Network Security: Firewalls & VPNs

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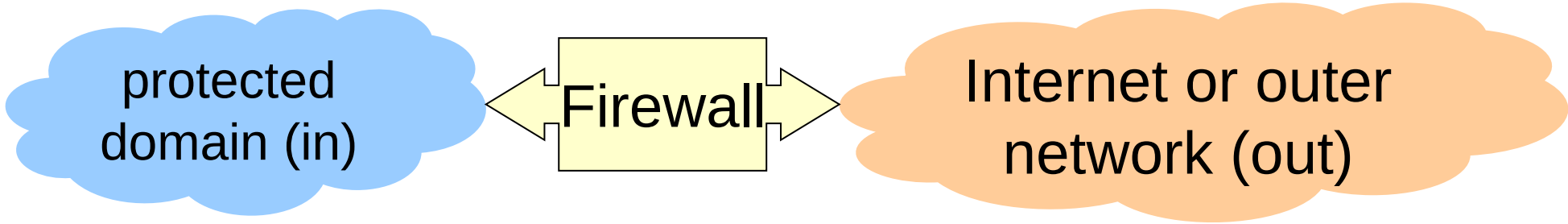
Firewalls: Objectives

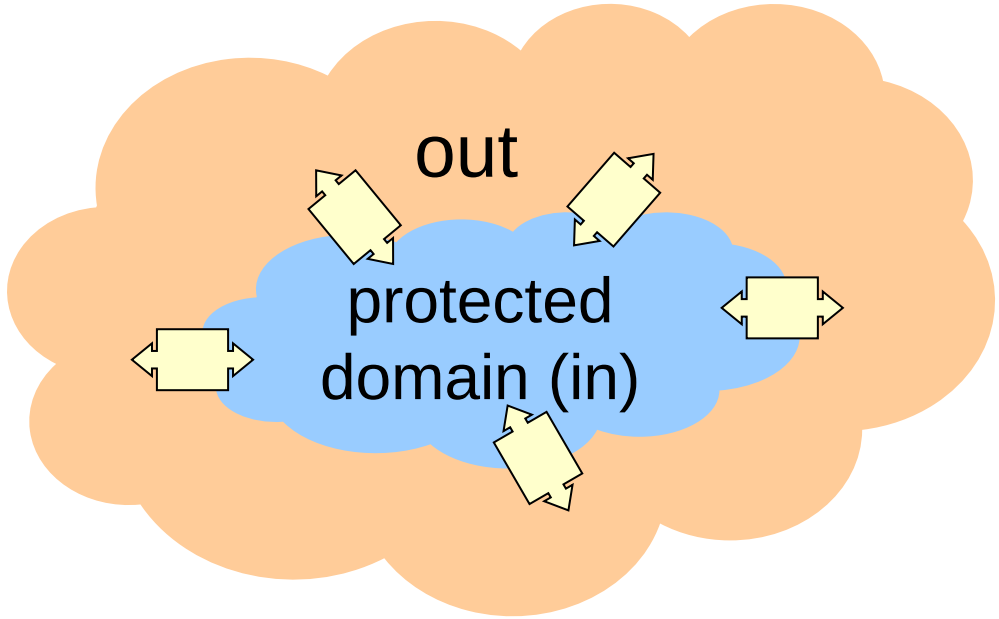
- Fundamental element to interconnect network domains
  - Access control
  - Flow control
  - Content control
- Centralized implementation of security policies
  - Minimizes the impact of local vulnerabilities
    - Known or unknown
  - Makes it easier to take more drastic actions
  - Centralizes problem detection
    - and its treatment

Firewall definition (Cheswick & Bellovin)

- Link between network domains
  - of a protected perimeter (set of networks and machines)
  - to an insecure network
    - Internet
    - Other untrusted local networks
- Component set
  - Hardware and software
- Properties
  - In the path of all in ⇔ out traffic
    - Controls the traffic passing through it
  - Immune to penetration (by definition)

Firewalls: Definition (Cheswick & Bellovin)





Firewalls: Functionalities

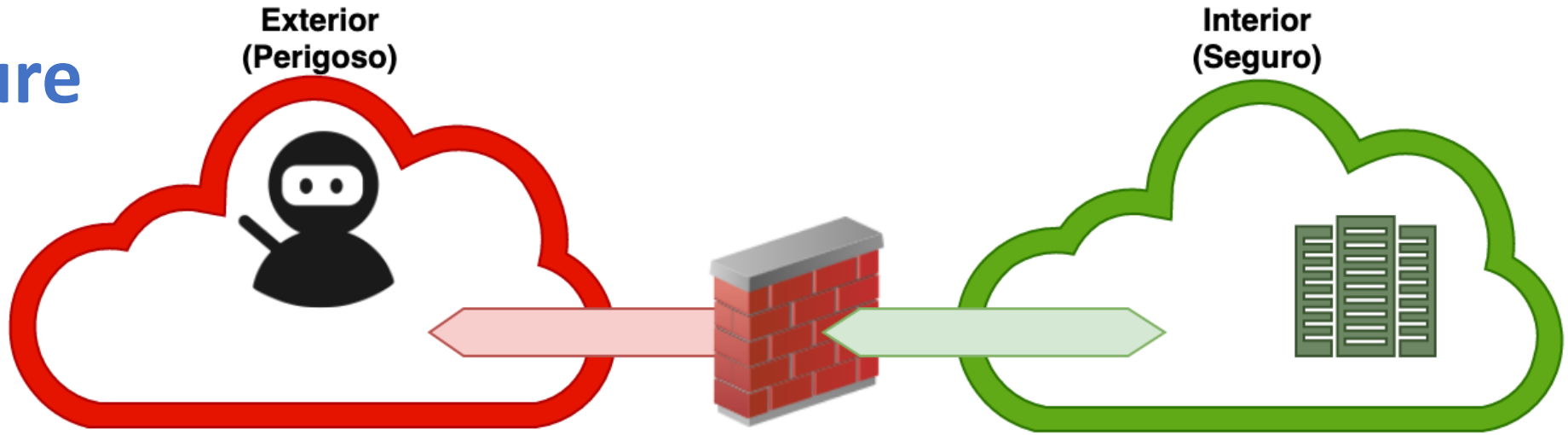
- Supervision of all in ⇔ out communication
  - Control
    - The use of internal resources by external hosts/requests
    - The use of external resources by internal host/requests
  - Defense from attacks
    - from outside the protected domain towards its resources
    - from the protected domain against external resources

- Activation of gateway mechanisms
  - To hide the structure from the protected perimeter
    - NAT (Network Address Translation)
    - Masquerading and Port Forwarding
  - To extend the security perimeter
    - Secure tunneling (VPN)

