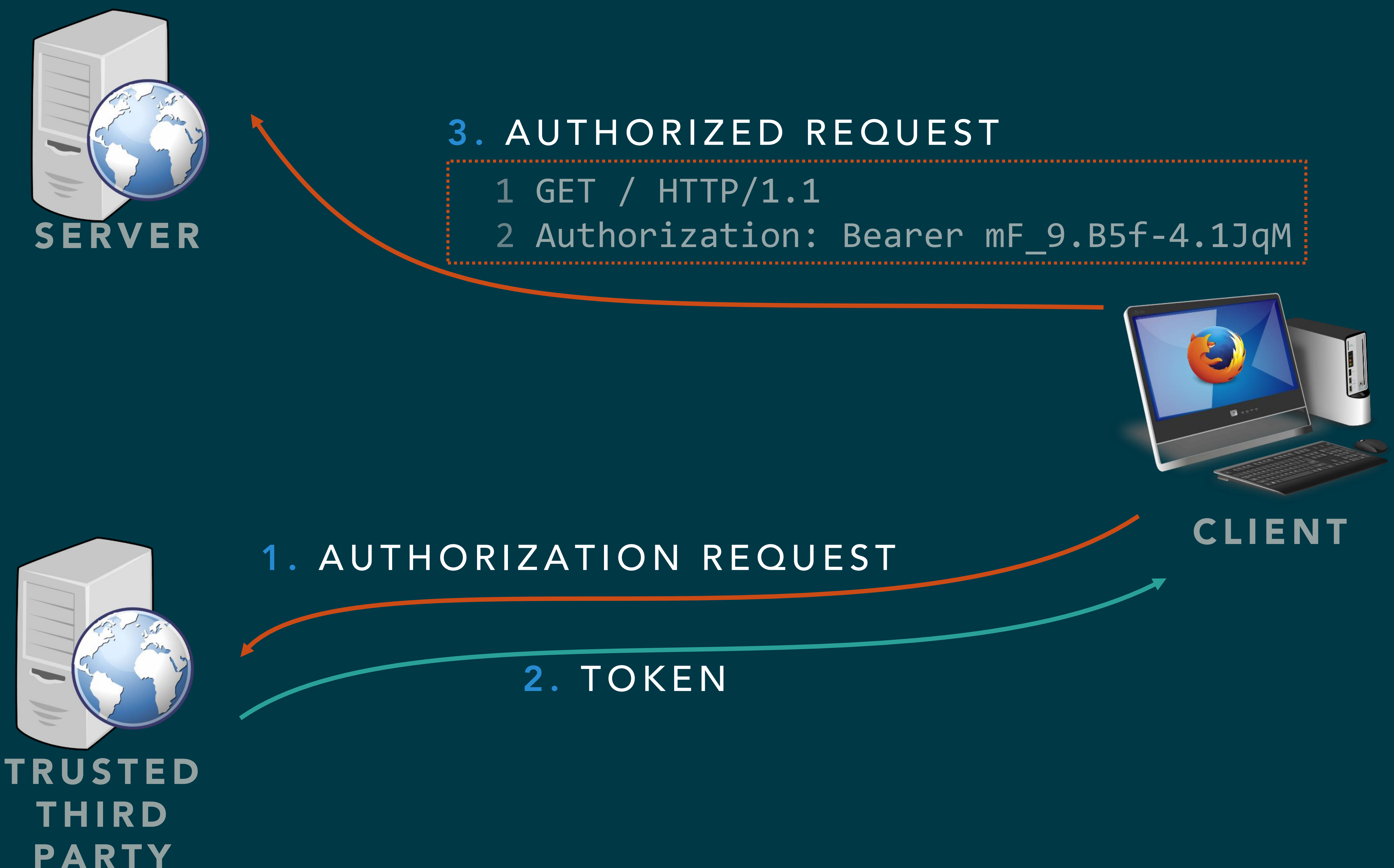

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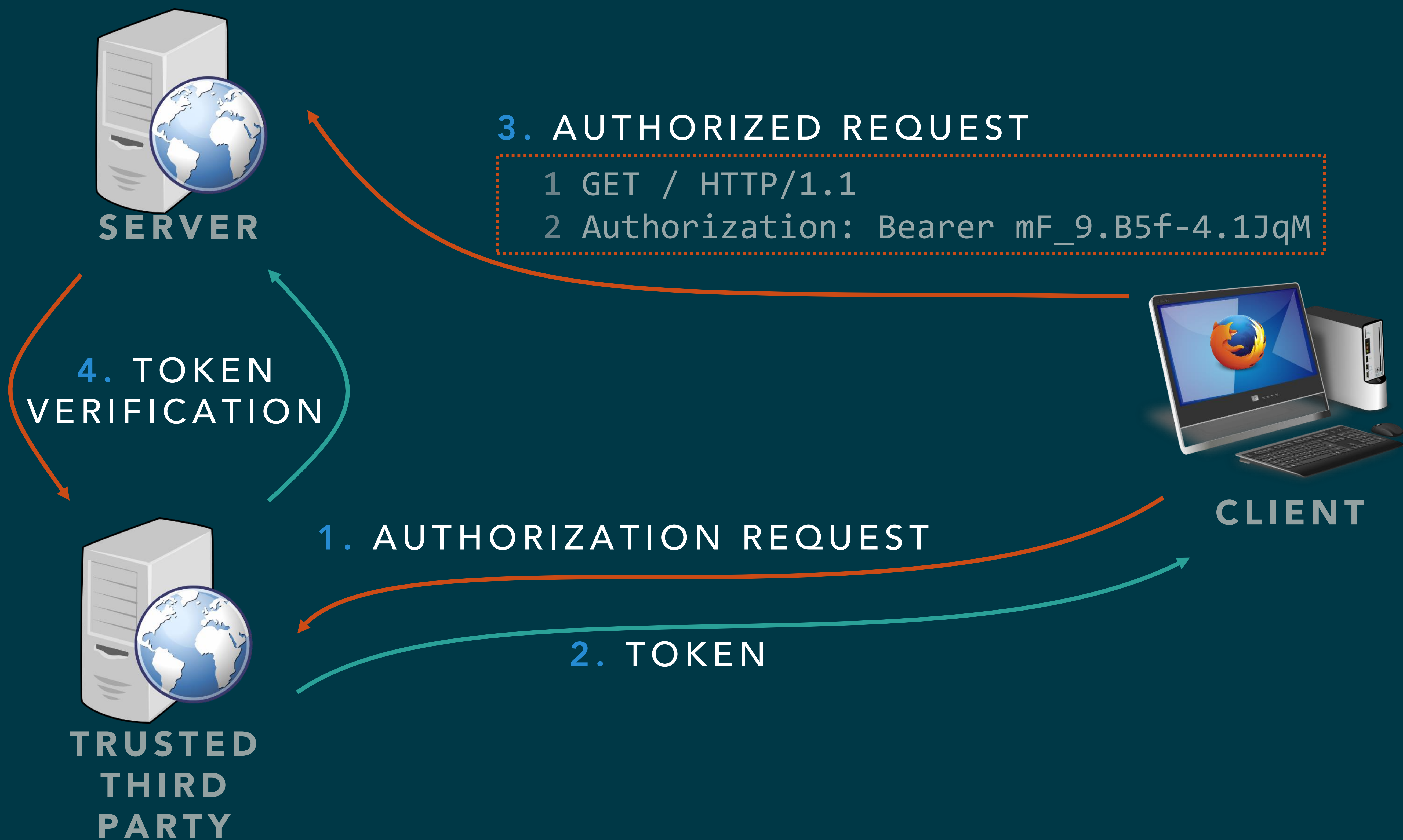

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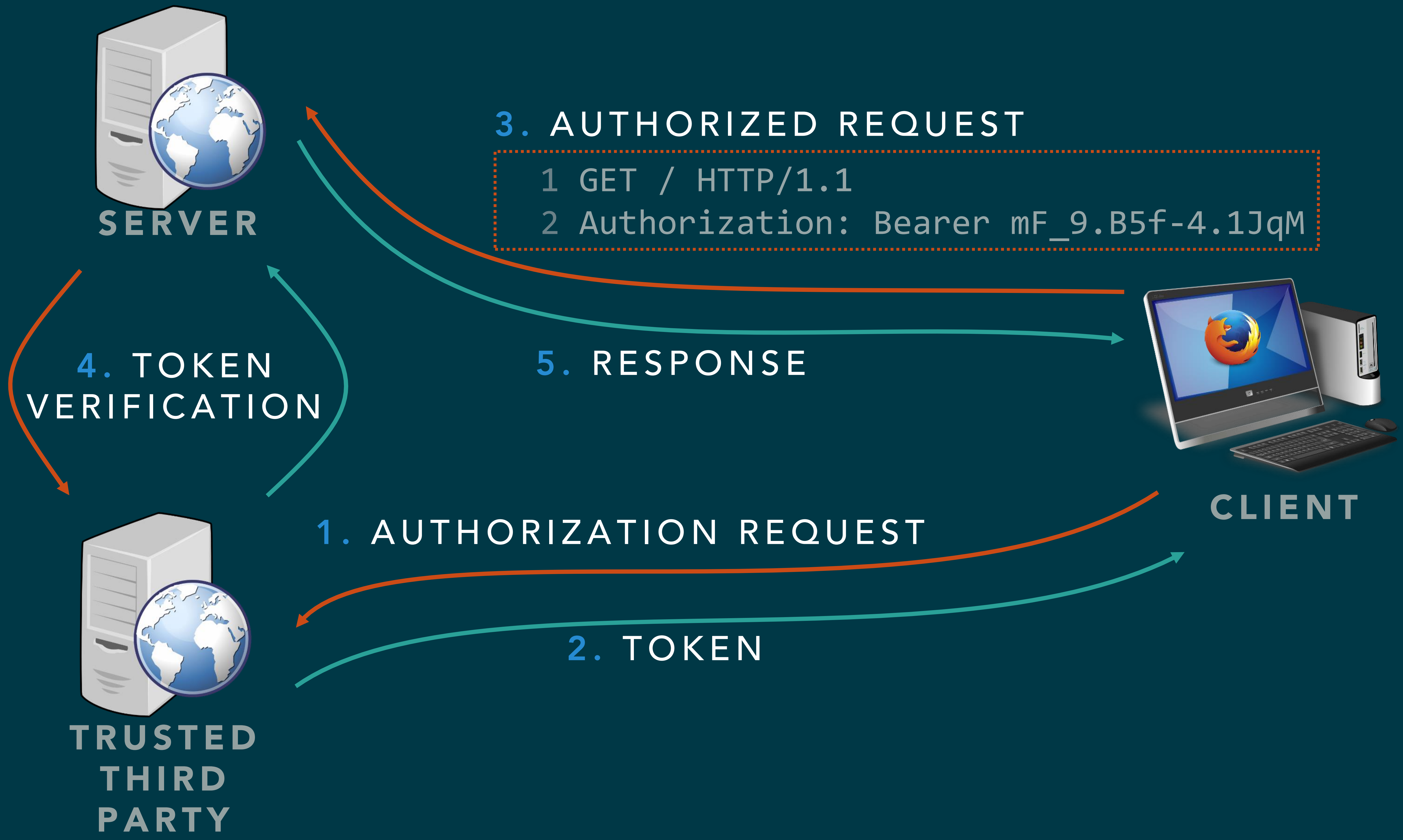

CLIENT IDENTIFICATION
HTTP BEARER AUTHENTICATION

- Advantages:
  - The server may not know credentials of the client and still identify it
  - The server does not store any sensitive information
- Disadvantages:
  - The token may leak through unencrypted connection
  - Limited support in implementations, requires developer's intervention

HTTP CONNECTIONS

- How do HTTP messages move through the network?

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- A **TCP connection** must be established between the client and server before they can communicate with each other.

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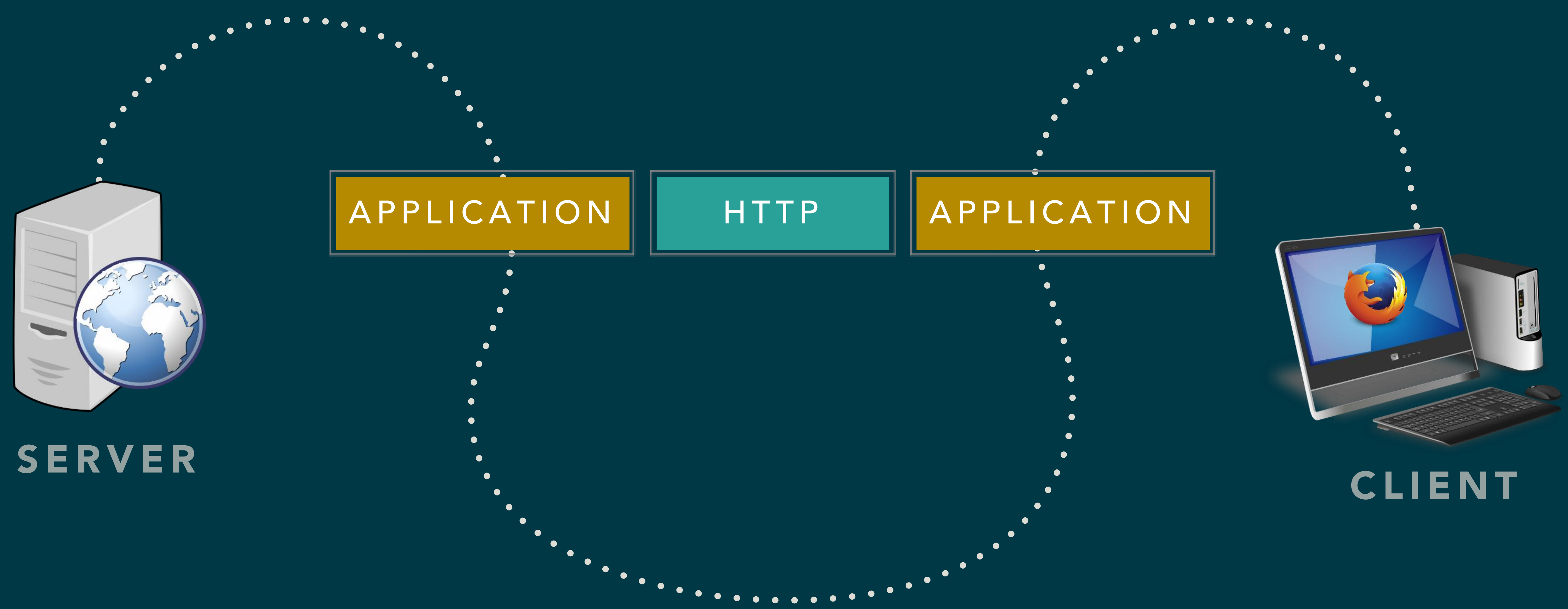

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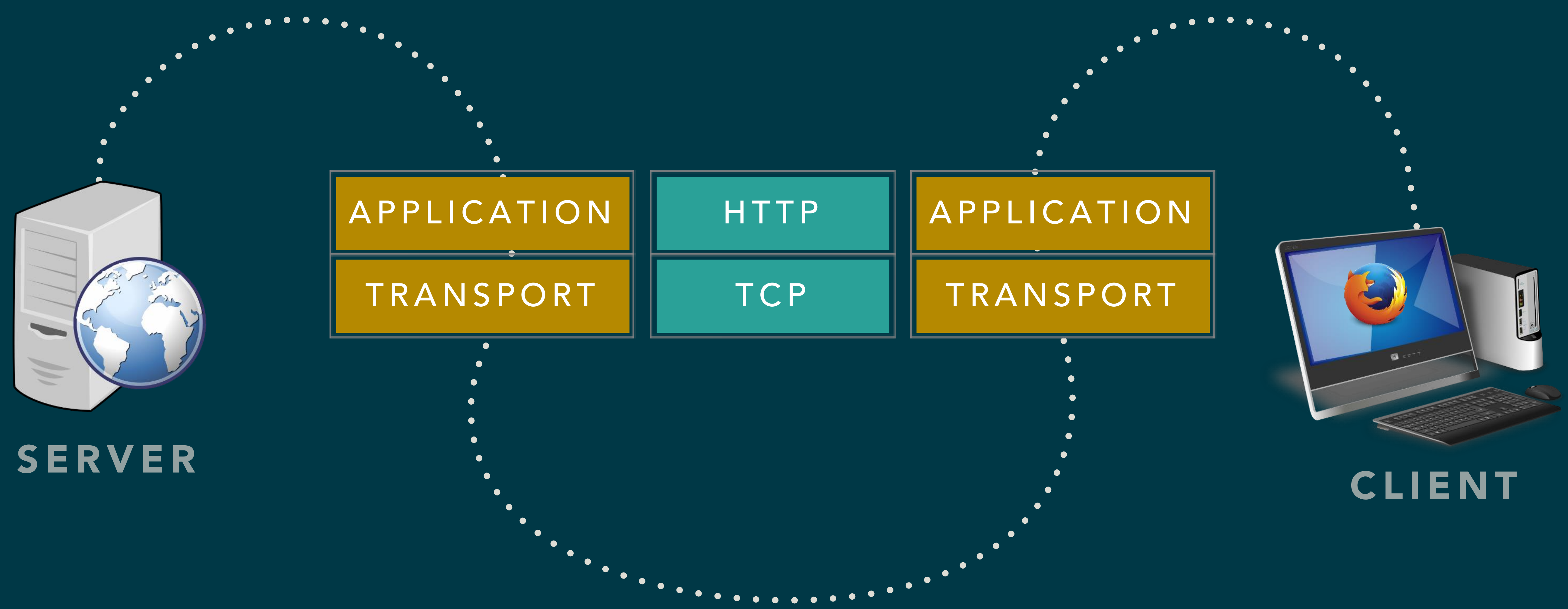

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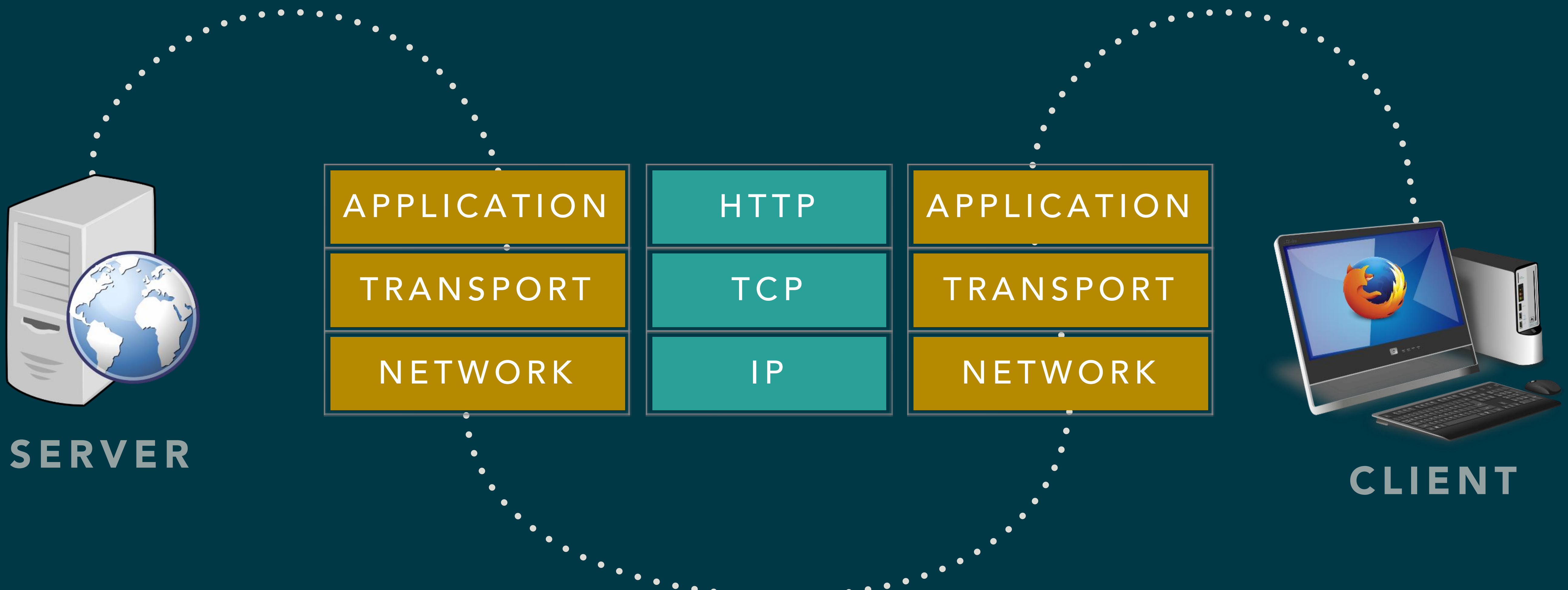

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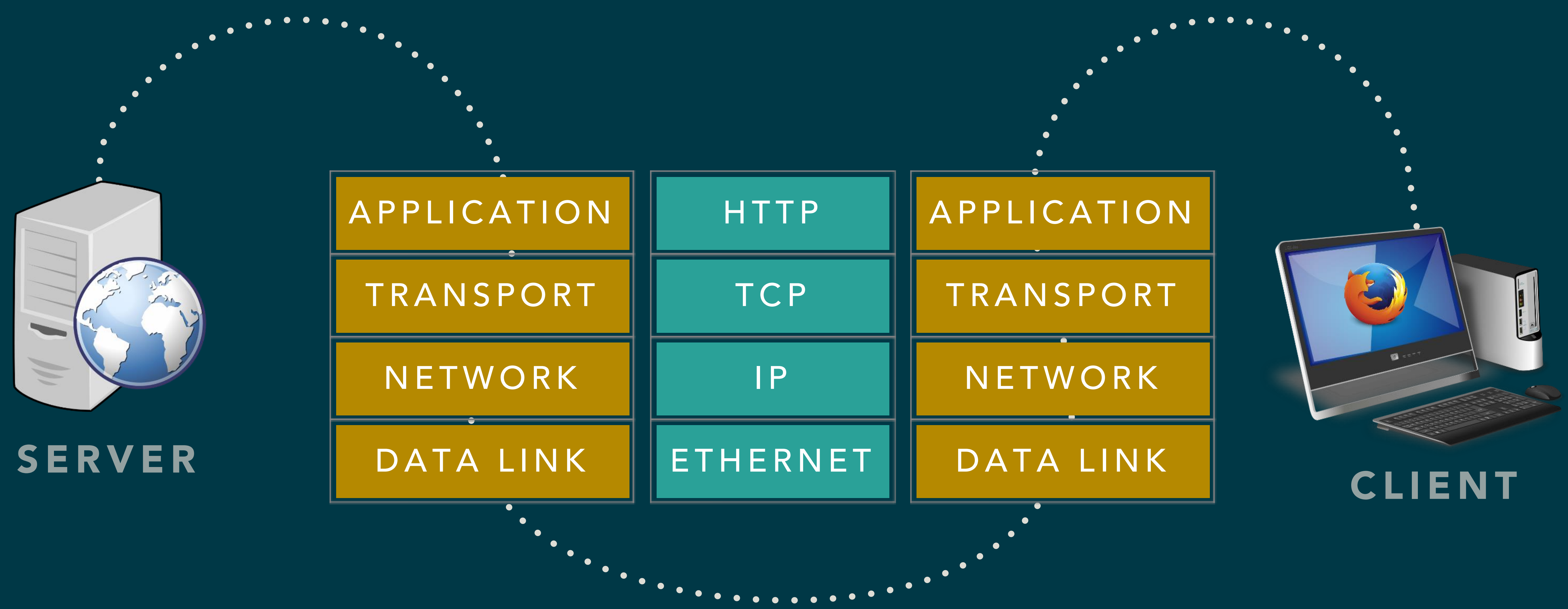

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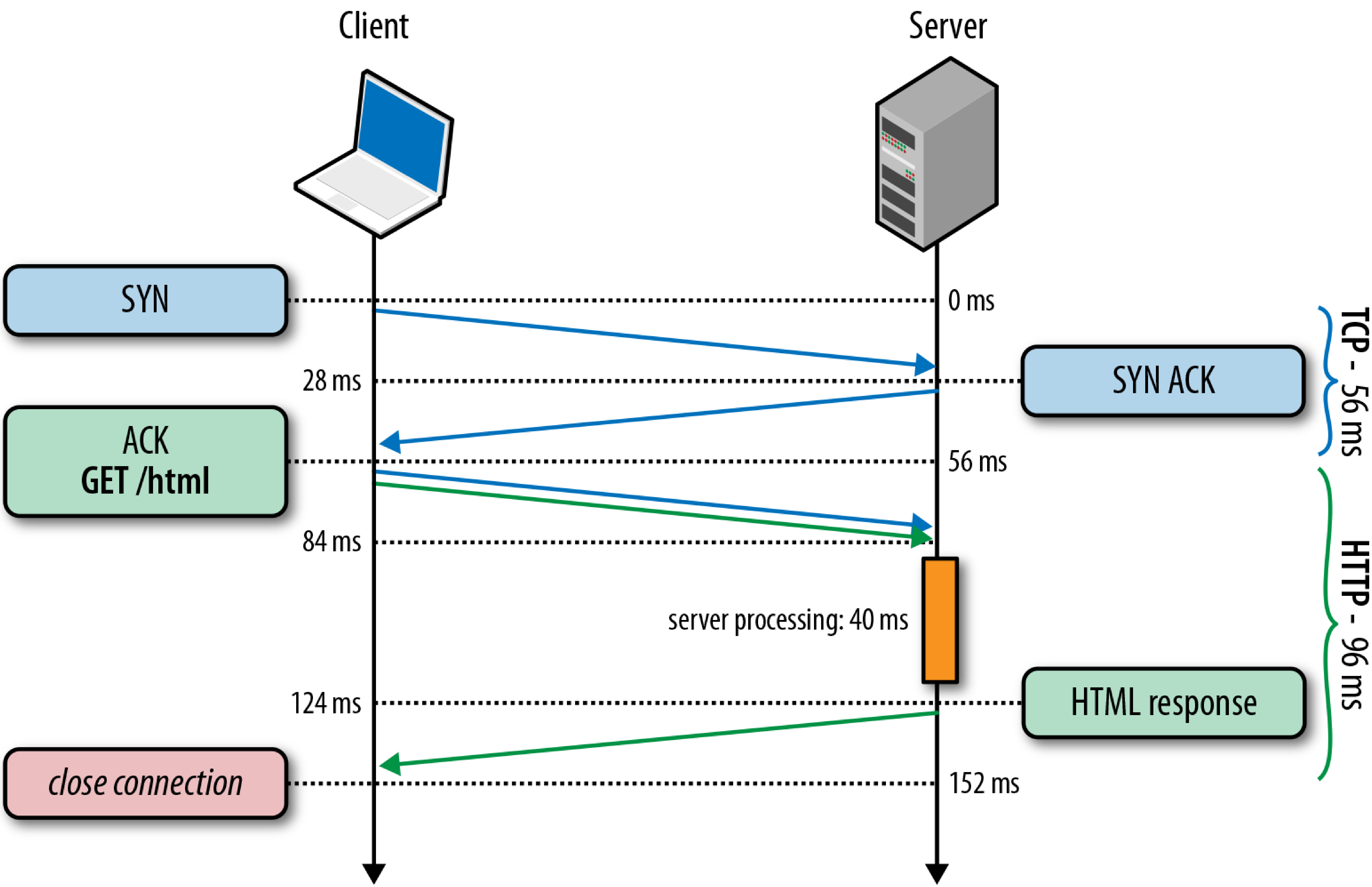
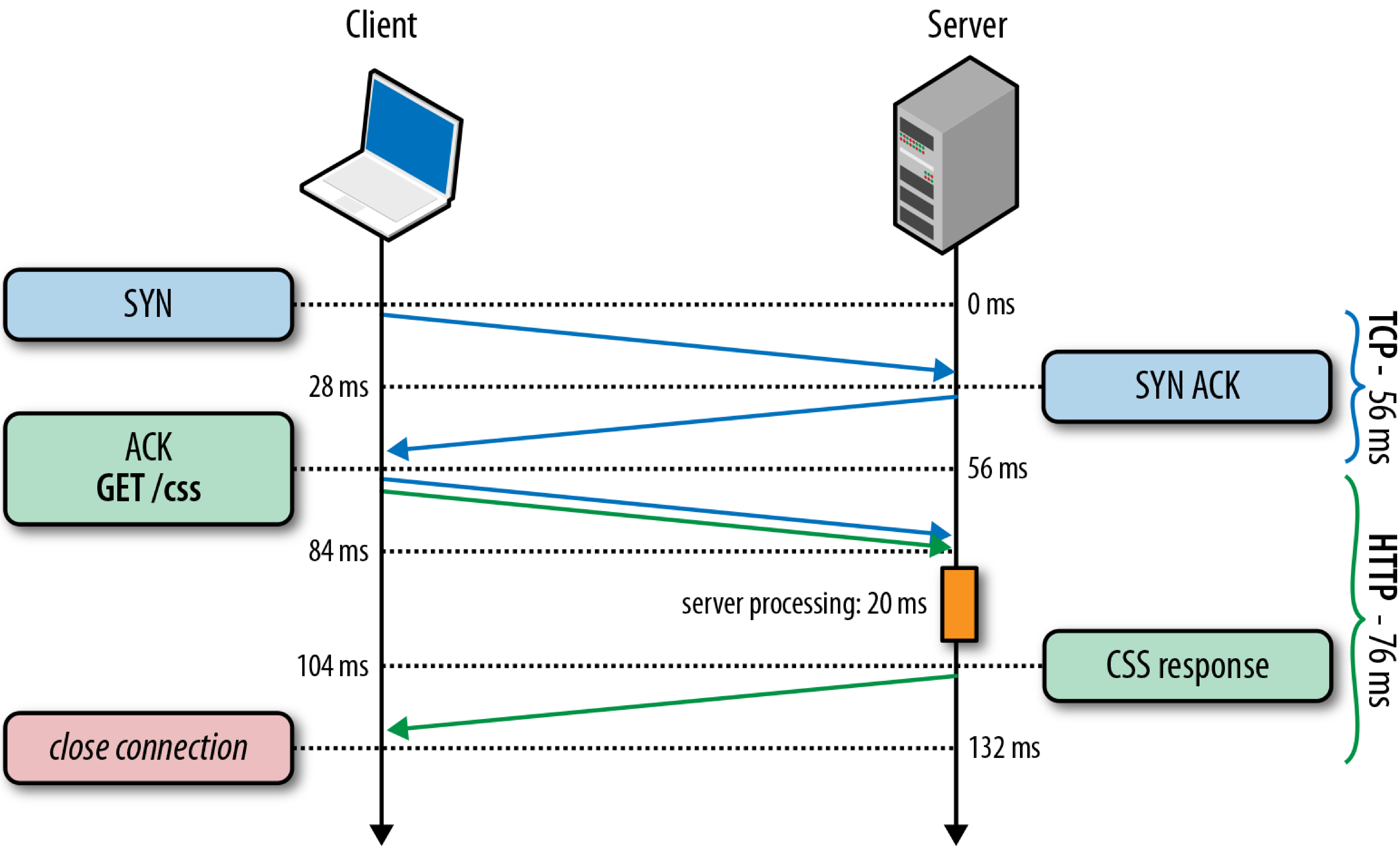
  - Lot of network delays due to **three-way handshake** and **slow-start**.

