Firewalls

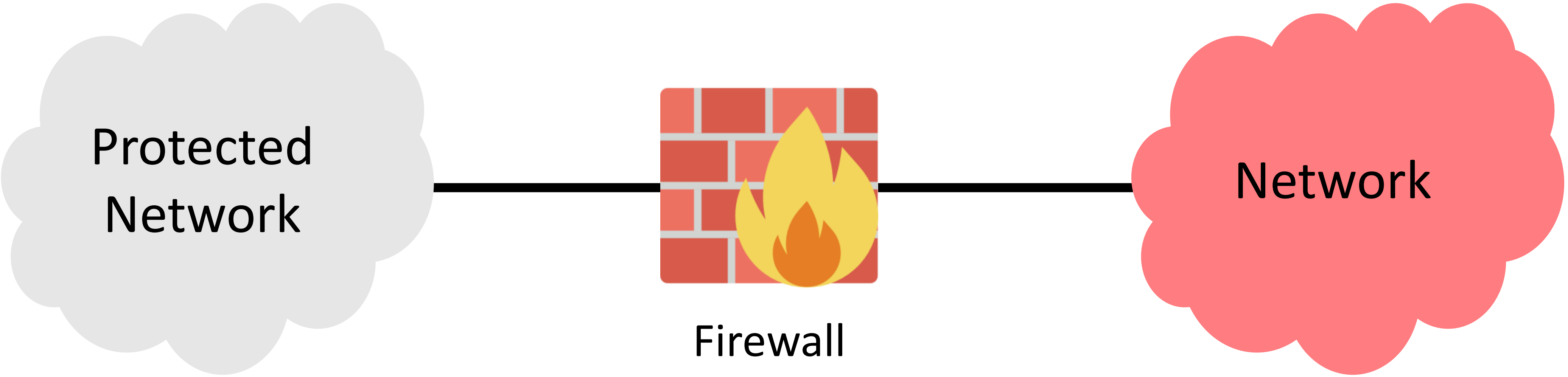
Outline

- What is a Firewall?
- Types of Firewalls
  - Packet filtering
  - Proxy server
- Evading Firewalls

Firewall Overview

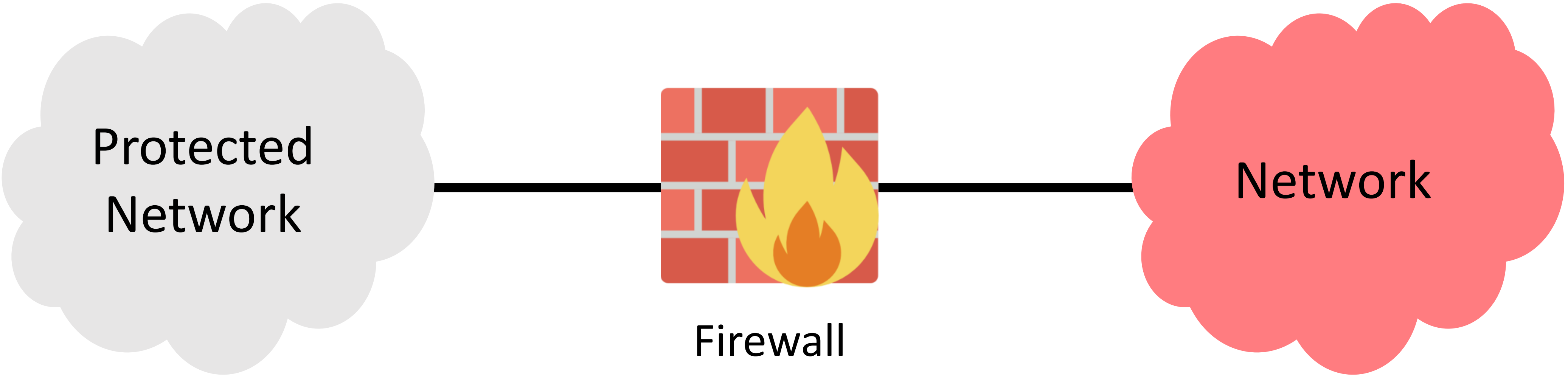
What is a Firewall?

- A component that stops unauthorized traffic flowing from one network to another.



What is a Firewall?

- Often separates **trusted** and **untrusted** networks.
- Differentiates networks within a trusted network.
- Can be implemented in software, hardware, or as a combination.



Requirements of a Firewall [Bellovin and Cheswick'94]

- All traffic between two trust zones should pass through a firewall.

- Only authorized traffic, defined by the **security policy**, should be allowed to pass through.

- The firewall must be immune to penetration.

Firewall Policy

- User Control
  - Controls access to data based on the user role
  - Often used for users within a firewall zone

- Service Control
  - Access is controlled by the type of the service offered by the host protected by the firewall
  - Needs access to network address, port number, protocol etc.

- Direction Control
  - Allows traffic based on its direction: inbound or outbound.

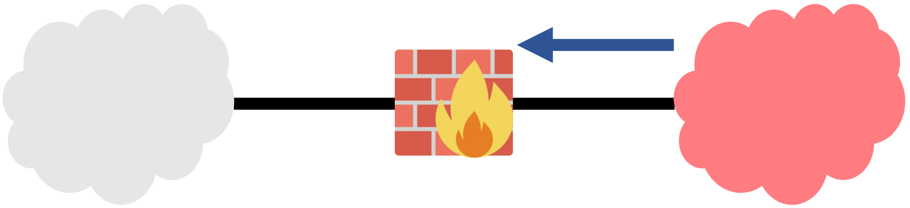
Firewall Actions

- Network packets going through a firewall result in one of three actions:
  - ACCEPT: Allowed to enter the protected host/network
  - DENIED: Not permitted to access the other side of the firewall
  - REJECTED: Similar to DENIED.
    - But the firewall attempts to tell the source of the packet abouts its decision.
    - Using ICMP

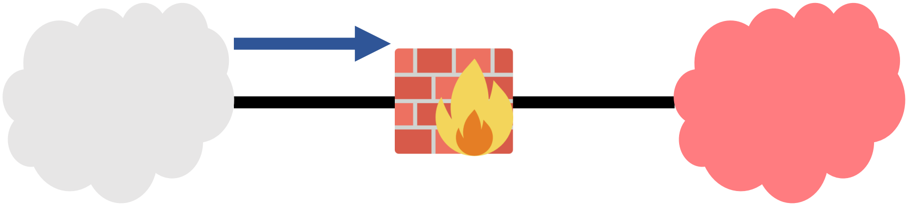
Ingress and Egress Filtering

- Firewalls can inspect traffic from both directions.

- Ingress filtering



- Egress filtering



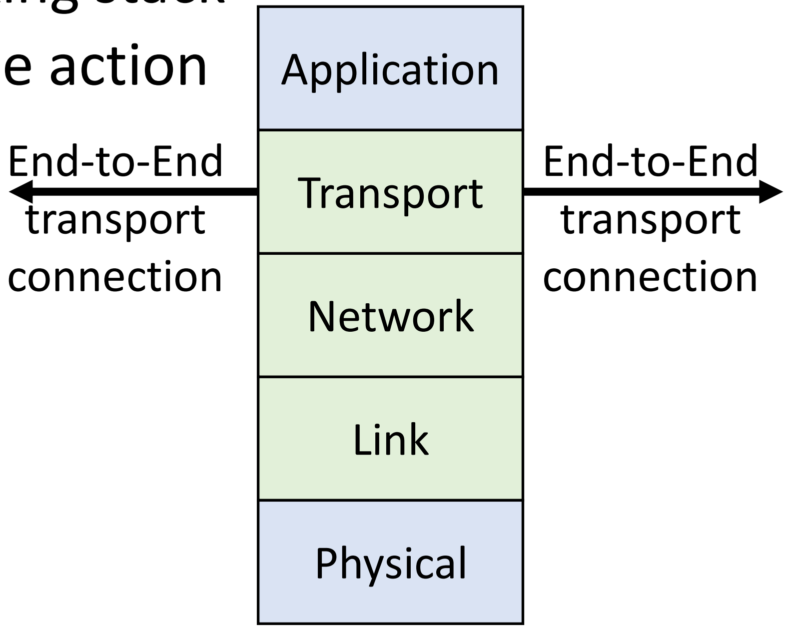
Other Functions

- Besides **protecting** a network, a firewall may:
  - rewrite packet headers to route packets between networks
    - act as a router
    - act as a NAT

Types of Firewalls

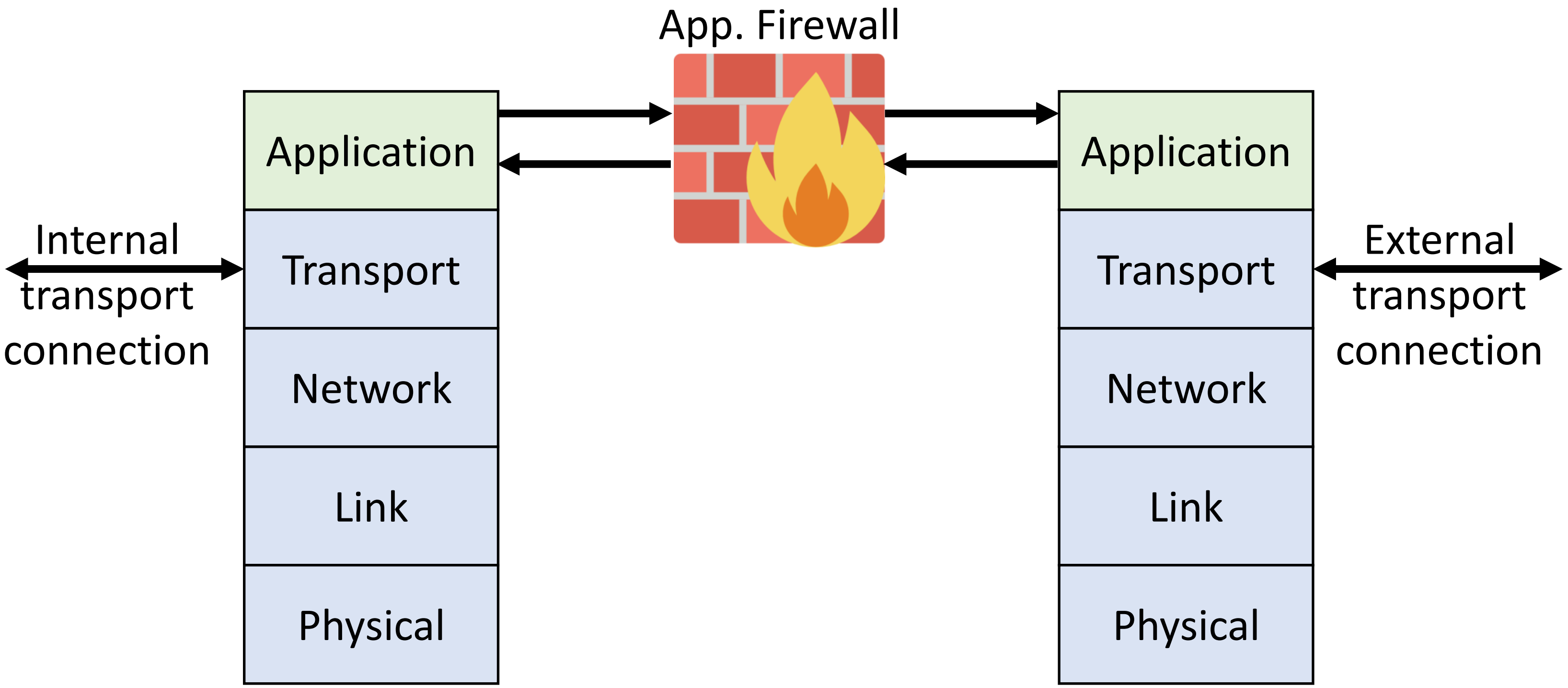
Types of Firewalls

- Packet Filtering
  - Most kernels implement TCP/IP stack
  - Filters are executed by hooking to the kernel's networking stack
  - The kernel is in a position to immediately determine the action
  - Stateless and Stateful firewalls
    - Does a packet belong to a stream of traffic?