Firewalls: Importance

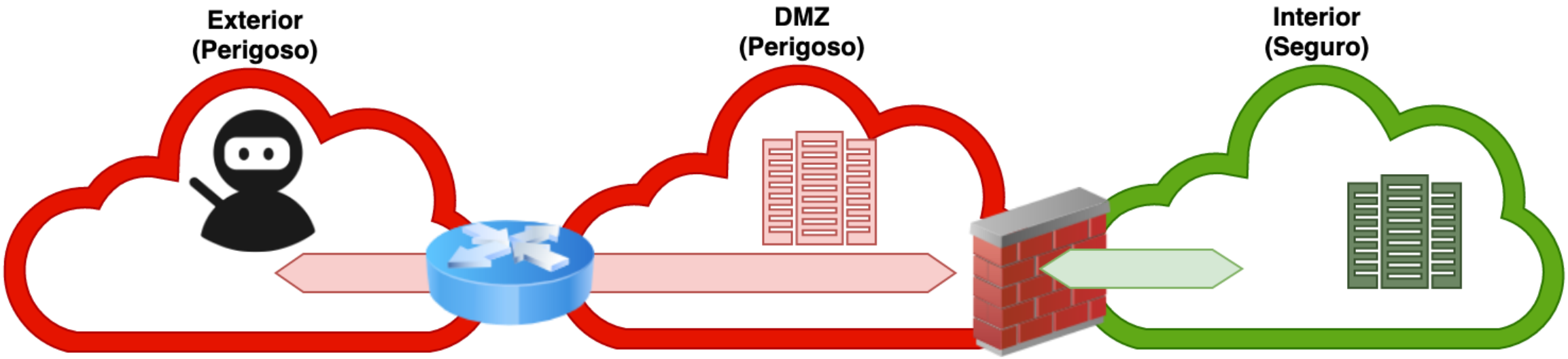
- Extreme!
- Attacks on public systems are constant
  - By specialized attackers
  - By standalone applications
- Systems do not always have adequate security mechanisms
  - Blocking after too many incorrect attempts
  - Validation of communications
  - Access control
- Necessary to apply mechanisms defined by the administrator, in accordance with domain policies
  - An application programmer is not aware of these

Generic structure



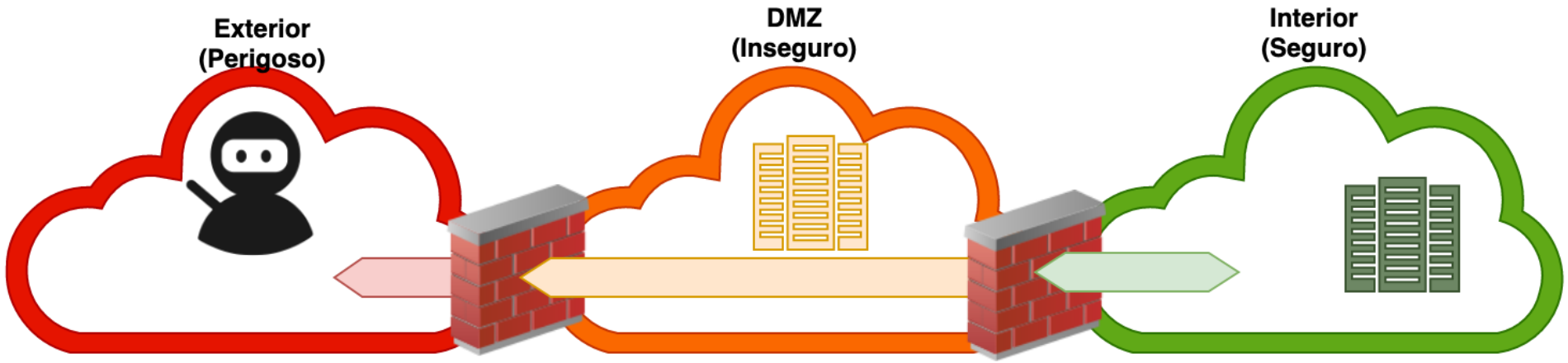
- Perimeter defense (of the domain)
  - Can be part of a defense in depth strategy
- Consider an unsafe environment and a safe one
  - Out: other domains or the Internet
  - Inside: internal network
- A single server: Bastion

Generic structure: with a DMZ



- DMZ: DeMilitarized Zone Network or Perimeter Network
  - Insecure network
  - Contains servers exposed to the world
  - Sometimes necessary to use specific services/applications

Generic structure: w/ DMZ and two firewall equipments



- DMZ may have some protection
  - System of two firewalls with different rules
- External firewall: quite permissive
  - Control access to all networks
- Internal firewall: more restricted
  - Control access to the internal network

Firewall types: Packet filters

- Reject unauthorized interactions based on the content of IP datagrams
  - IP addresses (source and/or destination)
  - IP/transport header options
  - Transport protocols and ports (origin and/or destination)
  - Directions for creating virtual circuits
  - Data sent via transport protocol
  - Datagram size
- Can analyze flow behavior
  - Example: detect port scans (with nmap)
- Typically supported by core OS components
  - Example: iptables, ipfw, pf

Firewalls types: Stateful packet filters

- Dynamic (or context-sensitive) packet filter
  - Sort of packet filter with historical context
  - Context is key to certain decisions
  - Common term: Stateful Packet Filter/Inspection (SPI)

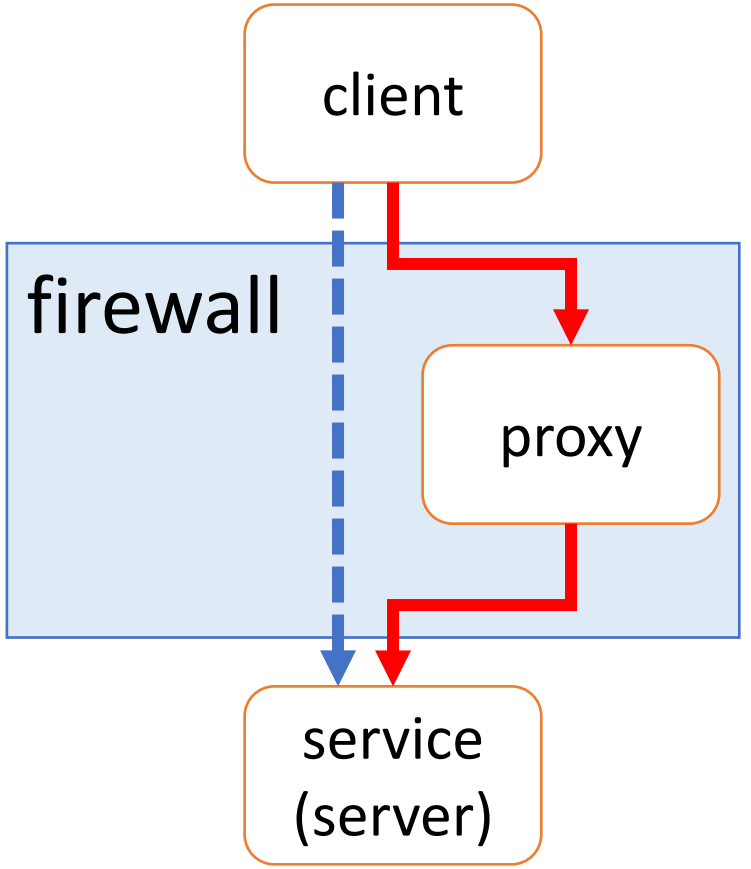
- Context examples:
  - Decisions made for IP packet fragments
    - Defragmentation before filtering
  - Established TCP virtual circuits
    - Circuit establishment requests are controlled
    - Established virtual circuits are allowed