TCP connection #1, Request #1: HTML request



TCP connection #2, Request #2: CSS request



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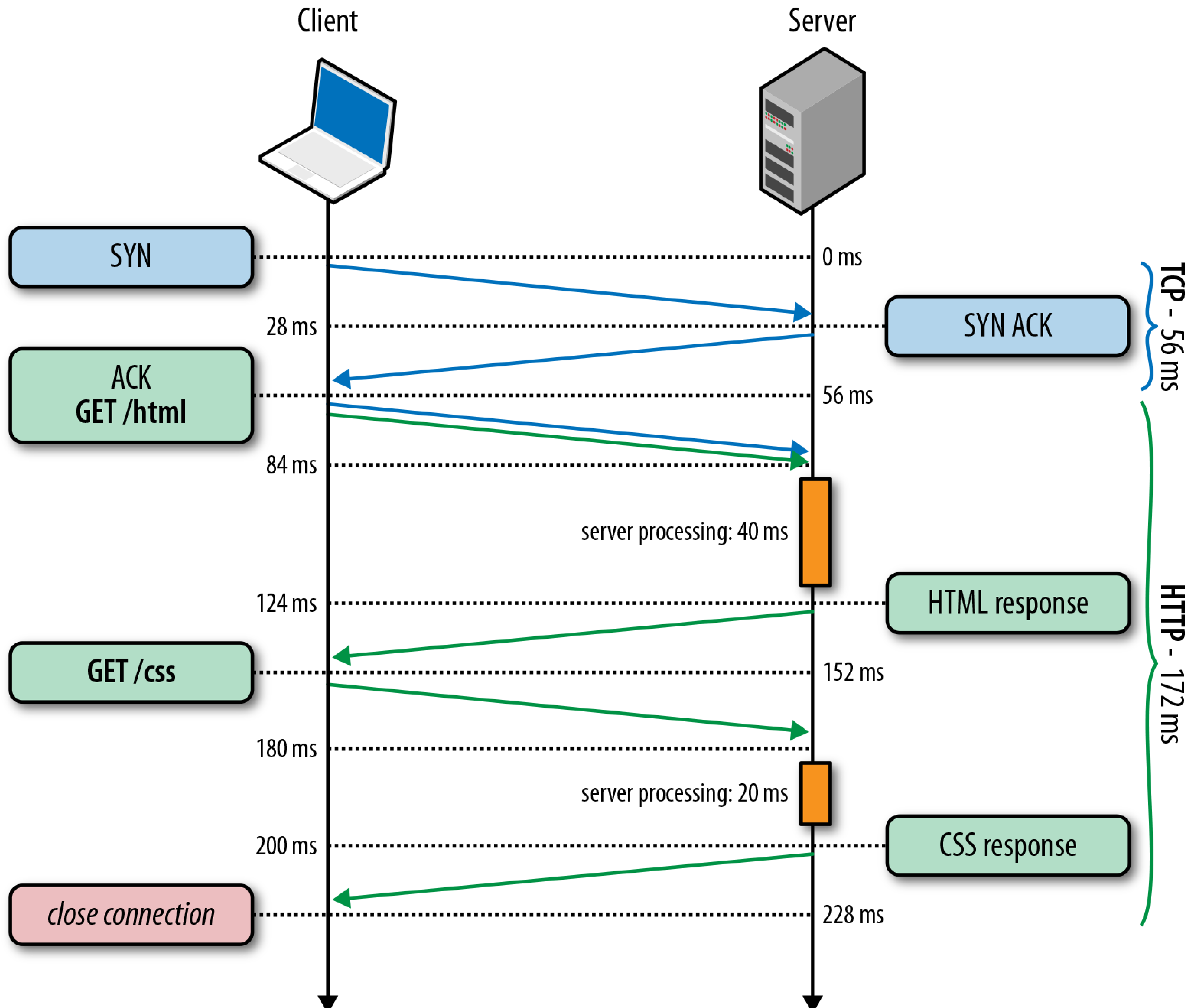
  - HTTP is stateless — it does not require extended connection lifetime.
  - Lot of network delays due to **three-way handshake** and **slow-start**.
- **HTTP/1.1** — introduced **persistent connections**:
  - Reducing connection-establishment delays,
  - Long-lived connections that stay open until the client closes them.
  - Persistent connections are **default**, `Connection: keep-alive` is redundant.
  - Close of the connection requires the client to set the `Connection: close` request header.
  - Most web servers close a persistent connection if it is **idle** for some period.

TCP connection #1, Request #1-2: HTML + CSS



PIPELINING REQUESTS

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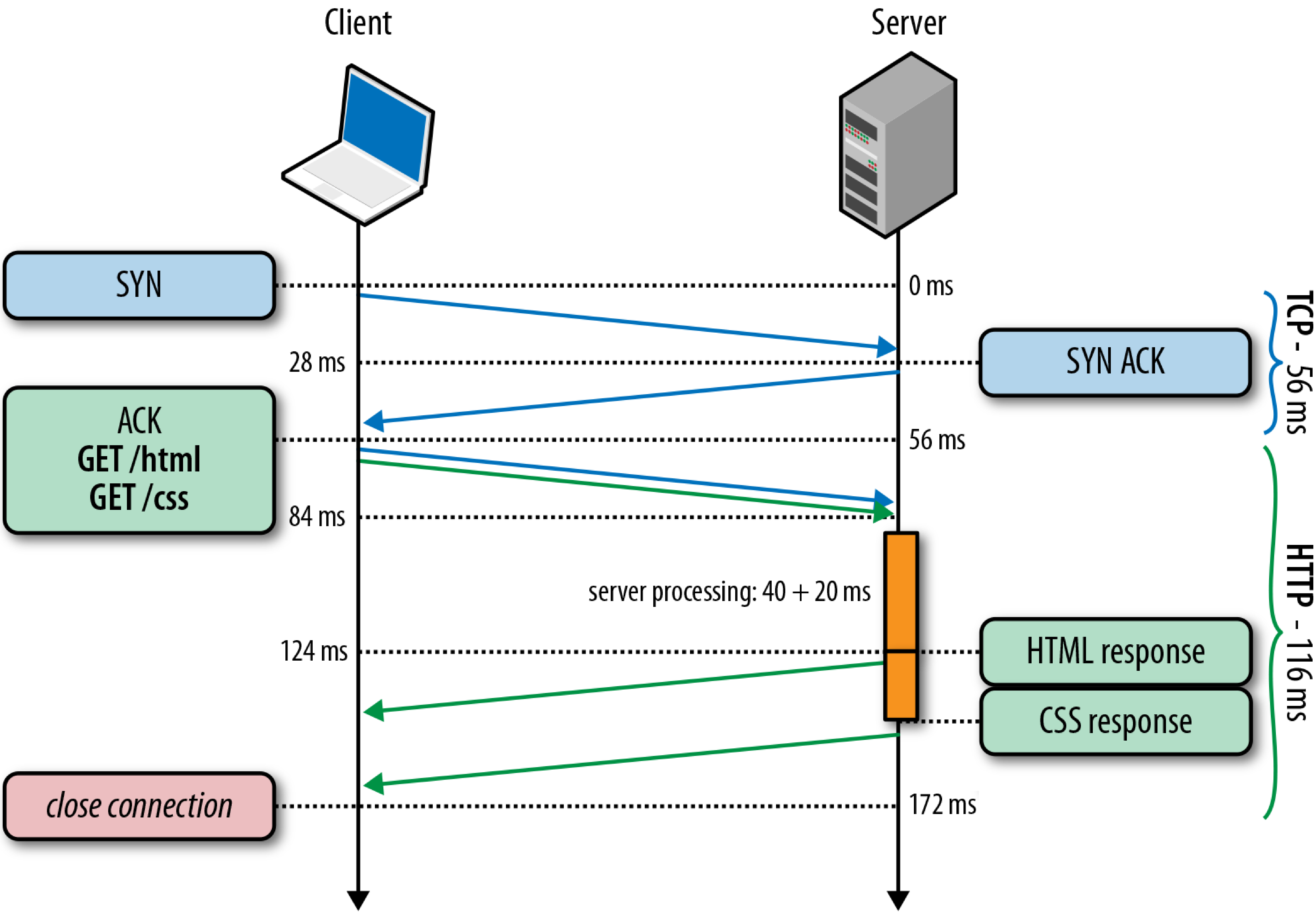
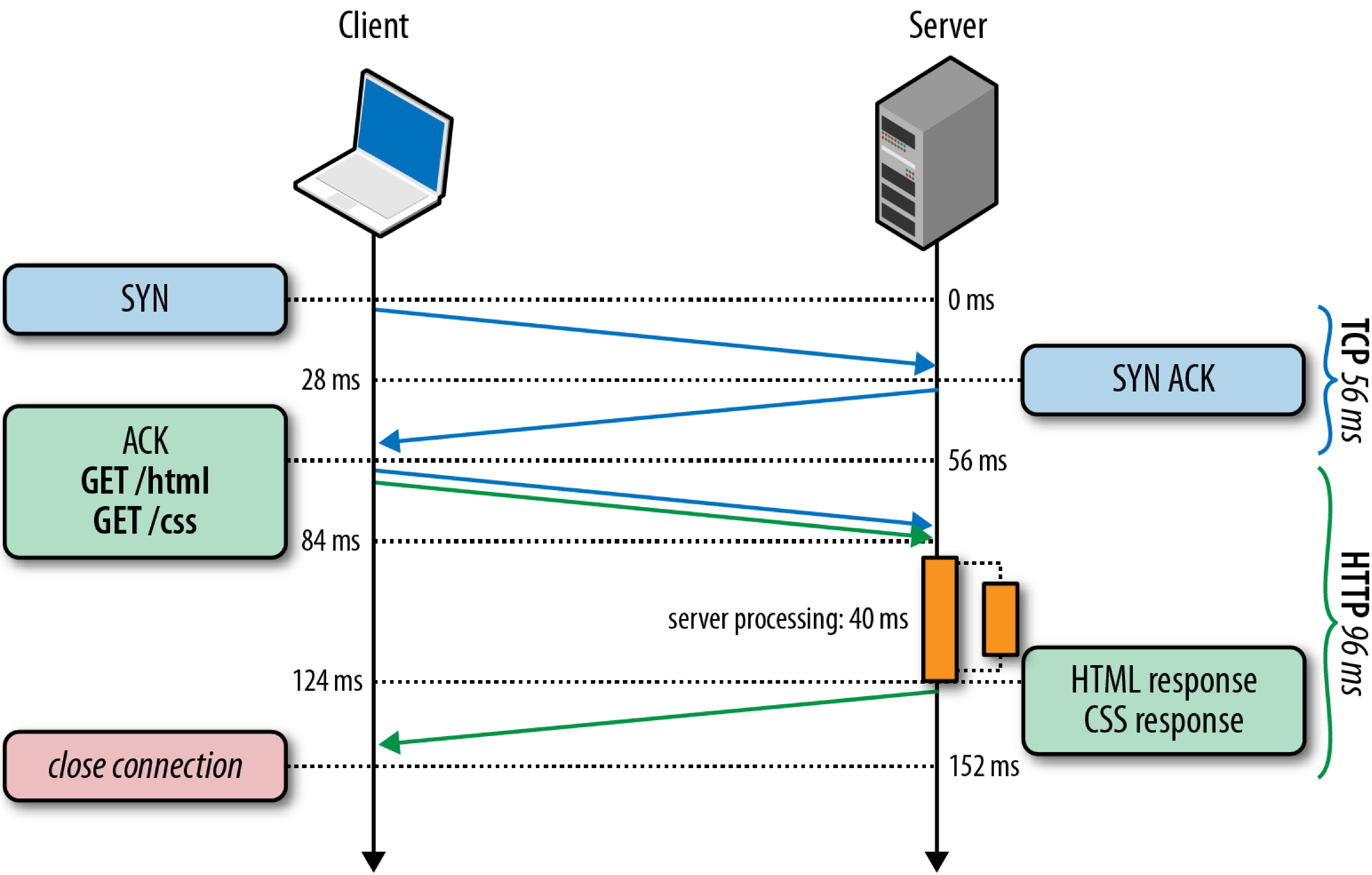
- Persistent HTTP allows us to reuse an existing TCP connection between multiple application requests, but it implies a strict first in, first out (**FIFO**) queuing order on the client.
- **HTTP pipelining** is a small but important optimization to this workflow, which allows us to relocate the FIFO queue from the client (**request queuing**) to the server (**response queuing**):
  - Browsers can send requests without waiting for responses.
  - Servers are responsible for submitting responses to browser requests in the order of their arrival.


Client
Server
SYN
0 ms
SYN ACK
28 ms
ACK
GET /html
GET /css
56 ms
84 ms
server processing: 40 + 20 ms
124 ms
HTML response
CSS response
close connection
172 ms
TCP - 56 ms
HTTP - 116 ms



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  - server buffering costs,
  - unpredictable latency delays for the client.

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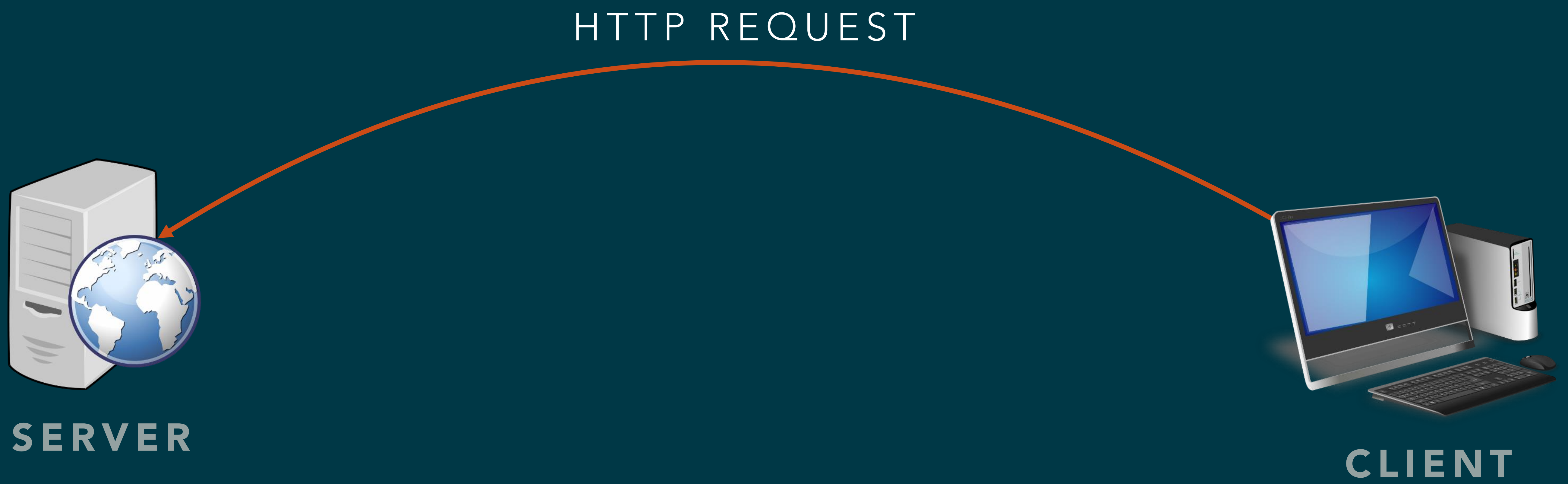
  - underutilized network links,
  - server buffering costs,
  - unpredictable latency delays for the client.
- **HTTP pipelining adoption has remained very limited despite its many benefits — some browsers support pipelining, usually as an advanced option, but most have it disabled.**

CONNECTIONS AND PROXIES

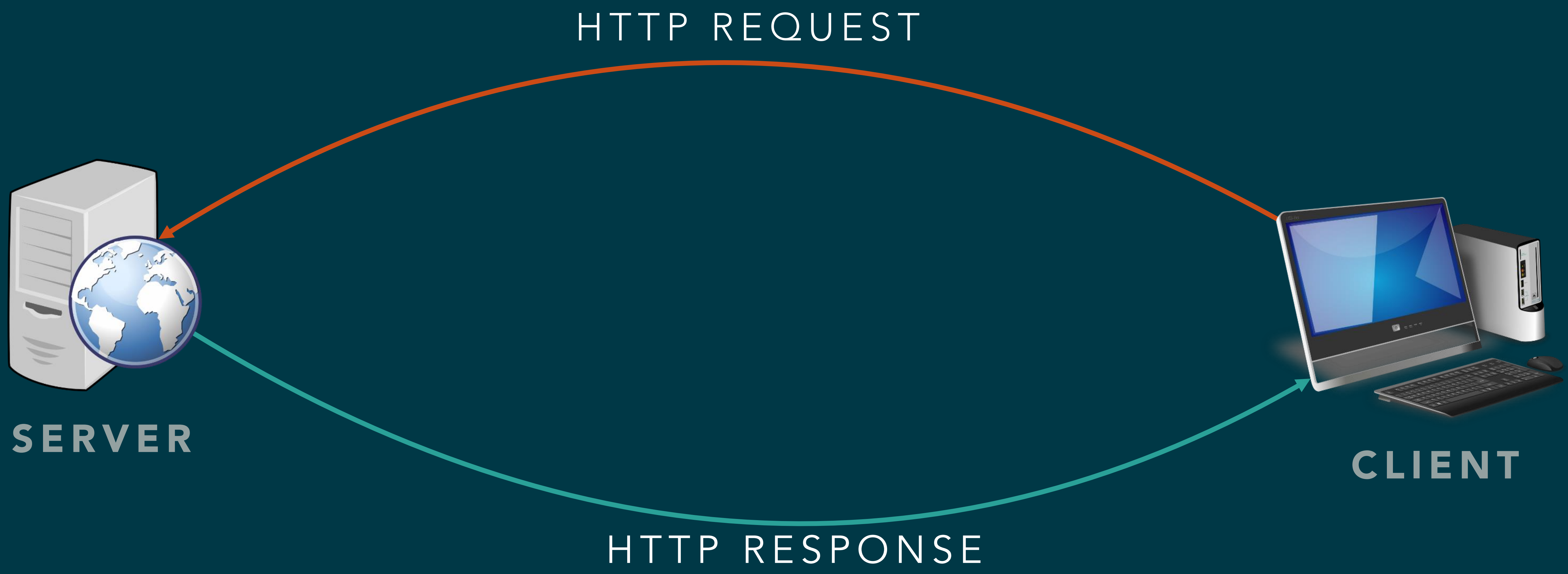
SERVER

CLIENT

CONNECTIONS AND PROXIES



CONNECTIONS AND PROXIES



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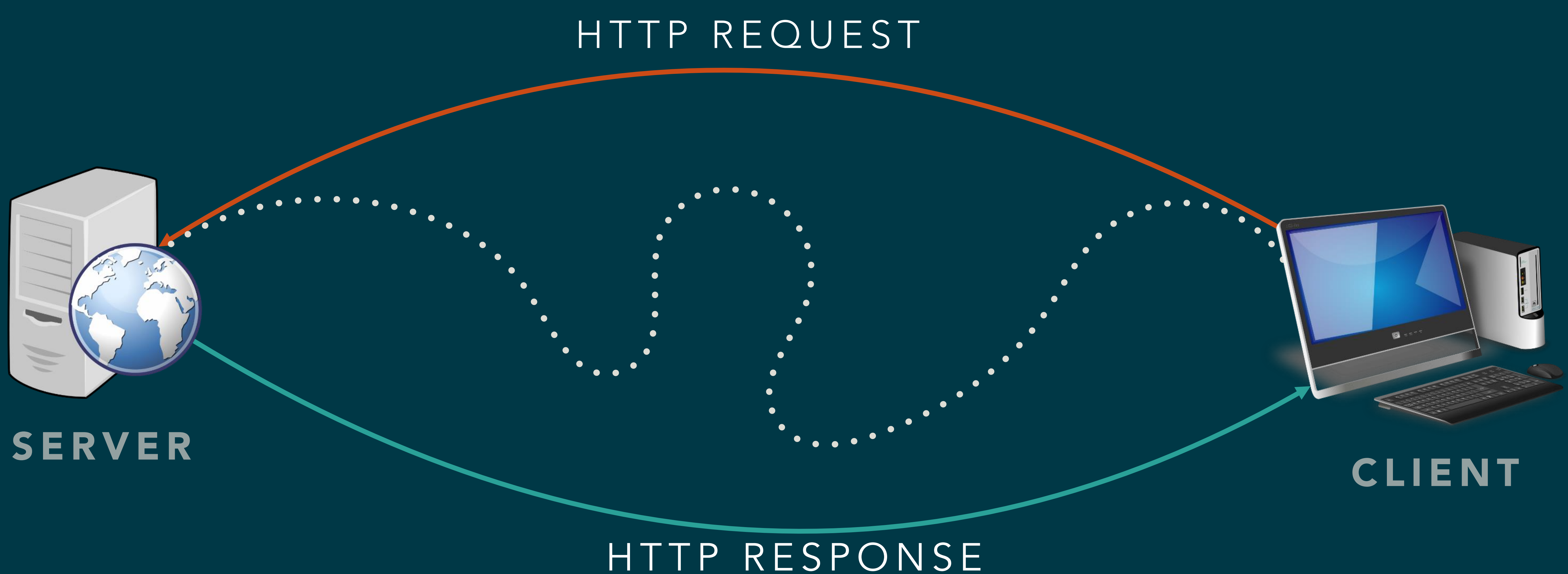
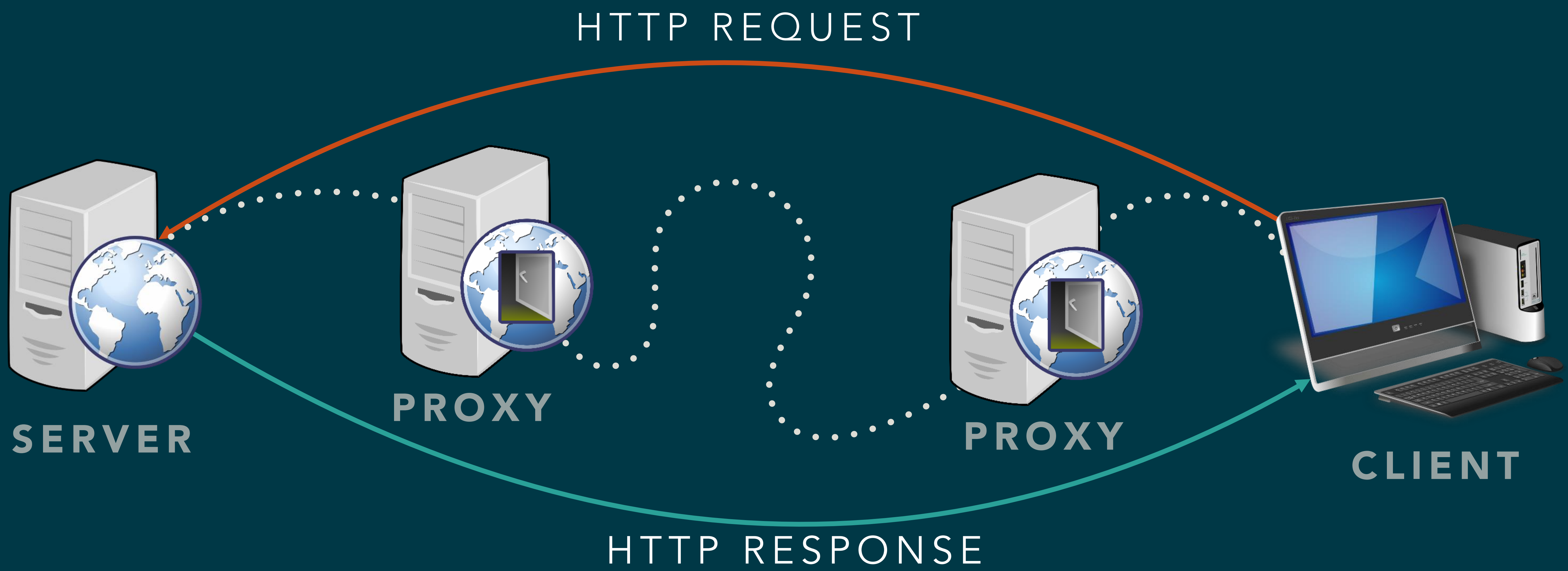


CONNECTIONS AND PROXIES



- **Connection** — a **virtual** circuit established between two programs for the purpose of communication.
- **Proxy** — an intermediary program which acts as both a server and a client for the purpose of making requests on behalf of other clients.