Types of Firewalls

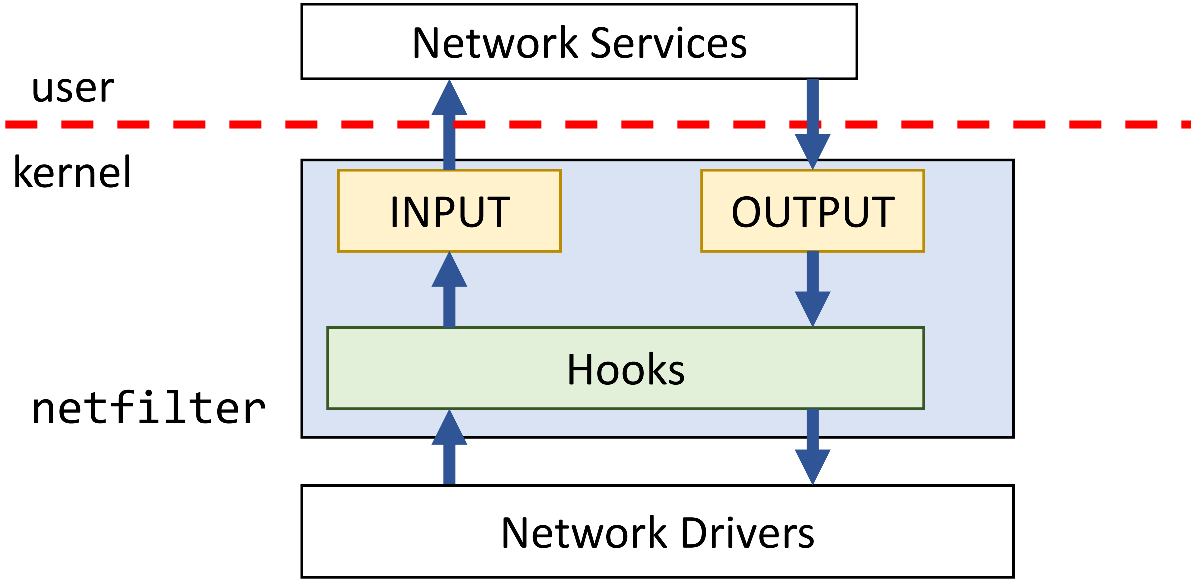
- Application Firewall
  - Used to scan web traffic to filter out web application attacks (e.g. SQL injection)
  - Often deployed as reverse proxy to impersonate the target it is protecting if a time delay is necessary to filter traffic



Packet Filtering Firewall

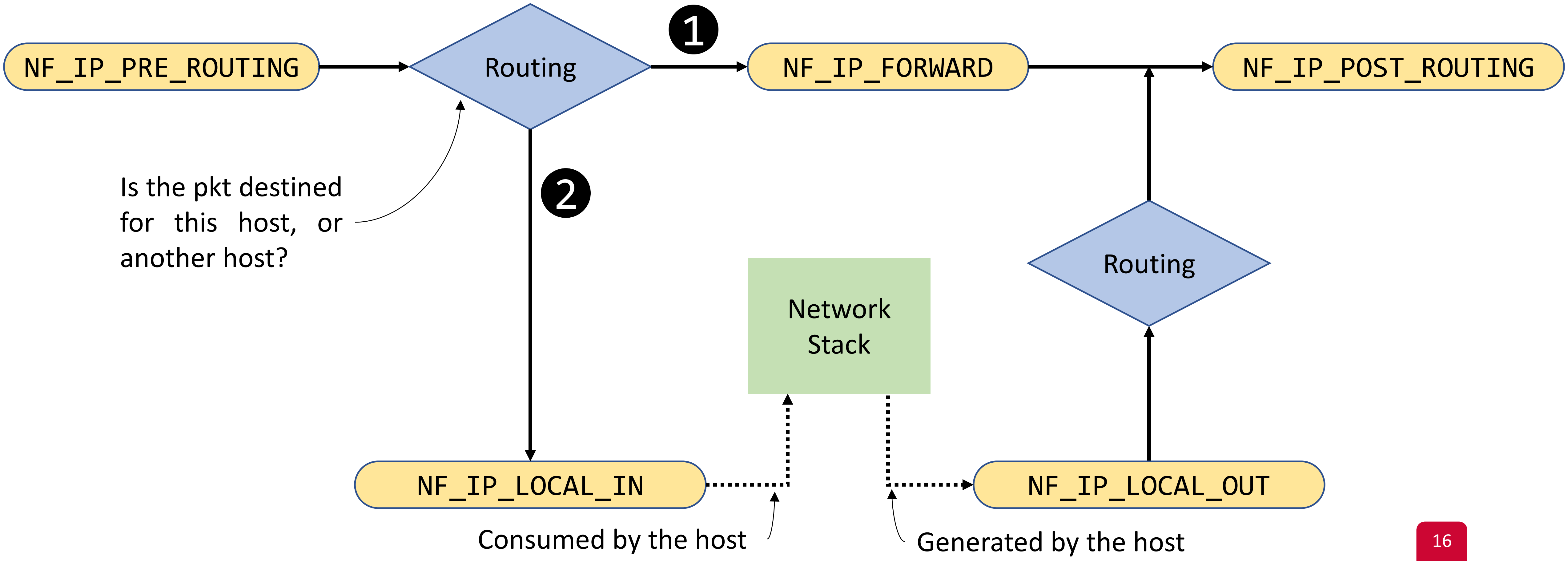
netfilter

- A framework inside the Linux kernel
- Allows different networking-related functions to be implemented
  - Uses hooks that a program can register with
  - As packets traverse the the stack, they will trigger the kernel modules that have registered with these hooks



netfilter Hooks

- A packet triggers the kernel modules that are registered with netfilter hooks



`netfilter` Calling Order

- Each registered kernel module provides a **priority** value
- `netfilter` calls a kernel module based on its priority

- What are possible decisions?

`netfilter` Return Values (targets)

- Each registered kernel module returns one of these values:
  - `NF_ACCEPT`: Let the packet go through the stack
  - `NF_DROP`: Discard the packet
  - `NF_QUEUE`: Pass the packet to the user space
  - `NF_STOLEN`: Ask `netfilter` to forget this packet, and move responsibility to the calling module
  - `NF_REPEAT`: Ask `netfilter` to call the calling module again

Example: Block Outgoing Telnet Packets

- https://linux-kernel-labs.github.io/refs/heads/master/labs/networking.html

```
unsigned int telnetFilter(void *priv, struct sk_buff *skb,
                          const struct nf_hook_state *state)
{
      struct iphdr *iph;
      struct tcphdr *tcph;

      iph = ip_hdr(skb);
      tcph = (void *)iph+iph->ihl*4;

      if (iph->protocol == IPPROTO_TCP && tcph->dest == htons(23)) {
            return NF_DROP;
      } else {
            return NF_ACCEPT;
      }
}
```

Example: Block Outgoing Telnet Packets

- Register our hook

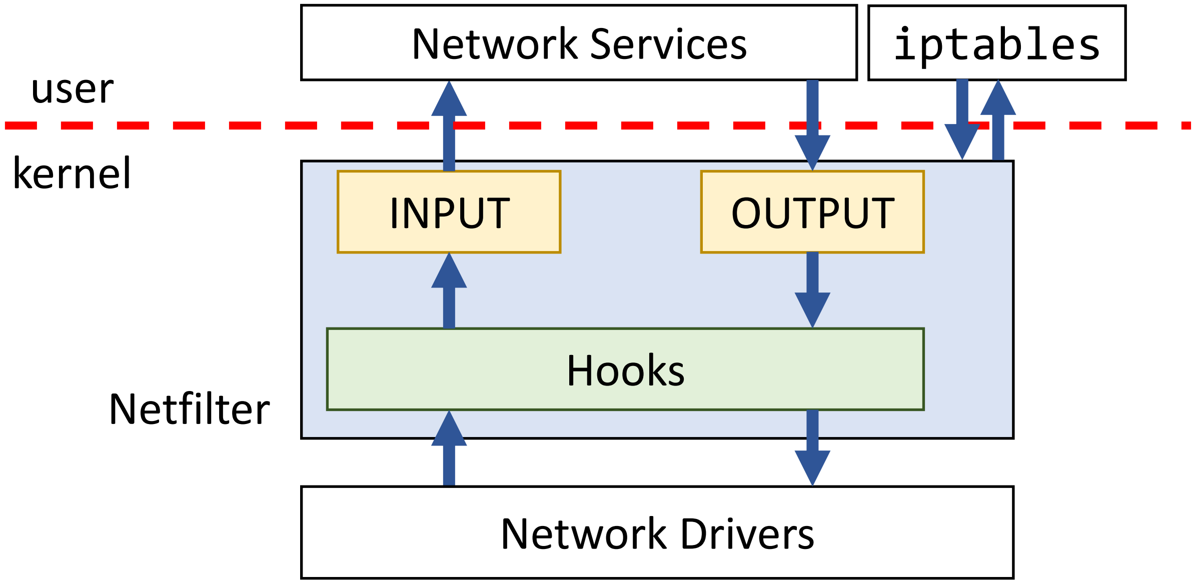
```
static struct nf_hook_ops telnetFilterHook;

int setUpFilter(void) {
        telnetFilterHook.hook = telnetFilter;
        telnetFilterHook.hooknum = NF_INET_POST_ROUTING;
        telnetFilterHook.pf = PF_INET;
        telnetFilterHook.priority = NF_IP_PRI_FIRST;

        // Register the hook
        nf_register_hook(&telnetFilterHook);
        return 0;
}
```

`iptables`

- A packet filter firewall is implemented using `iptables`
- Userspace program that interfaces with `netfilter`
- Installs and removes firewall rules
- Can implement *stateless* and *stateful* firewalls



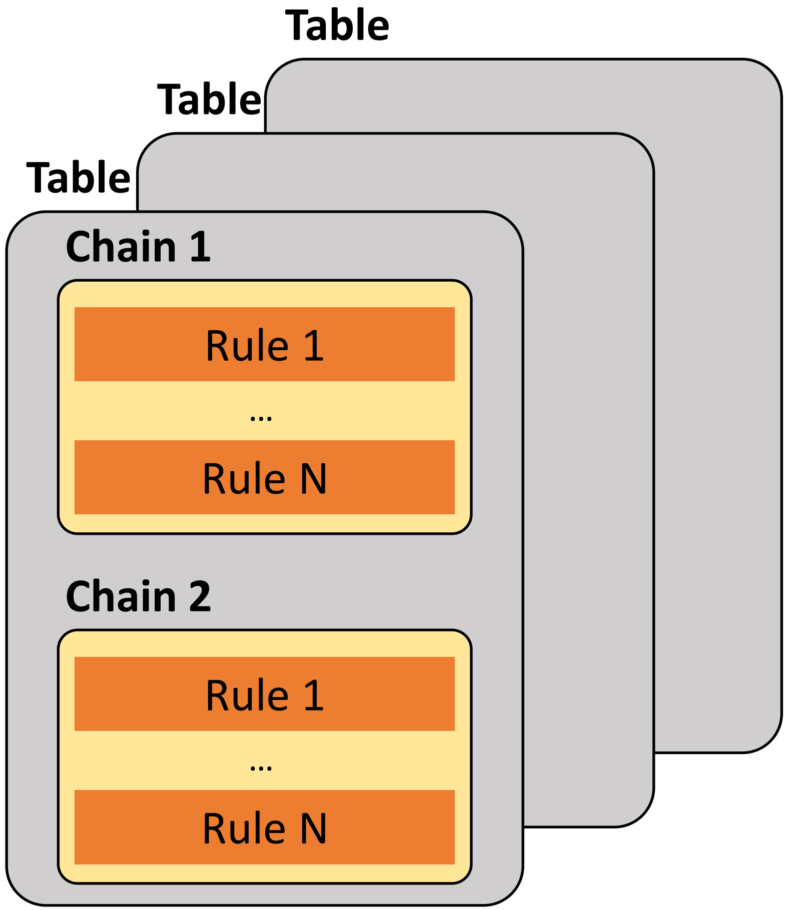
Rule Organization

- `iptables` firewall can:
  - filter packets, and
  - make changes to packets.

- Rules are organized in a hierarchical structure
  - Table
  - Chain
  - Rule

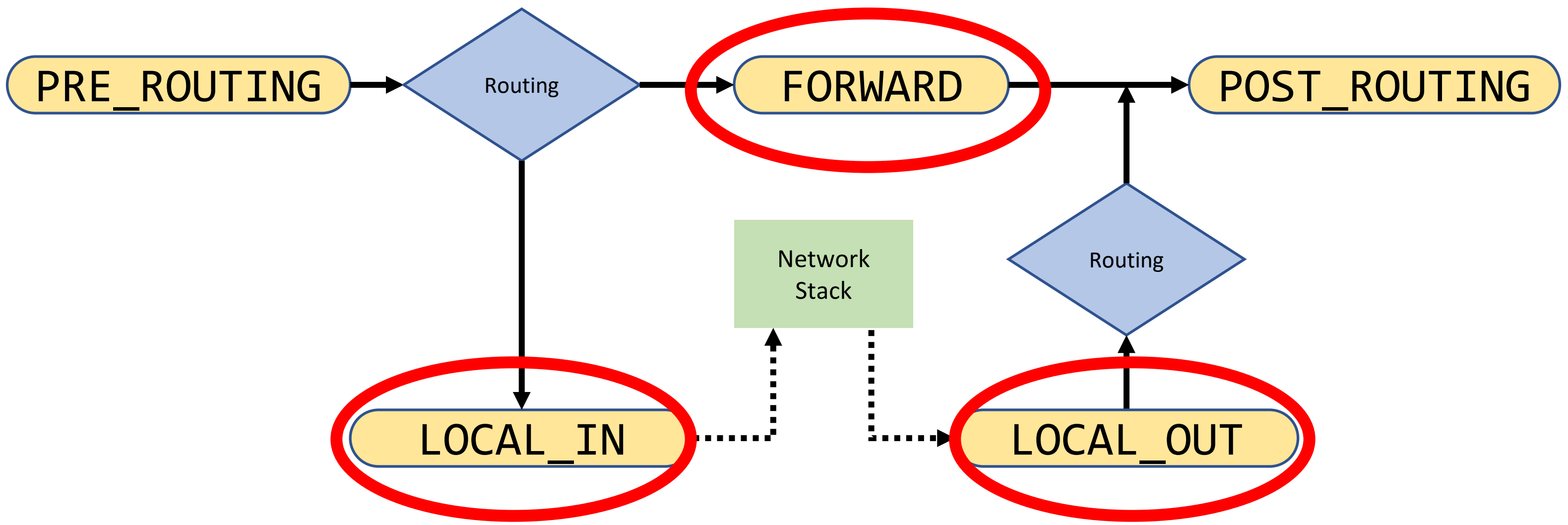
- A table reflects ***the purpose*** of the rules