Firewall types: Stateful packet filters

- Context examples (cont.):
  - Dynamic NAT tables
    - Creation of entries depending on observed traffic
  - Request/response interactions over UDP
    - Dynamic authorization of responses to authorized requests
    - Example: DNS name resolution
  - ICMP error messages
    - Related to previously sent TCP/UDP packets
  - Identification of application protocols from data flows
    - To handle flows that use dynamic or “stolen” ports
    - Examples: FTP, RPC protocols, P2P protocols
    - Utility: filtering, transparent proxying, QoS

Firewall types: Applicational gateways

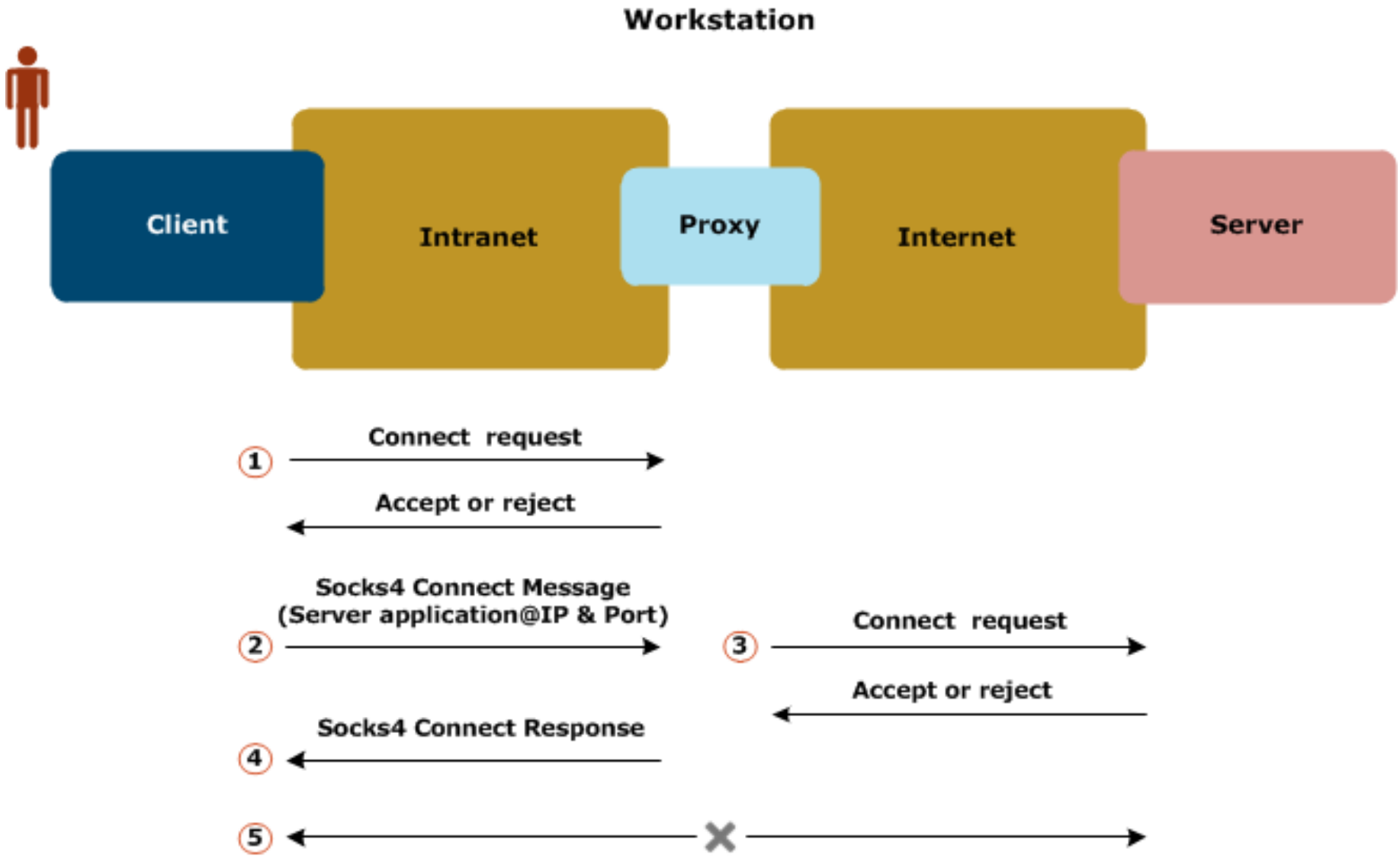
- Control interactions at the application level
  - But transparent to interacting applications
  - There is usually a different firewall per protocol (protocol proxy)
- Client -> Proxy -> service (server)
  - Proxies are servers
- Aspects of operating a proxy
  - User access control
  - Analysis and modification of content
  - Detailed logging
  - Impersonation (proxying)
    - Transparent replacement of one of the interlocutors