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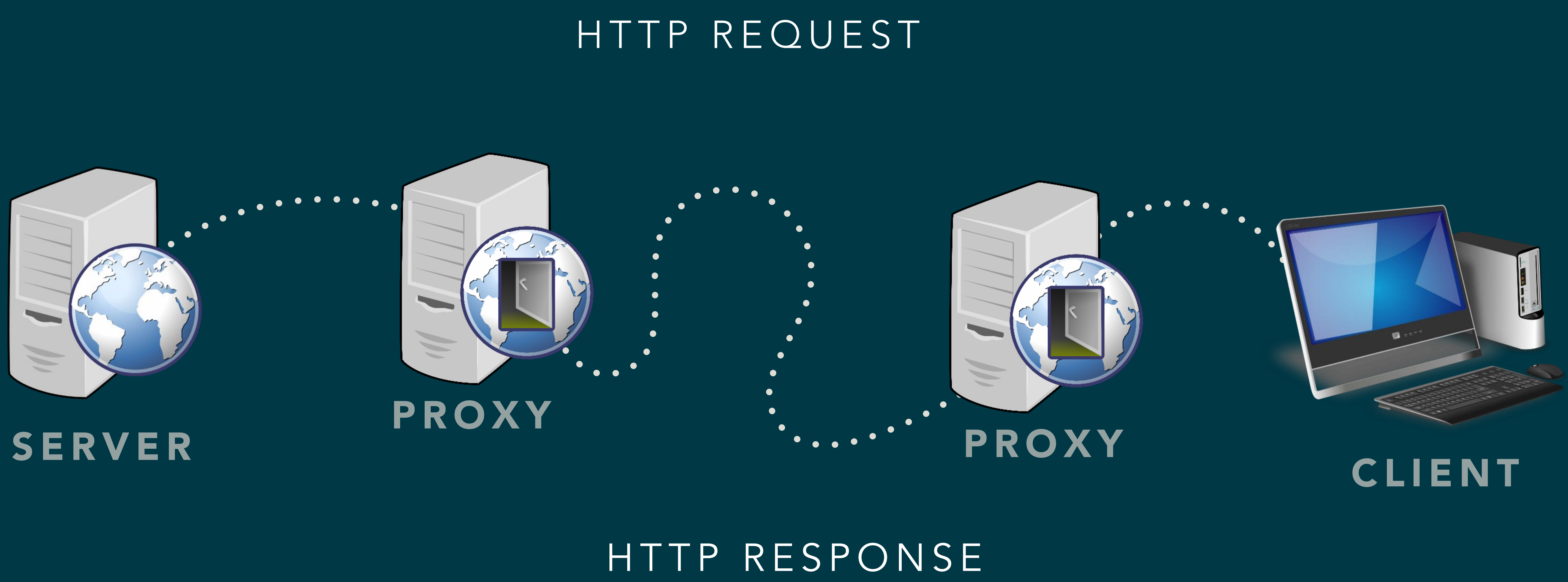

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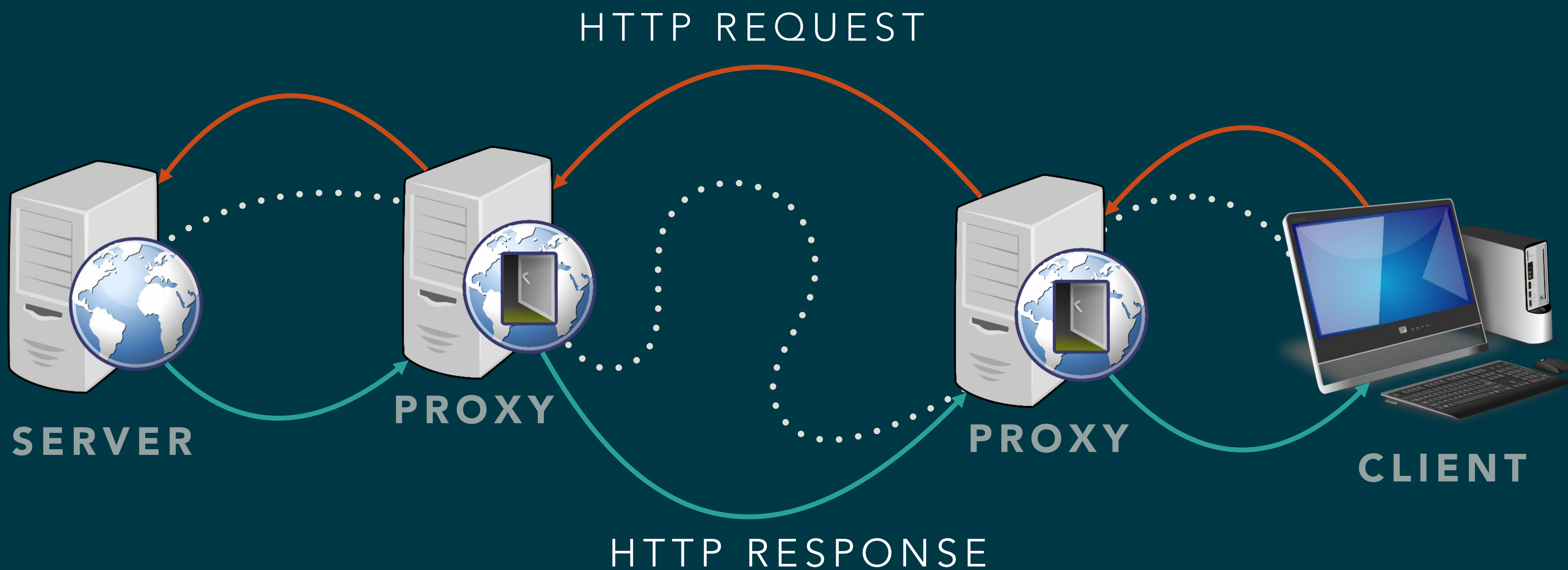

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TYPES OF PROXIES: TRANSPARENCY

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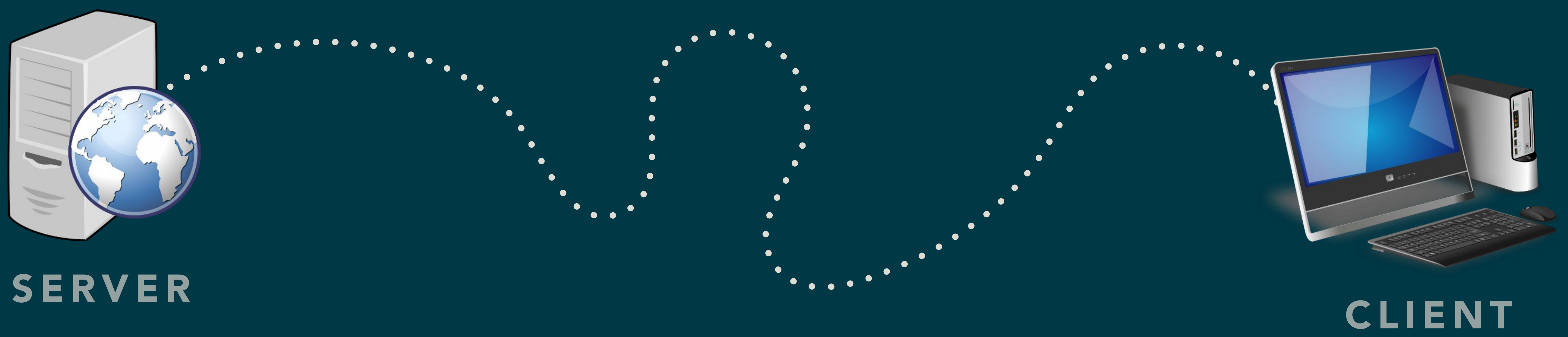
- A **non-transparent proxy** — modifies the request or response in order to provide some added **service**:
  - content filtering
  - removing confidential data
  - providing online anonymity

FORWARD AND REVERSE PROXIES

SERVER

CLIENT

FORWARD AND REVERSE PROXIES



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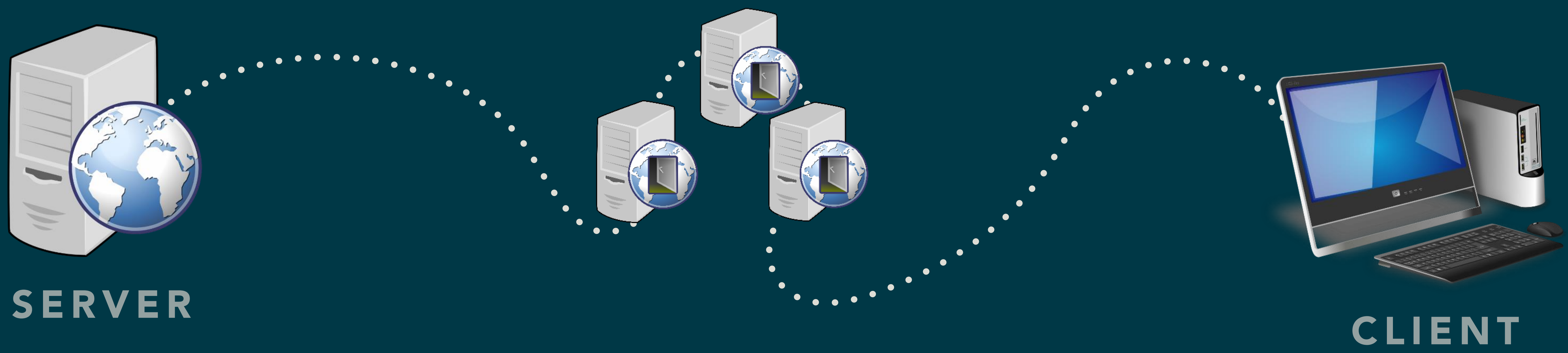

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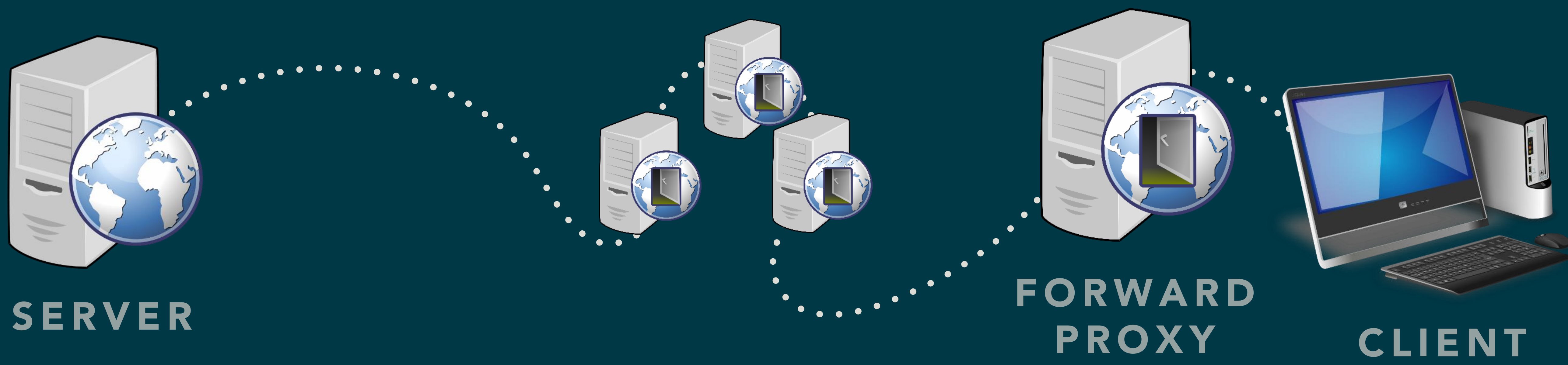

- **Forward** proxy — proxies in behalf of requesting hosts, each client must be configured to explicitly use this proxy.
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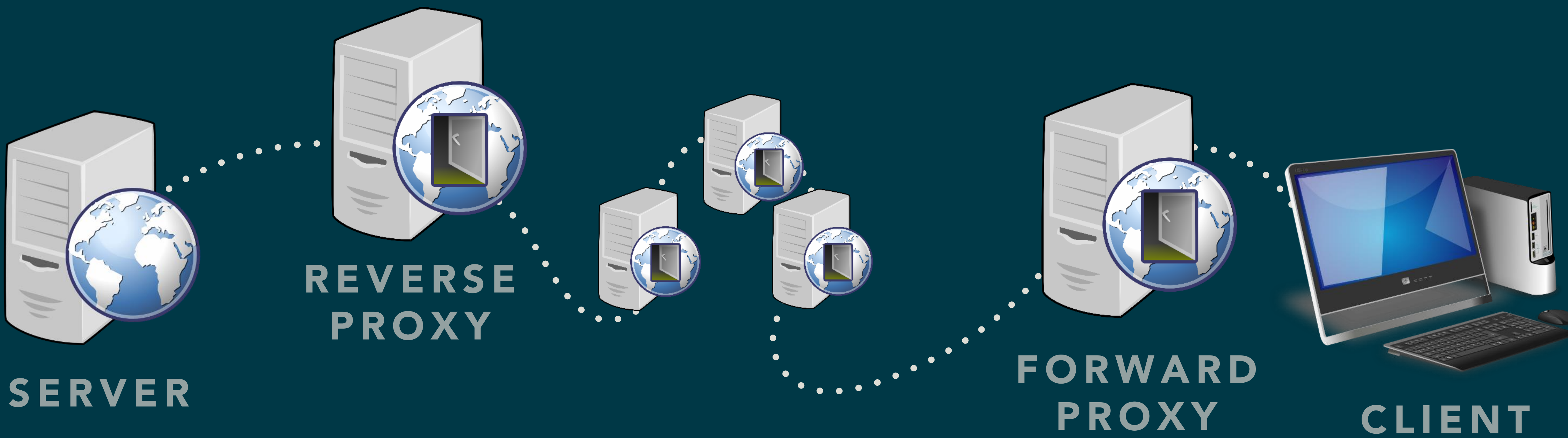
FORWARD AND REVERSE PROXIES



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- Caching can reduce **latency**, help prevent **bandwith bottlenecks** as well as improve user experience.
- Two types of caches can be employed:
  - **public** cache — shared among multiple users, resides on a **proxy** (forward or reverse).
  - **private** cache — stored by a **browser** for a single user.

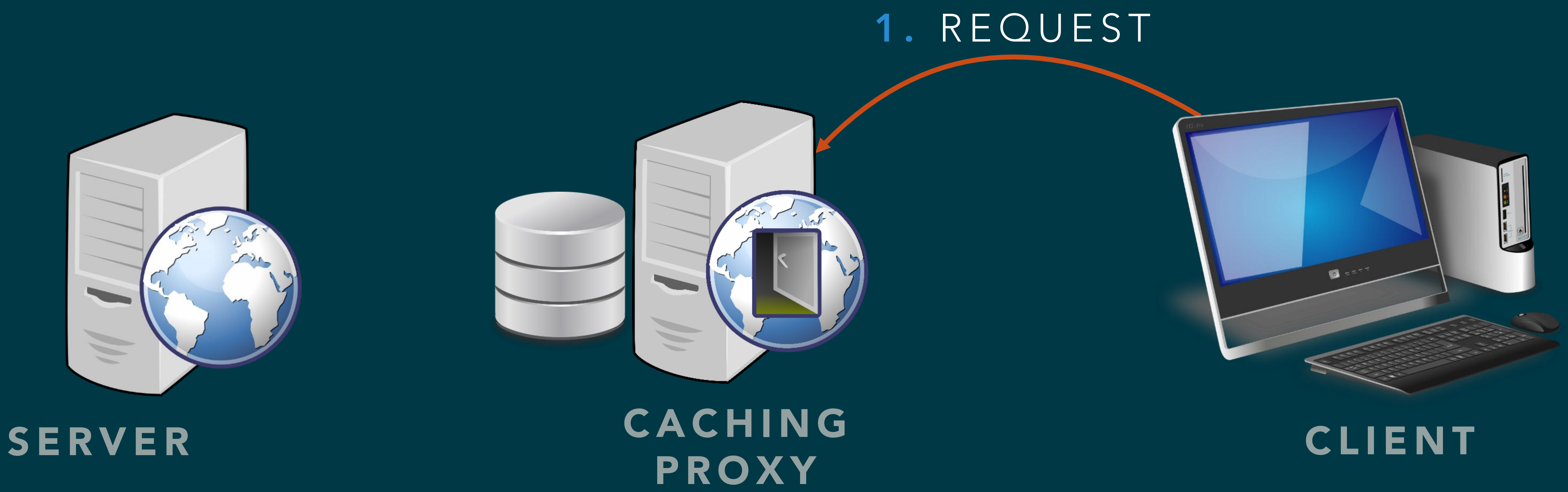
CACHING IN ACTION

SERVER

CACHING PROXY

CLIENT

CACHING IN ACTION



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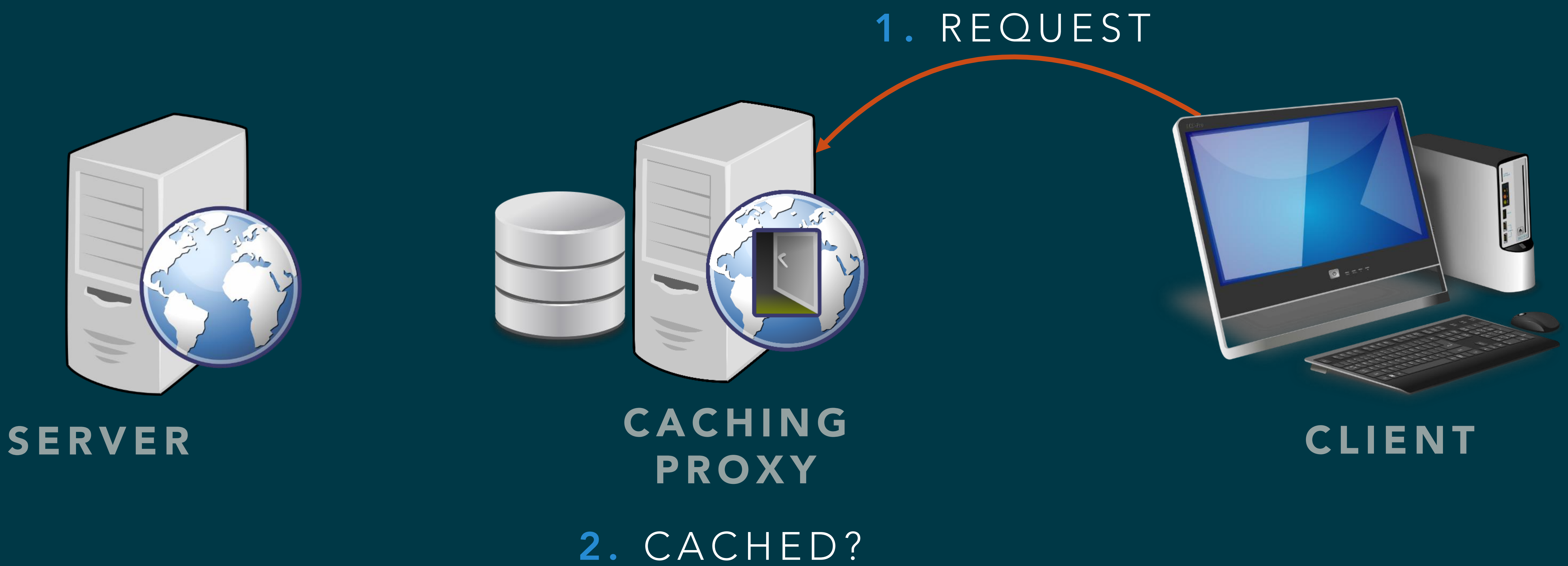

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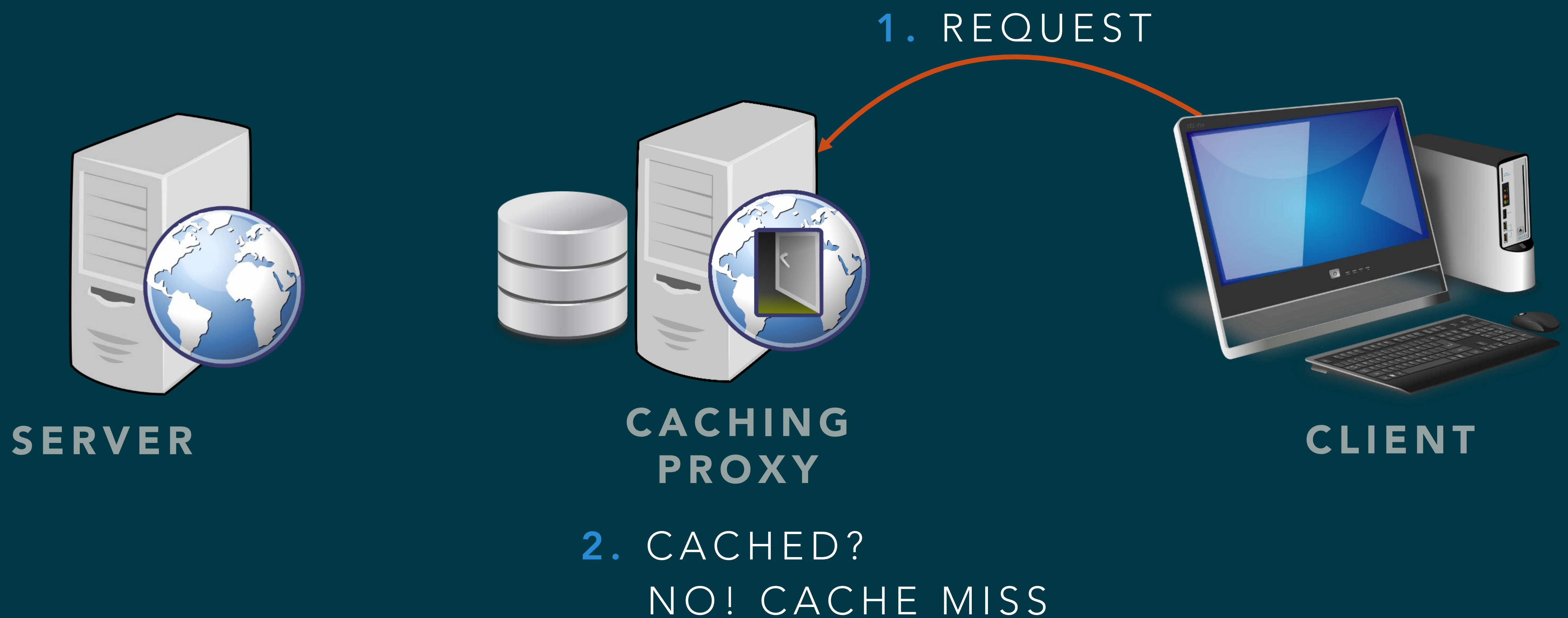

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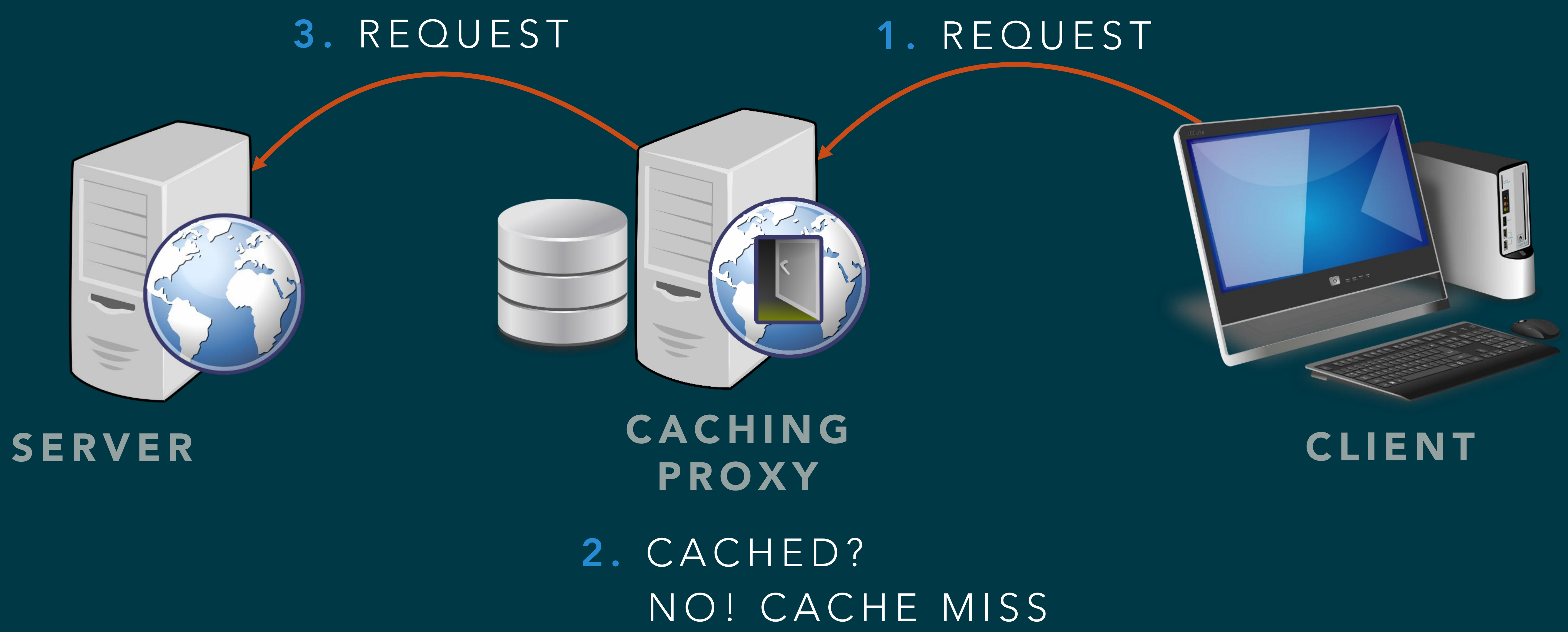

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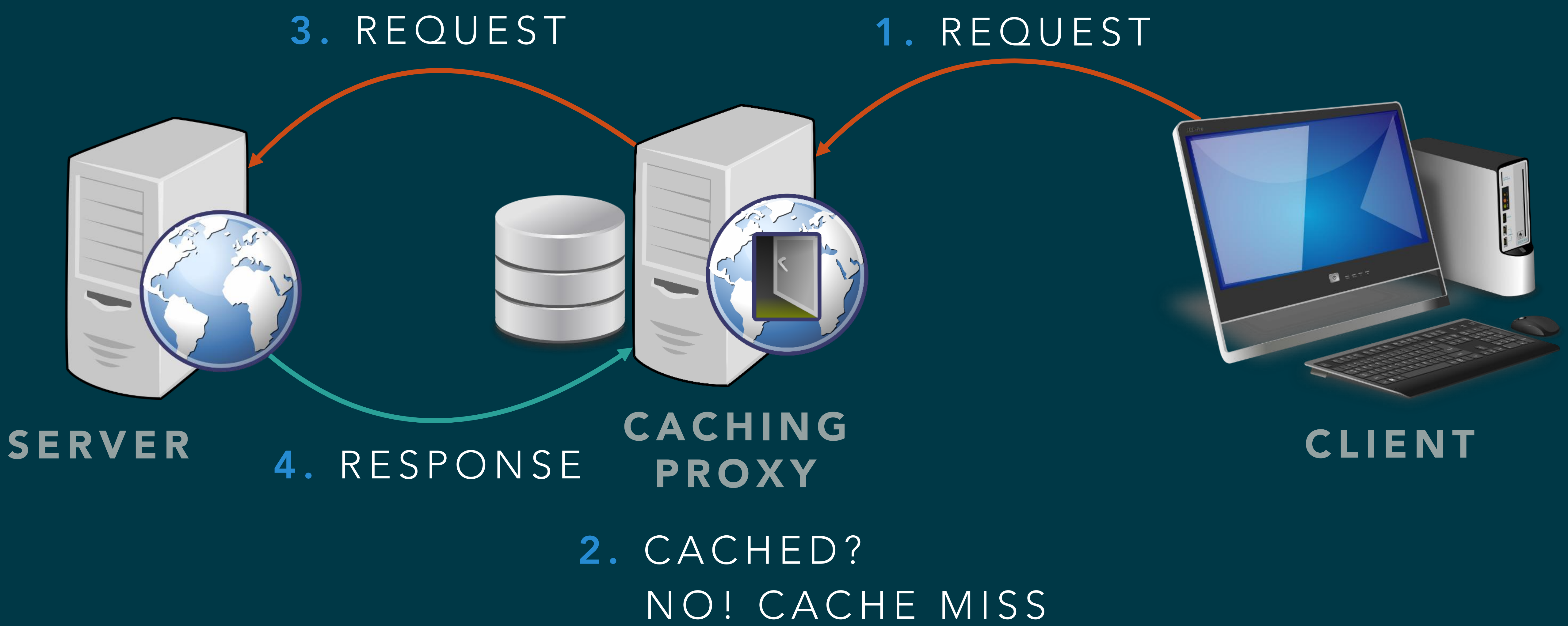