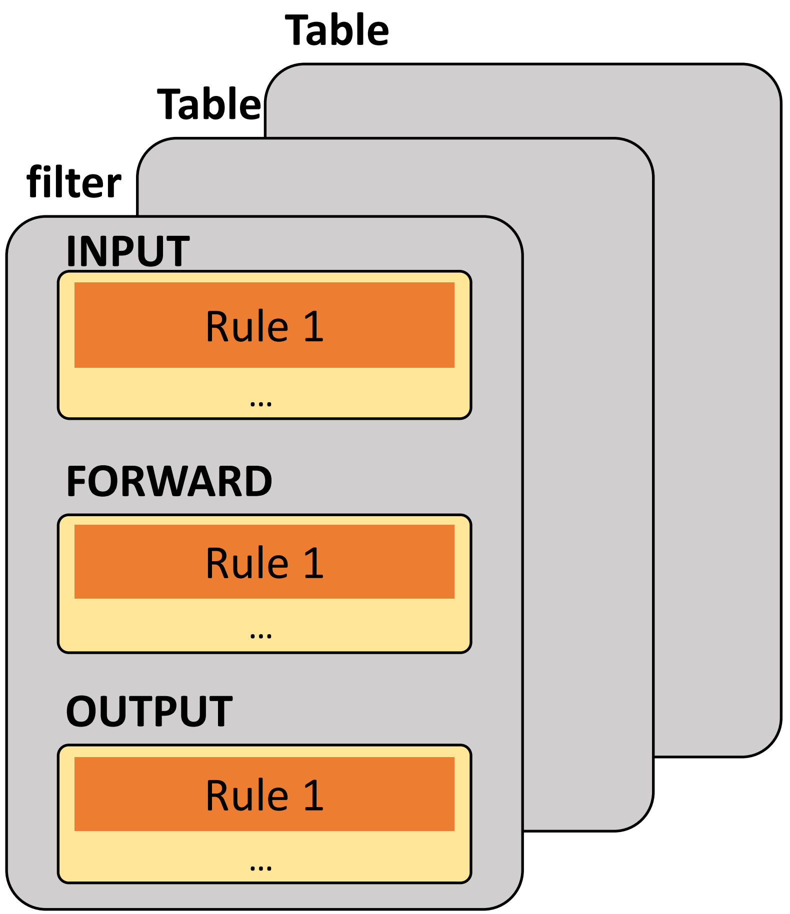
- A chain reflects ***when*** a rule is evaluated during the packet life cycle
  - Built-in chains correspond to the netfilter hooks



Rule Organization

- The table used for firewalls is the **filter** table
- **filter** table has three built-in chains:
  - INPUT: incoming packets
  - FORWARD: packets routed through this machine
  - OUTPUT: outgoing packets





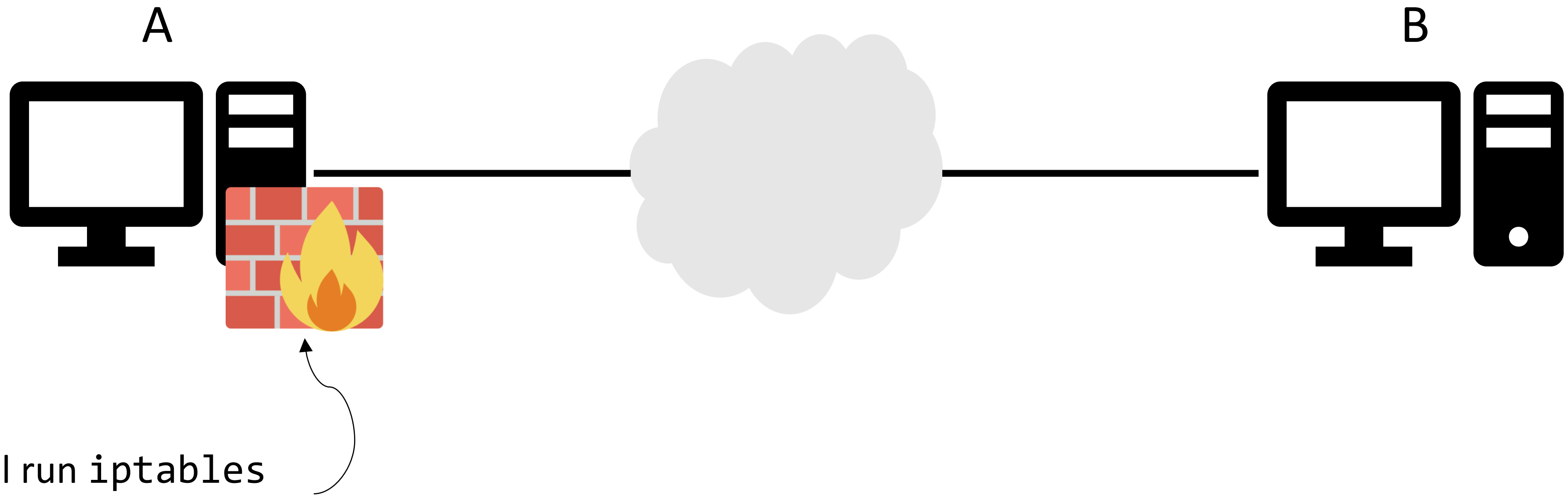
Targets

- A target is the action that is triggered when a packet meets the matching criteria of a rule.

- Terminating targets: Stops the evaluation within a chain. E.g.,:
  - ACCEPT

- Non-Terminating targets: Performs an action and continues the evaluation within a chain. E.g.,:
  - Jumping to user-defined chains

Example



We will run `iptables` at machine A

Checking Rules

```
$ sudo iptables -L

Chain INPUT (policy ACCEPT)
target prot opt source destination


Chain FORWARD (policy ACCEPT)
target prot opt source destination


Chain OUTPUT (policy ACCEPT)
target prot opt source destination

```

No rules yet!

```
$ sudo iptables –t filter -F
```

To flush **filter** table

Scenario 1

```
$ sudo iptables -A INPUT -p icmp --icmp-type echo-request -j DROP
```

Dropping all incoming ICMP echo requests

→ No one can ping machine A

Scenario 2

```
$ sudo iptables -A INPUT -p tcp --destination-port 22 -j ACCEPT
$ sudo iptables -A INPUT -j REJECT
```

Allow others to ssh to machine A

AND

Machine A does not respond to other service request

- What if we switch the rule order?

Scenario 2

```
$ sudo iptables –L

Chain INPUT (policy ACCEPT)
target prot opt source destination
ACCEPT tcp -- anywhere anywhere tcp dpt:ssh
REJECT 0 -- anywhere anywhere reject-with icmp-port-unreachable

Chain FORWARD (policy ACCEPT)
target prot opt source destination

Chain OUTPUT (policy ACCEPT)
target prot opt source destination
```

Scenario 2 Takeaways

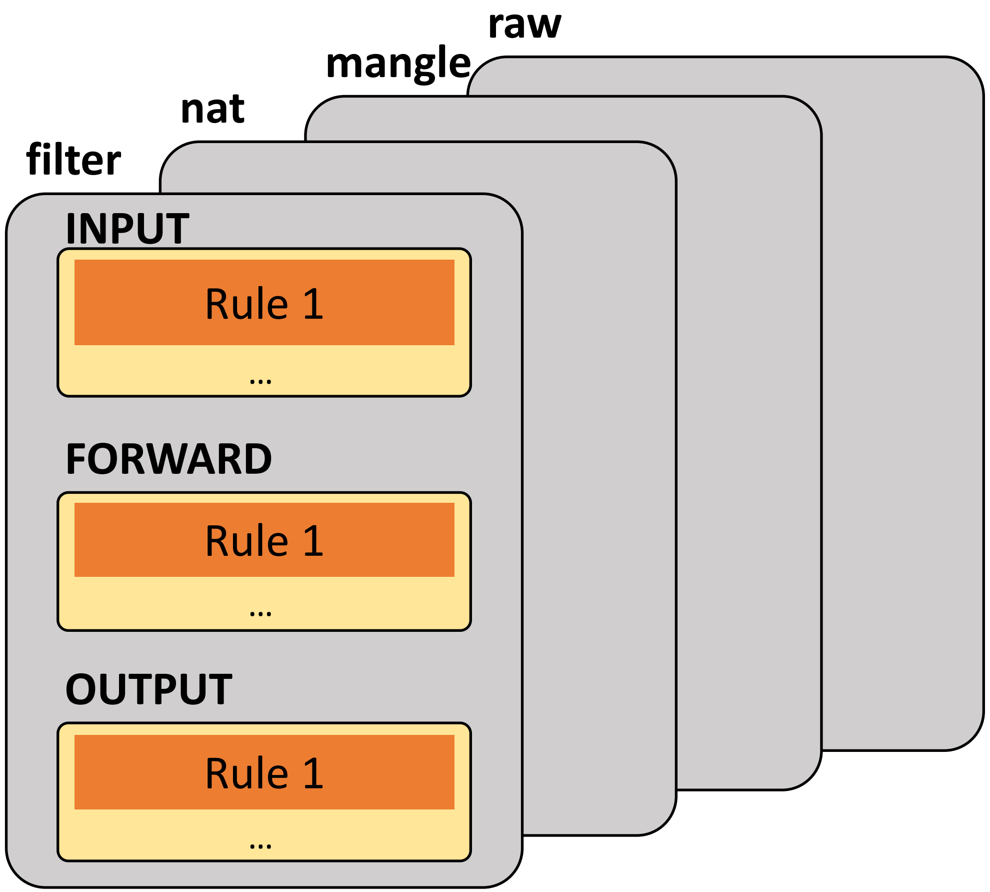
- REJECT
  - The port is closed

- DROP
  - The port is closed and invisible to the network

- Rule order is important (within a chain)
  - Rules are evaluated top-down

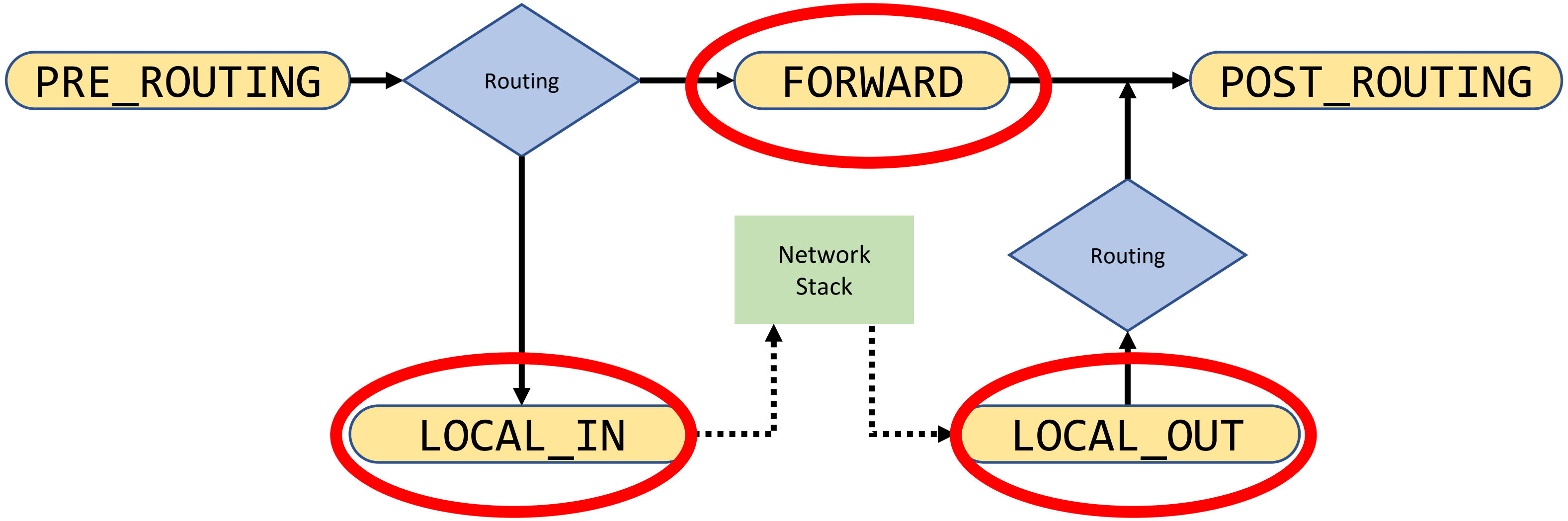
Tables

- `iptables` uses **four** tables to organize its rules
  - filter, nat, mangle, raw
- These tables classify rules according to the type of decisions they are used to make
- It is important to know which chains are implemented in each table