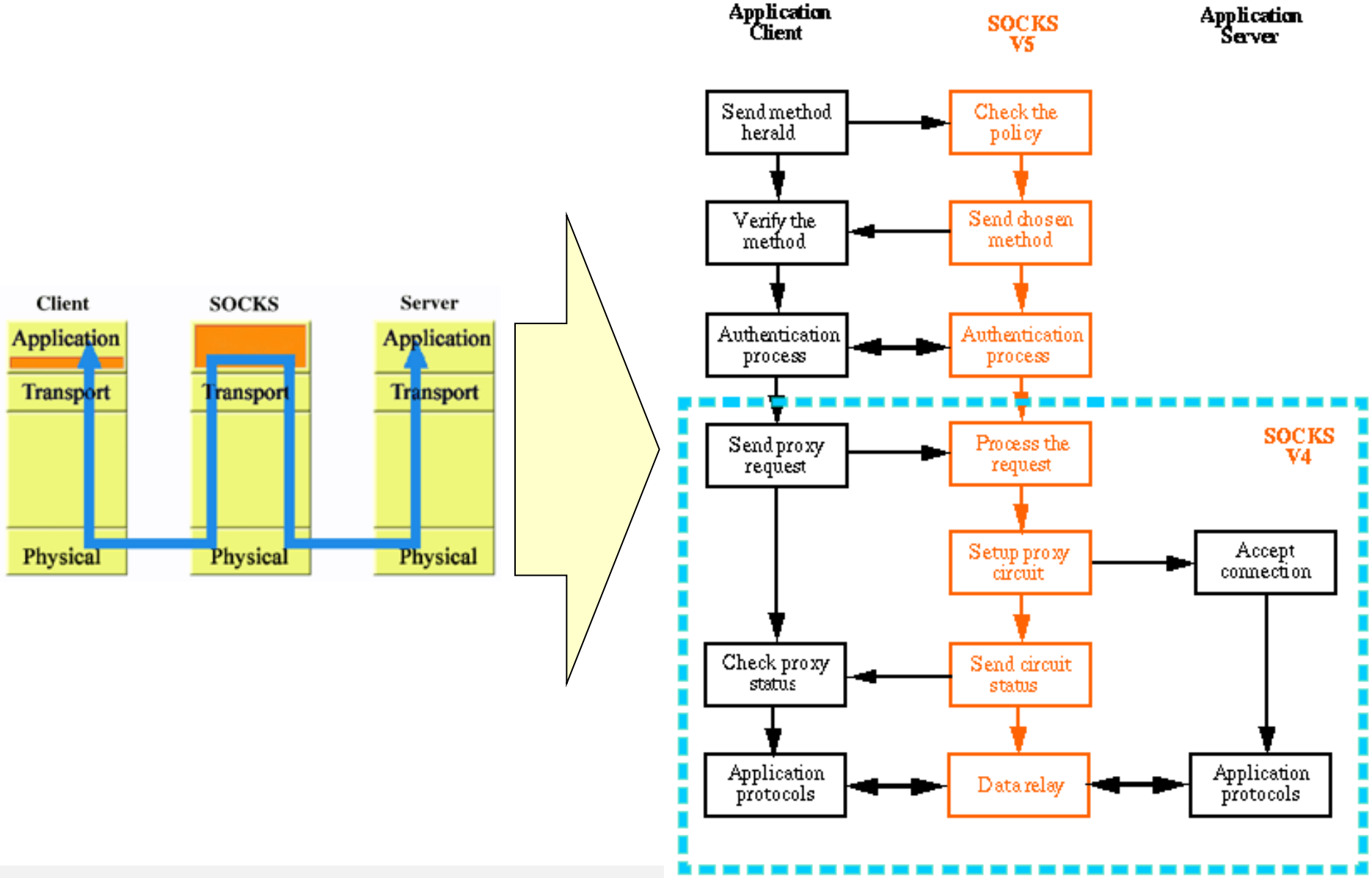
Firewall types: Circuit gateways

- Kind of application gateway
  - But contacted directly by client applications
  - Non-transparent interposition
- Interposition goals
  - Deploying domain-specific authentication and authorization policies and mechanisms
  - Deploying supplementary services
    - e.g. Tor proxy
- Typically requires changing client applications
  - Examples: SOCKS and HTTP Proxy

Example: SOCKS4 circuit gateways



Example: SOCKS v5 circuit gateways



Firewall bastion

- Must run secure versions of operating systems
  - With a secure configuration
  - Only essential services are installed
  - Telnet/SSH, DNS, FTP, SMTP and authentication proxies
- Public servers should not perform in a bastion
  - Examples: DNS, SMTP, HTTP, FTP, SSH, RAS, etc.
  - Must run on isolated machines within DMZs
    - Preferably one per service
  - Bastion only forwards traffic to the appropriate machines on a DMZ
    - And allows limited traffic from the DMZ

Firewall bastion

- It is often a platform for application gateways
  - But the more proxies, the lower its performance will be
  - Proxies can run on specific machines
    - Security appliances
  - Bastion only forwards traffic to and from the appliances

- Secure execution of application gateways
  - Independence
    - The compromise of one does not affect the rest
  - No special privileges
    - Their compromise does not allow to affect the host

Firewalls' security services

- Authorization
  - Data streams (packet filters)
    - Transport or network level
  - Users (application gateways / circuits)

- Traffic Redirection
  - For dedicated hosts
    - Local services (e.g., mail, www, ftp, etc.)
    - Proxies in security appliances
  - Proxying
    - Explicit (e.g., circuit gateways)
    - Transparent (e.g., NAT address translations)

Firewalls' security services

- Application content processing
  - Content analysis
    - Example: virus detection
  - Changing high-level protocols
    - Example: virus removal
- Secure communication
  - Virtual Private Networks (VPNs)
    - Encryption and integrity control of data flows over public (insecure)
  - Tunneling
    - IP domain extension to distant nodes
    - Example: PPTP, L2TP, IPSec

Firewalls' security services

- Defense against DoS attempts
  - Attack detection
    - Abnormal traffic volumes, high volume, etc...
  - Traffic scrubbing
    - Filtering dangerous or malformed datagrams
  - Activation of mitigation add-ons
    - Example: SYN flooding relay/semi-gateway
- Defense against information leaks (exfiltration attacks)
  - Abnormal traffic detection
  - Controlling behavior against known models

Firewalls' limitations

- Cannot tackle attacks from the internal network
  - Unless the internal network is segmented into multiple subnets
  - Switches typically do not support firewall operations
  - VLANs provide minimal segregation (DMZ type)
- Effectiveness in controlling all external connections
  - Which can be done in parallel in countless ways:
    - Unregistered WLANs & Aps
    - VPNs
- Lack of control over camouflaged/hidden interactions
  - Camouflaged interactions multiplexed by VPNs
  - IP tunnels over HTTP, ICMP, DNS, etc.
- Difficult to manage in environments with heterogeneous interests
  - Universities, ISPs

Personal firewalls

- Adopted for the protection of individual / personal hosts
  - Defense in depth vs. perimeter defense
- Owners can set additional control policies
  - Applications authorized to access the network
  - The protocols that applications can use
  - The hosts/networks that protocols/applications can interact with
- Reduce the risk of compromise between hosts on a network
  - Allows a machine to self-protect, independently of the protection given by its network
    - No assumptions regarding other network protections
  - Useful for machines that migrate between networks

Personal firewalls: issues

- Normal users are not network security experts
  - They don't normally understand how IP networks work
    - IP addresses, transport ports, transport protocols, etc.
  - They do not know how to assess whether a given interaction is normal, acceptable, etc.
  - They don't know the basic security policies they should apply
- Blocking suspicious interactions may nullify functionality
  - Network communication is currently commonplace
  - Applications do not inform users of their communication needs