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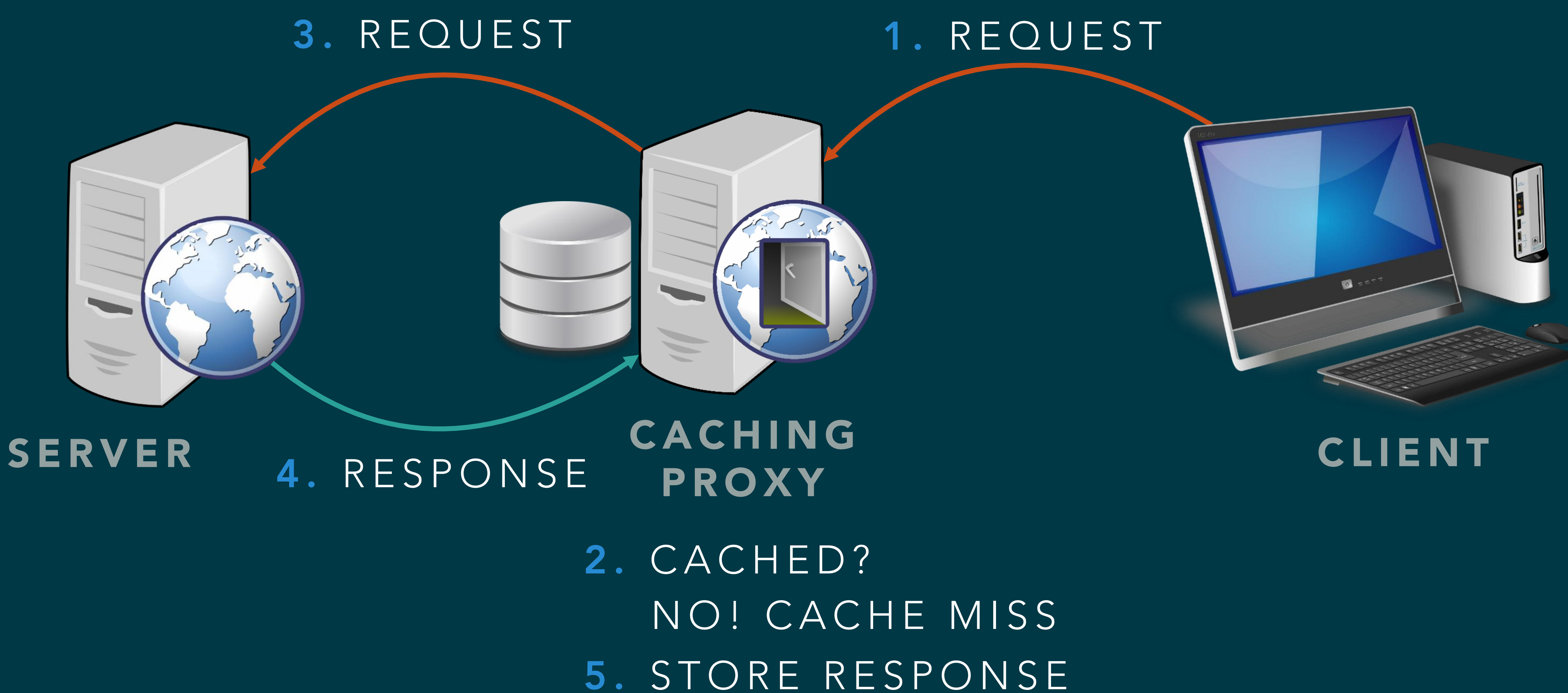

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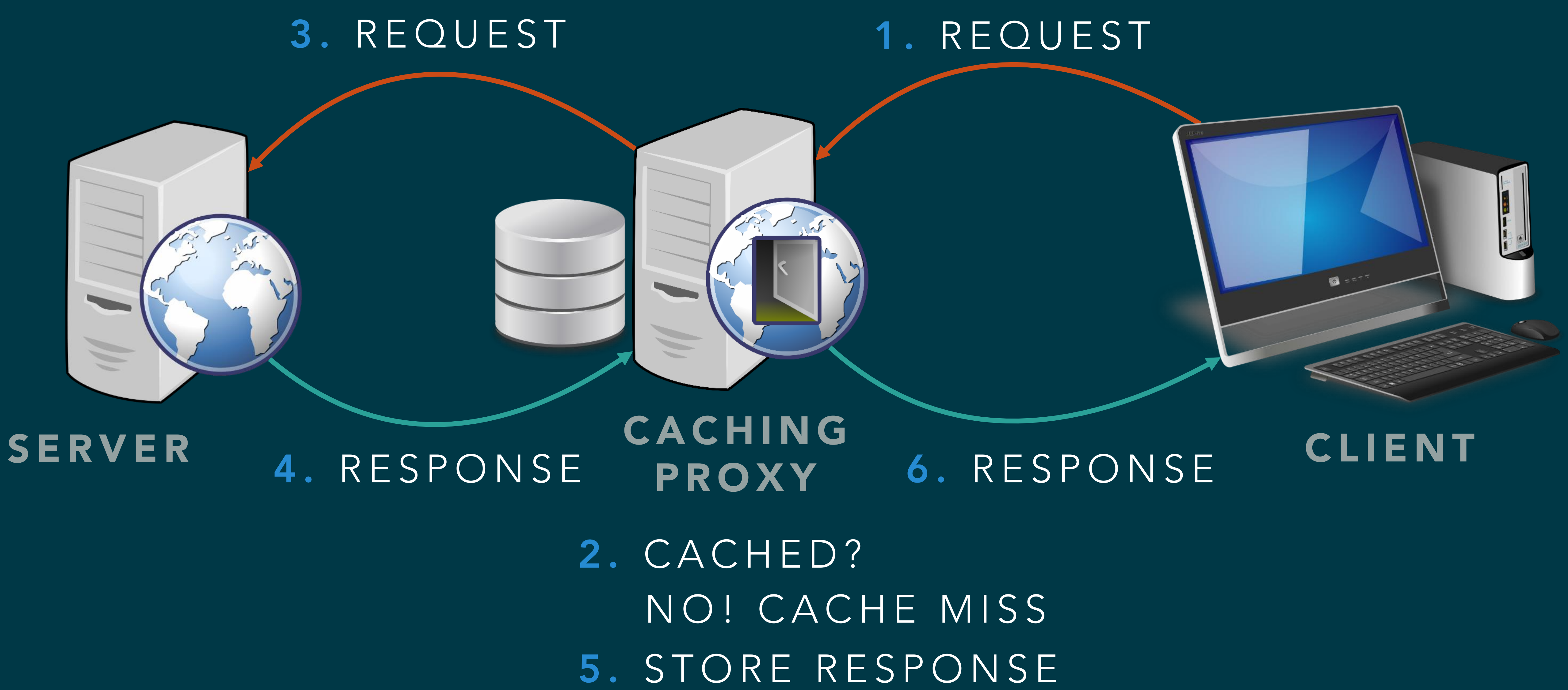

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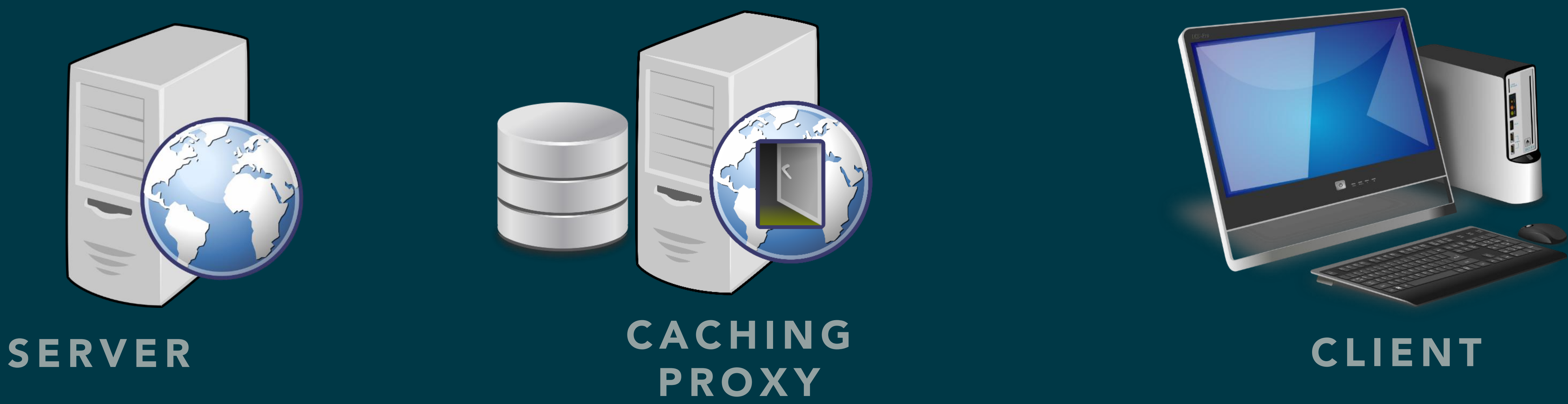
CACHE HIT



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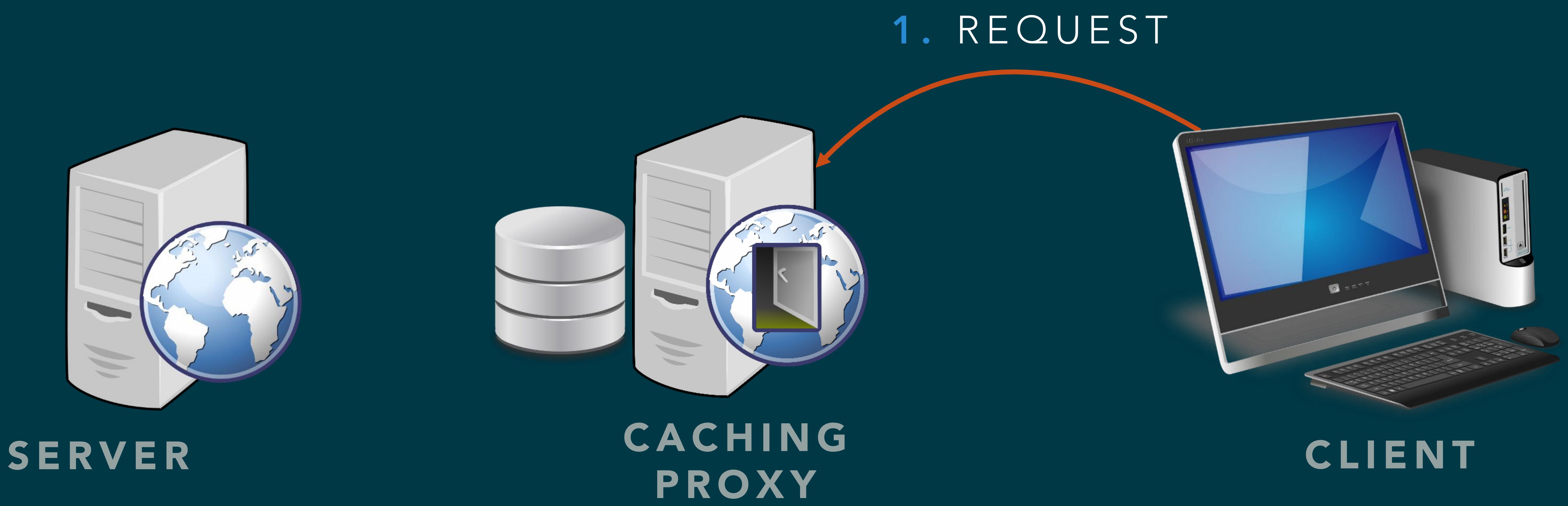

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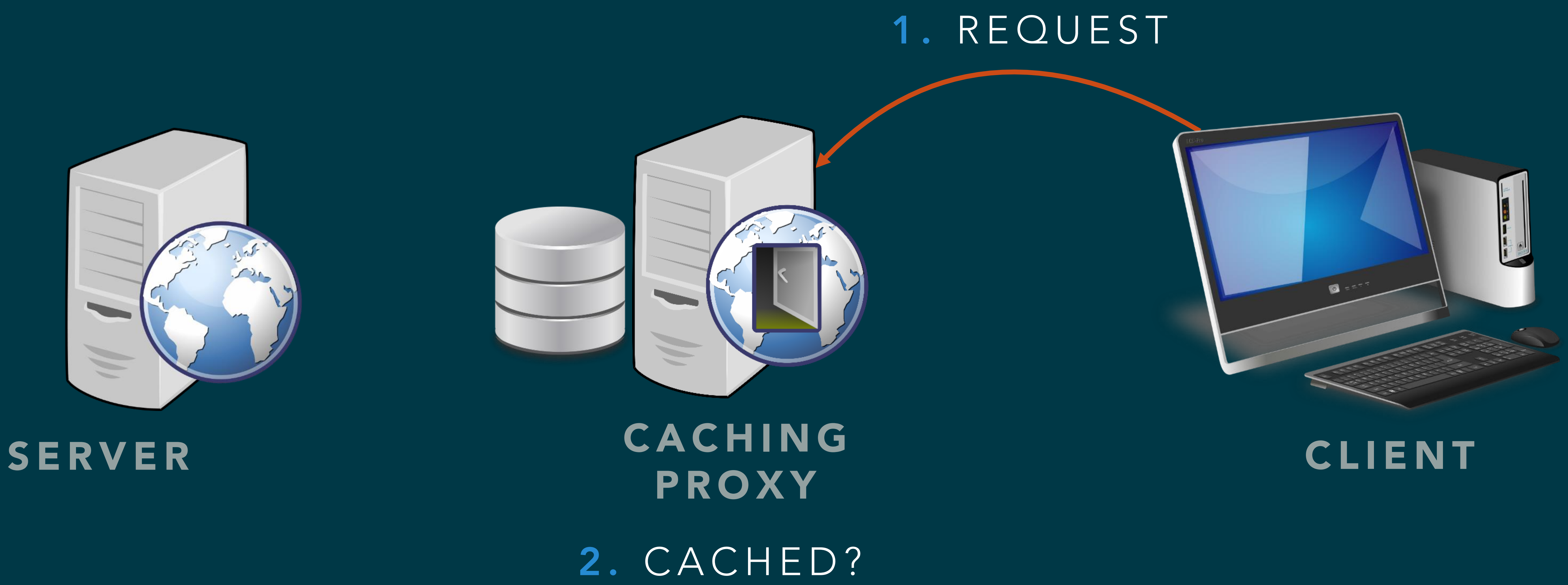

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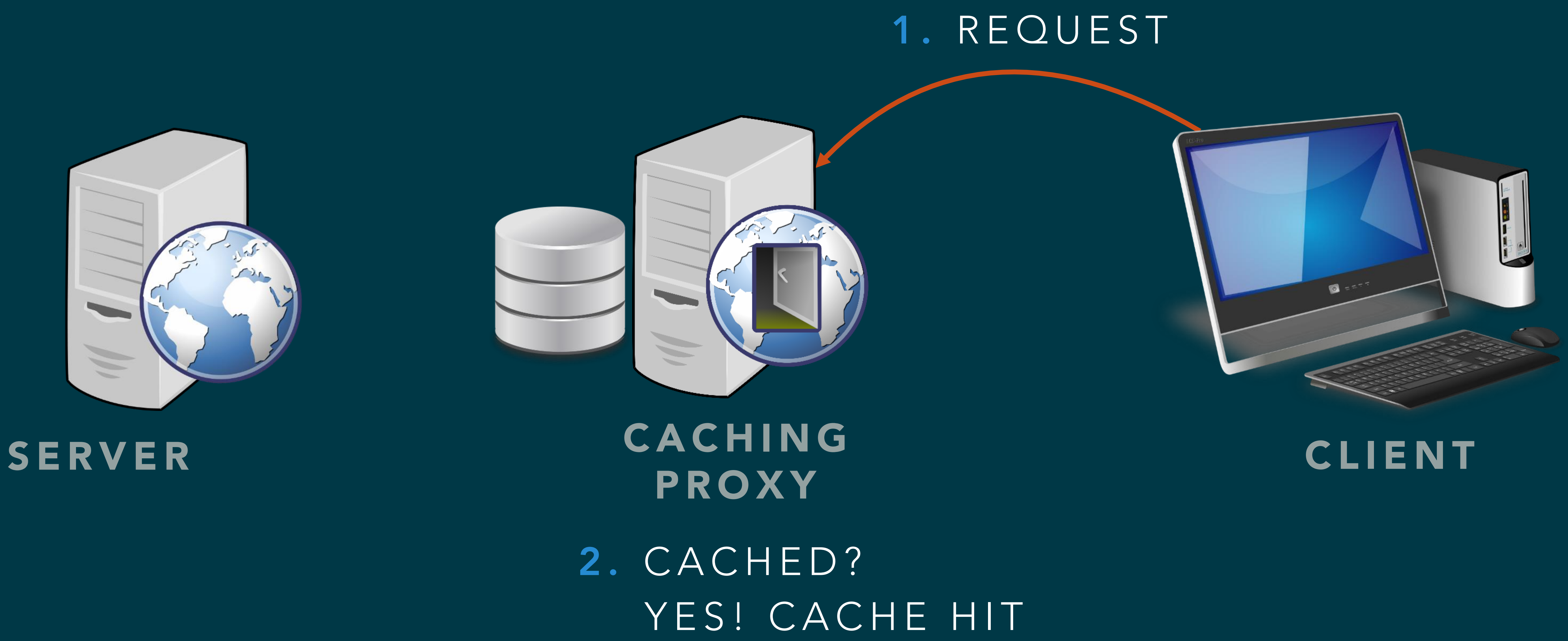
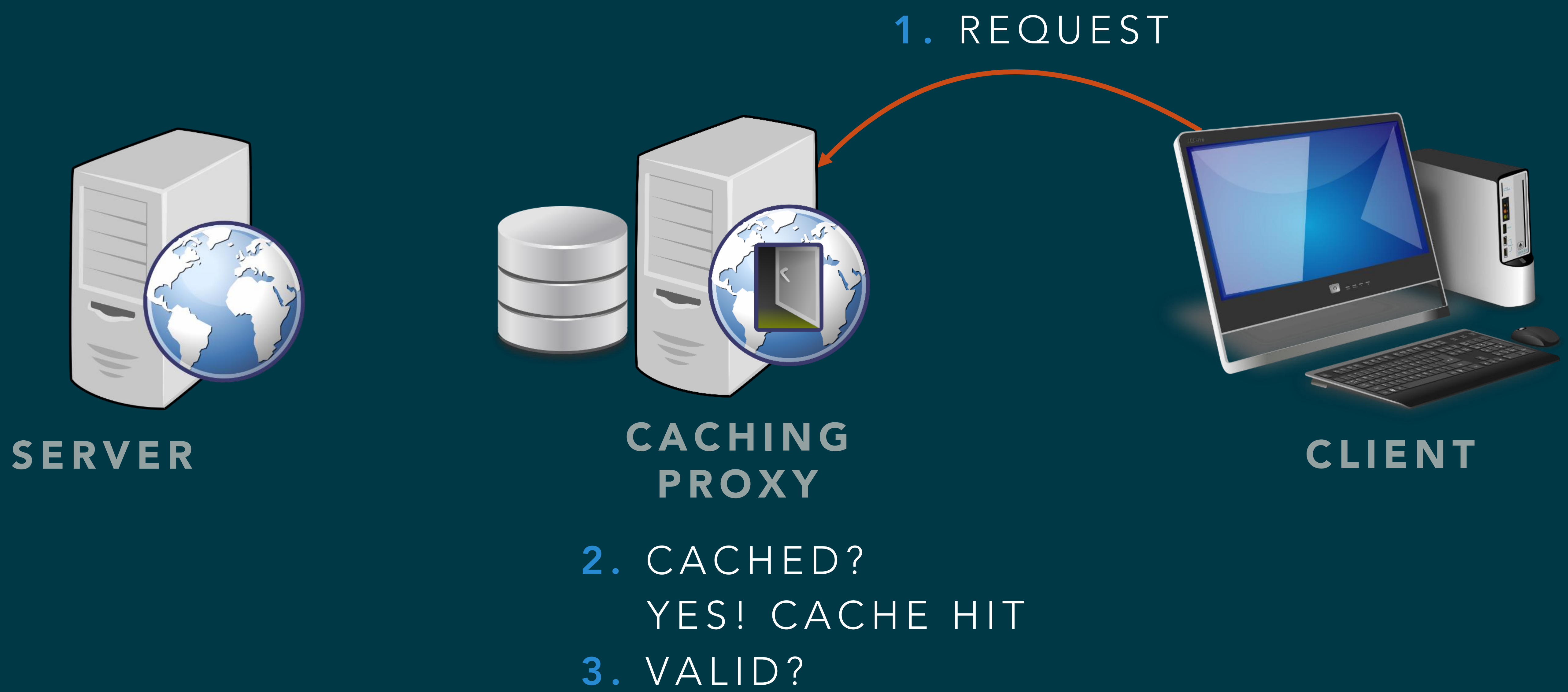

1. REQUEST
SERVER
CACHING PROXY
CLIENT
2. CACHED?
YES! CACHE HIT

CACHE HIT



- Keeping the content fresh is one of the primary responsibilities of the cache — HTTP provides a simple mechanism of **document expiration**.

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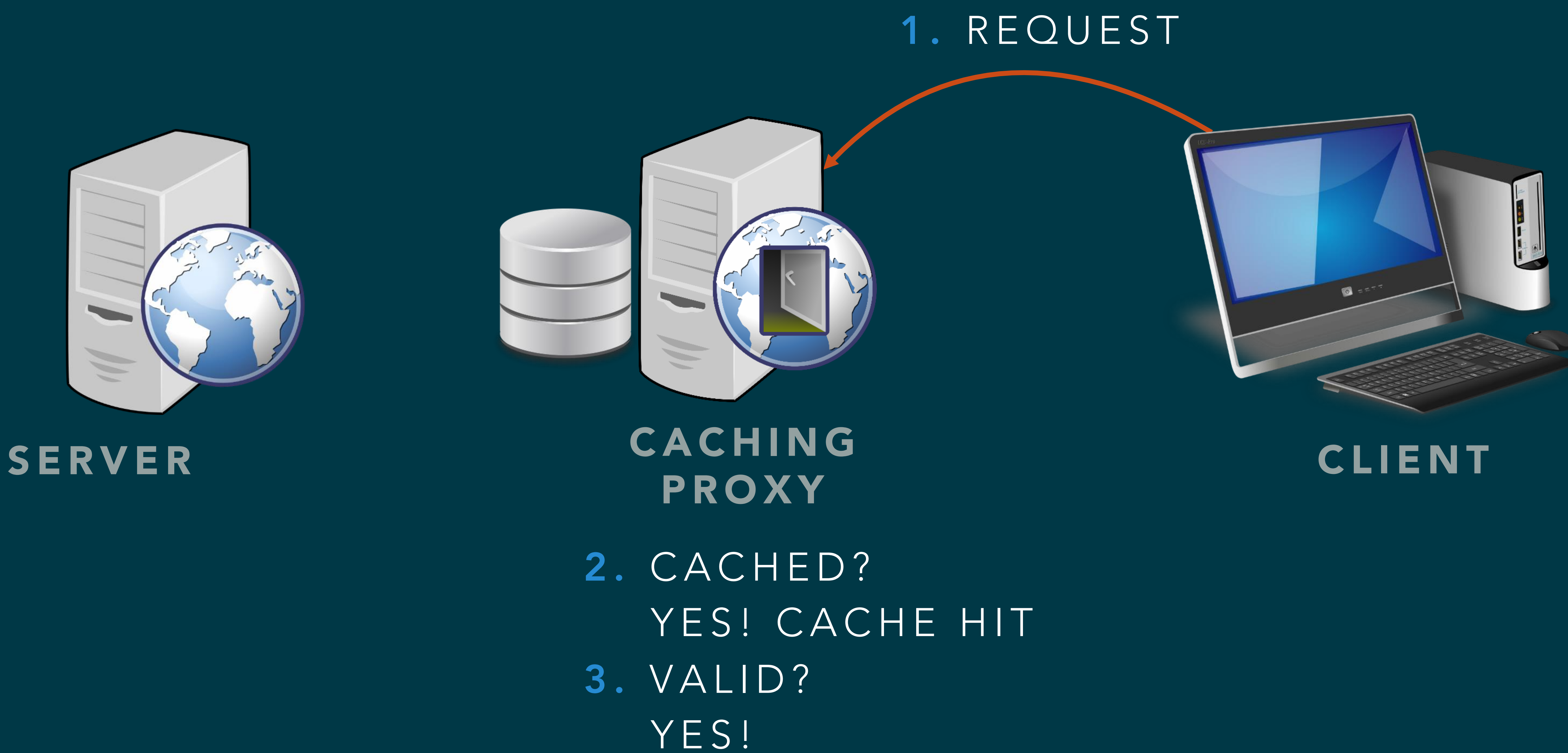

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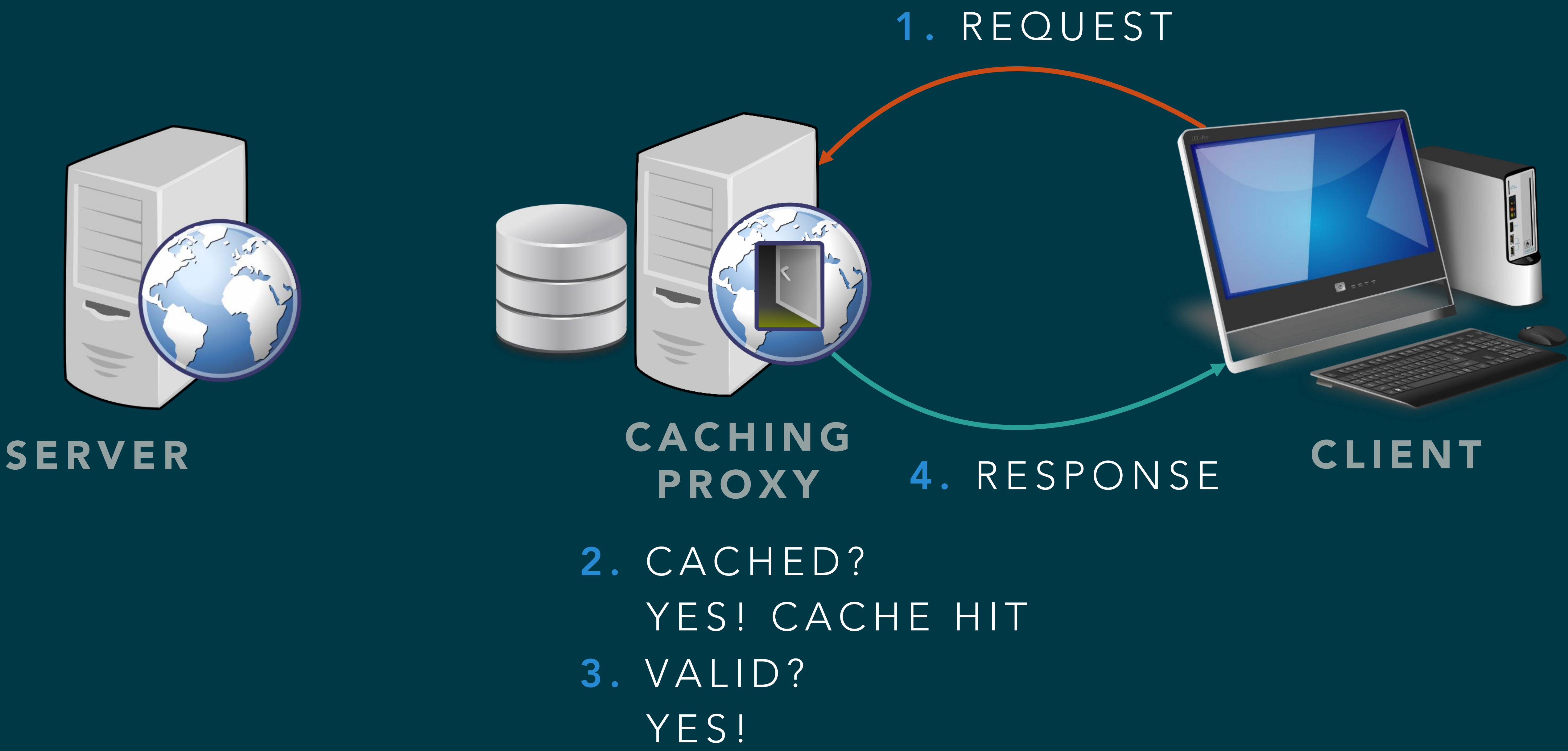

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DOCUMENT EXPIRATION

- HTTP server can attach an **expiration date** to each response using the `Cache-Control` and `Expires` headers.

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HTTP/1.1 200 OK
Last-Modified: Wed, 25 Jan 2012 17:55:15 GMT
Expires: Sat, 22 Jan 2022 17:55:15 GMT
Cache-Control: max-age=315360000,public
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- Once a cached document expires, the cache must **revalidate** with the server to check if the document has changed and **update** its local copy accordingly.