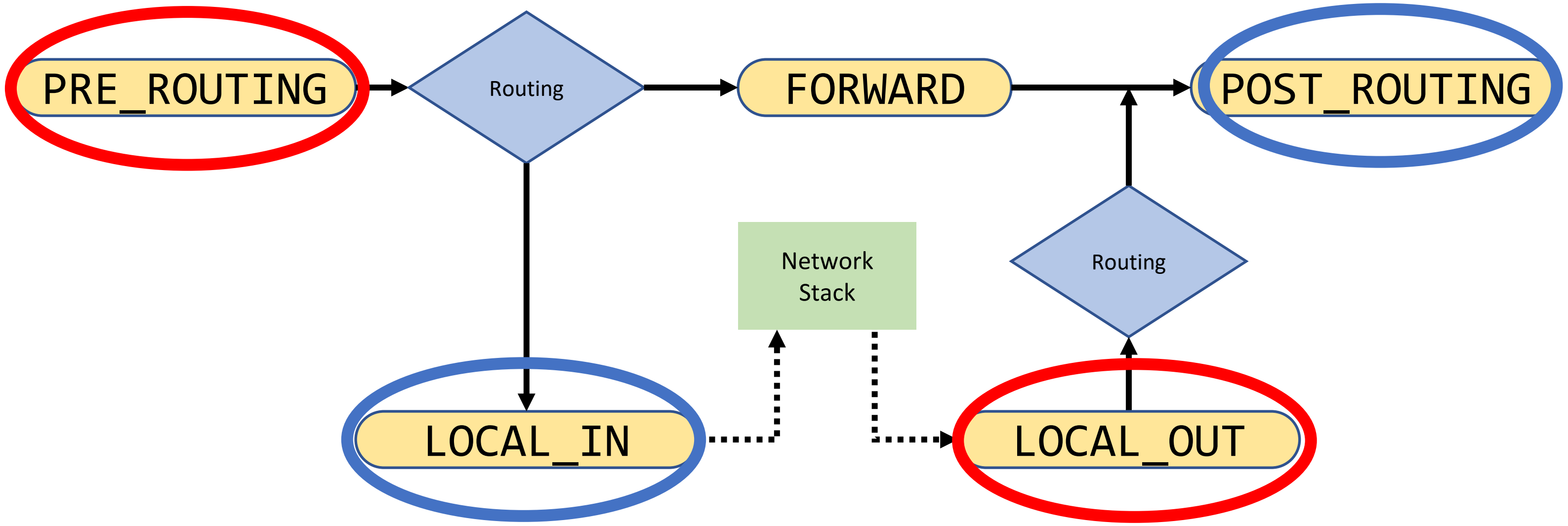
The filter Table

- Most widely used to implement firewalls
- Decides whether to accept the packet or not
- Implements three chains



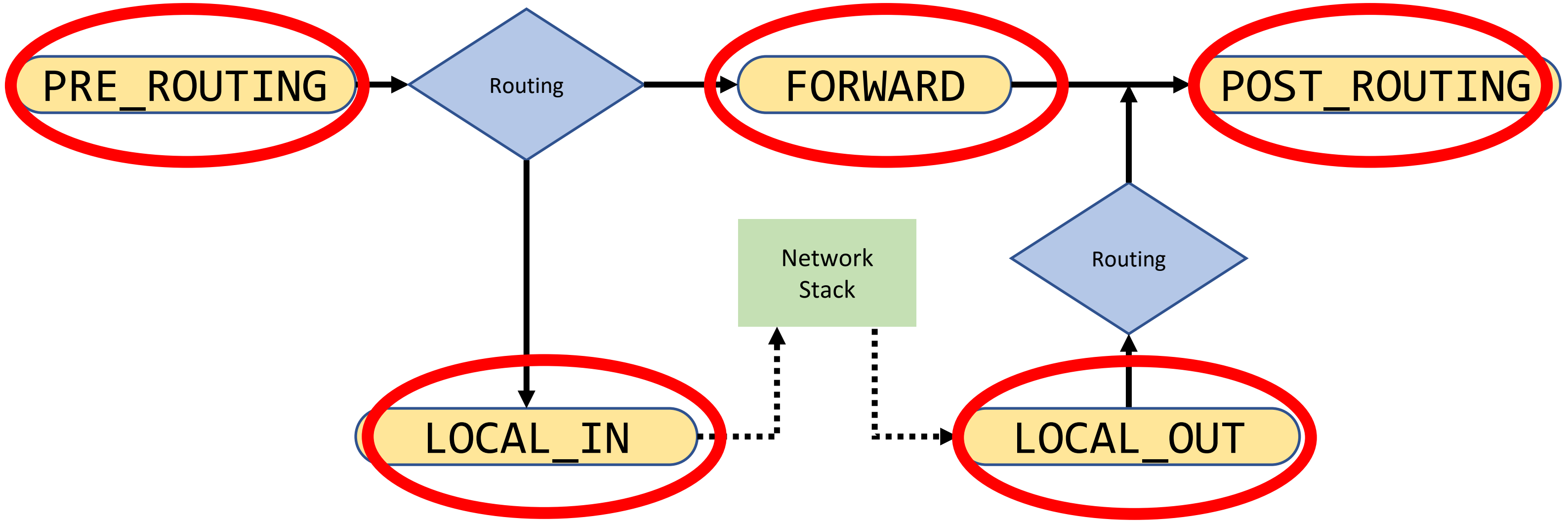
The nat Table

- Determines whether and how to modify the source or destination addresses
  - to impact the way that the packet and any response traffic are routed
- Destination NAT:
  - modify the dst address/port (for incoming packets to the private network)
- Source NAT:
  - modify the src address/port (for outgoing packets from the private network)



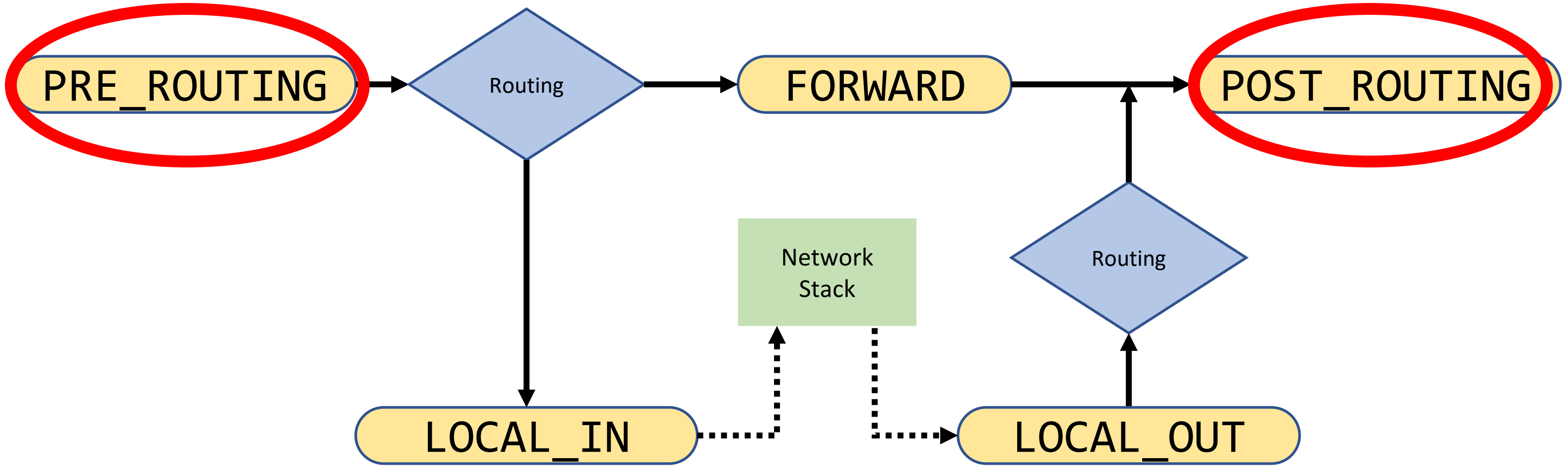
The mangle Table

- Used to alter the IP header
  - E.g., TTL value
- Also, to enable marking the packets
  - Other network tools or tables may read this mark to process the packet differently
  - Internal to the kernel (i.e., marking doesn't modify the actual packet)

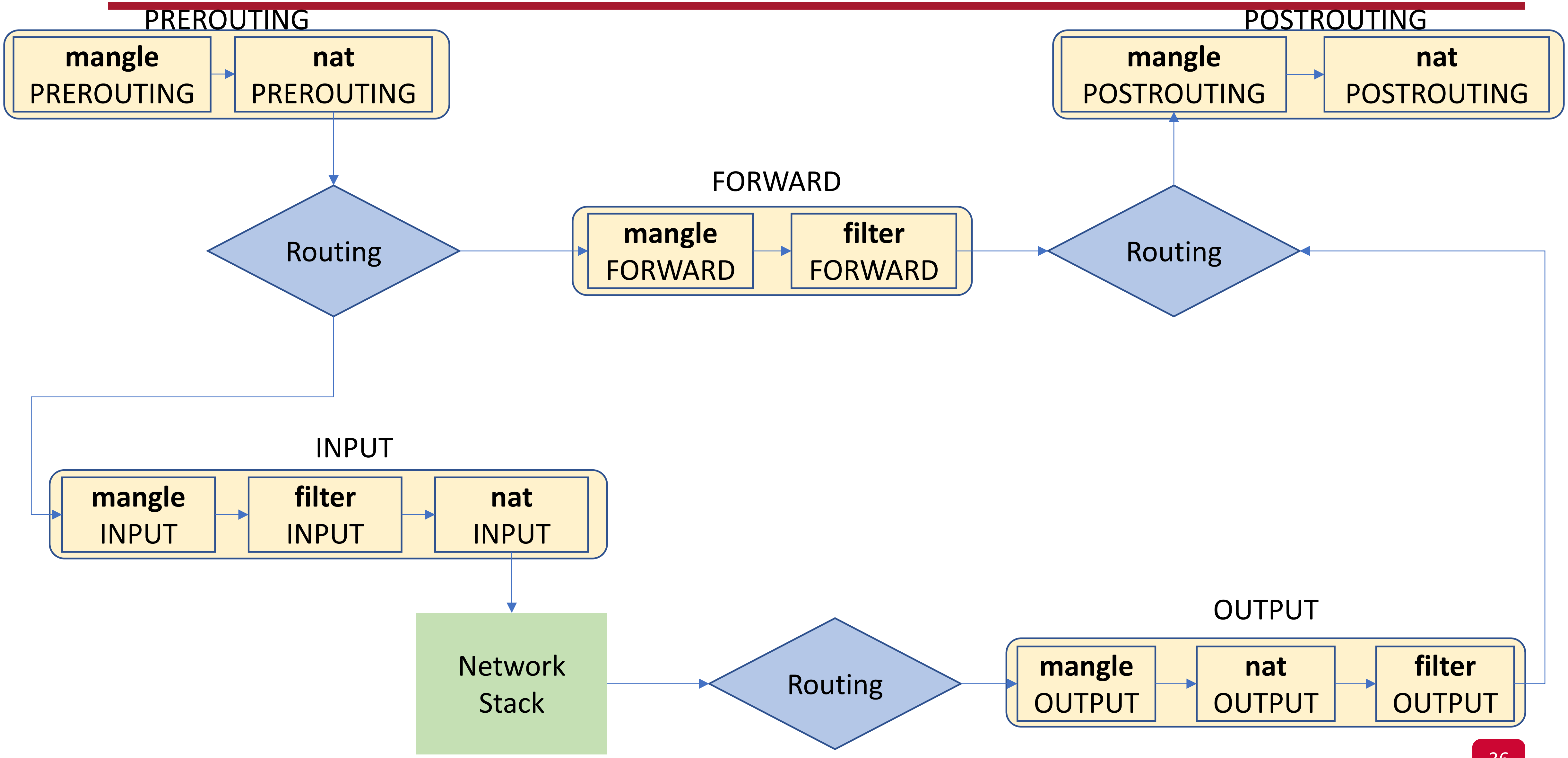


The raw Table

- Used to disable stateful firewall for some packets
- Set the mark called NOTRACK



Table/Chain Traversal Order



Example: Determine Table and Chain

- To increase the TTL for all packets
  - Packet modification → mangle table
  - All packets → PREROUTING chain

```
$ sudo iptables –t mangle -A PREROUTING –j TTL --ttl-inc 5
```

Extensions

- Adding more functionalities to the core of `iptables`
  - Installing kernel modules
  - E.g., `conntrack, owner, cgroup, cpu, etc.`

```
$ ls /lib/modules/`uname -r`/kernel/net/netfilter/

nf_conntrack_snmp.ko   nfnetlink_cttimeout.ko  nft_fib.ko
nft_reject_inet.ko  xt_comment.ko       xt_esp.ko
xt_LOG.ko           xt_quota.ko …
```

Extensions: Examples

- Disable telnet for a specific user
- Using the `owner` extension
  - Available at OUTPUT chain only

```
$ sudo iptables –A OUTPUT –m owner --uid-owner 1000 –j DROP
```

Extensions: Examples

- Redirecting packets based on the handling CPU number
- Using the cpu extension

```
$ iptables -t nat -A PREROUTING -p tcp --dport 80 -m cpu --cpu 0
-j REDIRECT --to-port 8080
```

Port forwarding

Building a Simple Firewall

- Requirements
  - Allow SSH, HTTP, and ICMP
  - Allow loopback interface
  - Allow DNS
  - Allow VPN and HTTPs
  - Allow all outgoing traffic