Personal firewalls: issues

- Operational complexity
  - Different operating environments → different policies
  - Different network interfaces → different policies

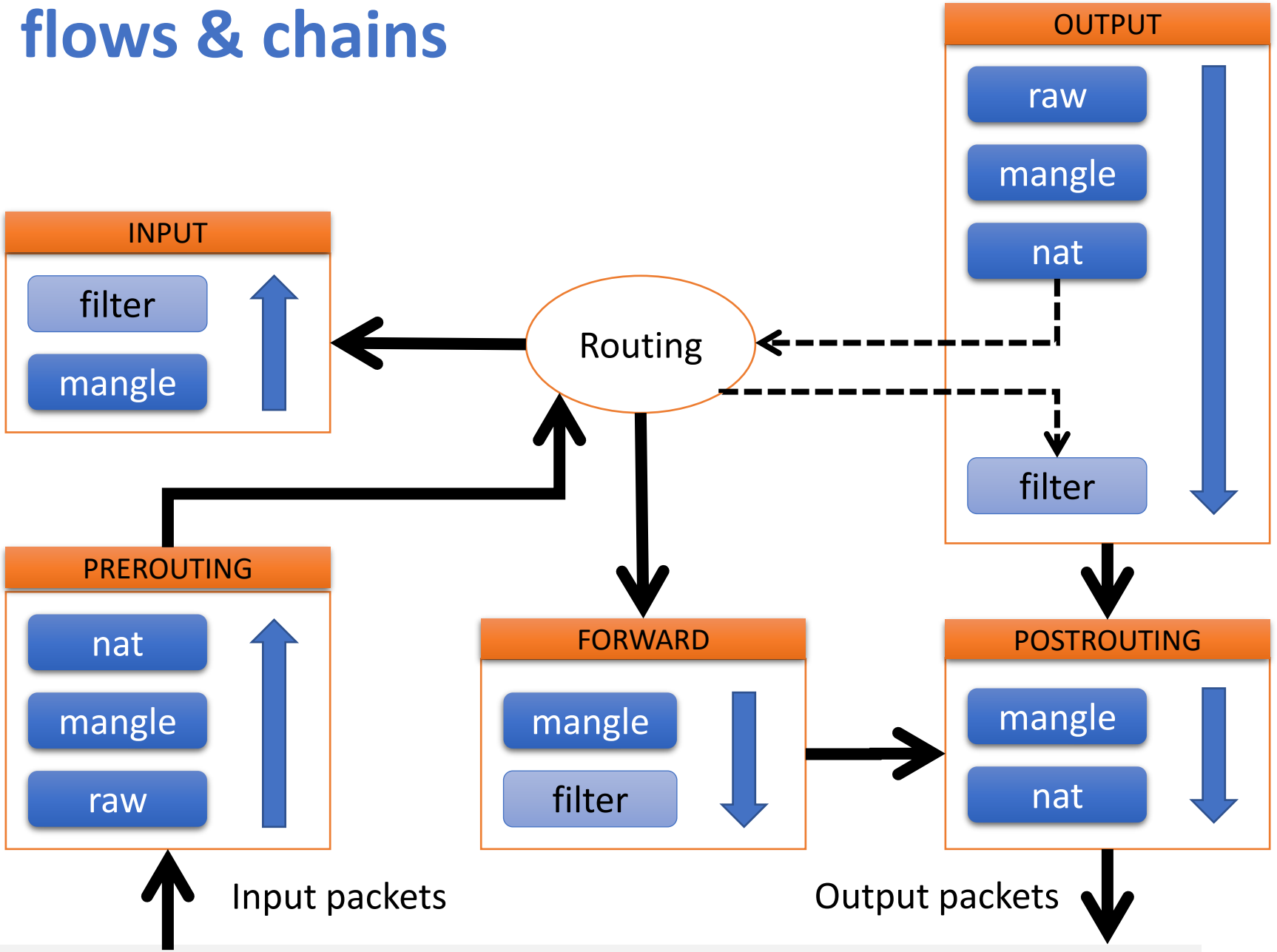
- The combination of operational scenarios, network interfaces and acceptable interactions for each case leads to a huge number of rules
  - Confusion, incoherence → difficulty to detect vulnerabilities

Linux OS firewall: iptables

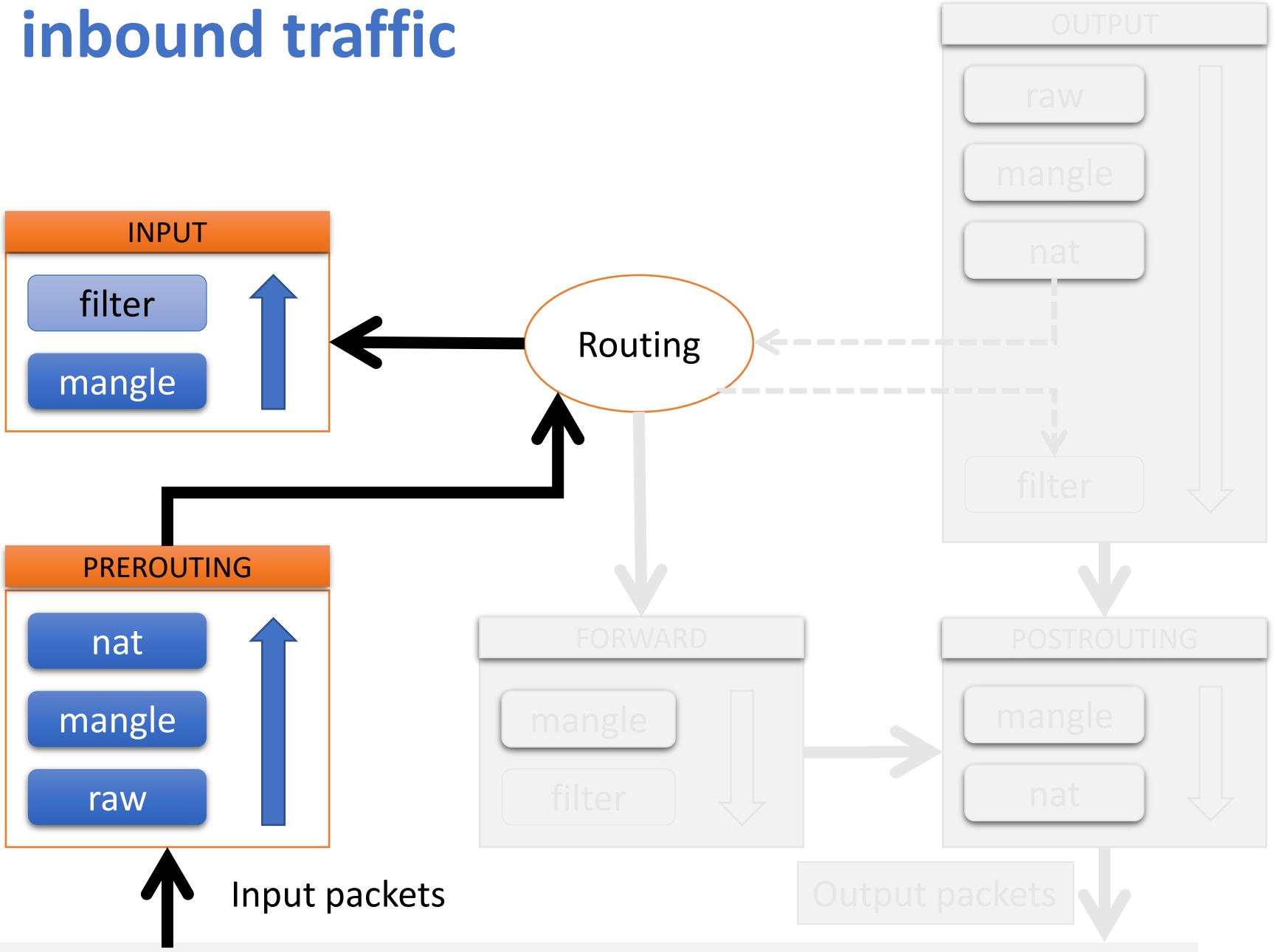
- Stateful packet filter
  - Integrated with the kernel TCP/IP
  - Can be extended in several ways
    - New core modules
    - User mode applications