REVALIDATE HIT

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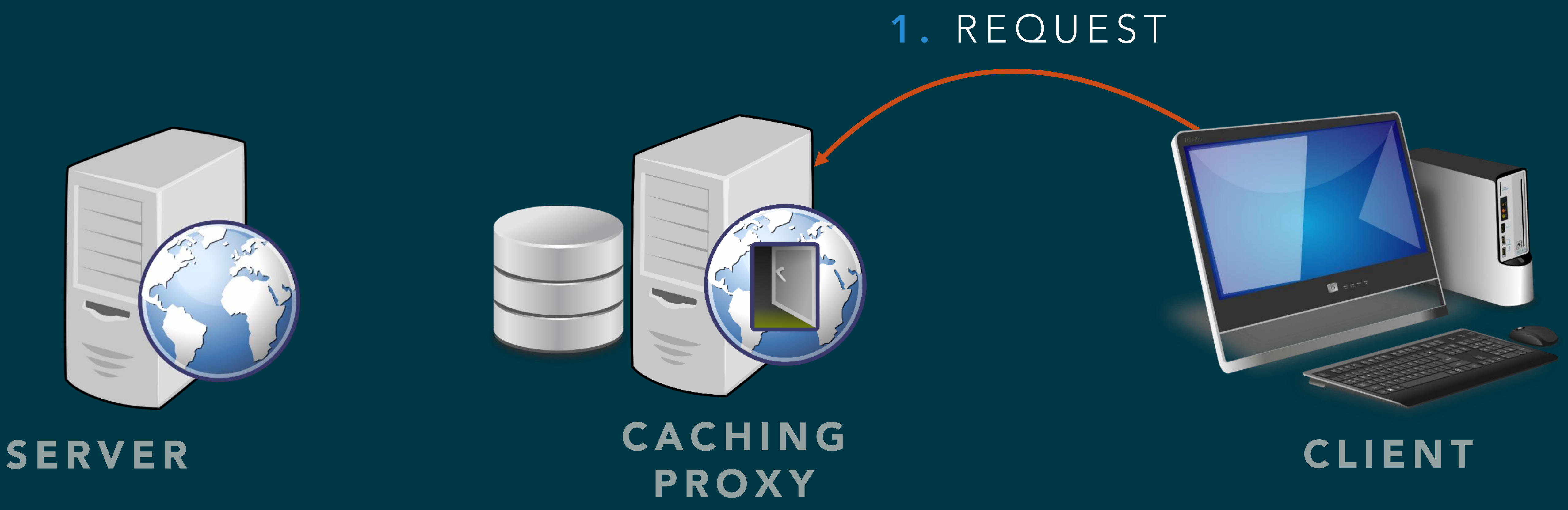

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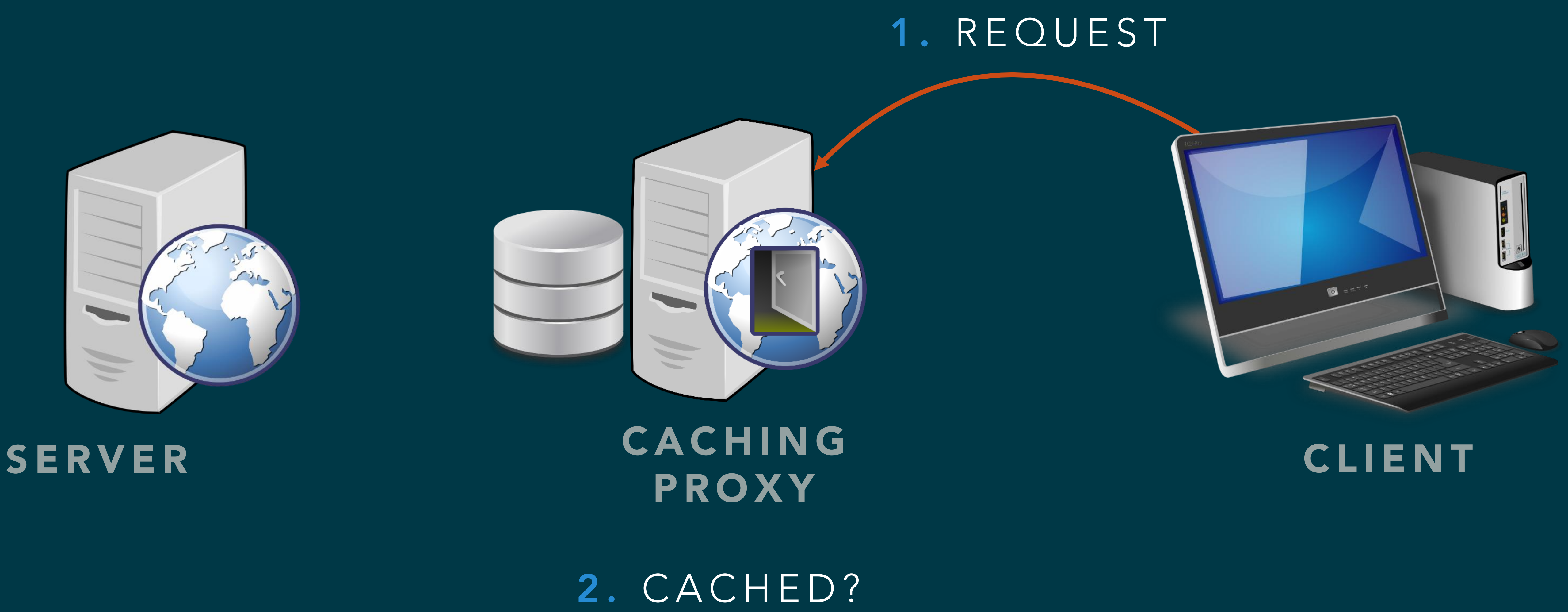

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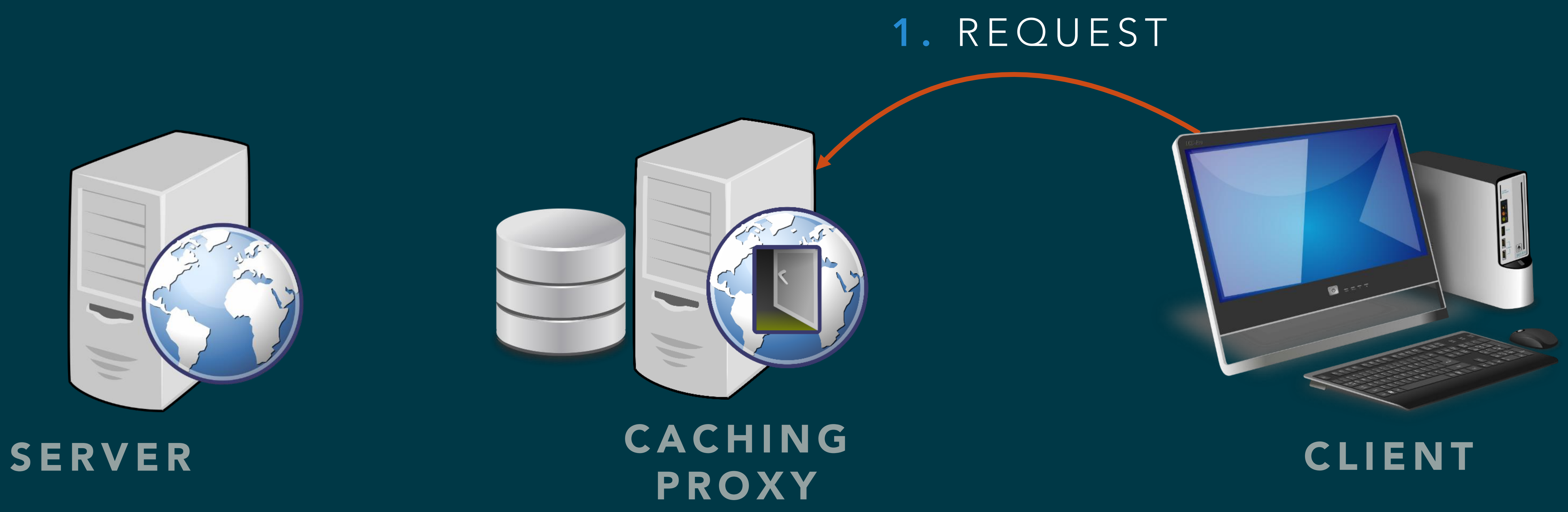
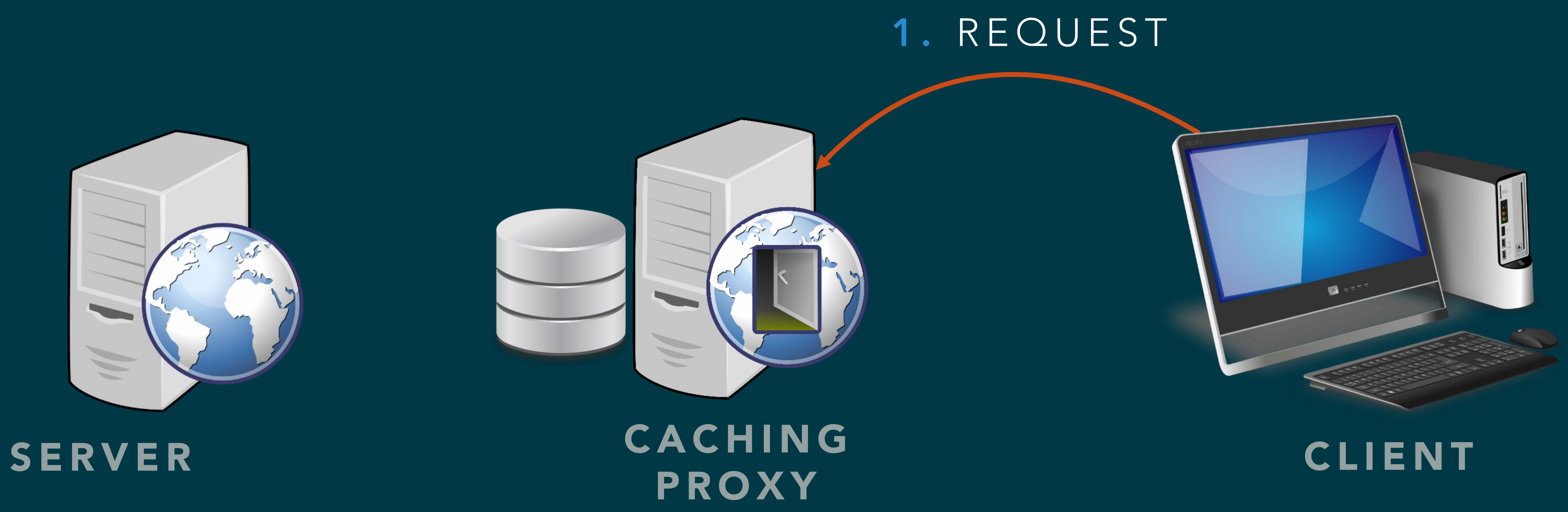


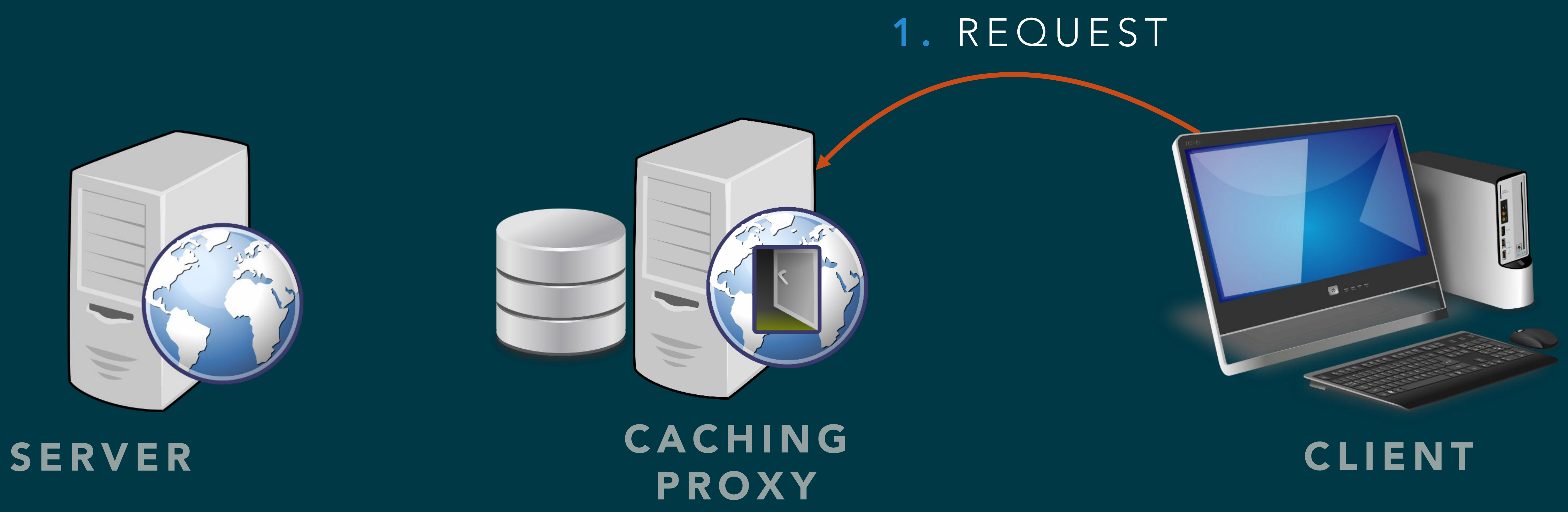
2. CACHED?
YES! CACHE HIT

REVALIDATE HIT



2. CACHED?
   YES! CACHE HIT
3. VALID?

REVALIDATE HIT



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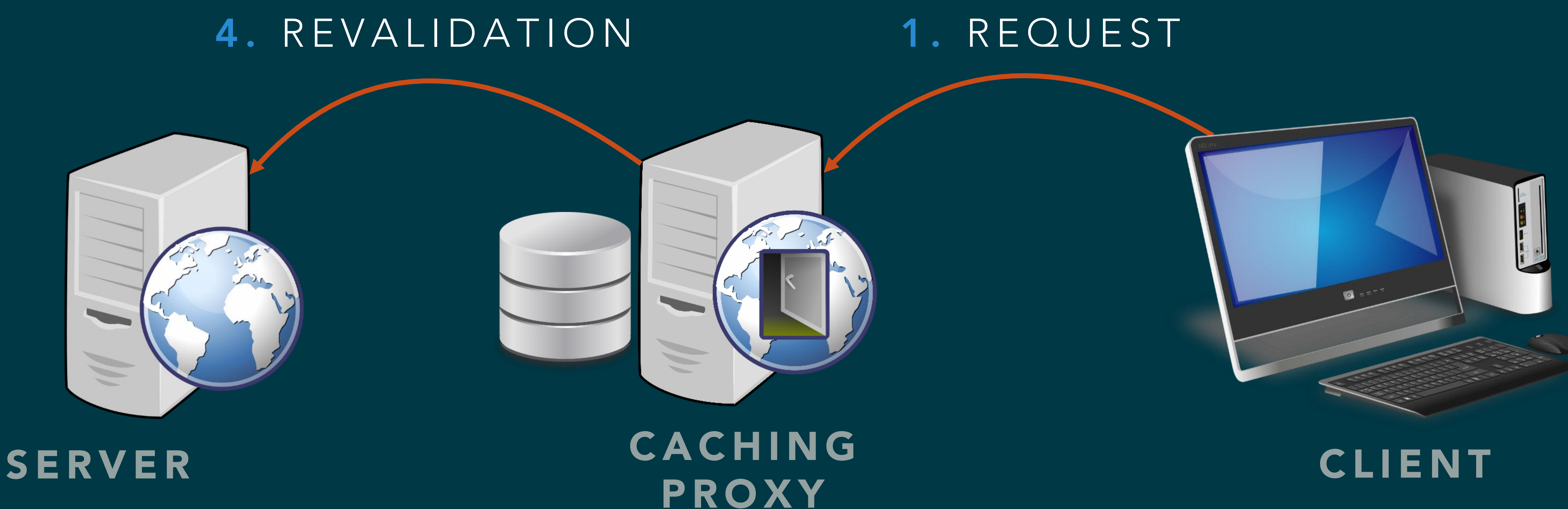

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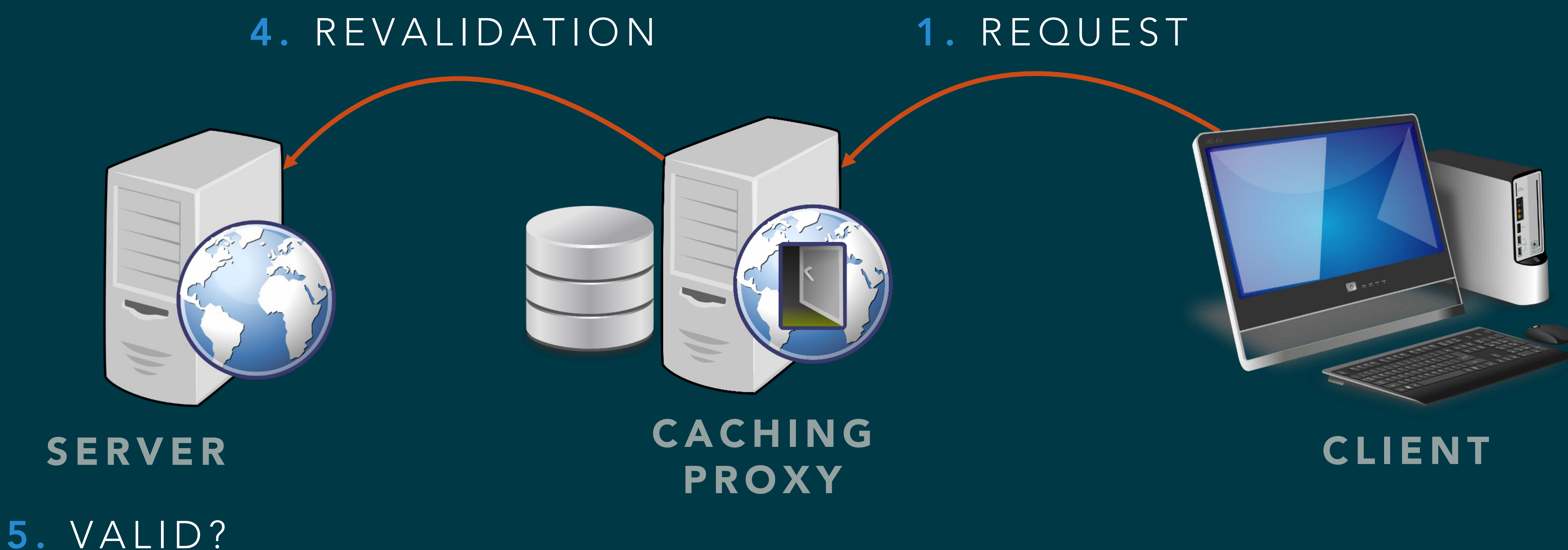

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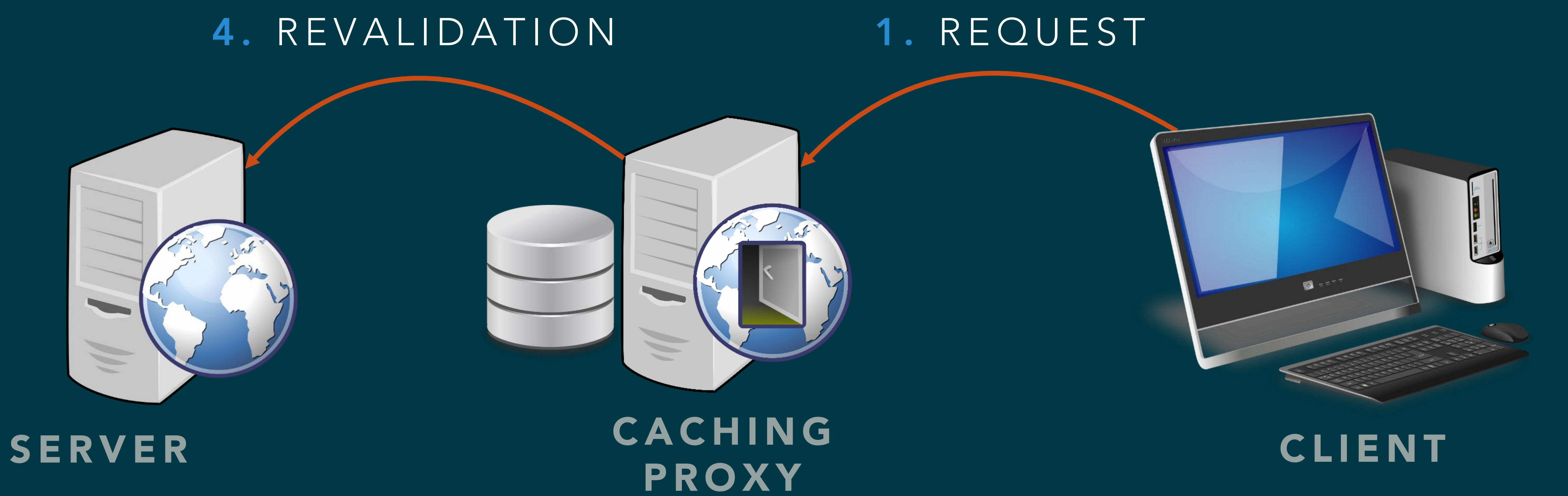

5. VALID?
YES!
REVALIDATE HIT

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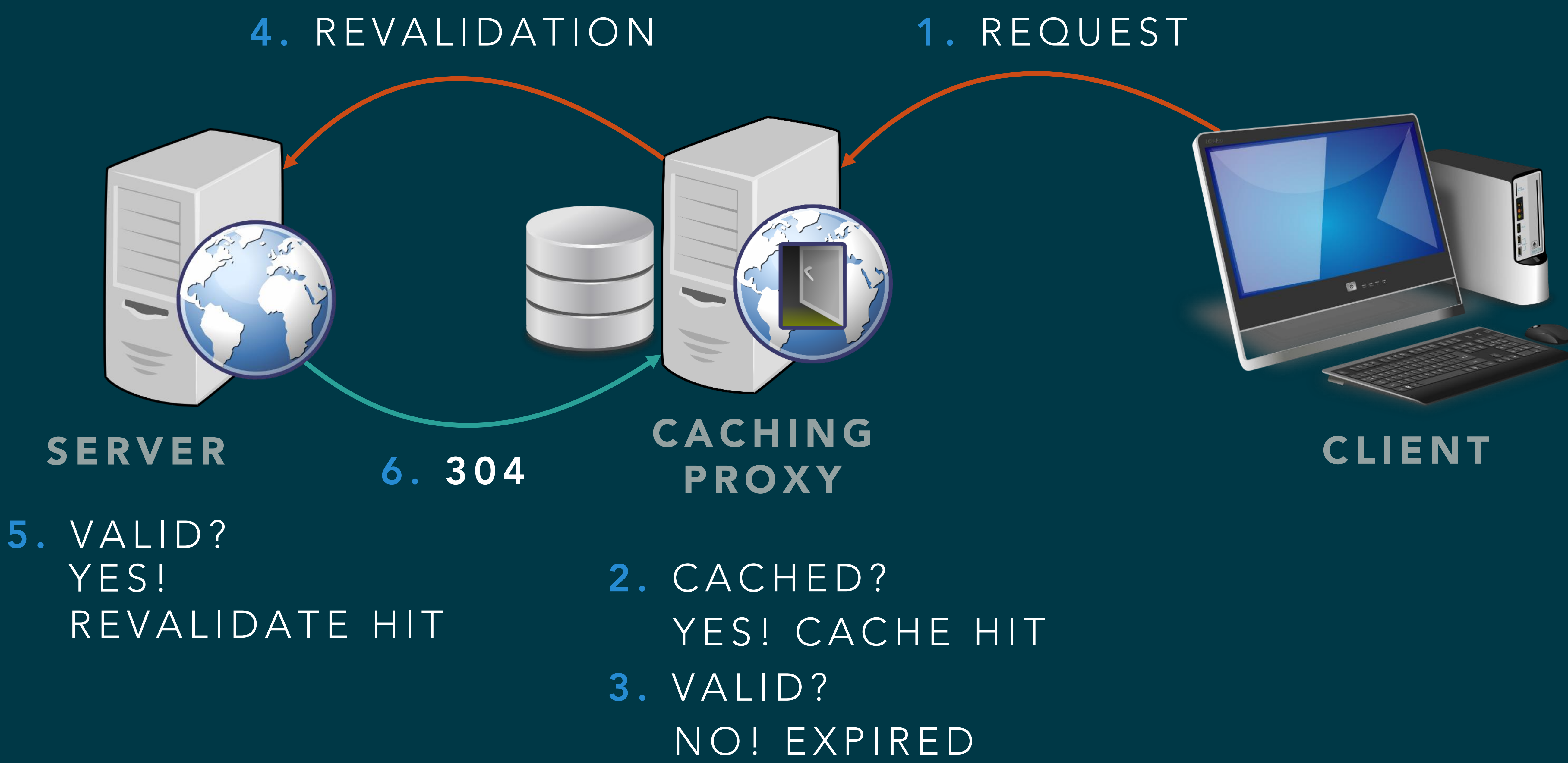
3. VALID?
NO! EXPIRED

REVALIDATE HIT



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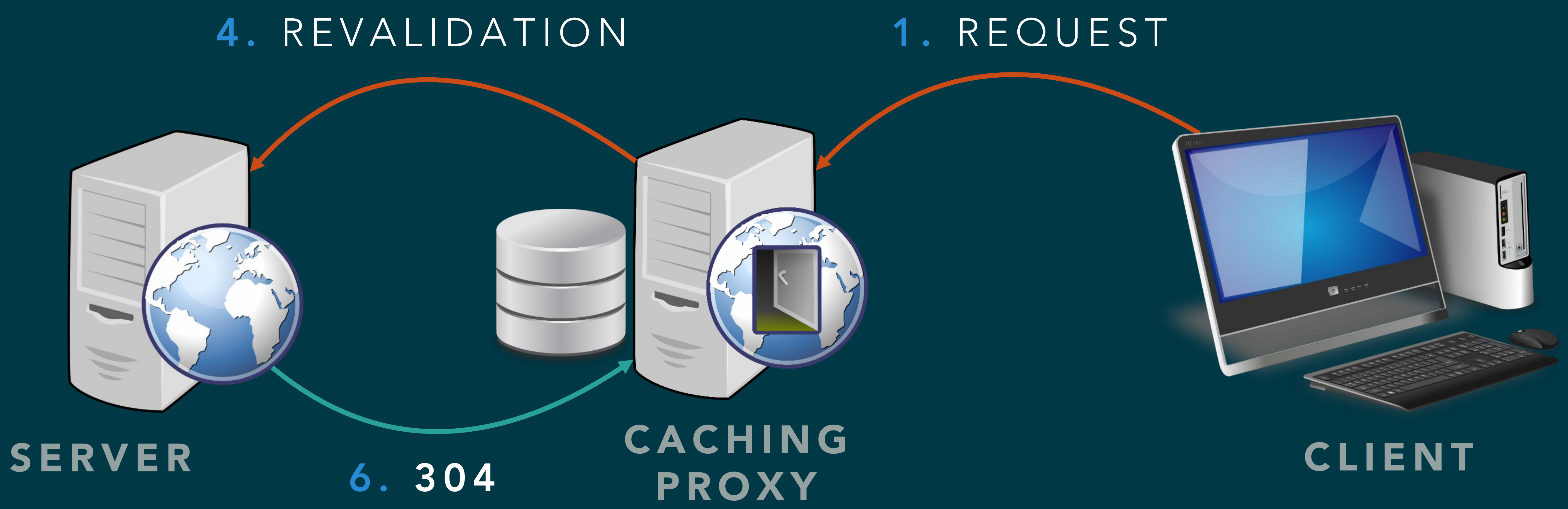
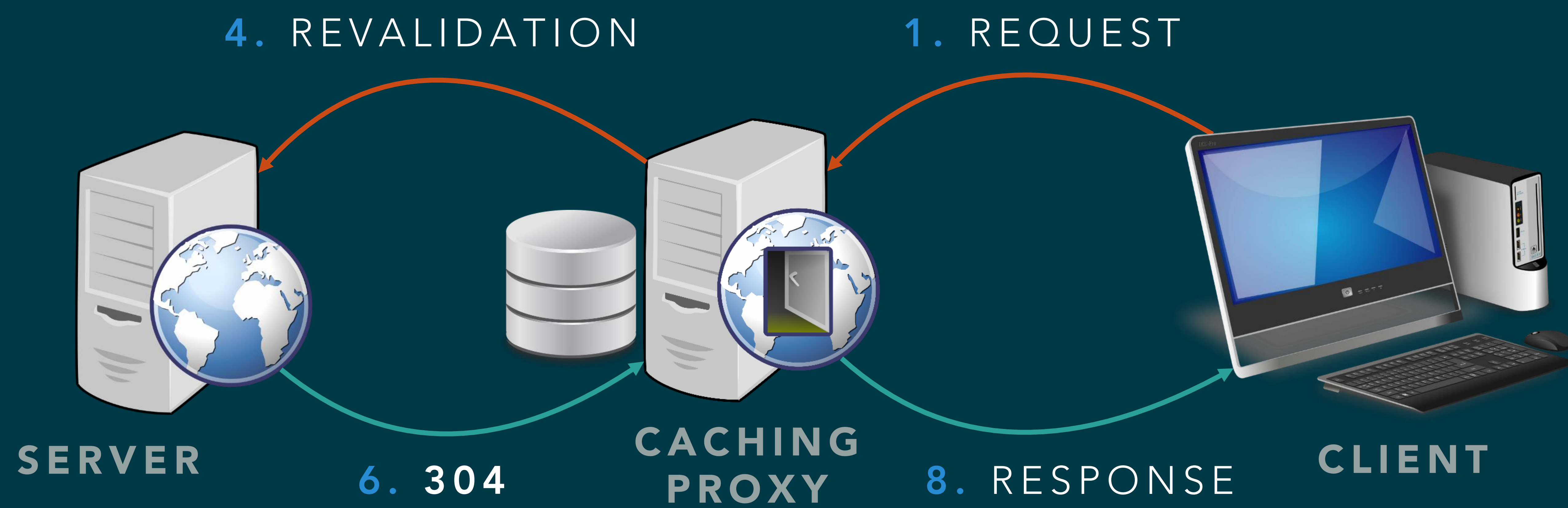