- What is missing?
- Let’s call it sFW

Our sFW: R1

Allow SSH, HTTP, and ICMP

```
iptables -A INPUT -p tcp --dport 22 -j ACCEPT
iptables -A INPUT -p tcp --dport 80 -j ACCEPT
iptables -A INPUT -p icmp --icmp-type any -j ACCEPT
```

Our sFW: R2

Allow loopback interface

```
iptables -A INPUT -p all -i lo -j ACCEPT
```

Our sFW: R3

Allow DNS

```
iptables -A OUTPUT -p udp  --dport 53 -j ACCEPT
iptables -A OUTPUT -p udp  --sport 53 -j ACCEPT
iptables -A INPUT  -p udp  --sport 53 -j ACCEPT
iptables -A INPUT  -p udp  --dport 53 -j ACCEPT
```

Our sFW: R4

Allow VPN and HTTPs

```
iptables -A INPUT -p 50 -j ACCEPT
iptables -A INPUT -p 51 -j ACCEPT
iptables -A INPUT -p udp --dport 500 -j ACCEPT
iptables -A INPUT -p udp --dport 10000 -j ACCEPT
iptables -A INPUT -p tcp --dport 443 -j ACCEPT
```

Our sFW: R5

Allow outgoing traffic

```
iptables -P OUTPUT ACCEPT
```

Drop all other traffic

```
iptables -P INPUT DROP
iptables -P FORWARD DROP
```

Stateful Firewalls

- Packets are often not independent
  - Part of a TCP connection
  - ICMP packets triggered by other packets

- Handling such packets independently may lead to inaccurate firewall
  - e.g. I want to allow the firewalled device to make connections to 1.2.3.4
  - If I don’t know the right services/port numbers, then I have to allow all response packets from 1.2.3.4

Stateful Firewalls

- They monitor incoming and outgoing packets over a period of time
  - Record connection state
  - Connection state: attributes such as IP addresses, port numbers, sequence number etc.
- When the state is recorded, filtering decisions can be done
  - Note: TCP connection state is not the same as the firewall connection state
  - Firewall connection state determines if a packet is part of a flow or not
  - Thus, firewall connection state is available for both connection-oriented and connection-less protocols

The Connection Tracking Framework in Linux

- The Linux kernel provides connection tracking framework
  - Called nf_conntrack
- Each packet is marked with a connection state:
  - NEW:
    - The connection is starting
    - This state exists for a connection if the firewall has only seen traffic in one direction
  - ESTABLISHED:
    - Two-way communication has been observed by the firewall
  - RELATED:
    - A packet that has a relationship with another ESTABLISHED connection
    - E.g., ICMP error messages

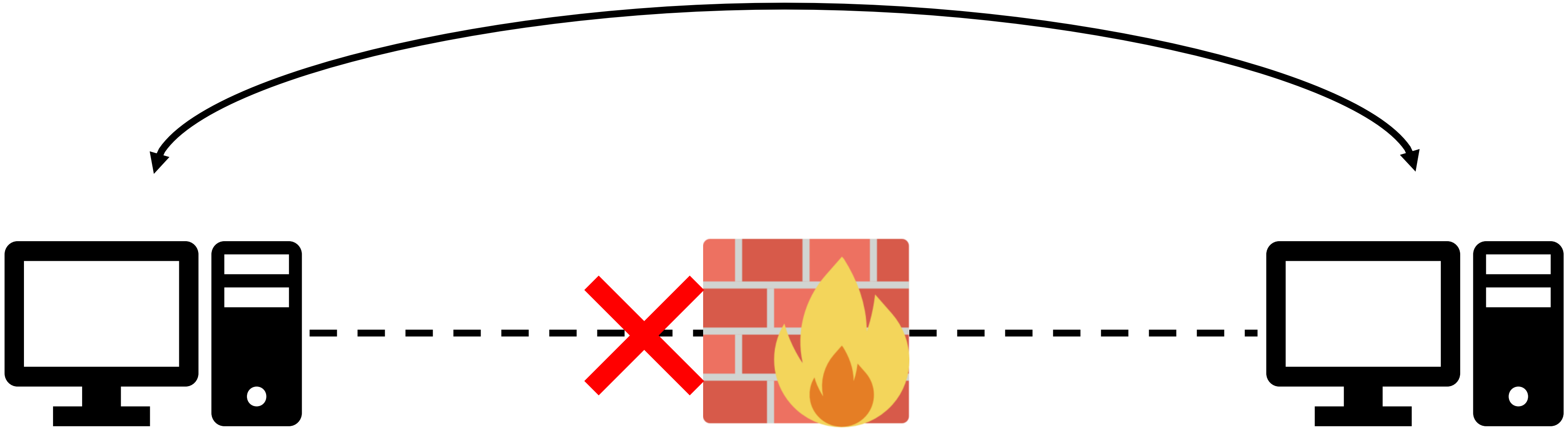
sFW and Connection Tracking

- Let's enable packets that are part of a stream
  - That stream is initiated by our machine

```
iptables -A INPUT -p all -m conntrack --ctstate
ESTABLISHED,RELATED -j ACCEPT
```

sFW: Putting it All Together

- Requirements
  - Allow SSH, HTTP, and ICMP
  - Allow loopback interface
  - Allow DNS
  - Allow VPN and HTTPs
  - Allow all outgoing traffic
  - Allow established connections
  - Drop other traffic

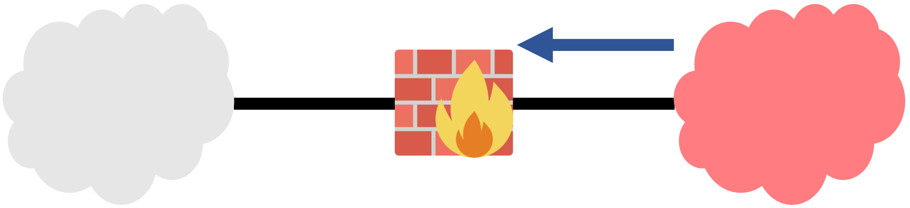


Evading Firewalls

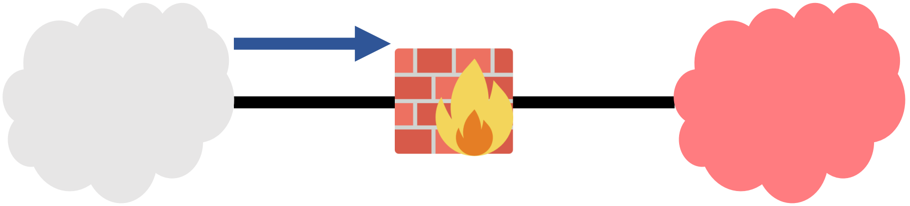
Recall: Ingress and Egress Filtering

- Firewalls can inspect traffic from both directions.

- Ingress filtering

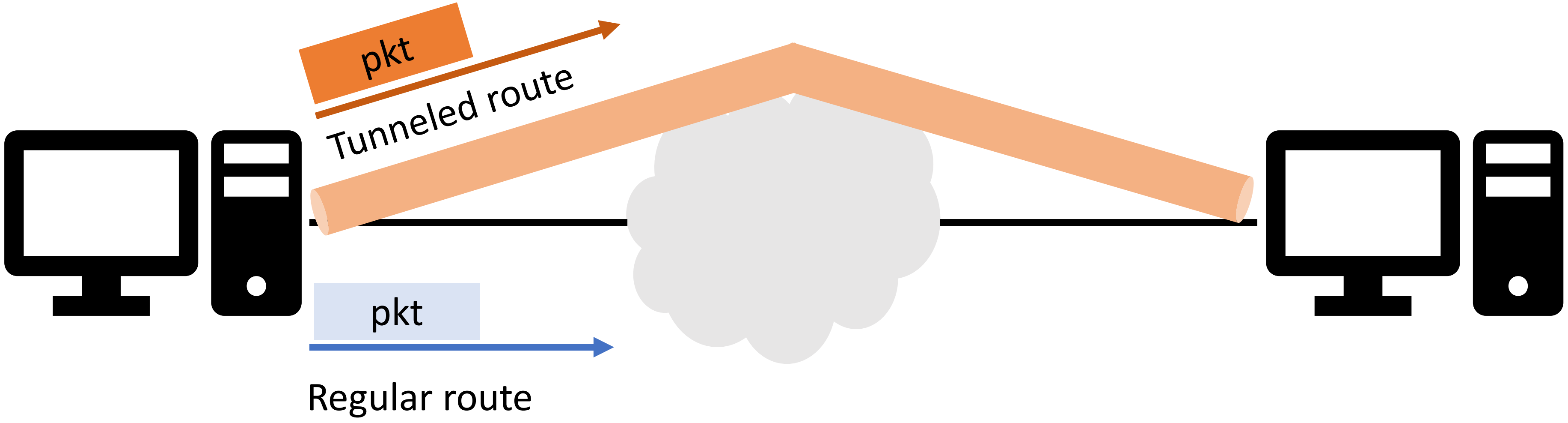


- Egress filtering



Evading Firewalls: Rationale

- Some firewalls are restrictive
  - E.g., Egress filtering may block users from reaching out to certain websites or services
- *Tunneling* is the main technique to evade firewalls.



- Two tunneling mechanisms: SSH tunnels, and VPN

SSH Tunneling

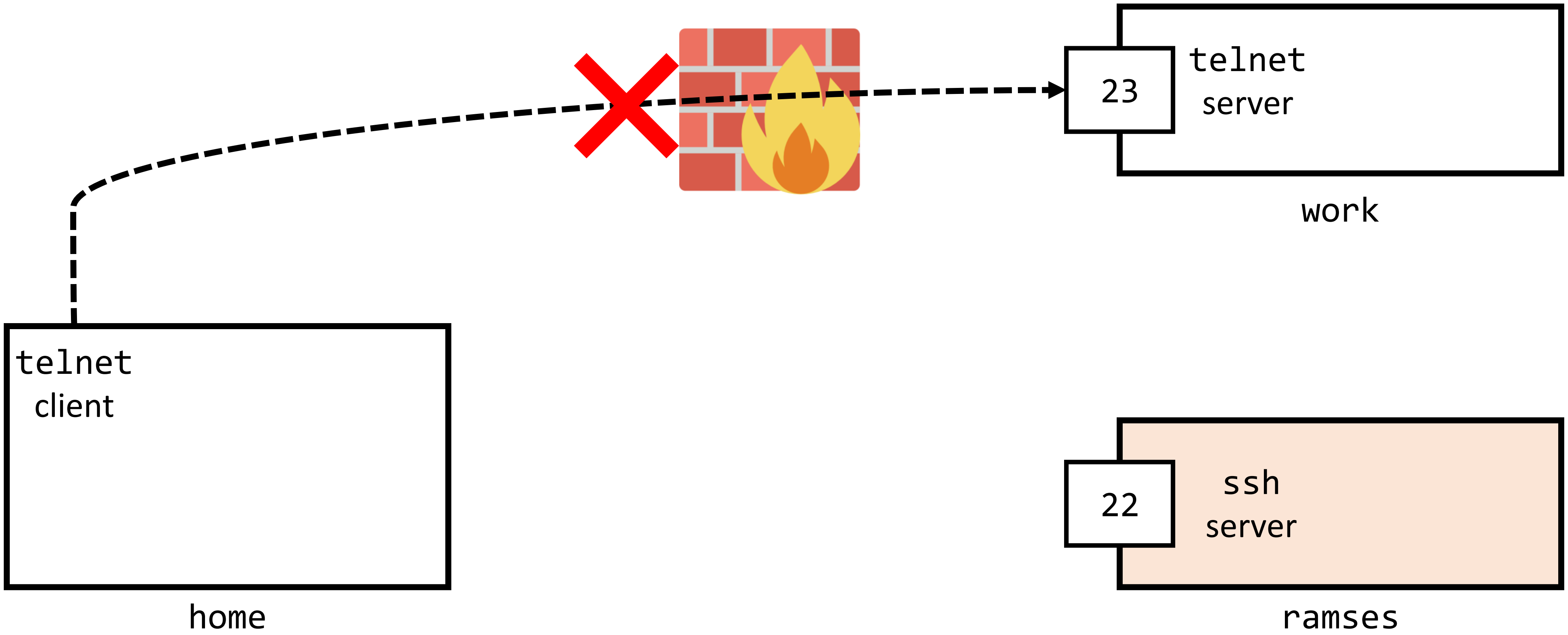
- SSH protocol:
  - Is used mainly to log in securely to a machine
  - Also supports tunneling and port forwarding
- An SSH tunnel consists of an encrypted link created through SSH protocol
  - Secure file transfers (e.g., FTP over an ssh tunnel)
  - Evading (or bypassing) firewalls

SSH Tunneling

- Two techniques:
  - Tunneling using local port forwarding:
    - the local host performs forwarding
  - Reverse tunneling using remote port forwarding:
    - a remote host performs forwarding