- 5 chains
  - INPUT, OUTPUT, FORWARD
  - PREROUTING, POSTROUTING
- 4 tables (per chain, but not for all)
  - raw, mangle, nat, filter
- Various extra modules
  - e.g., CONNTRACK (connection tracker, or flow follower)

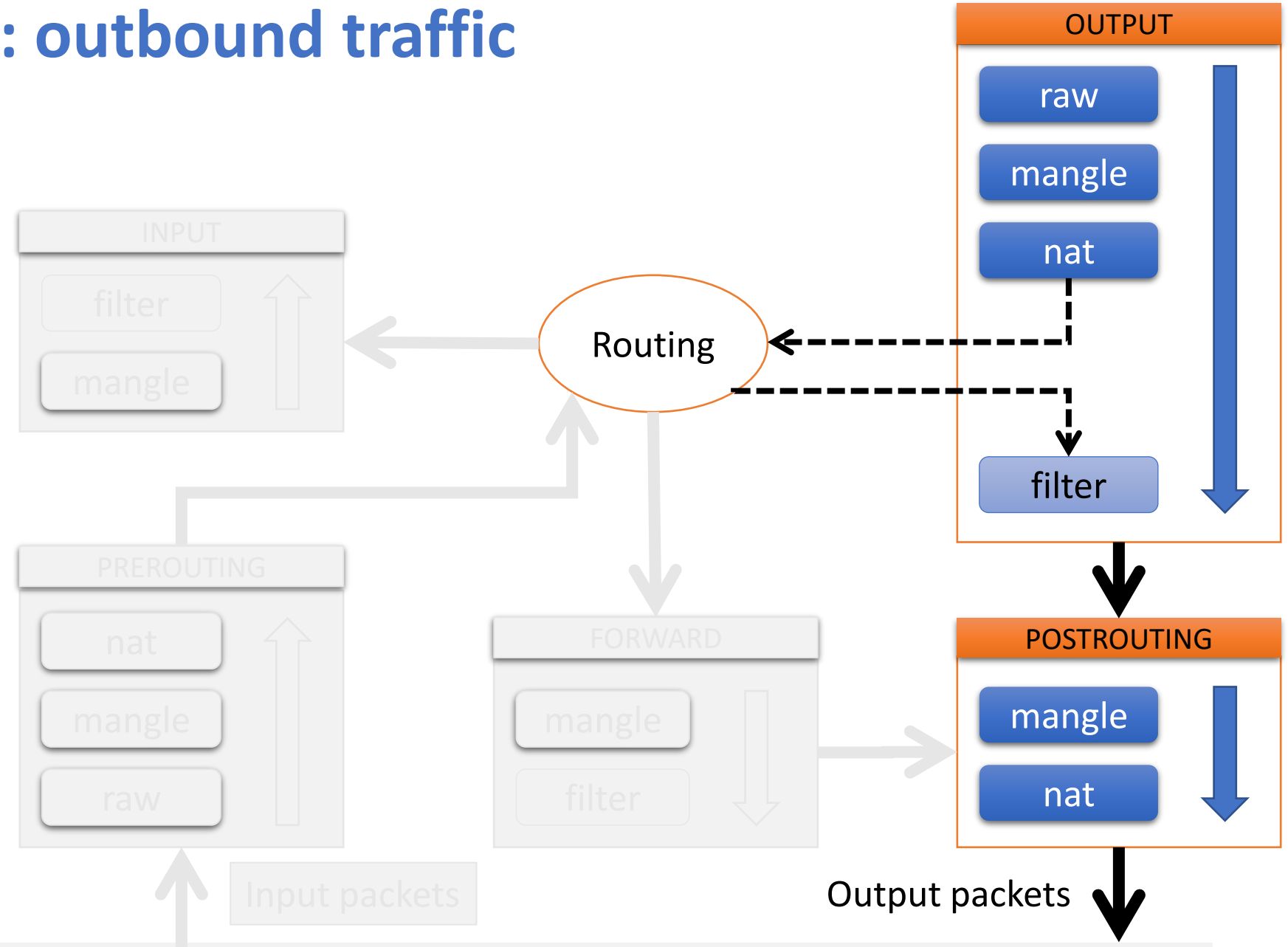