5. VALID?
   YES!
   REVALIDATE HIT

2. CACHED?
   YES! CACHE HIT
3. VALID?
   NO! EXPIRED
7. UPDATE EXPIRATION DATE

REVALIDATE HIT



5. VALID?
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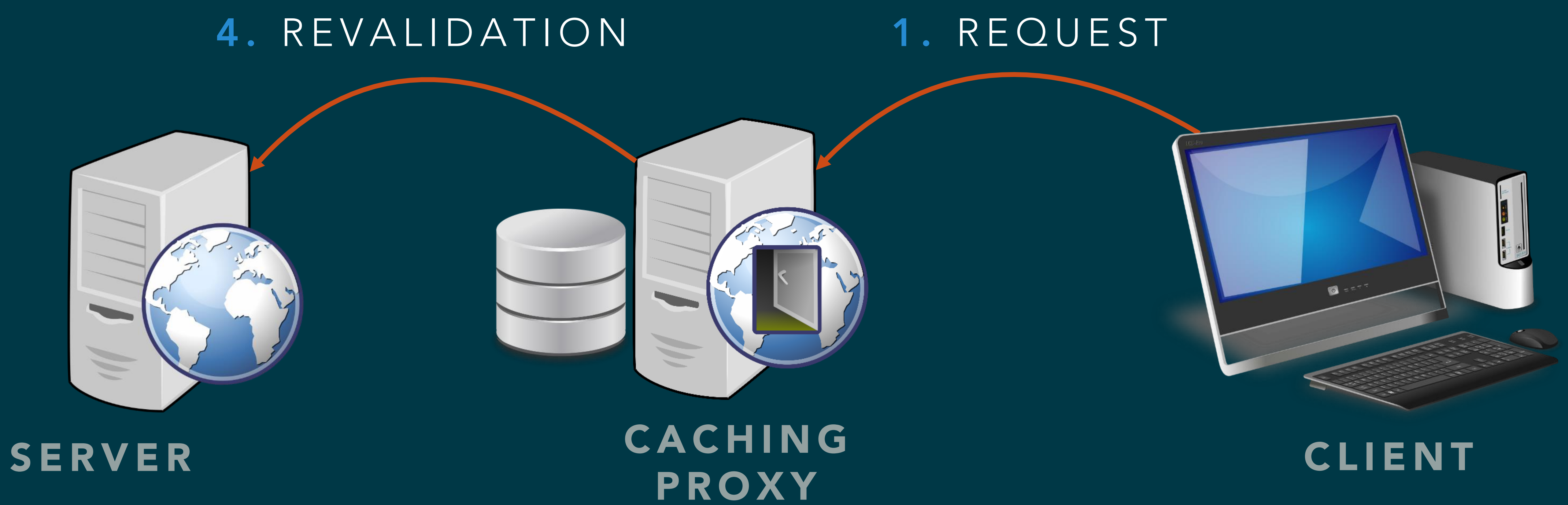
REVALIDATE MISS



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REVALIDATE MISS

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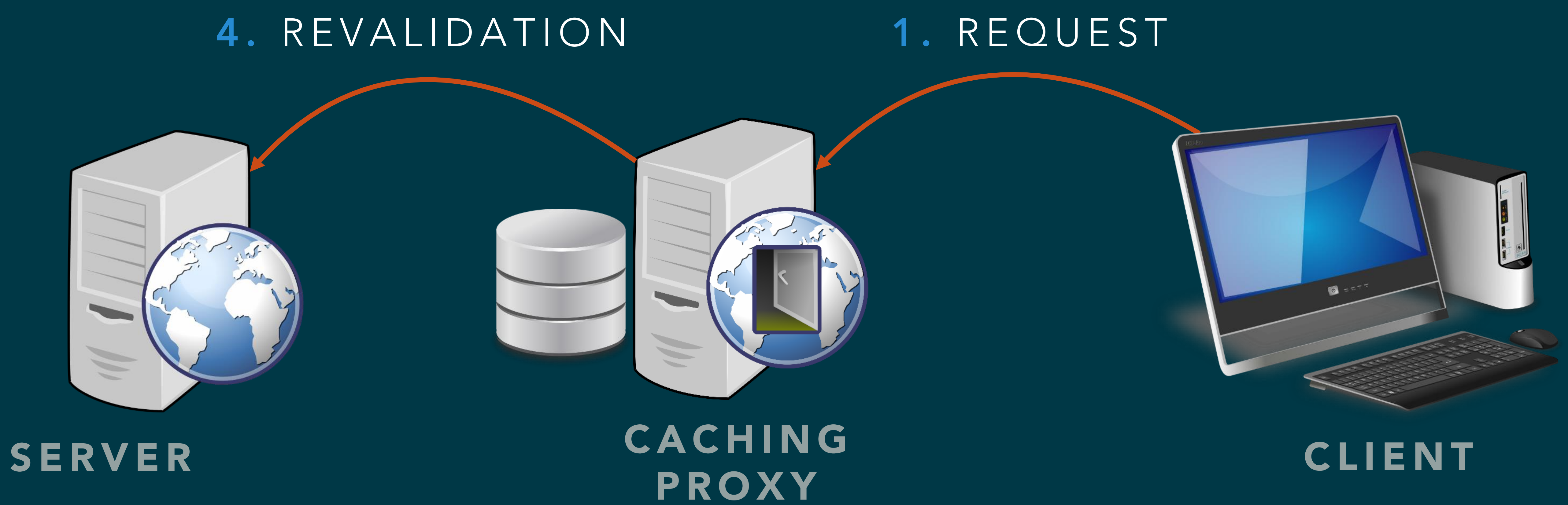

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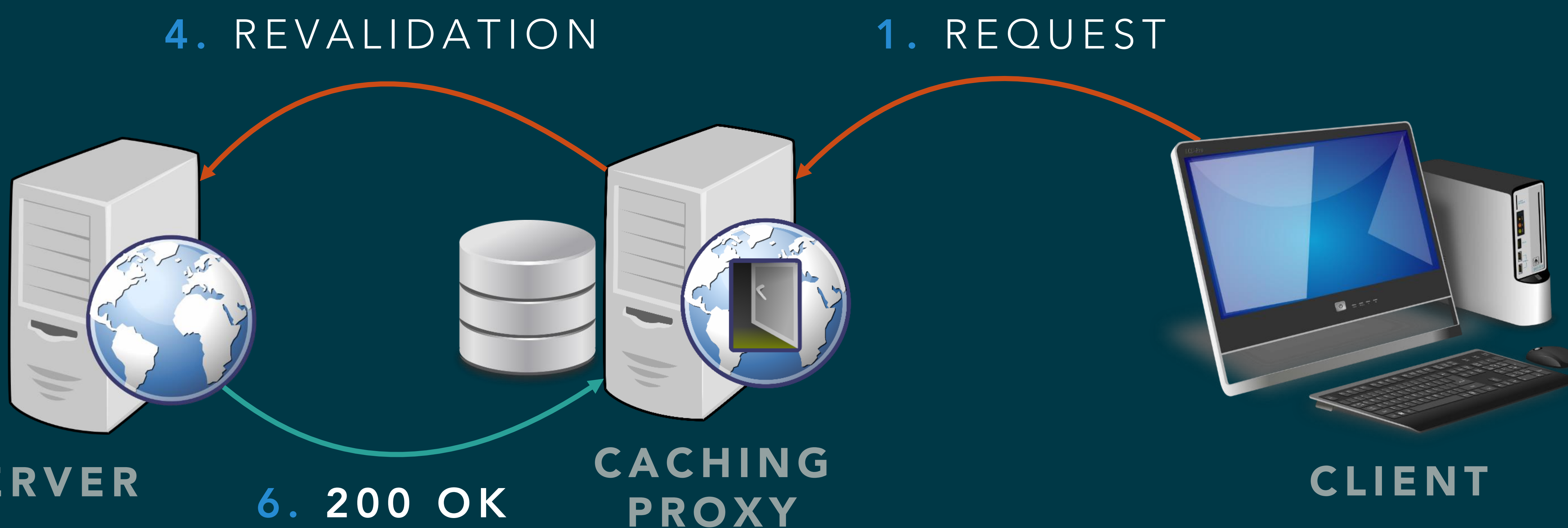

5. VALID?
   NO!
   REVALIDATE MISS

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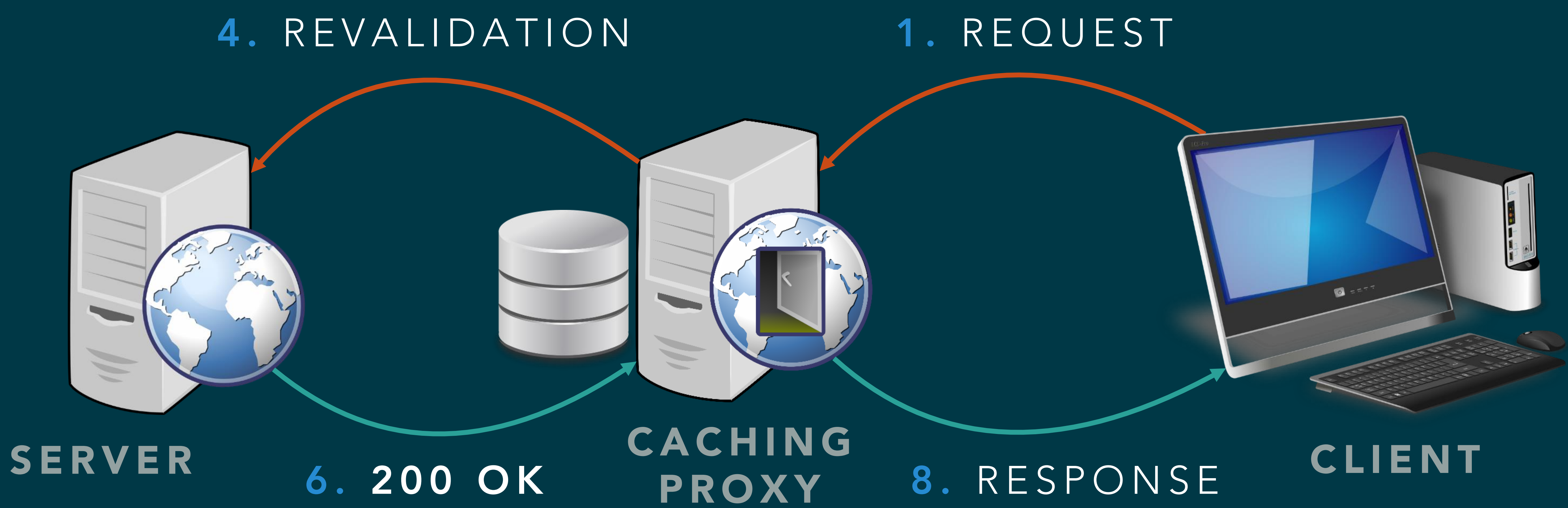
7. STORE RESPONSE

REVALIDATE MISS



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REVALIDATE MISS

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3. VALID?
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7. STORE RESPONSE

SERVER REVALIDATION

- **Document expiration**
  - The cache does not revalidate with the server for every request
  - Save of bandwidth, time and reduction of the traffic
- Server revalidation is made with **conditional methods**.
- **Conditional GET**
  - Ask the server to send back an object body only if the document is different than in the cache
  - Otherwise, server responses with a small `304 Not Modified` message without body
- Freshness check and the object fetch are combined into a single request by adding special **conditional headers**

SERVER REVALIDATION CONDITIONAL HEADERS

- HTTP defines **five** conditional request headers; **two** of them are commonly used for cache revalidation.

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- `If-None-Match` — the server may provide special tags (`ETag`) on the document that act like serial numbers. The `If-None-Match` header performs the requested method if the cached tag differs from the tag in the server's document.

SERVER REVALIDATION
ENTITY TAG REVALIDATION

- **Date-based revalidation** is the most common technique, but there are situations when it is not adequate:
  - Documents rewritten **periodically** but containing the same data,
  - Servers cannot **accurately** determine modification dates,
  - One-second **granularity** of modification dates is not enough.

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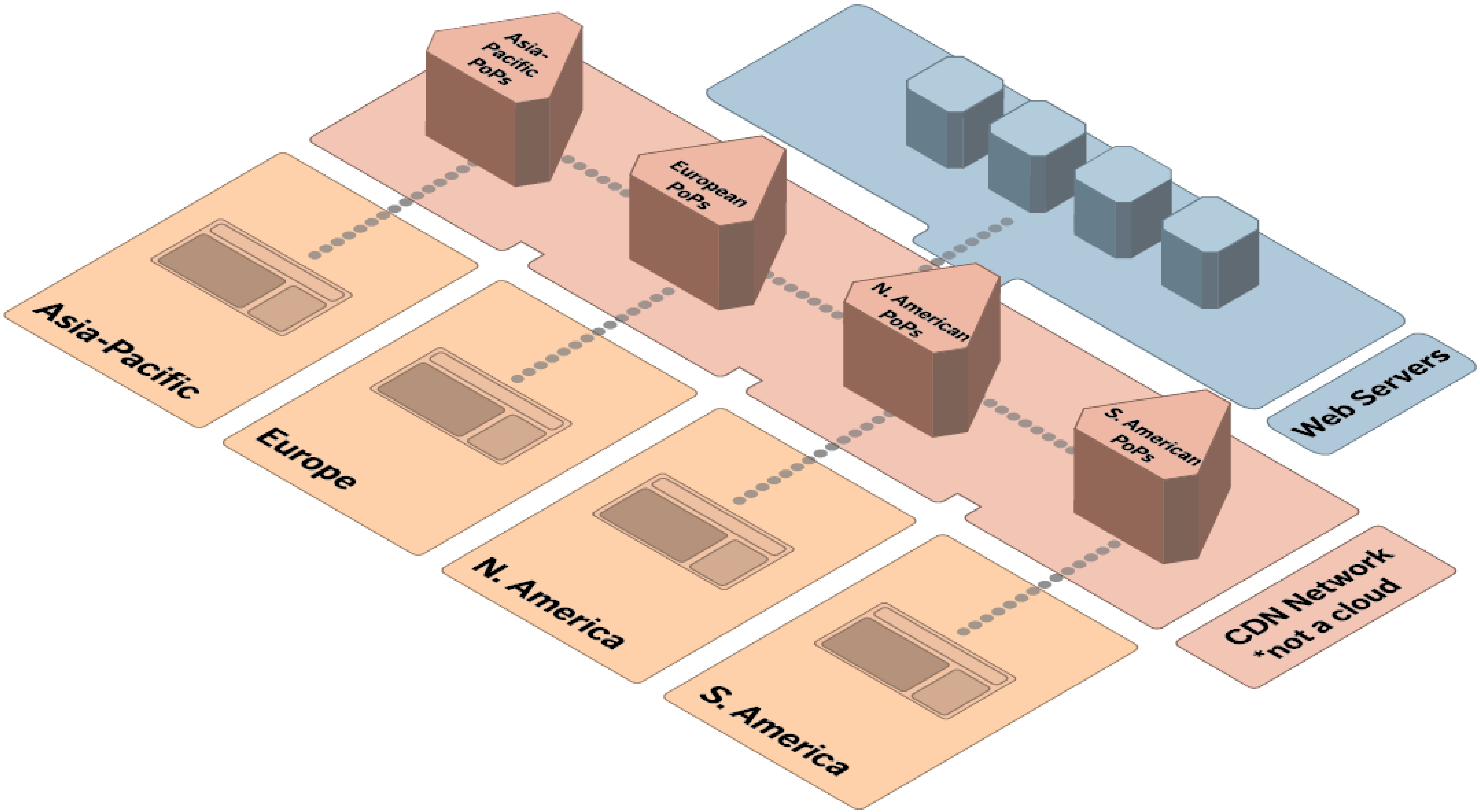
- HTTP allows you to compare **document version identifiers** called entity tags (ETags).
- Entity tags are arbitrary labels attached to the document which might contain a **serial number**, a **checksum** or other **fingerprint** of the document content.

CONTENT DELIVERY NETWORKS

- Content delivery network (CDN) — a large, **geographically distributed** network of specialized servers that accelerate the delivery of web content to internet-connected devices.
- The primary technique that a CDN uses to speed the delivery of web content to end users is **edge caching**.
- **Edge caching** entails storing replicas of static text, image, audio, and video content in multiple servers around the "edges" of the internet, so that user requests can be served by a nearby edge server rather than by a far-off origin server.



Asia-Pacific PoPs
European PoPs
N. American PoPs
S. American PoPs
Web Servers
Asia-Pacific
Europe
N. America
S. America
CDN Network
*not a cloud

CONTROLLING CACHABILITY

- `Cache-Control` header has a few different values to constrain how clients should cache the response.
- `public` — public proxy servers can cache the response
- `private` — only the browser can cache the response
- `no-cache` — one must not cache the response, or one must revalidate cached response with use of other criteria
- `no-store` — one must not cache the response

CONTROLLING CACHABILITY

- `Cache-Control: max-age` — sets a **relative** expiration time (in seconds) from the time the response is generated.
- `Cache-Control: s-maxage` — acts like `max-age` but applies only to shared (public) caches.

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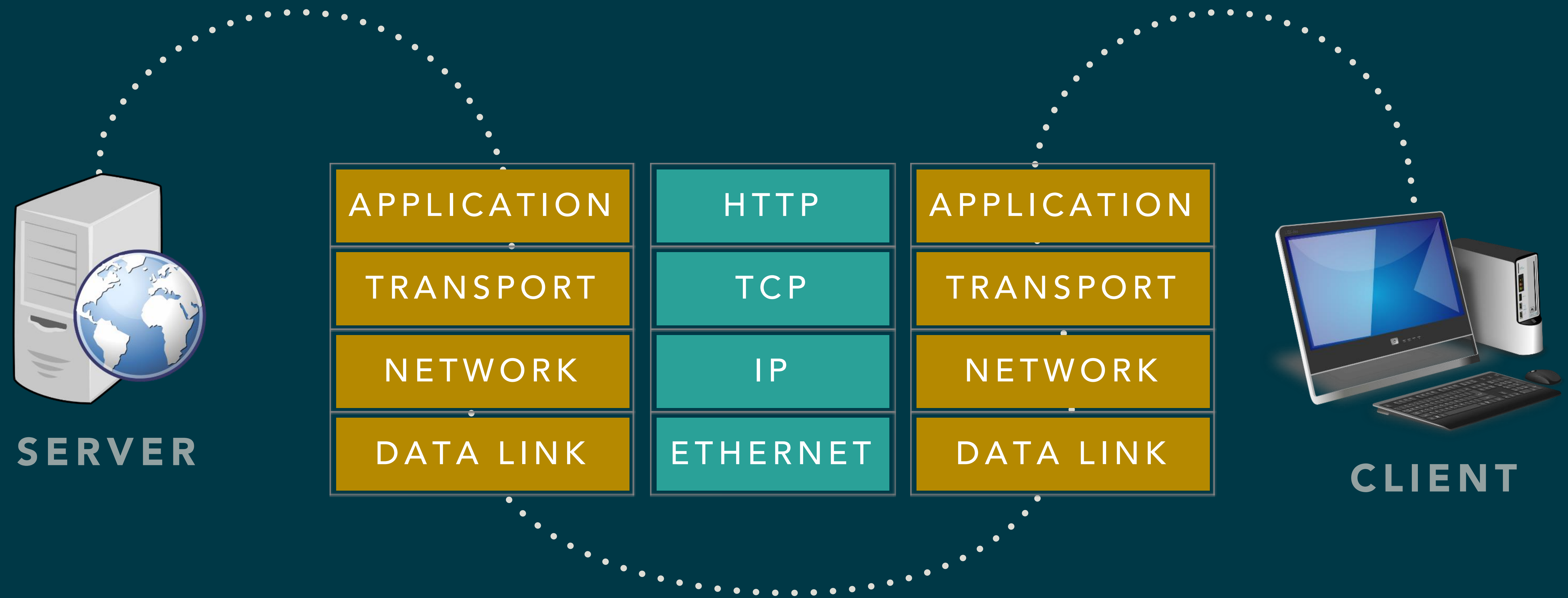
- `Cache-Control: must-revalidate` — tells caches they cannot serve a **stale** copy of this object without first revalidating with the origin server. Caches are still free to serve fresh copies without revalidating.

HTTPS — SECURE CONNECTIONS

- An additional security layer in the network protocol stack, between HTTP and TCP — the Secure Sockets Layer (**SSL**) or the improved Transport Layer Security (**TLS**).



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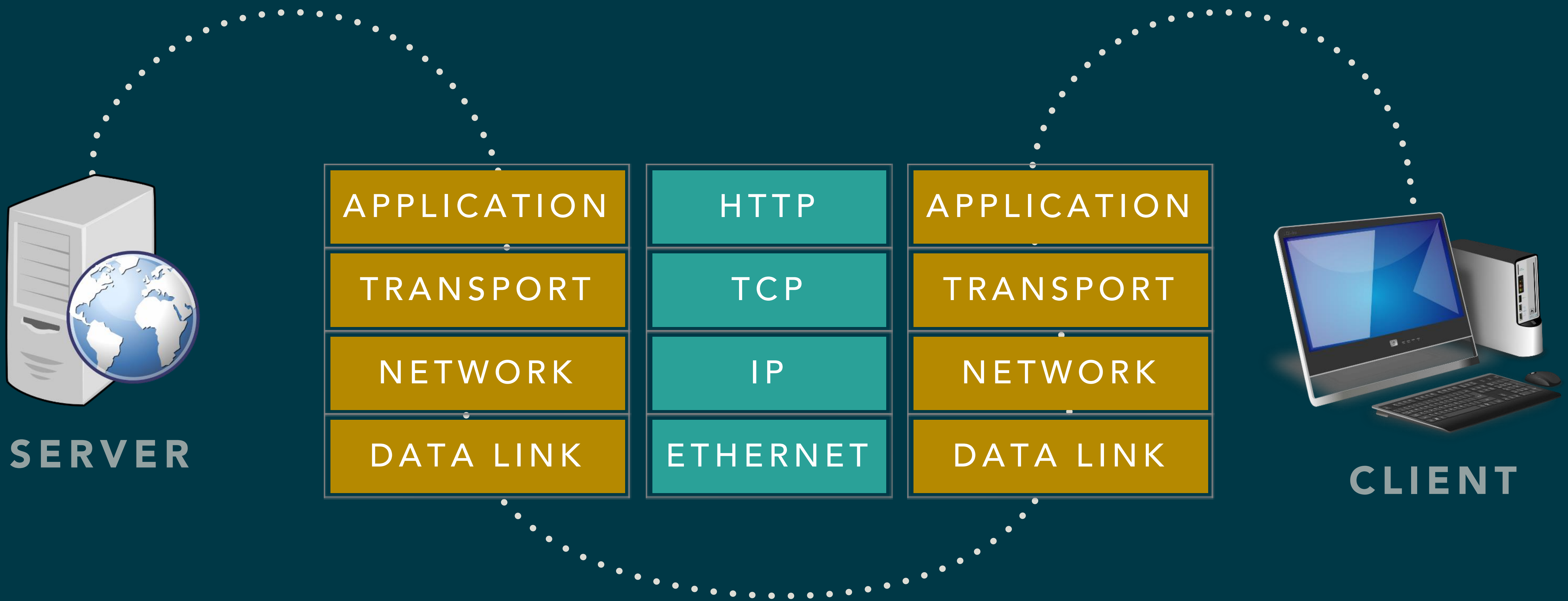

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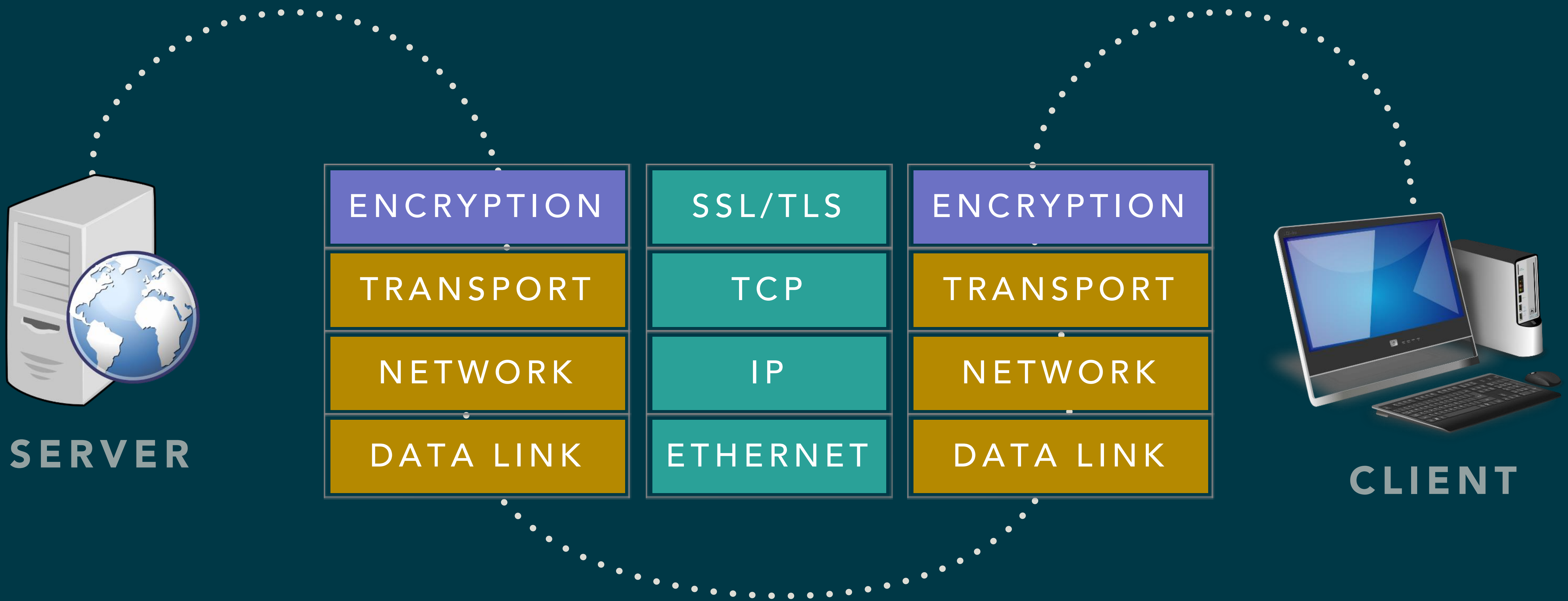

TRANSPORT LAYER SECURITY

- The TLS protocol provides three essential services that form a foundation of secure communication:
  - **encryption** — using public-key cryptography allows the peers to negotiate a shared secret key (within a TLS handshake).
  - **authentication** — to verify the identity of the server/client;
  - **integrity** — to detect message tampering and forgery.

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  - **encryption** — using public-key cryptography allows the peers to negotiate a shared secret key (within a TLS handshake).
  - **authentication** — to verify the identity of the server/client;
  - **integrity** — to detect message tampering and forgery.
- HTTPS encrypts all request and response traffic, including the HTTP **headers** and message **body**, and everything after the host name in the **URL**.