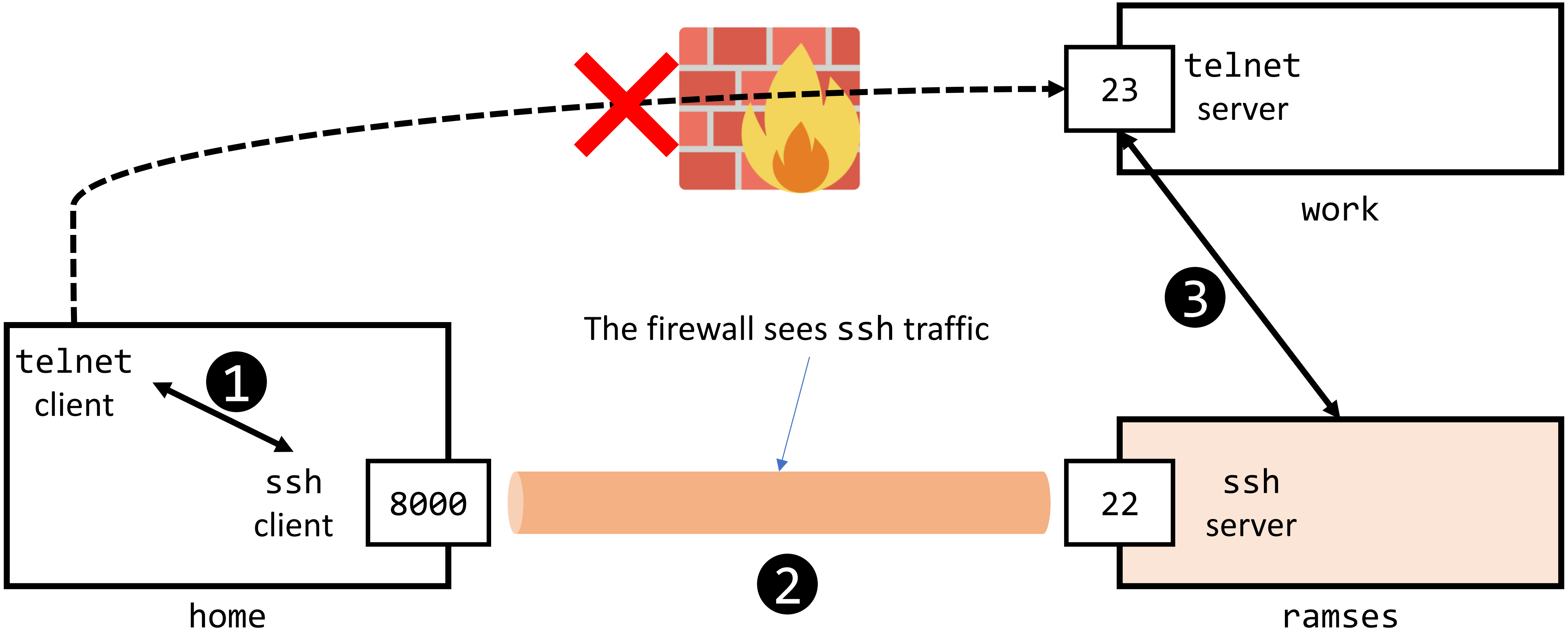
Local Port Forwarding: Evading Ingress Filtering

- `telnet` traffic from home → `work` is blocked by the firewall



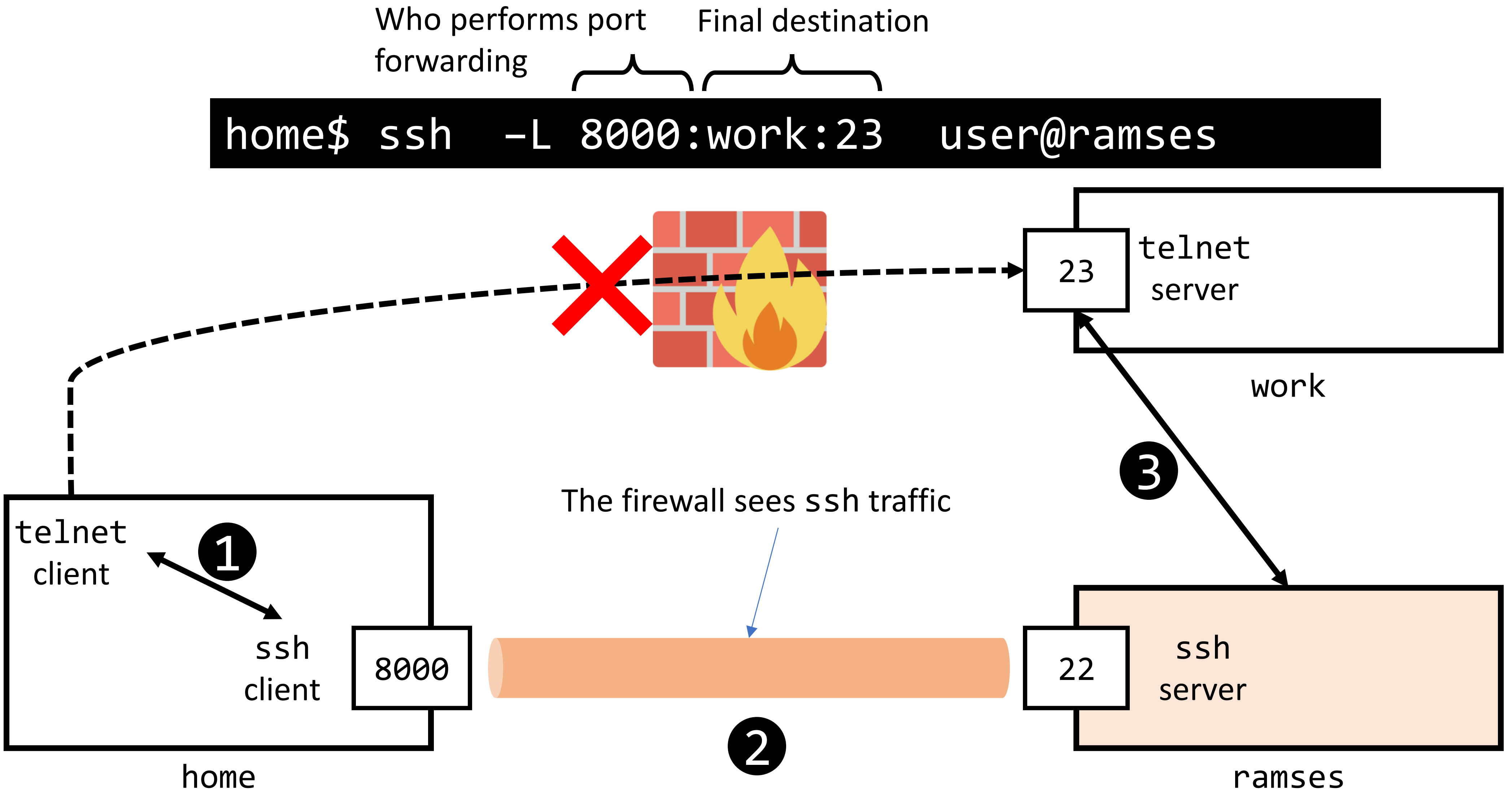
Local Port Forwarding: Evading Ingress Filtering

- We establish an `ssh` tunnel: home ←→ `ramses`
  1. On home endpoint, the tunnel receives TCP packets from `telnet` client
  2. The tunnel forwards TCP packets to `ramses` endpoint
  3. At `ramses`, the data is put in other TCP packets and sent to `work`



Local Port Forwarding: Evading Ingress Filtering

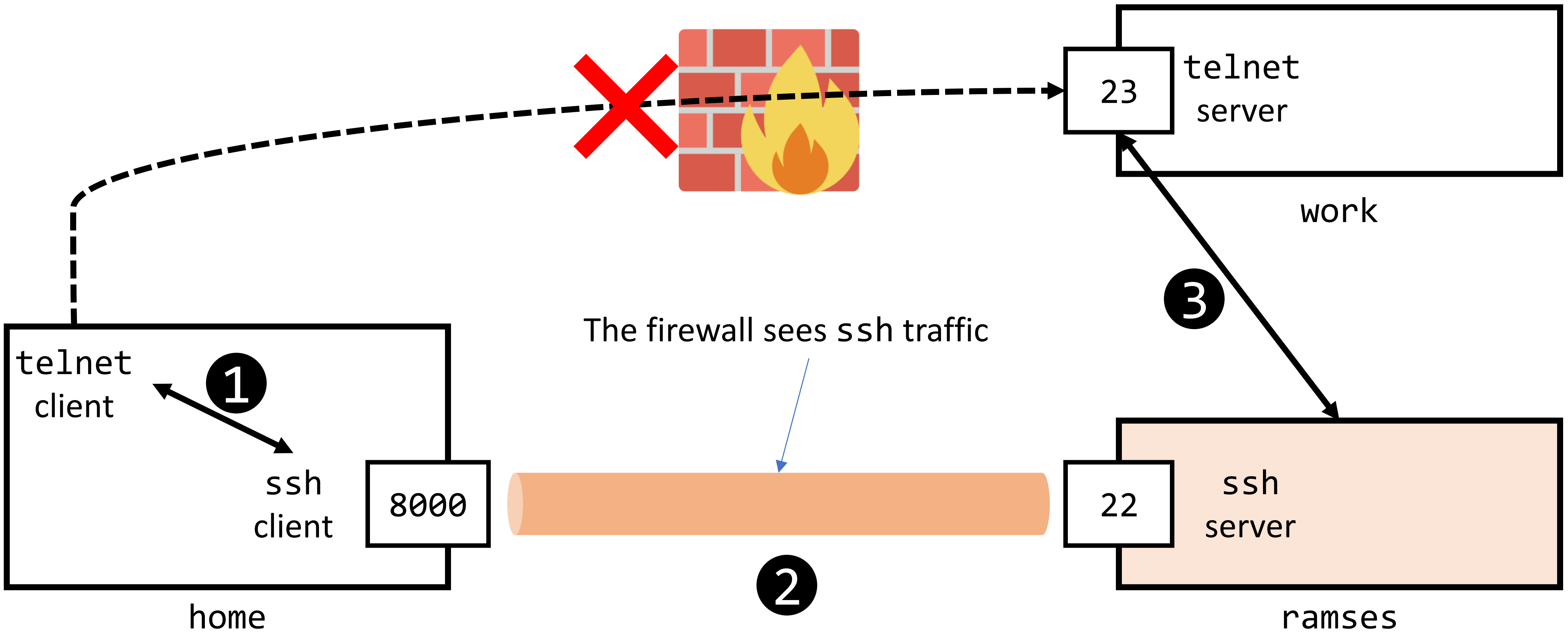
- Create an ssh tunnel:



Local Port Forwarding: Evading Ingress Filtering

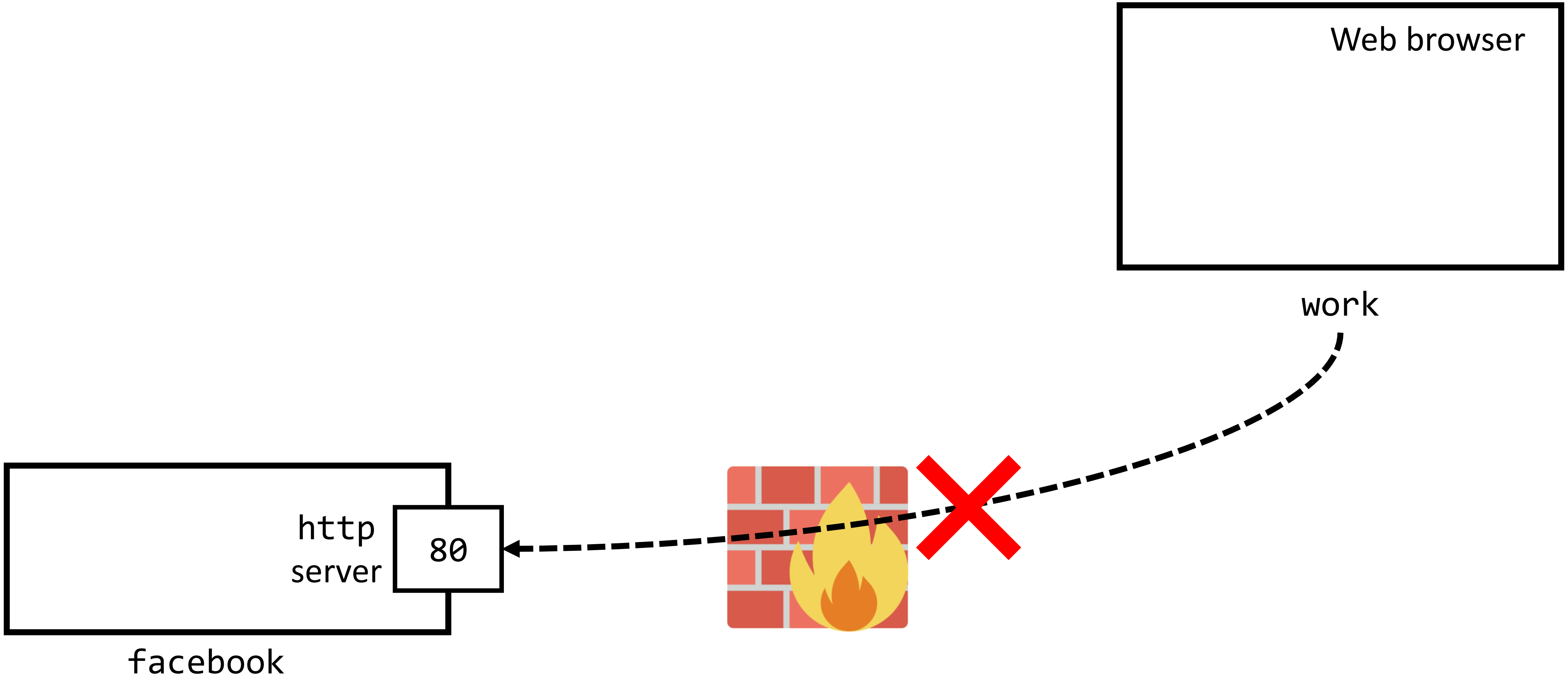
- Starting a `telnet` session at home:

```
home$ telnet localhost:8000
```