Iptables: flows & chains



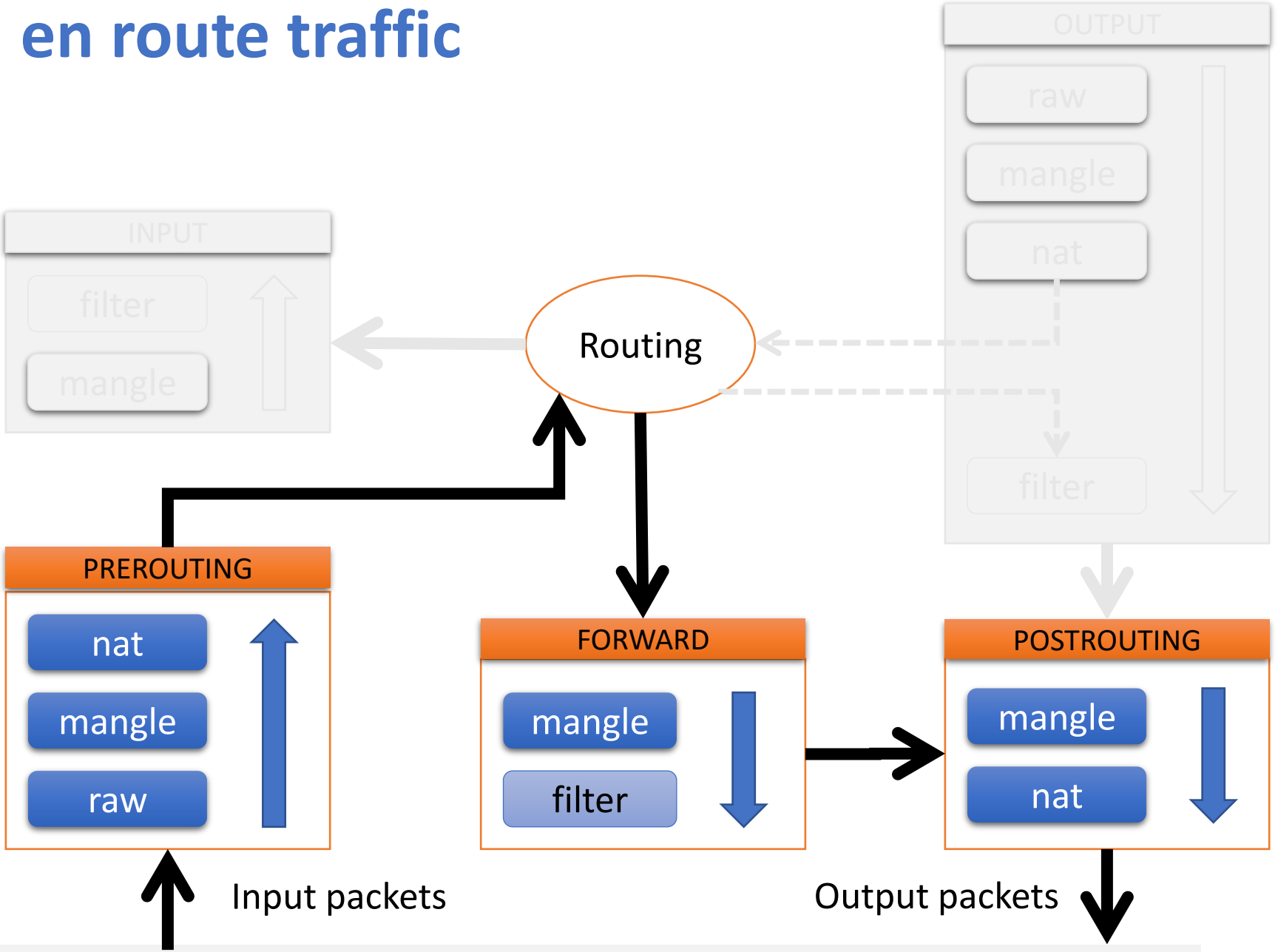
Iptables: inbound traffic



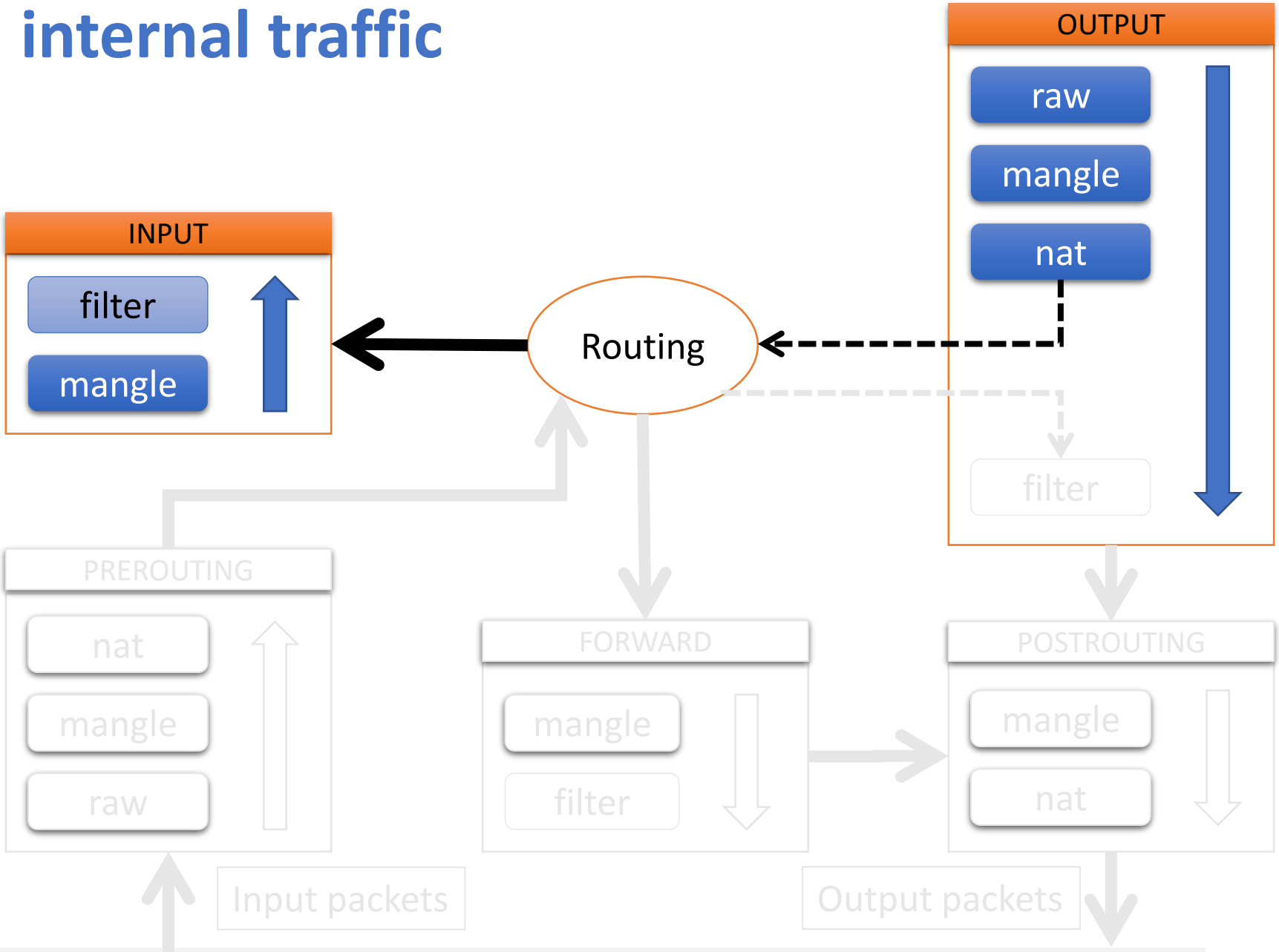
Iptables: outbound traffic



Iptables: en route traffic



Iptables: internal traffic



Iptables: decisions (or verdicts)