TLS HANDSHAKE

SERVER

CLIENT

TLS HANDSHAKE

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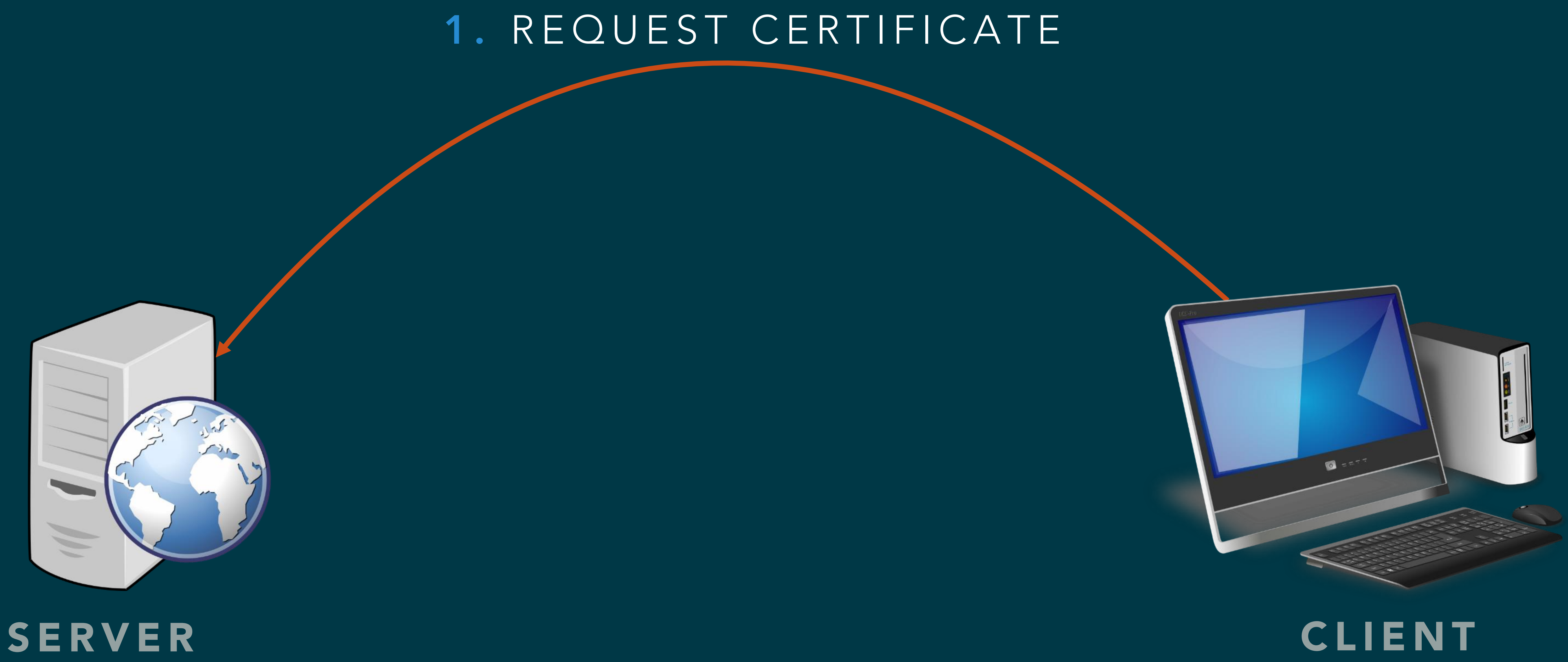
CLIENT

TLS HANDSHAKE



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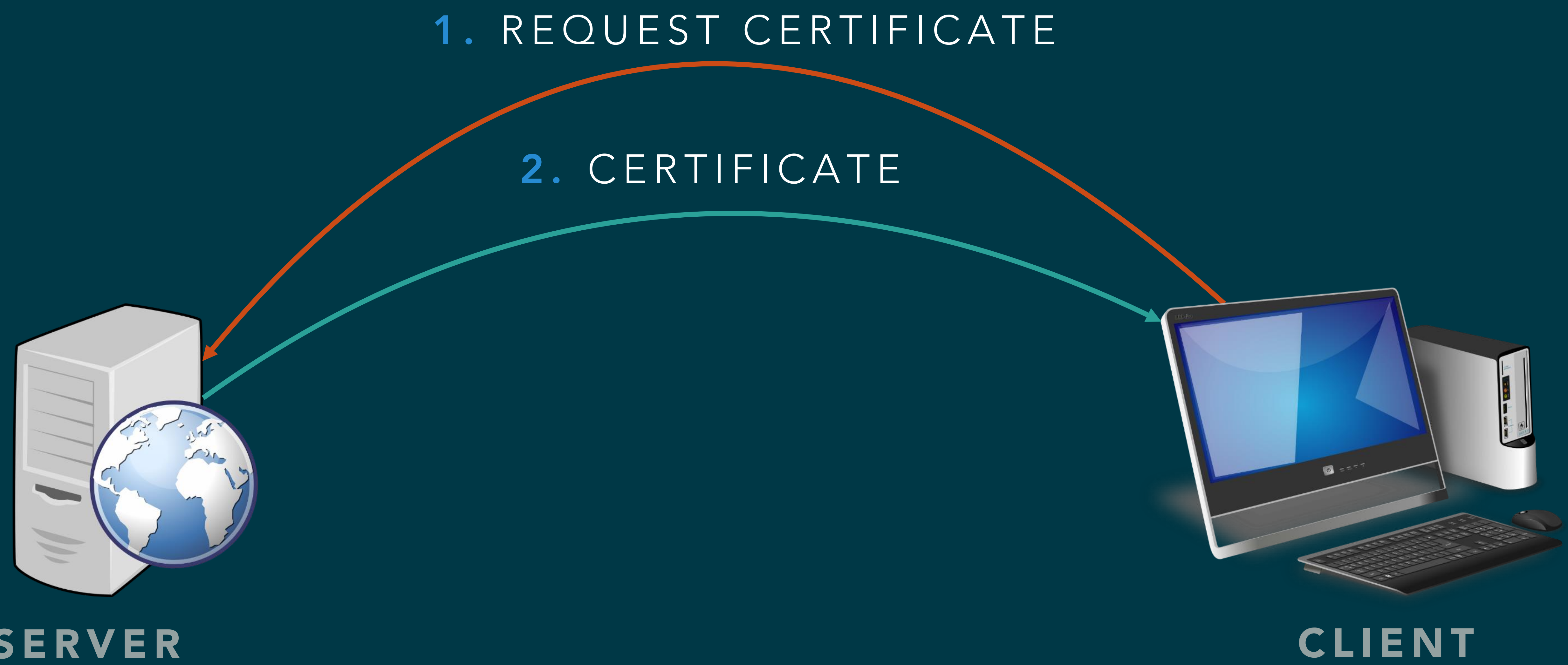

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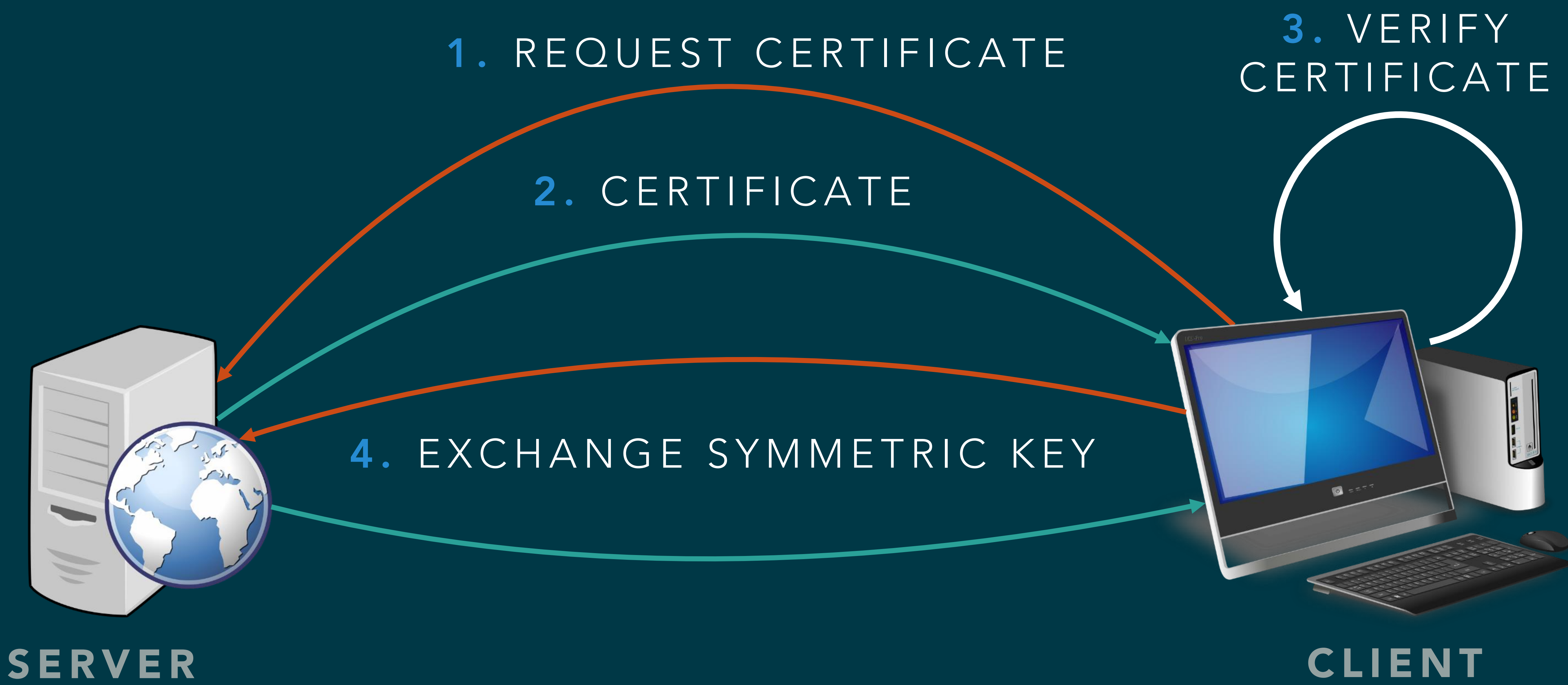

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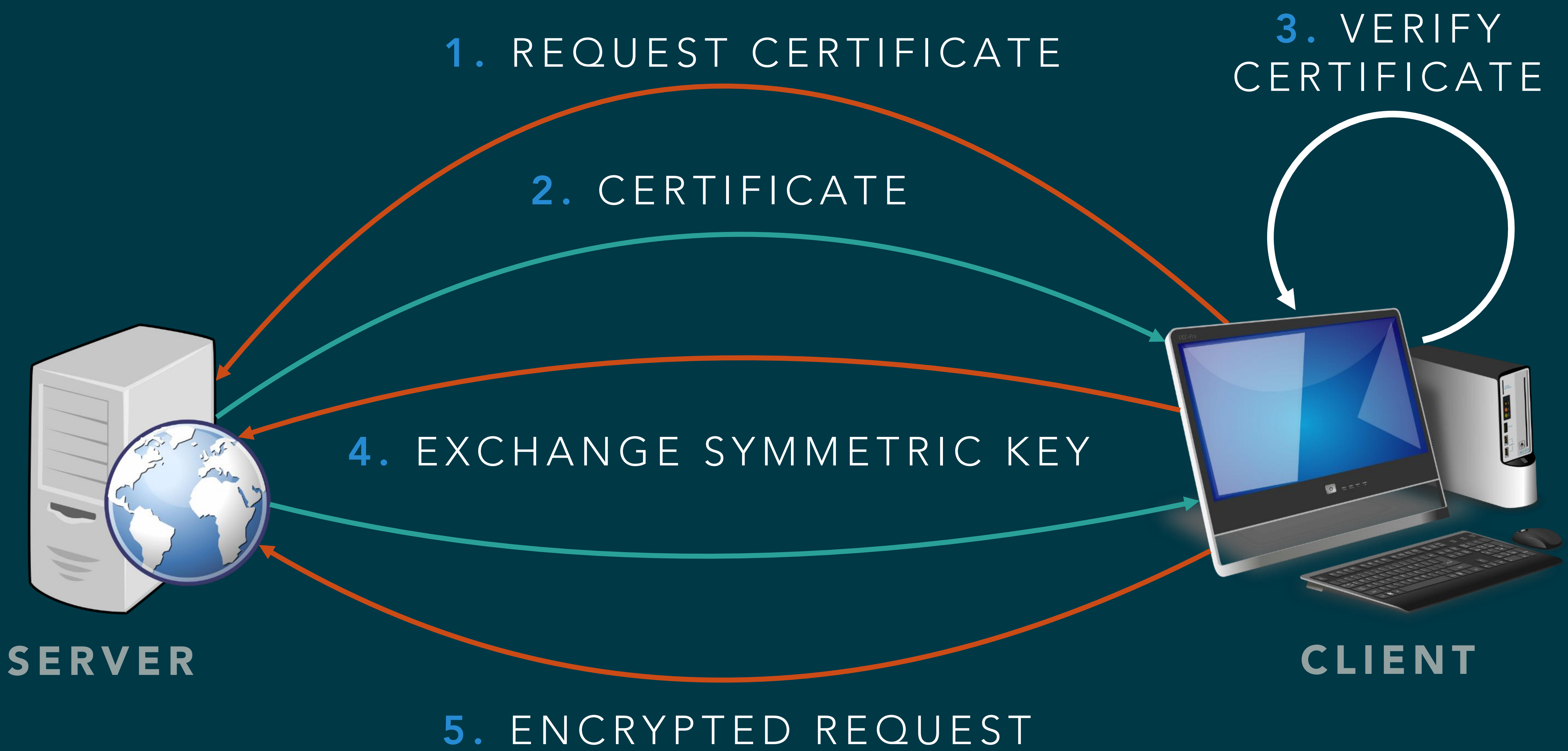

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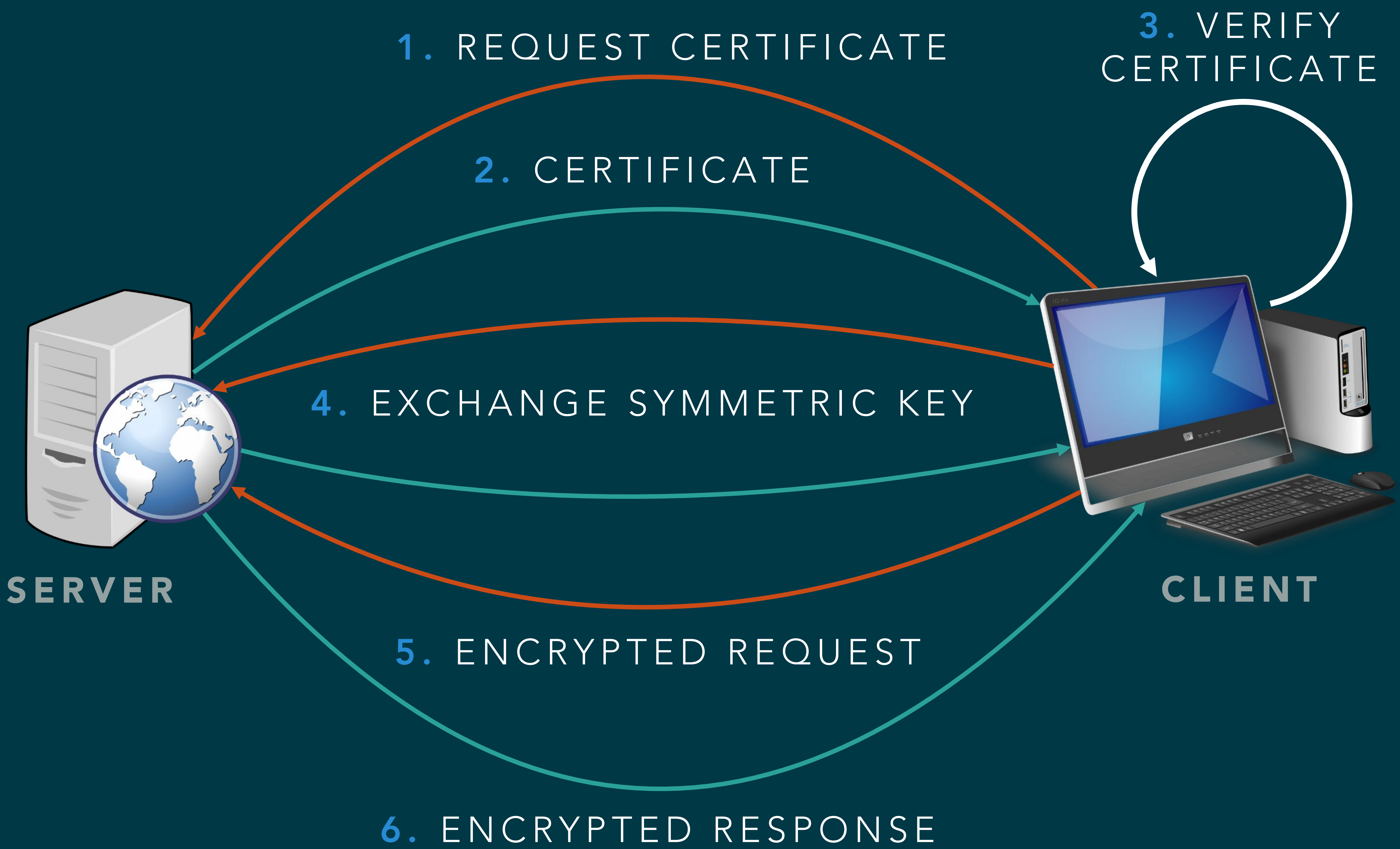

HTTP/2

- HTTP history:
  - 1991: HTTP 0.9
  - 1996: HTTP 1.0 (RFC 1945)
  - 1997: HTTP 1.1 (RFC 2068)
  - 1999: HTTP 1.1 improved (RFC 2616)
  - 05.2015 — HTTP/2 (RFC 7540, proposed standard)
- HTTP/2 maintains high-level compatibility with HTTP/1.1 (methods, status codes, header fields)
- Based on **SPDY** — developed by Google since 2009.

SPeeDY — MOTIVATION

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  - exclusively **client-initiated** requests
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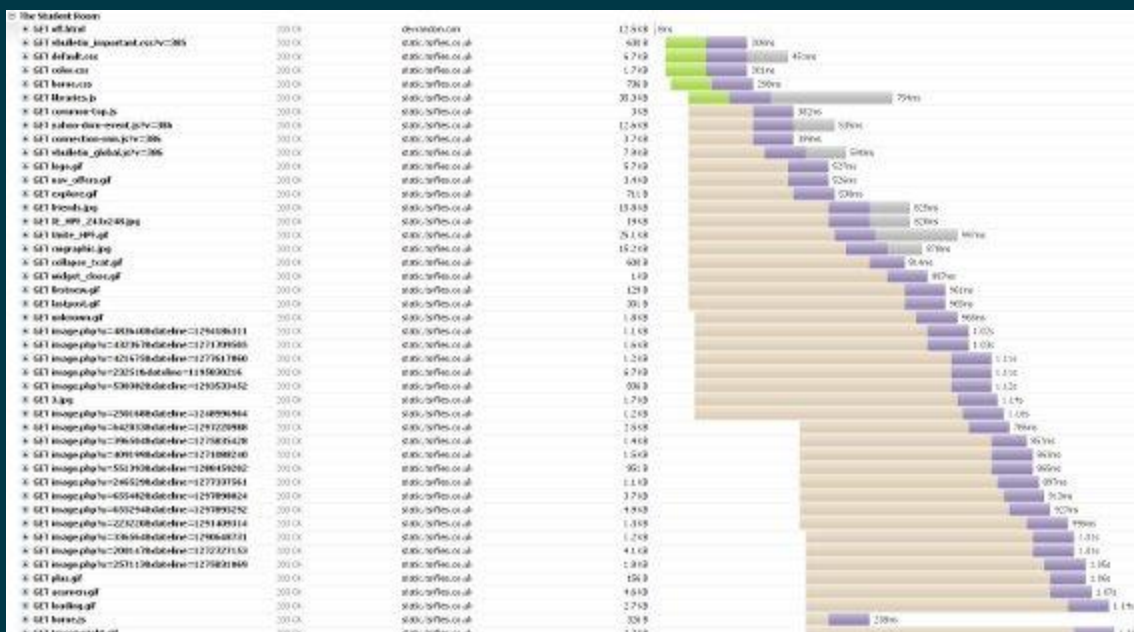
  - **optional** data compression
- Browsers and applications employ a number of **tricks** to improve the performance of the HTTP protocol.

PARALLEL CONNECTIONS

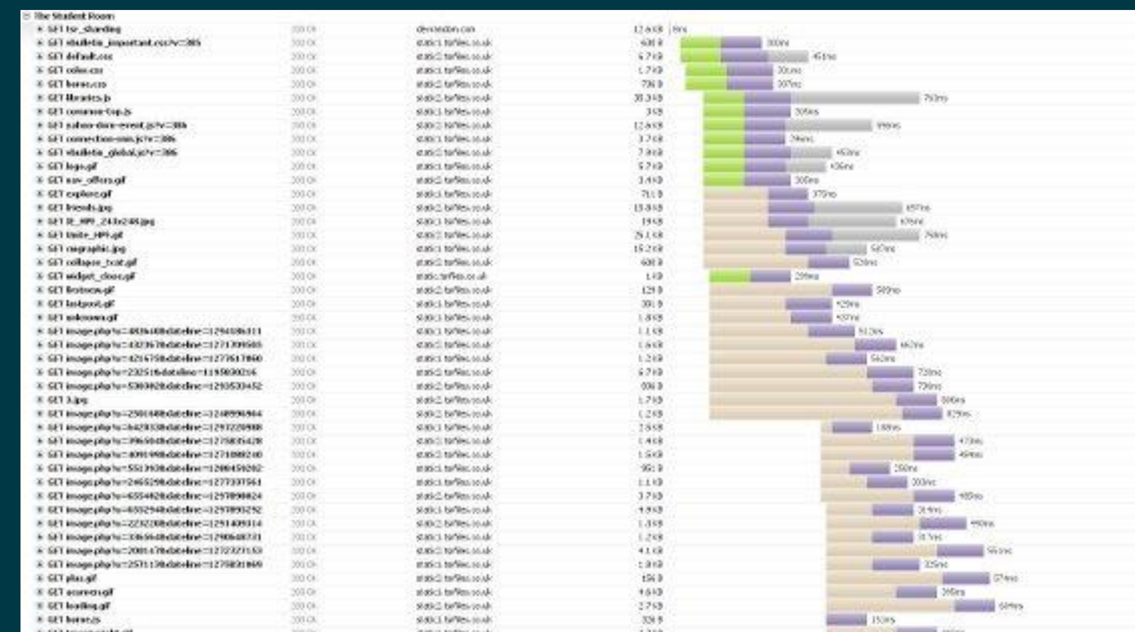
- **Parallel connections** — a technique employed by browsers to minimize network delays and improve overall performance.
- A **pool** of parallel connections allows the client to download the assets simultaneously rather than in a **serial** fashion.
- *According to* ***HTTP 1.1****: A single-user client SHOULD NOT maintain more than 2 connections with any server or proxy.*
- Most browser use a set of heuristics to decide on how many parallel connections to establish (typically from 4 to 8).

DOMAIN SHARDING

No sharding



Sharding

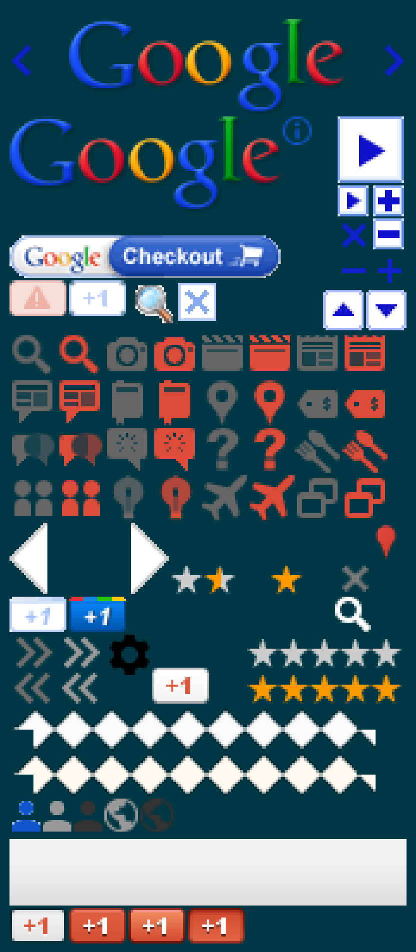


- **Domain sharding** — distributing web resources across multiple domains or content delivery networks.
- Domain sharding is often overused and can hurt performance due to additional DNS lookups and TCP slow-start.

Source: https://gtmetrix.com/parallelize-downloads-across-hostnames.html

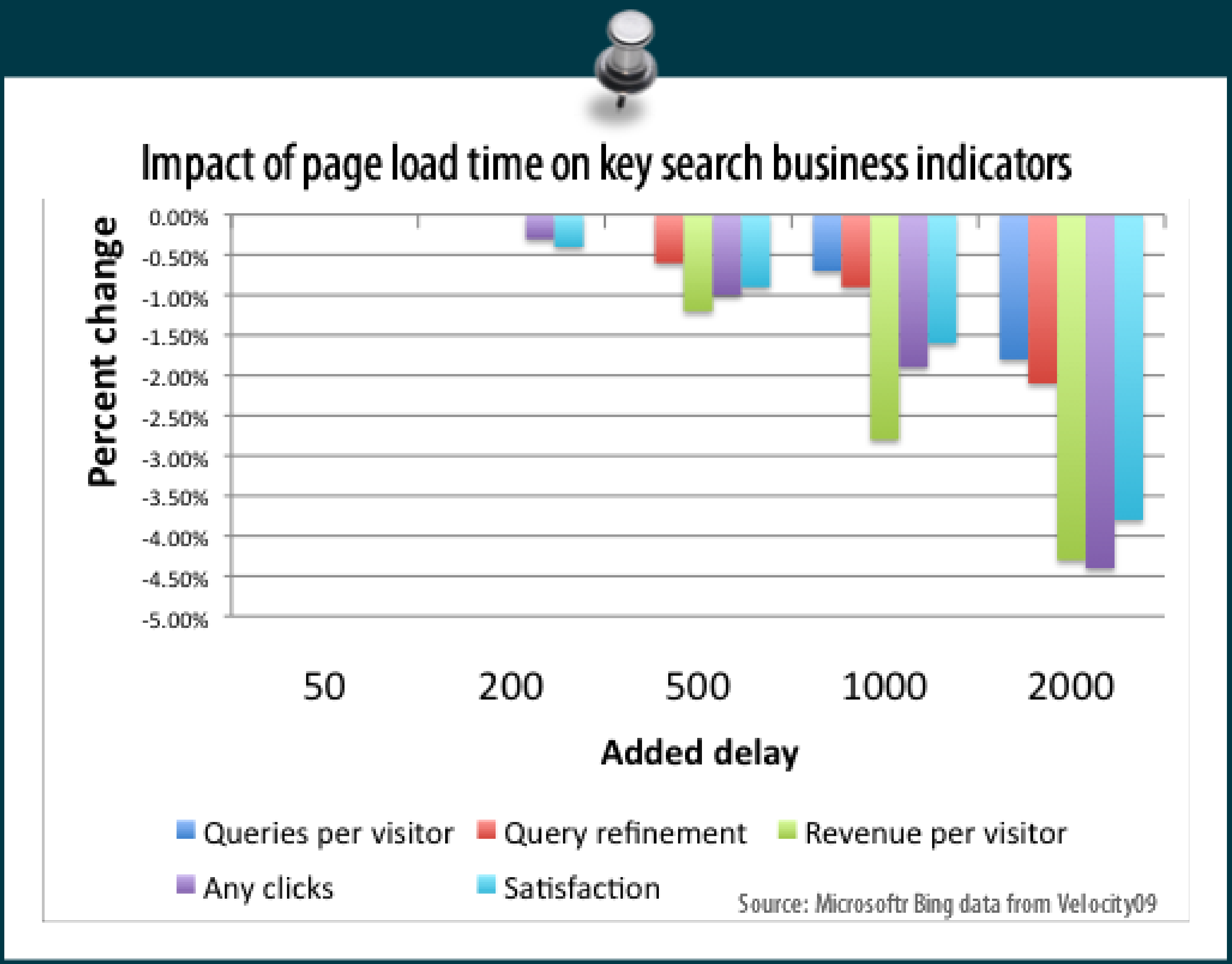
RESOURCE CONCATENATION, SPRITING AND INLINING

- *The fastest request is a request not made.*
- **Concatenation** — multiple JavaScript or CSS files are combined into a single resource.
- **Spriting** — multiple images are combined into a larger, composite image.
- **Resource Inlining**
  - JavaScript and CSS can be included in HTML via the appropriate tags
  - Binary data (e.g., images) can be included in HTML/CSS using data-URI



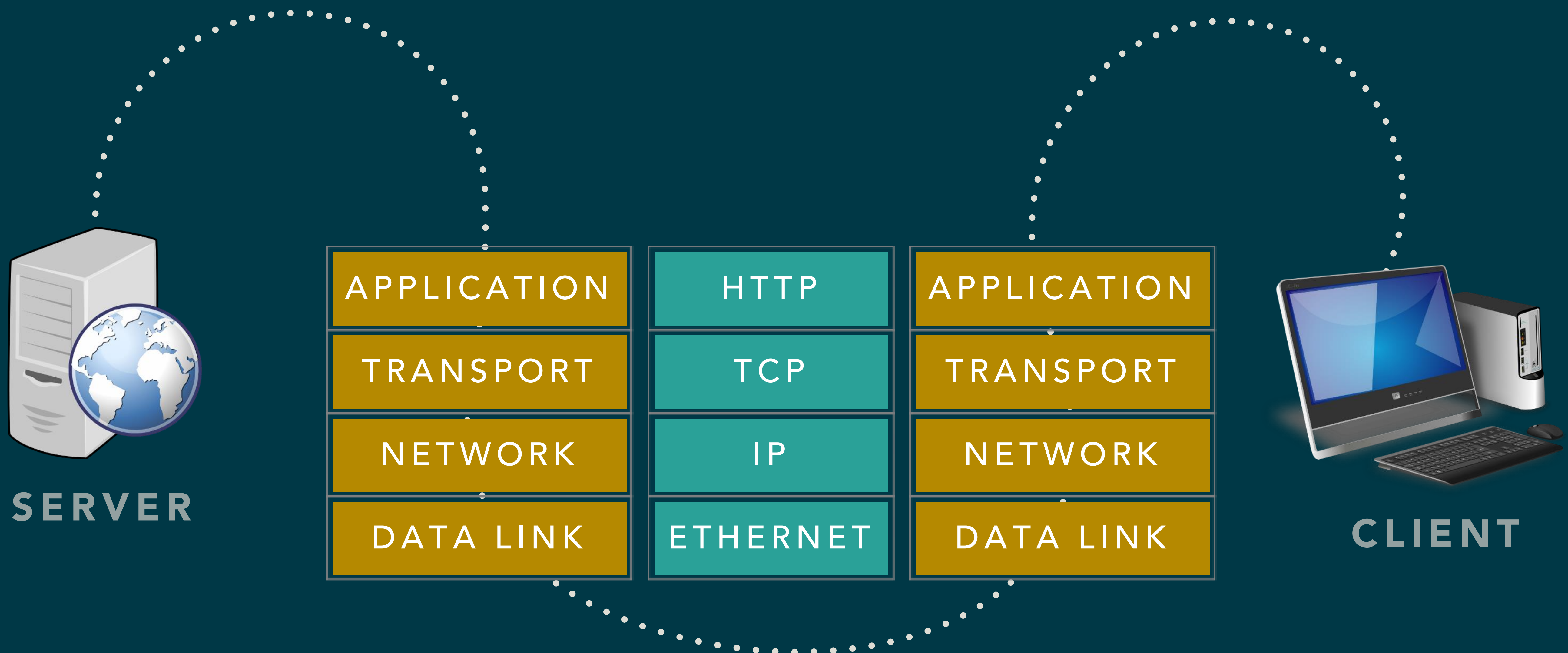
SPEEDY — BUSINESS MOTIVATION

- **SPDY** — a protocol for transporting content over the web, designed specifically for **end-user perceived latency** (the target was a 50% reduction in page load time).