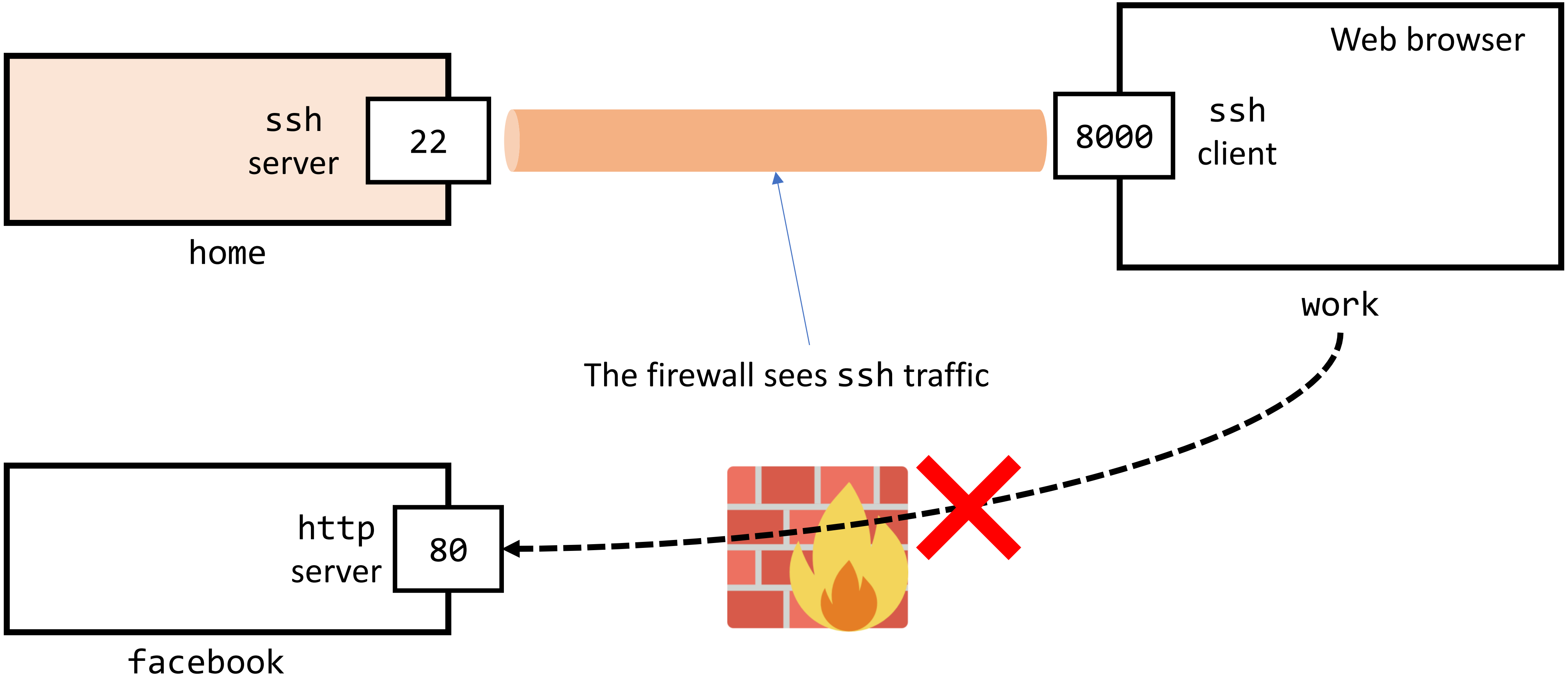
Local Port Forwarding: Evading Egress Filtering

- Some Internet services may be blocked to users



Local Port Forwarding: Evading Egress Filtering

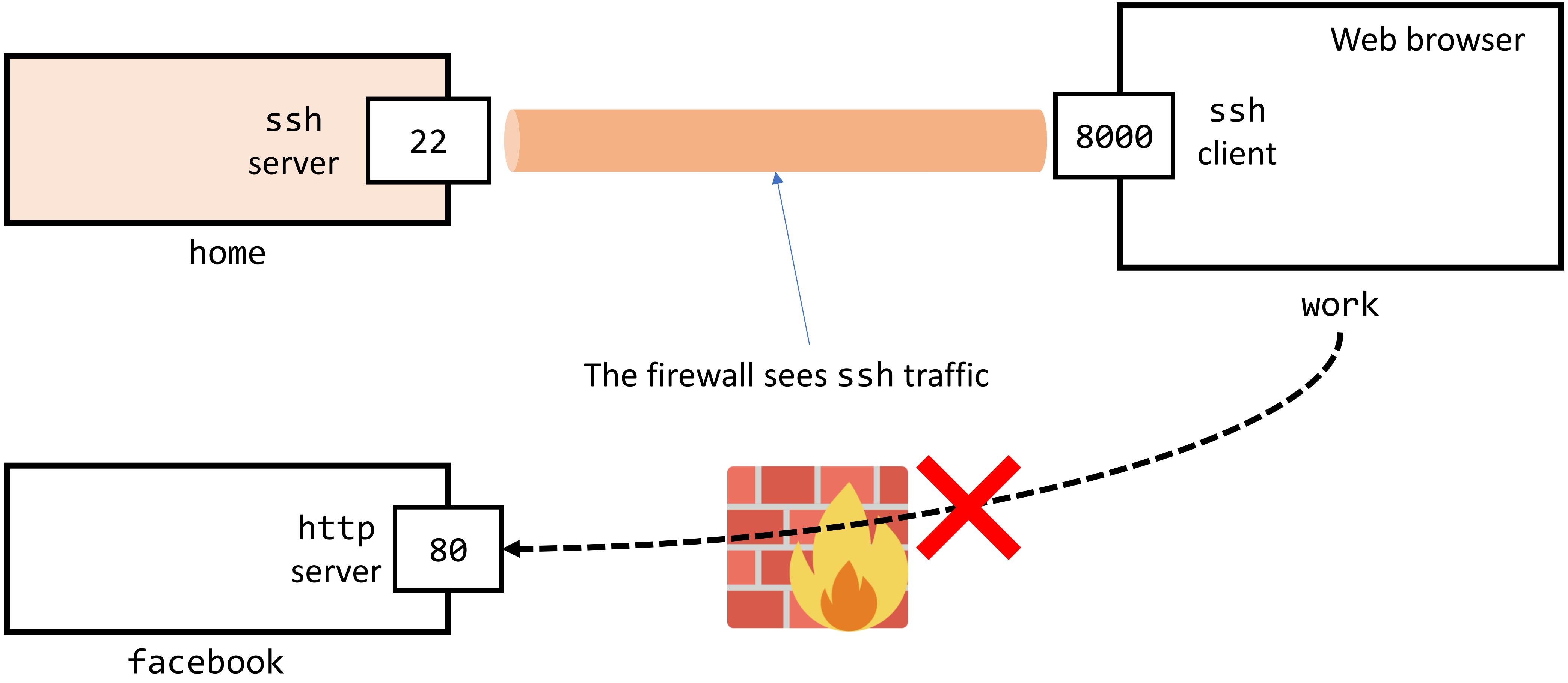
- We establish an `ssh` tunnel: `work` ←→ home to access an Internet service



Local Port Forwarding: Evading Egress Filtering

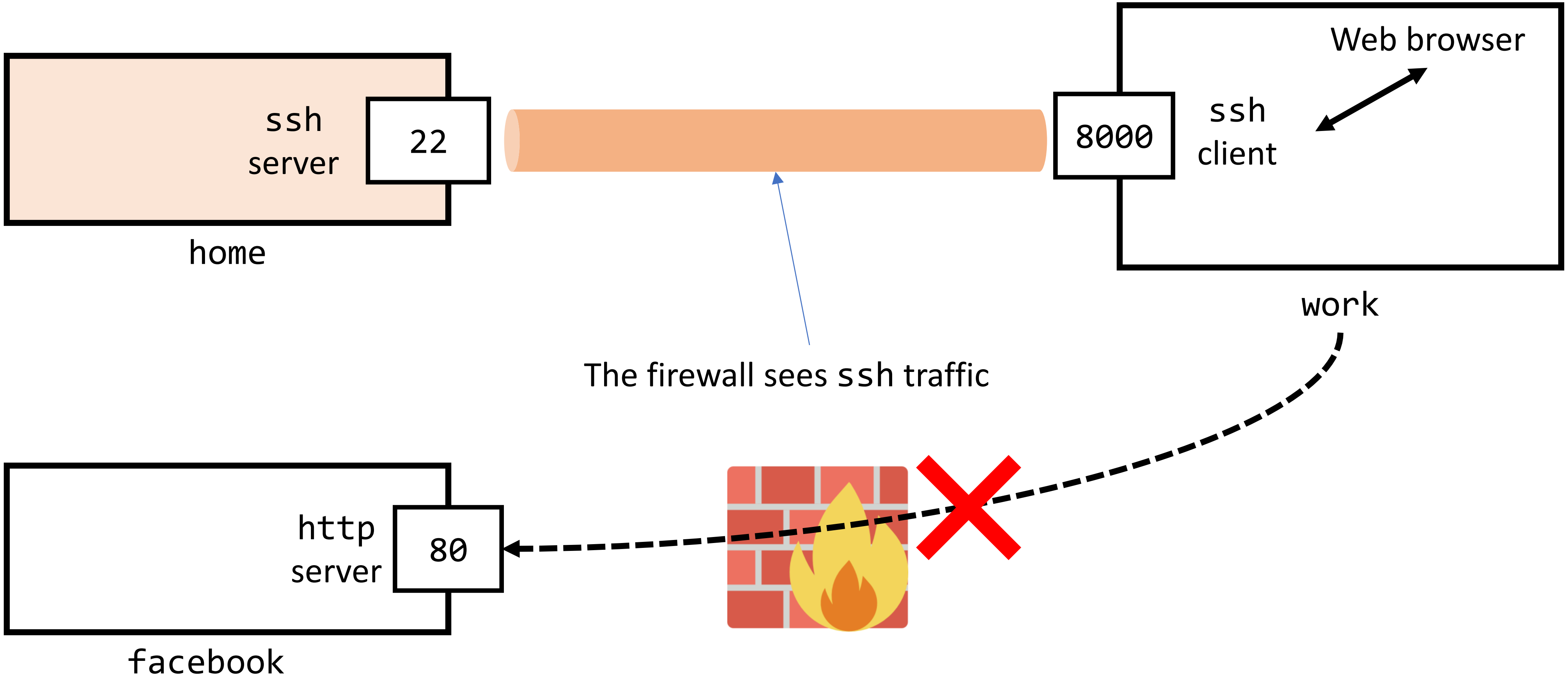
- Create an ssh tunnel:

```
work$ ssh  -L 8000:facebook.com:80  user@home
```



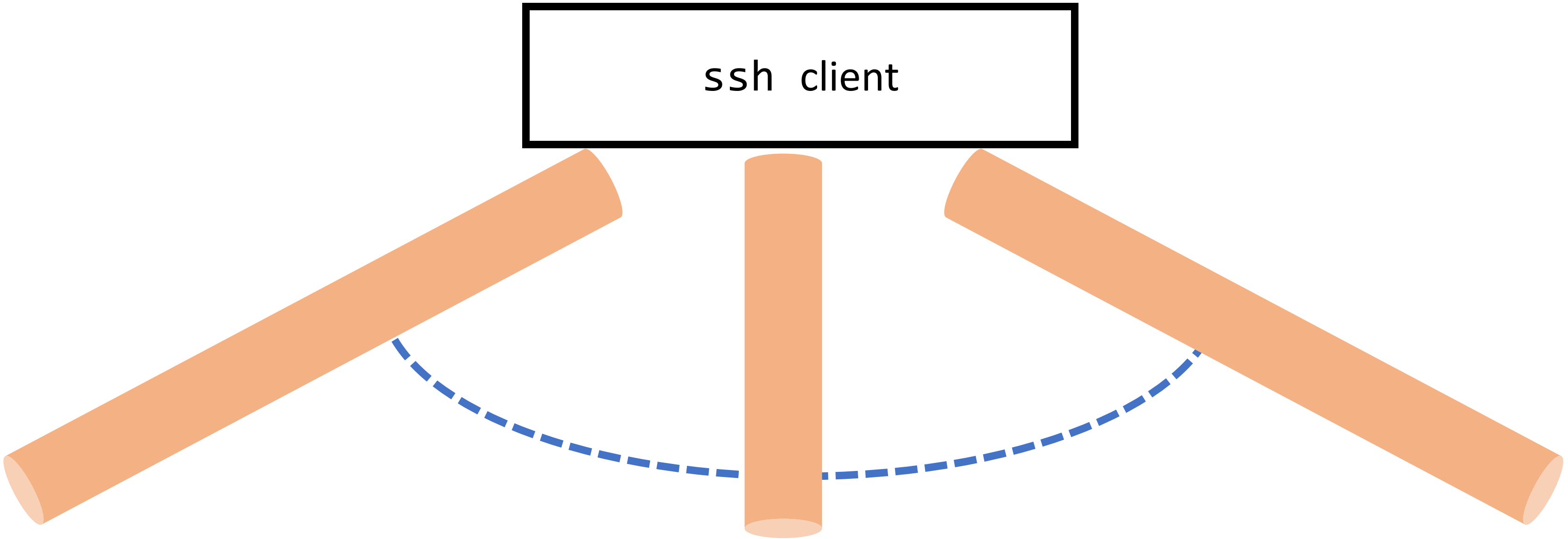
Local Port Forwarding: Evading Egress Filtering