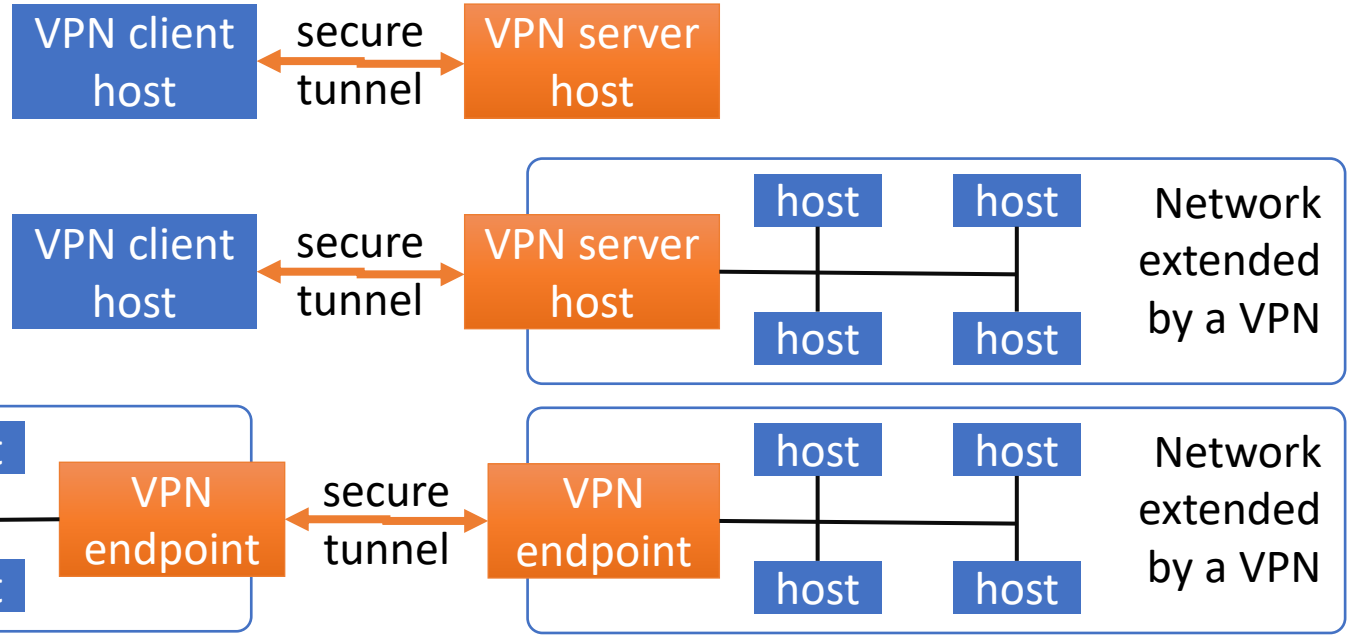
- Basic
  - ACCEPT
    - Let the package continue
  - DROP
    - Discard the package
  - CONTINUE
    - Use decisions from other rules
- Reusable Decisions
  - New chains
  - Jump to a new chain
    - The name of the chain is the decision
  - RETURN
    - Leave the current chain
- Other
  - LOG
  - MARK
    - With internal label
    - Useful for making coherent decisions across different chains
  - REJECT
    - Rejection with error message
  - SNAT, MASQUERADE
    - Source NAT (masquerading)
  - DNAT, REDIRECT
    - Destination NAT (port forwarding)
  - QUEUE
    - Forward to applications

VPN (Virtual Private Network)

- A VPN is a technology that extends a security perimeter
  - It allows traffic from a security perimeter to extend to hosts or networks physically far from it
  - The traffic in the VPN must be cryptographically protected

- In a nutshell, it combines two technologies
  - IP or TCP/UDP tunneling
    - Over IP, UDP, TCP, or an applicational protocol
  - Secure tunneling
    - Confidentiality & integrity control

- VPN types
  - Host-to-Host
  - Host-to-Net
  - Net-to-Net



Why do we need a VPN?

- To expose critical assets of a protected perimeter only to authorized people working geographically far from it
  - Work from home
  - Roaming personnel
- To guarantee that remote interactions with the protected perimeter do not reveal useful information for an attacker
  - Traffic eavesdropping is possible but useless, because it is encrypted
- To protect from malicious network providers
  - These can do all sorts of traffic manipulation, since they intercept the entire communication
  - By using a VPN, a user primarily uses network services from the protected perimeter
    - Example: DNS resolvers
  - **People should always use a VPN when using public networks!**

VPN examples: SSH

- An SSH session allows to define port-oriented tunnels
  - The SSH client can expose ports that represent ports in the SSH server host/network
  - The SSH server can expose ports that represent ports in the SSH client host/network
- A single SSH session can multiplex several tunnels
  - But these must be explicitly defined
- SSH tunnels are very convenient for several applications/scenarios
  - For implementing a secure FTP session, which uses two TCP streams
    - Control and data
  - For running X11 graphical applications on the server host that display on the client host
  - For remote accessing specific services in a protected network
    - Without exposing other network services

Firewall example: OpenVPN

- OpenVPN implements a network-based host-to-net VPN
  - All traffic from a client to a given network is routed to it through the VPN
  - The VPN server represents the VPN client in that network
  - The VPN server extends the security perimeter of the network it serves
- OpenVPN types
  - L2 (TAP): the server propagates L2 broadcast/multicast traffic to the client
  - L3 (TUN): the server propagates L3 (IP) unicast traffic to the client

Firewall example: IPSec

- IPSec is IP with some security-related modifications
  - Extra headers
  - Possible payload encryption

- Extra headers
  - AH (Authentication Header)
    - For adding source authentication & integrity control to IP packets (header and payload)
  - ESP (Encapsulating Security Payload)
    - For adding source authentication & integrity control and/or confidentiality to IP payloads

- IPSec modes
  - Transport (rarely used)
  - Tunnel (used for host-to-net or net-to-net VPNs)

Firewall example: IPSec

- An IPSec VPN is usually implemented with
  - IPSec in tunnel mode
  - ESP headers with source authentication, integrity control and confidentiality
- Original IP packets routed through the VPN are
  - Totally encrypted (both header and payload) on ingress
    - And decrypted and validated on egress
  - Become the payload of a VPN IP packet
  - The VPN IP packet has a proper ESP header
- But because of NAT, IPSec is tunneled over UDP
  - An extra UDP header allows NAT multiplexing