SPeeDY — DESIGN

- SPDY requires **no changes** to existing networking infrastructure.
- SPDY uses **TCP** as the transport layer but **requires** also **SSL/TLS**.



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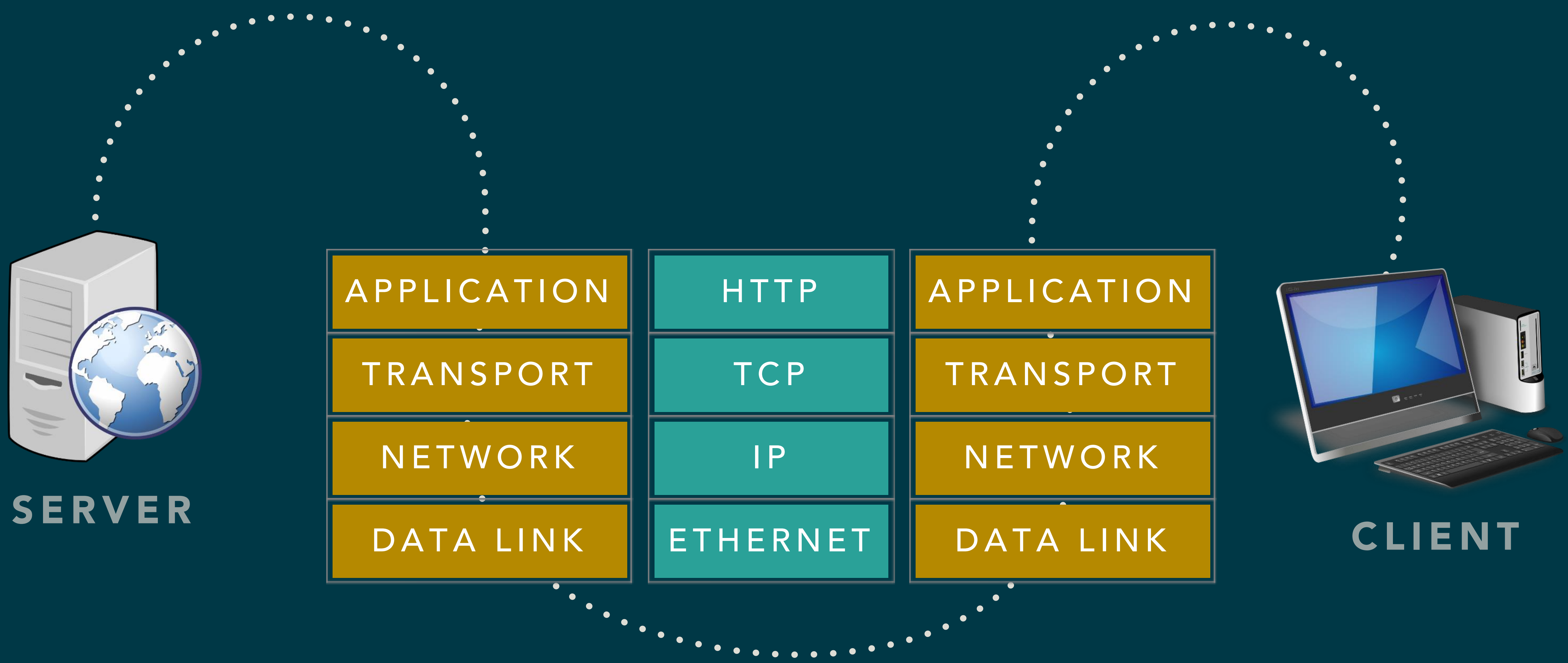

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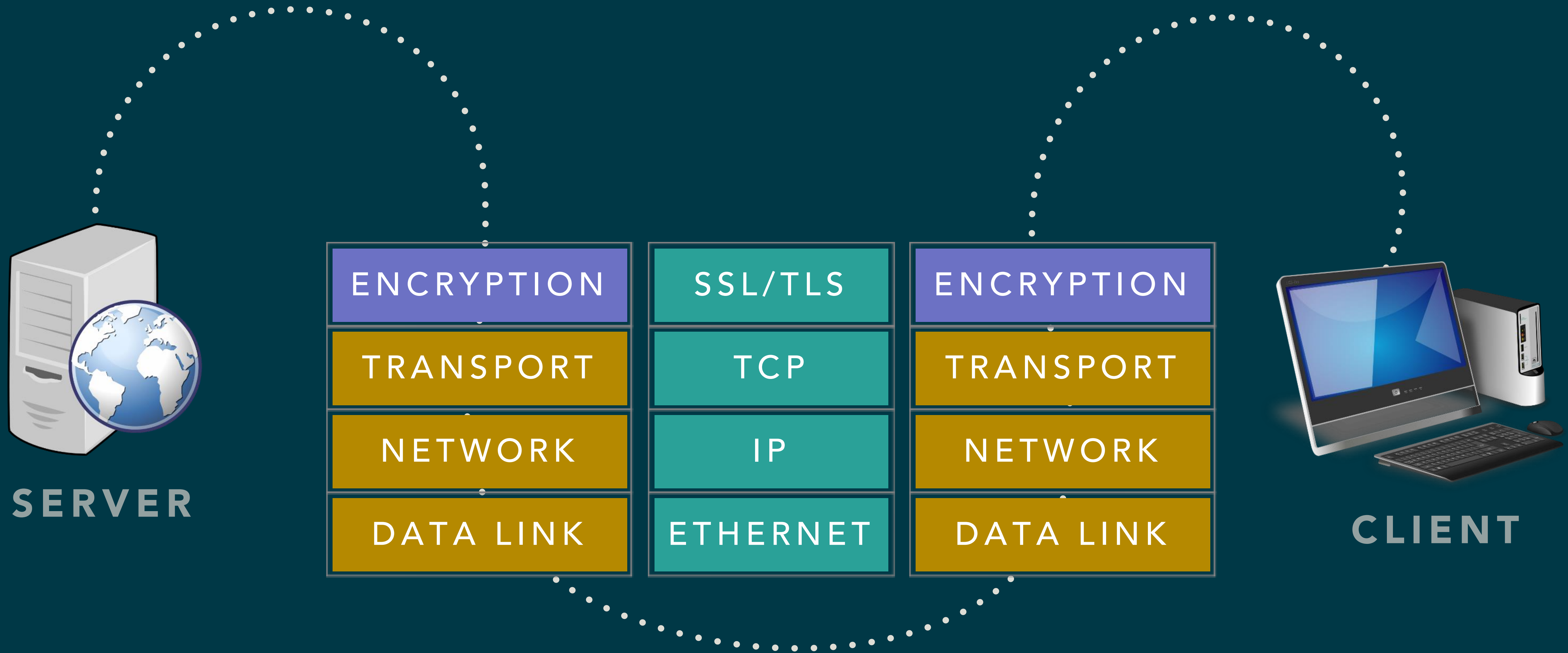

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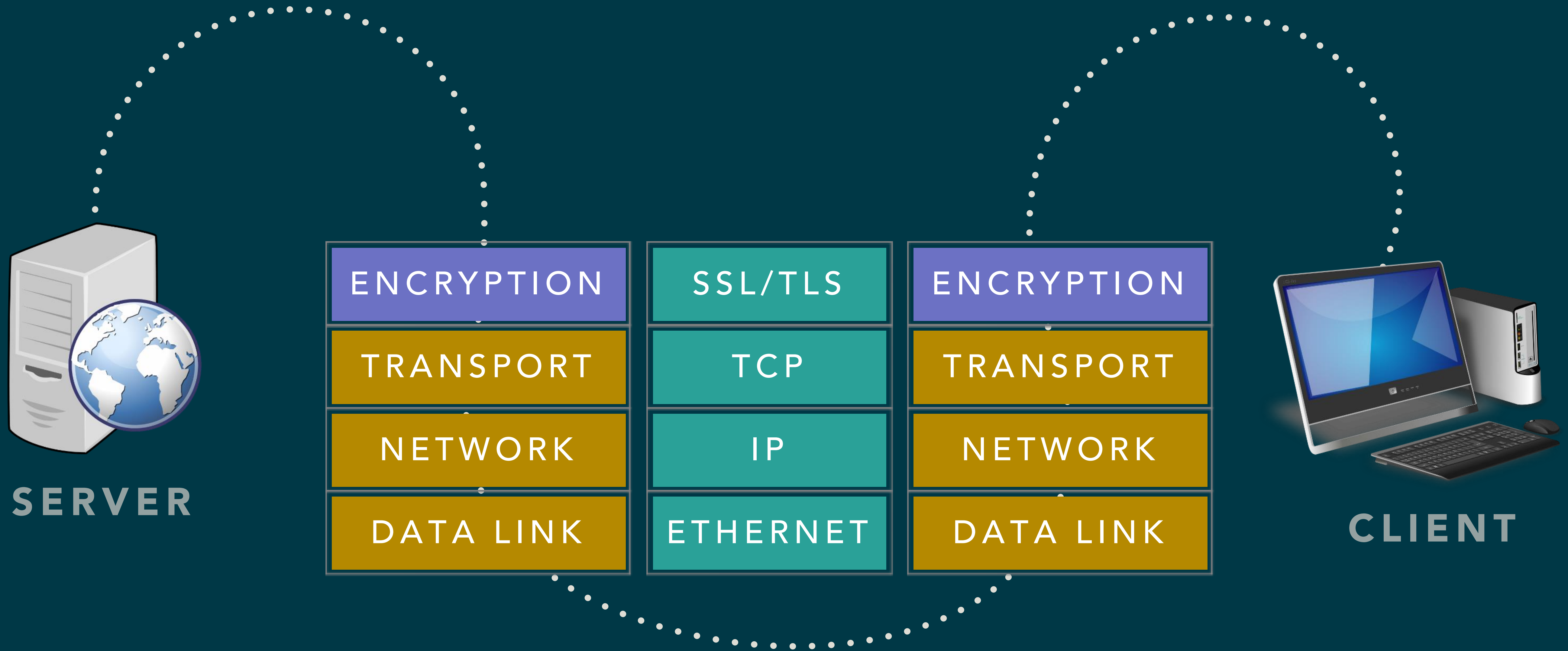

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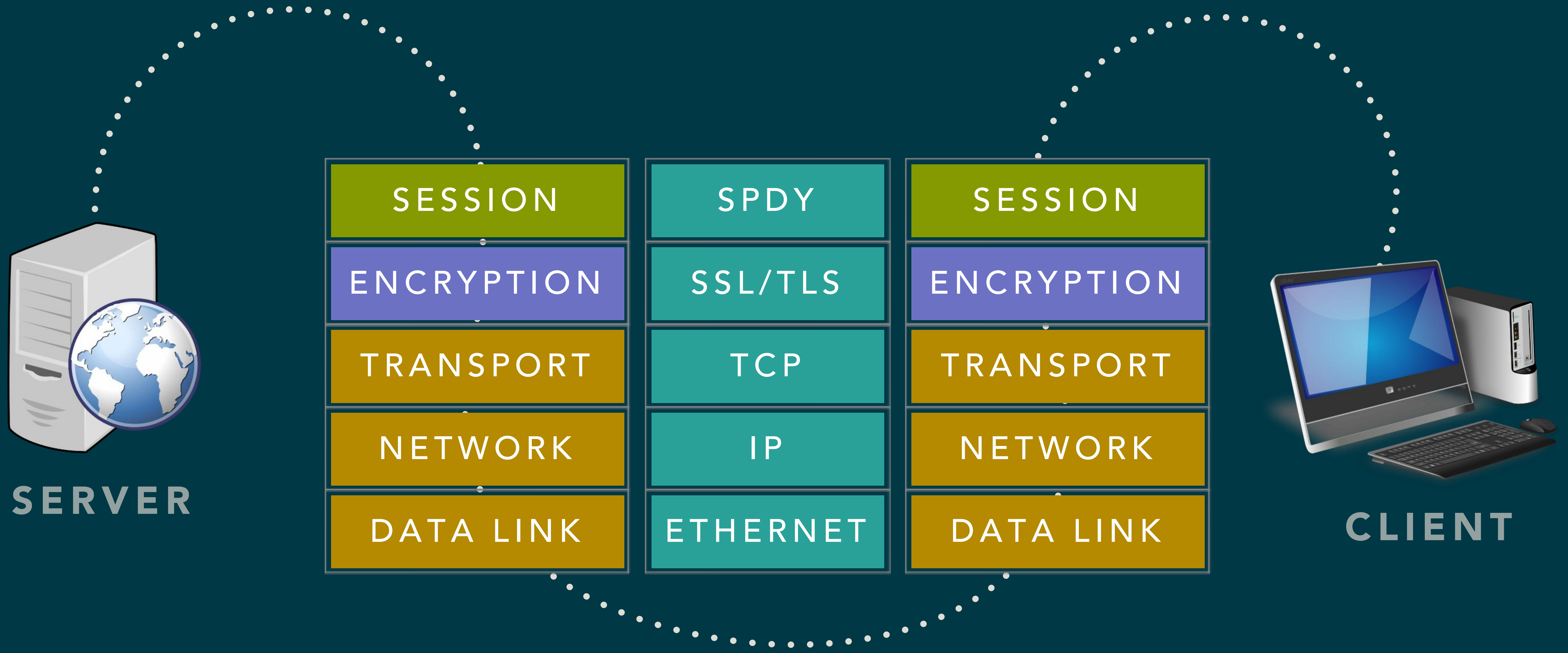

SPeeDY — FEATURES

- **Multiplexed streams** — SPDY allows for unlimited concurrent streams over a single TCP connection.
- The ability to divide HTTP messages into independent **binary frames**, interleave them, and reassemble them on the other end is the **most important enhancement** of SPDY and HTTP/2.

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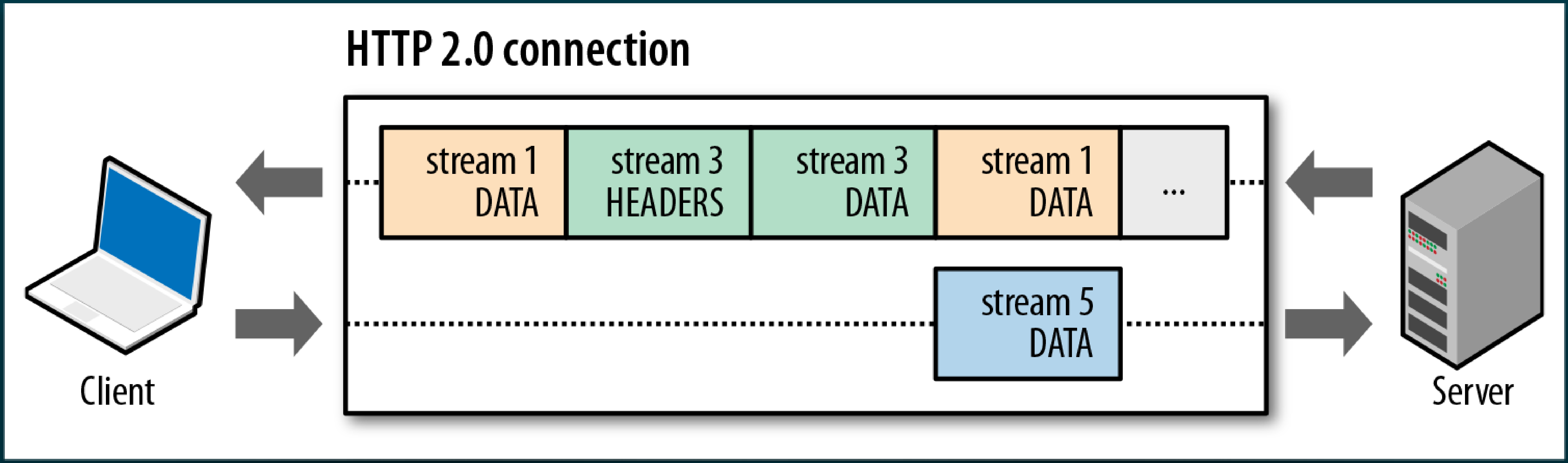


SPeeDY — FEATURES

- **Request prioritization** — the client can request many items from the server and assign a **priority** to each request.
- **HTTP header compression** — SPDY compresses request and response HTTP headers
- **Server-initiated streams** — allows to deliver content to the client without the client needing to ask for it:
  - **Server push** — server can push data to clients via `X-Associated-Content` header.
  - **Server hint** — server uses `X-Subresources` header to suggest to the client that it should ask for specific resources.

FROM SPeeDY TO HTTP/2

- *Chrome has supported SPDY since Chrome 6, but since most of the benefits are present in HTTP/2, it's time to say goodbye. We plan to remove support for SPDY in early 2016.*

  HTTP://BLOG.CHROMIUM.ORG/2015/02/HELLO-HTTP2-GOODBYE-SPDY.HTML

- Features inherited by **HTTP/2** from **SPDY**:
  - **multiplexed** streams — can use one connection for parallelism
  - priorities and **dependencies** — one stream can depended on another (the parent stream is processed by the server before its dependencies)
  - header **compression** — uses **HPACK** algorithm to reduce overhead
  - allows servers to "**push**" responses proactively into client caches
  - is **binary**, instead of textual HTTP/1.1
- However, in HTTP/2 **encryption** is not mandatory.

HTTP/2 IMPLEMENTATIONS

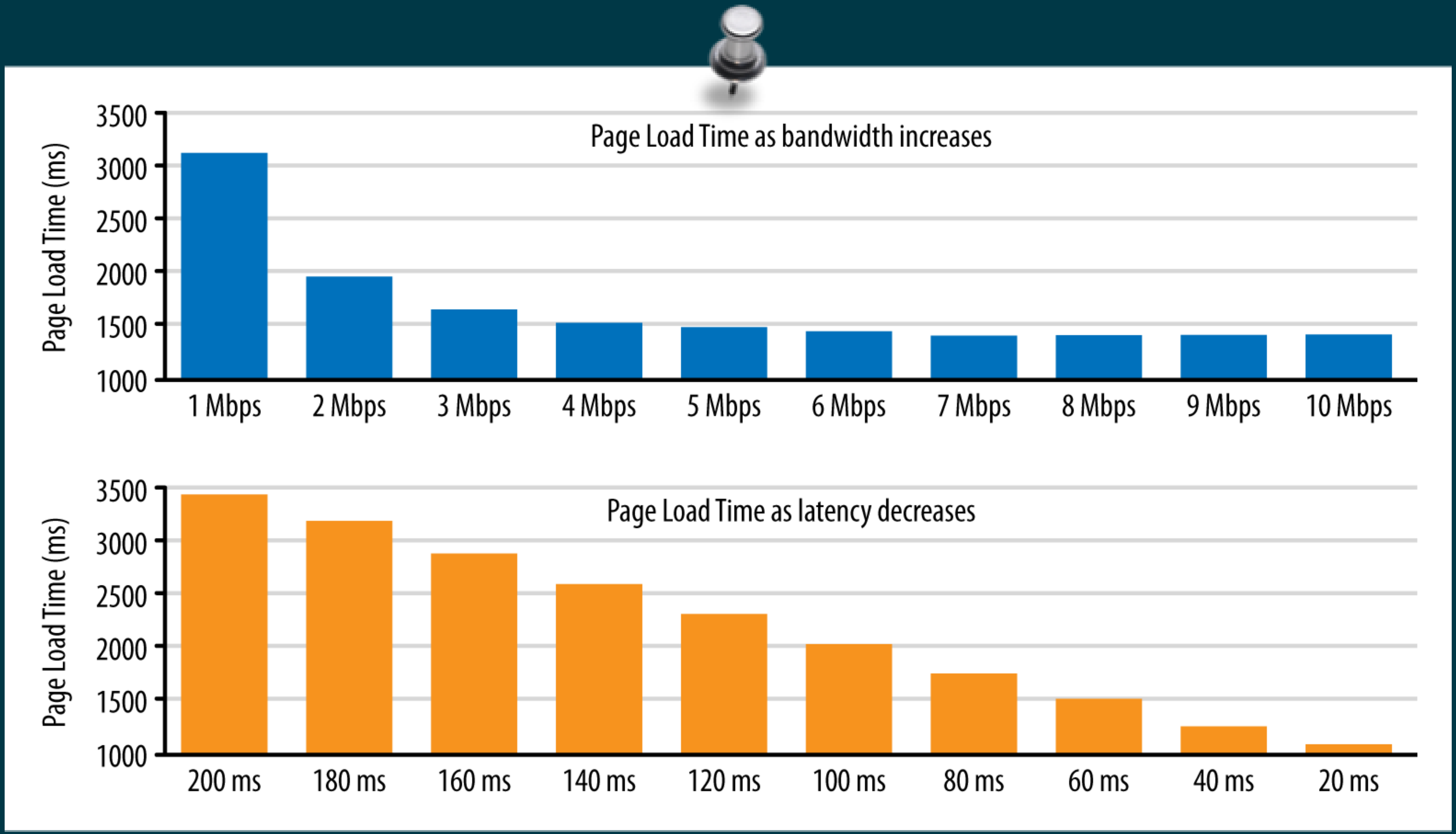
- Firefox:
  - experimental support for HTTP/2 in version 34
  - enabled by default in version 36
  - only supports HTTP/2 over encrypted connection (TLS)
- Google Chrome:
  - support from version 40
  - enabled by default in 41
  - only supports HTTP/2 over encrypted connection (TLS)
- Microsoft Edge:
  - support from version 12
  - only supports HTTP/2 over encrypted connection (TLS)
- Performance comparison:
  https://blog.httpwatch.com/2015/01/16/a-simple-performance-comparison-of-https-spdy-and-http2/
- Server adoption is worse:
  about 44% websites support HTTP/2 as of 03.2020:
  https://w3techs.com/technologies/details/ce-http2/all/all

THE SIGHT OF THE FUTURE

- HTTP/3 is currently under development
  - Draft of standard: https://tools.ietf.org/html/draft-ietf-quic-http-27
  - Experimental implementations available in Chrome and Firefox as of 03.2020
- HTTP/3 is an extension to HTTP/2 that adds binding to QUIC protocol instead of TCP at transport layer
- Quick UDP Internet Connections (QUIC)
  - Under development by Google
  - It does not use persistent connections
  - It supports multiplexed streams at transport layer, e.g., TLS handshake can be done at once using one packet sent by the client and one sent by the server instead of a sequence of packets sent each way

CONCLUSIONS

- *More Bandwidth Doesn't Matter (Much).*
- *Latency is a Performance Bottleneck.*



CONCLUSIONS

- HTTP is an essential building block of the Web and a prerequisite for utilizing the full power of Internet technologies.
- HTTP headers allow for more advanced features like caching, authentication or client identification.
- Performance of HTTP/1.x can be improved by using persistent and parallel connections.
- HTTP/2 offers further performance improvements, including multiplexed streams and header compression.

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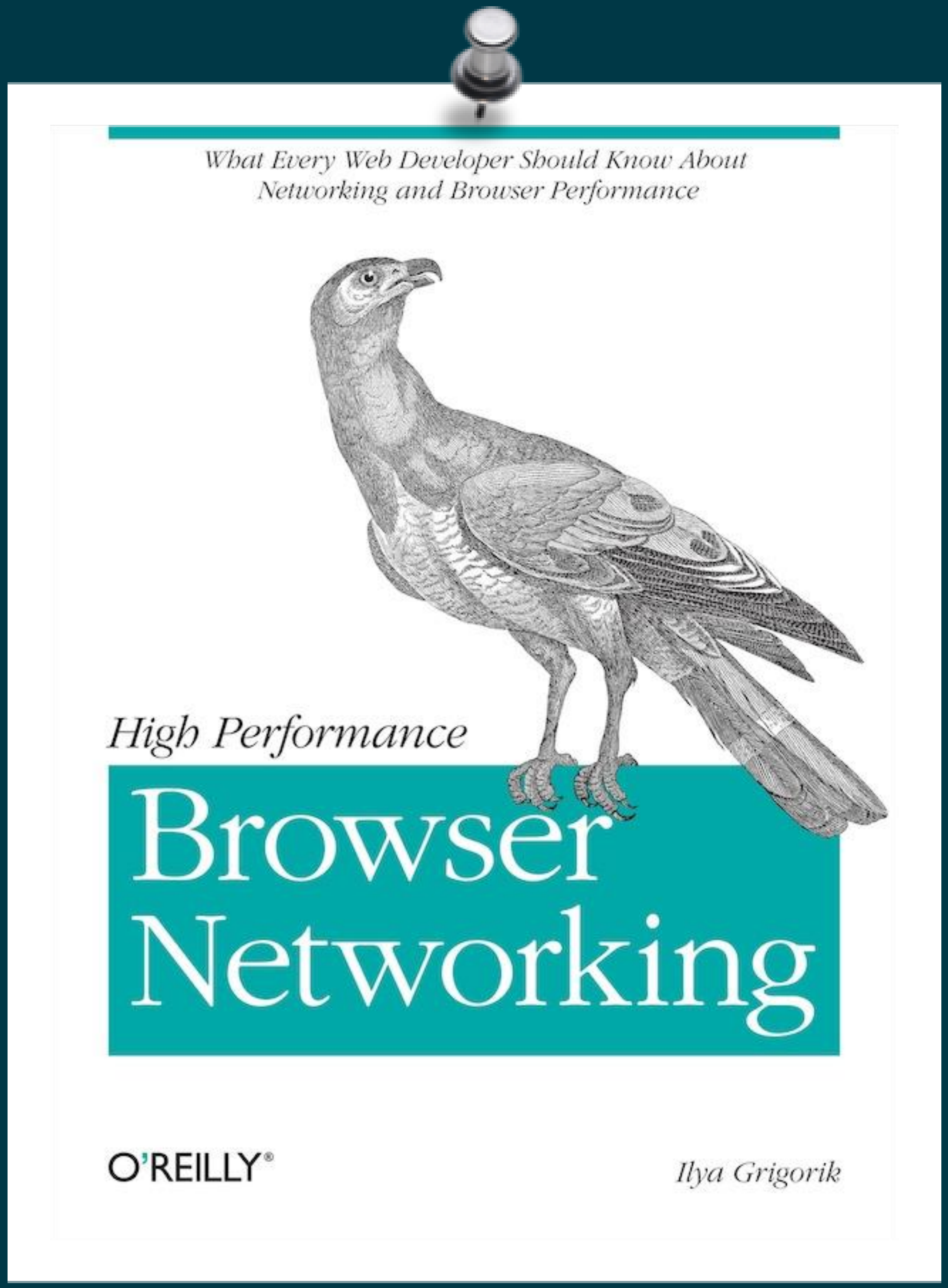

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