- Visit the website (from the browser) `localhost:8000`



Local Port Forwarding: Dynamic Port Forwarding

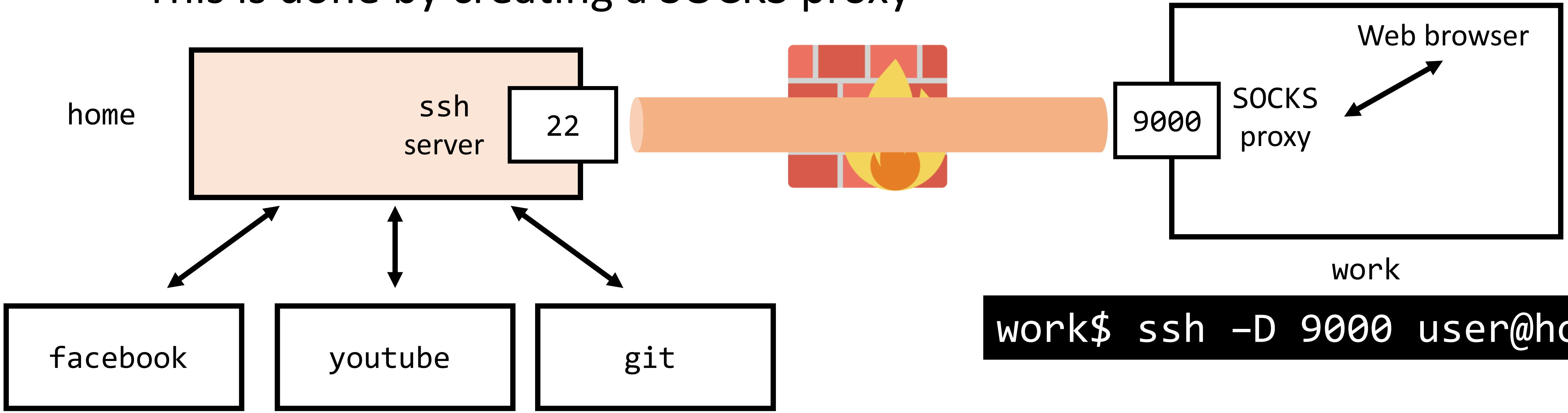
- Previous techniques use **static** port forwarding
- What happens if the firewall blocks many services?



Creating/maintaining individual tunnels is complex

Local Port Forwarding: Dynamic Port Forwarding

- Dynamic port forwarding allows configuring one local port for tunnelling data to all remote destinations
- This is done by creating a SOCKS proxy

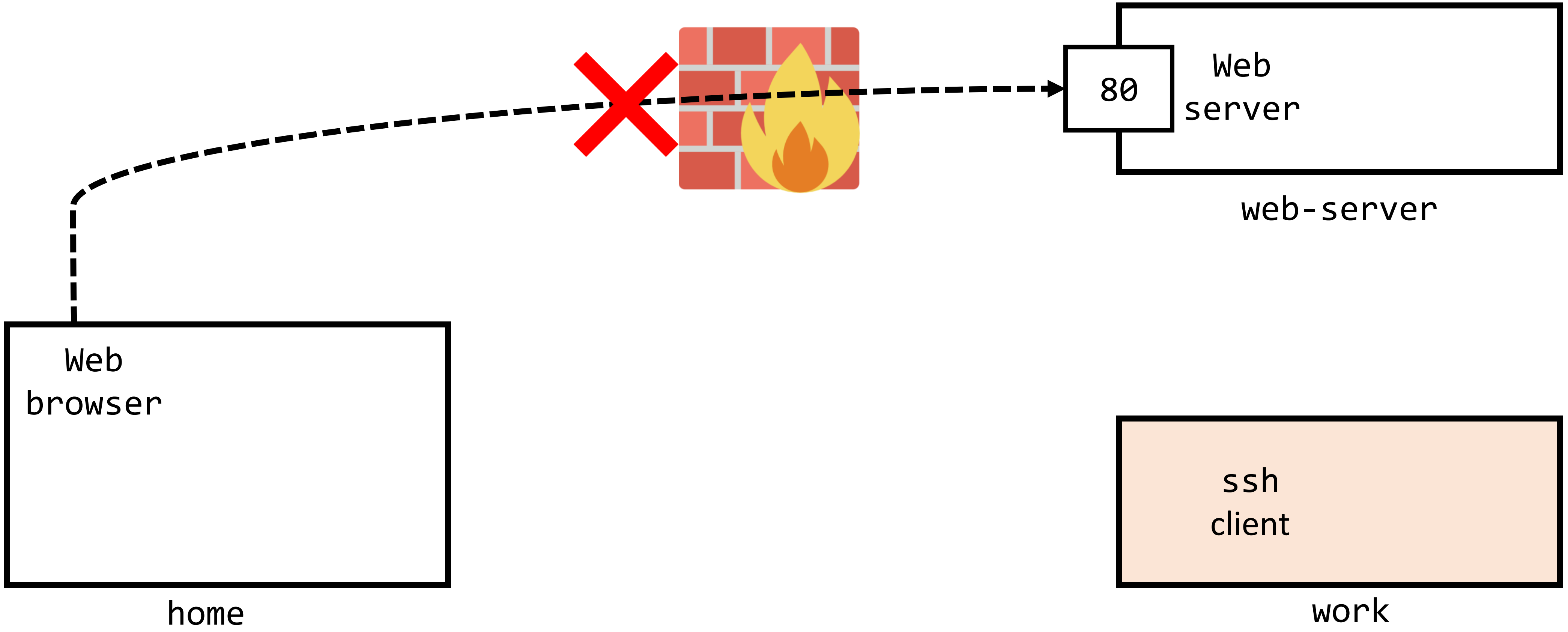



```
work$ ssh -D 9000 user@home
```

- The application (e.g., Web browser) needs to support SOCKS

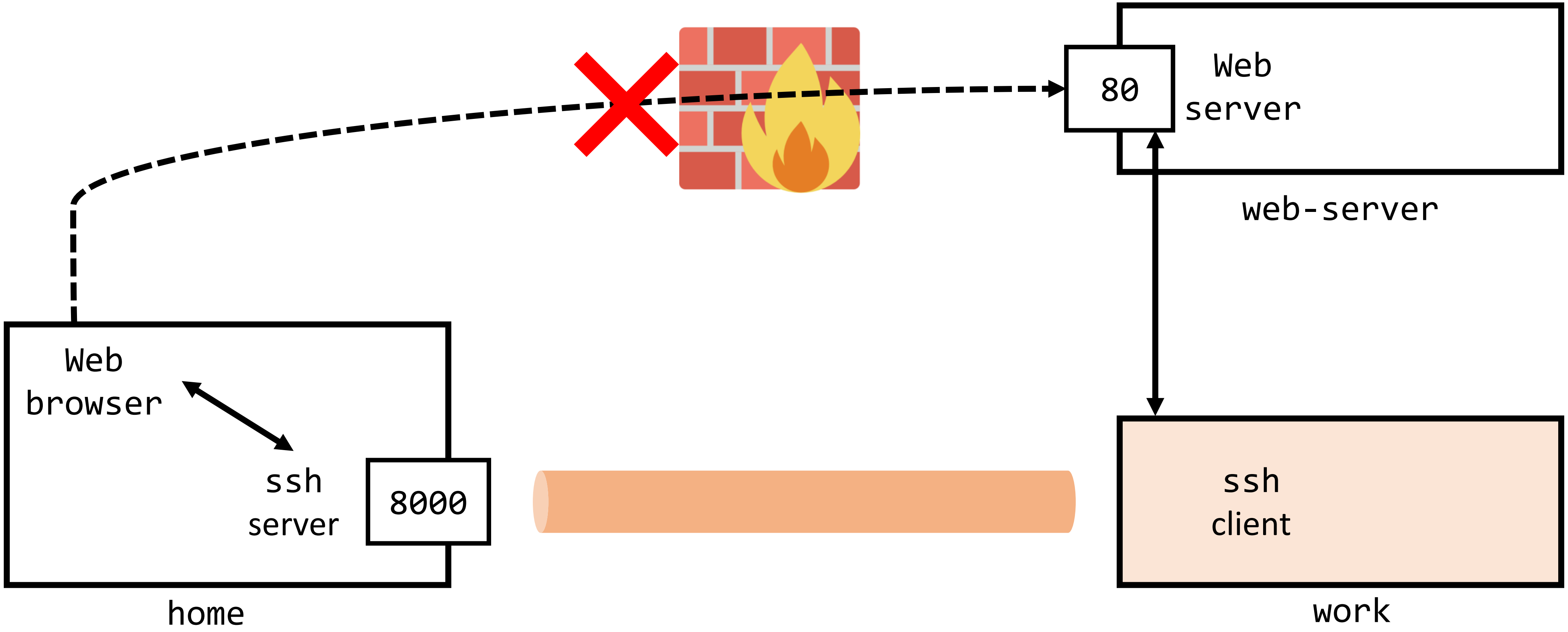
Remote Port Forwarding

- Used to access a service inside a private network
  - Especially, when inbound `ssh` is not allowed, but outbound `ssh` is allowed



Remote Port Forwarding

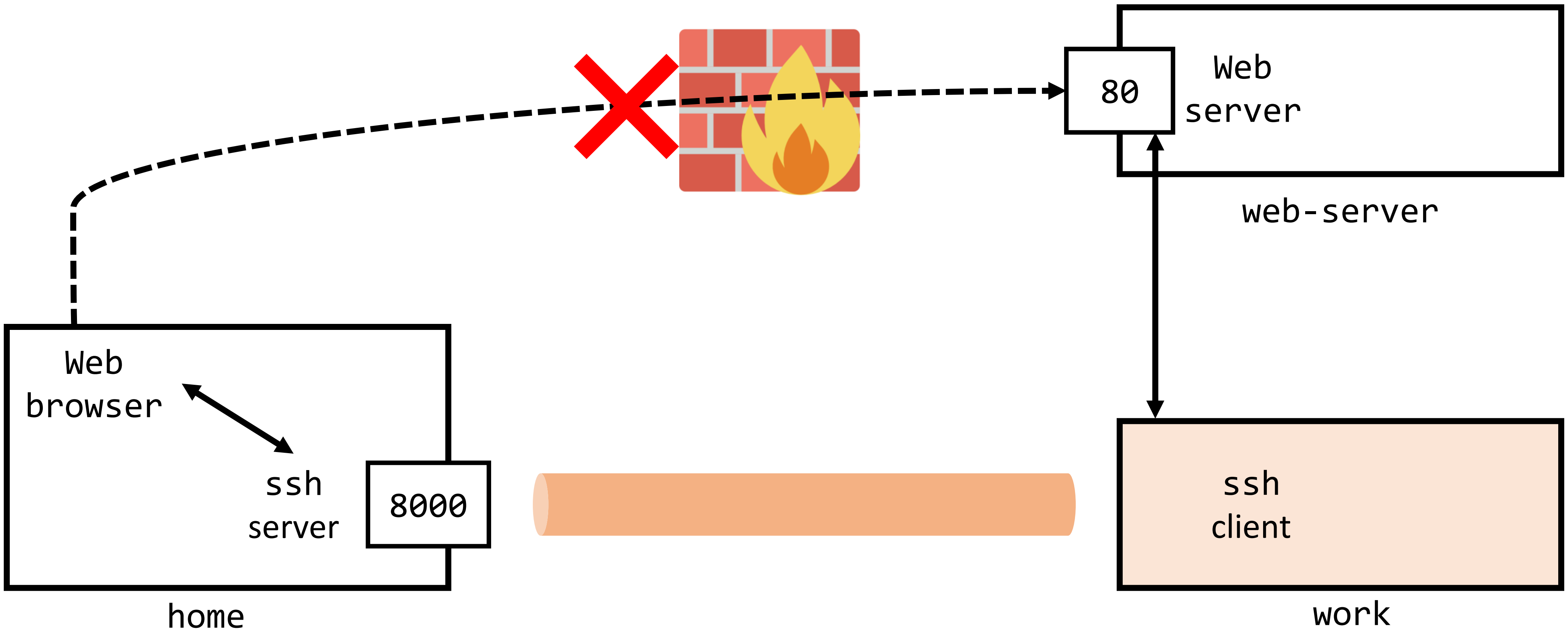
- We create a reverse SSH tunnel from work
  - On home, the user sends HTTP requests to port 8000
  - SSH tunnel forwards the requests to the SSH client on work
  - work forwards traffic to web-server



Remote Port Forwarding

- We create a reverse SSH tunnel

```
work$ ssh –R 8000:web-server:80 user@home
```



Questions?